**BEFORE THE HEARINGS PANEL**

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

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# SECTION 42A REPORT OF DR JOHN WILLIAM HAYES ON BEHALF OF HORIZONS REGIONAL COUNCIL

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# 1. INTRODUCTION

## My qualifications and experience

1. My full name is John William Hayes.

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

3. I have 27 years experience as a freshwater fisheries scientist. After graduating with my PhD in 1984 I worked as a fisheries research scientist at the Freshwater Fisheries Centre of the Ministry of Agriculture and Fisheries until 1992. Between then and 1994 I held a similar position with the National Institute of Water and Atmospheric Research (NIWA). I have been employed as a senior fisheries scientist with the Cawthron Institute, Nelson, since July 1994.

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

5. My experience with the assessment of environmental flow regimes includes about 20 years experience with instream habitat modelling within the analytical framework of the Instream Flow Incremental Methodology (IFIM). I have undertaken research developing habitat suitability curves, which are used with hydraulic models to predict instream habitat. I have also undertaken or supervised 13 IFIM habitat analyses on New Zealand rivers.

6. Over the past 10 years I have managed a research group studying habitat requirements of salmonids and developing flow-related bioenergetics models for drift-feeding salmonids. The latter are advanced models that are aimed at improving biological realism in instream habitat modelling.

7. I have extensive experience providing consulting advice to regional councils, energy companies, fish and game councils, and the Department of Conservation on the flow and water quality requirements of river ecosystems and fisheries. I have written more than 80 such reports for clients.

8. I have been closely involved in the development of environmental flow regime assessment concepts, methods and guidelines at regional and national levels since the late 1980s. During this time I worked closely with Ian Jowett (formerly of NIWA), who has had most influence on this science in New Zealand. Mr Jowett and I advised Southland Regional Council on flow regime assessment and flow allocation rules for the Southland Regional Plan. The resulting report (Jowett & Hayes 2004) was used by Horizons to guide the process for assessing and setting environmental flow regimes in the Proposed One Plan. Several of the key concepts articulated in the Southland report were later incorporated into the Ministry for the Environment's (MfE's) National Ecological Flow Standards (NES). I contributed to the development of the technical support document produced for MfE as a part of the NES, entitled Draft guidelines for the selection of methods to determine ecological flows and water levels (Beca Infrastructure Ltd., 2008). I also contributed to the report entitled A guide to instream habitat survey methods and analysis (Jowett, Hayes & Duncan, 2008), which is the most up to date review of habitat-based methods for environmental flow assessment, as they are applied in New Zealand. The report also includes comment on historic and holistic flow (natural flow paradigm) methods.

9. I co-authored the report entitled Instream flow assessment options for Horizons Regional Council (Hay & Hayes, 2006), which is a key document underpinning the instream flow assessment process in the Proposed One Plan.

10. Examples of recent hearings for which I have presented evidence regarding freshwater fisheries and instream habitat include:

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

11. 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**

12. My colleague Joe Hay and I have been Horizons' main analysts and advisors on environmental flow assessment for the Proposed One Plan since 2004. Our advice has included recommendations on environmental flow assessment methods, and recommendations on minimum flows and allocation levels. I have also communicated our recommendations on methodology for environmental flow regime assessment and flow allocation to DoC and Wellington Fish and Game staff attending One Plan stakeholder meetings.

13. I have supervised instream habitat surveys and analyses of several rivers in the Manawatu and Rangitikei catchments, the results of which have been used by Horizons for setting minimum flows and allocation rules for the Proposed One Plan.

14. I was also involved in the Tongariro Power Development (TPD) consents hearing where I presented evidence on behalf of Genesis Energy on effects of the TPD on the Tongariro and Lake Taupo trout fishery. This evidence included consideration of the flow regime.

**Scope of evidence**

15. The following summarises the structure of my evidence.
    a. The process by which environmental flow regimes have been assessed and set in New Zealand in recent times and recommended by the Ministry for the Environment (MfE), taking account of:
        i) evolving scientific understanding of environmental flows and my role in this;
        ii) the MfE Flow Guidelines; and
        iii) the National Ecological Flow Standards (NES).
    b. Environmental flow assessment methods, in particular:
        i) holistic flow methods;
        ii) IFIM hydraulic habitat methods; and
        iii) historic flow methods.
    c. Validation and monitoring of methods for environmental flow setting.
    d. Scope of environmental flow assessment for regional planning.

e. The process followed for environmental flow assessment, minimum flow setting and flow allocation in the Proposed One Plan, and its consistency with national guidelines, standards and practices.

f. My involvement in developing the water quality standards for the protection of trout in the Proposed One Plan.

## 2. EXECUTIVE SUMMARY OF EVIDENCE

16. The process and methods employed by Horizons for environmental flow assessment, minimum flow setting and water allocation in the Proposed One Plan are consistent with the MfE Flow Guidelines and National Ecological Flow Standards.

17. Environmental flow regimes include the key minimum flow and flow variability features that maintain a river's physical and natural character, structure and the function of its ecosystem and dependent values. These features are shown in Figure 2.

18. Following the MfE Flow Guidelines and NES, the environmental flow assessment and minimum flow setting process for the Proposed One Plan takes the following steps:

a. instream values are identified, including their significance;

b. instream management objectives are defined for maintaining instream values;

c. flow-critical instream values and factors are identified for setting minimum flows;

d. levels of habitat or flow maintenance at the minimum flow are defined for the critical values;

e. technical instream flow assessment methods are applied commensurate with the significance of instream values and the degree of hydrological alteration expected as a result of water allocation;

f. minimum flows are set based on conservative levels of flow or habitat retention relative to the mean annual low flow (MALF), which is an ecologically relevant flow statistic;

g. complementing a-f above with conservative flow limits for core allocation based on flow duration and frequency analyses that balance the security of supply instream with out-of-stream uses, being mindful of the need to avoid prolonged periods of flat-lining at the minimum flow.

19. Instream values were identified through review of existing information (Ausseil & Clark, 2007) and consultation with stakeholders (Wellington Fish and Game and Department of Conservation staff).

20. The environmental flow assessment and management process is holistic, taking due account of the key flow regime features likely to be affected by run-of-river abstractions, which comprise the majority of water allocation in the Proposed One Plan. Specifically, the process is appropriately focused on minimum flows and maintenance of flow variation in the low–median flow range, which are the key features affected by run-of-river abstraction.

21. The process takes a tiered approach to environmental flow assessment, minimum flow setting and water allocation; it involves default conditions based on historic flow records where instream values and water demand is low, through to conditions based on levels of habitat retention where instream values and water demand are high. It provides for cost-effective, risk-based water resource planning that takes account of uncertainty.

22. The habitat methods are employed within the conceptual assessment and analytical framework of the Instream Flow Incremental Methodology (IFIM), which in New Zealand is now applied in a holistic manner. The use of IFIM habitat methods in New Zealand is supported by a good scientific understanding of river ecosystems and their relationships with flow regime (ie. they are scientifically defensible).

23. The choice of scientifically-based habitat suitability criteria for instream habitat modelling was based on professional judgement and in my opinion those chosen were appropriate to the identified instream values.

24. To avoid the problems associated with assessing flow requirements for a range of values with different habitat (and flow) preferences, minimum flows were set to retain a high level of habitat for flow-critical values, usually trout. In my opinion this practice is appropriate and pragmatic, and is supported by the MfE Flow Guidelines and NES.

25. Trout were identified as the critical value after review of existing information on values and consultation between staff from Horizons, Wellington Fish & Game and Department of Conservation.. The critical value status of trout was based on them being both highly valued and being among the most flow-demanding fish present. Trout have high flow requirements owing to their large size, and drift-feeding behaviour which requires them to swim up in the water column, exposed to the current. They are highly valued as a sports fish by both domestic and tourist anglers. Although an introduced fish, their valued fisheries status is recognised by statute in Section 26B of the Conservation Act 1987 and the RMAct sections 7c (the maintenance and enhancement of amenity values) and 7h (protection of the habitat of trout and salmon).

26. The method adopted for determining minimum flows that retain the target level of habitat retention follows that recommended by myself and my colleagues. The minimum flow is the flow that retains the target percentage of habitat available at the naturalised MALF for an identified flow-critical value, or a proportion of maximum habitat if the maximum occurs at a flow less than MALF. This concept is illustrated in Figure 7.

27. Minimum flows set on the basis of habitat retention for trout (the most flow demanding, highly valued species), coupled with the conservative allocation limits specified in the Proposed One Plan will, in my opinion, provide for a high level of protection for trout and other instream values. Sufficient habitat will be retained for a high level of life supporting capacity for benthic invertebrates and native fish species, and for maintaining biodiversity.

28. Provision for supplementary flow allocation is made in the Proposed One Plan, in addition to core allocation. Strict restrictions apply, targeted at appropriate environmental flows. Specifically, they are designed to maintain minimum flows, and flow variability over the low to median flow range which supports most instream production. These strict restrictions are warranted and will maintain physical and ecosystem functioning of rivers and their dependent instream values.

29. In my opinion the policies and rules in the Proposed One Plan governing minimum flows and water allocation will maintain instream values at levels similar to those currently occurring.

30. I understand that Horizons is committed to monitoring and adaptively managing the effects of One Plan rules on instream values, with adaptive management achieved through the plan change process. This commitment to monitoring should influence conditions on water resource consents and the design of State of the Environment monitoring. I support this commitment because it will facilitate more efficient water allocation and stakeholder acceptance.

