BEFORE THE HEARINGS PANEL

IN THE MATTER	**of hearings on submissions concerning the Proposed One Plan notified by the Manawatu-Wanganui Regional Council**

SECTION 42A REPORT OF MR JOSEPH HAY

ON BEHALF OF HORIZONS REGIONAL COUNCIL

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1. INTRODUCTION

My qualifications/experience

1. My full name is Joseph Hay. I am employed as a Freshwater Biologist in the Coastal/Freshwater Group at Cawthron Institute in Nelson. I have been employed there since January 2004.

2. The majority of my work during this period has been focused on issues of flow management, including how changes in flow impact on instream habitat and freshwater fisheries. I have also been involved in research and consulting on a range of issues related to freshwater ecosystems, mainly focusing on fish, and published more than 35 reports to clients. Approximately half of these reports have involved instream habitat modelling and issues related to water allocation planning and consenting.

3. At the request of Mr Ian Jowett, the developer of RHYHABSIM instream habitat modelling software and the person with most experience in instream habitat modelling in New Zealand, I have acted as a peer reviewer of two of his most recent documents on instream habitat modelling – *A guide to instream habitat survey methods and analysis* (Jowett et al. 2008), and *Habitat use by New Zealand fish and habitat suitability models* (Jowett & Richardson 2008).

4. I have previously given evidence before the consent hearings for TrustPower's proposed hydro-electric power scheme on the Wairau River, the Central Plains Water irrigation scheme in Canterbury, and for New Zealand Energy's proposed hydro-electric power scheme on the Matiri River, on the potential effects of water abstraction on native fish and sports fish in the affected reaches.

5. I hold a BSc. (Hons.) degree in Environmental Science from University of Canterbury, where the majority of my study was focused on ecology, including freshwater ecology. I am a member of the New Zealand Freshwater Sciences Society and the New Zealand Ecological Society.

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

My role in the One Plan

7. Since 2004 my colleague Dr John Hayes and I have provided advice and analyses to Horizons on environmental flow regimes, including recommendations on minimum flows and water allocation, which have been incorporated in the One Plan. This work is the subject of my main brief of evidence. In summary:

   i. I have checked and reanalysed existing instream habitat modelling datasets to inform minimum flow setting for eight rivers in Horizons' jurisdiction (Table 1, see page 11 of this brief of evidence). I have also been involved with survey site selection, habitat mapping and cross-section selection (these three components are the first stage of field work required to collect a dataset for instream habitat modelling), as well as instream habitat analysis in a further four rivers (Table 1).

   ii. In addition, I have provided verbal instruction on field techniques to Horizons staff involved in recent habitat survey data collection, and have acted as an external peer reviewer for the Upper Manawatu Water Resource Assessment (Roygard *et al*., 2006; review described in Hay & Hayes, 2005b) and the Regional Water Allocation Framework Report (Hurndell et al., 2007 a & b, review described in Hay 2007a included as Appendix 1 to this brief of evidence).

   iii. I was involved in recommending water quality guideline levels to protect trout fishery values on the basis of a search of existing literature (Hay *et al*., 2006).

   iv. Along with Dr Hayes I have also given advice to Horizons on instream flow assessment and minimum flow setting options and how they might be applied in the Region (e.g. Hay and Hayes, 2007a).

8. I will discuss my involvement in these projects in greater detail in my main body of evidence.

Scope of evidence

9. My evidence describes my involvement in Horizons' water allocation programme. As stated above, this has mainly involved conducting instream habitat modelling to inform minimum flow setting, as well as acting as an external peer reviewer of water allocation reports and providing advice on instream flow assessment and minimum flow setting options for Horizons.

2. EXECUTIVE SUMMARY OF EVIDENCE

10. The majority of my involvement in the development of Horizons' Proposed One Plan has been conducting instream habitat modelling analyses, which have underpinned minimum flow recommendations for several rivers in the Horizons Region. An overview of instream habitat modelling, and the rationale for interpreting the results and recommending minimum flows are discussed in the evidence of my colleague Dr John Hayes.

11. My involvement with Horizons began in July 2004, following a review conducted by Dr Hayes of instream habitat modelling work previously undertaken by Horizons in the Rangitikei River and the upper Manawatu catchment.

12. Since that time I have checked and reanalysed existing instream habitat modelling datasets to inform minimum flow setting for eight rivers in Horizons' jurisdiction (Table 1). I have also been involved with survey site selection, habitat mapping and cross-section selection, as well as instream habitat analysis in a further four rivers (Table 1).

13. In addition, I have provided verbal instruction on field techniques to Horizons staff involved in recent habitat survey data collection.

14. I have recently made changes to eight of the instream habitat modelling datasets to address concerns raised by Ian Jowett, the developer of RHYHABSIM instream habitat modelling software and the person with most experience in instream habitat modelling in New Zealand. His concerns were mainly related to the calibration of rating curves at some of the cross-sections, and the changes to address these concerns were made in collaboration with Mr Jowett.

15. Following these alterations I am satisfied that the datasets on which the instream habitat analyses for Horizons were based meet expectations of data quality. The relatively minor changes to minimum flow recommendations resulting from the changes made to these eight datasets illustrate that the process is relatively robust, in my opinion.

16. The minimum flow recommendations based on these instream habitat analyses have been incorporated into the Proposed One Plan, as detailed in the evidence of Raelene Hurndell.

17. I have also acted as an external peer reviewer for water allocation reports produced by Horizons. I consider that Horizons' allocation framework is a sound, pragmatic approach to water allocation.

18. I consider that the tiered approach to setting minimum flows, depending on the level of hydrological information, abstraction demand, and instream values, is sensible and should maintain high levels of instream habitat and life supporting capacity, and that the approach to setting core allocation taken by Horizons should insure that the frequency and duration of minimum flows is not excessively high.

3. EVIDENCE

19. The majority of my involvement in the development of Horizons' Proposed One Plan has been conducting instream habitat modelling analyses, which have underpinned minimum flow recommendations for several rivers in the Horizons Region. An overview of instream habitat modelling and the rationale for interpreting the results and recommending minimum flows are discussed in the evidence of my colleague Dr John Hayes. I will briefly describe the process of data collection and habitat modelling to provide context for the description of my work for Horizons.

The instream habitat modelling process

20. Instream habitat modelling involves constructing a computer model to predict how instream habitat availability for selected species varies over a range of flows. These predictions can be used to inform decision-making regarding allocation of water resources. All of the instream habitat modelling that I have been involved with for Horizons was undertaken using RHYHABSIM (River HYDraulics and HABitat SIMulation; Jowett 2004), purpose designed software developed by Mr Ian Jowett (formerly of NIWA). This type of habitat modelling is based on combining predictions from a series of cross-sections, which have been selected to provide a reasonable representation of the variability in habitat throughout the reach of interest.

21. The fieldwork component of the process involves:

    i. reach selection
    ii. habitat mapping
    iii. cross-section placement
    iv. water-level and flow measurements over a range of flows, for calibration
    v. survey of depths, velocities and substrate at each cross-section.

22. The objective of an instream habitat survey is to get the best possible representation of the characteristics of a segment of river. The morphology of a segment of river depends on the gradient, strength of the bed material, and the magnitude of channel forming flood flows. If any of these factors changes along the length of a river (e.g. due to tributary inputs, or the river flowing into a different underlying geology), then the morphological character of the river will change. This needs to be taken into consideration when selecting a reach, or reaches, for habitat modelling, along with the location of existing or potential water abstraction pressure and instream values (e.g. reaches with high fisheries values). The idea is to select a reach or reaches that are representative of a longer segment of river (in terms of gradient, flow and channel confinement) in which the flow regime is to be altered by abstraction.

23. Habitat mapping involves recording the proportion of each habitat type (e.g. run, riffle, pool) comprising a relatively long reach of the stream, often by pacing out or measuring a representative length of the reach. This information is used to decide how many cross-sections should be allocated into each habitat type, and in the modelling process each cross-section is given a percentage weighting based on the proportion of the habitat in the reach that it represents. The predictions of subsequent modelling then relate to the reach that was mapped, with the underlying assumption that the cross-sections measured provide a reasonable representation of the variability in habitat throughout the reach and the broader river segment of interest.

