# Integrated water resource management for the Benger Burn and Ettrick Basin Aquifer

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# Overview

## Background

Otago Regional Council's (ORC) Regional Plan: Water (the Water Plan) provides the direction for better use and protection of water so that the values, opportunities and needs of Otago's communities can be reasonably met. A major aim of the Water Plan is to progressively implement management flow regimes for streams and rivers to maintain aquatic ecosystems and natural character during periods of low flow, and to set sustainable allocation limits for both surface-water and groundwater use. The setting of appropriate allocation limits and promoting water-use efficiency are integral for ensuring reliable access to the water resource.

## Why is a management flow necessary for the Benger Burn?

The Benger Burn, located about 10km south of Roxburgh, supports a spawning run of brown trout and Chinook salmon when there is sufficient flow during the spawning season. Longfin eel, shortfin eel, upland bully, common bully and Clutha flathead galaxias are also found in the catchment.

The purpose of this report is to investigate the flows needed to maintain the habitat of the fish species in the Benger Burn, and to recommend a sustainable allocation limit for the Ettrick Basin Aquifer. The selection of an appropriate minimum flow depends on evaluating instream values and balancing these against the needs of other water users.

## What has this study found?

As flows in the Benger Burn are linked with the underlying Ettrick Basin Aquifer, both need to be considered when determining a surface-water management flow.

Once the Benger Burn flows out of the hill country and onto the flats, there is a significant loss of surface flow into the Ettrick Basin Aquifer. This losing reach extends to the SH8 bridge, where groundwater from the aquifer resurfaces into the Benger Burn and creates a gaining reach down to the Clutha confluence. Despite a steady base flow entering the lower reaches of the Benger Burn, the river will probably run dry in an average or dry year.

Using the results of habitat modeling, this study recommends flows for each fish species of the Benger Burn. The following minimum flows are recommended to maintain the key instream values of the catchment:

- A minimum flow of 400 l/s at the Booths flow recorder, for all takes from April to August, will provide for trout and salmon spawning.
- A minimum flow of 75 l/s is to be maintained at the Booths Road flow recorder from September to March for all takes upstream of the flow recorder.
- No minimum flow is to be implemented from September to March for all takes downstream of the Booths flow recorder.

A water balance study has been carried out for the Ettrick Basin Aquifer to ensure the aquifer is managed so as to protect it from any long term outflows set out in Policy 6.4.10A(ii). All water allocated as groundwater needs to be managed for the protection of the aquifer and the maintenance of any long-term groundwater takes.

The Ettrick Basin Aquifer has an estimated recharge of 5.5 $Mm^3$/yr. The recommended allocation limit under Policy 6.4.10A of the Water Plan is 2.75 $Mm^3$/y, which is 50% of the mean annual recharge for the aquifer. This coincides with its current total allocation, which suggests that it has reached its default allocation limit.

## What should be done next?

The range of flows required to maintain aquatic values and the sustainable groundwater allocation limit should be used as part of future policy discussions for determining minimum flows and allocation limits in the Benger Burn and Ettrick Basin Aquifer.

# Technical summary

The purpose of this report is to investigate the flows required to maintain the habitat of the fish species in the Benger Burn and to recommend a sustainable allocation limit for the Ettrick Basin Aquifer.

The Benger Burn has a catchment area of 131 km$^2$ and is located about 10 km south of Roxburgh, on the true right of the Clutha River/Mata Au. The Ettrick Basin Aquifer is 14.3 km$^2$ and sits underneath the Ettrick Flats on both sides of the Clutha River/Mata Au, which includes the lower reaches of the Benger Burn and Ettrick township.

There are currently three consented consumptive surface-water takes in the Benger Burn catchment, with a combined rate of take of 212 l/s. However, much of this allocation is only used for frost fighting between September and December.

Continuous flow recorders were installed in the Benger Burn, in the lower gorge of the main stem (Booths Road) and at the State Highway 8 (SH8) bridge in the lower reach. Once the Benger Burn flows out of the hill country and onto the flats, there is a significant loss of surface flow into the Ettrick Basin Aquifer. This losing reach extends to the SH8 bridge, where groundwater from the aquifer resurfaces into the Benger Burn and creates a gaining reach down to the Clutha confluence. Despite a steady base flow entering the lower reaches of the Benger Burn, the river would probably naturally run dry in an average or dry year.

The seven-day Mean Annual Low Flow (MALF) and low-flow return periods have been calculated for the Benger Burn to give an indication of low flows in the catchment.

Instream habitat surveys were carried out, and flow requirements for resident species assessed by examining the relationships between flow and available habitat using Instream Flow Incremental Methodology (IFIM).

The Benger Burn supports a spawning run of brown trout and Chinook salmon when there is sufficient flow during the spawning season. Longfin eel, shortfin eel, upland bully, common bully and Clutha flathead galaxias are also found in the catchment.

Using the results of habitat modeling, flows have been recommended for each fish species found in the Benger Burn.

A minimum flow of 400 l/s at the Booths flow recorder, for all takes from April to August, will provide for trout and salmon spawning. All takes in the catchment should be subject to this minimum flow, which provides for the 300 l/s recommended for salmon spawning, and allows for 100 l/s surface flow loss in the losing reach.

A minimum flow of 75 l/s at the Booths flow recorder from September to March, for all takes upstream, will provide sufficient flows for upstream populations of Clutha flathead galaxias. It will also allow for dewatering of the losing reach, which will remove trout, thereby enabling the furthest downstream population of Clutha flathead galaxias to persist.

A minimum flow for takes downstream of the Booths flow recorder will have little benefit to instream values in the catchment, as this section is naturally intermittent and tends to dry during most summers. It is recommended, therefore, that no minimum flow is implemented between September and March for all takes downstream of the Booths flow recorder.

The Ettrick Basin Aquifer has an estimated recharge of 5.5 Mm3/yr. The recommended allocation limit under Policy 6.4.10A of the Water Plan is 2.75 $Mm^3$/y, which is 50% of mean annual recharge for the aquifer. This figure coincides with the current total allocation from the aquifer, which suggests that the aquifer has reached and exceeded its default allocation limit.

Water meter usage indicates only 30% of the consented groundwater is being used. As groundwater usage metering increases, more water may be made available for allocation.

The range of flows needed to maintain aquatic values and the sustainable groundwater allocation limit should be used as part of future policy discussions for determining minimum flows and allocation limits in the Benger Burn and Ettrick Basin Aquifer.

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# 1. Introduction

The objectives of the Regional Plan: Water for Otago[1,2] 2004 (Water Plan) sets out as one of its objectives 'to retain flows in rivers sufficient to maintain their life-supporting capacity for aquatic ecosystems and their natural character' and 'to maintain long-term groundwater levels and water storage in Otago's aquifers". As a means of achieving these objectives, the Water Plan provides for the setting of minimum flows in Otago's rivers[2] and limiting groundwater takes as 50% of mean annual recharge for Otago's aquifers'.[3]

The purpose of this report is to provide relevant information on the Ettrick Basin Aquifer and Benger Burn to determine groundwater allocation limits and the flows desirable for sustaining the river's aquatic habitat.

To manage a stream for aquatic ecosystems, there needs to be a clear focus on management objectives. Schedule 1A of the Water Plan[4] identifies the ecosystem values that must be sustained, including spawning habitat for trout and salmon and significant habitat for koaro.

Further to those values listed in Schedule 1A, the Benger Burn also supports populations of the threatened longfin eel and Clutha flathead galaxias.

In this report, fish habitat modelling data have been discussed, with a focus on management objectives and the natural low-flow regime of the Benger Burn. Flows to maintain habitat for the fish species of the Benger Burn have also been suggested.

As part of the report, a water balance study of the Ettrick Basin Aquifer to ensure that the aquifer is managed to protect it from the long-term outflows outlined in Policy 6.4.10A(ii). All water allocated as groundwater needs to be managed for the protection of the Ettrick Basin Aquifer and the maintenance of any long-term groundwater takes. Schedule 4B of the Water Plan identifies water levels at which the taking of groundwater in the Ettrick Basin Aquifer will be restricted, and identifies the nature of the restriction in terms of a reduction in the take of water authorised by water permits.

Hydrological data have been summarised and analysed to determine low-flow return periods for the Benger Burn. Rainfall data are given to show the variation in rainfall throughout the catchment. A brief overview of the topography, vegetation, land use and environmental concerns within the catchment has been provided, along with a summary of the recreational and biodiversity value. A physical habitat study (Instream Flow Incremental Methodology or IFIM) was carried out to determine the effects of low flows on the availability of habitat for both the native and introduced sports fish found within the catchment.

A water balance model has been calculated for the Ettrick Basin Aquifer, and the aquifer's geology and hydrogeology have been discussed.

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[1] Objective 6.3.1 of the Regional Plan: Water for Otago (2004), p. 6-7
[2] Objective 6.3.2A of the Regional Plan: Water for Otago (2004), p.6-7
[2] Policy 6.4.4 of the Regional Plan: Water for Otago (2004), p.6-20
[3] Policy 6.4.10A(ii) of the Regional Plan: Water for Otago (2004), p.6-27
[4] Schedule 1A of the Regional Plan: Water for Otago (2004), p.20-27

## 1.1. The Benger Burn catchment

The Benger Burn has a catchment area of 131 km$^2$ and is located about 10 km south of Roxburgh, on the true right of the Clutha River/Mata Au.

The catchment borders the upper Pomahaka catchment to the west, Clutha River to the east and Spylaw Burn to the south. To the north, it abuts the eastern faces of Mt Benger (Figure 1-1).


**Figure 1-1 The Benger Burn catchment**

The two branches of the Benger Burn run roughly south-north, before converging about 2 km upstream of the Clutha/Mata Au confluence. The North Branch spans 77 km$^2$, while the South Branch has an area of 52 km$^2$.

### 1.1.1. Vegetation

Vegetation in the catchment consists of exotic pasture and orchards on the river flats, with low producing pasture and over-sown tussock in the hill country.