## 3. PROCESS FOR ASSESSIING AND MANAGING ENVIRONMENTAL FLOW REGIMES

### What is an environmental flow regime?

31. The National Ecological Flow Standards (Beca Infrastructure Ltd., 2008) describe the process of establishing environmental flows and water levels as being nested within wider environmental flow decisions. Environmental flows and water levels describe the

water that remains in water bodies to provide for ecological, tangata whenua, cultural, recreational, landscape and other values. An environmental flow includes an 'ecological flow'. An ecological flow regime is defined as: the flows required to provide for the ecological integrity of the vegetation and fauna present within rivers and their margin. Therefore, the ecological function of a water body must always be provided for when setting environmental flow management objectives; although other critical values may need to be taken into account in order to meet community expectations. An important component of ecological flows is that they quantify the amount of the water available for allocation and also address requirements for both low and high flows throughout the year.

**Overview of environmental flow assessment process**

32. Figure 1 shows a flow diagram of the framework for environmental flow assessment based on the MfE (1998) Flow Guidelines with adaptations from Hayes & Jowett (2004).

33. The key steps are: 1) identifying values, both instream values and their significance, and out-of-stream water values (and water demand); 2) identifying flow-critical instream values; 3) setting instream management objectives targeted at instream values to be maintained; 4) identifying critical factors to maintain instream values; 5) assigning levels of habitat maintenance commensurate with the significance of instream values; 6) considering the level of water allocation and how greatly it will alter the flow regime; 7) applying technical methods for assessing environmental flow requirements commensurate with the significance of instream values and the degree of hydrological alteration expected as a result of water allocation; and 8) monitoring the outcome of the resulting managed flow regime, reassessing and adaptively managing flows if necessary. In the following sections of my evidence I discuss these steps in more detail.

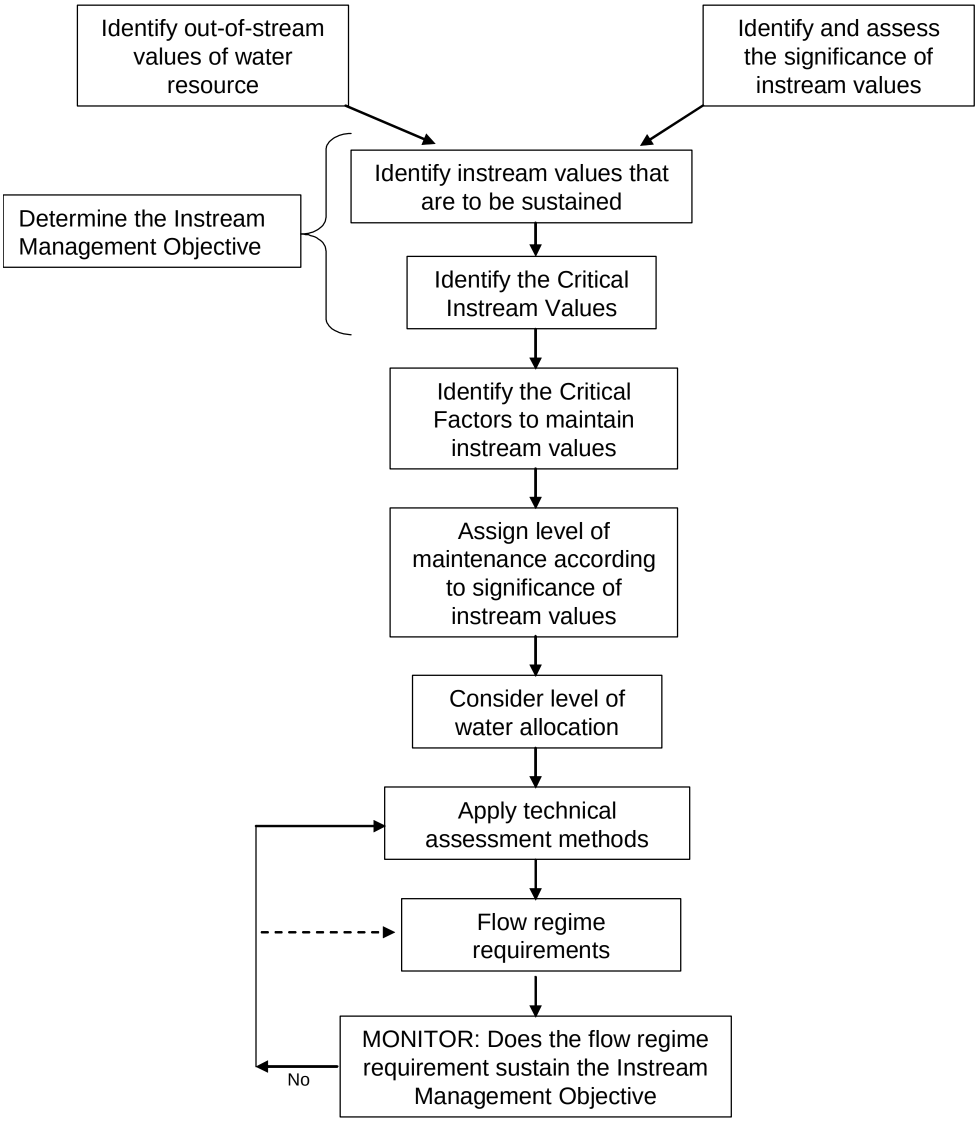


**Figure 1.** Framework for environmental flow assessment, based on MfE (1998) Flow Guidelines for instream values, with adaptations from Hayes & Jowett (2004).

**Assessment of instream values and critical factors**

34. A basic principle established in the MfE Flow Guidelines is that instream values and their requirements be identified and appraised within the context of definite instream management objectives. Without these, instream values that are expressed in (non-monetary) environmental or amenity terms may receive less consideration than out-of-stream uses of water, whose values can be expressed in terms of dollars. However, where objectives have been developed consultatively to reflect community aspirations,

they can be accorded appropriate weight, even though they might not be expressed in monetary terms.

35. So the first step in environmental flow regime assessment is to identify significant instream values supported by the river, including ecological, recreational, and cultural values, then set management objectives to maintain them. The science of instream flow assessment has mainly focused on ecological values. These include indigenous fauna and flora (eg. fish and birds), species supporting fisheries (eg. native eels and galaxiids and introduced trout and salmon), and species underpinning life supporting capacity (eg. algae and aquatic invertebrates). There is also some understanding of the flow needs of recreational values including fishing, boating and swimming, and of how the perception and realisation of Māori cultural values is influenced by flow and other environmental factors. A tangible example of a Māori cultural value is mahinga kai, and more specifically fisheries species such as eels and galaxiids (eg. whitebait). While methods that quantitatively assess and predict the flow needs of Māori cultural values are yet to be developed, the flow-related habitat requirements of species underpinning cultural fisheries can be quantified within conventional habitat assessment frameworks such as the IFIM.

36. Of course, there are other values to consider when managing water allocation, namely the flow demands of out-of-stream uses such as irrigation, stock water, hydropower generation, and town supply. However, the environmental flow regime assessment component of water allocation is focused on providing sufficient quantity and pattern of flow to maintain *instream* values.

37. The next step is to define goals and management objectives targeted at maintaining the significant values (Ministry for the Environment, 1998). Councils should do this in consultation with the public and institutional organisations. For assessing environmental flows it is helpful to identify the flow-dependent critical instream values and critical factors for sustaining these and the other values. Critical factors may include habitat availability, flow variability, water quality, and aquatic invertebrate food producing habitat – which itself has intrinsic life supporting capacity values.

38. A report which I co-authored with Mr Jowett for Environment Southland and the MfE defined critical values as follows: "The concept of critical values is that by providing sufficient flow to sustain the most flow-sensitive, important value (species, life stage, or recreational activity), the other significant values will also be sustained" (Jowett & Hayes 2004, p.8). The MFE Flow Guidelines recommend a similar approach, although the

terminology used differs slightly. Basing decision-making on critical instream values circumvents the complexities of interpreting different habitat-flow relationships for a range of species and life-stages.

39. While the aim is to sustain the critical values and the full range of species, it is unrealistic to expect that all values will be maintained at original levels when flows change.

40. The MfE's draft National Environmental Standard on methods for establishing ecological flows also recommends a critical values and factors approach to assessing environmental flow requirements (Beca, 2008).

**Ecologically relevant flow statistics**

41. Ecological flow assessments usually include modelling of instream habitat. These models predict how various habitat indices vary with flow. When setting minimum flows and allocation on the basis of instream habitat modelling predictions (and other methods), the assumption is made that there is a relationship between habitat change and population change. For this to occur, habitat or food needs to be limiting. However, usually there is insufficient information to determine whether habitat is limiting in Assessments of Environmental Effects (AEEs) and water resource assessments undertaken for regional plans. Even if it were shown that habitat was not limiting, one would need to quantify the relationship between habitat and instream value in order to know by how much habitat could be reduced before the value declined significantly. Therefore, in the absence of such information it is precautionary to assume habitat and food is limiting, and base flow decisions on risk assessment of the degree of habitat or flow reduction (for the fish or bird species or its food). Alternatively, the results can be expressed as the level of habitat, or flow, retained instream. I discuss this further in Section 7 of my evidence.

