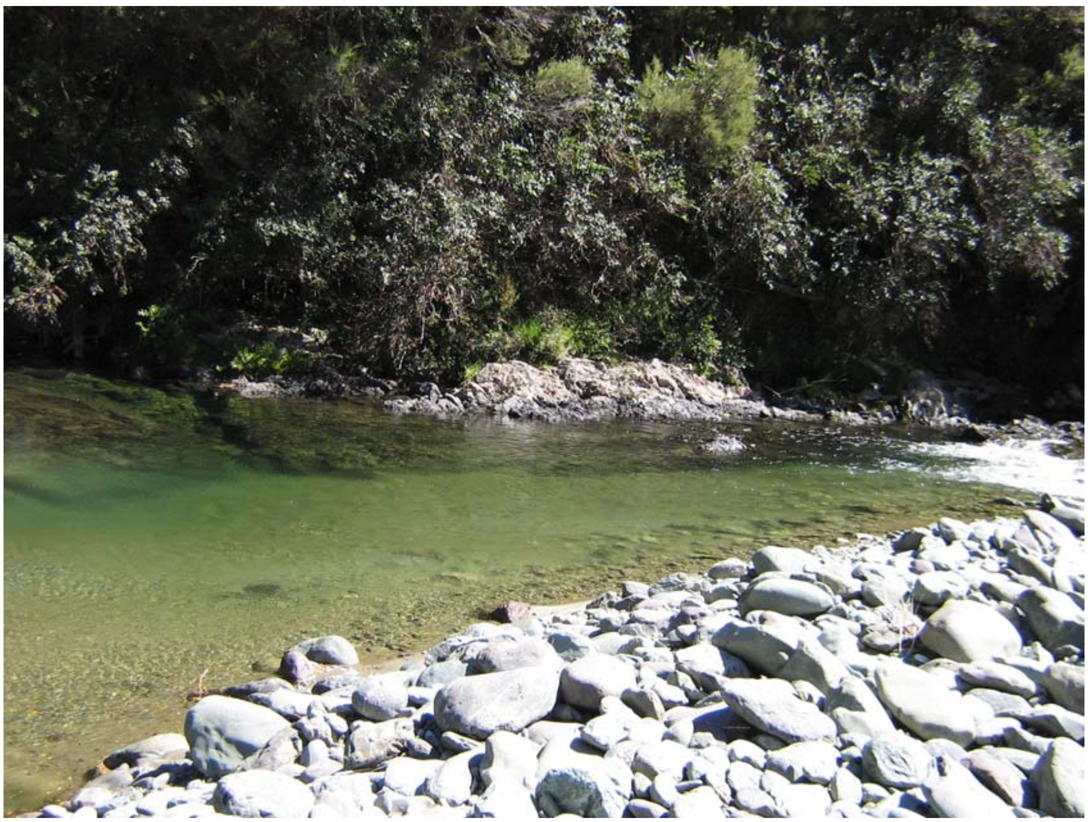
CAWTHRON

Report No. 1061

Instream Habitat Flow Analysis for the Waimea River and provisional minimum flows for proposed dam sites in the upper Wairoa and Lee catchments



Prepared for

Waimea Water Augmentation Committee

November 2005

Instream Habitat Flow Analysis for the Waimea River and provisional minimum flows for proposed dam sites in the upper Wairoa and Lee catchments

Prepared for

Waimea Water Augmentation Committee

by

Joe Hay and Roger Young

Cawthron Institute
98 Halifax Street East
Private Bag 2
NELSON
NEW ZEALAND

Phone: +64.3.548.2319
Fax: +64.3.546.9464
Email: info@cawthron.org.nz

Cover Photo: Lee River: Roger Young, October 2005

EXECUTIVE SUMMARY

This report assessed the minimum flows required to provide instream habitat in the Waimea River and at two potential alternative dam sites as part of a feasibility study into the potential to augment flow in the Waimea from a water storage reservoir in its catchment. In each case we provide three alternative minimum flows to span a range from an environmental benchmark minimum flow that would be conservative in terms of environmental protection, to a minimum flow that would be weighted towards out-of-stream values.

The proposed water augmentation can be seen as an opportunity to redress the balance between instream and out-of-stream water uses. Current water allocation in the catchment is heavily biased toward out-of-stream users, and the instream values have suffered as a result.

Instream flow requirements for the Waimea River in the section upstream of the Appleby Bridge were assessed using physical habitat modelling within the Instream Flow Incremental Methodology (IFIM). These analyses update earlier habitat modelling undertaken in this reach by Hayes (1998).

The proposed minimum flows provided for this reach were based on maintenance of adult brown trout habitat. Brown trout attract relatively high angler use of the Waimea River and have the potential to support a valued fishery, given sufficient maintenance flows. Brown trout are also among the most flow demanding freshwater fish in New Zealand rivers, and so providing adequate flow for them should also provide for the flow needs of other species, including most native fishes.

The estimated natural MALF of 1.3 m^3s^{-1} is proposed as the environmental benchmark minimum flow for the Waimea River immediately upstream of the Appleby Bridge. A minimum flow of 0.5 m^3s^{-1} would retain 70 % of the adult brown trout habitat available at the natural MALF, while a minimum flow of 0.8 m^3s^{-1} would retain 80 % of the habitat available at the natural MALF for adult brown trout. Any of these proposed minimum flows would be an improvement over the present situation.

Historical flow statistics were used to provide a range of potential minimum flows at the potential dam sites that can be used to assess the feasibility of these sites. Once a site is chosen a more detailed analysis (*e.g.* IFIM habitat modelling) could be undertaken to give a more robust indication of the instream habitat requirements at the chosen site, and support a more scientifically defensible minimum flow decision for that site.

Maintenance of the existing MALF is suggested as the environmental benchmark minimum flow situation immediately below the potential dam sites, while the 1 in 10 year low flow and the 1 in 5 year low flow would be less conservative options.

When considering minimum flow regimes for the Waimea and the potential location of dams, the need to maintain flow variability, in particular flows capable of flushing out nuisance algal growths, must also be considered.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

Report reviewed by:	Approved for release by:
Dr John Hayes, Senior Fisheries Scientist	Rowan Strickland, Freshwater Group Manager

1. INTRODUCTION

This report outlines the results of habitat modelling, undertaken as part of an Instream Flow Incremental Methodology (IFIM) analysis of the Waimea River, Tasman District, New Zealand, and provides some recommendations on potential flow management for this river. It also provides provisional flow recommendations based on historical flow statistics for two sites which have been identified as potential locations for a water storage dam in the Waimea Catchment.

Water in the Waimea catchment has come under increasing demand for out-of-stream uses, particularly irrigation, to the extent that in the lower catchment water currently is over allocated. Augmentation of flow in the river during periods of low flow, from a water storage reservoir, is currently being considered. It is hoped that this development would make it feasible to alleviate some of the pressure on instream values, including fisheries values, and allow recharge of groundwater resources, while still meeting the needs of out of stream water users.

The sites currently being considered as locations for the reservoir are in the Lee River and in the Upper Wairoa River (Figure 1).

Part of the feasibility study for this proposal is to assess the minimum flows required to provide acceptable levels of instream habitat in the Waimea River itself and at the proposed dam sites. In each case we provide alternative minimum flows to span a range from an environmental benchmark minimum flow that is conservative in terms of environmental protection, to a minimum flow that is weighted towards out-of-stream values.

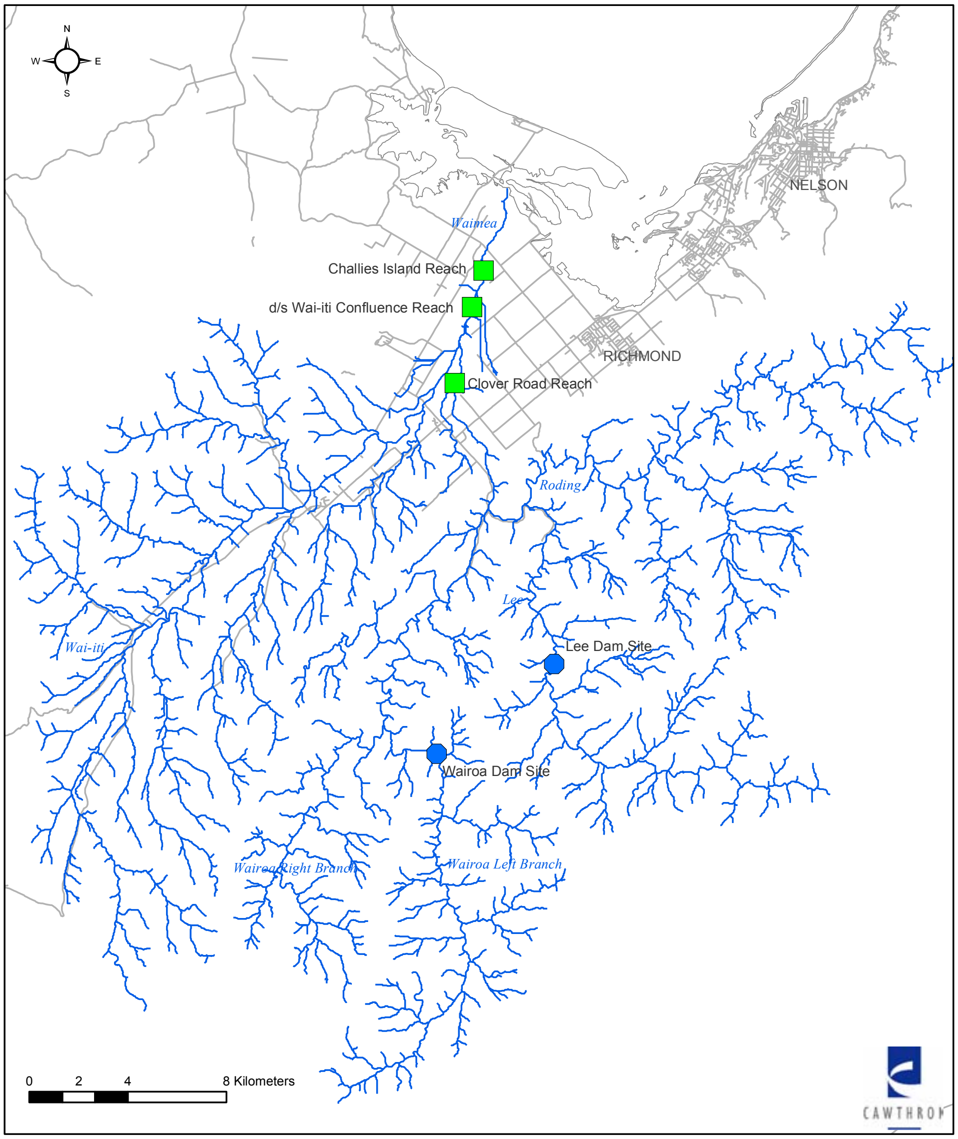


Figure 1 The Waimea Catchment showing proposed dam locations and the reaches surveyed for IFIM habitat analysis

2. METHODS

2.1 Habitat modelling in the Waimea River

Instream flow requirements for the Waimea River in the section upstream of the Appleby Bridge were assessed using physical habitat modelling within the Instream Flow Incremental Methodology (IFIM). These analyses update earlier habitat modelling undertaken in this reach (Hayes 1998), which modelled the effect of flow on habitat availability in riffles and runs only, due to cost constraints. The rationale for considering riffles and runs only, was that these habitat types are more directly impacted by the level of flow than pool habitat, since pools vary less with flow and will generally still contain wetted habitat even under conditions of zero flow. However, in the current analyses pool habitat was included to provide a more complete understanding of how instream habitat availability might be expected to change with flow. Pools are the dominant microhabitat type in the lower Wairoa and the Waimea River.

2.1.1 *Habitat modelling within the IFIM*

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). Within this process, computer modelling of instream habitat availability for selected species, over a range of flows, provides a basis for decision making regarding allocation of water resources.

Habitat modelling within the IFIM entails measuring water depths and velocities, as well as substrate composition, across a number of stream cross-sections at a given flow (referred to as the survey flow). Points on the banks, above water level, along the cross-sections are also surveyed to allow model predictions to be made at flows higher than the survey flow. The stage (water level) at zero flow is also estimated at each cross-section to facilitate fitting of rating curves and for making model predictions at low flows. Other data for fitting rating curves are obtained from additional measurements of water level at each cross-section, relative to flow, on subsequent visits. These data allow calibration of a hydraulic model for predicting how depths, velocities and the area of different substrate types covered by the stream will vary with discharge for the surveyed reach.