### 1.1.2. Land use

Fruit production, pastoral farming (sheep and beef) and some dairy production are the dominant land uses on the Ettrick Flats, which include the lower reaches of the Benger Burn. The hill country of both the North and South Branches support low intensity sheep and beef production.

### 1.1.3. Topography and soils

The Ettrick Basin has a favourable combination of geography, soils and climate, making the 20 square kilometre area suitable for horticulture (Hewitt, 1983). The best soils for horticulture in the area are deep sandy loams and fine sandy loams. Stony loamy sand soils, close to the Clutha River/Mata-Au terrace, restrict rooting depth and have limited water holding capacity.

## 1.2. The Ettrick Basin Aquifer

The Ettrick Basin Aquifer sits underneath the Ettrick Flats on both sides of the Clutha River/Mata Au, which includes the lower reaches of the Benger Burn and Ettrick township (Figure 1-1).

### 1.2.1. Site Geology and Hydrogeology

The 14.3 $km^2$ basin comprises an unconfined Quaternary alluvium aquifer underlain by a thick mudstone sequence of the Tertiary Manuherikia Group coal measures, which, in turn, lies on the impermeable basement schist rock. A possible confined or semi-confined sandy aquifer is located at the base of the Manherikia Group, some 150-200 m below ground level. However, little is known about this aquifer beyond what is found in coal investigation drilling logs (Bekesi, 2006).

### 1.2.2. Geological Setting

The southern Central Otago district is underlain by schist and semi-schist of the Torlesse and Caples supergroups. These schists are formerly deep-water marine sediments that have been metamorphosed to low- and medium-grade meta-sedimentary rocks. The rocks contain the fundamental minerals of quartz and feldspar, and are termed ‘quartzo-feldspathic’ as a result. The process of metamorphosis has segregated these minerals into distinct bands of crystalline quartz, feldspar and mica in a groundmass of non-crystalline (lithic) lithologies. Metamorphosis has also over-printed the original sedimentary-bedding pattern with a metamorphic foliation pattern. These patterns give a distinct grain to the schist rocks and provide pore spaces for groundwater in the schist.

The Ettrick basin is a sediment-filled topographic depression that formed as a result of movement on a normal fault at its western boundary. This geological structure, called a ‘half-graben’, is created when one side of the fault is thrust up and the other is thrust down. This movement creates a depression, deepest at the escarpment margin. The depression performs a dual role. It not only preserves softer sediments from extensive erosion, but it also leaves a topographic hollow for the accumulation of new sediments. In the case of the Ettrick basin, the schist hills on the west moved upward, while the schist basement rock below the basin moved down. This early Pleistocene displacement allowed the preservation of the Miocene coal measures. Subsequent Pleistocene glacial outwash sedimentation over time created the Ettrick outwash terraces we see today.

# 2. Water allocation

## 2.1. Surface water allocation

At present, there are three consented consumptive surface water takes in the Benger Burn catchment (Figure 2-1), with a combined rate of take of 212 l/s. One 5 l/s take is located in a small tributary in the upper reaches of the Benger Burn, and 40 l/s is taken from a small groundwater fed tributary that joins the Benger Burn less than 50 m from the Clutha confluence. The peak take of 212 l/s is used for frost fighting between September and November, and the actual take for the latter part of the irrigation season is approximately 85 l/s, 41 l/s of which is taken from the main stem of the Benger Burn.

There are also two further groundwater takes, with a combined rate of take of 57 l/s, which are managed as surface water due to their proximity to, and interaction with, the Benger Burn.


**Figure 2-1 Consented surface water and groundwater takes in the Benger Burn catchment**

The current primary allocation limit for the catchment is 0 l/s (50% of MALF), based on the default allocation limit set under Policy 6.4.2 of the Water Plan. As the existing primary allocation is 207 l/s, there is no further primary allocation available in the catchment.

## 2.2. Groundwater allocation

A review of the ORC's groundwater database indicates that there are 130 wells in the Ettrick area. Of these, 16 have current groundwater take consents, 25 have expired or have been decommissioned, and 18 are within 100 m of either the Clutha River/Mata-Au or the Benger Burn. All 16 current consented takes are for irrigation, horticultural, stock and domestic supply and have a paper-total take of 2.85 $Mm^3$/yr. While metering of water use in the Ettrick basin is not widespread, the water-meter data from four wells indicates that a maximum of 30% of the allocated water take is being used. This data is comparable to that found in allocation studies in other areas.

### 2.2.1. Restriction levels for groundwater takes

Schedule 4B of the Water Plan identifies water levels at which the taking of groundwater will be restricted and identifies the nature of the restriction, in terms of reduction in the take of water authorized by water permits.

The Calder bore (G43/0032) is the referenced bore for the Ettrick Basin Aquifer. Restriction for water use at trigger levels is listed in Table 2.1.

**Table 2.1 Restriction levels for groundwater takes in the Ettrick Basin Aquifer.**

| Aquifer | Aquifer reference Bore | Aquifer maximum height (mRL) | Restriction Levels (mRL) | | |
|---|---|---|---|---|---|
| | | | 20% restriction | 50% restriction | 100% restriction |
| Ettrick | Calder bore | 172.29 | 170.29 | 169.79 | 169.29 |

# 3. Rainfall patterns, hydrology and hydrogeology of the Benger Burn and Ettrick Basin Aquifer

## 3.1. Rainfall patterns

The Benger Burn sits in the rain shadow of the Umbrella Mountains and the upper Pomahaka catchment. The catchment tends to experience less rainfall than those bordering it to the south and west. However, with 650-750 mm/year in the hill country and 600-650 mm/year on the flats (Figure 3-1), the median rainfall tends to be higher than other catchments in Central Otago.

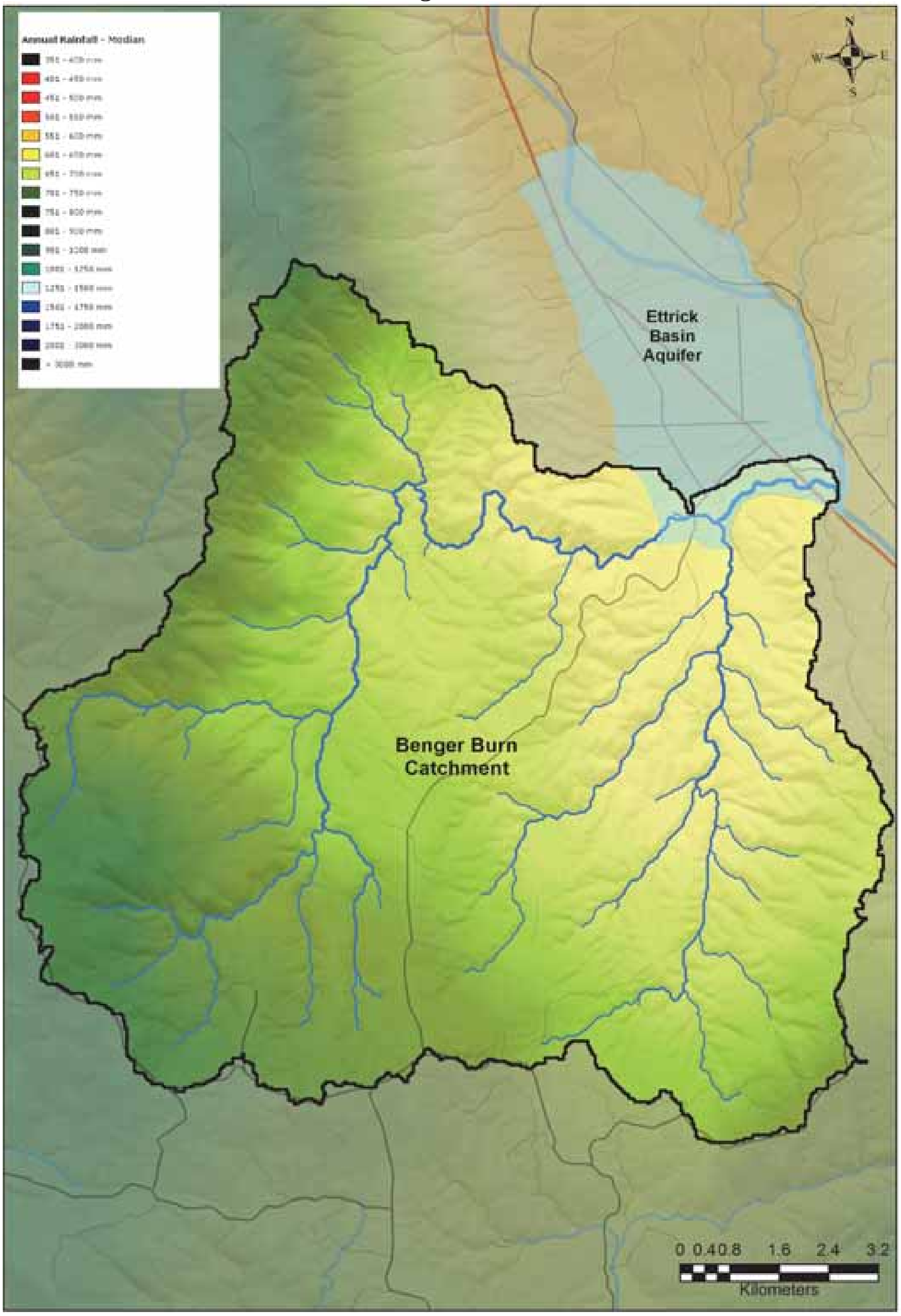

**Figure 3-1 Median annual rainfall in the Benger Burn catchment (from growOtago)**

Due to its aspect and higher altitude, the upper reaches of the North Branch receive higher annual rainfall than the south branch.

## 3.2. River hydrology

This section provides a description of river flows at the two flow recorders in the Benger Burn, and includes general flow statistics and seasonal flow patterns.

