Management flows for aquatic ecosystems in the Lindis 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.

Otago Regional Council's 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 the 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 Lindis River has a significant trout spawning and juvenile habitat and there are also several disjointed populations of the Clutha flathead galaxiid in many of the tributaries, which is listed as being in gradual decline. Primary allocation is also severely over-allocated. 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 of the Lindis River.

The Lindis River is situated in Central Otago and has a catchment area of 1,055 km^2, flowing into the Clutha River/Mata-Au approximately 6 km upstream of Lake Dunstan. The upper Lindis Catchment receives substantial rainfall during winter and spring, however the lower Lindis Catchment is one of the driest areas in New Zealand with very little rainfall throughout the summer months. Flows in the Lindis River are generally high during spring due to rainfall and snow-melt, but are greatly reduced during summer. Based on anecdotal evidence, long-term flow and rainfall monitoring, it is believed that the lower Lindis River naturally runs dry during extreme droughts.

The Lindis Catchment is severely over allocated, with an allocation limit of 0.7 m^3/s and total primary allocation of 3.600 m^3/s, which is comprised mainly of deemed permits (mining privileges). Such is the extent of surface water abstraction from the Lindis River, the lower reaches of the river become dewatered for much of the irrigation season, resulting in fish kills and loss of habitat for several kilometres upstream of the Clutha confluence.

Instream habitat surveys were carried out and flow requirements for all of the resident species assessed by examining the relationships between flow and suitable habitat using Instream Flow Incremental Methodology (IFIM). Habitat suitability was determined from general habitat suitability curves developed from studies in other rivers.

The 7-day Mean Annual Low Flow (MALF) and low flow return periods have been calculated for the middle (Lindis Peak) and lower (Ardgour Rd) reaches of the Lindis River to give an indication of low flows experienced by the catchment. Rainfall data have also been summarised to give an indication of annual totals and seasonal distribution throughout the Lindis Catchment.

The Lindis River is listed in Schedule 1A of the Water Plan as having significant trout spawning and juvenile habitat as well as the presence of adult trout and eels. The Lindis River supports a small adult brown trout fishery in the middle and upper sections of the river as well as significant spawning and juvenile habitat in its lower reaches. There are also several disjointed populations of the Clutha flathead galaxiid (*Galaxias sp.D*) in many of the tributaries of the Lindis River, which is listed as being in gradual decline (Hitchmough *et al* 2005). The IFIM study showed that maximum adult brown trout habitat was provided by a flow of 4 m^3/s, with available habitat falling sharply when flows drop below 2 m^3/s. Maximum juvenile brown trout habitat was provided by a flow of 1.4 m^3/s with available habitat falling sharply when flows drop below 0.75 m^3/s. Maximum rainbow trout spawning habitat is provided by a flow of 2.2 m^3/s while the optimum flow for brown trout spawning is 1.4 m^3/s.

Detailed flow monitoring of the lower Lindis River has shown that flow losses in this reach are controlled by surface water/groundwater interactions. As groundwater levels decline over the irrigation season due to lack of recharge from the upper catchment,

surface flows become decoupled from the water table and there is a constant loss of 0.44 m³/s between the Ardgour Rd flow recorder and the Clutha confluence.

Despite the differing hydrology of the upper and lower Lindis River, it is recommended that management flows are based on the Ardgour Rd flow recorder and are applied to the entire catchment. The small number of takes upstream of Lindis Peak means that there would be little discernable environmental benefit in having a second management flow at this site.

It is proposed that a management flow of **0.75 m³/s** is implemented at Ardgour Rd during the irrigation season to ensure that habitat for juvenile brown trout is maintained and that surface flows are sustained to the Clutha confluence.

During natural extreme low flow events it is proposed that a dynamic management flow regime is implemented at Ardgour Rd. When flows at Lindis Peak fall below 0.96 m³/s (1 in 10-year low flow), the management flow at Ardgour Rd will switch to **0.4** m³/s. The **0.4 m³/s** management flow will remain in place until flows at Lindis Peak reach the MALF value of 1.6 m³/s, after which it will return to **0.75 m³/s**. This dynamic management flow will reflect natural extreme low flows and may lead to the temporary dewatering of approximately 430 m of stream bed upstream of the Clutha confluence. However, it is not believed that this will have a significant effect on fish populations due to the occurrence of these extreme events under natural conditions as well the infrequency and short duration of these events.

The Lindis River provides important spawning habitat for both brown and rainbow trout. It is proposed that a management flow of **2.2 m³/s** be implemented at the Ardgour Rd flow recorder between the months of May and September (inclusive) to provide optimum spawning habitat for these species.

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 natural values of the Lindis River which have been taken from Schedule 1A of the Water Plan.

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1. Introduction

The 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". As a means to achieve this objective, the Water Plan provides for the setting of management flows in Otago rivers[1].

The purpose of this report is to provide information on the Lindis River that is relevant to determining the flows desirable for sustaining aquatic habitat. Hydrological data have been summarised and analysed to determine low flow return periods for the Lindis River. Rainfall data have been provided 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 values of the Lindis River. A physical habitat study (Instream Flow Incremental Methodology or IFIM) has also been 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 detailed monitoring study of the hydrology and instream values of the lower Lindis River is also provided.

1.1 Focus of document

In order to manage a stream for aquatic ecosystems there needs to be a clear focus on what is the management objective. Schedule 1A of the Water Plan[2] identifies the ecosystem values that must be sustained, and the key values that require sufficient flow are adult brown trout in the middle reaches of the Lindis River and juvenile brown trout in the lower reaches. Other ecosystem values listed in Schedule 1A are expected to be maintained at flows provided to sustain brown trout (*Salmo trutta*). IFIM data have been discussed with a focus on the management objective and the natural low flow regime of the Lindis River. Flows to sustain these aquatic ecosystem values in both the upper and lower Lindis River have been suggested.

[1] Policies 6.4.1 – 6.4.11 of the Regional Plan: Water for Otago (2004), pp 58-69.
[2] Schedule 1A of the Regional Plan: Water for Otago (2004), pg 273.

2. The Lindis Catchment

The Lindis River is situated in Central Otago and has a catchment area of 1,055 km^2, flowing 70km in a south-west direction from its headwaters in the Dunstan Mountains to its confluence with the Clutha River/Mata-Au approximately 6km upstream of Lake Dunstan (Figure 2.1). The catchment consists of a steep river valley ranging in elevation from 300m at it’s confluence with the Clutha and 1000m at the top of the Dunstan Mountains.

Figure 2.1 The Lindis Catchment

2.1 Vegetation

The upper Lindis Catchment is dominated by snow tussock and low producing grassland, while in the lower catchment, high producing exotic grassland predominates.

2.2 Land use

With its dry climate and low water availability the Lindis Catchment is dominated by sheep and sheep/beef farming, with a recent increase in viticulture in the lower catchment.

2.3 Topography and soils

Soils throughout the Lindis Catchment are sandy loam-based with low fertility. Topography varies from river flats in the lower reaches to gently undulating and strongly rolling hinterland moving up the catchment.

2.3.1 Environmental monitoring sites

The Lindis Catchment contains two permanent flow recorders (Figure 2.2) at Lindis Peak (datalogged) and Ardgour Rd (datalogged and telemetered). Most surface water takes in the Lindis River are located between these two flow recorder sites. The two rainfall sites in the Lindis Catchment (Tarras and Morven Hills) are no longer operating, however, both of these sites have sufficient data sets to give useful indications of long-term rainfall patterns at these locations. Although not in the Lindis Catchment, the nearby Wanaka Automatic Weather Station located at Wanaka airport is the closest datalogged and telemetered rainfall site, and gives an accurate, up-to-date picture of rainfall patterns in the area.

Figure 2.2 Flow sites, rainfall sites, and surface water takes in the Lindis Catchment

2.4 Rainfall and flow patterns in the Lindis Catchment

The upper Lindis Catchment can receive large amounts of snow and significant rainfall due to its topography, however, the lower Lindis River is one of the driest areas in New Zealand (Figure 2.4).

The Lindis Catchment is known for its extreme dry periods, which is depicted in Figure 2.3 which shows long-term flow data from Lindis Peak and rainfall data from Morvan Hills and West Wanaka.

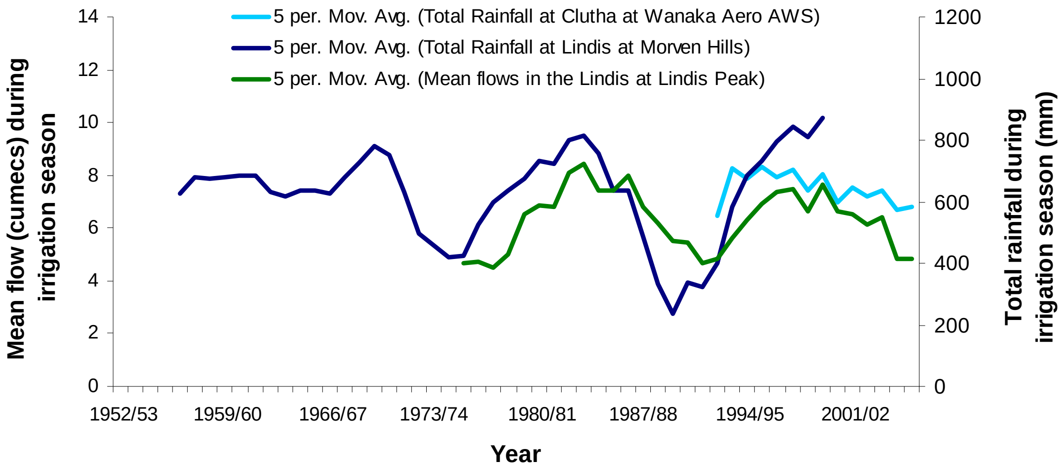

Figure 2.3 Long-term average (5 year moving average) flow and rainfall trends in the Lindis Catchment and Wanaka

Figure 2.3 shows that there have been at least three extreme low flow and low rainfall events since records began in 1952. There has been some anecdotal evidence to suggest that flows in the lower reaches may naturally run dry during the extreme events, but with the long history of surface water abstraction and the relatively short flow and rainfall monitoring dataset it is difficult to assess the validity of this.

2.4.1 Rainfall patterns

The average monthly rainfall has been calculated for all three rainfall sites (Figure 2.4) and shows that although averages differ between sites, the overall monthly rainfall trends are similar between all sites in the area.

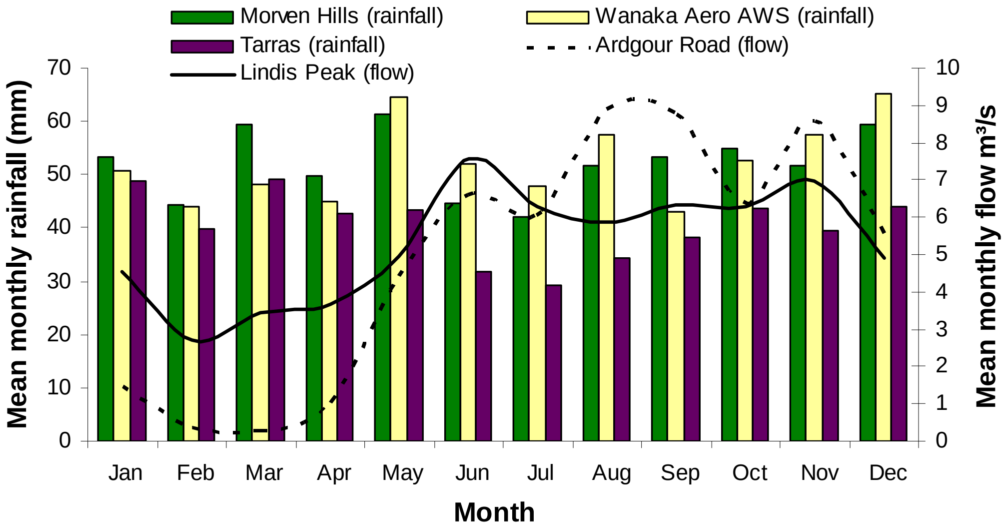

Figure 2.4 Rainfall and flow pattern in the Lindis Catchment

Figure 2.4 shows rainfall patterns in the mid Lindis Catchment (Lindis Peak), lower Lindis River (Tarras) and Wanaka. The periods of highest average rainfall occur in May and December, while periods of lowest rainfall generally occur in February as well as in mid-winter.

2.4.2 River hydrology

The hydrology of the Lindis River is heavily influenced by water abstraction in the middle and lower catchment. The effects of abstraction can be seen in Figure 2.5, which compares flows at Lindis Peak (upstream of surface water abstraction) and Ardgour Rd (downstream of surface water abstraction).

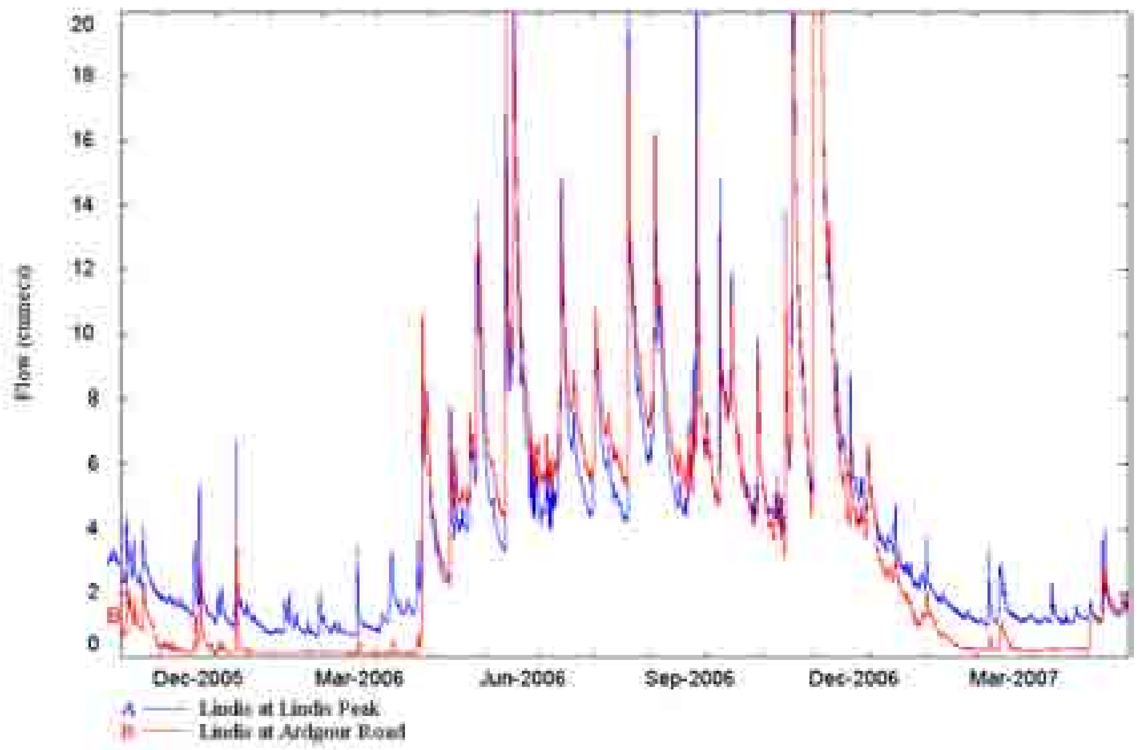

Figure 2.5 Comparison of flows at Lindis Peak (upper catchment) and Ardgour Rd (lower catchment)

During the non-irrigation season (May-Sept) flow patterns at Lindis Peak and Ardgour Rd are similar, with generally higher flows at Ardgour Rd. Flows are high during spring due to snow melt from the upper catchment, but once flows subside there is a substantial deficit between Lindis Peak and Ardgour Rd. During the irrigation season there is a deficit of up to 3 m³/s, with the Lindis Peak always recording more flow than Ardgour Rd. This indicates that the majority of the water passing Lindis Peak is being abstracted for irrigation in the lower reaches of the Lindis Catchment.

2.4.3 Annual flow statistics

Information gathered from flow recorder sites at Ardgour Rd and Lindis Peak have been analysed to provide stream flow statistics within the catchment (Table 2.1). It should be noted that the flow statistics for Ardgour Rd are based on less than three years of data and are heavily influenced by surface water abstraction.

Table 2.1 Summary of annual statistics of the Lindis River flow sites

Site	Location	Catchment size (km²)	Term of Record (years)	Min recorded flow (m³/s)	Max recorded flow (m³/s)	Mean flow (m³/s)
Ardgour Road	Lower Lindis River	1045	2	0.126	59.372	3.794
Lindis Peak	Mid Lindis River	542	31	0.186	322.203	6.318

Due to the differences in record length, a meaningful comparison between the two sites is difficult, however it can still be seen that the mean flow at Ardgour Rd is substantially less than that of Lindis Peak. This is due to the large amount of surface water abstraction between the two sites. The extremely low minimum recorded flow for Lindis Peak is due to the river (and flow recorder) freezing during an extreme cold period, while minimum flows at Ardgour Rd occur during the summer and are due to surface water abstraction.