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

The habitat modelling described in this report was undertaken using RHYHABSIM version 4.0 (Jowett 2004).

2.1.2 *Weighted Usable Area - the currency of flow decision making*

Modelled habitat availability is expressed as an index called Weighted Usable Area (WUA), which is calculated as the sum of the area weighted products of the combined habitat suitability scores (*i.e.* depth x velocity x substrate suitabilities) for the measurement points on the cross-sections. Although traditionally expressed in terms of m^2/m, WUA is in fact a dimensionless index providing an indication of the relative *quantity* of available habitat predicted at a given flow (although predicted habitat quality is also integrated into this index).

Traditionally there has also been an alternative expression of WUA as a percentage. This was intended to provide an indication of the *quality* of predicted habitat (I. Jowett, NIWA *pers. comm.*). However, it has frequently been interpreted as another quantitative metric, indicating the percentage of the reach that will provide suitable habitat at a given flow. This metric has been changed in the most recent versions of RHYHABSIM (version 3.31 and above) to a Habitat Suitability Index (HSI, ranging between 0 and 1) in an attempt to reduce confusion around interpretation. This metric is the average habitat suitability score taken over the modelled reach and is intended to provide an indication of the relative *quality* of the predicted available habitat (I. Jowett, NIWA *pers. comm.*).

It is important to realise that both of these metrics provide only a relative measure of how predicted habitat availability changes with flow. Therefore, when interpreting the WUA or HSI curves, that are the output of modelling, it is the shape of the curves (*e.g.*, the level of flow where the optimum and major changes in slope occur) that are of interest, rather than the magnitude (or height) of the WUA x flow curves. These outputs provide an indication of how habitat availability is predicted to change with flow. WUA serves as a currency which stakeholders can use for interpreting effects of flow change on instream habitat and for negotiating flow decisions.

The HSI x flow curves generally show similar trends to the WUA x flow curves, although the former generally peak at lower flows. Flow decisions based on the WUA x flow curves are therefore likely to be more conservative.

2.1.3 Reach selection for IFIM habitat modelling

There are two approaches that can be followed for selecting locations of the cross-sections, which form the basis of the field survey component of habitat modelling; *habitat mapping* or the *representative reach* (Jowett 2004). In the habitat mapping approach the proportion of each habitat type (*e.g.*, run, riffle, pool) comprising a relatively long reach of the stream is mapped and each cross-section is given a percentage weighting based on the proportion of the habitat in the reach that it represents. The predictions of subsequent modelling then relate to the reach that was mapped.

In the representative reach approach a relatively short (typically 50 -150 m) reach of river is selected that is thought to be representative of a longer section of river (Jowett 2004). The cross-sections are closely spaced (at a scale of metres) at longitudinal points of habitat change along the reach, with note being taken of the distance between cross-sections, and all cross-sections being surveyed to a common datum. The subsequent modelling predictions are then assumed to be applicable to the section of river that the chosen reach represents.

Whichever of these approaches is employed, the underlying assumption is that the cross-sections measured provide a reasonable representation of the variability in habitat throughout the reach of interest. The habitat mapping approach was followed in the present study.

2.1.4 Field data collection

Data were collected from cross-sections in three reaches of the Waimea/Wairoa River upstream of the Appleby Bridge (Figure 1). These three reaches were chosen for Hayes' (1998) original analyses to cover the variability in habitat through this section of the Waimea River, and to take account of any unexpected variability in flows downstream through this section resulting from groundwater influences.

These data were collected on two occasions. Cross-sectional data for Hayes (1998) analyses were collected from riffle and run habitats in the three reaches on 30 April 1997, with follow up gaugings on 5 and 7 May 1997. Data from pools in these same reaches were subsequently collected by Tasman District Council staff, with the main survey on 24 February 2005 and additional gaugings on 4 February, 18 March and 23 March 2005.

Sampling habitat types on different occasions is valid with the habitat mapping approach, assuming that the general geomorphology of the river channel has not changed between the sampling occasions. In other words, the average cross-sectional shapes of riffles, runs and pools over the survey reach are expected to remain similar despite changes to individual riffles, runs and pools that naturally occur with floods.

Pool habitat dominated in these reaches through both sampling periods (Appendix 1), accounting for between 44 % and 71 % of each reach during the most recent sampling period. To account for this dominance three cross-sections located in pools were surveyed in each reach, in addition to the two cross-sections in each of the other two habitat types in each reach, already surveyed by Hayes (1998). Habitat weighting of cross-sections was based on the habitat observed prior to the 2005 survey. A total of 3.165 km was habitat mapped on this occasion.

During the 1997 habitat survey the flow in the Wairoa at Clover Road reach was 4.562 m^3s^{-1}, with flows in the Waimea of 4.827 m^3s^{-1} and 5.257 m^3s^{-1} at the reach d/s Wai-iti confluence and the Challies Island reach, respectively. During the 2005 survey flows in these reaches were 3.441 m^3s^{-1}, 3.119 m^3s^{-1} and 2.642 m^3s^{-1}, respectively (N.B. decreasing flow downstream during the second survey [summer] but not during the first [autumn]).

Stage – discharge relationships for each cross-section were constructed from two or three measurements in addition to the gauging and cross-section water level measurements at the survey flow. The stage at zero flow was also estimated at all cross-sections to facilitate modelling of low flows.

2.1.5 *Data checking*

The cross-sectional data sets from each reach were entered into RHYHABSIM. Aside from the standard checks performed within the program's built-in data checking function;

- Cross-sections were plotted and visually checked for any obvious anomalies (*i.e.* unrealistic depth and velocity spikes).

- Rating curves were checked to see that they exhibited a good fit to the expected power curve relationship, and that the different types of rating curves calculated in RHYHABSIM did not substantially differ from one another. Where ever possible, rating curves that had exponents falling in the recommended range, 1.5 – 3.5 (Jowett 2004), were used in subsequent modelling.

- The Velocity Distribution Factors (VDFs) were checked to see that points falling above the water surface at the survey flow had been edited to give reasonable VDF values (*i.e.* vary around a value of 1, and generally decrease toward the banks). This consideration is important when modelling flows above the survey flow.

2.1.6 *Habitat Suitability Criteria*

The fish species modelled were based on those recorded from the Waimea River in the New Zealand Freshwater Fisheries Database (NZFFD 2005) and reviewed by Hay &

Young (2005). These included: brown trout, longfin eel, shortfin eel, upland bully, redfin bully, common bully, bluegill bully, common smelt, inanga and torrentfish. These were the same species included in Hayes (1998) analyses. The NZFFD also contains records of yellow eyed mullet and Chinook salmon from the Waimea River (Hay & Young 2005). However, neither of these species is considered to be a usual resident of the Waimea River (both have been recorded only once each from the catchment) so they were excluded from the analyses.

IFIM habitat modelling predictions are most sensitive to the habitat suitability criteria applied (Jowett 2004). The HSC chosen for a study must be appropriate for the species which are known to (or are likely to) occur in the study river. When different sets of HSC are available for various life history stages of a species (as is the case with brown trout) criteria should be selected to best represent the habitat needed to maintain a population of the species of interest (i.e the critical HSC). The HSC applied in the current analyses were the same as those applied by Hayes (1998) for most species. However, new HSC have recently been developed for longfin eel (Jellyman *et al.* 2003) and these were applied in preference to the older criteria.

Although Raleigh *et al*.'s (1986) criteria for juvenile brown trout have been used extensively in previous IFIM applications in NZ, they may underestimate flow requirements due to the inclusion of observations of resting fish in the development of the criteria, which biases for slower water habitat (a common problem in older habitat suitability criteria; Hayes 2004).

Besides requiring feeding habitat and juvenile rearing habitat, a viable trout population requires access to suitable spawning habitat. We applied spawning HSC developed by Shirvell & Dungey (1983) in our analyses, as did Hayes (1998). These criteria were developed on New Zealand rivers. However, Shirvell & Dungey's velocity suitability criteria are based on near bed velocities rather than mean column velocities (*i.e.* usually measured at 0.4 x depth) upon which the IFIM habitat model is based. Consequently, when used in the IFIM habitat model, they will tend to underestimate flow requirements of spawning fish. However, the underestimation will be fairly small for the shallow waters preferred by spawning trout because the velocity profile (which is approximated by a power relationship to depth) is compressed in shallow water.

Rather than considering individual macroinvertebrate species, the general instream habitat requirements of macroinvertebrates were assessed using Water's (1976) food producing (*i.e.* food for fish) HSC. These general HSC for benthic macroinvertebrates were developed in the USA, but have been widely applied to habitat analyses in New Zealand and have been found to be correlated with trout abundance (Jowett 1992).

Plots of the habitat suitability criteria used in this report are provided in Appendix 2.

Habitat availability for the species outlined above was modelled over the flow range 0.2 – 5 m^3s^{-1}, which spans from below the estimated natural 1 in 50 year low flow to well above the mean annual low flow (MALF) in each of the reaches modelled, and encompasses the existing minimum flow (225 l/s).

3. RESULTS AND DISCUSSION

3.1 Habitat modelling in the Waimea River

3.1.1 Response of habitat to flow – individual reaches

Habitat response curves for most species modelled were broadly similar between the Challies Island and d/s Wai-iti confluence reaches (Figures 2 & 3). Habitat availability (*i.e.* WUA) for trout of all life stages was generally predicted to increase with flow over the modelled range. The exception was spawning habitat, which was predicted to peak slightly above 1 m^3s^{-1} in the d/s Wai-iti confluence reach and at slightly lower flows in the Challies Island reach. Average habitat quality (*i.e.* HSI) for trout showed similar patterns to WUA in both of these reaches, except that the HSI curve for yearling (15-25 cm) trout based on Raleigh *et al.*'s (1986) HSC peaked at lower flows than did the equivalent WUA curve. The Raleigh yearling HSI indicates that habitat quality is highest at 2.0 m^3/s (Challies Island) or 0.8 m^3/s (d/s Wai-iti), whereas WUA indicates that the quantity of habitat in both reaches increases over the flow range modelled.

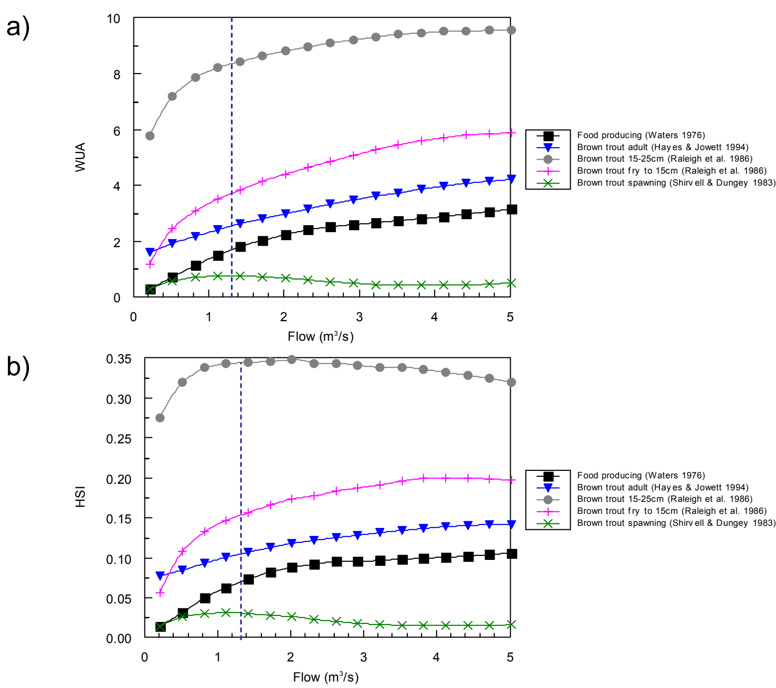


Figure 2 Predicted WUA (a) and HSI (b) response curves for trout and macroinvertebrate producing habitat in the Challies Island reach. The MALF is shown with the vertical dotted line.

a)

b)

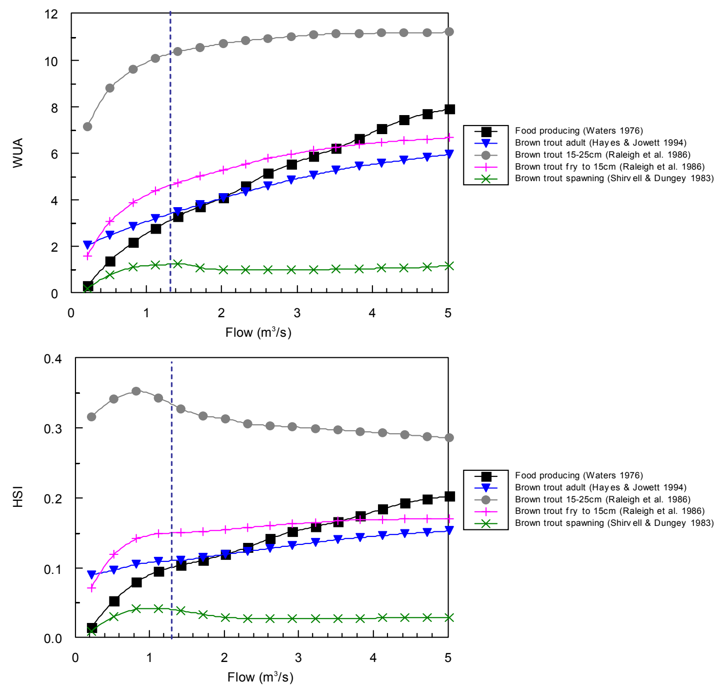


Figure 3 Predicted WUA (a) and HSI (b) response curves for trout and macroinvertebrate producing habitat in the d/s Wai-iti confluence reach. The MALF is shown with the vertical dotted line.