Previous work undertaken by ORC has shown that the Benger Burn loses a significant amount of surface water into the underlying Ettrick Basin Aquifer where the river hits the alluvial gravels on the flats. To gain a better understanding of natural inflows and losses in the lower reaches, two flow recorders were installed in the Benger Burn (Figure 3-2). Benger Burn at Booths is positioned up stream within the schist foothills, west of the Basin. The other, Benger Burn at SH8, is positioned downstream, near where the Benger Burn meets the Clutha.


**Figure 3-2 Location of the Booths and SH8 flow recorders**

Both of these recorders have been operating since December 2011, and have captured flow data over two irrigation seasons. Figure 3-3 shows the recorded flows from October 2012 to May 2013.

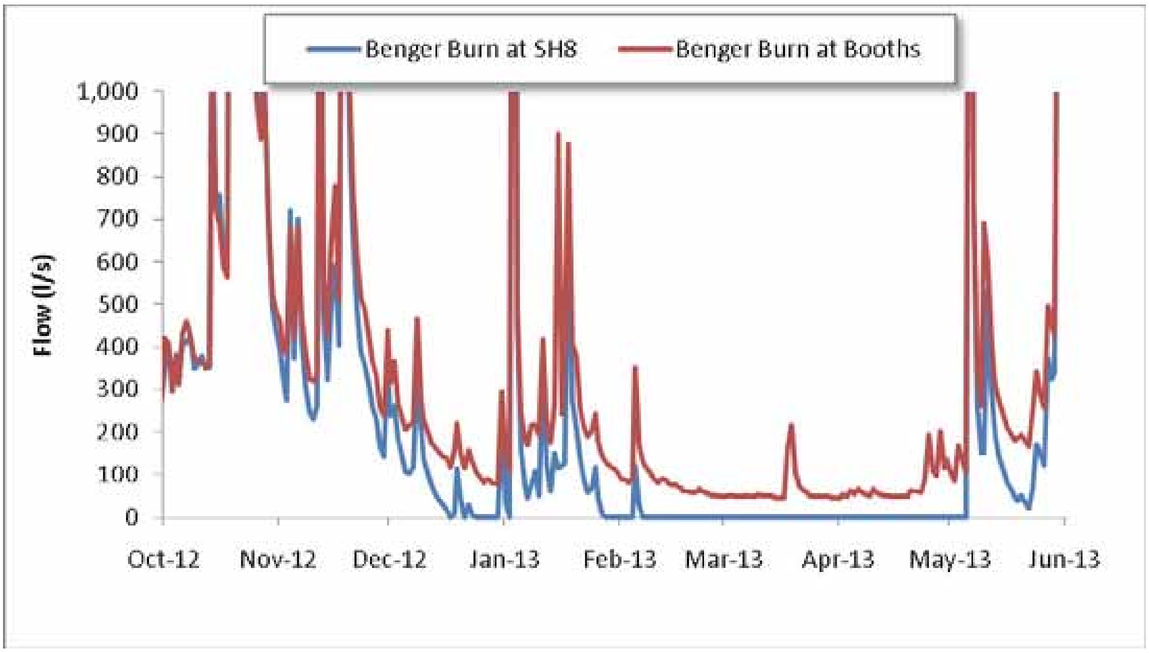


**Figure 3-3 Recorded flows in the Benger Burn for 2012/13**

Figure 3-3 shows that, despite a base flow of 60 l/s at the Booths flow recorder, there was no surface flow at SH8 during the latter part of the irrigation season. Water abstraction probably accounts for some of the flow losses between the two recorders; however, as the one take in this reach is currently not metered, it is difficult to quantify its effect.

The estimated irrigation take for this consent is 41 l/s; however, as it is subject to a residual flow of 50% of the measured inflow, it is unlikely that more than 30 l/s would be abstracted during March or April 2013. It is also unlikely that flow losses of over 100 l/s, observed in late April/early May 2013, are due to irrigation, which tends not to occur during this period.

Figure 3-4 shows the changes in flow between Booths and SH8. Negative values indicate flow loss, and positive values indicate an increase in flow between the two sites.

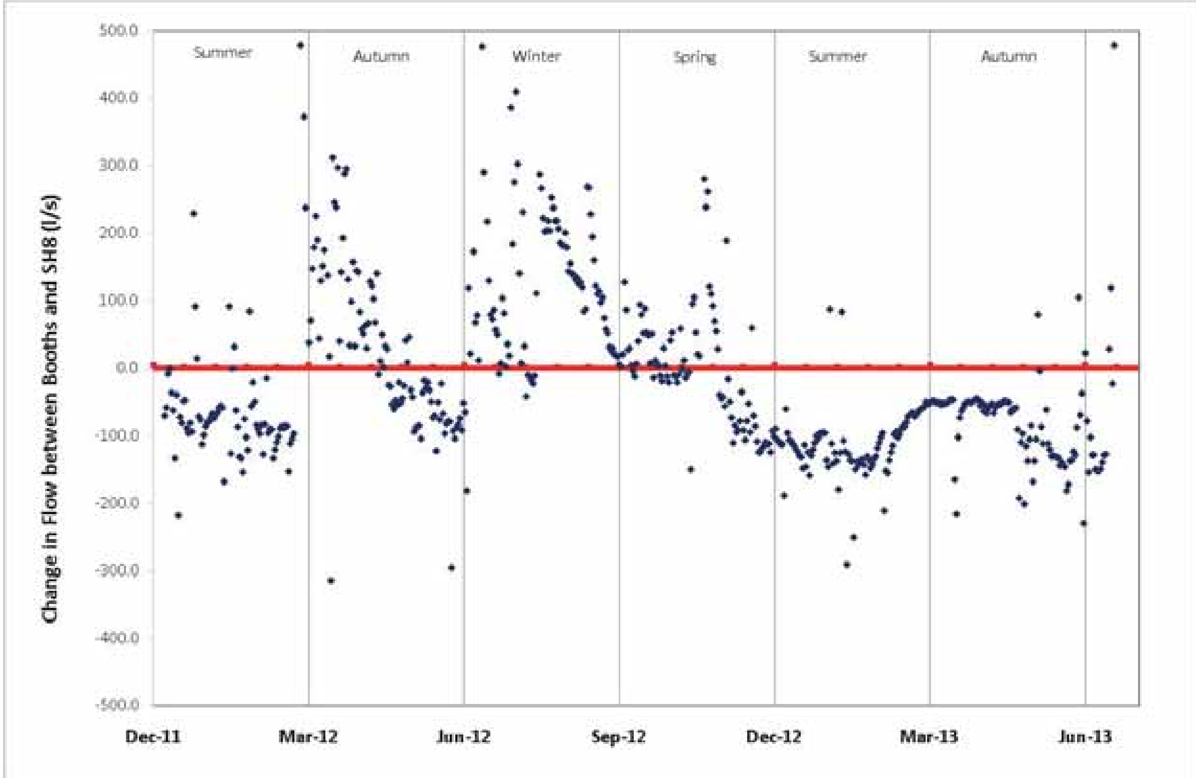


**Figure 3-4 Change in flow between the Booths (upstream) and SH8 (downstream)**

Figure 3-4 shows that there is consistent flow loss between Booths and SH8 under low flow conditions, even during late autumn when no irrigation is occurring. The gain in flows observed during winter and spring is probably due to increased flow from the southern branch of Benger Burn, which makes a confluence with the main stem between the two gauging stations. Due to a combination of low rainfall and losses to groundwater in its lower reaches, the South Branch does not significantly contribute to surface flows in the Benger Burn during the irrigation season.

The difference of flow monitored at these two locations not only shows changes in flows between the two sites, but it also provides insight into how the Benger Burn contributes to the groundwater system.

Some of the loss of stream flow into the Ettrick Basin Aquifer is probably associated with the lower reaches of the South Branch of the Benger Burn. However, no gauging station exists to confirm this. Most observed flow losses are probably recharging the aquifer, making the Benger Burn a major source of Ettrick groundwater. It is also likely that the extraction groundwater from the 16 irrigation bores will induce the loss of surface water into the aquifer during the irrigation season.

### 3.2.1. Synthetic flow record for the Benger Burn

To gain a better understanding of the long-term flow characteristics of the Benger Burn, a synthetic flow has been calculated using a regression analysis between the Benger Burn and the nearby Glenken flow recorder on the Pomahaka River (Figure 3-5).

The $R^2$ value, in Figure 3-5, is a measure of the ‘goodness of fit' of the data points to the trend line: the higher the $R^2$ value (on a scale between 0-1), the stronger the relationship between the measured flow and the synthetic flow for which the regressions are used.

