**BEFORE THE ENVIRONMENT COURT**
**AT CHRISTCHURCH**

**ENV-2010-CHC-115, 123, 124 AND 135**

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| **IN THE MATTER** | **of Appeals pursuant to Section 120 of the Resource Management Act 1991** |
| **BETWEEN** | **WEST COAST ENT INC**<br>**Appellant** |
| **AND** | **ROYAL FOREST AND BIRD PROTECTION SOCIETY OF NEW ZEALAND INC**<br>**Appellant** |
| **AND** | **WHITE WATER NEW ZEALAND INC**<br>**Appellant** |
| **AND** | **DIRECTOR GENERAL OF CONSERVATION**<br>**Appellant** |
| **AND** | **WEST COAST REGIONAL COUNCIL AND BULLER DISTRICT COUNCIL**<br>**Respondents** |

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# STATEMENT OF EVIDENCE OF
# HENRY ROLAND HUDSON
FOR DIRECTOR-GENERAL OF CONSERVATION
Dated: 22 May 2012

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**AND** **MERIDIAN ENERGY LIMITED**
**Applicant**

**AND** **FRIDA INTA**
**Section 274 Party**

**AND** **WHANAU PIHAWAI WEST –**
**RICHARD WAYNE BARBER AND IRI**
**MAY BARBER MILNER**
**Section 274 Party**

**AND** **J MacTAGGART**
**Section 274 Party**

**AND** **ORION ENERGY NZ LTD,**
**ALPINE ENERGY LTD, MAIN**
**POWER NZ LTD AND**
**ELECTRICITY ASHBURTON**
**LTD**
**Section 274 Party**

**AND** **NZ RAFTING INC**
**Section 274 Party**

**AND** **ANN SHERIDAN**
**Section 274 Party**

**AND** **BULLER ELECTRICITY**
**Section 274 Party**

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# 1. QUALIFICATIONS AND EXPERIENCE

1.1. My full name is Henry Roland Hudson. I am a scientist and Director of Environmental Management Associates. I have a BA and MA in Geography from the University of Canterbury and PhD specialising in river systems from the University of Alberta. I undertook postgraduate study in engineering (Doctoral candidate, Civil Engineering, Alberta 1984-1985). I was trained in Instream Flow Incremental Methods (IFIM) with the United States Fish and Wildlife Service (the developers of IFIM) and worked on the development and applications of the methodologies in Canada.

1.2. I have authored more than 200 technical reports and presented addresses to hearings, Environment Court and international symposia on matters related to this hearing including instream habitat ("IFIM" "environmental flow" "instream flow") and hydro-geomorphological investigations in the Cardrona, Eglington, Mangaotea, *Mokihinui*, Opihi, Pomahaka, Shag, Taieri, Tongariro and Wilberforce rivers for the Department of Conservation; Eyre Creek and the Aparima, Ashburton, Cam, Hutt, Kaiapoi, Makarewa, Mataura, Motupiko, Oreti, Orewia, Upukerora and Waipahi rivers for regional and district councils; and the Ashburton, Charwell, Conway, Fraser, Greenstone, Mokauiti, Rakaia, Rangitata, Stour, Waikaka, Waimakariri and Wairau rivers and Oterenga Stream for others.

1.3. Other recent relevant peer reviewed works include an invited paper to the Hydrological Sciences Journal on quality assurance in hydrological measurements; a keynote address on river management for the International Gravel Bed Rivers Workshop; a keynote address on linking the physical form and processes of rivers with ecological responses for the IAHS-UNESCO International Symposium on the Structure, Function, and Management Implications of Fluvial Sedimentary Systems; and two keynote addresses on instream flow modelling to Australasian Hydro Power Conferences; and an invited review of instream flow habitat modelling in New Zealand.

1.4. I am familiar with the Mokihinui River, and other rivers in the region, to which these proceedings relate.

1.5. I have read the Environment Court's Code of Conduct for Expert Witnesses, and I agree to comply with it. I confirm that the issues addressed in this brief of evidence are within my area of expertise.

1.6. I have not omitted to consider material facts known to me that might alter or detract from the opinions expressed. I have specified where my opinion is based on limited or partial information and identified any assumptions I have made in forming my opinions.

1.7. My opinions rely in part on the evidence presented by the applicant to the council resource consent hearing and this hearing, and the data exchanged in 2011. I focus on the overview of Dr James, the evidence and reports of Dr Hicks (2007, 2011) and Mr Jowett (2007, 2009 & 2011). I participated in expert meetings in 2008 and 2010 and I am a signatory of the Joint Statements on "Aquatic Ecology" and "River Sediment and Geomorphology."

## 2. SCOPE OF EVIDENCE

2.1. I have prepared evidence on behalf of the Department of Conservation (DOC). My evidence will deal with the following:

(a) River form and processes in the lower river from the proposed dam to the tidal limit (river km 3 to 12);

(b) Instream habitat in the lower river (river km 3 to 12); and

(c) Aspects of the hydro-geomorphology of the lower Mokihinui gorge (river km 12 to 26) and reservoir in support of the evidence of Dr Lloyd concerning riparian vegetation.

2.2. I limit my evidence to a consideration of environmental effects. In this evidence statement, unless I state otherwise, all references to evidence of the applicant's witnesses refers to evidence in chief provided in 2011.

## 3. KEY FACTS AND OPINIONS

### Instream Habitat

3.1. There are well documented concerns regarding the lack of rigour and misuse of instream habitat modelling with resulting poor outcomes. It would be reassuring if the national track record for instream flow recommendations and assessments was excellent, but this is not the case historically, or for the Mokihinui instream flow assessment. The Mokihinui modelling results are unreliable.

3.2. The proposed flow ramping (from 16 $m^3/s$ to 126 $m^3/s$ up to twice daily) would result in a faunal and florally denuded river. The situation is more extreme than previously thought with reductions of at least 70% of habitat, to elimination of habitat, depending on species and life stage. Habitat will be concentrated into constantly moving progressively narrower bands as flows ramp.

3.3. The bed will be severely disturbed. Dr Hicks (paragraph 6.32) now reports sand <u>and gravel</u> will be mobilised “Thus for pebbles [gravel], the effect will be more like the twice-daily sweeping of a broom.”

3.4. With the proposed ramping, the minimum flows will frequently be reduced to about the mean annual low flow. For this situation Mr Jowett had proposed the minimum flow should be raised to provide close to the optimum habitat (i.e. 27 $m^3/s$ to 50 $m^3/s$ for indicator species).

3.5. The river will change downstream of the dam with a loss of sand and gravel, with the bed becoming coarser. Habitat quality will decrease for some species and there is a risk the bed may become too armoured to be suitable habitat for benthic invertebrates and native fish.

3.6. As bedrock is exposed (by the removal of gravel, cobbles or boulders) habitat will become less suitable for most species and will be eliminated for trout spawning, adult trout that utilise cobble/boulder habitat, bluegill bully and torrentfish.

3.7. Structural changes (e.g. degradation of riffles, and deepening of pools) have not been considered by the applicant, but could be important.

3.8. It is unlikely that fish habitat and benthic invertebrate habitat will improve post dam because: the amount of sand in the riverbed is already less than guideline values; sediment will still be contributed from the tributaries, and from upstream in flood flows; and sand and gravel will be frequently mobilised with the flow ramping.

3.9. The flow ramping could be modified (beyond the whitebait season), and the proposed minimum flow doubled, to mitigate adverse effects. Degradation, coarsening of the river bed and exposure of bedrock will fundamentally change the available habitat in the river from the present condition. These changes will not be able to be avoided, remedied or mitigated at the scale required.

**River form and processes**

3.10. The major point of difference is the magnitude and rate of the projected channel changes. In my opinion the modelling assumptions, and lack of calibration of degradation, probably lead to underestimates of the rate and depth of degradation.

3.11. I found that far greater than projected bed level changes occur. The upper kilometre of river is not shallow bedrock as previously assumed. In this reach there are deep scour holes and bed level changes of up to 1.7 m occur from event to event. In the Seddonville reach up to 4 m of recent erosion is evident. In the bridge reach side bars have been removed and the bed has degraded across about two thirds of the channel since 1957

3.12. Scour and fill presently causes significant turnover of the Mokihinui river bed. When the supply of bed load is interrupted by the dam, the bed material required to fill in the scoured channels will no longer be available in present day quantities, and I expect the bed will degrade far in excess of the model projections.

3.13. It is not possible for the river to develop static armour to arrest degradation from local material or exotic sources (i.e. out of the river bed). These sources do not supply large boulders in sufficient quantities to provide extensive bed protection.

3.14. An additional concern raised by the 2011 investigations is the assumption of bedrock stopping erosion. Relatively rapid erosion into the mudstone bedrock of the lower Mokihinui River is evident.

3.15. I now conclude that the proposed bank protection mitigation measures are unlikely to be successful without extraordinary expenditure and may never be implemented at a cost to the operator of the MHP scheme.

3.16. The proposed mitigation measures will not address the potential decrease in habitat quality because of a loss of gravel, exposure of bedrock, or evolution of the river bed.

3.17. Also, the proposed mitigation measures will not address the decrease in habitat quality caused by the frequent sweeping of sand and gravel from the riverbed with the flow ramping.

## Mokihinui gorge hydro-geomorphology

3.18. The riparian turf zone generally occurs to an elevation 3 to 4 m above the median flow level; but this varies depending on specific site conditions:

(a) Highly exposed bedrock is largely devoid of any vegetation, with turf vegetation in some of the fractures (particularly in the greywacke rock);

(b) In less exposed areas, where sediment accumulates, the riparian turf dominates; and

(c) In low velocity areas, shrub vegetation extends to around the median flow water level.

3.19. The riparian turf zone is frequently inundated by freshes and floods, with high water velocities, in a narrow channel (typically 40 m wide at the water surface and 60 m wide at the turf-shrub transition).

3.20. The most significant effect of the creation of the reservoir is that the effective width of flowing water will increase greatly (typically a width around 200 m up to 500 m). My expectation is that the typical velocities will drop dramatically, and will probably be much closer to the low velocities shelters in the present gorge where shrub vegetation is found to around the median flow water line.

3.21. I expect the hydro-geomorphological characteristics of the gorge that determine the viability of the riparian turf will be eliminated, and this effect cannot be avoided, remedied or mitigated.

## 4. INSTREAM HABITAT

4.1. Instream habitat ("instream flow") modelling is one of the tools used to make instream flow decisions. It requires rigorous application, measures of confidence, and verification. The modelling requires a great deal of judgement, and is not a substitute for common sense, critical thinking about stream ecology or careful examination of the consequences of flow modification.

4.2. Internationally and nationally there are well documented concerns regarding the lack of rigour and misuse of instream habitat modelling to guide flow decisions for hydro power schemes. (Appendix 2). The results can be devastating.

4.3. It would be reassuring, with the degree of uncertainty before the Court, if the track record for instream flow recommendations was excellent. Unfortunately, this is not the case historically, or for the Mokihinui.

4.4. In terms of history, Mr Jowett cites success in 5 of 6 case studies. I have examined these case studies and found the claims are not supported (Appendix 1). In brief:

(a) The post-hoc assessments of prescribed flows did not rigorously compare before and after instream effects on aquatic life. Alternative flows were not trialled (e.g. prescribed flow plus 5 $m^3/s$, prescribed flow plus 10 $m^3/s$). In short, even if an improvement were shown, we have no idea whether a greater or less flow would be more suitable;

(b) Other evidence demonstrates the purported instream benefits to benthic invertebrates and sports fish have not occurred or are unlikely to have occurred;

(c) Other evidence suggests significant adverse effects have occurred to native fish with the prescribed flows compared with a natural flow regime; and

(d) Different flows to those originally prescribed were implemented (Monowai and Waiau), occurred (Tekapo), or were recommended (Waipara).

4.5. In terms of the Mokihinui, Mr Jowett has made a number of unreliable judgements about variability of river characteristics (Appendix 2); designation of habitat units (Appendix 3), the role these units play in flow-habitat relationships (Appendix 4), and calibration and verification (Appendix 5). From my investigations I conclude:

(a) I concur with the developers of instream habitat modelling – the accurate designation and weighting of habitat units is critically important in establishing flow-habitat relationships;

(b) The calibration in 2007 (which continues to form the basis of Mr Jowett's evidence) was contrary to recommended practice, and the erratic nature of the modelled velocity profiles and extreme velocities in many cross sections, are sufficient grounds to dismiss the hydraulic calculations as unreliable; and

(c) There is no verification of the habitat calculations, or measures of confidence, which are expected steps in rigorous scientific investigations.

4.6. A critical concern is that additional investigations in 2011 reveal fundamentally important differences in channel conditions which strongly influence instream habitat and future river characteristics. However, the conclusions of the applicant have not changed. In my view the conclusions should be substantially different.

4.7. A critical point of difference is that Mr Jowett (4.21) opines "The addition of the 2011 survey data <u>changed</u> the calculated values of water level and instream habitat <u>slightly</u>. These changes were <u>not sufficient to alter</u> the conclusions that I presented in the resource consent hearing" [My emphasis]. I disagree for the reasons outlined below.

4.8. In terms of hydraulics the changes are not slight – they are greater than the effects of many proposals before hearing commissioners or the Court:

(a) The 2007 cross sections are located in areas that could be surveyed from a jet boat. Some critical shallow areas were avoided, and deep pools were avoided. No surveys were undertaken in the middle-upper reaches (Figure 1). "Impossible to survey" sites were surveyed in 2011 with the extension into the middle and upper river below the proposed dam;

(b) The average measured width increased from 56 m (2007 survey) to 78 m (2011 survey);

(c) The average measured depth increased by 7%, but there is more than twice the variability in average depth in the 2011 cross sections. The average depth of the deepest pool increased 264% (from 1.42 m in the 2007 survey to 3.74 m in the 2011 survey); and

(d) The average velocity decreased by 63% from 0.55 m/s (2007 survey) to 0.35 m/s (2011 survey).

4.9. In terms of habitat the changes are not slight – they are significant:

(a) Changes in velocity and depth are fundamentally important to the habitat suitability for various species and life stages (Figure 2);

(b) The peak of food producing habitat is 25% greater in the combined survey (2007 plus 2011 surveys) than in the original 2007 survey (Figure 3);[1]

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[1] Adult brown trout and/or food producing habitat (Waters 1976) are often used as critical values in instream flow assessments (e.g. Jowett 1993; Hay & Hayes 2004; Hudson 2010). The rationale is provided in Jowett & Hayes (2004) and repeated in Jowett et al. (2008) and the proposed National Environmental Standard (Beca 2008). "In New Zealand, it has generally been assumed that minimum flows set for salmonids will be adequate to maintain native fish populations."

(c) The peak in food producing habitat occurs at less than half the flow in the combined survey (i.e. 27 $m^3/s$ against 58 $m^3/s$; Figure 3);

(d) Slight differences occur between the surveys for adult brown trout habitat with peak habitat in both surveys around 31 $m^3/s$ (Figure 4). However, the curves diverge at higher flows with 13% more habitat in the combined survey at the median flow;

(e) The peak for adult brown trout habitat for a cobble/boulder dominated river[2] occurs at 52 $m^3/s$ (Figure 4); and

(f) The shape and position of the flow-habitat relationships for native species change greatly (e.g. Figure 5).

4.10. I conclude the normal target species (adult brown trout) optimum habitat occurs between 30 and 50 $m^3/s$. Food producing habitat peaks at 27 $m^3/s$. As expected, native fish low velocity and shallow water habitat is limited to the edges of the channel.

4.11. Based on the logic of Mr Jowett, and the use of adult trout and food production as critical values, the minimum flow should be at least twice the minimum flow recommended by Mr Jowett (i.e. more than 30 $m^3/s$, not 16 $m^3/s$). I reach this conclusion based on the following:

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[2] The use of the brown trout adult feeding boulder suitability curve (BTA boulder) is logical because the bed surface is already cobble/boulder dominated and will become coarser over time as the sand and gravel is swept downstream and not replenished.

(a) Minimum flows will occur up to twice daily for protracted periods. Mr Henderson notes (paragraph 7.4) “Nearly 35% of the time would be spent at or below the minimum flow, compared with 3% of the time at or below this flow naturally” and

(b) “If the flow is likely to be at that minimum frequently, I usually recommend flows closer to the optimum.” (Mr Jowett paragraph 7.3).

4.12. I remain critical of the flow ramping. I do not consider a flow fluctuation range of 16 to 46 $m^3/s$ is a reasonable scenario to examine effects of flow ramping (Mr Jowett paragraph 6.19). I disagree for the following reasons:

(a) As noted by Mr Watts and Dr James, frequently there will be twice daily flow releases increasing the flow from 16 to 126 $m^3/s$; and

(b) As noted by Dr Kelly, the natural flow daily flow ramps 110 $m^3/s$ or more (equivalent to 16 to 126 $m^3/s$) on approximately 5% of flow days for the 25-year modelled flow record between 1972-1993. Thus daily flow changes of this magnitude occur slightly less than on a monthly basis. There were no such occasions where this change in flow occurred twice in one day as proposed by the applicant.

4.13. There is a critical difference with the 2007 investigations regarding flow ramping:

(a) Previously, Hicks et al. (2007) reported "...the modal sand fraction (1.4 mm) would just become mobile during the high shear stress phases when the flow was ramped-up rapidly;"

(b) Dr Hicks (paragraph 6.32) now reports that the daily flow fluctuations will entrain sand and gravel. "Thus for pebbles [gravel], the effect will be more like the twice-daily sweeping of a broom;"

(c) Mr Jowett (paragraph 4.11) describes a suitable flow regime as removing excess fine sediment, not disturbing the gravel/cobble bed;

(d) Jowett (2003b) reports reduced benthic invertebrate abundance where substrates are frequently disturbed; and

(e) Mr Bonnett (paragraph 7.6) does not appear to be aware that the sand and gravel will be moved during the frequent flow fluctuations, which undermines his opinion of improvements in habitat for invertebrate food and native fish.

4.14. I modelled flow ramping over the range 16 to 126 $m^3/s$. I concur with Dr Death that the ramping would result in a faunal and florally denuded river with concomitant effects on the fish and birds that depend on them for food in that downstream ecosystem. I found the following:

(a) The cross section analysis shows that the denudation occurs throughout the entire modelled reach;

(a) Food production habitat will decline by 91% and Deleatidium habitat by 76% (these losses are greater than predicted in my 2007 survey analysis);

(b) There will be no brown trout spawning habitat;

(c) Bluegill, common and redfin bully habitat will almost be eliminated; small longfin eel habitat will be reduced more than 80%; and large longfin eel habitat will be reduced more than 70%. Habitat will be concentrated into a constantly moving progressively narrower band as flows ramp; and

(d) There will be no periphyton habitat (diatoms, long filamentous algae and short filamentous algae) (the loss is recognised by Mr Jowett in paragraph 5.16).

4.15. Mr Jowett (paragraph 61.5) comments "Fish surveys below the Waitaki Dam indicated that there were high densities of native fish, trout and benthic invertebrates, despite large flow fluctuations..." I conclude the reference to the Waitaki is not helpful for the following reasons:

(a) The average daily fluctuation in the Waitaki is around 80 $m^3/s$ but the median flow is about ten times greater than the proposed Mokihinui median flow (i.e. 375 $m^3/s$; Jowett 2003a);

(b) Pro-rated by the median flow, the daily flow fluctuation of the Mokihinui would be less than 10 $m^3/s$; and

(c) For a 10 $m^3/s$ ramping habitat reduction for food production would be less than 20% (against 91%), and Deleatidium habitat by about 12% (against 72%). Brown trout spawning habitat would be reduced by ~36%, not eliminated.

4.16. I conclude that the flow ramping will be highly disruptive and will be additive to the disruption of flood flows.

4.17. I remain critical of the lack of rigorous assessment of the consequences of channel changes. Mr Jowett (2009 paragraph 3.27 & 3.28) previously opined that he considered potential channel changes and potential changes in bed material and states “I do not believe that the basic morphology will change.... In my 40 years of experience with hydro-electric schemes I have seen no evidence of biologically significant substrate change or erosion caused by reduced sediment transport.” I disagree for the following reasons:

(a) I concur with Dr Hicks that the riverbed below the dam will lose sand and gravel and the surface material will become coarser; and that the river downstream of the dam will degrade; and

(b) There is an extensive international literature of the changes in river morphology and stream ecology below dams (e.g. Dr Surens evidence paragraph 6.16 on marked differences in invertebrate communities).

