Assessment of potential effects on instream habitat with reduced flows in the Hutt River at Kaitoke

Prepared for Greater Wellington Water
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Summary

This report is an amalgamation of previous reports, reviews and discussions with stakeholders, concerning effects on instream habitat with a reduction in streamflow below the Kaitoke water intake on the Hutt River.

The Kaitoke take has been in operation since 1957. Prior to 2001 there was no minimum flow requirement at Kaitoke (river km 42), but the Regional Fresh Water Plan (RFWP, WRC 1999) specified a minimum flow of 1200 L/s at Birchville (river km 26) and a minimum flow at Kaitoke of 600 L/s. The Birchville minimum flow was based on a hydraulic habitat analysis at Birchville. The Kaitoke minimum flow is speculative.

It is proposed to reduce the minimum flow at Kaitoke Weir from 600 L/s to 400 L/s for a 3 year period to provide additional water while the Stuart Macaskill Lakes are drained for seismic enhancement and increasing storage capacity. The maximum allowable take will remain unchanged at 1850 L/s and the scheme will shut down in high flows as at present.

The emphasis of the instream flow assessment has been on the lower reaches below Birchville where the greatest numbers of medium and large trout are reported. Over ten surveys the median number of trout increases downstream from ~9 medium and large trout in the upper reaches (Kaitoke and Te Marua) to 36 in the middle reaches (Birchville and Whakatikei) and 61 per km in the lower reaches (Heretaunga, Taita, Avalon and Melling).

Based on existing hydraulic habitat surveys at Birchville (km 26), Silverstream (km 15), Taita (km 13) and Melling (km 4), with adult brown trout or food producing habitat as critical values, I found the following hydraulic-habitat relations using the model RHYHABSIM:

- Lowering the minimum flow specified on the Kaitoke Weir abstraction consent to 400 L/s would maintain the 1200 L/s minimum flow at Birchville specified in the RFWP (the RFWP is based on retention of 66% of habitat);
- Taking a far more conservative view, with a Birchville flow of 2250 L/s at least 90% of the adult trout and/or food production habitat available at the existing mean annual low flow (MALF) will be retained throughout the system for at least 96% of the time with the proposed reduction in minimum flows at Kaitoke;
- With a Birchville flow of 2700 L/s at least 90% of the naturalised MALF (N-MALF) habitat can be retained throughout the system for at least 93% of the time with the proposed reduction in minimum flows at Kaitoke; and

- Reducing the minimum flow at Kaitoke Weir from 600 L/s to 400 L/s will have no material effect on food production habitat availability at the existing or naturalised median flow.

In addition, for the 5800 m reach of the Hutt River between Birchville and the gorge, effects of reduction in flows were assessed using the 100 rivers brown trout abundance model. The trout abundance model predictions align with observed long term average trout counts throughout the river. Reducing the existing MALF by 200 L/s is predicted to reduce trout counts by 1 to 2 large and medium trout per kilometre. This is not considered to be material in the context of the large natural variation in the number of trout which is probably attributable to flooding events which can devastate young, medium and large trout.

There is a strong relationship between measured water temperature at Te Marua, Birchville and Taita, and solar radiation with pronounced variability with cloud cover, time of day and season. Water temperature changes with additional flow abstraction were modelled in RHYHABSIM using Birchville hydraulics and local climatic inputs. Additional abstraction is expected to change water temperatures less than 1ºC in the 30 km below the gorge.

A reduced minimum flow at Kaitoke will have no material effect on the high flows required for channel formation and channel maintenance. The existing flow regime is very flashy, with significant, frequent bed disturbance.

It is concluded that the effects of the reduction in minimum flows from 600 L/s to 400 L/s over a three year period at the Kaitoke water intake is no more than minor.

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1 Situation analysis

1.1 Water supply issues

Greater Wellington Regional Council (GWRC) is responsible for promoting the sustainable management of the Hutt River within the broader context of the social, cultural and economic wellbeing of the people of the region and the Regional Freshwater Plan for the Wellington Region (RFWP; WRC 1999). Greater Wellington Water (GWW) is responsible for providing high quality water to meet the reasonable needs of the people of greater Wellington in a cost effective and environmentally responsible way (GWW 2004).

Hutt River at Kaitoke Weir has been the major water source for greater Wellington since 1957 (Figure 1).

Prior to 2001 there was no requirement to maintain a residual flow downstream of the Kaitoke weir. Since then the abstraction consent has required a minimum flow of 600 L/s.

The Kaitoke minimum flow was developed through consultation and consensus with stakeholders (McCarthy 2000). The objective was to increase the amount of habitat available for brown trout and to ensure that the minimum flows in the lower river are maintained (Harkness 2000).

GW Regional Water Network

Water from the weir is piped to Upper Hutt, Porirua and Wellington; and is supplemented by Wainuiomata River abstraction; and from aquifers in the lower Hutt River floodplain (Waterloo). Usually Upper Hutt, Porirua and Wellington's northern suburbs are supplied from Kaitoke, Lower Hutt is supplied from Waterloo and Wellington's central business district and southern and eastern suburbs are supplied by a combination of Waterloo and Wainuiomata. If required, water can be pumped from one main pipeline to the other, so any city can receive water from more than one source.[1] There is limited storage in the supply system following the closure of the Upper Karori Dam (1908-1992) and Morton Dam (Wainuiomata; 1911-1988) due to earthquake risks. Storage is now limited to the Te Marua storage lakes (and treatment plant) which opened in 1987.

(Based on History of the water network in www.gw.govt.nz accessed August 2007.

GWW is seeking a variation to the resource consent conditions to abstract water from at Kaitoke Weir to reduce the minimum low flow from 600 l/s to 400 l/s for a period of 3 years while the Stuart Macaskill lakes are drained to allow works on seismic enhancement and increasing storage capacity. The maximum allowable take will remain unchanged at 1850 L/s and the scheme will shut down during high flows as at present.

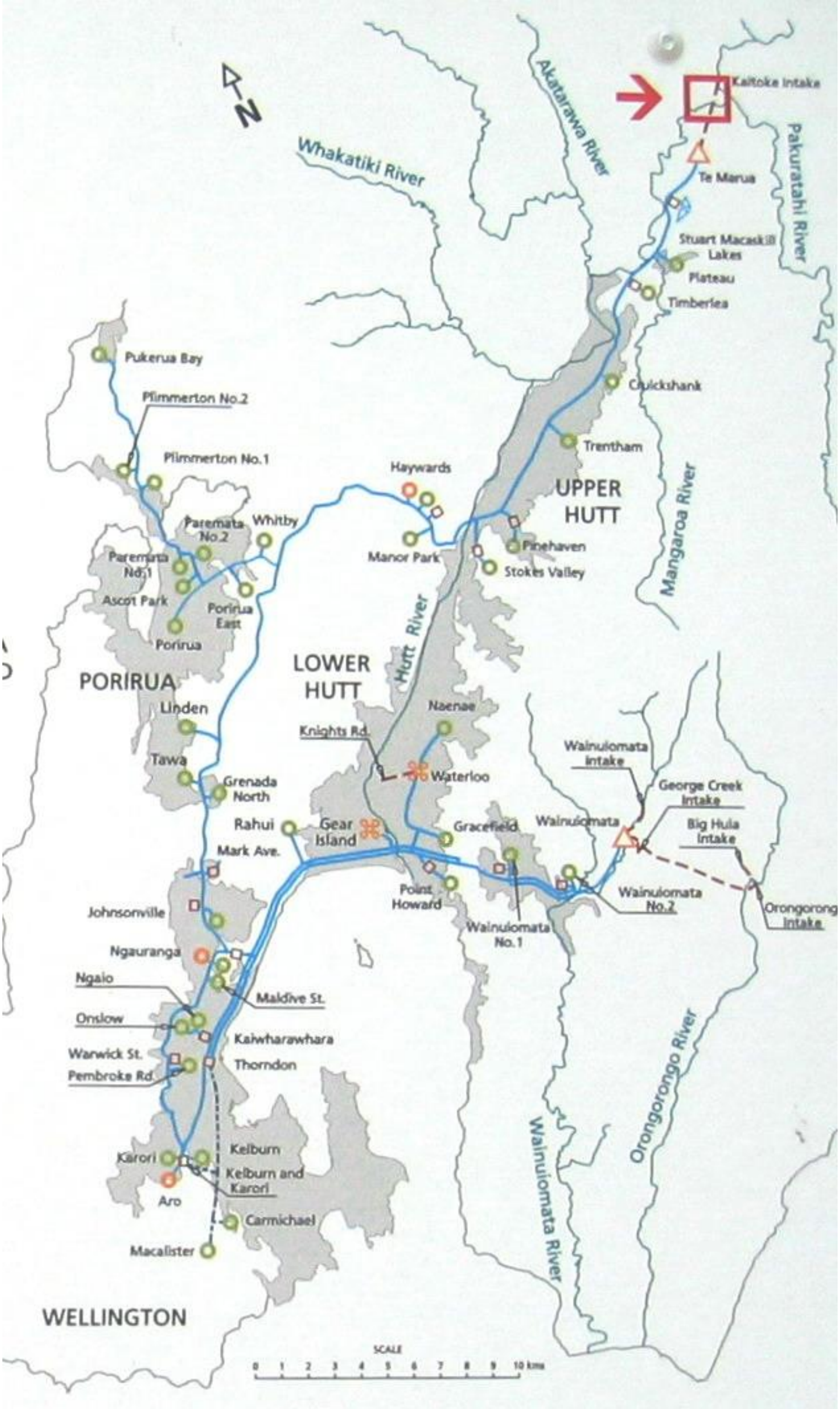

Figure 1 Greater Wellington regional water supply (GWW Kaitoke Weir sign)

1.2 Approach

As part of an application to reduce the minimum flow below Kaitoke Weir an assessment of the effects of this alteration is required. As discussed in Section 9.6.1 of the RFWP "*Policies on minimum flows and water allocation in rivers provide guidance for consent authorities as to the desirable minimum flows which should be maintained in rivers and streams. For larger rivers and streams, the desirable minimum flow is based on habitat methods (for example, the Instream Flow Incremental Methodology (IFIM)).*"

There is often confusion between the IFIM process and the tools used to quantify habitat changes (e.g. RHYHABSIM, WAIORA) (Hudson et al. 2003). IFIM addresses the decision making environment as well as the tools for quantifying incremental differences in habitat in a stream that result from alternative flow regimes.

The intention is to present an IFIM investigation in the manner proposed by the developers (Bovee 1982, 1997; Bovee et al. 1998; Waddle ed. 2001), and reiterated by Hudson et al. (2003), and Watts & Hurndell (2005 draft). RHYHABSIM (River Hydraulics Habitat Simulation) is used as a tool to describe the hydraulic geometry and estimate habitat availability at various flows using habitat suitability criteria.

There are several sequential phases, and various activities, in an IFIM analysis. The first step is and to identify the flow related issues; and to determine if habitat modelling is appropriate to address these issues.

Problem identification was undertaken in several workshops.[1] Four main issues were identified: (a) reductions in habitat availability in the river below the gorge; (b) low flow barriers to fish passage in the Hutt gorge below Kaitoke Weir; (c) water quality and risk of periphyton proliferation below the gorge; and (d) status of macroinvertebrates. Hudson & Harkness (2010) examined fish passage in the gorge; and Goldsmith & Ryder (2008) examined water quality and flow management to reduce the risk of periphyton proliferation. MWH (2008) examined macroinvertebrates. This report assesses habitat availability in the Hutt River below the gorge. Other aspects of the IFIM process are discussed elsewhere in this report.

In terms of effects of reduced flows on habitat availability, one could logically question why habitat was chosen as the decision variable when there are other factors such as stream productivity or fish mortality, but the simple reason is that impacts of changing flow on habitat are the most direct and quantifiable (Stalnaker et al. 1995). Further, limits of habitat availability must, by some means, control the size and dynamics of fish populations (Nehring & Andersen 1993; Minns et al. 1995; Cunjak & Therrien 1997), which are often used as an indicator of aquatic ecosystem health. Also, changes in stream flow may be linked, through biological considerations, to environmental and social, political and economic outcomes

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[1] Participants included Department of Conservation, Fish & Game, Greater Wellington Regional Council and consultants as described in the acknowledgements.

(Stalnaker et al. 1995). Therefore, a habitat modelling approach was considered appropriate for the Hutt River evaluation.

1.3 Outline

This report evaluates habitat availability in the lower Hutt River at various flows. Several steps are taken leading to an instream flow recommendation to provide for the requirements of the RFWP. In this regard the major topics addressed are:

- Aspects of the Hutt River catchment, hydrology, morphology and fisheries are described to provide the context for the investigations
- The framework for an instream flow assessment
- Water temperature
- Flow variability
- Discussion and
- Conclusion and recommendations

Supporting information is appended.

2 The Hutt River

2.1 The Hutt catchment

A detailed description of the Hutt River catchment, climate and rainfall, and surface water and groundwater hydrology is provided in "Hydrology of the Hutt Catchment" (WRC 1995). Wilson (2006) provides an update of the low flow hydrology. Here aspects of the Hutt River catchment, hydrology, morphology and fisheries are described to provide the context for the instream flow investigations; with more detail in Appendix A.

The 54 km long Hutt River has a mountainous source in the southern end of the Tararua Ranges. Two main branches (Eastern and Western Hutt) converge to form the Hutt River 4 km above Kaitoke intake (km 42; Figure 1 & Figure 2).

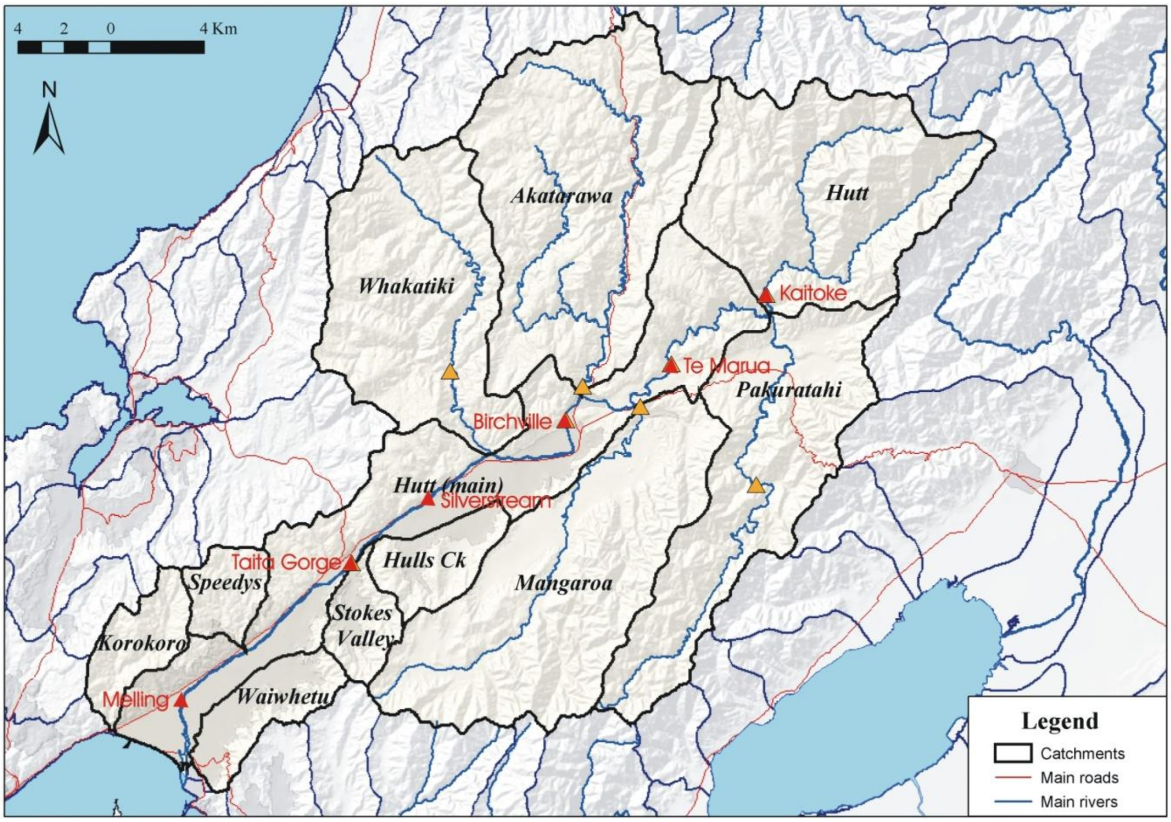

Figure 2 Hutt River catchment, gauging stations & survey locations (based on Wilson 2006)

The 65688 hectares Hutt catchment drains mainly hilly or mountainous terrain. Over 40% of the Hutt catchment is covered by indigenous forest, which is mainly confined to upper parts of the catchment drained by the Whakatikei, Akatarawa, Hutt and Pakuratahi rivers (Figure 2). The rest of the catchment consists of a mixture of grassland, scrub and exotic forest. Much of the low-lying terrain in the Upper and Lower Hutt basins is urban residential land (about 10% of the catchment). The catchment geology is dominated by greywacke basement rocks. The main valleys are filled with deposits of Quaternary alluvial gravels overlain by impermeable marine sediments. There are downstream surface flow gains and losses into these gravel aquifers.

2.2 Aspects of rainfall & streamflow

The greater Wellington water supply relies largely on run of river flows because stored water volumes are relatively small (McCarthy 2006). *"Peak [water] demand typically occurs in January or February …. Typically, river flows are lowest in March or April, i.e. they are not usually coincident with the period of highest demand. Occasionally, if a very dry spring causes river flows to drop earlier than usual, or a long hot summer causes high demand in March or April, problems may be encountered in meeting the demand for water."* (McCarthy 2006).

The primary water source is the Hutt River at Kaitoke Weir (Figure 1). Kaitoke intake is well sited because the greatest rainfall occurs in the Hutt River headwaters. At mean annual low flow Kaitoke abstraction has a marked effect on flows through the gorge, and a diminishing proportional effect further downstream as major tributaries contribute to the Hutt River (Figure 2). Droughts, and low flows, can vary between the sub-catchments, depending on prevailing wind-direction over the summer. As a result, low flow events from the tributaries are not necessarily synchronous, which mitigates the effects of water abstraction from Kaitoke on the Hutt River below the gorge.

As well as short term events and seasonal variability in rainfall and flow, long term trends occur. Rainfall-runoff modelling shows that over a period of more than 100 years, recent flow records reflect generally higher flow conditions. For three phases of the Inter-decadal Pacific Oscillation, the daily natural mean annual low flow (N-MALF) at Birchville was predicted as follows: 1922-1944 2304 L/s; 1947-1977 2439 L/s; and 1978-1998 3278 L/s (Table A 10; page 90).[2] This suggests a cautious approach is warranted in recommending minimum flows for the future; and that streamflow records should be standardised to a common base period to compute water budgets.

One day mean annual low flows (MALF) for the existing flow records were estimated for the period 1971-2006 for the Hutt River at Birchville, Silverstream, Taita and Melling (Figure 2; Table 1). Flows at Silverstream were estimated from Birchville based on low flow concurrent gaugings relations. To coincide with the Birchville record, Watts (2006) established a mean daily low flow relation between Birchville and Taita Gorge, and used that relation to extend the Taita record. The flow at Melling was estimated from Taita based on low flow concurrent gaugings.

In the workshops stakeholders requested that naturalised flows should be evaluated.

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[2] Tables & Figures with an A before the number refer to Tables & Figures in Appendix A.

Table 1 MALF estimates from streamflow records & concurrent gaugings 1971-2006 (data from Wilson 2006 & Watts 2006) (L/s)

Location	**Mainstem**	**Gains/Loss**
Hutt at Kaitoke	1341	
Calculated abstraction		-763
Pakuratahi River input		410
Hutt at Te Marua	988	
Mangaroa River input		343
Akatarawa River input		998
Hutt at Birchville	2274	
Whakatikei River input		462
Unspecified gain		90
Hutt at Silverstream*	2826	
Calculated unspecified inputs		294
Hutt at Taita Gorge**	3120	
Calculated loss		-759
Hutt at Melling Bridge***	2361	

* Silverstream = 1.208*Birchville+79 L/s (r^2=0.84) (Wilson 2006)

** Taita Gorge flow from record extension by correlation with Birchville (Watts 2006)

** Melling = 1.022*Taita Gorge–828 L/s (r^2=0.96) (Wilson 2006)

Three approaches are employed to estimate natural stream flows downstream of Kaitoke Weir: (1) Ibbitt (2006) simulated streamflow based on rainfall-runoff modelling for the period 1890-2005; (2) Wilson (2006) calculated flows at Te Marua based on records of abstraction and streamflow for the period 2003-2005; and (3) water budgets were calculated from streamflow records and estimates of abstraction for various periods. These approaches are discussed in Appendix A.

Using the water budget approach, it was estimated that the natural one day MALF (N-MALF) is about 760 L/s greater for Birchville than the recorded MALF of 2270 L/s (i.e. 3030 L/s). This estimate is consistent with the simulated natural streamflow estimate for the same period (i.e. 3037 L/s), with the baseflow recession estimates of Wilson (2006) (Appendix A) and with the SYM modeling (minutes of the 20-05-2009 Workshop).

Streamflow in the Hutt River changes inconsistently downstream of Birchville because of gains and losses to the alluvial gravel aquifers. To conservatively estimate downstream naturalised mean annual low flows, 760 L/s was added to the estimates of MALF at Silverstream, Taita and Melling. For the purposes of modelling the flow estimates were rounded to the nearest 10 L/s (Table 2).

Table 2 One day mean annual low flow (MALF) & naturalised one day mean annual low flow (N-MALF) estimates for Hutt River study sites 1971-2006

Location	MALF (L/s)	N-MALF (L/s)
Birchville	2270	3030
Silverstream	2830	3590
Taita	3120	3880
Melling	2360	3120

2.3 Morphology

The Hutt is a gravel bed river with three main river segments:

1. A highly modified channel from the estuary (Hutt River km 0) to the Mangaroa confluence (Hutt River km 29.5) (Figure 3; 4);
2. Above the Mangarora confluence to Te Marua structural bank protection is largely replaced with willow bank protection and the river has a wider channel with some islands (Figure 5); and
3. A gorge segment upstream of Te Marua (km 32.4) Figure 6.

Figure 3 Hutt River view downstream from ~km 11 (left) & ~km 19 (right) (based on GW website photographs)

Within the segments, there are sections of river that differ in character. The lower 4 km is tidal, and does not generally have exposed gravel bars. Upstream to the Brown Owl reach, the river is characterised by alternating gravel bars with extensive bank protection (Figure 3, right), and some local bedrock exposures. At Brown Owl (km 25) the river is highly confined with exposed bedrock and a uniform channel.

Bedrock exposure is common further upstream through the Akatarawa confluence reach (km 27) to the Te Marua alluvial plains (~km 28-32) (4).

Figure 4 Hutt River at Akatarawa confluence (km 27) view upstream (left) & downstream (right)

For a short section of river extending ~1600 m above the Mangaroa confluence (29.5), the Hutt River is relatively unconfined, with limited structural bank protection, with some islands and extensive exposed gravel (Figure 5).

Figure 5 Te Marua reach (2003 GWRC aerial photograph)

The gorge segment of the Hutt river extends upstream of Te Marua (km 32.4). The gorge is characterized by bedrock valley walls, a boulder bed with extensive bedrock (Figure 6. The channel has deep pools, with sections of rapids. The gorge reach is described in more detail in the fish passage report of Hudson & Harkness (2010).

Figure 6 Hutt river gorge, view downstream to Te Marua water treatment plant from ~km 33.2

The lower river is below mean sea level, and the bed elevation increases gradually (~1m/km) exposing the gravel bed around km 5 (Figure 7). In the exposed gravel bed reach the slope increase to ~2.7 m/km from km 5 to 10; and to ~3.5 m/km in the upper reaches to the gorge. Fluctuations in the minimum bed levels (thalweg) reflects the pool-riffle nature of the bed and the close spacing of the transects in the Greater Wellington river bed surveys (~100 m apart) (Figure 7).

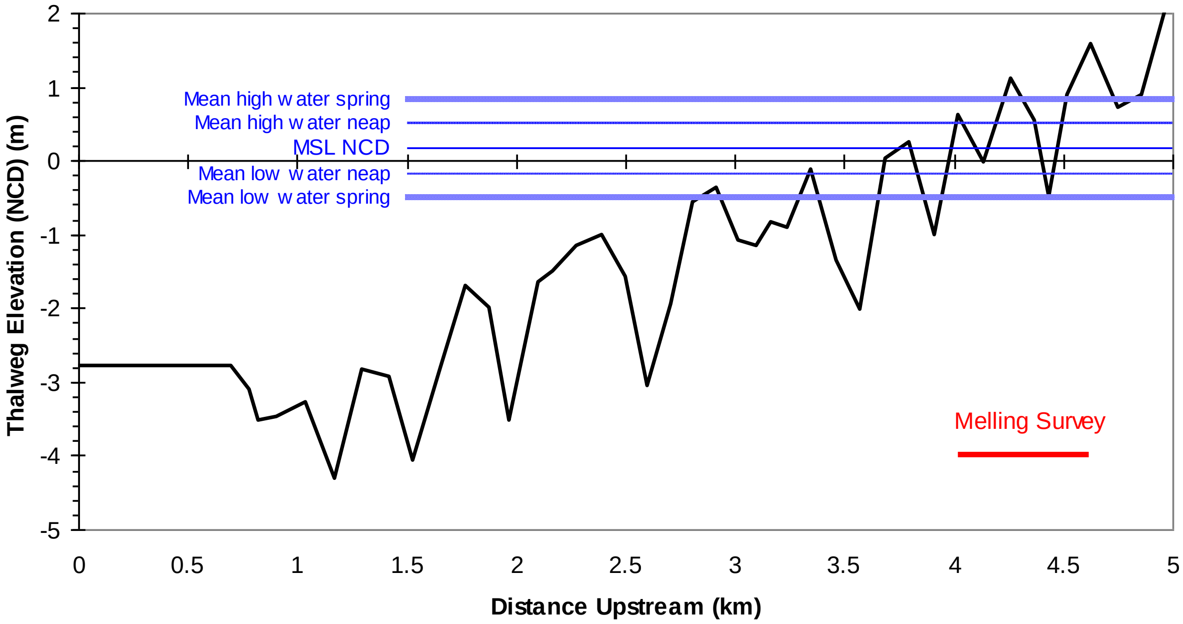

Figure 7 Bed elevation, Hutt River (GW bed survey data; LINZ sea level data; new city datum)

Pool-riffle counts are undertaken as part of the flood protection works evaluations. File Note N/50/3/17 reports 55 pools and riffles in the reach from Ewen Bridge (km 3.1) to above the Akatarawa confluence (at km 28). The average spacing of riffles decreases upstream from 620 m in the Ewen Bridge-Silverstream Bridge reach (km 3.1-14.6); to 460 m in the Silverstream-Maoribank reach (to km 24.3); and 340 m from km 24.3 to km 28.

There is a long history of flood protection and river control works in the Hutt River. GW cross section surveys show channel widths are far less than their natural state, with extensive bank protection with rock and willow, and local bedrock confinement (Figure 3 & Figure 8). The habitat survey reaches (Melling, Taita, Silverstream and Birchville) and the trout survey drift dive reaches, described in section 2.5, are marked.

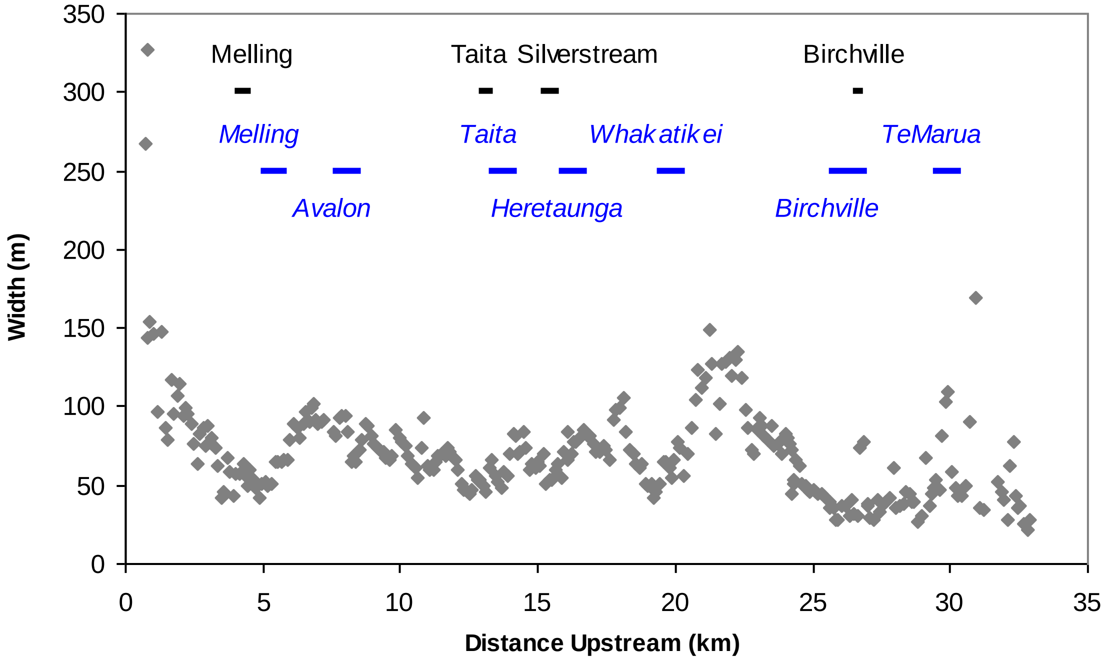

Figure 8 Hutt River active channel width, habitat survey reaches (black) & drift dive survey reaches (blue italics)

The likely consequence of the bank protection and development of berm lands is the loss of aquatic and terrestrial habitat (Blakely & Mosley 1987). On the other hand, Blakely & Mosley (1987 state: "*The planting of willows, poplars and other species has significantly increased the food supply for fish by improving insect habitat, leading to an increase in the river's invertebrate drift, and important food source for stream living fish*."

Gravel extraction, for the purpose of managing bed levels and channel capacity for flood control, was reinitiated in 2001 (Borrer 2004). Extraction occurs from Ewen Bridge (km 3.1) to Kennedy Good Bridge (km 6.8) with a recommended extraction rate of 30,000 m^3/year, subject to review. Gravel beaches upstream of the Silverstream bridges (km 14.6), and between the Whakatikei Confluence (km 20.3) and Totara Park Bridge (km 23) are actively managed by limited extraction, cross-blading, and relocation of material to other river reaches.

Gravel extraction is contentious, and has lead to a programme to monitor trout numbers and habitat structures (pool and riffles) (Taylor 2005). The concern is that gravel extraction, as undertaken in the Hutt River, appears to decrease habitat diversity, (e.g. eliminating deep pools).

As noted by Harkness (2002) "*The Hutt 2* [Taita in Figure 8] *reach was chosen, as it is in an area of the river that has recently been modified by flood protection works. There are very few pools in this area and a survey was desired to ascertain the habitat available in such situations.*"

2.4 Native fish

Strickland & Quarterman (2001) ranked the Hutt River below Kaitoke Weir as very important for native fish based on their review of the New Zealand Freshwater Fish Database (NZFFDB). They note the Wellington Region records are quite intensive for the Ruamanhanga and western catchments, but with knowledge gaps elsewhere. The native fish information was updated from the freshwater fish database and the location of the reported fish is summarised in terms of river distance from the sea (Table 3).

Species	River km	Species	River Km
Shortfin eel	6.5 - 26.1	Common bully	6.5
Longfin eel	15.0 - 42.3	Giant bully	4.7
Dwarf Galaxias	41.6 - 42.4	Bluegill bully	15.0 - 42.3
Inanga	6.5 - 15.0	Redfin bully	6.8 - 42.9
Lamprey	6.8 - 18.8	Giant kokopu	10.9 - 15.0
Crans bully	26.1 - 42.4	Koaro	20.7 - 42.4

River distances in the fish data base are from the river environment classification GIS (Snelder et al. 2004) and differ somewhat from the Hutt River cross section river distances which are reported elsewhere

Table 3 Native fish in the Hutt River (based on national fisheries data base accessed May 2009)

Joy & Death (2004) also surveyed fish in the Wellington region, but have not reported additional species in the Hutt River to the national fisheries data base.

None of the native fish in Table 3 is listed as "Nationally critical", "Nationally Endangered", "Nationally Vulnerable" or in "Serious Decline" in the New Zealand threatened species list (Hitchmough et al. 2007). However, longfin eel, dwarf galaxias and giant kokopu are listed as being in "Gradual Decline"; and lamprey is listed as "Sparse". The other fish listed in Table 3 are not threatened.

Historically the Hutt River supported a productive whitebait fishery. However, while it is still fished, the fishery has undoubtedly declined because of river engineering works and unsuitable river banks in the tidal influenced spawning areas (Taylor & Kelly 2001).

In the Hutt River instream flow workshops it was recognised that native species may be under represented in the national fisheries data base. For example, Chadderton et al. (2004) note "*… populations of threatened short-jawed kokopu continue to persist in the headwaters above Kaitoke Weir."* These are listed as "Sparse" in the threatened species list (Hitchmough et al. 2007).