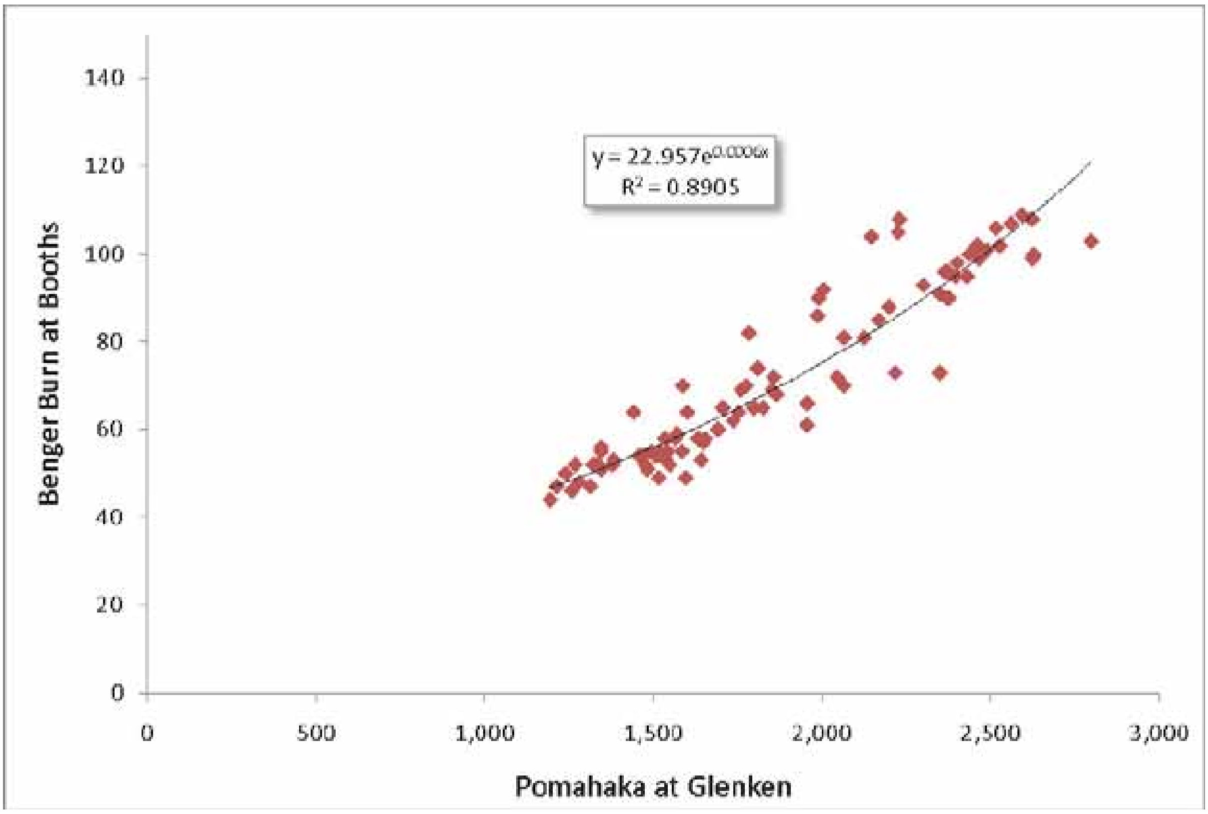


**Figure 3-5 Low flow regression analysis between the Pomahaka at Glenken and the Benger Burn at Booths (2012-13)**

The Pomahaka receives significantly more rainfall (and therefore high flow events) than the Benger Burn, which reduces the $R^2$ value when flows are above 3,000 l/s at the Glenken flow recorder. The MALF of the Pomahaka at Glenken is 1,800 l/s, therefore it is likely that the range of the regression analysis (0-3,000 l/s) is appropriate for calculating a long-term MALF for the Benger Burn.

In Figure 3-5, a low-flow regression analysis has been used to develop a relationship between the two sites at 'base flows', which are the long periods between high flow events that tend to occur during summer. During this period, demand for water resources is also at its highest.

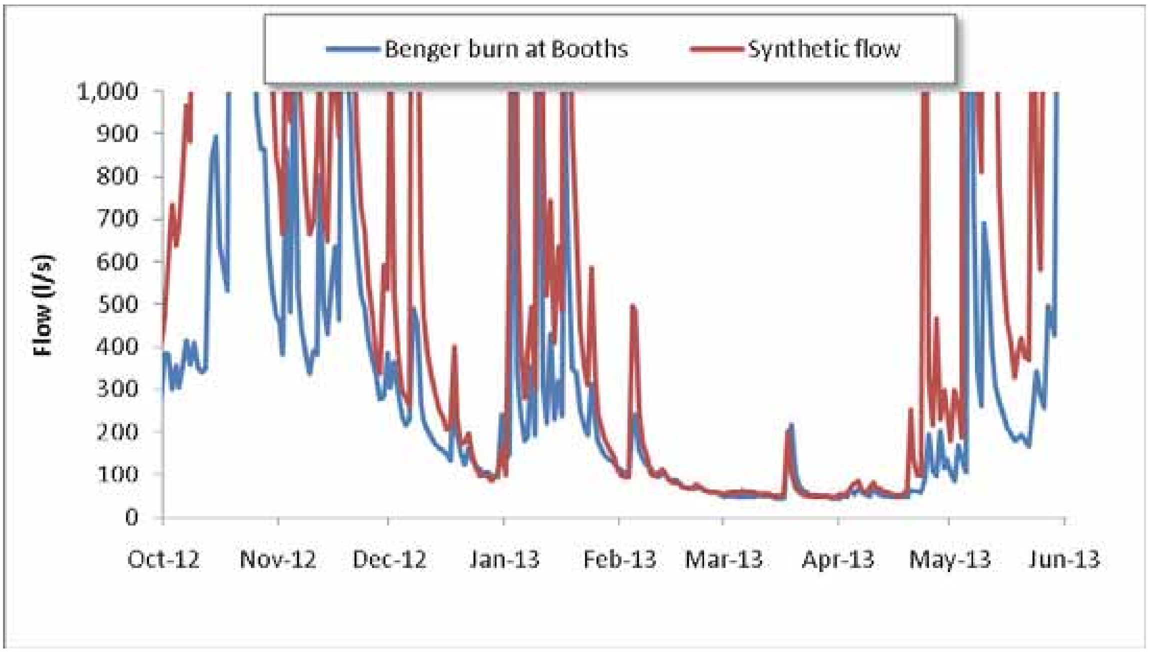


**Figure 3-6 A comparison of the synthetic and recorded flows for the Benger Burn at Booths from December 2012 to June 2013**

Figure 3-6 shows that the synthetic flow significantly overestimates higher flows, and therefore should not be used to calculate high flow statistics, such as mean and median.

### 3.2.2. Flow statistics of the Benger Burn

Using the synthetic flow, long-term low flow statistics have been calculated for the Benger Burn at Booths. Because the low flow regression is not suitable for calculating high flow statistics, rainfall runoff coefficients from GrowOtago have been used to calculate mean and median flow.

Flow statistics have been calculated for the Benger Burn (Table 3-1). Note that all long term (mean and MALF) flow statistics are calculated *above* the losing reach.

**Table 3-1 Flow statistics for the Benger Burn at SH8**

| Site | Mean (l/s) | Median (l/s) | 7-day MALF (l/s) | Catchment area (km²) | Catchment yield at MALF (l/s/km²) |
|---|---|---|---|---|---|
| Booths | 1,170 | 740 | 80 | 74 | 1.1 |
| SH8 | NA | NA | 0 | 130 | 0 |

Table 3-1 shows that the naturalised MALF for the Benger Burn at Booths is 80 l/s, while the MALF at SH8 is 0 l/s, due to the combination of abstraction and losses to groundwater. These losses of surface flow upstream of SH8 make it difficult to develop a correlation with any long term sites, so long term statistics, such as median and mean, cannot be calculated.

## 3.3. The hydrogeology of the Ettrick Basin Aquifer

Available shallow bore log data indicate that the unconfined aquifer is between 4 and 30 m thick and comprises boulders, cobbles, sandy gravels, silty gravels and clay-bound gravels, inter-fingered with lenses of silt and clay. The aquifer is 30 m thick along the western boundary (adjacent to the schist outcrop) and thins to some 4 m in the east as it approaches the Clutha River/Mata-Au. However, the saturated thickness of the aquifer is only between 4 and 11 m.

**Table 3.2 Estimated hydrogeological parameters of the Ettrick Basin Aquifer, based on short drawdown tests**

| | Area (ha) | Hydraulic Conductivity (m/day) | Transmissivity ($m^3$/d) | Thickness (m) | Saturated Thickness (m) |
|---|---|---|---|---|---|
| Max. | 1430 | 500 | 2700 | 30 | 11.3 |
| Min. | 1430 | 70 | 550 | 4 | 4 |
| Average | 1430 | 160 | 1100 | 20 | 7 |

The Clutha River/Mata-Au and Benger Burn dominate the water balance in the Ettrick basin. The mean annual flow of the Clutha is some 17,000 $Mm^3$/yr and is the main discharge zone for the basin. The Clutha is not thought to play a big part in groundwater recharge, apart from episodic flood events that are not predictable or regular enough to allow inclusion in an annual water balance.

## 3.4. Recharge to the Ettrick Basin Aquifer

Sources of recharge for the Ettrick basin aquifer include:

- Rainfall;
- Range-front recharge;
- Benger Burn; and
- Clutha River/Mata-Au River.

Irrigation has not been included in the water balance study due to the limited amount of water meter data available. As water meter data is made available, an assessment of irrigation recharge can be included in the water balance.

### 3.4.1. Rainfall recharge

A numerical model was created in 2012 to assess the nitrogen sensitivity of the Ettrick basin. As input to this model, rainfall was applied over the 14.3 $km^2$ area of the model, using the equivalent soil-moisture modelling of recharge over the Roxburgh basin (Wilson and Lu, 2011). This figure equated to a long-term mean of 88 mm/yr (or 1.3 $Mm^3$/yr as applied across the 14.3 $km^2$ basin).

### 3.4.2. Range front recharge

Range front recharge occurs at the contact between the ranges (essentially foothills to Mt Benger) and the flatter basin area, when creeks, streams and runoff infiltrate into the soils. The runoff rate for the Benger Burn was calculated using the synthetic flow described in 3.2.1 was then applied to the area of the range front to derive a range front recharge of 1.4 $Mm^3$/yr.

### 3.4.3. Benger Burn

Flow data indicates that the mean annual flow for the Benger Burn is some 16 $Mm^3$/yr. A detailed discussion of the comparison of flow between the two flow gauging stations is set out in Section 3.2 of this report. In summary, flow data suggests the average flow loss from the Benger Burn is 0.09 $m^3$/s. Therefore, rate of groundwater recharge from the Benger Burn is 2.8 $Mm^3$/yr

### 3.4.4. Clutha River/Mata-Au

The Clutha River/Mata-Au has a mean annual flow of some 17,000 $Mm^3$/yr and is considered to be a main discharge area (or sink) for groundwater, as groundwater levels are generally higher than the river most of the year. However, it is possible that, during periods of high flow, the river level rises above the groundwater level, resulting in the Clutha River/Mata-Au recharging the aquifer (Bekesi, 2006). Histogram data comparing the water levels at the Ettrick cemetery bore (1 km west of the Clutha) and the Clutha River/Mata-Au at Roxburgh Dam show a direct link with the groundwater level and flow of the Clutha River/Mata-Au (Figure 3-7).

