BEFORE THE COMMISSIONERS ON BEHALF OF THE OTAGO REGIONAL COUNCIL

Consent No. RM16.093.01

BETWEEN	**CRIFFEL WATER LIMITED**
	Applicant
AND	**OTAGO REGIONAL COUNCIL**
	Consent Authority

AFFIDAVIT OF IAN GEORGE JOWETT

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AFFIDAVIT OF IAN GEORGE JOWETT

I, **Ian George Jowett** of Tairua, Hydroecologist solemnly and sincerely **Swear**:

1. My full name is Ian George Jowett I am a Hydroecologist residing at Tairua.

Qualifications and Experience

2. I have a Bachelor of Engineering degree from Canterbury University in 1968 and became a registered engineer in 1970, but have worked in the field of biology since 1984. In December 2016, I was awarded an honorary doctorate by the University of Waikato.

3. I am a member of the New Zealand Hydrological Society and the New Zealand Freshwater Sciences Society, and have received awards from them for outstanding contributions in 1985 and 2007, respectively. In 2016, I received an award for exceptional achievement and service to their profession from the Ecohydraulics Committee of the International Association for Hydraulic Research.

4. Between 1969 and 1984, I worked for the Ministry of Works and Development on the investigation, operation and environmental impact of hydroelectric schemes. In 1984, I was employed by MAF Fisheries, now part of the National Institute of Water and Atmospheric Research ("NIWA"). I retired from NIWA on 31 October 2007.

5. In NIWA, I began research into the factors influencing the abundance and distribution of trout. As part of this study, I initiated the "100 rivers" survey and collected data on trout densities and comparable biological, hydrological, and chemical data for more than one hundred rivers.

6. From the "100 rivers" data, I developed models that predicted brown trout abundance from river characteristics. These results were published in the North American Journal of Fisheries Management (Jowett 1992). I have carried out research to determine factors that influence the distribution and abundance of trout and native fish. I have authored or co-authored over fifty scientific publications on hydrology,

instream habitat and flow requirements of benthic invertebrates, brown trout and native fish.

7. I have carried out instream habitat surveys of more than 250 reaches and assessed minimum flow requirements for more than 50 rivers. For many of these, I have prepared reports and presented evidence to regional council and Environment Court hearings on the effect of flow on stream invertebrates, native fish and trout.

8. With more than 40 years of experience, I have been able to observe the biological consequences of my flow recommendations as well as observing the response of aquatic populations to natural flow changes.

9. I have examined methods available for assessing flow requirements for rivers and their use in the flow management process. Results of this work have been incorporated into the Ministry for the Environment's "Flow guidelines for in-stream values" (MFE 1998) and into Environment Southland's Proposed Regional Fresh Water Plan for Southland following a review which I co-authored with Dr Hayes, Cawthron Institute, (Jowett & Hayes 2004). I have also been involved in the preparation of a proposed National Environmental Standard on methods for use in assessing flow regime requirements.

Background

10. I prepared the 2004 Report "Flow requirements for fish habitat in Luggate Creek, Arrow River, Nevis River, Stoney Creek, Sutton Stream, Trotters Creek, and Waiwera River" (Jowett 2004). That report was utilised by the Otago Regional Council in assessing and setting minimum flows in the Luggate Creek.

11. This year I was engaged by Criffel Water Limited and more recently Luggate Irrigation Company Limited and Lake McKay Station Limited to update the information within my Jowett 2004 Report to inform the assessment of their respective applications to replace their deemed permits. Pursuant to that engagement I produced the report "Fish Habitat in Luggate Creek", August 2019 (IJ902) which is attached as exhibit "**IGJ-1**".

J.P.

JP

12. I confirm that I have read the 'Code of Conduct' for expert witnesses contained in the Environment Court Practice Note 2014. I prepared the report attached at exhibit **IGJ-1** in compliance with that Code. In particular, unless I state otherwise, the report contents is within my sphere of expertise and I have not omitted to consider material facts known to me that might alter or detract from the opinions I express in it.

13. I confirm that the report attached as exhibit "**IGJ-1**" is true and correct.

SWORN at Tairua)
this 24th day of)
September 2019) ....
before me:) Ian George Jowett

Brooks J.P
....
~~A Solicitor/Deputy Registrar of the High Court of New Zealand~~

Larraine J. Brooks, JP
#98307
TAIRUA
Justice of the Peace for New Zealand

"IGJ-1"

Jowett Consulting Limited

This is the annexure marked "**IGJ-1**" referred to in the within affidavit of **Ian George Jowett** sworn at Tairua this 24th day of September 2019 before me:

Brooks JP

~~Solicitor/Deputy Registrar of the High Court of New Zealand~~

Larraine J. Brooks, JP
#98307
TAIRUA
Justice of the Peace for New Zealand

Fish habitat in Luggate Creek

Client Report: IJ1902

August 2019

Fish habitat in Luggate Creek

Ian Jowett

Jowett Consulting Ltd.

Client Report: IJ1902

August 2019

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Contents

Executive Summary

The purpose of this report is to update the information in the 2004 report "Flow requirements for fish habitat in Luggate Creek, Arrow River, Nevis River, Stony Creek, Sutton Stream, Trotters Creek, and Waiwera River" (Jowett 2004). The 2004 report defined flows that provided maximum habitat and the flow at which habitat begins to decline sharply. It is difficult to define where habitat begins to decline sharply as the decline is generally a smooth curve. Subsequently, a habitat retention method was developed based on retaining a percentage of the amount of habitat at MALF. This means that minimum flow assessments could be based on a standard of protection (the amount of habitat retained) consistent with the species present and management goals.

This report uses the 2004 instream habitat survey of Luggate Creek to calculate habitat for koaro, longfin eels and trout using revised habitat suitability curves. The standards of protection (percentage of habitat at MALF retained) provided by the present minimum flow of 180 L/s is evaluated in two reaches. The lower reach is near the site of the present water level recorder below the SH6 highway bridge. The upper reach is below the Criffel intake weir.

Juvenile brown and rainbow trout are abundant in the Luggate Creek but koaro are rare. Brown trout are present in the lower reach and rainbow trout are in the upper reach. Koaro have been found in both reaches and are a rare species in the Clutha catchment found at 4% of the sampling sites. Most of the occurrences are associated with the large lakes. The occasional adult longfin eel has been observed in this creek but they could be more abundant if elver transfers from Roxburgh dam are made to this catchment or the upper Clutha River.

A minimum flow of 180 L/s in the lower reach would maintain 80% of juvenile brown trout habitat, 80% of juvenile eel habitat, 83% of adult eel habitat and 70% of koaro habitat. The winter (1 May to 31 October) minimum flow of 500 L/s would maintain maximum brown trout spawning habitat. Optimum flows for adult and yearly trout are likely to be 1 m^3/s or higher suggesting that the stream is a spawning stream rather than a year-round habitat for yearling and adult trout.

Flows in the upper reach just below the Criffel weir will be lower than those in the lower reach. Because of abstractions and low flows from tributaries, some flow must be maintained past the Criffel weir to maintain a flow of 180 L/s at the recorder site. A residual flow of 90 L/s has been proposed by Criffel Water and with leakage and sub-surface flow this should increase the flow in the upper reach to 140 L/s.

A flow of 140 L/s in the upper reach would maintain 65% of adult eel habitat and 65% of koaro habitat.

1 Introduction

This report is prepared for Criffel Water. Criffel Water abstract water from the Luggate Stream at the Criffel weir for irrigation. The purpose of this report is to update the information in the 2004 report "Flow requirements for fish habitat in Luggate Creek, Arrow River, Nevis River, Stony Creek, Sutton Stream, Trotters Creek, and Waiwera River" (Jowett 2004).

The reasons for this update are that the habitat suitability curves used in 2004 have been updated (Jowett & Richardson 2008) and that there are additional methods of flow assessment based on habitat retention (Jowett & Hayes 2004).

Management of minimum flows and water allocation involves a process of deciding upon management objectives and levels of maintenance (habitat retention levels), as described in the Flow Guidelines (Ministry for the Environment 1998) and the Proposed National Environmental Standard on Ecological Flows and Water Levels (Ministry for the Environment 2008).

Most aquatic species live in specific physical conditions defined by water depth, velocity and substrate. Within a stream, the most suitable habitat for a species will be physical conditions where the densities are highest, and the poorest habitat will be the conditions that are not used by the species. The suitability of physical conditions for particular species is described by habitat suitability curves. The amount of suitable habitat in a stream will vary with flow. If flows are too low, the water velocities or depths may not be sufficient to sustain the species. If the flow is too high, velocities in much of the stream may be too high for the species to remain at its location. The way in which the area of suitable habitat varies with flow is determined by carrying out an instream habitat survey of the stream and predicting the variation in weighted usable area (AWS) with flow. This method is described in Appendix I.

This report describes the 2004 instream habitat survey of Luggate Creek and updates the information on hydrology and fish species. The instream habitat survey is used to assess the present minimum flow of 180 L/s in terms of retaining a percentage of the habitat available at the "naturalised" mean annual low flow.

2 Description

Luggate Creek is a tributary of the upper Clutha River with the confluence being close to Luggate township. The stream drains the Criffel Range and the northern end of the Pisa Range with the headwater areas at an altitude of nearly 2000 m. For much of its length Luggate Creek is steep and incised within a gorge.

Instream habitat surveys were carried out of 2 reaches of Luggate Creek in 2004. A total of 15 cross-sections was measured in each reach.

The lower reach was between the main highway and the Clutha River confluence (Fig. 1) at an elevation of 275 m with a catchment area of about 123 km^2. The lower reach was mainly willow lined with grassed stock paddocks running up to the creek sides (right). It was more open and steeper at the top of reach with willows (left). There were more runs and riffles than pools, but the pools were generally longer, as shown in the left photo. Cobbles were the dominant substrate type. This section of stream comprised almost equal proportions of run, riffle and pool habitat.

Figure 1 **Lower Luggate Creek**: between main highway and Clutha confluence.

Figure 2 **Upper Luggate Creek:** below the Criffel weir.