4.18. In the following paragraphs I examine the consequences of the expected morphological changes.

4.19. Mr Jowett (paragraph 6.37) now opines “...the substrate will be primarily boulders and cobbles, as it is now, but possibly with less gravel. From a biological point of view, any change in substrate composition will have a minor beneficial effect on habitat quality...” I disagree for the following reasons:

(a) The bed material sampling undertaken by Dr Hicks shows that ~25 to ~50% of the surface material, and ~40 to 60% of the subsurface material is gravel size. This gravel will be progressively swept downstream from the bed surface;

(b) Gravel is highly suitable habitat for most species and life stages (Table 1);

(c) Coarsening of the riverbed from gravel dominated to cobble/boulder dominated improves potential habitat for benthic invertebrates, adult brown trout, other eels, torrentfish and bullies (Table 1);

(d) Conversely, trout spawning habitat becomes unsuitable; and there is an adverse effect on habitat quality for brown trout fry and large longfin eel; and

(e) One of the proposed mitigation measures in the draft Aquatic Ecology Management Plan (AEMP) is "Enhancement of spawning areas downstream of the dam ... by supplementing gravel supply..."

4.20. In terms of the substrate becoming coarser, Kilroy et al. (2005) found that in the Waiau River (Southland), below the Manapouri Hydro Scheme diversion, the "Lack of *Deleatidium* most likely reflects the fact that the substrate here is heavily armoured, with very large embedded particles. Under such conditions, lack of interstitial spaces reduces the habitat suitability for large, soft-bodied animals such as *Deleatidium* and some caddisflies."

4.21. In addition, bedrock is exposed downstream of the damsite and presumably the area of exposed bedrock in other sections of river will increase over time (the latter is unstated by Dr Hicks). The consequences are as follows:

(a) As bedrock is exposed (by the removal of gravel, cobbles or boulders) habitat suitability may improve (longfin eel), or remain the same (adult trout – Hayes & Jowett 1994) (Table 1);

(b) In most cases, the habitat will become less suitable (food producing habitat, Deleatidium, Zealandoperla, trout <100 m , trout fry, red fin bull, and longfin eel <300 mm); and

(c) Habitat is eliminated for trout spawning, adult trout that utilise cobble/boulder habitat, bluegill bully and torrentfish.

4.22. There was no evidence to support the contention that fish habitat and benthic invertebrate habitat will improve as sand is lost from the riverbed (Mr Jowett paragraph 6.38). This evidence is relied upon by others (e.g. Dr Surren paragraph 3.4 & 6.24). I continue to think habitat improvements are unlikely for the following reasons:

(a) There is agreement that the bed is already largely devoid of fine sediment, with limited patches of sand in beaches, pools, ends of bars and behind boulders. Transient sand ribbons do occur;

(b) The amount of fine material (<2 mm) in surface deposits (<10%) and subsurface deposits (<10%) is already less than in the proposed NZ sediment guidelines to protect salmonid spawning, native fish and benthic invertebrate habitats (the threshold is <20%) (Clapcott et al. 2011);

(c) Therefore it is unclear where or how the improvement in substrate habitat quality will occur.

4.23. The emphasis now is on a reduction in sediment transport providing improved habitat (Mr Jowett paragraphs 3.6, 6.24, 6.38 & 7.6). However, I note the following:

(a) There is recognition that any improvements in habitat are likely to be minor or less than minor (Mr Bonnett paragraph 7.16); and

(b) Dr Surren (paragraph 6.2) notes "The Mokihinui frequently carries sediment as a result of the frequent rainfall in the catchment, and the invertebrate communities are used to high sediment load, and indeed are typical of communities in other rivers carrying high suspended sediment loads."

4.24. In addition, I previously suggested that structural changes may occur. In my opinion the following changes are likely to occur, but have not been assessed:

(a) Riffles will probably evolve into rapids as the bed degrades and/or becomes coarser:

(b) Runs will probably degrade and form shallow pools; and

(c) Shallow pools will probably become deeper pools.

## 5. RIVER FORM AND PROCESSES

5.1. I concur with Dr Hicks that the sediment budget will substantially change and that the river bed downstream of the proposed dam will degrade and become coarser. The major points of difference concern the magnitude and timing of the projected channel changes; and the implications of channel changes on stream habitat.

5.2. I concur with Dr Hicks that the following morphological effects will occur downstream of the dam:

(a) Presently the Mokihinui carries a large sediment load to the coast. The delivery of fine sediment will be reduced by trapping in the reservoir. I have not tested the sediment budget modelling but it seems reasonable that initially about 40% of the fine sediment will pass through the reservoir, with more fine sediment delivery downstream as the reservoir fills with sediment. Suspended sediment bypassing will occur after about 200 years of sediment deposition in the reservoir;

(b) The supply of gravel to the lower river (and coast) will be cut off by trapping in the reservoir. Again, it seems reasonable that the reservoir will be substantially filled with sediment and gravel bypassing will occur some 450 years from now;

(c) Under existing conditions, there is relatively minor replenishment of fine sediment and gravel from the tributaries and channel erosion downstream of the damsite;

(d) The riverbed below the dam will lose sand and gravel and the surface material will become coarser over time;

(e) Bedrock is exposed downstream of the damsite and presumably the area of exposed bedrock will increase over time (the latter is unstated);

(f) The daily flow fluctuations will entrain sand and gravel in short bursts on a daily basis;

(g) The scheme will not materially change the flood regime or the ability of the river to maintain a riverbed substantially free of vegetation; and

(h) Bank erosion is occurring and bed degradation may increase the risk of bank erosion.

5.3. In my opinion the modelling assumptions probably lead to underestimates of the rate and depth of degradation. My previous concerns with the modelling assumptions have been reinforced with the 2011 investigations. Specifically,

(a) The channels are not relatively uniform and relatively shallow as previously assumed, but are typically asymmetric which influences shear stress distribution hence the erosive power of the river (**Figure 6**). This remains problematic because "... the SRH-1D model predicts a spatially-averaged bed shear stress and may underestimate the local bed shear stress at sections where the channel cross-section is not uniform." (Dr Hicks paragraph 6.16);

(b) In my opinion, many of the cross sections are not uniform, hence degradation is probably underestimated. The asymmetric channel correction applied by Dr Hicks (which scales up the model predicted bed-shear) doubles the typical degradation depths. (paragraph 6.17). I am of the view that this correction is a step in the right direction. However, this correction is based on a single gauging cross section (Burkes Creek gauge);

(c) In the dam to tidal reach the subsurface bed material is not uniform, but varies from a $D_{90}$ of ~400 mm at Rough & Tumble Lodge to ~145 mm below Chasm Gorge. In the Seddonville-Bridge reach (i.e. below Burke Creek) the $D_{90}$ varies from ~145 to 185 mm. The variation in $D_{90}$ strongly influences the force required to degrade the river (**Figure 7**), and the size of material available to develop a static armour;

(d) The first kilometre of riverbed below the dam was assumed to be bedrock.[3] The 2011 habitat survey shows the channel immediately below the proposed damsite to be laterally confined by bedrock with a gravel-cobble dominated bed surface. The bed downstream through the Rough and Tumble Lodge and Burkes Creek reach is predominantly cobble-boulders, not bedrock. Dr Hicks only sampled bed material downstream of Rough and Tumble Lodge (about 1450 m downstream of the proposed dam);

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[3] Hicks et al. (2007:90) “The bed is bedrock in the upper 1 km of the modelled reach, past the Welcome Bay cableway.”

(e) Potential degradation is not limited by shallow bedrock for much of the river as previously assumed (with bedrock usually <1 m below the bed surface in the upper reach) (**Figure 8**). Long reaches do not have bedrock exposures in the bed of the river, and it is now assumed the bedrock is at least the depth of the deep scour holes (**Figure 8**). Much of the river is not likely to have degradation arrested by bedrock; and

(f) An additional concern raised by the 2011 investigations is the assumption of bedrock stopping erosion. Rapid degradation into soft mudstone and sandstone has been measured elsewhere (Lai et al. 2011); and relatively rapid erosion into the mudstone bedrock of the lower Mokihinui River is evident (e.g. **Figure 9**). Hicks et al. (2007) estimate lateral erosion of 0.3 m per year into the bedrock.

5.4. My previous concerns with model calibration remain, and new concerns arise with the application of the new model (SRH-1D; Sedimentation and River hydraulics one dimension). Specifically:

(a) Previously the model hydraulics were calibrated against an assumed flood level (i.e. bankfull was assumed to equate to a mean annual flood).[4] The model has now been

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[4] In 2007 the model was calibrated by adjusting channel and bank form roughness so that the mean annual flood flow (1840 m3/s) just filled the bankfull channel. This assumes the bankfull channel capacity coincides with the mean annual flood, However, for a large number of South Island New Zealand rivers, bankfull flows have a recurrence interval of 1 to 10 years, with a median value of about 18 months (Mosley 1981).

calibrated at flows 81 $m^3/s$ and 3177 $m^3/s$. While this is an improvement, I still do not have a great deal of confidence in the hydraulic calibration for the following reasons:

(b) The high flow discharge (3177 $m^3/s$) was estimated by the model based on measured flood levels. This is not independent calibration. Further, the estimated flow differs from the gauge record (2866 $m^3/s$ on 28-12-2010) by more than an acceptable gauging error. There was extensive overbank flooding;

(c) From Figure 7 of Dr Hicks, the predicted water level near the Welcome Bay gauge is about 675 mm higher than the observed water level. Based on the stage-discharge relation for the gauge, the equivalent flow at the predicted water level would be around 215 $m^3/s$ not 81 $m^3/s$; and

(d) Further downstream the water level errors are greater in places (e.g. about 1000 mm 1225 m downstream) or less than the calibrated water level error at the gauge. The flow error is probably far greater than at the gauge because the channel is about twice the width at xs 1225 and the predicted water level is difference is greater.

5.5. Calibration of degradation is limited to “conditioning the bed” by adjusting inputs so that the observed bed surface is approximated before the bed load feed is stopped (i.e. the post dam condition). While this is an expected step in model calibration, it is less than what is required to provide a robust prediction of degradation. I reach this conclusion following discussion with Dr Greimann (US Bureau of Reclamation), a principal developer of SRH-1D, the model used by Dr Hicks. From the discussion and literature provided (e.g. Lai et al. 2011), I found the following:

5.6. The erosion width should preferably be calibrated based on measured channel changes over time. There is no reference to this aspect of calibration in the evidence of Dr Hicks;

(a) The entrainment threshold stress should be locally calibrated based on changes in cross sections over a period of years. This is important because the model is very sensitive to the entrainment threshold stress (Paragraph 6.20 of Dr Hicks). Changing the entrainment threshold stress at Burke Creek gauging section within logical bounds changes the predicted degradation from 0.5 m to 2.4 m. The generality of this local relation has not been tested (e.g. at the Welcome Bay gauging section where far greater changes occur as noted below; or by comparison of channel changes elsewhere in the river); and

(b) In my opinion there is insufficient calibration to have confidence in the predictions of the rate and magnitude of degradation..

5.7. There is no independent verification of the modelling, which to me is central to the difference in the opinions of myself and Dr Hicks about the rate and magnitude of degradation, as explained below.

5.8. Dr Hicks concludes (paragraph 9.5) “The rate of bed degradation would be checked by the progressive formation of a surface armour that was coarser, more uniform, and more stable than the “dynamic” armour currently observed on the bed surface.” While this sounds plausible, it is problematic because it requires introduction of substantial quantities of exotic (out of river) large boulders. Specifically,

> “... after 100 years with the dam in place, the model predicts that a very coarse, boulder armour, with a median size between 266 and 385 mm, would develop in the reach between the dam-site and Burke Creek. This would be rendered from the cobbles and boulders currently found in the bed there and supplied by Burke Creek, Podge Creek, the Gorge, and from erosion of the Pleistocene terrace that forms the true left bank. In comparison, the existing median bed-surface size is up to around 120 mm.” (Dr Hicks paragraph 6.14e) [My emphasis];

5.9. In my opinion, it is unlikely that adequate large boulders will be supplied to the river to form the static armour to arrest degradation. I reach this conclusion based on the following:

(a) “Almost everywhere, the river bed surface material is coarser on average than the sub-surface material...” (Dr Hicks paragraph 5.10). Hence, exposure of subsurface material will not provide boulders that are larger than the present surface material;

(b) If the coarsest surface material sampled by Dr Hicks is censored (i.e. all the sand and gravel is removed so that only the cobbles and boulders remain) then the resultant median size is far less than predicted 266 to 385 mm median size. Hence, even the residual cobbles and boulders available on and in the bed will not provide the required median particle size. An exotic source (beyond the river bed) is required;

(c) Burke Creek and the eroding left bank terrace immediately downstream provide large boulders to the river. However, Hicks et al. (2007) note the supply of bedload (let alone large boulders) is relatively small, the available boulders in the bank are less than 500 mm, and the boulders delivered to the channel have not moved far from their source. These sources cannot provide sufficient quantities of the boulders required to create the modelled static armour;

(d) In my opinion Coal Creek is unlikely to contribute large boulders. While there are boulders at the road bridge, the bed near the mouth is predominantly gravel. Podge Creek surface bed material is predominantly cobble and small boulder, not large boulders; and

(e) Bed material supply from the Gorge will be cut off; hence large boulders will not be supplied to the lower river.

5.10. Further downstream it is predicted that after damming the size of the static bed armour will increase by about 50 mm. “...the armour would be smaller, with a median surface size decreasing from about 200 mm [below Coal Creek] to about 100 mm in the estuary, although this would still be 50 mm coarser than the existing dynamic armour.” (Dr Hicks paragraph 6.14e). Again this is problematic for the following reasons:

(a) An exotic source of large cobbles and boulders is required to achieve the predicted median size with a censored local bed material (i.e. with the sand and gravel removed); and

(b) Bank erosion through the Seddonville reach does not presently provide a supply of the boulders required to create the static armour (e.g. Figure 10); and there are no apparent sources of boulders in the Chasm Creek to bridge reach.

5.11. I conclude that the ability of the river to develop a static armour by increasing the size of the bed material from local material is not possible given the size limitations of the local stock of material, and that exotic sources (i.e. out of the river bed) do not provide sufficient large boulders to provide extensive bed protection.

5.12. The following conclusions of Dr Hicks (paragraph 6.14b), can be tested. “Degradation is predicted along most of the channel, although the extent varies and aggradation is actually predicted at a few sections. The typical degradation after 100 years is between 0.1 and 0.4 metres. The most degradation, up to 0.95 metres, occurs in the first ~ 1600 metres downstream from the dam. The degradation also locally exceeds 0.4 metres in the estuary (around chainage 12000 metres) where the river constricts at the mouth. The degradation in the vicinity of the State Highway Bridge ranges from zero to about 0.2 metres.” To test these conclusions I examined channel changes.

5.13. I found that observed rates and magnitudes of degradation are far in excess of the projections of Dr Hicks.

5.14. Previously, Dr Hicks predicted that there would be no erosion in the 1000 m below the dam. Now it is predicted that there will be up to 0.95 m in the first 1600 m downstream from the dam. From Dr Hicks Figure 31, the greatest change (0.95 m) occurs 125 m from the dam. A little further downstream, at the Welcome Bay cableway, the predicted change in bed level over 100 years is around 0.6 m.

5.15. In contrast, at the Mokihinui gauge (Welcome Bay) I found the following:

(a) Far greater than projected bed level changes occur from event to event, not decades or tens of decades (Figure 11). The mean bed level and minimum recorded bed level has varied by about 0.7 m and 1.7 m, respectively since 1980;

(b) The mean bed levels and minimum bed levels of Figure 11 provide an incomplete picture. The deepest part of the channel can shift across the bed, because of scour and fill (e.g. Figure 12), but there is not necessarily a change in mean bed level or minimum bed level; and

(c) When the supply of bedload stops, my expectation is that the mean bed level could drop by 1 to 2 m (perhaps more depending on the level of the bedrock) in a single large event or series of events within a few years.

5.16. Similar analysis has not been undertaken for Mokihinui River Burke Creek gauge. The gauging cards are hand written and must be retrieved from archive.

5.17. I concur with Dr Hicks (2007) that there are no systematic historic cross-section surveys at multiple locations from which to determine bed level trends. However, I disagree with the statement "... neither is there geomorphic evidence of aggradation or degradation, at least in the alluvial reaches." I reach this conclusion based on an examination of 2011 cross section surveys and a comparison of channel changes in available aerial photographs. I noted there was an evolution in the channel position from the 1955 to 1966, 1973, 1987 and 2007. My findings include the following:

(a) Channel evolution is ongoing as illustrated in Figure 10 to Figure 16

(b) The present regime maintains a riverbed that is substantially free of shrubs and trees.

Inundation by flood water is usually not sufficient to uproot trees and shrubs (Figure 13), they must be undermined by lateral erosion;

(c) Bank protection works that were constructed in the lower Seddonville reach have been isolated as the deepest part of the channel has shifted from the left to the right bank (Figure 14 and Figure 15);

(d) Aerial photographs show large channel shifts, in places from bank to bank, occur (e.g. from 1966, 1973, 1987 2007). In Figure 15 I illustrate changes at cross sections where unequivocal shifts have occurred and bed surveys are available. My analysis shows that scour of the river bed of 2 to 3 m is likely to have occurred since 1966 to facilitate the channel shifts. If the channel laterally shifted (as suggested by the 1973 and 1987 aerial photographs) then up to about 4 m of bed was eroded since 1966; and

5.18. In the plane bed reach around the State Highway Bridge, there is evidence of scour and fill in the bridge reach and degradation at the bridge. I reach this conclusion based on the following:

(a) Exposed bars along the side of the channel have been removed in the bridge reach, but the depth of scour cannot be accurately estimated from the aerial photographs and cross section surveys of Dr Hicks (Figure 16); and

(b) Dr Hicks (paragraph 6.28) notes "...the mid-channel bridge piers extend to approximately 2.8 metres below mean sea level, with over 4 metres of pier buried in the river bed. Our modelling suggests that general degradation at the bridge section would be of the order of 0.2-0.4 metres over 100 years..." I disagree, for the following reasons:

(c) The 1957-1958 bridge plans state the nominal depth of burial of these particular piles was 17 feet (5.2 m). The "as built" survey shows a burial depth of 5.4 m for Pier G and 5.5 m for Pier H;

(d) The bridge plans show the piles of Pier F near the left bank are buried. Presently, they are exposed;

(e) Since the bridge surveys the bed appears to have degraded across about two thirds of the channel by about the amount Dr Hicks predicts in the 100 years post dam (Figure 17). There is little apparent change at the mid channel piers, but this may reflect a "snap shot" of a dynamic system (e.g. Figure 11 & Figure 12): and

(f) I would expect that as the river moves out of a quasi equilibrium (with the supply of bedload changing) that the cut and fill process that occurs in the bridge reach to maintain a vegetation free river bed will cross a threshold and degradation will result.

5.19. I conclude that scour and fill presently causes significant turnover of the Mokihinui river bed. This requires that the armour is breached and reforms on the waning flood and subsequent events. When the supply of bed load is interrupted by the dam, then the bed material required to fill in the scoured channels will no longer be available in present day quantities, and the bed will degrade.

5.20. The implications of these morphological changes on habitat for fish and benthic invertebrates in the lower river are contested. I discuss habitat implications in the section on Instream Habitat.

5.21. I remain of the view that the proposed mitigation measures will not address the potential decrease in habitat quality because of a loss of gravel. Further, I am of the view that measures to supplement gravel supplies would be extremely expensive, and likely to fail (Hudson 2002), particularly in this high energy environment (e.g. Figure 10).

5.22. I remain of the view that the proposed mitigation measures will not address the potential decrease in habitat quality because of the evolution of the river bed with the probable degradation. Further, the probable exposure of large areas of bedrock will reduce habitat quality for many species and will not be able to be effectively mitigated.

5.23. I have revised my position from that which I provided at the council hearing about the effectiveness of the proposed

Erosion Monitoring and Management Plan presented by Dr Hicks. In my view it would be extremely expensive to construct effective bank protection works in this high energy environment. Also, in my view it would be extremely difficult, if not impossible, to prove definitively that bank erosion at any particular point and time had been accelerated or caused by the MHP. Therefore, it is unlikely that responsibility for bank protection will shift from the Council and/or landowners.

5.24. I add the concern that the mitigation measures will not address the decrease in habitat quality caused by the frequent sweeping of sand and gravel from the riverbed with the flow ramping.

5.25. I conclude that the potential morphological effects of the scheme are underestimated and the implications for habitat are not considered but will probably significantly alter the habitat suitability for benthic invertebrates, fish and periphyton.

5.26. I conclude that the proposed morphological mitigation measures are unlikely to be successful without extra ordinary expenditure and may never be implemented at a cost to the operator of the MHP scheme.

## 6. MOKIHINUI GORGE HYDRO-GEOMORPHOLOGY

6.1. Dr Lloyd discusses the significance of the riparian vegetation in the Mokihinui Gorge. Here I provide some supporting information on the hydrology and geomorphology of the gorge.

