Management Flows for Aquatic Ecosystems in Waiwera River

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Foreword

The future development and prosperity of Otago depends on water. However, much of Otago has long been recognised as a water-short area and consequently Otago is constantly at the forefront of water management in New Zealand. In many cases, irrigation, particularly in these drier areas, is critical to the continued well being of the people and communities who rely on the primary production it supports.

The Regional Policy Statement provides the overall framework for the future management of water in Otago. The Water Plan provides the direction for better utilisation and protection of water so that the values, opportunities and needs of Otago's communities can be reasonably met.

A key thrust of the Water Plan is its emphasis on the progressive implementation of minimum flow regimes for streams and rivers throughout the region. The goal of these minimum flows is to maintain the stream's aquatic ecosystem and natural character during periods of low flow. Furthermore, setting appropriate allocation limits and promoting water use efficiency are integral for ensuring reliable access to the water resource.

In Otago, surface water supplies are heavily allocated. Over-abstraction can result in degradation of a stream's natural values and character. Therefore, careful management is required to keep rates of taking sustainable. The best way forward is to use this valuable water resource to our advantage and to implement allocation limits and minimum flows so that over-abstraction does not occur.

The Waiwera River contains a brown trout fishery along with five species of native fish. Currently, there is one water take from the catchment that is used to irrigate approximately 270 ha. The catchment still has water available for primary allocation. Clearly, there is a need to manage the stream for its natural values while allowing access to the water resource for the local community.

Executive summary

The purpose of this report is to investigate the flows required to maintain acceptable habitat for the fish species found in the Waiwera River.

Flow statistics such as the 7-day Mean Annual Low Flow (MALF) and 7-day 10 year low flow ($Q_7$10) have been calculated to give an indication of the low flows experienced by the catchment. Rainfall data have also been summarised to give an indication of annual rainfall and seasonal distributions.

Recreational and biodiversity information has been obtained from both Fish and Game Otago and the Department of Conservation. This information has been incorporated into this report along with fisheries and climate data collected by Otago Regional Council.

Instream habitat surveys were carried out in the Waiwera River and flow requirements for all the known resident species assessed by examining the relationships between flow and suitable habitat using instream habitat modelling. Habitat suitability was determined from general habitat suitability curves developed from studies in other rivers.

The Waiwera River contains a regionally significant trout fishery, and it also contains several species of native fish of conservation importance. The habitat information showed that optimum flows for the different native fish species varied from 0.1 m^3/s for longfin eels and upland bullies to 0.8 m^3/s for common bullies. Optimum habitat for adult brown trout was provided by flows of 3.0 m^3/s. Flows below which habitat declines sharply for native fish ranged from 0.05 m^3/s for upland bullies to 0.15 m^3/s for common bullies. Adult brown trout habitat declined sharply once flows fall below 1.3 m^3/s.

The selection of an appropriate minimum flow depends on the fish species present and the flow management objectives that balance the degree of environmental protection against the value of water for other uses. This report focuses on the Waiwera River's natural values which have been taken from Schedule 1A of the Regional Plan: Water for Otago 2004 (Water Plan).

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1. Introduction

The Regional Plan: Water for Otago[1] 2004 (Water Plan) sets out as one of its objectives "to retain the flows in rivers to maintain their life-supporting capacity for aquatic ecosystems and their natural character". As a means to achieve this objective the Water Plan provides for the setting of minimum flows in Otago rivers[2].

The purpose of this report is to provide information on the Waiwera River that is relevant to determining the flows desirable for sustaining aquatic habitat. Hydrological data are summarised and analysed to determine low flow return periods for the Waiwera River. Rainfall data are provided to show the variation in rainfall throughout the catchment. A brief overview of the topography, vegetation, and land use within the catchment is provided along with a summary of the recreational and biodiversity values of the Waiwera River. A physical habitat study (the Instream Flow Incremental Methodology or IFIM) has also been carried out to determine the flow requirements for both native fish and introduced sports fish found within the catchment.

1.1 Focus of document

In order to manage a stream, there needs to be a clear focus on what the management objective is. Allocation limits for the Waiwera River have been determined and a clear management objective for the river is proposed. The management objective has been drawn from Schedule 1A of the Water Plan[3]. That schedule identifies the ecosystem values that must be sustained, and a key value that requires sufficient flow is the significant presence of brown trout (*Salmo trutta*). IFIM data are discussed with a focus on the management objective and the natural low flow regime of the Waiwera River. Flows to sustain these aquatic ecosystem values in the Waiwera River are recommended.

[1] Objective 6.3.1 of the Water Plan, pg 55.
[2] Policies 6.4.1 – 6.4.11 of the Water Plan, pp 58-69.
[3] Schedule 1A of the Water Plan, pg 296.

2. The Waiwera Catchment

The Waiwera Catchment is found in South Otago. It extends for approximately 30 km and has an area of approximately 207 km^2. The Waiwera Catchment is known to have relatively high, reliable rainfall. Its headwaters are found in the Wisp Range from which it flows in a northerly direction to its junction with the Clutha River/Mata-Au downstream of Clydevale (Figure 2.1).

2.1 Vegetation

Red tussock dominates the upper catchment with small pockets of podocarp forest. The remainder of the catchment is highly developed and consists of pasture grasses. There is also some production forestry in the upper catchment.

2.2 Land use

The upper catchment of the Waiwera is primarily used for extensive sheep and beef grazing. The mid and lower reaches of the catchment are dominated by pastoral farming with smaller farms with higher stocking rates relative to the upper catchment. In recent years, dairy farming has become increasingly common in the lower catchment.

2.3 Topography and soils

The Waiwera Catchment is bounded by the Wisp Range to the south and the Clutha River/Mata-Au to the north. The land to the east and west is generally rolling pasture land (Figure 2.1). Soils within the Waiwera Catchment, particularly on the river flats and terraces are considered fertile. Yellow grey earths dominate the Waiwera Catchment (Greenwood 1999).

2.4 Environmental concerns

Water quality is the main environmental concern for the Waiwera River. The bulk of the Waiwera runs through intensively farmed land and therefore it receives moderate to high levels of non point-source pollution. Any decrease in flow would potentially decrease the dilution factor for contaminants. If more water was made available for agriculture, this would allow further intensification of land use and potentially create larger volumes of non point-source pollution.

Fish and Game Otago have concerns about decreases in the Waiwera Catchment's water yield. Much of the headwaters in the Waiwera, along with other South Otago streams, are characterised by large areas of red tussock. As more of this tussock is lost due to pasture conversion and wetlands being drained, water yield in the catchment will decrease.

These issues are recognised and understood by the Otago Regional Council, in particular that increased water quantity will result in greater dilution of contaminants. Otago Regional Council policy is to address water quality issues at source, including where possible addressing non-point source contamination, rather than simply providing sufficient flows to assimilate waste. Efficiency of water application will

reduce wasteful practices that result in runoff. For these reasons, it is considered inappropriate to restrict consumptive use of water in order to achieve water quality outcomes. Water quality is not directly considered by this report, but by providing flows sufficient for aquatic ecosystem, there will be indirect benefit to the assimilation of some contamination.