If other native species were found, these could be modelled. However, it is unlikely that the flow recommendations would change. In this regard, it is important to note the physical habitat suitability for the species that have been reported. There is clearly a major separation of habitats based on the most suitable depths and velocities (Figure 9; Jowett 2003a). Native fish tend to occupy shallow water, with the fast-water species, such as bluegill bullies, in velocities in excess of 0.8 m/s, and common and upland bullies in velocities less than 0.4 m/s. Therefore, by modelling the habitat availability for members of the fast water and slow water guilds of native fish, it is likely that habitat suitability for any species missing from Table 3 should be represented.

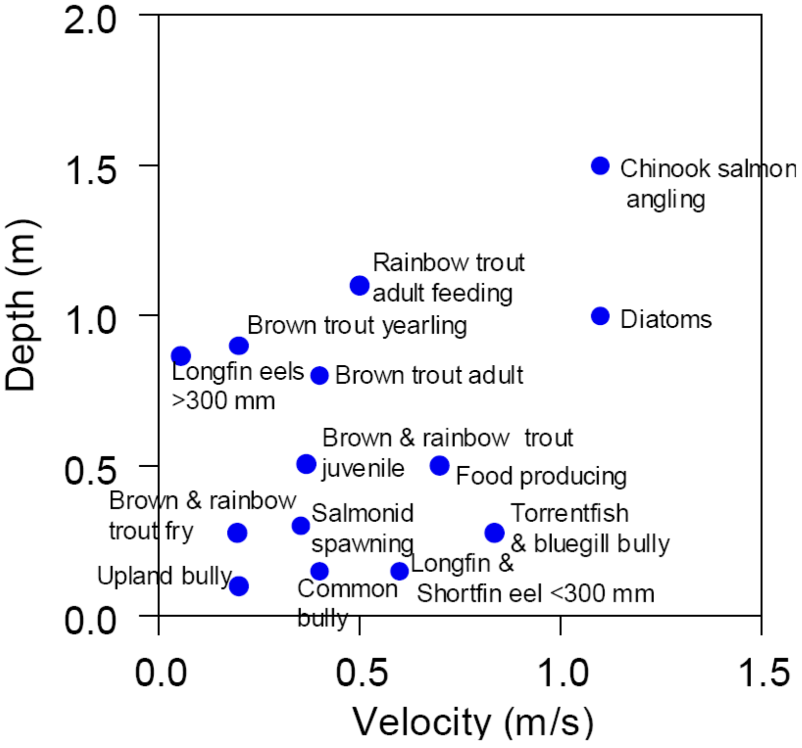

Figure 9 Physical habitat suitability as a function of optimal depths and velocities for some common species (after Jowett 2003a)

2.5 Sport fish

The Fish and Game Wellington Region website[3] describes freshwater sports fishing in the region as follows: "*In the midst of one of the most densely populated areas of New Zealand, Wellington has a surprising array of fishing waters close at hand. Indeed Wellington is probably unique worldwide in having such a range of quality brown trout fishing within a major city…. The Hutt, largest of the Wellington*

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[3] http://www.fishandgame.org.nz/SITE_Default/SITE_your_region/SITE_Wellington/Fishing/access.aspx (accessed 21 February 2006)

rivers, dominates angling interest. Access is easy with riverside parks or access tracks along most of its length…."

Taylor (2005) states: "*Angler use of the river has varied significantly over the past twenty years. Smith (1989) recorded about 6,209 (± 2,192) angler visits during the 1985/86 fishing season and this rose sharply in the 1994/95 fishing season when Unwin and Brown (1998) recorded about 19,960 (± 2,020) visits. This dropped equally sharply for the 2001/02 season when Unwin and Image (2003) recorded 6160 (± 830) visits*."

The trout reach is defined in the RFWP as Melling Bridge (km 4.4) to Benge Creek (km 32.4) (the start of gorge). However, drift dive surveys also show trout in relatively low abundance in the survey reach below the Pakuratahi confluence (km 39.2 to 41.2) (Table 4). Chadderton et al. (2004) mention that in the headwaters above Kaitoke Weir, brown trout, although present, do not appear to be abundant. Hay (Cawthron Institute, pers. comm.) suggested that it is unlikely that trout upstream of the weir will be impacted by a reduced minimum flow downstream.

Fish and Game undertake annual drift dives of the Hutt River, for the primary purpose of assessing the impacts of river works, <u>not minimum flows</u>. As noted by Taylor (2005): "*The Flood Protection Group, Wellington Regional Council, was granted resource consent in 1999 to carry out various activities within beds of the Hutt and Waikanae Rivers'. Fish and Game NZ, Wellington Region, believe one such activity, cross blading, to be particularly harmful to the river environment, compromising the preferred habitat requirements of trout. The Flood Protection Group acknowledged the likely-hood of this adverse effect and, with Fish and Game NZ, agreed to monitor trout abundance over the term of their consent*."

Table 4 is based on data provided by Steve Pilkington of Fish & Game Wellington Region (F&G). The complete data set differs in some instances from the summary counts reported by Taylor (2005). The top row of data for each reach is the trout count reported by Taylor (2005) and the second row is the trout count in the Fish and Game data set. Counts are undertaken in the summer, usually in February or March.

Fish counts are reported per kilometre (Table 4). Over the period 1999 to 2009 the survey reach length was 1000 m at Avalon, Heretaunga and Melling; 1450 m at Birchville; and 1600 m at Te Marua. The reach length varied at Kaitoke, changing from 2000 m to 1500 m in 2007; from 1000 m to 900 m at Taita in 2006; and from 1000 m up to the 2003 survey, to 1200 m in 2005 and 1100 m in subsequent surveys at Whakatikei.

There is year to year variability in the counts. For example, Taylor (2005) reported that there were 16% fewer large brown trout and 45% fewer medium brown trout per kilometre within the reaches counted in 2005 compared with 2003. In the 7 years to 2005 the average increase was 26% per year for large brown trout and 15% per year for medium brown trout; with an average rate of increase of 11% over nine years for medium and large trout to 2007 (Taylor 2005, 2007). However, a major decline in trout numbers was reported in 2008 in both the Hutt and Waikanae rivers (Taylor 2008).

Reach	**Count of large and medium trout per km**					
River km	**1999**	**2000**	**2001**	**2002**	**2003**	**2005**
Kaitoke	5	3	12	7	11	10
Km 41.2	4.5	3.0	12.0	6.5	10.5	9.5
Te Marua	4	2	16	13	29	22
Km 29.9	2.5	1.3	10.0	8.1	18.1	13.8
Birchville	18	11	36	42	72	83
Km 26.3	17.9	10.3	33.8	39.3	64.1	77.2
Whakatikei	19	25	28	47	80	41
Km 19.9	19	25	28	47	80	34.2
Heretaunga			95	74	114	46
Km 16.3			95	74	114	46
Taita	46	22	74	54	138	
Km 13.8	46.0	22	74	54	138	
Avalon	29	18	19	29	43	58
Km 8.1	29	18	19	29	43	58
Melling			85	93	147	148
Km 5.4			85	93	147	148
Median	18.5	14.2	30.9	43.2	72.1	46.0

	2006	**2007**	**2008**	**2009**	**Median**	**StDev**
Kaitoke	9					
	9.0	11.3	13.3	6.7	9.3	3.4
Te Marua	9.4					
	11.3	11.9	8.8	8.8	9.4	5.0
Birchville	53.3					
	49.7	40.7	24.1	27.6	36.6	20.7
Whakatikei	34.5					
	34.5	35.5	22.7	40.9	34.4	17.4
Heretaunga	38.9					
	35	32	12	9	40.5	38.5
Taita	155.6					
	155.6	141.1	30.0	34.4	54.0	53.1
Avalon	76.3					
	61	165	14	21	29.0	45.1
Melling	141					
	141	82		19	93.0	47.1
Median	42.3	38.1	14.0	20.0	34.5	18.3

No counts presented for 2004
River distances from coordinates in Taylor (2005) & GWRC river survey distances
Top row: counts reported in Fish & Game annual reports
Bottom row: counts reported in Fish & Game database

Table 4 Drift dive counts of large & medium brown trout in the Hutt River

There are gaps in the fish counts in the lower reaches (Heretaunga, Taita, Avalon and Melling), but the comparable data shows there are fewer fish in the lower reaches in 2008 and 2009 than in several previous years (Table 1). However, the recent numbers are similar to 1999 and 2000 and overall abundance increased from 2008 to 2009.

The 2008 report by Taylor notes "*The decrease is most noticeable in the medium size class (200-400 mm) and it is possibly related to large spring floods in 2006 severely impacting on trout fry and fingerling survival. The possible cause(s) of large trout (>400 mm) also found to be in much lower numbers is unknown.*"

As discussed in Section 4.3, it is likely that direct mortality of large trout occurs in Hutt River floods as reported in other rivers (e.g. Jowett & Richardson 1989; Young et al. 2010).

As well Taylor (2005) notes that fishing pressure may be important stating "*Livingston (1983) mooted that there may be a relationship between floods and angler opinion on the relative state of the Hutt River fishery. Angler harvest, particularly in years when weak year classes are present, may be additive to natural mortality thus contributing to a decline in trout >200 mm.*"

In the original stakeholder meetings it was agreed that emphasis on effects on instream habitat would be placed in the lower river, primarily because that was where fish abundance was far greater. Recently Fish & Game suggested that the upper reaches of the Hutt River (Kaitoke and Te Marua) may provide a "safe haven" for medium and large trout which increases the importance of the upper reaches for the overall Hutt River fishery.

The upper reaches differ from the middle and lower reaches in terms of trout abundance and recent changes in abundance. The upper reaches have a median count of 9.35 in the reported survey period (Table 1). There are more than three times the number of fish in the "middle reaches" (Birchville and Whakatikei) than the upper reaches. The "lower reaches" (Heretaunga, Taita, Avalon and Melling) have several times as many fish on average than the upper reaches.

In terms of recent changes, the upper reach had more fish in 2008 than 2007 (Table 4). In contrast, the middle and lower reaches had a median of 22.7 fish per km in 2008, which is just above the lowest on record (median of 20 fish per km in 2000). At face value, this would support the contention that the upper reaches may have more stable fish counts than the lower river. However, the following should be considered:

- Historically fish numbers have been much lower in the upper reaches (e.g. 4 fish per km in 2000);
- There was ~50% decline in the number of trout per km at Kaitoke from 2008 to 2009;
- Trout numbers were stable at Te Marua from 2008 to 2009 retaining more than 90% of the long term median count; and

- For the Birchville and Whakatikei reaches the combined 2009 count is greater than the counts in 1999, 2000, 2001 and 2008; and is about 95% of the median combined count for the ten surveys.

The surveys show that the upper fish survey reaches (Kaitoke and Te Marua) differ from the middle (Birchville and Whakatikei) and lower fish survey reaches (Heretaunga, Taita, Avalon and Melling) in terms of trout abundance and recent changes in abundance. Further, the upper reaches do not appear to provide a more stable fishery than the middle reaches. Therefore, the emphasis placed on the lower reaches for the instream flow analysis based on detailed hydraulic habitat modelling is supported.

3 Framework for Instream Flow Assessment

A review of habitat retention levels and instream flow requirements was recommended in the workshops. Therefore, the instream flow objectives, as related to levels of habitat retention, were re-examined.

The first step of the process of determining an appropriate flow regime is that the resource management objectives must be defined (Bovee 1982; MFE 1998). The second step is to establish the context and set goals for the rivers, and reaches of river, in question. The rationale is that the objectives and goals should reflect the merits of the instream values. Such objectives and goals have been stated in the RFWP as described above. The third step is to establish the levels of habitat retention. This is more problematic, as many decisions involve a trade off between various species and life stages, and competing demands for water (Bovee 1982). In this report the focus is on the aquatic habitat to provide guidance for the flow regime requirements.

3.1 Regional Freshwater Plan (RFWP)

Management objectives, policies and rules are set out in the Regional Freshwater Plan (RFWP) for the Wellington Region (WRC 1999; operative December 1999). The RFWP recognises that the Hutt River is vital for the public supply of water to the Wellington Metropolitan Area (2.6.2). Objective 6.1.1 of the RFWP states "*People and communities are able to take, use, dam, or divert surface water, and take and use groundwater, while ensuring that the flows in rivers, and water levels in lakes and wetlands, are sufficient to maintain the natural and amenity values of water bodies*."

The RFWP stipulates minimum flows in Policy 6.2. Specifically, for the Hutt River, the minimum flow in Table 6.1 of the RFWP is 1200 L/s at Birchville and applies to the Hutt River between the confluence with the Pakuratahi River (river km 41) and the boundary of the coastal marine area. These flows were determined using habitat methods as specified in Section 9.6.1 of the RFWP.

In explanation, the RFWP states (page 79-80):

> *"The minimum flow is a guide that provides an indication of flows in the river or stream that will.*
>
> - *safeguard the life-supporting capacity of ecosystems; and*
> - *meet the needs of future generations; and*
> - *provide for adequate water quality.*
>
> *Under most circumstances, the flows in the river or stream should not fall below the minimum flow. However, in low flow conditions, rivers may occasionally drop below the minimum flows even if no water is abstracted.*
>
> *The minimum flow is not necessarily intended to provide for all recreational uses of a river or stream. Natural fluctuations (at*

> *times of low flows) also restrict some of these uses. Some recreational uses (e.g., swimming) may be accommodated but others (e.g., canoeing or rafting) will not always be provided for over a section of river at these flows. Further comment on this issue has been made in section 2.6.2 of the Plan.*

In interpretation, the RFWP (page 32) defines "minimum flow" in the context of Policy 6.2.1; and provides a rationale (page 81):

> *"For the Hutt River at Kaitoke …. the minimum flow is intended as a minimum flow below which all abstractions of water should cease."*
>
> *"For the upper reaches of the major water supply rivers… there are no core or stepdown allocations. This means that the water supply authority… has less security of supply than the users of other rivers in Table 6.1 at times of low flow. However, the water supply authority already has, or is anticipating, alternative sources for its water. In return for the reduction in security of supply, clause 3 of this policy allows the allocation of all the water above the minimum flow in the Hutt… this approach allows the water supply authority to take more water from these rivers at higher flows that can then be stored and used in periods of lower flows."*

The Freshwater Plan "*Principal reasons for adopting objectives, policies and methods*" states (page 171):

> *"The approach to managing flows and water allocation in the Hutt, Orongorongo and Wainuiomata Rivers is different to other rivers. For these rivers, the upper reaches are managed primarily for water supply purposes while the middle and lower reaches of the Hutt and Wainuiomata Rivers have recreational and fish habitat values….*
>
> *In the middle and lower reaches of the Hutt and Wainuiomata Rivers the water allocation regime is the same as for other rivers in the Region, and takes account of the fisheries, ecological, recreational and amenity values of those rivers. Flow records show that if the minimum flow in the upper reaches of these rivers is retained then the minimum flow in the middle reaches should always exceed that shown in Table 6.1."*

As discussed in Section 9.6.1 of the RFWP "*Policies on minimum flows and water allocation in rivers provide guidance for consent authorities as to the desirable minimum flows which should be maintained in rivers and streams. For larger rivers and streams, the desirable minimum flow is based on habitat methods (for example, the Instream Flow Incremental Methodology (IFIM)).*"

In addition, RFWP specifically mentions managing water quality for native fish; and for the trout fishery and spawning (Policy 5.2.3). In Appendix B Part B, "*Surface Water to (be) Managed for Aquatic Ecosystem Purposes*" mention is made of management of "*All water bodies and river beds within the catchment of the Hutt River above the Wellington water supply intake weir…*" Appendix D Clause 6 states water quality is to be managed for fishery and fish spawning purposes in "*The Hutt River from R26 899 118 to R27 700 985.*" (i.e. from adjacent to the Te Marua reservoirs to Melling Bridge at about the tidal limit).

The RFWP accepted the use of hydraulic-habitat modelling ("IFIM"). A Birchville flow of 1200 L/s was adopted in the plan (RFWP Table 6.1); with a MALF at that time of 2009 L/s (Jowett 1993). Analysis of habitat availability was undertaken by Jowett (1993) using RHYHABSIM, a hydraulic-habitat model. In suggesting a minimum flow for the Hutt River at Birchville of 1200 L/s Jowett (1993) noted:

> *"Relationships between flow and WUA (Figs. 2-4) were used to estimate the proportion of each river's mean annual low flow which retains:*
>
> - *a minimum amount of habitat equivalent to that exceeded by 85% of the national survey rivers at their mean annual low flow, and*
> - *two thirds of the amount of habitat at existing or "natural" mean annual low flow.*
>
> *Generally in the larger rivers the two-thirds food producing guideline is the one which determines the minimum flow (Table 4), whereas in the smaller rivers, the minimum food producing habitat guideline tends to determine minimum flow. In most of the Wellington rivers surveyed, retaining two thirds (i.e. reducing habitat by one third) is tantamount to selecting a minimum flow which is approximately one third less than the mean annual low flow because in most cases habitat declines uniformly to zero as the flow falls below the low flow."*

The RFWP assessment is based on using the percentage weighted usable area (%WUA). The %WUA of food production (Waters 1976) and brown trout are combined for the comparative ranking in Jowett (1993). (The habitat suitability index/curve/criteria for brown trout in Jowett (1993) is identical to the Hayes & Jowett (1994) curve for adult brown trout drift feeding, which is used in this investigation).

Although Jowett (1993) used %WUA for his analysis of the Wellington region, stakeholders requested that WUA was re-calculated in m^2/m. The physical meaning of %WUA has been questioned, because the value is scaled to a varying residual width so ultimately a high percentage index of habitat might be retained but for a very small channel (Hudson 2004).[4] Further, habitat evaluation using WUA m^2/m has been used in recent investigations in the Wellington region (e.g. Harkness 2002, Watts 2003), and often provides a higher flow requirement for maintenance of habitat than %WUA (Hay & Hayes 2007b).

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[4] This is not to say that %WUA is not useful. The %WUA can be interpreted as an index of habitat quality (i.e. the combined score of the depth, velocity and substrate suitabilities) and there may be a trade off between quantity and quality as discussed by Waddle et al (2001).

3.2 Critical values, benchmark flows & habitat retention

It is clear that the Hutt River is a trout fishery of regional significance, and that the RFWP seeks to maintain the fishery.[5] In determining a level of habitat maintenance for the Hutt River, it is instructive to review critical values, benchmark flows, and levels of habitat retention recommended in similar high value rivers.

Trout habitat and/or food production habitat are often used as critical values (e.g. brown trout habitat, Manawatu River, Hay & Hayes 2005; rainbow trout habitat, Rangitikei River, Hay & Hayes 2004; food production habitat, Hutt River, Jowett 1993). As discussed by Jowett & Hayes (2004) "*In New Zealand, it has generally been assumed that minimum flows set for salmonids will be adequate to maintain native fish populations. The rationale for this is that trout, because of their large size and drift-feeding requirements, have higher depth and velocity requirements than most native fishes. Many native fishes are most abundant in small streams or on the margins of larger rivers (e.g., upland bullies, redfin bullies, inanga). Therefore, habitat for these species is maximal at low flow. The river margins will still provide some habitat for these native fishes at the higher flows required by salmonids. The fast water habitat native fish guild comprising torrentfish and bluegill bully have similar flow requirements to adult trout.*"

One day mean annual low (MALF) is an appropriate benchmark flow (e.g. Hutt River, Jowett 1993; Manawatu River, Hay & Hayes 2005; Rangitikei River, Hay & Hayes 2004). As noted by Hay (2007b) "*The crux of the rationale being that the amount of habitat available at the MALF is thought to act as a bottle neck for trout, and potentially other annual spawning fishes, because it is indicative of the average annual minimum living space.*"

In the review of the proposed Hutt River instream flow investigations, Hay (2007a, b) suggests that the median flow is more relevant than the MALF to macroinvertebrates. In explanation, Hay (2007b) states "*The intent was that the impact of allocation on habitat availability for invertebrates at the median flow be considered, along with minimum flow setting, not that minimum flows should be set based on retention of invertebrate habitat at the median flow.*" While I do not concur that the median flow is more relevant, an analysis of food production habitat availability (Waters 1976) at median flow and with flow abstraction is presented for completeness.

In this investigation, habitat retention levels of 66% of MALF (following Jowett 1993 for the Wellington region) to 90% (as suggested for high value fisheries in Table 5), are evaluated. This is

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[5] Deans et al. (2004) Table 41.1: Top ranked rivers in New Zealand: 1: Mataura 53,000 angler days; 12: Manawatu 13,700 angler days; 29: Hutt 6,200 angler days; 32: Rangitikei 5,900 angler days. Hay (pers. comm.), citing Unwin & Image (2003), indicated the Manawatu River is 1st ranked among 51 water bodies in the Wellington Fish & Game Region, the Hutt is ranked 2nd, and the Rangitikei is 4th ranked.

consistent with other rivers in the region. For the Manawatu River Hay & Hayes (2005) recommended retention of 70 to 90% of brown trout available at the one day MALF. In the Rangitikei River Hay & Hayes (2004) recommended use of rainbow trout as the critical species; and retention of 90% of habitat available at the one day MALF.

Table 5 Suggested significance ranking of critical values and levels of habitat retention (Jowett & Hayes 2004)

Critical value	**Fishery quality**	**Significance ranking**	**% habitat retention**
Large adult trout – perennial fishery	High	1	90
Diadromous galaxiid	High	1	90
Non-diadromous galaxiid	-	2	80
Trout spawning/juvenile rearing	High	3	70
Large adult trout – perennial fishery	Low	3	70
Diadromous galaxiid	Low	3	70
Trout spawning/juvenile rearing	Low	5	60
Redfin/common bully	-	5	60
Ranking: 1 highest; 5 lowest			

It is recognised that the habitat retention levels recommended in Table 5 are conservative. Jowett & Hayes (2004) noted *"The suggested levels of habitat retention are conservative, in that we believe that they are unlikely to be proportional to a population response. Theoretically, a change in available habitat will only result in a population change when all available habitat is in use (Orth 1987). In most cases, we believe that because flows are varying all the time, population densities are at less than maximum levels. That being the case, a habitat retention level of, say 90%, would maintain existing population levels, whereas retention levels of 50% might result in some effect on populations, especially where densities were high."*

3.3 Instream flow objectives - conclusions

The RFWP (1999) adopted a one-third loss of existing habitat, expressed as percent weighted usable area (%WUA), as determined by hydraulic-habitat methods. Here the same hydraulic-habitat method was used, but the instream flow recommendation was based on the WUA in m^2/m. This is often more precautionary (Hay & Hayes 2007b).

The one day mean annual low flow (MALF) with retention of 66% (RFWP) to 90% of habitat for adult brown trout feeding and/or food production habitat (whichever is more demanding) as the threshold is appropriate and used here. Both existing and naturalised flows are evaluated; and effects of reducing the median flow with abstraction are assessed for food production habitat availability.

4 Instream flow assessment

4.1 Introduction

As part of an instream flow assessment, physical habitat modelling is often used to predict changes in potential habitat availability. However, first it is ascertained if physical habitat is potentially limiting, or if other factors, such as water quality, override physical habitat availability as a bottleneck (Waddle et al. 2001). In this regard, before the physical habitat modelling is discussed, water quality and disturbance are discussed. In subsequent sections, changes in physical attributes (width-wetted perimeter, depth and velocity) and the potential availability of habitat at different flows are evaluated.

4.2 Water quality

Greater Wellington routinely monitor the Hutt River at four locations from Te Marua (km 32) to Melling Bridge (km 4) (Milne & Perrie 2006). River and stream water quality is assessed at monthly intervals by measuring a range of physio-chemical and microbiological variables, including dissolved oxygen, temperature, pH, conductivity, visual clarity, turbidity, faecal indicator bacteria, total organic carbon, and dissolved and total nutrients. Water quality is also assessed through annual biological monitoring, incorporating semi-quantitative assessments of the instream periphyton and macroinvertebrate communities during the summer autumn period.

Guideline values are discussed by Milne & Perrie (2006). Of particular note, they adopt an 80% saturation threshold for dissolved oxygen (DO). In terms of temperature, Milne & Perrie (2006) comment "*The RFP uses a guideline based on the Third Schedule of the RMA that water temperatures at fresh water sites managed for trout fishery and spawning values should not exceed 25 ºC.*"

These guidelines are consistent with other findings. Free swimming brown trout require >5 - 6 mg/l dissolved oxygen (Baker et al. 1993), but at least 80% saturation (Mills 1971 in Elliot 1994). Water temperature is discussed in 5. In brief, the 25ºC threshold appears to be appropriate for native fish and invertebrates. The optimum temperature range for adult trout is 12 to 19^{0}C, and the upper limit is 25 to 30^{0}C, but this depends on the acclimatisation temperature. Scott & Poynter (1991) found that the northernmost limit of trout in New Zealand appears to be determined by high winter temperatures, rather than high summer temperatures.

The water quality grades and macroinvertebrate health scores range from good to very good; with a small decline in these measures with distance downstream (Milne & Perrie 2006). To be "very good" the median value for all six water quality index variables must comply with guideline values. To be classed as "good" five of the six variables must comply, including dissolved oxygen.

It is concluded that water quality is unlikely to be a habitat bottleneck. Potential effects of abstractions on water temperature are discussed in Section 5.

4.3 Disturbance regime

Freshets and floods are of particular importance in determining taxonomic composition, biomass, and abundance in New Zealand stream communities (see reviews of Jowett 1997; Hudson et al. 2003).

In general flood flows need to exceed about 20 times the median flow to have significant effects on invertebrate abundance and taxonomic richness (Quinn & Hickey 1990a). However, smaller more frequent events (in the order of three times the median flow) are capable of having significant influence (Clausen & Biggs 1997). (Flow variability is discussed further in Section 6).

Surren & Jowett (2006) examined effects of floods and low flows on invertebrates in a gravel bed river and found invertebrate communities "*…were controlled by both floods and low flows, but that the relative effects of floods were greater than even extended periods of extreme low flow*."

For native fish in the gravel bed Rakaia River, Glova & Duncan (1985: 178) concluded "*We believe that present native fish stocks of the Rakaia River are limited by the effects of floods rather than low flows…. the WUA available to native fish species may be underused, even at low flow, because of their low density.*"

Similarly, trout in the Hutt River are thought to be limited by floods. Taylor (2005) notes: "*Because the abundance of trout (>200mm) in the Hutt River in the period 1997-2001 declined markedly compared to 1983-1989, and the extent of cross blading appears to have varied little, other factors causing trout numbers to fluctuate need to be considered. The severity of floods in rivers August through November, is believed to reduce trout recruitment (Haves 1995).*"

This is consistent with the findings of Jowett & Richardson (1989) from pre and post flood drift dive counts on seven rivers. They reported "*In 6 of the 7 rivers, brown trout (Salmo trutta) abundance decreased significantly, with small fish (10-20 cm fork length) being reduced by 90-100%, medium fish (20-40 cm FL) by 62-87%, and large fish (> 40 cm FL) by 26-57 %*." The floods were 19 to 38 year events for five rivers and extreme events for two rivers (>100 year floods). The floods occurred in March.

Large losses of adult trout were reported following a 50 year flood in the Motupiko River in the upper Motueka catchment. Young et al. (2010) found at least 60% of the adult trout population were killed during the March 2005 flood. In another tributary of the Motueka a similar reduction (65%) in juvenile trout abundance occurred in the same flood.

Given the disturbance regime, as noted by Jowett & Hayes (2004) the habitat retention levels suggested in Table 5, and used in this investigation, are probably conservative (i.e. precautionary).

4.4 Habitat modelling – approach, assumptions and limitations

Modelling physical habitat availability has two essential components – a description and prediction of the physical attributes of the river (the hydraulics: width, depth, velocity; and bed material); and the application of habitat suitability criteria to the predicted or measured changes in the hydraulics. (The bed material and bed levels are assumed not to change).

There are basically two major types of hydraulic model in the IFIM tool box – one dimensional models (1D models) and two dimensional models (2D models). A 1D model, RHYHABSIM (Jowett 1989), was applied in the Hutt River (Jowett 1993, Harkness 2002) and the hydraulic information from these surveys was reanalysed here.

1D models are based on individual transects or groups of transects – measurements of width, depth and velocity in a line across a channel. These measurements may be repeated to develop a stage (water level) – discharge (streamflow) relationship for the transect. Individual transects are weighted to represent a certain proportion of the river or transects can be analysed individually or in groups to describe responses of various habitats (e.g. pool and riffles). Here the transects were weighed for habitat mapping.

Physical habitat simulation combines habitat suitability criteria with simulated water depth and velocity, and substrate, to predict habitat availability for various species and life stages at various streamflows. The combinations of suitability's (depth, velocity and substrate) are calculated across each transect to provide a habitat suitability index (HSI) score at each point along a transect. These scores are combined to provide a measure of habitat available at points, across the channel, and for the whole reach by combining results from the transects.

The underlying assumptions of habitat simulation are (Bovee 1982):

- Each species exhibits preferences within a range of habitat conditions that it can tolerate;
- These ranges can be defined for each species;
- The area of stream providing these conditions can be quantified as a function of discharge and channel structure; and
- Stream populations are limited by the habitat available for one of the life stages, or for some other organism that the species relies on for food.

In addition, there are concerns in the IFIM literature that are explored with NZ examples in the Hudson et al. (2003) review. These include:

- Sampling and measurement problems associated with representing river reaches;
- Sampling and measurement problems associated with developing the suitability curves and transferring these curves to different locations; and

- Problems with assigning physical and biological meaning to weighted usable area (WUA and %WUA).

There is no doubt that species have tolerances for a range of conditions and have preferences for particular conditions. However, it is difficult to adequately quantify habitat preferences (Castleberry et al. 1996); habitat use may not be independent of streamflow (Pert & Erman 1994); and the use of simple variables such as depth, velocity and substrate may be insufficient to define a habitat preference (Freeman et al. 1997).

It is recognised that stream communities are structured by a combination of biotic and abiotic factors (see review of Hudson et al. 2003). These include water quality (e.g. temperature and dissolved oxygen), flow regime (e.g. floods and droughts), habitat structure, energy source (e.g. organic matter sources) and biotic interactions (e.g. competition, predation, disease, and parasitism). In terms of physical habitat, as discussed in Section 4.2, water quality is unlikely to be a bottleneck. However, it is thought that in flood dominated streams, such as the Hutt River, it is likely that aquatic populations are not limited by the habitat available for one or all of the life stages, but rather by the flood regime (Section 4.3).

In terms of sampling and measuring the river reaches, habitat assessment surveys were undertaken in four reaches of the Hutt River (Jowett 1993; Harkness 2002) (Figure 8):

- Birchville, (Jowett) downstream of the Akatarawa confluence, centered on river km 26;
- Silverstream (Harkness Hutt 1 “upper”) centred on river km 15.5;
- Taita (Harkness Hutt 2 “middle”) centred on river km 13.2; and
- Melling (Harkness Hutt 3 “lower”) centred on river km 4.4.

These reaches and transects are accepted as representing morphology and hydrology of the Hutt River below the gorge described in Section 2.3. Specifically, the Birchville survey is intended to represent a sample of the habitat available, at least in the upper reaches (Jowett 1993). Two sections were surveyed but they were combined in the analysis of Jowett (1993). Jowett’s combined surveys are used in this study.

Habitat surveys by Harkness (2002) were undertaken as part of a programme to review minimum flows set in the RFWP. Harkness considers his upper section to be representative of the river from the Akatarawa confluence (km 27) to the Silverstream Bridge (km 14.6) which includes Birchville; his middle section, at Taita Gorge, was chosen to evaluate the effects of river works; and the lower survey represents the lower reaches of the river around Melling Bridge (Figure 7) where the gradients are less and velocities slower than upstream. Melling reach has a tidal influence. Reaches were chosen by stakeholders (Opus International acting for GW, and Fish & Game). The surveyed sections encompass a range of hydrological conditions (changing flows and tidal influence). The survey methodologies of Jowett and Harkness are very similar[6] with 13 to 15 transects per reach. These surveys reflect accepted IFIM practice for 1D modelling (i.e. RHYHABSIM).

"*The greatest single constraint … is the use of accurately derived habitat suitability curves*" (Gore & Nestler 1989). Different habitat suitability curves (HSC)[7] for the same species and life stage can produce markedly different results; so the choice of HSC is critical (Hudson et al. 2003). Available habitat suitability criteria (HSC) for target species and life stages are appended from the RHYHABSIM library (Appendix B). Criteria used in this investigation are listed in Table 6.

Table 6 Habitat suitability criteria from RHYHABSIM

Species	Suitability Criteria
Native fish	
Shortfin eel <300 mm	Jowett & Richardson 1995
Longfin eel ><300 mm	Jellyman et al. 2003
Dwarf Galaxias	Jowett & Richardson 1995
Inanga feeding	Jowett 2002
Crans bully	Jowett & Richardson 1995
Common bully	Jowett & Richardson 1995
Bluegill bully	Jowett & Richardson 1995
Redfin bully	Jowett & Richardson 1995
Koaro	Jowett & Richardson 1995
Brown trout	
Spawning	Shirvell & Dungey 1983
Juvenile	Bovee 1995
Adult	Hayes & Jowett 1994
Macroinvertebrates	
Food production	Waters 1976
Deleatidium (mayfly)	Jowett & Richardson 1990

Although testing of the transferability of habitat suitability criteria is good practice, it is infrequently undertaken mainly due to the time and cost involved and debate over transferability criteria (Hudson et al. 2003). A pragmatic approach, given funding constraints, is to select habitat suitability criteria that were developed in similar rivers. In this regard, Hay (2007a) provides a useful commentary on habitat suitability criteria for salmonids (Appendix C).