The upper reach was about 8 km upstream of the Clutha confluence and just below the Criffel intake weir (Fig. 2) at an elevation of 393 m with a catchment area of about 71 km^2. The upper section was steep (left) below the weir, with mainly bedrock and boulders. Further downstream, the gradient was lower with more pools and stock access. Runs and riffles were the predominant habitat types, but the pools were generally longer than the runs and riffles. Boulders were the dominant substrate type. As in the lower reach, this section of stream comprised almost equal proportions of run, riffle and pool habitat. There is a steep section of gorge between the upper and lower reaches which appears to be a barrier to upstream trout passage.

3 Hydrology

The Otago Regional Council estimated a low flow water yield of 4.5 $L/s/km^2$ using a combination of rainfall/runoff estimates and correlation of gaugings of Luggate Creek with recorded Cardrona River flows. This estimate of low flow water yield has not been updated since 2004.

The low flow water yield gives estimated mean annual 7-day low flows (MALF) of 550 L/s in the lower reach below the SH6 bridge and 320 L/s in the upper reach.

A water level recorder was established by the Otago Regional Council in 2016 at the State Highway 6 road bridge, and records of water abstraction have been kept. Daily mean naturalised flows were calculated by adding takes from the Criffel weir, Alice Burn (Luggate irrigation and Lake McKay) to the flow recorded at the ORC recorder site below the SH6. The period of record is short (from 2 February 2016 to 30 April 2018) with only 1 complete year of record but covering 3 irrigation seasons[1].

Table 1: Recorded flows (m^3/s) in Luggate Creek and estimated natural flow (m^3/s) at the Luggate recorder (3/2/2016-30/4/2018).

Statistic	Luggate Creek (recorded)	Criffel	Alice Burn	Lake McKay	Luggate Creek (naturalised)
Mean flow	1.17	0.37	0.08	0.05	1.64
Mean annual flow (for complete year)	1.34	0.43	0.08	0.06	1.89
Median flow	0.99	0.33	0.08	0.08	1.44
Coefficient of Variation	0.76	0.32	0.14	0.72	0.53
Fre3 (frequency of flows > 3 x median per year)	3.13				0.89
MALF (mean annual 7-day low flow for 3 seasons)	0.16	0.24	0.07	0.00	0.65

Over the 3 irrigation seasons of naturalised flow record the estimated 7-day low flow was 0.38, 0.64, and 0.87 m^3/s giving a 7-day MALF of 0.65 (Table 1) which is 0.1 m^3/s higher than the estimated MALF in the 2004 report. Comparison with the natural flow for the Lindis River at Lindis peak suggests that an estimate of 0.65 m^3/s for the long-term MALF is not an under-estimate and that natural low flows in Luggate Creek are approximately 55% of those at Lindis Peak.

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[1] There is a small possibility that the 7-day low flow occurred in the few months before the start of record in 3/2/2016.

4 Fish species

Allibone (2019) has described the fish species in Luggate Creek and its tributaries. In his electric fishing survey above and below the Criffel weir, he found only rainbow trout. NIWA's freshwater fish database has 22 records for Luggate Creek and tributaries. These show low numbers of koaro and abundant brown and rainbow trout. The brown trout records are only from the lower Luggate Creek and the rainbow trout records are only from the upper Luggate (below the Criffel weir).

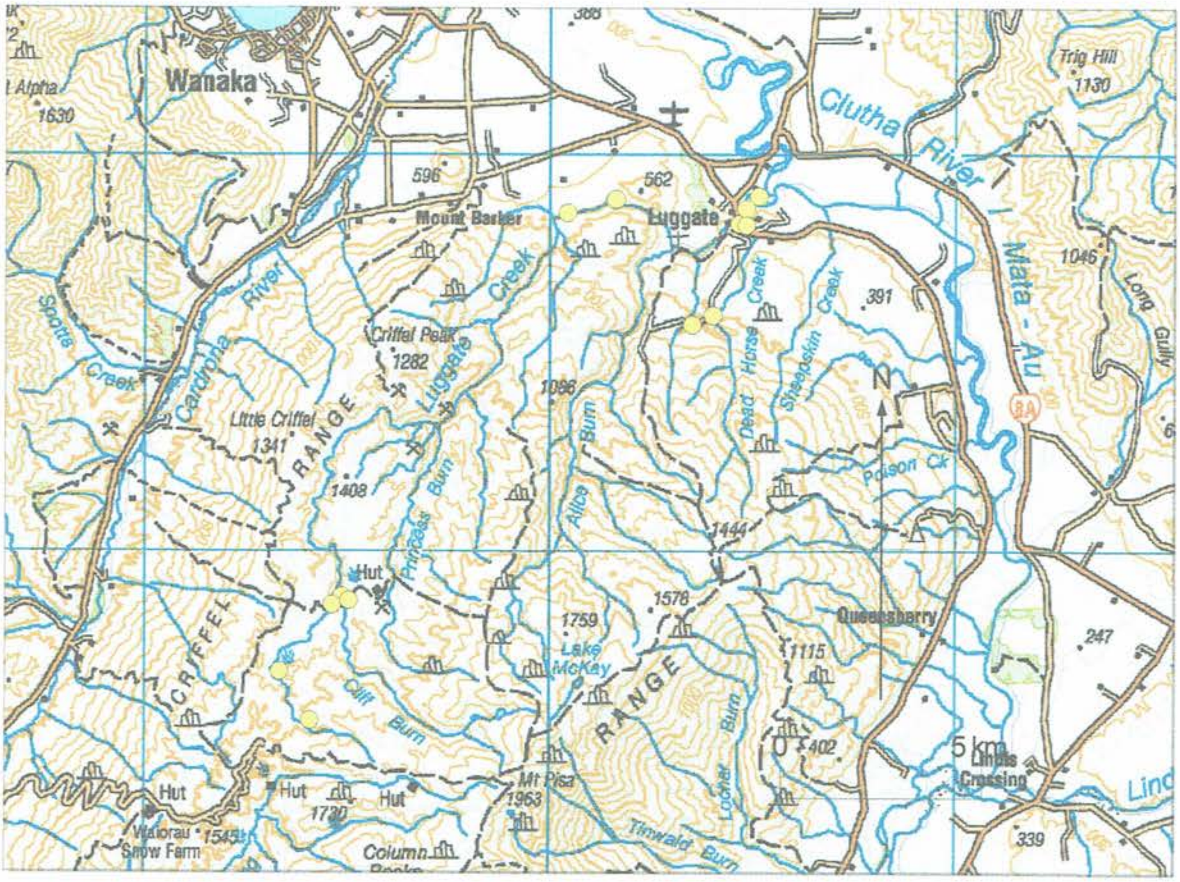

Figure 3: NZFFD fish sampling sites (yellow circles) in the Luggate Creek catchment.

4.1 Habitat suitability curves

The fish habitat suitability curves used for this analysis are from Jowett & Richardson (2008). These habitat suitability curves were based on data from 124 different rivers with 5,000 sampling locations and 21,000 fish. The fish species present or likely to be present in Luggate Creek were koaro, longfin eel[2], brown trout and rainbow trout. Habitat for yearling trout was not evaluated as there are no NZ derived habitat suitability curves. Habitat requirements for yearling trout will be higher than for trout less than 100 mm.

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[2] If elvers transfered from Roxburgh Dam are released in the stream or upper Clutha River.

The koaro in the Luggate Stream are land-locked and the first record is in 1990 before Lake Dunstan was formed. The koaro probably originate from the population in Lake Wanaka. The habitat suitability curves for koaro are based on measurements in the Onekaka Stream (sea migratory population) and the Ryton Stream (land locked population from Lake Coleridge). Habitat use in these two streams was similar (Table 2). The habitat use of both of these populations was similar, although the substrate was smaller in the Ryton. The Ryton is a trout spawning stream and koaro were abundant in riffles.

Table 2: Average depths, velocities and substrate sizes used by koaro in the Onekaka and Ryton streams, Standard deviations shown in brackets.

Stream	Depth (m)	Velocity (m/s)	Substrate size (mm)
Ryton	0.21 (0.09)	0.62 (0.30)	59 (38)
Onekaka	0.20 (0.08)	0.64 (0.29)	103 (10)

The habitat suitability curves used in this study are shown in Appendix II.

5 Instream habitat analysis

5.1 Method

The instream habitat survey of Luggate Creek was carried out by NIWA staff in 2004. Cross-sections were selected in 5 runs, 5 riffles and 5 pools. Each cross-section profile was surveyed, water velocities measured, and visual estimates of substrate composition made. Substrates were classified as bedrock, boulder (264 mm), cobble (264-64 mm), gravel (64-10 mm), fine gravel (10-2 mm), silt (<<0.06 mm), and vegetation (terrestrial or aquatic vegetable matter). At each cross-section, water level was measured and referenced against a temporary staff gauge. This was done so that the water level could be measured at different flows on return visits. Habitat mapping was carried out over the reach to determine the weightings for each of the habitat types.

The habitat analysis for each river proceeded as follows:

1. Flows were computed from depth and velocity measurements for each cross-section.
2. A stage-discharge relationship was developed for each cross-section fitted through the surveyed flow and stage (water level) and two calibration measurements at different stages and flows.
3. Water depths and velocities were computed at each measurement point across each cross-section for a range of simulated flows, and the habitat suitability index (HSI) was evaluated (see Figure A1.2 in Appendix I) at each measurement point from habitat suitability curves for each fish species.

4. The weighted usable area (AWS[3]) for each simulated flow was calculated as the sum of the habitat suitability indices across each cross-section, weighted by the proportion of the habitat type which each cross-section represented in the river.

5. Weighted usable area was plotted against flow and the resulting curves examined to determine the flow that provided maximum habitat and the flow required to maintain 90% of habitat (AWS) available at MALF and to retain 90% of maximum habitat.

The surveys were made at relatively low flows (0.18 m^3/s in the lower reach and 0.05 m^3/s in the upper reach) with calibration measurements at higher flows. Flows of up to 1 m^3/s were modelled to show the overall effect of flow changes on instream habitat.