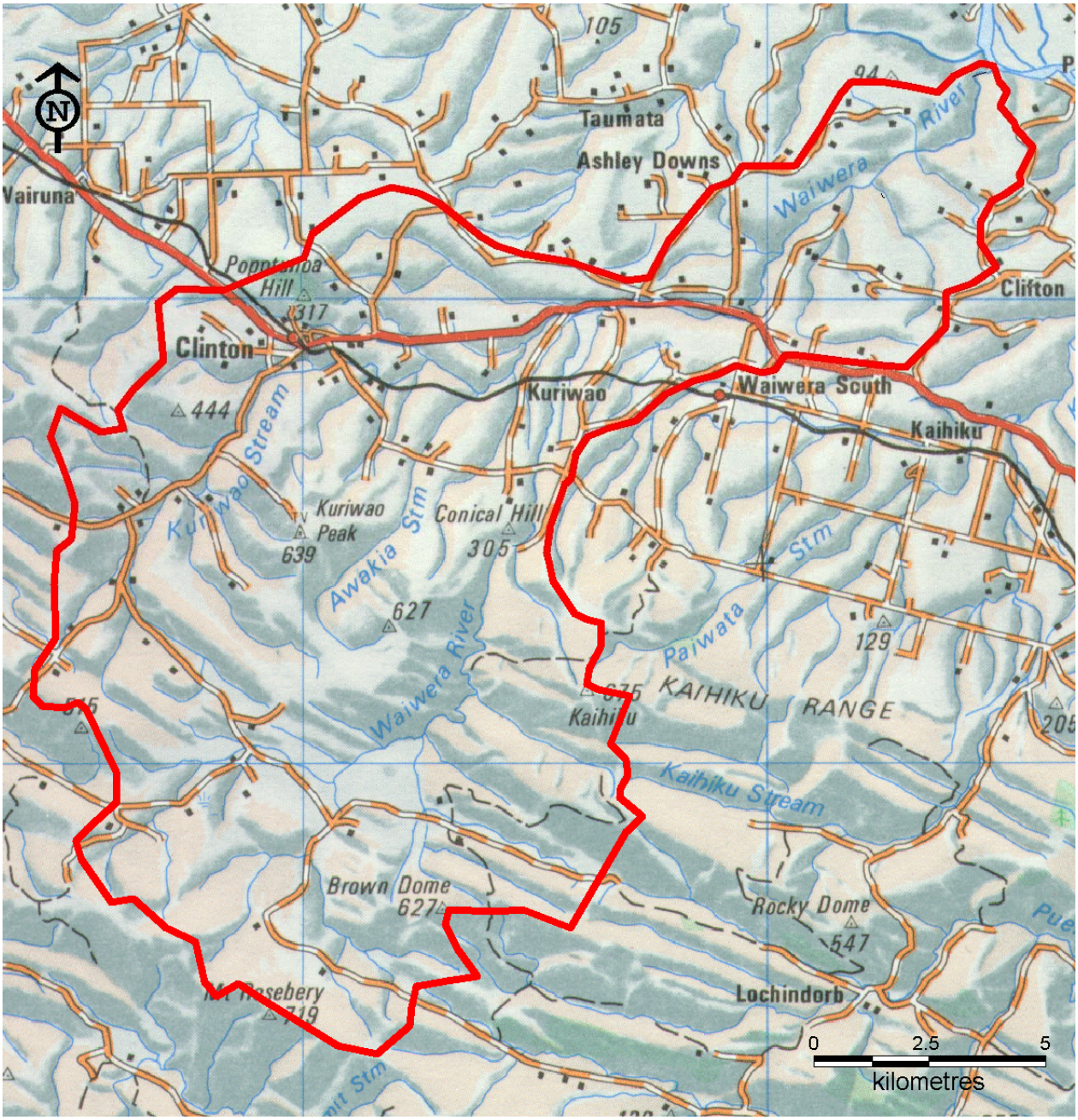

Figure 2.1 The Waiwera Catchment, Otago, New Zealand

2.5 Rainfall

The Waiwera Catchment's climate is considered mild, with consistent rainfall throughout the year (Figure 2.2). Annual rainfall for the catchment generally varies from around 700 mm in the low altitude parts of the catchment through to nearly 1400

mm in the upper catchment (ORC data). Rainfall intensities vary greatly throughout the catchment due to a combination of factors such as altitude, aspect and topography (Figure 2.2).

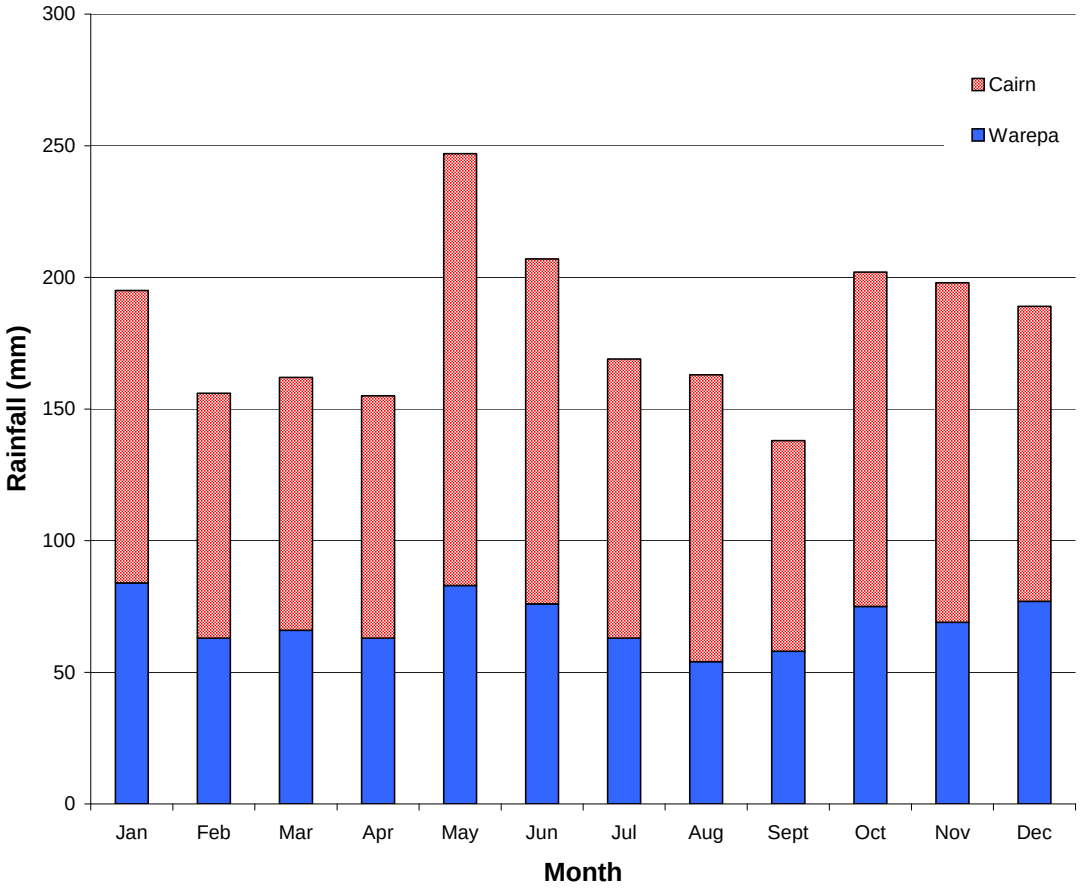

Figure 2.2 Mean monthly rainfall for the Waiwera Catchment. Warepa represents the lower Waiwera Catchment while Cairn is representative of the higher yielding upper catchment

2.6 Hydrology

The Waiwera River is a small stream entering the Clutha River/Mata-Au downstream of Clydevale. Several sites within the Waiwera Catchment have been analysed to extract information about the long-term statistics of the stream flows within the catchment (Figure 2.3). It must be noted that all flow data that have been collected are one off gaugings, as there is no continuous flow recorder on the Waiwera River.

