# Investigation into the Wakatipu Basin Aquifers

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# Overview

## Background

The Otago Region Council (ORC) is responsible for managing Otago's water resources on behalf of the Crown and the community. The basin investigations that ORC conducts from time to time for the 20-plus groundwater areas around Otago are important building blocks in delivering informed water resource management. In recognition of population increase and land-use change in the Wakatipu Basin in the last 20 years, ORC saw the need for a fresh groundwater-resource investigation into its aquifers, including the Shotover floodplain and Frankton Terrace.

## Why is allocation of groundwater necessary?

Compared to surface water, groundwater resources are not visible. Instances of the over-exploitation of groundwater elsewhere have caught communities by surprise, partly due to this lack of visibility. Signs of over-exploitation are hard to spot and occur gradually, often over decades. Placing a limit on the amount of groundwater that can be taken in any particular year, and implementing other controls, helps to prevent the resource from being outstripped.

## Why is water quality management needed?

Substances that can affect groundwater quality tend not to be visible, either. Often the only signs that groundwater quality is becoming affected by contaminants are long-term trends observed in regular analysis of bore water. Once water in an aquifer becomes contaminated, it can take years or decades for the contaminants to be flushed out. It is important, therefore, to look periodically for any discernible trends and to forecast the potential of contamination using scientific techniques.

## What has this study found?

The Wakatipu Basin aquifers were found to be scattered areas of glacial-gravel deposits, separated by schist ridges and major bedrock hills, such as Slope Hill and Morven Hill. The main groundwater system associated with the Mill Creek/Hayes Creek drainage was found to be further subdivided by the waterfall at Millbrook Resort and Lake Hayes. Outlying aquifers were also found at Hawthorn and Morven Ferry. In addition, the Shotover River has lain down gravel deposits to either side of its channel between Arthurs Point and the Kawarau River confluence that contain an alluvial aquifer. The Frankton Terrace has an underlying aquifer of considerable depth and substantial groundwater volume, with the water table lying at Lake Wakatipu level. The various aquifers throughout the Wakatipu Basin are mainly of value for providing domestic water to public, communal and individual water supplies, with very little high volume abstraction being used for irrigation or industry. The aquifers are replenished by rainfall, rivers, creeks, feed springs and out-flowing seepage into the basin.

## What should be done next?

At a regulatory level, the value of the Wakatipu Basin aquifers for providing drinking water should be recognised as ‘groundwater protection zones’ (GPZs). This report proposes that maximum-abstraction limits be taken to the public and water users for consultation and ultimate adoption.

# Technical summary

On the basis of groundwater hydrology, inferred from detailed mapping of geological deposits, (Barrell *et al.*, 1994), this investigation has found that the Wakatipu Basin encompasses six distinct groundwater zones. These aquifers tend to consist of glacial outwash, lake fans and alluvium, containing sand, silt and gravel. Aquifer testing throughout the basin indicated that transmissivity ranged from 700 $m^2$/d to 10,000 $m^2$/d, suggesting moderate to high groundwater yield. Groundwater quality is generally very good, containing low-dissolved solids, low iron and low nutrient. Some minor and isolated arsenic concentrations of health concern are considered to have a natural origin in the basement-rock geochemistry.

Geologically, the Wakatipu Basin is a strongly post-glacial environment, with geomorphology giving rise to basement ridges consistent with *roche moutonnée*[1] landforms. These basement-rock ridges and prominent hills, such as Slope Hill and Morven Hill, have separated the wider basin into a number of aquifers. The aquifers tend to have an up-gradient backdrop against low permeability material, such as schist, lake silts or glacial till and receive recharge from rainfall excess and adjoining surface water before discharging their groundwater as spring and base flows.

Municipal, communal and individual domestic water supplies are the main uses for the Wakatipu Basin aquifers. The Queenstown Lakes District Council (QLDC) maintains public water supply bores at Bush Creek (Arrowtown), Arthurs Point, Rutherford Road spring and Lake Hayes Estate. Extra subdivisions use bores that draw on the Shotover alluvial ribbon aquifer for domestic water supplies.

In this study, as the six aquifers function independently from each other, individual recharge modelling was developed to estimate replenishment rates, allowing the characterisation of each aquifer's water balance, with the exception of the Frankton Flats Aquifer. We propose that glacial outwash and alluvial aquifers be allocated at 50% of mean annual recharge (MAR), as defined in the tables below.

| | Upper Mill Creek Aquifer (Figure 3) ($Mm^3$/y) | Mid-Mill Creek Aquifer (Figure 4) ($Mm^3$/y) | Frankton Flats Aquifer (Figure 8) ($Mm^3$/y) |
|---|---|---|---|
| Mean annual recharge | 0.46 | 0.27 | 0.48 |
| 50% of mean annual recharge | 0.23 | 0.135 | 0.24 |
| Consented allocation | 0.023 | 0.006 | 0.055 |
| Remaining allocation volume [in accordance with Policy 6.4.10A(a)(ii)(1)] | 0.207 | 0.129 | 0.185 |


[1] Rock formation from the passing of a glacier over underlying bedrock, resulting in asymmetric erosion with smooth abrasion on the up-ice side of the rock and plucking on the down side

| | Upper Mill Creek Aquifer (Figure 3) ($Mm^3/y$) | Mid-Mill Creek Aquifer (Figure 4) ($Mm^3/y$) | Frankton Flats Aquifer (Figure 8) ($Mm^3/y$) |
|---|---|---|---|
| Mean annual recharge | 1.19 | 1.02 | 0.42 |
| 50% of mean annual recharge | 0.6 | 0.51 | 0.21 |
| Consented allocation | 0.022 | 0.843 | 0 |
| Remaining allocation volume | 0.57 | Over-allocated (by 0.33 $Mm^3/y$) | Undetermined, aquifer to be managed as surface water |

Remaining undifferentiated glacial-deposit groundwater and fractured-rock groundwater systems in the Wakatipu Basin should continue to be managed under the default groundwater-allocation provisions of the Regional Plan: Water (the Water Plan) (i.e. 50% of MAR). The Shotover alluvial ribbon aquifer should be allocated as surface water, and included in the Water Plan, Schedule 2C.

We suggest that the outwash and alluvial aquifers within the Wakatipu Basin are defined as 'groundwater protection zones' (GPZs) in the Water Plan. In view of the importance of these aquifers for communal drinking-water supply, it is also suggested that the grade of GPZs for these aquifers is set at 'groundwater protection zone A' (GPZ-A). The nitrogen-sensitive zones (NSZs) affecting the Wakatipu Basin should also be retained.

In this report, we suggest that the site of ORC groundwater-level monitoring at the Skinner well in the upper Mill Creek Aquifer be discontinued. The continuous level monitoring should be relocated to the mid-Mill Creek or the Windemeer Aquifers. We propose that wherever ORC installs custom monitoring bores in the Wakatipu Basin, continuous level monitoring is installed at the same time, as a means of improving the quality of the level record.

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# 1. Introduction

The Wakatipu Basin has significant resource and economic importance in the Otago region. Queenstown is the region's second largest urban centre, after Dunedin, and is a significant centre of wealth, due to burgeoning tourism and real-estate markets. Queenstown's urban area lies next to the Wakatipu Basin, on which the township relies to sustain its residential land and infrastructural services. The basin also contains the peripheral urban communities of Frankton, Lake Hayes and Arrowtown, all of which are satellites of Queenstown.

The Wakatipu basin's water and mineral resources have a shared history and remain critical to the social and economic well-being of the area's inhabitants. Groundwater is a significant component of these resources, as it provides the drinking and domestic water for the surrounding population. As groundwater resources require explicit evaluation and management, the Otago Regional Council (ORC) has had a strong interest in studying the basin's aquifers since the early 1990s. This present investigation assesses the groundwater resource and its condition, using available and new information. Its aim is to inform the community of available choices when managing the groundwater resource or water quality in the future.

## 1.1 The study's objectives

1. To characterise the hydrogeology and groundwater hydrology of the aquifers.
2. To provide guidance on the technical considerations in future groundwater-management of the Wakatipu Basin aquifers.

# 2. Background

## 2.1 Location and geography

The Wakatipu Basin is a topographic feature bounded by the south face of Coronet Peak, Crown Terrace, the Kawarau River and Lake Wakatipu. It encloses several communities, including Arrowtown, Lake Hayes and Frankton. The basin lies to the east of Queenstown, the second largest urban area in Otago, and shares a significant community of interest with the town's residents. It is located at the terminus of three large rivers: the Kawarau, the Shotover and the Arrow.

In 1998, ORC produced a series of maps of Otago's aquifers. The map of the Wakatipu Basin aquifer encompassed the non-alpine parts of the Mill Creek-Hayes Creek catchment, the western bank of the Arrow River downstream of Arrowtown, the eastern bank of the Shotover River downstream of Arthurs Point, and the northern bank of the Kawarau River, between the Shotover and Arrow confluences. The area covered in this investigation not only includes all these areas, but also extends onto the Frankton Flats to Lake Wakatipu.

## 2.2 Soils

The Wakatipu Basin has a range of soil types and soil-water properties. ORC has systemised the classification of Otago soils in terms of their hydrological properties. The basin has nine distinct soil-hydrological classes overlying aquifer compartments, which receive rainfall recharge (Table 1).

**Table 1 List of soil hydrology classes, profile available water (PAW) capacities and descriptions**

| Soil-hydrology class | PAW (mm) | Description |
|---|---|---|
| 1 | 30 | Stony sand |
| 2 | 80 | Deep sands |
| 3 | 80 | Shallow, stony soils and moderately deep sands |
| 4 | 150 | Mod. deep sandy loam to silt loam |
| 5 | 150 | Mod. to deep fine, sandy loam, silt loam, silty clay |
| 6 | 180 | Mod. to deep fine, sandy loam, silt loam, silty clay |
| 7 | 60 | Shallow stony soils |
| 10 | 30 | Shallow hill soils |
| 12 | 200 | Deep, sandy loam to silt loam |

## 2.3 Land use

The Wakatipu Basin is a mixed land use area. A study of the status and changes in land use in the Lake Hayes catchment (White and Komischke, 2005) found that rural land (i.e. farming) made up 75% of the land area over the basin floor. Rural residential, low-density residential, resorts and golf courses make up another 11%. Since 1960, there has been a growing trend of over 7% towards these land uses (White and Komischke, 2005). It is considered that the mix of uses and land-use changes in the Mill Creek catchment reflects the rest of the basin, even though the urbanisation of Frankton and Lake Hayes Estate has increased at higher rates.

## 2.4 Geology

### 2.4.1 Basement schist

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

The area west of the basin is a suture zone between the Caples and Torlesse terranes, although these terranes have subsequently been over-printed by the regional metamorphic foliation fabric. The metamorphic textural grade of the area is generally ‘textural zone four’ (TZ IV), which is the second-highest metamorphic grade.

### 2.4.2 Tertiary sediments

The Tertiary sediments of the Manuherikia Formation found elsewhere in inland Otago are not present in the Wakatipu Basin. The basin was deeply glaciated and eroded during tectonic displacement, so any geologic material atop the schist basement is exclusively from the Pleistocene or Holocene periods, largely glacial in origin.

### 2.4.3 Quaternary deposits

The last 2-2.3 million years have seen about 20 glacial periods, punctuated by warming and interglacials. The last glacial period in New Zealand, which occurred between 75,000 to 14,000 years ago, is termed the ‘Otiran Glaciation’. The present interglacial is called the ‘Aranuian’ and includes the Holocene period (last 10,000 years to present day). The Holocene period is characterised by stable sea level and climate, as opposed to the preceding glacial period. The Wakatipu Basin has received repeated intrusions of glacier ice lobes that curled off the main Wakatipu glacier, which extended down the rest of Lake Wakatipu to just beyond Kingston. In some glacial advances, the ice lobes extended a short distance down the Kawarau valley.

The Wakatipu Basin is characterised by several basement-rock ridges running diagonally between the Shotover and Arrowtown rivers, notably Slope Hill and Morven Hill. These ridges display *roche moutonnée*[2] features, such as asymmetry and plucking on the downstream side. The ridges on either side of Speargrass Flat Road display these features clearly.

Aside from shaping the basement rocks, the glacial and interglacials left several characteristic deposits in their wake. Those deposits from the Aranuian interglacial (14,500 yBP[3] to present), Otiran glacial (75,000 yBP), Kaihinuan interglacial (125,000 yBP) and Waimean glacial (180,000 yBP) are the best preserved and thus the most prominent fluvio-glacial deposits in the basin. The resulting glacial/interglacial deposits are included in the following categories, with definitions also found in the glossary:

- basal till: un-stratified, compact, gravelly, sandy and silt/clay deposited at the base of the glacier
- ablation till: loose, clayey gravel or sandy gravel deposited by melting ice
- ice-margin till: layered, sandy gravel, sand and silt deposited on ice-lobe margins
- lake deposits: layered/bedded, micaceous silt (sometimes referred to as 'pro-glacial till', when deposited against the moraine of a pro-glacial lake, or 'varved lake beds', when the bedding patterns are particularly well developed)
- fan and delta deposits: well-graded, sandy gravel deposited into lakes close to the fan or delta
- terrace alluvium: layered, sandy gravel, with minor layers of silt and sand deposited as glacial outwash downstream of terminal moraines, mainly as aggradation surfaces (terraces)
- recent floodplain and lake-beach deposits: coarse-grained alluvial deposits in accordance with their respective modern depositional environments.

The mean Lake Wakatipu water level used to be between 355 m to 400 m above mean sea level (AMSL) (Barrell *et al.*, 1994) higher than its current level of 310 m AMSL. This raised level has left lake, delta, fan and older beach deposits between these elevations. A lengthy still-stand in lake level at 355 m is postulated from the probable down-cutting of the Kingston Moraine to the underlying schist invert (Brockie, 1973), which is correlated with the terminal elevation of lake fans, delta and strand deposits found through significant parts of the basin.

The resulting Quaternary deposits are variable, but the most profound influences on groundwater flow are thought to be provided by the geometry of the basement schist and contrasts within Quaternary deposits, such as contacts between sandy gravel and lake silts.

[2] A rock formation created by the passing of a glacier. The passage of glacier ice over underlying bedrock often results in asymmetric erosional forms as a result of abrasion on the 'stoss' (up-ice) side of the rock and plucking on the 'lee' (down-ice) side.
[3] yBP = 'years Before Present'

## 2.5 Water use

The Wakatipu Basin is served by the following sets of water infrastructure:

- the Arrow Irrigation Company Ltd's water scheme, which uses above-ground pipelines and open water races
- QLDC water supplies and water-scheme extensions, using the following water sources:
  - Lake Wakatipu
  - Arthurs Point bores
  - Bushy Creek bores
  - Rutherford or Slope Hill spring (Lake Hayes)
  - Lake Hayes Estate bore (near Hayes Creek).
- numerous communal water supplies, mostly obtained from groundwater.

### 2.5.1 The Arrow River Irrigation Scheme

Dating back to 1926 or earlier, the Arrow River Irrigation Scheme is the earliest remaining operational water scheme in the Wakatipu Basin. The scheme uses a weir across the Arrow River, upstream of Arrowtown, to divert about 700 l/s into a steel pipeline that winds its way alongside the Arrow River to the Bushy Creek confluence. The water abstraction on the Arrow River is authorised by Mining Privilege 1440 AR, which allows the taking of 50 heads or 1,389 l/s of river water. The race and pipeline infrastructure is estimated to be capable of carrying half of the authorised rate, suggesting a diversion of about 700 l/s. Furthermore, irrigation water is discharged, through scour valves, at a few locations along the pipeline route, into the Arrow River, Bushy Creek or Mill Creek.

The pipeline passes upstream through the Bushy Creek gully and discharges into a set of water races on the industrial edge of Arrowtown. The two water races consist of the 14 km western branch (Hayes basin race) that crosses Mill Creek, Mooneys Swamp and the Shotover River in long pipeline siphons, and the 11 km Arrow Junction race that traverses the 400 m contour from Arrowtown to Morven Ferry Road. Both water races include surplus water-discharge structures ('by-washes') into Bushy Creek, Mill Creek and the Shotover River, and, at their respective termini, into Lake Wakatipu and the Kawarau River. The Hayes race also used to discharge by-wash into Lake Johnston as it passed near the saddle between the Shotover River and the lake, although this practice has been discontinued in recent years. The management company estimates the irrigation scheme command area to be 703 ha. Figure 1 maps the irrigation systems features as they pertain to the Wakatipu Basin. The command area has served only four farms in recent years, but includes several golf courses with significant water requirements. Examination of aerial photographs of the path of the water races notes the absence of border-dyke development, suggesting that almost all irrigation is undertaken using the 'wild-flood' method. Golf courses use pumps and sprinkler systems for watering fairways and greens.

