Instream Flow Requirements in the Riwaka River and Implications for Frost Fighting

Cawthron Report No. 1337

November 2007

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Instream Flow Requirements in the Riwaka River and Implications for Frost Fighting

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Prepared for

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(Envirolink Grant No. TSDC27)

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Reviewed by: Joe Hay

Approved for release by: Rowan Strickland

Recommended citation:
Young RG 2007. Instream flow requirements in the Riwaka River and implications for frost fighting. Prepared for Tasman District Council. Cawthron Report No. 1337. 11 p.

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EXECUTIVE SUMMARY

Most considerations of instream flow requirements are focused on the summer/autumn period when low river flows and peak irrigation demands coincide. However, a different situation exists in the Riwaka River, where there is also a growing demand for water from the river during late winter and early spring for frost fighting, to protect developing kiwifruit buds. This report considers instream flow requirements during the frost fighting periods in the Riwaka River and determines if existing flow management rules derived for typical summer irrigation abstractions are appropriate.

In very cold climates, fish often use deep pools and clusters of cobbles/boulders as refuges during the winter to minimise their energy expenditure, rather than the typical feeding habitats where they are normally found in the summer. Therefore, predictions of habitat use that are based on summer habitat preferences do not necessarily reflect the importance of these winter refuge habitats. However, in most New Zealand rivers water temperatures are relatively mild and feeding habitats are probably used throughout the year. This is particularly true in the Riwaka River which drains karst geology and has a very stable temperature regime. Relationships between flow and habitat use based on summer habitat preferences are probably still valid in the winter in the Riwaka River.

Adult trout are recognised as having among the highest flow demands of New Zealand's freshwater fishes. Consequently, minimum flow requirements are often derived for trout, under the assumption that these will also provide adequate flow to maintain habitat for the majority of other fish species.

Our current understanding of factors controlling adult trout densities is that they are limited by habitat availability for adults at the mean annual low flow and the availability of food producing habitat at the median flow. The habitat available at the mean annual low flow may also act as a 'bottleneck' for native fish populations. Flows in the Riwaka River are generally relatively high during the frost fighting period, therefore large volumes of water could be abstracted without reducing river flows below levels commonly observed during the summer months. Metabolic demands of fish and other aquatic life will also be lower during the frost fighting periods than in mid-summer, when water temperatures and associated metabolic costs are elevated. Therefore, a period of extreme low flows during winter/spring is likely to have a smaller effect on fish growth and carrying capacity than a period with the same low flows during summer. In addition, water abstraction for frost fighting will be spasmodic and only occur for a relatively short duration.

Trout spawn during the early winter and may migrate around the catchment to find suitable spawning areas. An analysis of some existing flow-habitat information from the Riwaka River indicated that once flows drop below 0.6 m^3/s some parts of the river will become too shallow to allow fish passage. Ideally flows should be maintained above this level to ensure that fish are able to move freely throughout the catchment. However, much of the migration is likely to occur during natural freshes in the river, so the effects of a short-term abstraction on fish passage are likely to be relatively minimal.

Substantial reductions in flow during the winter/spring period may have an effect on trout eggs incubating in spawning gravels. Incubation occurs from spawning (May-July) through to October, when the fry emerge from the gravels. Reductions in water level may reduce flow through the gravels

limiting the oxygen supply to the eggs, while larger reductions may result in trout redds (or nests) being left high and dry above the water level. In such situations, incubating eggs may be killed by desiccation or freezing. Habitat modelling predictions indicated that any abstraction between May and October resulting in flows being reduced to near the natural MALF would result in up to a 50% reduction in the availability of suitable spawning habitat compared to that available at the median flow in May when the eggs are deposited. However, this prediction exaggerates any effects since natural flow reductions will also affect habitat availability, and the spawning habitat suitability criteria that were used for the modelling will over-estimate the effect of reductions in water depth on egg incubation.

If the requirements of instream values are given precedence over out-of-stream users then a minimum flow, equivalent to the natural MALF at the Hickmotts flow recorder, should be set for the May to October period. However, if the needs of both instream and out-of-stream users are considered together then the current minimum flow and trigger levels in the Tasman Resource Management Plan may be considered appropriate. Note, however, that the current minimum flow is considerably lower than the natural MALF and could result in a considerable amount of habitat reduction compared to that available at the natural MALF. It may be timely to consider the appropriateness of the minimum flow in the plan. Consideration should also be given to setting an allocation limit during the May to October period to ensure that flows are not reduced down to the minimum flow for prolonged periods. This is unlikely, given the nature of water demand for frost fighting. However, an analysis of historic records of minimum flows during the frost fighting period indicated that a maximum permissible instantaneous take of 400 L/s throughout the catchment would ensure that flows would only rarely be reduced below the highest current trigger value (615 L/s) by abstraction.

