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 Dean Antony Olsen

Dated: 12 October 2012

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CHAPMAN TRIPP

QUALIFICATIONS AND EXPERIENCE

1. My name is Dean Antony Olsen. I reside in Dunedin where I am an Associate Director and Environmental Scientist at Ryder Consulting Limited. I hold the degrees of B.Sc. (Honours I) in Zoology and Ph.D. in Zoology, both from the University of Otago. I am a member of the New Zealand Freshwater Sciences Society and the North American Benthological Society.

2. I have 16 years experience as a freshwater ecologist, specialising in macroinvertebrate ecology. After completing my Ph.D. in 2003, I worked for two years as a Post-doctoral Research Associate at the University of Vermont in Burlington, Vermont, USA. Until recently I was employed as a Freshwater Scientist at the Cawthron Institute in Nelson (2005-2011).

3. I have worked on a variety of projects assessing the effects of flow diversion or abstraction on stream ecology including reviews of assessments of hydroelectric schemes in the Wairau[1] and Arnold Rivers[2] and investigations of the effects of diversions from rivers in the upper Waitaki Catchment[3]. I have also undertaken assessments for a major hydro-electricity scheme in the Central North Island and have recently undertaken assessments for a moderately sized scheme on a braided river in Canterbury. Neither of these schemes has been announced publicly.

4. I have presented evidence at eight hearings including two Environment Court hearings, one Special Tribunal hearing and five Regional Council hearings. Most of these hearings concerned the ecological effects of water abstraction.

5. I have published nine scientific papers in peer-reviewed international journals and one peer-reviewed report in the Department of Conservation *Research & Development Series*. I regularly peer-review manuscripts for international scientific journals including *Freshwater Biology, Fundamental and Applied Limnology, Hydrobiologia, Invertebrate Systematics, Journal of the North American Benthological Society, Marine and Freshwater Research* and *Restoration Ecology*.

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[1] Olsen, D.A. 2006. Macroinvertebrates of the Wairau River and the likely consequences of proposed hydro-electric development. Prepared for the Department of Conservation, Nelson-Marlborough Conservancy. *Cawthron Report No. 1124.* 22 p.; Olsen, D.A. (2006). Macroinvertebrates of the Wairau River and the likely consequences of proposed hydroelectric development. *DOC Research & Development Series 256.* Department of Conservation, Wellington. 25 p.

[2] Olsen DA; Hay J, Strickland RR, Hayes JW 2006. A Review of the Arnold River Hydro-Electric Power Scheme Assessment of Environmental Effects. Prepared for the Department of Conservation, West Coast, Tai Poutini Conservancy. *Cawthron Report No. 1228*. 24 p.

[3] Olsen DA 2009. Ecological Effects of a Micro-Hydro-Electric Power Scheme on Station Stream. Prepared for Lilybank Station Ltd. Cawthron Report No. 1556. 4 p; Olsen DA 2008. Station Stream Ecological Survey. Prepared for Lilybank Station. Cawthron Report No. 1438. 16 p.; Olsen DA 2008. Mistake River Ecological Survey. Prepared for Lone Star Godley Peaks. Cawthron Report No. 1437. 19 p.

6. I have over 20 years of fly fishing experience and have fished for trout since I was a young child. I have fished throughout New Zealand as well as in Australia and North America. I am particularly familiar with fisheries in the Southern South Island.

7. I was first author of the report presenting assessments of the effects of Meridian Energy Limited's ("Meridian") Amuri Hydro Project ("AHP") on aquatic communities in the Waiau River[4]. Much of my evidence is drawn from that document and the results of a subsequent survey conducted by Cawthron[5].

8. My evidence is within my area of expertise, except where I state that I am relying on the specific evidence of another person. I have not omitted to consider material facts known to me that might alter or detract from the opinions that I express.

9. I have read the Code of Conduct for Expert Witnesses 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.

SCOPE OF EVIDENCE

10. Meridian's submission on the Proposed Hurunui and Waiau River Regional Plan ("the Proposed Plan") generally supports the proposed Environmental Flow and Allocation Regimes for the Waiau and Hurunui Rivers contained in the Proposed Plan.

11. In my evidence I will only cover the Environmental Flow and Allocation Regimes proposed for the Waiau River. Meridian has lodged applications for the principal resource consents necessary to operate the proposed AHP, as outlined in the evidence of Mr Jeff Page. This scheme will take water at about the Leslie Hills bridge and discharge downstream of the township of Waiau. In this evidence I will refer to this section of the river as the Amuri Plains Reach. The findings in my evidence are based on work undertaken as part of the Assessment of Environmental Effects (AEE) of the proposed AHP[4] and subsequent work that has been undertaken since the AEE was prepared.

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[4] Olsen D, Maxwell I, Holmes R, Hay J, Allen C, Doehring K, Hayes J, Young R 2011. Assessment of the Amuri Hydro Project on the Waiau River, North Canterbury. Prepared for Meridian Energy Ltd. Cawthron Report No. 2011. 129 pp. plus appendices

[5] Hayes JD, Shearer KA, Doehring K, Berkett N 2012. Periphyton, Macroinvertebrates and Fish Surveys in the Waiau River, North Canterbury - January - February 2012. Prepared for Meridian Energy Limited. *Cawthron Report No. 2106*. 50 p. plus appendices.

12. I understand that the policy framework in the Proposed Plan has provisions relating to flow variability and invertebrate food production when making decisions on water allocation. I cover these matters in my evidence here.

13. Throughout this evidence I have compared the effects of the AHP flow regime, which is referred to here as the modelled proposal, with the status quo in the river. The status quo includes current irrigation and other water takes as described by Mr Mathamo in his evidence. I use the status quo as the basis for comparison because it reflects what actually occurs now in the Waiau River. Some comparisons are also made with the natural flow regime.

14. As outlined by Mr Steven Woods in his evidence, Meridian proposes to take up to 50 m^3/s of water for the proposed scheme when it is available. In summary, in combination with current and future irrigation abstraction, the proposed AHP would result in a median flow of 20 m^3/s in the Amuri Plains Reach and would result in flows between 20 m^3/s and 30 m^3/s for 223 days per year, on average. Freshes and floods above 200m^3/s would be retained, and the modelling assumes no water is taken for hydropower at flows above 200 m^3/s. The modelling carried out assumes the AHP will take up to 50 m^3/s of smaller freshes in the Waiau River, although it is possible that mitigation will include allowing some freshes down the river to promote flushing of periphyton accumulations and fine sediment from the bed.

15. As modelled the proposed AHP complies with the Environmental Flow and Allocation Regime proposed by the Plan for the Waiau River, except for the 2 m^3/s "gap" between the "A" and "B" allocation blocks which has not been provided for in the modelling (see the evidence of Steven Woods). The proposed AHP also represents the greatest practical use of the flow and allocation regime in the Proposed Plan. For this reason I consider that the assessment of effects I carried out for the proposed AHP can be used to assess the effects of the environmental flow and allocation regime (based on the provision of at least 20 million cubic metres of storage) in the Proposed Plan. I note also that the modelling undertaken takes into account all existing community water supply and irrigation abstractions, and likely future irrigation abstractions.

16. In preparing my evidence on the Proposed Plan I have reviewed the following evidence prepared for Meridian as it relates to periphyton and macroinvertebrates:

- Mr Steven Woods - Hydrology
- Dr Mark Mabin – River morphology and sediment transport
- Mr Ian Jowett - River braiding pattern and habitat modelling
- Dr John Hayes – Effects on other river biota
- Dr Mark Sanders - Birds

17. My evidence also considers the effects of the take associated with the proposed AHP and existing and future irrigation demand in the Amuri Plains Reach of the Waiau River on periphyton and macroinvertebrates.

SUMMARY OF FINDINGS

18. Periphyton is an essential part of stream ecosystems, capturing energy from the sun, which is then consumed by grazing invertebrates and then becomes available to higher trophic levels (e.g. fish, birds). However, under some circumstances periphyton can reach nuisance levels and impact on other values. Some species of cyanobacteria (a type of periphyton) are potentially toxic and can pose a health risk for river users and animals.

19. Periphyton communities in the Waiau River usually have low biomass and cover due to low nutrient concentrations, high sediment loads and the disturbance caused by freshes and floods. However, periphyton may reach high cover/biomass after prolonged periods of low flow. To date, Didymo (*Didymosphenia geminata*) has not been recorded from the river.

20. Macroinvertebrates are an essential link in the transfer of energy from plant matter, fungi and bacteria to the larger animals that live in or around rivers (e.g. fish, insectivorous birds). Consequently, anything that affects them is likely to have consequences for other parts of the ecosystem.

21. Nymphs of the mayfly *Deleatidium* are typically the most abundant macroinvertebrate in the Waiau River, although other species (such as chironomid midges) may proliferate under stable conditions and in some habitats. Other taxa that contribute significantly to the overall community included larvae of the cased caddis fly *Pycnocentrodes*, chironomid midges, the purse-cased caddis *Oxyethira albiceps,* the free-living caddis *Hydrobiosis* and the cranefly Eriopterini. These results are consistent with the findings from other South Island braided rivers.

22. There is the risk that the AHP flow regime, and hence the C Block allocation, will lead to an increase in the frequency and magnitude of nuisance periphyton proliferations compared with present conditions. For instance, the instream habitat modelling presented by Mr Jowett indicates that conditions will be more favourable for long filamentous algae as result of the Waiau River becoming slower and shallower for longer periods of time. Much of this effect occurs as a result of the C-block allocation and, if the proposed AHP proceeds, will be limited to the up to 29 km reach affected by the scheme.

23. The abundance of periphyton will still be controlled by naturally occurring floods and freshes. The frequency of flows in excess of 210 m^3/s that are effective at moving a large proportion of the bed of the Waiau River will be unchanged under the proposed AHP. However, to mitigate any risk of an increase in nuisance periphyton proliferations, there is the option to close the hydro intake for the first 24 hours of the rising limb of some or all of the smaller freshes (e.g. when flows exceed approximately 100m^3/s) following more than 30 days of low flows to allow the water to pass through Amuri Plains reach of the Waiau River and help scour algal proliferations from the bed of the river.

24. Instream habitat modelling suggests that the availability of habitat for the nymphs of the mayfly *Deleatidium* and food producing habitat increase with increasing flow across the modelled flow range (10-60 m^3/s).

25. Two approaches have been taken to assess the effects of the AHP modelled flow, and hence the C Block allocation, on macroinvertebrate habitat: (1) a median flow analysis, and (2) the Benthic Invertebrate Time-series HABitat SIMulation (BITHABSIM) model. The former approach has typically been used in habitat assessments while BITHABSIM is a recently developed, process-based model that takes the effects of flood disturbance on macroinvertebrate populations into account.