6.2. Survey details are in Appendix 6. In brief, the survey was undertaken on the Mokihinui River gorge from Specimen Creek to the Welcome Creek gauge cableway; and Karamea River gorge from below Greys Hutt to the Gorge gauge cableway. The surveys were undertaken at higher than median flow on the Karamea River and around the median flow on the Mokihinui. We walked the Karamea Gorge and rafted the Mokihinui Gorge. Vegetation surveys were undertaken at 11 sites on the Mokihinui River and 15 sites on the Karamea River.

6.3. Presently the Mokihinui gorge has large frequent floods. The water levels in the gorge can fluctuate by several metres. In the 28 December 2010 flood (about a 1 in 50 year event) the water level rose about 7 m over the median flow level. Our site investigations were on 7-9 April 2011.

6.4. The riparian turf zone generally occurs to an elevation 3 to 4 m above the median flow level; but this varies depending on specific site conditions.

6.5. Based on 17 years of complete flow records at the exit of the gorge, there are a large number of events that attain a water level of 4 m. There were over 120 events that had a water level of 4 to 5 m, 65 events with water levels of 5 to 6 m, 15 events with water levels of 6 to 7 m, and two events with water levels exceeding 7 m.

6.6. The flow velocities would be high. For example, at a gauged flow of 1017 $m^3/s$, the maximum velocity was 3.9 m/s. In asymmetric channels and in bends the velocities are likely to be greater.

6.7. The patterns of the riparian vegetation appear to be controlled by the degree of exposure to the high velocities of the river.

(a) Exposed bedrock forming the channel margins is largely devoid of any vegetation, with turf vegetation in some of the fractures (particularly in the greywacke rock);

(b) In less exposed areas, where sediment accumulates, the riparian turf dominates. There appears to be a positive feedback in this regard, with the turf and other vegetation trapping sediment; and

(c) In low velocity areas, shrub vegetation extends to around the median flow water level.

6.8. The most significant effect of the creation of the reservoir behind the dam is that the effective width of flowing water will increase dramatically:

(a) At median flow the present top width of the river is typically about 40 m; and the width at the typical riparian turf-shrub level is around 60 m[5]; and

(b) With the proposed reservoir the typical width will increase to around 200 m (500 m at its widest point; Hicks et al. 2007).

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[5] The Karamea gorge is somewhat wider. At the survey points the typical width at around the median flow was 53 m and the typical shrub height width was 72 m.

6.9. As a consequence of the dramatic increase in width, but with essentially the same flood regime, the typical velocities will drop dramatically, and will probably be much closer to the low velocity shelters in the present gorge where shrub vegetation is found to around the median flow water line.

## 7. CONCLUSIONS

7.1. The adverse effects of the proposed flow regime on instream habitat will be significant; and apart from the whitebait season when the scheme is run-of-river, these effects cannot be avoided, remedied or mitigated. The effects are compounded by frequent river bed disturbance; and probably by changes in the river channel characteristics.

7.2. I conclude the morphological effects on the Mokihinui River will probably be significant, and these effects cannot be avoided, remedied or effectively mitigated. I suspect the community will be left to face the consequences and costs of channel instability.

7.3. I conclude that the hydro-geomorphological characteristics of the gorge that determine the viability of the riparian turf will be eliminated, and will not be replaced by the reservoir. I can see no viable options to avoid, remedy or mitigate the loss of suitable hydro-geomorphological habitat for the riparian turf.

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# TABLES

## Table 1 Effects of changing substrate

| Class | Description | Food | Deleatidium | Zealandoperla | Trout spawn | Trout <100 mm | Trout fry | Trout adult JH | Trout adult boulder |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Vegetation | 0.3 | 0 | 0 | 0 | 1 | 0.76 | 1 | 0 |
| 2 | Silt | 0.2 | 0 | 0 | 0 | 0.6 | 0.76 | 0 | 0 |
| 3 | Sand | 0 | 0.2 | 0 | 0 | 1 | 0.76 | 0 | 0 |
| 4 | Fine gravel | 0.2 | 0.2 | 0 | 0 | 1 | 0.76 | 0.3 | 0 |
| 5 | Gravel | 0.6 | 0.75 | 0 | 1 | 1 | 1 | 0.8 | 0 |
| 6 | Cobble | 1 | 1 | 1 | 0 | 1 | 0.35 | 1 | 0.5 |
| 7 | Boulder | 0.8 | 0.62 | 1 | 0 | 1 | 0.04 | 1 | 1 |
| 8 | Rock | 0.6 | 0.12 | 0.5 | 0 | 0.5 | 0.04 | 1 | 0 |

| Class | Description | Bluegill bully | Redfin bully | Common bully | Torrent-fish | LF eel <300 | LF eel >300 | LF eel small | LF eel large |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Vegetation | 0 | 0 | 1 | 0 | 1 | 1 | 0.5 | 1 |
| 2 | Silt | 0 | 0 | 1 | 0 | 1 | 0.4 | 0.495 | 0.98 |
| 3 | Sand | 0 | 0.6 | 1 | 0 | 0 | 0.5 | 0.48 | 0.88 |
| 4 | Fine gravel | 0.6 | 0.75 | 1 | 0.4 | 0 | 0.9 | 0.47 | 0.7 |
| 5 | Gravel | 1 | 0.9 | 1 | 1 | 1 | 1 | 0.47 | 0.42 |
| 6 | Cobble | 1 | 1 | 1 | 1 | 1 | 1 | 0.71 | 0.42 |
| 7 | Boulder | 0.65 | 1 | 1 | 0.65 | 1 | 1 | 1 | 1 |
| 8 | Rock | 0 | 0.4 | 1 | 0 | 0.9 | 1 | 1 | 1 |

| | |
|---|---|
| 🟩 | Positive effect |
| ⬜ | Neutral effect |
| ▨ | Adverse effect |
| 🟥 | Unsuitable habitat |

Comment: Habitat suitability: Food producing (Waters 1976); Deleatidium and Zelandoperla (Jowett et al. 1991); brown trout spawning (Shirvell & Dungey 1983); brown trout <100 mm and native fish (Jowett & Richardson 2008) except for small and large longfin eel (Jellyman et al 2003); brown trout adult feeding boulder (Ryder pers. comm.).

As cobbles and boulders become more dominant (because gravel is swept out of the river bed) the potential habitat suitability will improve for some species or life stages (e.g. cobble is better habitat than gravel for food production). Conversely, habitat suitability will decrease for some species or life stages (e.g. fine gravel and gravel is more suitable habitat for trout fry than cobbles or boulders). In some case the habitat becomes unsuitable (e.g. trout spawning habitat suitability reduce from ideal to unsuitable).

Similarly, as more bedrock is exposed (by the removal of gravel, cobbles or boulders) potential habitat suitability may increase (e.g. large longfin eel), or decrease or become unsuitable (food producing, Deleatidium, Zealandoperla, trout spawning, trout fry, adult trout (boulder), bluegill bully, red fin bully, torrentfish and longfin eel <300 m).

# FIGURES

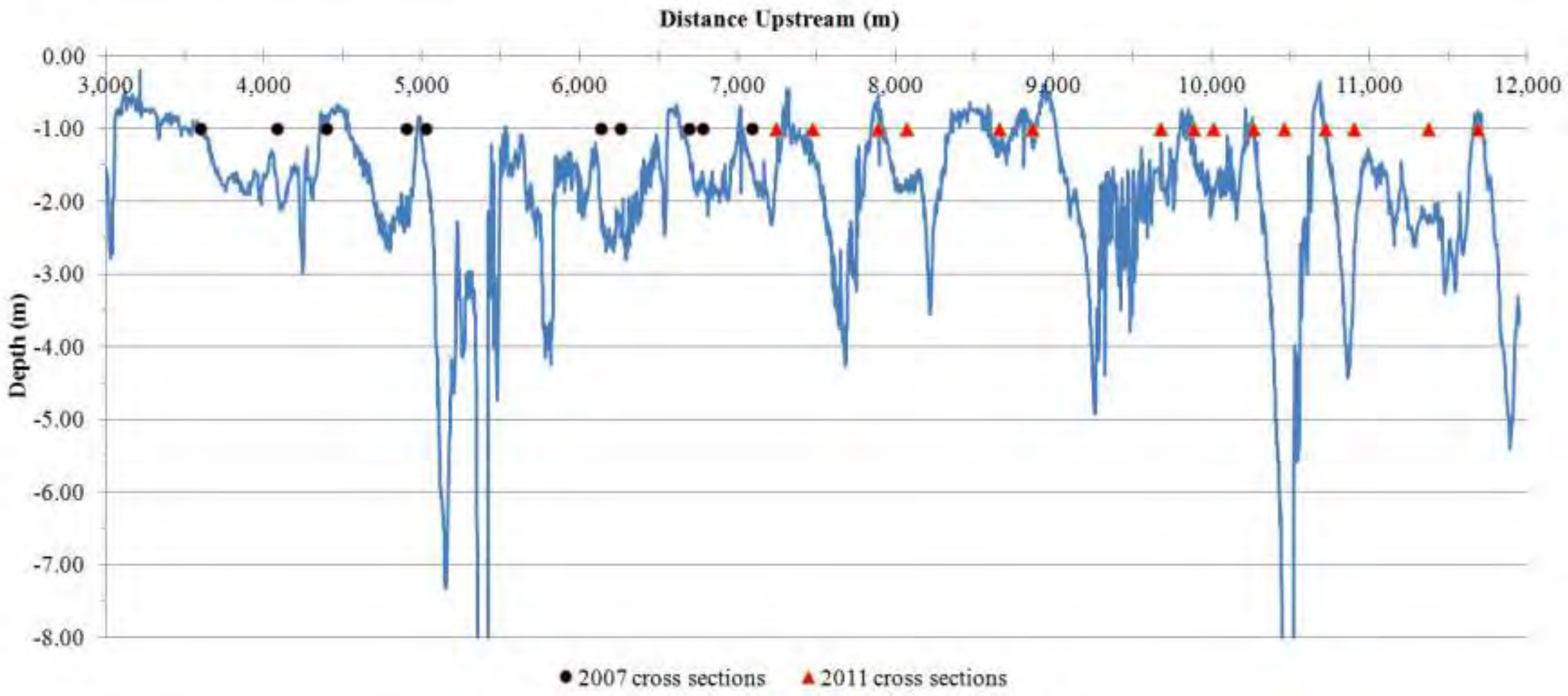

**Figure 1 Long profile and water depths**

Comment: Data courtesy of Dr Hicks/Meridian. Survey flow 81 $m^3$/s. Approximate positions of the 2007 and 2011 cross section locations are marked. The long profile path of the survey kayak is not necessarily the mid- point of the channel which is the habitat survey geo-reference.

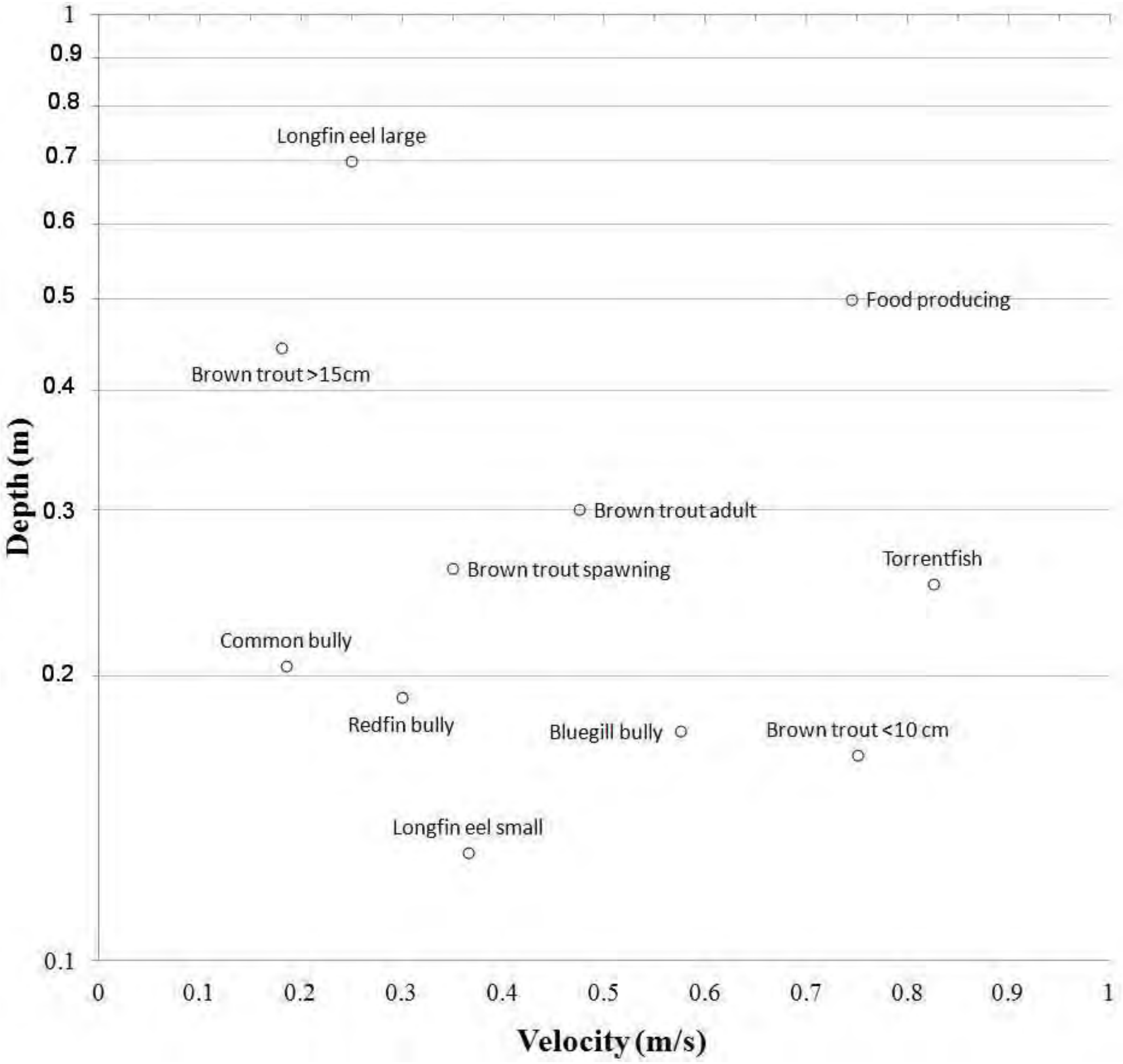

**Figure 2 Optimum depth and velocity suitability for various species and life stages**

Comment: Native fish and brown trout <100 mm (Jowett & Richardson (2008); food producing habitat (Waters 1976); brown trout >15 cm (Raleigh et al. 1986).

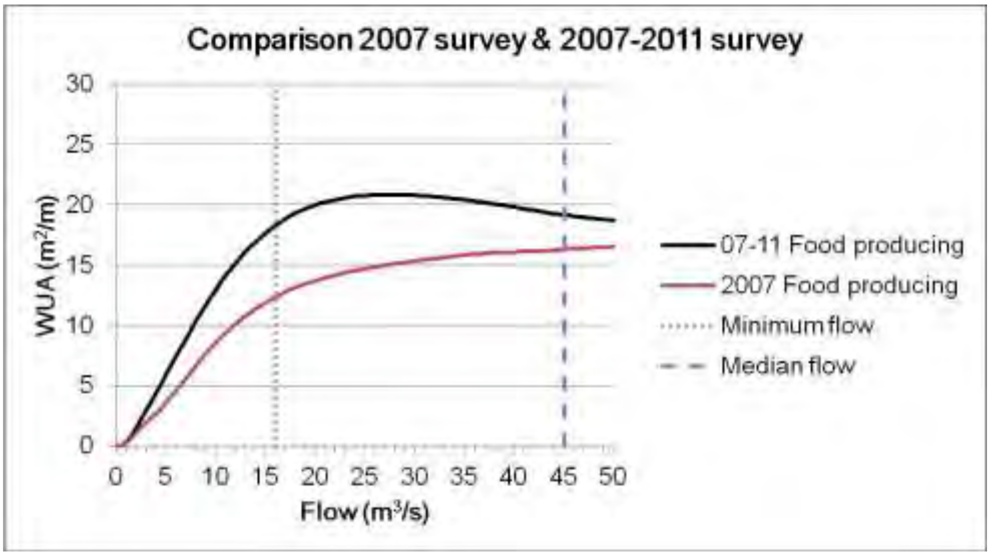

**Figure 3 A comparison of food producing habitat calculated from the 2007 survey and the combined survey (2007 plus 2011)**

Comment: The vertical blue lines are the proposed minimum flow (16 m$^3$/s) and the existing median flow (45 m$^3$/s). Waters (1976) habitat suitability curve is used.

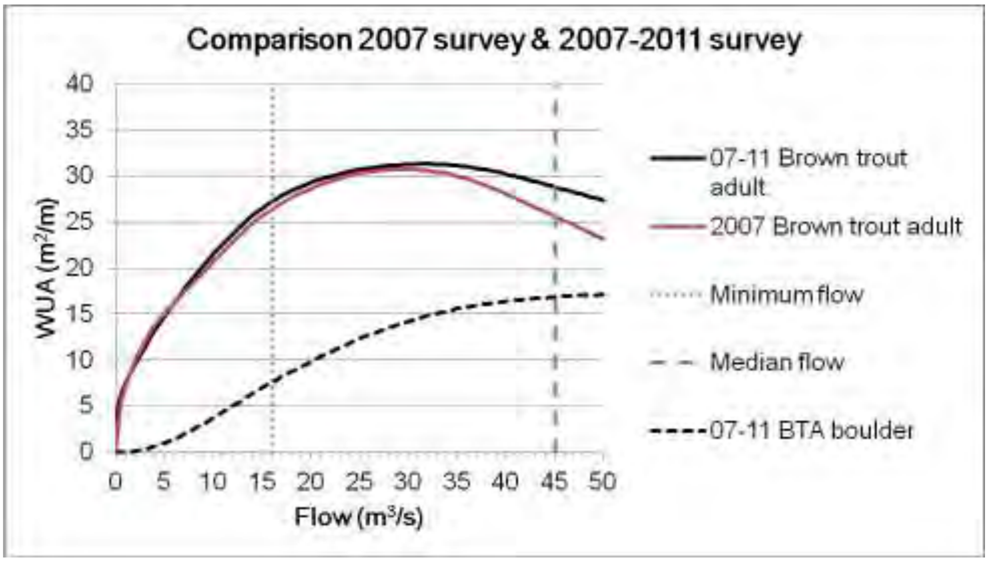

**Figure 4 A comparison of adult brown trout feeding habitat calculated from the 2007 survey and the combined survey (2007 plus 2011)**

Comment: Brown trout adult refers to the Hayes & Jowett (1994) habitat suitability curve. The brown trout adult suitability curve for a cobble-boulder dominated bed (BTA boulder) was developed on the West Coast by Dr Ryder in collaboration with others. BTA boulder peak habitat occurs at 52 m$^3$/s.