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1. INTRODUCTION

A detailed study of the flow requirements for fish and invertebrates in the Riwaka River was conducted by Hayes (1998) and aimed to assist the Tasman District Council (TDC) with setting minimum flow conditions for the Riwaka River. This study suggested that the mean annual low flow (MALF – 1015 L/s at SH60 bridge, Hickmotts Flow recorder site) would be an appropriate minimum flow if the requirements of the trout population were given precedence over the needs of out-of-stream users. Hayes (1998) also showed that instream habitat availability was predicted to decline linearly at flows less than the MALF. Therefore, there was no ecologically definable flow less than the MALF that would be an obvious choice for a minimum flow condition if the needs of both instream and out-of-stream users were considered together. The minimum flow and allocation limits that were set for the Riwaka Water Management Zone in the Tasman Resource Management Plan (Allocation limit – 200 L/s; Minimum flow 400 L/s) were determined through discussion between interested parties after considering the recommendations from Hayes (1998). It was assumed that some of the effects of low flows would be mitigated by the relatively cool summer water temperatures in the Riwaka River, with further potential mitigation through enhancing instream cover along the river (J. Thomas, pers. comm.). A series of trigger levels (615 L/s, 540 L/s, 500 L/s and 485 L/s) are also used to roster/ration water allocation.

Most considerations of instream flow requirements and minimum flow conditions are focused on the summer/autumn period, when low river flows and peak irrigation demands coincide. However, a different situation now exists in the Riwaka Catchment where there is also a large demand for water from the river during late winter and early spring. Kiwifruit are an important crop in the Riwaka Catchment and growers are increasingly requiring water for frost fighting in the period from late August to early November, to protect the tender kiwifruit buds from frosts. Water for frost fighting is also required in May to protect maturing fruit from frosts before being picked. However, frost fighting in May is only required after a long period of severe frosts, since the leaves protect the fruit from light frosts. During frost fighting, relatively large amounts of water are sprayed above the vines once critical low temperature thresholds (0.3°C) are reached. Frost fighting can take place sporadically for just a few hours, or can take place for 12+ hours per day for several days in a row depending on the weather patterns and severity of the frosts. The existing water allocation limits in the Tasman Resource Management Plan only apply for the period from November to April, so allocation during frost fighting is only limited by the minimum flow condition.

Using a small Envirolink grant (TSDC27), TDC commissioned the Cawthron Institute to consider instream flow requirements during the frost fighting periods in the Riwaka River and determine if existing flow management rules derived for summer irrigation abstractions are appropriate.

2. INSTREAM REQUIREMENTS DURING WINTER/SPRING

There is a limited amount of information available on how the habitat requirements of aquatic life varies throughout a year. Nevertheless, fish are known to occupy different types of habitats at different times of the year. In winter, for example, fish seek habitats where they can minimise energy expenditure rather than habitats where they can maximise food intake (Cunjak 1996). Fish are cold-blooded so their body temperature reflects that of the surrounding environment. Cold water temperatures mean that digestion is very slow in winter. Therefore, it doesn't make sense for a fish to use up valuable energy reserves to seek and capture food that can not be digested. Deep pools and clusters of cobbles and boulders are often used as winter refuges, at least in northern North American rivers, where water temperatures are close to freezing throughout the winter. Habitat suitability curves that are used in IFIM habitat modelling are usually based on data collected in summer and therefore do not necessarily represent habitat use at other times of the year. For example, the habitat preference curves for adult brown trout that are widely used throughout New Zealand to assist with flow management decisions were based on summer habitat use in three rivers and focused on fish that were actively feeding (Hayes & Jowett 1994). Therefore, the predictions from IFIM habitat modelling can not necessarily be directly applied to other times of the year, when habitat preferences may change. This would be particularly important in rivers where temperatures drop close to zero during the winter and the importance of microhabitats that minimise energy expenditure would be undervalued in the outputs of the modelling.