Habitat response curves for the more riffle dependent life stages of trout (*i.e.* spawning, fry and yearlings) showed a steepening rate of decline in habitat quality and quantity below approximately 1 m^3s^{-1} (Figures 2 & 3).

These predicted habitat responses, with WUA optima generally well above the MALF, suggest that the trout population in these reaches are likely to be limited by the habitat availability at the MALF (see section *3.1.3 Interpretation of WUA curves for flow management* for discussion of the reasoning behind this).

The predicted habitat response curves for most native fish species were generally relatively flat above about 0.5 m^3s^{-1} in the Challies Island and d/s Wai-iti confluence reaches (Figures 4 & 5; although WUA does increase at higher flows for most species in the d/s Wai-iti reach), indicating that incremental increases in flow make only minor changes to habitat availability for these species. The exceptions to this were inanga feeding, torrentfish and common smelt habitat response curves. The former increased steeply to peak at about 1 m^3s^{-1} before declining rapidly in both reaches, while the latter two increased reasonably steadily over the modelled flow range.

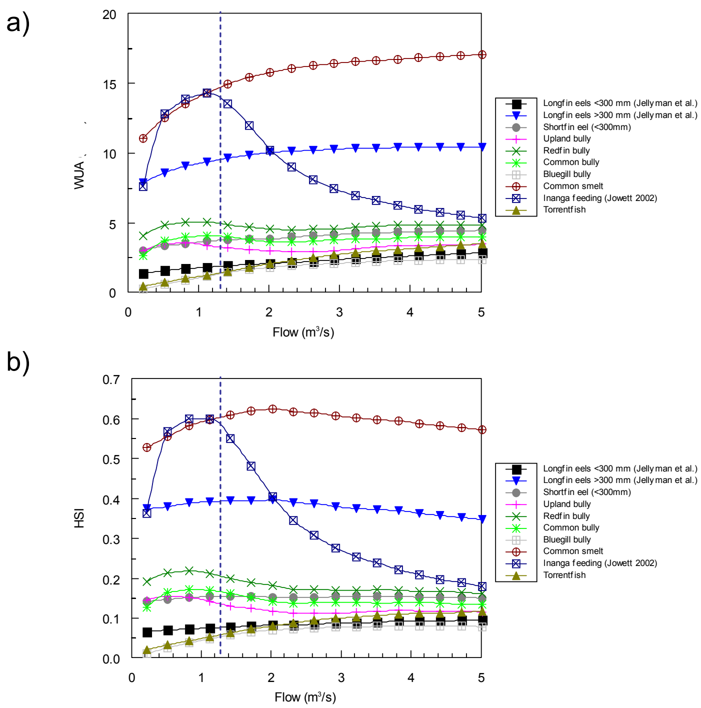


Figure 4 Predicted WUA (a) and HSI (b) response curves for native fish habitat in the Challies Island reach. The MALF is shown with the vertical dotted line.

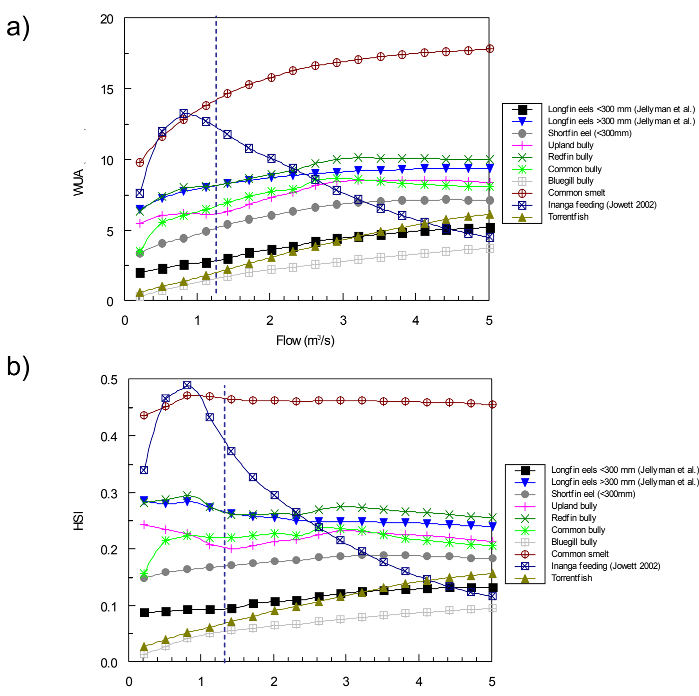


Figure 5 Predicted WUA (a) and HSI (b) response curves for native fish habitat in the d/s Wai-iti confluence reach. The MALF is shown with the vertical dotted line.

The HSI curves for the native fish species generally exhibited even flatter trajectories than their WUA response curves, in the Challies Island and d/s Wai-iti confluence reaches (Figures 4 & 5). This suggests that although incremental increases in flow, above approximately 0.5 m^3s^{-1}, would provide small incremental gains in habitat availability, the average quality of this habitat would change very little. This was exemplified by common smelt in the d/s Wai-iti confluence reach, which showed a reasonable increase in WUA with flow, but almost no change in HSI at flows greater than 0.8 m^3s^{-1}. Once again inanga feeding habitat and torrentfish habitat were the major exceptions to this general rule, with both WUA and HSI showing similar responses to flow (Figures 4 & 5).

Predicted habitat responded somewhat differently to flow in the Clover Road reach than in the other two reaches. Trout spawning habitat WUA and HSI both peaked at higher flows than in the other two reaches (approximately 2.0 m^3s^{-1} *c.f.* approximately 1 m^3s^{-1} in the other two reaches; Figures 2, 3 & 6).

Predicted WUA and HSI for adult trout, as well as habitat producing macroinvertebrates as food for trout and other fish, increased steadily over the range of flows modelled, as in the other two reaches (Figures 2, 3 & 6). However, the adult trout response curve for Clover Road declined slightly more steeply with reducing flow, than did those for the other two reaches.

a)

b)

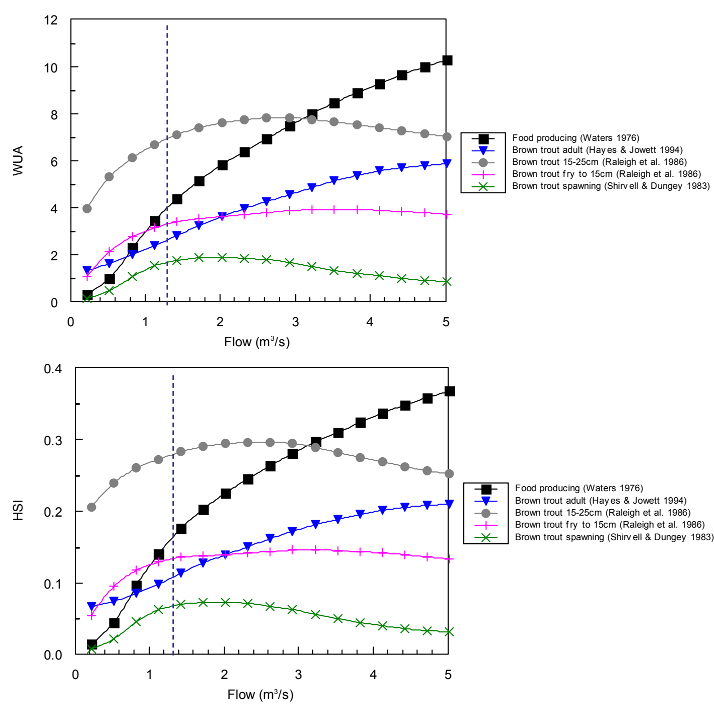


Figure 6 Predicted WUA (a) and HSI (b) response curves for trout and macroinvertebrate producing habitat in the Clover Road reach. The MALF is shown with the vertical dotted line.

Upland, common and redfin bully WUA peaked at lower flows than in the other two reaches, about 0.5 m^3s^{-1} for upland bullies and 1.5 m^3s^{-1} for the other two species (Figure 7). WUA and his curves for the other native fish species displayed broadly similar patterns to those seen in the other two reaches.

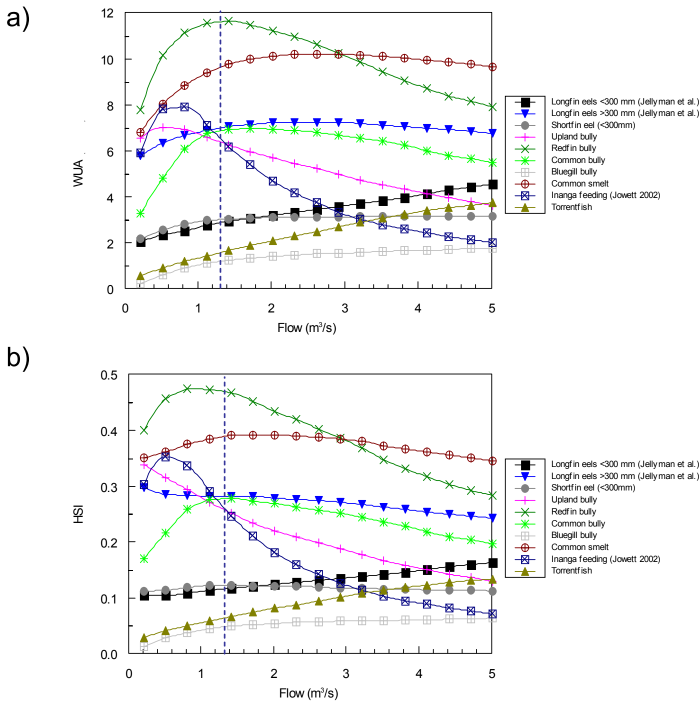


Figure 7 Predicted WUA (a) and HSI (b) response curves for native fish habitat in the Clover Road reach. The MALF is shown with the vertical dotted line.

The difference in the habitat responses of bully species in the Clover Road reach compared with the other two reaches appears to be due to underlying differences in the hydraulics of these reaches. In particular the average modelled water velocity increased more rapidly with flow in the Clover Road reach than in the other two reaches. Also, the proportion of the modelled reach with slow, tranquil, sub-critical flow (typical of pool and slow edgewater habitat) was more rapidly replaced by faster more turbulent flow (characteristic of runs) as flow increased in the Clover Road reach, than in the other reaches. These differences in hydraulics are likely to be due to the influence of additional sediment supply from the Wai-iti Catchment on the lower two reaches, contributing to a more open, unconfined channel form, but with larger pools.

3.1.2 Response of habitat to flow – all reaches combined

The estimated low flow statistics for these three reaches are relatively similar (Hayes 1998). Combining all three reaches together in the habitat analysis effectively averages out any variability between sites (with each reach representing approximately one third of the river channel between Brightwater and the Waimea River mouth), and offers two advantages:

1) The WUA and HSI response curves are then based on measurements from a larger number of cross-sections, potentially giving more robust predictions. Jowett (2004) recommends at least five cross-sections located in each habitat type, and a recent sensitivity analysis (Payne *et al.* 2004) showed that 18-20 cross-sections were generally required to produce a robust relationship between predicted habitat availability and flow. While each individual reach is represented by only 7 cross-sections (2 in runs, 2 in riffles and 3 in pools), combined they are represented by 21 cross-sections (6 in runs, 6 in riffles and 9 in pools) thus fulfilling both of these recommendations.