5.2 Results

The 2004 report (Jowett 2004) used slightly different habitat suitability curves from those used here and presented flows that provided maximum habitat (optimum) and flows at which habitat begins to decline more sharply (see section 8.2.1 for discussion). There are 3 records of koaro being found in Luggate Creek, 2 in the lower reach and 1 in the upper reach. The 2004 report did not suggest flow requirements for koaro in the lower reach (Table 3).

Table 3: Suggested flow requirements from Jowett (2004).

Stream	Fish species and life stage	Optimum flow (m^3/s)	Flow (m^3/s) below which habitat declines sharply
Luggate (lower)	trout spawning and rearing	0.55	0.3
Luggate (upper)	koaro	0.8	0.4

As can be seen in Fig. 4, it is difficult to define where habitat begins to decline sharply as the decline is generally a smooth curve. In some cases, this point can be above naturally occurring low flows. As low flows can limit fish populations, it makes little sense to have a minimum higher than natural low flows. For these reasons, Jowett & Hayes (2004) recommended assessing habitat in terms of the amount of habitat at MALF.

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[3] AWS is area weighted suitability and is a terminology change from WUA

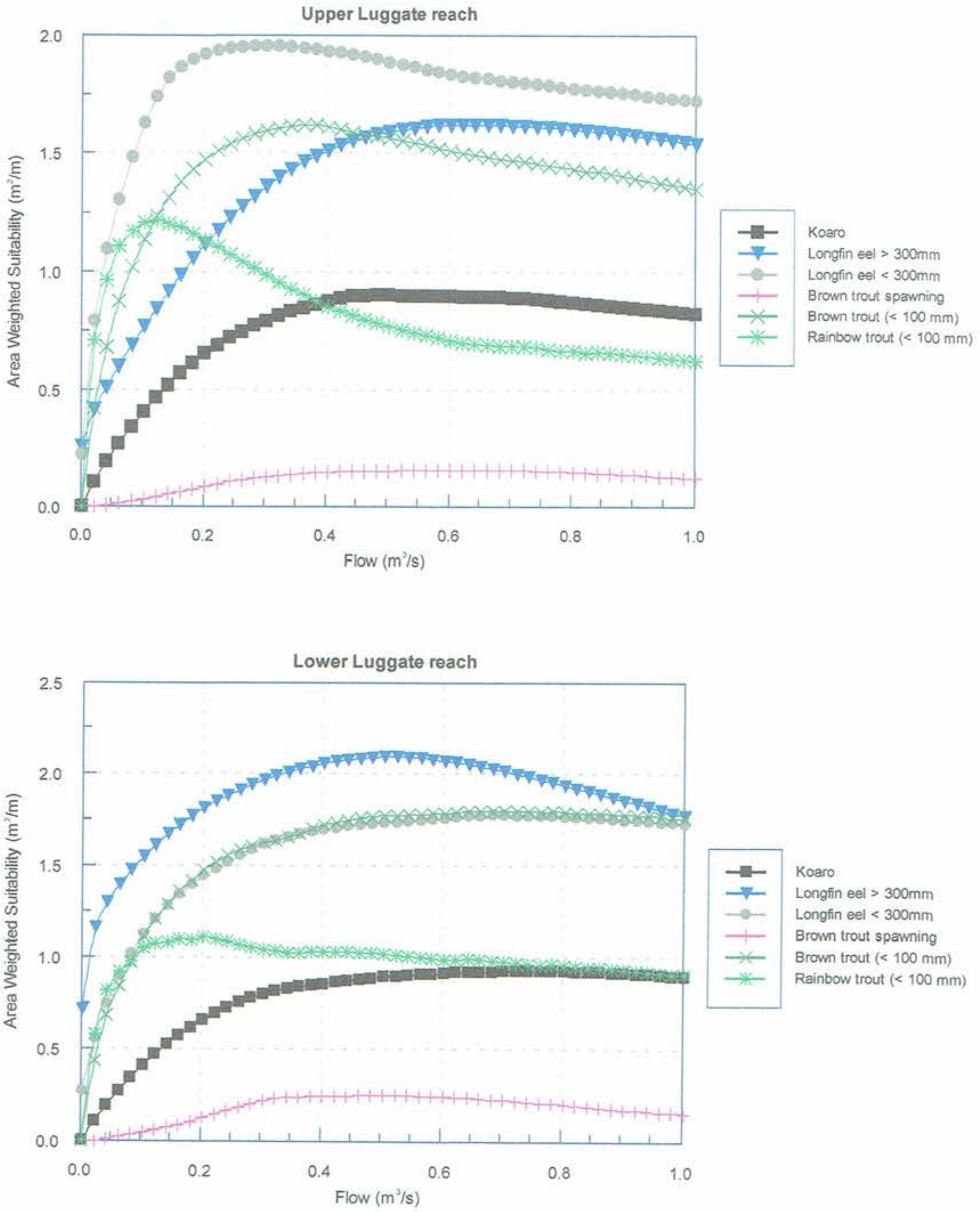

Figure 4: Relationships between weighted usable area (AWS) and flow in upper (above) and lower reaches (below) of Luggate Creek.

Table 4: Flows (L/s) in the lower reach that provide maximum habitat and 60% to 90% of the habitat available at the naturalised MALF of 550 L/s. Suitability curves from Jowett & Richardson (2008) were used unless otherwise noted.

Species/life stage	Maximum habitat	90%	80%	70%	60%
Brown trout (<100mm)	0.65	0.271	0.181	0.128	0.093
Rainbow trout (<100mm)[2]	0.19	0.056	0.039	0.031	0.022
Brown trout spawning[3]	0.50	0.306	0.274	0.246	0.221
Longfin eel (<300mm)	0.70	0.268	0.179	0.123	0.085
Longfin eel (>300mm)	0.51	0.24	0.139	0.076	0.032
Koaro	0.74	0.317	0.239	0.188	0.147

[2] either not present or rare in this section of creek

[3] Shirvell & Dungey (1983)

Table 5: Flows (L/s) in the upper reach that provide maximum habitat and 60% to 90% of the habitat available at the naturalised MALF of 320 L/s. Suitability curves from Jowett & Richardson (2008) were used unless otherwise noted.

Species/life stage	Maximum habitat	90%	80%	70%	60%
Brown trout (<100mm)*	0.37	0.185	0.132	0.097	0.072
Rainbow trout (<100mm)	0.12	0.031	0.024	0.018	0.013
Brown trout spawning[3]*	0.64	0.275	0.239	0.213	0.19
Longfin eel (<300mm)	0.30	0.124	0.091	0.067	0.047
Longfin eel (>300mm)	0.64	0.252	0.2	0.158	0.119
Koaro	0.48	0.249	0.198	0.159	0.128

* Brown trout are probably not present (NZFFD, Allibone 2016)

[3] Shirvell & Dungey (1983)

A minimum flow of 180 L/s in the lower reach would maintain 80% of juvenile brown trout habitat, 80% of juvenile eel habitat, 83% of adult eel habitat and 70% of koaro habitat available at a MALF of 550 L/s (Table 4). The winter (1 May to 31 October) minimum flow of 500 L/s would maintain maximum brown trout spawning habitat. Optimum flows for adult and yearly trout are likely to be 1 m^3/s or more suggesting that the stream is a spawning stream rather than a year-round habitat for yearling and adult trout.

Although ORC Schedule 2A specifies a MALF of 550 L/s, the actual MALF may be higher. With a MALF of 650 L/s there is relatively little change in the amount of habitat retained. A flow of 180 L/s would maintain about 79% of juvenile brown trout habitat, 79% of juvenile eel habitat, 87% of adult eel habitat and 67% of koaro habitat available at a MALF of 650 L/s.

Criffel Water is proposing to maintain a residual flow at the weir and this expected to increase flow to 140 L/s in the reach downstream of the weir. The flow past the weir is increased by leakage, flow from a pipe, and subsurface flows[4]. Criffel water propose a residual flow of 90 L/s past the weir and this should result in a flow of 140 L/s in the upper reach below the weir.

A flow of 140 L/s in the upper reach would maintain 65% of the amount of adult eel habitat at MALF and 65% of koaro habitat (Table 5). Brown trout do not appear to be present in this reach. For the local population of rainbow trout, a flow of 140 L/s would provide near maximum habitat for juveniles. Koaro have previously been recorded in this reach, although sampling by Allibone (2016) did not find any. Any juvenile koaro in this section of Creek would be able to climb past the intake weir.

6 Discussion

The minimum flow is the primary protection mechanism for aquatic ecosystems. The minimum flow can be selected to maintain instream conditions to a required standard (protection level). The protection level can be varied depending upon the value of the instream resource and the potential benefits of water uses.

The selection of appropriate minimum flow is a matter of judgement and objectives, where the habitat requirements and perceived values of the different species must be considered. The water plans of the Southland and Bay of Plenty Regional Councils specify habitat retention levels that depend on the perceived value of the species present and vary between 60% and 95% habitat retention.

Luggate Creek is a trout spawning stream that provides recruits to the Clutha River. As such, maintaining suitable habitat for trout rearing would be one management goal. Trout spawning would also be a goal for flows over the winter spawning period.

Koaro are a rare species in the Clutha catchment found at 4% of the sampling sites. Most of the occurrences are associated with the large lakes.

Longfin eels have not been found in this stream based on Freshwater Fish Database records but the water users are aware of some large individuals being present. Eels could become established if elver transfers from Roxburgh dam are made to this catchment or the upper Clutha River.

A flow of 180 L/s in the lower reach would maintain at least 70% of the habitat available at MALF for all fish species present.

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[4] River flow gaugings carried out by Richard De Joux in March 2015. File note available.

The Luggate Irrigation Company and Lake McKay Station abstract a flow of between 100 and 180 L/s[5] from the Alice Burn (the main tributary of Luggate Creek).

Advice from Criffel Water is that when Luggate Creek is at or about 180 L/s at the SH 6 flow site, more than 90 L/s must be released past the weir to maintain the minimum flow and compensate for abstraction and low flows from the Alice Burn and tributaries below the weir[6]. Consequently, Criffel Water proposes a residual flow at the weir of 90 L/s. Leakage and subsurface flow should increase the flow in the upper reach to 140 L/s.