Larger scale habitat selection also occurs on a seasonal basis in response to life-history requirements. For example, fish will move to seek appropriate spawning habitat. This can include suitable gravels in headwater streams for salmonids, or suitable vegetation in tidal reaches that are inundated by spring tides for inanga. Fish may also move large distances to exploit feeding opportunities, and/or more suitable water temperatures, that are only available on a seasonal basis (Northcote 1992).

In New Zealand the temperature regime in most rivers is much milder than in the North American rivers where the majority of the studies of winter habitat preferences have been conducted. Even in the coldest parts of winter, water temperatures in the Riwaka River are rarely below 5°C (Figure 1). During the frost fighting periods (May and August-November) water temperatures are around 10°C (Figure 1). This mild temperature regime in the Riwaka River means that fish are likely to feed throughout the year (Hayes *et al.* 2000) and therefore, the existing habitat suitability curves are still appropriate for use in the frost fighting period. The same situation is probably the case for other types of aquatic life in the Riwaka River, although I am not aware of any specific information on the effects of low temperatures on habitat selection of other common stream life in New Zealand.

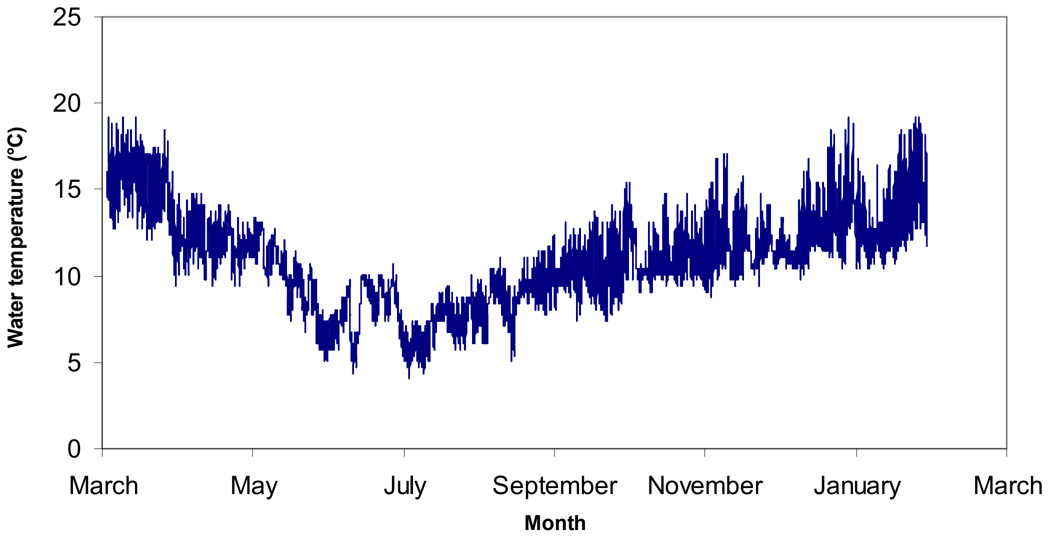

Figure 1. Intra-annual changes in water temperature in the Riwaka River at Hickmotts recorder. These data were recorded in 2001/02.

Brown trout spawn in early winter, therefore, flows need to be sufficient to allow fish passage during May. Adult eels move downstream into the sea in autumn and early winter, heading for their distant spawning grounds in the tropical Pacific and also need sufficient flows to enable passage. Inanga spawn during autumn on spring tides with the eggs hatching in early winter on subsequent spring tides. The effects of flow abstraction in May on inanga hatching are likely to be negligible since tidal fluctuations, rather than river flows, are primarily responsible for water levels in inanga spawning areas.

Substantial reductions in flow during the winter - spring period may potentially have an effect on trout eggs incubating in spawning gravels. Incubation occurs from spawning (May-July) through to about October, when the fry emerge from the gravels. Reductions in water level may reduce flow through the gravels, limiting the oxygen supply to the eggs, while larger reductions may result in trout redds (or nests) being left high and dry above the water level. In such situations, incubating eggs may be killed by desiccation or freezing during severe frosts. Water abstraction for frost fighting, however, would be only spasmodic and occur for relatively short periods, thus reducing the likely consequences of these effects.