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[6] I established this through discussion with the GW hydrologist involved in both surveys (Jon Marks); and by examining the survey data. The reports themselves are limited in the information provided.

[7] The terms Habitat Suitability Curves, Habitat Suitability Criteria, and Habitat Suitability Index are often used synonymously. Recently, in New Zealand, "index" or "indices" has been used to refer to the habitat suitability score (i.e. the combined depth, velocity and substrate value) at a point, or for a transect or reach. A reach score is equivalent to %WUA (Hay 2007).

Hay (2007a) agrees the habitat suitability criteria identified in the workshops and used in the investigations are largely appropriate.[8]

The native fish criteria were obtained primarily from Jowett & Richardson (1995); who sampled rivers throughout New Zealand. They noted *"Most native fish in the study rivers were riffle dwelling; overall fish abundance in riffles was about twice that in runs. However, when similar depths and velocities were compared in runs and riffles, there was no difference in fish abundance. The difference in fish abundance in these two habitats appears to be caused primarily by the different water depths and velocities that occur in them. Thus, evaluation of physical habitat need only be based on physical habitat (depth, velocity, and substrate) and can exclude any subjective classification of habitat type."*

The suitability criteria represent the best available information for hydraulic-habitat modelling in the Hutt River. However, it is recognised that the suitability criteria are meant to be developed in unexploited streams at carrying capacity (Bovee 1982). Such conditions must be rare in high – disturbance New Zealand streams (Hudson et al. 2003) (Section 4.3). Nevertheless the habitat criteria provide a measure of habitat availability changes with flow.

To calculate the habitat available at various flows, the combined scores for depth, velocity and substrate are multiplied by the cell area to generate a statistic called the weighted usable area (WUA).[9] Results are usually expressed as the weighted usable area for a unit length of river: WUA m^2/m or m^2/km. In terms of physical meaning, multiplication of actual surface area by dimensionless suitability variables results in a dimensionless habitat index that can no longer be properly referred to as area. Payne (2003) suggests it would be more accurate to describe this measure as "*probable usable habitat*." In my opinion "*potential usable habitat*" is preferable because the habitat suitability curves are not probability functions.

In terms of biological meaning, WUA implicitly considers each habitat unit as biologically equivalent (Bovee 1982). With this index large areas of poor habitat can sum to provide the same WUA value as small areas of high quality habitat. But as pointed out by Orth (1987) and Scott & Shirvell (1987), large areas of less than optimum habitat do not have the same productive capacity as small areas of optimum habitat. Further, several combinations of depth, velocity, and substrate can give the same amount of WUA, none of which may support a similar biomass (Mathur et al. 1985). A few cells containing high quality habitat, but a lesser WUA, may have more habitat value than a large area of poor habitat with a higher WUA. Waddle et al. (2001) caution "…*the peak of the total WUA curve does*

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[8] Hay (2007a) notes the Bovee (1995) curve may overestimate flow requirements, but the alternative Raleigh et al (1986) curve used previously (Hudson 2006b, c), may underestimate flow requirements. He also notes the choice of curves would not make a material difference to the interpretation of results, since adult brown trout and invertebrate food production have been treated as critical values.

[9] In representative reach surveys the cell area is distance between points of measurement in the cross section, multiplied by the distance between cross section.

not always correspond with the peak of highly suitable habitat conditions. The investigator should carefully consider the biological implications of selecting flows that maximize total WUA versus the consideration of an alternative flow that may maximize the area associated with high quality habitat."

Clearly there are limitations in using models such as RHYHABSIM to estimate the change in habitat availability, and ultimately population responses, as flows change in rivers. However, RHYHABSIM is in widespread use in New Zealand, and there are no viable modelling alternatives. Hayes (2004) recommended use of "*IFIM*": "*Regional councils best interests are served by proceeding with IFIM based habitat models because there are no viable alternatives that are as cost effective and are as scientifically advanced*."

In addition, to assess the importance of the upper reaches, and the potential effects of flow reductions on trout numbers, the brown trout model (Jowett, 1992) was applied. The brown trout model is based on catchment and characteristics and channel width and at MALF and median flow and available adult trout habitat at MALF and food production habitat at median flow. The latter are based on hydraulic habitat modelling in the upper reaches (Hudson & Harkness 2010).

4.5 Hydraulic geometry changes with flow

Changes in flow will result in changes in the hydraulic geometry (wetted perimeter,[10] width, depth and velocity) of the river. Wetted perimeter has been used as a measure of habitat for determining minimum flows (Gippel & Stewardson 1997). Interpretation is similar to habitat availability analysis from modelling. The critical minimum discharge is supposed to correspond to the point where there is a break in the shape of the curve. Below this discharge, wetted perimeter/habitat declines rapidly. Here wetted perimeter is used to quantify the size of the channel at different flow thresholds.

Hydraulic geometry was calculated for the four study sites described by Jowett (1993) and Harkness (2002) and in Section 4.4. The sites are referred to as Birchville, Silverstream Taita and Melling Bridge, and are about 26, 15, 13 and 4 km upstream, respectively. The RHYHABSIM input files were obtained from Mr Jowett and Mr Harkness. The hydraulic parameters were not changed, and the results of the previous studies could be replicated.

For each of the study sites the hydraulic geometry was calculated for small increments and the wetted perimeter, width, depth and velocity were plotted (Figure 10). Flow thresholds (discussed in Sections 4.6 & 4.7) are indicated on the plots; and in Table 7 the hydraulic geometry for specified habitat retention flows are tabulated. These terms are now explained.

"RFWP min" refers to the minimum flow specified in the RFWP at Birchville (1200 L/s). The nominal RFWP minimum flows at sites

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[10] The wetted perimeter (WP) is the distance across the bed of the channel that is wet. WP is equivalent to measuring the distance from bank to bank with a weighted tape measure lying on the bed. "Width" is a measure from waters edge to waters edge straight across the water surface.

downstream were estimated using the concurrent gauging relations described in Section 2.2. "Nominal flow" refers to the estimated flows at downstream sites for various threshold flows at Birchville. These "RFWP min" nominal minimum flows are 1529 L/s at Silverstream, 1560 L/s at Taita and 766 L/s at Melling (Figure 10; Table 7).

"66% MALF (2270 L/s)" refers to the one day mean annual low flow estimate for Birchville as discussed in Section 2.2. For example, with a MALF flow of 2270 L/s at Birchville, the nominal flow which is used to calculate habitat at Silverstream is 2830 L/s (Table 2).

"Habitat Flow" refers to the flow required to retain 66% (or 90%) of the habitat available at the respective nominal flow for the most demanding target species (specifically, brown trout adult, food production, or Deleatidium - mayfly). Habitat is discussed in the following section.

Wetted perimeter, width, depth and velocity for the habitat flows are plotted and tabulated (Figure 10; Table 7). In wide, relatively shallow rivers, the wetted perimeter and width are almost identical. Higher habitat flows result in greater wetted perimeter and width, with a strong tendency for average depth and velocity to increase. The curves in Figure 10 are steeper at lower flows; usually with little gain at higher flows. For example, at Birchville, wetted perimeter increases from 18.1 m at 1200 L/s (RFWP min); to 20.0 m at 1980 L/s (90% MALF); to 21.4 m at 2600 L/s (90% N-MALF). As flows increase by more than 200% (from 1200 to 2600 L/s), the wetted perimeter increases by less than 20%.

There is also a relatively small increase in depth from 0.37 to 0.42 m (~10%) as habitat flows increase from 1200 to 2600 L/s (>200%). Velocity has a greater relative increase over the same flow range (~40% increase). In short, much of the increase in flow is accommodated by increased velocity.

4.6 Existing flow regime – habitat relations

4.6.1 Methodology

Potential habitat availability was evaluated for the Birchville, Silverstream, Taita and Melling reaches, which were described in Sections 2.3 & 4.4. The RHYHABSIM input data and hydraulic parameters were not changed, and the results of the investigations by Jowett (1993) and Harkness (2002) were replicated.

The species and life stages listed in Table 6 were evaluated in RHYHABSIM using the habitat suitability criteria plotted in Appendix B. The rationale for using these criteria is discussed in Section 4.4, with further detail in Appendix C. Flow-habitat relations for these species are plotted in Appendix D.

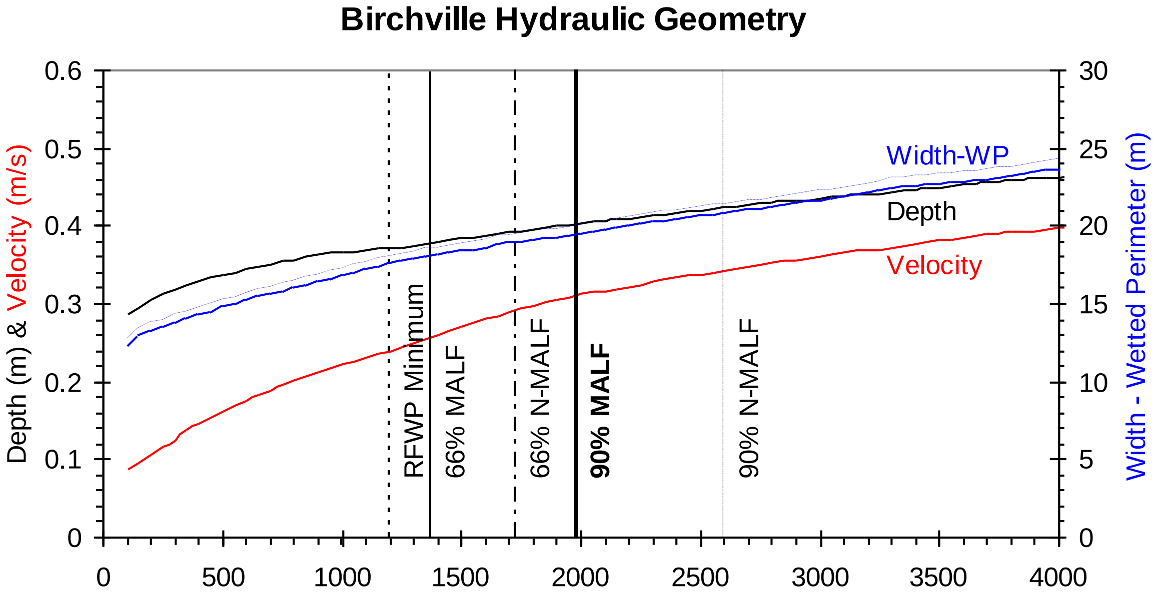
Table 7 Hutt River study site hydraulic geometry at various flow thresholds

Hutt River location	Nominal Flow (L/s)	Habitat Flow (L/s)	WP (m)	Width (m)	Depth (m)	Velocity (m/s)
Birchville						
RFWP min 1200 L/s	1200	1200	18.1	17.6	0.37	0.24
66% MALF (2270 L/s)	2270	1370	18.6	18.1	0.38	0.26
90% MALF (2270 L/s)	2270	1980	20.0	19.5	0.40	0.31
66% N-MALF (3030 L/s)	3030	1730	19.5	19.0	0.39	0.29
90% N-MALF (3030 L/s)	3030	2600	21.4	20.9	0.42	0.34
Silverstream						
Nominal flow at RFWP min	1530	1529	20.2	19.8	0.53	0.25
Nominal 66% MALF	2830	1470	20.0	19.6	0.52	0.25
Nominal 90% MALF	2830	2370	22.3	21.9	0.63	0.29
Nominal 66% N-MALF	3590	1810	21.1	20.7	0.56	0.26
Nominal 90% N-MALF	3590	2980	24.4	23.8	0.70	0.27
Taita						
Nominal flow at RFWP min	1560	1560	29.3	29.3	0.19	0.27
Nominal 66% MALF	3120	2380	31.8	31.7	0.23	0.31
Nominal 90% MALF	3120	2900	33.0	32.9	0.25	0.33
Nominal 66% N-MALF	3880	2790	32.8	32.7	0.24	0.33
Nominal 90% N-MALF	3880	3480	34.2	34.1	0.27	0.35
Melling						
Nominal flow at RFWP min	766	766	23.3	23.1	0.33	0.15
Nominal 66% MALF	2360	1650	28.9	28.7	0.44	0.18
Nominal 90% MALF	2360	2140	33.5	33.3	0.46	0.20
Nominal 66% N-MALF	3120	2090	33.2	33.0	0.46	0.19
Nominal 90% N-MALF	3120	2730	36.2	36.0	0.49	0.21

WP: wetted perimeter

Habitat availability was calculated as weighted usable area in square metres per metre of river channel length (WUA m^2/m). For each species and life stage habitat was calculated in 10 L/s increments and exported to a spreadsheet from RHYHABSIM (plots in Appendix D are at a larger increment for clarity). The 66% and 90% WUA values were calculated and the flow corresponding to these areas was tabulated for each species and life stage.

Flow-habitat relations for RFWP minimum, MALF and N-MALF flow thresholds, as described in Section 4.5, are plotted for the target species (Figure 12 & Figure 13) and summarised for all species for each study site and flow scenario.



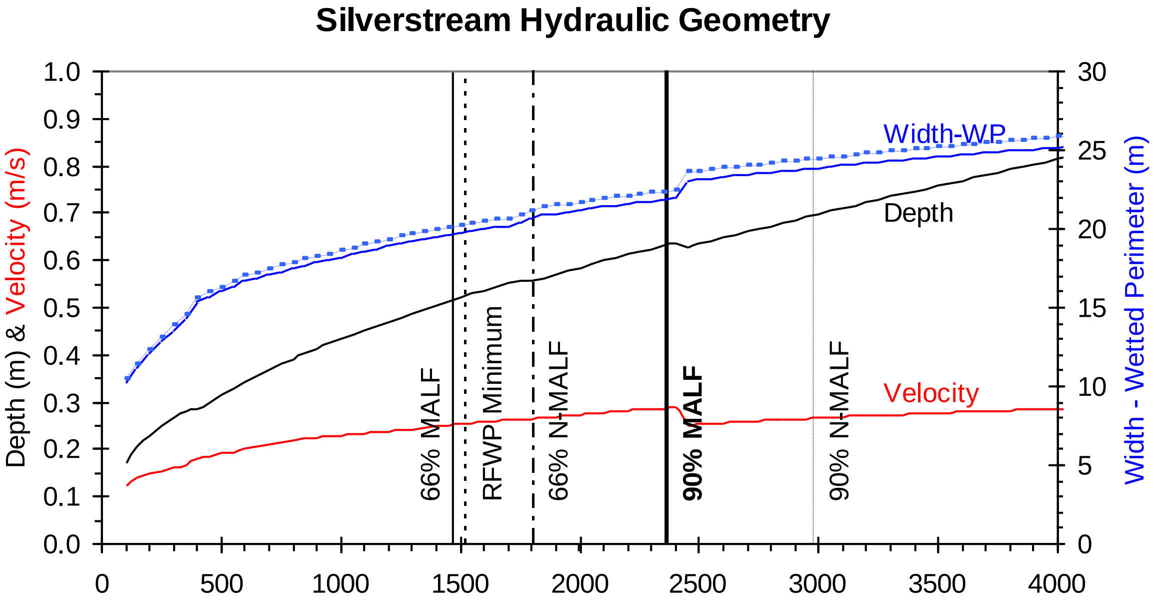


Figure 10 Hydraulic geometry & flow thresholds at Birchville & Silverstream

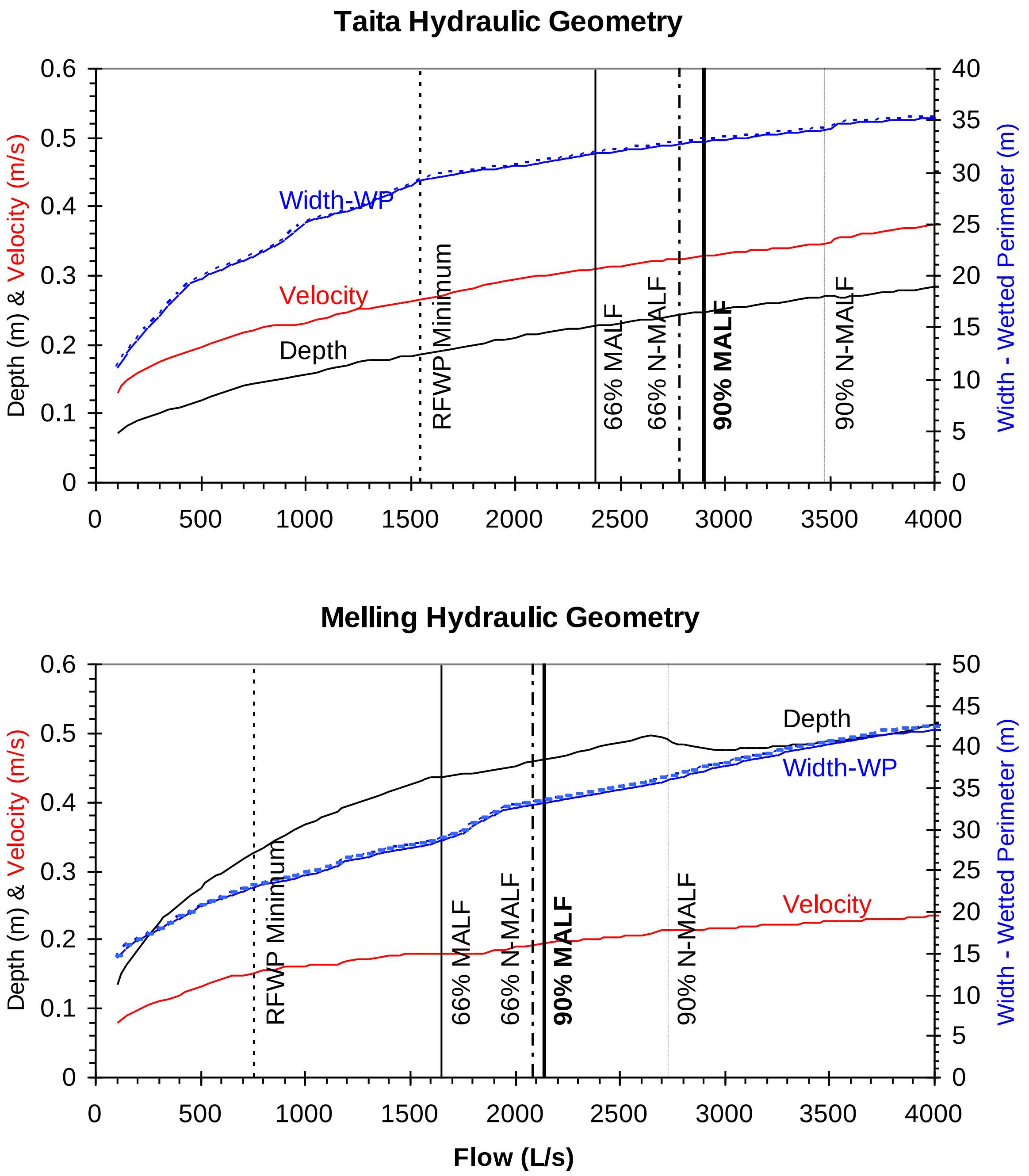


Figure 11 Hydraulic geometry & flow thresholds at Taita & Melling

4.6.2 Birchville existing flow

As discussed in Section 3.1, the rationale for the 1200 L/s minimum flow at Birchville was provided by Jowett (1993) as part of a regional assessment for the RFWP. The minimum flow was based on WUA percent, not WUA m^2/m, and retention of 66% of MALF habitat at Birchville. Jowett (1993) used a flow of 2009 L/s, which is the MALF. Repeating his analysis, using WUA m^2/m, results in flow requirements of 1230 L/s for food production, 630 L/s for Deleatidium, and 1110 L/s for adult brown trout. Using WUA m^2/m rather than %WUA makes little differences in this instance.

Increasing the habitat retention level to 70 or 90% of MALF habitat (which is more in line with current thinking for perennial quality trout rivers), makes a small difference for 70% habitat retention, and a large difference for 90% habitat retention (Figure 12). A 90% threshold requires flows of 1760 L/s, 1480 L/s and 1730 L/s, respectively, for the target species at a 2009 L/s MALF.

The RFWP Birchville analysis was repeated for updated flow records (1971-2006; Table 8). With a longer period of record the MALF for Birchville increased from 2009 L/s (Jowett 1993) to 2274 L/s (Appendix A; Table 1). With the updated flow records, the revised RFWP minimum flow at Birchville (with 66% habitat retention) is 1370 L/s for food production (Table 8). A flow of 1980 L/s is required to retain 90% of MALF habitat. Deleatidium and native fish require lower flows (Table 8).

A flow exceeding 1370 L/s is expected to occur more than 99% of the time; and a flow exceeding 1980 L/s is expected to occur more than 98% of the time (Table A 5, page 84).

In terms of the capacity of the river to provide for increased abstraction at Kaitoke or Te Marua, the water surplus was calculated.[11] The surplus is the balance of the existing MALF (i.e. accounting for present abstraction) minus the threshold retention flow minus the 200 L/s additional abstraction (Table 8). Additional abstraction can be accommodated at Birchville, leaving a 700 L/s surplus with 66% habitat retention, and a 90 L/s surplus with 90% habitat retention for the target species (in this instance food production). Surpluses are greater for other species/life stages.

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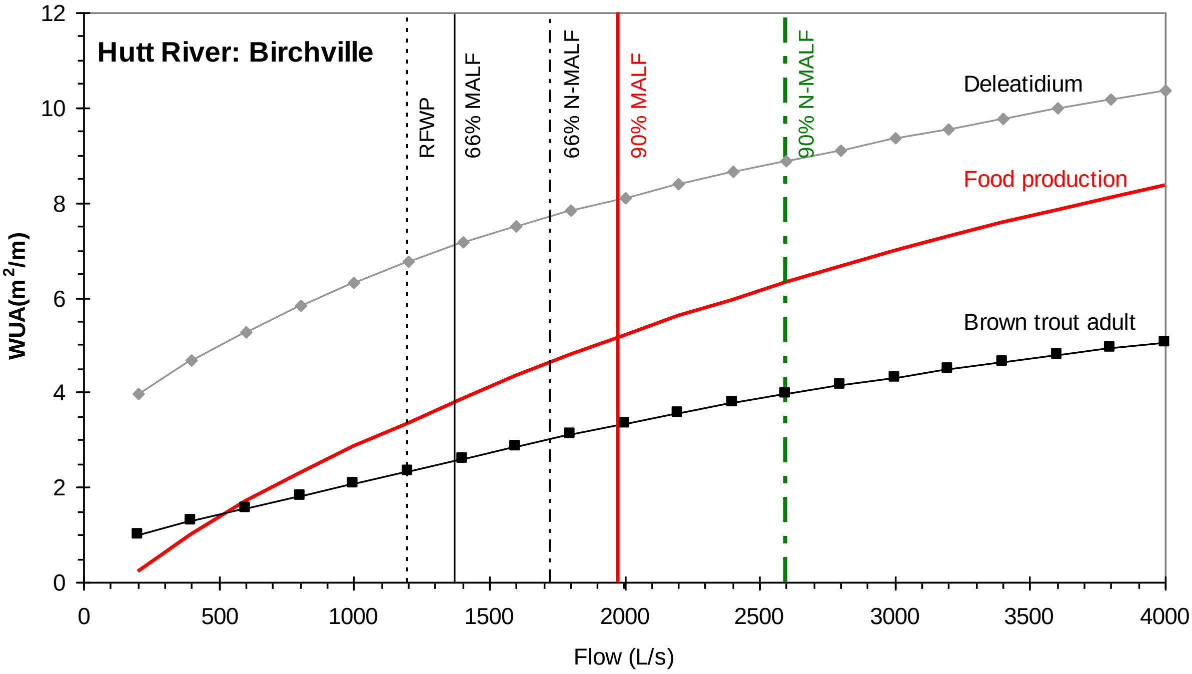
[11] The "surplus" is the volume of water (L/s) above that required to provide the prescribed level of habitat retention as determined by the hydraulic habitat modelling.



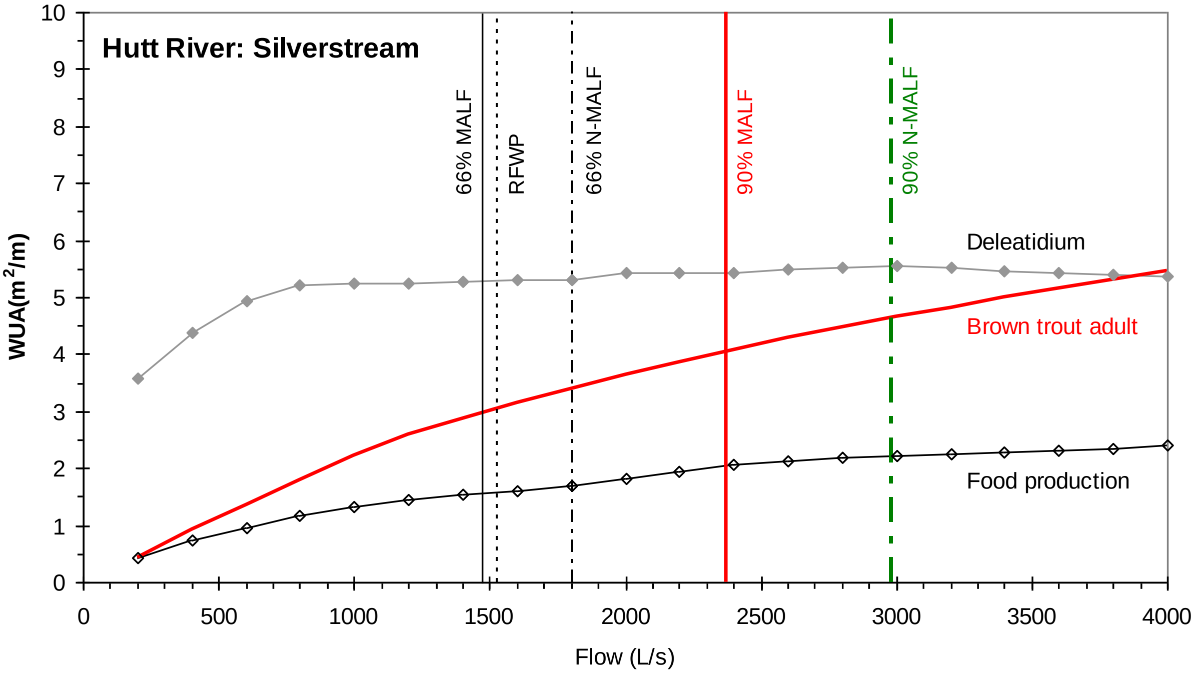
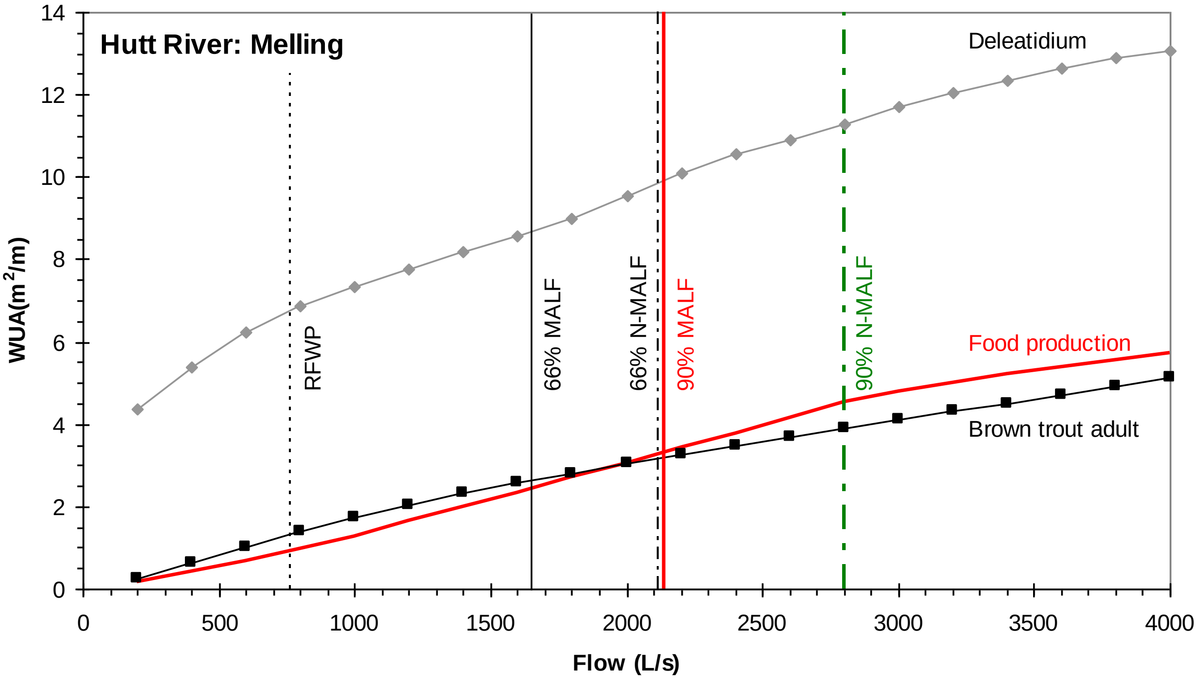


Figure 12 Flow-habitat relations, & habitat flow thresholds at Birchville & Silverstream



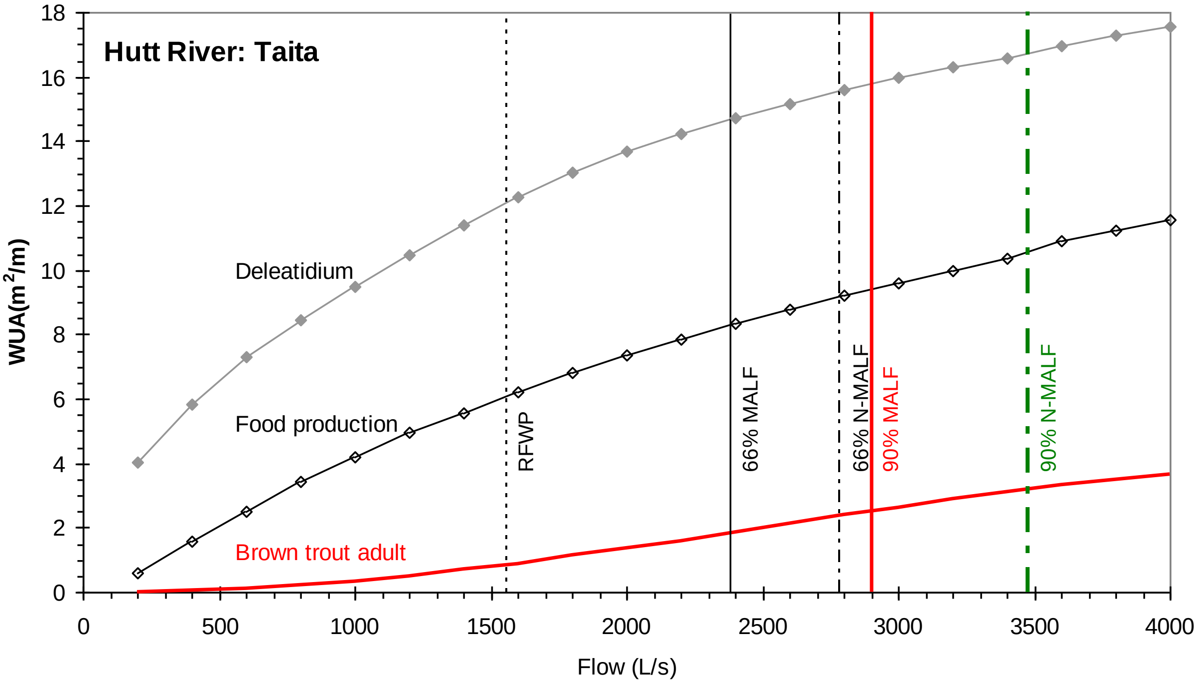


Figure 13 Flow-habitat relations, & habitat flow thresholds at Taita & Melling

Table 8 Birchville habitat (WUA), flows required to retain habitat levels & surplus with 200 L/s additional abstraction

Birchville 1971-2006 MALF 2270 L/s	66% MALF habitat		90% MALF habitat		Surplus flow at MALF with 200 L/s more abstraction	
Species	WUA (m^2/m)	Flow (L/s)	WUA (m^2/m)	Flow (L/s)	66% WUA Retention (L/s)	90% WUA Retention (L/s)
Food producing	3.78	1370	5.15	1980	700	90
Deleatidium (mayfly)	5.60	710	7.63	1670	1360	400
Shortfin eel <300 mm	2.14	460	2.92	1370	1610	700
Longfin eels <300 mm	2.12	860	2.90	1770	1210	300
Longfin eels >300 mm	2.50	110	3.41	1050	1960	1020
Dwarf Galaxias	3.14	110	4.29	950	1960	1120
Inanga feeding	3.33	50	4.54	150	2020	1920
Crans bully	3.35	20	4.57	170	2050	1900
Common bully	4.08	470	5.56	1200	1600	870
Bluegill bully	1.11	1130	1.52	1860	940	210
Redfin bully	5.16	160	7.03	570	1910	1500
Koaro	2.10	1020	2.86	1770	1050	300
Brown trout spawn	1.02	900	1.40	1610	1170	460
Brown trout juvenile	4.18	710	5.70	1670	1360	400
Brown trout adult	2.41	1260	3.28	1940	810	130
Median	3.14	710	4.29	1610	1360	460

4.6.3 Silverstream existing flow

The RFWP nominal minimum flow at Silverstream for the period 1971-2006, based on concurrent low flow gaugings, is 1530 L/s (Table 1 end note). The RFWP nominal flow provides almost the same amount of habitat as 66% MALF habitat retention (Figure 12).