42. Research on New Zealand rivers has found relationships between flow-related habitat and trout and native fish abundance, when habitat indices are referenced to ecologically relevant flow statistics. This research underpins the now common practice of referencing the predictions of instream habitat to ecologically relevant flow statistics in environmental flow assessments. The practice shortcuts the need to analyse time series of habitat over varying flows (ie. over hydrographs). The concept can be broadened to *environmentally* relevant flow statistics, for angling and potentially for other forms of recreation and Māori cultural values.

43. The mean annual low flow (MALF) is ecologically relevant to trout carrying capacity (Jowett, 1992) because it is indicative of the average annual minimum living space for adult trout and probably other annual spawning fishes. Mr Jowett found that trout abundance in New Zealand rivers was correlated with the quality of adult trout habitat (indexed by adult trout Habitat Suitability Index (HSI)) at the mean annual low flow (MALF). He also found that the quality of benthic invertebrate habitat (indexed by "food producing" HSI) at the median flow, was strongly correlated with trout abundance. The correlation was even stronger with aquatic invertebrate biomass.

44. Aquatic invertebrates have much faster colonisation times than annual spawning, and multi-aged fishes. Some taxa, such as the common mayfly *Deleatidium*, have multiple generations per year. Denuded habitat is quickly recolonised by invertebrates drifting from refugia and by winged adults laying eggs. Benthic invertebrate communities have been found to recolonise river braids within 30 days after drying.

45. Because of their rapid recolonisation times the median flow is an ecologically relevant flow statistic when assessing the effects of flow regime change on aquatic invertebrates.

46. The MALF is also relevant to native fish species with generation cycles longer than one year, at least in small rivers where the amount of suitable habitat declines at flows less than MALF. Research in the Waipara River, where native 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 & Duncan, 2008). Research on the Onekaka River in Golden Bay also showed that, when habitat availability was reduced by flow reduction, abundance of native fish species responded in accord with predicted changes in habitat availability in both direction and magnitude (Jowett, Hayes & Duncan, 2008).

47. The amount of fish habitat at the MALF, and benthic invertebrate habitat at the median flow, are surrogate metrics of space and food, which are considered to be primary factors regulating stream fish populations. This rationale underpins the common practice of referencing minimum flow decisions on New Zealand rivers to fish habitat available at the MALF, and benthic invertebrate habitat to the median flow.

48. When assessing and setting environmental flows, the flow statistics on which they are based ought to be naturalised (ie. the natural MALF).

49. Provision for seasonal flow variation may also be sensible, to allow for seasonally varying food requirements of fish and birds and nesting requirements of the latter. Fish

have higher food requirements in summer because their metabolic and consumption rates are higher at warmer water temperatures. Average summer minimum flows (usually summarised by the MALF) ought to be relevant to minimum space requirements for fish, while median summer flows ought to be relevant to maintenance of fish feeding opportunities and fish production. In some cases higher winter flows may be prescribed for trout spawning habitat, although water demand is often lower in winter – at least for irrigation.

50. Similarly, referencing benthic invertebrate habitat to the summer median flow, or even to monthly median flows, may be appropriate given the rapid recolonisation times of invertebrates.

**Levels of habitat maintenance**

51. The next step in laying the foundation for environmental flow assessment is deciding on the levels at which instream values should be maintained. These levels are referenced to the habitat sustained at the ecologically relevant flows. This is relatively simple where there are established water quality standards, such as for dissolved oxygen and ammonia. However, acceptable levels of instream habitat are more difficult to decide. MfE's Flow Guidelines suggest that the level of maintenance should reflect the merits of instream values in a particular river (eg. the quality and use of a recreational fishery, the biological diversity of a stream ecosystem, the conservation status of river bird population, the availability of alternatives, or means of mitigation). The concept of retaining a percentage of the "natural" condition is one means of defining the level of maintenance, with the proportion of habitat retained varying according to the merits of the instream values and community aspirations.

52. Levels of habitat maintenance provided by minimum flows are usually set arbitrarily. This in part reflects the state of knowledge on the effects of flow change, which is insufficient to confidently predict the response of stream ecosystems, and particularly fisheries. It is also because instream habitat simply declines steadily toward zero as flow falls below the optimum value, although the rate of habitat change may vary with flow. And in unconstrained channels, such as braided rivers, there often is no optimum flow.

53. Setting levels of habitat retention (or maintenance), boils down to a weighing up of values and risks. If a significant instream value is very high then the level of habitat

protection ought to be high in order to manage the risk that a reduction in habitat might pose to the maintenance of that value.

54. In our report to Environment Southland, advising on the Southland Regional Plan (Jowett & Hayes, 2004), Mr Jowett and I suggested that water managers could consider varying the percentage habitat retention level, depending on the value of instream and out-of-stream resources within the ranges presented in Table 1. A high quality fishery of national significance, or a threatened species of national or international conservation status, might warrant at least a 90% habitat retention level. A low valued fishery of local significance might warrant up to 70% habitat retention, and a moderately valued fishery – say of regional significance – would fall somewhere in between these levels of habitat retention. Species with intrinsic value but no special conservation significance might rank as low value, perhaps warranting at least 60% habitat retention with the implicit understanding that the resultant habitat loss (40%) runs a high risk of reducing life supporting capacity. This might be acceptable for widespread species with only intrinsic value. Note though that for these species ecosystem functioning should also be taken into consideration when ascribing value and significance. For instance, native fish, such as bullies, with no direct fishery value, and benthic invertebrates, are prey for fish with fisheries value (such as trout and eels) and for birds, some of which have threatened conservation status (eg. black-fronted terns and wrybills).

**Table 1.** Suggested significance ranking (from highest (1) to lowest (5)) of critical values and levels of habitat retention for selected values (Jowett & Hayes, 2004).

| Critical value | Fishery quality | Significance ranking | % habitat retention |
|---|---|---|---|
| Large adult trout – perennial fishery | High | 1 | 90 |
| Diadromous galaxiid | High | 1 | 90 |
| Non-diadromous galaxiid | - | 2 | 80 |
| Trout spawning/juvenile rearing | High | 3 | 70 |
| Large adult trout – perennial fishery | Low | 3 | 70 |
| Diadromous galaxiid | Low | 3 | 70 |
| Trout spawning/juvenile rearing | Low | 5 | 60 |
| Bullies eg. upland, common, bluegill | - | 5 | 60 |

55. In my opinion the suggested levels of habitat retention in Table 1 are conservative, in that they are unlikely to be directly proportional to a population response. Theoretically, a change in available habitat will only result in a population change when all available

habitat is in use (ie. the population is at carrying capacity). In most rivers, because flows are varying all the time, population densities probably are at less than maximum levels. That being the case, and speaking very broadly, a habitat retention level of, say 90%, should maintain existing population levels, whereas a habitat retention level of 50% probably will result in some detrimental effect on populations, especially where densities are high.

56. In assessing the amount of habitat to be retained at low flow, it is important to realise that for some species, including many native fishes and juvenile trout, maximum habitat can occur at quite low flows. When the minimum flow is set at higher flows, as is the case when trout are the critical value, it will provide less than maximum habitat for the low-flow species. The risk of detrimental effect from increasing the flow above that which provides maximum habitat for low-flow species is not as great as decreasing the flow – and low flow species will always have some habitat available in the stream margins.

**Key hydrological features of flow regimes for sustaining river ecosystems and instream values**

57. Concerning the flow regime specifically, the MfE Flow Guidelines state that there are two critical parameters of a flow regime that need to be prescribed for sustaining instream values that are dependent on proper functioning of river ecosystems. These are: 1) a minimum flow to fulfil water quality an d habitat requirements, and 2) flow variability.

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

59. Minimum flows are usually required for maintaining instream habitat but in some cases also for water quality.

60. Provision of flow variability at a variety of scales is required for maintenance of channel form, sediment and periphyton flushing, benthic invertebrate productivity, fish and bird feeding opportunities, and fishing opportunities.

61. Mechanisms for prescribing flow regimes to maintain the features that I have just described include:

a. annual or seasonal minimum flows for maintaining instream habitat;

b. allocation limits, or flow sharing rules, for maintaining flow variability and avoiding flat-lining of the minimum flows.

62. Figure 2 illustrates the key flow features and Figure 3 shows the effect on them of a run-of-river abstraction with a relatively large allocation volume of 2.6 x MALF.

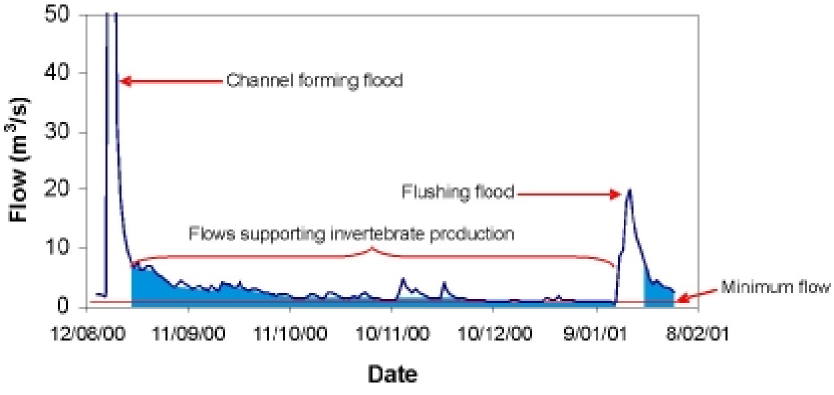


**Figure 2.** Illustrative hydrograph showing a minimum flow condition (1 m³/s) and key variable flow features with their physical and ecological function. Blue-shaded area represents that part of the hydrograph that potentially provides habitat for algal and benthic invertebrate production (following flood disturbance and resetting of communities).