3. HABITAT AVAILABILITY IN WINTER/SPRING

3.1. Feeding habitat

Our current understanding of trout populations is that they are limited by habitat availability for adults at the MALF and the availability of food producing habitat at the median flow (Jowett 1992). The MALF is closely correlated with annual low flow events, and as such provides an index of the minimum flow that can be expected from year to year (although the one year return period minimum flow would arguably be a more relevant statistic). The lowest flow that a river falls to each year sets the lower limit to physical space available for adult trout, although the duration of low flow is also relevant. This annual limit to living space potentially sets a limit to the average numbers of trout. The MALF is also indicative of the low flows likely to be experienced during the generation cycles of trout. Brown trout 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. The MALF has an expected return period of about 2.33 years in most rivers. Consequently, the MALF sets the lower limit to physical space likely to be experienced by trout before they are able to begin making a reproductive contribution to the population (*i.e.* it may be a factor in limiting the number of trout that are able to be supported through to reproductive age).

It seems reasonable that the MALF should be similarly relevant to native fish species with generation cycles longer than one year, at least in situations where their habitat declines toward the MALF. If the minimum flow restricts habitat for any species, there is potential for a detrimental effect on that population. NIWA research in the Waipara River, where habitat is limited at low flow, showed that the detrimental effect on fish numbers increased with the magnitude and duration of low flow (Jowett & Hayes 2004). Research on the Onekaka River, in Golden Bay, also showed that when habitat availability (estimated by WUA) was altered by flow reduction, abundance of three native fish species showed responses similar to those for habitat availability in both direction and magnitude (Richardson & Jowett 2006) (*i.e.* eels and koaro habitat was reduced and these species declined in abundance, while redfin bully habitat increased and so did their numbers).

The metabolic demands of fish and other aquatic life will be lower during the frost fighting periods than in mid-summer, when water temperatures and metabolic costs are elevated (Hayes *et al.* 2000). Therefore, a period of extreme low flows during winter/spring is likely to have a smaller effect on fish growth and carrying capacity than a similar period with the same low flows during summer.

The duration of low flow is also important. The effects of having flow artificially reduced to the mean annual low flow for prolonged periods are expected to be more pronounced than if flows were reduced to the same level for just a few days, although there is limited scientific information to confirm this expectation. Water requirements for frost fighting are expected to be relatively episodic, with consistent reductions in flow unlikely.

Flows are recorded at three sites in the Riwaka River (Figure 2). Water is currently abstracted for frost fighting from the North Branch of the Riwaka upstream of the confluence with the South Branch, and in several locations through the 4 km reach upstream of the SH60 bridge (Figure 2). Flows are generally relatively high during the frost fighting period, particularly in spring (Table 1). The natural flow minima would have typically occurred during the period from January to April and the natural MALF is estimated to be 1015 L/s at the Hickmotts flow recorder near the bottom of the catchment (Hayes 1998). Abstraction of at least 800 L/s during

August, September, October and November would be required to reduce flows to the equivalent of the natural MALF at Hickmotts, even when flows are at the median monthly minimum (*i.e.* the median over the period of flow record of the minimum flows recorded each year in a given month). Median monthly minimum flows in May were closer to the natural mean annual low flow and abstraction of as little as 43 L/s would reduce flows below the natural mean annual low flow at the Hickmotts Flow recorder (Table 1).