The irrigation races extend as far as the remaining pasture areas of the Frankton Flats, although urban encroachment has steadily diminished the land area under irrigation in recent years. Much of the land irrigated consists of schist-basement areas, rather than alluvial or glacial outwash, which is significant when considering groundwater hydrology (see section 2.7).

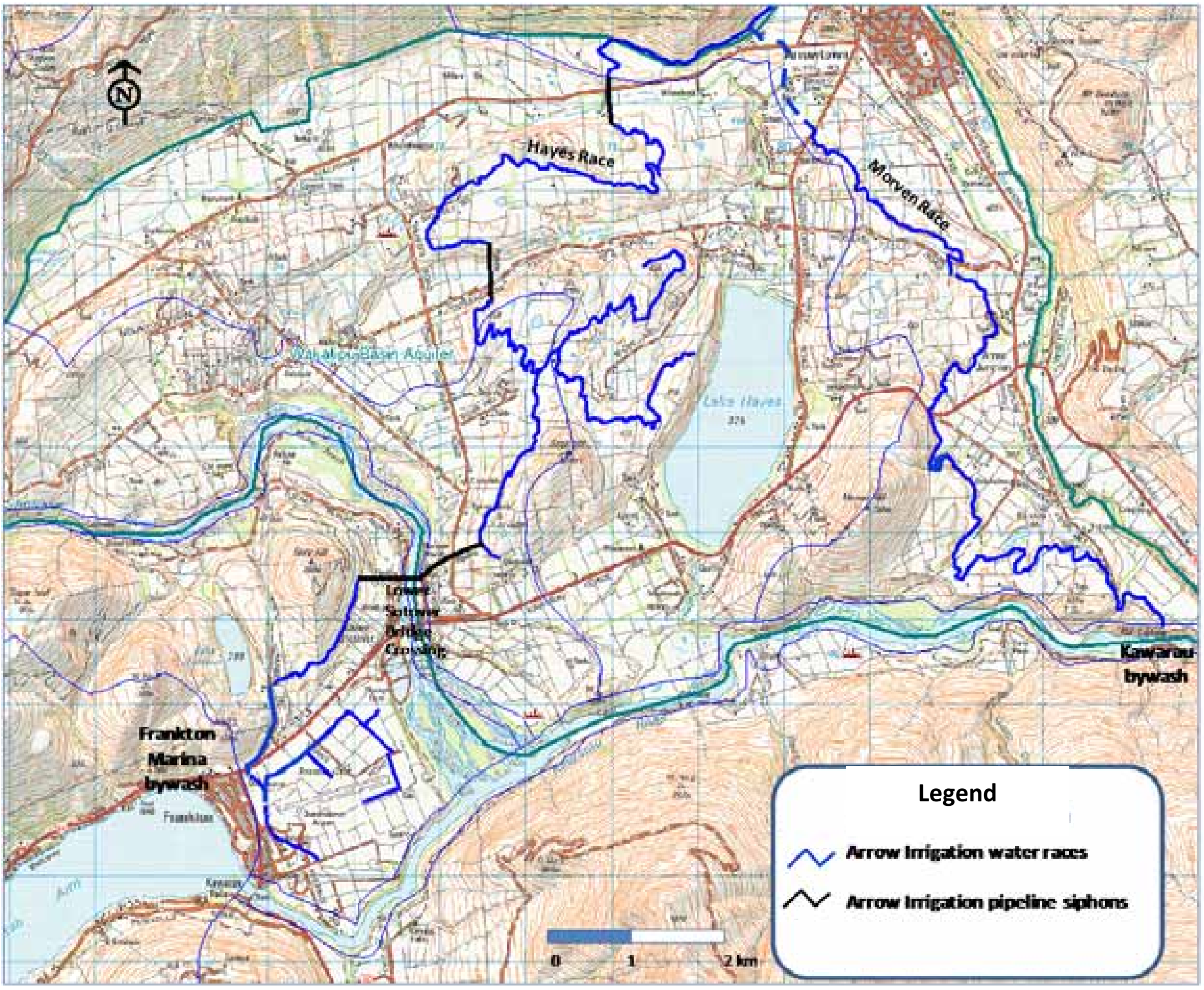


**Figure 1** **Alignment of the Arrow River Irrigation Scheme's water races, pipeline siphons and terminal by-washes**

### 2.5.2 The Queenstown Lakes District Council water supplies

The Queenstown Lakes District Council (QLDC) has developed its water supplies progressively as the population and water-service requirements in the Wakatipu Basin have grown. The first piped water supplies within the basin were an extension of the borough water supplies from Queenstown to the built-up area of Frankton and the supply of Arrowtown from Bushy Creek.

#### *2.5.2.1 Frankton Flats and Quail Rise*

The intake from Lake Wakatipu for use by Kelvin Heights feeds the water pipelines to the Frankton Flats and Quail Rise pressure zones. The Frankton pressure zone serves the residential and commercial areas of the Frankton Flats, including the watering of grassed areas.

#### 2.5.2.2 Arrowtown and Millbrook Resort

Arrowtown was originally supplied with water from Bushy Creek by open water races, without the use of bores. A series of wells and bores were progressively installed in the floodplain of Bushy Creek next to the township after World War II. Currently, a 15-m supply well and a 19-m bore provide the water requirements for Arrowtown and the adjacent Millbrook Resort.

The Arrowtown pressure zone encompasses 183 ha and coincides with the former Arrowtown Borough Council area. Millbrook Resort's pressure zone, connected after its development, south-west of Arrowtown, encompasses 197 ha. The registered community water-supply population is listed as 2,820 individuals.

#### 2.5.2.3 North Lake Hayes and Lake Hayes Estate

The current head-works for the North Lake Hayes' water supply was commissioned in 2001. The supply obtains raw water from a large spring on the shores of Lake Hayes at the end of Rutherford Road. Expansion of the semi-urban and rural-residential water requirements in the last 20 years has resulted in the extension of the supply zones to encompass the entire lake shore and overlooking slopes. The core supply area is 664 ha. An extra 160 ha of bulk connections have been made to the Windemeer and Morven Hill private water systems on the eastern shore of the lake. The registered community water-supply population is listed as 584 individuals.

The Lake Hayes Estate, south of the lake and SH6, was initially supplied as a private water scheme, established by the property developer in 2003. QLDC assumed ownership and operation of bore F41/0331 in 2006. The system serves a nominal 65 lots. Some literature mentions operational integration as at November 2007. It has been agreed that the 25-lot Hayes Creek subdivision is to be added to the Lake Hayes Estate water supply.

### 2.5.3 Private-communal water supplies

From 1969 onwards, several private water supplies have been established in response to the needs of increasing density of rural-residential development. The largest and earliest of these was the Dalefield Water Supply, which serves 78 lots, mostly 4 ha holdings subdivided in the 1970s as 10-acre blocks for lifestyle residences. The water supply serves a registered community population of 300 individuals. The 2006-mesh block covering the Dalefield group of properties indicates a resident population of 153 individuals in 51 dwellings, suggesting a high level of non-occupancy on many of these small holdings.

ORC has registered 54 wells or bores as communal water-supply sources in the course of compiling the database for the Wakatipu Basin. Examining the consent database for groundwater-take consents, about 25 private-communal water supplies for rural-residential or suburban housing have secured resource consent for groundwater. The estimated number of dwellings served under those groundwater consents is 370, although, in many cases, development has yet to be undertaken, or the service area has been incorporated into a QLDC water-supply scheme.

Available information suggests that small-scale private water schemes tend to use bores that have been installed in the Quaternary alluvial or outwash groundwater systems within the basin.

Where dwellings are not located over readily developed groundwater supplies (e.g. basement rock), then a community of interest is often formed to distribute water from the nearest convenient bore throughout a wider group. An example being that a land developer provides a communal bore-water system for the lots within the subdivision. In many cases, the private water supplies have been made redundant by the extension of public water supplies, especially the Lake Hayes and Lake Hayes Estate network. Figure 2 maps the public and significant private water supply areas, as well as those source bores for each of the supplies that occur in the Wakatipu Basin.

A feature of the location of the source bores for the private water schemes in the west of the basin is that they are located on the floodplain of the Shotover River (the Shotover alluvial ribbon aquifer (Section 5.8)). The Arthurs Point urban area is supplied from two bores on the floodplain opposite the Shotover Jet premises.

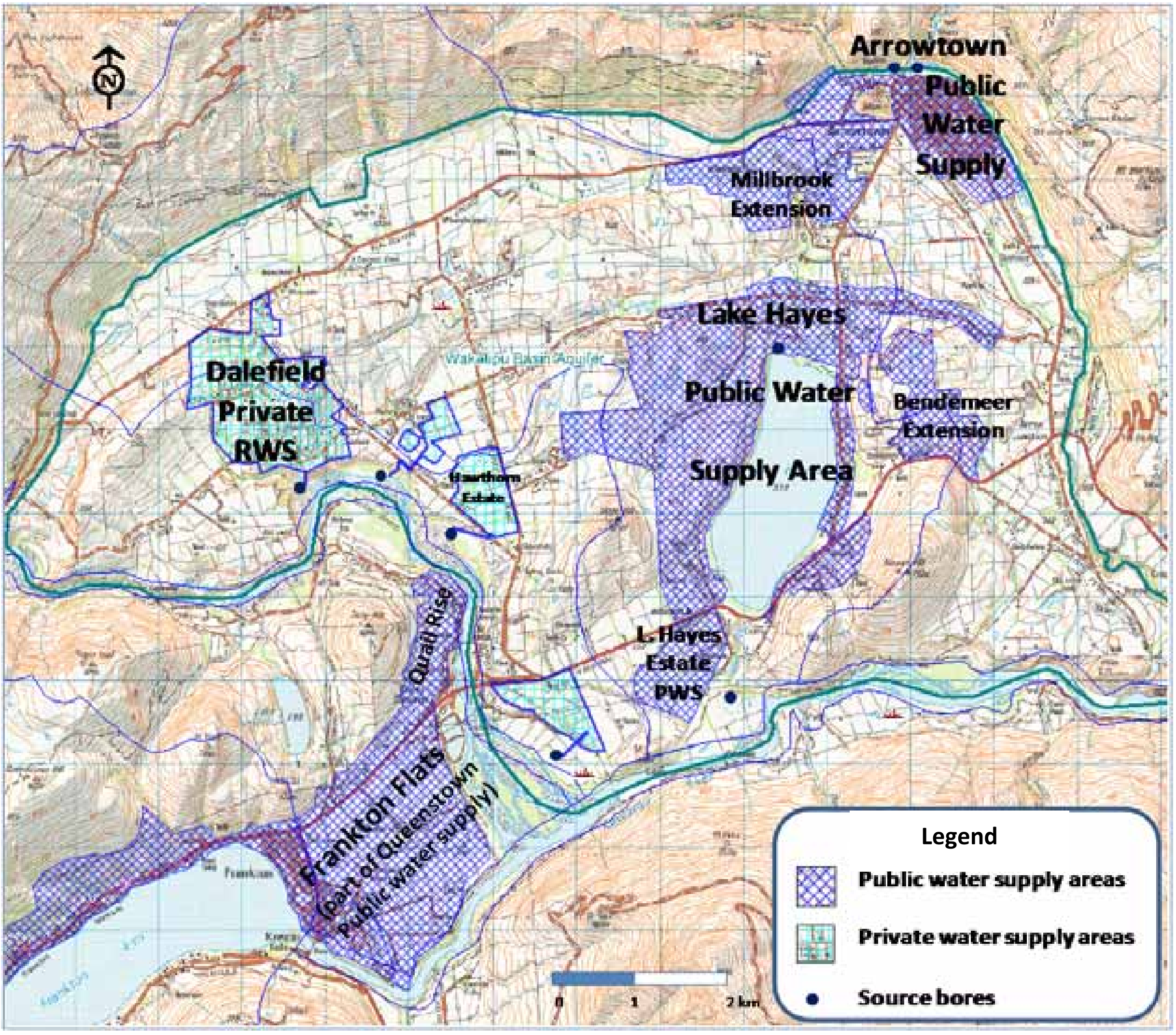


**Figure 2** **Distribution of public and significant private water supplies across the Wakatipu Basin**

### 2.5.4 Private-individual groundwater supplies

Besides the public water supplies and the larger private-communal water supply areas, the default water supply source is groundwater from bores, wells or springs. ORC records count 125 private-individual water wells or bores in the Wakatipu Basin. It would be unwise to ascribe the total number of wells and bores to operational individual water supplies because there has been progressive land-use change and spread of piped water supplies across the floor of the basin. The first integrated survey of water bores in the basin between 1995 and 1996 (Rosen *et al.*, 1997) noted a diminishing reliance on the existing private-bore network recorded in the survey.

To the west of the Dalefield water supply area, several properties along Littles Road obtain water for domestic and crop watering purposes from springs discharging at the flanks of Mountain View Ridge. Several individual water supplies in the Morven Ferry flats pump from a set of springs found above the banks of the adjacent Arrow River. A small number of domestic water supplies are drawn from the Arrow Irrigation water races where they pass by, although this practice does not have the approval of the irrigation company due to possible non-compliance with the drinking water regulations.

## 2.6 Wastewater discharges

The default household wastewater service in semi-rural areas such as the Wakatipu Basin is the on-site septic discharge. An on-site system is typically a holding tank for settling and primary treatment, which then doses the liquid overflow to the soil by slow infiltration. As the density of housing becomes greater, the ability to continue using the on-site septic discharge systems becomes less economically viable and can lead to insanitary conditions or poor downstream water quality outcomes. Instead, reticulated sewage collection has been installed within medium- to high-density residential areas of the basin. These areas include those reticulated with public water supply in Figure 2.

ORC holds current resource consents for the on-site discharge of wastewater for 33 dwellings and premises within the basin where the site lies outside a reticulated sewage network. However, the number of consents only counts those discharges within the Mill Creek catchment above Lake Hayes, within 50 m of a water body, within 50 m of a water bore, or for more than 2 cubic metres per day. All other on-site discharges require district council building consent, and many dwellings have existing use rights to discharge without consent. About 3,850 people are served with reticulated wastewater disposal in the basin. Reticulated wastewater is piped for treatment at the Frankton Wastewater Treatment Facility on the Shotover River floodplain at the Shotover delta. This facility discharges treated water into the Shotover River and is transitioning to a shallow subsurface discharge into floodplain gravels. The Frankton Flats are fully reticulated for wastewater, including the Frankton urban area, the airport and industrial areas.

## 2.7 Hydrology

### 2.7.1 Surface water

The basin is a significant junction in the surface water hydrology of the Clutha/Mata Au catchment. Lake Wakatipu discharges into the Kawarau River at Frankton. A short distance downstream, the Kawarau River is joined by the smaller Shotover River at the Shotover delta. The Shotover River enters the Wakatipu Basin at Arthurs Point and has a median flow of 30.85 cubic metres per second ($m^3/s$). The combined Kawarau-Shotover River flow is measured at the Chard Road recorder site, 8.2 km downstream, and the median-flow rate is 188.2 $m^3/s$. The median-flow rate of the Arrow River is 2.69 $m^3/s$ and it enters the Kawarau River, downstream of the Chards Road recorder site. The Arrow River is significantly abstracted by irrigation intakes, as described above.

### 2.7.2 Groundwater

As groundwater hydrology is covered in sections 4 and 5, a brief introduction only is given here. The GNS Science report (1997) found the Wakatipu basin to hold pockets of groundwater, mainly within alluvium and glacial outwash (Rosen *et al.*, 1997), and encompasses the 'Wakatipu Basin aquifer' area later delineated by ORC. Subsequently, ORC undertook, but did not publish, a groundwater-resource assessment (ORC, 2003). An investigation into the groundwater beneath the Frankton Flats Aquifer was carried that explored the option to supply water for the proposed Five Mile development in the Frankton Terrace. The study found a highly transmissive outwash aquifer with an apparent hydraulic connection to Lake Wakatipu, Kawarau River and Shotover River (Taulis *et al.*, 2007). The floodplain alluvium of the Shotover and Kawarau rivers also has significant groundwater resources, albeit in close connection with the associated rivers.