The estimated MALF at Silverstream, calculated from concurrent low flow gaugings and Birchville flow, is 2830 L/s (Table 1; Table 2). The flow required to provide 66% of the habitat for food production is 1210 L/s; and 1470 L/s is required for adult trout feeding (Figure 12; Table 9). A residual flow of 2230 L/s is required to retain 90% of food production habitat and 2370 L/s is required for adult brown trout. Some native fish species require similar flows to food production and adult brown trout for 90% habitat retention (Table 9; Appendix D).

Table 9 Silverstream habitat (WUA), flows required to retain habitat levels & surplus with 200 L/s additional abstraction

Silverstream 1971-2006 MALF 2830 L/s	66% MALF habitat		90% MALF habitat		Surplus flow at MALF with 200 L/s more abstraction	
Species	WUA (m^2/m)	Flow (L/s)	WUA (m^2/m)	Flow (L/s)	66% WUA Retention	90% WUA Retention
Food producing	1.45	1210	1.98	2230	1420	400
Deleatidium (mayfly)	3.65	220	4.98	620	2410	2010
Shortfin eel <300 mm	1.88	50	2.57	180	2580	2450
Longfin eels <300 mm	1.53	300	2.09	1060	2330	1570
Longfin eels >300 mm	6.02	1170	8.21	2060	1460	570
Dwarf Galaxias	2.66	40	3.63	90	2590	2540
Inanga feeding	4.53	190	6.18	360	2440	2270
Crans bully	3.34	50	4.55	50	2580	2580
Common bully	2.11	70	2.88	370	2560	2260
Bluegill bully	0.45	570	0.62	2390	2060	240
Redfin bully	3.73	70	5.09	180	2560	2450
Koaro	0.94	360	1.28	1170	2270	1460
Brown trout spawn	0.62	1200	0.84	2430	1430	200
Brown trout juvenile	4.23	480	5.76	850	2150	1780
Brown trout adult	2.97	1470	4.05	2370	1160	260
Median	2.66	300	3.63	850	2330	1780

Based on concurrent flow gauging relations, and flow duration at Birchville (Table A 5, page 84), a flow of 2370 L/s is expected to occur more than 98% of the time at Silverstream. With additional abstraction of 200 L/s, flows are exceeded 97% of the time.

There is water available for the abstraction of an additional 200 L/s; with a surplus of 1160 L/s for adult brown trout (the most demanding flow requirement) at 66% habitat retention; and a surplus of 260 L/s for adult brown trout at 90% habitat retention (Table 9).

4.6.4 Taita existing flow

The nominal RFWP minimum flow at Taita, based on concurrent gaugings and Birchville flow, is 1560 L/s (Table 2). The RFWP minimum flow provides 73% of food production habitat, 82% of Deleatidium habitat, and 47% of adult brown trout habitat that occurs with the 66% MALF threshold (Figure 13).

Adult brown trout are the most flow demanding with 2380 L/s required to retain 66% of MALF habitat; and 2900 L/s to retain 90% of MALF habitat (Table 10). Native fish require lower flows. A flow exceeding 2380 L/s is expected to occur around 99% of the time; and a flow exceeding 2900 L/s is expected to occur around 97% of the time (Table A 5, page 84).

Table 10 Taita habitat availability (WUA), flows required to retain habitat levels & surplus with 200 L/s additional abstraction

Taita 1971-2006 MALF 3120 L/s	66% MALF habitat		90% MALF habitat		Surplus flow at MALF with 200 L/s more abstraction	
Species	WUA (m^2/m)	Flow (L/s)	WUA (m^2/m)	Flow (L/s)	66% WUA Retention (L/s)	90% WUA Retention (L/s)
Food producing	6.50	1700	8.87	2640	1220	280
Deleatidium (mayfly)	10.66	1240	14.54	2320	1680	600
Shortfin eel <300 mm	5.91	710	8.06	1510	2210	1410
Longfin eels <300 mm	3.42	1040	4.66	2130	1880	790
Longfin eels >300 mm	2.39	1370	3.26	2470	1550	450
Dwarf Galaxias	8.59	380	11.71	1150	2540	1770
Inanga feeding	0.36	1470	0.49	2760	1450	160
Crans bully	9.27	290	12.64	1020	2630	1900
Common bully	10.56	600	14.40	1330	2320	1590
Bluegill bully	2.88	1480	3.92	2530	1440	390
Redfin bully	13.70	510	18.69	1350	2410	1570
Koaro	3.32	1030	4.52	1970	1890	950
Brown trout spawn	3.05	1180	4.15	2170	1740	750
Brown trout juvenile	6.87	1880	9.37	2720	1040	200
Brown trout adult	1.83	2380	2.50	2900	540	20
Median	5.91	1180	8.06	2170	1740	750

The calculated surplus of water with increased abstraction of 200 L/s is 540 L/s for adult trout at 66% habitat retention, reducing to 20 L/s at 90% habitat retention (Table 10). The surplus for food production habitat is greater (1220 L/s at 66% habitat retention; and 280 L/s at 90% habitat retention).

4.6.5 Melling existing flow

The RFWP nominal flow at Melling, based on concurrent gaugings and Taita Gorge flows, is 766 L/s. (Downstream of Taita to Melling there is a loss of river flow to groundwater; Table 1). The RFWP nominal flow is far less than the estimated MALF flow of 2360 L/s.

Compared with the habitat available at 1650 L/s (to retain 66% of MALF food production habitat), the RFWP nominal flow provides 38% of food production habitat, 78% of Deleatidium habitat and 50% of adult brown trout habitat (Figure 13). When compared with the flow threshold to retain 90% of MALF food production habitat (2140 L/s), the RFWP nominal flow provides 28% of food production habitat, 68% of Deleatidium habitat and 42% of adult brown trout habitat (Figure 13; Table 11). Native fish require lower flows than for food production (Table 11; Appendix D).

Table 11 Melling habitat availability (WUA), flows to retain habitat levels & surplus with 200 L/s additional abstraction

Melling 1971-2006 MALF 2360 L/s	66% MALF habitat		90% MALF habitat		Surplus flow at MALF with 200 L/s more abstraction	
Species	WUA (m^2/m)	Flow (L/s)	WUA (m^2/m)	Flow (L/s)	66% WUA Retention (L/s)	90% WUA Retention (L/s)
Food producing	2.45	1650	3.34	2140	510	20
Deleatidium (mayfly)	6.93	810	9.45	1960	1350	200
Shortfin eel <300 mm	5.72	650	7.80	1890	1510	270
Longfin eels <300 mm	2.32	780	3.16	1940	1380	220
Longfin eels >300 mm	4.82	1140	6.57	1980	1020	180
Dwarf Galaxias	8.30	480	11.32	1950	1680	210
Inanga feeding	3.66	150	5.00	300	2010	1860
Crans bully	8.73	190	11.90	1890	1970	270
Common bully	7.30	930	9.96	1930	1230	230
Bluegill bully	2.16	1400	2.95	2100	760	60
Redfin bully	9.86	420	13.44	1920	1740	240
Koaro	1.22	1130	1.66	1980	1030	180
Brown trout spawn	2.24	1730	3.06	2140	430	20
Brown trout juvenile	5.51	870	7.51	1840	1290	320
Brown trout adult	2.27	1360	3.09	2040	800	120
Median	4.82	870	6.57	1950	1290	210

Based on concurrent flow gaugings and reported flow durations (Table A 5, page 84), a flow of 1650 L/s is expected to occur more than 99% of the time; and 2140 L/s is expected to occur more than 97% of the time.

There is a surplus of flow with increased water abstraction of 200 L/s (Table 11). For food production at 66% habitat retention the surplus is 510 L/s; decreasing to 20 L/s for 90% retention of food production habitat and 120 L/s for adult brown trout habitat.

4.7 Naturalised flow habitat relations

Naturalised flows for the period of hydrological record (1971-2006) at Birchville were computed (Section 2.2). The one day natural mean annual low flow (N-MALF) is estimated to be 760 L/s greater than the existing MALF flow at Birchville, Silverstream, Taita Gorge and Melling (Table 2).

Flows-habitat relations were modelled and the flow threshold to retain 66% and 90% of habitat at N-MALF were calculated for each study reach (Figure 12; Appendix D). The surplus or deficit with an additional 200 L/s abstraction at Kaitoke or Te Marua was calculated by combining the existing low flow abstraction of 760 L/s with the 200 L/s additional abstraction for a total low flow take of 960 L/s during N-MALF conditions (Table 12 to Table 15).

4.7.1 Birchville naturalised flow

At Birchville the N-MALF is 3030 L/s, compared with 2270 L/s for the existing MALF. A flow of 1730 L/s is required to retain 66% of food production habitat; and 2600 L/s is required to retain 90% of food production habitat at N-MALF (Figure 12; Table 12). Native fish require lower flows than food production or adult trout to retain the threshold habitat levels (Table 12).

Table 12 Birchville habitat (WUA), flows required to retain habitat levels & surplus/deficit with 200 L/s more abstraction with naturalised flow

Birchville 1971-2006 N-MALF 3030 L/s	66% N-MALF habitat		90% N-MALF habitat		Surplus/deficit at N-MALF with 200 L/s more abstraction	
Species	WUA (m^2/m)	Flow (L/s)	WUA (m^2/m)	Flow (L/s)	66% WUA Retention (L/s)	90% WUA Retention (L/s)
Food producing	4.63	1730	6.32	2600	340	-530
Deleatidium (mayfly)	6.19	940	8.44	2240	1130	-170
Shortfin eel <300 mm	2.25	570	3.07	1650	1500	420
Longfin eels <300 mm	2.45	1250	3.34	2430	820	-360
Longfin eels >300 mm	2.56	140	3.49	1210	1930	860
Dwarf Galaxias	3.24	120	4.42	1170	1950	900
Inanga feeding	3.33	50	4.54	150	2020	1920
Crans bully	3.35	20	4.57	170	2050	1900
Common bully	4.16	490	5.67	1320	1580	750
Bluegill bully	1.22	1290	1.66	2180	780	-110
Redfin bully	5.16	160	7.03	560	1910	1510
Koaro	2.28	1170	3.11	2130	900	-60
Brown trout spawn	1.03	920	1.41	1640	1150	430
Brown trout juvenile	4.58	910	6.24	2170	1160	-100
Brown trout adult	2.87	1620	3.92	2550	450	-480
Median	3.24	910	4.42	1650	1160	420

With 200 L/s additional abstraction there is sufficient water at N-MALF to provide for the 66% natural MALF habitat retention level for all species. For the most demanding species/life stage (food production) there is a surplus of 340 L/s (Table 12). However, there is a deficit of 330 L/s at the 90% N-MALF threshold with the existing abstraction; increasing to 530 L/s for food production with the proposed additional abstraction of 200 L/s (Table 12). The deficit will be short lived.

A flow of 2600 L/s (for 90% food production retention) is expected to occur more than 95% of the time with the existing abstraction. With an additional 200 L/s abstraction at Kaitoke or Te Marua, the required flow at Birchville is expected to occur more than 94% of the time (Table A 5, page 84).

4.7.2 Silverstream naturalised flow

In Table 13 flows to retain threshold habitat levels are presented for naturalised Silverstream flows. A flow of 1810 L/s is required to retain 66% of the N-MALF habitat for adult brown trout; and 2980 L/s is required to retain 90% of the adult brown trout habitat available at N-MALF (Figure 12; Table 13). Food production requires lower flows (1400 L/s and 2470 L/s, respectively). Native fish require lower flows than adult trout (Table 13; Appendix D).

Table 13 Silverstream habitat (WUA), flows to retain habitat levels & surplus/deficit with 200 L/s more abstraction with naturalised flows

Silverstream 1971-2006 N-MALF 3590 L/s	66% N-MALF habitat		90% N-MALF habitat		Surplus/deficit at N-MALF with 200 L/s more abstraction	
Species	WUA (m^2/m)	Flow (L/s)	WUA (m^2/m)	Flow (L/s)	66% WUA Retention	90% WUA Retention
Food producing	1.53	1400	2.09	2470	1230	160
Deleatidium (mayfly)	3.66	220	4.99	620	2410	2010
Shortfin eel <300 mm	1.88	50	2.57	180	2580	2450
Longfin eels <300 mm	1.55	310	2.12	1200	2320	1430
Longfin eels >300 mm	6.48	1310	8.84	2550	1320	80
Dwarf Galaxias	2.66	40	3.63	90	2590	2540
Inanga feeding	4.53	190	6.18	360	2440	2270
Crans bully	3.34	50	4.55	100	2580	2530
Common bully	2.11	70	2.88	370	2560	2260
Bluegill bully	0.46	590	0.63	2440	2040	190
Redfin bully	3.73	70	5.09	180	2560	2450
Koaro	0.94	350	1.28	1170	2280	1460
Brown trout spawn	0.62	1200	0.85	2470	1430	160
Brown trout juvenile	4.23	480	5.76	850	2150	1780
Brown trout adult	3.40	1810	4.63	2980	820	-350
Median	2.66	310	3.63	850	2320	1780

With an additional abstraction of 200 L/s, there is a surplus of 820 L/s for 66% habitat retention of adult trout habitat (Table 13). With 90% habitat retention there is a surplus for all species and life stages apart from adult brown trout. The deficit for adult trout at the 90% threshold for existing abstraction is 150 L/s; increasing to 350 L/s with additional abstraction of 200 L/s (Table 13). At the 350 L/s deficit a high level of habitat is retained (84% against 90%) and the duration of the shortfall is brief.

Based on the flow duration at Birchville (Table A 5, page 84), and concurrent flow gaugings, a flow of 2980 L/s is expected to occur more than 96% of the time at Silverstream with the existing Kaitoke abstraction. Additional abstraction of 200 L/s will reduce the flow exceedance from more than 96% to more than 95% of the time at Birchville and Silverstream.

4.7.3 Taita naturalised flow

In Table 14 and Figure 13, habitat retention levels and flows are presented for the Hutt River at Taita. The reach had river works prior to the habitat survey (Harkness 2002). For 66% N-MALF habitat retention 2050 L/s is required for food production, and 2790 L/s for adult trout feeding. For 90% retention the flows are 3320 and 3480 L/s, respectively for an estimated natural MALF of 3880 L/s (Table 14). Native fish require relatively high flows.

Table 14 Taita habitat (WUA), flows required to retain habitat levels & surplus/deficit with 200 L/s more abstraction with naturalised flows

Taita 1971-2006 N-MALF 3880 L/s	66% N-MALF habitat		90% N-MALF habitat		Surplus/deficit at N-MALF with 200 L/s more abstraction	
Species	WUA (m^2/m)	Flow (L/s)	WUA (m^2/m)	Flow (L/s)	66% WUA Retention	90% WUA Retention
Food producing	7.50	2050	10.23	3320	870	-400
Deleatidium (mayfly)	11.47	1420	15.64	2820	1500	100
Shortfin eel <300 mm	6.06	770	8.26	1600	2150	1320
Longfin eels <300 mm	3.71	1200	5.06	2830	1720	90
Longfin eels >300 mm	2.59	1580	3.53	2930	1340	-10
Dwarf Galaxias	8.59	380	11.71	1150	2540	1770
Inanga feeding	0.42	2270	0.57	3210	650	-290
Crans bully	9.27	290	12.64	1020	2630	1900
Common bully	10.72	620	14.61	1500	2300	1420
Bluegill bully	3.19	1720	4.35	3110	1200	-190
Redfin bully	13.70	510	18.69	1350	2410	1570
Koaro	3.46	1110	4.72	2240	1810	680
Brown trout spawn	3.24	1300	4.42	2730	1620	190
Brown trout juvenile	7.93	2220	10.81	3280	700	-360
Brown trout adult	2.36	2790	3.21	3480	130	-560
Median	6.06	1300	8.26	2820	1620	100

With 200 L/s additional abstraction there is sufficient water to provide for the 66% threshold for all species. For the most demanding species/life stage (adult trout) there is a surplus of 130 L/s (Table 14). However, there is not sufficient water to continuously provide for the 90% habitat threshold with existing abstraction (the shortfall is 360 L/s). With 200 L/s additional abstraction the deficit increases to 560 L/s for adult trout and 400 L/s for food production (but there is a 100 L/s surplus for Deleatidium). The deficits are expected to occur for short periods.

A flow of 3480 L/s (for 90% adult trout habitat retention) is expected to occur more than 96% of the time with the existing abstraction. With an additional 200 L/s abstraction at Kaitoke or Te Marua, the threshold flow is expected to occur more than 95% of the time at Taita (Table A 5, page 84). This is consistent with the longer term record at Birchville where the coincident flow of 2710 L/s occurs about 95% of the time with existing abstraction, and more than 93% of the time with 200 L/s additional abstraction.

4.7.4 Melling naturalised flow

At Melling a flow of 2090 L/s is required to retain 66% of the food production habitat at the naturalised MALF flow of 3220 L/s; and 2730 L/s is required to retain 90% of the food production habitat (Table 15; Figure 13). Flow requirements for several native fish are similar to food production (Table 15; Appendix D). A complicating factor in this reach is that the flows have a strong tidal influence.

Food production has the most demanding flow requirement. With 200 L/s additional abstraction there is sufficient water available to provide for food production habitat at the 66% threshold; leaving a 170 L/s surplus (Table 15). There is not sufficient water to continuously provide for the 90% habitat threshold with existing abstraction (the shortfall is 270 L/s). With an additional take of 200 L/s, the deficit is 470 L/s (Table 15).

Extrapolation of the flow duration data from Taita Gorge (based on Table A 5, page 84; and concurrent gauging relations) suggests that with existing abstractions the 90% habitat threshold flows at Melling will be exceeded more than 96% of the time. With additional abstraction of 200 L/s the 90% threshold flow will be exceeded more than 95% of the time.

A flow at Birchville of 2710 L/s is required to provide a flow of 2730 L/s at Melling. This would occur about 95% of the time at Birchville with existing abstraction, and more than 93% of the time with 200 L/s additional abstraction (Table A 5, page 84).

Table 15 Melling habitat availability (WUA), flows to retain habitat levels & surplus/deficit with 200 L/s more abstraction with naturalised flow

Melling 1971-2006 N-MALF 3120 L/s	66% N-MALF habitat		90% N-MALF habitat		Surplus/deficit at N-MALF with 200 L/s more abstraction	
Species	WUA (m^2/m)	Flow (L/s)	WUA (m^2/m)	Flow (L/s)	66% WUA Retention	90% WUA Retention
Food producing	3.24	2090	4.42	2730	170	-470
Deleatidium (mayfly)	7.86	1250	10.71	2480	1010	-220
Shortfin eel <300 mm	6.41	1160	8.73	2420	1100	-160
Longfin eels <300 mm	2.52	1100	3.43	2130	1160	130
Longfin eels >300 mm	5.51	1450	7.52	2510	810	-250
Dwarf Galaxias	8.77	610	11.96	2100	1650	160
Inanga feeding	3.95	180	5.38	370	2080	1890
Crans bully	9.07	240	12.36	240	2020	2020
Common bully	7.47	1020	10.19	1970	1240	290
Bluegill bully	2.82	1990	3.85	2790	270	-530
Redfin bully	10.46	540	14.27	2110	1720	150
Koaro	1.38	1390	1.88	2430	870	-170
Brown trout spawn	2.83	2020	3.87	2640	240	-380
Brown trout juvenile	6.27	1170	8.55	2500	1090	-240
Brown trout adult	2.79	1780	3.81	2700	480	-440
Median	5.51	1170	7.52	2430	1090	-170

4.8 Median flow

Hay (2007a) argued "*that the median flow is more relevant than the MALF to macroinvertebrates…*" with the intent that the impact of allocation on habitat availability for invertebrates at the median flow be considered. While I disagree with his point of view, habitat availability is evaluated using RHYHABSIM at Birchville and Taita where median flow values were reported (Wilson 2006; Table A 4, page 82).

Food production habitat WUA is 11.60 m^2/m at the Birchville existing median flow of 12420 L/s. Decreasing the existing median flow by 200 L/s provides a slight increase in food production habitat (<1%) (Figure 14). (The 200 L/s flow reduction equates to the minimum flow at Kaitoke being reduced from 600 L/s to 400 L/s). However, increasing the median flow, by adding back the estimated average Kaitoke abstraction of 760 L/s, reduces the available habitat by 2%.

At Taita the existing median flow is ~14240 L/s. There is little change in available habitat if the existing median flow is reduced by 200 L/s; but there is a slight increase in food production habitat if the average Kaitoke abstraction of 760 L/s is added back (from 17.49 m^2/m to 17.78 m^2/m) (Figure 14).

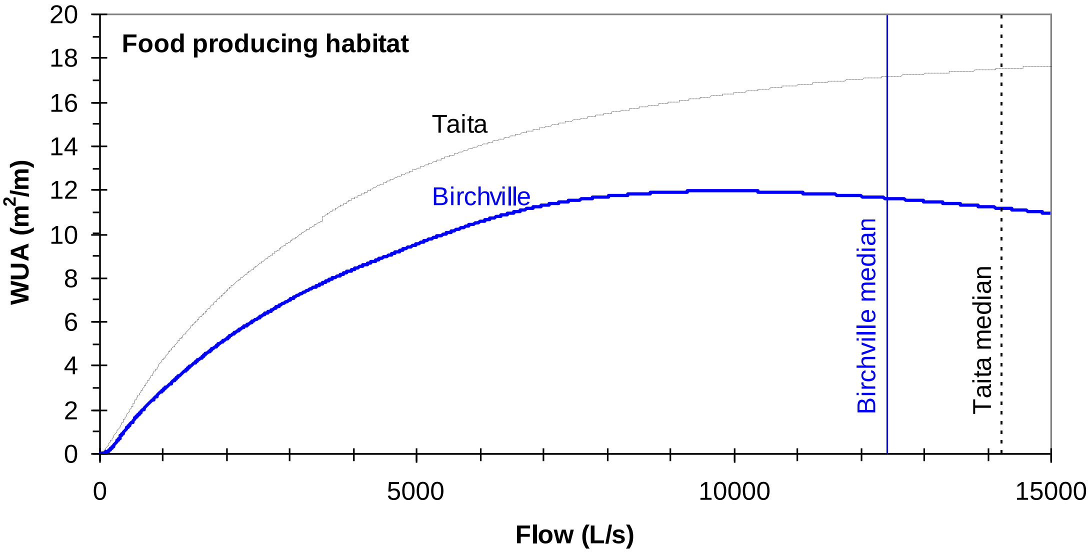


Figure 14 Food production habitat at median flow

I conclude that reducing the minimum flow at Kaitoke Weir from 600 L/s to 400 L/s will have no material effect on food production habitat availability at around the median flow.

4.9 Trout abundance model

The emphasis of the instream flow assessment is on the lower reaches where the greatest numbers of medium and large trout were reported. This was agreed with stakeholders at the onset of the investigations. The rationale was that there are far fewer trout above Birchville and that the extensive pools in the upper reaches and gorge would not materially change with the proposed flow reduction.

Over ten surveys the median number of trout increases downstream from ~9 medium and large trout in the upper reaches (Kaitoki and Te Marua) to 36 in the middle reaches (Birchville and Whakatikei) and 61 per km in the lower reaches (Heretaunga, Taita, Avalon and Melling) (Table 4).

Hydraulic changes are calculated in the fish passage report (Hudson & Harkness 2010). They show that changes in hydraulic geometry are relatively small even for the riffles and pool-riffle transitions. The extensive pools had small changes. The average width decreased by 0.1 to 0.5 m for an average pool width of 24 m, depth decreased 0.02 to 0.03 m and velocity decrease of 0.01 to 0.02 m/s, with a flow reduction from 600 to 400 L/s. These changes are modest when the optimum depth and velocity requirements of adult brown trout are considered in context (Appendix B).

To assess the effects of flow reductions on the 5800 m of river between Birchville and the gorge the 100 rivers brown trout model (Jowett, 1992) was applied. This model predicts trout numbers based on several physical parameters including flow, channel width, weighted usable area for adult trout as a percent of wetted width, and food production habitat at median flow. The input parameters are as follows with calculations from a spreadsheet solution provided by Mr Jowett.

Parameter	Units	Te Marua	Birchville	Taita
MALF flow	m^3/s	0.988	2.274	3.298
Median flow	m^3/s	5.841	12.42	14.243
Width natural MALF	M	13.6	21.7	35.2
Width MALF flow	M	11.9	20.2	33.7
Width MALF -200 L/s	m	11.5	19.8	33.3
Width median flow	m	17.1	28.1	44.4
WUA trout N-MALF	% of wetted width	21	20	10.5
WUA trout MALF	% of wetted width	13	18	8.9
WUA trout MALF -200L/s	% of wetted width	10	17	8.2
WUA food N-median flow	% of wetted width	48	40	39
WUA food median flow	% of wetted width	49	41	39
WUA food median -200L/s	% of wetted width	49	41	39
Cover from all fish surveys	rating range	2.5 - 4.0	5.0 - 6.5	2.5 - 4.0
Calibrated cover	rating	2.3	4.8	4.4
Sand	% in survey	0	2.9	4.8
Elevation	m above sea level	98	68	24
Gradient	dimensionless	0.0054	0.005	0.003
Pasture	% of catchment	7	17	15
Lake	% of catchment	0	0	0

Table 16 Input parameters for the 100 rivers brown trout abundance model

Streamflows were taken from Tables A3 and A4. The width and percent weighted usable area were from additional RHYBABSIM instream flow modelling (Birchville & Taita), and from the fish passage report ("Benje Creek," Hudson & Harkness 2010). The latter cross sections are near the confluence of Benge Creek below the Te Marua treatment plant. They describe the shallowest part of the channel at the riffle crest and the pool transition upstream of the riffle.

Elevations are from the Hutt River cross sections. Gradients were calculated from the RHYHABSIM survey data at Birchville and Taita and from the bed elevation and river distances used in the reports. Percent pasture was calculated from the river environment classification by Summer Warr (GWRC).

Cover ratings are the range of values reported in the drift dive surveys to quantify features providing protection for aquatic species (Table 16).[12] Cover values play a large role in determining the predicted trout abundance.[13] The "calibrated cover" rating refers to an iterated value where observed and predicted trout abundance closely match (other factors being equal).

The calibrated cover values, and other values in Table 16, are used to predict the effects of changing flows. The natural MALF (i.e. existing plus 760 L/s), existing MALF (i.e. recorded flows), and the existing MALF minus 200 L/s are evaluated (Table 17).

Abundance	Te Marua	Birchville	Taita
Observed 1999-2009	9	37	54
Natural flows	13	41	59
Existing flows	9	37	53
Existing -200 L/s	8	35	51

Table 17 Observed and predicted brown trout abundance (medium and large trout per km) at various flows

The trout abundance model predictions align with observed trout counts for the existing flow regime. This provides some assurance that the calculations showing that reducing flows by 200 L/s will have little effect on trout abundance are robust. As discussed in Section 4.3, large, frequent disruptive flow events are probably more important than low flow in determining trout abundance.

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[12] Cover rating (ranging from 0 to 9) are annotated during the drift dive surveys. The rating refers to structural materials (e.g. boulders and logs) and channel features (e.g. undercut banks, deep pool) that provide protection for aquatic species.

[13] Predictions of trout abundance vary by a factor of two or three difference between the low and high predictions for each reach due to cover. For example, in the Birchville reach for existing flows the predicted abundance varies from 41 trout per km with a cover value of 5 to 81 trout per km with a cover value of 6.5.

5 Water temperature

Changes in water temperature can have a substantial effect on aquatic ecosystems for the following reasons:

- Temperature influences the physiology of the biota (e.g. growth and metabolism, reproduction timing and success, mobility and migration patterns, and production may all be altered by changes to the ambient temperature regime); and ecosystem functioning (e.g. through changes in the rate of microbial processes and altered oxygen solubility) (ANZECC 2000);
- New Zealand native fish have a wide temperature tolerance and temperatures may have to exceed 30°C to be lethal (Richardson et al. 1994). Snails, riffle beetles and a few species of caddis-fly are particularly resistant to high water temperatures (Jowett 1997), whereas stoneflies are particularly sensitive and are usually restricted to rivers with summer water temperatures that do not exceed 19°C (Quinn & Hickey 1990b; Quinn et al. 1994). Temperatures of 24-26°C are lethal to many stream invertebrates (Jowett 1997). However, the water column temperature probably does not represent the temperature near or in the substrate in many gravel bed rivers;
- Brown trout spawn in winter and egg mortality increases when water temperature exceeds c. 10°C (Scott & Poynter 1991). The optimum temperature range for adult trout is 12–19°C, and the lethal temperature is 25–30°C, but the limits for each life stage depend on the acclimatisation temperature (citations in Elliot 1994). Lobón-Cerviá & Rincón (1998), for example, found brown trout in Northern Spain grew more rapidly and at higher temperatures than predicted by Elliot et al. (1995); and
- Water temperature may act as a migratory block for some species (e.g. salmonids - McCullough 1999).

The dominant component of the heat budget of rivers and streams is the net solar radiation; which is affected primarily by season, weather patterns (particularly cloud cover), the sun angle, and shading (e.g. topography and trees along the river banks). Net radiation varies by season, from day to day, and over the course of the day (Figure 15 to Figure 19); resulting in distinctive and repetitive patterns over time and space.

Over the course of a year water temperatures are highly variable. For example, for the Birchville period of water temperature record (March 2007 to present) temperatures ranged from 4 to 23°C; (Figure 15). The summer peak temperatures at Te Marua was around 20-21°C; and around 25°C at Taita Gorge (Figure 15).