2) It provides a summary of the way that habitat availability varies with flow over the entire lower section of the Waimea – Wairoa River upstream of Appleby Bridge, rather than on a reach by reach basis. This simplifies interpretation of the predictions and allows minimum flows to be proposed that are applicable to this section of river in its entirety, rather than specifying different minimum flows for each reach. This would ultimately simplify minimum flow compliance monitoring.

For these reasons the habitat analyses were rerun with the three reaches combined.

Habitat response curves for the combined reaches were intermediate between those of the individual reaches (Figures 8 & 9). Habitat quantity (*i.e.* WUA) for trout of all life stages was generally predicted to increase with flow over the modelled flow range (Figure 8). The exception was spawning habitat, which was predicted to peak at approximately 1.3 m^3s^{-1}. Average habitat quality (*i.e.* HSI) for trout showed similar patterns to WUA, except that the HSI curve for yearling trout based on Raleigh *et al.*'s (1986) HSC peaked at lower flow than did the equivalent WUA curve.

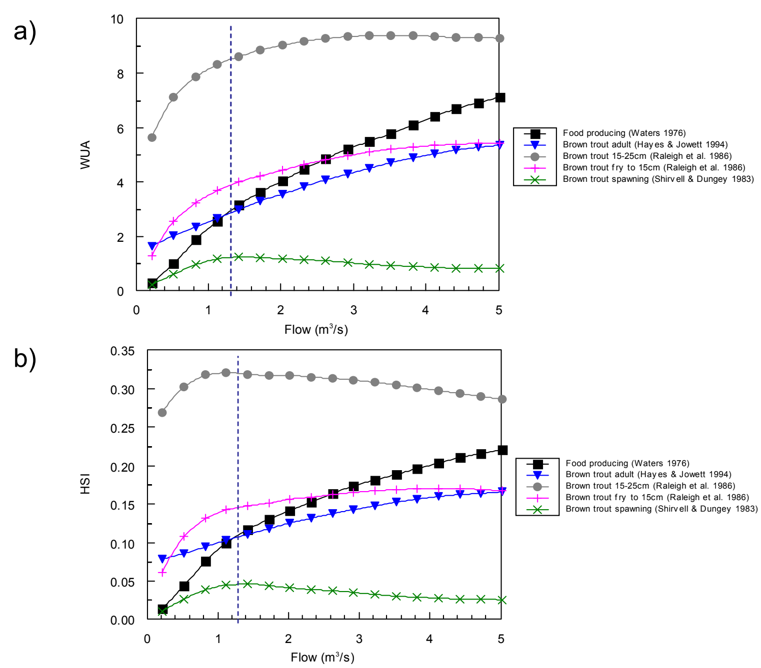


Figure 8 Predicted WUA (a) and HSI (b) response curves for trout and macroinvertebrate producing habitat in the combined reaches. The MALF is shown with the vertical dotted line.

Habitat response curves for the more riffle dependent life stages of trout (*i.e.* spawning, fry and juveniles) showed a steepening rate of decline in WUA and HSI below approximately 1 m^3s^{-1} (Figure 8).

The predicted WUA response curves for most native fish species were generally relatively flat above about 0.5-1.0 m^3s^{-1} (Figure 9), indicating that incremental increases in flow would be predicted to make only minor changes to habitat availability for these species. The exceptions to this were inanga feeding, torrentfish and common smelt habitat response curves. The former increased steeply to peak slightly below 1 m^3s^{-1} before declining rapidly, while the latter two increased reasonably steadily over the modelled flow range.

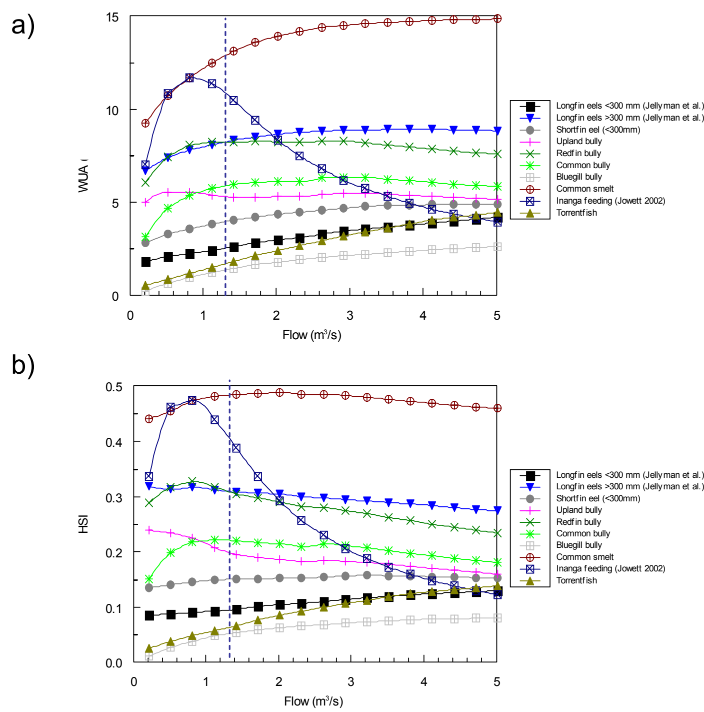


Figure 9 Predicted WUA (a) and HSI (b) response curves for native fish habitat in the combined reaches. The MALF is shown with the vertical dotted line.

The HSI curves for native fish species generally exhibited even flatter trajectories than their WUA response curves (Figure 9). Thus, for most native fish species in these two reaches although incremental increases in flow, above approximately 0.5-1.0 m^3s^{-1}, would provide small incremental gains in habitat quantity, the average quality of this habitat would change very little. As shown earlier, this was exemplified by common smelt, which showed a reasonable increase in WUA with flow, but an almost flat HSI response curve trajectory. Once again inanga feeding habitat, and torrentfish habitat were the major exceptions to this general rule, with both WUA and HSI showing similar responses to flow (Figure 9).

3.1.3 *Interpretation of WUA curves for flow management*

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 mean annual low flow and median flows are ecologically relevant flow statistics governing trout carrying capacity and stream productivity. Jowett (1990, 1992) found that instream habitat for adult brown trout at the MALF was correlated with adult brown trout abundance in New Zealand rivers. The habitat metric that he used to quantify instream habitat was percent WUA. The adult brown trout habitat suitability criteria used in Jowett's analysis were developed by Hayes & Jowett (1994). The inference arising from Jowett's research was that adult trout habitat (WUA %) at the mean annual low flow (MALF) acts as a bottleneck to brown trout numbers. He also found that the percentage of invertebrate food producing habitat (defined by Waters' (1976) general invertebrate habitat suitability criteria) 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 primary factors regulating stream salmonid populations (Chapman 1966). The reason why the MALF is a potential limiting factor, for trout populations, is that it is the commonly used flow statistic most indicative of the average annual minimum living space for adult trout. Trout populations respond to annual limiting events because their cohorts (year classes) are annual (*i.e.* they reproduce only once per year). This contrasts with aquatic invertebrates, many of which have multiple cohorts per year so their populations respond to more frequent limiting events (*e.g.*, floods or low flows that occur over the time-scale of months). Other flow statistics that define, or are closely correlated with, average annual minimum flows, should be similarly relevant, as the MALF, to adult trout abundance.

Jowett's research provides empirical and conceptual justification for the validity of WUA as a habitat index for trout populations in New Zealand rivers. The insights gained from this research can also provide a basis for identifying hydrological statistics that are ecologically relevant to trout populations

These insights have led to a recent move toward interpreting WUA curves in conjunction with flow statistics (notably the MALF) when making decisions on minimum flows (Jowett & Hayes 2004). It has been suggested that if the WUA optima should occur at flows above the MALF, then habitat availability will be limited by the MALF. In this case flow decisions should be made so as to preserve a proportion of the habitat (*i.e.* WUA) available at the MALF, in order to cater for the needs of both instream values and out-of-stream water uses. In the case where predicted optimum WUA occurs below the MALF, then flows should be managed to maintain a proportion of the habitat available at optimum WUA.

It is then necessary to address how the flow requirements predicted by various WUA versus flow relationships for different species can be reconciled. Jowett & Hayes (2004) suggest that flow dependant critical instream values should be identified and flow decisions made with a focus on managing these values. Candidates for critical value status might include flow sensitive rare or endangered species, or species with high fishery value. "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). In their document "Flow guidelines for instream values", Ministry for the Environment recommend a similar approach (MfE 1998), although the terminology used differs slightly. Basing decision making on critical instream values circumvents the complexities of interpreting all the different species' WUA curves independently.

There have been no rare or endangered fish species recorded from the Waimea River itself, although dwarf galaxias have been recorded further up the catchment.

Trout in the Waimea River, and its wider catchment, provide a valued recreational fishery resource (Hay & Young 2005). Although not known for the size of its trout, the Waimea River does attract considerable numbers of anglers (Unwin & Brown 1998; Unwin & Image 2003), mainly due to its proximity to urban and suburban centres of the Nelson and Richmond area. Large sea-run trout can also be caught in the lower catchment (Richardson *et al.* 1984). This suggests trout as a good candidate for critical value status. Trout, especially adult trout, have the highest flow requirements of the species considered in this report (with the possible exception of torrentfish and benthic invertebrates). Therefore, providing for the flow needs of trout will, arguably, provide for the flow needs of less flow demanding species, as the latter will be able to utilise slower or shallower habitat along the river margins or in riffles.

The habitat requirements of adult brown trout are arguably the most pertinent to minimum flow setting for this section of the river. The Waimea River and lower Wairoa have the potential to provide good habitat for large adult trout, with favourable pool habitat combined with reasonable food producing riffle habitat. Provision of flows which maintain adult trout habitat should also provide some habitat suitable for other life stages of trout in the Waimea River. However, habitat for younger trout are of lesser importance in the Waimea and lower Wairoa, since spawning and juvenile rearing habitat is likely to be found in tributaries higher up in the catchment. Moreover, it is likely that floods, rather than low flow, limit juvenile trout recruitment and abundance (cf. Hayes 1995).

Based on the above rationale we recommend that maintenance of adult brown trout habitat be adopted as the critical instream management goal for minimum flow decision making in the lower Wairoa/Waimea rivers. The flow requirements of inanga could be considered too, since they have the potential to support a valuable whitebait fishery in the catchment.

Finally, the decision remains as to what level of habitat availability should be maintained. The level of habitat retention is arbitrary, and scientific knowledge of the response of river ecosystems, and fish populations in particular, is insufficient to identify levels of habitat below which ecological impacts will occur. A carefully designed and well funded monitoring programme might detect effects of a 50 % reduction in habitat on fish populations but is unlikely to detect effects of a 10 % reduction in habitat – due mainly to the large natural spatial and temporal variability typical of fish populations. It is uncertain whether any effects of a 20 % reduction in habitat on fish populations would be detectable.

Jowett & Hayes (2004) recognise that, in practice, the choice of a habitat retention level is based more on risk management than ecological science. The risk of ecological impact increases as habitat is reduced. When instream resource values are factored into the decision making process, then the greater the resource value the less risk is acceptable. With this in mind, Jowett & Hayes (2004) suggest that water managers could consider varying the percent habitat retention level, depending on the value of instream and out-of-stream resources (*i.e.* highly valued instream resources warrant a higher level of habitat retention than low valued instream resources). This concept is consistent with conservative flow decisions in national water conservation orders (usually no more than 5 % habitat reduction). Table 1 shows how Jowett & Hayes (2004) envisage that percentage habitat retention could be varied to take account of variation in instream values.

Table 1 Suggested significance ranking (from highest (1) to lowest (5)) of critical values and levels of habitat retention.

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
Redfin/common bully	-	5	60

Table taken from Jowett & Hayes (2004)

Applying these criteria to minimum flow setting in a river that has already been heavily impacted by flow reduction presents an interesting challenge. When minimum flows are set prior to the reduction in flow being implemented, they are generally formulated with protection of a given resource in mind (*e.g.* a trout fishery). However, if the system has already been subjected to reduced flows it becomes necessary to consider the value that the resource may have had in its unimpacted state. As well as having its flow reduced by abstraction, the Waimea River has had its channel heavily modified with flood control works.