The main aquifer areas in this study are shown in Figure 3 to Figure 6.


**Figure 3** **Outline of Upper Mill Creek Aquifer, including estimated water-table contours**

The upper Mill Creek aquifer is a thin, elongated valley deposit, containing glacial outwash. The aquifer follows upper Mill Creek until the creek passes onto low permeability schist rock and the Millbrook waterfall.

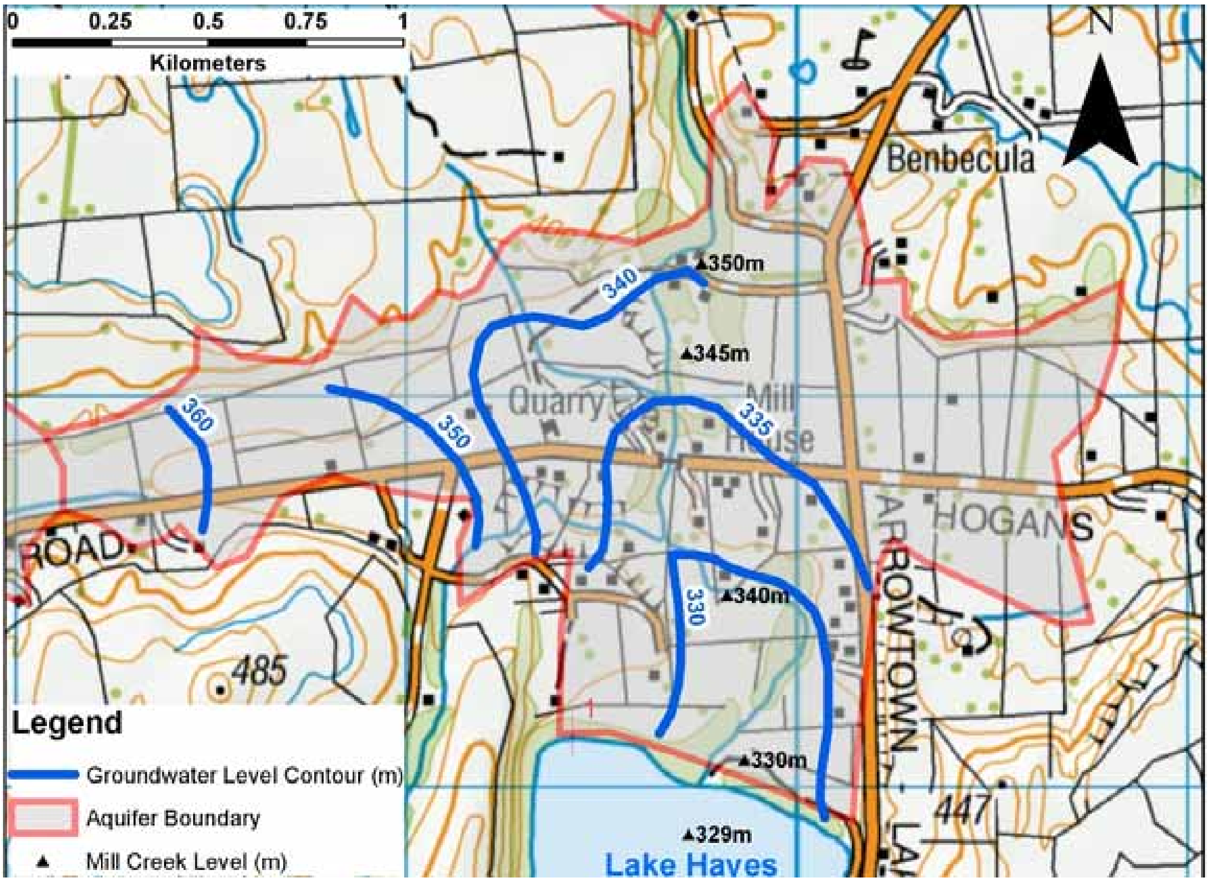


**Figure 4** **Outline of the mid-Mill Creek aquifer, including estimated water-table contours**

The mid-Mill Creek Aquifer includes outwash and fan deposits at the head of Lake Hayes. The aquifer begins near the base of the Millbrook water fall and ends at the lake shore. The Speargrass Flat and Hogan Gully arms of the aquifer are significant sub-branches, as is the Slope Hill Gully arm. The Rutherford spring is found at the end of Rutherford Road, close to the lake shore. Its bore level is marked with a value of 333.68 m in Figure 4.

The drilling contractor estimated groundwater level contours by using survey bore collar elevation and 1996 dipped water levels or land surface elevations and initial dipped water levels. The groundwater level contours are consistently lower than the overlying Mill Creek water levels. The difference in water levels suggests that the creek is perched above the water table. This configuration allows for the creek to lose water through creek bed infiltration to the aquifer.

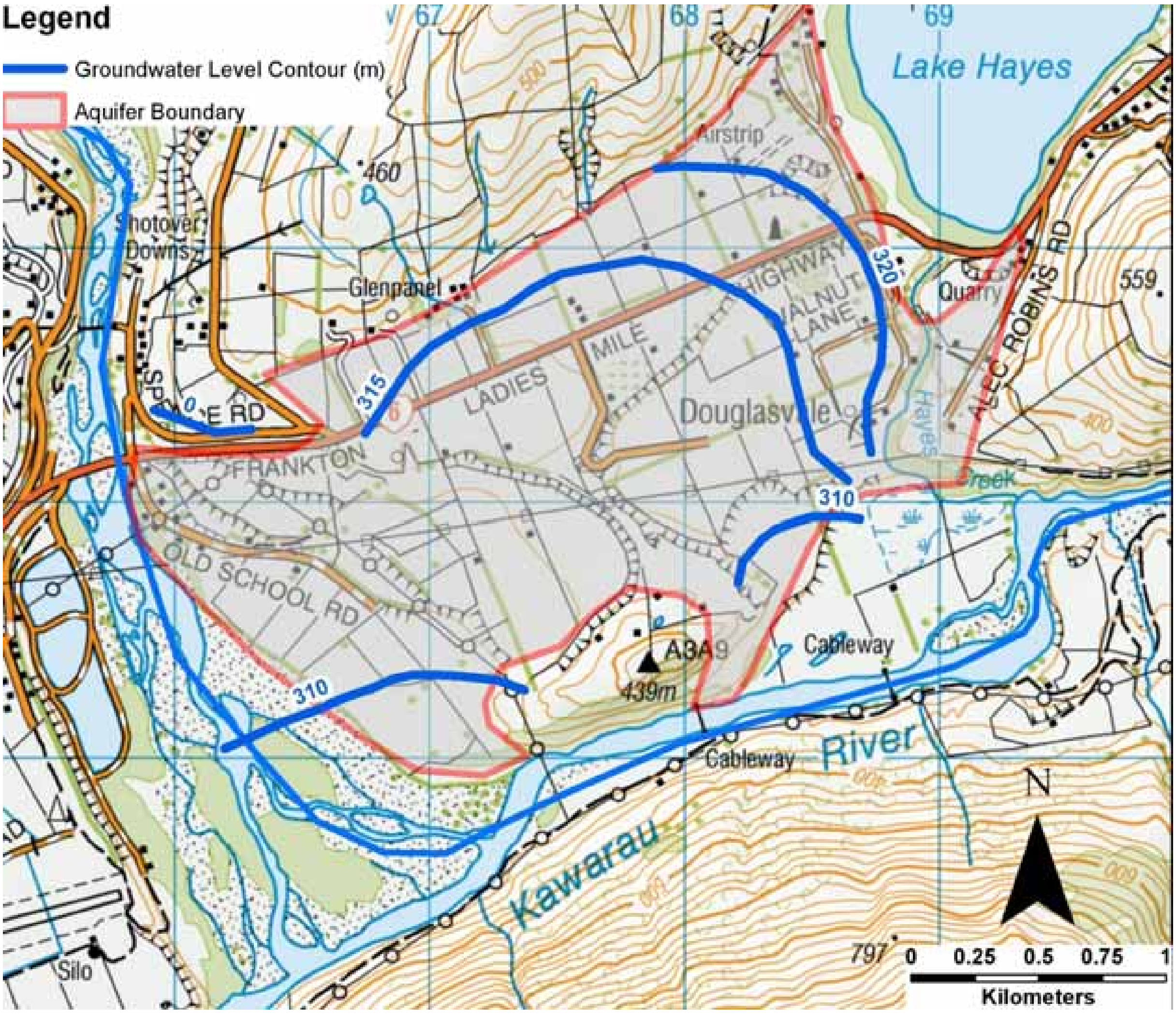


**Figure 5** **Outline of the Windemeer Aquifer, including estimated water-table contours**

The Windemeer Aquifer comprises outwash and outwash fans contemporaneous with the Frankton terrace opposite it on the true right bank of the Shotover River. The main terrace has a mean surface elevation of 355 m AMSL, while the next terraces down average 340 m AMSL. The aquifer is split to south-east and south-west by a schist rock ridge overlooking the Kawarau River. A narrow isthmus extends between the 355 m terrace and the schist ridge.

The water table rests at elevations between 320 m and 310 m AMSL beneath both sets of terraces. The low groundwater gradient across the aquifer suggests a relatively high aquifer permeability or low recharge rates. As Lake Hayes' contact with the Windemeer Aquifer is believed to be interrupted by low permeability, varved silt lake sediments, the flow of lake water, from a mean elevation of 329 m AMSL into the aquifer, is considered to be minimal.

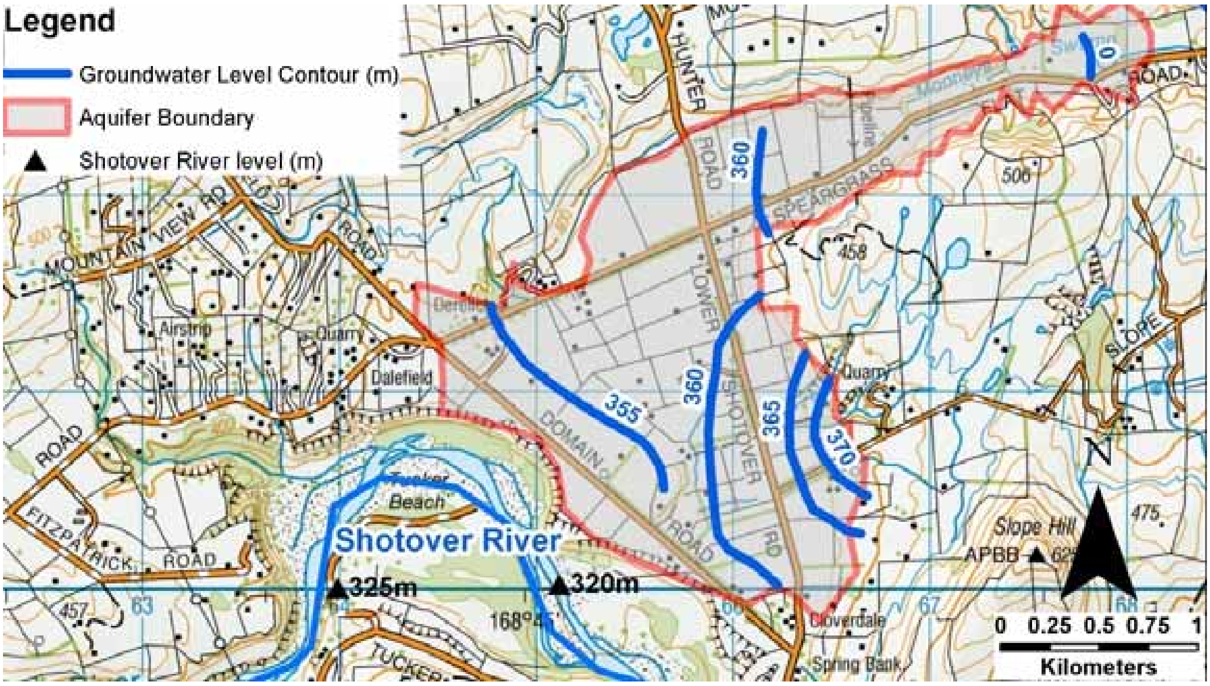


**Figure 6** **Outline of the Hawthorne-Speargrass Aquifer, including estimated water-table contours**

The Hawthorne-Speargrass Aquifer consists of coalescing fan deposits, truncated by modern down-cutting by the Shotover River. The Speargrass Flat arm of the aquifer joins the mid-Mill Creek Aquifer at Mooneys Swamp, but grades south-west towards the Shotover River. This arm of the aquifer has a gentler groundwater gradient, as indicated in Figure 6, and higher rates of spring flow than the Hawthorne arm next to it. Both phenomena suggest that the Speargrass Flat arm is more permeable.

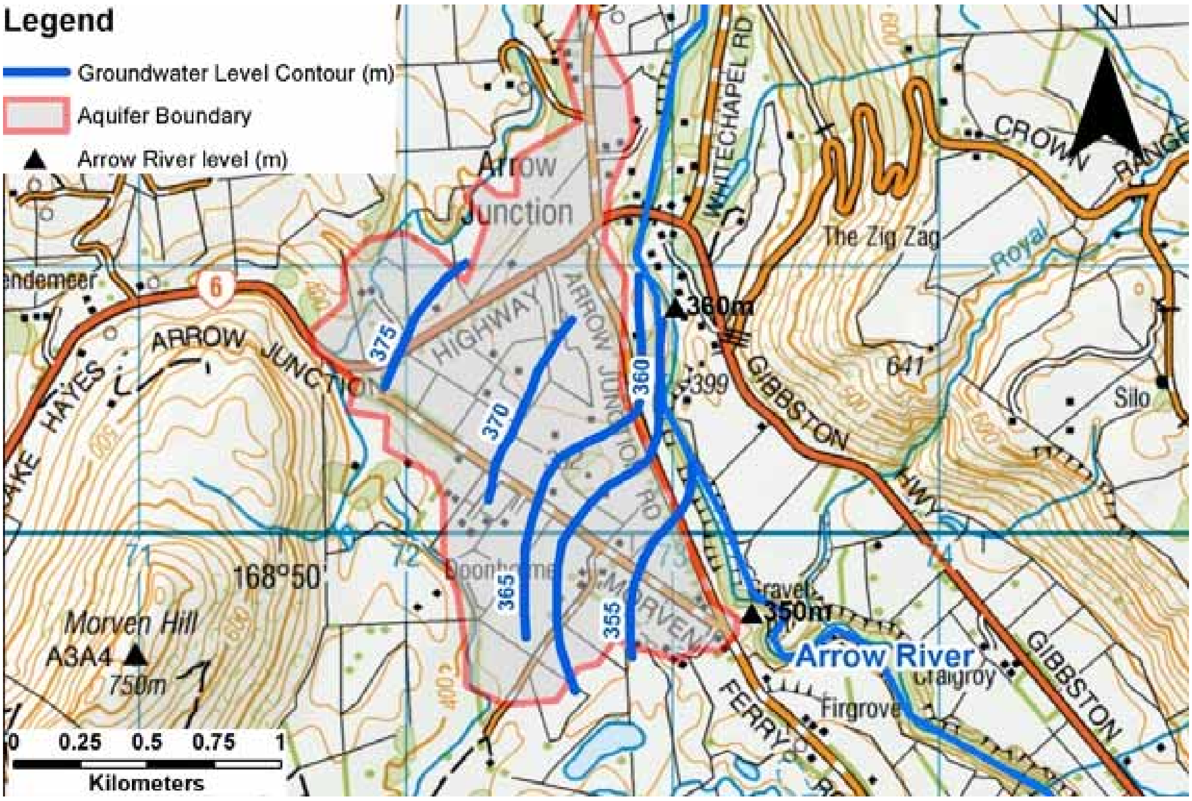


**Figure 7** **Outline of the Morven Aquifer, including estimated water table contours**

The Morven Aquifer consists of outwash terraces and alluvium associated with the Arrow River. The aquifer thickness is highly variable, from 3 m in some bores, to 25 m in a single bore (F41/0263) in the south-east. Water table contours suggest a hydraulic gradient to the south-east. Indeed, the largest spring discharges on the bank of the Arrow River are found in the south-east of the Morven Aquifer. In September 2012, the combined spring flow, in the position marked in Figure 7, was approximated by bucket gauging at 5 l/s.