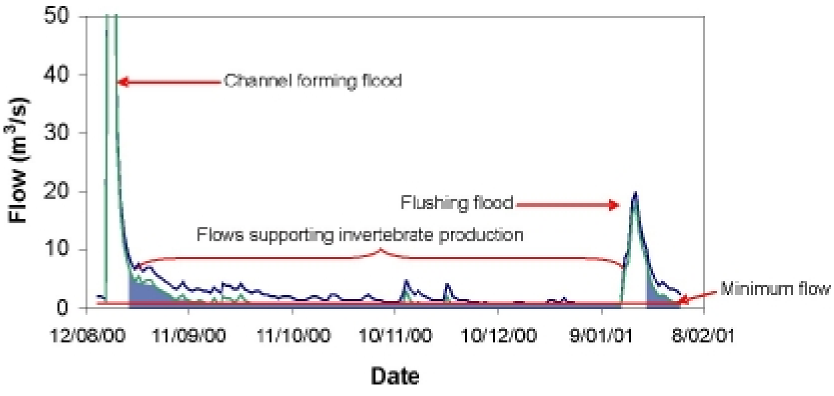


**Figure 3.** Illustrative hydrograph showing effect of run-of-river abstraction with relatively large allocation volume (2.6 x MALF) on key flow features. Natural flows are represented by the blue line and flows after abstraction by the green line. Allocation = 3 m³/s, MALF = 0.774, median flow = 2.04 m³/s). Blue-shaded area represents that part of the hydrograph that potentially provides habitat for algal and benthic invertebrate production (following flood disturbance and resetting of communities).

63. Lesser breaches of an allocation limit increase the frequency of flat-lining at the minimum flow. Many flow assessments in the past have focused on the minimum flow, with either the MALF or a proportion of it set as the minimum flow condition. However, this practice assumes that appropriate flow allocation limits or flow sharing rules are set to largely maintain the natural flow variability and avoid prolonged periods of flat-lined flow. Referencing minimum flow to the mean annual low flow, or less, in the absence of appropriate allocation limits or flow sharing rules has been likened to a doctor prescribing a patient's worst state of health as a life-time condition. There is a risk that water quality conditions may become marginal after prolonged periods at the minimum flow (eg. high temperature and low dissolved oxygen levels), although the minimum flow ought to be set high enough to avoid this. Living space for fish is likely to be limiting at the minimum flow, and with fish concentrated in the remaining habitat, there will be increased competition and risk of predation – potentially resulting in lower growth and survival. Of course all of these potential effects will worsen if flow is drawn below the minimum, and will be exacerbated the longer low flows are sustained.

64. Abstraction above the minimum flow potentially reduces benthic invertebrate production. Flow recessions following floods wet a greater area than is wetted at the minimum flow. Periphyton and benthic invertebrates colonise such habitat after flood disturbance and contribute to annual production, with some of that production being cropped by fish and birds. The effect of run-of-river abstraction on flows that contribute to invertebrate production is illustrated in Figure 3. Flow recessions appear to enhance trout fishing opportunities in some rivers, with fish being more active and catchable than at low flow.

**Taking account of the degree of hydrological alteration and existing state of knowledge**

65. From the preceding points it may be appreciated that the degree of hydrological alteration allowed under a regional plan or resource consent is an important consideration when assessing environmental flow regimes. Hydrological alternation is the degree to which low flows and flow variation will be changed by abstraction or flow regulation.

66. Various features of the flow regime may need consideration depending on the degree of hydrological alteration. When the degree of hydrological alteration is large, such as occurs with damming, impoundment and flow regulation for hydro-power generation, the entire pattern of flow, including channel forming floods, flushing flows, flow recessions and minimum flows need attention. However, in most cases where small to medium

levels of abstraction occur on a run-of-river basis, attention needs to given only to minimum flows and flow recessions. Water allocation as proposed in the Proposed One Plan for the majority of water management zones is of this nature.

67. The NES prescribes a decision-making framework that takes account of the degree of hydrological alteration and significance of instream values for guiding choice of flow regime assessment methods. The framework evolved from the Hayes & Jowett (2004) report to Environment Southland and has been adopted by Horizons in the Proposed One Plan.

68. The NES values-based framework essentially is that "technical methods [for assessing environmental flows] need to be cost-effective and take a risk-based approach, with simple methods used where the risk or environmental consequences of not achieving goals is low and more complex methods used where aquatic values are high or the hydrological regime is highly modified". It recommends "a cautious approach to setting flows [and allocation] that builds in buffers for risk and unknown outcomes".

69. The NES gives a useful summary of ecological effects for different water demands varying in respect of degree of hydrological alteration. Usually when water is taken for "water supply or irrigation, often with seasonally varying demand, the biologically relevant component affected is the magnitude of low flows, with a minor effect on duration. For example, abstraction of up to 10% of the mean annual low flow (MALF) is barely measurable and therefore unlikely to result in significant biological effects in any stream. With large-scale diversions or abstractions "the biologically relevant components affected are the magnitude and duration of low flows. The frequency of flushing flows may also be affected if the capacity of the diversion is sufficiently large (eg. > 1.5 times the mean flow). With large-scale diversions or abstractions, the quality and amount of habitat at minimum flow will directly affect the biological communities because flows are at the minimum for substantial periods of time. Consequently, the minimum flow required to support these communities should be higher than the minimum flow that would be applied to situations with short-duration low flows".

70. Water storage schemes (eg. those involving damming and impoundment or large-scale diversion to an impoundment) have the biggest effects on a river's hydrology and can affect all biologically important components of the flow regime.

71. The state of knowledge of values and the sensitivity of instream habitat and values to flow change should also influence the choice of flow assessment methods and flow

regime recommendations (Jowett & Hayes, 2004). For instance where the allocated flow is small (eg. < 10% of MALF – cf paragraph 66) or significance of values are known to be low, and/or knowledge from elsewhere indicates the allocated flow will have a small effect on habitat or values, a default method might suffice over more detailed and expensive methods.

**Environmental flow assessment methods**

72. The main methods that that have been applied to environmental flow regime assessment and management in New Zealand are the historic and hydraulic-habitat methods, the latter applied as part of the IFIM. Traditionally these methods have been used to define minimum flows, but in recent years habitat methods have been also been used to determine degrees of flow variation necessary to maintain desirable composition and levels of periphyton and invertebrate communities. The latter has occurred in tandem with a growing awareness internationally of the need to take a holistic approach to environmental flow regime assessment and management.

*Holistic, natural flow methods*

73. The goal of the 'holistic' approach is to maintain a natural flow regime including low flows, seasonal variation, and flood frequency, in order to protect aquatic fauna. Various methods have been published in the international flow management literature in recent years promoting the holistic (or natural flow paradigm (Poff *et al*.,1997)) theme, some attracting the attention of conservation stakeholders in New Zealand. In particular, the range of variability approach (RVA) (Richter *et al.*, 1996) has been promoted by the Department of Conservation as deserving of consideration. The natural flow paradigm is a simple construct based on the assumption that if you do not change the flow regime (and non-flow related factors also remain unchanged), the natural ecosystem will be maintained. A minimum-flow policy that restricts abstractions to the level of naturally occurring low flows and maintains major elements of the natural flow regime will maintain stream fauna, essentially in a natural state. This is a 'safe' environmental policy and one that will ensure the protection of aquatic resources in most situations, but it may unnecessarily constrain out-of-stream use of water. While some species may be adapted to a specific aspect of flow, this does not imply that the entire flow regime is necessary to maintain a healthy aquatic ecosystem or a given value. The natural flow paradigm does not take into consideration the flexibility in habitat requirements and life-history strategies of biota that enable them to cope with certain degrees of change.

74. The RVA is essentially a ‘standard setting’ approach based on historical, hydrological flow data. The RVA, and the associated indicators of hydrologic alteration (IHA), allows an “appropriate” range of variation, usually taken to be one standard deviation from the mean, in a large set of hydrologic parameters derived from the “natural” flow record (Richter *et al*,. 1997, 2006). Parameters are grouped into five ‘environmental flow components’ (EFCs): extreme low flows, low flows, high flow pulses, small floods and large floods. The implicit assumption in this method is that the natural flow regime has intrinsic values or important ecological functions that will be maintained by retaining the key elements of the natural flow regime.

75. The RVA method has been used in the United States mainly in regulated rivers to maximise the benefit of high-flow pulse releases of water from dams at a targeted magnitude, frequency, timing, duration, and rate-of-change. To date the method has not been used in New Zealand for setting ecological flows and levels, and for that reason was not recommended as a flow regime assessment method in the NES. We proposed in the technical support document to the NES that further research be undertaken on the relationship of RVA parameters to the water quality, geomorphology, and biology of river systems. Some such research related to geomorphology and hydrology is currently being undertaken by NIWA. Also, the utility of the RVA method for setting ecological flows in New Zealand, particularly relating to abstraction, needs to be demonstrated. A recommendation in the NES is that until this research is carried out, ‘analysis of hydrological variation’ should be included in the schedule of methods for rivers with a high significance of instream values. While analysis of hydrological variation will not by itself allow the setting of ecological flows, it will act as a ‘flag’ to other methods to illustrate the extent of hydrological change, and how these hydrological parameters may be affected by the ecological flow decision. Analysis of hydrological variation can be carried out using the RVA software or any other standard hydrological software that calculates flow statistics. Similarly, simple flow duration curves can be used where the proposed degree of hydrological alteration is low. Both analysis of flow variability and flow duration curves are standard hydrological techniques that have been routinely used in the past in New Zealand in various ways to assess degree of hydrological alteration; essentially, they are ‘flags’ to the potential importance of flow variability rather than ecological flow-setting methods in their own right.