Consideration should also be given to the potential effects of habitat reduction. If fish numbers are high, available habitat will be occupied and a reduction in habitat could reduce fish numbers by increasing competition and the space available for each fish. However, if fish numbers are low then a reduction in habitat is unlikely to affect fish numbers, because there will be sufficient space available for each fish and if necessary, fish can move to more suitable habitat. The low numbers of koaro in Luggate Creek do not appear to be caused by poor habitat, as observed by Allibone (2016) and this suggests that it is unlikely that an increase in minimum flow would result in an increase in koaro numbers.

7 References

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Jowett, I.G.; Richardson, J. (2008). Habitat use by New Zealand fish and habitat suitability models. NIWA Science and Technology Series No. 55.

Ministry for the Environment (1998). Flow guidelines for instream values (2 volumes). Ministry for the Environment, Wellington.

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[5] Water metering data from ORC.

[6] Pers Comms Mandy Bell, Chair of Criffel Water Limited

Ministry for the Environment (2008). Proposed National Environmental Standard on Ecological Flows and Water Levels. Publication ME 868, Ministry for the Environment, Wellington.

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8 Appendix I: Flow Regime Assessment Methodology and Rationale for Assessment of Minimum Flow Requirements

8.1 Methodology

Long-term solutions to river flow management need to take a holistic view of the river system, including geology, fluvial morphology, sediment transport, riparian conditions, biological habitat and interactions, and water quality, both in a temporal and spatial sense.

The instream flow incremental methodology (IFIM; Bovee 1982) is an example of an interdisciplinary framework that can be used in a holistic way to determine an appropriate flow regime by considering the effects of flow changes on instream values, such as river morphology, physical habitat, water temperature, water quality, and sediment processes (Figure A1.1). Its use requires a high degree of knowledge about seasonal and life-stage requirements of species and the inter-relationships of the various instream values or uses.

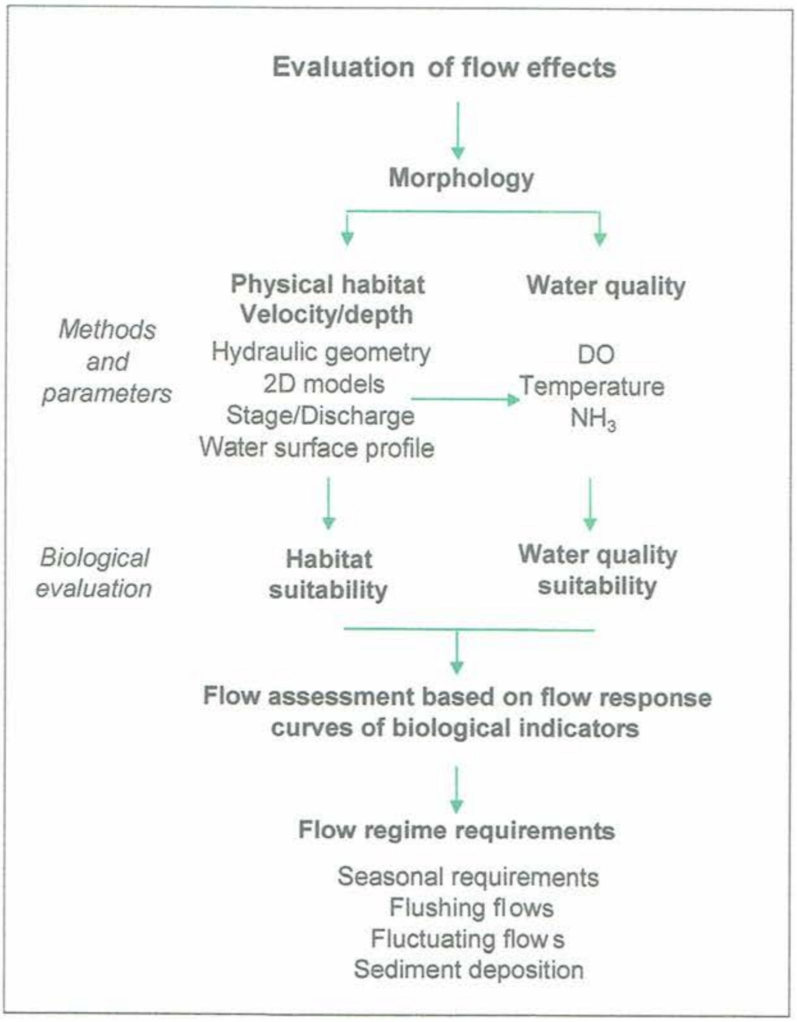


Figure A1.1: A framework for the consideration of flow requirements.

Other flow assessment frameworks are more closely aligned with the "natural flow paradigm" (Poff et al. 1997). The range of variability approach (RVA) and the associated indicators of hydrologic alteration (IHA) allow an appropriate range of variation, usually one standard deviation, in a set of 32 hydrologic parameters derived from the 'natural' flow record (Richter et al. 1997). 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. Arthington et al. (1992) described a holistic method that considers not only the magnitude of low flows, but also the timing, duration and frequency of high flows. This concept was extended to the building block methodology (BBM), which "is essentially a prescriptive approach, designed to construct a flow regime for maintaining a river in a predetermined condition" (King et al. 2000). It is based on the concept that some flows within the complete hydrological regime are more important than others for maintaining the river ecosystem, and that these flows can be identified and described in terms of their magnitude, duration, timing, and frequency.

A holistic consideration of every aspect of flow and sediment regime, river and riparian morphology, and their associations with the life cycles of the aquatic biota requires a degree of knowledge about individual rivers that is rarely available. Fortunately, the large proportion of consents considered by regional councils in New Zealand involves changes to the low flows rather than the high flows, and thus there is no significant effect on the sediment transport regime and river morphology. The aim of the minimum flow is to retain adequate water depths and velocities in the stream or river to maintain important instream values. The flow assessment considers physical habitat at a meso- to macro-habitat level, rather than microhabitat. In this way, suitable average depths and velocities can be maintained in the main habitats, with a degree of habitat diversity that is generated by the morphology of the river, and is largely independent of flow. Although the flow-related ecological processes that are associated with low to median flows are generally taken into consideration in instream flow methods, special issues, such as fish passage or seasonal flow requirements, may need to be investigated in some situations. Consideration should also be given to downstream effects. The effect of an abstraction is usually greatest immediately below the abstraction site, but diminishes as the river flow is supplemented by contributions from tributaries and the proportional change in flow reduces. However, there may be situations where the critical effect is well downstream. This is most likely where the cumulative effect of abstractions from tributaries may result in unacceptably low flows in downstream reaches.

Instream flow methods can be classified into three basic types; historic flow, hydraulic, and habitat-based methods. Historic flow methods are coarse and largely arbitrary. An ecological justification can be argued for the mean annual low flow (MALF) and retention of the natural flow regime, and the concept of a low flow habitat bottleneck for large brown trout has been partly justified by research (e.g., Jowett 1992), but setting flows at lower levels (e.g., the 5-year 7-day low flow — $Q_{7,5}$ etc.) is rather arbitrary. Hydraulic methods do not have a direct link with instream habitat, and interpretation of ecological thresholds based on breakpoints or other characteristics of hydraulic parameters, such as wetted perimeter and mean velocity, are arbitrary and depend on rules of thumb and expert experience. On the other hand, habitat-based methods have a direct link to habitat use by aquatic species. They predict how physical habitat (as defined by various habitat suitability models) 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, offering the possibility of allocating more flow to out-of-stream uses while still maintaining instream habitat at levels acceptable to other stakeholders (i.e., the method provides the necessary information for instream flow analysis and negotiation).

The ecological goal of habitat methods is to provide or retain a suitable physical environment for the aquatic organisms that live in a river. The consequences of loss of physical habitat are well known; the environmental bottom line is that if there is no suitable habitat for a species it will cease to exist. Habitat methods tailor the flow assessment to the resource needs and can potentially result in improved allocation of resources. Although it is essential to consider all aspects such as food, shelter, and living space (Orth 1987; Jowett 1995), appropriate habitat suitability curves are the key to the successful application of habitat-based methods.

The procedure in an instream habitat analysis is to select appropriate habitat suitability curves or criteria (e.g., Figure A1.2), and then to model the effects of a range of flows on the selected habitat variables in relation to these criteria. The habitat suitability index (HSI) at each point is calculated as a joint function of depth, velocity and substrate type using the method shown in Figure A1.2. The area of suitable physical habitat, or weighted usable area (AWS), is calculated by multiplying the area represented by each point by its joint habitat suitability. So, for example in Figure A1.2, at a given point in the river (it is really an area of reasonably uniform depth and velocity) where the depth is 0.1 m, depth suitability is only 65% optimal, according to knowledge of the depth requirements of the fish. Similarly, the velocity recorded at the point is 0.25 m/s, which is optimal (suitability weighting of 1), and the substrate is fine gravel (sub-optimal with a weighting of 0.4) and cobbles (optimal with a weighting of 1). Multiplying these weighting factors together, we get a joint habitat suitability weighting of 0.455 for that point in the river for the selected fish species. If the depth had been 0.2 m and there had been no fine gravel, then that point in the river would have been optimal (i.e., 1 for depth × 1 for velocity × 1 for substrates = 1).

This calculation is repeated within the habitat assessment model for the depth/velocity/substrate types in every grid square across the river, and the area covered by each square is multiplied by the point suitability. These areas, weighted by their respective point suitability values, are then summed to get a measure of total area of suitable physical habitat for the given species at the given flow. This process is then repeated for a series of other flows, with the depths, velocities, and habitat suitability being modelled for the new flows as described above. The total area of suitable physical habitat is then plotted as a function of flow, to show how the area of suitable physical habitat for a given species changes with flow. Variations in the amount of suitable habitat with flow are then used to assess the effect of different flows for target organisms. Flows can then be set so that they achieve a particular management goal.