Figure 15 Hutt River water temperatures & net radiation at Lower Hutt (GW preliminary data) March 01 2007 to February 26 2008

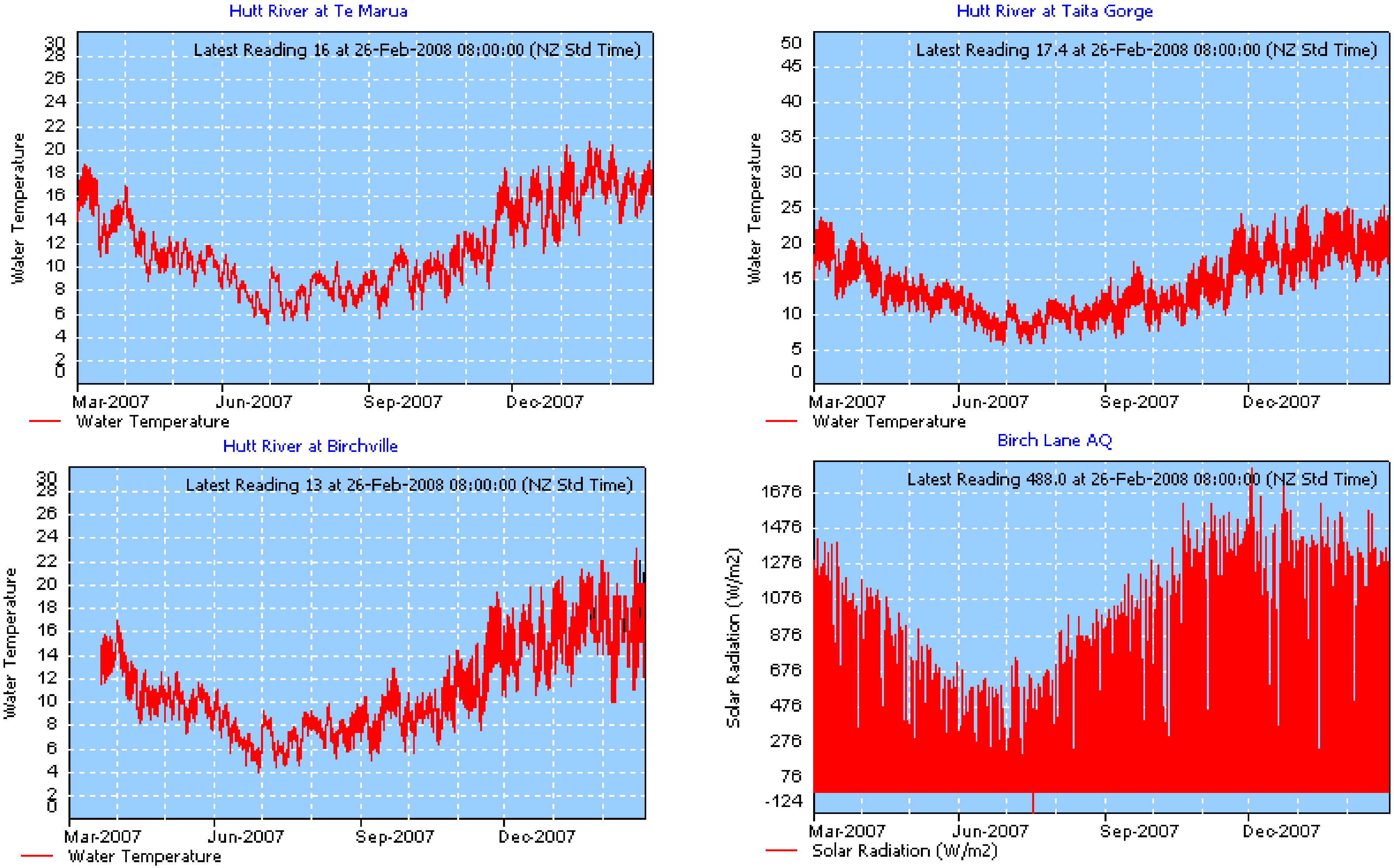


Figure 16 Hutt River Te Marua flow, water temperatures, rainfall & net radiation (GW preliminary data) 16-26 February 2008

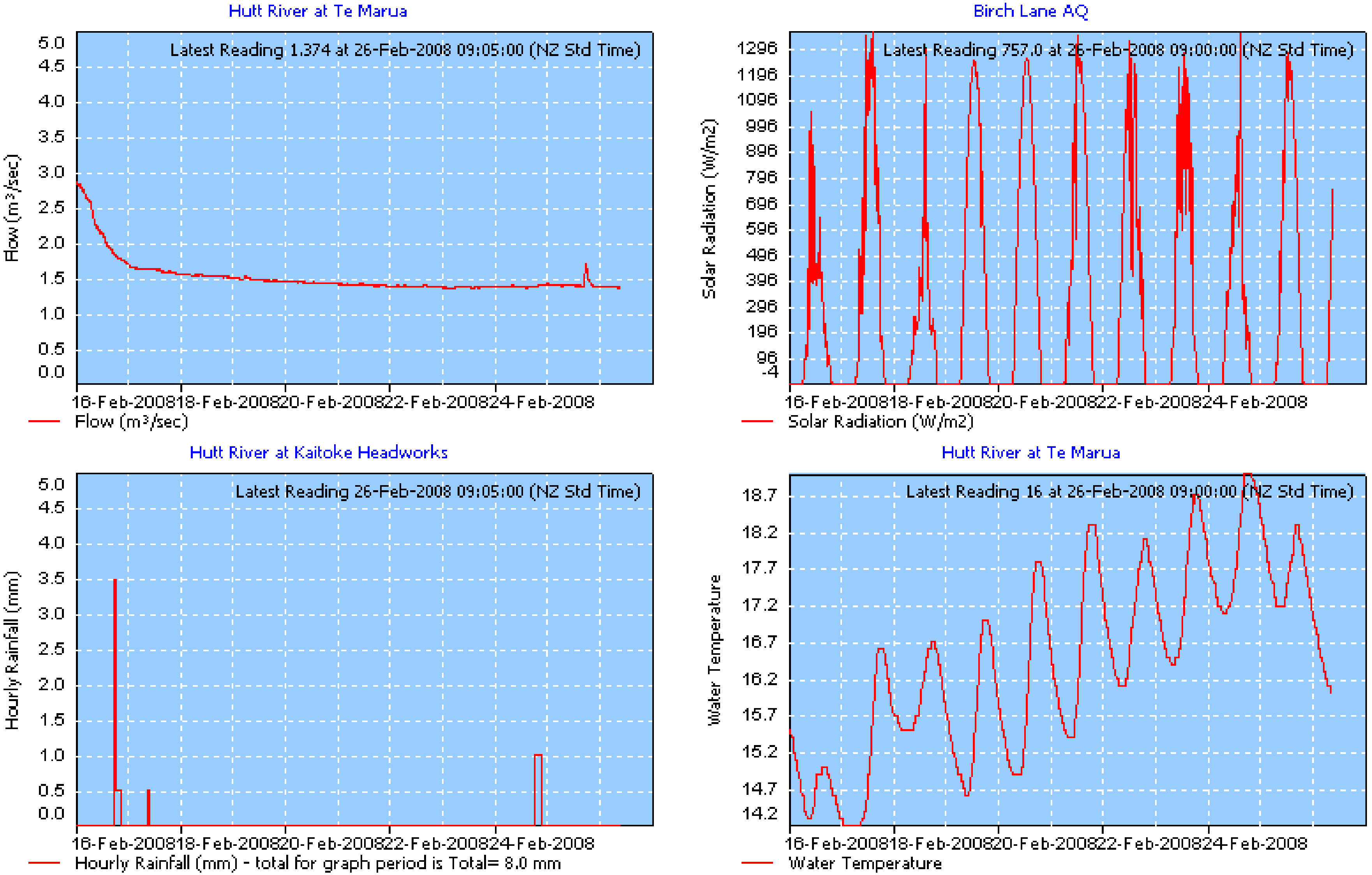


Figure 17 Hutt River Birchville flow, water temperatures, rainfall & net radiation(GW preliminary data) 16-26 February 2008

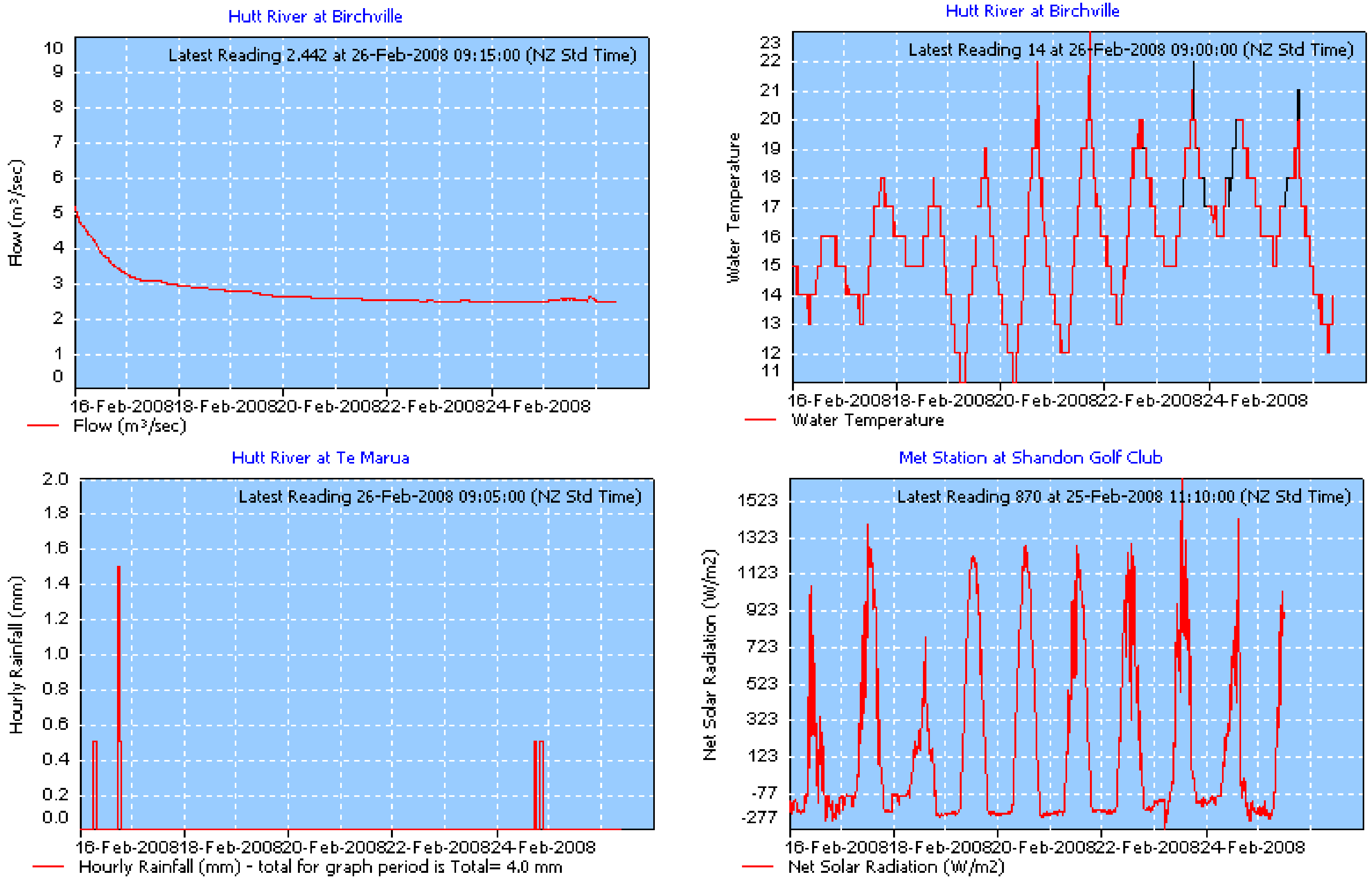


Figure 18 Hutt River Taita Gorge flows, water temperatures, rainfall & net radiation (GW preliminary data) 16-26 February 2008

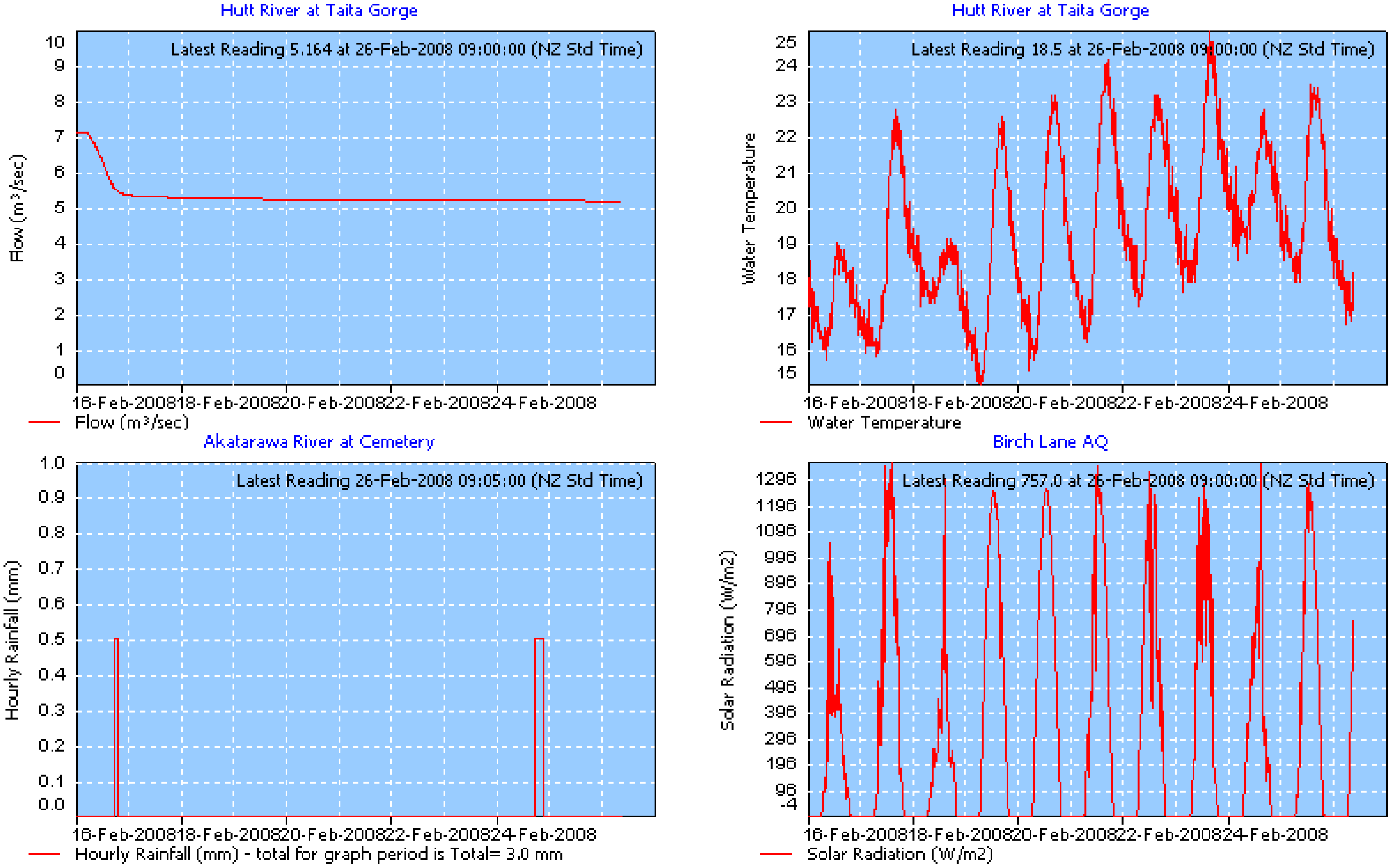
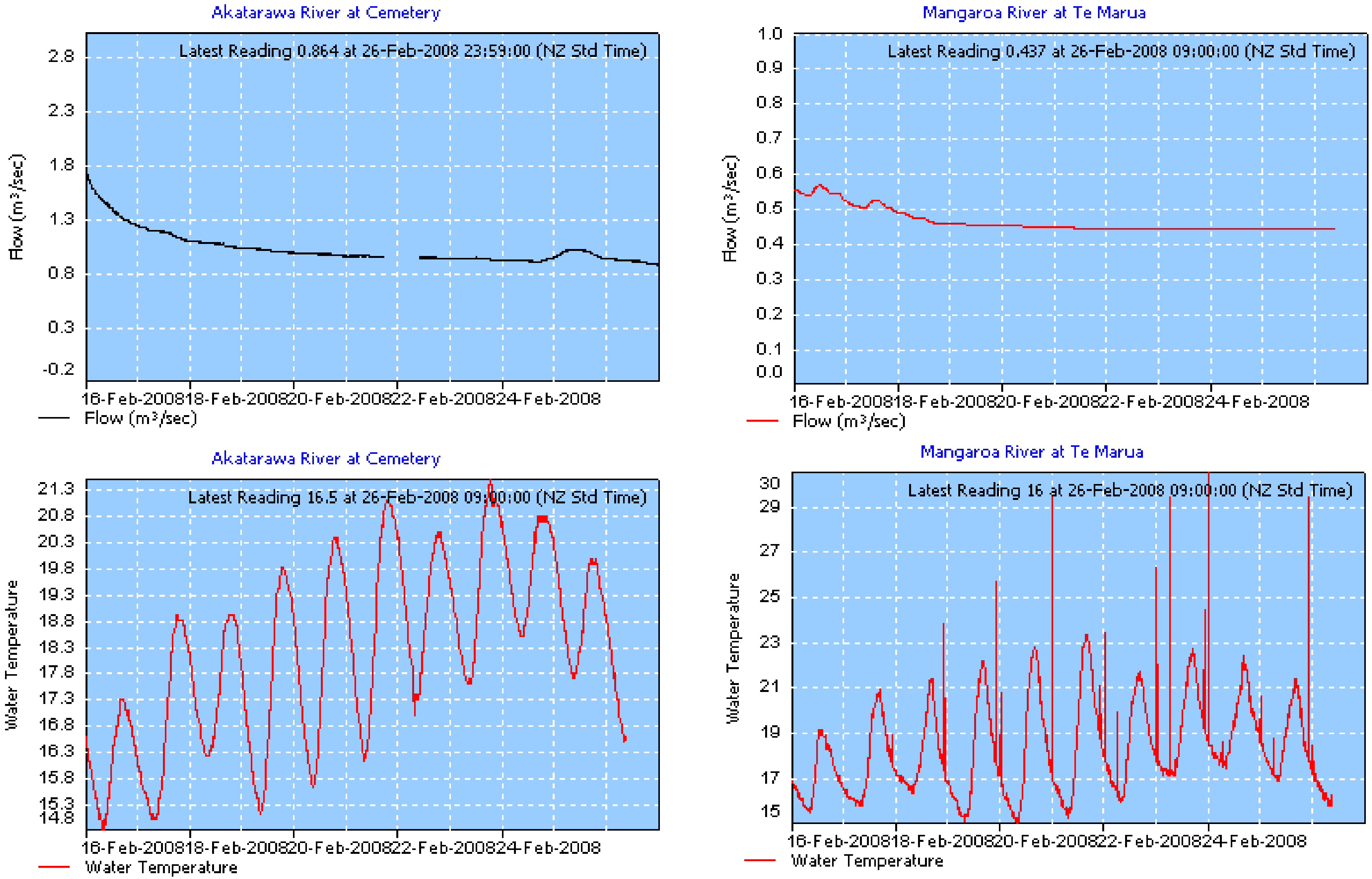


Figure 19 Akatarawa & Mangaroa flows, water temperatures, rainfall & net radiation (GW preliminary data) 16-26 February 2008



From experience, water temperature in the gorge is low. This is attributed to altitude and shading. Temperatures increases downstream from the gorge are attributable to lower altitude and more exposure to sun as the Hutt valley widens and shade is essentially limited largely to riparian trees. Sun exposure is high because long reaches have few trees (e.g. Figure 3) and flow is in a southerly direction. As well, the Akatarawa and Mangaroa are relatively warm tributaries (Figure 19).

There is a strong relationship between the Hutt River water temperatures and the solar radiation even though radiation is measured at Lower Hutt (Birch Lane, Figure 15). At Te Marua, Birchville and Taita Gorge there is often about a six hour lag between the peak in net radiation (noon) and the peak in water temperature (~18:00 hours) (Figure 14 to Figure 18). The peaks in the water temperature are strongly related to the amount of net solar radiation. During a period of very slowly receding flow, there was a strong tendency for water temperatures to increase. However, cloud cover plays a strong role in mediating solar radiation. For example, on 24 February 2008, which was the lowest flow for the year to date at Birchville (2442 L/s), the peak water temperature was 20.0°C, which was lower than preceding days by up to 3°C (Figure 16). Similarly at Taita Gorge, during steady flows (~5200 L/s) peak temperature varied by up to 6°C, with the 24th being about 2°C lower than the 23rd (Figure 18). However, at Te Marua the peak temperature was recorded on February 24, with a lower peak temperature on the 25th (Figure 16). These differences in peak temperature timing are attributed to variability in cloud cover and net solar radiation (e.g. Figure 16 , Birch Lane in Upper Hutt; compared to Figure 17, Shandon Golf Club in Petone).

The relationship between water temperature and stream flow is complicated by cloud cover and rain. The general tendency is that temperatures are lower during periods of high flows, but this is coincident with lower net radiation during periods of rain or with cloud. For example, lower water temperatures, higher flows and less net radiation are coincident with widespread rain late in the day on 16 February (Figure 16 to Figure 18).

The essential issue is whether reducing the streamflow with additional abstraction would significantly increase temperatures, perhaps into the critical zones discussed earlier. Preliminary modelling using RHYHABSIM hydraulics at Birchville and local climatic inputs (from WAIORA; NIWA 2004), and conservative exposure values, indicates minimum, mean and maximum temperatures are expected to change by less than 1ºC in the 30 km below the gorge. This is consistent with other rivers (e.g. Waitaki and Rangitata River - Jowett 2003a, b). A significant investigation would be required to predict downstream temperature change including the contribution of the major tributaries and groundwater exchanges.

I conclude that the predicted temperature increase as the result of the proposed decrease in Kaitoke minimum flow is probably less than 1ºC.

6 Flow variability

Aspects of flow variability include channel forming flows (floods); maintenance flows (smaller events that usually occur several times per year); and periods of low stable flows.

Channel forming flows are generally regarded as being flood events, with frequent reference to bankfull floods (e.g. FISRWG 2001). In New Zealand rivers, bankfull flows have a recurrence interval of 1 to 10 years, with a median value of about 18 months (Mosley 1981). The average annual flood at Birchville is 677 m^3/s and at Taita Gorge is 777 m^3/s (Table A 9, page 86). Water abstraction at Kaitoke ceases during high flows when water is turbid, and resumes on the flow recession. Therefore, reducing the minimum flow at Kaitoke by 200 L/s will have no perceptible effect on channel forming flows and channel maintenance flows.

FRE3, the number of events greater than 3 times the median flow, is often used as a benchmark for flow variability, which in part explains the ability of algae, macro-invertebrates and other aquatic biota to become established. Duncan & Woods (2004) show the Hutt River at Birchville has 28.9 FRE3 events per year on average. Of the 66 rivers they describe, only 3 have more FRE3 events than the Hutt. The median flow at Birchville is 12400 L/s (Wilson 2006; Table A 4, page 82).

An area where there may be a potential effect is in the flow recession, when abstraction resumes, and in the frequency and duration of stable flow periods. Wilson (2006) describes a flattening of the flow-recession curve as being most apparent in the period of 8-18 April 2003 (Figure A 6, page 85). The flattening is a response to abstraction ceasing on the rising limb because the clarity of the water is poor; with abstracting resuming on the declining limb of the hydrograph, in order to take advantage of high flows in the river. The abstraction rate is reduced further as baseflow continues to recede. He suggests that if abstraction was increased at Kaitoke Weir, flattening of the baseflow hydrograph at Te Marua would be more prevalent. However, there is a high degree of variability in the hydrographs below Kaitoke Weir, and at Te Marua (Figure A 6, page 85). Protracted periods of stable flows do not generally occur. Further downstream, tributary inflows more than double the flows of Hutt at Kaitoke, thus masking the effect further.

7 Discussion

7.1 Situation analysis

The Regional Freshwater Plan (RFWP; WRC 1999) and stakeholders recognise that the Hutt River is vital for the public supply of water to the Wellington Metropolitan Area. The major source of water is from the headwaters of the Hutt River at Kaitoke Weir (river km 42). Existing conditions on the consent to abstract water from Kaitoke Weir require a downstream residual flow of 600L/s. The RFWP sets a minimum flow at Birchville of 1200L/s.

It is proposed to reduce the minimum flow at Kaitoke Weir from 600 L/s to 400 L/s for a 3 year period to provide additional water while the Stuart Macaskill lakes are drained for seismic enhancement and increasing storage capacity. The maximum allowable take will remain unchanged at 1850 L/s and the scheme will shut down in high flows as at present.

Prior to the new Resource Consent conditions of October 2001, there were times when the entire flow at Kaitoke was abstracted (Harkness 2001). The minimum flow of 600 L/s was developed though consultation and consensus with stakeholders (McCarthy 2000). Harkness (2001) noted "*This extra 600 L/s in the river will increase the amount of instream habitat available downstream for brown trout and should ensure that the minimum flows [in the lower river] determined in this study are maintained*."

The 1200 L/s minimum flow at Birchville was based on habitat methods (IFIM) as endorsed in Section 9.6.1 of the RFWP. As part of an ongoing programme to review the minimum flows set out in the RFWP, Harkness (2002) evaluated instream flows in the lower river. His study sites have been used in the investigations reported here. Following Jowett (1993), Harkness (2002) proposed retention of 66% of MALF habitat with flows of 1200 L/s at Birchville; and 1550 L/s at Hutt 1 (Silverstream), 1500 L/s at Hutt 2 (Taita) and 1900 L/s at Hutt 3 (Melling), based on his own evaluation. There were uncertainties about the MALF estimates, further investigations of streamflow were recommended, and the proposed minimum flow recommendations lapsed.

Additional abstraction of 200 L/s at Kaitoke or Te Marua would not breach the RFWP minimum flow of 1200 L/s at Birchville. However, at the stakeholder workshops, and in the review process, it was agreed to investigate other aspects of the minimum flow at Birchville and downstream sites not specified in the Resource Consent.

7.2 Lowered minimum flow at Kaitoke

The concern of major stakeholders (in particular Department of Conservation and Fish & Game) was maintenance of fish passage through the gorge with reduced flows. It was considered that there would be little effect on habitat in the deep pools in the gorge; and that water temperature was unlikely to be affected by increased abstraction. (The gorge is narrow and highly shaded).

Potential effects of the reduced flows on fish passage through the gorge were investigated by Hudson & Harkness (2008). They modelled contiguous and total passage width, using free passage criteria for native fish and trout, and concluded it is unlikely that barriers to fish passage would occur under either the present or proposed minimum flows.

7.3 Birchville minimum flows

Reducing the minimum flow at Kaitoke will in effect reduce flows downstream on occasion by 200 L/s. However, the 1200 L/s minimum flow at Birchville specified in the RFWP will almost invariably be exceeded given the tributary inputs combined with the existing and proposed minimum flow at Kaitoke (Figure A 4).

The MALF at Birchville in the period 1971-2006 was 2274 L/s (Table 1) and the lowest recorded flow (when there was no minimum flow for the Kaitoke abstraction) was 1090 L/s (Table A 4, page 82), during a major dry phase (February 1971) (Appendix A, Climatic influences). Once in 20 years a flow of 1328 L/s is expected (Table A 8, page 86). With the additional abstraction of 200 L/s, threshold flows are expected to occur more than 99% of the time (Table A 5, page 84).

7.4 Review of minimum flows

At the stakeholder workshops, it was agreed to review minimum flow requirements taking account of the following:

1) The use of percent weighted usable area (%WUA) as a measure of habitat availability;
2) The effect of a longer flow record;
3) Use of MALF as the benchmark flow;
4) Critical values and habitat retention levels;
5) Habitat availability with existing flows; and
6) Habitat availability with natural flows.

7.4.1 Percent WUA

The RFWP minimum flow is based on using the percentage weighted usable area (%WUA); which has been criticised (Section 3.1). Reappraisal was recommended by stakeholders. WUA was re-calculated in m^2/m using the same food production and adult brown trout habitat suitability criteria as Jowett (1993).

Repeating Jowett's analysis at Birchville, 66% habitat retention requires 1230 L/s for food production, 630 L/s for Deleatidium, and 1110 L/s for adult brown trout. Using WUA m^2/m for food production and adult trout rather than %WUA makes little differences to the flow recommendation in this instance.

7.4.2 Long flow records

With a longer period of record (1971-2006), the MALF for Birchville increases from 2009 L/s (Jowett 1993) to 2274 L/s (Wilson 2006). With the updated flow records, the revised RFWP minimum flow at

Birchville (with 66% habitat retention) is 1370 L/s for food production and 1260 L/s for adult trout (Table 8).

It could be argued that the minimum flows at Birchville should be updated from 1200 to 1370 L/s to reflect the higher MALF flow with a longer period of record. However, the risk is that the present relatively wet period will revert to historic drier conditions with a resultant decrease in MALF. As discussed in Appendix A, the estimated natural MALF from rainfall-runoff modelling in the period 1890-1956 was 2227 L/s against 2858 L/s in the period 1957-2005, and 3011 L/s for the period of flow records at Birchville (1971-2005) (Figure A 7, page 86 & Table A 10, page 90).

7.4.3 Benchmark flows

As noted in section 3.2, flow recommendations were made to retain a proportion of the habitat available at the MALF; or a proportion of the optimum habitat available if the optimum occurs below the MALF. The mean annual low flow (MALF) is the arithmetic mean of the lowest daily flow from each year of record. Because the time step is daily, the flow may be designated MALF. The MALF-7d is the average of the lowest weekly flow (seven day time step) from each year of record.

MALF was used for this instream flow assessment for two reasons. First, MALF is commonly used as a benchmark, including the Hutt River (Jowett 1993), the Manawatu River (Hay & Hayes 2005) and Rangitikei River (Hay & Hayes 2004), which are important trout fisheries in the Fish & Game Wellington Region. Second, MALF flow data was provided for this investigation (e.g. Ibbitt 2006 data; Wilson 2006; Watts 2006).

In the review of the proposed Hutt River instream flow investigations, Hay (2007a, b) suggests that the median flow is more relevant than the MALF to macroinvertebrates. I do not concur with this point of view and refer to the weak relation between total invertebrate biomass and median flow or mean annual low flow in the original data sets upon which this view is constructed. In terms of flows, the strongest relationships to measured total invertebrate biomass were with indices of flow variability (Jowett & Duncan 1990; Quinn & Hickey 1990a). Relationships of invertebrate abundance to MALF or median flows were equally weak.

While I do not concur that the median flow is more relevant, an analysis of food production habitat availability (Waters 1976) at median flow and with flow abstraction was presented for completeness. For the Hutt River there is no difference, to 2% more habitat available when flows decrease from the existing or natural median flow with existing and proposed abstraction (Figure 14).

7.4.4 Critical values & habitat retention levels

The 1200 L/s minimum flow at Birchville specified in the RFWP was based on retaining 66% of the habitat available at the existing one day mean annual low flow (MALF) for both adult brown trout and the habitat which generates food for them (Jowett 1993). After a decade more investigation on minimum flows, Jowett & Hayes (2004) confirm that trout are a critical species (at least for rivers such as the Hutt); and recognised that habitat retention levels are inherently arbitrary and that retention levels of 70 to 90% for large adult trout are conservative.

Habitat retention levels of 70-90% are considered conservative because the high level of disturbance means habitat availability is not likely to be limiting (Section 4.3). If population densities are less than maximum levels, reducing habitat will not have a proportional response on populations. Proportional population responses are likely to occur only if population densities were very high Jowett & Hayes 2004).

For the critical values adopted in this investigation (habitat for food production and adult brown trout feeding), the maximum habitat available occurs at flows in excess of MALF (Figure 12 & Figure 13). Habitat was calculated for 66%, 70% and 90% retention of habitat available at MALF for critical values. For native fish optimum habitat availability often occurs at flow below MALF; thus threshold flow requirements are often far less than MALF (Table 8 to Table 15).

The 70% values are essentially a reiteration of the 66% values specified in the RFWP, so are not presented. There is invariably more habitat available at the 90% retention. To be precautionary, and sensitive to stakeholders, a habitat retention level of 90% of the habitat available at MALF for critical values (food production and adult trout habitat) was adopted for the Hutt River.

7.4.5 Existing flow habitat availability

Mean annual low flows vary downstream. Compared with Birchville, flows are greater at Silverstream and Taita Gorge, and similar at Melling (Table 1 & Table 2). As a result, flows required to retain 90% of the critical habitat vary downstream.

A flow of 1980 L/s is required to retain 90% of critical value habitat (in this case food production) at Birchville. Concurrent low flow gaugings show that at a minimum flow of 1980 L/s at Birchville, the downstream flows at Silverstream would exceed threshold requirements (2470 L/s estimated flow, with a required flow of 2370 L/s). However, with a Birchville flow of 1980 L/s, the flow at Taitia is estimated as 2550L/s; with 1780 L/s at Melling. The estimated Taita and Melling flows are less than required to meet the 90% habitat retention threshold. For Taita a flow of 2900 L/s is required; and 2140 L/s is required at Melling.

Taita and Melling are special cases. Taita survey reach was chosen to evaluate the effects of river works. The Melling site is tidal and the flow-habitat relations pertain for short periods at low flow on outgoing tides (Figure 7).

Taita has a greater threshold flow requirement than the other sites for adult trout (2900 L/s against 1940 L/s at Birchville, 2370 L/s at Silverstream, and 2040 L/s at Melling); and less habitat (WUA of 2.50 m^2/m, against 3.28 m^3/m, 4.05 m^2/m, and 3.09 m^2/m, respectively). The hydraulic geometry differs. The wetted perimeter at Taita is relatively wide, and it is shallower and faster flowing that the upstream sites (Table 7). These differences suggest that the river works may have an adverse effect on adult trout habitat (but not food production habitat).

It is uncertain if river engineering operations would change to a more habitat oriented approach and if such changes would reduce the flow requirements of reaches such as Taita (Hudson 2000, 2002). Therefore, it is prudent to increase the minimum flow at Birchville to 2250 L/s to provide the 90% existing MALF habitat retention threshold at Taita and Melling.

With the proposed minimum flow reduction at Kaitoke Weir, a net flow of 2250 L/s at Birchville would occur at all survey sites for ~97% of the time.

7.4.6 Natural flow habitat availability

Stakeholders requested a reappraisal of the minimum flow at Birchville and downstream sites based on the natural flow regime (i.e. not including existing abstraction) and 90% habitat retention levels. Therefore, habitat retention was assessed for adult trout and food production and for other species and life stages, against the estimated natural MALF. Also, effects on food production habitat at naturalised median flows were evaluated.

Various approaches were investigated to estimate the natural MALF (i.e. flows without Kaitoke abstractions). The best estimate is that the natural one day MALF (N-MALF) is about 760 L/s greater for Birchville than the existing MALF of 2270 L/s (i.e. 3030 L/s). There are gains and losses to streamflow downstream of Birchville because of interchange with aquifers in the lower reaches. Thus, to conservatively estimate downstream naturalised mean annual low flows, 760 L/s was added to the estimates of existing MALF at Silverstream, Taita and Melling.

At all sites the 66% N-MALF threshold provides less habitat for food production and/or adult trout habitat than the 2250 L/s minimum flow at Birchville recommended above. Setting the minimum flow at Birchville at 2700 L/s retains 90% of the naturalised MALF habitat at downstream sites for much of the time.

At Birchville there is a deficit of 330 L/s at the 90% N-MALF threshold with the existing abstraction; increasing to 530 L/s for food production with the proposed additional abstraction of 200 L/s (Table 12). With existing abstraction the deficits downstream are 150 L/s at Silverstream; 360 L/s at Taita; and 270 L/s at Melling (Table 13 to Table 15). However, the deficits are short lived, with flows exceeding the 90% threshold requirement around 95% of the time with existing abstraction and more than 93% of the time with additional abstraction at the four study reaches.

7.4.7 Conclusions on existing and natural flows

Flows of 1980 L/s (existing MALF) and 2600 L/s (naturalised MALF) are required to retain 90% of critical value habitat at Birchville. These flows at Birchville provide more than the required flows at Silverstream, but not at Taita and Melling.