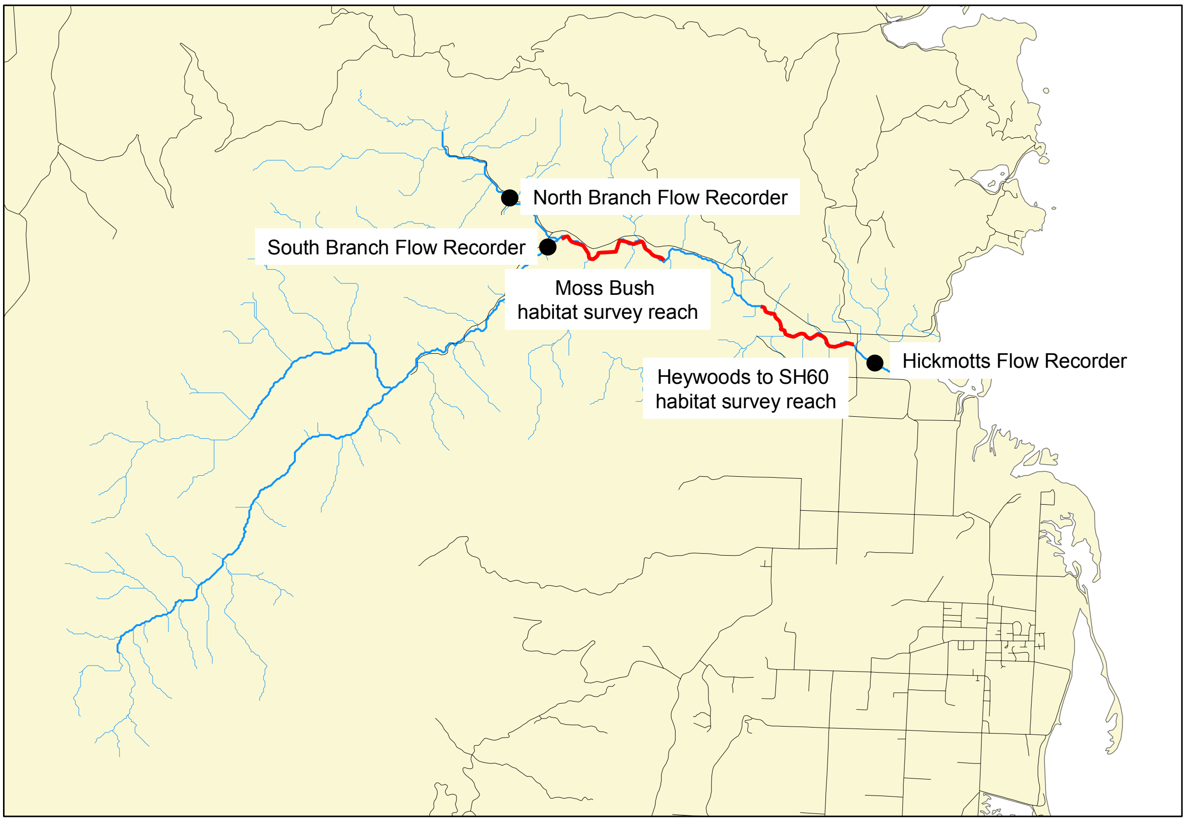

Figure 2. Map of the Riwaka Catchment showing the location of the flow recorder sites and reaches where habitat surveys were conducted by Hayes (1998).

Table 1. Flow statistics for the three hydrological recording sites in the Riwaka Catchment.

Site	Month	Mean flow (L/s)	Median flow (L/s)	Median monthly minimum flow (L/s)
Riwaka North Branch	May	1359	641	386
	August	1808	953	627
	September	1846	992	633
	October	1842	928	593
	November	1336	745	564
Riwaka South Branch	May	2368	1267	845
	August	3227	1901	1113
	September	3261	1945	1255
	October	3082	1831	1126
	November	2495	1528	1048
Riwaka @ Hickmotts	May	4297	2193	1058
	August	5082	3289	2165
	September	5740	3175	2045
	October	6030	3240	2121
	November	4298	2530	1898

3.2. Fish passage

As mentioned above, fish often need to migrate in order to reach spawning or feeding grounds. Adult brown trout are the largest bodied fish in the Riwaka (with the possible exception of some large longfin eels), so probably are the most demanding in terms of depths and velocities for passage (especially given that eels are known to be capable of moving over obstacles with very shallow water cover, or without water). Using the flow-habitat surveys that were conducted by Hayes (1998) it is possible to predict how the availability of suitable depths and velocities for passage of adult trout will change with flow. The minimum width of river providing suitable depths (>0.18 m) and water velocities (<2.6 m/s) for adult trout passage (Thompson 1972) throughout the surveyed reaches was predicted using a hydraulic habitat model (RHYHABSIM) and is shown in Figure 3. Trout can negotiate short riffles (a few metres in length such as occur in small streams) which are shallower than these depths but the above depths may be marginal for trout passage if the riffles are very long (*e.g.* tens of metres).

In the upstream reach at Moss Bush (downstream of the confluence of the North and South branches), much of the river width is suitable for passage at flows greater than 1 m^3/s (Figure 3). However, once flows drop below 0.5 m^3/s, depths across the entire cross-section of the river are predicted to become too shallow for passage in some riffles. Similarly, in the downstream reach between Heywood's Bridge and SH60, fish passage is predicted to be limited in some places once flows drop below 0.6 m^3/s. Ideally flows should be maintained above these levels to ensure that fish are able to move freely throughout the catchment. However, much of the migration is likely to occur during natural freshes in the river, so the effects of a limited abstraction on fish passage are likely to be relatively minimal, especially if flow reductions caused by abstraction are of relatively short duration.