2.4.4 Annual 7-day low flows and their frequency analyses

Mean annual 7-day low flows[3] (MALF or $Q_{7,m}$ in m^3/s) and the corresponding specific yield at MALF[4] (SMALF) have been provided in Table 2.2 at the two flow recorder sites in the Lindis Catchment. The Lindis Peak flow recorder (as well as occasionally the river itself) is prone to freezing during winter, giving false low flow readings and negatively skewing MALF and low flow return periods (Table 2.2 & Table 2.3). To correct this, MALF and low flow return periods have also been calculated using data from October to April (inclusive). These data are also more applicable when considering management flows as it focuses on the period where water abstraction is greatest. Due to the short data period for Ardgour Rd, it is not appropriate to calculate seasonal data for this site.

Table 2.2 Summary of annual statistics in the Lindis Catchment flow sites

Site	Data period	Term of record (years)	Catchment Area	Lowest recorded flow (m^3/s)	MALF (m^3/s)	SMALF ($l/s/km^2$)
Lindis Peak	All year	31	542	0.186	1.394	2.572
Lindis Peak	Oct - April	31	542	0.723	1.616	2.982
Ardgour Rd	All year	2	1045	0.126	0.177	0.169

A comparison of the MALF values of the Lindis Peak and Ardgour Rd flow sites quantifies the flow pattern that is shown in Figure 2.4 and Figure 2.5. It would be expected that under a naturalised flow regime, the Ardgour Rd 7-day MALF would be similar to that of Lindis Peak, due to low inflows between the sites. However, due to surface water abstraction the 7-day MALF at Ardgour Rd is just 13% of that at Lindis Peak.

[3] The mean of the lowest 7-day average flow for each hydrological year of record.
[4] Specific discharge from one unit catchment area at MALF

The SMALF of the lower Lindis River does not accurately reflect the specific yield of the catchment upstream of Ardgour Rd. Although it is probable that the SMALF for Ardgour Rd would be less than that of Lindis Peak under a naturalised flow regime due to the low rainfall in this area (Figure 2.4), this effect is skewed due to the large amount of abstraction upstream of this site.

Table 2.3 shows the low flow return periods for flow sites in the Lindis Catchment. The accuracy of the low flow return period analysis is limited by the term of record, with any return periods of more than twice that of the length of data period being considered unreliable. Due to the short term of record for Ardgour Rd, it is not feasible to calculate low flow return periods for this site.

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

Site	Lowest recorded flow (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)	$Q_{7,50}$ (m^3/s)	Method used to determine frequencies
Lindis Peak (all year)	0.186	1.349	1.083	0.967	0.887	0.812	GEV** dist fitted to raw data
Lindis Peak (Oct - April)	0.608	1.616	1.078	0.961	0.883	0.808	GEV** dist fitted to log transformed data
Ardgour Rd (all year)	0.126	0.177	*	*	*	*	
Ardgour Rd (Oct - April)	0.126	0.177	*	*	*	*	

* Insufficient data

** Generalised Extreme Value distribution

The lowest recorded flow at Lindis Peak occurred during winter and was most likely caused by freezing. Due to the short duration of these winter freezing events, the management instantaneous flows are much less than the 50 year 7-day low flow (**$Q_{7,50}$**) Table 2.3 also shows that the 7-day MALF at Lindis Peak for the whole year is over 0.2 m^3/s less than the 7-day MALF for summer. The 7-day MALF for Ardgour Rd is 0.177 m^3/s using data from the irrigation season and for the entire year, indicating that freezing has not occurred at Ardgour Rd since the site was installed and that the lowest flows for the year occur over the irrigation season.

2.5 The Lindis River's fish species

The Lindis River supports five species of native fish and two species of introduced sports fish (NIWA Freshwater Fish Database). The spatial and temporal distribution of these species within the catchment is controlled by both reach specific hydrology and (in the case of *Galaxias sp D.*) predation from trout. Figure 2.6 shows the distribution of native fish in the Lindis River Catchment.

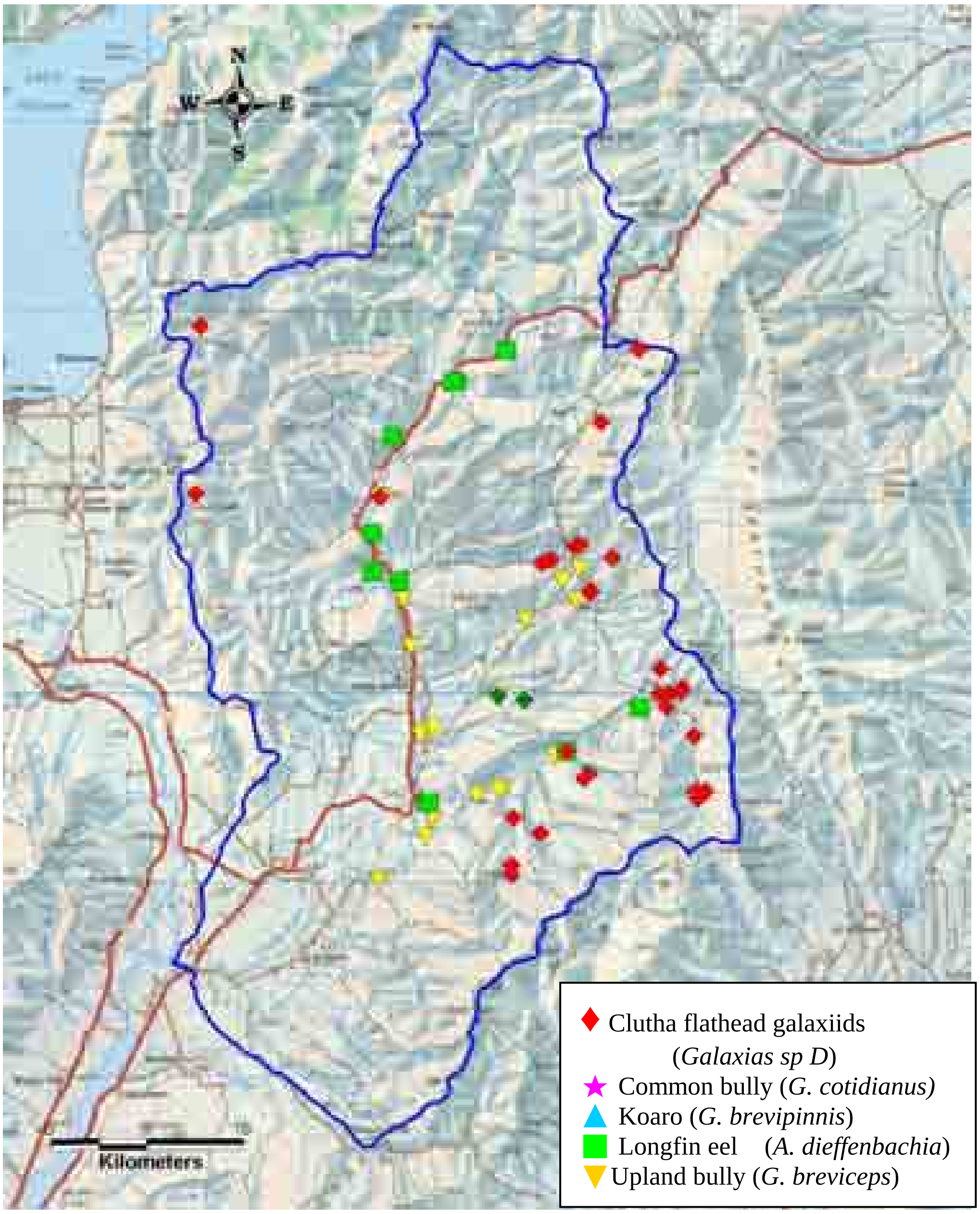

Figure 2.6 Distribution of native fish species in the Lindis Catchment

Figure 2.6 shows that the Lindis River supports several populations of the Clutha flathead galaxiid (*Galaxias sp. D*) in the upper reaches of many of its tributaries. It is likely that this distribution of Clutha flathead galaxiid is restricted by the presence of large trout in the main stem of the Lindis River and its larger tributaries. Longfin eels have been recorded along the main stem of the Lindis River, although it is likely this population is in serious decline due to the prevention of upstream migration of elvers by the Roxburgh and Clyde dams. Upland bully are distributed throughout most of the catchment. There are also several records of common bully and koaro from the middle reaches of the Lindis River. A monitoring study undertaken by the Otago Regional Council in 2007 confirmed that brown trout, rainbow trout, upland bully, common bully and koaro are present in the lower Lindis River.

2.5.1 Sports fish

There are two species of introduced sports fish present in the Lindis River; brown trout and rainbow trout (Figure 2.7).

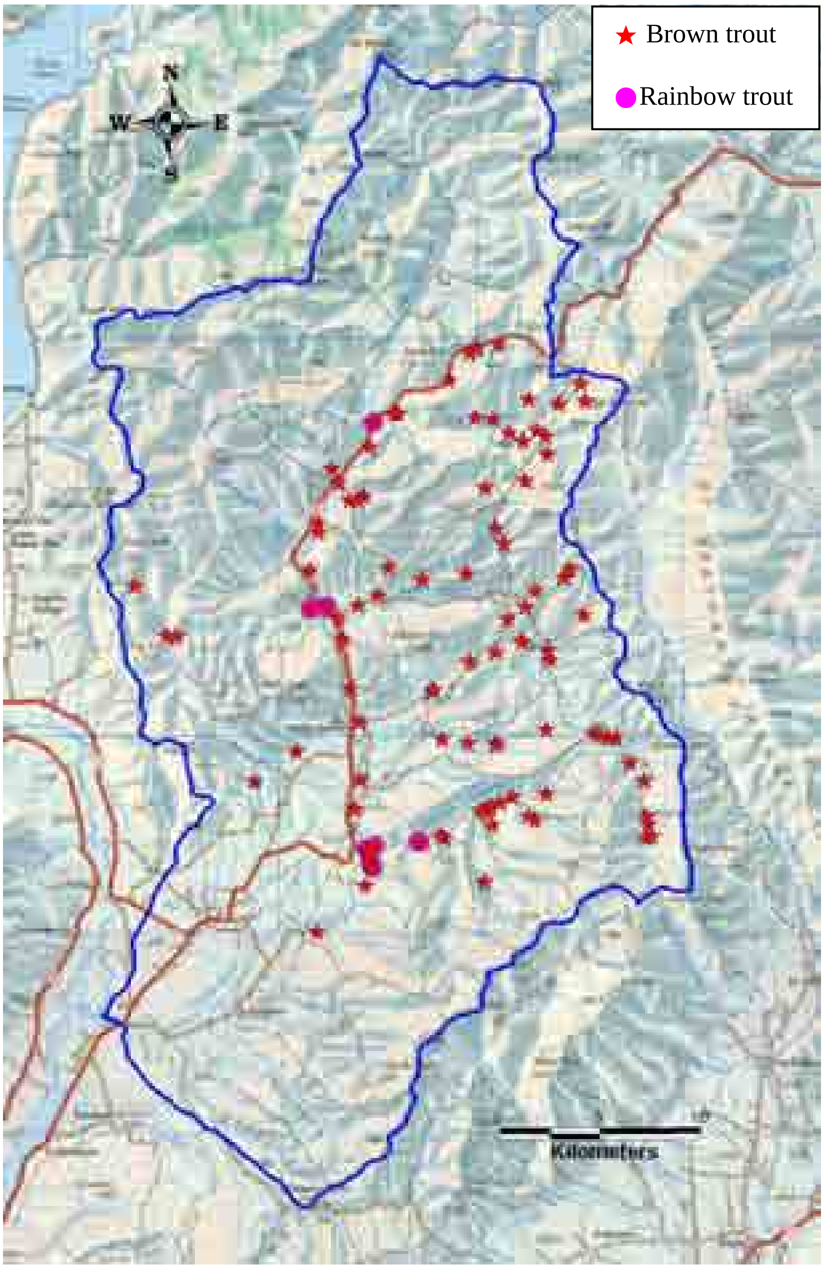

Figure 2.7 Distribution of introduced sports fish in the Lindis Catchment

Figure 2.7 shows that brown trout are spread widely throughout the Lindis Catchment, while rainbow trout are largely restricted to the main stem. The perennial reaches of the Lindis River support large populations of adult brown trout while the ephemeral lower reaches are dominated by juvenile brown trout.

3. Natural values of the Lindis River

The Lindis River, like many of Central Otago's rivers, is recognised for both its scenic, recreational and biodiversity values. It is recognised in Schedule 1A of the Water Plan as having a high degree of naturalness above 900 m and is free of pest macrophytes, although its lower reaches are now infected with the invasive diatom *Didymosphenia geminata*.

3.1 Recreational values

The most important recreational uses of the Lindis River are trout angling and swimming. Although anecdotal evidence has suggested that the Lindis River provides a locally significant brown trout fishery, an angler survey undertaken in 2001/02 (Unwin & Image 2003) has shown that there were only approximately 150 angler days on the Lindis River during this period. This figure is relatively low compared to the 5,630 angler days spent on the adjacent Manuherikia Catchment during the same period.

The Lindis River is listed in the Water Plan as having a significant presence of adult trout as well as significant habitat for juvenile trout and trout spawning. The Lindis River is also used to a lesser degree for kayaking.

3.1.1 Angling

The middle and upper reaches of the Lindis River support a valued brown trout fishery (A. Horrel, *pers comm.*), with fish averaging between 1 and 2 kg and the occasional fish over 3kg. The river supports an annual spawning migration from Lake Dunstan and the Clutha River/Mata-Au with progeny from spawning important for replenishing Lindis River fish stocks and maintenance of the regionally and nationally recognised Upper Clutha and Lake Dunstan fisheries (C Halford, *pers comm.*).

3.2 Biodiversity values

The Lindis River supports several populations of Clutha flathead galaxiid, which is listed as being in gradual decline (Hitchmough *et al* 2005). It is likely that the Clutha flathead galaxiid was once widely distributed throughout the Clutha Catchment and is now restricted almost exclusively to tributaries above trout barriers and in areas where flow conditions are not conducive to trout survival.

Most of the Clutha flathead galaxiid populations in the Lindis Catchment occur upstream of physical barriers to trout migration that are unaffected by changes in flow regimes. However, there are cases (such as Wainui Creek in the lower catchment) where trout numbers are kept sufficiently low due to sub-optimum conditions caused by surface water abstraction to allow Clutha flathead galaxiid population to exist without the presence of physical barriers. This phenomenon has also been observed in the nearby Manuherikia River (Leprieur *et al* 2006).

4. Physical habitat survey

The Otago Regional Council contracted the National Institute for Water and Atmospheric research (NIWA) to carry out a study to determine the flows required to maintain acceptable habitat for the fish species present in the Lindis River.
The primary aims of the study were to:

- Conduct instream habitat surveys in critical reaches of the Lindis 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 discharge.
- Assess flow requirements for the Lindis River based on the habitat requirements of the native and introduced fish species.

4.1 Instream Flow Incremental Methodology (IFIM) summary

The instream flow incremental methodology (IFIM; Bovee 1982) is a holistic way 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 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). The IFIM strength lies in the 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).

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 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 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 US (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.

The procedure in an instream habitat analysis is to select appropriate habitat suitability curves or criteria and then to model the effects of a range of flows on the selected habitat variables in relation to these criteria. The area of suitable habitat, or weighted usable area (WUA), is calculated as a joint function of depth, velocity and substrate type for different flows. Instream habitat is expressed as the total area of suitable habitat (WUA (m^2/m). WUA (m^2/m) is the measure of the total area of suitable habitat per metre of stream.

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 IFIM for the Lindis River

Two reaches were surveyed in the Lindis River; Lindis Crossing and Cluden Hill. At Lindis Crossing, the river is relatively unconfined with gravel substrate, alternating gravel bars and varying river width. Further upstream at Cluden Hill, the river is more confined with pool/run/riffle sequences and moderate willow growth.

Flows differed between these reaches because of abstraction and tributary flows. Each reach was calibrated separately and then combined for the assessment of flow requirements.

The habitat survey of the lower reach, just upstream of the SH8 bridge, was carried out at a flow of 5.2 m^3/s, with a calibration measurement at 1.2 m^3/s. This reach was dry at the time of the second calibration measurement. The upper reach at Cluden Hill was surveyed at the same time, but the flow was slightly higher at 6 m^3/s, with calibration at flows of 1.8 m^3/s and 0.4 m^3/s. At the survey flows of 5.2-6 m^3/s, the average width of the river was 18.6 m, depth 0.37 m and velocity 0.72 m/s. Boulder substrate (>256 mm) was common (65%) in the upper reach, with gravel and cobbles making up the remaining substrate. The lower reach contained finer substrate, made up of mainly cobbles (45%) and gravels (38%). The estimated average width, depth, and velocity at the 7-day mean annual low flow of 1.58 m^3/s was 14 m, 0.24 m, and 0.43 m/s respectively.

Figure 4.1 shows variation in instream habitat (WUA) with changes in flow.