The effect could also be due to heavy rainfall associated with the floods simulating recharge through the range-front and soil. Following the October – February irrigation season, the groundwater level falls back to pre-irrigation levels. During the winter months, the groundwater levels continue to decline (discharging to the Clutha River/Mata-Au) and flatten out when the flow of the Clutha increases during the snow melt spring.

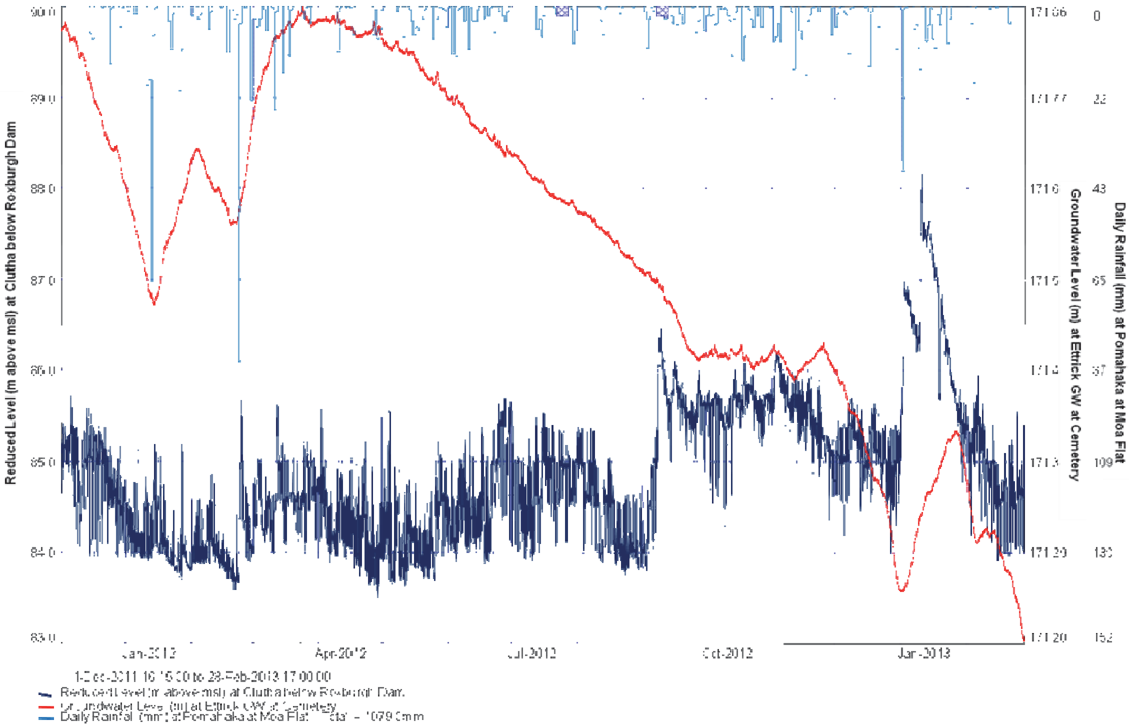

Figure 3-7 Hydrograph, comparing groundwater level, flow of the Clutha River and rainfall

The ORC's Otago Natural Hazards Database stores information about flood-hazard areas within the Ettrick basin. The flood-hazard area has been designated based on photographs and debris present during site visits after flood events. The flood map of Ettrick township shows that the Clutha River/Mata-Au rises above the terraces, south of the Manuherikia outcrop (Figure 3-8), supporting the idea that, during episodic events, the river is a local source of recharge to the aquifer. The volume of recharge to the aquifer has not been calculated, because when the river levels lower, the groundwater will probably discharge back into the river, reverting to normal conditions.

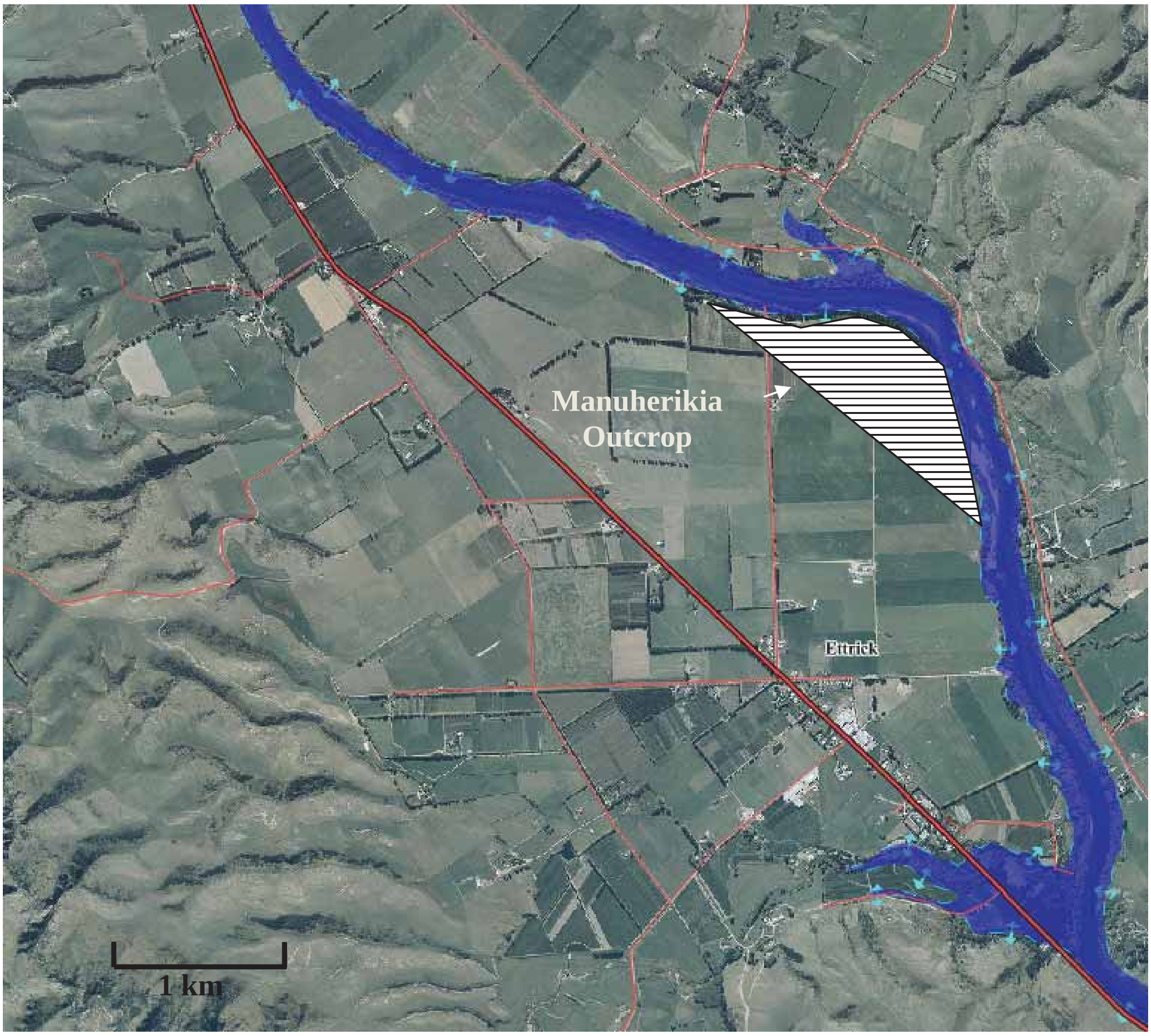


**Figure 3-8 Flood map of Ettrick township (sourced from ORC's Otago Natural Hazards Database)**

## 3.5. Outflows from the Aquifer

### 3.5.1. Groundwater takes

All 17 current consented takes were for irrigation, horticultural, stock and domestic supply. One groundwater take (2006.462) is within 100 m of the Benger Burn and is therefore not included in the groundwater allocation assessment. Using the methodology for calculating assessed maximum annual take for groundwater, set out in Section 15.8.3 of the Water Plan the 16 current groundwater take consents total 2.85 $Mm^3$/yr of groundwater abstracted from the Ettrick basin. While metering the water use in the basin is not wide spread, the meter data (from four wells) indicates that a maximum of 30% of the allocated water take is being used, which is comparable to that found by allocation studies of other areas. Therefore, as to water balance, the aquifer outflow from groundwater extraction is about 1.0 $Mm^3$/yr.

### 3.5.2. Clutha River/Mata-Au

As mentioned in Section 3.4.1, the Clutha River/Mata-Au is thought to be a sink for groundwater discharge. This correlates well to the easterly groundwater flow direction predicted in the 2012 numerical flow model and the patterns observed in Figure 3-7. The Clutha River/Mata-Au stretches for about 7.5 km north of the Benger Burn, through the Ettrick basin. The Manuherikia outcrops for approximately 2.5 m (Figure 3-8). Therefore, 5 km of the area is expected to be an outflow point for groundwater. Assuming a permeability of 100 m/day and a hydraulic gradient of 0.03 (2012 Groundwater Model, ORC), discharge to the Clutha River/Mata-Au is estimated to be 5.5 $Mm^3$/yr. (Note that this outflow amount is assuming no extraction from groundwater takes. Any groundwater take would decrease the amount discharged to the Clutha River/Mata-Au.)

Due to the deep water table in the aquifer, discharge of groundwater through evaporation is negligible.

## 3.6. Water Balance Summary

The Clutha River/Mata-Au and Benger Burn dominate the water balance in the Ettrick basin. The mean annual flow of the Clutha is some 17,000 $Mm^3$/yr and is the main discharge zone for the basin. Because the Clutha River/Mata-Au is not considered to play a big part in groundwater recharge, apart from episodic flood events that are unpredictable and irregular, it has not been included in an annual water balance.