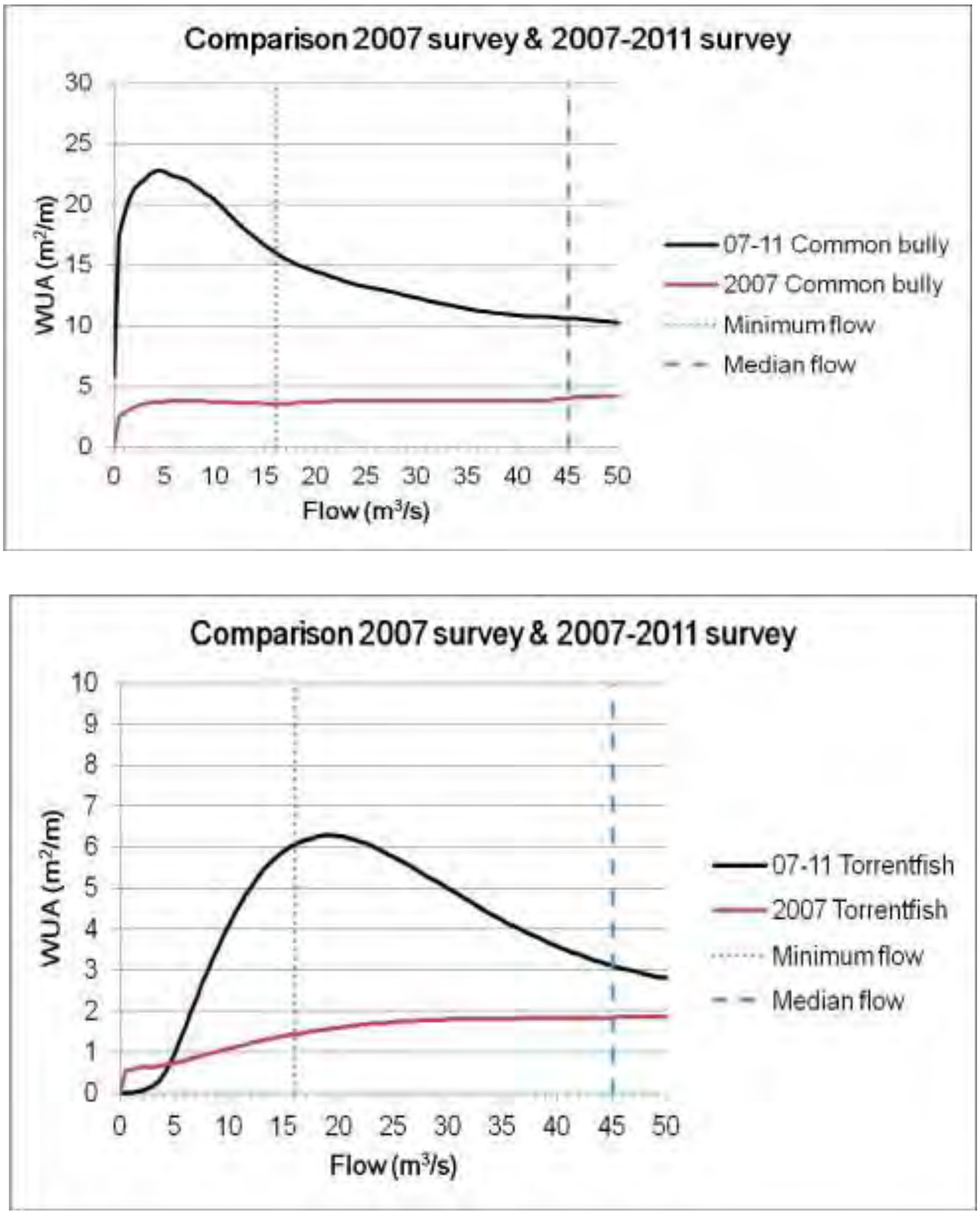

**Figure 5 A comparison of native fish habitat calculated from the 2007 survey and the combined survey (2007 plus 2011)**

Comment: The 2007 survey modelling used the Jowett & Richardson (1995) habitat suitability curves and the 2007-2011 survey modelling used the updated curves (Jowett & Richardson 2008).

Mr Jowett (paragraph 5.8) used Jowett & Richardson (1995) in the 2007 calculation and Jowett & Richardson (2008) in the combined 2007-2011 survey modelling. In paragraph 5.10 Mr Jowett claims the updated "... curves showed a similar result."

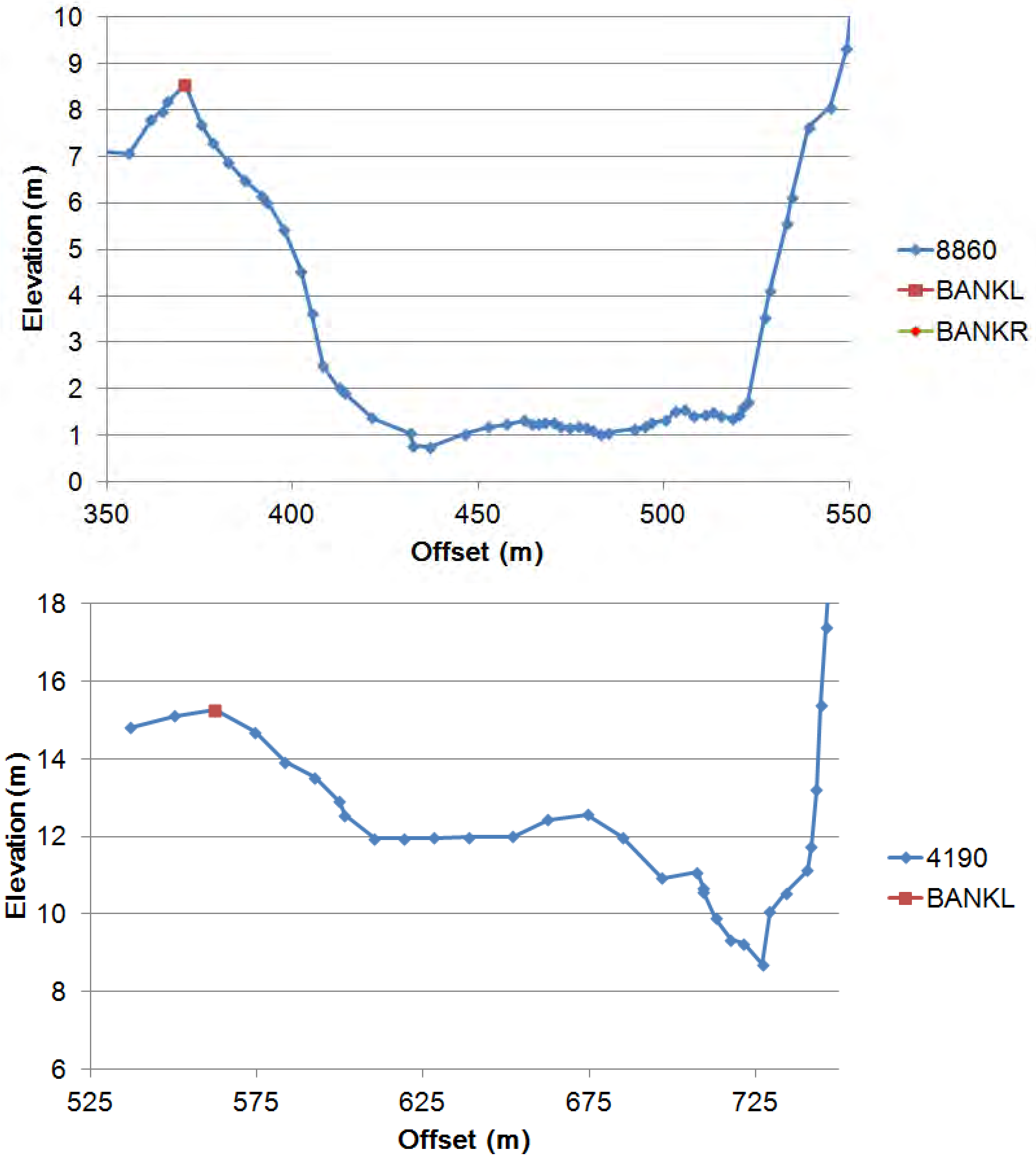

**Figure 6 Channel profiles range from uniform near the bridge (top) to highly asymmetric in the Seddonville reach (bottom)**

Comment: SRH-1D uses fully defined cross sections. (Previously it was assumed that the bed was flat at a level representing the mean level of the active channel bed between the sloping banks). While this should improve predictions, SRH-1D still represents the local hydraulics and sediment properties by cross-section average values. This is a reasonable approximation in wide uniform cross sections. However, in asymmetric cross sections (e.g. v-shaped) the section-averaged bed shear stress under-represents the local shear stress in the deepest parts and over-represents it towards the margins. It is assumed that bed material variability across the channel will compensate for the over and under estimates of local shear stress.

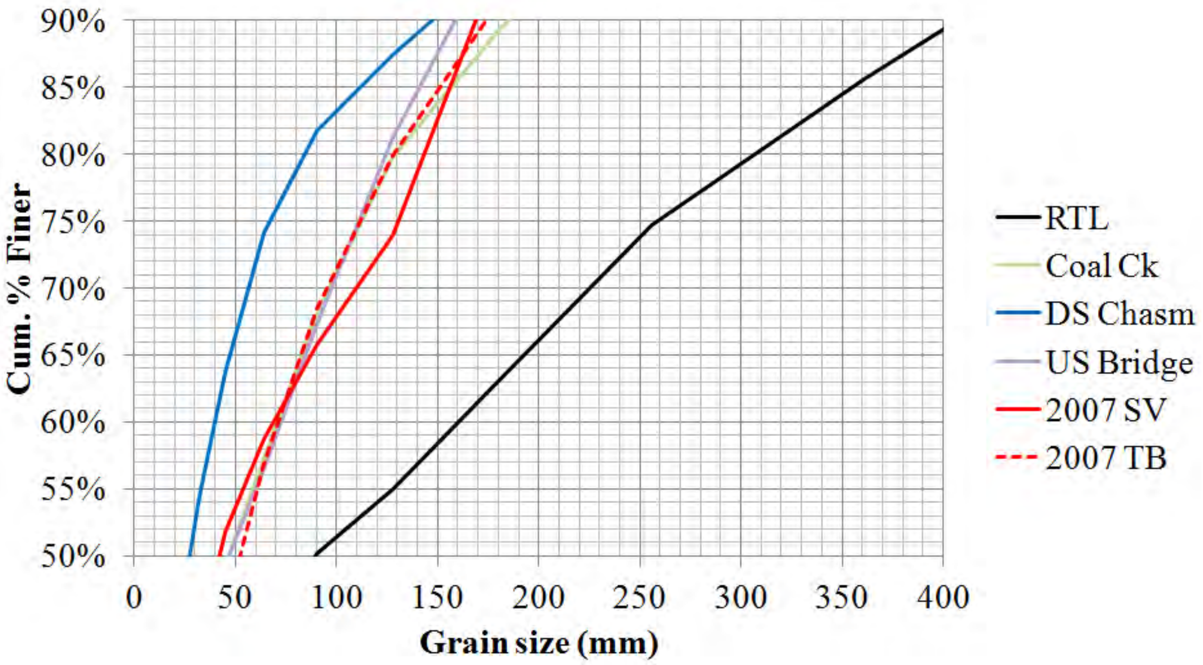

**Figure 7 Subsurface bed material**

Comments: In the 2007 modelling it was assumed that the subsurface bed material in the reach below Burke Creek was uniform and typified by the average of the Seddonville sample (2007 SV) and Tidal Bar sample (2007 TB) ($D_{90}$ of ~170 mm). The 2011 subsurface samples show that within the Seddonville Reach the $D_{90}$ varies from ~145 to ~185 mm; with bed material size increasing upstream to a subsurface $D_{90}$ of more than 400 mm at Rough and Tumble Lodge (RTL about 1500 m downstream of the proposed dam).

Carson & Griffiths (1987) developed relations between velocity and incipient motion for normally packed gravel bed rivers. Meridian kindly provided gauging information for the Mokihinui at Welcome Bay. From the reported discharge and mean velocities, the flow required to initiate motion of bed material was calculated. For a $D_{90}$ of 145 mm (downstream of Chasm Creek) the incipient velocity occurs at ~1060 $m^3/s$; and for the 400 mm boulders at RTL incipient velocity occurs at ~1950 $m^3/s$.

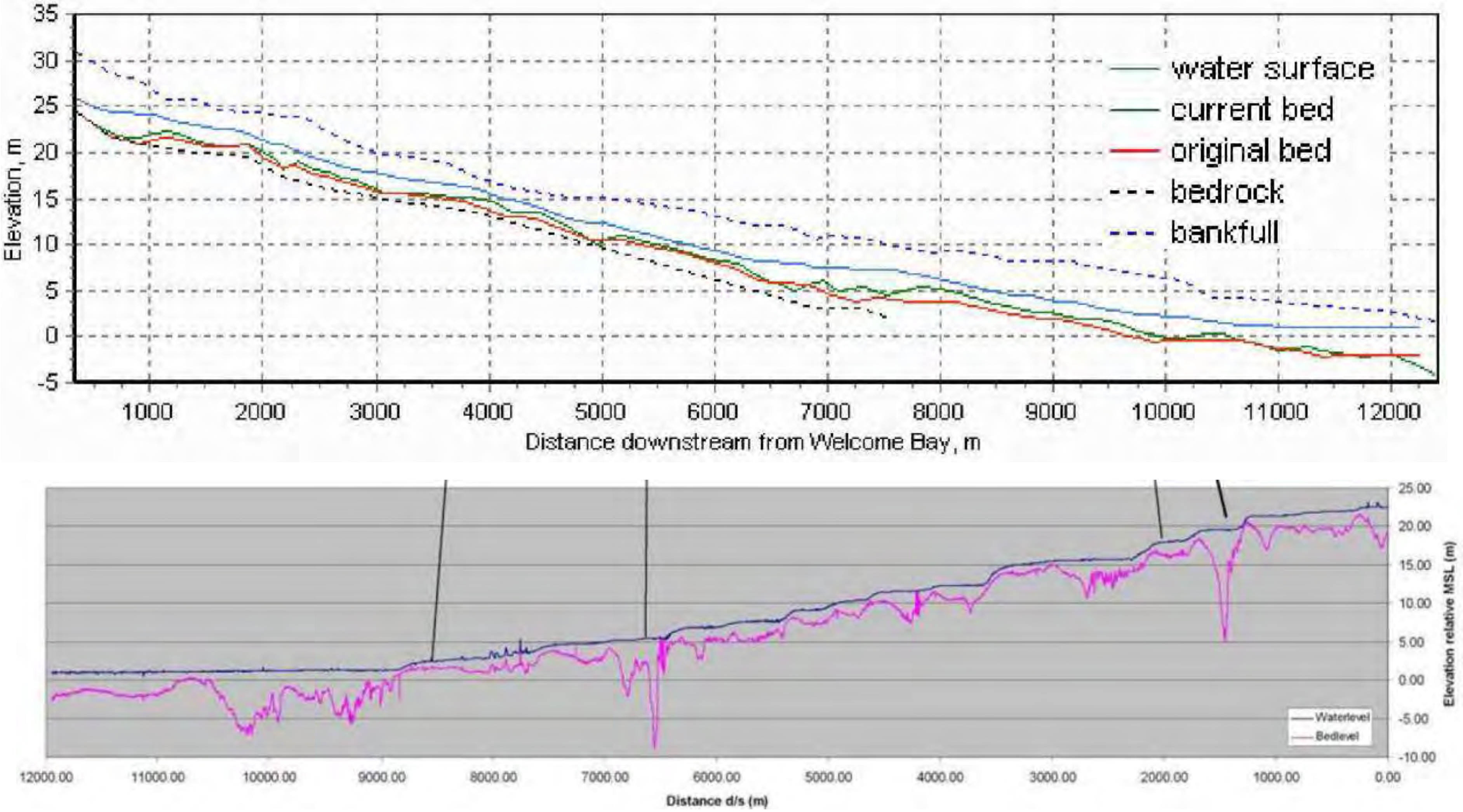

Figure 8 Long profiles from the dam to the coast showing the assumed level of bedrock, and the river bed and water level for the 2007 modelling (top) and measured bed level and water level in 2011 (bottom) (Source Dr Hicks)

**Figure 9 View upstream Mokihinui River below Burke Creek left bank erosion into mudstone overlain by moraine about 2550 m downstream of the proposed dam**

Comment: Hicks et al. (2007: 57) estimate erosion of 0.3 m/y over a 1 km length with an average height of 5 m, which yields ~1500 $m^3$/y. Bedrock is exposed up to half way across the low flow channel (49 Mokihinui bedrock exposure).

Bed rock exposure is evident across much of the channel in the lower river several hundred metres downstream from the bridge (Figure 6 of Dr Hicks).

**Figure 10 View downstream of bank erosion on the true left bank (top) and true right bank (bottom) in the Seddonville reach**

Comment: The boulders in mid left top picture are the remnants of bank protection works that were eroded in the December 2010 flood. The base of the right bank in the bottom picture is bedrock. The river overtopped the bank in this reach. The top photograph is taken ~6.8 km upstream and the bottom photograph ~6.4 km upstream of the river mouth

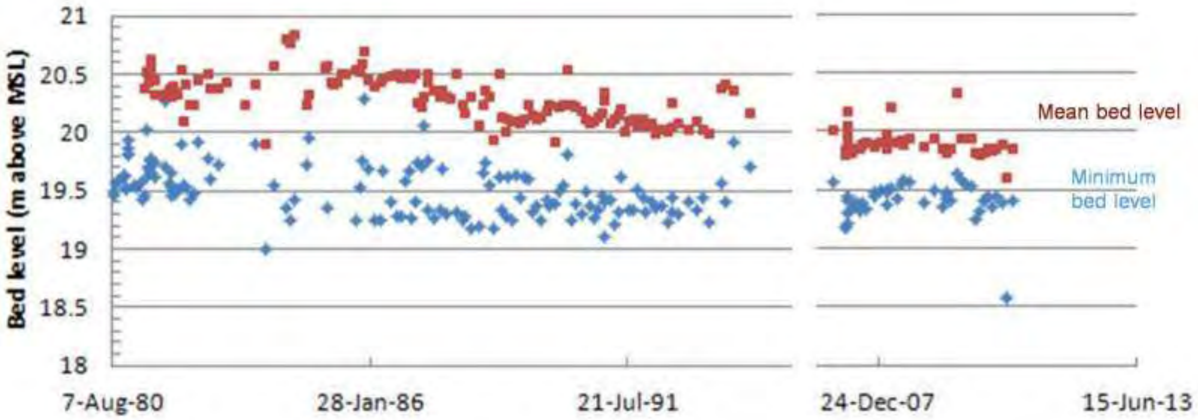

**Figure 11 Mean and minimum bed levels Mokihinui River Welcome Bay gauge (plot courtesy of Dr. Hicks)**

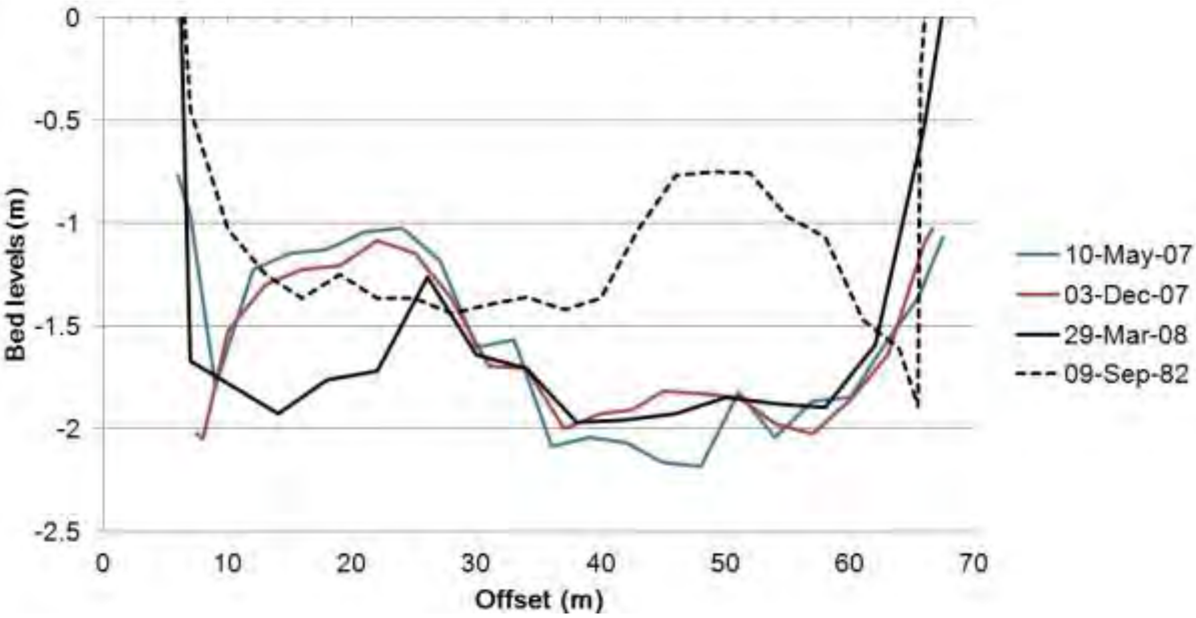

**Figure 12 Standardised bed levels from recent streamflow gaugings Mokihinui River at Welcome Bay (data courtesy of Meridian & NIWA)**

Comment: The recent gaugings are as follows: 10 May 2007 65.3 $m^3/s$; 03 Dec 2007 14.1 $m^3/s$ and 29 Mar 2008 1013 $m^3/s$. The 09 Sep 1984 gauging of 124 $m^3/s$ is also shown to illustrate the higher historic bed levels and channel shift. The gaugings are from a cableway, so are in same position over time. The bed levels were normalised to a stage of 1.0 m to more clearly show the change in bed levels over time. At any point across the channel this limited set of recent gaugings show bed surface changes of about 1 m occur. Greater changes occur when a longer period is considered as illustrated in Figure 11 and with the 1982 gauging. When the supply of bed material from upstream stops (because of the dam), the material that has been scoured from the bed will not be replaced. As a result, the bed will degrade.

**Figure 13 Mokihinui River ~km 6.3 during high flows and post flood**

Comment: The top photograph, from the left bank, was taken on 2011-01-30 at a flow of 950 m3/s (the previous day the flow peak was 1345 m3/s. The bottom photograph, which is a view upstream, was taken on 2011-02-16 at a flow of 28.2 m3/s. Prior to these events the river peaked at 2866 m3/s on 28 December 2010. Mid channel vegetation was not uprooted by the flood, but there was damage to the vegetation and overbank flooding. Elsewhere, lateral scour removed vegetation.