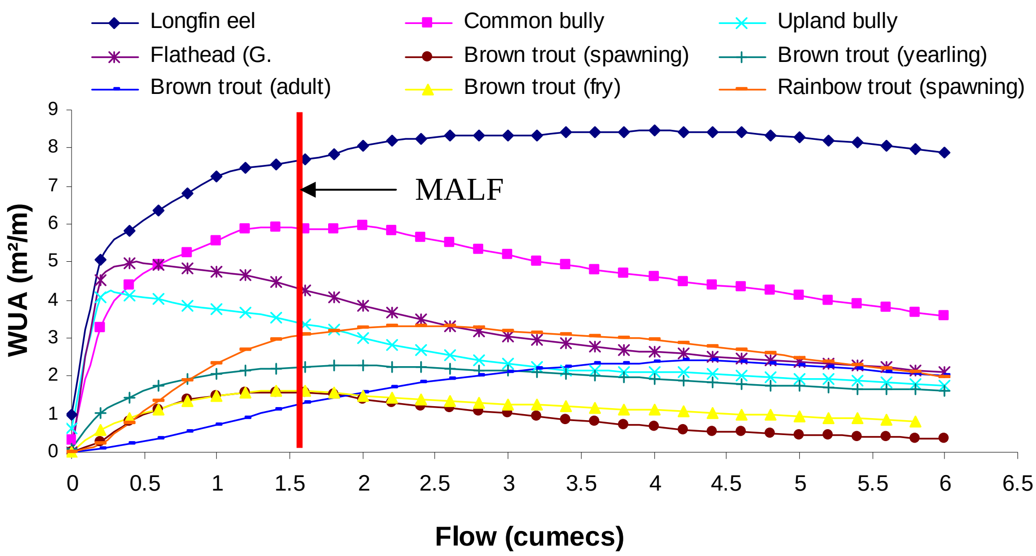

Figure 4.1 Variation of instream habitat in the Lindis River with flows up to 6 m³/sec and flows below the 7-day MALF

Maximum habitat for brown and rainbow trout spawning was provided by flows of 1.4 m^3/s and 2.2 m^3/s respectively (Figure 4.1). Maximum adult brown trout habitat was provided by a flow of 4 m^3/s and the amount of suitable adult trout habitat began to fall sharply when flows fell below 2 m^3/s (Figure 4.1). Maximum juvenile brown trout habitat was provided by a flow of 1.4 m^3/s, with a sharp reduction occurring when flows fall below 0.75 m^3/s. Flow requirements of native fish were lower than those of trout, with a flow of 0.4 m^3/s providing maximum habitat for upland bullies and flathead galaxiid and a sharp reduction in suitable habitat as flows fell below 0.2 m^3/s.
Table 4.1 shows the suggested flow requirements for the fish species of the Lindis River.

Table 4.1 Suggested flow requirements for fish habitat in the Lindis River based on IFIM analysis

Target fish species	Recorded 7-day mean annual low flow	Optimum Flow	Flow below which habitat declines sharply
Upland bully, flathead galaxiid	1.6	0.4	0.2
Rainbow trout spawning (winter)	1.6	2.2	1.6
Brown trout spawning (winter)		1.4	0.75
Juvenile brown trout	1.6	1.4	0.75
Adult brown trout	1.6	4	2

Figure 4.1 shows that adult brown trout require substantially higher flows than any other species present in the Lindis Catchment, with native fish requiring far less flows than any of the salmonid life stages.

4.2.1 Flow distributions and available fish habitat

Flow distribution curves have been calculated for Lindis peak and Ardgour Rd for the irrigation season (October – April) and for the non-irrigation season (May – September) to estimate the frequency that flows at these sites exceed the thresholds provided by IFIM.

4.2.1.1 *Irrigation season (October to April, inclusive)*

IFIM modelling has indicted that the optimum flows for juvenile and adult brown trout are 4 m³/s and 1.4 m³/s, respectively. The point of inflection for adult and juvenile brown trout is 2 m³/s and 0.75 m³/s respectively. Figure 4.2 shows how often these values are exceeded during the irrigation season.

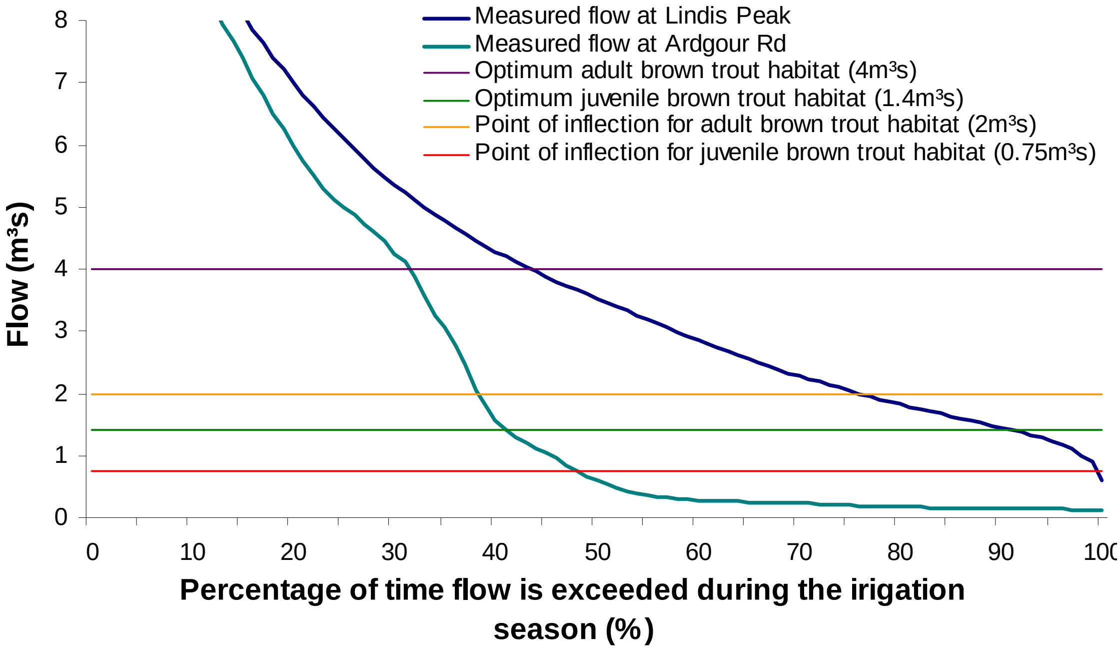

Figure 4.2 Lindis River at Ardgour Rd and Lindis Peak irrigation season flow distribution curve (October - April inclusive) showing the flow required for optimum adult and juvenile brown trout habitat (4 m³/s and 1.4 m³/s respectively) and the infection point (2 m³/s and 0.75 m³/s, respectively) of both life stages

Figure 4.2 shows the flows at Lindis Peak fall below the optimum flow (4 m³/s) for adult brown trout 57% of the irrigation season and below the point of inflection (2 m³/s) 24% of the time. This is an indication that the adult brown trout population in the Lindis River is habitat limited in the upper reaches. The 93% exceedence of the optimum flow for juvenile brown trout habitat, and the 99% exceedence of the inflection point, indicates that juvenile trout habitat is not limited by flow in the upper catchment.

Despite the relative short data period available for Ardgour Rd, it is clear from Figure 4.2 that low flows severely limit available habitat for adult brown trout during the irrigation season, with flows dropping below the optimum flow 67% of the time and falling below the point of inflection 61% of the time. Juvenile trout habitat is also limited, with flows falling below optimum for 58% of the irrigation season and below the point of inflection 52% of the time.

4.2.1.2 Non-irrigation season (May to September, inclusive)

IFIM modelling has indicated that the optimum flow for rainbow trout spawning is 2.2 m^3/s and that maximum habitat for brown trout spawning is provided for at 1.4 m^3/s (Table 4.1). Figure 4.3 shows the non-irrigation season (May-September inclusive) flow distribution curves for Lindis Peak and Ardgour Rd to assess the availability of suitable habitat during the spawning season.

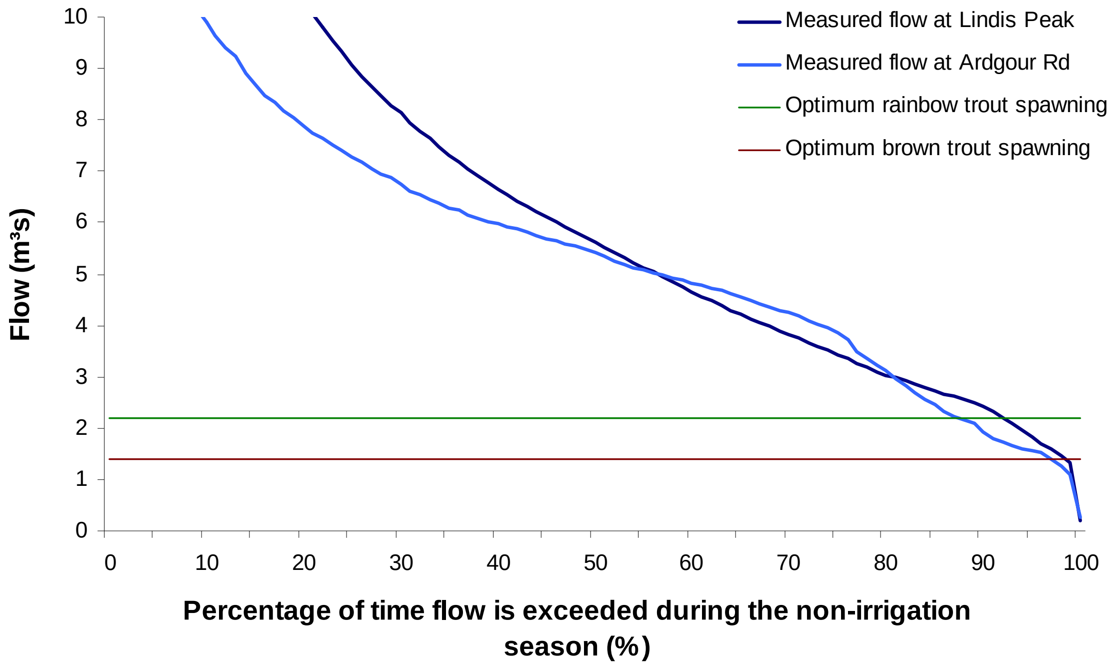

Figure 4.3 Lindis River at Ardgour Rd and Lindis Peak winter flow distribution curve (May - September inclusive) showing the flow required for optimum brown trout (1.4 m^3/s) and rainbow trout (2.2 m^3/s) spawning habitat

Figure 4.3 shows that winter flows at Lindis Peak exceed the optimum flow for rainbow trout spawning 92% of the time and 88% of the time at Ardgour Rd. The flow requirements for brown trout spawning are less than that of rainbow trout, with the optimum spawning flow being exceeded 97% of the time at Ardgour Rd and 99% of the time at Lindis Peak. The extreme low flows observed (frequency <1%) is due to the river and sampling equipment freezing during periods of severe cold.

5. Hydrology of the lower Lindis River

The major objective of this report is to provide an understanding of the flows needed in the Lindis River is to ensure that sufficient flow is maintained to provide for Schedule 1A (Water Plan) values. To ensure these values are maintained within the entire river, it is essential that surface flow is sustained to the Clutha River/Mata-Au confluence.

To gain an understanding of the flows required to achieve this, the hydrology of the lower Lindis River was closely monitored over the 2006/07 and 2007/08 irrigation season. In addition to the two permanent flow recorders at Lindis Peak and Ardgour Rd, two additional temporary flow recorders were installed at Lindis Crossing and at the Clutha River/Mata-Au confluence (Figure 5.1).

Figure 5.1 Permanent and temporary flow recorders used during the 2007 and 2008 monitoring period

5.1 Flow patterns in the Lindis River during the 2006/07 irrigation season

A tru-track flow recorder was installed at the Lindis Crossing Bridge in February 2007 to give a comparison of flows between this site and the Ardgour Rd flow recorder with the aim of calculating the management flow required to maintain instream values in the lower Lindis River to the Clutha River/Mata-Au confluence (Figure 5.2).

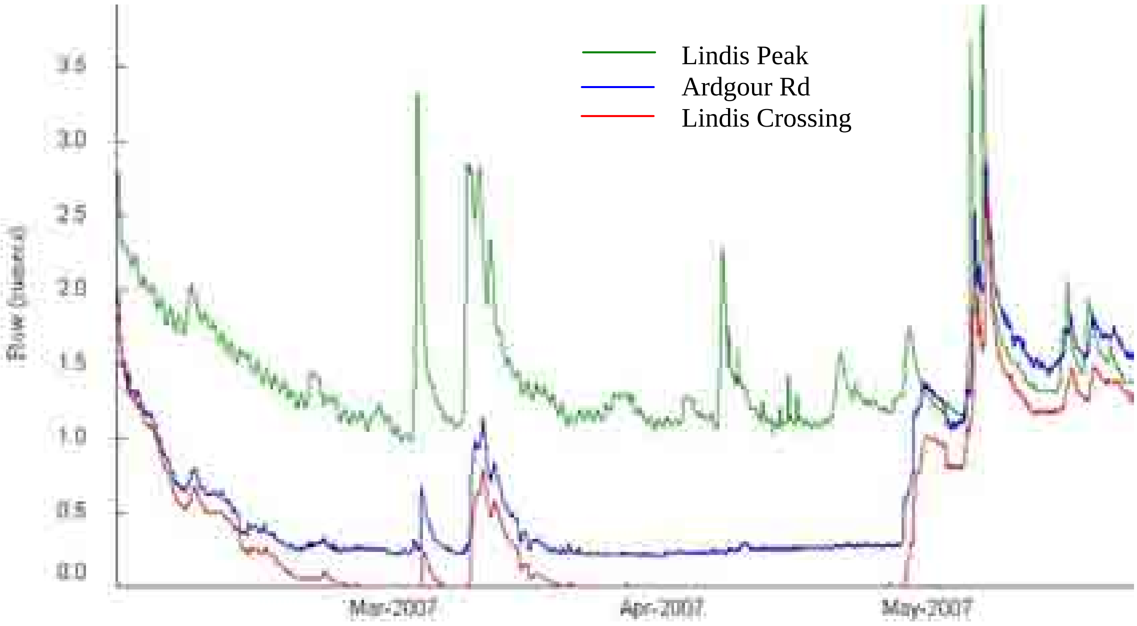

Figure 5.2 Comparisons of flows at Lindis Peak, Ardour Rd and Lindis Crossing

The flow differential between Lindis Peak and Ardgour Rd gives an indication of the volume of water that is taken for irrigation in this reach (Figure 5.2). Figure 5.2 also shows that flows at Ardgour Rd and Lindis Crossing are similar early in the data period, with Lindis Crossing recording flows slightly higher than that of Ardgour Rd. Despite a lack of surface water abstraction between Ardgour Rd and Lindis Crossing, flows at Lindis Crossing dropped below that of Ardgour Rd in early February and remain that way for the remainder of the study. It is likely that this effect is due to losses to groundwater as water levels in the aquifer drop due to a lack of recharge during the summer months

Flows at Ardgour Rd and Lindis Crossing have been more closely examined in Figure 5.3 in an attempt to identify the point at which flows at Ardgour Rd and Lindis Crossing diverge due to losses to groundwater.

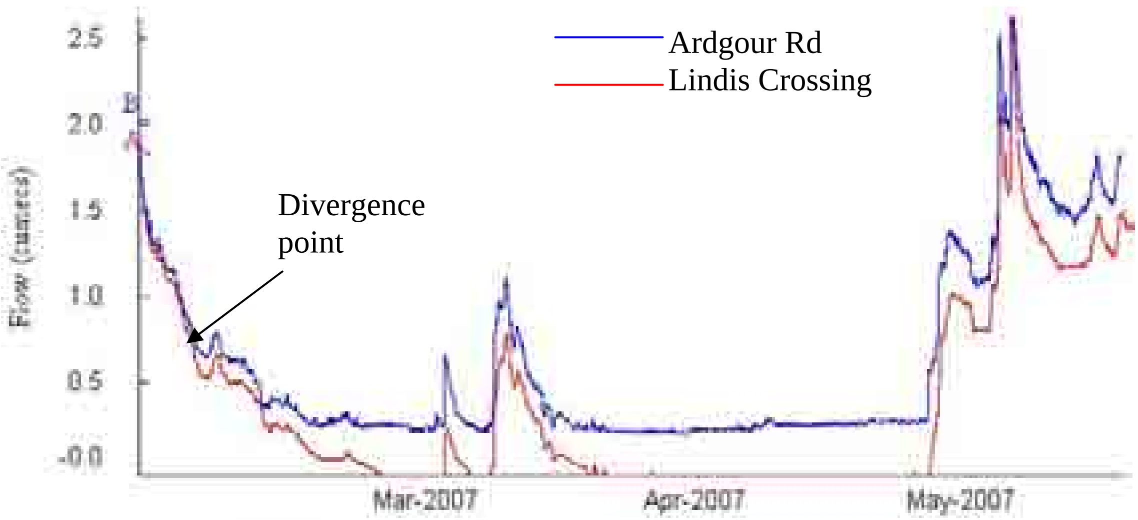

Figure 5.3 Comparison of flows at Ardgour Rd and Lindis Crossing

Figure 5.3 shows that the point at which flows at Ardgour Rd and Lindis Crossing begin to diverge is approximately 0.7 m^3/s, after which there is a noticeable difference in flows between the two sites. It is difficult to estimate the maximum rate of loss between the two sites due to the cessation of surface flows at Lindis Crossing. However, it is clear that flows between 0.3 and 0.4 m^3/s at Ardgour Rd are insufficient to maintain surface flows at Lindis Crossing.