*Assessing flow change in the context of knowledge of New Zealand river ecosystems*

76. When assessing the significance of hydrological alteration in the context of a holistic approach to flow management, it is helpful to consider what is known about New

Zealand river ecosystems and their relationships with flow regime. These are quite well understood in comparison with overseas, allowing us to make some broad conclusions about the ability of our ecosystems to cope with flow regime change.

77. New Zealand flow regimes differ according to climate and river type, yet the aquatic communities are broadly similar across these regimes; this demonstrates the existence of what Jowett & Biggs (*in press*) termed 'ecological redundancy' in relation to flow requirements. In general, New Zealand river ecosystems are characterised by populations that have evolved to be resilient and opportunistic, and able to cope with a wide range of flow variability within and among rivers. Algae and aquatic invertebrates have flexible poorly synchronized life-histories with non-seasonal or weakly seasonal patterns of development (Jowett & Biggs *in press*). Many native fish are also opportunistic generalists, the common species being widely distributed and found over a wide variety of rivers and flow regimes. Introduced brown and rainbow trout, and particularly the former, are also able to cope with a wide range of flow variability, although they are most abundant in rivers with low flow variability. These features of New Zealand river ecosystems are not surprising given the lack of strong seasonality in flow regimes.

78. Research commencing in the mid-1980s focused on linking the physical, hydrological, hydraulic, chemical and biological characteristics of New Zealand rivers (Jowett & Biggs i*n press*). One goal of this work was to establish quantitative links between the flow regimes and ecosystems to allow for more informed decisions on flow management that would enable protection of instream values while also determining how much water might be available, and when, for societal abstractive use. Since then, numerous survey and experimental based studies have been carried out in New Zealand to further test these links between biological responses and flow regime, and to understand and model the relevant processes.. This research has provided the scientific foundation for understanding river processes, identifying ecologically relevant flows, and designing flow regimes that exploit the inherent ecological redundancy to allow out-of-stream use while protecting the identified instream values. Hydraulic-habitat methods have played a key role in the development of this science and in its practical application to assessing and designing environmental flow regimes.

*Habitat methods*

79. According to a review by the Environment Agency in the UK on river flow objectives, "Internationally, an IFIM-type approach is considered the most defensible method in existence [for assessing instream flow requirements]" (Dunbar et al. 1998).

80. The IFIM is a decision-support system (or framework), which provides a process for solving water allocation problems where there are concerns for maintaining instream habitat (Bovee *et al*., 1998).

81. The Freshwater Research Institute of the University of Cape Town in South Africa states, "IFIM is currently considered to be the most sophisticated, and scientifically and legally defensible methodology available for quantitatively assessing the instream flow requirements of rivers" (Tharme, 1996). A review of flow assessment methods in the book "Instream flows for riverine resource stewardship" (Annear *et al*., 2002) described IFIM as the "most appropriate for relative comparisons of habitat potential from among several alternative flow management proposals" and as "the method of choice when a stream is subject to significant regulation and the resource management objective is to protect the existing healthy instream resources by prescribing conditions necessary for no net loss of physical habitat".

82. Nevertheless, controversy has accompanied the development of the IFIM, in particular hydraulic and habitat models such as PHABSIM and RHYHABSIM (Hudson *et al.*, 2003). Despite these criticisms, IFIM and similar hydraulic habitat methods have a biological basis and are used in approximately 58 countries (Tharme, 2003). Experience with its use in New Zealand has confirmed the view of the developers of the IFIM that it is a sufficiently flexible, interdisciplinary framework within which to harness scientific understanding of instream habitat requirements and ecosystem processes to hydraulic and water quality models in order to predict the effects of flow regime change.

83. Since its development in the 1970s, the way in which the IFIM has been applied in New Zealand has evolved in tandem with flow assessment and management paradigms. The IFIM is now applied in a holistic manner, with the degree of hydrological alteration and significance of instream values influencing which parts of the flow regime are investigated for maintenance. This is consistent with the NES, which recommends an approach that is cognisant of the holistic natural flow paradigm, while maintaining the biologically important elements of the flow regime.

84. Experience in six New Zealand rivers has shown that flow regimes designed using habitat methods, and very different from the natural flow regime, can sustain excellent fish and invertebrate populations and achieve instream management objectives (Jowett and Biggs, 2006).

85. The basic premise of habitat-based methods is that if there is no suitable physical habitat for the given species, then they cannot exist. However, if there is physical habitat available, then the species may or may not be present in a survey reach, depending on other factors not directly related to flow, or to flow related factors that have operated in the past (eg. floods). In other words, habitat methods can be used to set the "outer envelope" of suitable living conditions for the target biota.

86. Habitat-based methods have a direct link to habitat use by aquatic species. They predict how habitat (as defined in by various habitat suitability indices or criteria) varies with flow, and the shapes of these characteristic curves provide the information that is used to assess flow requirements. Habitat-based methods allow more flexibility than historic flow methods thus offering the possibility of allocating more flow to out-of-stream uses while still maintaining instream habitat at levels acceptable to other stakeholders (ie. the method provides the necessary information for instream flow analysis and negotiation).

87. The main component of the IFIM is hydraulic-habitat modelling. The great strength of these models is that they can quantify the loss of habitat caused by incremental changes in the natural flow regime, which assists the evaluation of alternative flow proposals.

88. The main hydraulic-habitat model used in New Zealand is RHYHABSIM (a 1-dimensional – ie. cross-sectional model), developed by Ian Jowett. This was used for all hydraulic-habitat modelling for the Proposed One Plan.

89. Hydraulic-habitat models can be separated into a hydraulic component and a habitat component. The hydraulic model predicts water velocity, depth and other hydraulic variables at a given flow, for each point, represented as a cell in a grid covering the stream area under consideration. In addition, information on bed substrate and other relevant factors such as cover, shade, aquatic vegetation and temperature can be recorded for each cell. Hydraulic data is provided to the models from cross-section survey of the river bed (in the case of 1-dimensional models) or from topographic survey

(in the case of 2-dimensional models); including depth, velocity, substrate and water level measurements.

90. Mr Hay provides evidence on the detail of hydraulic-habitat surveys and specifics of RHYHABSIM analysis that he has conducted for the Proposed One Plan.

91. Biological information is supplied to the models as habitat suitability criteria (or curves) for a particular species and life stage. A suitability value is a quantification of how well suited a given depth, velocity or substrate is for the particular species and life stage. Other relevant factors, such as cover, aquatic vegetation and presence of other species, can be incorporated into the evaluation of habitat suitability, although this is not common. Suitability criteria usually range between 0 and 1, with 0 indicating unsuitable habitat and 1 indicating most suitable habitat. Figures 4 and 5 show examples of habitat suitability criteria for three common fish species in New Zealand rivers.

92. The result of an instream habitat analysis is strongly influenced by the habitat suitability criteria that are used. If these criteria specify deep water and high velocity requirements, maximum habitat will be provided by a relatively high flow. Conversely, if the habitat requirements specify shallow water and low velocities, maximum habitat will be provided by a relatively low flow and habitat will decrease as the flow increases. In contrast to historic flow methods, the habitat method does not automatically assume that the natural flow regime is optimal for all aquatic species in a river.

93. Selection of appropriate habitat suitability criteria, and determination of habitat requirements for an appropriate flow regime, requires a good understanding of the species' life cycles, scaling of habitat use with fish size, and food requirements.

94. For each measurement point in the surveyed reach, velocity and depth are predicted for a simulated flow; together with the point substrate score, suitability scores for each of these predictions are calculated from the suitability criteria. The depth, velocity and substrate scores are then combined (usually by multiplication) to produce a joint habitat suitability score for each point. These data are then used to calculate two reach-scale indices: the habitat suitability index (HSI or %WUA in earlier model applications) and weighted usable area (WUA). HSI (which ranges between 0 and 1) is the average of the joint habitat suitability scores in the surveyed reach. It is intended to provide an indication of the relative quality of the predicted available habitat. WUA is calculated by weighting the joint habitat suitability scores for each point by the area that each point represents in the surveyed reach and then summing these for the reach. WUA is an

index of the quality and quantity of available habitat. This simulation procedure is then repeated for other flows, to produce a graph of reach-scale HSI or WUA versus flow for the given species. For rivers with confined channels (ie. other than braided rivers), a WUA graph has a typical shape (shown in Figure 6), with a rising part to a maximum and then a decline with further increase in flow. The decline occurs when the velocity and/or depth exceed those preferred by the given species and life stage. Thus, in large rivers, the curve may predict that physical habitat will be at an optimum at flows less than the naturally occurring MALF or median.