26. Both the status quo (A Block with the existing minimum flow) and full irrigation development (A+B Block) scenarios are predicted to have a minor effect on macroinvertebrate habitat with the greatest effects predicted to occur in summer as a result of the irrigation abstraction demand being greatest then. A median flow analysis predicts that the AHP modelled flow, and hence the C Block allocation, will reduce macroinvertebrate habitat in most months during dry and average conditions, reducing *Deleatidium* habitat by up to 28% and food producing habitat by up to 30%. BITHABSIM predicts that the AHP modelled flow will reduce overall *Deleatidium* habitat by 9-24%, with reductions of more than 30% predicted to occur in some months.

27. The median flow analysis predicted that the modelled proposal will reduce *Deleatidium* and food producing habitat by 20-30% in most months in dry and average years but effects will be minor (<10%) in wet years when compared with existing (status quo) flows. Analysis using BITHABSIM indicates that when compared with existing flows, the overall effect of the modelled proposal will be to reduce habitat for *Deleatidium* by 9-19%, with reductions of up to 10-20% predicted in most months and reductions of 20-30% predicted for summer months, particularly in the average and wet years considered.

28. I do not anticipate that the AHP modelled flow, and hence the C Block allocation will have more than a minor effect on populations of macroinvertebrates, particularly *Deleatidium*, in the Waiau River. This is because the naturally variable flows in the Waiau will reduce the effect of any abstraction on invertebrate populations by limiting invertebrate populations and the relatively short section of river affected (up to 29 km). The significance of any effects of the AHP modelled flow on macroinvertebrates on other values is considered by Dr Hayes (fish) and Dr Sanders (birds).

BACKGROUND

Periphyton

29. The term periphyton refers to the algae, fungi and bacteria that are attached to the surface of rocks or other substrates (e.g. macrophytes, wood). Along with inputs of terrestrial vegetation, periphyton forms part of the base of the food web, providing much of the energy that is available to primary consumers (macroinvertebrates). In braided rivers, periphyton is the primary source of energy fuelling the freshwater food web (Figure 1).

30. Periphyton biomass at any point in time reflects the balance of two opposing processes: biomass accrual and biomass loss[6]. The rate of cell division controls the rate of biomass accrual, and is controlled by factors such as the availability of nutrients, light and water temperature[6]. Meanwhile, the rate of biomass loss is governed by physical disturbance (substrate instability, water velocity and suspended solids) and grazing (by invertebrates)[6].

31. While periphyton is an essential part of a functioning stream ecosystem, under favourable conditions it may proliferate to nuisance levels, where it may start to impact upon other values (Table 1).

32. Periphyton can also affect water chemistry. For example, the uptake of nutrients during the growth of periphyton can result in significant improvements in water quality but very high biomasses of periphyton can lead to large variations in dissolved oxygen and carbon dioxide concentrations and pH (as a result of dissolved carbon dioxide concentrations).

[6] Biggs BJF 2000. New Zealand periphyton guideline: detecting, monitoring and managing enrichment of streams. Prepared for Ministry for the Environment. 1-122 p.

33. Some types of periphyton can also have important consequences for human and animal health. Cyanobacteria (also known as blue-green algae) are part of the periphyton community and can form blooms under suitable conditions. Some species of cyanobacteria can produce hepatotoxins[7], neurotoxins[8] and dermatotoxic[9]. Cyanobacterial neurotoxins have been confirmed as the cause of dog deaths in the Hutt River near Wellington (Wood *et al.* 2007). Cyanbacterial toxins have also been implicated as the most probable cause of dog deaths in several rivers around the country including in the Ashley[10], Selwyn[10] and Waitaki[11] Rivers. The toxins produced also pose a health threat to humans[12]. It should be kept in mind that not all cyanobacteria produce toxins, and that the presence of a potentially toxin-producing species does not necessarily guarantee the presence of toxins. Previous studies have noted a correlation between the abundance of cyanobacteria mats and water temperature and a lack of flushing flows[13].

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[7] Toxins that affect the liver including microcystins, nodularins and cylindospermopsins.

[8] Toxins that affect the nervous system including anatoxin-a, homoanatoxin-a, anatoxin-a(S) and saxitoxins.

[9] Toxins that affect the skin, including lipopolysaccharides, β-N-methylamino-l-alanine (BMAA).

[10] Dr. Susie Wood (Cawthron Institute), Personal communication

[11] Wood, S.A., Heath, M., McGregor, G., Holland, P.T., Munday, R., McGregor, G.B., Ryan, K. (2011). Identification of a benthic microcystin-producing filamentous cyanobacterium (Oscillatoriales) associated with a dog poisoning in New Zealand *Toxicon* **55**: 897-903.

[12] Ministry for the Environment and Ministry of Health (2009) Draft New Zealand Guidelines for Managing Cyanobacteria in Recreational Waters. Prepared by S.A. Wood, D.P. Hamilton, W.J. Paul, K.A. Safi, W.M. Williamson. Wellington: Ministry for the Environment. 89 p.

[13] Milne JR, Watts L 2007. Toxic benthic cyanobacteria proliferations in Wellington's rivers in 2005/06. Greater Wellington Regional Council; Wood SA, Selwood AI, Rueckert A, Holland PT, Milne JR, Smith KF, Smits B, Watts LF, Cary CS 2007. First report of homoanatoxin-a and associated dog neurotoxicosis in New Zealand. *Toxicon* **50**: 292-301; Heath MW, Wood SA, Ryan KG 2011. Spatial and temporal variability in *Phormidium* mats and associated anatoxin-a and homoanatoxin-a in two New Zealand rivers. *Aquatic Microbial Ecology* **64**: 69-79.

Table 1 Instream values affected by periphyton proliferations and the nature of such effects (from Biggs 2000[5]).

Instream value	Potential problem
Aesthetics	Degradation of scenery, odour problems
Biodiversity	Loss of sensitive invertebrate taxa through habitat alteration, possible reduction in benthic biodiversity
Contact recreation	Impairment of swimming, odour problems, dangerous for wading
Industrial use	Taste and odour problems, clogging intakes
Irrigation	Clogging intakes
Monitoring structures	Fouling of sensor surfaces, interferes with flow
Potable supply	Taste and odour problems, clogging intakes
Native fish conservation	Impairment of spawning and living habitat
Stock and domestic animal health	Toxic blooms of cyanobacteria
Trout habitat/angling	Reduction in fish activity/populations, fouling lures, dangerous for wading
Waste assimilation	Reduces stream flow, reduces ability to absorb ammonia, reduces ability to process organics without excessive DO depletion
Water quality	Increased suspended detritus, interstitial anoxia in stream bed, increased DO and pH fluctuations, increased ammonia toxicity, very high pH
Whitebait fishing	Clogging nets

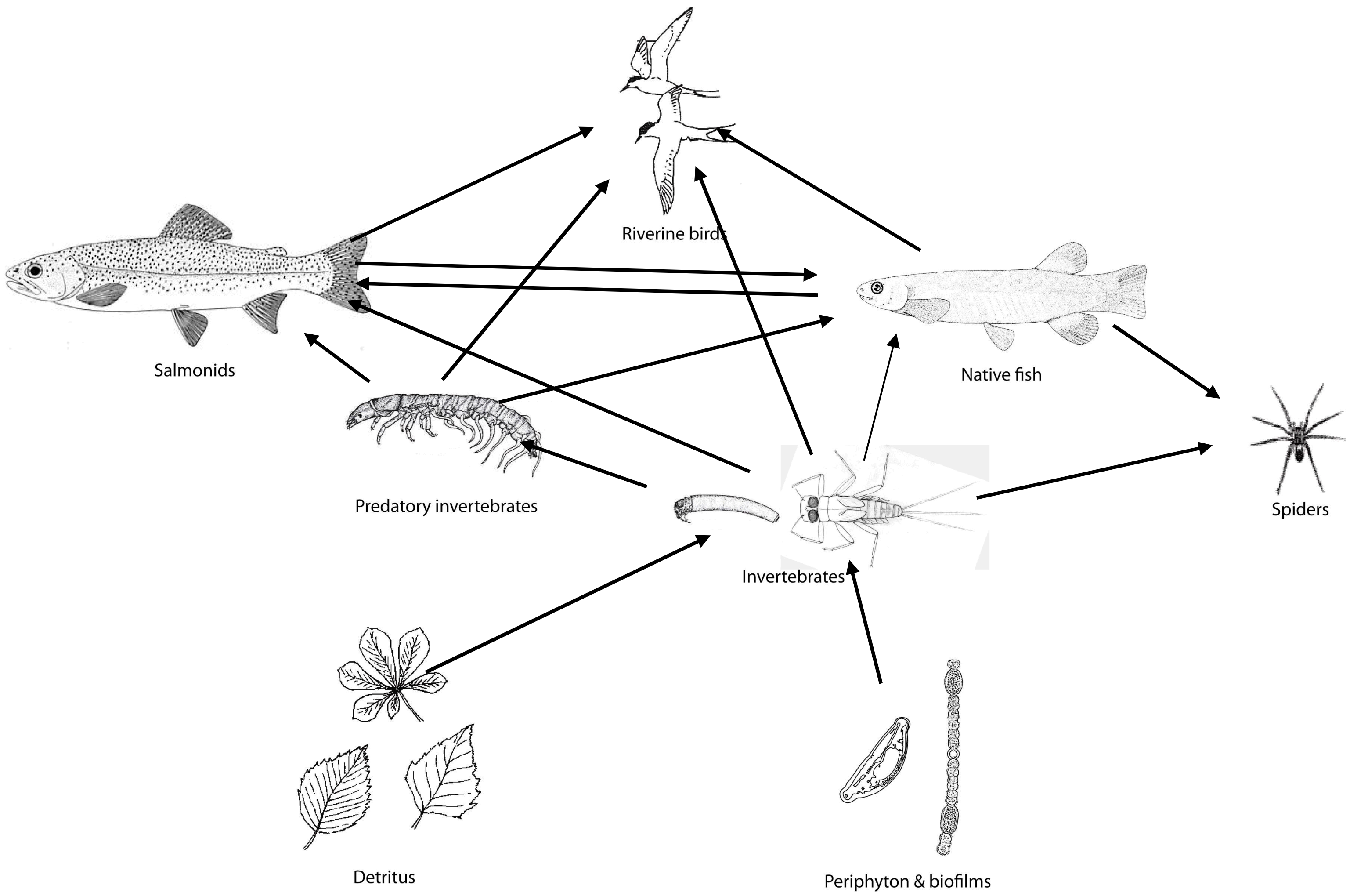

Figure 1 Simplified hypothetical riverine food-web showing possible consumptive links between invertebrates and other trophic levels. Arrows indicate the direction of energy flow.

Macroinvertebrates

34. Macroinvertebrates are the worms, insects, crustaceans, mites and molluscs that live in and on the streambed. They are an essential link in the transfer of energy from plant matter, fungi and bacteria to the larger animals that live in (e.g. fish) and around the stream (e.g. predatory invertebrates and insectivorous birds) (Figure 1). Thus, it is important to consider the effects of flow modification on invertebrates as anything that affects them is likely to have consequences for other parts of the ecosystem.