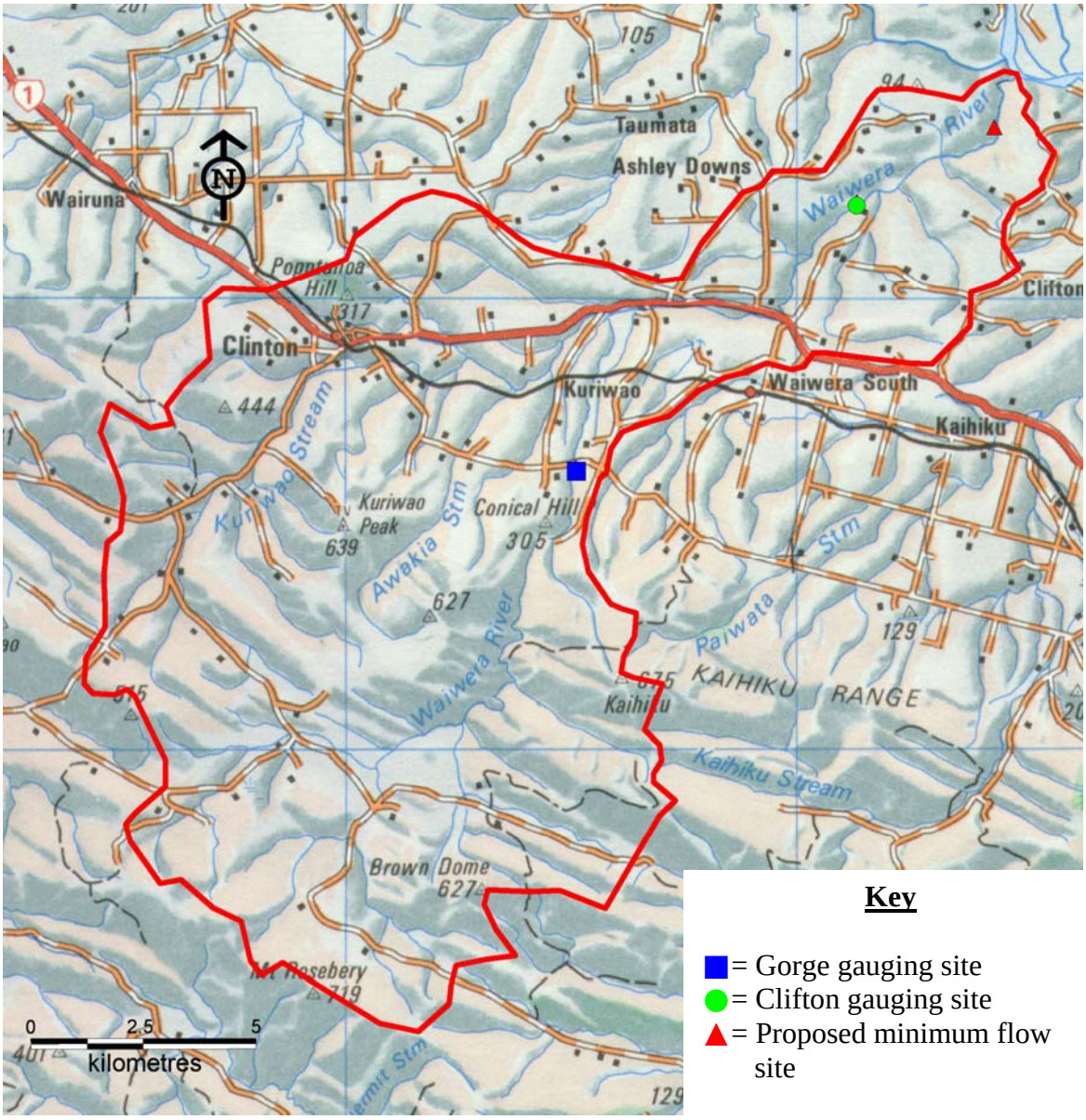

Figure 2.3 Flow gauging sites within the Waiwera Catchment

2.7 Calculating the mean annual 7-day low flow (MALF) for the Waiwera River

The naturalised MALF needed to be calculated in order to determine primary allocation for the Waiwera Catchment (Water Plan[4]) and to get an indication of the average natural low flow experienced by the river. This was complicated by two factors: there is no permanent flow recorder in the Waiwera Catchment and different techniques for 7-day MALF estimation can produce differing results. For a detailed assessment of the 7-day MALF estimation refer to Appendix 1 and Appendix 2. Section 2.8 provides the 7-day MALF value used in this document for the Waiwera River and the rationale behind estimating it in the absence of continuous flow data.

[4] Policy 6.4.2 of the Water Plan, pg 59.

2.8 Mean annual 7-day low flow (MALF) for the Waiwera River

Table 2.1 shows the predicted 7-day MALF values for the two methods used, the regression method and catchment area/rainfall method. The mean of the summer flow gaugings for the period January to April at each site is also shown (Table 2.1). In calculating the mean values, records of flows higher than would be expected during low flow condition were removed.

Table 2.1 Summary of the two methods used to estimate the 7-day MALF for the Waiwera River in relation to the mean gauged flows at each site from January to April

Site	Regression Method MALF (m^3/s)	Catchment/Rainfall Method MALF (m^3/s)	Mean gaugings for January to April (m^3/s)
Waiwera at Gorge	N/A	0.183	0.2
Waiwera at Clifton	0.269	0.275	0.253
Waiwera at proposed minimum flow site	N/A	0.31	0.314*

* One gauging only

MALF values predicted by both the regression method and catchment/rainfall method for the Waiwera at Clifton are consistent with the mean of the summer flow gaugings for the period January to April (Table 2.1). The above gauging data were collected where there were no irrigation takes, therefore they represent natural flows.

The catchment/rainfall method 7-day MALF of 0.31 m^3/s reflects the only gauged low flow at the bottom of the catchment of 0.314 m^3/s (February 2004). Therefore, a 7-day MALF of **0.31 m^3/s** has been chosen as this is the only predicted value available for the entire catchment (Table 2.1). In order to gain a more accurate 7-day MALF value, Council may need to consider installing a permanent flow recorder at the bottom of the Waiwera Catchment.