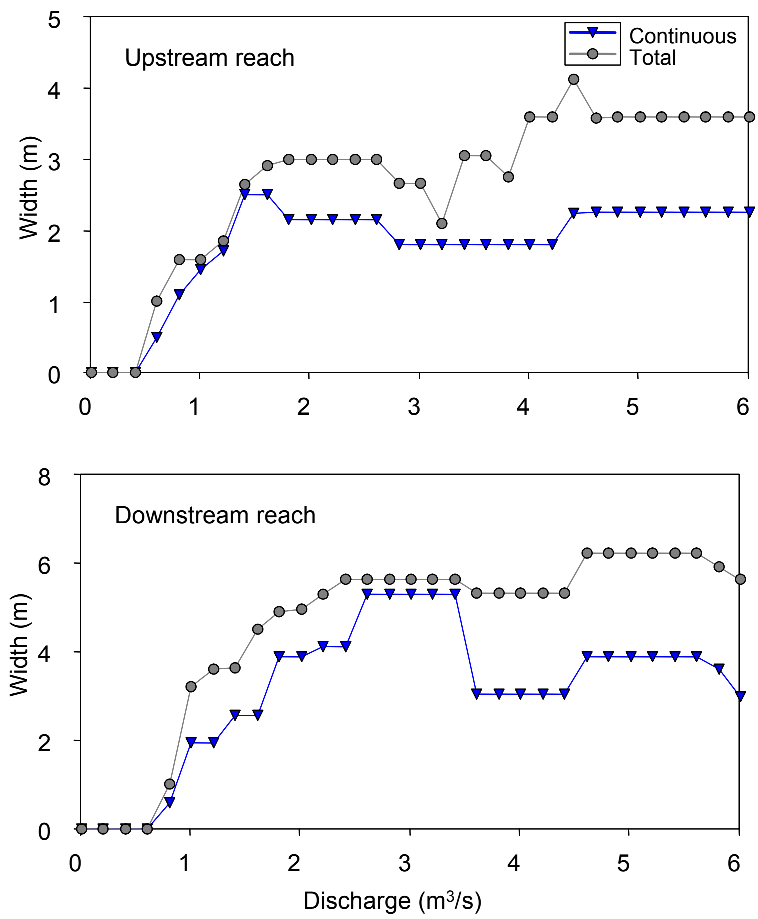

Figure 3. Changes in the minimum width of river channel that is suitable for adult trout passage, in the upstream (Moss Bush) and downstream (Heywood's Bridge to SH60) reaches of the Riwaka River. Continuous width refers to the largest single part of the cross-section that is suitable for passage, while total width is the sum of all the suitable parts.

3.3. Spawning habitat and egg incubation

Brown trout typically spawn in early winter, therefore the availability of spawning habitat during May provides an indication of the areas in which they are likely to spawn. As mentioned previously, a large abstraction of water at any stage while the trout eggs are still incubating in the gravels has the potential to expose the eggs to desiccation and/or freezing. To model the potential for this to occur, I again used the flow-habitat survey data that was collected by Hayes (1998). The availability of spawning habitat at the median flow in May was considered to represent that likely to be available to spawning fish in most years. Using existing flow records, the median flow in May was 1.9 m^3/s and 2.2 m^3/s in the upstream and downstream reaches, respectively. The effects of flow reductions below this level were predicted using the RHYHABSIM hydraulic model and are shown in Figure 4. In the upstream reach any abstraction between May and October (when the eggs hatch) resulting in flows being reduced to near the MALF (~1.0 m^3/s) was predicted to result in a 35% reduction in the availability of suitable spawning habitat compared with that at the median flow in May

(Figure 4), according to the habitat suitability criteria for brown trout spawning (Shirvell & Dungey 1983; Figure 5). Similarly, in the lower reach of the Riwaka River, any abstraction between May and October that resulted in flows being reduced to near the MALF was predicted to result in a 50% reduction in the spawning habitat availability compared with that available at the median flow in May (Figure 4). However, natural low flows during the May to October period will also result in reductions in spawning habitat availability, therefore the above predictions could be considered as a worst case scenario. Flows approaching the MALF are very rare during the August to October period, but have been recorded during May (Table 1).