35. Macroinvertebrates are regularly used to assess water and habitat quality in rivers and streams in New Zealand. Macroinvertebrate indices such as the Macroinvertebrate Community Index (MCI) and its semi-quantitative (SQMCI) and quantitative (QMCI) variants are regularly used in such biomonitoring and distil macroinvertebrate community data down to a single number which is indicative of the degree of organic pollution and/or sedimentation[14]. Other indices that are used to assess water quality include percent EPT[15] taxa percent EPT abundance (the percentage of the total number of invertebrates that belong to the EPT groups).

36. Algal proliferation can affect the abundance and diversity of macroinvertebrates[16] (as well as macroinvertebrate community structure[17] by reducing the abundance of EPT taxa and increasing the relative abundances of tolerant taxa such as riffle beetles (Elmidae), purse-cased caddis flies (*Oxyethira albiceps*) and chironomids. Invertebrates can directly affect periphyton biomass and the composition of periphyton communities.

37. Aquatic macroinvertebrates are critical to life supporting capacity, especially in the context of sustaining the productive capacity of the ecosystem for maintaining the other instream management objectives (e.g. fishery values). In this context it is important to maintain the diversity, density and productivity of macroinvertebrate communities in the Waiau River.

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[14] Stark, J.D. (1985). A macroinvertebrate community index of water quality for stony streams. Water & Soil Miscellaneous Publication 87: 53 p. National Water and Soil Conservation Authority, Wellington; Stark, J.D. (1993) Performance of the Macroinvertebrate Community Index: effects of sampling method, sample replication, water depth, current velocity, and substratum on index valus. *New Zealand Journal of Marine and Freshwater Research* **27**: 463-478; Stark, J.D. (1998). SQMCI: a biotic index for freshwater macroinvertebrate coded abundance data. *New Zealand Journal of Marine and Freshwater Research* **32**: 55-66.

[15] Ephemeroptera (mayflies), Plecoptera (stoneflies) and Trichoptera (caddis flies), taxa that are generally associated with cool, clean water.

[16] Reviewed in Dewson ZS, James ABW, Death RG 2007. A review of the consequences of decreased flow for instream habitat and macroinvertebrates. *Journal of the North American Benthological Society* **26**: 401-415.

[17] Towns DR 1981. Effects of artificial shading on periphyton and invertebrates in a New Zealand stream. *New Zealand Journal of Marine and Freshwater Research* **15**: 185-192; Quinn JM, Hickey CW 1990. Magnitude of effects of substrate particle size, recent flooding, and catchment development on benthic invertebrates in 88 New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research* **24**: 411-427; Quinn JM, Cooper AB, DaviesColley RJ, Rutherford JC, Williamson RB 1997. Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research* **31**: 579-597.

VALUES OF THE EXISTING ENVIRONMENT

Periphyton

38. Periphyton has been sampled at three sites in the Waiau River on several occasions since 2004 by Environment Canterbury ('ECan') (Table 2). These surveys indicate that periphyton cover is relatively low (median value 20-40%), with proliferations of thick mats and long filamentous algae occurring on occasion (Table 2). Benthic cyanobacteria, including *Phormidium*, have been recorded at the bridge near Waiau township on two out of the eighteen sampling occasions (Table 2).

Table 2 Summary of periphyton cover (%) recorded from three sites in the Waiau River by Environment Canterbury.

Site location	Sampling occasions	Periphyton (long filament)		Periphyton (thick mats)		Periphyton (total cover)		Occasions *Phormidium recorded*
		Median	Range	Median	Range	Median	Range	
Leslie Hills	6	5	0 - 70	0	0 - 25	20	0 - 70	None
Waiau Township	18	0	0 - 15	5	0 - 80	40	0 - 95	2
SH 1	7	0	0 - 0	0	0 - 30	25	0 - 80	1

39. Periphyton cover in the Waiau River was surveyed by Cawthron staff in late January 2012[18]. The results of this survey are consistent with the ECan data, with periphyton coverage comprised mostly of thin films dominated by light brown mats or films (Table 3), which usually consist of diatoms and cyanobacteria (Biggs and Kilroy 2000). Periphyton coverage was generally lower in major channels and highest in minor and seepage channels (Table 3). This is likely to reflect the relative stability and depth of these habitat types.

40. The Cawthron survey was undertaken in late January 2012 following a flood (mean daily flow >800 m^3/s, recurrence interval c.5 years) in November 2011, which in turn was followed by two freshes (>200 m^3/s), the most recent of which occurred nine days prior to the survey. Therefore, the low biomass and cover of periphyton present, especially in major channels, is not surprising given the disturbance (such as sediment movement, sand-blasting) caused by these high-flow events.

[18] Hayes JD, Shearer KA, Doehring K, Berkett N 2012. Periphyton, Macroinvertebrates and Fish Surveys in the Waiau River, North Canterbury - January - February 2012. Prepared for Meridian Energy Limited. *Cawthron Report No. 2106*. 50 p. plus appendices.

41. The high periphyton scores recorded during the January 2012 survey are indicative of low periphyton biomass and are consistent with low nutrient enrichment and recent flood disturbance. Taken together, the results of ECan and Cawthron surveys indicate that periphyton biomass in the Waiau River is usually low due to low nutrient concentrations, high sediment loads and the disturbance caused by freshes and floods. Based on these results, I expect that high periphyton biomass is limited to some localised areas of higher nutrient concentrations (e.g. spring-fed channels where higher nutrients in groundwater may locally enhance periphyton growth) and to periods of prolonged low flows.

42. Didymo (*Didymosphenia geminata*) was not recorded during this survey, and has not been previously recorded from the Waiau River, North Canterbury.

Table 3 Summary of the cover (% of bed) of different types of periphyton recorded in various habitat types in two reaches of the Waiau River by Hayes *et al.* (2012)[12].

		Hanmer Plains		**Amuri Plains**						
	Enrichment score	**Major run**	**Minor run**	**Major run**	**Major riffle**	**Medium run**	**Medium riffle**	**Minor run**	**Minor riffle**	**Seep riffle**
Thin mat/film										
Light green	7	5	13	1	-	-	-	-	-	-
Light brown	10	49	76	69	93	78	82	93	99	100
Dark brown	10	-	-	-	-	-	-	-	-	-
Medium mat										
Light brown	7	-	-	-	0.7	-	-	-	-	-
Mean periphyton score[19]		**9.54**	**9.40**	**9.80**	**9.98**	**10.00**	**10.00**	**10.00**	**10.00**	**10.00**
Mean % cover		**54**	**89**	**67**	**93**	**78**	**82**	**93**	**99**	**100**

[19] The mean periphyton score provides an indication of the degree of nutrient enrichment that the periphyton developed under. It is calculated using the percent cover of different periphyton groups and the 'periphyton enrichment indicator scores' of Biggs & Kilroy (2000).

Macroinvertebrates

43. Environment Canterbury has conducted macroinvertebrate sampling within the Amuri Plains reach of the Waiau River on two occasions (February 2008 and November 2010) using a semi-quantitative method[20]. On both occasions, the mayfly *Deleatidium* numerically dominated the macroinvertebrate community, representing 79 and 51% of the community, respectively[13]. In February 2008, the next most abundant invertebrate was the sand-cased caddis *Pycnocentrodes* while in November 2009, chironomid midges (Chironominae and Orthocladiinae, 15 and 12%, respectively) and the purse-cased caddis *Oxyethira albiceps* (13%) were the next most abundant taxa after *Deleatidium*[13]. The community composition on the November 2009 sampling occasion suggests that flows had been low and stable prior to sampling being undertaken.

44. These results are consistent with the *Deleatidium*-dominance of many unstable, braided river systems, such as the Ashley and Rakaia, as well as some sites in the Rangitata, Waimakariri and Wairau Rivers[21].

45. Extensive macroinvertebrate sampling was conducted by Cawthron staff in late January 2012[12]. This sampling consisted of fourteen Surber samples taken from the Hanmer Plains reach (to act as a control) and 47 Surber samples taken from the Amuri Plains reach. Within each reach, a variety of habitats (runs and riffles within major, intermediate and minor channels and a riffle within a seepage channel) were sampled[12]. Since these samples were collected using a quantitative sampling method (Surber sampler), they can be used to estimate the density and biomass of invertebrates in the Waiau River and the contribution of different habitat types to the overall 'productivity' of this system.

46. As outlined in paragraph 40, the Cawthron survey was following a significant flood event in November 2011 followed by two freshes (>200 m^3/s), the most recent of which occurred nine days prior to the survey. Therefore, this survey reflects the

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[20] Olsen D, Maxwell I, Holmes R, Hay J, Allen C, Doehring K, Hayes J, Young R 2011. Assessment of the Amuri Hydro Project on the Waiau River, North Canterbury. Prepared for Meridian Energy Ltd. Cawthron Report No. 2011. 129 pp. plus appendices

[21] Sagar, P.M. (1983). Benthic invertebrates of the Rakaia River. *Fisheries Environmental Report No.* **36**. Ministry of Agriculture and Fisheries, Christchurch. 60 p.; Bonnett, M.L. (1986). Fish and benthic invertebrate populations of the Rangitata River. Fisheries Environmental Report No. 62. Fisheries Research Division, N.Z. Ministry of Agriculture and Fisheries, Christchurch; Hughey, K., Fraser, B.R., Hudson, L.G. (1989). Aquatic invertebrates in two Canterbury rivers - related to bird feeding and water development impacts. *Science & Research Series No*. **12**, Department of Conservation, Wellington; Scrimgeour GJ, Winterbourn MJ 1989. Effects of floods on epilithon and benthic macroinvertebrate populations in an unstable New Zealand river. *Hydrobiologia* **171**: 33-44; Stark, J.D. (2001). Statement of evidence on invertebrate communities presented on behalf of the Central South Island Fish and Game Council to the Rangitata Conservation Order Hearing in Timaru. (8 October 2001). 21 p; Ryder, G.I. (2006). Statement of evidence presented on behalf of the TrustPower Ltd. to a Marlborough District Council hearing for resource consents for the proposed Wairau Valley Power Scheme (July 2006); Goldsmith, R. & Ryder, G. (2011). Lake Coleridge Project. Benthic Ecology and Water Quality Assessment of Effects – Technical report for Consultation Purposes. Prepared for TrustPower Limited. Ryder Consulting Ltd. Dunedin. 70 p.

macroinvertebrate community expected in the Waiau following a moderately wet summer period.

47. A total of 33 taxa collected from the Amuri and Hanmer Plains reaches, with 19 of these found in both reaches. Communities comprised mainly the common mayfly *Deleatidium* spp., the free-living caddisfly *Hydrobiosis* and midge (Chironomidae) fly larvae (Table 4). *Deleatidium* dominated the community in all mesohabitats except for the run in the intermediate channel in the Amuri reach (Table 4). The proportion of midge fly larvae (Orthocladiinae, *Stictocladius*, Chironomidae and *Tanytarsus*) was higher in the major and intermediate channels than the minor and seepage channel in the Amuri reach, with a similar pattern seen between the major and minor channel in the Hanmer reach (Table 4).