95. The relationship between habitat and flow (Figure 6) can be used to define a preferred flow range, a minimum flow, or a preferred maximum flow. The minimum flow can be defined as the breakpoint in the WUA flow curve, or as the flow at which the habitat has dropped to a certain percentage of its value at the mean annual low flow (MALF) or median flow (or some other ecologically relevant flow statistic).

96. It is important to realise that HSI and WUA provide only relative measures of how predicted habitat changes with flow. Therefore, when interpreting the WUA x flow or HSI x flow curves, it is the shape of the curves that are of interest, rather than the magnitude (or height) of the WUA x flow curves (eg. the flows at which the optimum WUA and major changes in slope occur). These outputs provide an indication of how habitat availability is predicted to change with flow.

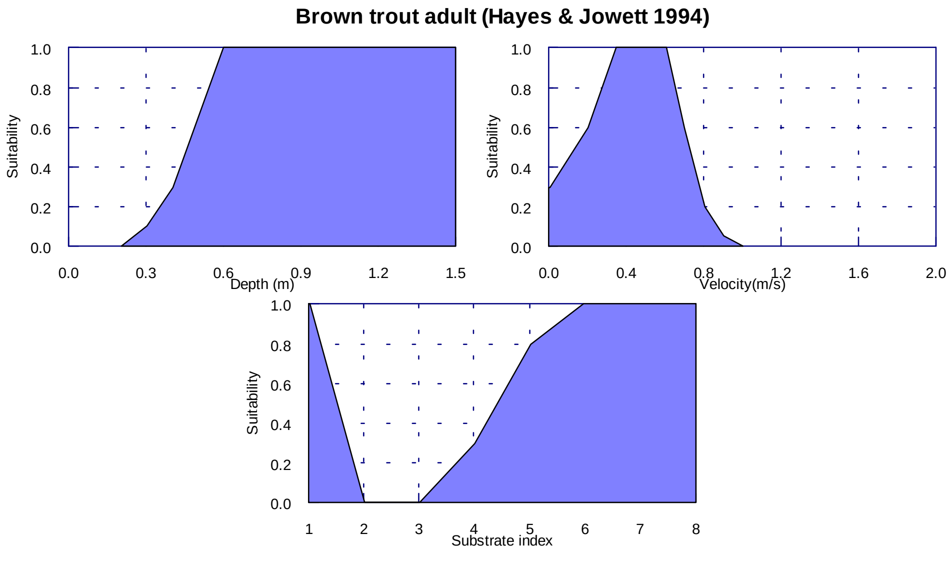


**Figure 4.** Example of habitat suitability criteria (curves) for introduced adult brown trout (based on Hayes & Jowett 1994)

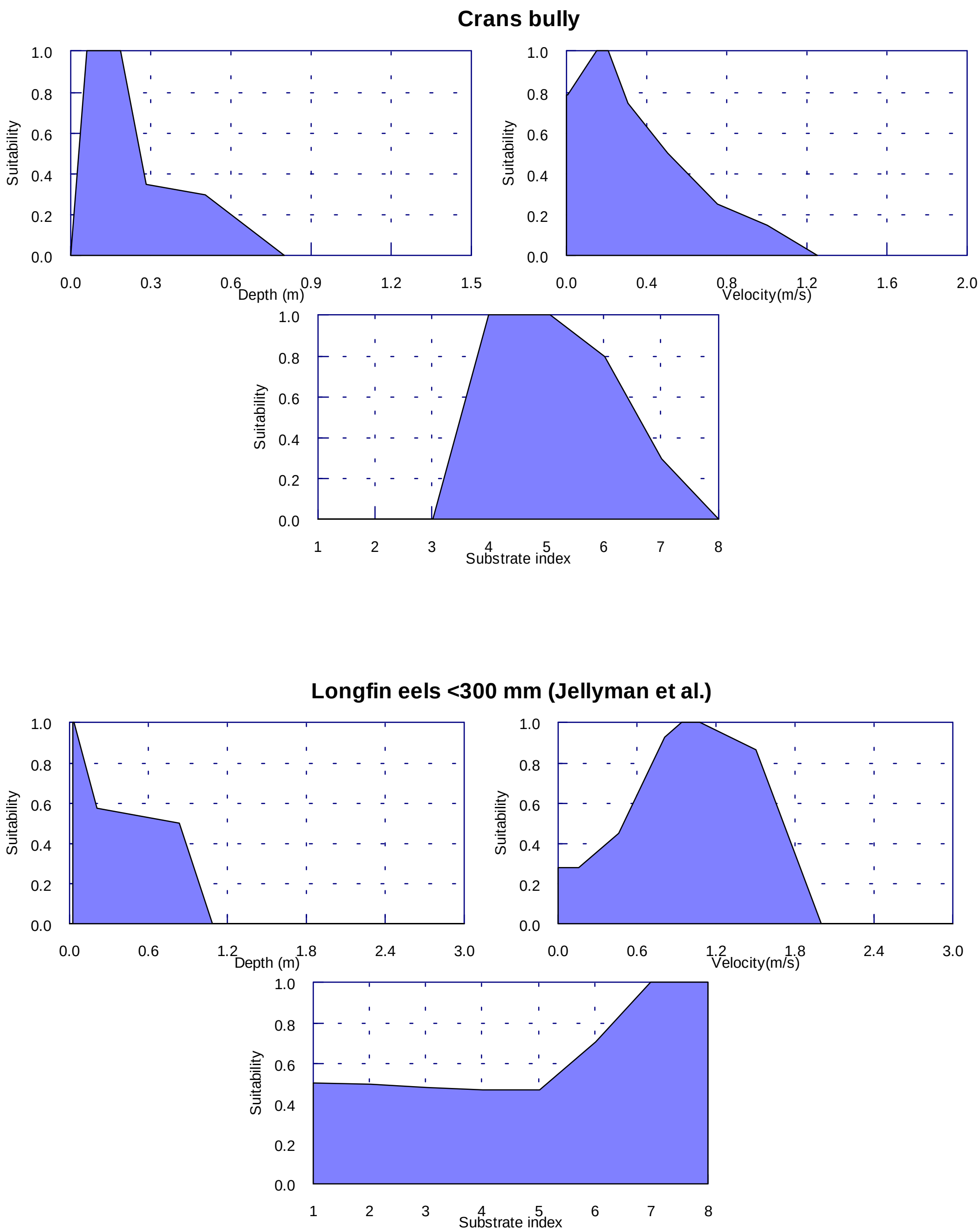


**Figure 5.** Examples of habitat suitability criteria (curves) for native fish – Cran's bully and longfin eels (Jowett & Richardson 2008)

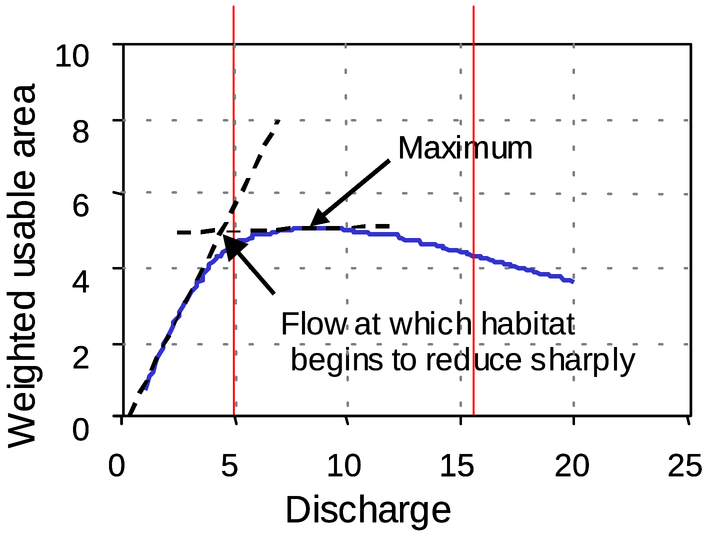


**Figure 6.** Typical WUA x flow relationship for a river with a confined channel, in this case for adult brown trout. The breakpoint is shown (ie. the point at which habitat begins to decline sharply with further flow reduction). Rough locations of MALFs for small versus large rivers are also shown, indicating that in large rivers habitat can sometimes be improved by reducing flows, whereas for small rivers MALF is usually below the flow at which WUA is at maximum (optimum) and so habitat declines as flow is drawn below the MALF.

*Historic flow methods*

97. These methods are based on flow records and are the simplest and easiest to apply. They are generally desktop, rule-of-thumb methods that are used to set minimum flows. A historic flow method is based on the flow record and uses a statistic to specify a minimum flow, below which water cannot be abstracted. The statistic could be the average flow, a percentile from the flow duration curve, or an annual minimum with a given exceedance probability. For example, a method might prescribe that the flow should never be drawn below 10% or 20% of the MALF (ie. 80-90% of the MALF be retained).

98. The aim of historic flow methods is to maintain the flow within the historical flow range, or to avoid the flow regime deviating largely from the natural flow regime. The underlying assumption is that the ecosystem has adjusted to the flow regime and that a reduction in flow will cause a reduction in the biological state (abundance, diversity, etc.)

proportional to the reduction in flow. It is usually also assumed that the natural ecosystem will only be slightly affected as long as the changes in flow are limited and the stream maintains its natural character. Unlike habitat methods, historic flow methods implicitly assume that the ecological state cannot improve by changing the natural flow regime.

99. Historic flow methods are most appropriate for rivers where the relationships between habitat, ecosystem integrity and flow requirements are poorly understood.