24. There is an alternative approach to cross-section placement, known as the representative reach approach. This involves identifying a relatively short reach of river (typically 50-150 m over at least one riffle – run – pool sequence) that is thought to be representative of a longer segment of river. The cross-sections are closely spaced (at a scale of metres) at longitudinal points of habitat change along the reach. Note is taken of the distance between cross-sections, and the water levels on all cross-sections are surveyed to a common datum. The subsequent modelling predictions are then assumed to be applicable to the section of river that the chosen reach represents. A draw-back of this approach is that it is often difficult to find a contiguous short reach that adequately represents the variability in habitat throughout the broader river segment of interest. The habitat mapping approach overcomes this difficulty by allowing cross-sections to be sampled from a longer stretch of river to provide a representative sample. The habitat mapping approach was applied in all of Horizons' instream habitat modelling studies that I have been involved with.

25. Following habitat mapping, cross-sections are selected to cover the range of variability in habitat types. The number of cross-sections required will depend on the morphological variability of the channel; fewer cross-sections will be required in relatively homogenous channels. Studies have shown that relatively few cross-sections can reproduce the shape of the weighted usable area (WUA; habitat index) versus flow relationship obtained from a survey with a large number of cross-sections. For example, Payne *et al*. (2004) sub-sampled several very large data sets to determine how many cross-sections were required to produce a robust WUA versus flow relationship. They found that 18-20 cross-sections gave results nearly identical to results for 40-80 cross-sections per reach and that only a few cross-sections were required to reproduce the general shape of the relationship. Several such studies were summarised in a recent guide to instream habitat surveys and modelling (Jowett et al. 2008). The recommendation from that guide was that the total number of cross-sections needed to generate a robust result should be proportional to the complexity of the habitat hydraulics. They suggested 6-10 cross-sections for simple reaches and 18-20 for diverse reaches. They also recommended that the number of cross-sections should be sufficient to ensure that no individual cross-section receives a weighting of more than 5-10%, to minimise the influence of outliers. I agree with these recommendations and have followed this approach to cross-section selection in the instream habitat surveys I have been involved with.

26. At each cross-section a temporary staff gauge, usually a Warratah or short length of reinforcing bar, is driven into the bed. This allows changes in the water level (or stage) at each cross-section to be recorded at several measured flows (referred to as calibration flows), and this information is used to calibrate the model.

27. At one flow (referred to as the survey flow) water depths, velocities and substrate composition are recorded at a series of points across each cross-section. These measurements describe the cross-sectional shape of the channel and the velocity distribution across it. Points on the banks, above water level, along the cross-sections are also surveyed to allow model predictions to be made at flows higher than the survey flow. The stage at zero flow (i.e. the water level at which surface flow would cease and water would simply be ponding in hollows in the bed) is also estimated at each cross-section to facilitate fitting of rating curves and for making model predictions at low flows.

28. These data allow calibration of a hydraulic model to predict how depths, velocities and the area of different substrate types covered by the stream will vary with discharge in the surveyed reach. For each cross-section a rating curve is developed, describing how

water level changes with flow. In combination with the cross-sectional survey data these rating curves are used to predict the changes in depth and therefore cross-sectional area at each cross-section, and the model can then predict how velocities across the cross-section would have to change to accommodate the change in discharge.

29. Modelled depths, velocities and substrate types can then be compared with habitat suitability criteria (HSC) describing the suitability of different depths, velocities and substrate sizes as habitat for given species of interest. These criteria take the form of habitat suitability curves, which have been developed by observing the depths and velocities used by various species in rivers, both in New Zealand and overseas. Comparison of the HSC with the modelled physical characteristics of the study stream provides a prediction of the availability and quality of habitat in the stream. Habitat modelling is undertaken over a range of flows to predict how habitat availability will change with flow.

My involvement in instream habitat modelling for Horizons

30. My involvement with Horizons began in July 2004, following a review conducted by Dr Hayes of instream habitat modelling work previously undertaken by Horizons in the Rangitikei River and the upper Manawatu catchment. In his review Dr Hayes recommended that several datasets should be reanalysed, applying different habitat suitability criteria than those used in the original studies.

31. The results of instream habitat analyses are most sensitive to the habitat suitability criteria applied. The criteria need to be representative of the species, life stages and sizes known to, or likely to, occur in the river, and when criteria developed elsewhere are applied consideration must be given to their transferability to the study river. The habitat suitability criteria that I have applied in my analyses have been selected by Dr Hayes and I to provide what we consider to be the best representation of habitat requirements in the study rivers on the basis of the suitability criteria available. The habitat suitability criteria that each minimum flow recommendation was ultimately based on are listed in Table 2 (on page 13 of this brief of evidence), and they are also depicted in Appendix 2, along with some brief background information on each set of criteria.

32. Following this review I conducted a reanalysis of the Rangitikei datasets under the supervision of Dr Hayes, and subsequently reanalysed datasets from the upper Manawatu and tributaries (Table 1). On the basis of these analyses we made recommendations of minimum flows required to sustain instream ecological values,

which were detailed in our reports (Hay & Hayes 2004, 2005a, 2007b[1]). Since then the minimum flow recommendations for some of these sites have been altered in light of updated flow statistics (e.g. Hay & Hayes 2007b). The recommendations for some sites have also altered due to a software bug I discovered in RHYHABSIM, and due to changes to some of the underlying datasets to improve calibration of the models as a result of discussion with Mr Jowett. I will discuss these changes later in my evidence.

33. In January 2005, following consultation with Mr Peter Taylor, then at Fish & Game, Dr Hayes and I assisted Horizons staff with reach selection, habitat mapping and cross-section placement for an instream habitat modelling survey in the Pohangina River, to get an understanding of the instream values in this river. Horizons staff conducted the remaining fieldwork. On the basis of these data I calibrated an instream habitat model in RHYHABSIM and Dr Hayes and I used the predictions of this model as the basis for recommending a minimum flow for the Pohangina River (Hay & Hayes 2006).

34. In the summer of 2005 Dr Hayes and I also assisted Horizons staff with reach selection, habitat mapping and cross-section placement on the Oroua River. This time we were also accompanied in the field by Mr Taylor, representing Fish & Game. Unfortunately, these cross-sections were washed out in a flood. Horizons staff repeated the habitat mapping and cross-section placement in February 2006, and collected the remaining calibration and survey data. I used these data to calibrate a RHYHABSIM model, which I used to provide minimum flow recommendations for the Oroua River (Hay 2006). These recommendations were revised in light of updated flow statistics in February 2007 (Hay 2007b), and again following changes to the underlying dataset, to improve calibration of the model during preparation of this evidence (I will discuss these changes later).

35. The most recent instream habitat modelling exercise that I have been involved in with Horizons was focused on the Makotuku and Makara rivers, near Raetihi. I assisted Horizons staff with reach selection habitat mapping and cross-section placement in April 2007.

36. At the request of Horizons I returned in May 2007 to provide instruction to the field crews collecting the survey and calibration data. I explained how the data they were collecting would be used to construct a habitat model in RHYHABSIM, to predict habitat available at other flows, and highlighted the key points to bear in mind when collecting the field

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[1] Hay & Hayes 2007b is a re-issue of the earlier report Hay & Hayes 2005a, but with an addendum detailing changes to the proposed minimum flows for several reaches in light of updated flow statistics (updated in August 2007).

data for habitat modelling (e.g. the need for accuracy in water-level measurements, in particular, and adequate depth and velocity measurements to accurately describe the channel cross-section shape and velocity distribution). I also assisted with collection of survey data on the Makara Stream.

37. Horizons staff collected the remaining survey and calibration data, and I recommended minimum flows based on instream habitat models that I calibrated with those data (Hay 2007c).