48. None of the taxa collected during the Cawthron 2012 survey are rare or threatened (Hitchmough *et al*. 2007).

49. In both reaches, the taxonomic richness, density and biomass of invertebrates was highest in the seepage channel (Amuri Plains only), followed by the minor braids and then the intermediate and major braids[12]. This is consistent with the expected order of substrate stability in these habitats – more stable habitats have a richer species assemblage. Such stable areas may provide refuges, from moderate-sized floods at least, for young invertebrates and fish, and for them to complete their life histories, and serve as sources of colonists for major/intermediate channels[22].

50. The presence of *Hydrobiosis* pupa only in the riffles in the seepage and minor channels in the Amuri Plains reach, and 70 % of all chironomid pupae collected during the survey being found in the seepage channel, is also consistent with substrate stability being higher in the small channels. Pupae are the final life-stage for caddis flies and midges before they emerge as terrestrial adults. They are often sessile (for example, caddis pupae develop in a sealed case attached to the substrate prior to emergence). As a consequence, pupae are particularly vulnerable to disturbance by high-flow events.

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[22] Gray D, Harding JS 2010. Spatial variation in invertebrate communities in New Zealand braided rivers. *Science for Conservation* **302**. Department of Conservation. 43pp.

Table 4 Relative abundance, taxonomic richness (total no. taxa collected (±SE)), mean total density (±SE), and percentage of EPT taxa for macroinvertebrate communities sampled from the Waiau River (January 2012). The biotic indices MCI and QMCI (described in paragraph 35) are also presented. Shading indicates the matching habitat types between the Hanmer and Amuri reaches.

Reach	**Hanmer**		**Amuri**						
Channel type	**Major**	**Minor**	**Major**	**Major**	**Intermediate**	**Intermediate**	**Minor**	**Minor**	**Seep**
Habitat type	**Run**	**Run**	**Riffle**	**Run**	**Riffle**	**Run**	**Riffle**	**Run**	**Riffle**
Ephemeroptera (mayflies)									
Deleatidium spp.	78.8	91.5	55.8	37.0	62.8	8.3	62.0	59.5	79.6
Diptera (flies)									
Austrosimulium spp.	-	-	*	-	*	-	*	-	5.4
Chironomidae	*	*	*	-	*	*	*	*	*
Ceratopogonidae	-	-	-	-	-	-	*	9.6	*
Eriopterini	-	*	*	-	*	6.3	*	6.4	*
Orthocladiinae	5.1	*	7.7	14.8	13.7	12.5	*	*	*
Stictocladius sp.	-	*	7.7	-	-	43.8	*	*	*
Tanytarsus sp.	-	*	*	*	*	14.6	8.4	*	*
Trichoptera (caddisflies)									
Aoteapsyche spp.	*	*	*	*	*	-	*	-	5.5
Hydrobiosis frater	*	*	*	11.1	-	-	7.1	*	*
Hydrobiosis spp.[1]	*	*	7.7	11.1	*	*	6.4	*	*
Oxyethira sp.	*	*	*	7.4	*	*	-	*	*
Mean taxonomic richness	4 (0.7)	5 (0.7)	4 (0.5)	3 (0.6)	4 (0.9)	3 (0.9)	8 (0.4)	9 (1.2)	13 (2.3)
Mean total density (individuals/m^2)	169 (35.4)	606 (80.2)	74 (11.7)	39 (7.1)	146 (44.3)	69 (41.1)	560 (95.6)	490 (109.8)	2868 (780.5)
% EPT_{taxa} (minus *Oxyethira*)[†]	53	55	42	40	50	30	44	40	44
MCI	103	89	95	84	91	86	93	101	102
QMCI	7.18	7.82	6.46	5.30	6.25	5.00	6.66	6.82	7.18
N	7	7	7	7	7	7	7	7	5

-indicates taxa that were not collected

*denotes that this taxa representing ≤5 % of the total invertebrate abundance for either the control and Amuri Plains reaches

[1]*Hydrobiosis* larvae (*i.e.* not including pupae)

[†]*Oxyethira* were not included in the % EPT_{taxa} calculation as they are small animals, often associated with algae; their inclusion in the calculation can result in % EPT overestimating stream health and food potential for fish and birds.

51. Generally QMCI scores were indicative of 'excellent' water/habitat quality[23]. QMCI scores for run habitats in major and intermediate channels were indicative of 'good' water/habitat quality[14].

ASSESSMENT OF EFFECTS OF THE PROPOSED PLAN REGIME

52. The minimum flow on this part of the Waiau River is currently seasonal and varies between 15-25 m³/s depending on the month (described in the evidence of Mr Steven Woods). The irrigation season typically occurs between September/October and April which is when the river usually experiences both its highest (Sept-Oct) and its lowest (February- March) natural flows.

53. I consider the effects of four hydrological scenarios (from the evidence of Mr Steven Woods):

    a. Natural Flow – taken as the flow at the Marble Point recorder.

    b. Status Quo - uses the current Waiau River minimum flow rules and the current estimated irrigation demand along the Amuri Plains Reach ('A' Block only).

    c. Modelled Full Irrigation Development – uses the proposed 'A' and 'B' Block flow allocation rules on the Waiau River and the 'A' and 'B' Block irrigation demand profiles.

    d. Modelled Proposal – as for the modelled full irrigation development series with the additional abstraction of up to 50 m³/s of water for hydro generation purposes taken from the 'C' Block, and from the 'A' & 'B' Blocks when these are not required for irrigation.

54. The modelled proposal (A+B+C Blocks) (see the evidence of Mr Steven Woods) predicts that the median flow in the Amuri Plains reach will reduce to 20m³/s. This compares with 63.9m³/s, which is the median flow with existing irrigation takes, and 73m³/s under the natural flow (as measured at the Marble Point flow recorder).

55. The mean annual minimum flow (instantaneous mean annual low flow; MALF) would be similar under the modelled proposal (A+B+C Blocks) (20.0 m³/s) compared with full irrigation development (A+B Blocks) alone (20.8 m³/s) and the status quo (A Block with existing minimum flows; 19.8 m³/s); however the modelled proposal regime would result in flows being held at or near the low flow of 20 m³/s for much longer.

[23] According to the criteria of Stark, JD, Maxted, JR (2007). A user guide for the Macroinvertebrate Community Index. Prepared for the Ministry for the Environment. Cawthron Report No. 1166. 58 p.

Under the modelled proposal the 7-day MALF is 20.0 m^3/s compared with 21.4 m^3/s under the full irrigation development regime, 21.7 m^3/s under the status quo and 32.2 m^3/s under the natural flow (see Table 6.1 in the evidence of Mr Steven Woods). The magnitude of flow reduction as a result of modelled proposal would tend to be least during the late summer, since the flows are naturally low at that time and much of the flow above the minimum flow will be taken up by irrigation.

Effects on periphyton

56. Predicting the effects of the flow and allocation regime in the proposed plan on periphyton biomass and cover requires evaluation of the factors that can affect the balance of two opposing processes: biomass accrual (gain) and biomass loss[6].

57. The availability of nutrients and light are generally the primary factors affecting the rate of biomass accrual, with shortages of either retarding the rate of accrual[6]. Water temperature can also affect the rate of cell division, particularly if nutrient and light are not limiting the rate of cellular division[6].

58. Water quality monitoring at the Leslie Hills Bridge since 2005 (on a quarterly basis) indicates that nutrient concentrations were generally well within ANZECC guidelines[24] for upland rivers. Median nitrate-nitrogen concentration was 0.01 mg/L (*c.f.* ANZECC guideline of <0.167 mg/L) and total nitrogen was 0.08 mg/L (*c.f.* <0.295 mg/L). The median ammoniacal nitrogen concentration (0.01 mg/L) was at the guideline value (<0.01 mg/L). Median dissolved reactive phosphorus (0.005 mg/L) and total phosphorus concentrations (0.011 mg/L) were also well within guideline values (<0.009 mg/L and <0.026 mg/L, respectively).

59. These results suggest that algal growth rates are likely to be nutrient limited, and it is likely that both nitrogen and phosphorus are limiting on occasion. This does not mean that periphyton would not be able to grow to nuisance levels in the Waiau River, but rather that the rate of growth of periphyton would have been slower than if nutrient concentrations were higher. In other words, the accrual period for periphyton to reach nuisance levels is likely to be longer than in many other rivers. Some periphyton communities (e.g. some cyanobacteria) may be able to fix atmospheric nitrogen and so may be constrained by low nitrogen concentrations to a lesser degree than other species.

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[24] Australian and New Zealand Environment and Conservation Council (ANZECC) and Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) (2000). Australian and New Zealand guidelines for fresh and marine water quality. National Water Quality Management Strategy. Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand.

60. The amount of light reaching a particular area of substrate is influenced by two factors, water clarity and depth. The taking of water associated with the AHP is not expected to markedly affect water clarity while water depth is taken into account in instream habitat analysis in the habitat suitability curves used for each periphyton group (Figure 2).

61. To assess the cumulative effects of the various allocation scenarios, habitat quality under each of the flow scenarios (status quo, modelled full irrigation development and modelled proposal) was compared with the habitat under natural flows. Instream habitat modelling predicts that the modelled proposal (A+B+C Blocks) will result in more favourable conditions for long filamentous growths of algae through much of the year, compared with the status quo and full irrigation development scenarios (Table 5). In contrast, the modelled proposal is predicted to reduce the suitability of the affected reach for the more desirable native diatom species (Table 6). The modelled proposal is not expected to markedly affect the suitability of this reach for short filamentous algae (Table 7).