Applying these criteria to the reaches considered here would suggest a 70 % habitat retention level for the Waimea River, given the low to medium value of its brown trout fishery, but with its relatively high level of angler use. The potential whitebait fishery value provided by inanga would warrant a similar level of habitat retention. This would be expected to provide adequate habitat to maintain the trout population of the Waimea River, although at a level slightly below what might be supported by this river under its natural flow regime.

However, the Waimea would arguably have supported a more highly valued trout fishery before water abstraction and stop banking. There is evidence that the trout fishery in this river was substantially better historically (Spackman 1892; Graynoth & Skrzynski 1974). Therefore, a higher level of habitat retention, say 80 %, may be justified.

Maintaining the natural MALF as the minimum flow would be the ideal situation in cases where the predicted habitat optimum occurs above the MALF (based on the rationale presented in the first paragraph of this section). On the other hand, if the predicted habitat optimum occurs at flows below the MALF, then a reduction in the minimum flow could potentially be beneficial.

This report provides proposed minimum flow options that are predicted to retain 100 %, 80 % and 70 % of adult brown trout habitat available at the MALF or at the WUA optimum, whichever occurs at the lesser flow. Minimum flows based on the same criteria are also presented for other trout life stages, macroinvertebrate food producing habitat, and inanga feeding habitat, for comparison. The decision on which level of retention is appropriate should be based on consultation with interested parties, bearing in mind the relative instream values (*e.g.*, fisheries values), and out-of-stream demand.

3.1.4 Proposed minimum flows

Based on the rationale outlined above, the proposed minimum flows provided here are derived from the results of habitat analysis on the three reaches combined (Table 2). The natural 7 day MALF of 1.3 m^3s^{-1} is proposed as the environmental benchmark minimum flow for the Waimea River in the reaches upstream of Appleby Bridge. [see Appendix 3 for an explanation of the derivation of the MALF for this section of river]. A minimum flow of 0.5 m^3s^{-1} would retain 70 % of the adult brown trout habitat available at the natural MALF (Table 2). An intermediate option is a minimum flow of 0.8 m^3s^{-1}, which would retain 80 % of the habitat available at the natural MALF for adult brown trout (Table 2).

Table 2 Three levels of proposed minimum flow for the Waimea and lower Wairoa based on retention of adult brown trout habitat (highlighted bold), the MALF as the benchmark, 70 % habitat retention, and 80 % habitat retention as an intermediate option. Other life stages and species are shown for comparison.

MALF (m^3s^{-1})	Habitat Suitability criteria	Flow at WUA Optimum (m^3s^{-1})	Flow at 80% of MALF or WUA Optimum (which ever is the lesser) (m^3s^{-1})	Flow at 70% of MALF or WUA Optimum (which ever is the lesser) (m^3s^{-1})
1.3	Brown trout adult (Hayes & Jowett 1994)	> 5.0	**0.8**	**0.5**
	Brown trout yearling 15 - 23 cm (Raleigh et al. 1986)	3.5	0.4	0.3
	Brown trout fry < 14 cm (Raleigh et al 1986)	> 5.0	0.7	0.6
	Brown trout spawning (Shirvell & Dungey 1983)	1.4	0.8	0.7
	Food producing (Waters 1976)	> 5.0	1.0	0.9
	Inanga feeding (Jowett 2002)	0.8	0.4	0.3

All of these proposed minimum flows are substantially higher than the previous minimum flow (0.225 m^3s^{-1}) stipulated in the 1991 Waimea Catchment Water Management Plan, and are also higher than, or equal to (in the case of 70 % habitat retention) the existing summertime minimum flow of 0.5 m^3s^{-1} stipulated in the proposed Tasman Resource Management Plan (Part IV, Chapter 31, TRMP 2005). This highlights the potential for improvement of current instream habitat through augmentation of flows in the lower Waimea Catchment. As mentioned above, the Waimea River has been substantially altered, not only by water abstraction and reduced minimum flows, but also through the effects of flood control works. The quality of the local trout fishery has also undergone a historical decline, with a notable decline in annual catch rates between the 1940s to 1960s, in particular (Graynoth & Skrzynski 1974). However, the basis of a reasonable fishery still exists, with deep holding pools and food producing riffle habitat available, given sufficient maintenance flows. The Waimea water augmentation scheme may provide the means to deliver these flows.

Increasing the minimum flow in the Waiau River, flowing from Lake Manapouri in Southland, has resulted in a dramatic increase in trout abundance in that river (Young *et al*. 2004). Previously the Manapouri Power Scheme diverted almost all of Lake Manapouri's inflow through their power station to Doubtful Sound, with only a small residual flow (approximately 0.29 m^3s^{-1}) being released into the Waiau. Conditions agreed upon during the renewal of resource consents for the power scheme included increasing the minimum discharge past the Mararoa Weir, to 16 m^3s^{-1} in summer and 12 m^3s^{-1} in winter. Since these higher minimum flows were instituted there has been a marked increase in trout abundance in the Waiau River downstream of the weir, from approximately 100 trout/ km prior to the new minimum flow, to approximately 300-400 trout/ km after. Anecdotal reports suggest that the trout fishery has also improved in the Opihi River, in South Canterbury, following flow augmentation from a dam on one of its tributaries, the Opuha.

The benchmark minimum flow for the Waimea River upstream of the Appleby Bridge (the natural MALF of 1.3 m^3s^{-1}) would maintain the naturally occurring annual habitat minimum in this river. The predicted habitat optimum (*i.e.* WUA peak) for adult brown trout occurred at flows well above the MALF, indicating that some degree of habitat limitation is likely to occur even at this flow. However, the MALF is the highest minimum flow that could be sustained by the natural flow regime. A minimum flow condition equivalent to the MALF would therefore minimise any exacerbation of habitat limitation of the Waimea River's trout population caused by water abstraction.

A minimum flow of 0.5 m^3s^{-1} would provide 70 % of the adult brown trout habitat available at the natural MALF. A reduction in habitat of this magnitude would be expected to cause some level of decline in trout abundance from the condition at the natural MALF.

Jowett (1992) developed multiple regression models that predict the abundance of adult brown trout in New Zealand rivers based on physical and biological variables. These models were based on trout abundance data from drift dives in more than 80 rivers throughout New Zealand, and became known as the "100 rivers models". Of these, the model with the strongest predictive ability (Model C, R^2 = 87.7) included HSI for adult brown trout at the MALF and HSI for macroinvertebrate food producing habitat at the median flow as predictive variables. This model took the form:

"100 rivers Model C" (Jowett 1992):

ln(brown trout numbers/ ha + 1) = TempFactor * (1.095 + 0.032.WUABt + 0.132.Lake - 0.071.Sand + 0.443.Cover - 26.7.Gradient + 0.037.WUAFood - 0.002.Elev - 0.007.Devel)

Where:

TempFactor = winter water temperature preference factor (t): 1 for $t \leq 10$; 11- t for $10 < t < 11$, 0 for $t \geq 11$

WUABt = WUA% (*i.e.* 100 x HSI) for adult brown trout at the MALF using Hayes and Jowett (1994) adult brown trout HSC

Lake = % lake in catchment

Sand = percent sand in substrate
Cover = instream trout cover grade (0-9)
Gradient = gradient of reach (m/m)
WUAFood = WUA% (*i.e.* 100 x HSI) for invertebrate food producing habitat at the median flow using Waters (1976) HSC
Elev = elevation of reach (m)
Devel = % of catchment above reach in pasture, crop or horticulture

This model can be used to predict the likely impact of changes in the minimum flow on the abundance of adult brown trout (by substituting WUABt at the MALF for WUABt at the proposed new minimum flows). Note that the effects of any changes in median flow as a result of water augmentation are not included here.

Based on this model, adult brown trout abundance (numbers per km of river length) in the combined IFIM reaches in the Waimea River is predicted to be 18 % lower under the proposed 70 % habitat retention regime than numbers predicted at the natural MALF. A flow of 0.8 m^3s^{-1}, providing 80 % of the adult brown trout habitat available at the natural MALF is predicted to result in approximately 12 % fewer trout than the number predicted at the natural MALF. However, both of these proposed minimum flows would still be an improvement on the current situation (approximately 28% lower than numbers predicted at natural MALF).

Predictions of the 100 Rivers trout abundance model can be compared with trout abundances assessed by drift diving. The average abundance observed during four drift dives through pools in the Waimea River between 1997 – 2001 (20 trout/ km; Hay & Young 2005) is slightly higher than that predicted by the "100 rivers model" based on the current minimum flow condition of 0.225 m^3s^{-1} (15 trout/km). However, at least one of these drift dives took place during a period of very low flows (in 1997), when trout may have been concentrated in the pools, potentially inflating the observed counts. Excluding data from this dive reduced the average to 16 trout/km, which compares well with the "100 rivers model" predictions.

Predicted trout abundance can be compared with the observed counts from the 305 drift dive sites surveyed in NZ (including the original 100 rivers data set). Based on the predicted abundance for the combined reaches at the natural MALF (21 brown trout/km), the Waimea would rank in approximately 117th place - or between the mean (34 brown trout/km, rank 85th) and the median (14 brown trout/km, rank 152nd). Reducing flow in these reaches to the level proposed under the 70 % habitat retention regime reduces the predicted ranking down to approximately 133rd place, with 17 trout/km. Based on the average abundance observed during the three most recent drift dives through pools in the Waimea (*i.e.* excluding data from the 1997 dive, which was undertaken at very low flow) this section of river currently ranks approximately 141st place, with 16 trout/km, under its present flow regime.

These proposed minimum flows compare well with those suggested by Hayes (1998). He suggested that, given that the goal was to maintain instream habitat for trout to protect the trout fishery, an appropriate minimum flow for these reaches would fall between 1-2 m^3s^{-1}. Increasing the minimum flow to within this range was expected to have a neutral or mildly beneficial effect on most native fish. However, the minimum flow in place at the time was only 0.225 m^3s^{-1}, which led him to suggest a compromise minimum flow of 0.5 m^3s^{-1}, with a slightly higher minimum flow in winter (0.65 m^3s^{-1}) to allow spawning trout free passage upstream over shallow riffles. Hayes (1998) pointed out that this suggested minimum flow was still only equivalent to the estimated 1 in 50 year low flow at Challies Island, and as such was still heavily weighted in favour of out-of-stream water users. The proposed water augmentation scheme offers a chance to opt for a minimum flow that balances the requirements of instream values and out-of-stream uses more equitably.

How the requirements of instream and out-of-stream uses are balanced will ultimately be a matter for informed negotiation. One option might be to adopt the lower proposed minimum flow, but use a flow sharing approach to minimise the amount of time that the flow is at the minimum, since long periods of low flow are expected to have larger effects than the same low flow for short periods. This approach would involve setting an allocation limit that would decrease as flows reduce (i.e. a fixed proportion of the flow is available for allocation). The present system where allocation is systematically reduced as flows drop below various trigger points already provides some degree of flow sharing.

Another issue to be considered in minimum flow setting for this section of river is flow variability. Unsightly accumulations of algae already occur in the Waimea, lower Wairoa and lower Wai-iti rivers during periods of stable low flow (Hay & Young 2005). Periodic freshets are required to scour these algae from the substrate and flush them out of the system. Locating a dam in the upper catchment has the potential to reduce the magnitude of small to moderate sized freshets, although larger flood flows are unlikely to be adversely affected. Reducing the frequency of natural flushing flow events will potentially lead to an increase in these nuisance blooms. The Opihi River augmentation scheme provides an example of this, where relatively constant flows following augmentation were implicated in the development of nuisance algal blooms and the scheme was not designed to provide for artificial flushing flows. This should be taken into account when considering the location of the dam, so that smaller freshet flows are not intercepted from a large proportion of the overall catchment, thereby reducing the magnitude of small to moderate freshets. Provision for flushing should be incorporated in the design of the dam and economic analysis of the scheme.

3.2 Historical minimum flows at the proposed dam sites

The proposed dam sites in the upper Wairoa and the Lee River (Figure 1) have only recently been short listed as the most feasible locations for the dam, from a more extensive list of potential locations. Habitat modelling has not been carried out on these sites at this stage. Therefore, proposed minimum flows for the proposed dam sites were based on historical flow statistics for these sites.