Table 1. Details of instream habitat analyses in the Horizons Region with which I have been involved

River	Reach	Extent of involvement	Report/s
Rangitikei	Otara	Reanalysis	Hay J, Hayes JW 2004. Instream Flow Assessment for the Rangitikei River: Additional Analyses. Prepared for Horizons Regional Council. *Cawthron Report No. 930.* 21 p.
	Onepuhi	Reanalysis	
	Hampton's	Reanalysis	
Manawatu	Hopelands Bridge	Reanalysis	Hay J, Hayes JW 2005. Instream flow assessment for the Upper Manawatu River and tributaries: Additional analyses. Prepared for Horizons Regional Council. *Cawthron Report No. 1029.* 72p. Plus: Addendum prepared by J Hay and J Hayes August 2007
Manawatu	Weber Rd	Reanalysis	
Manawatu	Maunga Rd	Reanalysis	
Manawatu	Ormondville Takapau Rd	Reanalysis	
Manawatu	State Highway 2	Reanalysis	
Mangapapa Stm	Oxford Rd	Reanalysis	
Raparapawai Stm	Gaisford Rd	Reanalysis	
Raparapawai Stm	Maharahara Rd	Reanalysis	
Oruakeretaki Stm	State Highway 2	Reanalysis	
Kumeti Stm	State Highway 2	Reanalysis	
Kumeti Stm	Te Rehunga	Reanalysis	
Tamaki Rvr	State Highway 2	Reanalysis	
Tamaki Rvr	Water Supply Weir	Reanalysis	
Mangatoro	Weber Rd	Reanalysis	
Pohangina	Mais	Reach selection, habitat mapping, cross-section selection and analysis	Hay J, Hayes J 2006. Instream flow assessment for the Pohangina River. Prepared for Horizons Regional Council. *Cawthron Report No. 1080.* 25p.
Oroua	Boness Rd	Reach selection and analysis	Hay J 2006. Instream flow assessment for the Oroua River. Prepared for Horizons Regional Council. *Cawthron Report No. 1179.* 25p. Plus: Addendum prepared by J Hay February 2007
Makotuku	Upstream of New Zealand Energy Ltd's abstraction	Reach selection, habitat mapping, cross-section selection and analysis	Hay J 2007. Instream Flow Assessment for the Makotuku and Makara rivers. Prepared for Horizons Regional Council. Cawthron Report No. 1350. 31 p.
	Downstream of New Zealand Energy Ltd's abstraction	Reach selection, habitat mapping, cross-section selection and analysis	
Makara		Reach selection, habitat mapping, cross-section selection and analysis	

38. In 2007 Dr Hayes and I produced a report for Horizons reviewing instream flow assessment and minimum flow setting options, and how they might be applied in the Region (Hay and Hayes 2007a). Much of the content of this review is covered in the evidence of Dr Hayes, including the approach to interpreting the results of instream habitat modelling for setting minimum flows, and the need to set allocation limits in conjunction with the minimum flow to maintain ecologically relevant flow variability. In this report we also assessed the potential applicability to Horizons' rivers of a relatively new method, generalised habitat models. These generalise the predictions of instream habitat modelling, by fitting a statistical model (or curve) to the output (HSI or WUA versus flow, but with flow standardised by stream width) from a large number of streams, so that the shape of the curve can be used to derive minimum flows for a new target stream with substantially reduced field data requirements.

39. We recommended a tiered approach to minimum flow setting, as recommended by Jowett & Hayes (2004), depending on the level of abstraction demand and relative instream values. As discussed in the evidence of Dr Hayes, Ms Hurndell and Dr Roygard, Horizons staff ultimately adopted a slightly different tiered approach; the approach they took to generalising the results of instream habitat modelling from the streams where it has been applied to other streams in the Region was also different. They used a specific proportion of mean annual low flow (MALF) to set minimum flows in streams where sufficient hydrological data existed, based on statistical relationships between MALFs and minimum flows recommended from instream habitat analyses already undertaken on rivers in the Horizons region (Hurndell et al., 2007). As discussed in the evidence of Dr Roygard, a recent adaptation of this method has been to vary the proportion of MALF applied depending on the size of the river or stream, as indicated by the magnitude of the MALF (95%, 85% or 80% of MALF for small, medium and large streams, respectively). This adaptation takes into account that available habitat (e.g. WUA or HSI) tends to decline more rapidly with flow reductions below the MALF in small streams than in large rivers. I consider this method and the tiered approach to minimum flow setting to be sound and pragmatic, as I discuss further below in relation to my role as an external peer reviewer of Horizons' water allocation framework.

40. As discussed in the evidence of Dr Hayes, the approach that we have taken to interpreting the WUA outputs from instream habitat modelling to guide minimum flow recommendations involves identifying a critical instream value, generally the species with the highest flow requirements. Candidates for critical value status might include flow-sensitive rare or endangered species, or species with high fishery value. The

assumption is made that by providing sufficient flow to sustain this critical value, there should also be sufficient flow for other values with lower flow requirements, because less flow demanding species will be able to use slower or shallower habitat along the river margins, or in riffles or pools. Our minimum flow recommendations were then made based on retaining a proportion of the habitat available at either the mean annual low flow or the habitat optimum, whichever occurs at the lower flow.

41. Trout are often an obvious candidate for this critical value position, because they are recognised as being among the most flow-demanding fish in New Zealand rivers, and also because they support valued recreational fisheries. For all of the instream habitat modelling studies that I have undertaken for Horizons, trout have ultimately been identified as the critical value on which minimum flow recommendations have been based (see the evidence of Ms Hurndell, and the evidence of Dr Hayes paragraphs 35, 52, 111, 23 and 124 for further discussion of the rationale for this approach). However, the relevant species and life stage of trout has varied between rivers and seasons, depending on the species or life stages known to be supported by the river (Table 2). In some cases a higher minimum flow was suggested for winter and spring to maintain spawning habitat, where this had higher flow requirements based on the habitat modelling. In Appendix 2 I have provided figures of the habitat suitability criteria for the critical values on which minimum flow recommendations where based in each habitat modelling study undertaken for Horizons, and some brief notes on the derivation of each set of criteria.

42. When making minimum flow recommendations we have usually suggested two alternative levels of habitat retention (Table 2), in recognition that the level of habitat retention is arbitrary and is based on balancing the relative levels of risk versus value. We intended that these alternative minimum flows might provide a basis for negotiations on the relative values of instream and out-of-stream water use. The levels of habitat retention that we have suggested were based on those suggested by Jowett & Hayes (2004) in a report to Environment Southland and Ministry for the Environment (these levels of habitat retention are discussed further in the evidence of Dr Hayes), and the levels have varied slightly depending on the relative fishery values (Table 2).

Table 2 Habitat suitability criteria for the critical values on which minimum flow recommendations were based for rivers in Horizons' jurisdiction, and the levels of habitat retention suggested for alternative minimum flows

River	Reach	Habitat Suitability Criteria	Habitat retention levels suggested
Rangitikei	Otara	Rainbow trout adult (Bovee 1995)	90% & 80%
	Onepuhi	Rainbow trout adult (Bovee 1995)	90% & 80%
	Hampton's	Rainbow trout adult (Bovee 1995)	90% & 80%
Manawatu	Hopelands Bridge	Brown trout adult (Hayes & Jowett 1994)	90%
Manawatu	Weber Rd	Brown trout adult (Hayes & Jowett 1994)	90%
Manawatu	Maunga Rd	Brown trout adult (Hayes & Jowett 1994)	90%
Manawatu	Ormondville Takapau Rd	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
	During spawning	Brown trout spawning (Shirvell & Dungey 1983)	90% & 70%
Manawatu	State Highway 2	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
	During spawning	Brown trout spawning (Shirvell & Dungey 1983)	90% & 70%
Mangapapa Stm	Oxford Rd	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
Raparapawai Stm	Gaisford Rd	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
	During spawning	Brown trout spawning (Shirvell & Dungey 1983)	90% & 70%
Raparapawai Stm	Maharahara Rd	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
Oruakeretaki Stm	State Highway 2	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
Kumeti Stm	State Highway 2	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
	During spawning	Brown trout spawning (Shirvell & Dungey 1983)	90% & 70%
Kumeti Stm	Te Rehunga	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
Tamaki Rvr	State Highway 2	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
	During spawning	Brown trout spawning (Shirvell & Dungey 1983)	90% & 70%
Tamaki Rvr	Water Supply Weir	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
Mangatoro	Weber Rd	Brown trout yearling - small adult feeding (Roussel et al 1999)	90% & 70%
	During spawning	Brown trout spawning (Shirvell & Dungey 1983)	90% & 70%
Pohangina	Mais	Brown trout adult (Hayes & Jowett 1994)	90% & 80%
Oroua	Boness Rd	Brown trout adult (Hayes & Jowett 1994)	80% & 70%
Makotuku	Upstream of New Zealand Energy Ltd's abstraction	Brown trout yearling - small adult feeding (Roussel et al 1999)	70% & 60%
	During spawning	Brown trout spawning (Shirvell & Dungey 1983)	70% & 60%
	Downstream of New Zealand Energy Ltd's abstraction	Brown trout yearling - small adult feeding (Roussel et al 1999)	70% & 60%
	During spawning	Brown trout spawning (Shirvell & Dungey 1983)	70% & 60%
Makara		Brown trout yearling - small adult feeding (Roussel et al 1999)	70% & 60%
	During spawning	Brown trout spawning (Shirvell & Dungey 1983)	70% & 60%