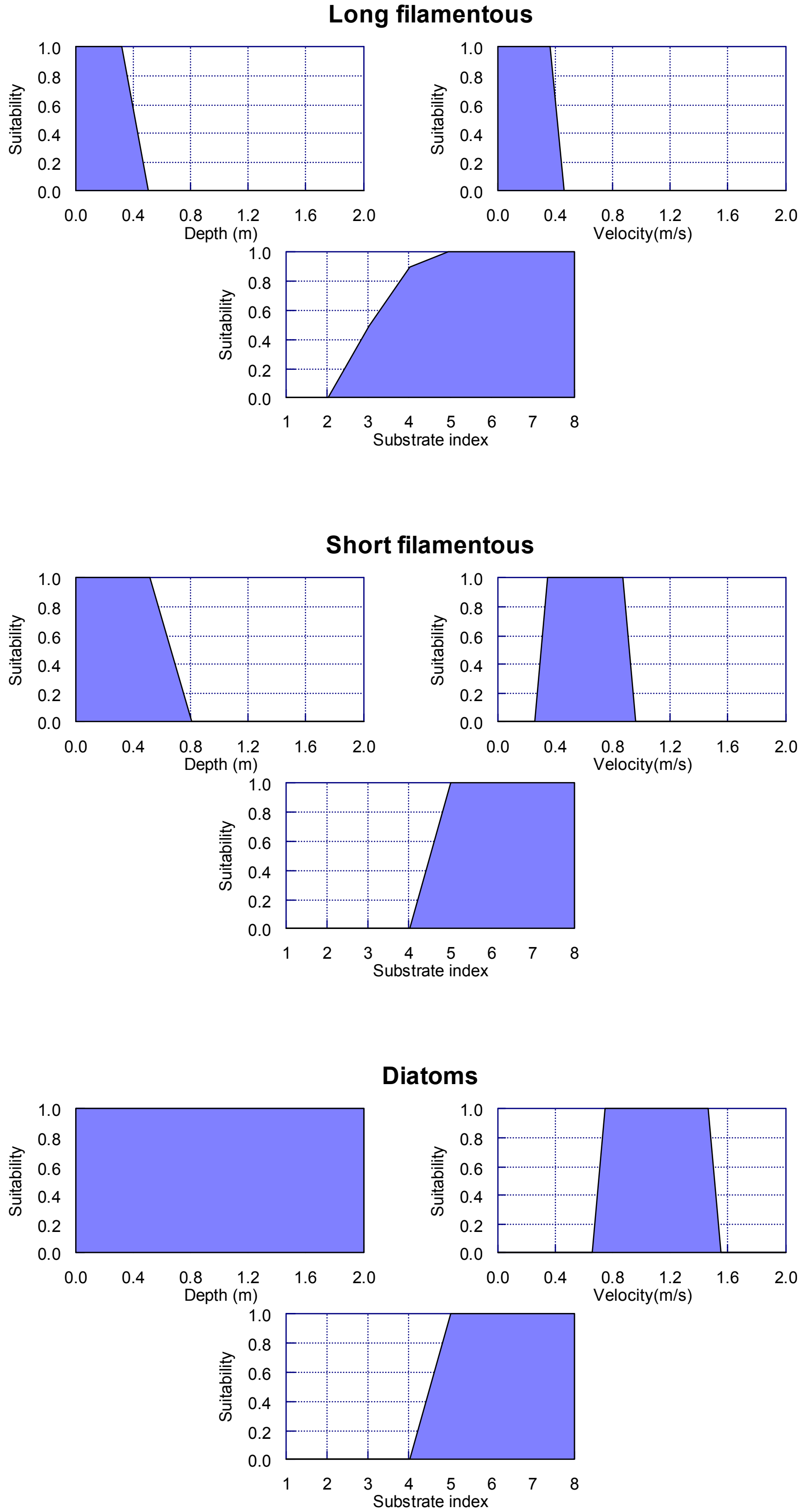

Figure 2 Habitat suitability curves for long filamentous algae, short filamentous algae and diatoms. From RHYHABSIM.

Table 5 Retention of habitat for long filamentous algae under flow regime scenarios expressed as a percentage of habitat available at natural flows for wet, dry and average months.

Month	Status quo			Modelled full irrigation development			Modelled proposal		
	Dry	Average	Wet	Dry	Average	Wet	Dry	Average	Wet
Jan.	125	121	100	134	130	100	134	181	108
Feb.	131	121	100	118	132	100	118	152	152
Mar.	125	119	100	113	129	100	113	147	147
Apr.	114	110	100	116	114	100	116	163	100
May	104	102	100	105	103	100	129	184	100
Jun.	100	100	100	101	100	100	145	192	100
Jul.	100	100	100	101	100	100	150	195	100
Aug.	100	100	100	101	100	100	155	177	100
Sep.	109	100	100	113	100	100	166	150	100
Oct.	113	100	100	120	100	100	185	123	100
Nov.	119	100	100	127	100	100	177	155	100
Dec.	119	103	100	130	109	100	157	204	100

Key:

Habitat loss	<70% retention	70-79% retention	80-89% retention	90-110% retention
Habitat gain	90-110% retention	111-120% retention	121-130% retention	>130% retention

Table 6 Retention of habitat for diatoms under flow regime scenarios expressed as a percentage of habitat available at naturalised flows for wet, dry and average months.

Month	Status quo			Modelled full irrigation development			Modelled proposal		
	Dry	Average	Wet	Dry	Average	Wet	Dry	Average	Wet
Jan.	76	87	100	67	82	100	67	53	94
Feb.	61	86	100	74	78	100	74	60	72
Mar.	65	87	100	80	78	100	80	62	74
Apr.	79	93	100	77	90	100	77	57	100
May	97	98	100	96	97	100	69	52	100
Jun.	100	100	100	99	100	100	63	54	100
Jul.	100	100	100	99	100	100	61	52	100
Aug.	100	100	100	100	100	100	59	63	100
Sep.	94	100	100	91	100	100	56	73	100
Oct.	91	100	100	88	100	100	52	86	100
Nov.	88	100	100	83	100	100	54	72	100
Dec.	87	98	100	81	93	100	59	48	100

Key:

Habitat loss	<70% retention	70-79% retention	80-89% retention	90-110% retention
Habitat gain	90-110% retention	111-120% retention	121-130% retention	>130% retention

Table 7 Retention of habitat for short filamentous algae under flow regime scenarios expressed as a percentage of habitat available at naturalised flows for wet, dry and average months.

Month	Status quo			Modelled full irrigation development			Modelled proposal		
	Dry	Average	Wet	Dry	Average	Wet	Dry	Average	Wet
Jan.	93	102	100	89	102	100	89	91	105
Feb.	85	102	100	90	99	100	90	90	111
Mar.	87	101	100	92	98	100	92	90	110
Apr.	92	100	100	91	101	100	91	90	100
May	99	101	100	99	102	100	88	92	100
Jun.	100	100	100	100	100	100	90	103	100
Jul.	100	100	100	100	100	100	90	100	100
Aug.	100	100	100	100	100	100	90	108	100
Sep.	100	100	100	101	100	100	90	111	100
Oct.	103	100	100	103	100	100	93	109	100
Nov.	101	100	100	101	100	100	90	111	100
Dec.	102	102	100	101	106	100	90	99	100

62. The expected changes in periphyton habitat when compared with existing allocation ("status quo") were assessed by comparing habitat quality under the modelled proposal scenario with habitat quality under status quo flows. These analyses indicate that, in general, the modelled proposal was predicted to increase habitat quality for long filamentous algae while habitat quality for diatoms was predicted to decrease compared with existing flows (Tables 8 & 9, respectively). In comparison, habitat for short filamentous algae was not predicted to be changed markedly by the modelled proposal relative to the status quo (Table 10).

63. However, factors such as nutrient availability and habitat suitability are only part of the picture. Flow variability plays a major role in determining periphyton cover and biomass as higher flows can lead to a loss of periphyton biomass as a result of high water velocities, scouring by sand particles, and/or bed movement. Flow of greater than three times the median flow (often referred to as FRE3 flows) is a general 'rule of thumb' used to estimate the magnitude of flows required to remove periphyton biomass. In the Waiau River, three times the median flow is about 220 m^3/s. Meridian has indicated that the AHP will shut when flows exceed 210 m^3/s to avoid large quantities of sediment entering the intake (paragraph 3.6 of Mr Woods' evidence), which is reflected in the modelled proposal. Thus, the modelled proposal will not affect the FRE3. However, higher or lower flows may be necessary to flush periphyton, depending on the characteristics of the river. In braided rivers, such as the Waiau, disturbance is a continuous process, with some bed movement occurring even at low flows[25].

64. Sediment transport modelling indicates that 60% of the area of bed at natural median flow will be surface flushed (movement of sand and fine gravels) and 40% deep flushed (movement of the armour layer) by flows of about twice the median flow[21, 26] (146 m^3/s). Flows of 100 m^3/s flush a comparable proportion of the bed wetted at the minimum flow of 20 m^3/s [21, 24]. Dr Mark Mabin presents a more extensive assessment of sediment transport, particularly as it relates to sediment loads in his evidence in chief.

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[25] Duncan M, Bind J 2008. Waimakariri River bed sediment movement for ecological resetting. Prepared for Environment Canterbury. *NIWA Client Report No. CHC2008-016*. 32 p.; Duncan M, Bind J 2009. Waiau river instream habitat based on 2-D hydrodynamic modelling. Prepared for Environment Canterbury. *NIWA Client Report: CHC2008-176*: 48 p.

[26] Snelder, T., Booker, D., Jellyman, D., Bonnett, M., Duncan, M. (2011). Waiau River mid-range flows evaluation. Prepared for Environment Canterbury. *NIWA Client report No. CHC2011-084.* 63 p. plus appendices.

Table 8 Retention of habitat for long filamentous algae under flow regime scenarios expressed as a percentage of habitat available under status quo flows for wet, dry and average months.

	Modelled proposal compared with Status quo		
Month	Dry	Average	Wet
Jan.	107	150	108
Feb.	91	126	152
Mar.	90	123	147
Apr.	101	148	100
May	124	180	100
Jun.	144	192	100
Jul.	149	195	100
Aug.	155	177	100
Sep.	152	150	100
Oct.	164	123	100
Nov.	148	155	100
Dec.	131	199	100

Key:

Habitat loss	<70% retention	70-79% retention	80-89% retention	90-110% retention
Habitat gain	90-110% retention	111-120% retention	121-130% retention	>130% retention

Table 9 Retention of habitat for diatoms under flow regime scenarios expressed as a percentage of habitat available under status quo flows for wet, dry and average months.

	Modelled proposal compared with Status quo		
Month	Dry	Average	Wet
Jan.	88	61	94
Feb.	121	70	72
Mar.	123	71	74
Apr.	97	61	100
May	71	53	100
Jun.	63	54	100
Jul.	61	52	100
Aug.	59	63	100
Sep.	60	73	100
Oct.	57	86	100
Nov.	62	72	100
Dec.	68	49	100

Key:

Habitat loss	<70% retention	70-79% retention	80-89% retention	90-110% retention
Habitat gain	90-110% retention	111-120% retention	121-130% retention	>130% retention

Table 10 Retention of habitat for short filamentous algae under flow regime scenarios expressed as a percentage of habitat available under status quo flows for wet, dry and average months.

	Modelled proposal compared with Status quo		
Month	Dry	Average	Wet
Jan.	95	90	105
Feb.	106	88	111
Mar.	106	89	110
Apr.	99	90	100
May	89	91	100
Jun.	90	103	100
Jul.	90	99	100
Aug.	90	108	100
Sep.	90	111	100
Oct.	90	109	100
Nov.	90	111	100
Dec.	88	97	100

65. NIWA has conducted analyses using periphyton data from the Hurunui and Waimakariri Rivers to predict periphyton accrual and the effects of flushing flows in the Waiau River[24]. These empirical models were used to estimate the probability of periphyton cover exceeding guidelines on any given day based on mean daily flow history. The guidelines assessed in this analysis were 20% cover of filamentous algae (guideline for Alpine –lower rivers in the operative Natural Resources Regional Plan) and a total periphyton cover (filaments + mats) of 30%.