5.2 Flow patterns in the Lindis River during the 2007/08 irrigation season

Following the results of the 2006/07 flow monitoring, further work was undertaken in 2007/08 to confirm the flows required to maintain connectivity throughout the lower Lindis River. In addition to the two permanent and one temporary flow recorder installed in the previous season, a second temporary recorder was installed 30m upstream of the confluence of the Lindis River and the Clutha River/Mata-Au (Figure 5.1).

Figure 5.4 shows the recorded flows in the Lindis River from 8 November 2007 to 8 January 2008.

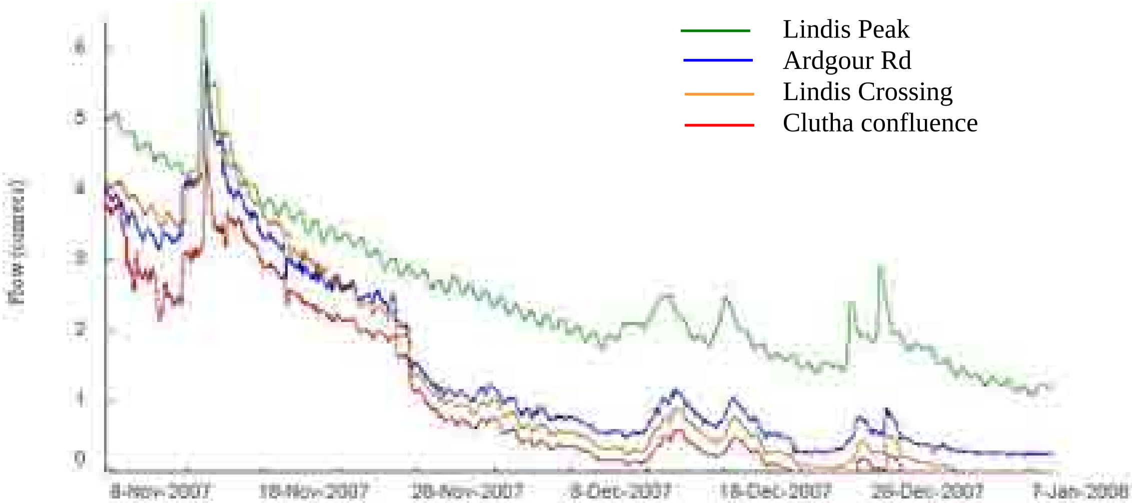

Figure 5.4 Comparison of flows between Lindis Peak, Ardgour Rd, Lindis Crossing and Clutha confluence November to January 2008

Figure 5.4 shows that there was already a substantial flow deficit between Lindis Peak and Ardgour Rd when the temporary flow recorders were installed in early November which is likely caused by surface water abstraction between the two sites.

As seen during the previous irrigation season (Figure 5.3) there is a defined point where flows in the lower Lindis River diverge. Unlike the previous season however, the divergence point occurs at a flow of approximately 1.6 m^3/s (Figure 5.4), indicating that the factors controlling this divergence are at least partially independent of surface flow.

Figure 5.4 also shows that there is an extended period during November and December where flow patterns for the three sites on the lower Lindis River are almost identical, which continues until surface flows cease at the lower sites towards the end of December. The lack of surface water abstraction downstream of Ardgour Rd, and the relatively constant flow deficit between the lower sites, indicates that flows in this reach are driven largely by groundwater interactions.

5.3 Interactions between groundwater and surface water

The spatial and temporal variation in flow losses and gains in the lower Lindis River, in the absence of surface water abstraction and surface water inflow, is an indication that there is significant interaction between surface water and groundwater in this reach.

Analysis of surface flow losses and groundwater monitoring has been undertaken to assess the significance of these interactions.

5.3.1 Groundwater/surface water interaction models

To accurately interpret the flow patterns observed in the lower Lindis River, it is essential to understand the underlying surface water/groundwater interactions that drive these patterns. A brief description of these interaction models is given below.

5.3.1.1 Gaining reach

Gaining reaches occur when the stream gains water from the surrounding shallow aquifer and requires the aquifer to be higher in altitude than the surface of the stream channel (Figure 5.5).

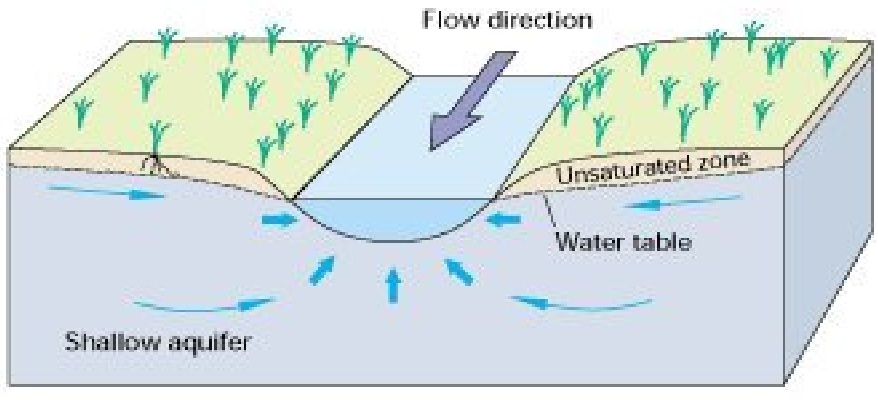

Figure 5.5 A gaining reach, where the stream gains water from a connected shallow aquifer (Winter *et al,* 1998)

This situation occurs in the Lindis River during spring and early summer when shallow aquifers are recharged from snow-melt and rainfall from the upper catchment.

5.3.1.2 Connected loosing reach

Connected losing reaches occur when the stream loses water to the underlying shallow aquifer and requires the shallow aquifer to be at a lower altitude than the stream surface and for it to be connected through a saturated zone (Figure 5.6).

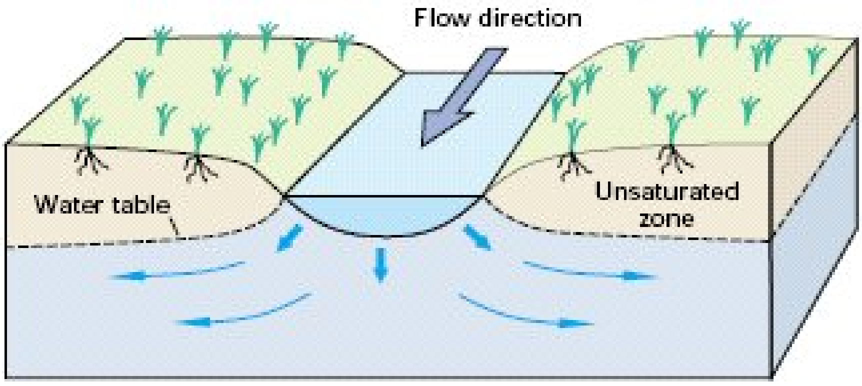

Figure 5.6 A connected loosing reach, where surface water is lost to the underlying aquifer through a saturated zone surrounding the wetted channel (Winter *et al*, 1998)

This situation is likely to occur in the Lindis River where recharge to shallow groundwater is reduced and the water table begins to drop due to a lack of recharge during the summer months and abstraction from the groundwater wells in the lower catchment. This scenario is characterised by a high degree of variability of the rates of loss as well as the potential for higher rates of loss. This is controlled largely by the difference in altitude between the surface of the stream and the underlying aquifer.

5.3.1.3 Disconnected loosing reach

If groundwater levels continue to decline, the stream channel becomes disconnected from the underlying aquifer and is separated by an unsaturated zone (Figure 5.7).

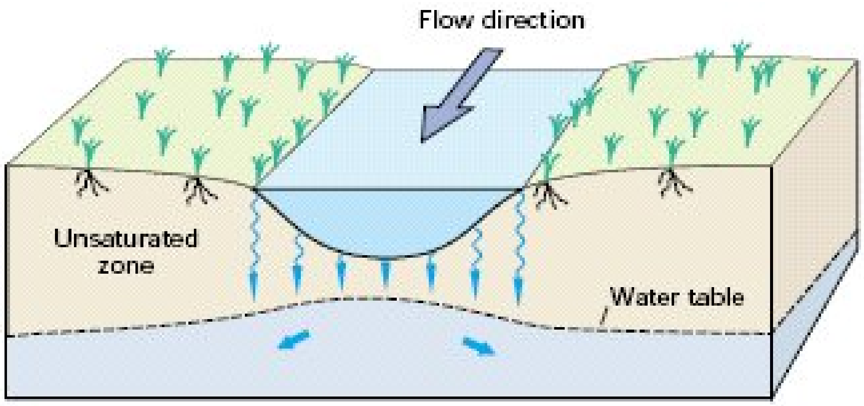

Figure 5.7 A disconnected losing reach, where surface water and groundwater become decoupled and a separated by an unsaturated zone (Winter *et al*, 1998)

An important feature of a disconnected loosing reach is that continued pumping and subsequent reduction of shallow groundwater levels does not cause a corresponding increase in surface water losses. Once groundwater and surface water become decoupled the rate of surface flow loss is constant, unlike the highly variable rates of loss associated with connected loosing reaches.

As high levels of groundwater abstraction persist throughout the irrigation season, the entire lower Lindis River is likely to become decoupled from the water table and turn into a disconnected loosing reach.

5.3.1.4 Bank storage

Bank storage occurs during high flows when water from the stream enters the banks of the channel and then re-enters the stream over a period of days or weeks (Figure 5.8). This can occur at any time, regardless of if surface water and groundwater are coupled or decoupled.

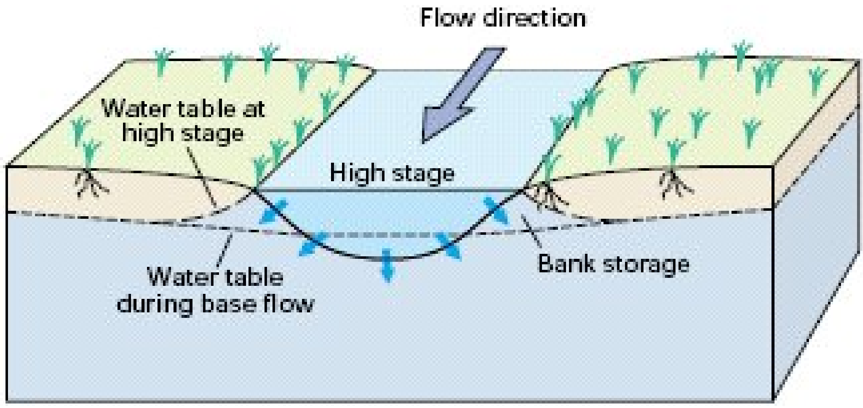

Figure 5.8 An example of bank storage, where surface water is lost to the banks either side of the channel and then reinfiltrated into the channel over a period of days or weeks (Winter *et al,* 1998)

Bank storage is common in most streams and has the effect of reducing flood peaks and supplementing stream flows as water is returned to the main channel.

5.3.2 Factors affecting losses of surface flow to groundwater

The rate of loss of stream flow to groundwater is affected by a number of factors; the significance of which is dependent on the volume of stream flow, channel morphology and wetted perimeter.

5.3.2.1 Interactions between channel morphology, stream flow, and wetted perimeter

The relationship between increases in flow (a derivative of stage height) and wetted perimeter is dependant largely on channel morphology. In a narrow confined channel (e.g. Ardgour Rd), increases in stage height does not significantly increase the wetted perimeter and the surface area through which flow can be lost is not greatly increased (Figure 5.9 – stream stage 2).

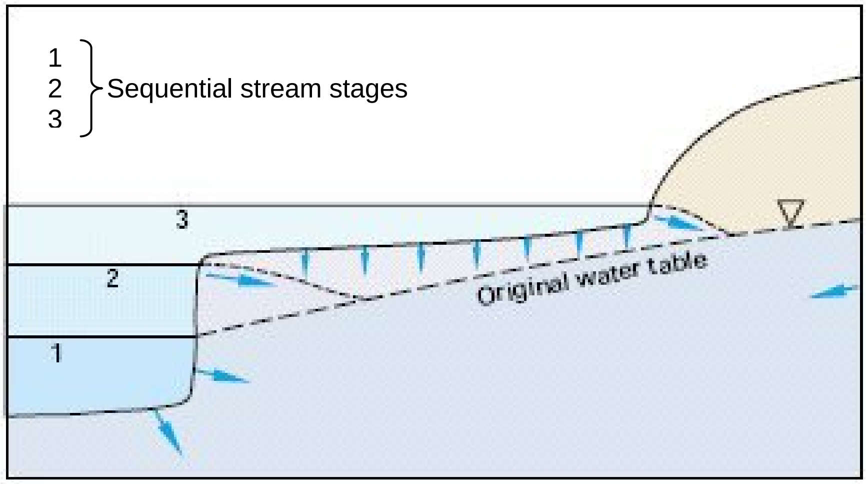

Figure 5.9 The effect of channel morphology on changes in wetted perimeter with increased stage height (Winter *et al*, 1998)

When the channel is more open and unconfined (e.g. downstream of Lindis Crossing), or stream flows overtop the main channel (Figure 5.9 – stream stage 3), there is a much greater surface area for flow to be lost to groundwater. During flood events, increases in wetted perimeter and subsequent losses of surface flows are a major source of recharge for shallow aquifers. However, when small increases in flow occur in an unconfined channel with a relatively large wetted perimeter, a large proportion of this water is quickly lost to the underlying shallow aquifer.

5.3.3 Groundwater/surface water interactions in the lower Lindis River

The interaction between groundwater and surface water in the lower Lindis River is illustrated in Figure 5.10, which shows flow in the Lindis River at Ardgour Rd and water level in a nearby groundwater monitoring bore.

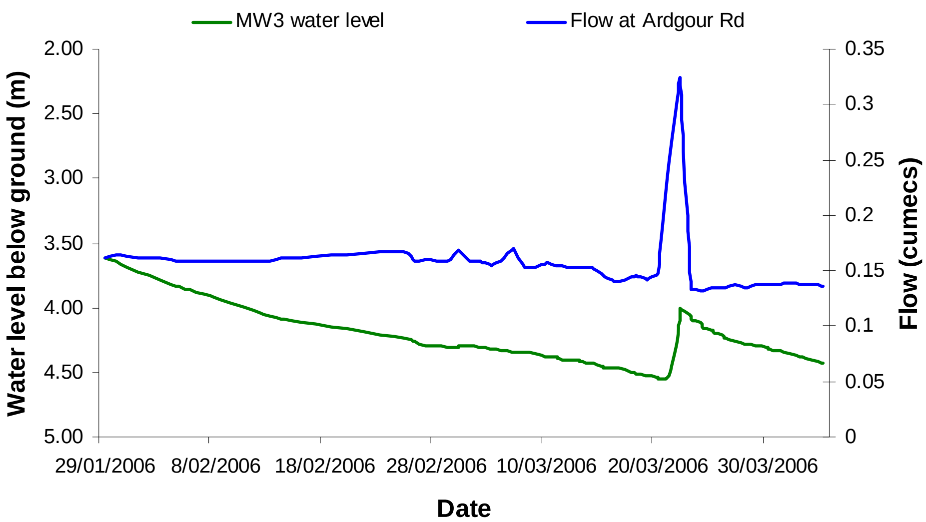

Figure 5.10 Comparison of surface water flows and groundwater levels in the lower Lindis River

Figure 5.10 shows that increased groundwater levels in monitoring bore MW3 increased by 50cm over a short period following the small fresh that occurred on 20 March. This indicates that there is a high level of interaction between surface water and groundwater in the lower Lindis River and that a substantial amount of surface flow is being lost to groundwater.

Figure 5.10 also indicates that there are factors other than stream flows controlling groundwater levels in the lower Lindis River. Flows at Ardgour Rd were relatively stable throughout most of the 2006 study, however with the exception of the small recharge event, groundwater levels declined steadily throughout this period. The most likely cause of declining aquifer levels is a lack of recharge throughout the summer with groundwater abstraction having a less significant effect.

5.3.4 Losses to groundwater during the 2007/08 irrigation seasons

Analysis of surface flow losses during the first half of the 2007/08 irrigation season allows for an accurate assessment of water/groundwater interactions in the lower Lindis River.

Figure 5.11 shows flows in the Lindis River at Ardgour Rd, Lindis Crossing and the Clutha Confluence as well as flow deficits between these sites. To reduce the noise created by small scale flow variation, surface flows and flow deficits have been plotted as a 24 hour moving average. Flows have also been time shifted to allow direct comparisons to be made between each site.