Recent alterations and reanalyses

43. As mentioned earlier, Mr Jowett and I have recently made alterations to some of Horizons datasets, to address concerns he had raised. These concerns were mainly related to the calibration of rating curves at some of the cross-sections. As well as these changes I also discovered a software bug in RHYHABSIM, which had affected the analysis of two of the reaches modelled in the Rangitikei River. Mr Jowett has since fixed this bug. The effects of the data changes that Mr Jowett and I made on the minimum flow recommendations were minor, and in some instances made no difference at all. By contrast, fixing the software bug made a significant difference to the minimum flow recommendations for the Otara and Onepuhi reaches of the Rangitikei River. The changes made are described in a short report attached as Appendix 3, however, I will summarise here.

44. The software bug caused the distance to each cross-section from the end of the reach to influence the results, if the distance was entered in descending order. In practise this measurement should not be used in the calculations within the model for datasets based on habitat mapping, as these datasets were. The distance measurements are used in the calculations for another approach to habitat modelling (the representative reach approach), and presumably this software bug caused the wrong routine to run if the distances were entered in descending order. Fixing this bug caused approximately a 2-3 m^3/s change in the minimum flows recommended for the Otara and Onepuhi reaches of the Rangitikei River, but in opposite directions (Table 3). However, from a discussion I had with Dr Jon Roygard I understand that the minimum flows originally adopted for the Rangitikei hinged on maintaining adequate flow further downstream, in the part of the river represented by Hampton's reach; consequently these changes to the minimum flow recommendations for the upper two reaches may not have much material effect. Furthermore, the MALF estimates for these reaches have recently been updated to take account of recent flow data, and I have provided new minimum flow recommendations based on these updated statistics, which have been incorporated into the Proposed One Plan (see the evidence of Ms Hurndell, Mr Brent Watson and Dr Roygard).

Table 3. The effect on minimum flow recommendations for two reaches on the Rangitikei River of repairing a software bug in RHYHABSIM, which caused the order of cross-section distances to influence model predictions (all flows are in m^3/s)

Reach	Original MALF	90% habitat retention Original recommended minimum flow	90% habitat retention Minimum flow with bug repaired	80% habitat retention Original recommended minimum flow	80% habitat retention Minimum flow with bug repaired
Otara	15.51	9.50	11.91	6.81	9.69
Onepuhi	17.93	14.55	12.58	12.23	10.13

45. The datasets about which Mr Jowett raised concerns are listed in Table 4. The changes that Mr Jowett and I made were to account for shortcomings in the data sets and apparent measurement and data entry errors by the survey teams. They mainly involved alterations to some of the rating curves. We deleted calibration gaugings that were very similar to the survey flow, but quite different in terms of water level; also in some cases we altered the water level at a calibration flow for a given cross-section, when that cross-section had displayed quite a different response to others in the reach (e.g. water level reduced by twice as much as the average change on all other cross-sections). We also removed two cross-sections that were very wide compared to all the others in their respective datasets, since they were not likely to be representative of average conditions in the reach and so were likely to cause bias in the habitat predictions (e.g. a ~150 m wide riffle in the Rangitikei River at Otara reach, where all of the other cross-sections were approximately 30-40 m wide). These cross-sections were surveyed to represent critical habitat for fish passage and so are not representative of average habitat conditions. We recognised two cross-sections in the Oroua River as being two channels in a single braided cross-section, and changed their calibration flows accordingly. Finally, we switched the cross-section weighting on two cross-sections in the Rangitikei River at Hampton's Reach which appeared to have been entered as the wrong habitat types, on the basis of the depths and velocities recorded from them.

46. As stated above, although these alterations improved our confidence in the quality of the datasets, they made no material difference to the minimum flow recommendations, as shown in Table 4. In the majority of cases they were within 2% of the original minimum flows, and the largest difference was a 6% change.

Table 4. Comparison of the original minimum flow recommendations and those based on the altered datasets, but the original MALFs for the eight reaches about which Mr Jowett had raised concerns (all flows are in m^3/s). **Note:** those minimum flows marked with a * were based on 80% habitat retention, in keeping with those in the original reports

			90% habitat retention		70% habitat retention	
River	**Reach**	**Original MALF**	**Original recommended minimum flow**	**Minimum flow based on updated dataset**	**Original recommended minimum flow**	**Minimum flow based on updated dataset**
Rangitikei	Otara	15.51	11.91	12.19	9.69*	9.94*
	Onepuhi	17.93	12.58	12.46	10.13*	10.03*
	Hampton's	18.58	10.23	10.18	7.81*	8.06*
Raparapawai	Maharahara Rd	0.050	0.047	0.045	0.041	0.042
Oruakeretaki	State Highway 2	0.350	0.293	0.294	0.232	0.229
Kumeti	State Highway 2	0.070	0.064	0.064	0.052	0.055
	During spawning		0.065	0.065	0.057	0.056
Tamaki	State Highway 2	0.350	0.296	0.297	0.209	0.209
	During spawning		0.311	0.310	0.238	0.236
Oroua	Boness Rd[1]	1.20	0.95*	0.93*	0.83	0.81

[1] Flow statistics for this site are referenced to the Oroua at Kawa Wool flow recorder site.

47. Following these alterations I am satisfied that the datasets on which the instream habitat analyses for Horizons were based meet expectations of data quality. In my opinion, the relatively minor changes to minimum flow recommendations resulting from the changes made to these datasets illustrate that the process is relatively robust.

48. I used these new adjusted datasets, along with the most recent MALF estimates, to produce new minimum flow recommendations for these reaches. These minimum flows are detailed in the evidence of Ms Hurndell.

Peer review of water allocation approach

49. I have acted as an external peer reviewer of Horizons' water allocation framework project. As stated above I reviewed the Upper Manawatu Water Resource Assessment (Roygard et al. 2006; review described in Hay & Hayes 2005b) and the Regional Water Allocation Framework Report (Hurndell et al., 2007 a & b, review described in Hay 2007a, included as Appendix 1 to this brief of evidence).

50. I consider that Horizons' allocation framework is a sound, pragmatic approach to water allocation. It addresses what I regard as the two key components of an effective water allocation regime for run-of-the-river abstractions: a minimum flow to provide adequate habitat for aquatic biota during periods of low flow and an allocation limit to ensure that flow is not drawn down to the minimum flow for excessive periods.

51. I agree with Dr Hayes (paragraph 106 in his brief of evidence) that the tiered approach to setting minimum flows adopted by Horizons, depending on the level of hydrological information, abstraction demand, instream values, and size of river, is sensible and should maintain high levels of instream habitat and life supporting capacity.

52. I also agree with Dr Hayes (paragraphs 107-108 in his brief of evidence) that Horizons' method of setting allocation limits in conjunction with minimum flows is a pragmatic approach, which takes appropriate account of the potential risks of changes to the frequency and duration of flows in the low to median flow range. When making minimum flow recommendations on the basis of instream habitat modelling, Dr Hayes and I have consistently stipulated that these minimum flow recommendations are intended to be applied in combination with suitable allocation limits, which insure that the frequency and duration of occurrence of the minimum flow is not excessively high. I consider that the approach to setting core allocation taken by Horizons has addressed this recommendation. Their approach quantifies the expected change in the frequency and duration of occurrence of the minimum flow, in response to different total allocation volume scenarios, allowing them to select a level of allocation that does not cause an excessively large increase in the natural rate of occurrence of the minimum flow. The frequency of occurrence and duration of the minimum flow will impinge on the surety of supply for abstractors (through abstraction restrictions), but also has the potential to have ecological effects, as discussed in the evidence of Dr Hayes.