66. While none of the flow scenarios considered in the NIWA analysis correspond exactly with the Environmental Flow and Allocation Regime set out in the proposed plan (20 m^3/s minimum flow, 18 m^3/s A Block, 2 m^3/s gap, 11 m^3/s B Block, 42 m^3/s C Block, total possible allocation 71 m^3/s), the closest equivalent to that in the proposed plan is Scenario 3 (20 m^3/s minimum flow, total allocation 65 m^3/s). One significant difference between the regime set out in the proposed plan and Scenario 3 of Snelder *et al.* (the NIWA report) is the slightly lower total allocation (65 vs 71 m^3/s) and the lack of a 2 m^3/s gap between the A block (20-38 m^3/s) and B blocks (40-51 m^3/s) that is present in the proposed plan. The NIWA work also assumes that the 65 m^3/s is taken all year round when available and at all flows. This is not the case; there is no irrigation take during winter and often in spring, and the AHP will not take water at flows over 210 m^3/s, so the frequency of freshes of about FRE3 or greater is not reduced. Importantly also, the AHP returns water to the river, so some of the effects predicted by Snelder *et al* from taking this volume of water will not occur due to the operation of the proposed hydro scheme (e.g. closure of the river mouth).

67. Based on the accrual model for the Hurunui River, Snelder *et al.* predicted that under natural conditions the cover of filamentous algae would exceed the guideline value on 2% of occasions and that this would increase to 4% under Scenario 3 and that the total periphyton guideline (30% cover by mats and filaments) would increase from 7.2% under natural conditions to 8.3% under Scenario 3[24].

68. Similarly, based on the accrual model for the Waimakariri River, they predicted that the occasions that the filamentous guideline was exceeded would increase from 0.3% of occasions to 0.8% of occasions under Scenario 3 and that exceedance of the total periphyton guideline would increase from 2.3% of the time to 3.7% under Scenario 3[24].

69. The results of NIWA's analyses are consistent with the results of periphyton monitoring conducted to date that indicate that nuisance periphyton proliferations occur infrequently in the Waiau River under existing conditions. Both models (using data from the Hurunui and Waimakariri Rivers) predict that the occurrence of proliferations of long filamentous algae will approximately double under the AHP.

However, given the limited reach affected by the AHP (up to 29 km) and the low current frequency of such events, I do not find this particularly concerning.

70. Based on accrual estimated from the Hurunui River, the occurrence proliferations of filamentous algae covering more than 20% of the bed will increase from approximately 7 days to 15 days. Predicted increases in the occurrence of total periphyton (mats+filaments) cover exceeding 30% are more modest, with the Hurunui accrual model predicting an increase from 26 days to 30 days.

71. The values that can be affected by such proliferations are summarised in Table 1. The main concerns of relevance to the Waiau River are the potential effects on aesthetics, habitat for invertebrates and fish and implications for recreation. Given the short duration of such events predicted by NIWA's analyses, I do not consider it likely that they will have any more than a minor effect on any of these values.

72. The option remains to manage this effect, if deemed necessary, by closing any intake during the first 24 h of some or all of the naturally occurring freshes ($Q>100\ m^3/s$) following an extended period of low flows (e.g. 30 days) to allow the water to pass through Amuri Plains section of the Waiau River. Flows of this magnitude are expected to be effective at removing periphyton biomass from low flow channels (see paragraph 62).

Conclusions - periphyton

73. There is the risk that the proposed environmental flow and allocation regime will lead to an increase in the frequency and magnitude of nuisance periphyton proliferations compared with present conditions, as a result of the Waiau River becoming slower and shallower and flows becoming more stable for longer periods of time. Much of this effect occurs as a result of the C-block allocation and, if the AHP proceeds, would be limited to the up to 29 km reach affected by the scheme.

74. Such growths will still be controlled by naturally occurring floods and freshes. The frequency of flows in excess of $200\ m^3/s$ that are effective at moving a large proportion of the bed of the Waiau River will be unchanged under the AHP. However, the option remains to manage this effect, if deemed necessary, by closing any intake during the first 24 h of some or all of the naturally occurring freshes ($Q>100\ m^3/s$) following an extended period of low flows (e.g. 30 days) to allow the water to pass through Amuri Plains section of the Waiau River.

Effects on Macroinvertebrates

75. Nymphs of the mayfly *Deleatidium* were the most abundant macroinvertebrate in most mesohabitats in the Waiau River (see Paragraphs 43-47) and was included in the instream habitat modelling conducted by Mr Jowett for this reason. 'Food producing habitat' habitat suitability curves have been shown to be related to the abundance of adult brown trout[27] and are probably a good indicator of general habitat for benthic invertebrates in large braided rivers like the Waiau.

76. Instream habitat modelling suggests that the availability of habitat for the nymphs of the mayfly *Deleatidium* and food producing habitat increase with increasing flow across the modelled flow range (0-60 m^3/s) (Figure 8 of the evidence of Mr Jowett).

77. Two approaches have been taken to assess the effects of the modelled proposal on macroinvertebrate habitat: (1) a median flow analysis, and (2) the Benthic Invertebrate Time-series HABitat SIMulation (BITHABSIM) model. The former approach has typically been used in habitat assessments and involves the comparison of habitat availability at monthly median flows between pre- and post-proposal scenarios. The change is expressed as the percentage of the habitat at the pre-proposal scenario retained under the post-proposal scenario. The pre-proposal scenario could be either naturalised (unmodified) or existing hydrological conditions. Median flow analysis does not account for the effects of the disturbance caused by high flows on macroinvertebrate communities.

78. BITHABSIM is a process-based model that takes the effects of disturbance on macroinvertebrate populations into account when considering the effects of flow alteration on macroinvertebrates. To do this, BITHABSIM requires more information than a median flow analysis, including: (1) an estimate of mortality of the macroinvertebrate caused by different magnitude flows, (2) an estimate of the recovery rate of the macroinvertebrate population, and (3) the relationship between flow and the wetted width of the channel (to account for the effects of wetting and drying of channel margins on macroinvertebrate habitat).

79. I will present the results of each of these assessments separately in the following sections. For each of these assessments, I will present tables of predicted habitat retention compared with naturalised flows. Habitat under the modelled full irrigation development and modelled proposal flows are compared with that under naturalised flows and status quo flows (A Block with existing minimum flow). Comparison with naturalised flows provides an indication of the <u>cumulative</u> effect of <u>all</u> water

[27] Jowett, I.G. (1992). Models of the abundance of large brown trout in New Zealand rivers. North *American Journal of Fisheries Management* **12**: 417-432.

abstraction (A+B+C Blocks allocated). Comparison of predicted habitat with that predicted under status quo flows provides an indication of the effect of the additional allocation (B+C Blocks) and altered minimum flows.

Median flow analysis - habitat retention compared with **natural** flows

80. Existing water allocation (status quo – A Block with existing minimum flow) in the Waiau River is expected to have a relatively minor effect on habitat for *Deleatidium*, with the greatest reductions evident in summer months and minor effects throughout average and wet years (Table 11). The effect of full irrigation development (A+B Blocks) is slightly smaller than the status quo due to the increase in minimum flow from 15 m^3/s to 20 m^3/s in summer, as provided for in the proposed plan (Table 11). Under the modelled proposal (A+B+C Blocks) scenario, there is a decrease of up to 28% in *Deleatidium* habitat when flows are average or less (Table 11).

Table 11 Retention of *Deleatidium* habitat under flow regime scenarios based on a median flow analysis expressed as a percentage of habitat available at naturalised flows for wet, dry and average months.

Month	Status quo			Modelled full irrigation development			Modelled proposal		
	Dry	Average	Wet	Dry	Average	Wet	Dry	Average	Wet
Jan.	86	95	100	81	93	100	81	73	99
Feb.	77	92	100	86	87	100	86	77	90
Mar.	79	92	100	90	87	100	90	78	91
Apr.	89	97	100	88	96	100	88	75	100
May	98	100	100	97	100	100	82	73	100
Jun.	100	100	100	100	100	100	78	76	100
Jul.	100	100	100	100	100	100	77	74	100
Aug.	100	100	100	100	100	100	76	82	100
Sep.	97	100	100	96	100	100	75	90	100
Oct.	97	100	100	96	100	100	73	97	100
Nov.	95	100	100	93	100	100	73	89	100
Dec.	94	100	100	89	99	100	76	72	100

Key:

Habitat loss	<70% retention	70-79% retention	80-89% retention	90-110% retention
Habitat gain	90-110% retention	111-120% retention	121-130% retention	>130% retention

81. The results for food producing habitat is similar to those for *Deleatidium* with existing water allocation (status quo) and full irrigation development expected to have relatively minor effects on food producing habitat, with the greatest reductions evident in summer months and minor effects throughout average and wet years (Table 12). The full irrigation development is expected to result in a decrease of up to 30% in food producing habitat when flows are average or less (Table 12).

Table 12 Retention of food producing habitat under flow regime scenarios based on a median flow analysis expressed as a percentage of habitat available at naturalised flows for wet, dry and average months.

Month	Status quo			Modelled full irrigation development			Modelled proposal		
	Dry	Average	Wet	Dry	Average	Wet	Dry	Average	Wet
Jan.	84	94	100	78	92	100	78	70	100
Feb.	72	92	100	84	85	100	84	74	91
Mar.	74	92	100	88	86	100	88	75	92
Apr.	87	97	100	86	95	100	86	72	100
May	98	100	100	97	100	100	79	70	100
Jun.	100	100	100	100	100	100	75	75	100
Jul.	100	100	100	100	100	100	74	73	100
Aug.	100	100	100	100	100	100	73	82	100
Sep.	97	100	100	96	100	100	71	91	100
Oct.	98	100	100	96	100	100	70	99	100
Nov.	94	100	100	92	100	100	70	90	100
Dec.	93	100	100	88	100	100	73	70	100

Key:

Habitat loss	<70% retention	70-79% retention	80-89% retention	90-110% retention
Habitat gain	90-110% retention	111-120% retention	121-130% retention	>130% retention

Median flow analysis - habitat retention compared with **status quo** flows

82. The modelled proposal is predicted to have a very similar effect on both *Deleatidium* and food producing habitat (Tables 13 & 14). The modelled proposal was predicted to have its greatest effect in the dry and average years, with reductions in *Deleatidium* habitat of up to 25% in the dry year, 28% in the average year and up to 10% in the wet year (Table 13). In comparison, the modelled proposal was predicted to reduce food producing habitat by up to 28% in the dry year, 30% in the average year and up to 9% in the wet year (Table 14).

Table 13 Retention of *Deleatidium* habitat under the modelled proposal based on a median flow analysis expressed as a percentage of habitat available at status quo flows for wet, dry and average months.

	Modelled proposal compared with Status quo		
Month	Dry	Average	Wet
Jan.	94	77	99
Feb.	112	83	90
Mar.	113	84	91
Apr.	99	77	100
May	84	73	100
Jun.	78	76	100
Jul.	77	74	100
Aug.	76	82	100
Sep.	77	90	100
Oct.	75	97	100
Nov.	77	89	100
Dec.	81	72	100

Key:

Habitat loss	<70% retention	70-79% retention	80-89% retention	90-110% retention
Habitat gain	90-110% retention	111-120% retention	121-130% retention	>130% retention

Table 14 Retention of food producing habitat under the modelled proposal based on a median flow analysis expressed as a percentage of habitat available at status quo flows for wet, dry and average months.