Flow setting based on historic flow statistics aims to maintain the flow within the historical flow range. The underlying assumption is that the ecosystem has adjusted to the flow regime and that a reduction in flow will cause a proportional reduction in the biological state (*e.g.* abundance, diversity) of the ecosystem (Jowett & Hayes 2004; Jowett 1997). This assumption precludes the possibility that the ecological state of the system could be improved by a reduction in flow. However, in the absence of other data this is probably a reasonable assumption to make, especially for small rivers.

Maintaining the natural MALF as the minimum flow would be the ideal situation, based on the same rationale as outlined above. The MALF defines the average minimum living space available to sustain species, with a life cycle greater than one year, through any given year. If a long lived species has managed to maintain a population from year to year in a given system, then presumably this species has been able to tolerate the level of habitat available at, or close to, the MALF.

By the same rationale, applying the one in five year low flow as a minimum flow would be expected to have some detrimental effect on the ecosystem, because it would reduce the average minimum living space experienced in any given year. However, for a long lived species to have persisted in a location historically it may be reasonable to assume that the individuals would have had to tolerate similar low flow conditions before. So, while a reduction in population size (and fishery productivity) may be expected to occur, a viable population would still be expected to persist.

Imposing low flows of lower return frequency as minimum flows would be expected to have larger detrimental effects. It is debatable whether a productivity fishery would be able to persist in the face of new flow regime where the annual minimum living space was equivalent to that provided by the one in ten year low flow, for example.

There are short comings with applying minimum flows based purely on historic low flows. In particular, it does not take into account that the effect of reducing flow is dependent on channel form. In a U shaped channel a relatively large reduction in flow is necessary to produce significant reduction in habitat availability, since the bottom of the channel will still remain largely wetted even at quite low flows. By contrast, habitat availability in a stream with a broad flat channel profile will change considerably with relatively small incremental reductions in flow, as large areas of the streambed will become dry.

However, in the present case historical flow statistics provide a range of potential minimum flows that can be used to assess the feasibility of the proposed dam sites. A more detailed analysis (*e.g.* IFIM habitat modelling) can then be applied to give a more robust indication of the instream habitat requirements at the chosen site, and support a more defensible minimum flow decision.

Based on the rationale outlined above, the MALF represent the environmental benchmark minimum flow situation (Table 3), while the 1 in 10 year low flow and the 1 in 5 year low flow would be less conservative options.

Table 3 Estimated historical flow statistics for the proposed dam sites in the Lee and Wairoa rivers. The MALF represents the environmental benchmark minimum flow, while the 1 in 10 year and 1 in 5 year low flows are less conservative options.

Site	Catchment Area (km^2)	Estimated Mean Flow (m^3/s)	7-Day MALF		7-Day 5-Year Low Flow		7-Day 10-Year Low Flow	
			Range (l/s)	Best Estimate (l/s)	Range (l/s)	Best Estimate (l/s)	Range (l/s)	Best Estimate (l/s)
Lee (2523520E, 5971640N)	83.8	3.58	400 to 600	470	300 to 500	360	250 to 400	310
Upper Wairoa (2518760E, 5967980N)	91.6	3.98	430 to 700	520	330 to 550	400	280 to 500	350

In the absence of flow records from the proposed dam sites these flow statistics were derived through catchment-area-weighted comparison with nearby flow recorder sites, which shared similar mean annual rainfall, geology and mean runoff characteristics within in their catchments. The flow recorder sites used included: 1) Motueka at Gorge, which has its headwaters adjacent to the upper Wairoa, 2) Wai-iti at Belgrove, which also has its headwaters adjacent to the upper Wairoa but is significantly drier and has different underlying geology, and 3) Wairoa at Gorge/Irvines, the catchment of which encompasses both the upper Wairoa River and Lee River catchments.

A relatively wide range was given for each flow statistic because of the uncertainty inherent in the low flow estimates for the two dam sites. The adopted "best estimates" were derived by scaling the specific low flow estimates of the Wairoa at Gorge/Irvines by the assessed specific mean flows at the dam sites.

It is possible that the low flow at the proposed dam site in the upper Wairoa could be an underestimate, if in fact it is more similar to the upper Motueka than assumed (the upper Motueka has (unusually) high specific low flows and baseflows). That is to say, the proposed dam site in the upper Wairoa could well have low flows between the "best estimate" and the upper bound of the "range" shown.

4. CONCLUSIONS

This report assessed the minimum flows required to provide instream habitat in the Waimea River and at two proposed dam sites as part of a feasibility study into the potential to augment flow in the Waimea from a water storage reservoir in its catchment. In each case we provide three alternative minimum flows to span a range from the environmental benchmark minimum flow that is conservative in terms of environmental protection, to a minimum flow that is weighted more towards out-of stream uses.

The proposed water augmentation can be seen as an opportunity to redress the balance between instream and out-of-stream water uses. Current water allocation in the catchment is heavily biased toward out-of-stream users and the instream values have suffered as a result.

Instream flow requirements for the Waimea River in the section upstream of the Appleby Bridge were assessed using physical habitat modelling within the Instream Flow Incremental Methodology (IFIM). These analyses update earlier habitat modelling undertaken in this section (Hayes 1998).

The minimum flows proposed for this reach were based on maintenance of adult brown trout habitat. Brown trout attract relatively high angler use of the Waimea River and have the potential to support a valued fishery, given sufficient maintenance flows. Brown trout are also among the most flow demanding freshwater fish in New Zealand rivers, and so providing adequate flow for them should also provide for the flow needs of other species.

The estimated natural MALF of 1.3 m^3s^{-1} is proposed as the environmental benchmark minimum flow for the Waimea River upstream of the Appleby Bridge. A minimum flow of 0.5 m^3s^{-1} would retain 70 % of the adult brown trout habitat available at the natural MALF, whereas a minimum flow of 0.8 m^3s^{-1} would retain 80 % of the habitat available at the natural MALF for adult brown trout.

Historical flow statistics were used to provide a range of potential minimum flows that can be used to assess the feasibility of the proposed dam sites. Once a site is chosen a more detailed analysis (*e.g.* IFIM habitat modelling) could be undertaken to give a more robust indication of the instream habitat requirements at the chosen site, and support a more defensible minimum flow decision for that site.

Maintenance of the existing MALF is suggested as the environmental benchmark minimum flow situation at the proposed dam site, while the 1 in 10 year low flow and the 1 in 5 year low flow would be less conservative options.

When considering minimum flow regimes for the Waimea and the potential location of dams, the need to maintain flow variability, in particular flows capable of flushing out nuisance algal growths, must also be considered.

5. ACKNOWLEDGEMENTS

Tasman District Council staff surveyed the IFIM cross-sections for both the 1998 and 2005 data sets, and provided flow statistics and other information for use in this report. We particularly thank Martin Doyle for coordinating the cross-section surveys and for assisting with the cross-section selection. We also thank Lawson Davey (Fish & Game) for help with the cross-section selection.

6. REFERENCES

Bovee, K.D.; Lamb, B.L.; Bartholow, J.M..; Stalnaker, C.B.; Taylor, J.; Henriksen, J. 1998: *Stream habitat analysis using the instream flow incremental methodology*. U.S. Geological Survey, Biological Resources Division Information and Technology Report USGS/BRD-1998-0004. viii + 131 pp.

Chapman, D.W. 1966: Food and space as regulators of salmonid populations in streams. *The American naturalist 100*: 346-357.

Graynoth, E.; Skrzynski, W. 1974: *The Nelson Trout Fishery.* MAF Fisheries Technical Report No. 119. 34p.

Hay, J.; Young, R. 2005: Review of biological data relating to the Waimea River Catchment. Prepared for the Waimea Water Augmentation Committee. *Cawthron Report No. 996.* 39p.

Hayes, J.W. 1995: Spatial and temporal variation in the relative density and size of juvenile brown trout in the Kakanui River, North Otago, New Zealand. New Zealand Journal of Marine and Freshwater Research 29: 393-407.

Hayes, J.W. 1998: *Instream Habitat Flow Analysis for the Wairoa/ Waimea and Wai-iti Rivers.* Prepared for Tasman District Council and Fish and Game New Zealand – Nelson/Marlborough. Cawthron Report No. 414. 21p + Appendices.

Hayes, J.W.; Jowett, I.G. 1994: Microhabitat models of large drift-feeding brown trout in three New Zealand rivers. *North American Journal of Fisheries Management 14*: 710-725.

Jellyman, D.J.; Bonnett, M.L.; Sykes, J.R.E.; Johnstone, P. 2003: Contrasting use of daytime habitat by two species of freshwater eel (*Anguilla* spp) in New Zealand rivers. In D. A. Dixon (ed.) *Biology, Management and Protection of Catadromous Eels*. American Fisheries Society Symposium 33, Bethesda, Maryland, USA.

Jowett I.G. 1990: Factors related to the distribution and abundance of brown and rainbow trout in New Zealand clear-water rivers. *New Zealand Journal of Marine and Freshwater Research 24*:429-440.

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

Jowett, I.G. 1997: Instream flow methods: a comparison of approaches. *Regulated Rivers 13*: 115-127.

Jowett, I.G. 2002: In-stream habitat suitability criteria for feeding inanga (*Galaxias maculates*). *New Zealand Journal of Marine and Freshwater Research* 36: 399-407.

Jowett, I.G. 2004: RHYHABSIM River Hydraulics and Habitat Simulation (Software Manual).

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

Jowett, I.G.; Richardson, J. 1995: Habitat preferences of common, riverine New Zealand native fishes and implications for flow management. *New Zealand Journal of Marine and Freshwater Research 29*: 13-23.

Ministry for the Environment 1998: *Flow guidelines for instream values*. Ministry for the Environment, Wellington.

NZFFD 2004: New Zealand Freshwater Fisheries Database. http://fwdb.niwa.co.nz/, (accessed on 18 January 2005).

Payne, T.R.; Eggers, S.D.; Parkinson, D.B. 2004: The number of transects required to compute a robust PHABSIM habitat index. *Hydroécologie appliquée 14*: 27-53.

Raleigh, R.F.; Zuckerman, L.D.; Nelson, P.C. 1986: Habitat suitability index models and instream flow suitability curves: brown trout, revised. *U.S. Fish and Wildlife Service Biological Report 82* (10.124).

Richardson, J.; Unwin, M.J.; Teirney, L.D. 1984: *The relative value of Nelson rivers to New Zealand anglers.* MAF Fisheries Research Division. Fisheries Environmental Report No. 45. 44p + Appendices.

Shirvell,C.S.; Dungey,R.G. 1983: Microhabitats chosen by brown trout for feeding and spawning in rivers. *Transactions of the American Fisheries Society 112*: 355-367.

Spackman, W.H. 1892: *Trout in New Zealand: Where to go and how to catch them.* Government Printer, Wellington, NZ.

TRMP 2005: Tasman Resource Management Plan (Proposed). Part IV - Water, Chapter 31 - Rules for Water Takes, Damming or Diversion. Tasman District Council, Richmond, NZ.

Unwin, M.; Brown, S. 1998: *The geography of freshwater angling in New Zealand*. NIWA Client Report No. CHC98/33. Prepared for Fish & Game New Zealand.

Unwin, M.; Image, K. 2003: *Angler use of lake and river fisheries managed by Fish & Game New Zealand: results from the 2001/02 National Angling Survey*. NIWA Client Report No. CHC2003/114. Prepared for Fish & Game New Zealand.

Waters, B.F. 1976: A methodology for evaluating the effects of different streamflows on salmonid habitat. In: Orsborn, J.F.; Allman, C.H. (eds). *Proceedings of the symposium and speciality conference on instream flow needs II*. American Fisheries Society, Bethesda, Maryland. Pp 224-234.

Young, R.; Smart, G.; Harding, J. 2004: Impacts of hydro-dams, irrigation schemes and river control works. In: Harding, J; Mosley, P.; Pearson, C.; Sorrell, B. (eds.). *Freshwaters of New Zealand*. New Zealand Hydrological Society Inc. & New Zealand Limnological Society Inc., Caxton Press, Christchurch, NZ.