**Figure 14 Isolated bank protection works on the left bank of the lower Seddonville reach**

Comment: The bank protection works were isolated as the flow shifted from the left bank to the right bank (a boulder groyne is evident about mid photo along the left bank). Near this groyne (at xs 5695) the left bank channel is 3.1 m higher than the right bank channel. If the present bar surface is indicative of the elevation of the bar on the right bank prior to channel change, then creation of the present day right bank channel would require more than 4 m of channel erosion since 1966 (see Figure 15).

**Figure 15 Seddonville reach of the Mokihinui River (1966 & 2007)**

Comment: Flow from bottom right to top left. At xs 5695 the channel has shifted from the left bank to the right bank. The left bank minimum channel elevation is 3.1 m higher than the right bank thalweg. Similarly at xs 5460 the difference is 3.2 m. At xs 4370 the channel has shifted to the right bank. The edge of the bar is 35 m from the left bank. The difference in elevation from the bar edge to the thalweg is 1.8 m. At xs 3081 the channel has shifted toward the left bank. The left bank bar is ~1.3 m higher than the present left side of the channel.

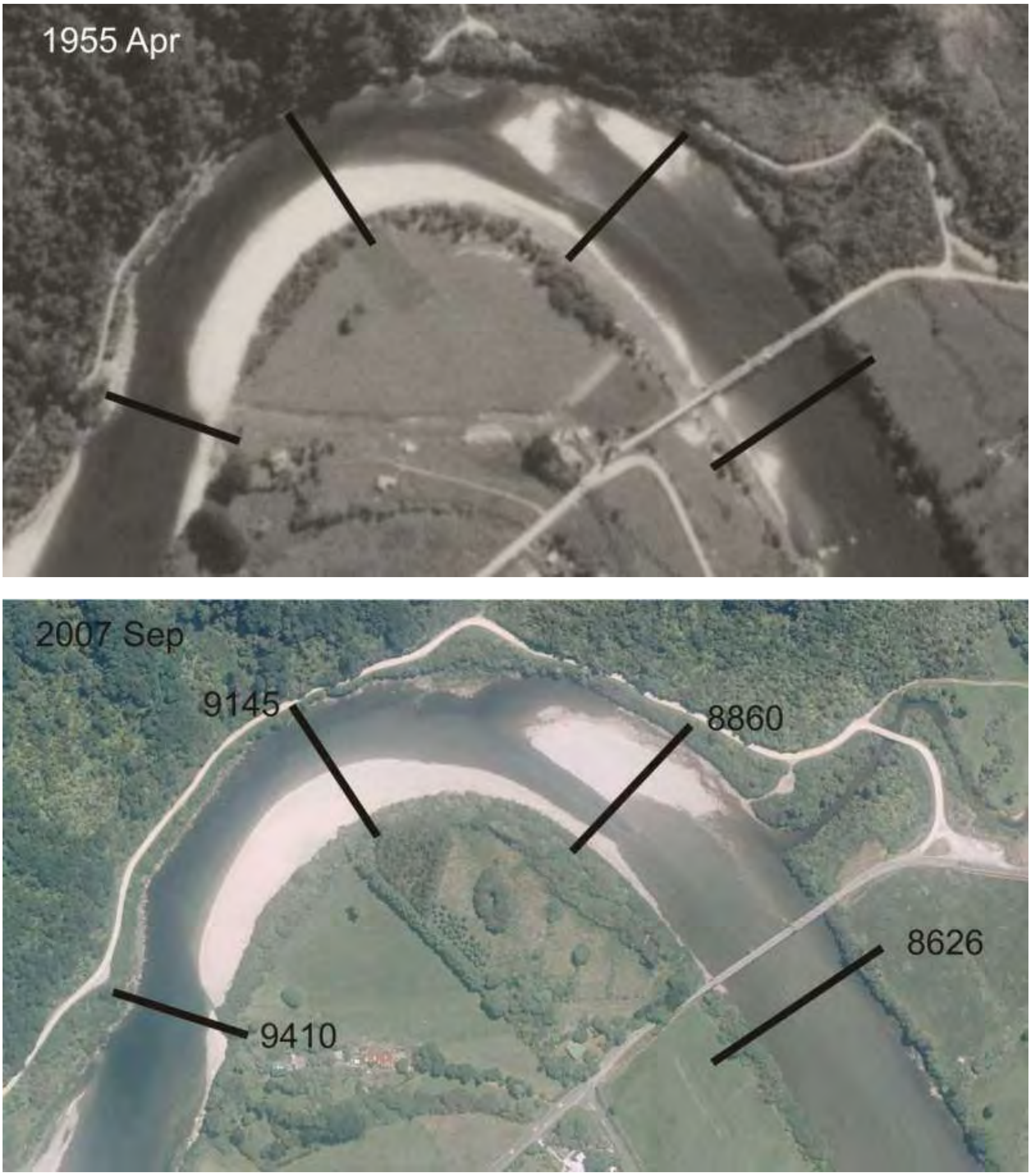

**Figure 16 Mokihinui SH 67 bridge reach 1955 and 2007**

Comment: Flows appear to be similar in the two photographs as shown by the exposure of the bedrock on the true right bank between xs 8860 and 9145 and the exposure of the point bar. The side bar evident along the left bank at xs 8626 in 1955 was eroded. A larger more exposed bar has developed at xs 8860, but the width and location of the deepest part of the channel is similar. There is little apparent change at xs 9145. The side bar on the right bank at xs 9410 is presently the deepest part of the channel.

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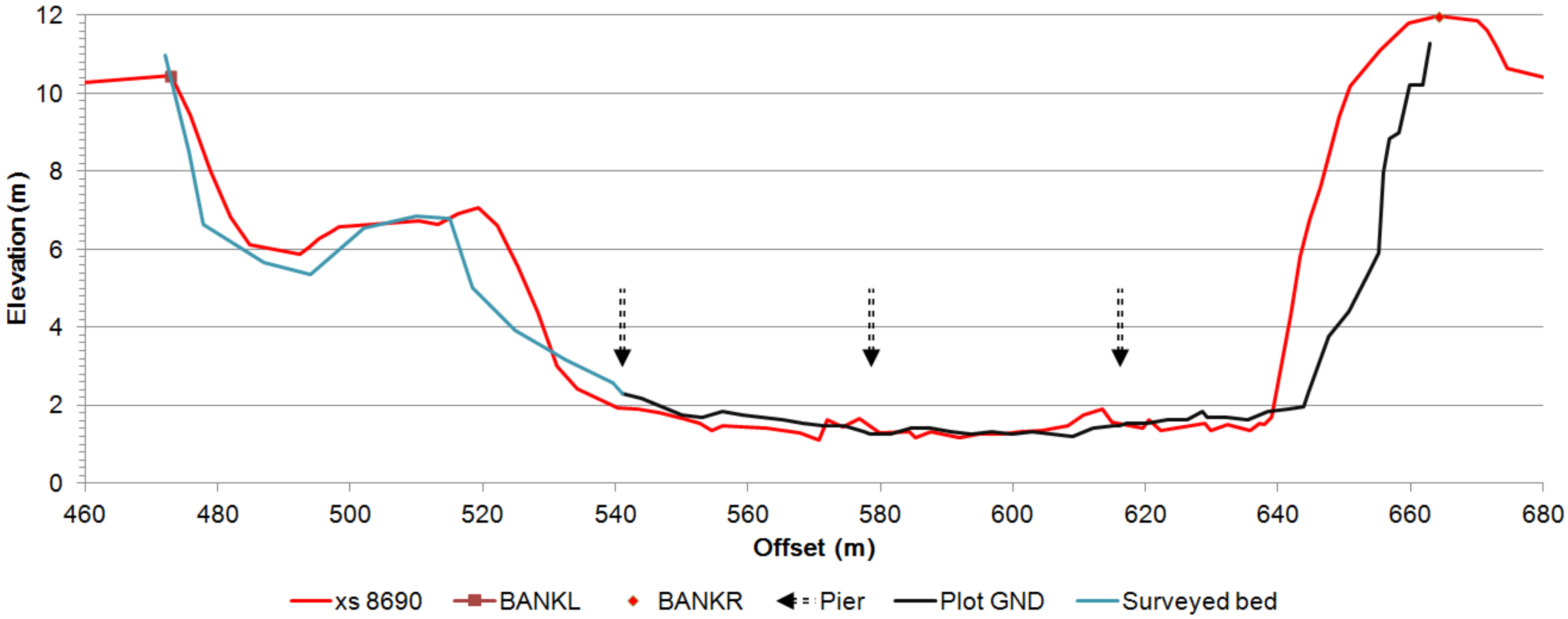

**Figure 17 Mokihinui SH 67 bridge "as built" cross section and 2011 cross section**

Comment: The bridge section bed levels are from surveyed offsets and elevations ("Surveyed bed") and scaled from the bridge plans ("Plot GND"). The bridge bed levels were adjusted to the mid channel pier height (flood survey data of Dr Hicks). There are problems with distortion in the bridge plans. Therefore, x and y dimensioned bed levels, pier heights and bridge features were used to scale bed levels for the "Plot GND" cross section.

The start and end points of the 2011 survey are not annotated in terms of bridge features. To superimpose the cross sections, the horizontal offset of the bridge survey was adjusted to align with the 2011 "left bank" survey point.

The alignment of the cross sections were not specified (e.g. upstream side, downstream side or mid bridge); and the banks differ, which suggest different alignments of the surveys. However, the difference in alignment is unlikely to influence comparative elevations given the uniform nature of the channel (Figure 24).

# APPENDIX 1

## Effectiveness of habitat based flow assessments

### Abstract

The biological effectiveness of habitat-based minimum flow assessments for six New Zealand rivers reported by Jowett & Biggs (2006) are reviewed. The claim that in six case studies the Ohau River "is the only case where predictions of trout abundance and maintenance of an associated fishery based on the quality of habitat were not successful" is not supported by the available evidence. There are five major issues.

The post-hoc assessments of prescribed flows did not rigorously compare before and after instream effects on aquatic life. Alternative flows were not trialled (e.g. prescribed flow plus 5 $m^3/s$, prescribed flow plus 10 $m^3/s$). In short, even if an improvement were shown, we have no idea whether a greater or less flow would be more suitable.

Other evidence demonstrates the purported instream benefits to benthic invertebrates and sports fish have not occurred or are unlikely to have occurred. Other evidence suggests significant adverse effects have occurred to native fish with the prescribed flows compared with a natural flow regime.

Finally, different flows to those originally prescribed were implemented (Monowai and Waiau), occurred (Tekapo), or were recommended (Waipara).

### Introduction

Several strong assertions are made regarding the biological effectiveness of habitat-based minimum flow assessments for six New Zealand rivers (Jowett & Biggs 2006). These assertions are reiterated in Jowett et al. (2008) and in evidence to Resource Management Act hearings and Environment Court in New Zealand. The case studies are reviewed.

### Tekapo River

Jowett & Biggs (2006) describe the physical aspect as follows.

> "The Tekapo River (mean flow 80 $m^3 s^{-1}$) was diverted into Lake Tekapo ... in 1978.... There was no provision for a minimum flow in the river at the diversion point, but flows from tributary streams progressively increase the mean flow in the river to about 10 $m^3 s^{-1}$ at a point about 40 km downstream where it flows into a lake. The habitat analysis showed that a flow of about 10-13 $m^3 s^{-1}$ provided near maximum trout spawning habitat and food producing habitat in the lower 20-40 km of the river [citation], although flows in the section above this were less than optimum. Thus, the analysis suggested that a residual flow from Lake Tekapo was not necessary to supplement flows in the lower part of the river, and that the flow

> reduction would be beneficial to trout habitat and potentially increase the trout population and the fisheries in the lower part of the river."
>
> "No monitoring was specifically carried out to test the predictions of the instream habitat modelling. ...there were no records of trout density prior to diversion as the Tekapo River was not considered an angling river and was not even mentioned in angling surveys of that time [citation]. From this, we conclude that angling in the river was poor, probably because trout numbers were low and river conditions unsuited to angling".
>
> Trout drift dive surveys 8 and 11 years after the flow diversion show high trout densities (94-240 large brown and rainbow trout per km) and the Tekapo River is now a popular angling river. "Six indigenous fish species are found in the Tekapo River. They are species commonly found in small upland stream and we have no reason to suspect that they have been detrimentally affected by the flow regime change."

There are major issues which preclude being able to state an apparent improvement in trout numbers validates a recommended flow of 10-13 $m^3/s$ in the lower Tekapo River:

1. The recommended flow is not actually achieved. For a few km below the diversion the riverbed is typically dry and for more than 30 km below the diversion the mean flow is less than 4 $m^3/s$. The mean flow in the lower 17 km to the mouth is $\leq 9.5$ $m^3/s$ (from data in Griffiths 2009);
2. The biological response is uncertain. There are no records of fish prior to the diversion. The anecdotal evidence of a lack of angling prior to diversion in 1978 may reflect the lack of access rather than a lack of fish;[6] and
3. Alternatives, such as providing a 5 or 10 $m^3/s$ residual flow below the diversion, were not tested.

### Waiau River

Prior to the 1970s the lower Waiau River flowed due south about 110 km from Lake Manapouri to the sea. About 10 km from the lake the river was blocked with a temporary weir (1970) and later the Manapouri Lake Control Structure (commonly known as the Mararoa Weir) (November 1976). Practically all of the natural flow of 450$m^3/s$ was diverted through the Manapouri Power Station to Doubtful Sound on the West Coast.

Following diversion there was little residual flow and very little instream habitat in the Waiau River immediately below the Mararoa Weir (Jowett 1993). For much of the time 0.29 $m^3/s$ was released through a fish pass. Flows were augmented by tributaries, notably Excelsior, Whare and

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[6] Access by four wheel drive vehicle is recommended by local fishing guides.

Redcliffs creeks, which joined the Waiau 1, 2, and 11 km respectively, below the weir. Just upstream of Redcliff Creek, the Redcliff Reach had a flow of 2.11 $m^3/s$, and the Blackmount Reach (~18 km downstream of the weir) had a flow of 3.9 $m^3/s$. Borland Burn and the Monowai River flow into the Waiau about 25 km downstream of the weir at which point the mean flow is about 37.5 $m^3/s$.

Instream habitat surveys were undertaken in three reaches "at approximately equal intervals between the Mararoa Weir and Borland Burn" (Jowett 1993). Jowett (1993) concluded "When the potential habitat in the three reaches was averaged to give a clearer appreciation of the overall variation with flow, it showed that a residual flow in excess of 10 $m^3/s$ would enhance adult brown trout and food producing habitat considerably.... Given the outstanding potential habitat in the river, I suggest that consideration be given to maintaining a minimum flow in excess of 10 $m^3/s$ in the Waiau River below the Mararoa Weir."

In the re-consenting of the Manapouri Power Scheme it was recognised that the minimum flow proposed by Jowett (1993) was too low and minimum flows ranging from 12 $m^3/s$ in winter to 16 $m^3/s$ in summer were implemented in 1997, with mitigation for loss of habitat available with a 30 $m^3/s$ minimum flow (Waiau Fisheries and Wildlife Habitat Enhancement Trust objectives). This differs from the statement by Jowett & Biggs (2006): "The instream habitat analysis (Jowett 1993c) indicated that a flow of 12 $m^3/s$ or greater would provide excellent brown trout habitat and a minimum flow regime of 12 $m^3/s$ in winter and 16 $m^3$ per second in summer was consequently implemented."

Jowett & Biggs (2006) conclude "Although river flows have reduced from 450$m^3$ $s^{-1}$ to 12–16$m^3$ $s^{-1}$, there is <u>no evidence of any detrimental effects on the fish community</u> probably because there are no indigenous fish species that are found solely or predominantly in large rivers in New Zealand. However, while the <u>high quality trout fishery and benthic community health has been reinstated</u> with only 3% of the natural mean flow, the visual appearance of the river has changed with a loss of the large river character." (My emphasis). No evidence is provided to support these contentions, but there is evidence to suggest the contentions are not correct.

1. Recent research suggests a significant adverse effect on eels. Jellyman et al. (2009) note "There are no quantified data for the size of the annual elver run prior to the diversion of water to MPS in 1969; however, an observation of stranded elvers below MLC in 1979/80 reported by Mitchell (1994), estimated the loss at 10 – 20 tonnes (this would equate to approximately 2.9 – 5.8 m juvenile eels)." Jellyman et al. (2009) caught and transferred an average of 71,200 elvers (juvenile eels) over 9 seasons since 1998/99. They conclude "It seems reasonable to assume that the net recruitment to this catchment has become substantially reduced with the reduction in flow of the lower Waiau River."
2. Jowett & Biggs (2006) noted a six fold increase in the number of large and medium trout from 1996-1997 to 2001 over a 20 km reach below MLC and increased angler usage. However, most of the

increase is for rainbow trout abundance, not the modelled brown trout, with most of the increase occurring immediately below the MLC in the Excelsior Reach (Southland Fish & Game data);

3. It is not possible to state that the fishery has been reinstated with only 3% of the natural mean flow. There are no comparable pre and post MLC trout abundance data for the Lower Waiau River. However, there are about 6 times as many large and medium trout (>20 cm) per kilometre in the Upper Waiau (which has a more natural regime) than the Lower Wairau with the prescribed regime (Southland Fish & Game data); and
4. No information was provided to show benthic invertebrates were reinstated to natural flow levels. Recent reports show benthic invertebrate densities were similar pre (1993 and 1997) and post low flow implementation to 2004 (Kilroy et al. 2009). However, the river is much smaller hence there is probably a considerable loss in productivity.

### Monowai River

The Monowai River flowed about 9 km from Lake Monowai to the Waiau River. In 1925 a power station and control structures were commissioned. The level of Lake Monowai was controlled with a dam at the lake outlet and flows into the Monowai River were controlled with gates (river km 9). The river was dammed at km 2.5 creating a headpond and flows were diverted into a canal and pipeline to the power station before discharging into the Waiau River.

Jowett & Biggs (2006) stated that flows to the power station varied frequently (usually daily) from near zero to 20 $m^3$/s. The residual flow was not quantified but is described as "...tributaries enter downstream so that the river always has a small flow from not far below the control structure." They continue "In 1994, instream flow assessments were used to determine a minimum flow of 6 $m^3$ $s^{-1}$ was required to provide habitat for a diverse benthic invertebrate community and 'healthy' river (19). However, daily fluctuations in flow from 6 $m^3$ $s^{-1}$ to 20 $m^3$ $s^{-1}$ would still occur." Jowett et al. (2008) state "In 1995 the minimum flow of the Monowai River was increased from about 0.2 $m^3$/s to 6 $m^3$/s to provide habitat for benthic invertebrates...."

The summary of Jowett & Biggs (2006) and Jowett et al. (2008) differs from the source document regarding both the minimum flow and purpose:

1. Mitchell & Associates (1994) report "The habitat-flow relationships were well defined with optimum adult brown trout drift feeding habitat at a flow of 4-5 $m^3$/s (Fig. 3) and optimum food producing habitat at 6-7 $m^3$/s ..."
2. Mitchell & Associates (1994) recommend a minimum flow of 3 $m^3$/s. "We suggest that a minimum flow of about 3 $m^3$/s would maintain acceptable habitat quality in this river and, given the overall habitat quality of the river, should be capable of sustaining a high quality fishery."

Jowett & Biggs (2006) noted benthic invertebrate densities and taxon richness almost doubled in the second to forth year after residual flows were implemented. They conclude "Thus, an improvement in river ecosystem health and the objectives of the modified flow regime were largely achieved." This conclusion is not supported:

1. Benthic invertebrate densities increased from 310 per $m^2$ to 630 per $m^2$ but remain less than a third of the median of New Zealand rivers (1,903 per $m^2$). (Taxon richness was slightly above the national median);
2. Southland Fish & Game (2011) report on trout abundance and suggest that "... food limitation may be important in this river." and
3. The expectation of a lake fed stream would be for greater than average benthic invertebrate densities.

The primary objective, to sustain a high quality fishery, is not addressed by Jowett & Biggs (2006). There were far more brown trout (the modelled species) in 1981 and 1984 than in 8 subsequent surveys (Mitchell & Associates 1994; Southland Fish & Game 2011).

### Moawhango River

"In 1979, the natural flow of the Moawhango River, about 9.6m3 s−1, was diverted out of catchment to the Tongariro River for hydro-power generation, leaving practically no flow from the hydro-impoundment dam. However, leakage and tributaries resulted in a 0.06m3 s−1, 9m wide, slow flowing river 1 km down stream of the dam (previously 21m wide and flowing" A small increase in minimum flows and flushing flows were implemented.

No evidence is provided to shown that the river provides excellent rainbow trout habitat as a result of the flow regime changes.

Further it is unclear if the habitat improvements for benthic invertebrates are the result of the flow regime; or the flushing of fine sediment and decaying vegetative matter (Death et al. 2009).