	Modelled proposal compared with Status quo		
Month	Dry	Average	Wet
Jan.	93	74	100
Feb.	117	80	91
Mar.	118	81	92
Apr.	98	74	100
May	81	70	100
Jun.	75	75	100
Jul.	74	73	100
Aug.	73	82	100
Sep.	74	91	100
Oct.	72	99	100
Nov.	74	90	100
Dec.	78	70	100

Key:

Habitat loss	<70% retention	70-79% retention	80-89% retention	90-110% retention
Habitat gain	90-110% retention	111-120% retention	121-130% retention	>130% retention

BITHABSIM

83. BITHABSIM is a process-based model that was developed by myself, Dr John Hayes (Cawthron) and Dr Doug Booker (NIWA). The intent of developing BITHABSIM was to increase the biological realism of instream habitat modelling for invertebrates. In particular, it was developed to incorporate the effects of the disturbance caused by high flow events and the recovery of invertebrate populations following such events. Floods are well known to be an important factor in determining invertebrate population dynamics in a wide range of stream systems in New Zealand[28] and elsewhere[29].

84. The BITHABSIM modelling was conducted by Mr Craig Allen (Cawthron) under the supervision of Dr John Hayes (Cawthron) and myself. We elected to model the common mayfly *Deleatidium* in this case because it was usually the most abundant invertebrate present in the Waiau River in the Cawthron survey[20] and it forms an important food source for resident trout and insectivorous birds (see evidence of Dr Mark Sanders). The technical detail of how the BITHABSIM modelling was carried out and the rationale behind the inputs used are outlined in Appendix A.

85. Because the channel of the Waiau River is unconfined, we elected to restrict the modelling to the median flow channel. This is because as flows rise in the Waiau River, the channel width will continue to rise. Whilst average habitat quality may decline as flows rise, the overall habitat for *Deleatidium* will continue to increase with flow (as a result of increases in wetted width). In reality, much of the bed will be unsuitable as habitat for *Deleatidium* due to substrate movement and much of the area wetted will be unsuitable as habitat for *Deleatidium*, as it will be inundated for only a short period of time that is insufficient for development of periphyton biofilms, upon which *Deleatidium* feeds. The fate of invertebrates that do move out into these areas with the rising flood waters is unclear[30], but it is likely that the rapid recession of flood flows results in many being stranded and, presumably, dying. It should be

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[28] Sagar, P.M. (1986). The effects of floods on the invertebrate fauna of a large, unstable braided river. *New Zealand Journal of Marine and Freshwater Research* **20**: 37-46; Scrimgeour, G.J., Davidson, R.J., Davidson, J.M. (1988). Recovery of benthic macroinvertebrate and epilithic communities following a large flood, in an unstable, braided, New Zealand river. *New Zealand Journal of Marine and Freshwater Research* **22**: 337-344; Suren, A.M., Jowett, I.G. (2006). Effects of floods versus low flows on invertebrates in a New Zealand gravel-bed river. *Freshwater Biology* **51**: 2207-2227.

[29] Fritz, K.M., Dodds, W.K. (2004). Resistance and resilience of macroinvertebrate assemblages to drying and flood in a tallgrass prairie stream system. *Hydrobiologia* **527**: 99-112; Lytle, D.A. (2000). Biotic and abiotic effects of flash flooding in a montane desert stream. *Archiv für Hydrobiologie* **150**: 85-100; Maier, K.J. (2001). The influence of floods on benthic insect populations in a Swiss mountain stream and their strategies of damage prevention. *Archiv für Hydrobiologie* **150**: 227-247; Robinson, C.T., Uehlinger, U., Monaghan, M.T. (2003). Effects of a multi-year experimental flood regime on macroinvertebrates downstream of a reservoir. *Aquatic Sciences* **65**: 210-222; Robinson, C.T., Aebischer, S., Uehlinger, U. (2004). Immediate and habitat-specific responses of macroinvertebrates to sequential, experimental floods. *Journal of the North American Benthological Society* **23**: 853-867.

[30] Matthaei, C.D. & Townsend, C.R. (2000). Inundated floodplain gravels in a stream with an unstable bed: Temporary shelter or true invertebrate refugium? *New Zealand Journal of Marine and Freshwater Research* **34**: 147-156.

noted that even when habitat modelling for *Deleatidium* is restricted to the median flow channel, WUA (the habitat index) is predicted to continue to rise above the median flow (Figure 3A). This is because the average quality of habitat within the median flow channel is expected to continue to rise at flows above the median flow. Thus, the relationships between flow and *Deleatidium* WUA, the % of the bed disturbed, and wetted width are all restricted to the median flow channel (Figure 3A, B & C).

86. The BITHABSIM analysis was conducted using mean daily flows for a full year, with a dry year (1973), average year (1987) and wet year (1983) selected to represent the effects of the modelled proposal across a range of hydrological conditions. As for the median flow analysis, four flow scenarios were considered: the naturalised (unmodified) hydrology, the status quo (A Block with existing minimum flows), flows under full irrigation development (A+B Blocks), and modelled proposal (A+B+C Blocks) (as set out in the evidence of Mr Woods).

<u>BITHABSIM – *Deleatidium* habitat retention compared with **natural** flows</u>

87. The BITHABSIM analysis predicts that the status quo scenario will have a relatively minor effect on habitat for *Deleatidium* in the Waiau River in any of the years considered (up to 10-14% reduction, Table 15). Full irrigation development is predicted to reduce habitat for *Deleatidium* by up to 16-17% (Table 15). For both the status quo and full irrigation scenarios, the largest overall effects were predicted for the average and wet year (Table 15). Under the modelled proposal, habitat for *Deleatidium* is predicted to decrease by up to 21-34%, with greatest effects predicted in wet and average years (Table 15). The prediction of the greatest effects in average and wet years is likely to reflect the greater amount of water able to be abstracted in these years and the natural constraint of macroinvertebrate populations that occurs during dry periods.

88. In the dry year (1973), the modelled proposal is predicted to reduce *Deleatidium* by more than 20% in one month (January) while it is predicted to increase habitat by more than 10% in six months (May, August-December) (Table 15). In the average year (1987), *Deleatidium* habitat is predicted to be reduced by 20-30% in ten months and of more than 30% in one month (October)(Table 15). Finally, in the wet year (1983), *Deleatidium* habitat was reduced by 20-30% in four months and by more than 30% in two months (November-December) (Table 15).

89. While the modelled proposal scenario is expected to result in significant reductions (>20%) in some months, these are generally limited in duration and overall retention

of *Deleatidium* ranges from 75% for the average year (1987) to 89% for the dry year (1973) (Table 15).

Table 15 Retention of *Deleatidium* habitat under flow regime scenarios based on a BITHABSIM analysis expressed as a percentage of habitat available at naturalised flows for wet, dry and average months.

	Status quo			Modelled full irrigation development			Modelled proposal		
Month	**Dry**	**Average**	**Wet**	**Dry**	**Average**	**Wet**	**Dry**	**Average**	**Wet**
Jan	87%	90%	98%	83%	85%	96%	79%	77%	74%
Feb	92%	91%	93%	92%	84%	90%	92%	77%	81%
Mar	96%	89%	90%	96%	83%	90%	96%	76%	87%
Apr	98%	90%	90%	98%	85%	89%	95%	77%	81%
May	100%	91%	91%	100%	87%	91%	85%	79%	83%
Jun	101%	92%	91%	101%	88%	91%	91%	76%	76%
Jul	101%	92%	91%	101%	88%	91%	94%	81%	78%
Aug	100%	93%	92%	100%	90%	92%	89%	77%	77%
Sep	97%	94%	94%	97%	91%	94%	86%	79%	80%
Oct	100%	95%	98%	99%	93%	98%	86%	66%	82%
Nov	99%	91%	91%	98%	88%	88%	81%	70%	66%
Dec	97%	95%	89%	94%	91%	84%	84%	72%	66%
Overall	**97%**	**92%**	**92%**	**97%**	**88%**	**91%**	**89%**	**75%**	**78%**

Key:					
Habitat loss		<70% retention	70-79% retention	80-89% retention	90-110% retention
Habitat gain		90-110% retention	111-120% retention	111-120% retention	>130% retention

90. BITHABSIM – *Deleatidium* habitat retention compared with **status quo** flows

91. The analysis conducted in BITHABSIM predicts that modelled full irrigation development (A+B Blocks) will retain a similar amount of habitat to status quo flows (Table 16). In comparison, the modelled proposal (A+B+C Blocks) is predicted to reduce the amount of habitat available for *Deleatidium* by 10-20% compared with the status quo flows in most months, particularly in average and wet years (Table 16). In both average and wet years, the modelled proposal is predicted to reduce habitat by 20-30% in three months, generally in late spring and early summer (Table 16).

92. Overall, BITHABSIM predicts that modelled full irrigation development will result in a very similar amount of *Deleatidium* habitat to the existing allocation (status quo), with overall habitat retention of 96-99% (Table 16). In comparison, overall, the modelled proposal is predicted to retain between 81% (average year) and 91% (dry year) of the *Deleatidium* habitat available under the status quo flows (Table 16).

Table 16 Retention of *Deleatidium* habitat under flow regime scenarios based on a BITHABSIM analysis expressed as a percentage of habitat available at status quo flows for wet, dry and average months.

Month	Modelled full irrigation development			Modelled proposal		
	Dry	Average	Wet	Dry	Average	Wet
Jan	95%	94%	98%	91%	85%	76%
Feb	100%	93%	97%	100%	85%	87%
Mar	100%	93%	100%	100%	85%	97%
Apr	100%	95%	100%	97%	85%	91%
May	100%	95%	100%	85%	86%	91%
Jun	100%	96%	100%	90%	83%	84%
Jul	100%	96%	100%	94%	88%	85%
Aug	100%	96%	100%	89%	83%	84%
Sep	99%	97%	100%	88%	84%	85%
Oct	99%	97%	100%	86%	70%	83%
Nov	100%	97%	97%	82%	76%	72%
Dec	97%	96%	94%	87%	76%	75%
Overall	**99%**	**96%**	**99%**	**91%**	**81%**	**84%**
Key:						
Habitat loss	<70% retention	70-79% retention	80-89% retention	90-110% retention		
Habitat gain	90-110% retention	111-120% retention	111-120% retention	>130% retention		

Conclusions - macroinvertebrates

93. Both the status quo (A Block with existing minimum flow) and full irrigation development (A+B Blocks) scenarios are predicted to have a minor effect on macroinvertebrate habitat. The greatest effects are predicted to occur in summer as a result of the abstraction demand being greatest then. A median flow analysis predicts that the modelled proposal (A+B+C Blocks) will reduce macroinvertebrate habitat in most months during dry and average conditions, reducing *Deleatidium* habitat by up to 28% and food producing habitat by up to 30%. BITHABSIM predicts that overall *Deleatidium* habitat will be reduced by 11-25%, with reductions of more than 30% predicted in some months.