Appendices

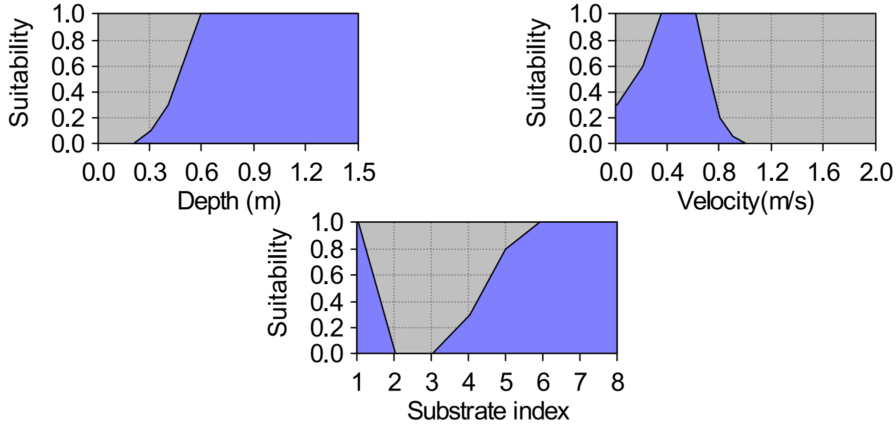
Appendix 1 A comparison of habitat mapping undertaken in river section represented by the three IFIM reaches based on Hayes' (1998) analysis and on additional data collected for this report (2005)

	1998 survey		2005 survey	
	Length surveyed (m)	% of reach	Length surveyed (m)	% of reach
Challies Island				
Pool	931	79	951	71
Riffle	103	9	291	22
Run	141	12	101	8
Total	1175		1343	
d/s Wai-iti confluence				
Pool	270	39	472	62
Riffle	140	20	161	21
Run	274	40	130	17
Total	684		763	
Clover Road				
Pool	1030	69	464	44
Riffle	110	7	246	23
Run	345	23	349	33
Total	1485		1059	

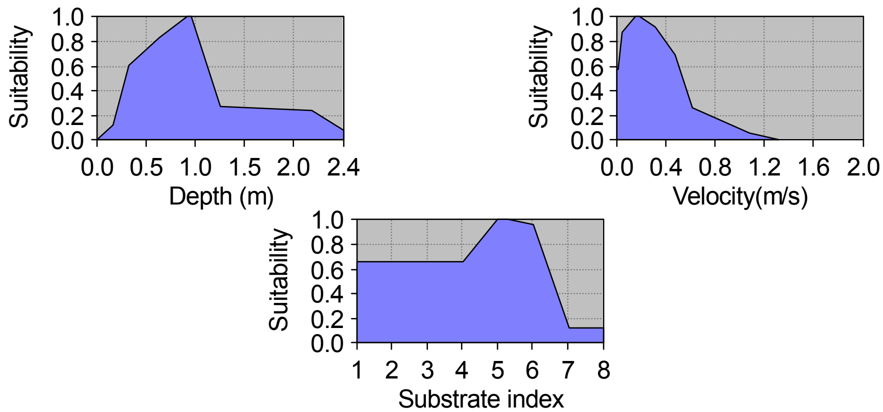
Appendix 2 Habitat suitability criteria used in this report

N.B. Where no citation is given for native fish suitability criteria they are assumed to be based on Jowett & Richardson (1995).

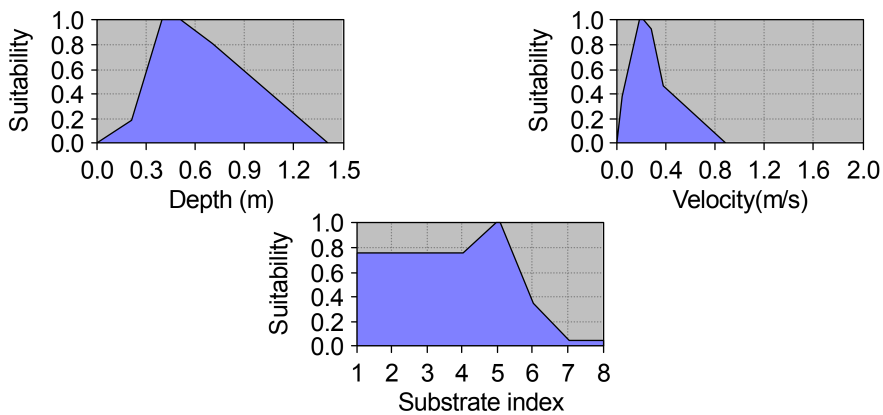
Brown trout adult (Hayes & Jowett 1994)



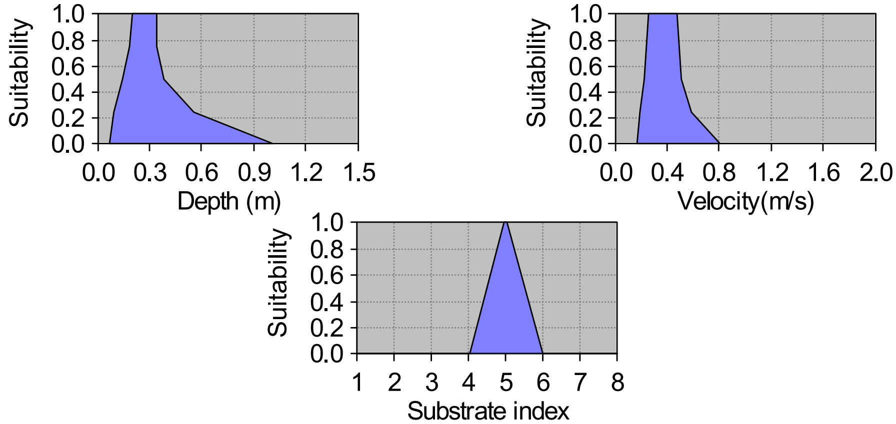
Brown trout 15-25cm (Raleigh et al. 1986)



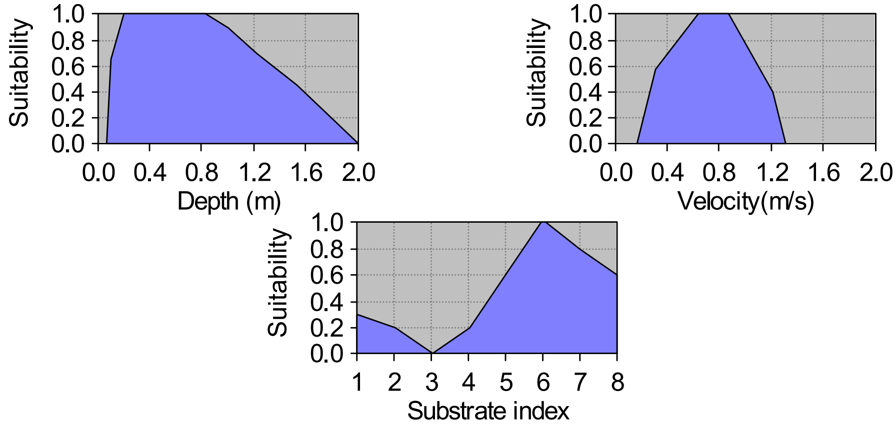
Brown trout fry to 15cm (Raleigh et al. 1986)



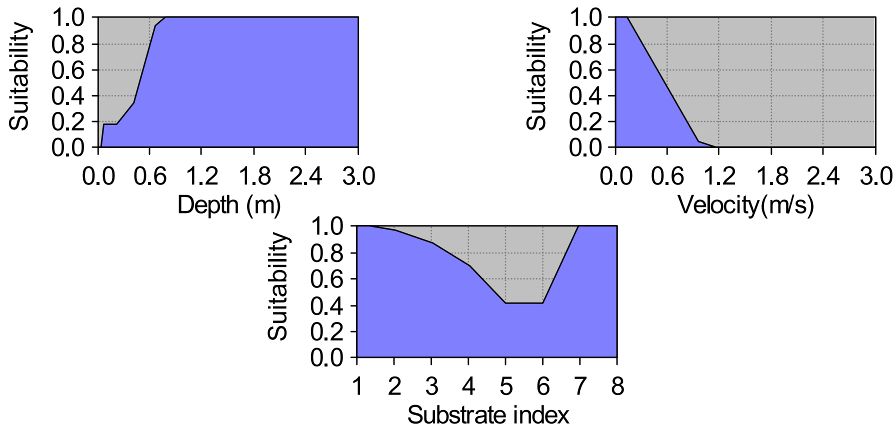
Brown trout spawning (Shirvell & Dungey 1983)



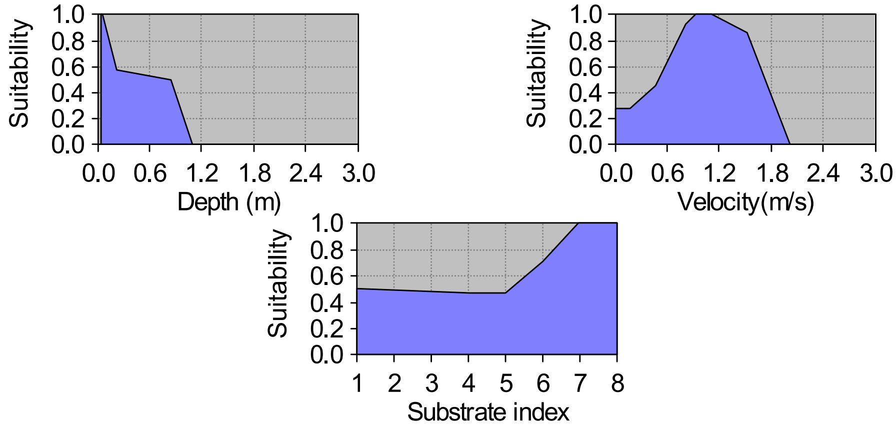
Food producing (Waters 1976)



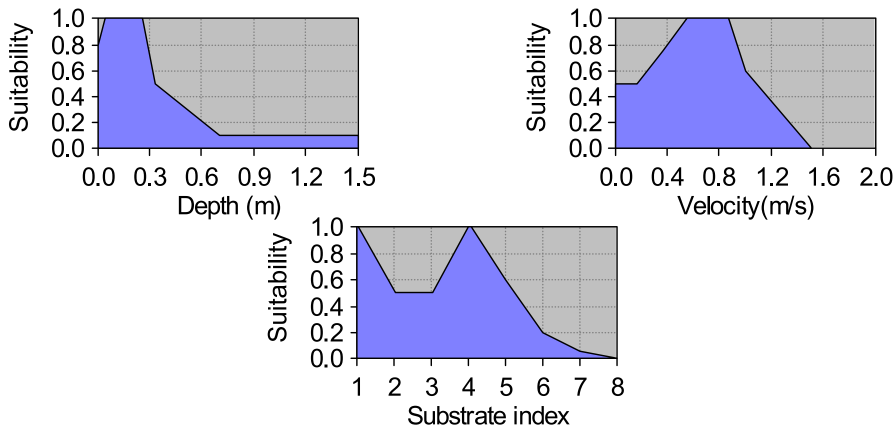
Longfin eels >300 mm (Jellyman et al.)



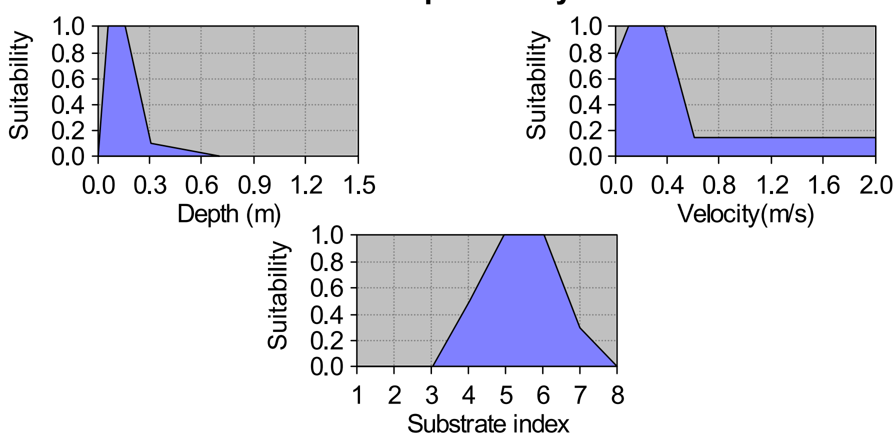
Longfin eels <300 mm (Jellyman et al.)