2.9 Annual 7-day low flows and their frequency analyses

Mean annual 7-day low flows (MALF or $Q_{7,m}$ in litres/sec) and the corresponding specific yield (SMALF or $SQ_{7,m}$ in litres/sec/km^2) have been calculated at three sites in the Waiwera Catchment (Table 2.2).

Table 2.2 Low flows for three gauging sites in the Waiwera Catchment

Site	Location	Min. (m^3/s)	MALF (m^3/s)	Area (km^2)	SMALF (l/s/ km^2)
Waiwera at Gorge	Upper Waiwera	0.182	0.183	76	2.4
Waiwera at Clifton	Mid-lower Waiwera	0.214	0.275	183	1.5
Waiwera at proposed minimum flow site	Lower Waiwera	0.314	0.31	207	1.5

The specific MALF for the Gorge site is significantly higher than that of either of the two other sites on the Waiwera River (Table 2.2). The higher specific yield at the Gorge site of the Waiwera River is more than likely due to a combination of high water yielding vegetation, high rainfall and topography (Figure 2.1 and Figure 2.2).

Table 2.3 Low flows for selected return periods in the Waiwera Catchment

Site	Min. (m^3/s)	MALF (m^3/s)	$Q_{7,5}$ (m^3/s)	$Q_{7,10}$ (m^3/s)	$Q_{7,20}$ (m^3/s)
Waiwera at Gorge	0.182	0.183	0.130	0.108	0.092
Waiwera at Clifton (Regression Method)	0.214	0.269	0.190	0.157	0.134
Waiwera at proposed minimum flow site	0.314	0.31	0.219	0.181	0.154

Low flow return periods in Table 2.3 were calculated using the same regression procedure (Appendix 1) as was used to derive the 7-day MALF for the Waiwera River. Return periods were then converted based on the chosen MALF values at the Gorge and proposed minimum flow site (Table 2.3). Table 2.3 shows that the gauged minimum flows are all very close to the predicted MALF values. This highlights the fact that historically there has been no irrigation within the Waiwera Catchment and that rainfall is fairly consistent from year to year.

Of note is that on the Waiwera River at Clifton there is only a 0.056 m^3/s difference in flow between a relatively minor 5-yr 7-day low flow and a much more severe 20-yr 7-day low flow (Table 2.3). This highlights the fact that irrigation taking on small streams can magnify the effects of low flows significantly, relative to much larger rivers.

2.10 The Waiwera fishery

The Waiwera River supports a diverse fishery, with six species of fish and one species of freshwater crayfish listed as being present in the catchment (NIWA freshwater database) (Figure 2.4). Brown trout (*Salmo trutta*) are the only sports fish species found in the Waiwera Catchment while the other five species found are native (Figure 2.4).

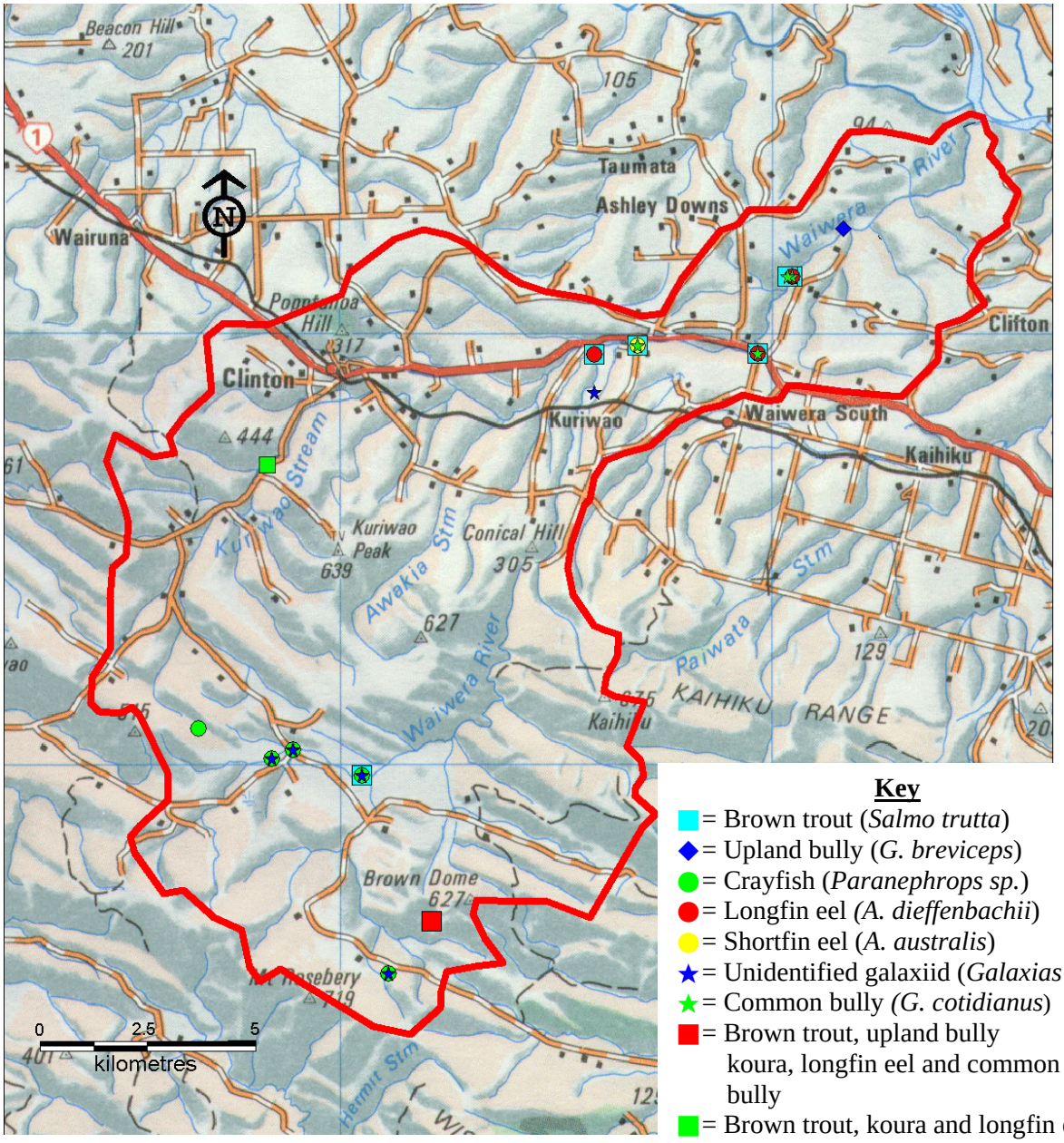

Figure 2.4 Fish distribution of the Waiwera Catchment from the NIWA freshwater fish database and ORC survey

3. Recreational, biodiversity and cultural values

The Waiwera River is a tributary of the Clutha River/Mata-Au, and has many biodiversity and cultural values that makes it of interest to stakeholder groups such as Kai Tahu, the Department of Conservation and Fish and Game Otago. Below is a summary of information available on the Waiwera Catchment with information incorporated from parties that have an interest in the flow regime of the Waiwera River.