4. REFERENCES

Hay J 2006. Instream flow assessment for the Oroua River. Prepared for Horizons Regional Council. *Cawthron Report No. 1179.* 25p.

Hay J 2007a. Comments on Horizons Regional Council's "Regional Water Allocation Framework (Technical Report to Support Policy Development)" Draft report, as part of an external peer review. Letter of review, prepared for Horizons Regional Council 15 June 2007. 3p.

Hay J 2007b. Addendum to Cawthron Report Number 1179: Instream flow assessment for the Oroua River. Prepared for Horizons Regional Council, February 2007. 2p.

Hay J 2007c. Instream Flow Assessment for the Makotuku and Makara rivers. Prepared for Horizons Regional Council. Cawthron Report No. 1350. 31 p.

Hay J, Hayes JW 2004. Instream Flow Assessment for the Rangitikei River: Additional Analyses. Prepared for Horizons Regional Council. *Cawthron Report No. 930.* 21 p.

Hay J, Hayes JW 2005a. Instream flow assessment for the Upper Manawatu River and tributaries: Additional analyses. Prepared for Horizons Regional Council. *Cawthron Report No. 1029.* 72p.

Hay J, Hayes J 2005b. Review of Horizons' Upper Manawatu Water Resource Assessment Draft Report. Prepared for Horizons Regional Council. *Cawthron Report No. 1121.* 8p.

Hay J, Hayes J 2006. Instream flow assessment for the Pohangina River. Prepared for Horizons Regional Council. *Cawthron Report No. 1080.* 25p.

Hay J, Hayes J 2007a. Instream flow assessment options for Horizons Regional Council. Prepared for Horizons Regional Council. Cawthron Report No. 1242. 39 plus appendices.

Hay J, Hayes JW 2007b[2]. Instream flow assessment for the Upper Manawatu River and tributaries: Additional analyses (with Addendum). Prepared for Horizons Regional Council. *Cawthron Report No. 1029.* 72p.

Hay J, Hayes J, Young R 2006. Water quality guidelines to protect trout fishery values. Prepared for Horizons Regional Council. *Cawthron Report No. 1205.* 17p.

Hurndell R, Roygard J, Watson J 2007. Regional water allocation framework volume 1 –Technical report to support policy development. Horizons Regional Council, Report No. 2007/EXT/809. ISSBN 978-1-877413-92-5.

[2] Hay & Hayes 2007b is a re-issue of the earlier report Hay & Hayes 2005a, but with an addendum detailing changes to the proposed minimum flows for several reaches in light of updated flow statistics (updated in August 2007).

Hurndell R, Roygard J, Watson J 2007. Regional water allocation framework volume 2 – Appendix to Volume 1: Technical report to support policy development. Horizons Regional Council, Report No. 2007/EXT/810. ISSBN 978-1-877413-93-3.

Jowett IG 2004. RHYHABSIM River Hydraulics and Habitat Simulation (Software Manual).

Jowett IG, Hayes JW 2004. Review of methods for setting water quantity conditions in the Environment Southland draft Regional Water Plan. *NIWA Client Report: HAM2004-018*. Prepared for Environment Southland, under NIWA Project: ENS04202.

Jowett IG, Hayes JW, Duncan MJ 2008. A guide to instream habitat survey methods and analysis. *NIWA Science and Technology Series No. 54*. 121p.

Jowett IG, Richardson J 2008. Habitat use by New Zealand fish and habitat suitability models. *NIWA Science and Technology Series No. 55*. 148p.

Payne TR, Eggers SD, Parkinson DB 2004. The number of transects required to compute a robust PHABSIM habitat index. *Hydroécologie appliqué 14*: 27-54.

Roygard J, Watson J, Clark M 2006. Water allocation project upper Manawatu catchment: Water resource assessment – Allocation limits and minimum flows. Technical report to support policy development. Horizons Regional Council Report No .2006/EXT/684, ISBN: 1-877413-20-8.

Mr Joseph Hay
August 2009

APPENDIX 1. LETTER OF REVIEW FOR WATER ALLOCATION PROJECT

CAWTHRON

Comments on Horizons Regional Council's "Regional Water Allocation Framework (Technical Report to Support Policy Development)" Draft report, as part of an external peer review.

By Joe Hay
15 June 2007

On the whole this looks like a good pragmatic approach to me. I have made a number of comments and suggested changes to the text in the document. In addition to those comments I would like to make more generic comments/ suggestions on what I see as the two key issues around minimum flows and abstraction/ allocation, those being the magnitude of the minimum flow, and the frequency and duration of the minimum flow (related to flow variability).

The minimum flow:
I think of the minimum flow as providing essentially a habitat refuge during periods of low flow (i.e. I don't think it should be thought of as providing adequate habitat to support fish populations over the long term, if flow is consistently held at the minimum, at least partly because food supply for fish is likely to be reduced. Rather, it should provide enough suitable habitat for fish to survive in, hopefully fairly comfortably, for a relatively short period before flow increases again).

The tiered approach to minimum flow setting that you have taken looks sensible. It is especially good to see that you have opted for more conservative minimum flows for zones where the data is poor (i.e. opting for the MALF in cases where Scenario 6 applies). Having said that though, the estimated MALF in cases where Scenario 6 applies may have a fair degree of error associated with it. Do you have mechanisms in place to alter the minimum flow upwards, if subsequent analysis based on more robust data suggests that the original minimum flow was too low?

Frequency (and duration) of minimum flow:
As well as the magnitude of the minimum flow, it is important to consider the frequency and duration of its occurrence (as you have done). The frequency of occurrence of the minimum flow will impinge on the surety of supply for abstractors (as abstraction restrictions), as recognized in the report. However, increasing the frequency and duration of the minimum flow is also likely to have ecological effects. Perhaps the most obvious potential ecological effect of prolonged low flow, due to abstraction, is proliferation of periphyton, to potentially nuisance levels. But impacts are likely to extend to higher trophic levels (i.e. invertebrates and fish) as well. Moderate to large scale water abstraction can alter flow regimes sufficiently to potentially impact on food availability by temporarily reducing invertebrate habitat, with associated reduction in invertebrate production. Generally, optimal invertebrate habitat occurs at higher flows than optimal fish habitat and because they have high rates of

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colonisation invertebrates can make productive use of extended flow recessions. For instance, they take about 30 days to fully colonise previously dry channels (or margins) (Sagar 1983). NIWA research in the Waipara River, where fish habitat is limited at low flow, showed that the detrimental effect on fish numbers increased with the magnitude and **duration** of low flow (Jowett & Hayes 2004).

Recognition of these potential effects is what has prompted inclusion of a clause along the lines "that maintenance of flow variability should also be considered when setting allocation limits in conjunction with this minimum flow", accompanying recommended minimum flows in our IFIM reports.

Horizons model for setting core allocation lends itself to this (i.e. defining a "management flow", based on consideration of historic flow frequency and duration data. The historic frequency of occurrence of the "management flow" indicates the expected frequency of occurrence of the minimum flow under the influence of allocation assuming the allocated flow is fully abstracted. Put another way the management flow (and therefore the core allocation) can be set taking into account the acceptable level of risk to the environment and to resource users of the minimum flow occurring. The amount of water available for allocation is then derived from:
Core Allocation = Management Flow – Minimum Flow)

I can see the appeal of setting allocation limits based on a standard proportion of the MALF, as you have done in this report. It is a simple approach, which is easy to understand and apply. However, it does translate into quite variable effects on the frequency (and presumably duration) of occurrence of flow restrictions (minimum flow conditions) between catchments (from as little as 6 days per year on average in the Pohangina to as more than 127 days in the upper Whangaehu River).

I wonder whether it would be better to decide on a frequency of minimum flow occurrence that is acceptable first, and then select the management flow to achieve this. Rather than setting the core allocation as a proportion of MALF, and then assessing what the effect of that will be on the frequency of minimum flow occurrence (and possibly opting for a different level of allocation, if the frequency seems too high, or low). Perhaps you could opt for an increase in the average occurrence of the minimum flow by a set number of days per year, or some proportion of the natural number of days per year, to take account of the natural variability in flow frequency distributions between catchments. You might also consider accepting greater, or fewer, days of restrictions (and minimum flows) depending on the relative instream values and abstraction demand in a given water management zone.