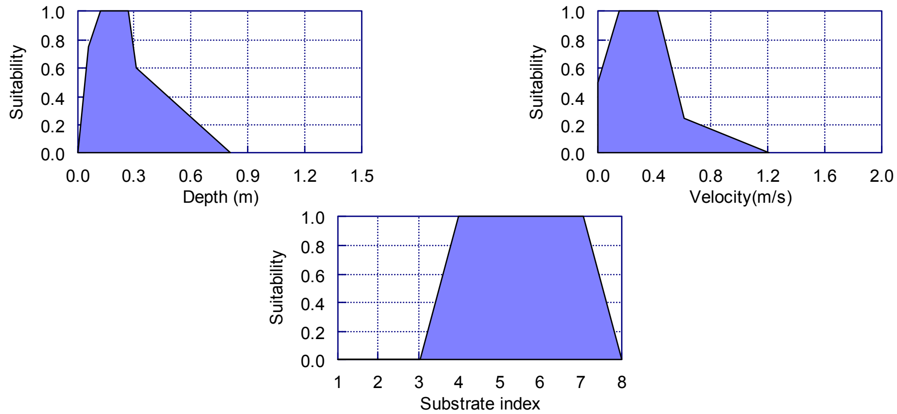
Shortfin eel (<300mm)



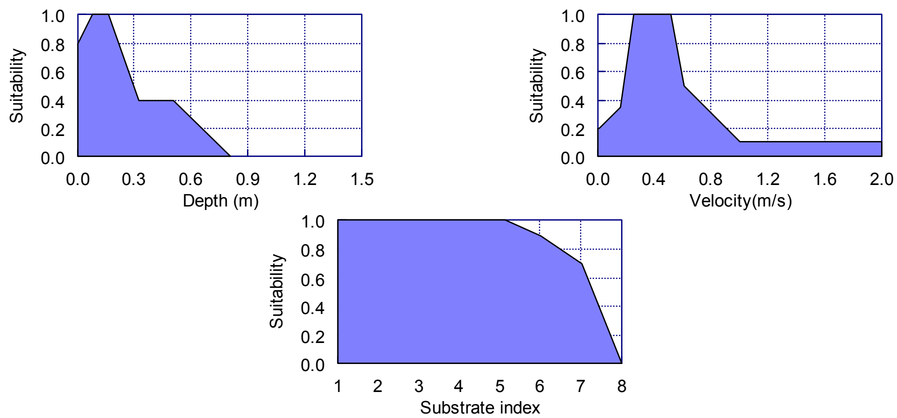
Upland bully



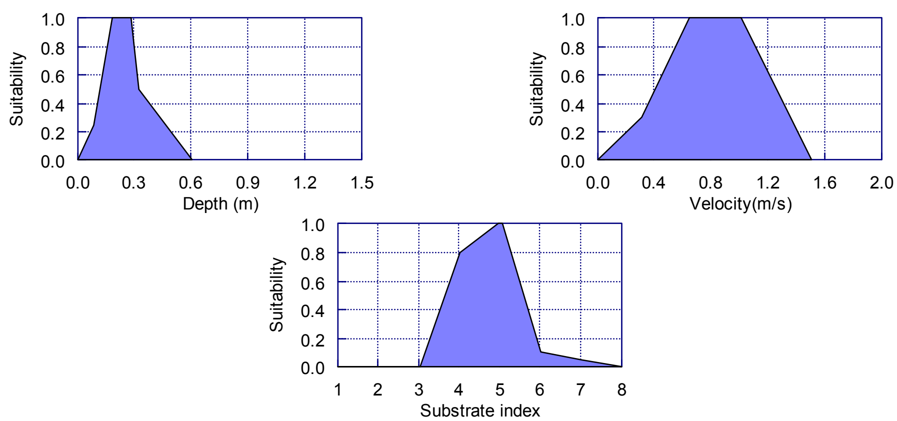
Redfin bully



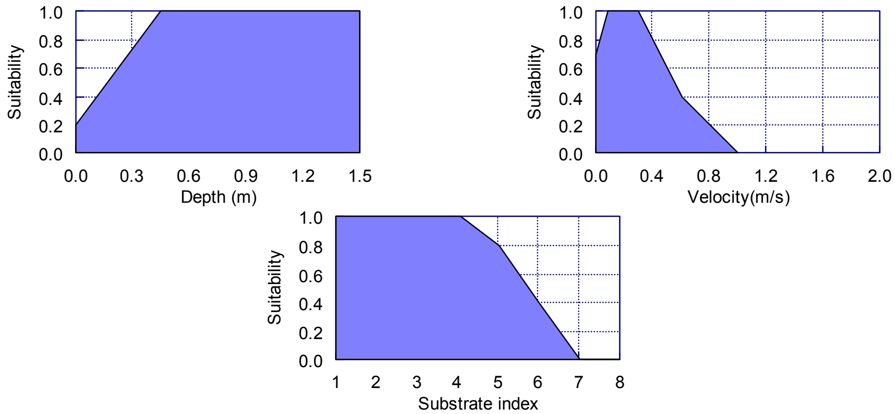
Common bully



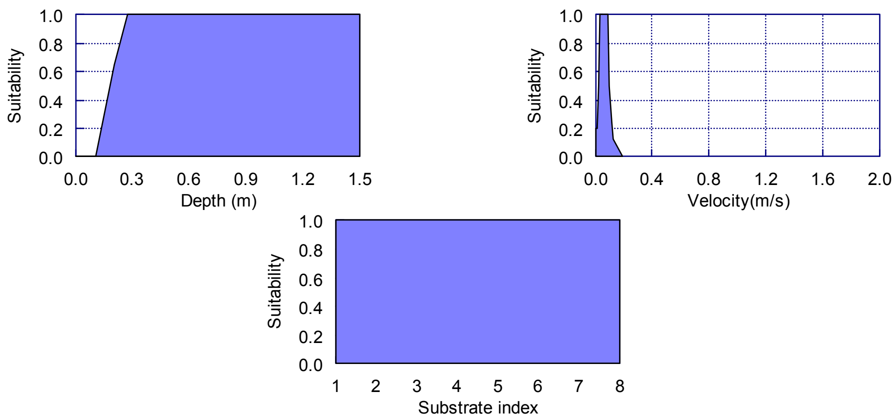
Bluegill bully



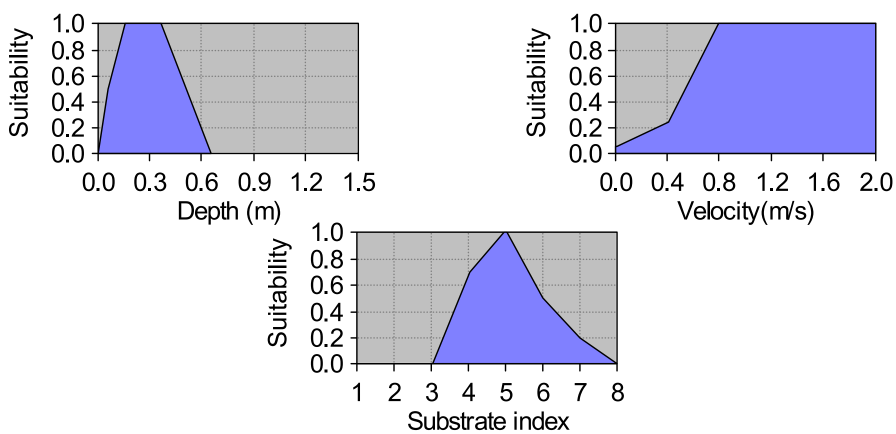
Common smelt



Inanga feeding



Torrentfish



Appendix 3 Estimation of "natural" flows in the Waimea River at Appleby Bridge (assuming no irrigation from the river or groundwater) – provided by Joseph Thomas and Martin Doyle (TDC)

Assessment of Low Flows at Appleby Bridge

Background:

The Wairoa River emerges onto the Waimea Plains from the gorge upstream of Brightwater. Downstream of its confluence with the Wai-iti River it becomes known as the Waimea River.

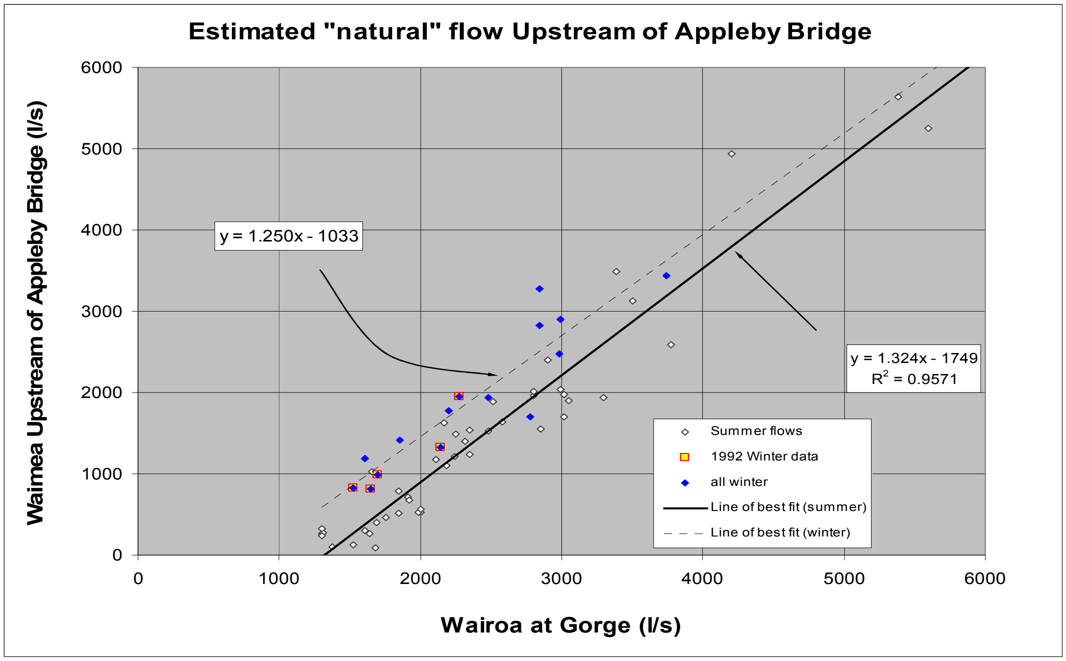
There is a dynamic relationship between river flows and adjacent groundwater in the Waimea Plains. Groundwater is the principal source for irrigation and urban/domestic/industrial water supply on the Waimea Plains. Groundwater loss patterns vary considerably over the seasons with a general increase in river flow losses downstream towards Appleby Bridge. The area immediately upstream of Appleby Bridge from a hydraulic point forms a flow constraint, as this area is where the flow tends to be the lowest. This area was dry for several weeks in the 2000/01 drought.

Flow Assessment

The Tasman District Council (TDC) has had a flow recorder at Wairoa Gorge for a long period of time and good flow statistics are available. In more recent times (since 2003) a new flow recorder has been installed upstream of Appleby Bridge, which also collects continuous information. Prior to this, TDC completed spot measurements of flow from time to time which were used to estimate natural flows at Appleby Bridge. This relationship is now able to be greatly improved with the use of information from the Appleby recorder.

TDC has also significantly improved and enhanced the river/aquifer model for the Waimea Plains. This model can assess daily water losses at different parts of the Waimea River for the years there is input data of the model variables.

The requirement for the IFIM analysis is the MALF value at around Appleby Bridge. As the MALF is a statistical value the model is unable to provide equivalence, as it provides daily values. To overcome this, flow correlation between Wairoa at Irvine's and Appleby at Nursery has been updated to include gauging data (prior to the Appleby recorder) and recent data from the Appleby recorder (until September 2005). The plot below shows the updated correlation.



The updated MALFs for the Wairoa Gorge (at Irvine's) show that the 7 day MALF is 2230 l/s and the one day MALF is 2050 l/s. The groundwater flow modelling shows that the average losses in spring time (no pumping) range between 400 – 580 l/s and for longer periods of flow stability the flow losses could be in the range of 800 – 1000 l/s (no pumping). MALF is a statistical number that takes into account flow throughout the year. In the case of the Waimea River even if there is no pumping in the summer the natural losses to groundwater are higher than that in winter/spring conditions and this is mainly due to the lower groundwater tables and higher evaporation losses. Hence this has to be accounted for in estimating MALF's at Appleby Bridge.

The plot above provides a correlation for average winter and average summer conditions. Hence the theoretical MALF is expected to be about mid-point between the summer and winter non-pumping losses. Hence the one day MALF upstream of Appleby Bridge is about 1300 l/s with the daily MALF about 1100 l/s.

J T Thomas & M C D Doyle
Tasman District Council
October 2005