3.1 Recreational values

The most significant active recreational pursuits carried out on the Waiwera River are angling and game bird hunting.

3.1.1 Sports fish species and angling reaches

The Waiwera River is a popular brown trout fishery with local anglers. Average fish size is around 1-1.5 kg with fish up to 3 kg occasionally caught, particularly in the upper reaches. An estimated 315 anglers visited the Waiwera in the 2001-02 season (Unwin & Image 2003).

To the angler, the Waiwera offers classic small stream fishing with a pleasant balance of runs, riffles and pools. The river is easily accessed from several road bridges or across farmland. Most of the angling takes place in the middle reaches, between approximately 2 km downstream of the SH1 bridge and approximately 2 km upstream of the Hillfoot Rd bridge. More adventurous anglers frequent the upper reaches, while the lower reaches are difficult to access due to crack willow infestation and a lack of public access in the area (Fitzpatrick 2004).

3.1.2 Game bird hunting and waterfowl habitat

The South Otago area has probably the highest use of any area in Otago by waterfowl hunters and the Waiwera River itself is a very popular waterfowl-hunting destination.

The Waiwera River and surrounding environment is a significant breeding ground and juvenile rearing habitat for mallard ducks, New Zealand shoveler, pukeko and paradise shelduck. It is also a moulting site for mallard ducks; particularly in the willow-infested lower reaches where there is little disturbance for birds during the vulnerable flightless stage of moulting. Any decrease in water flow would correspond with a decrease in food-producing areas such as backwaters and shallow margins (Fitzpatrick 2004).

3.2 Biodiversity values

The Water Plan[5] lists many natural values for the Waiwera River, including significant habitat for the native roundhead galaxiid, high invertebrate diversity and eel and rare fish habitat. Recent information from the Department of Conservation (DOC) suggests that the non-migratory galaxiid species found in the catchment is either Gollum galaxias (*G. gollumoides*) or *Galaxias "Species D"*, not roundhead galaxiid as listed in the Water Plan[5] (Neilson 2005). DOC suggests that once species identification of this non-migratory galaxiid is certain, it is likely the Waiwera will be added to their "Key Sites" list, pursuant to the New Zealand non-migratory galaxiid fishes recovery plan (DOC 2004). This plan requires the identification, protection and management of a minimum of 30 habitats with key populations of non-migratory galaxiid populations for each species. The longfin eel is also of conservation significance as its population is listed as being in gradual decline (Hitchmough 2002).

[5] Schedule 1A of the Water Plan, pg 296.

4. Physical habitat survey

The Otago Regional Council contracted NIWA to carry out a study to determine the flows required to maintain acceptable habitat for the fish species present in the Waiwera River.

The primary aims of this study were to:

- Conduct instream habitat surveys in critical reaches of the Waiwera River.
- Conduct a hydraulic analysis in the above streams using RHYHABSIM (Jowett 1989) to determine how weighted usable area (WUA) for brown trout and native fish habitat varies with (flow).
- Assess flow requirements for the Waiwera based on the habitat requirements of the native and introduced fish species.

4.1 Instream flow incremental methodology (IFIM) summary

The IFIM (Bovee 1982) is an example of a holistic way to determine an appropriate flow regime by considering the effects of flow changes on instream values, such as river morphology, physical habitat, water temperature, water quality, and sediment processes. As habitat methods are based on quantitative biological principles, they are considered more reliable and defensible than assessments made in other ways (White 1976; Annear & Conder 1984; Dunbar et al. 1998; Tharme 1996; Annear et al. 2002). Their strength lies in their ability to quantify the loss of habitat caused by changes in the natural flow regime, which helps the evaluation of alternative flow proposals (Jowett 2004).

Providing or retaining suitable physical habitat for aquatic organisms that live in a river is the ecological aim of IFIM assessments. The consequences of loss of habitat are well documented; the environmental bottom line is that if there is no suitable habitat for a species, it will cease to exist (Jowett 2004). Habitat methods allow for a more focused flow assessment and can potentially result in improved allocation of resources (Jowett 2004). However, it is essential to consider all aspects such as food, shelter, and living space and to select appropriate habitat suitability curves for an assessment to be credible (Orth 1987; Jowett 1995; Biggs 1996).

4.1.1 Habitat preferences and suitability curves

The aim of the IFIM is to maintain, or even improve, the physical habitat for instream values. The IFIM requires detailed hydraulic data, as well as knowledge of the ecosystem and the physical requirements of stream biota. The basic premise of habitat methods is that if there is no suitable physical habitat for the given species, then they cannot exist. However, if there is physical habitat available for a given species, then that species may or may not be present in a survey reach, depending on other factors not directly related to flow, or to flow related factors that have operated in the past (e.g., floods). In other words, habitat methods can be used to set the outer envelope of suitable living conditions for the target biota (Jowett 2004).

Biological information is supplied in terms of habitat suitability curves for a particular species and life stage (Jowett 2004). A suitability value is a quantification of how well suited a given depth, velocity or substrate is for the particular species and life stage (Jowett 2004). The result of an instream habitat analysis is strongly influenced by the habitat criteria that are used. If these criteria specify deep water and high velocity requirements, maximum habitat will be provided by a relatively high flow. Conversely, if the habitat requirements specify shallow water and low velocities, maximum habitat will be provided by a relatively low flow and habitat will decrease as the flow increases. The suitability curves developed in New Zealand for large, feeding adult brown trout (Hayes & Jowett 1994) specify higher depth and velocities than curves for adult brown trout developed in the U.S. (Raleigh et al. 1986). Whether this is due to differences in the sizes of fish has not been clarified. However, it is clear that it is important to use suitability curves that are appropriate to the river and were developed for the same size and life stage of fish, and behaviour, as those to which they are applied.

Generally, native fish are found in similar habitats over a wide range of rivers. McDowall (1990) has described these habitats in descriptive terms. The quantitative approach taken in New Zealand has been to develop general habitat suitability criteria for species of interest by using data collected from several rivers. To date, general habitat suitability curves have been developed for several native fish species, some of it published (e.g., Jowett & Richardson 1995) and some of it unpublished.

4.2 The Waiwera River

The Waiwera River flows from the Wisp Range. The upper reaches are confined by a gorge. The lower Waiwera River remains entrenched in a bedrock channel while flowing through rolling hinterland.

4.3 IFIM for the Waiwera River

The instream habitat survey was carried out at a flow of 0.290 m^3/s and calibration measurements for stage/discharge relationships at each cross-section were made at flows of 1.090 m^3/s and 3.600 m^3/s. At the survey flow of 0.290 m^3/s, the average river width was 7.63 m, the depth 0.34 m, and velocity 0.12 m/s. The substrate comprised mainly of bedrock (48.9%) and boulders (44.4%).