Gauging stations on the Benger Burn indicate that the mean annual flow before reaching the Ettrick basin is some 16 $Mm^3$/yr. The flow loss, calculated from the gauging station data, indicates that the Benger Burn contributes 2.8 $Mm^3$/yr of recharge to the aquifer.

Rainfall recharge is estimated to be 88 mm/yr over the 14.3 $km^2$ basin, which equates to 1.3 $Mm^3$/yr of rainfall recharge to the Ettrick Basin Aquifer. Based on averaged variables and numerical flow modelling results, the range front recharge is estimated to be 1.4 $Mm^3$/yr.

Shallow groundwater is stored in the gravel unconfined Ettrick Basin Aquifer. Approximately 100 wells are used for irrigation, stock, horticultural and domestic supply. Most of these wells operate under the permitted activity rules and are not consented, however 16 bores have current consents to take 2.85 $Mm^3$/yr of groundwater, although water meter data suggests only 0.85 $Mm^3$/yr is actually being used.

**Table 3-2 Water balance with mean annual figures**

| | Inflow (+) $Mm^3$/yr | Outflow (-) $Mm^3$/yr |
|---|---|---|
| Rainfall recharge | 1.3 | |
| Mountain range recharge | 1.4 | |
| Benger Burn | 2.8 | |
| Groundwater allocation | | 0.85 |
| Clutha River/Mata-Au | | 4.65 |
| **Total** | **5.5** | **5.5** |

## 3.7. Fish species of the Benger Burn

The Benger Burn supports five native fish species: the common bully, upland bully, longfin eel, shortfin eel and Clutha flathead galaxias. The longfin eel and upland bully are found throughout the catchment, while the common bully and shortfin eel are confined to the lower reaches. As lamprey have been recorded in nearby rivers such as the Tima Burn and Minzion Burn, and in the main stem of the Clutha River/Mata Au at the Roxburgh Dam, it is likely to be present in the Benger Burn as well.


**Figure 3-9 Distribution of native fish in the Benger Burn catchment**

Figure 3-9 shows that common bully are present in the lower reaches around the SH8 bridge, while upland bully are abundant between the Clutha confluence and the confluence of the South branch and main stem of the Benger Burn. Clutha flathead galaxias are very susceptible to predation by trout, and their distribution is limited to areas where trout are sparse or absent, such as regularly dewatered/unstable reaches or areas above large waterfalls.

The Benger Burn also supports two species of introduced sports fish: brown trout and Chinook salmon (Figure 3-10).

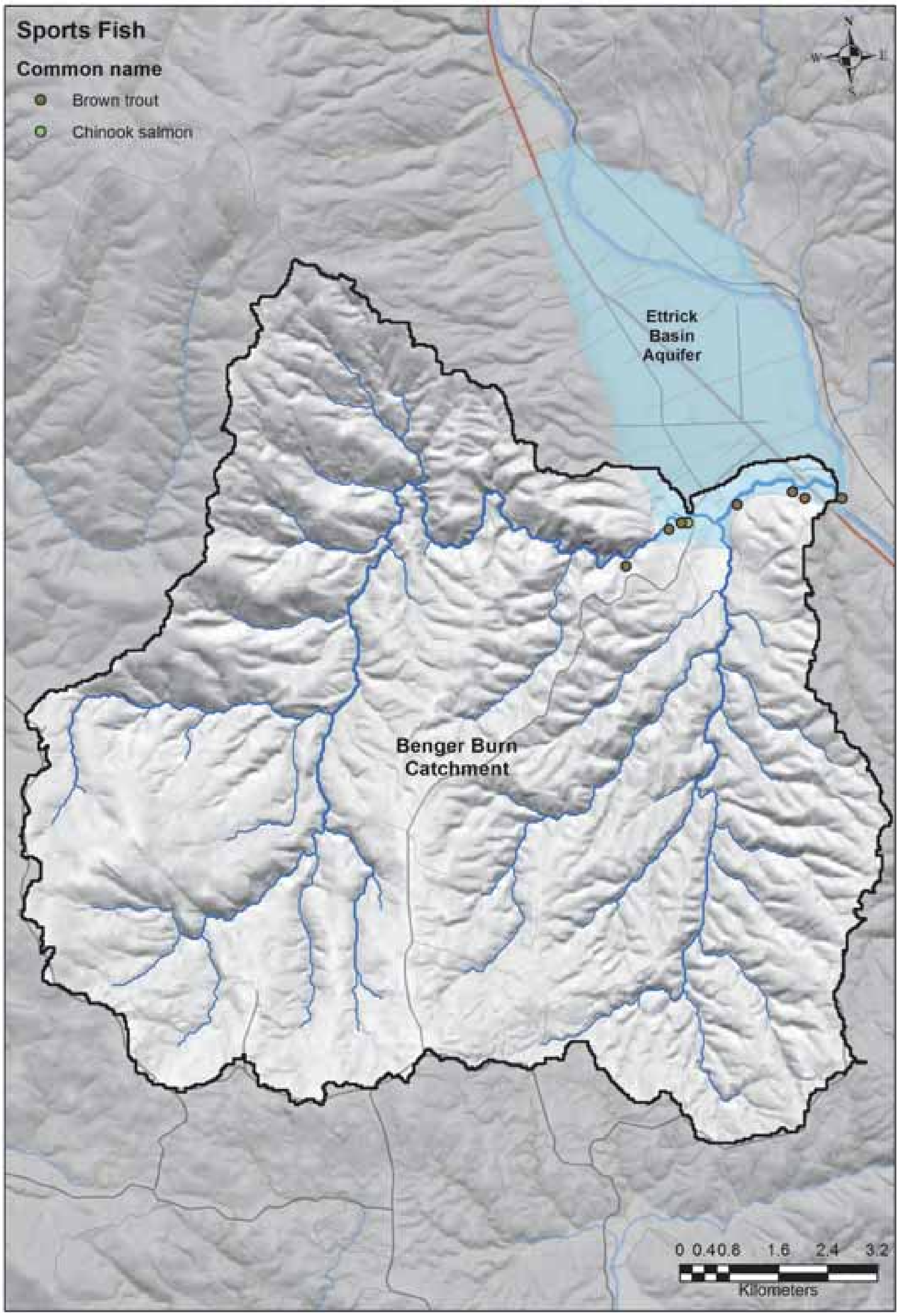


**Figure 3-10 Distribution of introduced sports fish in the Benger Burn catchment**

As the uppermost salmon spawning tributary before the Roxburgh Dam, the Benger Burn is considered to be an important component of the Clutha salmon fishery. However, its contribution to the fishery can be limited by the natural dewatering of the middle reaches (Figure 3-3) during the early part of the spawning season (April/May).

# 4. Natural values of the Benger Burn

The Benger Burn is identified within Schedule 1A of the Water Plan, which lists any natural and ecosystem values that may be associated with certain rivers in Otago. In the Benger Burn, these values include rare fish (koaro) and significant spawning habitat for trout and salmon.

## 4.1. Recreational values

The 2007/08 National Angling Survey (Unwin, 2009) recorded no angler visits to the Benger Burn for the 2007/08 fishing season (October-April). Anecdotal evidence suggests that, although some locals do occasionally fish the middle reaches early in the season, the Benger Burn is not considered to be a significant recreational fishery.

While the Benger Burn does not support its own recreational fishery, its value as a sports fishery lies in its contribution to brown trout and Chinook spawning and juvenile rearing in the lower Clutha River/Mata Au.

## 4.2. Biodiversity values

The Benger Burn supports two native fish species of conservation importance: the longfin eel and the Clutha flathead galaxias. Longfin eel, listed as ‘declining’ (Allibone, 2010), are present in the lower reaches. Although the Benger Burn does not provide much habitat for large adult eels, it does provide suitable habitat for juveniles.

The Clutha flathead galaxias is currently listed as ‘declining’ (Allibone, 2010). However, recent studies of this species indicate that it may soon be reclassified as ‘nationally critical’. This would make the Clutha flathead galaxias as one of the most threatened species in New Zealand, giving it the same threat status as the kakapo, lowland longjaw galaxias or the Maui’s dolphin.

# 5. Physical habitat survey

The ORC contracted the National Institute for Water and Atmospheric Research (NIWA) to carry out a study to determine the flows required to maintain an acceptable habitat for fish species in the Benger Burn.

The primary aims of the study are to:

- conduct instream habitat surveys in critical reaches of the Benger Burn
- conduct a hydraulic analysis in these streams using RHYHABSIM (Jowett, 1989) to determine how weighted usable area (WUA) for brown trout and native fish habitat varies with discharge
- assess flow requirements for the Benger Burn, based on the habitat requirements of the native and introduced fish species.

## 5.1. Instream Flow Incremental Methodology (IFIM): Summary

IFIM is a method to assess flow regimes by considering the effects of flow changes on instream values, such as river morphology, physical habitat, water temperature, water quality and sediment processes. As the habitat methods used are based on quantitative biological principles, they are considered to be more reliable and defensible than assessments made in other ways. IFIM's strength lies in its ability to quantify the loss of habitat caused by changes in the natural flow regime, which helps to evaluate alternative flow proposals (Jowett, 2004).

Assessing 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 could 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.

## 5.2. Habitat preferences and suitability curves

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 a given species, then they cannot exist. However, if there is physical habitat available for that species, then it may or may not be present in a survey reach, depending on 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).

Instream habitat is expressed as the total area of suitable habitat, Weighted Usable Area (WUA ($m^2$/m)). WUA ($m^2$/m) is the measure of the total area of suitable habitat per metre of stream.

## 5.3. IFIM for the Benger Burn

An IFIM survey was undertaken in 2005 near the Booths flow recorder in the lower gorge.

Figure 5-1 shows how habitat of native fish varies in relation to flow in the Benger Burn catchment.