**Figure 8** **Outline of the Frankton Flats Aquifer**

Figure 8 shows the extent of the Frankton Flats Aquifer. The aquifer is truncated in the south by the presence of low permeability lake sediments. The aquifer consists of sandy gravel, mainly fan and delta deposits formed in a pro-grading delta fan during lake levels higher than those that currently prevail. The deposit is characterised by silty, almost claybound, gravels for the first 40 m below the terrace surface, after which clean, sandy gravel is found. Exploratory borehole F41/0349 (or BHD in Figure 14) was drilled to 90 m without encountering a base of clean, sandy gravels. The water table was not contoured, due to a lack of widely spaced bores with corrected static water levels, but measured levels around bore F41/0349 rest at about 311 m AMSL throughout the aquifer core.

Undifferentiated glacial deposits host groundwater systems in scattered localities within areas of hard rock. The schist rock of the Wakatipu Basin also contains hard rock groundwater, sometimes termed ‘fractured-rock aquifers’. The drilling contractors active in Otago have noted that the Wakatipu Basin has higher yielding bores than elsewhere in the region, suggesting that the fracture permeability is greater than in other parts that are underlain by schist.

## Water quality

The water quality of both surface water and groundwater is generally very good in the basin. The Shotover River and Arrow River rise in erodible catchments and thus have inherent turbidity/suspended sediment load elevation that is affecting water clarity. The Kawarau River issues from Lake Wakatipu and has very low turbidity and thus high water clarity until its confluence with the Shotover River.

### 2.7.3 Groundwater quality: Baseline

Wakatipu Basin groundwater can be classified as 'calcium bicarbonate type' water. The dominant ions are thus calcium and bicarbonate, accounting for 80% of total composition. All groundwaters are enriched, relative to the seawater dilution line, suggesting that the effect of water-rock interaction is the source of dissolved ions. Other ionic constituents, such as sodium, potassium, sulphate and chloride, are all found at low concentrations compared to calcium and bicarbonate. The piper plot of the composition of basin groundwater in Figure 9 reflects the relatively homogenous and dilute chemistry pattern displayed in past surveys of the groundwater of both the Wakatipu and Wanaka basins (Rosen *et al*., 1997). The Frankton Flats Aquifer was sampled on one occasion (Taulis *et al*., 2007) and displayed water chemistry characteristics typical of the rest of the Wakatipu Basin aquifers.

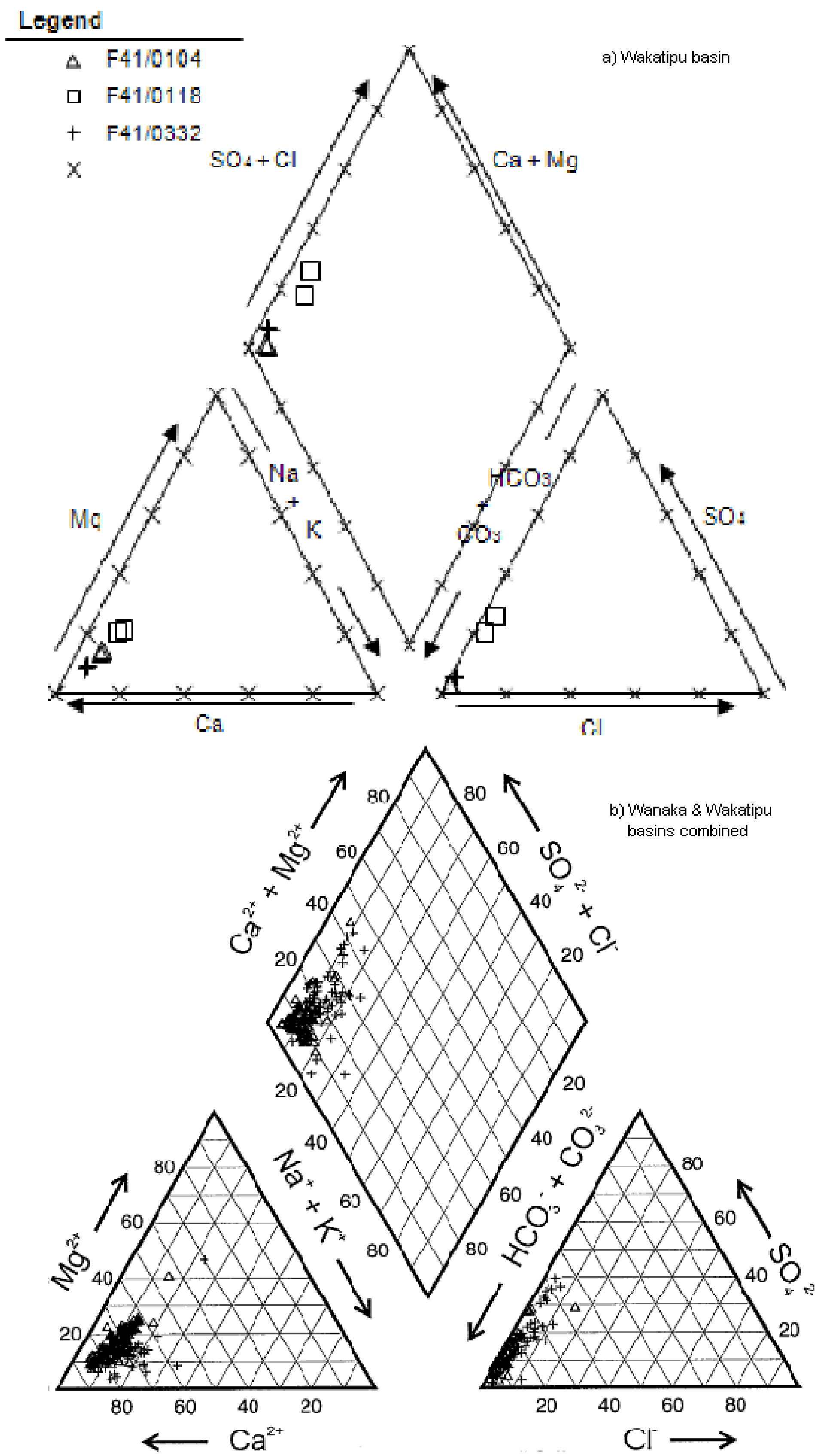


**Figure 9** **Piper plot of a) recent Wakatipu groundwater chemistry at SOE monitoring bores; b) historic Wanaka and Wakatipu chemistries presented in Rosen *et al.* (1997) for comparison**

Rosen *et al*. (1997) noted that anthropogenic impacts on groundwater were slight in Wakatipu Basin groundwater surveys, and monitoring has shown that nitrate concentrations are higher than the nominal concentrations of pristine groundwater (i.e. >0.4 $gNO_3$-N/$m^3$). The elevated nitrate-nitrogen concentrations show the effects of animal grazing and possibly nitrogen-fertiliser application too. As potassium was observed to be elevated or enriched in the Wakatipu Basin, relative to the Wanaka Basin groundwater, without an obvious geo-chemical source, the higher potassium concentrations were attributed to the 'spreading of K-rich fertilisers' (Rosen *et al*., 1997). Certainly, it is common practice to add potassium, typically as potassium chloride (KCl) salts, onto grazing land.

### 2.7.4 Areas of poor groundwater quality

The sole industrial areas in the Wakatipu Basin are found on the western edge of Arrowtown and the eastern edge of the Frankton Flats. An area of sheep-dip contaminated soil and groundwater is located over the Windemeer Aquifer on the south-west shore of Lake Hayes, where the contaminant is mainly arsenic. The Tuckers Beach QLDC municipal landfill is buried in the Shotover alluvial ribbon aquifer below Quail Rise. Landfill leachate has been detected in groundwater monitoring between the buried waste and the river. For several decades, the Frankton wastewater treatment facility, between the SH6 bridge and Kawarau-Shotover confluence's true-right bank, has discharged effluent into alluvial ribbon gravels and the Shotover River. In 2001, drilling investigations into groundwater quality found that the alluvium beneath and immediately down-gradient of the effluent treatment areas was contaminated with faecal coliforms and elevated ammonia nitrogen (MWH, 2001).

In general, grazing is not considered to have given rise to poor water quality in the basin aquifers. While slightly elevated nitrate-nitrogen concentrations have been found in shallow bores and the Rutherford Road spring, the drinking water standard has not been transgressed. Natural concentrations of dissolved arsenic have been found to slightly exceed the drinking water standard of 0.01 g/$m^3$ for health significance, especially at the monitoring site in the Windemeer Aquifer. Otago schist usually contains between 5-20 gAs/$m^3$, primarily as the gold-associated mineral, arseno-pyrite*.* The schist rocks in the Wakatipu Basin may be even more enriched, due to the higher mineralisation of schist, indicated by the presence of historical hard-rock and alluvial gold mining. The presence of natural concentrations of iron and manganese occur in a small number of wells, particularly deeper wells scattered throughout the basin, limit their use as drinking water.

Lake Hayes has an historical pattern of eutrophication relating to nutrient inputs of the upstream catchment and inherent factors of the lake. The Rutherford spring, on the northern shore of Lake Hayes, discharges a steady 25 l/s to 35 l/s into the lake. The mean nitrogen concentration of the spring water is 1.3 gN/$m^3$, so the annual load can be approximated as 1,200 kgN/y. Mill Creek dissolved inorganic nitrogen inputs, entering at the lake delta, account for another 4,700 kgN/y. So, groundwater from the Rutherford spring represents about 20% of the nitrogen flux to Lake Hayes. However, improvements to the nutrient yields in the upstream catchment may not produce improvements in lake status (Bayer and Schallenberg, 2009).

# 3. Groundwater management

## 3.1 Historic water management

Initial settlement of the Queenstown district was influenced by the area's river network, mineral and water resources. Gold mining on the Arrow River began in 1862, and hydraulic-mining water claims were administered by the Mine Warden's Court. Several mining privileges for water continue to be used today, including the Arrow Irrigation Company Ltd's abstraction of the Arrow River.

Groundwater take and bore consents began to be issued for the Wakatipu Basin in the 1980s, initially under the auspices of the Water & Soil Conservation Act 1967, and subsequently, under the Resource Management Act 1991 (RMA). A transition in land and water use from farming to rural residential has occurred in the last 20 years (Komischke and White, 2006). Water for domestic and communal-domestic water supply has also tended to shift from surface water to groundwater due to concerns about the water quality of surface water.

## 3.2 Current water management

### 3.2.1 The management of groundwater quantity

The Wakatipu Basin Aquifer is a declared aquifer within the Regional Plan: Water (the Water Plan) for Otago. However, beyond this declaration, the Wakatipu Basin aquifer does not yet have specific groundwater-management provisions, such as a tailored maximum allocation volume (MAV) or restriction levels. Default provisions apply to the aquifer, nonetheless.

The most relevant default provisions within the Water Plan include:

- permitted activity takes of groundwater up to 25 $m^3$/d;
- a controlled activity requirement to obtain consent for any drilling or bore construction within the aquifer;
- a restricted discretionary or discretionary activity requirement to obtain consent for the taking of groundwater from the aquifer (for takes over 25 $m^3$/d);
- a default groundwater-volume limit related to '50% of mean annual recharge (MAR)' has applied to the aquifer since 1 March 2012;
- the determination of MAR by ORC on the basis of scientific derivation of all anticipated sources of recharge to the aquifer;
- the consideration of hydraulically connected groundwater as allocated from surface water and subject to minimum-flow restrictions if taken within 100 m of the water course concerned since 1 March 2012; and
- the consideration of hydraulically connected groundwater as dually allocated from surface water and groundwater if the Jenkins equation (or equivalent) shows that the effect on surface water has been more than 5 l/s since 1 March 2012.

### 3.2.2 The current status of groundwater allocation

Thirty-three groundwater take consents were current in early 2013. The annual total volume of groundwater issued in 25 of those consents that draw on aquifers other than alluvial ribbons equates to 985,018 $m^3$/y (or 0.98 $Mm^3$/y). A further take of 234,000 $m^3$/y (0.2 $Mm^3$/y) is derived from bores installed in the Shotover and Kawarau alluvial ribbon aquifers and is included in the surface-water allocation of the Shotover River. With a couple of minor exceptions for small-scale irrigation, the consents for the take of groundwater within the Wakatipu Basin aquifer relate to communal domestic and public water supply takes. Table 2 lists the consented-allocation volumes for each aquifer in the wider basin, including miscellaneous aquifers and alluvial ribbon surface water allocation.

**Table 2 Summary of consent groundwater volumes issued in Wakatipu Basin authorisations**

| Aquifer | Consented volume ($m^3$/y) | Consented volume ($Mm^3$/y) |
|---|---|---|
| Hawthorne-Speargrass Aquifer | 23,490 | 0.023 |
| Mid-Mill Creek Aquifer | 843,340 | 0.843 |
| Morven Aquifer | 5,877 | 0.006 |
| Upper Mill Creek Aquifer | 21,641 | 0.022 |
| Windemeer Aquifer | 55,246 | 0.055 |
| Aquifer Total | 949,594 | 0.950 |
| | | |
| Undefined glacial deposit groundwater | 34,614 | 0.03 |
| Schist rock groundwater | 810 | 0.001 |
| | | |
| Total (aquifers + groundwater) | 985,018 | 0.98 |
| | | |
| Alluvial ribbon aquifers: Shotover, Arrow and Kawarau (Surface water allocation, including Arthurs Point, Arrowtown water supplies, respectively) | 2,162,360 | 2.1 |

The QLDC water supplies at Arrowtown and Arthurs Point lie just beyond the periphery of the Wakatipu Basin Aquifer, and are extracted using bores. These water supplies are considered to originate from the Arrow and the Shotover alluvial ribbon, respectively. The volume of water pumping under these consented takes is currently 1,928,400 $m^3$/y (1.93 $Mm^3$/y), but it is not mainly groundwater in origin and therefore not allocated against any aquifer other than the appropriate alluvial ribbon. No groundwater is allocated to consumptive uses from within the Frankton Flats Aquifer.

### 3.2.3 The management of groundwater quality

The National Environmental Standard (NES) for drinking water sources has had an escalating effect on the regulatory obligations of the regional authority and operator as to water quality, where the served population increases from the >25 person communal water supplies to the >501 person threshold for registration of public water supplies. In setting the thresholds for water-quality management, the NES also makes distinctions between water supplies that fully comply with drinking water standards and those that do not. In the Wakatipu aquifers, there are several water supply sources, including:

- **Arrowtown**
- **Lake Hayes**
- Lake Hayes Estate (from the Kawarau alluvial ribbon aquifer)
- Arthurs Point (from the Shotover alluvial ribbon aquifer).

Of these, the Arrowtown and Lake Hayes supplies (in **bold**) have populations exceeding 501 individuals, thus triggering the full range of regulations within the NES. These water supplies are believed to be compliant with the monitoring requirements of drinking-water standards in nitrogen-sensitive zones (NSZs), with the exception of *Cryptosporidium*. The NES places enforceable obligations on regional councils to avoid situations where water supplies are affected by contamination through the granting of consents, or implementing other measures such as permitted activities within the appropriate regional plan(s).

Groundwater protection zones (GPZs), NSZs and groundwater SOE monitoring are the main tools available for managing point-source and non-point-source effects on groundwater within the Wakatipu Basin. ORC has not yet defined GPZs within the basin in the Water Plan.

Proposed Plan Change 6A (Water Quality) includes a NSZ for the Wakatipu Basin aquifer, with the nitrogen-soil discharge limitation(s) of 20 kilograms of nitrogen per hectare per year (20 kgN/ha/y). The surface water catchment of Lake Wakatipu has also been proposed for inclusion as an NSZ within Plan Change 6A. If implemented, this proposal would attempt to limit nitrogen leaching beyond the base of the soil to a maximum 10 kgN/ha/y. As to the management of the Wakatipu Basin aquifer in particular, map H-3 indicates that the NSZ for the lakes area encompasses about a third of the Frankton Flats Aquifer closest to Lake Wakatipu (Proposed Plan Change 6A, 2013). In reality, this part of the Frankton Flats Aquifer is urban, so the limits on agricultural activity contained in the plan change would not have a practical application.