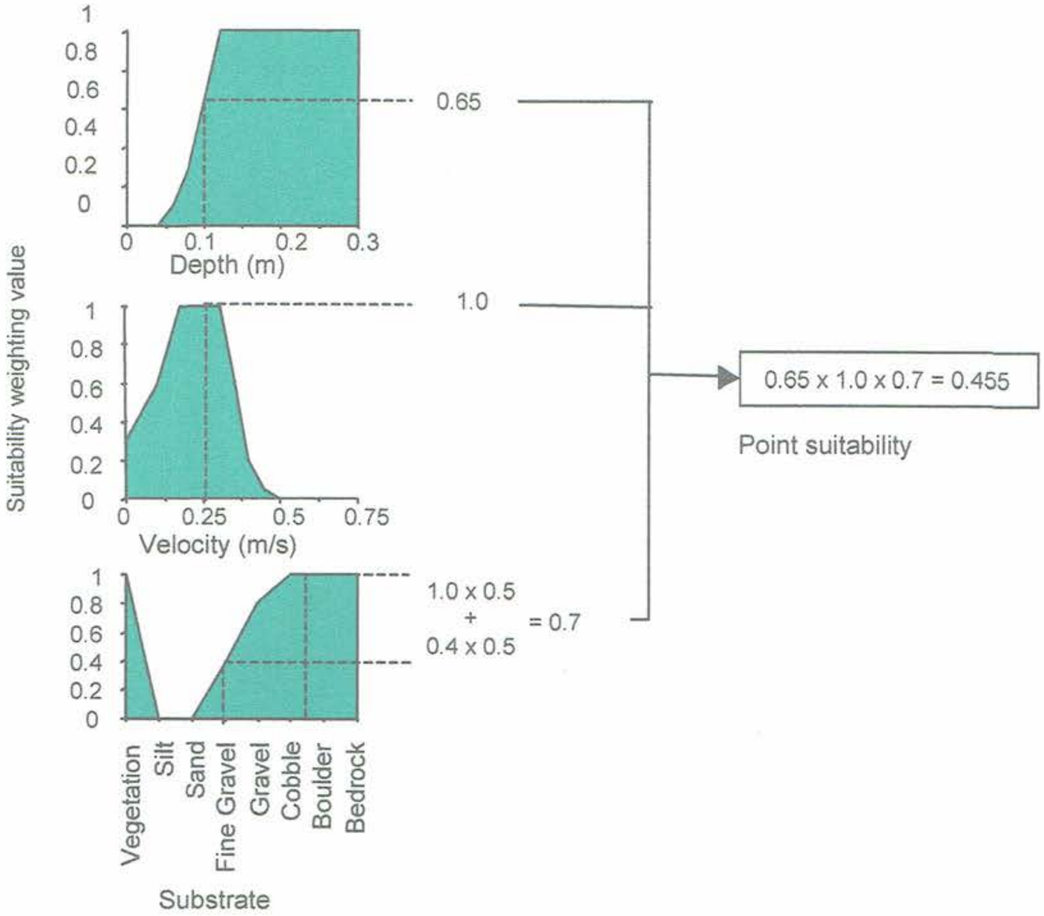
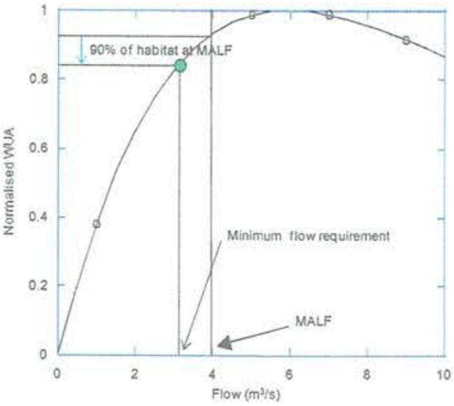


Figure A1.2: **Calculation of habitat suitability for a fish species at a point with a depth of 0.1 m, velocity of 0.25 m/s, and substrate comprising 50% fine gravel and 50% cobble. The individual suitability weighting values for depth (0.65), velocity (1.0), and substrate (0.7) are multiplied together to give a combined point suitability of 0.455.**

The flow-related habitat metrics used to quantify instream habitat are weighted useable area (AWS m^2/m) and the average habitat suitability index (HSI) (Bovee 1982; Stalnaker et al. 1995). HSI is numerically equivalent to AWS divided by the wetted river width.

Various approaches to setting levels of protection have been used, from maintaining a maximum amount of habitat, a percentage of habitat at median flow or mean annual low flow, or using a break point or "inflection point" of the habitat/flow relationship (Jowett 1997). The break point is a point of diminishing return, where proportionately more habitat is lost with decreases in flow than is gained by increases in flow. The habitat retention method is used to apply consistent assessment standards within a region. In the example below the AWS/flow relationship is derived for a target species and the minimum flow is set as the flow that provides 90% of the habitat available at the mean annual low flow.



Habitat methods can also incorporate flow regime requirements, in terms of both seasonal variation and flow fluctuations. Flow fluctuations are an important component of the habitat of most naturally flowing streams. Such fluctuations remove excess accumulations of silt and accumulated organic matter (e.g., from algal slimes) and rejuvenate stream habitats. Extended periods without a flow disturbance usually result in a shift in benthic community composition such as a reduction in diversity, and an increase in biomass of a few species within plant and animal communities.

8.2 Rationale for Assessment of Minimum Flow Requirements

Natural low flows limit the amount of available habitat and it is often assumed that frequently occurring low flows will limit fish populations. Fish can respond to low flows by moving to different habitats or adopting different behavioural patterns. If the low flow persists for long enough, there may be mortality or emigration. The MALF has been used as a measure of frequently occurring low flows for long-lived fish species (e.g., Jowett 1992). However, studies have also shown that flood flows can limit trout populations, with minor floods during incubation or rearing causing high mortality (Hayes 1995; Nehring & Miller 1987) and large floods can be devastating (Jowett & Richardson 1989).

The minimum flow is the primary protection mechanism for aquatic ecosystems. The minimum flow can be selected to maintain instream conditions to a required standard (protection level). The protection level can be varied depending upon the value of the instream resource and the potential benefits of water uses. Thus, minimum flow requirements are specific to each stream and river depending upon instream values, water uses, and stream type. A basic principle established in the Flow Guidelines (Ministry for the Environment 1998) is that instream values and their requirements must be identified and appraised within the context of definite instream management objectives. Case studies have shown that minimum flows selected to prevent a sharp decline in habitat have maintained instream management objectives for native fish, trout and benthic invertebrate communities to the desired standards (Jowett & Biggs 2006; Jowett et al. 2008).

In most small streams, taking water will reduce available habitat for fish and benthic invertebrates, and will reduce fish populations if the periods of low flow are sufficiently long. Reduction in habitat may cause some mortality, either during movement to better habitat or by increasing densities above holding capacity. The fast-water fish species (bluegill bullies, torrentfish and koaro) will be the first species affected, but eels, other bully species and (probably) galaxiids will be more tolerant. This opinion is based on studies of low flows in the Waipara (North Canterbury) and Onekaka (Golden Bay) rivers (Jowett et al. 2005; Jowett et al. 2008).

The detrimental effect of low flows increases with the duration of low flow. In years when flows are relatively high, native fish populations will be maintained at good levels. In years when flows are low for 30-60 days, the fast-water species and diadromous bullies will be affected, but will recover the following years if flows are higher. Short-term (a day or less) small reductions below the minimum flow are unlikely to have any detrimental effects, so that it is possible for maximum abstraction for one day to be set according to the flow the previous day. Such procedures are often used for irrigation.

The effect of abstraction will be greater on small streams than on large streams and rivers, and will be greater on gravel-bed streams than spring-fed streams that are relatively deep with steep banks.

8.2.1 Selection of minimum flow

The selection of an appropriate minimum flow is a matter of judgement and objectives, where the habitat requirements and perceived values of the different species must be considered. Minimum flows are often selected so that they maintain a percentage of habitat available at some index flow (usually the MALF) or where they prevent a serious decline in habitat, the breakpoint or flow below which habitat declines sharply.

The point of greatest change in the rate (the breakpoint) is often selected as the minimum flow. This is based on the premise that higher flows offer diminishing benefits for instream habitat, although there is no scientific evidence that the breakpoint is correlated with biological response. In assessing the amount of habitat to be retained at low flow, it is important to realise that if the low flow were to provide maximum habitat, then higher flows would provide less than maximum habitat. Such a situation may be less than optimum for the species in question, although the risk of detrimental effect of increasing the flow above that which provides maximum habitat is not as great as decreasing the flow, and any habitat loss may be balanced by an increase in food production or the amount of cover. The "best" brown trout rivers, such as the Mataura and Motueka, have flows that provide near maximum habitat between the mean annual low flow and the median flow.

The former method is more suited to incorporation in Regional Council plans because it is not subjective and allows protection levels to be applied consistently throughout a region. However, when a minimum flow is based on a hydrological statistic, such as the MALF, there can be difficulties in estimating the statistic, even if there is a flow record available for the river. For example, the value of the MALF changes as every additional year of flow record is collected and it could be argued that the minimum flow should also change. Ecologically, there would be no value, beneficial or detrimental, in changing the minimum flow unless there were substantial changes to the estimated value of the MALF. Levels of habitat maintenance provided by minimum flows are usually set arbitrarily. This is partly because our state of knowledge on the effects of low flow is insufficient to predict the response of stream ecosystems, and particularly fisheries, and partly because instream habitat simply declines continuously as flow falls below the optimum value, at least in streams and smaller rivers. Therefore, there is no clearly identifiable point at which instream conditions become good or bad, but rather habitat simply gets worse as flow falls below the optimal value – although the rate of habitat change may vary with flow. When habitat modelling results are available, the rate of change of habitat is often used as a basis for setting a minimum flow.