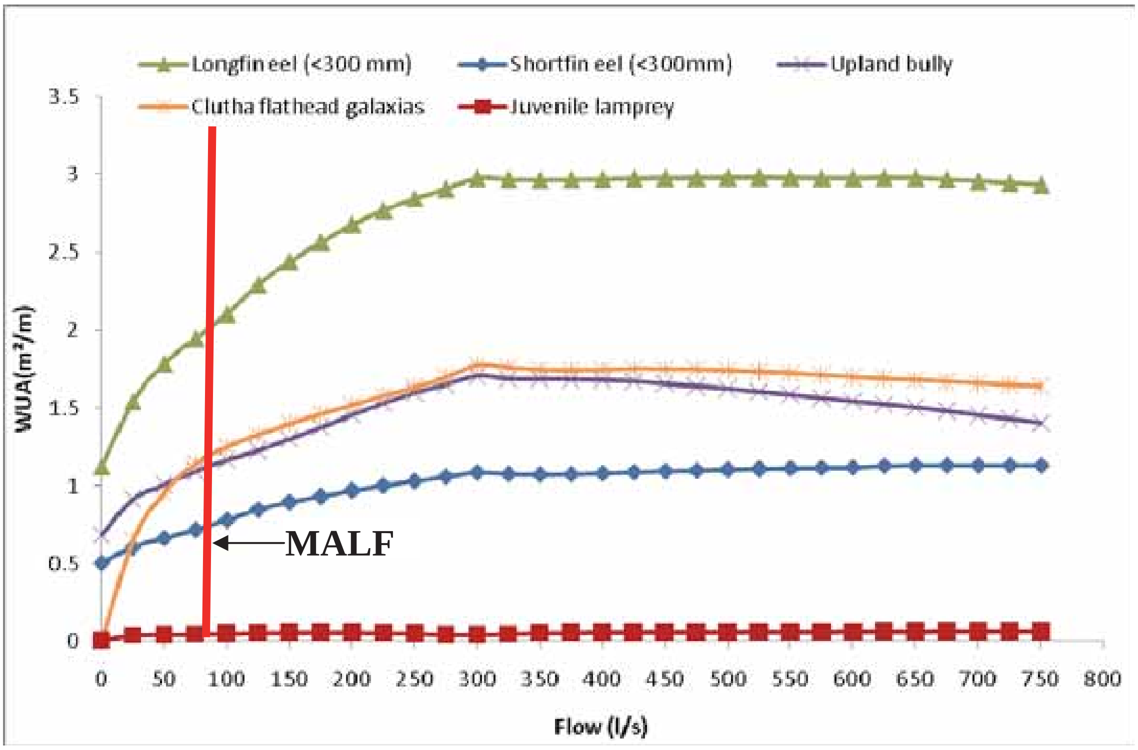


**Figure 5-1 Variation in instream habitat of native fish, relative to flow, in the lower gorge of the Benger Burn**

Figure 5-1 shows that MALF is approximately 30% of the optimum flow for longfin eel, upland bully and Clutha flathead galaxias, indicating that habitat is limited for these species under natural low flow conditions. Available habitat for juvenile lamprey is extremely low at all flows in the Benger Burn, probably due to a lack of suitable substrate (silt).

Figure 5-2 shows the variation in habitat with flow, for trout spawning, adult and juvenile brown trout, in the Benger Burn catchment.

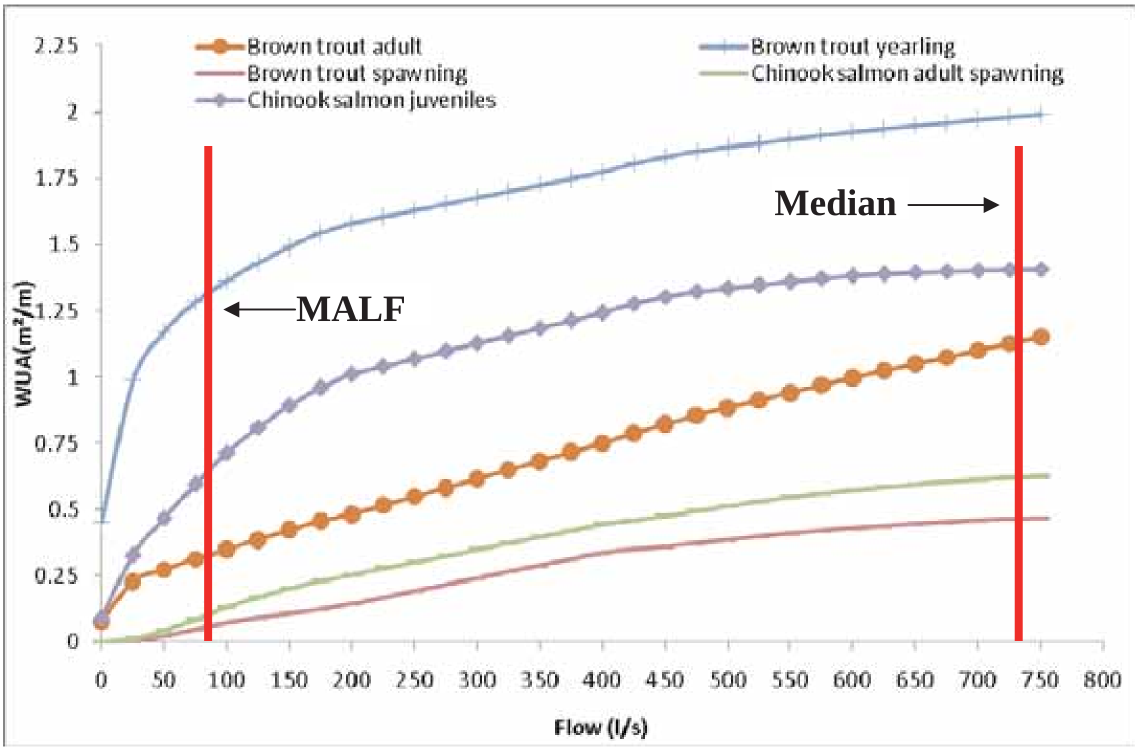


**Figure 5-2 Variation in instream habitat of brown trout, rainbow trout and Chinook salmon, relative to flow, in the lower gorge of the Benger Burn**

Habitat for adult brown trout, brown trout spawning and Chinook salmon increases in a linear fashion, with no clear point of inflection or optimum flow. The point of inflection for juvenile brown trout and Chinook salmon is 180 l/s, which is more than double MALF in the lower gorge. This indicates that habitat for salmoniids is limited by natural low flows in the Benger Burn.

It is important to note that flows in the lower Benger Burn will be much less than those in the lower gorge, further limiting available habitat for most fish species within this reach.

Tables 5-1 and Table 5-2 give the optimum flows and points of inflection of available habitat for native fish, trout and salmon in the Benger Burn. If the point of inflection or optimum flow is above MALF (80 l/s), it is assumed that the available habitat is limited naturally by low flows. Where no clear point of inflection or optimum flow is apparent below MALF, the flow that provides a percentage of the habitat available at MALF is used in accordance with Jowett and Hayes (2004, Appendix 1). The percentage of habitat retention depends upon the relative ecological/recreational values of the species. Because trout and salmon spawning tends to occur between May and September, the recommended flows for these values are not related to MALF, which generally occurs between January and April. The appropriate hydrological statistic for trout and salmon spawning is percentage of available habitat at *median* flow (Figure 5-2).

**Table 5-1 Recommended flow requirements for brown trout and salmon habitat in the Benger Burn, based on IFIM analysis**

| | Optimum flow (l/s) | Point of inflection (l/s) | % habitat retention | Flow at which recommended % of available habitat occurs (l/s) |
|---|---|---|---|---|
| **Brown trout adult** | NA | NA | 70 | <25 |
| **Brown trout yearling** | NA | 50 | 60 | 10 |
| **Brown trout spawning** | NA | NA | 60 | 337* |
| **Chinook salmon adult spawning** | NA | NA | 80 | 300* |
| **Chinook salmon juveniles** | NA | 125 | 80 | 38 |

* % habitat at median flow

Table 5-1 shows that the recommended flow for adult trout is <25 l/s, based on 70% of the habitat available at MALF. This flow is unlikely to provide sufficient habitat for any but the smallest adult fish, which is a reflection of the role of natural low flows in regulating trout populations in the Benger Burn. Similarly, trout and salmon spawning will probably be restricted in April/May during an average or dry year because surface flows in the middle reaches of the Benger Burn will not resume until after a significant rainfall event.

**Table 5-2 Recommended flows requirements for native fish habitat in the Benger Burn, based on IFIM analysis**

| | Optimum flow (l/s) | Point of inflection (l/s) | % habitat retention | Flow at which recommended % of available habitat at MALF occurs (l/s) |
|---|---|---|---|---|
| **Longfin eel** | 300 | NA | 60 | 5 |
| **Shortfin eel** | 300 | NA | 60 | 5 |
| **Upland Bully** | 300 | NA | 60 | 5 |
| **Clutha flathead galaxias** | 300 | 75 | 70 | 38 |
| **Juvenile lamprey** | NA | NA | 60 | 13 |

Table 5-2 shows that the flow requirement for native fish is well within the natural low ranges of the upper catchment; however, it is likely that dewatering in the middle reaches of the Benger Burn would naturally restrict these species. Bullies, eels and lamprey all prefer low water velocities, which is the primary reason for the very low flows recommended by IFIM. The exclusion of trout from sections of the losing reach is the most important factor governing the presence of absence of Clutha flathead galaxias, not the availability of habitat.

# 6. Discussion of flow requirements and groundwater allocation limits

## 6.1. Groundwater allocation limits for the Ettrick Basin Aquifer

The Water Plan (6.4.10A) indicates that an aquifer maximum allocation values is the greater of (as of 10 April 2010):

- The currently consented annual takes; or
- 50% of the aquifer mean annual recharge; or
- The volume listed in schedule 4A.