A 2250 L/s flow is required at Birchville to provide 90% critical habitat retention for the existing mean annual low flow (MALF) at all survey sites. The flow required at Birchville increases to 2700 L/s for 90% habitat retention for the naturalised mean annual low flow (N-MALF). With the proposed decrease in minimum flows at Kaitoke, the 2250 L/s Birchville threshold flow will be exceeded at least 96% of the time at all sites; and the 2700 L/s threshold flow will be exceeded at least 93% of the time.

I conclude that reducing minimum flows at Kaitoke from 600 L/s to 400 L/s will have no more than minor effects on habitat availability.

7.5 Other considerations

7.5.1 Water quality

As discussed in section 4.1, in some cases water quality determines the usability of physical habitat (Waddle et al. 2001). Water quality suitability for trout can be used as a critical value.

Unpolluted, well-oxygenated water is required for trout (Elliot 1994); which have strict water quality and temperature requirements relative to many native fish (e.g. Richardson et al. 1994). Jowett (1992) points out that New Zealand rivers are relatively unpolluted and there was no relationship between brown trout abundance and water quality in his study.

Monitoring of the Hutt River is appropriate for determining critical values. Water quality grades and macroinvertebrate health scores are good to very good (Milne & Perrie 2006). In Section 4.2 it is concluded that water quality is unlikely to be a habitat bottleneck.

7.5.2 Temperature

As discussed in section 5, water temperature responses to net solar radiation and streamflow were examined in the Hutt River at Te Marua, Birchville and Taita. Over the year temperatures vary by almost 20°C. For periods of steady low flow water temperatures were strongly related to variation in net radiation, with variability of 2 to 3°C in peak temperatures; and typical diurnal fluctuations of several degrees (Figure 15 to Figure 18).

To model temperature changes with abstraction, existing information was used, specifically RHYHABSIM hydraulics at Birchville, local climatic inputs, and conservative exposure values. These model parameters are unlikely to change. Improvements to the modelling would be related to the input of tributary stream and groundwater contributions below Birchville.

The existing temperature record shows that the temperature increase from Te Marua downstream to Birchville is at least partially attributable to Akatarawa and Mangaroa inputs. For the period of low flows discussed in Section 5, temperatures in these tributaries are similar to the temperature at Birchville (Figure 17; Figure 19). Data for other streams, and from groundwater inputs, in the lower river are not available. These inputs may moderate the downstream temperatures, but a network of temperature and flow recorders would have to be established to evaluate this proposition.

If a significant increase in temperatures were likely, additional monitoring and modelling would be warranted. However, the increase in temperature is expected to less than 1ºC in the 30 km below the gorge. This is consistent with other rivers (e.g. Waitaki and Rangitata River; Jowett 2003a, b) and is less than the permitted increase of 3ºC (RMA Schedule 3 & RFWP).

I conclude that effects of reduced minimum flows at Kaitoke Weir on water temperature will be no more than minor.

7.5.3 Flow variability-disturbance regime

Reducing minimum flows at Kaitoke Weir from 600 L/s to 400 L/s will have no material effect on the high flows required for channel formation and channel maintenance. The average annual flood at Birchville is 677 m^3/s and at Taita Gorge is 777 m^3/s (Table A 9, page 86).

With the present flow regime there are almost 30 events per year on average with flows greater than three times the median flow (the median flow at Birchville is 12.24 m^3/s; Table A 4, page 82). These events will cause significant bed disturbance.

As discussed in Section 4.3, it is likely that the frequency of disturbance limits the food production and fisheries more so than the usable habitat area at low flow.

7.5.4 Brown trout abundance model

The trout abundance model predictions align with observed long term average trout counts. Reducing the existing MALF by 200 L/s will have no material effect on trout numbers in the river system including the reach from Birchville to the gorge.

8 Conclusions

This report investigates the effects on habitat availability in the Hutt River below the gorge as a consequence of reducing the minimum flow at Kaitoke Weir from 600 L/s to 400 L/s.

Hydraulic-habitat modelling, following established instream flow incremental methodology (IFIM) procedures, shows that downstream effects on instream habitat availability of reducing minimum flows at Kaitoke Weir to 400 L/s will be no more than minor. With the reduced flows a higher level of habitat protection will be provided than in the Regional Freshwater Plan and historically (there was no minimum flow from the initial take in 1957 to 2001).

Trout abundance modelling shows that there may be 1 or 2 fewer trout per kilometre of river with a 200 L/s flow reduction at Kaitoke. This is not considered material in the context of the large year to year variations of trout numbers which are probably due to effects of floods rather than low flows. With the additional abstraction 8 medium and large brown trout are predicted per kilometre in the Te Marua reach increasing to 51 per kilometre in the Taita reach.

Reducing flows will increase temperatures by less than 1ºC in the 30 km below the gorge. It is concluded that effects of reduced minimum flows at Kaitoke Weir on water temperature will be no more than minor.

The existing flow regime is very flashy, with significant, frequent bed disturbance. It is concluded that a reduced minimum flow at Kaitoke will have no material effect on the high flows required for channel formation and channel maintenance.

It is concluded that the downstream effects on instream habitat availability of reducing minimum flows at Kaitoke Weir to 400 L/s will be no more than minor.

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Appendix A: Aspects of the climate & hydrology

Climatic influences

Wilson (2006) describes seasonal patterns and climatic cycles. Low-flow conditions are strongly influenced by the occurrence of anticyclones crossing the North Island. During summer, the anticyclone belt migrates southwards, reaching its southernmost position in February. This migration brings warm and settled conditions to the North Island. El Niño conditions result in lower-than-average rainfall in the Hutt catchment, particularly during autumn.

Annual and longer-term climate variability in New Zealand is influenced by two natural cycles: the El Niño Southern Oscillation, or ENSO, influences precipitation on a two- to seven-year timescale. The Inter-decadal Pacific Oscillation, or IPO, influences climate over a timescale of decades. La Niña conditions result in more northerly airflows across the country. This situation leads to drier-than-normal winter conditions in the Mangaroa catchment, which is sheltered by the Tararua Ranges. The worst-case scenario for drought conditions in the Hutt catchment occurs during La Niña events, where there is a continuation of low flows from winter through to summer. The lowest recorded flows on the Hutt River occurred during 1971, 1973 and 1978. The ENSO was predominantly in a La Niña phase during these low-flow events.

The Inter-decadal Pacific Oscillation (IPO) appears to modulate the impacts of the ENSO variability. Three phases of the IPO have been identified since 1920: a positive phase (1922-1944), a negative phase (1947-1977), and another positive phase (1978-1998). When the IPO is in a positive phase, westerly winds are stronger and El Niño events are more frequent. The negative phase brings weaker westerly winds, with more of a balance between El Niño and La Niña events.

Long term variability in low flow conditions is exhibited in data provided by Ibbitt (2006). Mean annual low flows for seven day intervals (MALF-7d) were modelled from climatic records (these exclude water takes). For the three periods defined by the IPO described above, the MALF-7d for Birchville were as follows: 1922-1944 2549 L/s; 1947-1977 2699 L/s; and 1978-1998 3626 L/s. This would suggest that recent flow records reflect generally high flow conditions.

Rainfall

Rainfall patterns are strongly controlled by prevailing climatic conditions and orography. Rainfall isohyets show that mean annual rainfall totals are greatest in the Tararua Ranges, where elevations are higher, and lowest in areas of lower elevation within the Hutt Valley itself (Figure A 1). The rainfall distribution pattern is also influenced by prevailing northwesterly airflows. These airflows create drier conditions to the southwest of the catchment, particularly the Mangaroa catchment (Figure A 2).

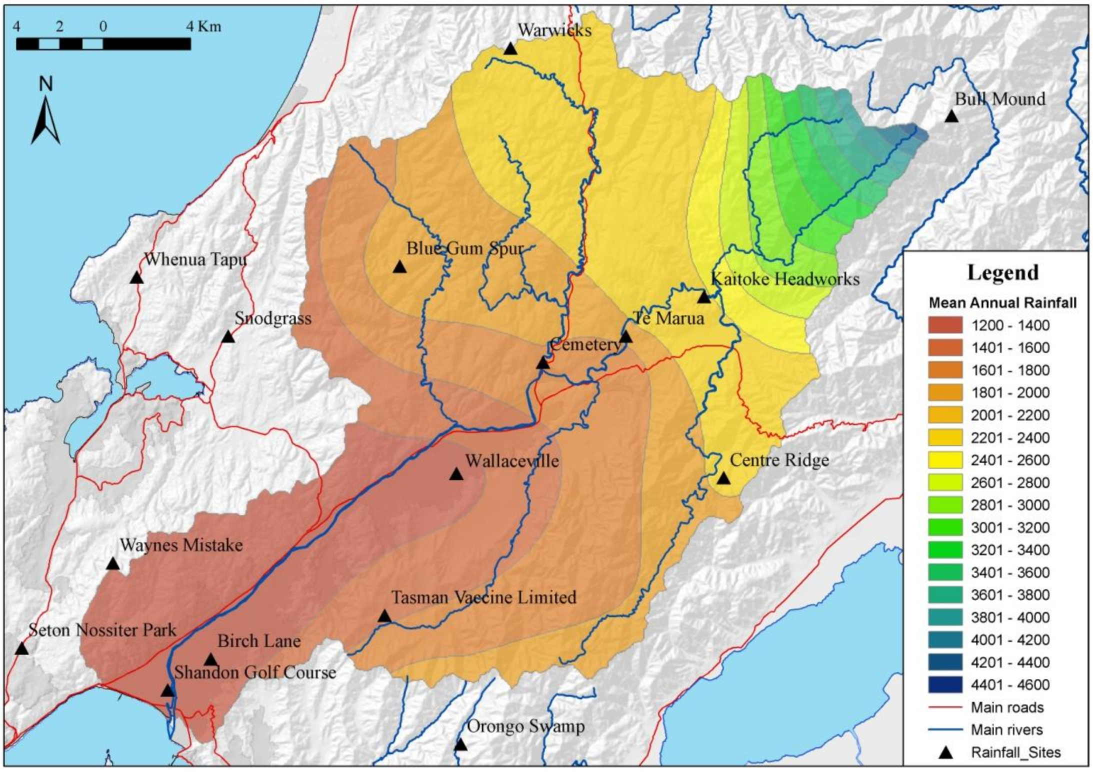


Figure A 1 Hutt Catchment mean annual rainfall (mm) and existing rainfall stations (Wilson 2006)

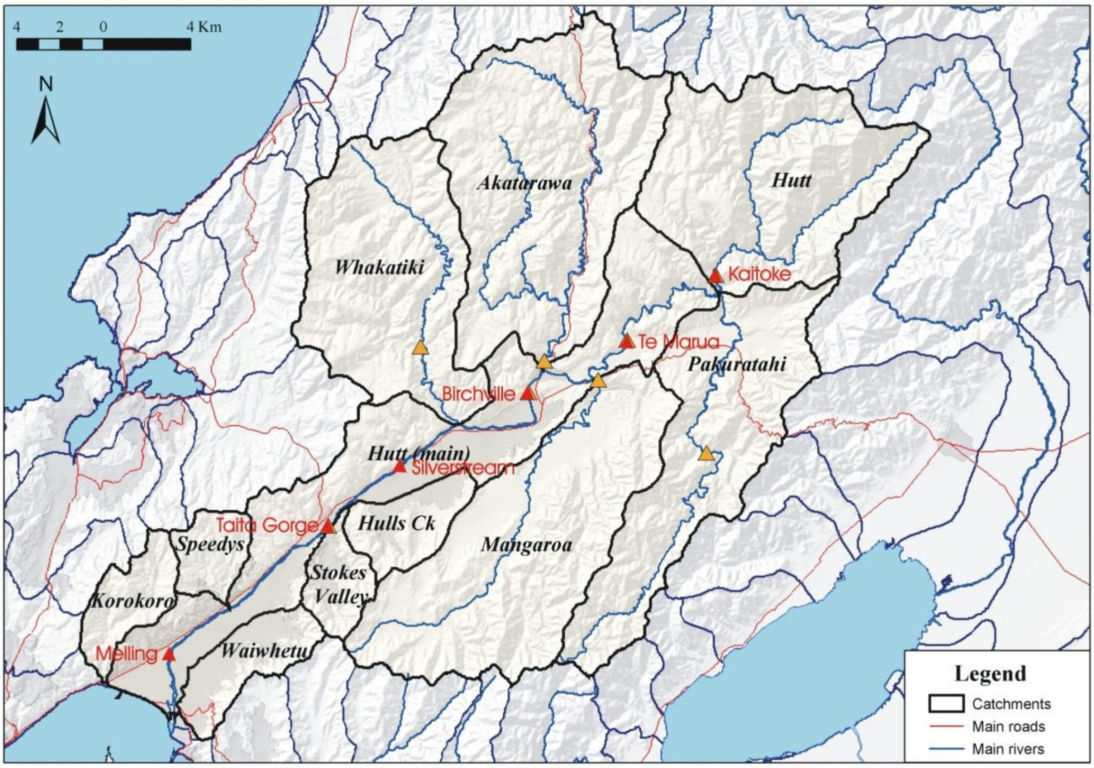


Figure A 2 Hutt River catchment (based on Wilson 2006)

River flows are strongly controlled by rainfall in the upper catchments; with much of the flow derived from the upper catchment. Low-flow conditions in the Hutt catchment are a response to a decline in catchment water storage. Mean monthly rainfall for each sub-catchment has been plotted in Figure A 3. The importance of the Tararua Ranges as a recharge source for the Hutt River is readily apparent from the rainfall at Bull Mound. In terms of drought prediction, the Bull Mound site is a key indicator of catchment rainfall storage. A low spring rainfall total at this site implies a deficiency of storage in the catchment to provide for river baseflow during the drier summer months.

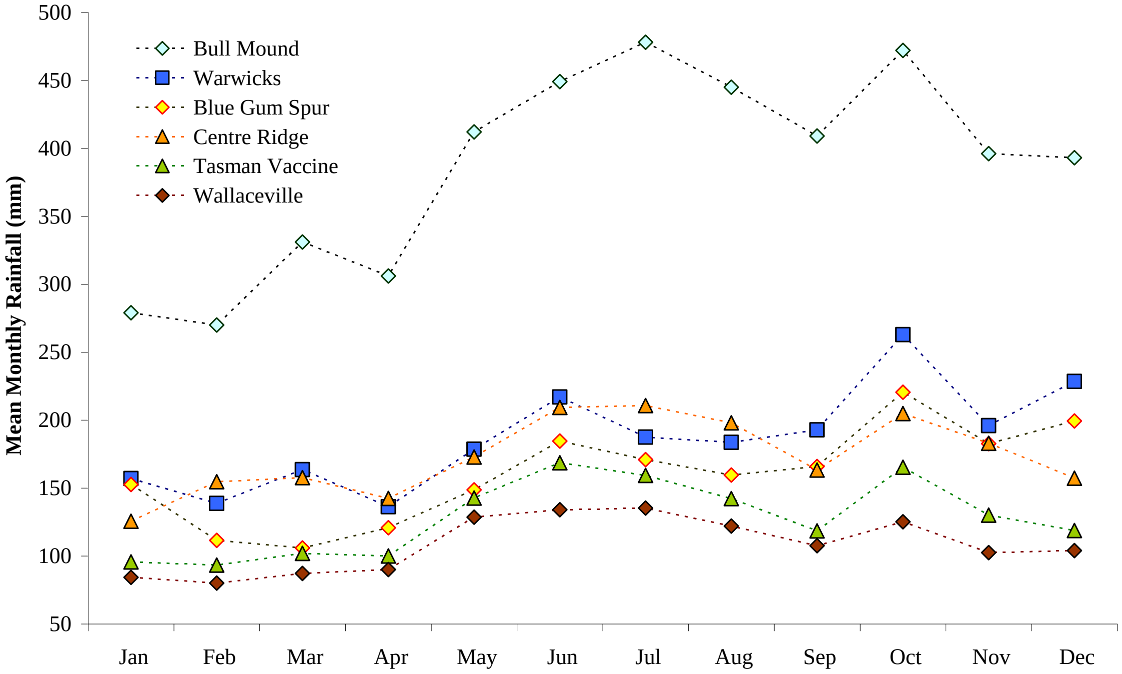


Figure A 3 Mean monthly rainfall for six representative sites in the Hutt catchment (Wilson 2006)

Drought events in the Hutt catchment can vary between the sub-catchments, depending on prevailing wind-direction over the summer. Representative rainfall stations for each sub-catchment were analysed for the predicted and observed frequency of low-rainfall events. The analyses were based on a hydrological year, from 1 July to 30 June. The spatial variation is illustrated by comparing Wallaceville, the longest running station (since November 1939), located in the Hutt Valley; Warwicks in the headwaters of the Akatarawa River; Centre Ridge in the Pakuratahi catchment; Blue Gum Spur in the Whakatikei catchment; Tasman Vaccine Ltd in the Mangaroa catchment; and Bull Mound, in the headwaters of the Hutt River above Kaitoke Weir (Figure A 1 & Table A 1

Hutt headwaters: Bull Mound

Duration	Start	Rainfall	Return	Mean Annual
30-day	Mar-85	36	25	111
60-day	Nov-74	191	40	365
90-day	Feb-01	343	30	679
120-day	Feb-01	567	30	1029
180-day	Nov-70	1114	50	1859
Hutt Catchment: Wallaceville				
30-day	Jan-05	0.2	35	17
60-day	Jan-78	26	55	83
90-day	Feb-01	68	60	159
120-day	Jan-01	105	100	256
180-day	Dec-00	203	140	458
Pakuratahi Catchment: Centre Ridge				
30-day	Feb-89	10	30	39
60-day	Jan-05	96	15	154
90-day	Dec-02	183	30	296
120-day	Jan-03	264	30	447
180-day	Nov-02	449	60	805
Akatarawa Catchment: Warwicks				
30-day	Mar-85	0.5	40	38
60-day	Jan-03	63	30	157
90-day	Jan-03	140	65	301
120-day	Dec-02	228	30	429
180-day	Nov-02	504	20	761
Whakatikei Catchment: Blue Gum Spur				
30-day	Mar-85	2	10	31
60-day	Jun-00	27	30	130
90-day	Dec-02	104	100	269
120-day	Dec-02	182	120	429
180-day	Nov-02	435	40	758
Mangaroa Catchment: Tasman Vaccine Ltd				
30-day	Mar-85	0.5	55	21
60-day	Nov-74	40	55	92
90-day	Feb-01	86	30	191
120-day	Feb-01	151	25	293
180-day	Nov-70	284	35	543

Table A 1 Observed rainfall minima for 30 to 180 day durations (based on Wilson 2006)

For these stations rainfall records show that rainfall minima are highly variable and not necessarily synchronous across the Hutt Catchment from year to year (Figure A 1 & Table A 1). None-the-less, the 30 day duration rainfall minima tend to start in March, with more variable start dates for 60 and 90 day minima. 120-day minima start dates occur in December, January and February; and 180-day rainfall minima usually start in November.

Streamflow – existing regime

The 54 km long Hutt River has a mountainous source in the southern end of the Tararua Ranges. Two main branches (Eastern and Western Hutt) converge to form the Hutt River 4 km above Kaitoke Weir (km 42; Figure A 2). The one day mean annual low flow (MALF) is 1341 L/s at the gauge above the weir (Figure A 4). During summer months, more than 50% of the flow is typically abstracted from the river at Kaitoke Weir for the Greater Wellington water supply (Section 1.1). About 850 m downstream of the weir, the Hutt River is supplemented by inflow from the Pakuratahi River which contributes an estimated 410 L/s at MALF (Figure A 4).

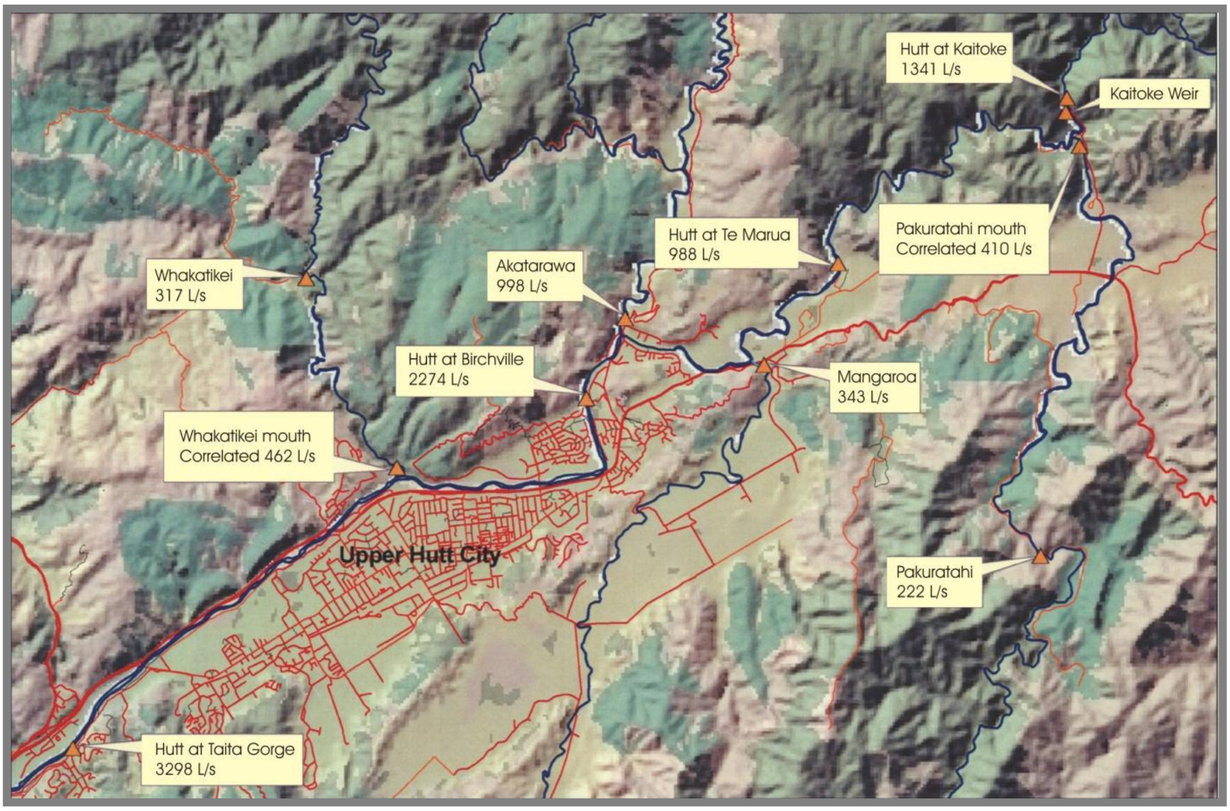


Figure A 4 Hutt Catchment recorder sites with 1-day mean annual low flow (data from Wilson 2006)

Hutt River gorge, which is entrenched in bedrock, extends downstream to Te Marua (km 32), has little potential for water storage in alluvium (Wilson 2006). Below Te Marua, where the valley widens and a thin layer of alluvial gravels overlay Torlesse basement rocks in the Te Marua basin, is the first major groundwater reservoir on the Hutt River (Figure A 4). MALF of the Hutt River at Te Marua is 988 L/s. In the natural flow regime (discussed later) this figure would be larger because it is directly affected by abstractions at Kaitoke.

Downstream of Te Marua the Hutt River flows to the sea over an extensive alluvial plain following the general strike of the Wellington Fault (Figure A 4). Hutt River flows increase with contributions from

Benge Creek (km 32.4), the Mangaroa River (km 29.5; MALF 343 L/s), and the Akatarawa River (km 27; MALF 998 L/s).

Downstream of the Akatarawa River confluence, the Hutt River flows over a Torlesse basement high between Birchville (km 25.6) and Maoribank (km 24.7) before entering the Upper Hutt alluvial basin (Figure A 4). At Upper Hutt, the river loses water to the Upper Hutt Aquifer on the southern side of the Wellington Fault. The river first crosses the fault approximately halfway between the Birchville and Maoribank gauging sites. The river stops losing flow when it crosses the fault again at McLeod Park, 750m upstream of the Whakatikei confluence (km 20). The river gains return flow from the Upper Hutt Aquifer when it crosses the fault again at Moonshine Bridge (km 18.8). This gaining reach continues until the river reaches Taita Gorge (gauge at km 12.9), where greywacke bedrock is exposed.

Downstream of Taita Gorge, the river loses flow to the Lower Hutt alluvial basin (Figure A 4). At Kennedy Good Bridge (km 7), the river crosses the Petone Marine Bed aquitard, which confines the Waiwhetu aquifer. From this point about 10% return flow occurs from the shallow gravels of Taita Alluvium. The volume of return flow downstream of Kennedy Good Bridge is largely determined by water demand, and available storage in the Waiwhetu Aquifer. The river is tidal downstream of about the Boulcott area (~km 6).

One day mean annual low flows (MALF) were estimated for the period 1971-2006 for the Hutt River at Birchville, Silverstream, Taita and Melling (Table A 2). Flows at Silverstream were estimated from Birchville based on low flow concurrent gaugings relations. To coincide with the Birchville record, Watts (2006) established a mean daily low flow relation between Birchville and Taita Gorge, and used that relation to extend the Taita record. The flow at Melling was estimated from Taita based on concurrent gaugings (Table A 2).

Table A 2 MALF estimates from streamflow records & concurrent gaugings 1971-2006

Location	Mainstem	Gains/Loss
Hutt at Kaitoke	1341	
Calculated abstraction		-763
Pakuratahi River input		410
Hutt at Te Marua	988	
Mangaroa River input		343
Akatarawa River input		998
Hutt at Birchville	2274	
Whakatikei River input		462
Unspecified gain		90
Hutt at Silverstream*	2826	
Calculated unspecified inputs		294
Hutt at Taita Gorge**	3120	
Calculated loss		-759
Hutt at Melling Bridge***	2361	

The following concurrent gauging relations at low flows were used (Wilson 2006):

Silverstream = 1.208*Birchville+79 L/s (r^2=0.84)

Melling = 1.022*Taita Gorge−828 L/s (r^2=0.96)

As shown in Figure A 4, during mean annual low flow (MALF) conditions Kaitoke abstraction has a marked effect on flows through the gorge, and a diminishing proportional effect further downstream as major tributaries contribute to the Hutt River. Despite an estimated 400 L/s MALF input from the Pakuratahi, flows are lower through the gorge section than at Kaitoke Weir. However, MALF flows at Birchville are almost double those at Kaitoke because of the input from the Akatarawa and other tributaries and flows continue to gain downstream.

The relative effect of the Kaitoke abstraction decreases with larger flows and distance downstream (Table A 3, Table A 4 & Table A 5). Effects of Kaitoke abstraction are clearly apparent at Te Marua for lower flows (exceeded ≥84% of the time). Further downstream there are significant increases in flow, with a proportionally smaller effect from Kaitoke abstractions.

Table A 3 Hutt River mean annual low flow values (L/s) (from data in Wilson 2006)

Hutt River at	MALF 1 day	MALF 7 day	MALF 14 day	MALF 28 day
Kaitoke	1341	1458	1612	2131
Te Marua	988	1173	1459	2434
Birchville	2274	2669	3107	4435
Taita Gorge	3298	3744	4303	5945

Table A 4 Hutt River mean median and lowest observed flows (from Wilson 2006)

Hutt River at	Mean (L/s)	Median (L/s)	Yield (L/s/km^2)	Lowest (L/s)	Date of lowest flow
Kaitoke	7840	4297	48.3	800	03-Mar-73
Te Marua	10822	5841	30.6	397	25-Mar-01
Birchville	22117	12420	29.1	1090	23-Feb-71
Taita Gorge	24514	14243	25.6	1628	20-Mar-89

Rainfall pattern shown in Figure A 1 & Figure A 3 are reflected in catchment yield (median flow divided by catchment area) (Table A 4). Kaitoke Weir has the highest yield with yield decreasing down the catchment due to lesser rainfall totals at lower altitudes, reduced yield in major tributary catchments, and abstraction from the Kaitoke Weir. However the relationship between rainfall and streamflow during low flow conditions is more complex.

In the previous section it was shown that rainfall minima are highly variable and not necessarily synchronous across the Hutt Catchment. Wilson (2006) noted that the lowest recorded flows on the Hutt River occurred during a predominantly La Niña phase in 1971 1973 and 1978. However overall there is little correspondence between the catchment rainfall minima of Table A 1 and the streamflow minima of Table A 6. This is attributable in part to the period of record and station location. The only other rainfall sites in operation in 1970 were in the lower catchment. The record for the Phillips gauge includes the 1973 and 1978 events. Conditions leading up to the 1973 event were not particularly dry at Phillips. The 1978 event was preceded by the fourth and fifth lowest rainfall totals for one-month and two-month periods respectively. Wilson (2006) suggests that Phillips may be situated too low in the catchment to predict low-flow conditions. Similarly the long term Wallaceville site and Kaitoke Headworks site also extend back to the early 1970's. Wilson (2006) concludes these sites are situated too low in the catchment to be useful for the prediction of low flow conditions.

While it is apparent that the majority of the low-flow events are preceded by low rainfall totals for the previous three months the ranking of events are not necessarily coincident. For example the annual event ranking of 90 day low rainfall totals at Bull Mound do not match Kaitoke low flow rankings (Wilson 2006 his Table 17).

In terms of synchronicity of the lowest recorded flows for various periods the streamflow minima at Kaitoke are not synchronous across the Hutt catchment (Table A 6). The most direct comparison in the tabulated minima is between Kaitoke (records starting in 1967) and Birchville (records starting in 1970). The Kaitoke minima occurred in 1973 and the Birchville minima in 1971. When the same period of record is considered Kaitoke minima are not synchronous with the other streamflow stations. For the same period of record as Te Marua the minimum instantaneous flow occurred on 28 Mar 2003 at Kaitoke and 25 Mar 2001 at Te Marua. For the same period of records as Taita Gorge, Pakuratahi and the Akatarawa River, the minimum instantaneous flow at Kaitoke occurred on 18 April 1985, which is not synchronous with the other minima. Similarly for the Mangarora and Whakatikei the minima at Kaitoke occurred on 19 March 1978 which is not synchronous with these sites.

The stress point for water supplies is illustrated in the monthly distribution of rainfall (Figure A 3) and runoff (Table A 7) and in reported water demand. The greater Wellington water supply relies largely on run of river flows because stored water volumes are relatively small (McCarthy 2006). *"Peak [water] demand typically occurs in January or February …. Typically river flows are lowest in March or April i.e. they are not usually coincident with the period of highest demand. Occasionally if a very dry spring causes river flows to drop earlier than usual or a long hot summer causes high demand in March or April problems may be encountered in meeting the demand for water."* (McCarthy 2006).