Another option might be to base the acceptable frequency of minimum flow around recognized periphyton accrual periods (these may have to vary depending on the nutrient status of the waterway. Table 15 in Biggs 2000, p15 might provide a starting point for this, but you'd probably want to get some guidance from a periphyton expert (e.g. Barry Biggs), or maybe the NIWA report on water quality that Roger Young has just been reviewing for you might have some relevant information). You would also have to bear in mind that you are working with the frequency of minimum flow, not low flows in general, and flow is presumably likely to have been relatively low for a while before the minimum flow is reached (on the descending limb of the hydrograph). So you would presumably have to aim for the duration of minimum flow being a bit less than the accrual periods in Biggs (2000) guidelines.

I think an approach along these lines might be easier to rationalize than selecting a proportion of MALF as the allocation limit, about half way between the examples, that John and I put forward, of what might be considered high or low allocation (i.e. 10% and 30% of MALF). Especially since the effect of allocating a fixed proportion of MALF is highly dependent on the flow regime characteristics of the river in question, as you demonstrated with the 160 odd days of flow restrictions predicted for the upper Whangaehu under 30% of MALF core allocation. On the other hand, the number of days per year of flow restriction that would be considered acceptable under the approach that I have suggested would still be somewhat arbitrary.

Another comparison that might be worthwhile including is the median flow before and after allocation. I imagine the post allocation median would be pretty close to the pre allocation median minus the core allocation. But it might be a useful comparison to illustrate the effect of allocation on the expected river flow.

Anyway that is a longwinded way of saying that I think the approach you have taken to setting minimum flows is good, but that there may be ways that you could achieve greater consistency in the effects of your core allocation on low flow frequency.

Reference:

Biggs BJF 2000. New Zealand Periphyton Guideline: Detecting, monitoring and managing enrichment of streams. Prepared for Ministry for the Environment by Barry, J.F. Biggs, NIWA, Christchurch. Ministry for the Environment, Wellington. 122p.

Jowett IG, Hayes JW 2004. Review of methods for setting water quantity conditions in the Environment Southland draft Regional Water Plan. NIWA Client Report: HAM2004-018. Prepared for Environment Southland, under NIWA Project: ENS04202.

Sagar PM 1983. Invertebrate recolonisation of previously dry channels in the Rakaia River. New Zealand Journal of Marine and Freshwater Research 17: 377-386.

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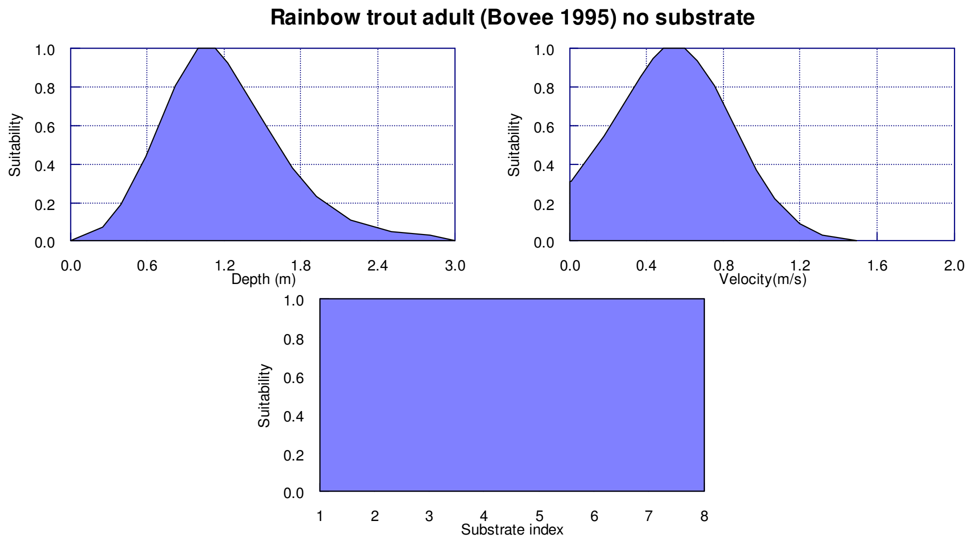
APPENDIX 2. HABITAT SUITABILITY CRITERIA USED FOR CRITICAL VALUES



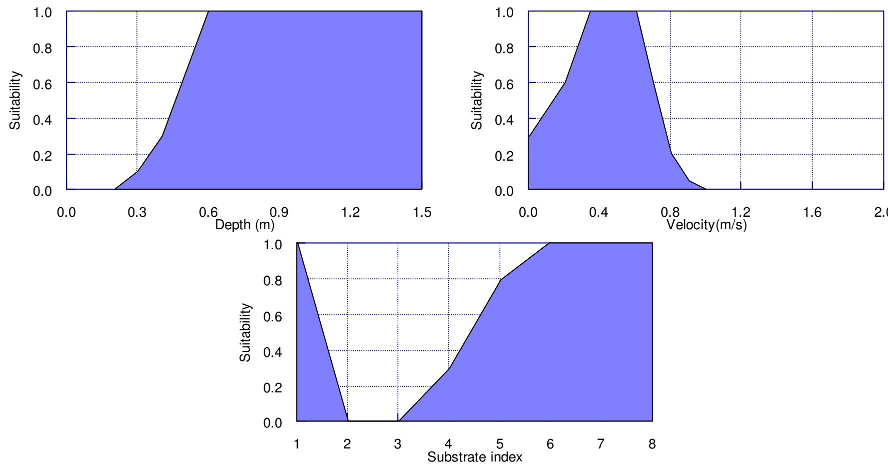
Bovee (1995) criteria for adult rainbow trout are actually from Thomas & Bovee (1993)[1], they are referred to as Bovee (1995) criteria in the RHYHABISM library files because the data were provided to Dr John Hayes by Dr Ken Bovee (one of the originators of the IFIM) in that year. These HSCs were developed from observations on the South Platte River, Colorado, United States of America, which is a relatively large river. The river is relatively steep (gradient 0.0058 m/m). The observations were made at flows of 7-18 m^3/s, and are based solely on observations of actively feeding fish[2].

These criteria were originally provided without substrate suitability criteria. Rather than adding substrate suitability criteria from another source, these criteria were applied without substrate suitability criteria. Setting the index of substrate suitability to a uniform value of one effectively removes substrate from the calculation of WUA, since weighted usable area (WUA) is calculated as the area weighted product of the three habitat suitability criteria (depth, velocity and substrate).

[1] Thomas JA, Bovee KD 1993. Application and testing of a procedure to evaluate transferability of habitat suitability criteria. *Regulated Rivers: Research and Management 8*: 285-294.

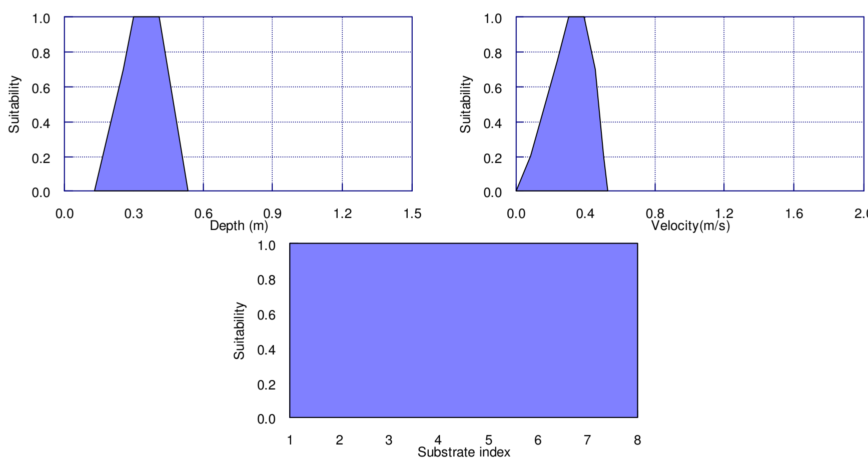
[2] A common problem with many, particularly older, HSCs is that there is often an apparent slow water bias. This is likely to be due to the inclusion of resting fish observations in the development of the criteria, and means that they are likely to underestimate flow requirements of drift feeding fish. Focussing observations on only actively feeding fish avoids this slow water bias.