*Validation and monitoring of methods*

100. Opponents of habitat methods in New Zealand, and elsewhere, have criticised practitioners for not demonstrating that the predictions actually do maintain instream values once the flow recommendations are implemented. The same criticism can be levelled at the application of historic flow and other methods, both in New Zealand and overseas. A common related criticism of habitat methods focuses on the inherent assumption that there is a relationship between habitat and abundance. Some studies have found such relationships, others have not (Jowett, Hayes & Duncan 2008).

101. It should not be surprising that studies seeking positive correlations between habitat availability and abundance have been equivocal, because species abundance is influenced by factors other than habitat that are not necessarily flow-related. Conditions preceding a study, such as a large flood, may have depressed abundance well below carrying capacity. However, it is intuitively reasonable to expect that the amount of habitat available would set an upper limit to population size, in the absence of other limiting factors (ie. habitat availability should set the outer envelope of abundance).

102. The only study undertaken in New Zealand on the performance of habitat methods in designing flow regimes is the one by Jowett and Biggs (2006), which I have already mentioned. It was carried out on rivers heavily modified for hydropower generation. These were the only New Zealand rivers that Jowett and Biggs could find for which there was enough data before and after managed flows were implemented to assess effects, and for some of those they had to rely partly on anecdotal information. Nevertheless, they concluded that the heavily modified flow regimes designed using habitat methods achieved instream management objectives by sustaining excellent fish and invertebrate populations. Jowett and Biggs' difficulty in finding case histories for their study highlights the lack of attention that has been given to monitoring effects of managed flow regimes by decision-makers and regional councils in the past.

103. In my opinion, there is a good foundation of theoretical and empirical science underpinning habitat methods, especially on New Zealand rivers, and consequently they provide more certainty than other methods. Although the more complex incremental methods based on hydraulic-habitat models could be used in every situation, it would not be cost-effective where values are low, nor would it be necessary to evaluate effects for aspects of the natural flow regime that would not be changed with proposed water allocation. When instream values are low, or the degree of hydrological alteration is low, historic methods are a cost-effective alternative.

104. In order to assemble more compelling evidence than I have already summarised for methods used to set environmental flow regimes, decision-makers need to impose adequate monitoring conditions. In addition, the need to understand flow allocation effects should also influence councils' State of the Environment (SoE) monitoring programmes. Sampling designs of both targeted and SoE monitoring programmes need to specifically address flow effects, which are expressed as the product of density and area. The latter is commonly overlooked in monitoring studies. This applies to monitoring of benthic invertebrates in addition to fishes. The main effects of flow change are likely to be on the production of higher trophic levels, such as fishes and birds, but these are the most difficult to monitor owing to sampling challenges and high spatial and temporal variability. Monitoring should include: 1) estimates of invertebrate density in addition to community structure, 2) intensive electrofishing surveys for native fish and juvenile trout (ie. more sites and better coverage of wetted area of larger streams), and 3) drift-dive surveys for trout. Analyses should extend to an assessment of effects on total populations (density x wetted area) rather than just presence/absence, community structure and density. In addition, the monitoring results should be analysed with respect to the frequency and duration of habitat availability (ie. integrated with the results of instream habitat modelling).

*Scope of environmental flow assessment for regional planning*

105. Most applications of habitat methods in New Zealand have been on run-of-river abstractions and are a condensed version of the IFIM, focusing on hydraulic habitat modelling of the low-to-median flow range. Traditionally, historic flow methods also have been focused on the minimum flow. This practice has attracted criticism from environmental stakeholders for its narrow focus, which seemingly flies in the face of holistic flow assessment. This view is based on a common misunderstanding of how run-of-river abstractions alter a river's hydrology. The hydrological alteration caused by small to modest run-of-river abstraction is usually confined to the low-to-medium flow

range. Channel forming floods, and usually flushing floods, are unaffected. When they are, such as occurs with major diversions and damming for water storage, the scope of environmental flow assessment is widened. For simple run-of-river abstractions though, the relevant flow regime features for assessment are the minimum flow (for annual or seasonal habitat) and flow recessions (for invertebrate production and fish feeding opportunities). The appropriate flow management mechanisms to maintain habitat and productivity in this case are: 1) an annual or seasonal minimum flow, and 2) setting conservative flow allocation limits that take account of minimum flow duration and flat-lining. This is the approach taken by Horizons in the Proposed One Plan for run-of-river abstractions, which comprise the bulk of water demand in the Region.

## 4. PROPOSED ONE PLAN APPROACH TO ENVIROMENTAL FLOW ASSESSMENT

### Overview

106. Surface water allocation in the Proposed One Plan broadly follows the process that I have outlined for assessing and managing environmental flow regimes. In this respect it is consistent with the MfE's Flow Guidelines and National Ecological Flow Standards. The process has included:

a. identification of instream values, and flow-critical values, in consultation with stakeholders;

b. defining instream management objectives for water management zones;

c. consideration of water demand for out-of-stream use; and

d. a tiered approach to environmental flow assessment (or choice of method), minimum flow setting and flow allocation, depending on the significance of instream values, knowledge of the water resource and water demand for out-of-stream use.

107. This tiered approach is based on Hayes and Jowett (2004) and the version in the Proposed One Plan can be summarised as follows:

a. Where a river is already subject to a National Water Conservation Order (NWCO), the minimum flows and allocation limits are set based on the intention of the Order to ensure that the objectives of the Order are not compromised by water abstraction. NWCOs apply on the Upper and Middle Rangitikei and the Manganui o te Ao rivers.

b. Where a river was originally subject to a Local Water Conservation Notice (LWCN), superseded SW Policy 3 and SW Rule 2 of the Horizons Regional Council Land and Water Regional Plan, 2003, the minimum flow in the Proposed One Plan is set at 90% of the MALF and core allocation is set at 15% of MALF.

The objective is to retain the intention of the LWCN – usually protection of regionally important trout fisheries.

c. Where water demand is low and a water resource assessment of a water management zone has not been undertaken, and a robust hydrological record does not exist, a precautionary default minimum flow and core allocation will be set according to Proposed One Plan Policy 6-17(b). The default minimum flow is the 1-day MALF and the default core allocation is 20% of MALF.

d. Where water demand is low and a water resource assessment of a water management zone has not been undertaken, but a robust hydrological record (> 10 years) does exist, a minimum flow equivalent to 90% of the 1-day MALF is set. This is based on relationships between MALFs and minimum flows recommended from IFIM habitat analyses already undertaken on rivers in Horizons' Region (Hurndell *et al.,* 2007). The IFIM recommendations were based on retaining 90% trout habitat. On average, IFIM recommended minimum flows were approximately 82% of the respective MALFs for rivers with MALFs less than 5 $m^3/s$. However, the 90% of MALF rule was chosen to be conservative. Core allocation is informed from a flow duration analysis that balances instream habitat requirements and surety of supply to abstractors.

e. Where water demand is high and/or instream values are high in a water management zone, a full-scale water resource assessment is undertaken, including IFIM habitat analysis to assess minimum, and other environmental, flow requirements. Because in these cases instream values are likely to be high, minimum flow recommendations will usually be made on a high level of habitat protection, usually 90%, for the flow-critical species which most often is trout. Core allocation is informed from a flow duration analysis that balances instream habitat requirements and surety of supply to abstractors.

f. In water management zones where water demand is high and/or instream values are high, but a water resource assessment has not been completed, IFIM habitat analysis has been undertaken, which informs minimum flow setting.

108. In my opinion, this tiered approach is sensible and will provide for a high level of maintenance of instream habitat and life supporting capacity. Use of IFIM habitat modelling for assessment of minimum flow requirements is scientifically defensible for the reasons I have already stated.

109. Maintenance of environmental flows under the Proposed One Plan focuses on setting minimum flows and setting flow allocation limits for maintenance of ecologically relevant flow variation in the low-median flow range. This is appropriate because the rules in the

Proposed One Plan cater in the main to run-of-river abstractions which affect low-median flows.

110. Flow duration analysis is a necessary adjunct to minimum flow setting to ensure against prolonged flat-lining of the minimum flow. The approach to setting allocation limits, in conjunction with minimum flows, involves 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 core allocation is then derived by subtracting the minimum flow from the management flow (ie. core allocation = management flow – minimum flow). This is a pragmatic risk-based approach to flow allocation in lieu of biological understanding of how sensitive river ecosystems are to changes in flow frequency over the low-median flow range. While environmental flow assessment methods can tell us how habitat varies with flow, and hence inform minimum flow setting, there is inadequate knowledge of the effects of holding flows at the minimum for various periods of time. All that can be said is that the risk of adverse effect increases with the duration of the minimum flow, and with increasing allocation volume.

111. The method adopted in the Proposed One Plan for determining minimum flows that retain the target level of habitat retention follows that recommended by Jowett and Hayes (2004) and Hay and Hayes (2007). The minimum flow is the flow that retains the target percentage of habitat available at the naturalised MALF for an identified flow-critical value, or a proportion of maximum habitat if the maximum occurs at a flow less than MALF. This concept is illustrated in Figure 7.

112. The Proposed One Plan has adopted the Jowett and Hayes (2004) suggestions in Table 1 for setting levels of habitat retention commensurate with values and their significance. The majority of cases where IFIM survey data has been collected in Horizons' Region have been on rivers supporting trout fisheries; for those supporting highly valued trout fisheries, a 90% level of habitat retention has been adopted. The range of habitat retention applied is 70-90%.