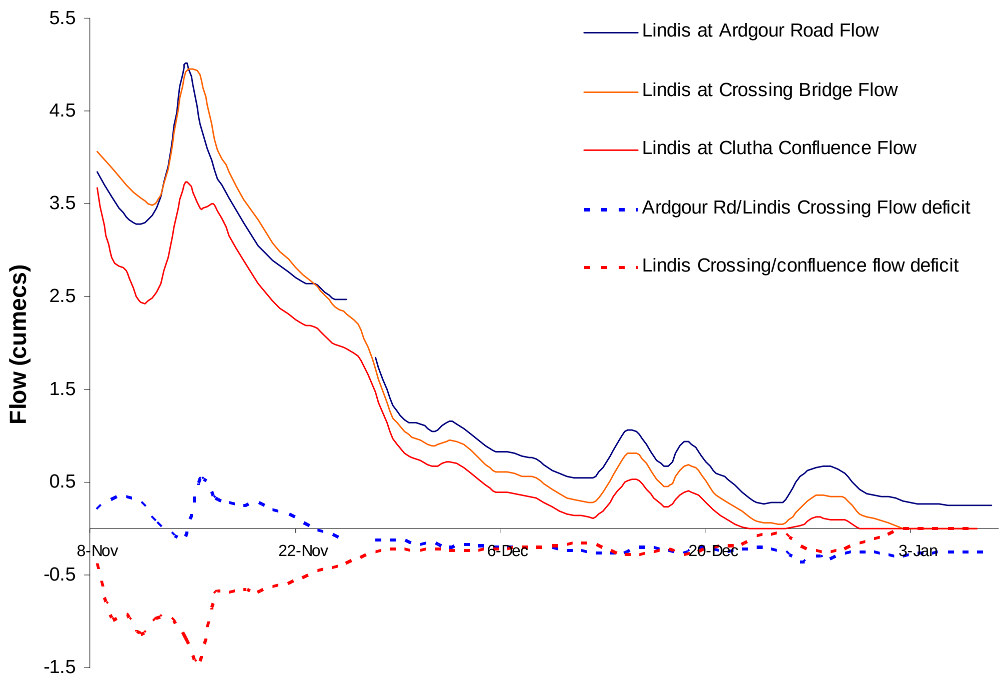

Figure 5.11 Average daily flows (24 hour moving mean) and flow losses in the lower Lindis River

Figure 5.11 shows that there is a gain in surface water flow between Ardgour Rd and Lindis Crossing throughout most of November. This indicates that groundwater levels are sitting above those of the stream channel and that this section is a gaining reach (Figure 5.5). Towards the end of November, surface flow gains decreased and this section of river underwent an inversion and became a connected losing reach (Figure 5.6) for a short period of time. Flow loss then stabilised at approximately 0.22 m^3/s and remained at that level until surface flows at Lindis Crossing ceased on 1 January 2008. The low variation of flow loss indicates that there has been a sharp drop in the water table and this section of the Lindis River has become a disconnected losing reach (Figure 5.7) that is decoupled from the underlying aquifer.

The highest flow deficits observed during the study period occurred during early November between Lindis Crossing and the Clutha confluence (Figure 5.11). It is likely that the large magnitude and highly variable nature of these losses is due a combination of this section being a connected losing reach (Figure 5.6) during this period, as well as its channel morphology. The broad, unconfined channel morphology in this section leads to a large increase in wetted perimeter under moderate flows which in turn leads to an increase in the rate of loss of surface flow (Figure 5.9). As with the Ardgour Rd/Lindis Crossing section, flow deficit variation decreased as surface flow and groundwater became decoupled late in November and then stabilised at approximately 0.22 m^3/s throughout December until surface flows ceased on 23 December. The double peak observed at the Clutha confluence during the high flow period in early November is most likely due to inflows from bank storage (Figure 5.8).

These data indicate that at low stable flows there is a constant loss of approximately 0.44 m^3/s between Ardgour Rd and the Clutha confluence once the river becomes decoupled from the water table. Flow losses become more variable downstream of Lindis Crossing under moderate flows due to the broad channel morphology and are generally more variable while surface flows are coupled to the water table.

Based on a flow loss of 0.44 m^3/s between Ardgour Rd and the Clutha confluence, it is very unlikely that surface flows in the lower Lindis River would cease in an average year if surface water abstraction did not occur. However, during an extreme event such as that observed in 1999 it is likely that surface flows would cease in the lower Lindis River. During the 1999 drought, flows at Lindis Peak reached a low of 0.608 m^3/s (the lowest on record), and taking into account natural losses between Lindis Peak and Ardgour Rd, it is unlikely that sufficient flow would have occurred at Ardgour Rd to sustain the loss of 0.44 m^3/s between this site and the Clutha confluence.

6. Physical habitat and fish assemblages of the lower Lindis River

A detailed study of instream habitat and fish assemblages was undertaken in the lower reaches of the Lindis River downstream from the Lindis Crossing Bridge (Figure 6.1)

Three site visits were planned for February 2007 (13th, 20th & 27th) to take flow measurements and sample aquatic habitat and fish assemblages at three sites below the Lindis Crossing, however the sample area was completely dry by February 27 so no samples were taken. A tru-track flow recorder was installed at the Lindis Crossing Bridge on February 1 to allow for the analysis of flow patterns between Ardgour Rd and Lindis Crossing.

Three monitoring sites were chosen downstream of the Lindis Crossing Bridge to sample aquatic habitat and fish assemblages (Figure 6.1). Site A is located 20m below the Lindis Crossing Bridge, while site B is located a further 100m downstream. Site C is approximately 450m downstream of Site A.

Figure 6.1 Aerial photograph of lower Lindis River showing sampling site locations

The tru-track flow recorder was located upstream of the Lindis Crossing Bridge (Figure 6.3), approximately 100m upstream of the gauging site. The location of the termination of surface flow on February 20 is also shown in Figure 6.1.

Manual gaugings were undertaken between sites A and B on both February 13 and 20 to give detailed bed profiles and total discharge for each sampling date (Appendix 2 and Appendix 3). The total discharge at the gauging site was **0.436** m³/s on February 13 and **0.066** m³/s on February 20 (Table 6.1).

Table 6.1 Lindis Crossing gauging summary

	Feb-13	Feb-20	% change
Total Discharge (m³/s)	0.4364	0.0665	-656
Total Width (m)	8.5	3.6	-236
Total Area (m²)	1.058	0.24	-441
Mean Depth (m)	0.124	0.067	-185
Mean_Velocity (m/s)	0.4125	0.2769	-149
Mean Temp (ºC)	12.94	16.45	79

Table 6.1 shows a substantial decrease in total width and area, as well as mean depth and velocity. Temperature readings taken during the gaugings show that there is an 80% increase in temperature between sampling dates.

Figure 6.2 shows the bed profiles and water levels for both sampling dates.

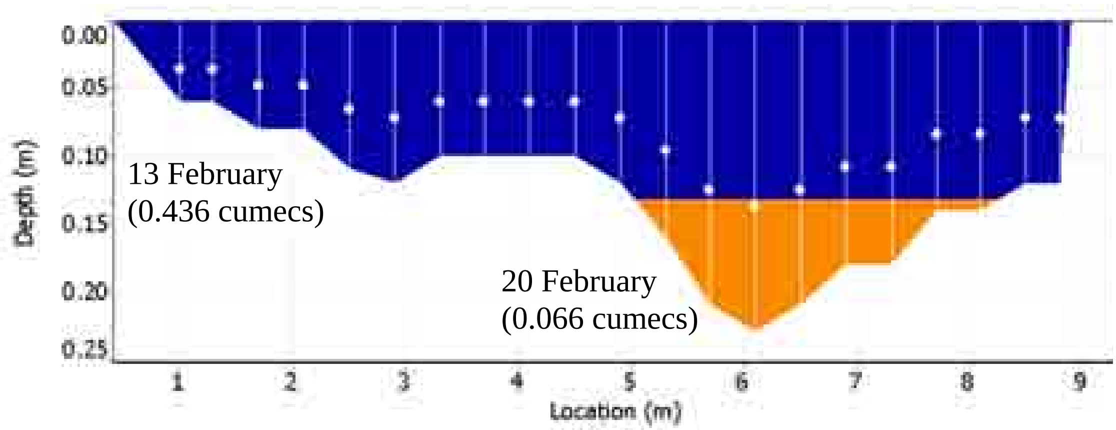

Figure 6.2 Bed profile of gauging site showing water levels for February 13 and 20

There is a significant reduction in channel width and depth at the gauging site between February 13 and 20 (Table 6.1 and Figure 6.2). This shows the effect of flow reduction on fish passage, with the maximum channel depth on February 20 only 0.12m (Figure 6.2).

6.1 Physical habitat

Table 6.1 gives a summary of the habitat type and substrate composition of the three sampling sites.

Table 6.2 Habitat and substrate composition of sampling sites

	Habitat Type (%)			Substrate composition (%)		
	Run	Riffle	Pool	Gravel	Cobble	Boulder
Site A	10	10	80	95	5	0
Site B	95	5	0	30	70	0
Site C	70	30	0	15	70	15

As can be seen in Table 6.2, there is a substantial difference in the habitat characteristics of the three sites. Site A is dominated by a large pool with a substrate comprised mainly of gravel, Site B is a long straight run with a fast riffle at its head and a substrate made up of a combination of gravel and small cobbles, while Site C is a large broad run with riffles at its tail and head and a substrate made up mainly of large cobbles.

Channel width was measured every five meters along the sampling sites to estimate the total wetted area of each site (Figure 6.3).

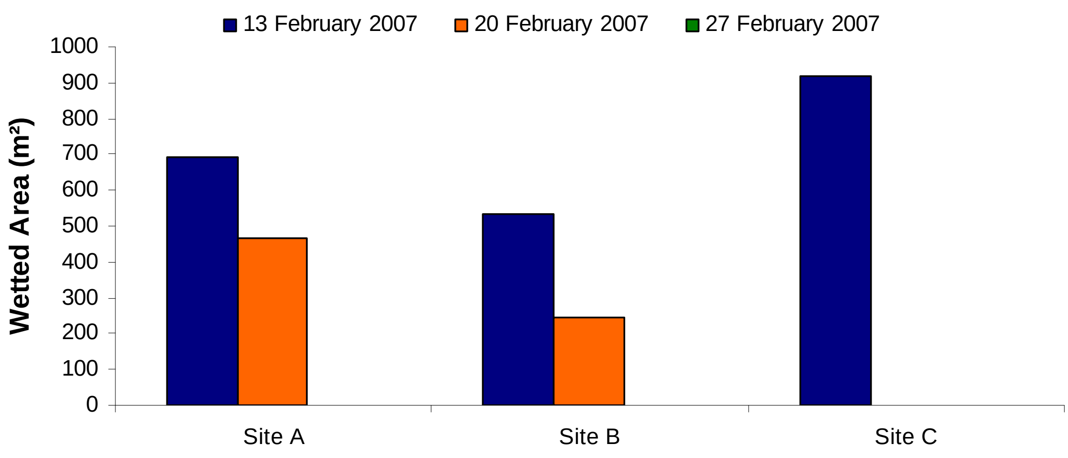

Figure 6.3 Wetted width at each monitoring site

Figure 6.3 shows that wetted width decreased substantially at all sites as flow declined. The extent to which wetted area is affected by changes in flow is dependant on channel morphology; shallow open channels (such as Site C) are more likely to exhibit a greater reduction in wetted width than deeper narrow channels (e.g. Site A).

The average maximum depth for each sampling site is shown in Figure 6.4.

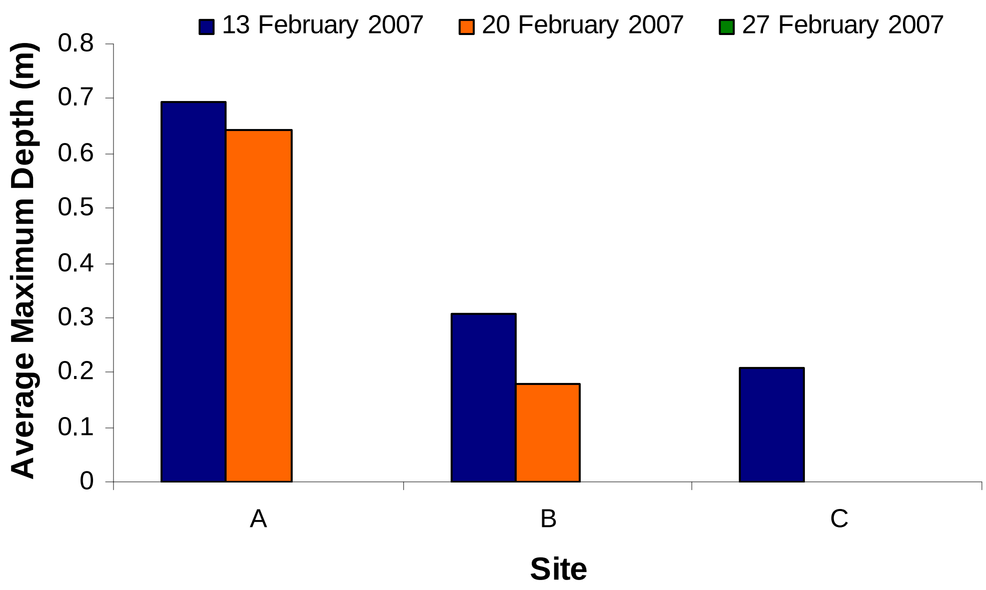

Figure 6.4 Average maximum depth at each monitoring site

As can be seen in Figure 6.4, Site A consists mainly of a large pool, the depth of which is relatively unaffected by reduction in flow. Site C and Site B are dominated by broad shallow run habitats (Table 6.2), exacerbating the effect of flow reduction on available habitat.

6.2 Electrofishing results

Electrofishing was undertaken at all sites on February 13 and at sites A and B on February 20. Site C was not fished on February 20 due to a lack of surface flow. The total estimated fish population for each site is shown in Table 6.3.

Table 6.3 Total fish population estimates

Site	Species	Feb 13	Feb 20
Lindis Crossing Bridge (A)	Brown Trout	34	29
	Common Bully	1*	1*
	Rainbow Trout	1	0
Lindis Crossing Bridge (B)	Brown Trout	32	121
	Common Bully	1*	4*
	Koaro	0	1*
	Rainbow Trout	4	1
	Upland Bully	1*	0
Lindis Crossing Bridge (C)	Brown Trout	86	0
	Common Bully	8*	0
	Koaro	1*	0

* Indicates where insufficient data exists to estimate total population, total fish caught is given instead.

Brown trout were by far the dominant species at all sites, comprising 92.6% of total fish caught during the study. There were also small numbers of common and upland bully present as well as rainbow trout and koaro (Table 6.2).

6.2.1 Brown trout

Brown trout were the only species found in sufficient numbers to estimate total population size (Figure 6.5) and to investigate age class distribution (Figure 6.6).

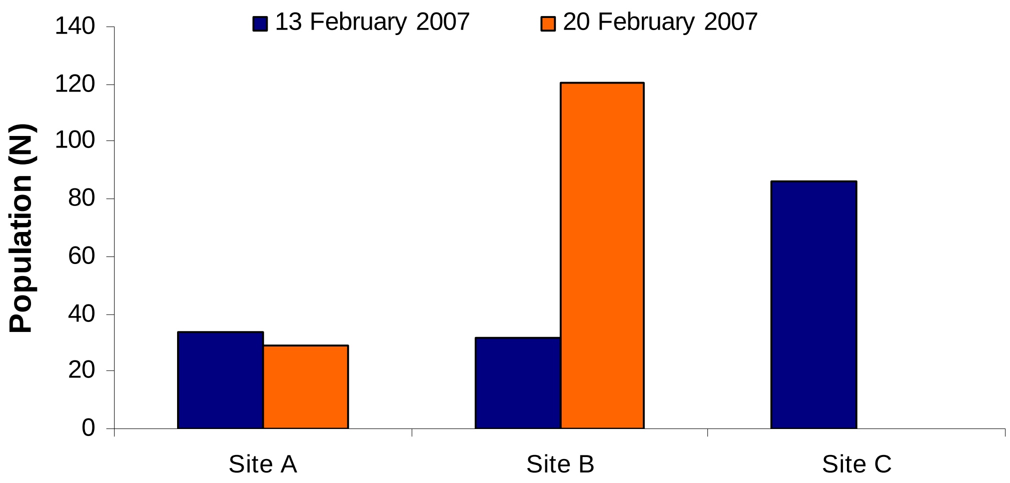

Figure 6.5 Estimated brown trout population

Figure 6.5 shows that the highest number of brown trout are concentrated at the downstream extremity of surface flow on February 13 (Site C) and on February 20 (Site B) when surface flow ceased at site C. Brown trout numbers at Site A remained largely unchanged between February 13 and 20.

Age class analysis was undertaken for brown trout (Figure 6.6), with all individuals measuring between 40mm and 140mm classed as young of the year (0+) and those measuring between 140mm and 210mm classed as over one year old (1+).