# 4. Aquifer water balance

## 4.1 Rainfall-recharge modelling

### 4.1.1 Region-wide modelling

This investigation has the advantage of having access to a recent ORC investigation into the rainfall recharge of 13 Otago aquifers (ORC, 2011). The methodology and climate data and parameters used in this recharge modelling can be found in the rainfall-recharge report (ORC, *ibid*).

Stations in the north and south of the Wakatipu Basin were chosen to provide climate data, such as rainfall and evapo-transpiration. Figure 10 shows the stations and dividing line for using these parameters.

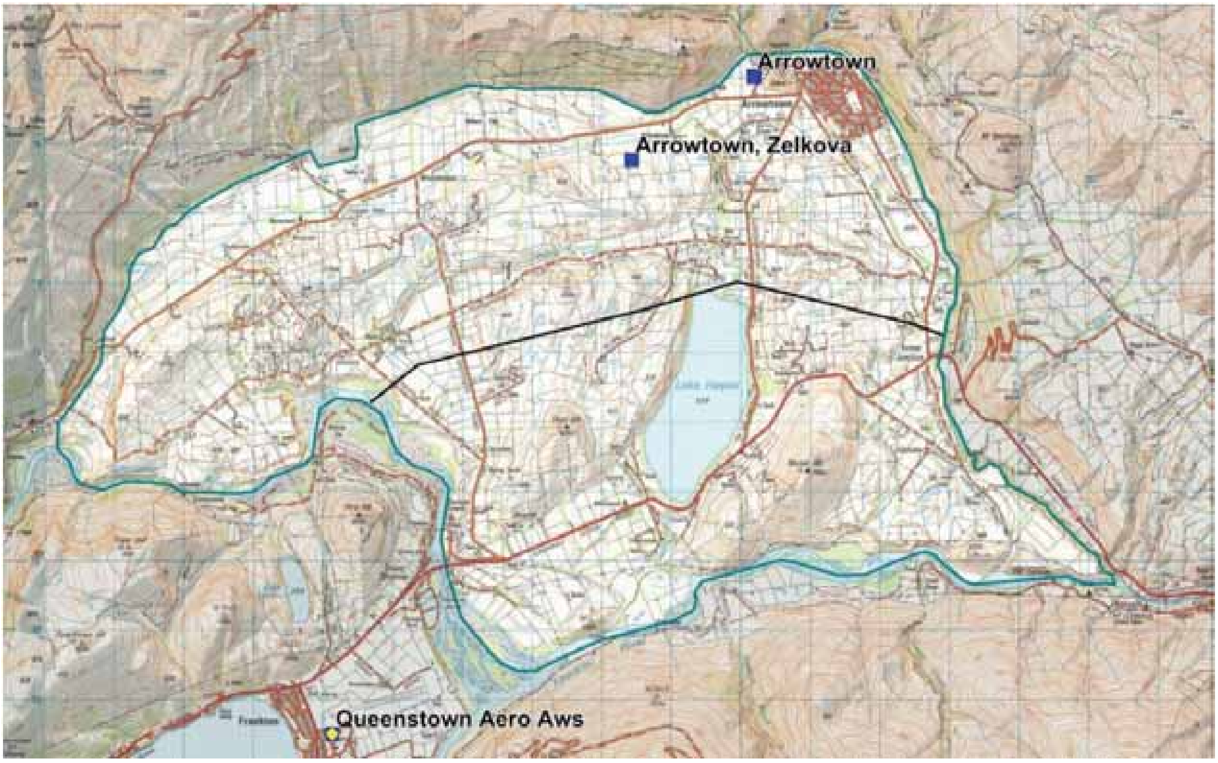


**Figure 10** **Climate stations used for modelling and dividing line for recharge zones**

Rainfall data for the northern section was sourced from three Arrowtown sites. Rainfall for the southern part was sourced entirely from the Queenstown Aero Automatic Weather Station (Queenstown Aero AWS), which has a complete record. The primary potential evapo-transpiration (PET) site used was Queenstown Aero AWS. This was augmented with the data from the Lauder EWS PET to extend the record from 1991 to 1985. Rainfall-recharge modelling for the Wakatipu Basin is summarised in Table 3 below.

**Table 3** **Summary of the Wakatipu Basin rainfall-recharge modelling results**

| | Mean recharge ($Mm^3/y$) | Rainfall (mm/y) | PET (mm/y) | Modelled recharge (mm/y) | Percentage of recharge (%) |
|---|---|---|---|---|---|
| Wakatipu Basin | 12.5 | 746 | 950 | 184 | 23 |

The results of rainfall recharge modelling indicate that almost 25% of rainfall is recruited to groundwater recharge in the Wakatipu Basin. In reality, the diversity in land slope and underlying geology would dictate that the annual volume of rainfall recharge is substantially less than indicated in Table 3. Rain falling on the slopes of Morven Hill, and other schist ridges within the basin, would not be expected to cause any significant recharge of groundwater. The reasons are that steep hill slopes have a greater tendency to produce overland runoff and, as the schist fractured rock has low hydraulic conductivity, it would tend to 'refuse' most potential recharge. Instead, excess rainfall on schist-sloping ground would tend to feed creeks and streams draining the basin. Accordingly, the modelled recharge rates would be expected to have application for recharge through the permeable soils of low relief alluvium and outwash.

### 4.1.2 The Wakatipu Basin aquifer: Recharge modelling

As shown in sections 2.7.2 and 5, and amplified in the paragraph above, the Wakatipu Basin groundwater system is broken up into six principal aquifers. Instead of having a surface area of 82 square kilometres ($km^2$) over the aquifers, the actual land that contributes land surface recharge to fluvio-glacial aquifers of the Wakatipu basin equates to only 24.9 $km^2$. When these six (sub) aquifers are modelled for the mean annual groundwater recharge volumes, the results are quite different from the basin-wide estimates in Table 3.

Table 4 lists the results of soil-moisture modelling to determine groundwater recharge for the six aquifers and nine soil classes that were found within these aquifers. The results are broken down further by splitting the basin into two rainfall zones: Arrowtown, to the north, and Queenstown Airport, to the south (see Figure 10 for location of climate stations and dividing line between rainfall zones). The five aquifers within the formally declared Wakatipu Basin Aquifer have a combined extent of 20.7 $km^2$, which is substantially less than the 76.7 $km^2$ of the whole basin. The modelled recharge volume of the five aquifers was estimated to be 2.8 $Mm^3/y$. By adding the Frankton Flats Aquifer to the recharge estimation, a further 0.42 $Mm^3/y$ is modelled to pass to the aquifer through Frankton Flats soils. Only the Hawthorn-Speargrass and Morven Aquifers are thought to be solely or principally recharged by rainfall excess. The upper Mill Creek, mid-Mill Creek and Frankton Flats Aquifers have gained part of their water-balance inflow from surface water.

**Table 4** **Modelled groundwater recharge for six Wakatipu Basin aquifers**

| | Aquifer | | | | | |
|---|---|---|---|---|---|---|
| **Climate station soil class** | Upper Mill Ck* | Mid-Mill Ck* | Hawthorn-Speargrass | Morven | Windemeer | Frankton Terrace* |
| Queenstown Aero AWS | ($m^3$/y) | ($m^3$/y) | ($m^3$/y) | ($m^3$/y) | ($m^3$/y) | ($m^3$/y) |
| 1 | | | | | 28,116 | |
| 3 | | | | | 66,863 | 180,265 |
| 4 | | | 156,904 | 2,196 | 176,349 | 124,491 |
| 5 | | | | 108,023 | | |
| 6 | | | | | 10,296 | |
| 7 | | | 18,360 | | | |
| 10 | | | 6,940 | 163,353 | 42,553 | |
| 12 | | | | | 155,794 | 114,575 |
| Arrowtown | | | | | | |
| 1 | | *42,580* | | | | |
| 2 | | *12,513* | | | | |
| 3 | *385,343* | *7,229* | *6,491* | | | |
| 4 | *63,348* | *226,426* | *231,514* | | | |
| 5 | *74,842* | | | | | |
| 6 | *196,445* | *7,428* | | | | |
| 7 | *313,281* | *37,439* | *27,077* | | | |
| 10 | *4,894* | *53,338* | *15,297* | | | |
| 12 | *154,497* | | | | | |
| **Total ($m^3$/y)** | **1,192,650** | **386,953** | **462,583** | **273,572** | **479,971** | **419,331** |
| **Total ($Mm^3$/y)** | **1.19** | **0.39** | **0.46** | **0.27** | **0.48** | **0.42** |

Note:

* Aquifer concerned also recharged by surface water

Soil class, as defined in Table 1

$Mm^3$/y = 1,000,000 $m^3$/y

*Italics* = population over 501 as per Section 3.2.3

## 4.2 Groundwater extraction

### 4.2.1 Groundwater extraction: Metering data

Some of the groundwater take consents include obligations for undertaking metering and recording of the quantities of water extracted. The recorded and archived groundwater consumption from eight consents in the Wakatipu Basin is listed in Table 5.

**Table 5 Summary data for consented water supplies with metered water use**

| **Take consent number** | **Water supply or owner** | Max. ($m^3/d$) | Min. ($m^3/d$) | Mean ($m^3/d$) | Metered ($m^3$) | Allocation ($m^3$) | % |
|---|---|---|---|---|---|---|---|
| 2001.822 | Lake Hayes PWS | 2,136 | 0 | 941 | 343,489 | 800,800 | 43% |
| 2002.666 | Hawthorne Estates | 79 | 4 | 13 | 4,590 | *59,520* | 8% |
| 2002.727 | Faulks Trust | 23 | 6 | 14 | 4,985 | *54,750* | 9% |
| 2002.728 | V M Buckham | 95 | 0 | 17 | 6,342 | *146,000* | 4% |
| 2006.338 | R F Monk | 12 | 8 | 9 | 3,359 | 10,220 | 33% |
| 2001.685.V1 | Cloverdale Estate | 22 | 5 | 15 | 5,393 | *13,140* | 41% |
| 2001.752.V1 | D G & J M Veint | 65 | 1 | 7 | 2,572 | 10,080 | 26% |
| 2006.478 | Lake Hayes Estate | 198 | 32 | 63 | 23,015 | 121,910 | 19% |

Note:

Mean length of record is only 2 years

PWS = Public water supply

Max. = maximum

Min. = minimum

Metered = Mean annual metered volume of groundwater taken under the respective consent

% = Percentage of annual allocation that was actually taken and metered

*Italics* indicate that the annual totals are not specified in the consent, so they have been extrapolated from the monthly limit.

In each case of metered water consumption, the actual annual groundwater extraction was significantly less than allocated extraction allowance. The variance in actual extraction ranged from 4% to 43% of allocated annual extraction. Such underuse is typical of many groundwater basins in Otago. The Wakatipu Basin has recently experienced a sequence of ‘boom and bust’ cycles in land development, resulting in inflated estimates of how much water was required to service residential developments during the booms. The Lake Hayes public water supply has also subsumed several of the adjoining private-communal water supplies. This public water supply tends to hit its instantaneous and daily limits during the summer vacation periods. The transient nature of the population residing in, or visiting, the Wakatipu Basin makes for a water-use pattern that differs from other urban areas.

In the interim, the major groundwater abstractions are the water-supply bores at Rutherford Road and Lake Hayes Estate. A reasonable estimate of the total annual groundwater abstraction from the Wakatipu Basin aquifers would be 400,000 $m^3$/y (or 0.4 $Mm^3$/y). There is no groundwater abstraction of the Frankton Flats Aquifer.

## 4.3 River and lake recharge

### 4.3.1 Arrow River

The Arrow River is mostly surrounded by schist outcrops through its course from headwaters to the Kawarau confluence. However, the river aggregate has been noted as coalescing at the point where it turns course at Arrowtown. The deceleration involved in the river changing course appears to have resulted in the aggradation of Arrow and Bushy Creek bed-load alluvium, sufficient to form a small alluvial aquifer at the Bushy Creek confluence. The Arrow River, and to a lesser extent Bushy Creek, recharges this pool of groundwater. The Arrowtown public water supply wells are the sole extractions from the Bushy Creek aquifer. Excess water in the aquifer tends to discharge back into the Arrow River as the alluvium thins and narrows downstream.

### 4.3.2 The Shotover River

The Shotover River enters the Wakatipu Basin downstream of Arthurs Point and remains in a schist-rock gorge until Tuckers Beach. The river may pass through another schist pinch-point at Edith Cavell Bridge before it enters the Lower Shotover reach. The lower Shotover River would provide recharge for the Shotover alluvial ribbon. The river has also been attributed with recharging the east side of the Frankton Flats Aquifer (Taulis *et al*., 2007).

### 4.3.3 Lake Hayes

Lake Hayes adjoins the Windemeer Aquifer on the south shore. Research by Barrell *et al.* (1994) showed that the south shore is lined with lake sediments, mainly pro-glacial silt. It is considered that if this silt margin intervenes continuously between lake and the Windemeer Aquifer, no appreciable lake recharge would occur. The distinct down 'step' in water levels from 329 m AMSL of the lake to 320 m AMSL in the proximal aquifer tends to support this inference. Therefore, it is assumed that no recharge the Windemeer Aquifer occurs from the lake.

### 4.3.4 Lake Wakatipu

Lake Wakatipu's Frankton Arm adjoins the west margin of the Frankton Flats Aquifer. Taulis *et al.* (2007) concluded that the Lower Shotover River, Lake Wakatipu, Kawarau River and the Frankton Flats Aquifer were in a dynamic equilibrium, whereby the groundwater gradient was very flat across the aquifer, and the direction of groundwater flow could shift in response to changes in the respective surface water levels. Hence, the usual aquifer recharge originated from the Shotover River, near the SH6 bridge. However, during high lake levels, the gradient could reverse, with lake waters tending to flow through the aquifer towards the Kawarau River.

### 4.3.5 Multiple site gauging: Lake Hayes catchment

Mill Creek takes in the Mill Creek aquifers, and there was reason to suppose that surfacewater-groundwater interactions were significant in its water balance. Gaugings were undertaken at two sites in upper Mill Creek, four sites in mid-Mill Creek and at the Lake Hayes outlet. The objective was to quantify losses or gains in surface water flow. The gaugings were carried out to take advantage of the natural breaks in the groundwater systems at the Millbrook waterfall and Lake Hayes. Figure 11 shows the location and gauged flow rate in the respective water courses. The gaugings were conducted on 6 March 2013, during a period of stable, dry weather.

The first observation is that little can be inferred from gauging the upper Mill Creek Aquifer. This aquifer has a number of flowing streams draining Coronet Peak and its foothills, and a by-wash from the Arrow River Irrigation Scheme. The mid-Mill Creek Aquifer could be characterised more easily. The creek at the base of the waterfall, the Mooneys Swamp and Slopehill Creek tributaries could be gauged where they coalesce at a drain outfall into Mill Creek (4 l/s). Surface flows into Lake Hayes could be gauged at Fishtrap and Rutherford spring gauging sites (294 l/s and 38 l/s, respectively). Mill Creek was estimated to lose about 20 l/s to the aquifer. The mid-Mill Creek Aquifer discharges into Lake Hayes as Rutherford Road spring flow and more diffuse seepage at the lakeshore margin. Allowing for reasonable catchment discharge between the northern and southern shore outflows, a reasonable estimate of diffuse groundwater seepage from the mid-Mill Creek Aquifer would be 10 l/s.