113. The minimum flows set according to target habitat retention levels for a flow-critical value are, of course, sensitive to the critical value and the habitat suitability criteria

chosen for that value. In all cases where minimum flows have been set in the Proposed One Plan on the basis of instream habitat modelling by Mr Hay and myself, trout have been identified as the critical value. This decision was informed by a review of instream values in the Manawatu-Wanganui Region (Ausseil & Clark, 2007) and by consultation involving staff of Horizons, Wellington Fish & Game and Department of Conservation. The critical value status of trout was based on them being both highly valued and being among the most flow-demanding fish present. Trout have high flow requirements owing to their large size, and drift-feeding behaviour, which requires them to swim up in the water column exposed to the current. They are highly valued as a sports fish by both domestic and tourist anglers. Although an introduced fish, their valued fisheries status is recognised by statute in Section 26B of the Conservation Act 1987 and the RMA sections 7c (the maintenance and enhancement of amenity values) and 7h (protection of the habitat of trout and salmon).

114. Depending on the main life stage supported by the stream, either adult brown or rainbow trout habitat, or juvenile brown trout habitat, was chosen as the critical factor. Mr Hay and I used our professional judgement on appropriate habitat suitability criteria for these trout species and life stages, and for native fish and benthic invertebrates included in the instream habitat modelling. Mr Hay conducted the instream habitat modelling and will present more detailed evidence on this. When choosing appropriate suitability criteria, Mr Hay and I drew from an archive of trout habitat suitability criteria which we have assembled from overseas and New Zealand research, and from a national collection of native fish and benthic invertebrate habitat suitability criteria held by Mr Jowett and recently reviewed by Jowett & Richardson (2008). For trout, we chose habitat suitability criteria appropriate to the size of fish and river being modelled, and when faced with alternative criteria we chose the ones that resulted in the highest minimum flows. In my opinion this was an appropriate, conservative approach of dealing with uncertainty.

115. Some of the streams to which the default minimum flow and allocation rule has been applied support either low numbers of trout or just a native fish community. Ms Hurndell provides the rationale for this in her evidence). Native fish generally have lower flow requirements than trout, so default minimum flows based on trout should be conservative and provide good protection for native fish habitat. A conservative minimum flow is warranted because, as Ms Hurndell points out, it will help guard against decline in water quality, instream conditions (including siltation) and aesthetics. Ms Hurndell correctly, in my opinion, concludes in her evidence that this will ensure a good level of instream habitat protection where there is insufficient knowledge of the instream system to confidently set the minimum flow lower .

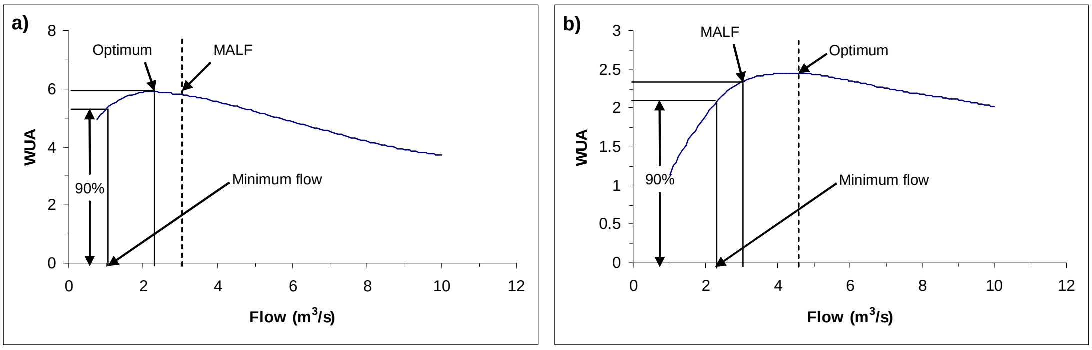


**Figure 7.** Derivation of minimum flow based on retention of a proportion (90% in this case) of available habitat (WUA) at a) the habitat optimum, or b) the MALF, whichever occurs at the lower flow

### Supplementary water allocation

116. In addition to Policy 6-16, which provides for core allocations, Policy 6-18 in the Proposed One Plan provides for a supplementary allocation from rivers in the following circumstances:

a. where water is taken only when the river flow is greater than the median flow, and the total supplementary take does not exceed 10% of the natural flow at the time of abstraction;

b. where it can be shown that the supplementary allocation will not:

   i) increase the frequency or duration of low flows;

   ii) cause any adverse effects on the values of the water body;

   iii) limit the ability of anyone to take water under core allocation.

117. In my opinion, these restrictions on supplementary allocation are warranted and will maintain physical and ecosystem functioning of rivers and their dependent instream values. The ecologically relevant components of flow regimes that supplementary allocation potentially affects are channel-forming and flushing floods, and flow recessions that support invertebrate production – in the-low to-median flow range. The default supplementary abstraction of 10% above the median is above this ecologically sensitive range and is small enough not to noticeably affect the frequency and duration of floods. Provisions i) and ii) under point b. of Policy 6-18 signal that more ambitious supplementary allocation applications should specifically address effects on frequency and duration of low flows and instream values. In such circumstances, I would expect that a detailed hydrological analysis of effects would be carried out, along with an IFIM instream habitat analysis that included a flushing flow analysis (Jowett, Hayes & Duncan

2008). The latter predicts the relationship between flow and the proportion of fine sediment and periphyton flushed from the bed. The results are used to determine the magnitude of flushing flows necessary to maintain healthy fine sediment and periphyton conditions. A similar, sediment transport, analysis can be conducted to determine the size and duration of floods necessary for maintaining the channel morphology. Such analyses of effects would be necessary for large-scale water storage schemes for hydropower generation, irrigation and town water supply reservoirs.

**Proposed procedure for monitoring managed flow regime environmental outcomes**

118. Horizons proposes to monitor the environmental outcomes of water allocation managed under the Proposed One Plan.

119. Monitoring the outcome of water allocation management under the Proposed One Plan is desirable for feeding back into adaptive management. This will facilitate more efficient water allocation and stakeholder acceptance. I understand that Horizons is committed to monitoring instream effects of Plan rules on instream values, and to adaptive management statutory plan change process.

## 5. PROPOSED ONE PLAN WATER QUALITY STANDARDS FOR TROUT

120. The water quality standards for the protection of trout in the Proposed One Plan are partly based on recommendations in a report that I co-authored with two Cawthron Institute colleagues (Hay, Hayes & Young, 2006). The information that we drew from for these recommendations came from various sources from overseas and New Zealand research. The source for recommendations on pH, dissolved oxygen, and ammoniacal nitrogen and other toxicants was the Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 (ANZECC guidelines). Information on faecal contaminants was sourced from the MfE. Information for the temperature standards was sourced from an overseas review and from the RMA. The recommendations for water clarity and turbidity arose from my own experience with drift foraging models for trout, and drew on: 1) overseas research on visual foraging behaviour by salmonids and its sensitivity to prey size, fish size, water clarity and turbidity, and 2) on New Zealand research on the relationship between water clarity and turbidity. The recommendations on periphyton and nutrients were based on the periphyton guidelines and those on benthic invertebrates were based on the Macronvertebrate Community Index (MCI).

121. Dr Young presents evidence on the water quality standards in the Proposed One Plan, including those for water management zones for which maintenance of trout fisheries is a management objective.

## 6. CONCLUSIONS

122. The process and methods employed by Horizons for environmental flow assessment, minimum flow setting and water allocation in the Proposed One Plan are consistent with the MfE Flow Guidelines and National Ecological Flow Standards.

123. The process is appropriately focused on aspects of flow regimes affected by run-of-river abstractions (ie. to minimum flows and flow variation in the low-median flow range).

124. The tiered approach to environmental flow assessment, minimum flow setting and water allocation; it involves default conditions based on historic flow records (where instream values and water demand are low), through to conditions based on levels of habitat retention (where instream values and water demand is high) provides for cost-effective, risk-based water resource planning taking account of uncertainty.

125. In my opinion, the use of instream habitat modelling methods for environmental flow assessment is appropriate and scientifically defensible.

126. Similarly the habitat suitability criteria used for instream habitat modelling are scientifically based. The choice of habitat suitability criteria for the habitat modelling was based on professional judgement and in my opinion those chosen were appropriate to the identified instream values.

127. Also in my opinion, setting minimum flows based on habitat retention of flow-critical values, is appropriate. It is a pragmatic solution to setting flows when faced with several values with varying flow preferences.

128. Minimum flows set on the basis of habitat retention for trout (the most flow demanding, highly valued species), coupled with the conservative allocation limits specified in the Proposed One Plan will, in my opinion, provide a high level of protection for trout and other instream values. Sufficient habitat will be retained for a high level of life supporting capacity for benthic invertebrates and native fish species, and for maintaining biodiversity.

129. The strict restrictions on supplementary allocation provided under the Proposed One Plan are warranted, targeted at the appropriate environmental flows, and will maintain physical and ecosystem functioning of rivers and their dependent instream values.

130. In my opinion, the policies and rules in the Proposed One Plan governing minimum flows and water allocation will maintain instream values at levels similar to those currently occurring.

131. I support Horizons' commitment to monitoring of the outcomes of water allocation under the Proposed One Plan, with provision for adaptive management of minimum flow and allocation rules through the statutory plan change process. This will facilitate more efficient water allocation and stakeholder acceptance.

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