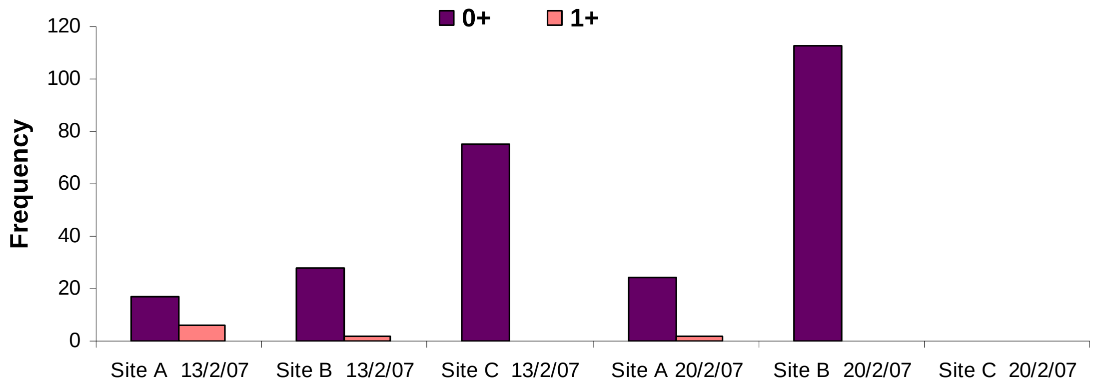

Figure 6.6 Age class distribution of brown trout

Age class distribution of brown trout at all sites was dominated by young of the year fish, which comprised 96.2% of all brown trout captured. All but one of 1+ fish was located in the pool at site A, with the remaining fish found at the top of site B.

The condition factor (K) was calculated for all brown trout (Figure 6.7) using the formula $K = \frac{10^N W}{L^3}$ (Fulton, 1902) where;

- N= 5 (used to standardise K values for brown trout)
- W= Weight (g)
- L= Length (mm)

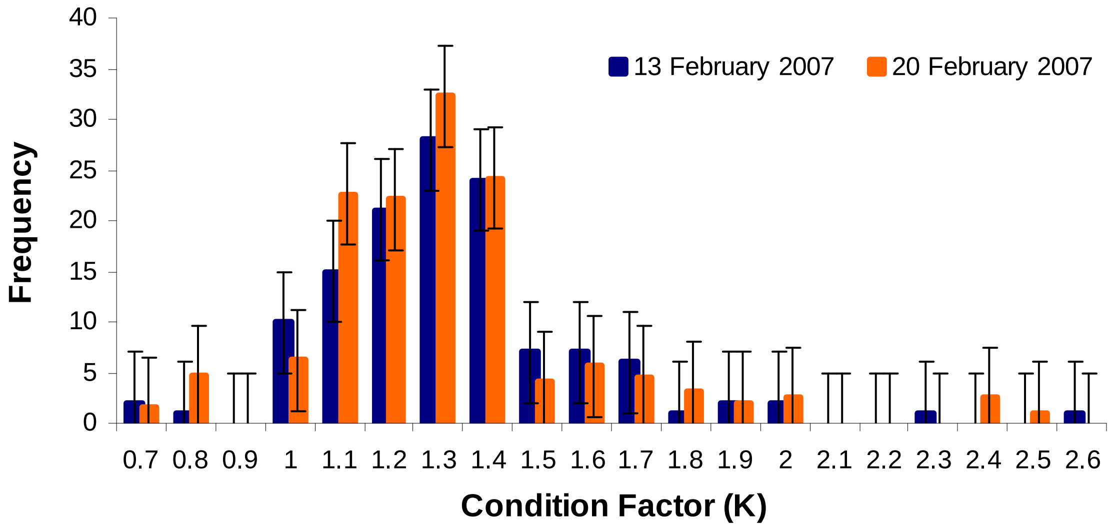

Figure 6.7 Condition factor distribution of brown trout

Figure 6.7 shows that there was no significant difference (P=0.42) in condition factor of brown trout between fish sampled on February 13 and February 20. This is not unexpected as there was only one week between the two sampling dates, which leaves little time for fish to loose condition.

To assess the overall condition of the brown trout population in the lower Lindis River, condition factors for all fish sampled on both sample dates have been pooled (Table 6.4).

Table 6.4 Condition factor (K) of brown trout in the lower Lindis River

Condition	K	% of total fish sampled	% exceedance
	0.7	1.3	100
Extremely Poor	0.8	2.1	**98.7**
	0.9	0.0	96.6
Poor	1	6.1	**96.6**
	1.1	14.1	90.5
Fair	1.2	16.2	**76.4**
	1.3	22.6	60.3
Good	1.4	18.0	**37.7**
	1.5	4.2	19.7
Excellent	1.6	4.7	**15.5**
	1.7	4.0	10.8
	1.8	1.5	6.8
	1.9	1.5	5.3
	2	1.7	3.8
	>2	2.1	2.1

Of the total of 267 fish sampled, 76.4% were considered to be in fair condition or better, with 37.7% in good condition or better (Table 6.4). Only 3.4% of fish sampled were in poor condition or worse.

6.3 Fish passage and refuge habitats

Refuge habitats such as deep pools are essential for fish survival during periods of extreme low flows (Elliot 2000). Most fish exhibit a strong tendency for upstream migration when faced with extreme flow reductions (Davey *et all* 2006, Armstrong *et al* 1998). Two main refuge pools were identified in the study reach; one at the downstream end of Site A (Pool 1) and another approximately 40m downstream of Site C (Pool 2: Figure 6.8).

Figure 6.8 Refuge pool downstream of site C - Feb 13

During sampling on February 13, most brown trout at site B were observed in Pool 1 and several trout were also observed in Pool 2 below Site C (Figure 6.8). The 86% reduction in flow between February 13 and February 20 caused surface flow to stop approximately 200m upstream of Site C (Figure 6.1) and caused Pool 2 to completely dry up (Figure 6.9).

Figure 6.9. Refuge pool downstream of site C – Feb 20

During sampling on February 20, a large number of juvenile brown trout were observed moving upstream at Site B and between Sites B and A in an attempt to find suitable refuge habitat. The increase in brown trout numbers sampled at Site B between February 13 and February 20 (Figure 6.5) indicate that a substantial number of fish had moved from downstream sections and had taken refuge in Pool 1. A fish kill was observed in Pool 2 (Figure 6.10) on February 20, indicating that this location had been utilised as a refuge habitat before drying. However, a lack of connectivity between pools 1 and 2 prevented these fish from further migration.

Figure 6.10 Fish kill in refuge Pool 2, downstream of site C

The relative suddenness of surface flow loss in the lower Lindis River between February 13 and 20 is illustrated by the stranding of several hundred fish in Pool 2. The species composition of the stranded fish was approximately 60% were brown trout, 30% bullies and 10% koaro. Figure 6.10 also shows that there were at least three age classes of brown trout present in the pool – 0+, 1+ and 2+. Although all brown trout in Pool 2 were dead, the majority of bullies and koaro present were still alive.

It is likely that the dewatering and subsequent fish kills observed on February 20 have occurred consistently in the lower Lindis River since high levels of surface water abstraction commenced in the catchment and is the likely reason behind the absence of adult trout in this reach during the study. However, it should be expected that during extreme dry periods these events would occur naturally. These infrequent drying events can be tolerated by fish and invertebrate populations in a climate as dry as that in Central Otago and it is unlikely that such events would cause a significant shift in stream assemblages.

7. Flow requirements: discussion and suggested management flows for aquatic habitat

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

7.1 Lindis River flows discussion based on technical information

With its large catchment size and steep gradient, precipitation patterns differ substantially between the upper and lower Lindis Catchment. The upper Lindis River can receive large amounts of snow and significant rainfall, however the lower Lindis River is subject to very dry conditions throughout most of the year (Figure 2.4).

The flows required to maintain habitat for brown trout are much higher than those required for any native fish species in the Lindis Catchment, therefore it is assumed that management flows implemented to manage brown trout habitat will also provide for native fish within the main stem of the Lindis River. The optimum flow for most fish species is often far greater than the flows required to simply maintain habitat. The flow at which available habitat begins to decrease sharply is known at the inflection point and represents the management flow required to maintain habitat for a given fish species.

Optimum brown trout habitat in the Lindis River occurs at a flow of 4 m^3/s, while the inflection point for adult brown trout habitat occurs at 2 m^3/s. Optimum juvenile brown trout habitat is provided by a flow of 1.4 m^3/s, while the inflection point for juvenile brown trout habitat occurs at 0.75 m^3/s (Figure 4.1). Examination of the hydrological statistics of the Lindis River shows that the 7-day MALF for Lindis Peak (1.6 m^3/s) is well below the optimum flow for brown trout habitat but above the point of inflection. This indicates that adult brown trout are limited by a lack of available habitat at natural low flows in the Lindis River. The 7-day MALF is greater than both the optimum flow and the point of inflection for juvenile brown trout habitat.

7.2 Suggested management flows for aquatic ecosystems

It is clear from the monitoring undertaken during the 2006/07 and 2007/08 irrigation seasons that surface flow losses in the lower Lindis River are due to losses to groundwater. The decline in groundwater levels observed in 2006 is likely due to lack of recharge over the summer period and is likely that this is representative of what occurred over the same period in 2007. Based on the 2007/08 monitoring there is approximately 0.22 m^3/s of flow lost between Ardgour Rd and Lindis Crossing and a further 0.22 m^3/s lost between Lindis Crossing and the Clutha confluence.

[5] Policy 6.4.3 of the Regional Plan: Water for Otago (2004), P. 61
[6] Policy 6.4.11 of t5he Regional plan: Water for Otago (2004), P. 69

The severity of the effect of extreme low flow on fish habitat in the lower Lindis River is largely dependant on channel morphology, with shallow runs and riffles losing surface flow earlier than pools. There was a significant increase in temperature (80%) associated with the reduction in surface flow, although this was below the lethal limits for trout on both sampling dates. Due to the rapid loss of surface flows, it is likely that an absence of surface water is likely to cause the death of fish before temperature becomes a significant issue.

Electrofishing results show that the lower Lindis River supports a significant juvenile brown trout fishery while there is sufficient flow to sustain the population. The river morphology of the lower sections of the Lindis River consist mainly of broad shallow runs and riffles with a substrate comprised mainly of cobbles and boulders – ideal habitat for juvenile trout but less suited to supporting an adult trout fishery. Of the 267 brown trout sampled on February 13 and 20, no adult trout were captured, with 96% of all brown trout captured being less than one year old. This indicates that most trout in this section of the river are either killed by loss of surface flow or able to migrate out of this reach before stranding occurs. The small number of brown trout in the 1+ age class are likely to have migrated into this reach from the Clutha River/Mata-Au or from further upstream.

It has been observed that upland bullies and Canterbury galaxiids (Davey *et al*, 2006) and trout (Armstrong, 1998) respond to extreme low flows by upstream migration. This is supported by the substantial increase in trout numbers seen at Site B when surface flow was lost at Site C and much of the connecting reach on February 20. Large numbers of trout were also observed moving upstream during the site visit on February 20. The dewatering of this section of the river and the lack of stable refuge habitat means that any fish unable to migrate upstream away from the drying reaches will become stranded. It has also been observed by Davey *et al* (2006) and Dale (unpublished data 2007) that under conditions where the cessation of surface flow occurs relatively quickly, fish are less likely to migrate upstream and are more likely to become stranded.

The loss of all surface water from Pool 2, which was approximately 1.8m below the surrounding river bed at its deepest point, indicates that there is also a significant loss of water from the hyporheic and shallow groundwater zones. The loss of hyporheic flow not only prevents the formation of refuge pools, but also removes the refuge habitat used by many invertebrates (Fowler 2004) and some fish species (Davey 2006). The hyporheic zone also acts as an important source of invertebrate colonists at the resumption of surface flows and the loss of this refuge habitat significantly increases recovery time after re-wetting (Boulton 2003). This also supports the conclusion that the lower Lindis River is a disconnected losing reach and is decoupled from the water table and separated by an unsaturated zone.

The Clutha flathead galaxiid is found almost exclusively in small tributaries of the Lindis River where trout are absent and there are no surface water takes, therefore it is not expected that a management flow set on the main stem of the Lindis River will have any effect on these populations.

Despite the differing hydrology of the upper and lower Lindis River, it is recommended that management flows are based on the Ardgour Rd flow recorder and are applied to the entire catchment. There are only a small number of takes upstream of Lindis Peak, therefore there would be little discernable environmental benefit in having a second management flow at this site.

7.2.1 Suggested management flows for Ardgour Rd

7.2.1.1 Suggested management flow for May – September (inclusive)

As discussed in 3.1.1, the Lindis River provides important spawning habitat for both brown and rainbow trout. Based on IFIM assessment, it is proposed that a management flow of **2.2 m^3/s** be implemented at the Ardgour Rd flow recorder between the months of May and September (inclusive). All surface water takes upstream of Ardgour Rd will be subject to this winter management flow, including those upstream of Lindis Peak.

7.2.1.2 Suggested management flow for October – April (inclusive)

Monitoring undertaken by the Otago Regional Council and the IFIM study completed by NIWA has indicated that this reach provides important habitat for juvenile brown trout. However, recruitment from this section is limited by high juvenile trout mortality caused by the loss of surface flows in the lower reaches during peak irrigation season due to water abstraction and losses to groundwater.

Direct observations by the Otago Regional Council and Fish and Game New Zealand during February 2007 has indicted that a flow of 0.4 m^3/s at Lindis Crossing is sufficient to maintain continuous flow and sustain refuge pools between this site and the Clutha River/Mata-Au confluence.

Detailed monitoring of groundwater/surface water interaction in the lower Lindis River has indicated that there is an average flow loss of 0.22 m^3/s between the Ardgour Rd flow recorder and Lindis Crossing and a loss of 0.22 m^3/s between Lindis Crossing and the Clutha confluence. A management flow of **0.75 m^3/s** at Ardgour Rd would ensure that 0.53 m^3/s would remain at Lindis Crossing and 0.31 m^3/s would flow through to the Clutha River/Mata-Au confluence once the water table becomes decoupled from surface flow.

7.2.1.3 Extreme dry year management flow for October – April (inclusive)

Due to the local community's high reliance on water from the Lindis River for both irrigation and stock, a dynamic management flow regime is required to meet the basic needs of the community during extreme low flow events. To provide the flexibility required to achieve this goal, it is suggested that the management flow implemented at Ardgour Rd is dependent on the flows at Lindis Peak, which are a more accurate reflection of the natural flow conditions in the catchment.

To reflect natural extreme low flow events, such as those observed in the 1999 drought, it is proposed that a management flow of **0.4 m³/s** be implemented at Ardgour Rd when flows at Lindis Peak drop below 0.96 m³/s ($Q_{7,10}$).

The trigger point to activate the 0.4 m³/s management flow is the 10 year return period 7-day low flow of 0.96 m³/s ($Q_{7,10}$), which is 60% of MALF. Small scale flow fluctuations around 0.96 m³/s at Lindis Peak can cause the management flow at Ardgour Rd to continuously switch between **0.4** m³/s and **0.75** m³/s, making it impossible for irrigators to respond to these rapid changes. Once flows have dropped below 0.96 m³/s, a bounce back value of 1.6 (MALF) at Lindis Peak will smooth out this effect, allowing irrigators to effectively manage water abstraction within the constraints of the management flows.

If flows at Ardgour Rd remain at 0.4 m³/s for an extended period when groundwater levels are low and decoupled from stream flows, it is likely that surface flows will cease in a portion of the lower reaches of the Lindis River. Based on monitoring data from the 2007/08 irrigation season, it is estimated that surface flows would cease approximately 430 m upstream of the Clutha River/Mata-Au confluence until flows returned to 0.75 m³/s at Ardgour Rd. However, the frequency and duration of these dewatering events is likely to be such that there will not be significant impact on stream assemblages and most refuge pools in this reach will be maintained.

7.3 Effects of management flows on hydrology

When setting management flows, the crucial factors influencing the effect of extreme low flows are low flow duration and flow variability (Fisher *et al* 1982, Jowett 1990, Jowet 1992, Peterson and Stevenson 1992, Dent and Grim 1999, Suren *et al* 2003a, Suren *et al* 2003b). Long duration low flows with little flow variability can promote excessive periphyton growth, lower invertebrate diversity, lower water quality and contribute to increased water temperatures which may impact on fisheries (Jowett 1990, Jowett 1992, Suren *et asl*. 2003a, Suren *et al* 2003b, Olsen 2006).

A key concern when setting a management flow is that flow variability is maintained, with the total amount of water allocated having a large effect on the flow variability in a given catchment. If the amount of water allocated is large relative to the natural flow of the stream a large portion of the stream variability can be removed. This effect can be seen in Figure 2.5 which shows flows at Ardgour Rd essentially flat-lining throughout the irrigation season with very little variation.

River flows in the latter months of the 06-07 irrigation season were among the lowest since records began at Lindis Peak in 1976 (Table 7.1), which allows for an accurate simulation of the effects of management flows during a dry irrigation season (Figure 7.1). Management flow simulations have also been undertaken using data from the 2006-07 irrigation season to simulate a more normal scenario (Figure 7.2).