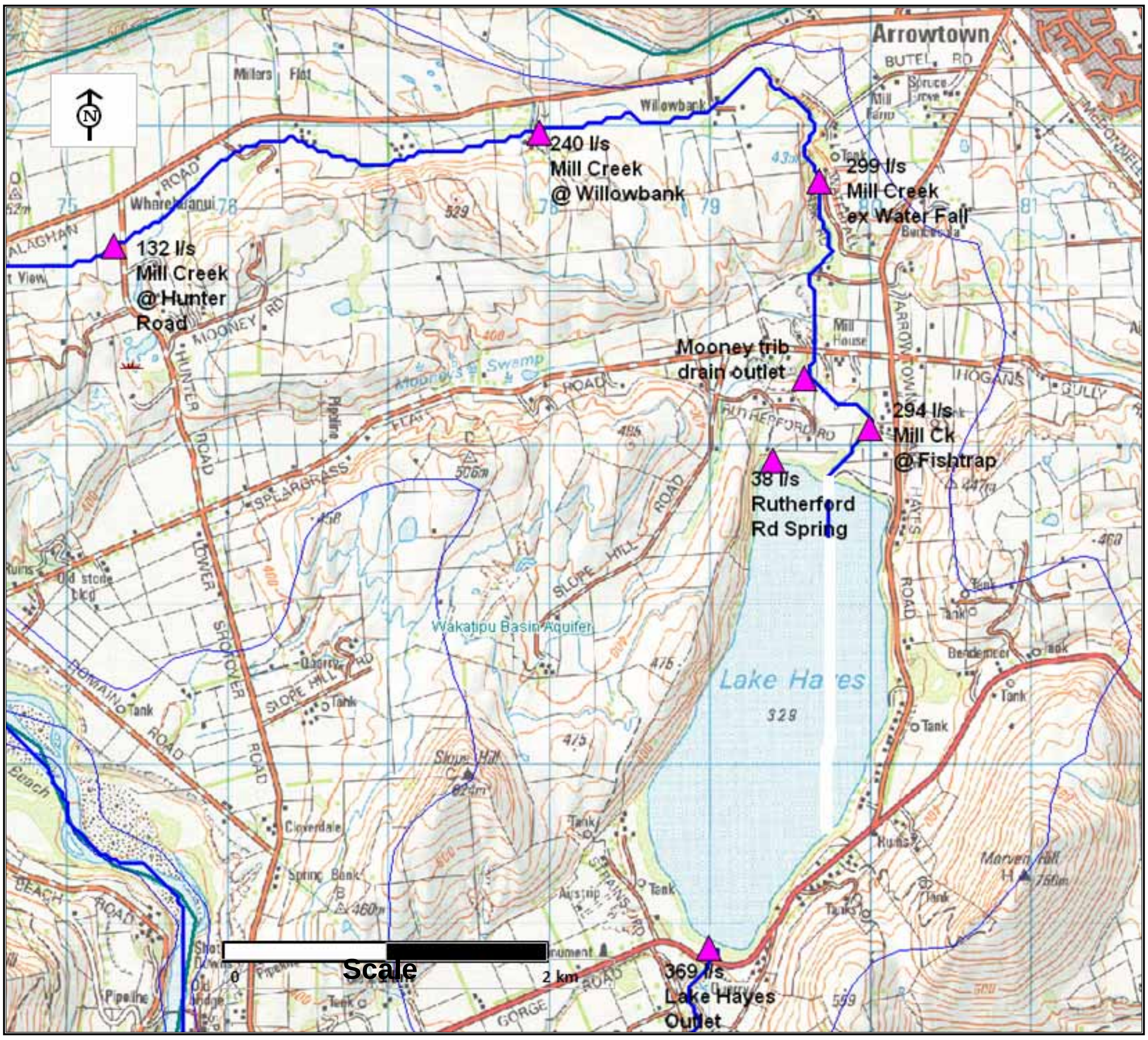


**Figure 11** **Indicative map of surface-water gauging campaign in the Lake Hayes catchment, 6 March 2013**

Based on the rainfall recharge modelling, longer-term monitoring of the Rutherford Road spring and the flow gauging campaign, the following estimations can be made for the mid-Mill Creek Aquifer:

- Rainfall recharge is equivalent to 15 l/s.
- Surface-water recharge from Mill Creek is 20 l/s.

The annual equivalents of these values can be used in allocating groundwater from the mid-Mill Creek Aquifer.

## 4.4 Overall water balance

Using estimates of rainfall recharge, surface water recharge, groundwater extraction and spring flow, it is feasible to make an overall estimate of the water balance for most of the Wakatipu Basin aquifers (Table 6).

Table 6

**Table 6** **List of estimated aquifer water balance for selected Wakatipu Basin aquifers**

| **All units in Mm$^3$/y** | Mean annual recharge (Rainfall LSR) | Mean annual recharge (Surface water) | Groundwater extraction (actual) | Outflow to surface water |
|---|---|---|---|---|
| Hawthorn- Speargrass Aquifer | 0.46 | _ | <0.01 | 0.46 |
| Morven Aquifer | 0.27 | _ | <0.01 | 0.27 |
| Windemeer Aquifer | 0.48 | _ | 0.02 | 0.46 |
| Upper Mill Creek Aquifer | 1.19 | _ | <0.01 | 1.19 |
| Mid-Mill Creek Aquifer | 0.39 | 0.63 | 0.34 | 0.68 |

A graphical representation of the balance of inflows and outflows[4] for the mid-Mill Creek Aquifer is illustrated in Figure 12.

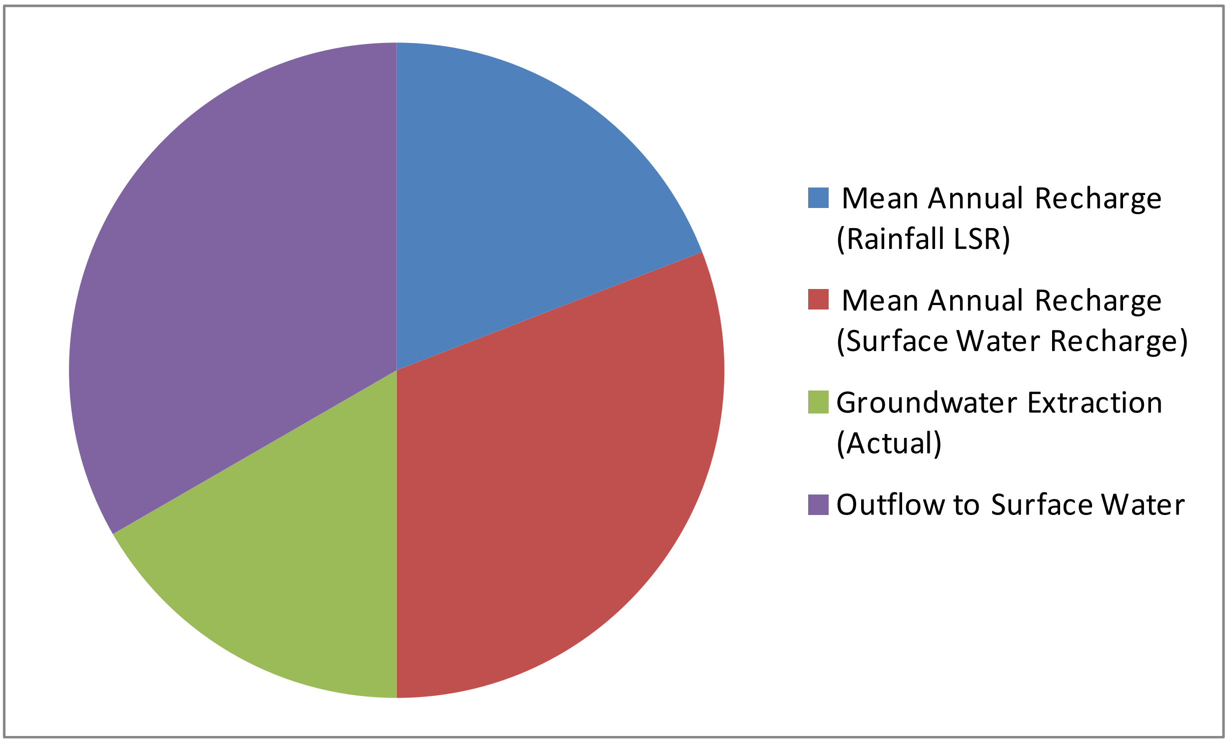


**Figure 12** **Graphic representation of the groundwater balance of the mid-Mill Creek Aquifer; outflows to the right, inflows to the left of the vertical bi-sector**

[4] LSR = Land Surface Recharge

# 5. Conceptual model

The Wakatipu Basin groundwater resource can be sub-divided into several compartments or aquifers. Basement ridges, groundwater flow divides and rivers laterally separate the various components of the basin's groundwater system, which is thought to consist of the thin, laterally distributed, unconfined aquifers shown in Figure 13. There is little evidence for vertical segregation of the groundwater system into semi-confined or confined aquifers.

The distribution of the Wakatipu Basin fluvio-glacial aquifers is shown in Figure 13.

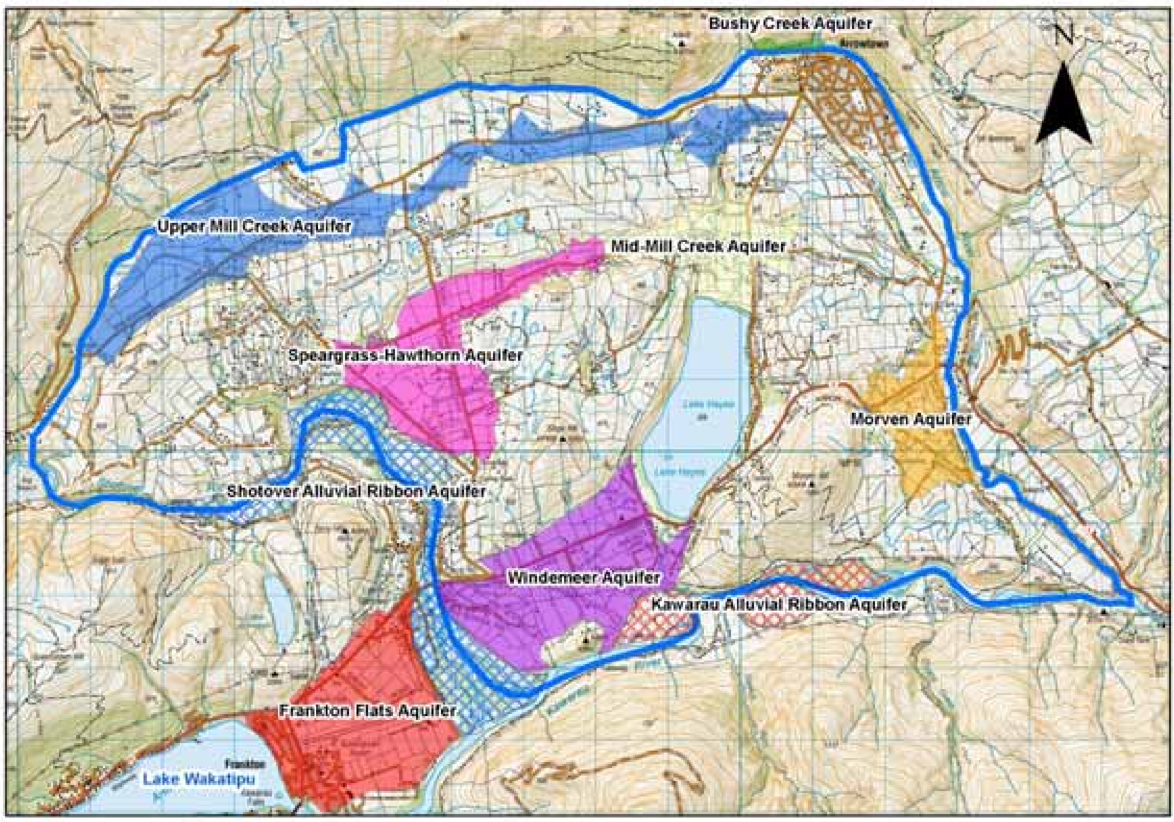


**Figure 13 Distribution of recognised aquifers within and adjoining the Wakatipu Basin aquifer**

## 5.1 Arrow-Bushy Creek Aquifer

The Arrow-Bushy Creek Aquifer is a small strip of river-terrace gravel and river alluvium found between where Bushy Creek emerges from a schist-rock gorge and downstream to the confluence of the creek with the Arrow River. For the purposes of water allocation, it is part of the Arrow alluvial ribbon. The aquifer has local significance as it is the source of the Arrowtown public water supply.

## 5.2 Upper Mill Creek Aquifer

The upper Mill Creek Aquifer consists of the groundwater resource below the slopes of Coronet Peak, downstream to the Millbrook waterfall. The waterfall crosses schist rock and thus separates the aquifer from the mid-Mill Creek Aquifer, which begins at its foot.

## 5.3 Mid-Mill Creek Aquifer

The mid-Mill Creek Aquifer consists of the outwash and alluvium between the Millbrook waterfall and Lake Hayes. The aquifer has two arms extending from the head of Mooneys Swamp, in the west, and Hogans Gully, in the east. It is locally significant because it provides the spring-flow discharge at the end of Rutherford Road that is used as source water for the Lake Hayes public water supply.

## 5.4 Speargrass-Hawthorn Aquifer

The Speargrass-Hawthorn Aquifer consists of a lobe of elevated-fan/delta deposits and outwash that extends from Speargrass Flat westward until it is truncated by the down-cutting Shotover River. Drilling records and the pattern of schist outcrops suggest that the southern part of the aquifer has a less active flow system. The main flow system is thought to follow the axis of Speargrass Flat Road and to discharge as springs onto the eroding flank of the terrace overlooking the Shotover River. A couple of private water supplies draw on the spring discharges at this point.

## 5.5 Windemeer Aquifer

The Windemeer Aquifer consists of a complex of outwash and river terraces between the lower Shotover River and Lake Hayes. The terminus of Lake Hayes is hydrologically defined and, to some extent, ‘dammed’ by lake sediment (horizontally layered, micaeous silt of low permeability), which separates the Windemeer Aquifer from any significant hydraulic connection with the lake. The erosional remnant of outwash-fan gravels is distinct from the lower Shotover-Kawarau terrace deposits and has retained an isthmus connecting the schist ridges to north and south. However, evidence suggests that the outwash is co-joined with the terrace’s groundwater system, combining it into one aquifer.

Due to inferred high aquifer transmissivity and thick terrace deposits, the depth to the water table can be very deep in parts of the Windemeer Aquifer, sometimes up to 40 m. The ancillary water supply bore for the Lake Hayes public water supply is located between Lake Hayes Estate and Hayes Creek (Figure 2).

## 5.6 Morven Aquifer

The Morven Aquifer has its western flank against schist and minor till, and its other flank lies to the east of the Arrow River. The aquifer consists of terrace alluvium, mainly sandy gravel, with accessory silt layers. The aquifer is mostly perched above the level of the incised Arrow River by lower permeability schist rock upon which it rests. Walking inspections of its banks suggest that the river makes little (if any) direct contact with the aquifer. Instead, springs have been found in several locations at the contact between the terrace alluvium and schist basement. Some of these springs were developed as individual water supplies, using centrifugal pumps and water rams to pump the water to houses on the terrace surface. The largest of these springs was gauged at a rate of about 5 l/s in September 2012.

## 5.7 Frankton Flats Aquifer

The Frankton Flats Aquifer is an extensive, deep, sandy gravel deposit between the Shotover River, Kawarau River and Lake Wakatipu. Research by Barrell *et al.* (1994) indicates the presence of lake deposits, mainly horizontally layered micaeous silt, of low permeability, on the southern point of the Frankton Terrace suggests that the aquifer is largely cut off from the Kawarau River between the lake outlet and the Shotover delta.

MWH New Zealand Ltd undertook the main groundwater exploration of the Frankton Flats Aquifer in 2007 (Taulis *et al*., 2007) for the Five Mile development. The company installed five boreholes, four observation bores and a test production bore and tested the aquifer to assess the potential water supply and the prospects for groundwater-source heat exchange as an energy source. These tests revealed that the Frankton Flats Aquifer was of high permeability and had depths of up to 90 m (in fact, no base was found).

## 5.8 Shotover alluvial ribbon aquifer

The Shotover River emerges from the Shotover canyon at Oxenbridge Tunnel. The river then goes into the Edith Cavell Gorge from Arthurs Point to Tuckers Beach. With the exception of the canyon and gorge, on the Kawarau River confluence, downstream of the delta, the Shotover River forms a braid plain and a floodplain, both of which define the aquifer. The aquifer is unconfined and consists of sandy gravel of high transmissivity, which is in direct communication with the Shotover River.

## 5.9 Kawarau alluvial ribbon aquifer

The Kawarau River drains Lake Wakatipu and flows generally eastwards along the southern boundary of the Wakatipu Basin. The delta of the Shotover River joins the Kawarau River 3 km downstream of Lake Wakatipu. The aquifer is unconfined and consists of sandy gravel of high transmissivity, which is in direct communication with the Kawarau River.