An alternative flow regime was not trialled.

### Ohau River

Jowett & Biggs (2006) describe the Ohau River as "the only case where predictions of trout abundance and maintenance of an associated fishery based on the quality of habitat were not successful." No information on trout abundance or benthic invertebrate abundance is provided. The conclusion is based on low angler number before and after the minimum flow regime was implemented and the lack of mention of the river in pre-scheme angler diaries.

It is speculated that "The lack of trout may be related to poor food production because of glacial silt deposits on the substrate and lack of flow variation, and/or problems with recruitment and fish passage between the lake and river or simply a preference for the lake environments."

An alternative flow regime has not been tested.

## Waipara River

A minimum flow of 120 L/s for the Waipara River at Teviotdale was recommended by Jowett (1994) for the maintenance of indigenous fish biodiversity values. Mr Jowett subsequently commented on the effectiveness of this recommendation in a number of publications.

Jowett & Biggs (2006) summarise a three year study on the Waipara River and comment “These results support the recommended minimum flow, and even suggest that the minimum flow recommendations for these indigenous fish species may have been unnecessarily high.”

In contrast, Jowett (2011), in evidence for Environment Canterbury, notes “A minimum flow of 0.2 $m^3/s$ [200 L/s] or higher is required at Teviotdale if the objective is to have no significant effect on fish.”

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# APPENDIX 2

## Survey reach & channel characteristics

### Introduction

There is a fundamental point of difference regarding the importance of the survey reach and channel conditions. Hudson et al. (2003) reviewed instream flow assessment in New Zealand and concurred with international findings that there were common problems regarding correctly sampling river characteristics, definition and use of habitat suitability curves and assigning biological meaning to measures of habitat availability.

In terms of sampling river characteristics, the developers of the instream flow methodology state "In order for a simulation model to be useful in the planning process, its output must be capable of extrapolation into space and into time."(Bovee & Milhous 1978). Further, the developers and critics of IFIM recognise the importance of correctly sampling habitats. The reason is simple, too few and incorrect location and description of cross sections produce WUA curves that are meaningless (Williams 1996, Bovee 1997).

The reason is quite apparent. River characteristics vary and so do the flora and fauna of these rivers. As discussed in Hudson et al. (2003): "Internationally, differences in channel character have been found to affect sensitivity to changing streamflows (Bovee & Milhous 1978). The effect of meso-habitat [rapids, riffles, pools etc.] has been widely recognised (e.g. Beschta & Platts 1986; Heede & Rinne 1990; Rabeni & Jacobson 1993) and has been associated with up to a fivefold difference in mean WUA for Atlantic salmon fry and a three-fold difference for parr between reaches with different channel form on the same river at the same discharges (Payne & Lapointe 1997). In the Rangitata River, optimum flows for food production and brown trout adults occurred at greatly different flows between (and within) channel types (single thread and braided) for a river with similar slope and discharge over the study reach (Hudson 2001c). In the Tongariro River ...."

A basic problem is a lack of understanding or rigour in undertaking the instream flow investigations. The instream flow manual notes the methodology "... is widely misconstrued, misinterpreted, and in some cases misused" (Bovee et al. 1998).

When Dr Stalnaker (a developer of the methodology) was asked to put the misuse of IFIM into perspective (considering other fish problems, such as water pollution, ocean over-fishing, or introduced predator species) he replied "On big alluvial rivers, it [IFIM misuse] has been devastating." (Woo 1999).

The situation is summarised by Platts (1981) in the title of his paper "Stream inventory garbage in-reliable analysis out: only in fairy tales."

## Mokihinui River

In my hearing evidence I stated: "...about 58% of the river length from the tidal limit to the proposed dam was not surveyed; and in my opinion these segments are composed of distinctive habitats that should have been surveyed." I illustrate the channel characteristics in Figure 1 and Figure 18 to Figure 24.

Mr Jowett took a contrary view. In his 2009 memorandum to the hearing commissioners, Mr Jowett stated (paragraph 3.6) "There is no significant change in flow, geology or river morphology between the dam and the SH bridge, so that the surveyed reach will be representative of the section of river." He concluded "... further survey work was not required."

This continues to be a critical point of difference. Mr Jowett (4.21) opines "The addition of the 2011 survey data changed the calculated values of water level and instream habitat slightly. The changes were not sufficient to alter the conclusions that I presented in the resource consent hearing." [My emphasis].

I use the hydraulic-habitat modelling ("IFIM") data of Mr Jowett which was provided to the resource consent hearing (Jowett 2007) and to the environment court ("Jowett 44 Mokihinui-All"). Mokihinui_All is a combination of the 2007 habitat survey (10 cross sections) and the 2011 survey (an additional 15 cross sections/transects).

I use RHYHABSIM, and the data provided without alteration, to calculate hydraulic geometry and habitat. I replicate the results of Mr Jowett and undertake additional analysis.

If there was no difference between the surveys as Mr Jowett opines, then the average width, depth and velocity should be the same. However, I found there were substantial hydraulic geometry differences between the 2007 survey and the combined 2007-2011 surveys (paragraph 4.8):

- The average measured width increased from 56 m (2007 survey) to 78 m (2011 survey);
- The average measured depth increased by 7%, but there is more than twice the variability in average depth in the 2011 cross sections. The average depth of the deepest pool increased 264% (from 1.42 in the 2007 survey to 3.74 m in the 2011 survey); and
- The average measured velocity decreased by 63% from 0.55 m/s (2007 survey) to 0.35 m/s (2011 survey).

To put this in context, I calculated the flows that were required in the 2007 survey to achieve the reach average width, depths and velocities of the combined 2007-2011 surveys. I used the median flow as a baseline for comparison. If there was no difference between the surveys, then the required flow would be the same as the median flow (i.e. 46 $m^3/s$). However, there are substantial differences:

- A flow that is more than five times greater than the median flow is required to achieve the same average width;

- A flow of more than twice the median flow is required to achieve the same average depth; and
- A flow that is about three quarters of the median flow is required to achieve the same average velocity.

I found there were substantial differences in habitat availability between the 2007 survey and the combined 2007-2011 surveys (paragraph 4.9):

- The peak of food producing habitat is 25% greater in the combined survey (2007 plus 2011 surveys) than in the original 2007 survey (Figure 3);
- The peak in food producing habitat occurs at less than half the flow in the combined survey (i.e. 27 $m^3/s$ against 58 $m^3/s$; Figure 3);
- Slight differences occur between the surveys for adult brown trout habitat with peak habitat in both surveys around 31 $m^3/s$ (Figure 4). However, the curves diverge at higher flows with 13% more habitat in the combined survey at the median flow;
- The peak for adult brown trout habitat in a boulder dominated river does not peak until 52 $m^3/s$ (Figure 4); and
- The shape and position of the flow-habitat relationships for native species change greatly (e.g. Figure 5).

To put this in context, I calculated the flows that were required in the 2007 survey to achieve the optimum habitat availability in the combined 2007-2011 surveys.

- More than twice the flow is required to achieve optimum food producing habitat, but the quantity of habitat available in the combined survey is not achieved at any flow in the 2007 survey;
- There is little difference for adult brown trout, but there is about three times as much optimum small brown trout habitat in the combined surveys, and that quantity of habitat is not achieved at any flow in the 2007 survey;
- There is more than five times the amount of common bully habitat, and that quantity of habitat is not achieved at any flow in the 2007 survey; and
- There is more than three times the amount of torrentfish habitat and that quantity of habitat is not achieved at any flow in the 2007 survey.

I conclude it is not credible to state that the addition of the 2011 survey data slightly changed the calculated hydraulic geometry or indeed the measured hydraulic geometry. The changes are far in excess minor.

Similarly, I conclude the changes in available habitat with the addition of the 2011 survey to be far in excess of minor.

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**Figure 18 Cross section placement in 2007(black lines) and 2011 (red lines)**

Comment: The survey cross sections are numbered in downstream sequence (1 to 25). The 2011 cross sections start near the proposed dam (1) and finish in the Seddonville Reach (15). The 2007 surveys continue with the numbering sequence (16 to 25), but are also identified by their original number (e.g. 20-05). Two cross sections (marked in yellow) were specified by the survey crew, but these were not surveyed by Mr Jowett. The omitted cross sections were between the two clusters of 2007 cross sections and in the plane bed immediately above the bridge (Figure 24). (Google Earth image 2008 & 2010).

**Figure 19 View upstream (top) and downstream (bottom) from xs-01**

Comment: View from Mokihinui gauge cableway. See Figure 18 for location.

**Figure 20 View upstream at xs-04**

**Figure 21 View upstream at xs-05**

Comment: At the time of survey the pools at the cross section was 48.7 m wide with a maximum depth of 8.7 m.

**Figure 22 View upstream (top) to xs-18-03, xs 19-04 and xs 20-05 and downstream from ~xs 20-05**

**Figure 23 View upstream to xs 22-08 (foreground) and xs 21-07 (mid photo) (top); View downstream to xs 24-09 from ~xs 23-08.**

**Figure 24 View upstream to x-17 (top) and downstream from x-17 (bottom)**

Comment: This very wide, shallow plane bed reach was marked by the survey team but not surveyed by Mr Jowett. The 2007 cross sections (21-06 to 25-10) are located in the constricted reach in the upper portion of the top photograph. (See Figure 18 for locations). Note the transient sand streaks.

# APPENDIX 3

## Delineation of habitat units

### Introduction

Contrary to the implication of Mr Jowett in paragraphs 4.23 and 5.2, the 2011 Mokihinui habitat designations and cross sections placements were by unanimous agreement of the DOC-EMA-NIWA field team. The habitat proportions were determined from the geo-referenced positions of the habitat units and cross section.

Mr Jowett and I disagreed about the proportion of habitat units in the Mokihinui River. The differences relate to the following:

1. Mr Jowett started his analysis at a bench mark rather than the first habitat unit which causes the units to be out of sequence (hence pools are classed as rapids, and riffles as pools etc.);
2. Mr Jowett calculates the length of habitat units as a straight line between waypoints rather than following the course of the river (hence bends are cut off); and
3. Mr Jowett omitted cross sections 01, 16 & 17 and the 2007 cross sections in his calculations. Cross section 1 is the gauge and this was subsequently included in the habitat analysis. However, Mr Jowett chose not to survey cross sections 16 (between his cluster of sites) and 17 (the extensive plane bed in the bridge reach).

Mr Jowett agreed to use the habitat designations from the field team and the habitat proportion I calculated, but it is unclear if he agrees with these designations and proportions. In this regard, Mr Jowett is of the opinion the designations are not material as discussed in Appendix 4 Influence of habitat units on flow-habitat relations. I disagree.

### Field survey procedure

Henry Hudson provided the survey team (two NIWA technicians, and Jo Stapleton of DOC) with a written overview of the rationale of habitat mapping surveys and a description of the habitat units to be delineated in the survey. There was agreement on these matters and how the units would be geo-referenced.

All of the habitat designations were agreed to by the survey team. In some cases, upon closer examination, the initial habitat classification was revised as the habitat unit was traversed (e.g. a run was classified as a plane bed or vice versa based on the bed and flow characteristics). The start point and end point of each habitat unit was geo-referenced as the survey crew traversed the length of the river from the proposed dam site to the tidal zone.

After the first traverse of the river Hudson, Mason and Stapleton reviewed the aerial photographs and agreed on the sequence of habitat units. The cross section placement approach of the developers of habitat mapping (Morhardt et al 1983) were again reviewed and the approach was confirmed.

In the second traverse of the river cross sections were placed in the various habitat units. Again, the cross section locations were discussed and agreed taking into consideration having a reasonable number of cross sections, the representativeness of cross sections surveyed, and site characteristics. The data was provided to Mr Jowett.

**Habitat units**

On 18 March 2011 Mr Jowett wrote regarding the habitat designations stating "Unfortunately there is a lot of difference as shown in the table below and I don't know the reason for the difference."

| Type | Hudson | Jowett |
|---|---|---|
| Rapid | 11.33% | 7.2% |
| Riffle | 16.79% | 24.0% |
| Run | 37.35% | 40.0% |
| Plane bed | 10.69% | 15.9% |
| Pool | 23.84% | 12.9% |

[Jowett 2007 reported 84% run, 6% riffle, 4% riffle/rapid and 6% pool habitat].

On 22 March 2011 Hudson replied "As explained in the attached note, I think the substantial difference between my results and yours are related to you starting your analysis at a bench mark (WP 01) rather than the first habitat unit (WP 02). This causes your whole habitat unit sequence to be out of phase with Pete's field notes and my analysis. When you apply the correct phasing our results will be similar, but not identical. Some suggestions are provided to make your analysis more accurate so our designations will be almost identical."

The attachment stated the following:

In my opinion the difference is largely related to your habitat sequence being out of phase by one step from mine and the field notes of Pete Mason (I use the same sequence as the field notes starting with a pool habitat at way point 2). I can reproduce something similar to your results if I apply the sequence out of phase as you have done, specifically:

| Type | Out of phase |
|---|---|
| Rapid | 6.7% |
| Riffle | 23.2% |
| Run | 42.9% |
| Plane bed | 15.2% |
| Pool | 11.9% |

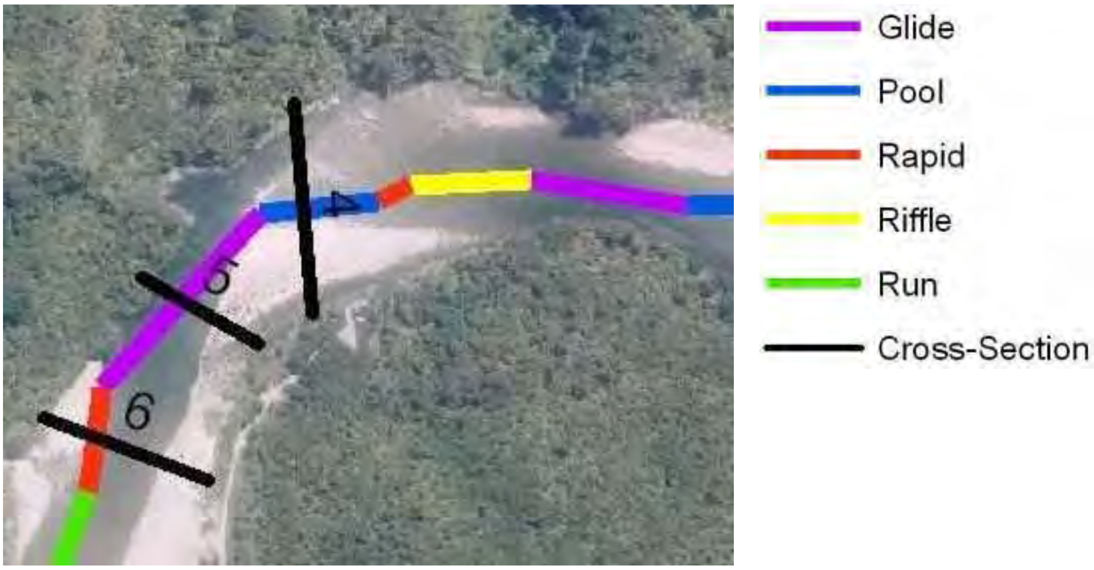
When you apply the correct phasing and sequence our results will be similar, but not identical for the following reasons:

- You calculate distance as a straight line between waypoints near the banks rather than follow the course of the river;
- You have omitted some cross sections (01, 16 and 17; and your cross section which should be part of the data set);
- You have incorrectly located some cross sections; and
- The alignment of some cross sections appears to be incorrect.

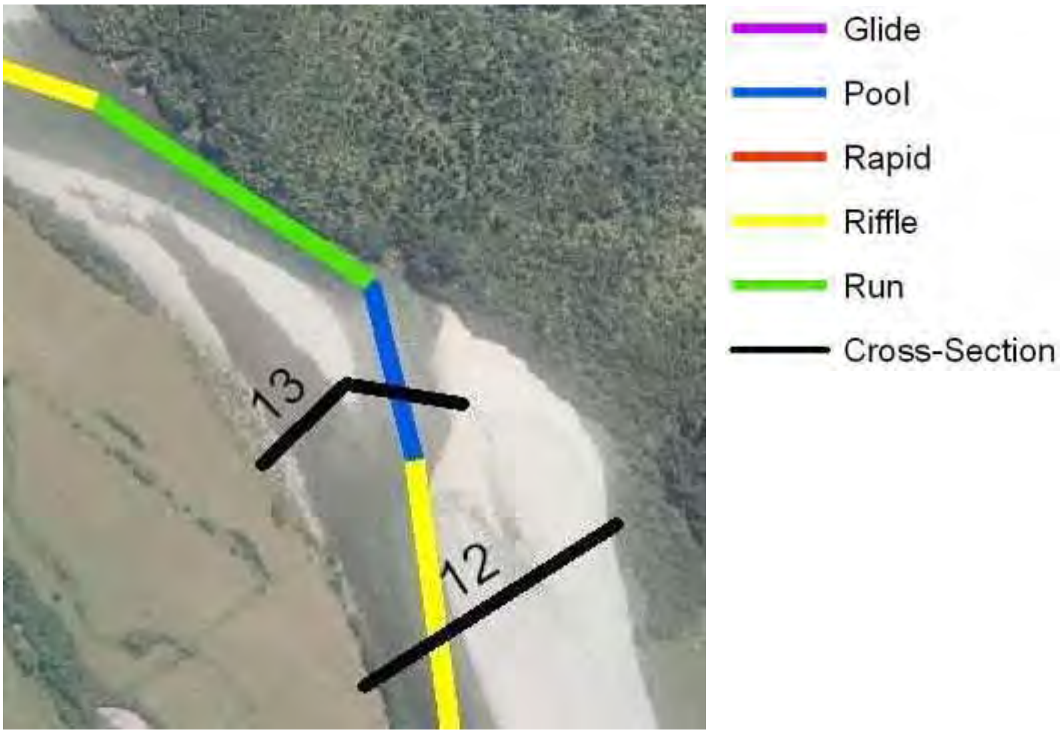
In terms of the phasing of the habitat sequence, the first way point (WP 01) is a temporary bench mark on the left bank at the proposed dam site. Both Pete and I use the first waypoint as a check on the GPS's used in the survey, not as the beginning of a habitat unit. You interpret this way point as the start of a pool that extends several metres (i.e. from the bank to the middle of the channel where the pool designation actually begins at WP 02). The difference is clear in the table below; and is obvious when the habitat units are superimposed on the aerial photographs as you have done in your map. We differ in the use of the term Plane bed and glide, but they are synonymous.

| **WPs** | **Hudson** | **Mason** | **Jowett** |
|---|---|---|---|
| **1** | BM LB | Dam site | Pool |
| **2** | Pool | Pool | Glide |
| **3** | Plane bed | Glide | Riffle |
| **4** | Riffle | Riffle | Run |
| **5** | Run | Run | Pool |
| **6** | Pool | Pool | Run |
| **7** | Run | Run | Pool |
| **8** | Pool | Pool | Riffle |
| **9** | Riffle | Riffle | Run |
| **10** | Run | Run | Glide |
| **11** | Plane bed | Glide | Pool |
| **12** | Pool | Pool | Glide |
| **13** | Plane bed | Glide | Riffle |
| **14** | Riffle | Riffle | Rapid |
| **15** | Rapid | Rapid | Pool |
| **16** | Pool | Pool | Glide |
| **17** | Plane bed | Glide | Rapid |
| **18** | Rapid | Rapid | Run |
| **19** | Run | Run | Rapid |
| **20** | Rapid | Rapid | Run |
| **21** | Run | Run | Pool |
| **22** | Pool | Pool | Run |
| **23** | Run | Run | Riffle |
| **24** | Riffle | Riffle | Run |
| **25** | Run | Run | Riffle |
| **26** | Riffle | Riffle | Rapid |
| **27** | Rapid | Rapid | Run |
| **28** | Run | Run | Pool |
| **27** | Rapid | Rapid | Run |
| **28** | Run | Run | Pool |
| **29** | Pool | Pool | Run |
| **30** | Run | Run | Riffle |
| **31** | Riffle | Riffle | Pool |
| **32** | Pool | Pool | Run |
| **33** | Run | Run | Riffle |
| **34** | Riffle | Riffle | Run |
| **35** | Run | Run | Riffle |
| **36** | Riffle | Riffle | Run |
| **37** | Run | Run | Riffle |
| **38** | Riffle | Riffle | Rapid |
| **39** | Rapid | Rapid | Run |
| **40** | Run | Run | Riffle |
| **41** | Riffle | Riffle | Run |
| **42** | Run | Run | Pool |
| **43** | Pool | Pool | Run |
| **44** | Run | Run | Rapid |
| **45** | Rapid | Rapid | Pool |
| **46** | Pool | Pool | Run |
| **47** | Run | Run | Riffle |
| **48** | Riffle | Riffle | Run |
| **49** | Run | Run | Glide |
| **50** | Plane bed | Glide | Riffle |
| **51** | Riffle | Riffle | Rapid |
| **52** | Rapid | Rapid | Run |
| **53** | Run | Run | Glide |
| **54** | Plane bed | Glide | Run |
| **55** | Run | Run | Riffle |
| **56** | Riffle | Riffle | Pool |
| **57** | Pool tidal | Pool tidal | |

In terms of the incorrect phasing of habitat units, the rapid habitat evident at cross section 4 is designated as a pool in your habitat mapping below. If the correct habitat sequence is used cross section 4 is in a rapid habitat and cross section 5 is in a pool habitat etc.