Table 7.1 Monthly average flows for the 2005-06 and 20006-07 irrigation seasons and long-term monthly average flows at Lindis Peak

	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Monthly average for 2005-06 irrigation season (m³/s)	5.533	2.759	1.744	1.351	0.96	0.939	2.476
Monthly average for 2006-07 irrigation season (m³/s)	6.484	9.642	11.25 8	3.223	1.656	1.397	1.22
Long term monthly average (m³/s)	9.572	6.99	4.92	4.563	2.602	3.341	3.684

7.3.1 Ardgour Rd management flow simulation: 2005/06 irrigation season

Based on instream habitat analysis and detailed habitat surveys of the lower Lindis River (Chapters 4 and 5), a management flow of 0.75 m³/s at Ardgour Rd will provide for juvenile brown trout habitat and maintain surface flows to the Clutha River/Mata-Au confluence. During extreme low flow events such as those observed during the 2005-06 season, it is likely that flows at Ardgour Rd would have dropped below 0.75 m³/s even if no irrigation was taking place upstream.

Due to the local community's high reliance on water from the Lindis River for both irrigation and stock, a dynamic management flow regime is required to meet the basic needs of the community during extreme low flow events. To provide the flexibility required to achieve this goal, it is suggested that the management flow implemented at Ardgour Rd is dependent on the flows at Lindis Peak, which are a more accurate reflection of the natural flow conditions in the catchment. If flows at Lindis Peak drop below a preset threshold level, then the management flow at Ardgour Rd will be reduced to allow for this natural low flow event (Figure 7.1).

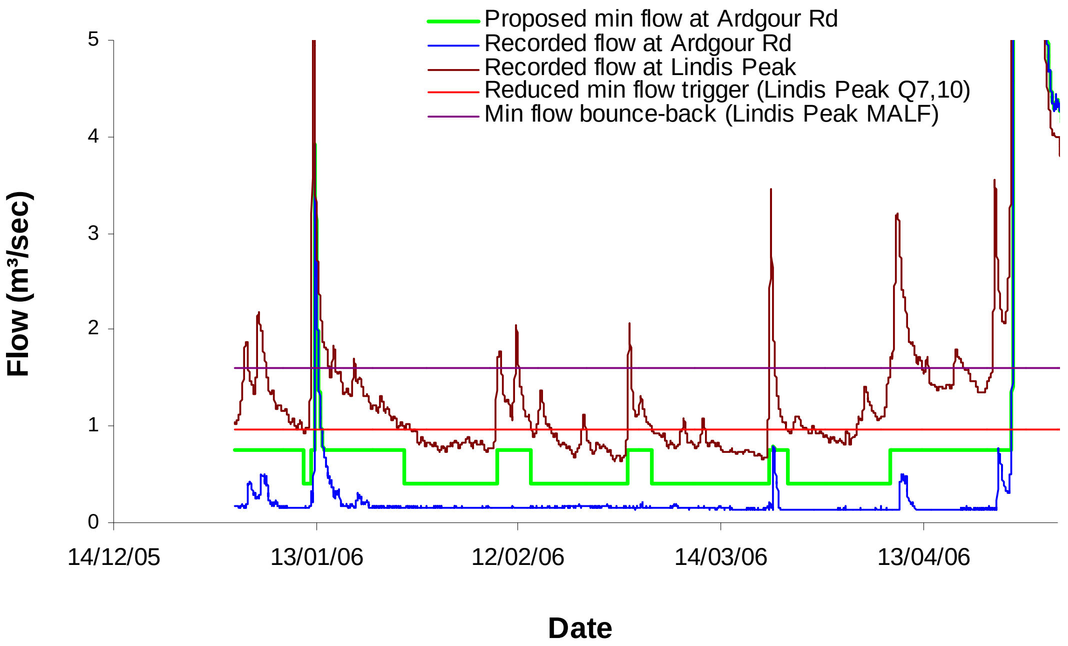

Figure 7.1 Recorded flows in the Lindis River at Ardgour Rd and Lindis Peak (January 1 2006 - June 1 2006). Also shown is the effect of a dynamic management flow based on flows at Lindis Peak, the trigger point of the 0.4 m³/s management flow (Lindis Peak $Q_{7,10}$) and the management flow bounce-back flow of 1.6 (Lindis Peak MALF)

Figure 7.1 shows that the management flow at Ardgour would have dropped to 0.4 m³/s four times during the 2005-06 irrigation season and remained at that level until flows increased due to significant rain events.

7.3.2 Ardgour Rd management flow simulation: 2006/07 irrigation season

Flows at Ardgour Rd during the 2006-07 irrigation season were voluntarily maintained at 0.3 m³/s by irrigators in the lower catchment following consultation with the Otago Regional Council in an attempt to maintain surface flows downstream of Lindis Crossing, with very little flow variability occurring from mid-February (Figure 7.2). As discussed in 2.4.2, the flow deficit observed between Lindis Peak and Ardgour Rd is due to the large amount of surface water abstraction that occurs between the two flow sites. Figure 7.2 shows the low flow variability associated with the large amount of water abstracted from the Lindis Catchment

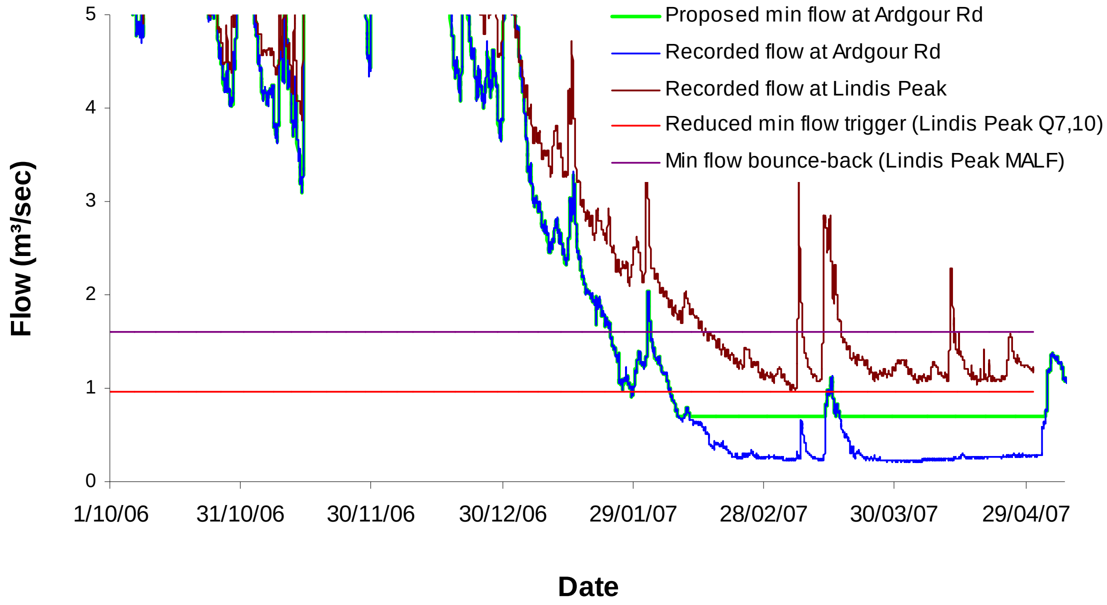

Figure 7.2 Recorded flows in the Lindis River at Ardgour Rd (October 1 2006 - June 1 2007). Also shown is the effect of a dynamic management flow based on flows at Lindis Peak, the trigger point of the 0.4 m³/s management flow (Lindis Peak $Q_{7,10}$), and the 0.75 m³/s management flow bounce-back flow of 1.6 (Lindis Peak MALF)

Under a simulated management flow of 0.75 m³/s at Ardgour Rd, small scale flow variation is likely to remain low due to the high level of upstream abstraction. However, this management flow is not designed to provide a natural flow regime, but to maintain a degree of surface flow to provide juvenile brown trout habitat and refuge habitat in the lower reaches of the Lindis River.

7.3.3 Lindis Peak flow distribution curves (irrigation season)

A flow distribution curve has also been calculated for Ardgour Rd to show the 0.75 m³/s and 4 m³/s management flows and the naturalised 7-day MALF (Figure 7.3).

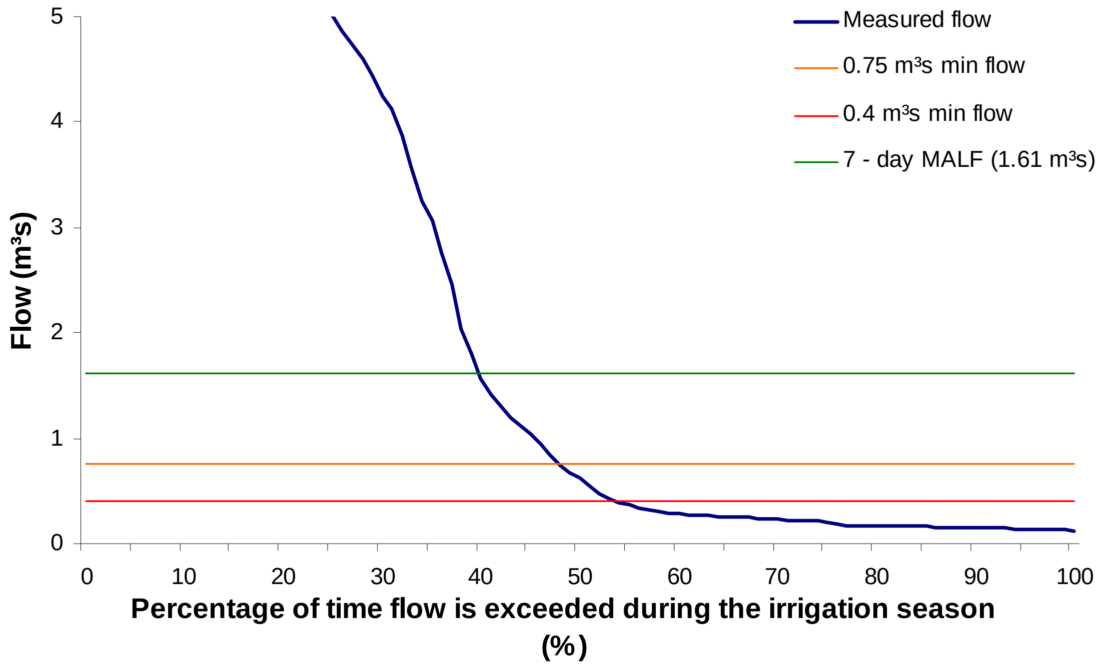

Figure 7.3 Lindis River at Ardgour Rd flow distribution curve (October to April, inclusive) showing the 7-day MALF and the 0.7 m^3/s and 0.4 m^3/s management flows

The flow distribution curve for Ardgour Rd is based on only two years of data and it is likely that the distribution curve is skewed due to the relatively low flows that have occurred over the past two irrigation seasons in the Lindis River. Under the current flow regime in the lower Lindis River, flows at Ardgour Rd fall below the naturalised 7-day MALF (1.6 m^3/s) for 60% of the irrigation season. Flows are below the proposed 0.75 m^3/s management flow for 49% of the irrigation season and fall below the 0.4 m^3/s management flow 46% of the time. The lower end of the flow distribution curve is influenced strongly by irrigation, therefore it is not expected that the management flows at Ardgour Rd would be as restrictive as indicated in Figure 7.3 if irrigation in the lower reaches is managed appropriately.

7.3.4 Lindis Peak flow distribution curves (irrigation season)

Flow duration curves have been calculated for Lindis Peak to show the percentage of time that flows exceed the 7-day MALF of 1.6 m^3/s and the $Q_{7,10}$ of 0.96 m^3/s (Figure 7.4), which is the trigger point for the 0.4 m^3/s management flow at Ardgour Rd.

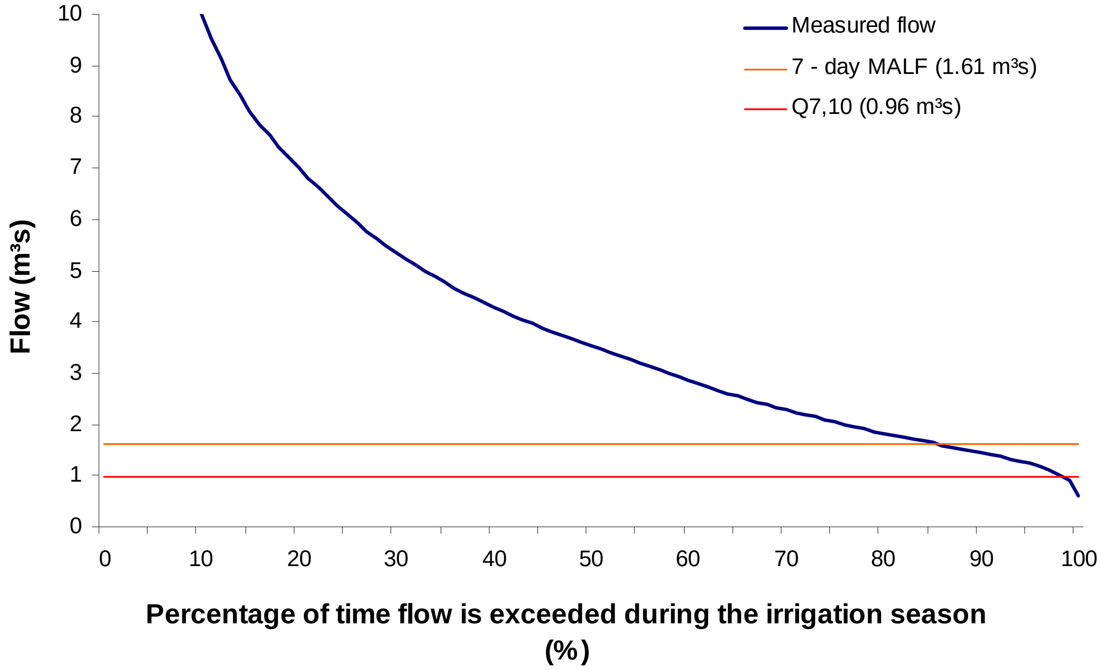

Figure 7.4 Lindis River at Lindis Peak flow distribution curve showing the 7-day MALF and $Q_{7,10}$ values

Figure 7.4 shows that flows dropped below the 7-day MALF (1.6 m^3/s) for 14.5 % of the irrigation season and below the $Q_{7,10}$ (0.96 m^3/s) for 2 % of the time.

7.4 Conclusions

Although the upper Lindis Catchment receives substantial rainfall during winter and spring, the lower Lindis River is one of the driest areas in New Zealand. Flows in the Lindis River are generally high during spring due to snow-melt but are greatly reduced during summer. Based on anecdotal evidence and long-term flow and rainfall monitoring, it is believed that the lower Lindis River naturally runs during extreme droughts.

The Lindis River is listed in Schedule 1A of the Water Plan as having a significant presence of trout, as well as significant habitat for juvenile trout and trout spawning. Detailed monitoring of the lower Lindis River has shown that this section is particularly important for both spawning and juvenile habitat.

There are significant isolated populations of the Clutha flathead galaxiid (*G.species D*) in several tributaries of the Lindis River, however, most of these populations are located above barriers to trout migration and upstream of surface water abstraction. Therefore, these populations will not be significantly affected by any management flow set on the main stem of the Lindis River.

The Lindis Catchment is severely overallocated, with an allocation limit of 0.7 m^3/s and total primary allocation of 3.600 m^3/s, which is comprised mainly of deemed permits (mining privileges).

Such is the extent of surface water abstraction from the Lindis River, the lower reaches of the river become dewatered for much of the irrigation season, resulting in fish kills and loss of habitat for several kilometres upstream of the Clutha confluence.
Instream habitat assessment has identified the following optimum flows and inflection points for fish species in the Lindis River (Table 7.2).

Table 7.2 Suggested flows requirements for fish habitat in the Lindis River based on IFIM analysis.

Target fish species	Recorded 7-day mean annual low flow	Optimum Flow	Flow below which habitat declines sharply
Upland bully, flathead galaxiid	1.6	0.4	0.2
Rainbow trout spawning (winter)	1.6	2.2	1.6
Brown trout spawning (winter)		1.4	0.75
Juvenile brown trout	1.6	1.4	0.75
Adult brown trout	1.6	4	2

Detailed flow monitoring of the lower Lindis River has shown that flow losses in this reach are controlled by surface water/groundwater interactions. As groundwater levels decline over the irrigation season due to lack of recharge from the upper catchment, surface flows become decoupled from the water table and there is a constant loss of 0.44 m^3/s between the Ardgour Rd flow recorder and the Clutha confluence.

Table 7.3 provides a summary of the proposed management flows based on instream habitat assessment and local hydrological conditions.

Table 7.3 Summary of proposed management flows for the Lindis River

Site	Management Flow (m^3/s)	Period implemented	Condition
Ardgour Rd	0.75	Oct-April	NA
Ardgour Rd	0.4	Oct-April	Only implemented when flows at Lindis Peak drop below 0.96 m^3/s and remains in place until flows at Lindis Peak exceed 1.6 m^3/s
Ardgour Rd	2.2	May - Sept	NA

It is proposed that a management flow of **0.75 m^3/s** is implemented at Ardgour Rd during the irrigation season to ensure that habitat for juvenile brown trout is maintained and that surface flows are sustained to the Clutha confluence.