## 5.10 Groundwater age

### 5.10.1 1994-1996: Age determinations

The Institute of Geological & Nuclear Science (GNS) groundwater investigations of the Wakatipu and Wanaka basins between 1994 and 1996 included sampling and analysis for tritium isotopes (Rosen *et al.*, 1997). Thirteen samples were taken across the basin, mainly from wells and bores. The range of tritium ratios (TR) was found to span 1.5 and 5 TR. Recent interpretation of the tritium and electrical-conductivity data from the 1994-1996 samples (van der Raaij, 2012) indicated that the age of the sampled bores lay between 17 and 48 years. The data also allowed an arithmetic relationship to be developed between TR and electrical conductivity of the basin's groundwater.

### 5.10.2 2012: Age determinations

In September 2012, the current investigation included sampling of the following three significant spring discharge sites and bore:

- Rutherford Road spring and mid-Mill Creek Aquifer
- Faulks spring, on the edge of the Hawthorne-Speargrass Aquifer
- Arrow spring and Morven Aquifer
- 60 m bore in Windemeer Aquifer (F41/0104).

The reason for choosing springs to sample was three fold:

1. To date the groundwater age on the downstream side of the aquifer concerned (i.e. the springs were mostly located next to the lowest water-table elevation for the aquifer and thus at the end of the flow path (Figure 4, Figure 6 and Figure 7)).
2. To characterise the age of groundwater that discharges out to the surface-water system
3. Because these springs appear to carry a significant amount of total aquifer discharge:
    a. The mid-Mill Creek Aquifer carries 35 l/s, and a mean of 26 l/s is discharged at Rutherford Road spring.
    b. The Morven Aquifer carries 8 l/s, and 5 l/s is discharged at one spring that was sampled for age determination.

Table 7 lists the results of isotope analysis in terms of mean groundwater age.

**Table 7 Mean age for Wakatipu Basin groundwater sampled in 2012**

| | Mean age (years) | | | | |
|---|---|---|---|---|---|
| | CFC-11 | CFC-12 | CFC-13 | SF6 | Tritium |
| Springs | | | | | |
| Mid-Mill Creek Aquifer | 19 (0 – 30) | 8 (0 – 22) | 11 (0 – 23) | 4 (0 – 12) | 5 (5 – 6) |
| Hawthorne Aquifer | – | – | <13 | 1 (0 – 7) | 2 (2 – 3) |
| Morven Aquifer | – | <13 | <13 | 2 (0 – 6) | 3 (3 – 4) |
| Bore | | | | | |
| F41/0104 | >273 | >153 | >112 | >212 | 287 |

Note: Date results expressed with a range of plausible ages in brackets (e.g. 5 (5-6) indicate that the most likely mean age is 5 years, with a range from 5 to 6 years).

It was a surprise to find that the sampled springs returned ages (mean residence times) of between two and five years. In contrast, the youngest bore-water age was considered to be 17 years (from 1994-1996 sampling). Bore F41/0104 groundwater proved to be over 200 years old.

### 5.10.3 Hydrogeological implications

Groundwater ages determined for springs and bores display a sharp contrast. The age of spring water, determined by the latest survey, is tightly clustered around five years or less. The age of bore water in the Wakatipu Basin is more broadly distributed through time, from 17 years to 287 yBP. The most likely explanation is stratification of groundwater flow within the respective aquifers. Glacial outwash and alluvial deposits tend to be stratified through having greater horizontal permeability than vertical permeability. Part of this effect is the tendency for gravel grains from higher textural zone schist to be flattened and laid flat at the time of deposition. This effect is called 'imbrication' and produces a difference in aquifer permeability by a factor of ten or more between the groundwater flow in the horizontal plane and the vertical plane. Accordingly, incoming water as recharge meets the water table and tends to sheet flow in the horizontal direction rather than sink through the aquifer.

Bores tend to have their intake screens placed towards the bottom of the aquifer as part of good bore-construction practice. Stratification of outwash-alluvial aquifers has been noted to produce bimodal groundwater-flow dynamics (Woodward *et al.*, 2013). This analysis of a catchment found that drainage could be distinguished as:

- near-surface flow (i.e. runoff and overland flow)
- fast groundwater
- slow groundwater.

Furthermore, slow groundwater was found to represent less than 10% of the volume of total groundwater discharged (Woodward *et al.*, 2013). The distinction between fast and slow groundwater is explained by aquifer stratification, with fast groundwater taking recharge rapidly to the aquifer's discharge zones (such as springs). Deeper groundwater would thus have a longer circulation pathway under much lower groundwater velocities because vertical movement occurs at a lower magnitude of permeability. The net result is that total aquifer output tends to be dominated by short residence-time (i.e. young) groundwater. The implications for the assessment of groundwater quality include the following:

- The lag times between water passing through the soil zone and entering the surface-water system at streams, wetlands, rivers or lakes are shorter than would be implied by the age determinations of private bores penetrating the aquifer concerned;
- Deeper groundwater accessed by private bores has a natural level of water quality protection; and
- Purpose-built groundwater-sampling bores that either sample groundwater at the water table or allow depth-discrete sampling at multiple depths are more likely to provide an accurate picture of the quality of fast groundwater discharge.

## 5.11 Aquifer properties

### 5.11.1 Arrow-Bushy Creek Aquifer

Arrowtown's water-supply bore F41/0258 was tested at flows of between 18.6 and 50 l/s in early 2000. This bore was located near the confluence of Bushy Creek and the Arrow River, and is screened across 8 m of sandy gravel and a boulder lag against the schist. Interpretation of the test derived a transmissivity (T) of about 9,280 $m^2$/d.

### 5.11.2 Upper Mill Creek Aquifer

The Hills Golf Club's communal water-supply bore (F41/0341) is located on the eastern edge of the upper Mill Creek Aquifer. The 14 m bore draws on basal gravel and the underlying schist interface. Interpretation of the test derived a transmissivity (T) of about of 1,100 $m^2$/d.

### 5.11.3 Mid-Mill Creek Aquifer

The Lake Hayes water-supply investigation bore (F41/0285), near the Rutherford Road spring, was 24 m deep and drew on sandy gravels, using a flowing artesian head. Interpretation of the test derived a transmissivity (T) of about 700 $m^2$/d.

### 5.11.4 Frankton Flats Aquifer

The Frankton Flats Aquifer was first described after drilling investigation revealed the presence of a thick, highly permeable, sandy gravel aquifer down to a depth of 90 m (Taulis *et al*., 2007). A pump bore (F41/0349 or BHD) was drilled, installed and developed in April 2007. An array of small-diameter piezometers (F41/0347 or OB1; and F41/0348 or OB2) and a 150 mm diameter bore (F41/0345 or BHA) were available for measuring surrounding drawdown response during the 22 hour aquifer test. The depth to the water table before pumping began lay between 45 m and 47.3 m below ground level (BGL), with an ambient static water elevation of 311.6 m AMSL. The three-metre well screen in the pumped bore lay between the depths of 87 m and 90 m BGL. The summary details of bores and piezometers used in the aquifer test are listed in Table 8, and their location is shown in Figure 14.

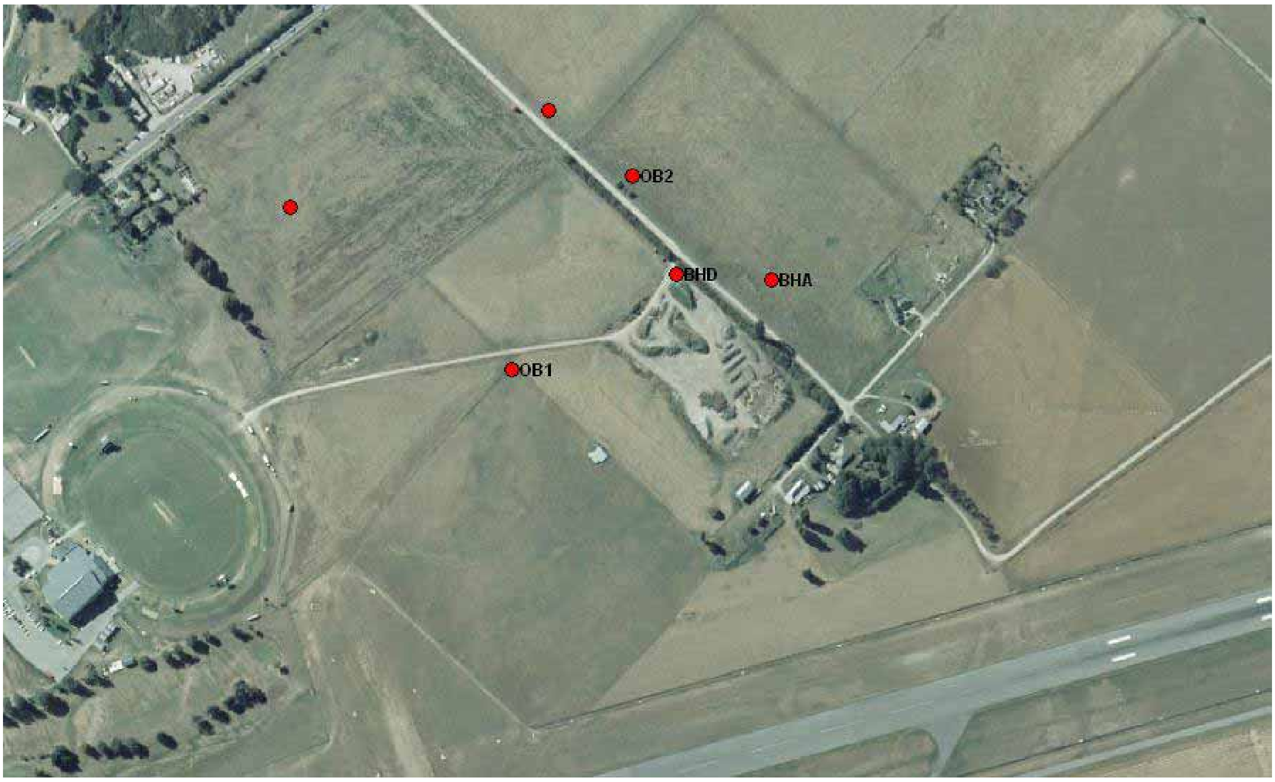


**Figure 14** **Location of Five Mile development aquifer test bores. BHD bore is the pumped bore.**

**Table 8** **Details of Five Mile aquifer test bores**

| Bore | Easting (m NZMG) | Northing (m NZMG) | Collar RL (m) | Depth (m) | Diameter (mm) | Radius (m) | SWL (BGL) (m) | SWL (AMSL) (m) |
|---|---|---|---|---|---|---|---|---|
| BHD[1] | 2174700 | 5568423 | 358.2 | 90 | 160 | 0.08 | 46.55 | 311.65 |
| BHA | 2174795 | 5568413 | 358.6 | 71 | 160 | 95 | 46.97 | 311.63 |
| OB2 | 2174660 | 5568516 | 358.9 | 60 | 20 | 102 | 47.27 | 311.63 |
| OB1 | 2174540 | 5568325 | 356.8 | 60 | 20 | 188 | 45.09 | 311.71 |

Note:

RL = Reference level

SWL = static water level; either below ground level (BGL) or above mean sea level (AMSL)

[1] BHD is the pumped bore.

'Radius' refers to distances from centre of pumped bore.

The pumped bore, BHD, was operated at a flow of 13.8 l/s. Its final drawdown was 8.18 m, which included significant screen head losses. Final drawdowns, measured at 95 m and 188 m radii, were 0.05 m and 0.02 m, respectively. Figure 15 illustrates the type-curve analyses undertaken on observation bore OB2.

Figure 16 illustrates curve-matching of observed drawdown to the Neuman-type curve, with the derived transmissivity in the mid-range of 2000 $m^2$/d.

The results of the test indicate that:

- transmissivity is in the low thousands (1,000 to 3,000 $m^2$/d)
- storage has a specific yield of 10% to 15% (0.10 to 0.15 dimensionless).

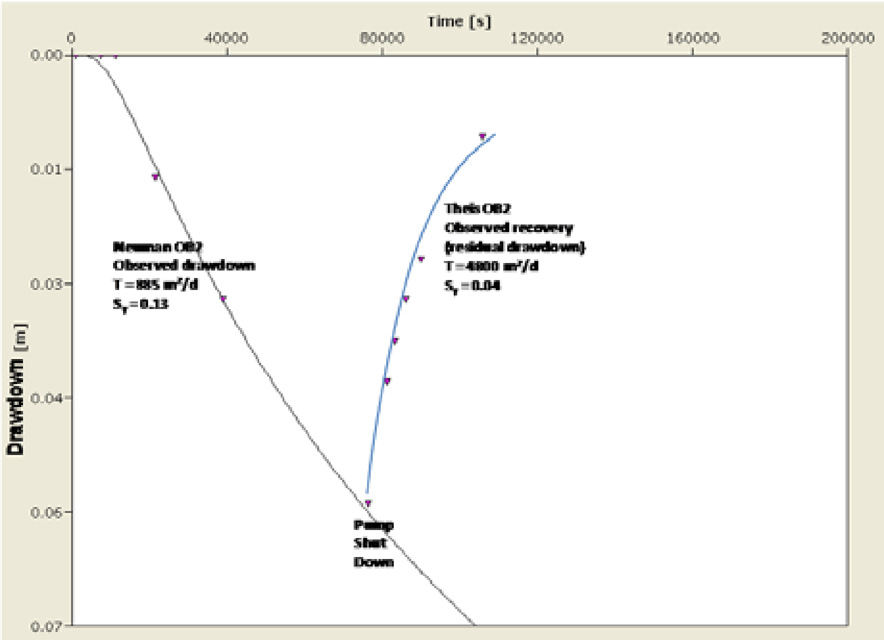


**Figure 15** **Plot of drawdown and recovery curve-matching analysis for OB2 data**

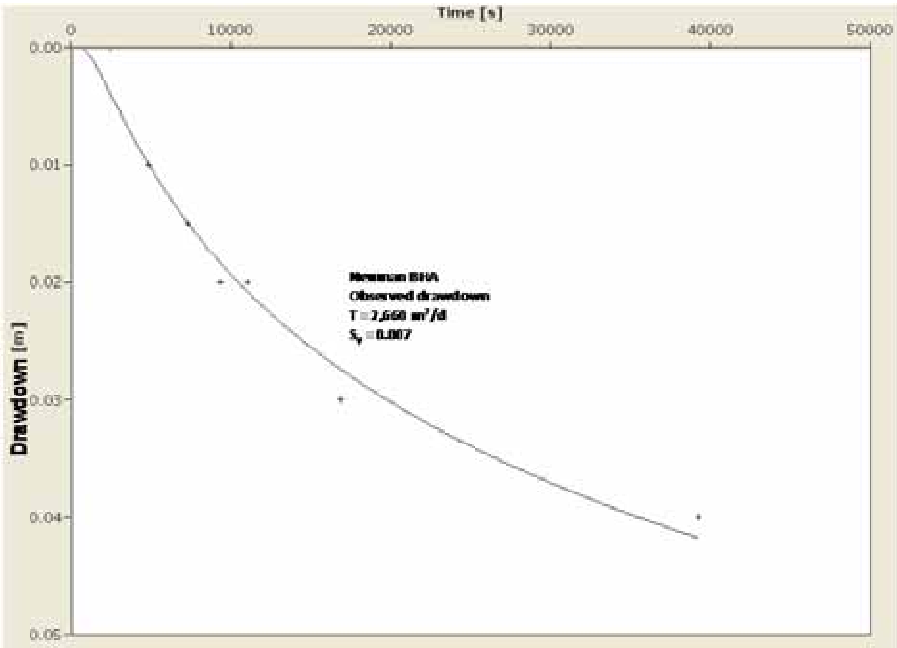


**Figure 16** **Plot of drawdown curve-matching analysis for BHA data**

# 6. Implications for management and conclusions

## 6.1 Future settings for groundwater management

### 6.1.1 Proposals for the allocation of groundwater

A core task of an ORC groundwater investigation is the production of a proposal for the allocation of the aquifer(s) concerned. The aquifer areas are not significantly irrigated by surface water, nor are groundwater-irrigation practices significant in allocating groundwater from the Wakatipu Basin. The Arrow River Irrigation Scheme mainly irrigates areas of basement schist in the Wakatipu Basin, rather than the flat land overlying any of the six aquifers. Accordingly, recharge modelling considered only rainfall inputs to the soil. The three aquifers that rely solely on rainfall recharge, according to the conceptual model, are listed in Table 9.