94. When compared with the status quo flows, the median flow analysis predicted that the modelled proposal will reduce *Deleatidium* habitat by up to 28% in some months and food producing habitat by up to 30%. Analysis using BITHABSIM indicates that the overall effect of the modelled proposal will reduce habitat for *Deleatidium* by 9-19%, with reductions of up to 30% predicted in some months.

95. Macroinvertebrate populations in braided rivers are naturally highly variable due to the disturbance caused by floods and associated bed movement and can vary by an

order of magnitude or more[31]. Thus, while reductions of more than 30% were predicted for some months, this should be viewed in the context of natural fluctuations caused by large floods.

CONCLUSIONS

96. There is the risk that the modelled proposal (A+B+C Blocks) will lead to an increase in the frequency and magnitude of nuisance periphyton proliferations compared with present conditions. Such growths will still be controlled by naturally occurring floods and freshes to some extent, with the frequency of flows in excess of 200 m^3/s unchanged under the modelled proposal. Closing the intake for the first 24 hours of the rising limb of some or all of smaller freshes (e.g. when flows exceed approximately 100 m^3/s) following more than 30 days of low flows is an appropriate starting point for any necessary mitigating any effects of the modelled proposal on periphyton. I believe the effect of the modelled proposal on periphyton can be appropriately managed so that it is no more than minor.

97. Both the existing (A block with existing minimum flow) and full irrigation development (A+B Block) scenarios are predicted to have a minor effect on macroinvertebrate habitat with the greatest effects predicted to occur in summer as a result of the abstraction demand being greatest then. A median flow analysis predicts that the modelled proposal (A+B+C Blocks) will reduce macroinvertebrate habitat in most months during dry and average conditions, reducing *Deleatidium* habitat by up to 28% and food producing habitat by up to 30%. BITHABSIM predicts that the AHP will reduce overall *Deleatidium* habitat by 9-24%, with reductions of more than 30% predicted to occur in some months.

98. The median flow analysis predicted that the modelled proposal will reduce *Deleatidium* and food producing habitat by 20-30% in most months in dry and average years but effects will be minor (<10%) in wet years when compared with existing (status quo) flows. Analysis using BITHABSIM indicates that when compared with existing flows, the overall effect of the modelled proposal will be to reduce habitat for *Deleatidium* by 9-19%, with reductions of up to 10-20% predicted in most months and reductions of 20-30% predicted for summer months, particularly in the average and wet years considered.

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[31] For example: Sagar, P.M. (1986). The effects of floods on the invertebrate fauna of a large, unstable braided river. *New Zealand Journal of Marine and Freshwater Research* **20**: 37-46; Scrimgeour, G.J., Davidson, R.J., Davidson, J.M. (1988). Recovery of benthic macroinvertebrate and epilithic communities following a large flood, in an unstable, braided, New Zealand river. *New Zealand Journal of Marine and Freshwater Research* **22**: 337-344; Hughey, K., Fraser, B.R., Hudson, L.G. (1989). Aquatic invertebrates in two Canterbury rivers - related to bird feeding and water development impacts. *Science & Research Series No.* **12**, Department of Conservation, Wellington.

99. I anticipate that the modelled proposal (A+B+C Blocks) will have no more than a minor effect on the viability of macroinvertebrate populations, particularly *Deleatidium*, in the Waiau River. The significance of any effects of the modelled proposal on macroinvertebrates on other values is considered by Dr Hayes (fish) and Dr Sanders (birds).

Appendix A

Details of modelling using BITHABSIM

In our application of BITHABSIM to the Waiau, we approximated mortality caused by high flow events using the relationship between flow and the proportion of the river bed moved, which can be estimated by instream habitat modelling. In this case, mortality (as a proportion of the population) was estimated from the proportion of the bed deep-flushed[32] predicted by the 1-D model of Mr Jowett up to the median flow (73.5 m^3/s) and by the 2-D model[33] at higher flows, up to 1,400 m^3/s (Figure 3B).

The pattern of recovery of invertebrate populations (in this case *Deleatidium*) is represented by the logistic equation[34] (Figure 3D). The logistic equation is often used to represent the theoretical growth in populations of organisms that are limited by some factor(s) (e.g. resources, space). It predicts a rapid rate of population growth at low population size (relative to the carrying capacity[35]), with the growth rate of the population slowing as it approaches the carrying capacity until no net population occurs (once the carrying capacity is reached). It should be kept in mind that when I refer to recovery of the invertebrate population in this context, I am referring to recovery towards the carrying capacity, not recovery to the population size prior to the disturbance event. It is likely that the frequency of disturbance in most New Zealand rivers prevents invertebrate populations from ever reaching carrying capacity.

The intrinsic growth rate (*r*) used in the modelling for the Waiau River was 0.025. I believe that this is a suitable value for use in an unstable braided river based on a review of studies that present information on invertebrate population dynamics following flooding in a number of braided rivers (Ashley[36], Rakaia[37], Rangitata[38], Waimakariri[39]).

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[32] Mobilisation of the armour layer (when shear stresses are sufficient to move all but the largest 15% of particles).

[33] Duncan, M.; Bind, J. (2009). Waiau River instream habitat based on 2-D hydrodynamic modelling. Environment Canterbury Technical Report R09/26.

[34] $$\frac{dN}{dt} = rN\frac{(K-N)}{K}$$

[35] The theoretical maximum population size

[36] Scrimgeour, G.J., Davidson, R.J., Davidson, J.M. (1988). Recovery of benthic macroinvertebrate and epilithic communities following a large flood, in an unstable, braided, New Zealand river. *New Zealand Journal of Marine and Freshwater Research* **22**: 337-344.

[37] Sagar, P.M. (1986). The effects of floods on the invertebrate fauna of a large, unstable braided river. *New Zealand Journal of Marine and Freshwater Research* **20**: 37-46.

[38] Bonnett, M.L. (1986). Fish and benthic invertebrate populations of the Rangitata River. Fisheries Environmental Report No. 62. Fisheries Research Division, N.Z. Ministry of Agriculture and Fisheries, Christchurch.

[39] Hughey, K., Fraser, B.R., Hudson, L.G. (1989). Aquatic invertebrates in two Canterbury rivers - related to bird feeding and water development impacts. Science & Research Series No. 12, Department of Conservation, Wellington.

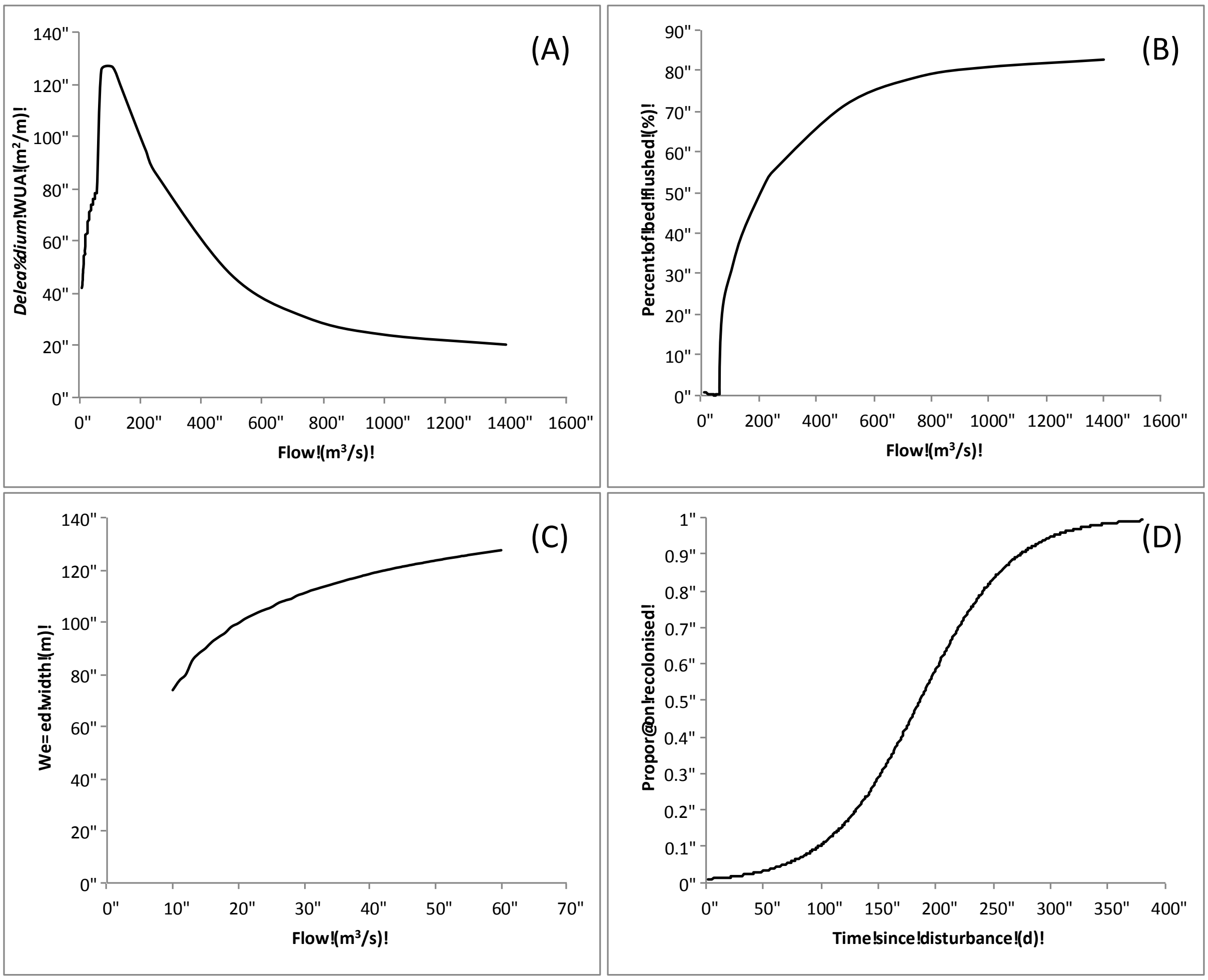

Figure 3 Inputs used in the BITHABSIM analysis of the effect of the AHP on *Deleatidium* in the Waiau River. (A) Flow-WUA (habitat) relationship for the median flow channel[40], (B) the percentage of the bed moving in the median flow channel at different flows[33], (C) Flow-wetted width relationship for the median flow channel [41], (D) Relationship between the time since disturbance and recovery of invertebrate population (proportion colonised) (Logistic equation, r=0.025).

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[40] Based on the 1-D instream habitat model of Mr Jowett for flows of less than 60 m^3/s and the 2-D model of Duncan & Bind. (2009, Waiau River instream habitat based on 2-D hydrodynamic modelling. Environment Canterbury Technical Report R09/26) for flows in excess of 73 m^3/s.

[41] Based on the 1-D instream habitat model of Mr Jowett extrapolated to the median flow (73.2 m^3/s).