Similarly, in my opinion it is clear that your designation of cross section 13 being in a pool (blue line) reflects your incorrect phasing of habitat units. In my opinion, the correct downstream sequence is run (at cross section 12), riffle (at cross section 13) and pool along the true right bank at the top of the photograph.



As noted previously, when you apply the correct phasing and sequence our results will be similar, but not identical because in my calculations I follow the course of the river in determining the length of habitat units, whereas you take a straight line distance between waypoints located near the edge of the channel. (These waypoints specify the location of the iron bar used as a reference for water levels for the cross section).

For example, in the Chasm Creek reach you cut through the forest with a designated "channel" length of about 250 m. In my opinion, the channel length between way points 46 & 47 is about 550 m with the main channel going between the two islands in mid channel. This type of error is significant and easily avoidable.

Regarding the point that some cross sections are incorrectly placed, I found cross section 2 is located between way points 6 and 7, and does not straddle the boundary as shown in your mapping and cross section 3 is located within the plane bed between way points 11 and 12 as illustrated in the photograph below ( a view upstream).

I hope that the cross section alignment shown in your habitat mapping below is not the alignment that has been surveyed. If so, some cross section will have to be resurveyed as shown below in red. For example cross section 3 is aligned upstream and cross section 4 has no relevance to the flow direction/morphology.

Would you please confirm the alignment of the cross sections?

Mr Jowett replied to the latter on 25 March 2011: “The cross-section alignments are nominal but should be through the pins that Pete placed on the cross-sections. All alignments were at right angles to the current, except for one which went across the head of a riffle that had some current angle.”

In my email of 26 March 2011 I wrote “I take your note of 25 March 2011 ...to mean that you now agree with my analysis of 03 March and explanation of why your results of 18 March were in error (my email and attachment of 22 March).” I attached the following tables and requested that Mr Jowett “Please confirm the agreed position so that we can report back to the Environment Court.”

Agreed delineation of habitat units Mokihinui River 25 March 2011

Proportions of habitat

| Type | Hudson 03 Mar 2011 | Jowett 18 Mar 2011 | Agreed 25 Mar 2011 |
|---|---|---|---|
| Rapid | 11.33% | 7.20% | 11.33% |
| Riffle | 16.79% | 24.00% | 16.79% |
| Run | 37.35% | 40.00% | 37.35% |
| Plane bed | 10.69% | 15.90% | 10.69% |
| Pool | 23.84% | 12.90% | 23.84% |

Habitat at cross sections

| Cross section | Hudson 03 Mar 2011 | Jowett 18 Mar 2011 | Agreed 25 Mar 2011 |
|---|---|---|---|
| xs 01 | Plane bed | Run? | Plane bed |
| xs 02 | Pool | Pool-Run | Pool |
| xs 03 | Plane bed | Glide-Pool | Plane bed |
| xs 04 | Rapid | Pool | Rapid |
| xs 05 | Pool | Glide | Pool |
| xs 06 | Plane bed | Rapid | Plane bed |
| xs 07 | Run | Rapid | Run |
| xs 08 | Rapid | Run | Rapid |
| xs 09 | Pool | Run | Pool |
| xs 10 | Run | Riffle | Run |
| xs 11 | Riffle | Run | Riffle |
| xs 12 | Run | Riffle | Run |
| xs 13 | Riffle | Pool | Riffle |
| xs 14 | Run | Riffle | Run |
| xs 15 | Run | Riffle | Run |
| J 01 | Riffle | Rapid? | Riffle |
| J 02 | Riffle | Run? | Riffle |
| J 03 | Rapid | Run? | Rapid |
| J 04 | Run | Run? | Run |
| J 05 | Run | Run? | Run |
| xs 16 | Pool | Run? | Pool |
| J 06 | Run | Run? | Run |
| J 07 | Run | Glide? | Run |
| J 10 | Riffle | Riffle? | Riffle |
| J 08 | Run | Riffle? | Run |
| J 09 | Run | Run? | Run |
| xs 17 | Plane bed | Run? | Plane bed |

xs 01 – xs 17 2011 survey ? not marked
J01 – J10 Jowett survey 2007 on map/ap

My Jowett replied “I forwarded the graph of habitat delineation so that you could check it and that check showed that it was incorrect and Pete confirmed that. Therefore the document you have prepared does not state our calculation of habitat delineation correctly. In my last email I said that I would use your habitat delineations and assessment of habitat types for the cross-sections. That is the position we can agree upon.”

# APPENDIX 4

## Influence of habitat units on flow-habitat relations

There is a fundamental point of difference between the experts as noted in the expert witness Joint Statement from 15 September 2010 "C. Physical Habitat":

> There is a difference between experts in that Mr Jowett considers that individual interpretations of habitat mapping and cross-section locations have no significant effect on analysis of habitat. Dr Hudson considers delineation of habitat units and locations of cross sections are highly significant. [My emphasis].

Mr Jowett's contention is contrary to the developers of the survey methodologies and the critics of the methodology:

- The developers and critics of the instream flow incremental methodology (IFIM) instream habitat modelling recognise the importance of correctly sampling habitats. The reason is simple, too few and incorrect location and description of cross sections produce WUA curves that are meaningless (Williams 1996, Bovee 1997).
- The developers of the habitat mapping approach (Morhardt et al. 1983) stress that each cross section is weighted in proportion to the cumulative length of each habitat unit the cross section represents. Therefore, the type of habit unit becomes critical in assessing the weight of individual cross sections (i.e. how much of the river each cross section represents).

The proposition can be tested by comparing the original Jowett (2007) habitat proportions and the revised habitat proportions applied to the 2007 data set.[7] From Appendix 2, the differences in proportion are as follows:

| Type | 2007 | 2011 |
|---|---|---|
| Rapid | 4% | 11.3% |
| Riffle | 6% | 16.8% |
| Run | 84% | 37.5% |
| Plane bed | | 10.7% |
| Pool | 6% | 23.8% |

In my opinion, the differences are large and significant in terms of modelled habitat availability. The differences are larger than opposing points of views results in many water resource hearings. For example, in the Hutt River (Hudson 2010) Fish and Game argued for use of naturalised mean annual

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[7] I use the hydraulic-habitat modelling ("IFIM") data of Mr Jowett which was provided to the council resource consent hearing (Jowett 2007) and to the Environment Court. I use RHYHABSIM, and the data provided without alteration, to calculate hydraulic geometry and habitat. I replicate the results of Mr Jowett and undertake additional analysis.

low flows because of the significant increase in the channel width (e.g. an increase in width from 19 m to 20.9 m at Birchville).

In the Mokihinui, the average width at mean annual low flow increases from 49 m to 58 m merely by changing the habitat proportions (Figure 25). To put this in context, an average width of 58 m would not occur with the original habitat designations until the flow exceeded 50 $m^3/s$ (i.e. the flow has to be more than a factor of 3 larger to get the same width).

At mean annual low flow the potential adult brown trout feeding habitat (Hayes & Jowett 1994) decreases by about 12% merely by changing the habitat proportions (Figure 26).

There are large differences in the shape and position of the food producing habitat – flow relations that result merely from changing the habitat designations (Figure 27). The maximum habitat is 25% greater with the revised habitat, but occurs at 27 $m^3/s$ not 58 $m^3/s$.

I conclude the opinion of Mr Jowett that "...individual interpretations of habitat mapping and cross-section locations have no significant effect on analysis of habitat." is contrary to the observed changes in hydraulic geometry and habitat of typical target species.

## References

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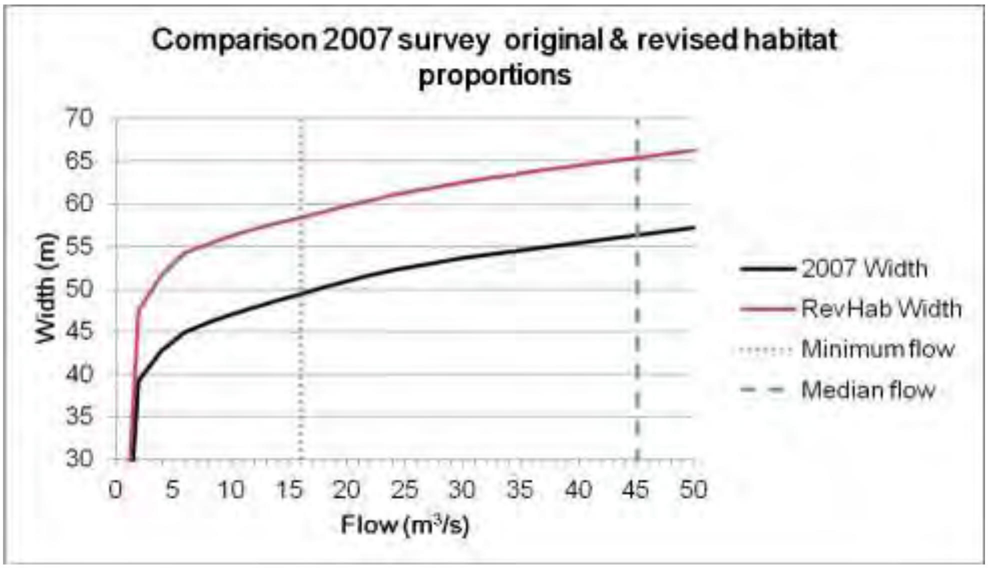

**Figure 25 Comparison of the affects of habitat designations on reach average channel width**

Comment: Channel width was calculated using Jowett's (2007) habitat designations ("2007 Width") and the survey team habitat designation ("RevHab Width").

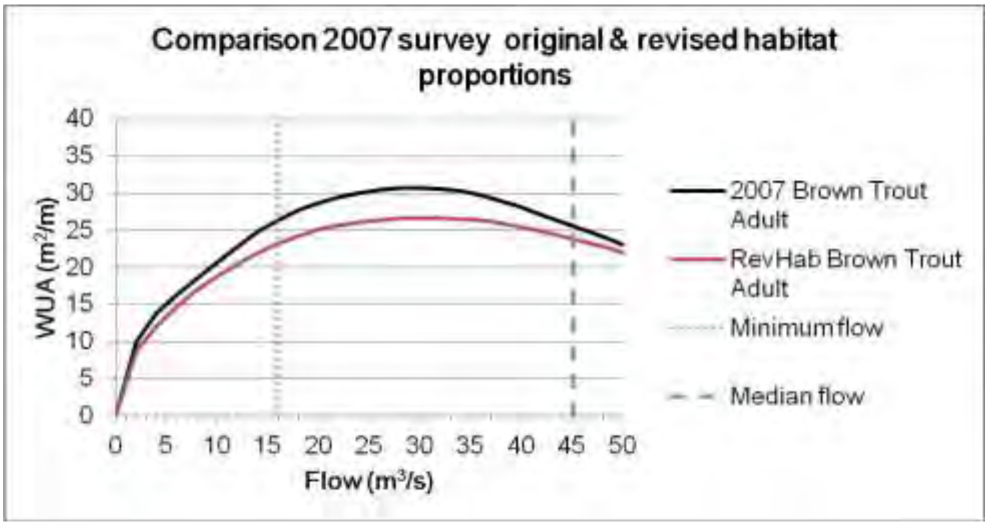

**Figure 26 Comparison of the affects of habitat designations on adult Brown trout feeding habitat**

Comment: Adult brown trout habitat was calculated using Jowett's (2007) habitat designations ("2007 Brown Trout Adult") and the survey team habitat designation ("RevHab Brown Trout Adult").

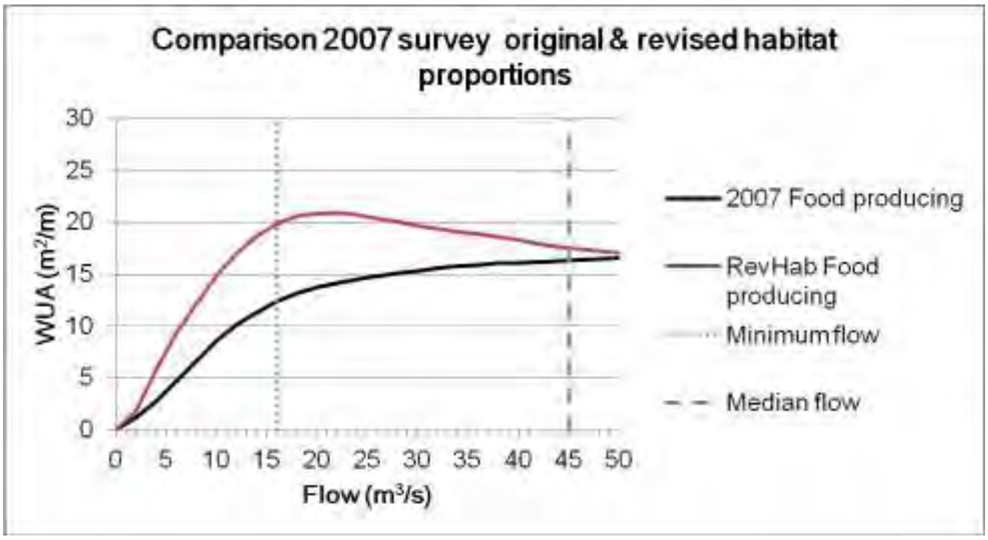

**Figure 27 Comparison of the affects of habitat designations on food producing habitat**

Comment: Food producing habitat was calculated using Jowett's (2007) habitat designations ("2007 Food producing") and the survey team habitat designation ("RevHab Food producing").

# APPENDIX 5

## Calibration & verification of the hydraulic-habitat model

### Calibration

I was critical of aspects of the Mokihinui habitat assessment of Mr Jowett (2007) including the limited range of flows that were measured for model calibration, and lack of model verification. The 2007 survey provides 10 of the 25 cross sections used in the combined 2007-2011 modelling. Hence the errors from 2007 are highly relevant. In addition, there are errors in the 2011 survey which are also discussed.

Calibration is limited to measuring water levels at the cross sections for a range of assumed flows at the sections. It is unclear from Mr Jowett's evidence (paragraphs 4.25 to 2.27) how errors related to the spatial and temporal variation in flow during the period of measurements were accounted for. Also, errors in reading water levels are not quantified.

There is a difference between the survey flows (based on streamflow gaugings at the cross section) and the "measured flow" calculated by RHYHABSIM for both the 2007 and 2011 data sets (Table 2). The RHYHABSIM calculated flows range from 81% to 146% of the surveyed flows. Accepted stream gauging accuracy is ±8% (DSIR 1991). It is uncertain where the error lies.

Extrapolation beyond the range of measured flow is seriously flawed for the 2007 survey. The 2007 survey calibration is based on a survey flow and one (XS-18-03) or two other water levels and assumed flows. The range of flows surveyed is very limited (Table 2). In most cases the survey flow is ~18 $m^3/s$ and the calibration flows are closely spaced (~42 and 45 $m^3/s$), whereas the daily flow ramping is from 16 to 126 $m^3/s$. The adopted procedure is contrary to recommended practice. As noted by Mosley & Jowett (1985);

> "...extrapolation to flows beyond the range measured is increasingly a matter of guesswork..."

I was critical of the extrapolation, but Mr Jowett (2009) opined that "Rating curves were verified by comparing them with rating curves calculated by different methods.... The rating curves calculated by these two methods were practically indistinguishable from those used for the analysis, giving me confidence in the measurements. In addition, the rating curves were compared with each other, and as expected they were very similar, again giving me confidence in the quality of the field work and rating curves. In my opinion, these are the best methods of verifying rating curves." [My emphasis]. Mr Jowett provided one rating curve to demonstrate his point.

The example provided by Mr Jowett 9200(0 was a close match, but:

- The rating curve is based on two points which is meaningless; and
- Other rating curves are not "very similar" or "practically indistinguishable."

I am of the opinion that the rating curves are not indistinguishable relative to national and international standards (DeGagne et al. 1996; Hudson et al. 1999).

I examined the range of flow predicted by the "very similar"-"practically indistinguishable" curves and found the flow at 126 $m^3$/s for the best fit curve deviated from the other curves by hundreds of percent. As a middle of the range example, at xs 23-08 a water level of ~2.75 m results in flow estimates of 126 $m^3$/s to 310 $m^3$/s (Figure 28).

Errors are far beyond the accepted stream gauging accuracy of ±8% (DSIR 1991).

### Verification

A standard requirement of the scientific method is that model results are compared (verified) with independent, randomly collected data (Williams 1996). In paragraph 3.10 of his consent hearing evidence Mr Jowett notes no verification was undertaken, because he considers it unnecessary. No evidence of verification is provided to the environment court.

I examined two lines of evidence to assess the reliability of the hydraulics of the habitat modelling:

1. I examined the integrity of the calculated depths and velocities; and
2. I compared the model with gauged flows.

I replicated the results of Mr Jowett's analysis. Plots of width, depth and velocity overlay the hydraulics and habitat are calculated with the velocity distribution factors.

Using Mr Jowett's RHYHABSIM settings I plotted the depths and velocities across the channel at the proposed daily ramping maximum of 126 $m^3$/s. I consider the modelled flows are probably unreliable for the following reasons:

1. In many cases the velocity profiles are erratic with very large, unexplained, differences from point to point across the channel (e.g. Figure 29 & Figure 30); and
2. Pont velocities are extreme in many cases, with several cross sections having point velocities exceeding 3 m/s (e.g. xs-04 4.38 m/s; xs-08 3.54 m/s; xs-16-01 5.78 m/s; xs-17-02 3.32; xs-18-03 6.74 m/s; xs-23-08 4.14 m/s). In comparison, the highest velocity measured in the Mokihinui Gorge at 1017 $m^3$/s was 3.9 m/s.

### Conclusions

The erratic nature of the modelled velocity profiles, and the extreme velocities in many cross sections, indicate the hydraulic calculations are unreliable.

## References

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**Table 2 Survey flow and calculated "measured" flow**

| X-S | Survey flow (m3/s) | Minimum rated flow (m$^3$/s) | Maximum rated flow (m$^3$/s) | RHYHABSIM "Measured Flow" (m$^3$/s) | Measured / Survey |
|---|---|---|---|---|---|
| **1** | 25.61 | 11.94 | 112.35 | 25.55 | 100% |
| **2** | 15.95 | 25.61 | 124.4 | 15.36 | 96% |
| **3** | 15.95 | 25.61 | 123.66 | 12.85 | 81% |
| **4** | 15.95 | 25.61 | 122.92 | 23.36 | 146% |
| **5** | 15.95 | 25.61 | 122.17 | 15.92 | 100% |
| **6** | 15.95 | 25.61 | 121.43 | 15.93 | 100% |
| **7** | 16.15 | 25.82 | 93.31 | 17.29 | 107% |
| **8** | 16.35 | 26.07 | 120.88 | 16.98 | 104% |
| **9** | 16.35 | 26.07 | 111.72 | 17.51 | 107% |
| **10** | 16.35 | 26.07 | 110.98 | 14.12 | 86% |
| **11** | 16.35 | 26.07 | 118.66 | 17.01 | 104% |
| **12** | 16.35 | 26.07 | 117.94 | 15.44 | 94% |
| **13** | 16.35 | 26.07 | 117.2 | 14.97 | 92% |
| **14** | 16.35 | 26.07 | 116.46 | 15.08 | 92% |
| **15** | 16.35 | 26.07 | 115.72 | 17.57 | 107% |
| **16-01** | 17.9 | 41.97 | 45.47 | 18.65 | 104% |
| **17-02** | 17.9 | 41.97 | 45.47 | 17.48 | 98% |
| **18-03** | 17.9 |  | 45.47 | 18.71 | 105% |
| **19-04** | 17.9 | 41.97 | 45.47 | 18.27 | 102% |
| **20-05** | 17.9 | 41.97 | 45.47 | 17.84 | 100% |
| **21-06** | 17.9 | 41.97 | 45.47 | 17.43 | 97% |
| **22-07** | 45.47 | 17.9 | 41.97 | 45.47 | 100% |
| **23-08** | 17.9 | 41.97 | 45.47 | 18.06 | 101% |
| **24-09** | 17.9 | 41.97 | 45.47 | 16.77 | 94% |
| **25-10** | 41.97 | 17.9 | 45.47 | 41.97 | 100% |

Comment: Cross sections 1-15 are from the 2011 survey and cross sections 16-01 to 25-10 are the ten cross sections from Jowett (2007). "**Survey flow**" refers to the flow reported at the time of the cross section survey. The "**Minimum Rated Flow**" and "**Maximum Rated Flow**" refer to the lowest and highest flows used to establish the rating relation for each cross section (along with the survey flow). "**RHYHABSIM measured flow**" is the flow at the time of survey calculated by RHYHABSIM and reported as the measured flow.