Brown trout adult (Hayes & Jowett 1994)



Hayes & Jowett's (1994)[3] suitability criteria have been used most widely in New Zealand for modelling adult drift-feeding brown trout habitat since their development. These HSCs were developed based on observations of habitat preferences of large (45–65 cm) actively feeding brown trout on moderate sized rivers (upper Mataura, Travers, upper Mohaka) over the flow range 2.8–4.6 m^3/s. These rivers range in gradient between 0.0016-0.0211 m/m.

Brown trout yearling - small adult feeding (Roussel et al 1999)



Roussel et al. (1999)[4] developed HSCs for juvenile to small adult brown trout, taking care to only include actively feeding fish. These criteria were developed in France, based on observations in the Saint Sauveur Brook (a tributary of the River Scorff in

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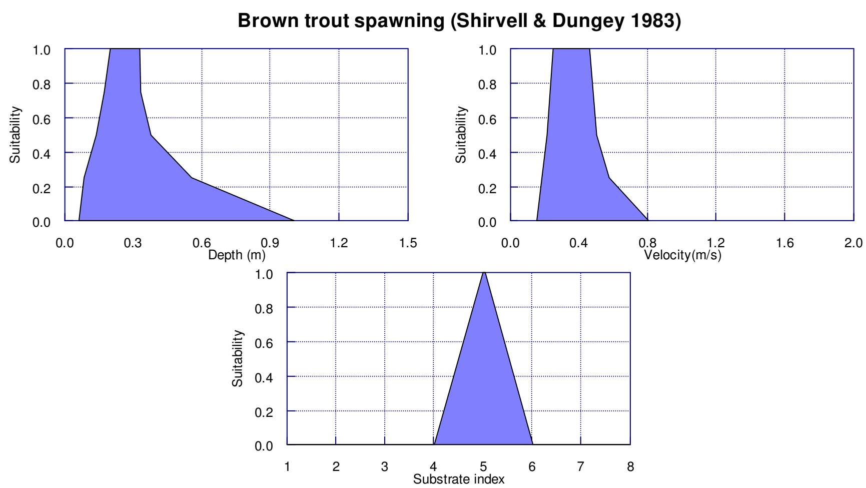
3 Hayes JW, Jowett IG 1994. Microhabitat models of large drift-feeding brown trout in three New Zealand rivers. *North American Journal of Fisheries Management 14*: 710-725.

4 Roussel JM, Bardonnet A, Claude A.1999. Microhabitats of brown trout when feeding on drift and when resting in a lowland salmonid brook: effects on Weighted Usable Area. *Arch Hydrobiol. 146*: 413-429.

Brittany), which has a gradient of approximately 0.001 m/m. Although these HSCs have not been widely applied in New Zealand before, they may be the best available HSCs for application to relatively small rivers and streams, because they were developed on a small stream (110 l/s during the observations on which the HSCs were based), and include only actively feeding fish observations. However, the suitability criteria for substrate from Roussel et al. (1999) do not comply with expectations, based on both experience and the weight of evidence in the literature. While it is generally accepted that juvenile brown trout are associated with coarse substrate (cobbles and boulders), the substrate criteria in this set of HSCs showed them to prefer fine sandy substrate. This anomaly may have been caused by the larger substrate elements being embedded in sandy substrate, in the stream where these criteria were developed. For this reason, these HSCs were applied with the effect of substrate removed in the analyses.



Shirvell & Dungey (1983)[5] developed HSCs for brown trout spawning in New Zealand rivers and these criteria have been widely used in New Zealand IFIM habitat modelling applications. Shirvell & Dungey's velocity suitability criteria are based on near bed velocities rather than mean column velocities (ie. usually measured at 0.4 x depth) upon which the IFIM habitat model is based. Consequently, when used in the IFIM habitat model, they will tend to underestimate flow requirements of spawning fish. However, the underestimation will be fairly small for the shallow waters preferred by spawning trout because the velocity profile (which is approximated by a power relationship to depth) is compressed in shallow water.

[5] Shirvell CS, Dungey RG 1983. Microhabitats chosen by brown trout for feeding and spawning in rivers. *Transactions of the American Fisheries Society 112*: 355-367.

APPENDIX 3. REPORT ON CHANGES TO DATASETS AND MINIMUM FLOWS

Changes to Some of Horizons' Instream Habitat Datasets and Recommended Minimum Flows

Joe Hay

Prepared for

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Approved for release by: Rowan Strickland

Recommended citation:
Hay J 2009. Changes to Some of Horizons' Instream Habitat Datasets and Recommended Minimum Flows. Prepared for Horizons Regional Council. Cawthron Report No. 1601. 5 p.

1. INTRODUCTION

This short report describes updated analyses of several of Horizons Regional Council's instream habitat modelling datasets (listed in Table 1, along with the reports detailing the original analyses of these datasets). These datasets were re-analysed to address three issues:

1. Mr. Jowett (formally of NIWA), the developer of the instream habitat modelling package RHYHABSIM used to analyse these datasets, had expressed concerns regarding some aspects of data quality, his chief concern being with the fit of some of the stage-discharge rating curves.
2. A software bug was discovered in RHYHABSIM which influenced the original results for two of the datasets from the Rangitikei River (Otara Reach and Onepuhi Reach). The distance between cross-sections in these two reaches was originally entered in descending order. This variable is not used in habitat modelling calculations based on habitat mapped reaches such as these, so this should not have influenced the modelling results. However it did, with flow-on effects to the minimum flow recommendations. I brought this to Mr Jowett's attention and he has since repaired the bug.
3. Horizons has recently updated the estimates of the mean annual low flow (MALF) for some of the sites, in light of more recent hydrological data. Since the minimum flow recommendations are based on retention of a proportion of the modelled habitat at the MALF or of the habitat optimum (whichever occurs at the lower flow), a change in MALF may affect the minimum flow recommendation.

Table 1. Instream habitat modelling reaches re-analysed for this report, and the reports where their original analysis was described.

River	Reach	Report/s
Rangitikei	Otara Onepuhi Hampton's	Hay J, Hayes JW 2004. Instream Flow Assessment for the Rangitikei River: Additional Analyses. Cawthron Report No. 930. 21 p.
Raparapawai Oruakeretaki Kumeti Tamaki	Maharahara Rd State Highway 2 State Highway 2 State Highway 2	Hay J, Hayes JW 2005. Instream flow assessment for the Upper Manawatu River and tributaries: Additional analyses. Cawthron Report No. 1029. 72 p. Plus: Addendum prepared by J Hay and J Hayes August 2007
Oroua	Boness Rd	Hay J 2006. Instream flow assessment for the Oroua River. Cawthron Report No. 1179. 25 p.
Makara	Below NZ Energy	Hay J 2007. Instream Flow Assessment for the Makotuku and Makara river. Cawthron Report No. 1350. 31 p.

The methods and habitat suitability criteria applied in these re-analyses were the same as described in the original reports. Only the resulting minimum flow recommendations are described in the present report.

2. RESULTS AND DISCUSSION

2.1. Changes due to software bug

Repair of the software bug caused the minimum flow recommendations for the Otara and Onepuhi reaches of the Rangitikei to change by 2-3 m^3/s, but in different directions (Table 2). The recommended minimum flow for the Otara reach increased, while that for the Onepuhi reach decreased. However, it is my understanding that the minimum flows adopted for the Rangitikei hinged on maintaining adequate flow further downstream, in the part of the river represented by Hampton's reach, and consequently the changes to the minimum flow recommendations for the upper two reaches may not have much material effect (Jon Roygard, Horizons, pers. comm.).

Table 2. The effect on minimum flow recommendations for two reaches on the Rangitikei River of repairing the software bug in RHYHABSIM (all flows are in m^3/s).