Although there is access to the sea for the fish community, longfin eels and common bullies are the only diadromous fish species recorded in the catchment. A flow of 3.0 m^3/s would provide maximum adult brown trout habitat, but adult trout habitat is severely reduced by natural low flows that are a tenth of the optimum for adult brown trout. Near-maximum habitat for the other fish species and trout life stages is provided by a flow of 0.5 m^3/s or less (Figure 4.1). Maximum habitat for longfin eels and upland bullies is provided by a flow of 0.1 m^3/s and habitat for common bullies begins to drop sharply at this point.

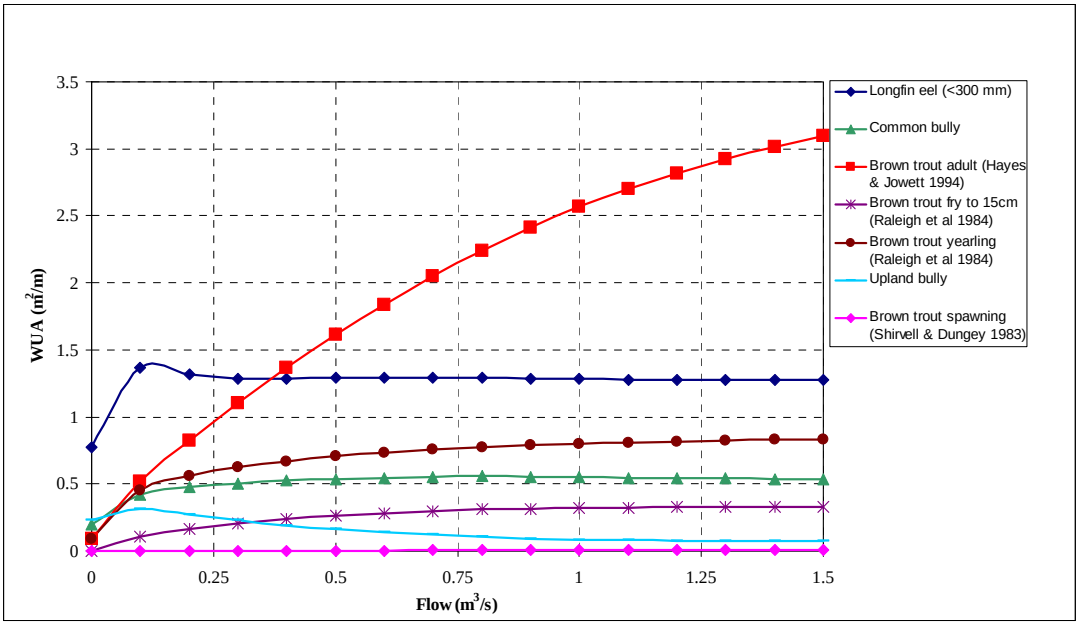

Figure 4.1 Variation of instream habitat (weighted usable area WUA) with flow in the Waiwera River

4.4 Discussion – IFIM and management objective

The IFIM data provide an overview of the flow requirements of different fish species to maintain their preferred habitat requirements (Table 4.1). Flow requirements can be selected so that they provide maximum habitat, or selected so that they prevent a serious decline in fish habitat. The flow below which habitat declines sharply is known as the point of inflection. It is a point of diminishing return, where proportionately more habitat is lost with decreasing the flow than is gained with increasing the flow by the same increment. Different fish species and even different size classes of fish have different points of inflection (Table 4.1). Ecologically the point of inflection represents the flow below which there is serious risk of losing sufficient habitat to maintain a species of fish or size class.

Clear management objectives are necessary when applying IFIM data (Hudson et, al. 2003; Jowett & Wilding 2003). The 1994/1996 National Angling Survey (Unwin and Brown 1998) showed that the Waiwera River received 112 angler visits. This increased dramatically to an estimated 315 anglers' visits to the Waiwera during the 2001-02 season (Unwin & Image 2003). Information submitted by Fish and Game Otago reiterates this (Section 3.1). Therefore the recommended management objective for the Waiwera River is to maintain the fish that are present in accordance with Schedule 1A of the Water Plan[6], which identifies the ecosystem values that must be sustained.

[6] Schedule 1A of the Water Plan, pg 296.

Table 4.1 Flow requirements for fish species at each IFIM site in the Waiwera Catchment

Fish species	7-day MALF (m^3/s)	Optimum Flow (m^3/s)	Flow below which habitat declines sharply (m^3/s)
Upland bully	0.31	0.1	0.05
Common bully		0.8	0.15
Longfin eel		0.1	0.1
Roundhead galaxiid		0.3	0.1
Adult brown trout		3.0	1.3
Yearling brown trout		1.8	0.4
Brown trout fry		1.0	0.4

5. Flow requirements: Discussion and suggested management flows for aquatic habitat

Under the Water Plan[7], Otago rivers will have minimum flows set to provide for the maintenance of aquatic ecosystems and natural character under low flow conditions. Under the Water Plan[8], when minimum flow levels are reached, all consents that are subject to that minimum flow are to cease taking.

5.1 Waiwera River flows discussion based on technical information

Optimum flows for the different native fish species vary from 0.1 m^3/s for longfin eels and upland bullies to 0.8 m^3/s for common bullies (Table 4.1) (Jowett 2004). Optimum habitat for adult brown trout is provided by flows of 3.0 m^3/s. Flows below which habitat declines sharply for native fish range from 0.05 m^3/s for upland bullies to 0.15 m^3/s for common bullies (Table 4.1) (Jowett 2004). Adult brown trout habitat declines sharply once flows fall below 1.3 m^3/s (Figure 4.1).

Jowett (1990; 1992) found that the percentage of adult trout habitat at the 7-day MALF acts as a bottleneck to trout density. A flow of 0.31 m^3/s (MALF) provides only a fraction of the weighted usable area for adult brown trout compared to the optimum flow of 3.0 m^3/s (Figure 4.1). Therefore, the natural low flows of the Waiwera River are restricting the adult brown trout fishery as the MALF for the Waiwera is far below the flows that provide optimum habitat and the point of inflection for adult brown trout (Table 4.1).

As the management aim for the Waiwera River is to maintain the current fishery (Section 4.4), it is necessary to identify a flow that represents a compromise between the flows preferred by the fish species that prefer high and low velocity environments. From the IFIM data, the difference between the amount of habitat available at 0.25 m^3/s and the optimum for each of the native species is negligible (Figure 4.1). At 0.25 m^3/s, brown trout of all size classes have significantly less habitat than would be provided by their respective optimum flows as assessed by the IFIM.

A flow of **0.4 m^3/s** at the Waiwera minimum flow site is likely to ensure the sustainability of the fish community in the Waiwera River during the high flow period May to September inclusive. A flow of **0.2 m^3/s** at the Waiwera minimum flow site is likely to ensure the sustainability of the fish community in the Waiwera River during the lower flow period October to April inclusive, and it is recommended that flows should not be allowed to drop below those outlined above due to consumptive use.

The low flow period minimum flow of **0.2 m^3/s** is well below the point of inflection indicated by the IFIM survey for adult brown trout, juvenile brown trout and trout fry (Table 4.1). As shown earlier for adult brown trout the MALF (0.31 m^3/s) also restricts the habitat available for juvenile brown trout and trout fry, hence there is no significant habitat difference for these species at flows of 0.31 m^3/s compared to **0.2 m^3/s** (Figure 4.1).