8.2.2 Significant elements of the flow regime

Historically, the focus of instream flow studies has been on determining the low flow conditions required to maintain particular instream values, because at this time there is the greatest competition for the limited amount of water that is available, and the river ecosystem is most under stress. However, several aspects of a river's flow regime may influence its ability to maintain particular instream values. These may be summarised as follows:

Large floods, in the order of the mean annual flood and greater, are responsible for the overall form of an alluvial river channel. They are known as channel maintenance flows and also influence the nature of the river corridor – the floodplain surface, vegetation cover, and need for river control measures, such as willow planting and groynes. Hence, large floods have a significant influence on the natural character of a river (RMA Section 6(a)), on the presence of areas of significant indigenous vegetation and significant habitats of indigenous fauna (RMA Section 6(c)), and on the amenity, intrinsic and heritage values of the river corridor (RMA Section 7(c), (d), (e)). Large floods are also a major cause of disturbance to the river ecosystem, with potentially significant impacts (at least for a time) on life-supporting capacity, as aquatic biota are displaced and their habitats temporarily destroyed. Large floods during October to December can be particularly disruptive of bird species that nest on river beds, such as the wrybill plover, although such birds may re-nest once or twice if not too late in the season (Hughey 1985). Similarly, floods that occur during incubation, emergence or early fry stages of salmonids (August-November) can severely affect a river fishery in subsequent years by reducing recruitment to the population (Hayes 1995).

Smaller floods and freshes, with a frequency of a few times each year, are contained within the channel, and therefore have a more restricted effect than large floods. Nevertheless, they are able to mobilise sediment on at least some areas of the river bed, remove periphyton and other aquatic vegetation, and assist juvenile salmonids and larvae of diadromous native fish in their passage to the sea. They generally "flush" and "refresh" the river bed by removing silt and algal coatings, and inhibit vegetation from colonising the riverbed gravels that are not covered by flowing water. In terms of flow requirements, these flows are known as flushing flows. As with large floods, the effects of freshes can be both positive and negative; i.e. the effect of "flushing" and "refreshing" the river on the one hand, and the effect of disturbing and disrupting parts of the ecosystem on the other. The time between freshes is of particular importance significance for flushing the river. The time required for aquatic biota to re-establish after disturbance by a fresh depends on the life cycle of the species. Macroinvertebrates tend to re-colonise streams within weeks (Sagar 1983), whereas trout may take years to re-establish.

Flow recessions are the period during which the river flow is declining after a flood or fresh, and this can be important for amenity values. For much of the time, flows in small to medium-sized rivers are less than desirable for recreational boating, and may restrict angling. During a flood recession, flows are higher than usual for a few days, and offer enhanced recreational opportunity.

Low flows are particularly important because they are the times at which there is greatest competition for water, the total wetted area is least, and the aquatic ecosystem is likely to be under the greatest stress (apart from the catastrophic stresses that occur with large floods). On the other hand, stable low flows offer periods of high biological productivity, which permit recolonisation of the riverbed by macroinvertebrates and fish after a flood, and the re-establishment of aquatic vegetation. Analysis of instream habitat requirements and general observations suggest that good native fish and benthic invertebrate populations occur small streams with relatively low flows, but that higher flows are required for juvenile salmonids, while adult trout and salmon are most numerous in larger rivers and have the highest flow requirements of all the fish species in New Zealand.

Annual flow regime is the pattern of flows through the year, in response to the annual distribution of rainfall, evapotranspiration, and snowmelt. This regime is an element of the natural character of a river, and in some cases may be sufficiently distinctive, that its maintenance is included as an instream management objective. The seasonal variation of flows may also have an important biological function, such as spring floods that open a river mouth and enable diadromous fish to migrate upstream.

Flow variability is caused by floods and freshes, annual variability or flood recessions. Many people consider that flow variations (recessions) are an essential element of the flow regime that should be maintained, and that long periods of constant flow ("flat lining"), which could result from adherence to a minimum flow, should be avoided. However, consideration of periphyton growth rates and native fish responses (Jowett et al. 2005) to low flows suggest that flows must be low for 4-6 weeks before instream values are affected significantly.

8.2.3 Relative importance of minimum flow and flow variability

Before the effects of flow abstraction can be examined, it is necessary to appreciate the inter-relationships between flow variability and the magnitude and duration of low flows. Although flow variability is often thought to be an essential element of the flow regime that should be maintained, there is little published biological evidence that flow variability is essential. Similar biological communities are often found in streams and rivers with very different patterns of flow variability, and valued biological communities can be maintained in rivers where the flow regime has been extensively modified by hydroelectric operations, such as in the Monowai, Waiau, and Tekapo rivers (Jowett & Biggs 2006).

The term "flow variability" also confuses the discussion, because high flow variability is often bad for the aquatic ecosystem and low flow variability good, depending on how flow variability is measured. Jowett & Duncan (1990) used hydrological indices, particularly the coefficient of variation, to define flow variability. They found that rivers with high flow variability had long periods of low flow and occasional floods, rivers with low flow variability were lake- or spring-fed, and rivers with moderate flow variability had frequent floods and freshes that maintained relatively high flows throughout the year. Rivers with high flow variability (i.e., long period of low flow interspersed with occasional floods) contained poorer "quality" aquatic communities than rivers with low to moderate flow variability. This suggests that the magnitude and duration of low flows is more important than flow variability *per se*. However, flow variability can also be associated with the frequency of floods and freshes. Clausen & Biggs (1997) used the frequency of flows greater than three times the median (*Fre3*) as an index of flow variability and showed, not surprisingly, that periphyton accumulation was less in rivers with more frequent floods (high *Fre3*) and that invertebrate densities in rivers with moderate values of *Fre3* (10-15 floods a year) were higher than those in rivers with high and low *Fre3* values. However, as with the Jowett & Duncan (1990) study, the rivers with low *Fre3* were also rivers in which there were long periods of low flow without floods.

The effects of flow abstraction on the frequency of floods and freshes and on the duration and magnitude of low flows depend on the specific proposals for use of the river, such as damming, large-scale run-of-river abstraction, or minor abstractions. Potentially, damming can have the greatest effect both on the frequency of floods and freshes and on the duration and magnitude of low flows. In fact, damming is the only way the flow regime can be modified sufficiently to affect the channel-forming floods that maintain the character and morphology of the river. Large-scale diversions can increase the duration and decrease the magnitude of low flows significantly and can also reduce the frequency of freshes, but usually have little effect on the channel-forming floods. On the other hand, minor abstractions usually have little effect on the frequency of floods and freshes, even cumulatively, but certainly can reduce flows significantly during periods of low flow.

Large-scale projects like damming and major diversions usually require detailed and specific studies to determine downstream flow requirements, such as minimum flows and their seasonal variation, and flushing and channel-forming flows. Because minor diversions have little effect on floods and freshes, the main environmental concern is the minimum flow.

Flow variability and movement of bed sediments can have profound effects on stream ecosystems. Stable, spring-fed streams are subject to few floods, and the fish and plants that live in such streams are often unable to develop or even to survive in less stable environments. On the other hand, gravel-bed rivers and their aquatic biota are in a constant state of change caused by extreme flows (floods and droughts) and mobile bed sediments.

Floods are the most important element of flow variability, and flood frequency has been used in several biological models as the primary factor for classifying periphyton communities (Biggs et al. 1998). In streams with frequent floods, fish and invertebrates that are small and can colonise new areas rapidly are often dominant (Scarsbrook & Townsend 1993), and the periphyton community is usually sparse, with low species richness and diversity (Clausen & Biggs 1997; Biggs & Smith 2002). In streams with stable flow regimes, aquatic communities are thought to be influenced more by biological processes, such as competition between species and grazing/predation, than by external environmental factors (Poff & Ward 1989; Biggs et al. 1999).

The biological effects of flow variability usually refer to the effects of floods or the effects of long periods of low flows. However, I am not aware of any studies that demonstrate that small-scale flow variation is biologically important. In fact, frequent flow variations are usually considered detrimental. Daily and weekly flow fluctuations are often a feature of rivers downstream of hydropower stations. These fluctuations in flow create a varial zone that is wetted and dried as water levels rise and fall. With frequent flow fluctuations, this zone will not sustain immobile plant and invertebrate species. Mobile species such as fish, and probably some invertebrate species, can make some use of this zone, especially for feeding in recently inundated areas, where there may have been some terrestrial invertebrates in the substrate. However, a varial zone that is wetted and dried at more frequent intervals than a week is unproductive and can be regarded as lost habitat.

8.2.4 Effect of minor diversions on flow duration

When a minimum flow condition is applied in a river below abstraction points, the abstraction of flow reduces the river flow to the minimum flow as long as the capacity to abstract flow (i.e., the allocation limit) exceeds the water available above the minimum flow, and this prolongs the time that the flow is at the minimum. If the minimum flow restricts habitat for any species, there is potentially a detrimental effect on that population. NIWA research in the Waipara River (Jowett et al. 2005), where habitat is limited at low flow, showed that the detrimental effect on fish numbers increased with the magnitude and duration of low flow. An instream habitat survey (Jowett 1994) showed that fish habitat began to decline sharply when flows fell below 120 L/s, slightly greater than the MALF of 112 L/s. In the first summer (1998/1999, mean flow 1190 L/s), daily mean flows were less than 120 L/s for 31% of the time and fell to 32 L/s. That year, there was a substantial decline in abundance of three of the four common native fish species in the river. The following summer (1999/2000, mean flow 1243 L/s) there was little change in native fish abundance when daily mean flows were less than 120 L/s for 10% of the time and fell to 69 L/s. In the third year, flows were less than 120 L/s for 61% of the time and fell to 47 L/s, and two of the four common fish species declined in abundance. The effect was more severe on fast-water species (torrentfish and bluegill bullies) than on species that prefer lower velocity water (upland bullies and Canterbury galaxias).

Minor flow variations appear to ameliorate the detrimental effects of low flow by limiting the time that the flow is at the minimum, and conversely abstraction of water prolongs the time that flows are less than naturally occurring minimums. For example, the Mokau River at Totoro has a median flow of 23.3 m^3/s and a MALF of 3.4 m^3/s. If 10% of the median flow were abstracted from the river, the amount of time that the river was at or below the MALF would increase from 0.6% to 5%. Any further increase in the amount of water abstracted would further increase the amount of time that the river is at low flow.

The rise and fall in level, and consequent increase and decrease in water velocities associated with minor flow variations, could have a small beneficial cleansing effect along the stream margins. Along the margins, a small part of the stream bed will be alternatively wetted and dried and the fine sediment in this zone could be removed by wind when dry. Where the margins remain wetted, the small variations in velocity that occur could redistribute fine sediment from the margins of riffles to pools. However, these effects are hypothetical and very much smaller than those that occur during freshes.