During natural extreme low flow events it is proposed that that a dynamic management flow regime is implemented at Ardgour Rd. When flows at Lindis Peak fall below 0.96 m^3/s (1 in 10 year low flow), the management flow at Ardgour Rd will switch to **0.4 m^3/s**. The **0.4 m^3/s** management flow will remain in place until flows at Lindis Peak reach the MALF value of 1.6 m^3/s, after which it will return to **0.75 m^3/s**. This dynamic management flow will reflect natural extreme low flows and may lead to the temporary dewatering of approximately 430 m of stream bed upstream of the Clutha confluence. However, it is not believed that this will have a significant effect on fish populations due to the occurrence of these extreme events under natural conditions as well the infrequency and short duration of these events.

It is also proposed that a management flow of **2.2 m^3/s** be implemented at Ardgour Rd during the non-irrigation season (May to September inclusive) to provide for rainbow and brown trout spawning habitat.

8. Acknowledgments

The assistance of many people within the Otago Regional Council is much appreciated in the preparation of this report, particularly those who have shared their technical and local knowledge. Assistance from Fish & Game New Zealand and the Clutha Fisheries Trust has also been invaluable as has been the support provided by the Department of Conservation and the National Institute for Water and Atmospheric Research (NIWA).

9. References

Armstrong, J. D., Braithwaite, V. A. & Fox, M. 1998. The response of wild Atlantic salmon parr to acute reductions in water flow. *Journal of Animal Ecology* **67**: 292–297.

Boulton. J.A. 2003. Parallels and contrasts in the effects of drought on stream macroinvertebrate assemblages. *Freshwater Biology* **48**: 1173-1185

Dent. C.L., & Grim. N.B. 1999. Spatial heterogeneity of river water nutrient concentrations over successional time. *Ecology* **80:** 2283-2298

Elliot. J.M. 2000. Pools as refugia for brown trout during two summer droughts: trut responses to thermal and oxygen stress. *Journal of Fish Biology*. **56**: 938-348

Fisher, S.G., Gray, L.J., Grimm, N.B., Busch, D.E. 1982. Temporal succession in a desert river ecosystem following flash flooding. *Ecological Monographs* **52:** 93-110

Fowler. R.T. 2004. The recovery of benthic invertebrate communities following dewatering in two braided rivers. *Hydrobiologica* **523**: 17-29.

Fulton, T. W. 1902. The rate of growth of fishes. *20th Annual Report of the Fishery Board of Scotland 1902*, **3**:326-446.

Hitchmough. R., Bull. B., & Cromarty. P. 2005. New Zealand Threat Classification System Lists. *Department of Conservation*

Jowett, I.G. 1990. Factors related to the distribution and abundance of brown and rainbow trout in New Zealand clear–water rivers. *New Zealand journal of marine and freshwater research* **24**: 429-440.

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

Jowett, I.G. 1995. Spatial and temporal variability in brown trout abundance. *Rivers* **5**: 1-12.

Jowett, I.G. 1989. River hydraulic and habitat simulation, RHYHASIM computer manual. New Zealand Fisheries Miscellaneous Report 49. Ministry of Agriculture and Fisheries, Christchurch

Jowett, I.G.; Richardson J. 1995. Habitat preferences of common, riverine New Zealand native fishes and implications for management flow assessments. *New Zealand Journal of Marine and Freshwater Research 29*: 13-24.

Leprieur. F., Hickey. M. A., Arbuckle. C. J., Closs. G. P., Brosse. S., and Townsend. C. R. Hydrological disturbance benefits a native fish at the expense of an exotic fish. *Journal of Applied Ecology* **43:** 930-939.

Olsen. D.A. 2006. Macrinvertebrates of the Wairau River and the likely consequences of the proposed hydroelectric development. *Department of Conservation Research and Development Series* ***256***.

Peterson, C.G. & Stevenson, R.J. 1992. Resistance and resilience of lotic algal communities importance of disturbance timing and currant. *Ecology* **73:** 1445-1461.

Raleigh R.F., L.D. Zuckerman and P.C.Nelson. 1986. Habitat Suitability Index models and Instream Flow Suitability curves: Brown trout, revised. *U.S. Fish. Wild. Serv. Bio*. Rep. 82: 10-124.

Suren, A.M., Biggs, B.J.F., Kilroy, C., Bergey, L. 2003a. Benthic Community dynamics during summer low-flows in two rivers of contrasting enrichment 1. Periphton. *New Zealand journal of marine and freshwater research* **37**: 53-70.

Suren, A.M., Biggs, B.J.F., Duncan, M.J., Bergey, L. 2003b. Benthic Community dynamics during summer low-flows in two rivers of contrasting enrichment 2. Invertebrates. *New Zealand journal of marine and freshwater research* **37**: 71-83.

Unwin. M. & Image. K. 2003. Angler usage of lakes and river fisheries managed by Fish
And Game New Zealand: Results from the 2001/02 National Angling Survey. *NIWA Client Report CHC2003-114.*

Winter. T.C., Harvey. J.W., Franke. O.L., & Alley. W.M. 1998. Ground Water and Surface Water: A Single Resource. *U.S. Geological Survey Circular* ***1139***.

Appendix 1 Lindis River management flow investigation protocol

A. Select three 30m stream reaches that contains riffle and pool habitats.
1. Between Lindis Crossing bridge and the Clutha River/Mata-Au
2. In the vicinity of the Lindis Crossing bridge
3. Between Lindis Crossing Bridge and the Ardgour flow site.

Place permanent markers at the top and bottom of the site or take GPS readings to allow revisits to accurately identify the original fishing area.

B. Once an area has been selected place stop nets at the top and bottom of the section. This is carried out prior to fishing to reduce fish escapement.

C. The entire reach is fished as a single section. It is recommended that fishing commences in the upstream section and progresses down through the site. Only two nets are required as the site is fished as one section.

D. Three pass electric fishing will be employed with 15 min rest between each pass. If catches have not declined in the first three sweeps, continue fishing until the catch declines to less than 25% of the initial sweep's catch.

E. All fish captured are measured (to the nearest mm) and weighed (to the nearest 0.1 g).

F. Establish transects at 5 equidistant points along the reach (i.e. 0m, 7.5m, 15m, 22.5m and 30m). Measure stream widths at these points. Record water depth readings at 10 equidistant points across these transects.

G. Establish a straight reference line, perpendicular to the flow, drawn between two points at each end of the 30 m reach. Draw a scale sketch of the wetted area, by measuring the distance from the reference line to the edge of the wetted area at 2m intervals – record measurements on sketch and include major objects (e.g. rocks, gravel bars, logs shrubs, trees etc.). The idea is to determine the change in wetted area over time and in different flow conditions.

H. Photograph each site to provide a visual record of in-stream conditions and riparian vegetation. This may require several photographs at each site. In-stream cover and substrate types and percentages should also be estimated (see New Zealand Freshwater Fish Database forms).

I. Record water temperature, dissolved oxygen, ph and tds.

J. Take flow gauging using recognised protocol.

Appendix 2 Gauging summary – February 13

Discharge Measurement Summary

Date Generated: Wed Jun 20 2007

File Information

File Name	Lindis Crossing 13-2-07.WAD
Start Date and Time	2007/02/13 09:24:21

Site Details

Site Name	LINDIS CROSSING
Operator(s)	MD

System Information

Sensor Type	FlowTracker
Serial #	P1438
CPU Firmware Version	3.0
	2.01

Units (Metric Units)

Distance	m
Velocity	m/s
Area	m^2
Discharge	m^3/s

Discharge Uncertainty

Category	ISO	Stats
Accuracy	1.0%	1.0%
Depth	0.4%	1.7%
Velocity	0.6%	1.4%
Width	0.1%	0.7%
Method	1.9%	-
# Stations	2.2%	-
Overall	3.1%	2.4%

Summary

Averaging Int.	40	# Stations	23
Start Edge	LEW	Total Width	8.500
Mean SNR	11.2 dB	Total Area	1.058
Mean Temp	12.94 °C	Mean Depth	0.124
Disch. Equation	Mean-Section	Mean Velocity	0.4125
		Total Discharge	**0.4364**

Measurement Results

St	Clock	Loc	Method	Depth	%Dep	MeasD	Vel	CorrFact	MeanV	Area	Flow	%Q
0	09:24	0.40	None	0.000	0.0	0.0	0.0000	0.00	0.0000	0.000	0.0000	0.0
1	*09:24*	*1.00*	*0.6*	*0.060*	*0.6*	*0.024*	*0.1225*	*1.00*	*0.0612*	*0.018*	*0.0011*	*0.3*
2	*09:25*	*1.20*	*0.6*	*0.060*	*0.6*	*0.024*	*0.1767*	*1.00*	*0.1496*	*0.018*	*0.0027*	*0.6*
3	*09:27*	*1.70*	*0.6*	*0.080*	*0.6*	*0.032*	*0.2534*	*1.00*	*0.2148*	*0.028*	*0.0060*	*1.4*
4	*09:28*	*2.10*	*0.6*	*0.080*	*0.6*	*0.032*	*0.1808*	*1.00*	*0.2166*	*0.032*	*0.0069*	*1.6*
5	*09:29*	*2.50*	*0.6*	*0.110*	*0.6*	*0.044*	*0.3800*	*1.00*	*0.2804*	*0.038*	*0.0107*	*2.4*
6	*09:31*	*2.90*	*0.6*	*0.120*	*0.6*	*0.048*	*0.2656*	*1.00*	*0.2728*	*0.046*	*0.0127*	*2.9*
7	*09:32*	*3.30*	*0.6*	*0.100*	*0.6*	*0.040*	*0.4974*	*1.00*	*0.4315*	*0.044*	*0.0190*	*4.4*
8	*09:33*	*3.70*	*0.6*	*0.100*	*0.6*	*0.040*	*0.4626*	*1.00*	*0.4800*	*0.040*	*0.0192*	*4.4*
9	*09:34*	*4.10*	*0.6*	*0.100*	*0.6*	*0.040*	*0.5472*	*1.00*	*0.5049*	*0.040*	*0.0202*	*4.6*
10	*09:35*	*4.50*	*0.6*	*0.100*	*0.6*	*0.040*	*0.5787*	*1.00*	*0.5629*	*0.040*	*0.0225*	*5.2*
11	09:36	4.90	0.6	0.120	0.6	0.048	0.5063	1.00	0.5425	0.044	0.0239	5.5
12	*09:37*	*5.30*	*0.6*	*0.160*	*0.6*	*0.064*	*0.3601*	*1.00*	*0.4332*	*0.056*	*0.0243*	*5.6*
13	09:39	5.70	0.6	0.210	0.6	0.084	0.5140	1.00	0.4370	0.074	0.0323	7.4
14	09:40	6.10	0.6	0.230	0.6	0.092	0.5075	1.00	0.5107	0.088	0.0449	10.3
15	09:41	6.50	0.6	0.210	0.6	0.084	0.4747	1.00	0.4911	0.088	0.0432	9.9
16	09:42	6.90	0.6	0.180	0.6	0.072	0.4092	1.00	0.4419	0.078	0.0345	7.9
17	09:44	7.30	0.6	0.180	0.6	0.072	0.3254	1.00	0.3693	0.072	0.0266	6.1
18	09:45	7.70	0.6	0.140	0.6	0.056	0.4066	1.00	0.3679	0.064	0.0235	5.4
19	09:46	8.10	0.6	0.140	0.6	0.056	0.4155	1.00	0.4110	0.056	0.0230	5.3
20	09:48	8.50	0.6	0.120	0.6	0.048	0.3914	1.00	0.4034	0.052	0.0210	4.8
21	09:49	8.80	0.6	0.120	0.6	0.048	0.3105	1.00	0.3549	0.036	0.0128	2.9
22	09:49	8.90	None	0.000	0.0	0.0	0.0000	0.00	0.3552	0.006	0.0010	0.2

Rows in italics indicate a QC warning. See the Quality Control page of this report for more information.

Appendix 3 Gauging summary – February 20

Discharge Measurement Summary

Date Generated: Fri Jun 15 2007

File Information

File Name	Lindis Crossing 20-2-07.WAD
Start Date and Time	2007/02/20 10:42:13

Site Details

Site Name	LINDIS CR
Operator(s)	MD

System Information

Sensor Type	FlowTracker
Serial #	P1438
CPU Firmware Version	3.0
	2.01

Units (Metric Units)

Distance	m
Velocity	m/s
Area	m^2
Discharge	m^3/s

Discharge Uncertainty

Category	ISO	Stats
Accuracy	1.0%	1.0%
Depth	0.5%	2.2%
Velocity	1.4%	1.9%
Width	0.2%	0.2%
Method	2.4%	-
# Stations	[illegible]	
Overall	4.3%	3.1%

Summary

Averaging Int.	40	# Stations	15
Start Edge	LEW	Total Width	3.600
Mean SNR	20.9 dB	Total Area	0.240
Mean Temp	16.45 °C	Mean Depth	0.067
Disch. Equation	Mean-Section	Mean Velocity	0.2769
		Total Discharge	**0.0665**

Measurement Results

St	Clock	Loc	Method	Depth	%Dep	MeasD	Vel	CorrFact	MeanV	Area	Flow	%Q
0	10:42	0.00	None	0.000	0.0	0.0	0.0000	0.00	0.0000	0.000	0.0000	0.0
1	10:42	0.20	0.6	0.060	0.6	0.024	0.2364	1.00	0.1182	0.006	0.0007	1.1
2	10:43	0.40	0.6	0.080	0.6	0.032	0.3405	1.00	0.2884	0.014	0.0040	6.1
3	10:44	0.60	0.6	0.110	0.6	0.044	0.4282	1.00	0.3843	0.019	0.0073	11.0
4	10:46	0.80	0.6	0.120	0.6	0.048	0.3923	1.00	0.4102	0.023	0.0094	14.2
5	10:46	1.00	0.6	0.120	0.6	0.048	0.4082	1.00	0.4002	0.024	0.0096	14.5
6	10:47	1.20	0.6	0.110	0.6	0.044	0.3545	1.00	0.3813	0.023	0.0088	13.2
7	10:49	1.40	0.6	0.100	0.6	0.040	0.3400	1.00	0.3516	0.021	0.0074	11.1
8	10:50	1.60	0.6	0.070	0.6	0.028	0.2367	1.00	0.2937	0.017	0.0050	7.5
9	10:51	1.80	0.6	0.070	0.6	0.028	0.2216	1.00	0.2202	0.014	0.0032	4.9
10	10:52	2.00	0.6	0.050	0.6	0.020	0.1820	1.00	0.2015	0.012	0.0024	3.6
11	10:53	2.20	0.6	0.040	0.6	0.016	0.1391	1.00	0.1608	0.009	0.0014	2.2
12	10:54	2.40	0.6	0.040	0.6	0.016	0.1005	1.00	0.1198	0.008	0.0010	1.4
13	*10:58*	*3.40*	*0.6*	*0.050*	*0.6*	*0.020*	*0.1564*	*1.00*	*0.1284*	*0.045*	*0.0058*	*8.7*
14	10:59	3.60	None	0.000	0.0	0.0	0.0000	0.00	0.0782	0.005	0.0004	0.1

Rows in italics indicate a QC warning. See the Quality Control page of this report for more information.

Appendix 4 The 10 lowest average monthly flows at Lindis Peak

Oct		Nov		Dec		Jan		Feb		Mar		Apr		May	
2001	2.177	1989	2.129	2005	1.744	2006	1.351	2006	0.96	2006	0.939	1978	1.216	2007	1.533
1989	3.418	2001	2.561	2003	2.348	1978	1.637	1978	1.035	1978	1.025	2007	1.22	2001	1.72
1999	3.66	2005	2.759	1977	2.451	1999	1.645	1999	1.099	1992	1.2	2001	1.28	2002	1.72
2005	5.533	1990	3.571	1986	2.509	1992	1.79	1992	1.398	2001	1.261	1992	1.407	1988	1.872
1976	6.109	1986	3.728	1991	2.595	1982	1.956	1995	1.536	2007	1.397	2003	1.611	1992	2.026
1977	6.367	1977	4.045	1988	2.632	1981	2.076	1981	1.557	1982	1.511	2002	1.633	2003	2.567
2006	6.484	2002	4.106	1981	2.895	1979	2.084	1982	1.626	1999	1.588	1982	1.897	1991	2.679
1985	6.509	1993	4.238	1987	3.011	1993	2.134	2007	1.656	1993	1.624	1990	1.949	1995	2.71
1997	6.749	1981	4.308	2000	3.39	1989	2.158	2001	1.667	2003	1.652	1988	2.116	1985	2.794
2002	7.036	1997	4.46	1998	3.406	1987	2.205	1998	1.84	1991	1.729	1993	2.321	1978	3.083

Red: 2005-06 season

Blue: 2006-07 season