Table A 5 Hutt River gauging station flow durations for the period of record (data from Wilson (2006)

Kaitoke (L/s)

%	0	1	2	3	4	5	6	7	8	9
0	393481	63358	43666	34308	28526	24500	21606	19419	17651	16185
10	14980	13983	13132	12384	11747	11185	10680	10229	9821	9440
20	9092	8777	8486	8208	7945	7711	7492	7285	7088	6903
30	6726	6555	6389	6225	6075	5931	5792	5660	5535	5413
40	5295	5186	5077	4969	4864	4760	4662	4567	4476	4386
50	4297	4209	4127	4046	3967	3891	3814	3740	3669	3599
60	3527	3461	3397	3337	3277	3218	3160	3101	3043	2987
70	2929	2871	2815	2761	2704	2650	2594	2540	2488	2435
80	2379	2323	2266	2209	2155	2099	2041	1983	1924	1863
90	1801	1733	1673	1616	1555	1488	1415	1336	1250	1133
100	800									

Te Marua (L/s)

%	0	1	2	3	4	5	6	7	8	9
0	582985	86858	60680	48313	40510	35380	31433	28363	25918	23881
10	22175	20711	19496	18454	17513	16662	15948	15277	14621	14057
20	13541	13042	12606	12212	11841	11480	11126	10779	10443	10127
30	9831	9558	9292	9043	8794	8543	8290	8062	7848	7636
40	7445	7262	7091	6927	6770	6608	6438	6274	6125	5979
50	5841	5701	5559	5423	5293	5162	5032	4904	4772	4646
60	4525	4406	4288	4176	4069	3964	3853	3745	3644	3548
70	3453	3357	3260	3167	3080	2994	2909	2828	2741	2657
80	2568	2471	2374	2276	2172	2081	1991	1901	1819	1738
90	1653	1567	1496	1431	1366	1286	1197	1113	988	786
100	397									

Birchville (L/s)

%	0	1	2	3	4	5	6	7	8	9
0	1388041	169228	118456	95172	80820	70857	63416	57555	52812	48887
10	45514	42657	40217	38051	36200	34502	32993	31660	30402	29238
20	28170	27212	26309	25465	24683	23949	23250	22571	21935	21320
30	20725	20140	19575	19048	18530	18017	17546	17127	16693	16261
40	15837	15431	15032	14651	14306	13976	13645	13307	12990	12707
50	12420	12127	11844	11565	11309	11050	10805	10529	10272	10019
60	9770	9540	9299	9066	8827	8612	8399	8176	7968	7766
70	7569	7378	7175	6984	6793	6611	6428	6242	6051	5864
80	5667	5460	5266	5069	4860	4658	4463	4268	4070	3871
90	3683	3486	3284	3086	2887	2700	2488	2248	2015	1713
100	1090									

Taita Gorge (L/s)

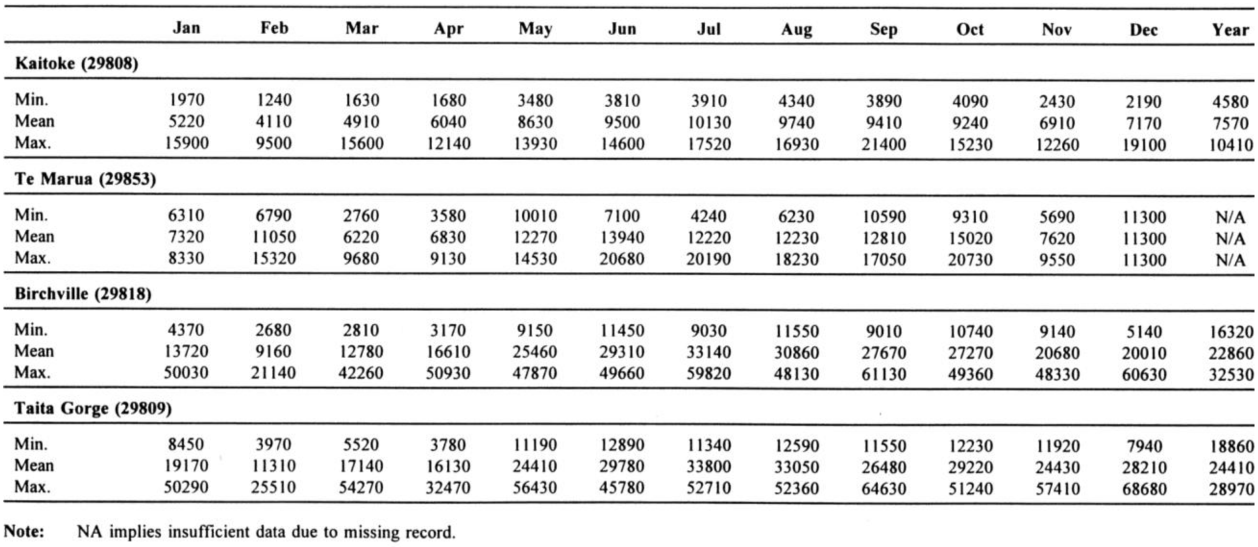
%	0	1	2	3	4	5	6	7	8	9
0	1540061	185115	1129504	102351	85155	74029	65549	59130	54058	50053
10	46761	43984	41482	39356	37471	35714	34192	32790	31579	30542
20	29514	28613	27793	26999	26243	25535	24845	24177	23539	22952
30	22379	21822	21286	20748	20258	19787	19322	18856	18411	17968
40	17552	17174	16827	16463	16124	15799	15489	15172	14858	14540
50	14243	13944	13670	13378	13100	12819	12525	12254	12000	11748
60	11509	11261	11016	10789	10580	10367	10164	9945	9734	9515
70	9320	9109	8891	8684	8478	8276	8075	7860	7641	7418
80	7194	6987	6764	6531	6308	6086	5898	5689	5472	5264
90	5032	4817	4570	4305	4057	3807	3572	3273	2886	2526
100	1628									

Table A 6 Minimum recorded flow Hutt River and major tributaries (data from Wilson 2006)

Kaitoke (since Dec 1967)

Duration	Event Date	Flow (L/s)	Return Period (years)
Instantaneous	03-Mar-73	800	50
1-day	03-Mar-73	809	60
7-day	25-Feb-73	855	70
14-day	18-Feb-73	929	40
28-day	04-Feb-73	1131	20
Te Marua (since Aug 1991)			
Instantaneous	25-Mar-01	396	20
1-day	25-Mar-01	403	25
7-day	19-Mar-01	492	20
14-day	18-Feb-01	759	25
28-day	04-Feb-01	1338	15
Birchville (since Sep 1970)			
Instantaneous	23-Feb-71	1090	35
1-day	22-Feb-71	1150	35
7-day	08-Mar-78	1189	40
14-day	05-Mar-78	1263	45
28-day	24-Feb-78	1557	25
Taita Gorge (since Mar 1979)			
Instantaneous	20-Mar-89	1628	25
1-day	20-Mar-89	1796	20
7-day	08-Apr-85	2004	20
14-day	06-Apr-85	2022	30
28-day	23-Mar-85	2232	35
Pakuratahi River at Truss Bridge (since May 1978)			
Instantaneous	02-Feb-87	110	35
1-day	03-Feb-87	115	30
7-day	03-Mar-83	141	20
14-day	24-Feb-83	145	25
28-day	24-Feb-83	164	20
Mangaroa River (since May 1977)			
Instantaneous	15-Mar-81	63	45
1-day	15-Mar-81	73	45
7-day	09-Mar-81	117	35
14-day	02-Mar-81	136	30
28-day	16-Feb-81	187	30
Akatarawa River (since Feb 1979)			
Instantaneous	12-Mar-00	625	40
1-day	12-Mar-00	639	35
7-day	25-Apr-03	677	35
14-day	15-Mar-03	726	40
28-day	23-Mar-85	815	45
Whakatikei River at Dude Ranch (since Sep 1976)			
Instantaneous	20-Mar-89	200	10
1-day	19-Mar-89	205	10
7-day	16-Mar-89	215	10
14-day	21-Feb-78	171	60
28-day	19-Feb-78	184	35

Table A 7 Monthly flows (L/s) Hutt Catchments (GWRC 1995)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Kaitoke (29808)													
Min.	1970	1240	1630	1680	3480	3810	3910	4340	3890	4090	2430	2190	4580
Mean	5220	4110	4910	6040	8630	9500	10130	9740	9410	9240	6910	7170	7570
Max.	15900	9500	15600	12140	13930	14600	17520	16930	21400	15230	12260	19100	10410
Te Marua (29853)													
Min.	6310	6790	2760	3580	10010	7100	4240	6230	10590	9310	5690	11300	N/A
Mean	7320	11050	6220	6830	12270	13940	12220	12230	12810	15020	7620	11300	N/A
Max.	8330	15320	9680	9130	14530	20680	20190	18230	17050	20730	9550	11300	N/A
Birchville (29818)													
Min.	4370	2680	2810	3170	9150	11450	9030	11550	9010	10740	9140	5140	16320
Mean	13720	9160	12780	16610	25460	29310	33140	30860	27670	27270	20680	20010	22860
Max.	50030	21140	42260	50930	47870	49660	59820	48130	61130	49360	48330	60630	32530
Taita Gorge (29809)													
Min.	8450	3970	5520	3780	11190	12890	11340	12590	11550	12230	11920	7940	18860
Mean	19170	11310	17140	16130	24410	29780	33800	33050	26480	29220	24430	28210	24410
Max.	50290	25510	54270	32470	56430	45780	52710	52360	64630	51240	57410	68680	28970

Note: NA implies insufficient data due to missing record.

Flow statistics for the Hutt River at Birchville and Taita Gorge are posted on the GW website (accessed February 2008) (Table A 8 & Table A 9).

Table A 8 MALF & MALF-7d flow statistics Hutt River at Birchville

Return Period (Years)	Average Annual Possibility (%)	Flow (L/s)	
		1 Day	7 Day
2	50	2274	2669
5	20	1577	1752
20	5	1328	1456
50	2	1008	1157
100	1	1003	1056

Table A 9 Flood return periods Birchville & Taita Gorge

Return Period (Years)	Average Annual Possibility (%)	Birchville (m^3/s)	Taita (m^3/s)
2	50	677	777
5	20	973	1089
10	10	1169	1296
20	5	1356	1494
50	2	1598	1751
100	1	1780	1944

Naturalising flows

In the workshops it was acknowledged that without the existing Kaitoke water abstraction flows would be greater downstream. It was determined that the water abstraction could be added back to estimate the "natural" (i.e. without abstraction) flow for assessment of potential effects on habitat.

Conceptually establishing the natural flow of the Hutt River is simply a matter of adding back the Kaitoke water abstraction to the measured flows downstream. However, there are several confounding issues.

Historic abstraction records are available as annual flow summaries for average annual abstraction average abstraction in the peak demand week and maximum abstraction for each year since 1972 (Figure A 5). Wilson (2006) provided an analysis of available flow records for Kaitoke Weir (Figure A 6). However updated data is not available (Jon Marks GW hydrologist pers. comm.).

Rates of abstraction vary considerably over the short term and long term (Figure A 5 & Figure A 6). Peak demand does not necessarily coincide with low flow seasonally or in the short term. For example in February 2003 flows were ~1500 L/s, but demand varied from ~1000 L/s to ~500 L/s. On Friday 21 March abstraction varied from ~635 to 700 L/s, and on the weekend abstraction dropped to ~325 L/s although this was a warm period where relatively high demand might be expected (Figure A 6). Also abstraction ceases on the rising limb of floods and resumes on the recession.

Rainfall and runoff is spatially variable; and variable over time. Rainfall-runoff simulations for the period 1890-2005 indicate the 1900-1940 period had low rainfall and runoff; with rainfall and runoff tending to increase since then (Figure A 7 & Table A 10; Ibbitt 2006). Kaitoke abstraction began in 1957 and streamflow monitoring began at several sites in the Hutt River and tributaries in the late 1960s or 1970s.

Several tributaries have a major effect on streamflow in the Hutt River (Figure A 4). The flow is essentially constant at low flow from the Pakuratahi confluence downstream through the gorge to Te Marua. Further downstream major tributaries include the Akatarawa Whakatikei and Mangaroa, which are all monitored. The net result is that the effects of Kaitoke flow abstractions have a proportionally smaller effect on flows downstream.

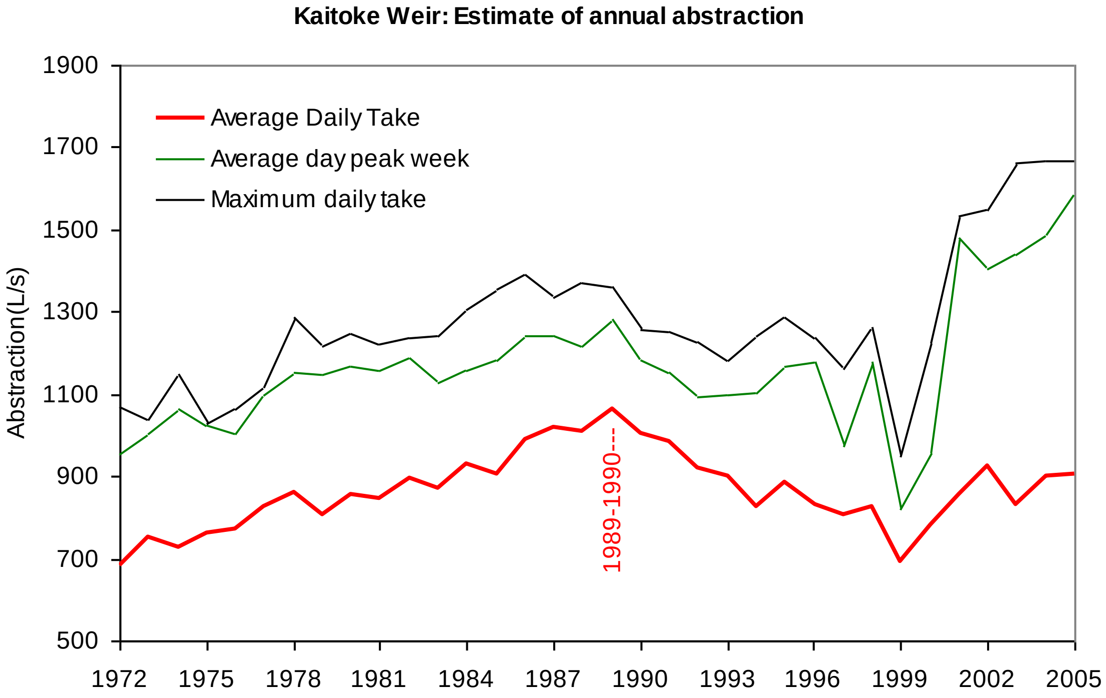


Figure A 5 Summary of annual Kaitoke abstraction and residual flows (based on GWW data)

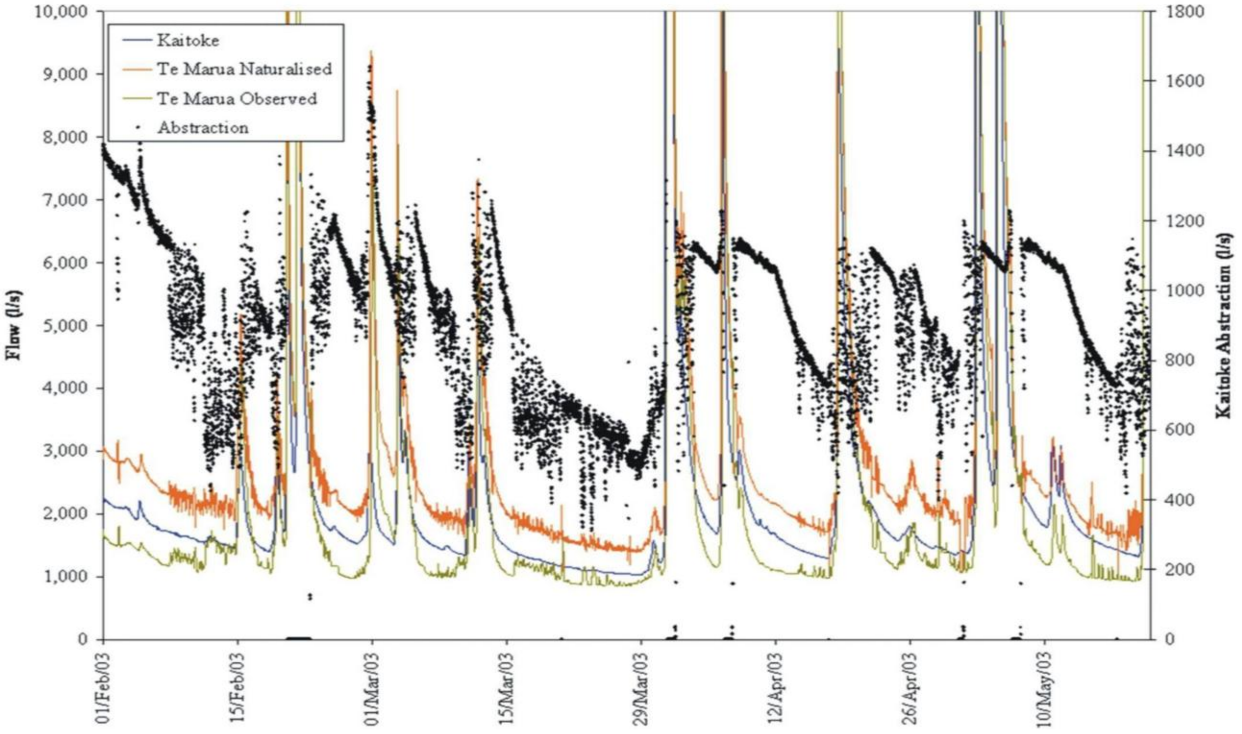


Figure A 6 Instantaneous flows Hutt River at Kaitoke Kaitoke abstraction & observed & naturalised flows Hutt River at Te Marua (after Wilson 2006)

For the sites downstream of Te Marua other sources of streamflow are undefined. While alluvial storage is limited in the Hutt gorge downstream of Te Marua, there are significant exchanges between the alluvial aquifer and the Hutt River. The role of urban runoff is undefined. The combined effects are significant. For example in the Birchville to Taita Gorge reach the Whakatikei River contributes 462 L/s to MALF as the major tributary, but the flow increases from 2274 L/s at Birchville to 3298 at L/s at Taita Gorge (i.e. more than 560 L/s is unaccounted for) (Figure A 4).

Natural flow estimates

Three approaches were employed to estimate natural stream flows downstream of Kaitoke Weir: (1) Ibbitt (2006) simulated streamflow based on rainfall-runoff modelling for the period 1890-2005; (2) Wilson (2006) calculated flows at Te Marua based on records of abstraction and streamflow for the period 2003-2005; and (3) here water budgets were calculated from streamflow records and estimates of abstraction for various periods.

The flow simulation of Ibbitt (2006) is useful in providing a long term perspective of natural flows (Figure A 7). It is clear that over more than 100 years (1890 to 2005) flows are tending to increase with time. These long term flow estimates are used to adjust MALF from short term data to the longer term record. The simulated naturalised average flow for Birchville for various periods is illustrated in Figure A 7 and summarised in Table A 10.

Figure A 7 Hutt River at Birchville simulated natural flows (data from Ibbitt 2006)

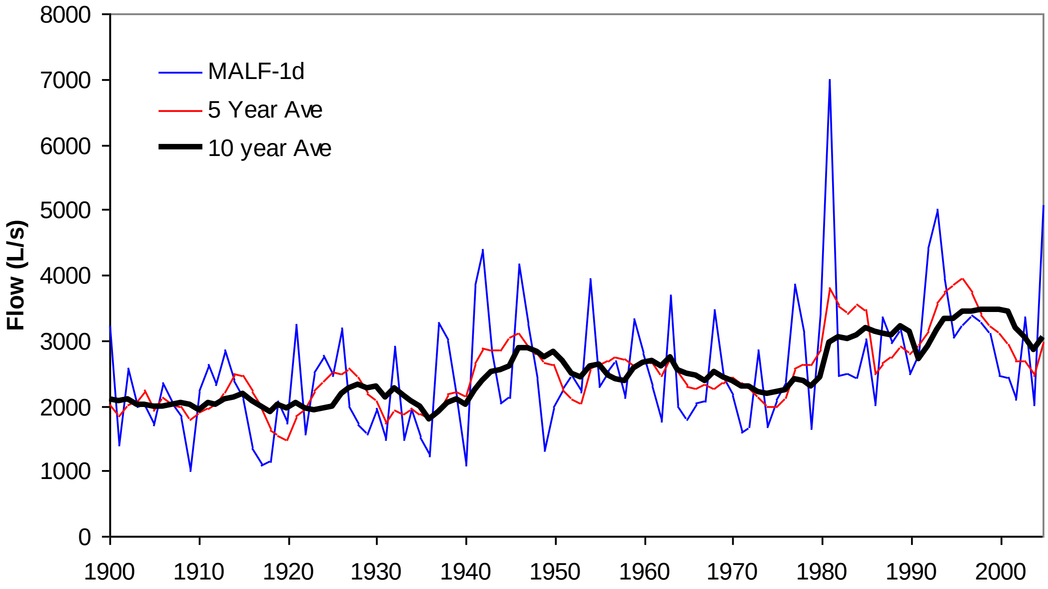


Table A 10 Simulated Hutt River at Birchville average flows for various periods (data from Ibbitt 2006)

Period	MALF
1890-2005	2495
1890-1956	2227
1957-1970	2475
1971-1990	2783
1991-2005	3314
1957-2005	2858
1971-2005	3011
1922-1944	2304
1947-1977	2439
1978-1998	3278

Ibbitt (2006) provides MALF flow estimates for Kaitoke Weir below the Pakuratahi River Te Marua below the Mangaroa Birchville and Taita. However over the long term the Pakuratahi River is estimated to contribute 130 L/s with a gain of 93 L/s downstream to Te Marua (Ibbitt 2006). This is inconsistent with the 410 L/s MALF from the Pakuratahi reported by Wilson (2006) based on flow records (Figure A 4) and therefore can not reasonably be used to determine a water budget for the upper catchment and hence to estimate the effect of abstraction at Kaitoke on the natural flow. Also in Ibbitt's (2006) modelling there is no accounting for the aquifer interchange in the lower river.

Wilson (2006) analysed flow records and reported that the average instantaneous abstraction in the period 2003-2005 was 880 L/s. This is consistent with the average daily abstraction illustrated in Table A 11[14] and with the recent increase in high period demands illustrated in Figure A 5.

Table A 11 Annual Kaitoke abstractions (L/s) for various periods (data from GWW)

Period	Average Daily	Average day /peak week	Maximum day
1957-1970	544	886	908
1957-1990	732	1029	1090
1957-2005	771	1084	1167
1971-1990	864	1130	1217
1971-2005	862	1163	1270
1991-2005	859	1208	1340
2003-2005	880	1504	1665

As a result of Kaitoke abstractions flows at Te Marua are typically lower than Kaitoke Weir (Figure A 6). Wilson (206) reports that during periods of baseflow recession the abstraction typically reduces

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[14] Daily average abstractions were extrapolated by regression from the 1972-2005 data provided by GWW

flow at the Kaitoke Weir by 50-65%. The impact at Te Marua is considerably less with a flow reduction of 35-50%.

Based on reported MALF (Figure A 4) average abstraction under low flow conditions can be calculated. The Kaitoke input is 1341 L/s; and with 763 L/s abstraction the residual at Kaitoke weir is 578 L/s. The Pakuratahi inputs 410 L/s to provide 988 L/s for Te Marua. Abstraction of 763 L/s equates to a flow reduction of 56.9% at Kaitoke Weir; which is consistent with Wilson (2006). Similarly during low flow conditions flows are reduced by 35.75% at Te Marua with abstraction of 763 L/s. Therefore for the period of recorded flows[15] naturalised flows in MALF conditions at Te Marua are 763 L/s larger than the recorded flows (i.e. 1751 L/s).

Hutt River streamflow inconsistently changes downstream of Birchville because gains and losses to the alluvial gravel aquifers occur. To conservatively estimate downstream naturalised mean annual low flows 760 L/s was added to the estimates of MALF at Silverstream Taita and Melling in Table A 2. For the purposes of modelling the flow estimates were rounded to the nearest 10 L/s in Table A 12.

Table A 12 Hutt River naturalised flow estimates 1971-2006

Hutt River at:	N-MALF
Birchville	3030 L/s
Silverstream	3590 L/s
Taita Gorge	3880 L/s
Melling	3220 L/s

The 760 L/s additional flow is consistent with streamflow record analysis of Wilson (2006); and the rainfall-runoff model estimate for Birchville by Ibbitt (2006). Data from Ibbitt (2006) indicates that for the period of record the Birchville naturalised flow was 3011 L/s (Table A 10) compared with 3030 L/s computed here (Table A 12). The difference is considerably less that the accepted gauging error (±8% for 95% of records). Therefore the abstraction estimate of 760 L/s is considered to be a reasonable to naturalise low flows.

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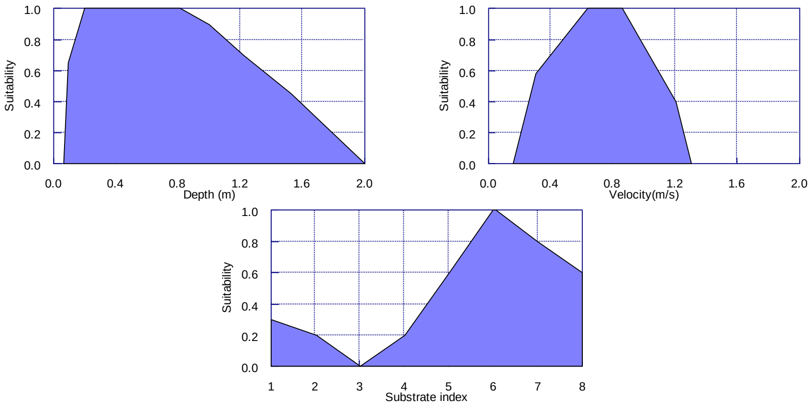
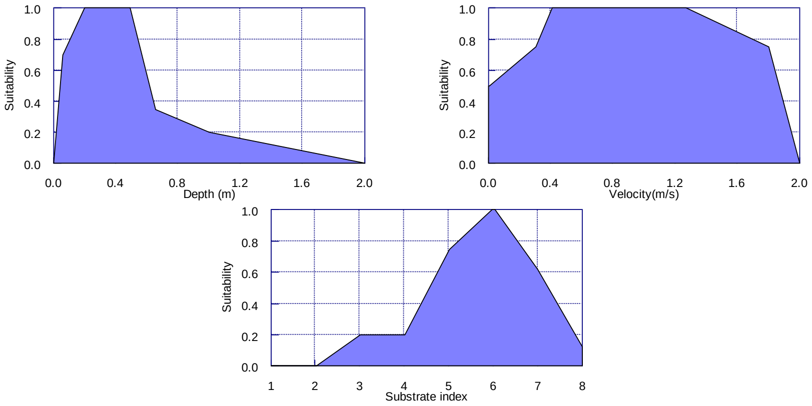
[15] Kaitoke Dec 1967-2006; Te Marua Aug 1991-2006; Birchville Sep 1970-2006; Taita Gorge Mar 1979-2006; Pakuratahi Truss Bridge May 1978-2006; Mangaroa Te Marua May 1977-2006; Akatarawa cemetery Feb 1979-2006; Whakatikei Dude Ranch Sep 1976-2006.

Appendix B: Habitat suitability criteria

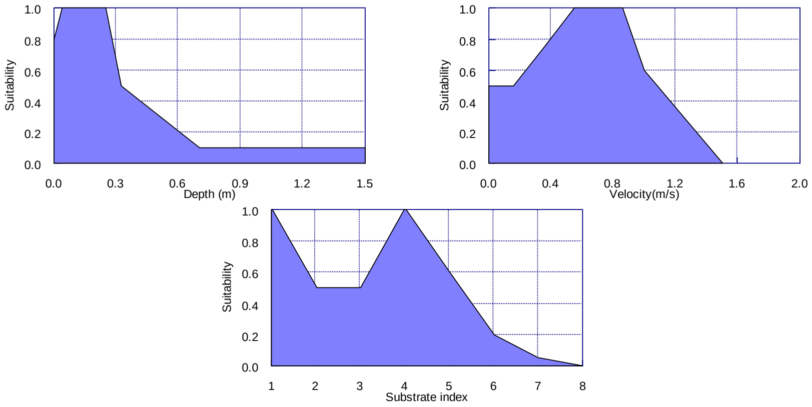
Food producing (Waters 1976)



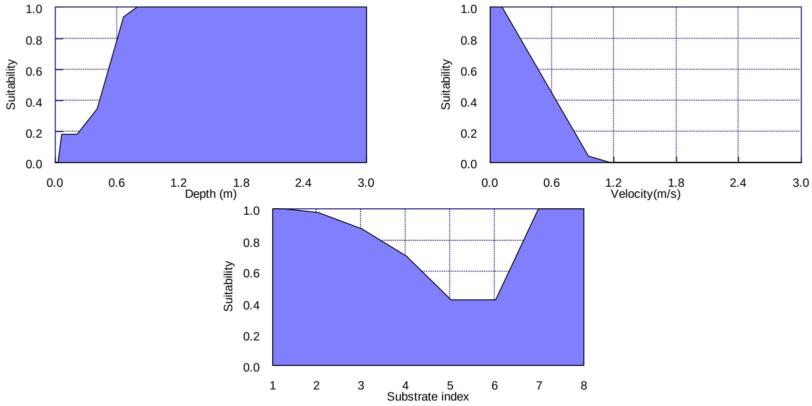
Deleatidium (mayfly) (Jowett et al. 1991)



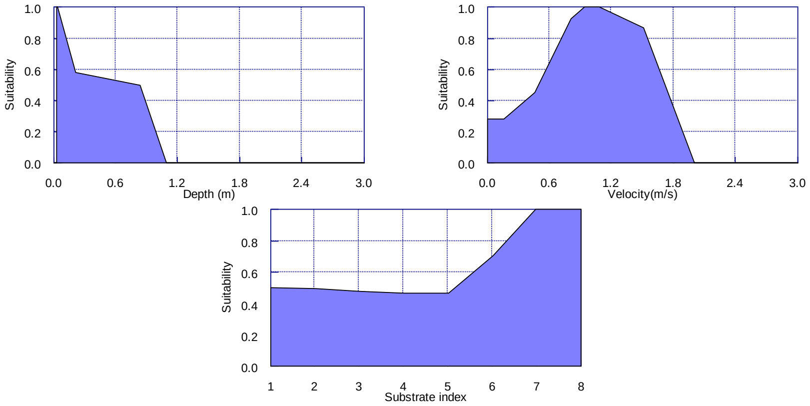
Shortfin eel (<300mm) (Jowett and Richardson 1995)



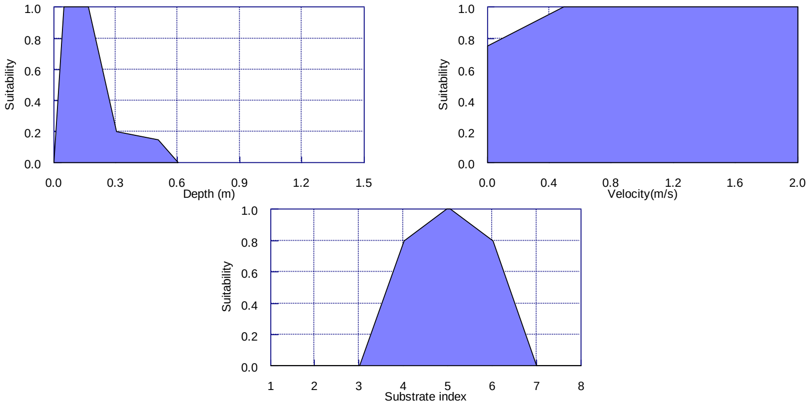
Longfin eels >300 mm (Jellyman et al. 2003)



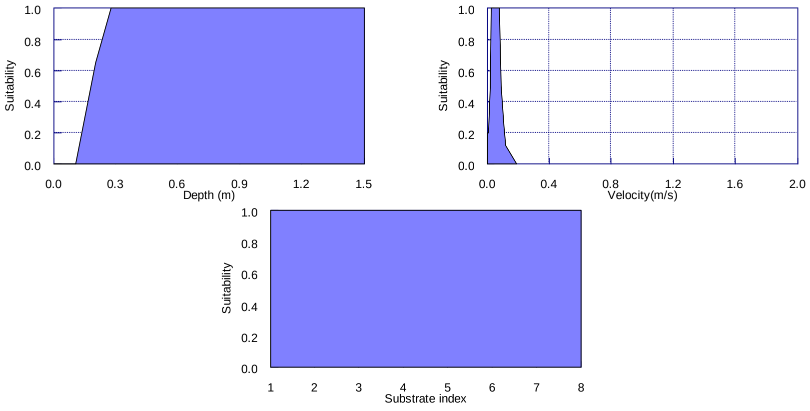
Longfin eels <300 mm (Jellyman et al. 2003)



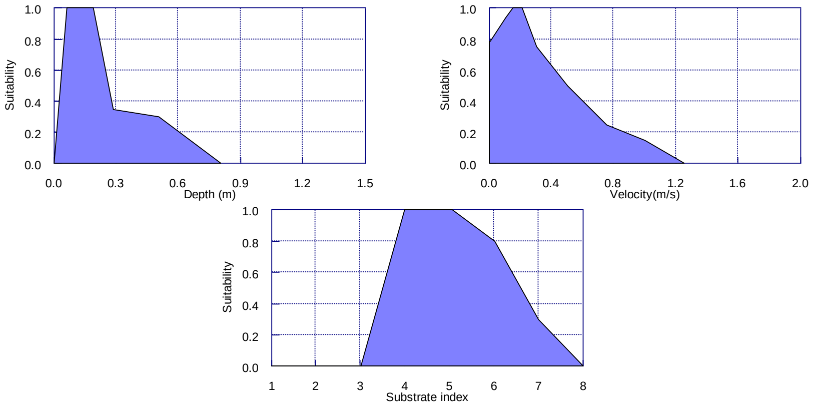
Dwarf Galaxias (Jowett and Richardson 1995)



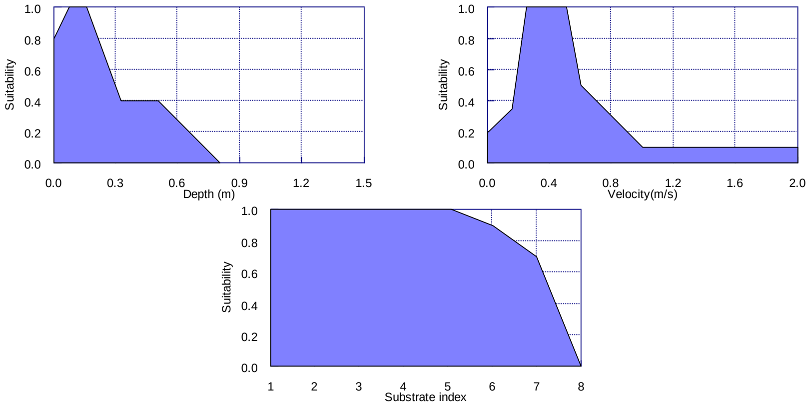
Inanga feeding (Jowett 2002)