[7] Schedule 2A of the Water Plan, pg 314.
[8] Policy 6.4.11 of the Water Plan, pg 69

The high flow period (May – September) minimum flow of **0.4 m^3/s** represents the point of inflection indicated by the IFIM survey for juvenile brown trout and trout fry (Table 4.1). A flow of **0.4 m^3/s** will provide significant habitat for all species of fish with the exception of adult brown trout. However, it is the natural hydrology that is the cause of the restriction on adult trout habitat.

5.2 Suggested management flows for aquatic ecosystems

Seasonal management flows of **0.2 m^3/s** and **0.4 m^3/s** are suggested for the Waiwera Catchment. This would recognise that there is clear seasonal variation in flows in the Waiwera River, with high flows occurring from May to September and lower flows typically occurring from October to April. By implementing higher minimum flows during the period when there is naturally high flows in the river (May to September inclusive) some seasonal flow variation is provided for. Flow variation is seen as important for numerous ecological reasons including removing algal growth, lowering water temperatures and providing for fish migration. Brown trout migration and spawning tend to occur over the winter period when flows are naturally higher, allowing for upstream migration.

Flows of **0.2 m^3/s** and **0.4 m^3/s** should also maintain the natural character of the Waiwera River, thus fulfilling the criteria of Objective 6.3.1 of the Water Plan.

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8. Glossary of terms

7-Day MALF	The mean of the lowest 7-day average flow for each hydrological year of record (MALF).
$Q_7$10	The 7-day low flow with the likelihood of occurring once in a 10 year period.
Pool	Aquatic habitat characterised by slow flowing, deep water with an unbroken surface.
Return Period	Sometimes called the recurrence interval. Return period is the means of expressing the statistical likelihood of a low or flood flow occurring.
Riffle	Aquatic habitat characterised by shallow, stony, fast flowing (where the surface of the water is broken) conditions, favoured by most aquatic invertebrates.
Run	Aquatic habitat characterised by obvious flow, but without the rapid, broken surface conditions of a riffle.
SMALF	Specific discharge from one unit catchment area at times of the 7-day mean annual low flow (MALF).
Weighted Usable Area (WUA)	WUA (m^2/m) is the measure of the total area of suitable habitat per metre of stream.

Appendix 1 - Waipahi River at Waipahi flow relationship with the Waiwera River

The most intensely gauged sites on the Waiwera River are at the SH 1 bridge and slightly downstream at Clifton (Figure 2.3). The above two gauging sites are considered close enough (approximately 3 km apart, with no major tributaries entering between them) to lump the data recorded into one set to make any relationships drawn with the Waipahi River more statistically robust. Flows gauged in the Waiwera are unaffected by irrigation takes and are considered natural (Figure A. 1). Recorded flows in the Waipahi River at Waipahi are also unaffected by irrigation takes. The Waiwera River Catchment is also relatively close to the long-term continuous recorder site at Waipahi on the Waipahi River, with similar land use, rainfall and topography.

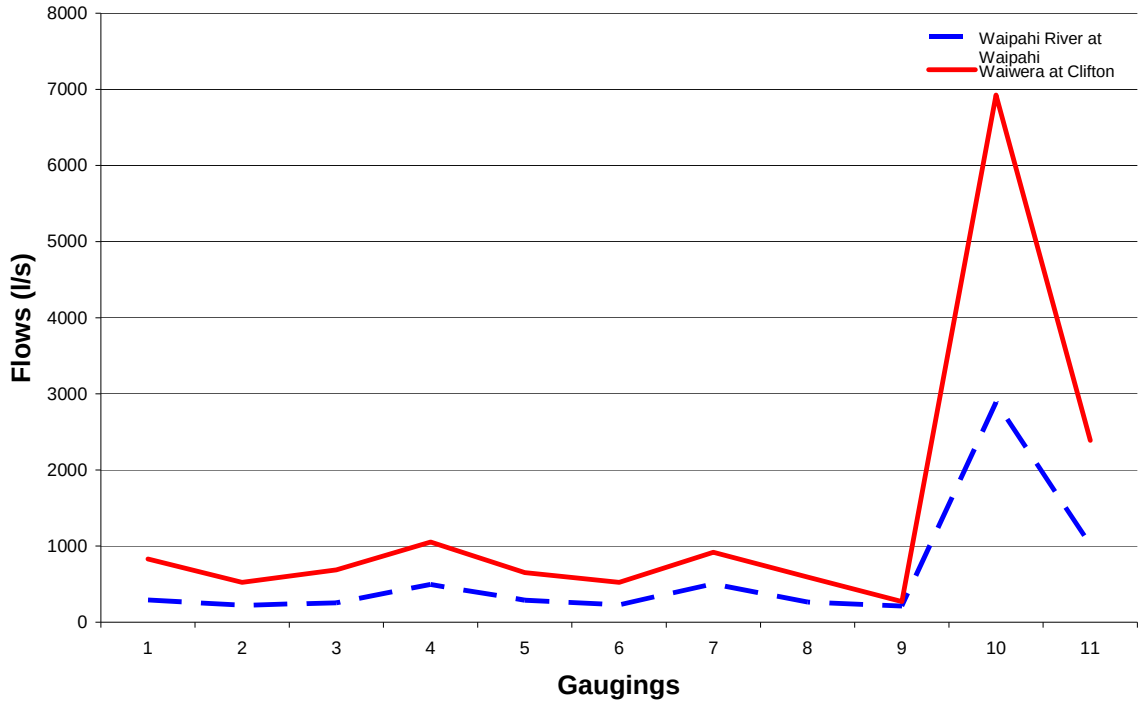

Figure A. 1 Gauged flows for the Waiwera River compared to daily mean flow recorded at Waipahi on the Waipahi River

Regression analysis was carried out on this data resulting in an R^2 of 0.7349, which suggests a fair relationship between flows in the Waipahi River at Waipahi and the Waiwera River at Clifton (Figure A. 2).