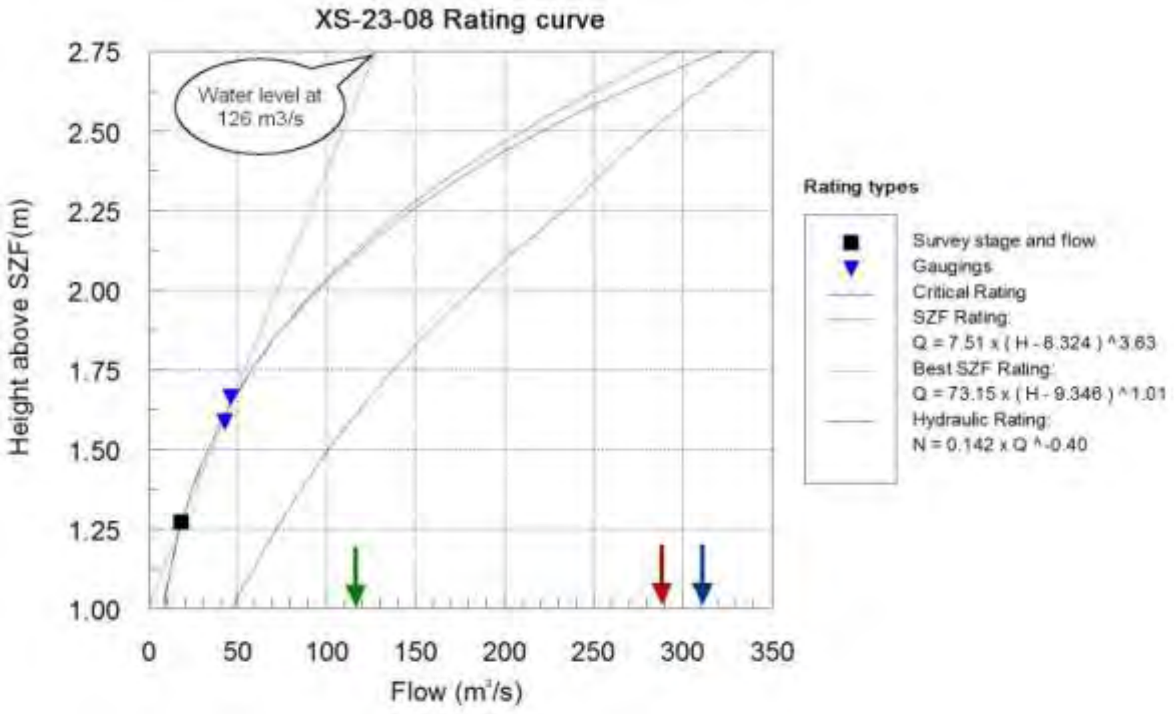


**Figure 28 Comparison of rating curves**

Comment: Flows are estimated based on the water level. The 2007 survey calibration flows were relatively low and the rating curves diverge at higher flows. Cross section 23-08 is middle of the range for this divergence (some are better and some are worse). At 126 $m^3$/s the best fit curve (green) has a water level of ~2.75 m. At that water level the SZF (stage zero flow) rating (red) flow is ~285 $m^3$/s and the hydraulic rating (blue) flow estimate is ~310 $m^3$/s.

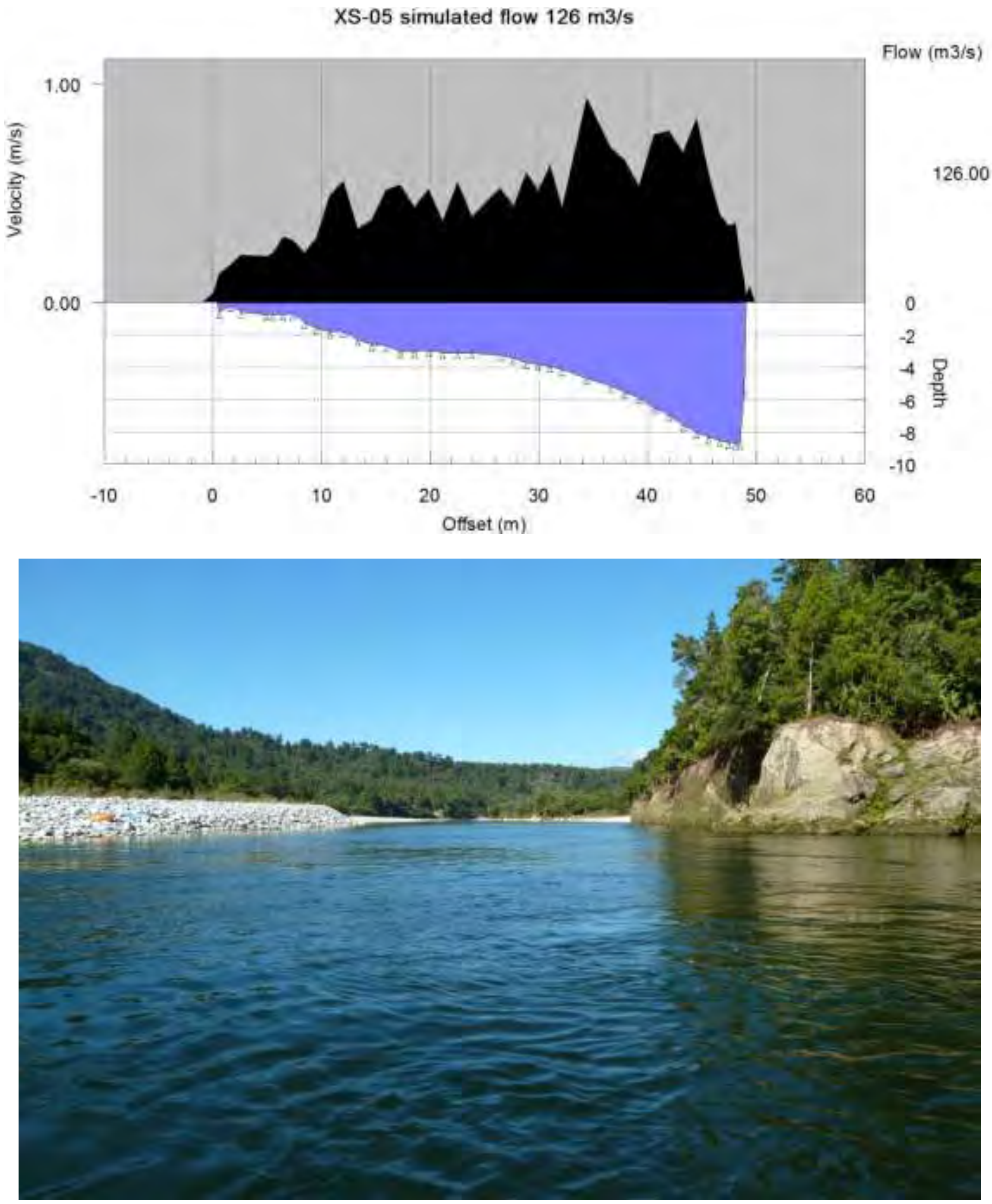


**Figure 29 Model verification: bed and velocity profiles at XS-05 (top); view downstream to xs-05**

Comment: There are no apparent obstructions that would cause large changes in velocity from point to point across the channel at a flow of 126 $m^3/s$. The depth profile (blue infill) is the measured depth at the time of survey. Measurement points of water depth (bed level) and velocity are marked with a triangle. The velocity profile (black infill) is the simulated velocity at points across the channel. (Scale: depth to 10 m, velocity 0-1.0 m/s).

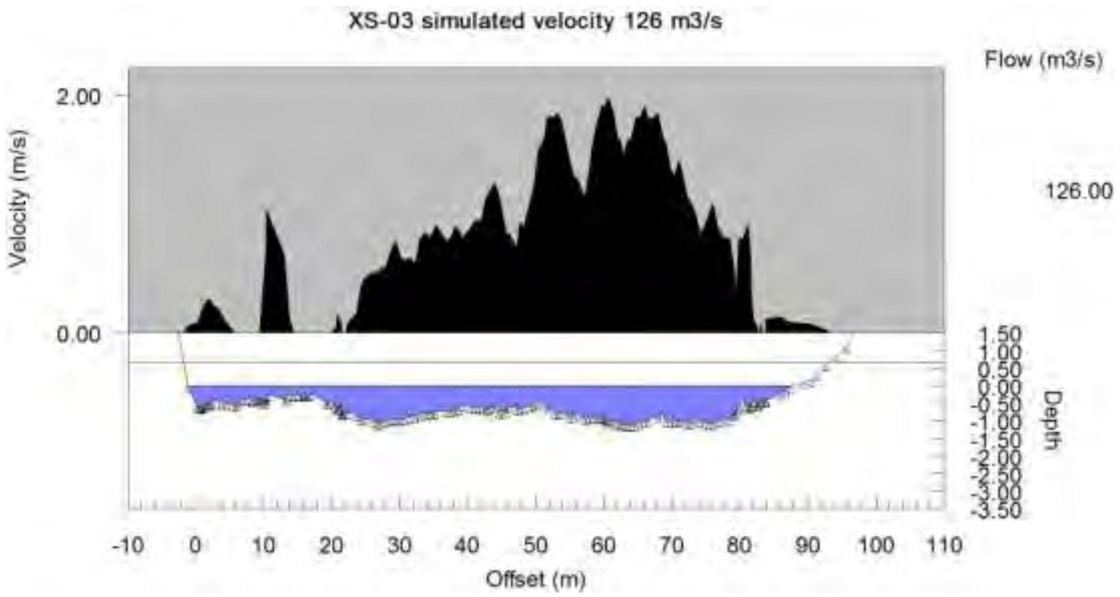


**Figure 30 Model verification: bed and velocity profiles cross section (xs) 03**

Comment: Points with zero velocity are not expected across a relatively uniform channel bed at a flow of 126 $m^3/s$. There are no apparent obstructions that would cause large changes in velocity from point to point across the channel. The depth profile (blue infill) is the measured depth at the time of survey, and the horizontal black line is the modelled water level at 126 $m^3/s$. Scale: depth to -3.5 m, velocity 0-2.0 m/s and width (offset) 120 m. The bank survey to 1.5 m above the survey water level is shown.

# APPENDIX 6

## Riparian hydro-geomorphological assessment Karamea and Mokihinui gorges

Dr Henry R Hudson

Environmental Management Associates

06 July 2011

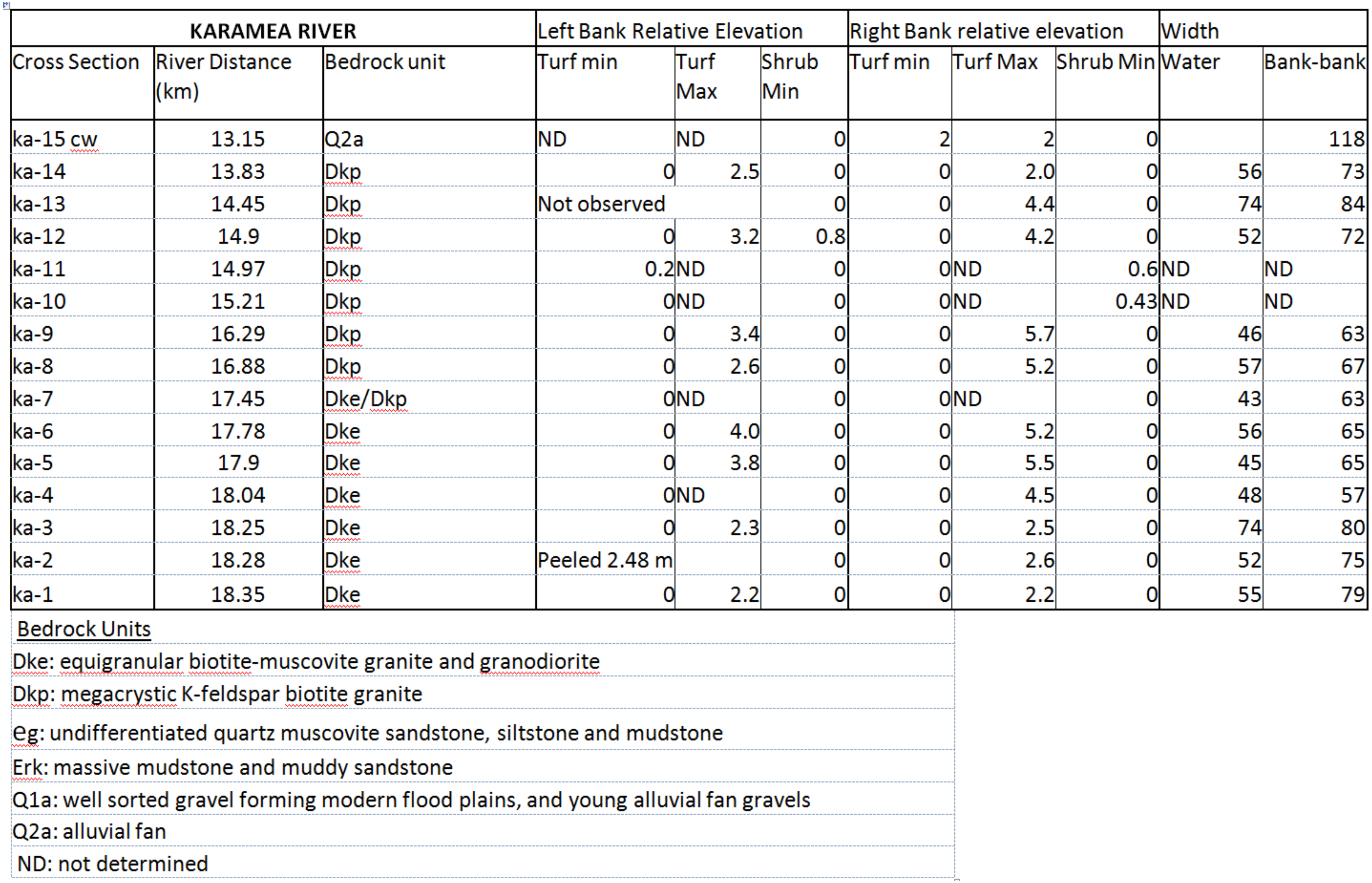
Survey locations: Mokihinui River gorge from Specimen Creek to the Welcome Creek gauge cableway; Karamea River gorge from below Greys Hutt to the Gorge gauge cableway

Survey dates: 7 April 2011 Karamea Gorge, 8-9 April 2011 Mokihinui Gorge

Survey team: Dr Kelvin Lloyd, Dr Henry Hudson

Survey discharge: Karamea mean daily flow 274 $m^3/s$ 7 April; Mokihinui 49 $m^3/s$ 8 April and 37 $m^3/s$ April 2011 (median flow 73 $m^3/s$ and 46 $m^3/s$ , respectively)

Survey location, distance upstream following the centre of the channel (km), rock type, elevation range of riparian turf and shrub on left and right bank relative to water level at the time of survey, channel widths. Elevations and width in metres.



| KARAMEA RIVER | | | Left Bank Relative Elevation | | | Right Bank relative elevation | | | Width | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cross Section | River Distance (km) | Bedrock unit | Turf min | Turf Max | Shrub Min | Turf min | Turf Max | Shrub Min | Water | Bank-bank |
| ka-15 cw | 13.15 | Q2a | ND | ND | 0 | 2 | 2 | 0 | | 118 |
| ka-14 | 13.83 | Dkp | 0 | 2.5 | 0 | 0 | 2.0 | 0 | 56 | 73 |
| ka-13 | 14.45 | Dkp | Not observed | | 0 | 0 | 4.4 | 0 | 74 | 84 |
| ka-12 | 14.9 | Dkp | 0 | 3.2 | 0.8 | 0 | 4.2 | 0 | 52 | 72 |
| ka-11 | 14.97 | Dkp | 0.2 | ND | 0 | 0 | ND | 0.6 | ND | ND |
| ka-10 | 15.21 | Dkp | 0 | ND | 0 | 0 | ND | 0.43 | ND | ND |
| ka-9 | 16.29 | Dkp | 0 | 3.4 | 0 | 0 | 5.7 | 0 | 46 | 63 |
| ka-8 | 16.88 | Dkp | 0 | 2.6 | 0 | 0 | 5.2 | 0 | 57 | 67 |
| ka-7 | 17.45 | Dke/Dkp | 0 | ND | 0 | 0 | ND | 0 | 43 | 63 |
| ka-6 | 17.78 | Dke | 0 | 4.0 | 0 | 0 | 5.2 | 0 | 56 | 65 |
| ka-5 | 17.9 | Dke | 0 | 3.8 | 0 | 0 | 5.5 | 0 | 45 | 65 |
| ka-4 | 18.04 | Dke | 0 | ND | 0 | 0 | 4.5 | 0 | 48 | 57 |
| ka-3 | 18.25 | Dke | 0 | 2.3 | 0 | 0 | 2.5 | 0 | 74 | 80 |
| ka-2 | 18.28 | Dke | Peeled 2.48 m | | 0 | 0 | 2.6 | 0 | 52 | 75 |
| ka-1 | 18.35 | Dke | 0 | 2.2 | 0 | 0 | 2.2 | 0 | 55 | 79 |

Bedrock Units

Dke: equigranular biotite-muscovite granite and granodiorite

Dkp: megacrystic K-feldspar biotite granite

eg: undifferentiated quartz muscovite sandstone, siltstone and mudstone

Erk: massive mudstone and muddy sandstone

Q1a: well sorted gravel forming modern flood plains, and young alluvial fan gravels

Q2a: alluvial fan

ND: not determined

| MOKIHINUI RIVER | | | Left Bank Relative Elevation | | | Right Bank relative elevation | | | Width | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cross Section | River Distance (km) | Bedrock unit | Turf min | Turf Max | Shrub Min | Turf min | Turf Max | Shrub Min | Water | Bank-bank |
| Mg-11 WLR | 11.46 | RB: eg LB: Q2a | 0.2 | 4.6 | 0.3 | 0.3 | 3.0 | 0.4 | 47 | 59 |
| Mg-10 | 14.02 | eg | 0.2 | 1.2 | 1.0 | gravel-boulder bar | | 1.2 | 57 | 99 |
| Mg-09b | 15.74 | Dkm | 0.7 | 3.9 | 3.4 | 0.2 | 4.5 | 1.9 | 41 | 56 |
| Mg-09a | 15.81 | Dkm | 0.4 | 4.6 | 2.9 | 0.4 | 3.1 | 2.2 | 43 | 62 |
| Mg-08d | 17.40 | RB: eg LB: Q1a | gravel-boulder bar | | 6.6 | 0.0 | 4.2 | 3.8 | 25 | 70 |
| Mg-08c | 17.43 | RB: eg LB: Q1a | gravel-boulder bar | | 5.0 | 0.2 | 6.1 | 2.3 | 50 | 90 |
| Mg-08b | 17.50 | RB: eg LB: Q1a | 2.6 | 4.7 | 3.1 | 0.0 | 6.6 | 1.5 | 35 | 69 |
| Mg-08a | 17.53 | RB: eg LB: Q1a | 1.2 | 3.9 | 1.6 | 0.0 | 4.8 | 2.4 | 41 | 75 |
| Mg-07 | 18.77 | RB: eg LB: Q1a | 0.0 | 3.5 | 1.8 | 0.0 | 1.6 | 0.0 | 45 | 146 |
| Mg-06 | 21.14 | eg | 0.4 | 3.8 | 1.4 | 0.3 | 3.6 | 2.1 | 42 | 50 |
| Mg-05 | 21.95 | eg | ND | 5.1 | 3.0 | 0.0 | 5.5 | 2.9 | 39 | 48 |
| Mg-04 | 22.75 | eg LB: talus | 0.0 | 3.3 | 0.7 | 0.6 | 3.0 | 2.4 | 36 | 53 |
| Mg-03 | 23.59 | eg | 0.4 | 4.5 | 2.5 | 0.0 | 4.2 | 4.0 | 32 | 58 |
| Mg-02 | 24.45 | eg | 0.0 | 4.0 | 0.5 | 1.3 | 4.0 | 1.7 | 23 | 54 |
| Mg-01 | 25.35 | LB: eg/Erk; RB: Erk | 0.0 | 5.1 | 2.5 | 0.0 | 4.0 | 0.5 | 39 | 61 |

Karamea Gorge waypoints (flow right to left)

Mokihinui Gorge waypoints (flow right to left)