Increasing the amount of water abstracted can also influence the reliability of the supply. If we assume a hypothetical minimum flow of 2.76 m^3/s (80% of the MALF) in the previous Mokau River example, and assume that total abstractions are 5% of the median flow (i.e., 1.165 m^3/s), the total allocated flow of 1.165 m^3/s can be abstracted whenever the river flow is above 3.925 m^3/s (2.76 + 1.165). According to the flow duration curve, 3.925 m^3/s is exceeded 99% of the time, so that abstraction will only be restricted for 1% of the time. However, if the total abstraction increased to 2.33 m^3/s (10% of the median flow), abstraction would be restricted whenever the flow falls below 5.09 m^3/s (2.76 + 2.33). The flow duration curve shows that under this scenario there would be restrictions for 5% of the time.

The environmental effect of low flow obviously varies with the duration of that flow. A near zero flow for a short time may have no adverse effects, whereas if it were in place for weeks or months, there would probably be serious effects. Such an argument suggests that the minimum flow should be varied with the percentage of time that flows are at or below the minimum. For example, where there is a major diversion or dam, flows can be controlled to such an extent that the minimum flow is effectively the median flow. In this situation, the minimum flow requirement is higher than in semi-natural situations where the minimum flow only persists for a short time.

8.2.5 Flow-related habitat limitation

If instream conditions at the minimum flow are adequate (i.e., provide optimal habitat quality or habitat levels that occur with annual natural low flows), then biota should not be detrimentally affected, provided that the frequency of higher flows remains unchanged. However, if instream conditions at the minimum flow provide less than optimal habitat quality (where quality is measured by the average habitat suitability index), an increase in the duration of low flows increases the risk of detrimental effects.

When setting minimum flows for instream values, the assumption is made that low flow is a limiting factor. Research in New Zealand indicates that the MALF and median flows are ecologically relevant flow statistics governing trout carrying capacity and stream productivity. I found that the amount of adult instream habitat at the MALF was correlated with brown trout abundance in New Zealand rivers (Jowett 1990, 1992). The habitat metric that was used to quantify instream habitat was percent weighted useable area (AWS), the flow-related habitat index used in the Instream Flow Incremental Methodology (IFIM) (Bovee 1982; Stalnaker et al. 1995). AWS is calculated from channel cross-section surveys of depths, velocities, and substrate composition matched with trout "suitability of use" curves derived for those physical variables. The adult brown trout habitat suitability curves used in my analysis were developed by Hayes & Jowett (1994). The inference arising from my research was that the percentage of adult trout habitat (AWS%) at the MALF acts as a bottleneck to trout numbers. I also found that the percentage of invertebrate food producing habitat at the median flow was strongly associated with trout abundance (Jowett 1990, 1992). These two habitat metrics are surrogate measures of space and food, which are considered to be the primary factors regulating stream salmonid populations (Chapman 1966).

My research provides empirical and conceptual support for the validity of AWS as a habitat index for brown trout populations in New Zealand rivers and provided a justification for the minimum flow standards specified in the TRC Fresh Water Plan.

The reason why the MALF and median flow are likely limiting factors is related to the generation cycles of trout and benthic invertebrates. Brown trout are usually mature at between two and five years of age, with age three for first spawning being most common in rivers. On average, a trout makes the greatest reproductive contribution to the population over the first two or three years of spawning. Because of their large size and feeding habits, adult trout have amongst the highest flow requirements for living space of all New Zealand's freshwater fish species. The lowest flow that a river falls to each year sets the lower limit of physical space available for adult trout. This annual limit to living space potentially sets a limit to the average numbers of trout. This concept is intuitively sensible to anyone who has spent a lot of time looking for trout in rivers. Rivers that fall to very low flows each year hold few trout, while those that sustain higher flows hold more trout.

In contrast to long-lived species such as trout, most benthic invertebrates have generation cycles less than or equal to one year, although some have 2-3 year life histories. Invertebrate recolonisation is rapid, in the order of weeks in most cases. In other words, benthic invertebrate populations can respond relatively quickly to medium-term improvements in habitat conditions. The invertebrate AWS at median flow provides an approximation of invertebrate habitat conditions prevailing most of the time. This is an important consideration for maintenance of stream ecosystem and fisheries productivity. A flat line minimum flow will reduce invertebrate production that would otherwise accrue during times when the natural flow exceeds the minimum flow for weeks at a time. This could be considered as a reduction in life supporting capacity, as the resultant potential reduction in food resources could affect fish production.

River size, channel morphology, and hydrology affect the relationship between habitat and flow. In very large rivers with confined channels, optimal conditions for adult trout and other species with high flow requirements may occur at flows at, or even below, the MALF as a consequence of the relatively high mean water velocities that occur in large rivers at normal flows. In smaller, shallower rivers, it is much more likely that habitat for many species will decline linearly from the MALF through to zero at zero flow. This means that a minimum flow condition, say equivalent to the 1 in 5 year (or even 1 in 10 year) low flow, on a large, confined river channel may provide the same relative level of habitat protection as a more conservative minimum flow (such as the MALF) would on a small, shallow river.

8.2.6 Target species

The concept of target species is that by providing sufficient flow to sustain the most flow sensitive, important values (species, life stage, or recreational activity), other significant values will also be sustained. "Sustain" means different things to different people, and it is unrealistic to expect that all values will be maintained at original levels when flows change. Identification of target species and appropriate habitat retention standards are an essential basis for the assessment of instream flow requirements. When considering ecological protection, target species are usually fish species selected according to their perceived value and flow requirements. The target species will depend on the stream, its size, location, and morphological type.

Target species and their associated habitat suitability criteria can be perceived in two ways. In most cases, they are applied to provide habitat for the target species/life stage, with the added aim of providing for species with lower flow requirements. They can also be used in the generic sense of providing general instream conditions that, based on experience, are considered appropriate for the ecological function and potential range of instream communities. In this latter situation, the habitat criteria act as general descriptors of instream conditions and stream size; the "target species" is secondary and may in fact not actually be present. Examples include:

- trout spawning criteria, which also provide good depths and velocities for invertebrate habitat (which sustains the fish food base) in small streams;
- juvenile eel, redfin and common bully habitat criteria, which also provide good general instream conditions for streams slightly larger than those dominated by diadromous galaxiids.

8.2.7 Target species as substitutes for other significant values

In New Zealand, it has generally been assumed that minimum flows set for salmonids will be adequate to maintain native fish populations. The rationale for this is that trout, because of their larger size and drift-feeding requirements, have higher depth and velocity requirements than most native fishes. Thus, for trout spawning streams or trout fisheries, the minimum flow that supports trout will also provide habitat for native fish, mostly along the margins of riffles.

The fast-water fish species (torrentfish and bluegill bullies) have similar flow requirements to adult trout (i.e., maximum habitat for these species typically occurs at high flows). Similarly, the optimum flows for many benthic invertebrate taxa occur at higher flows than are required for trout. Minimum flows are rarely set for these fast-water species alone because they are not regarded as having sufficiently high value.

Native fish and benthic invertebrate species are widespread and relatively common in most rivers. The relevant flow management aim for these species is maintenance of biotic natural character, using the native fish species as an indicator of biotic value. Many of the native fishes have life history features that impart resilience to flow disturbance. A large percentage of the native fish fauna in a given river reach is likely to be diadromous, especially close to the sea. These populations are believed to be recruited from a common gene pool – at least at the regional level. Therefore, environmental change in a given river may not necessarily affect recruitment of the population. Many of the common non-diadromous native fish species have a high intrinsic rate of increase, a feature that is well suited to variable flow conditions.

Nevertheless, there are situations in which the conservation status of certain native fish species warrants special attention. These include some of the non-migratory galaxiids (dwarf galaxias) and large diadromous galaxiids (giant, shortjaw, and banded kokopu). Usually these species do not co-occur with trout. These galaxiids all have lower flow requirements than trout, and in addition to flow, they may require other features, including riparian and instream cover, and preferably native forest in the catchment or on the stream margins.

The flow requirements of recreational swimming are modest. A flowing river, with clean water and substrate, and swimming holes, is all that is required.

Provision for flow variability in those rivers which have naturally varying flows should sustain boating values. High flows, such as occur during flood recessions, are often required on smaller rivers for jet boating and kayaking. Provision for flow variability is an integral part of the recommended flow management rationale for maintenance of productive habitat. Maintenance of high levels of adult trout habitat, with flow variability, ought to provide sufficient depths over riffles to sustain boating values in larger rivers.

Tipa & Teirney (2003) identified Maori values for streams in the Otago region. They showed that some of the values identified by Maori were highly correlated with biological measures of stream health, such as the macro-invertebrate community index (MCI) and a similar index described by Biggs et al. (1998). This relationship with biological indices of stream health suggests that flow recommendations that maintain healthy invertebrate communities would maintain Maori values, at least partly. However, Tipa & Teirney (2003) and the Ministry for the Environment's *Flow Guidelines* (1998) suggest iwi participation in the determination of a suitable flow regime.

8.2.8 Habitat retention levels

Habitat retention levels aim to achieve consistent standards of protection for minimum flows and are usually set arbitrarily. This is partly because our state of knowledge of the effects of low flow is insufficient to predict the response of stream ecosystems, particularly fisheries, and partly because instream habitat simply declines continuously as the flow falls below the optimum value, at least in streams and smaller rivers. Therefore, there is no clearly identifiable point at which instream conditions become good or bad, but rather habitat simply gets worse as flow falls below the optimal value – although the rate of habitat change may vary with flow.

The rate of change of habitat can be used as a basis for setting a minimum flow, i.e., the point of greatest change in the rate (the breakpoint) is often selected as the minimum flow. This is based on the premise that higher flows offer diminishing benefits for instream habitat, although there is no scientific evidence that the breakpoint is correlated with biological response. However, although this method is useful for individual streams, it is subjective and difficult to apply consistently over a region.