Reach	Original MALF	90% habitat retention: Original recommended minimum flow	90% habitat retention: Minimum flow with bug repaired	80% habitat retention: Original recommended minimum flow	80% habitat retention: Minimum flow with bug repaired
Otara	15.51	9.50	11.91	6.81	9.69
Onepuhi	17.93	14.55	12.58	12.23	10.13

2.2. Changes due to dataset alterations

To address the issues raised by Mr. Jowett, he and I met and on his advice we made some alterations, mainly affecting the calibration of some rating curves in the models (Table 3). We deleted calibration gaugings that were very similar to the survey flow but quite different in terms of water level. For some cross-sections we altered the water level at a calibration flow, when the cross-section showed a substantially different response to others in the reach (*e.g.* water level reduced by twice as much as the average change on all other cross-sections). These disparities suggest either field measurement or data entry errors. We also removed two cross-sections that were very wide compared with all of the others in their respective datasets, since they were likely to be unrepresentative of average conditions in the reach and cause bias in the habitat predictions (*e.g.* a ~150m wide riffle in the Rangitikei at Otara reach, where all of the other cross-sections were approximately 30-40 m wide). We recognised two cross-sections in the Oroua as being two channels in a single braided cross-section, and changed their calibration flows accordingly; and finally we switched the cross-section weighting on two cross-sections in the Rangitieki at Hamptons reach, which appeared to have been entered as the wrong habitat types, on the basis of the depths and velocities recorded from them.

Although these alterations improved confidence in the datasets, they made only minor differences to the recommended minimum flows based on habitat retention, as shown in Table

4. The minimum flows based on the updated datasets were within 2% of the original minimum flow recommendations for the vast majority of reaches. The largest difference was for the Kumeti Stream at State Highway 2, for which the minimum flow based on 70% habitat retention increased by 6%. However the minimum flow adopted for this reach was that based on 90% habitat retention, which was unchanged by the alterations made to the dataset.

Table 3. Alterations made to eight of Horizons' habitat modelling datasets.

River	Reach	Alterations
Rangitikei	Otara	Removed one excessively wide cross-section (Stn 7 Rif 3) in a riffle ~145 m wide *c.f.* other reaches ~30-40 m wide. This cross-section was initially selected to look at potential fish passage barriers, but was not representative of the wider reach.
		Deleted one calibration gauging from all cross-sections (14.24 m^3/s), since this gauging was too similar to the survey flow (14.35 m^3/s) to give reliable measure of water level change with flow (this represents less than a 1% change in flow).
		Raised the survey water level at one cross-section (Stn6 Run4) by 25 mm so that the rate of change of water level with flow for this section was similar to other cross-sections in the reach.
		Altered some stage at zero flow estimates to improve rating fit.
	Onepuhi	Deleted one calibration gauging from all cross-sections (14.7 m^3/s), since this gauging was too similar to the survey flow (14.4 m^3/s) to give reliable measure of water level change with flow.
		Lowered the survey water level at one cross-section (Stn11Rif5) by 20mm so that the rate of change of water level with flow for this section was similar to other cross-sections in the reach.
	Hampton's	Renamed Stn13 Rif5 as a run and Stn 9 Run6 as a riffle, and changed the cross-section weightings accordingly. The recorded depths and velocities on these cross-sections suggested that they had been miss-labelled in the field.
		Altered some stage at zero flow estimates to improve rating fit.
Raparapawai	Maharahara Rd	Changed survey flow for all cross-sections from 0.114 m^3/s to 0.119 m^3/s, based on average of flows measured in all cross-sections at the time of the survey.
		Raised one calibration water level at one cross-section (Maha4) by 35 mm so that the rate of change of water level with flow for this section was similar to other cross-sections in the reach.
Oruakeretaki	State Highway 2	Lowered the survey water level at two cross-sections (Orua1 and Orua2) by 10 mm so that the rate of change of water level with flow for this section was similar to other cross-sections in the reach.
		Altered one stage at zero flow estimate to improve rating fit.
Kumeti	State Highway 2	Raised one calibration water level at two cross-sections (Kum2-9 and Kum2-2 by 8 mm and 2 mm, respectively) so that the rate of change of water level with flow for this section was similar to other cross-sections in the reach.
		Altered two stage at zero flow estimates to improve rating fit.

River	Reach	Alterations
Tamaki	State Highway 2	Changed survey flow for all cross-sections from 0.358 m^3/s to 0.397 m^3/s, based on average of flows measured in all cross-sections at the time of the survey, with one outlier excluded.
Oroua	Boness Rd	Deleted one calibration gauging from all cross-sections (1.92 m^3/s), since water level measurements at this gauging appeared too high at many cross-sections relative to the other calibration flows. Removed one excessively wide cross-section (10a) in a riffle ~70 m wide *c.f.* other reaches ~10-30 m wide. This cross-section did not appear to be representative of the wider reach. Two fast run cross-sections appeared to represent a single cross-section through a braided reach (FR5a and FR5b), as the measured survey flow in these cross-sections was about half that in the other cross-sections in the reach. Changed calibration accordingly. Lowered two calibration water levels at one cross-section (R8) by 26 mm so that the rate of change of water level with flow for this section was similar to other cross-sections in the reach. Altered some stage at zero flow estimates to improve rating fit

Table 4. Comparison of the original minimum flow recommendations and those based on the altered datasets (all flows are in m^3/s). Note: those minimum flows marked with a * were for 80% habitat retention, in keeping with those in the original reports.

River	Reach	Original MALF	90% habitat retention		70% habitat retention	
			Original recommended minimum flow	Minimum flow based on updated habitat dataset	Original recommended minimum flow	Minimum flow based on updated habitat dataset
Rangitikei	Otara	15.51	11.91	12.19	9.69*	9.94*
	Onepuhi	17.93	12.58	12.46	10.13*	10.03*
	Hampton's	18.58	10.23	10.18	7.81*	8.06*
Raparapawai	Maharahara Rd	0.050	0.047	0.045	0.041	0.042
Oruakeretaki	State Highway 2	0.350	0.293	0.294	0.232	0.229
Kumeti	State Highway 2	0.070	0.064	0.064	0.052	0.055
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Tamaki	State Highway 2	0.350	0.296	0.297	0.209	0.209
	During spawning		0.311	0.310	0.238	0.236
Oroua	Boness Rd	1.20	0.95*	0.93*	0.83	0.81

2.3. Changes due to updated MALFs

The updated MALFs generally resulted in larger changes to the recommended minimum flows based on habitat retention than those caused by the alterations to the habitat modelling datasets (Table 5). The only change affecting the Makara was a change in the MALF, and no changes were made to the dataset for this site.

Table 5. Recommended minimum flows based on two alternative levels of habitat retention for the modelled reaches, using the altered datasets and the most recent MALFs provided by Horizons (all flows are in m^3/s). Note: those minimum flows marked with a * were based on 80% habitat retention, and minimum flows for the Makara were based on 70% and 60% habitat retention, in keeping with those in the original reports.

River	Reach	updated MALF	recommended minimum flow based on updated MALF	
			90% habitat retention	70% habitat retention
Rangitikei	Otara	16.1	12.53	10.17*
	Onepuhi	16.4	12.10	9.81*
	Hampton's	16.5	10.18	7.89*
Raparapawai	Maharahara Rd	0.044†	0.040	0.038
Oruakeretaki	State Highway 2	0.275†	0.248	0.206
Kumeti	State Highway 2	0.112	0.091	0.072
	During spawning		0.092	0.087
Tamaki	State Highway 2	0.49†	0.391	0.259
	During spawning		0.405	0.298
Oroua	Boness Rd	1.355	1.03*	0.89
Makara	Below NZ Energy	0.060	0.047 (70% retention)	0.042 (60% retention)

† These MALFs have not been altered since previous updates.

3. REFERENCES

Hay J, Hayes JW 2004. Instream Flow Assessment for the Rangitikei River: Additional Analyses. Prepared for Horizons Regional Council. Cawthron Report No. 930. 21 p.

Hay J, Hayes JW 2005. Instream flow assessment for the Upper Manawatu River and tributaries: Additional analyses. Prepared for Horizons Regional Council. Cawthron Report No. 1029. 72 p. Plus: Addendum prepared by J Hay and J Hayes August 2007.

Hay J 2006. Instream flow assessment for the Oroua River. Prepared for Horizons Regional Council. Cawthron Report No. 1179. 25 p.

Hay J 2007. Instream Flow Assessment for the Makotuku and Makara river. Prepared for Horizons Regional Council. Cawthron Report No. 1350. 31 p.