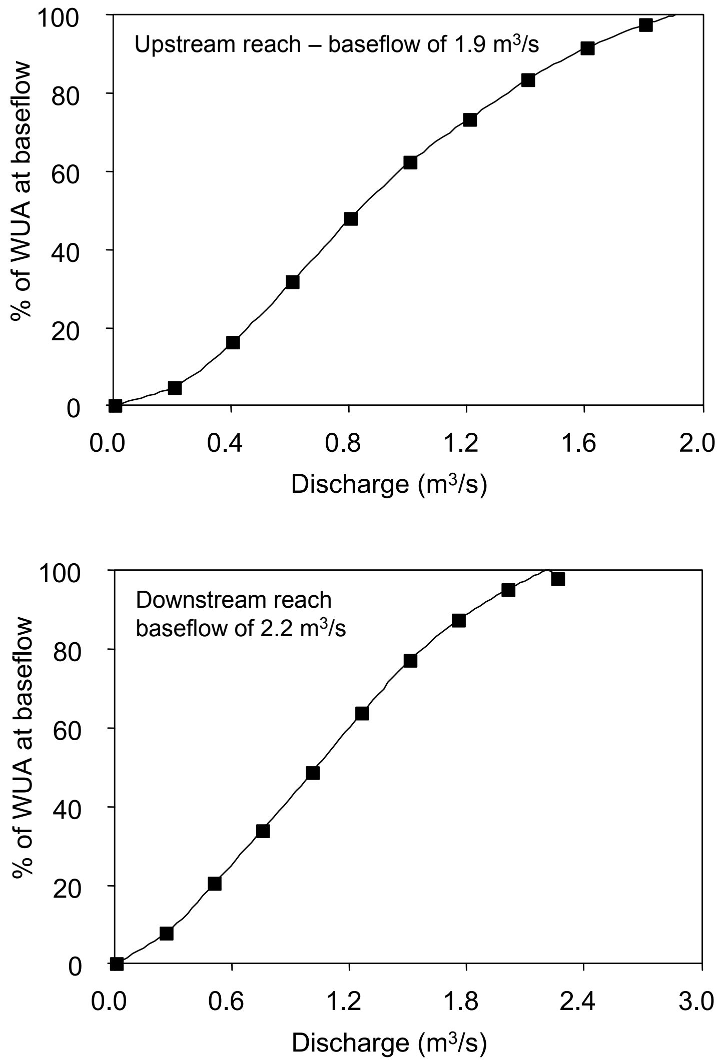

Figure 4. Reductions in the availability of brown trout spawning habitat at flows below the May median flow in the upstream (Moss Bush) and downstream (Heywood's Bridge to SH60) reaches of the Riwaka River.

One thing to consider with this analysis is that spawning habitat suitability primarily considers the suitability of the location for adult trout access so they can spawn and assumes that fish are able to choose areas that are suitable for egg incubation. Therefore, the effects of flow reductions on the availability of spawning habitat that are mentioned above will exaggerate the effects on egg incubation. For example, egg development will continue to occur in the gravels even if water depth at that location becomes too shallow to allow access for adult trout. Egg mortality will only occur if the gravels are completely exposed and the eggs are desiccated or frozen, or if reductions in flow of water through the gravels limit oxygen supplies to, and waste product removal from, the developing eggs.

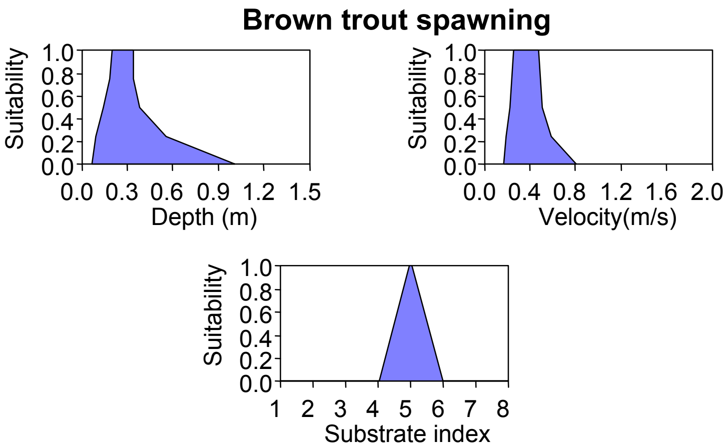

Figure 5. Habitat suitability curves for brown trout spawning from Shirvell & Dungey (1983). Substrate indices are 1 = Vegetation, 2 = Silt, 3 = Sand, 4 = Fine gravel, 5 = Gravel, 6 = Cobbles, 7 = Boulders, 8 = Bedrock.