Habitat retention is a more suitable method to use over a region. In small streams and rivers, the flow that provides maximum habitat for many taxa will be higher than naturally occurring low flows (e.g., the MALF) and a protection level as a percentage of the MALF allows for a balance between retaining some habitat and some out-of-stream use of water during low flows. The disadvantage of this method is that it is based on a hydrological statistic, and hydrological statistics change as more information on flow is collected. To a degree, the method is very similar to the commonly used method of setting the minimum flow as a percentage of the minimum flow. For example, if the flow is set to retain 70% of habitat at the MALF, this will be close to 70% of the MALF for the species with the highest flow requirements. The advantages of the method are that it results in consistent estimates within a region and provides more information about the potential effects on the species present in the stream.

9 References

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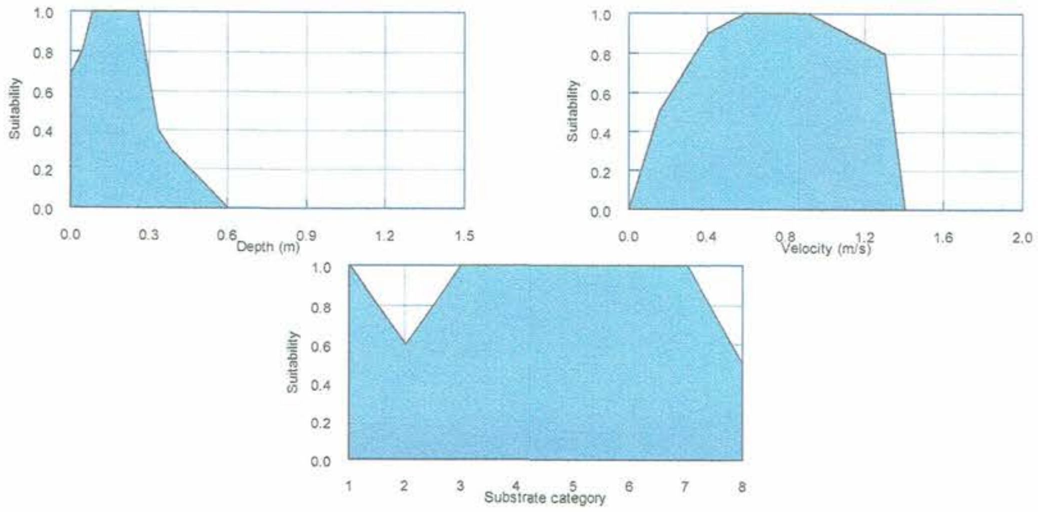
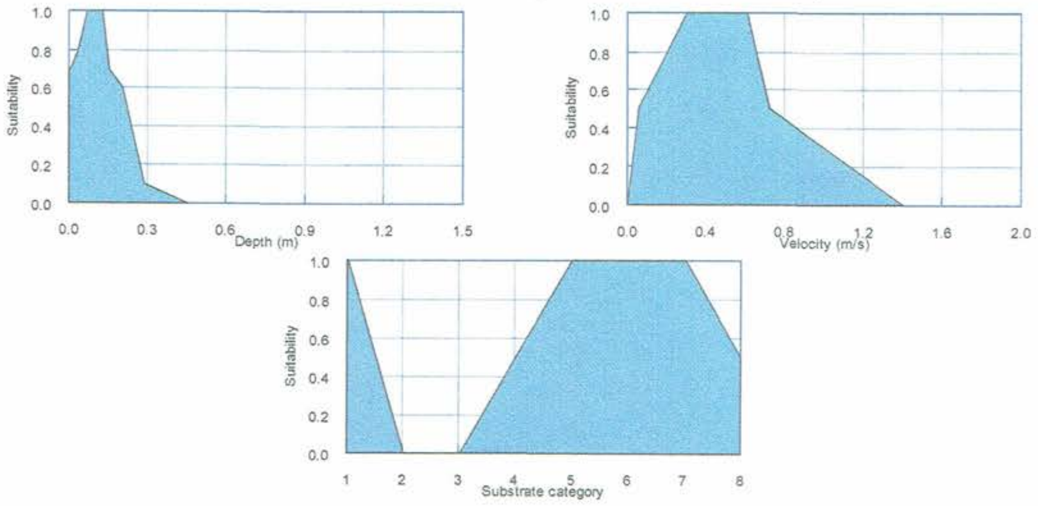
10 Appendix II - suitability curves used in this study

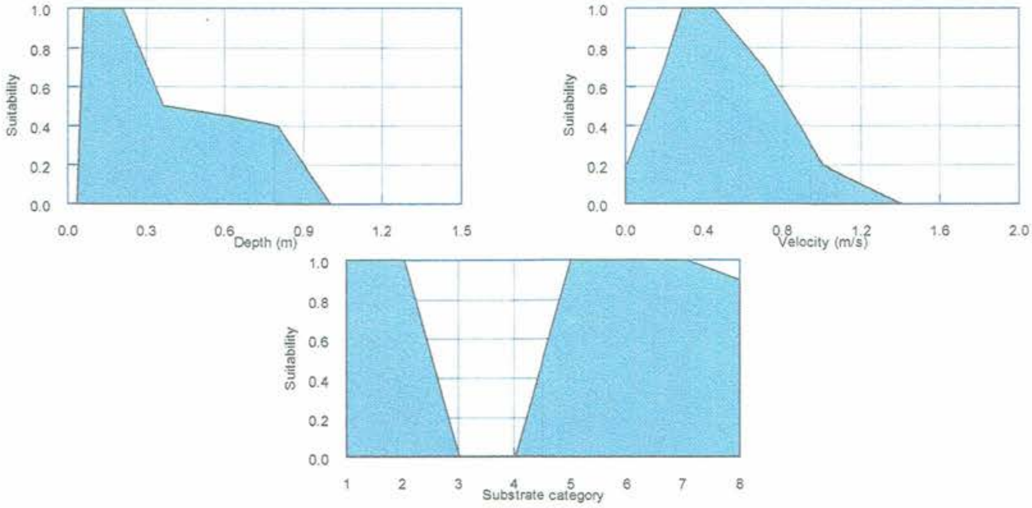


Brown trout (< 100 mm) (Jowett & Richardson 2008)

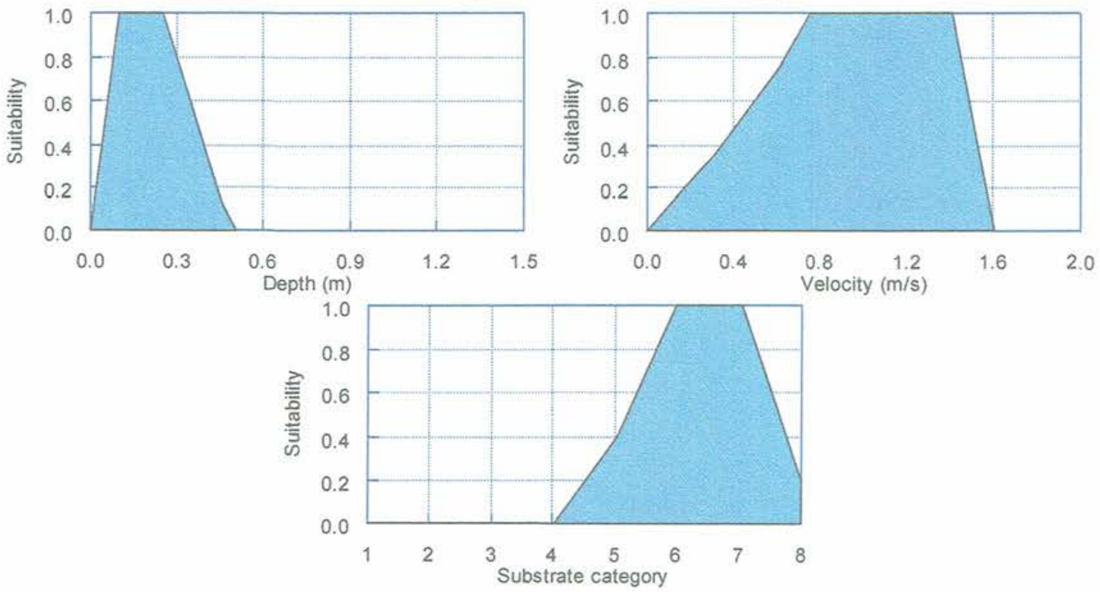


Rainbow trout (< 100 mm) (Jowett & Richardson 2008)

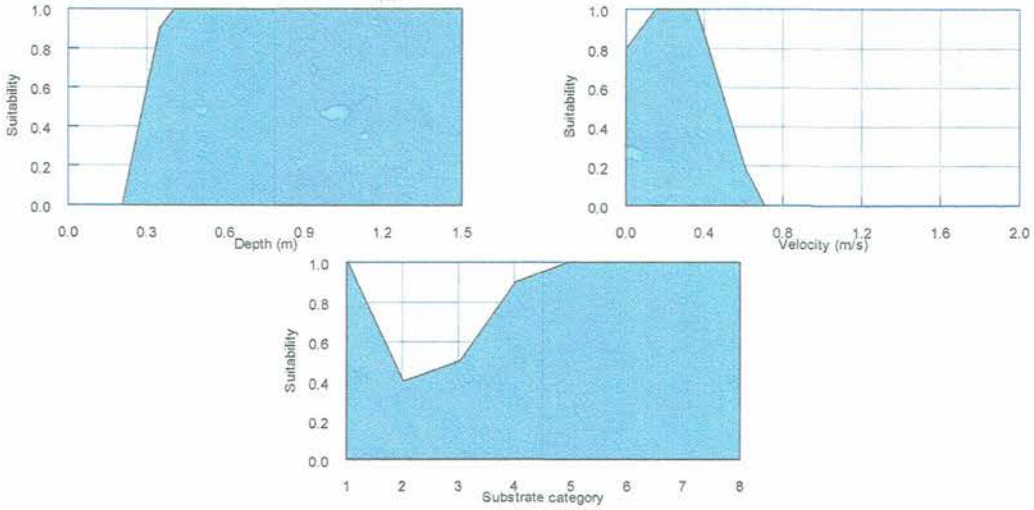
Longfin eel < 300mm (Jowett & Richardson 2008)



Koaro (Jowett & Richardson 2008)



Longfin eel > 300mm (Jowett & Richardson 2008)



Brown trout spawning (Shirvell and Dungey 1983)