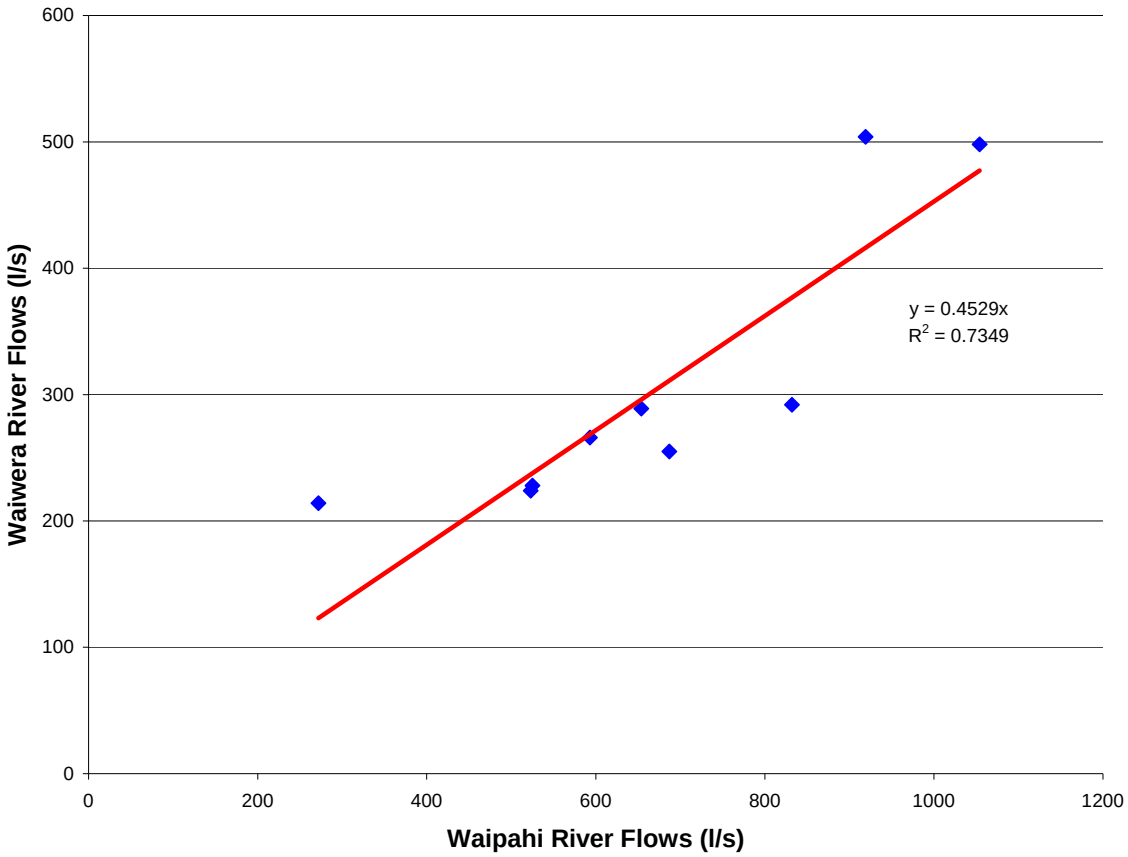

Figure A. 2 Regression analysis comparing flows in the Waipahi River at Waipahi and the Waiwera at Clifton

The linear relationship between flows in the Waipahi River at Waipahi and the Waiwera at Clifton can be used to get an idea of MALF for the Waiwera River. MALF for the Waipahi River at Waipahi is **593 l/s**. Therefore, using the regression equation from Figure A. 2, Y = 0.4529X (where Y = Waiwera flows and X = flows at Waipahi), we can see that the corresponding MALF value for the Waiwera River at Clifton is **269 l/s** (Y = 0.4529 x 593)**.**

Appendix 2 - Mean annual 7-day low flow based on catchment area and rainfall

Catchment area and rainfall relationships are often used to determine 7-day MALF values. Table A. 1 - Table A. 3 are the MALF values calculated using the available rainfall and catchment data for the Waiwera Catchment. Table A. 1 - Table A. 3 also provide some justification as to why certain values were chosen.

Table A. 1 7-day MALF value for the Waiwera River at the Gorge

Location	G46:351-363
Site Description	Waiwera River at Hillfoot Rd (Gorge)
Basin Area (km^2)	76
Precipitation (m/yr)	1.4 (from rainfall contour maps 1:250,000)
SMALF Q7,m ($l/s/km^2$): 1- Pearson's Contours 2- Pearson's Regression 3- Otago's Regression 4- Observed low flows Waiwera at Gorge SMALF 5- Nearby locations Waipahi River at Waipahi Pearson's Contours Pearson's Regression Observed SMALF	 0.5 –1. 0 (NIWA's Package) 0.5 – 2.0 (NIWA's Package) 1.58 $P^{3.618}$ = 5.3 2.39 – 2.92 (1996 – 2004 gaugings) 1.0 –2.0 (NIWA's Package) 1.0 - 2.0 (NIWA's Package) 1.67 (observed)
Nominated SMALF	2.4
Justification	More weight has been given to Waiwera gaugings and their SMALF value as the catchment above Hillfoot Rd receives high levels of rainfall.
MALF $Q_{7,m}$ (l/s)	2.4* 76 **= 183**
Nominated Q_m / $Q_{7,m}$:	10.0 (similar to Waipahi)
Mean Flow Q_m (l/s)	**1830 l/s**

Table A. 2 7-day MALF value for the Waiwera River at Clifton

Location	G45:413-421
Site Description	Waiwera River at Clifton
Basin Area (km^2)	183
Precipitation (m/yr)	1.23 (from rainfall contour maps 1:250,000)
SMALF Q7,m ($l/s/km^2$): 1- Pearson's Contours 6- Pearson's Regression 7- Otago's Regression 8- Observed low flows Waiwera at Clifton SMALF 9- Nearby locations Waipahi River at Waipahi Pearson's Contours Pearson's Regression Observed SMALF	 0.5 –1. 0 (NIWA's Package) 0.5 – 2.0 (NIWA's Package) 1.58 $P^{3.618}$ = 3.17 1.2 – 2.7 (1999 – 2004 gaugings) 1.0 –2.0 (NIWA's Package) 1.0 - 2.0 (NIWA's Package) 1.67 (observed)
Nominated SMALF	1.5
Justification	More weight has been given to Waiwera gauging and Waipahi observed SMALF as it is located in a similar region and lies within the range estimated from the other methods.
MALF $Q_{7,m}$ (l/s)	1.5* 206.7 = **275**
Nominated Q_m / $Q_{7,m}$:	10.0 (similar to Waipahi)
Mean Flow Q_m (l/s)	**2750 l/s**

Table A. 3 7-day MALF value for the Waiwera River at its minimum flow site

Location	G45:447-450
Site Description	Waiwera River at minimum flow site 1 km upstream of confluence with the Clutha River/Mata-Au.
Basin Area (km^2)	206.7
Precipitation (m/yr)	1.05 (from rainfall contour maps 1:250,000)
SMALF Q7,m ($l/s/km^2$): 1- Pearson's Contours 10- Pearson's Regression 11- Otago's Regression 12- Observed low flows Waiwera at Clifton SMALF 13- Nearby locations Waipahi River at Waipahi Pearson's Contours Pearson's Regression Observed SMALF	 0.5 –1. 0 (NIWA's Package) 0.5 – 2.0 (NIWA's Package) 1.58 $P^{3.618}$ = 1.9 1.2 – 2.7 (1999 – 2004 gaugings) 1.0 –2.0 (NIWA's Package) 1.0 - 2.0 (NIWA's Package) 1.67 (observed)
Nominated SMALF	1.5
Justification	More weight has been given to Waiwera gauging and Waipahi observed SMALF as it is located in a similar region and lies within the range estimated from the other methods.
MALF $Q_{7,m}$ (l/s)	1.5* 206.7 = **310**
Nominated Q_m / $Q_{7,m}$:	10.0 (similar to Waipahi)
Mean Flow Q_m (l/s)	**3100 l/s**