4. OTHER POTENTIAL EFFECTS

Large-scale application of frost fighting water throughout the Riwaka Valley has the potential to increase the delivery of nutrients and sediment to the river from the surrounding orchards. This could occur if large volumes of water are applied to saturated areas of soil beneath the kiwifruit resulting in surface runoff from the land into the river. However, this is probably a relatively minor effect given the relatively small proportion (<2%) of the total catchment where kiwifruit is grown.

Large abstractions of water from the Riwaka River also have the potential to affect water temperatures in the river, since the remaining water would have less thermal inertia and more closely reflect air temperatures. However, this effect is likely to be insignificant unless river flows were reduced to near zero since water temperature is relatively insensitive to flow (Theurer *et al.* 1984).

5. IMPLICATIONS FOR FLOW MANAGEMENT

Water allocation in the Riwaka water management zone is currently managed using a minimum flow of 400 L/s that applies at all times throughout the river, an allocation limit of 200 L/s that applies only during the period from November to April, and a series of trigger levels (615 L/s, 540 L/s, 500 L/s and 485 L/s) which are used to roster/ration water allocation. At present there is no allocation limit during the frost fighting periods.

If the requirements of instream values are given precedence over out-of-stream users then a minimum flow, equivalent to the natural MALF (*i.e.* 1015 L/s at the Hickmotts flow recorder), should be set for the May to October period. This would help to protect fish passage during this period. Setting the minimum flow at the MALF during this period would also enable protection of developing trout eggs deposited in river gravels and ensure that habitat limitation for fish was no worse than what would be expected during a natural summer low flow. However, if the needs of both instream and out-of-stream users are considered together then the current minimum flow and trigger levels in the Tasman Resource Management Plan may be considered appropriate. Note, however, that the current minimum flow is considerably lower than the estimated natural MALF. Approaches to setting minimum flows below the MALF have developed somewhat since 1998 (Jowett & Hayes 2004) and it may be timely to consider the amount of habitat reduction that this minimum flow represents compared to that available at the natural MALF.

Consideration should also be given to setting an allocation limit during the May to October period. The main ecological reason for requiring an allocation limit is to ensure that flow fluctuations are maintained in the river and flows are not held at the minimum flow for prolonged periods. Sensible allocation limits are also required to ensure security of supply for water users. Allocation limits are sometimes set using rules of thumb (*e.g.* 10% of MALF) or alternatively as the difference between a 'management' flow and the minimum flow. The later system uses the historic frequency of the management flow to indicate the expected frequency of the minimum flow under the influence of allocation. However, for frost fighting the water takes will be episodic and only over a relatively short-term, so flat-lining of river flows is unlikely. Looking at the historic records of minimum flows during the frost fighting period (Table 1), an allocation limit of 400 L/s throughout the catchment between May and October would ensure that flows would only rarely be reduced below the highest current trigger value (615 L/s).

6. REFERENCES

Cunjak RA 1996. Winter habitat of selected stream fishes and potential impacts from land-use activity. Canadian Journal of Fisheries and Aquatic Sciences 53 (Suppl. 1): 267-282.

Hayes JW 1998. Riwaka River instream habitat flow analysis. Cawthron Report No. 400. Prepared for Tasman District Council and Fish & Game NZ – Nelson/Marlborough region.

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

Hayes JW, Stark JD, Shearer KA 2000. Development and test of a whole-lifetime foraging and bioenergetics growth model for drift-feeding brown trout. Transactions of the American Fisheries Society 129: 315-332.

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

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

Northcote TG 1992. Migration and residency in stream salmonids - some ecological considerations and evolutionary consequences. Nordic Journal of Freshwater Research 67: 5-17.

Richardson J, Jowett IG 2006. Testing habitat-based in-stream flow methods for native fish. NIWA Poster presented at the New Zealand Freshwater Sciences Society Conference 27-30 November 2006, Rotorua.

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

Thompson KE 1972. Determining streamflows for fish life. In: Proc. Instream Flow Requirement Workshop, Pacific N.W. River basins Comm., Portland, Oregon. Pp.31-50.

Theurer FD, Voos KA, Miller WJ 1984. Instream water temperature model. Instream flow information paper 16. United States Fish & Wildlife Service, Fort Collins, Colorado.