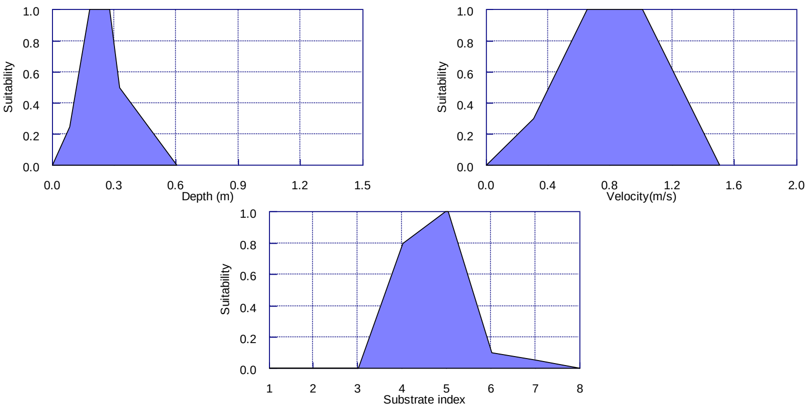


Crans bully (Jowett and Richardson 1995)

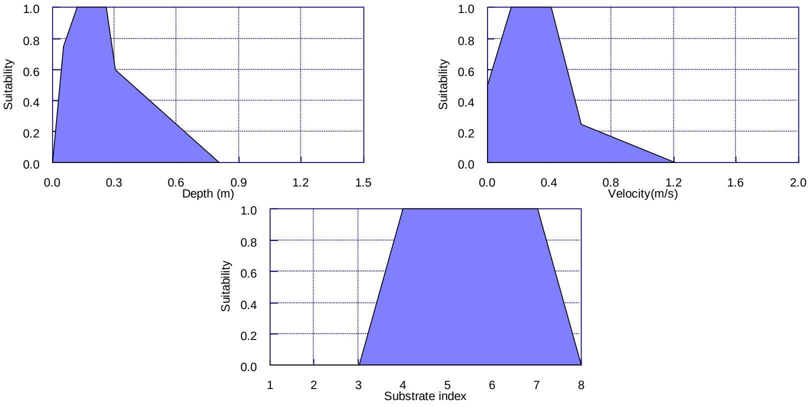


Common bully (Jowett and Richardson 1995)

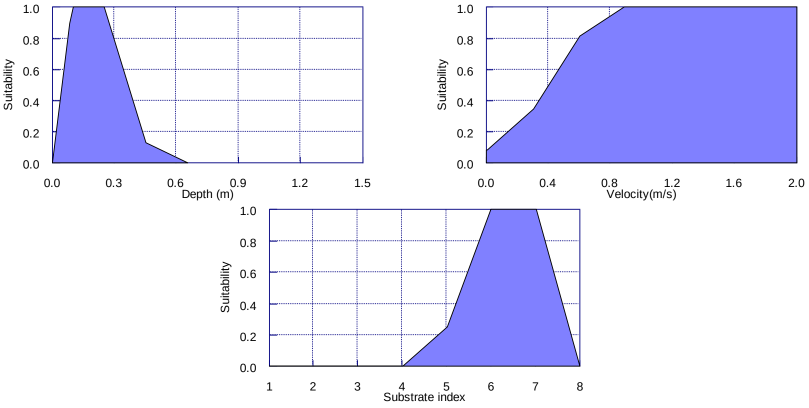




Bluegill bully (Jowett and Richardson 1995)

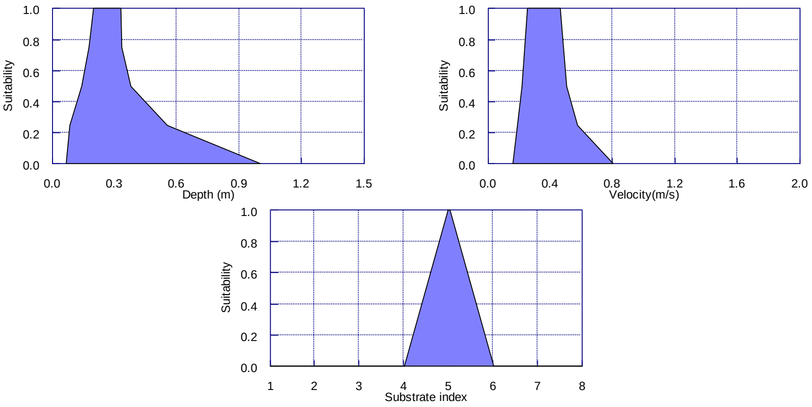


Redfin bully (Jowett and Richardson 1995)

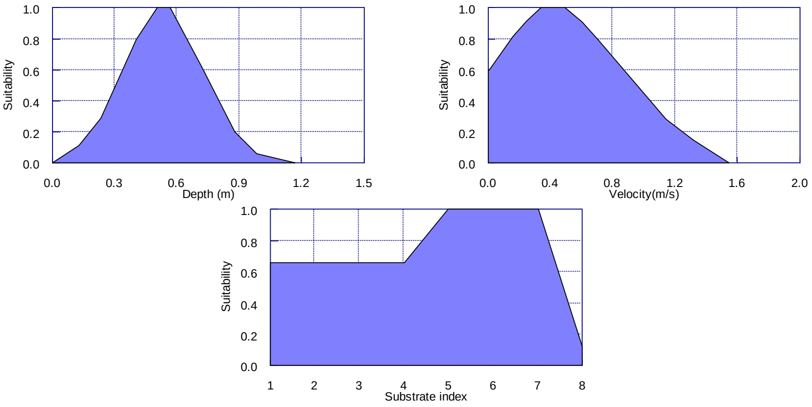


Koaro (Richardson and Jowett 1995)

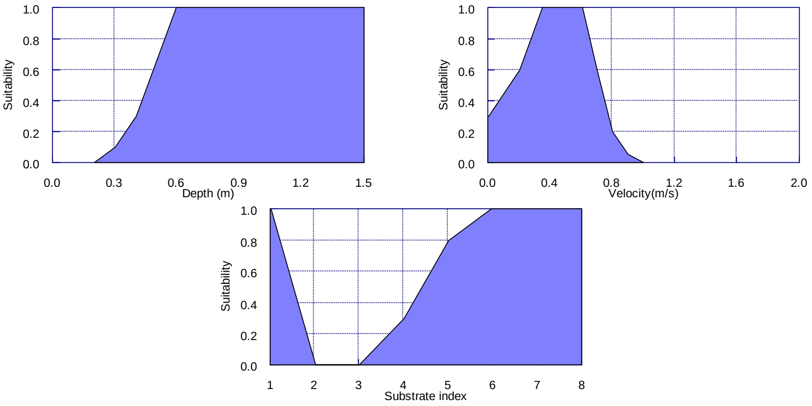
Brown trout spawning (Shirvell and Dungey 1983)



Brown trout juvenile (Bovee pers. comm.)



Brown trout adult (Hayes and Jowett 1994)



Appendix C: Selection of habitat suitability criteria

The following is taken from review comments of the proposed investigation (Hay, J. 2007. Review of "Draft instream flow assessment." Prepared for Greater Wellington Regional Council. Cawthron report No 1256. 12 pages).

"The habitat suitability criteria (HSC) applied were largely appropriate for the situation although it would be helpful to have the HSC used presented as an appendix to the report so that the reader can assess how these conform to their knowledge of habitat use. Instream Flow Incremental Modelling (IFIM) habitat modelling predictions are most sensitive to the HSC applied (Jowett 2004). Therefore the HSC chosen for a study must be appropriate for the species and life stages which are known to (or are likely to) occur in the study river. When several different sets of HSC are available for a given species (as is the case with brown trout for example) the suitability criteria should be selected to best represent the habitat needed to maintain a population of the species of interest. Consideration must also be given to the transferability of HSC developed on other rivers to the study river. It seems reasonable to expect that HSC developed on rivers with similar physical characteristics to the study river should be more readily applicable than HSC developed on physically different rivers. I provide some background information below mainly to help inform stakeholders regarding the HSC that have been applied in this case.

Hayes & Jowett's (1994) suitability criteria have been used most widely in New Zealand for modelling adult drift-feeding brown trout habitat since their development. These HSC were developed based on observations of habitat preferences of large (45–65 cm) actively feeding brown trout on moderate sized rivers (upper Mataura Travers upper Mohaka) over the flow range 2.8–4.6 m3/s. This compares reasonably well with the flow range of interest in the Hutt River in the lower reaches with MALFs in the order of 3 m^3/s. The river gradient in the reaches of the Hutt below the gorge where the surveyed reaches were located also compares well with the gradients of Hayes & Jowett's (1994) study rivers (approximately 0.0038 m/m versus 0.0016-0.0074 m/m respectively). Therefore this set of HSC should provide a reasonable indication of the flow requirements of adult brown trout in the Hutt River in these reaches.

The HSC for yearling brown trout and brown trout fry cited as Raleigh et al. (1984) in the key of Hudson's Figure 1 are in fact sourced from Raleigh et al. (1986) the 1984 reference being for rainbow trout. I believe this is simply a result of these HSC having been mislabelled with the dates transposed in the RHYHABSIM HSC library an error that I discussed with Ian Jowett (the developer of RHYHABSIM) some time ago and which has hopefully been rectified in more recent versions. The criteria for yearling brown trout and brown trout fry developed by Raleigh et al. (1986) have been used extensively in New Zealand IFIM habitat modelling applications although they may underestimate flow requirements due to the inclusion of resting fish observations in the development of the criteria which tends to give them a bias toward slower water habitat (a common problem in older habitat suitability criteria; Hayes 2004). HSC developed by Raleigh et al have fallen out of favour with fisheries managers and the US Geological Survey IFIM practitioners in Colorado because they were found to be unrelated to trout abundance in Colorado rivers (K. Bovee pers. comm.).

Bovee's (1995) criteria for juvenile brown trout developed to replace HSC developed by Raleigh et al. may provide a more conservative estimate of habitat availability since they are based solely on observations of actively *feeding fish. These HSC were developed from observations on a larger slightly steeper river (South Platte River Colorado United States of America 0.0058 m/m) at reasonably high flows (7-18 m3/s) compared with those in the low flow range (i.e. the range of interest in minimum flow setting) experienced in the Hutt. The relatively high velocity suitability indicated by these criteria may result in overestimation of the optimal flow requirements of juvenile brown trout in smaller less steep rivers such as the Hutt but they do have an advantage over the Raleigh criteria in that they are based on actively drift-feeding fish. Bovee's (1995) habitat suitability criteria are based on unpublished data sourced from Ken Bovee one of the original developers of the IFIM. The study site and methods used to gather these data are described in Thomas & Bovee (1993) which also presents rainbow trout habitat suitability data. Bovee's (1995) criteria were originally provided without substrate suitability criteria. It is not clear whether substrate suitability criteria from another source have been added in this case or if the criteria were applied without substrate criteria (this could be assessed if the HSC applied were presented in an appendix).*

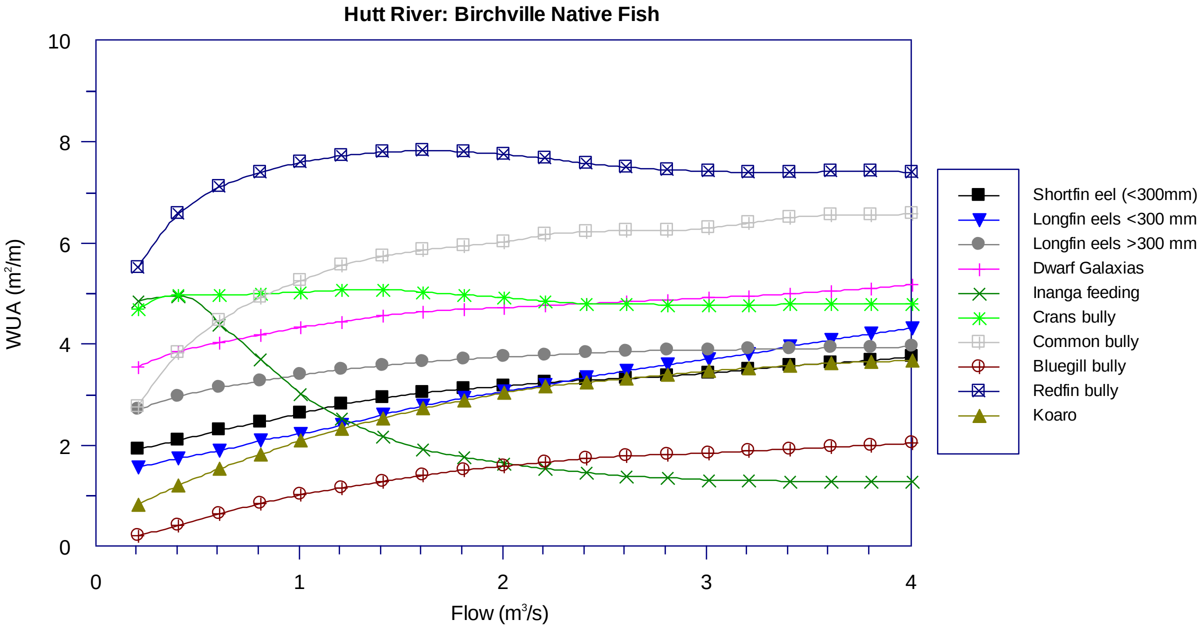
Bovee (1995) developed criteria for actively feeding adult brown trout as well. These could have been applied in this case to provide a comparison with the predictions based on Hayes & Jowett's (1994) criteria. However they may also be expected to overestimate flow requirements for the same reason given for juvenile trout. Bovee's (1978) HSC for brown trout fry share the slow velocity bias evident in the criteria of Raleigh et al. (1986) and it was intended that the HSC presented by the latter would supersede Bovee's (1978) criteria. They both have been superseded by Bovee's (1995) HSC – at least for Colorado rivers.

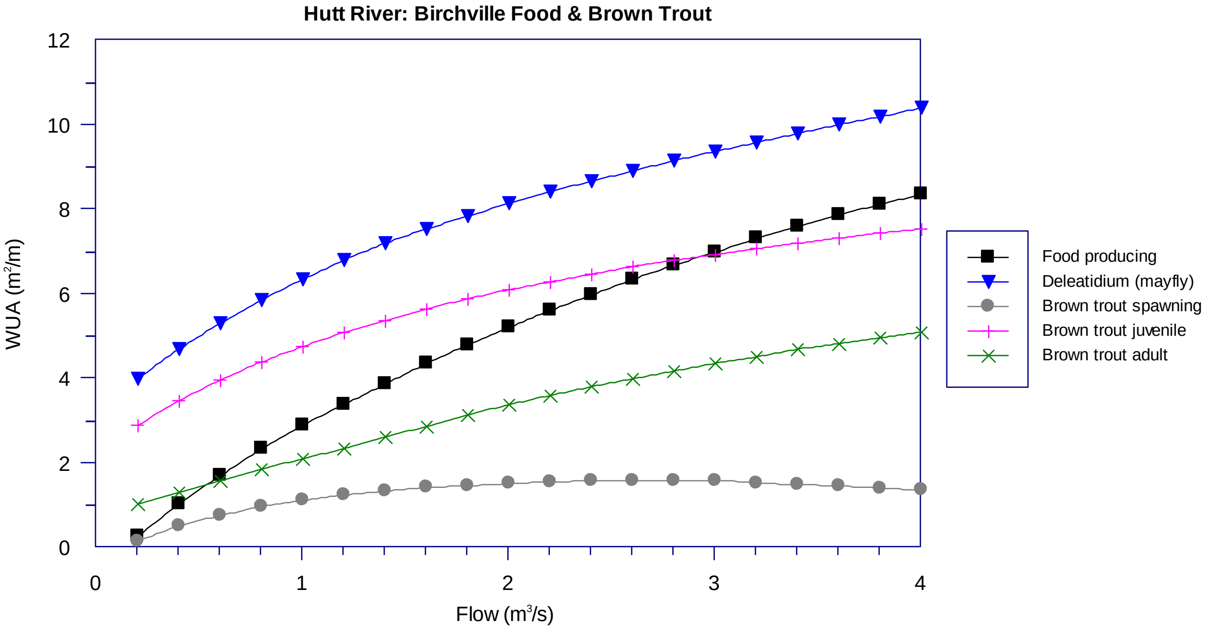
Shirvell & Dungey's (1983) trout spawning HSC were developed on New Zealand rivers. However Shirvell & Dungey's velocity suitability criteria are based on near bed velocities rather than mean column velocities (i.e. usually measured at 0.4 x depth) upon which the IFIM habitat model is based. Consequently when used in the IFIM habitat model they will 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.

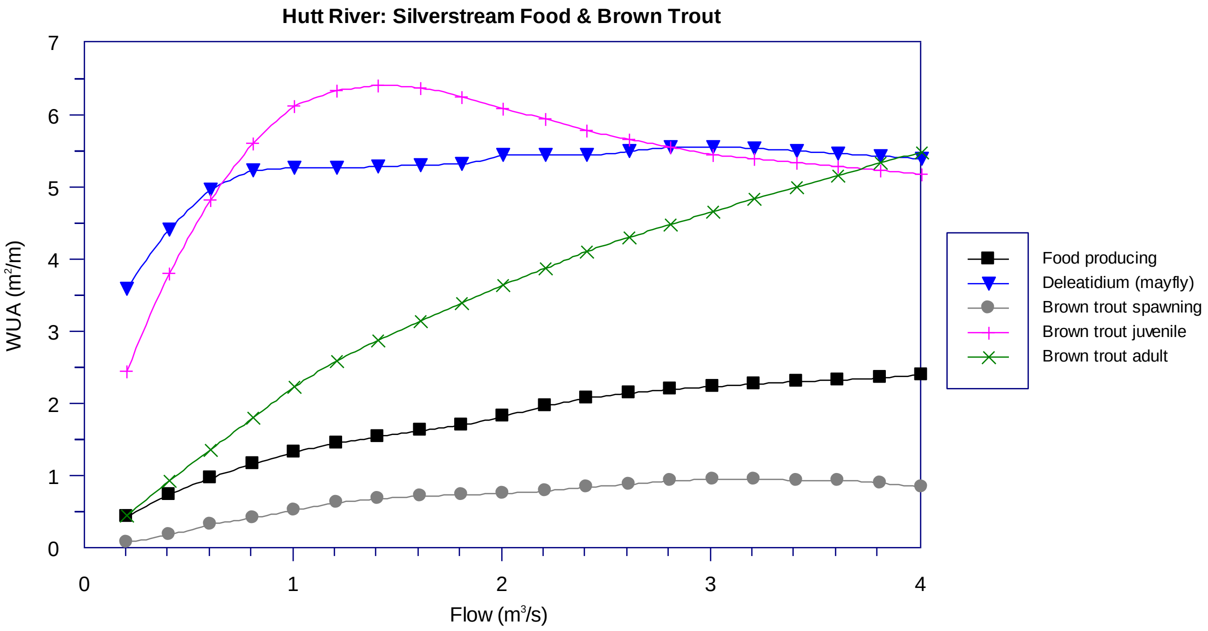
The general instream habitat requirements of macroinvertebrates were assessed using Water's (1976) food producing (i.e. food for fish) habitat suitability criteria. These general HSC for benthic macroinvertebrates were developed in the United States of America but have been widely applied to habitat analyses in New Zealand and Jowett (1992) found that WUA based on them was correlated with trout abundance in New Zealand rivers.

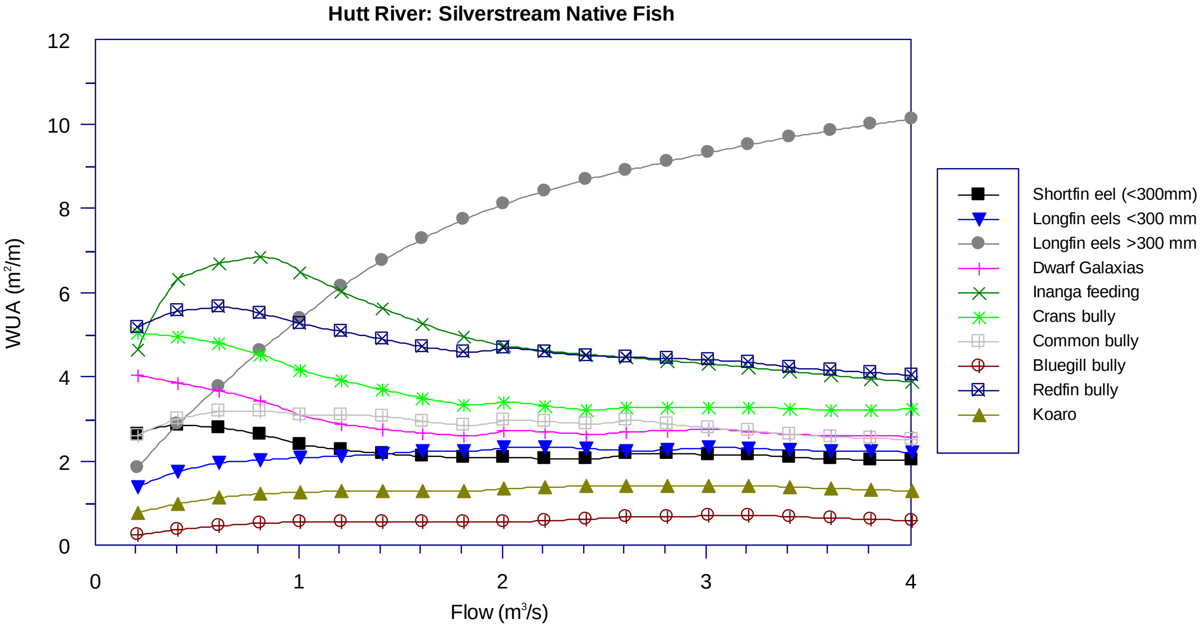
Hudson also applied HSC for Deleatidium mayfly perhaps the most ubiquitous mayfly genera in New Zealand rivers and a commonly utilised food for fish. These HSC were based on sampling in four New Zealand rivers (Clutha Mangles Mohaka Waingawa) with a range of size source and flow regime but having similar predominant substrates (cobbles and gravels) (Jowett et al. 1991). These HSC should be well suited to the Hutt River."

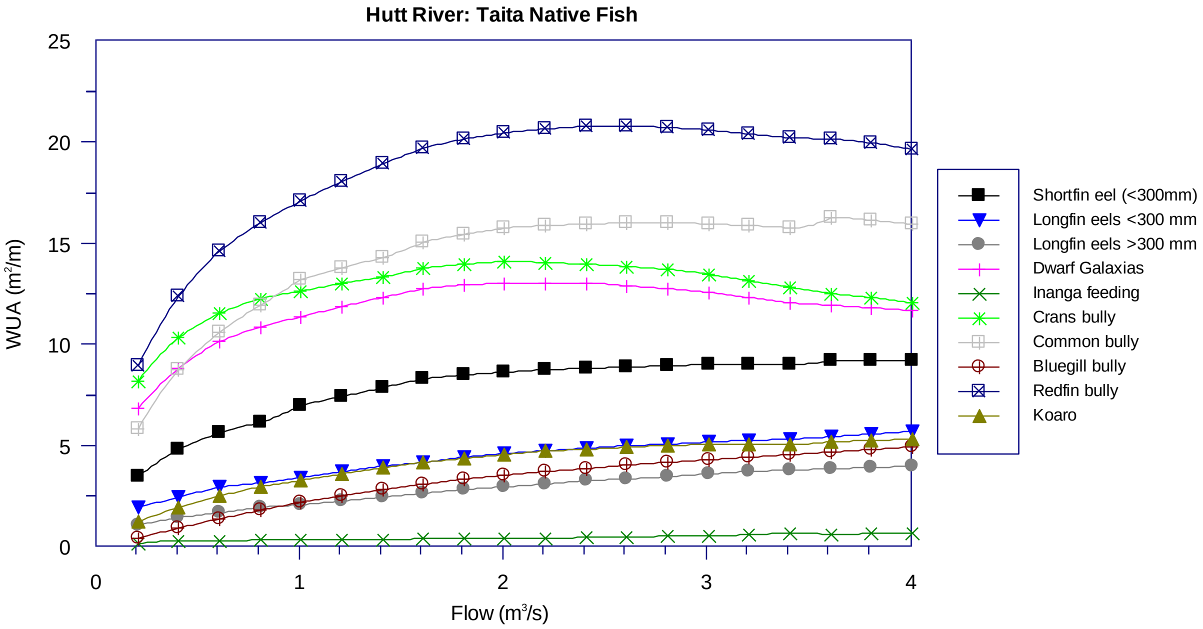
Appendix D: WUA-flow relations

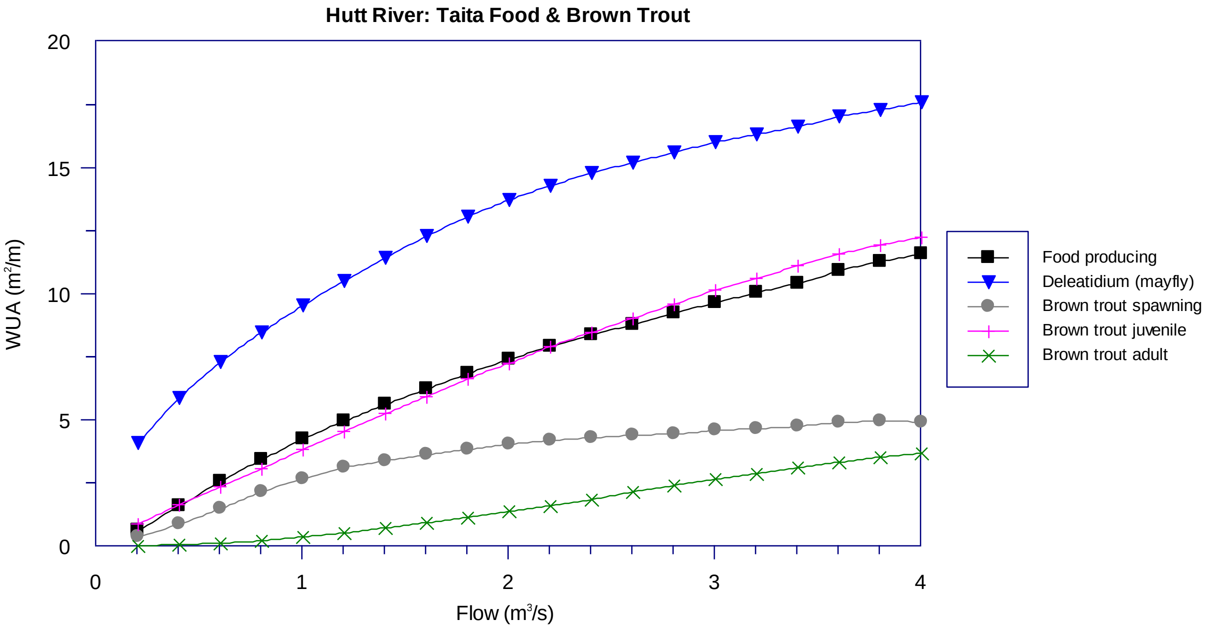


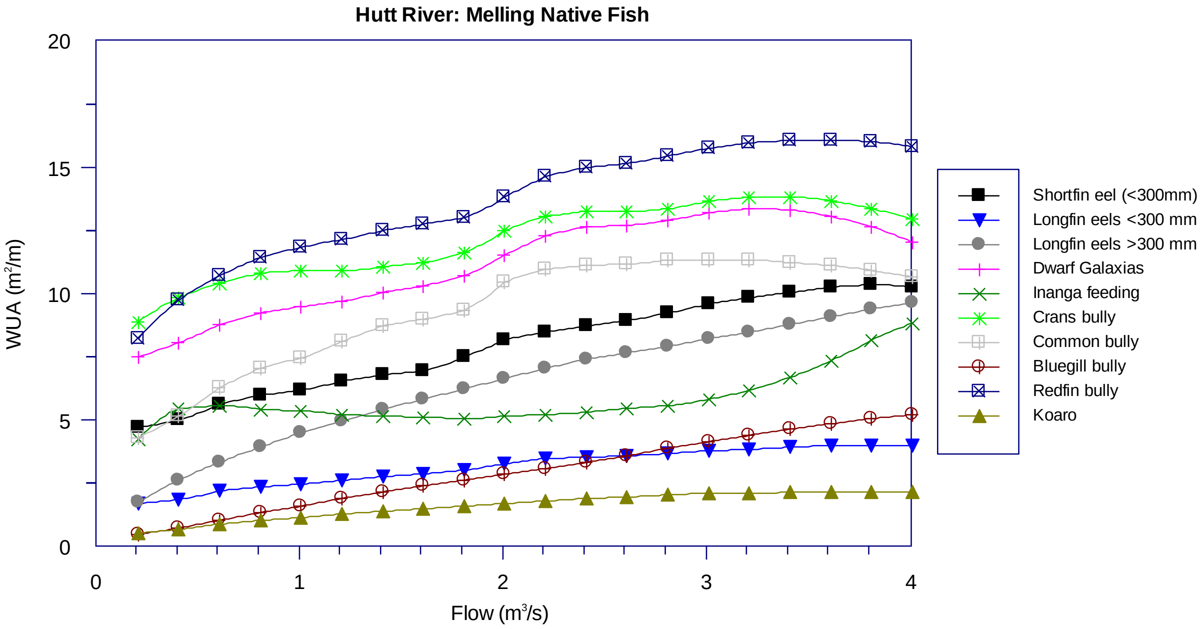


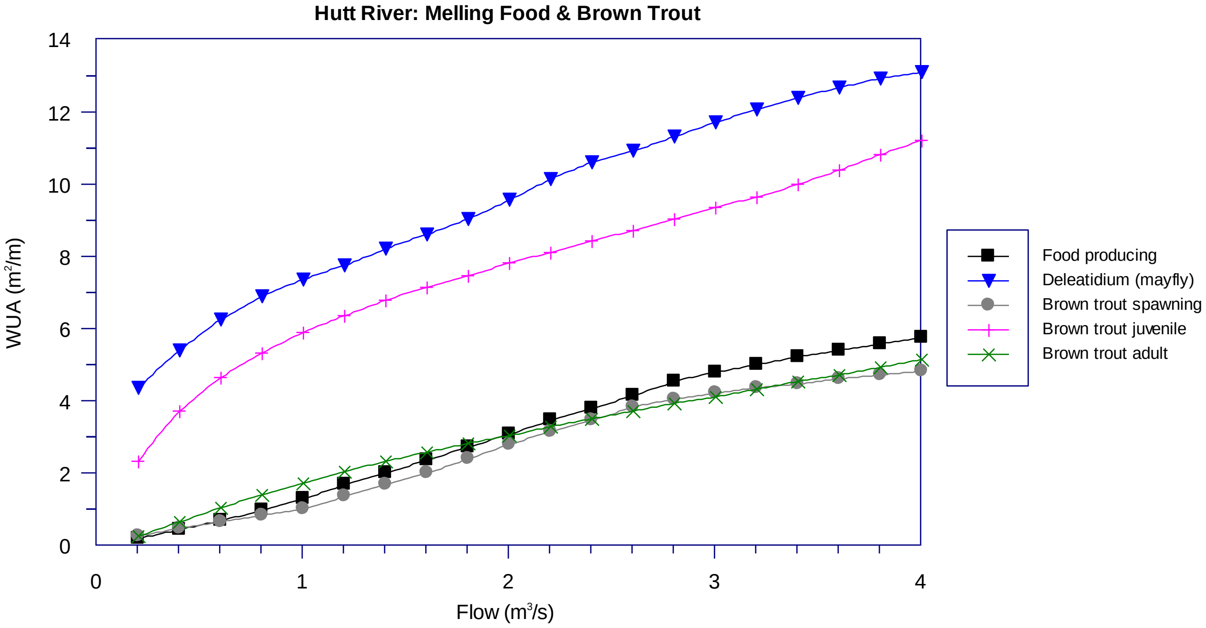

Hutt River: Silverstream Food & Brown Trout
WUA (m²/m)
Flow (m³/s)
0
1
2
3
4
5
6
7
0
1
2
3
4
Food producing
Deleatidium (mayfly)
Brown trout spawning
Brown trout juvenile
Brown trout adult


Hutt River: Silverstream Native Fish
WUA (m²/m)
Flow (m³/s)
0
2
4
6
8
10
12
0
1
2
3
4
Shortfin eel (<300mm)
Longfin eels <300 mm
Longfin eels >300 mm
Dwarf Galaxias
Inanga feeding
Crans bully
Common bully
Bluegill bully
Redfin bully
Koaro


Hutt River: Taita Native Fish
WUA (m^2/m)
25
20
15
10
5
0
0
1
2
3
4
Flow (m^3/s)
Shortfin eel (<300mm)
Longfin eels <300 mm
Longfin eels >300 mm
Dwarf Galaxias
Inanga feeding
Crans bully
Common bully
Bluegill bully
Redfin bully
Koaro


Hutt River: Taita Food & Brown Trout
WUA (m^2/m)
20
15
10
5
0
0
1
2
3
4
Flow (m^3/s)
Food producing
Deleatidium (mayfly)
Brown trout spawning
Brown trout juvenile
Brown trout adult


Hutt River: Melling Native Fish
WUA (m^2/m)
0
5
10
15
20
Flow (m^3/s)
0
1
2
3
4
Shortfin eel (<300mm)
Longfin eels <300 mm
Longfin eels >300 mm
Dwarf Galaxias
Inanga feeding
Crans bully
Common bully
Bluegill bully
Redfin bully
Koaro


Hutt River: Melling Food & Brown Trout
WUA (m^2/m)
0
2
4
6
8
10
12
14
Flow (m^3/s)
0
1
2
3
4
Food producing
Deleatidium (mayfly)
Brown trout spawning
Brown trout juvenile
Brown trout adult