Using the methodology for calculating assessed maximum annual take for groundwater set out in Section 15.8.3 of the Water Plan, the current consented annual take as of 10 April 2010 is 3.02 $Mm^3$/yr. Fifty percent of the mean annual recharge is 2.75 $Mm^3$/yr. Based on this study, the recommended aquifer maximum allocation value is 50% of the aquifer mean annual recharge. Therefore, the adopted MAR is 2.75 $Mm^3$/yr. As set out in Section 3.5.1, the total current (30/01/14) consented groundwater takes is 2.85 $Mm^3$/yr. Based on this data, it can be concluded that the Ettrick Basin Aquifer has reached and exceeded its maximum allocation. However, available water meter data from four consented groundwater takes indicates that only 30% of the consented amount of groundwater is being consumed. This is summarised in Table 6-1 below.

**Table 6-1 Aquifer allocation summary (all units are in $Mm^3$/yr)**

| 50% Aquifer MAR | 100% currently consented takes | Remaining allocation |
|---|---|---|
| 2.75 | 2.85 | - 0.1 |
| **50% Aquifer MAR** | **30% currently consented takes** | **Remaining allocation** |
| 2.75 | 0.85 | 1.9 |

### 6.1.1. Groundwater Conclusions

The unconfined Ettrick Basin Aquifer has an estimated recharge of 5.5 $Mm^3$/yr, which consists of 1.3 $Mm^3$/yr from rainfall recharge, 1.4 Mm3/yr from mountain range recharge and 2.8 $Mm^3$/yr from the Benger Burn. The Clutha River/Mata-Au is likely to provide some recharge during high flow events; however, the amount has not been calculated as it is believed that once the river levels lower, the groundwater will then discharge back into the river, reverting to normal conditions.

The Benger Burn is listed as a natural value in Schedule 1A of the Water Plan and is directly connected to and supplies groundwater recharge to the Ettrick Basin Aquifer. Care should be taken in future to ensure that any new wells installed do not deplete the base flow of the Benger Burn.

Monitoring of the Benger Burn flow rates should continue, and gauging sites be added. The data compiled for this report was collected over a one-year period. Continuous monitoring over several years, and with several gauging stations, will give a better indication of how much recharge the aquifer is gaining from the Benger Burn.

The Ettrick Basin Aquifer provides water for domestic, stock, frost fighting and irrigation supply. The volume of groundwater allocated in consents is 2.85 $Mm^3/y$, which exceeds the 50% of mean annual recharge and suggests that the aquifer has reached its default allocation limit under Water Plan Policy 6.4.10A and is closed for future allocation.

Water meter usage from four consented groundwater takes suggests that only 30% of the consented groundwater is being used.

## 6.2. Flow requirement for the instream values of the Benger Burn

Under the Water Plan[5], rivers will have minimum flows set to provide for the maintenance of aquatic ecosystems and natural character under low flow conditions. Furthermore, when minimum flow levels are reached, all consents subject to the minimum flow are to cease taking[6].

The distribution of native fish in the Benger Burn tends to be driven by the natural dewatering of the middle reaches, and presence or absence of trout, so will be largely unaffected by a minimum flow. It is likely that Clutha flathead galaxias are able to maintain a viable population in the upper parts of the losing reach due to the exclusion of trout due to low flows and high water temperatures.

Spawning and juvenile rearing for brown trout and salmon are the main sports fishery values in the Benger Burn catchment. Providing sufficient habitat for spawning between April and September, and flow continuity in December and January, is necessary to ensure recruitment into the lower Clutha fishery. However, it is important to note that much of the trout and salmon spawning and juvenile rearing habitat is naturally dewatered as early as December and as late as May.

### 6.2.1. Minimum flow: Conclusions

To maintain instream values in the Benger Burn, it is recommended that a minimum flow regime is implemented, which reflects the seasonality of the flow regime and life history traits of those values.

A minimum flow of 400 l/s at the Booths Road flow recorder for all takes from April to August will provide for trout and salmon spawning. All takes in the catchment should be subject to this minimum flow, which allows the 300 l/s recommended for salmon spawning and the 100 l/s surface flow loss in the losing reach. This minimum flow will only affect surface water availability in April, which may be mitigated by using alternative sources.

A minimum flow of 75 l/s at Booths from September to March, for all takes upstream of the flow recorder, will provide sufficient flow for upstream populations of Clutha flathead galaxias. This flow will also allow for dewatering of the losing reach, which

[5] Policy 6.4.3 of the Regional Plan: Water for Otago (2004), P. 61
[6] Policy 6.4.11 of the Regional Plan: Water for Otago (2004), P. 69

will remove trout, thereby enabling the most downstream population of Clutha flathead galaxias to persist. Of the current consented takes, this minimum flow will only affect the 5 l/s take in the upper reaches, but will provide protection for instream values in the event of future changes in land use and irrigation practice.

A minimum flow for takes downstream of the Booths flow recorder will have little benefit to the instream values, as this section is naturally intermittent and tends to dry during summer. Therefore, it is recommended that no minimum flow be implemented from September to March for all takes downstream of the Booths flow recorder.

# 7. Acknowledgments

The assistance of many people within the Otago Regional Council is greatly appreciated in the preparation of this report, particularly those who undertook data collection and shared their technical and local knowledge.

# 8. Glossary

**Abstraction**
See *water abstraction*

**Allocation limit or allocation volume**
The maximum flow or quantity of water in a water body able to be allocated to resource consents for taking

**Alluvium**
Sediments that have been deposited by a river.

**Aquifer**
A saturated geological unit, or group of units, with sufficient storage and permeability to yield economic volumes of water.

**Catchment**
The area drained by a river or body of water

**Confined Aquifer**
An aquifer in which water is stored under elastic pressure. Confined aquifers are generally (but not always) encountered at a depth below the ground surface where low permeability mud, silt or clay have overlain permeable sediments such as gravels.

**Consumptive use**
A use that results in a net loss of water from the water body

**Drawdown**
The lowering of water levels in response to pumping

**Hydraulic Conductivity**
The rate at which water can pass through a permeable medium in m/day.

**Hydraulic Gradient**
The slope of the water table or piezometric surface.

**Hydrogeology**
The study of aquifers and groundwater

**Instream Flow Incremental Methodology (IFIM)**
An instream habitat model used to assess the relationship between flow and available habitat for fish and invertebrates

**Instantaneous take**
All takes of water occurring at a particular time

**Irrigation**
The artificial application of water to the soil, usually for assisting the growing of crops and pasture

**Main stem**
The principal course of a river (i.e. does not include tributaries)

**Mean Annual Low Flow (MALF)**
The average of the lowest seven-day low flow period for every year of record (see also seven-day low flow)

**Mean flow**
The average flow of a watercourse (i.e. the total volume of water measured divided by the number of sampling intervals)

**Median flow**
The recorded flow value such that 50% of the recorded flows are greater, and 50% of the recorded flows are less

**Minimum flow**
The flow below which the holder of any resource consent to take water must cease taking water from that river

**Non-consumptive**
A water use that returns all water to the catchment from which it was taken

**Permeability**
The ability of a rock or sediment to transmit water. Highly permeable gravel will allow water to flow quite freely.

**Piezometer**
A small diameter observation well used to monitor water levels (often abbreviated to "piezo")

**Point of inflection**
The point at which there is a sharp decrease in the available habitat relative to flow in an IFIM habitat curve

**Primary allocation**
The volume of water established under Policy 6.4.2 of the Water Plan that is able to be taken, subject to a primary allocation minimum flow

**Quaternary**
The most recent geological Period (2-6 million years ago to the present day)

**Reach**
A specific section of a stream or river

**Return period**
An estimate of the average interval of time between events (e.g. flood or low-flow event)

**River**
A continually or intermittently flowing body of fresh water that includes a stream and modified watercourse, but does not include any artificial watercourse (such as an irrigation canal, water supply race or canal for the supply of water for electricity power generation and farm drainage canal)

**Seven-day low flow**
The lowest seven-day low flow in any year is determined by calculating the average flow over seven consecutive days for every seven consecutive day period in the year and then choosing the lowest.

**Stock water**
Water used as drinking water for livestock

**Taking**
The taking of water is the process of extracting the water for any purpose and for any period of time

**Terrace**
A flat topographic feature formed by erosion or deposition of sediment by a river

**Tranmissivity**
A measure of the permeability of an aquifer (i.e. the ease with which water can move through an aquifer). "Transmissivity" is equivalent to hydraulic conductivity multiplied by the aquifer thickness and is reported as $m^2/d$.

**Unconfined aquifer**
Typically shallow aquifers, recharged directly from rainfall infiltration onto the ground surface, or from water flowing from surface water bodies. Streams, lakes and wetlands are usually the surface expression of an unconfined aquifer.

**Vegetation**
Plant cover, including trees, shrubs, plants or grasses

**Water abstraction**
The extraction of water from a water body (including aquifers)

**Water body**
Fresh water or geothermal water in a river, lake, stream, pond, wetland or aquifer, or any part thereof, which is not located within the coastal marine area

**Water permit**
A permit granted under the Resource Management Act (1991) to take water

**Water table**
The water surface of an unconfined aquifer in which the pressure is atmospheric

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# Appendix 1

**Guidelines of habitat retention required for instream values (Jowett & Hayes, 2004)**

| Critical value | Fishery value | Significance ranking | Recommended % of habitat retention |
|---|---|---|---|
| Large adult trout - perennial fishery | High | 1 | 90 |
| Diadromous galaxiid | High | 1 | 90 |
| Trout spawning/juvenile rearing | High | 2 | 80 |
| Non-diadromous galaxiid | - | 3 | 70 |
| Large adult trout - perennial fishery | Low | 3 | 70 |
| Diadromous galaxiid | Low | 3 | 70 |
| Trout spawning/juvenile rearing | Low | 5 | 60 |
| Bully species | - | 5 | 60 |