**Table 9 List of proposed groundwater allocation in rainfall-recharged aquifers**

| | Hawthorn- Speargrass Aquifer ($Mm^3/y$) | Morven Aquifer ($Mm^3/y$) | Windemeer Aquifer ($Mm^3/y$) |
|---|---|---|---|
| Mean annual recharge (from Table 4) | 0.46 | 0.27 | 0.48 |
| 50% of mean annual recharge | 0.23 | 0.135 | 0.24 |
| Consented allocation (from Table 2) | 0.023 | 0.006 | 0.055 |
| Remaining allocation volume [in accordance with Policy 6.4.10A(a)(ii)(1)] | 0.207 | 0.129 | 0.185 |

Water balance studies of the mid-Mill Creek Aquifer included limited gauging of Mill Creek and tributaries. Flow measurements were also available for the Rutherford Road spring. With the estimated water balance, including the surface-water interactions, MAR recharge can be reliably estimated alongside allocation considerations, as in Table 10.

**Table 10 Proposed groundwater allocation in the mid-Mill Creek Aquifer**

| | Mid-Mill Creek Aquifer ($Mm^3/y$) |
|---|---|
| Mean annual *rainfall* recharge (from Table 4) | 0.39 |
| Mean annual *surface-water* recharge | 0.63 |
| *Total:* Mean annual recharge (all sources) | 1.02 |
| 50% of mean annual recharge | 0.51 |
| Consented allocation (from Table 2) | 0.843 |
| Remaining allocation volume [in accordance with Policy 6.4.10A(a)(ii)(1)] | Over-allocated (by 0.33 Mm3/y) |

The mid-Mill Creek Aquifer is over-allocated, mainly due to the QLDC well at Rutherford spring. The well is located on the margins of the aquifer where the groundwater is discharging into Rutherford spring under existing groundwater gradients. The extraction of water from this well would be balanced by reduced spring flow. In this sense, the QLDC extraction of groundwater is non-consumptive. We propose, therefore, that the mid-Mill Creek Aquifer should have a tailored-allocation regime from one of two following available options:

- The Rutherford Road groundwater take is considered non-consumptive in terms of the Water Plan, Policy 6.4.10A(a)(2)(A).
- The mid-Mill Creek Aquifer MAV is tailored by setting it higher than 50% of MAR at a volume of 1 $Mm^3/y$.

Of the remaining aquifers, the following factors make the estimation of MAR difficult:

- The quantification of recharge from all available sources is not feasible for the upper Mill Creek Aquifer.
- The interaction of the Frankton Flats Aquifer with Lake Wakatipu, Shotover River and Kawarau River are reliably believed to be dynamic.

Accordingly, the proposals for groundwater allocation of these aquifers are as follows:

4. The mid-Mill Creek Aquifer should be allocated on the basis of rainfall-recharge calculation of 50% of MAR, the groundwater-surface-water allocation policies and rules in the Water Plan [i.e. 6.4.1A(b) and 6.4.1A(c)].

5. The Frankton Flats Aquifer should be added to the Water Plan, Schedule 2C, as an alluvial ribbon aquifer and managed as surface water (with the exception of the discovery of a confined aquifer).

These proposals for the upper Mill Creek and Frankton Flats Aquifers are summarised in Table 11.

**Table 11 Proposed groundwater allocation in the upper Mill Creek and Frankton Flats Aquifers**

| | Upper Mill Creek Aquifer ($Mm^3/y$) | Frankton Flats Aquifer ($Mm^3/y$) |
|---|---|---|
| Mean annual *rainfall* recharge (from Table 4) | 1.19 | 0.42 |
| 50% of mean annual recharge | 0.6 | 0.21 |
| Surface-water mean annual recharge | Undetermined | Undetermined |
| Consented allocation (from Table 2) | 0.022 | Nil |
| Remaining allocation volume | 0.57 | Undetermined, aquifer to be managed as surface water |

The usual policies and rules relating to groundwater-surface water allocation in the Water Plan [i.e. 6.4.1A(b) and 6.4.1A(c)] would also apply to any groundwater-take application in the upper Mill Creek Aquifer. So, any take for consenting within 100 m of the creek would be subject to the 180 l/s minimum flow, as measured at Fishtrap (Figure 11). Any take that would deplete Mill Creek would require allocation from the creek's primary allocation block to account for the depletion effect. The available surface water allocation of Lake Wakatipu, the Kawarau River and the Shotover River is high and unlikely to be outstripped by foreseeable future groundwater extraction.

In this report, we propose that the remaining undifferentiated glacial-deposit groundwater and fractured rock groundwater systems in the Wakatipu Basin continue to be managed under the default groundwater allocation provisions of the Water Plan. In practice, this would require the definition of a contributing surface area for the calculation of recharge. A basis for delineating the area around a proposed groundwater bore might mean defining its radius of influence by analytical means (e.g. Bear, 1979).

### 6.1.2 Protection of water supplies

Public and communal water supplies, and not irrigation, are the salient issues for the management of Wakatipu Basin groundwater. In the last 45 years, land-use change, from grazing to rural-residential and tourism services (Komischke and White, 2006), has been significant, supporting the conclusion that irrigation assumes less importance in managing the basin's water. In any case, the Arrow River Irrigation Scheme, which is drawn from surface water, provides wide coverage of soils underlain by schist and serves most irrigation or lawn-watering requirements. The scheme's flood and spray irrigation areas are largely over the basement ridges or till, although some pod or gun irrigation has moved onto parts of the aquifers.

Public, private communal and individual water supplies rely on the availability and good quality of the common-good resource, groundwater. The Wakatipu Basin has several glacial or alluvial aquifers and a fractured-schist system to provide accessible groundwater for raw water to water supplies. In relation to this study, only the Frankton Flats and Quail Rise supplies are drawn from Lake Wakatipu. The larger public water supplies include water treatment and contamination monitoring, while the small communal and individual supplies do not. There is not much redundancy or resilience in most parts of the water supply systems. The options for providing alternatives are often limited once a groundwater supply or group of supplies fails.

Assessments of risk to public health employ a 'multiple barrier' philosophy, meaning that rather than favouring a single barrier between exposure to an environmental contaminant, there is a preference for many barriers to exist. The benefit of 'multiple barriers' is that the breaching of a single barrier does not by itself result in a population being exposed to contamination. In terms of public health engineering of groundwater-sourced water supplies, the 'multiple barrier' approach includes:

- wastewater engineering;
- Soil profiles;
- Agricultural good practice, by minimising contaminant emissions;
- sub-soils;
- groundwater system/aquifer contaminant attenuation properties;
- *regional council management / monitoring of groundwater quality;*
- appropriate location and construction of groundwater extraction devices;
- monitoring of raw water;
- appropriate treatment of water;
- monitoring of treated water;
- well engineered distribution and reticulation of treated water; and
- backflow prevention.

Only the barrier *in italics* falls within the responsibilities of ORC to manage. The remaining barriers are the responsibilities of wastewater managers, farmers and water-supply managers. QLDC is the responsible party in the case of some, but by no means all, wastewater and water supply systems. For the smallest, privately owned water supplies, the number of barriers and robustness of each control measure may be minimal. It should be noted that these water supplies rely heavily on the Shotover alluvial ribbon aquifer.

The above discussion highlights the important role that regional council management and monitoring of groundwater quality plays in providing a barrier against contaminant exposure. However, the barrier that regional council management and monitoring provides is not physical, as in other cases.

### 6.1.3 The management of groundwater quantity

The main threat to the physical availability of groundwater in the Wakatipu Basin is over-draught and resultant declining water levels. The lesser threat of depletion of surface water is there too, but it is unlikely to create significant decreases in the basin's available surface water resources, given the prodigious volume of water bodies such as Lake Wakatipu or the Kawarau and Shotover rivers. The more limited water resource of Mill Creek is recognised by setting the MAV of the upper Mill Creek Aquifer to 50% of rainfall recharge, and using the Water Plan's groundwater-surface water allocation policies and rules [i.e. 6.4.1A(b) and 6.4.1A(c)] to control the potential for depletion of the creek.

As a default, the Wakatipu aquifers have an allocation volume limit of 50% of MAR under the Water Plan. The respective MAR totals have been estimated for this purpose in Table 9 to Table 11. We suggest that limits of 50% of MAR be adopted and maintained as part of the basin's groundwater management. This water-allocation setting allows at least half of the water entering the aquifer to leave it, thereby providing the necessary role in sustaining other aquatic values, such as groundwater-dependent ecosystems.

### 6.1.4 The management of groundwater quality

The two modes of threat to groundwater quality in the Wakatipu Basin are point source and non-point source. Point source contamination is discrete and localised in its distribution (e.g. municipal wastewater application to land). By contrast, non-point source contamination may be widespread if the causative land use is also widespread. An example is nitrate-nitrogen in unconfined aquifers, due to the leaching of nitrified nitrogen from intensive grazing or cropping on overlying agricultural soils.

The Regional Plan: Waste (the Waste Plan) would also play a part in groundwater protection. The control and management of contaminated sites, hazardous-waste facilities and landfills is underpinned by the RMA's requirements of the Waste Plan, which include identifying, avoiding, assessing and monitoring contaminant discharges.

This report suggests that the outwash and alluvial aquifers within the Wakatipu Basin are defined as GPZs within the Water Plan. In view of the importance of these aquifers for communal drinking-water supply, we suggest that the grade of GPZs for these aquifers is set at GPZ-A.

### 6.1.5 Protection of general water quality

Groundwaters and surface waters are all somewhat linked. In the Wakatipu Basin, we can see that water from the two of the basin's rivers (Arrow and Shotover Rivers) infiltrates and joins groundwater. On the downstream side, we can also detect groundwater entering surface water with entrained nutrients. This report suggests that the proposed NSZs for the Wakatipu Basin are retained and implemented as a means of managing general water quality with respect to diffuse agricultural nutrients.

## 6.2 Groundwater monitoring

### 6.2.1 Current level and quality monitoring

Regional council monitoring of groundwater level and quality has continued since exploratory investigations began in the late 1990s. Level monitoring of the upper Mill Creek Aquifer began in November 1995 and the Morven Aquifer by July 1997. Monitoring is ongoing at both sites (F41/0161, at Skinner Well, and F41/0203, at Morven Ferry).

We recommend that groundwater level monitoring is undertaken with the following objectives:

- To provide surveillance of adverse events such as water-table drops or aquifer contamination;
- To establish an environmental baseline of level and quality data that are inherently variable in nature;
- To allow the correlation of influences on the water table with responses in the water table height (e.g. level response to recharge pulses); and
- To provide a data set for scientific modelling (e.g. numerical-model calibration, especially transient models).

Monitoring needs to reflect groundwater conditions as a whole. The level record obtained to date has been relatively continuous and useful in meeting monitoring objectives. Continuation of the current automatic level recording is justified in view of the results obtained and in the interests of maintaining continuity of record.

Groundwater quality has been undertaken at Windemeer, Morven, mid-Mill Creek, upper Mill Creek and Hawthorne-Speargrass Aquifers since March 1995. The monitoring network was revised in 2007, and groundwater quality is currently monitored at three sites in the Windemeer, Morven and Hawthorne aquifers.

**Table 12 Summary of groundwater level and quality monitoring in the Wakatipu Basin**

| **Monitoring bore/aquifer** | Level monitoring | Quality monitoring |
|---|---|---|
| F41/0161 Skinner well, upper Mill Creek | Auto-level recorder | |
| F41/0203* Moonlight Stables, Morven | Auto-level recorder | |
| F41/0118* Morven | Manual, quarterly | Quarterly |
| F41/0104 Windemeer | Manual, quarterly | Quarterly |
| F41/0332 Hawthorn - Speargrass | Manual, quarterly | Quarterly |

* adjoining bore locations for F41/0203 and F41/0118

### 6.2.2 Suggested future monitoring of groundwater level and quality

SOE monitoring is mainly directed towards defining baseline conditions and identifying long-term trends, rather than the surveillance of more immediate effects on groundwater. There is value in maintaining long-term occupation of level and water quality monitoring bores. However, there is sometimes a need to review and renew a monitoring network. This report provides such an opportunity.

The question has arisen as to whether the Skinner well (F41/0161) provides useful information. Figure 17 and Figure 18 examine and compare the well with other Wakatipu Basin groundwater resources to determine if it is representative.

The Skinner well monitoring site was installed in November 1995. However, its topographic setting in a *cul de sac* of the aquifer suggests that it is not connected to the upper Mill Creek Aquifer. Adjoining ponds also act as a fixed head to the groundwater behaviour measured in the Skinner well. This effect is supported by the strong correlation in level between Mill Creek and Skinner well (Figure 17).

When the Morven level recorder (F41/0203) and the Skinner well are exposed to the same climate and recharge influences, it is clear that there is a weak correlation between level variations. The discrepancy between the hydrographs of these two monitoring sites is evident in Figure 18. While the Morven hydrograph is relatively smooth and cyclical, the Skinner well hydrograph is choppy and episodic.

Essentially, the Skinner well is more representative of surface water than it is of the basin's groundwater level. In recognition of the lower value of the Skinner well, we suggest that the site of ORC groundwater level monitoring is re-located to the mid-Mill Creek or the Windemeer Aquifers. Both aquifers have more significance as sources of public water supply, in terms of their quantity.

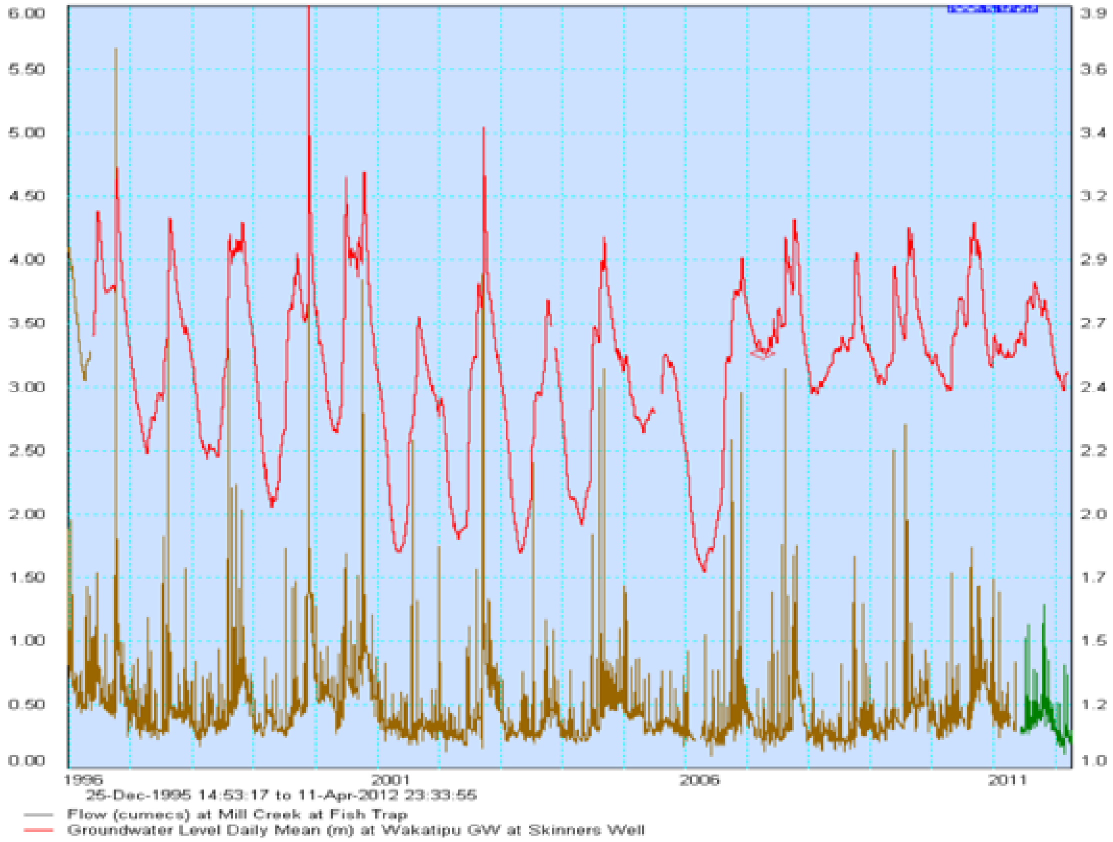


**Figure 17** **Comparison of Skinner well groundwater level and Mill Creek flow**

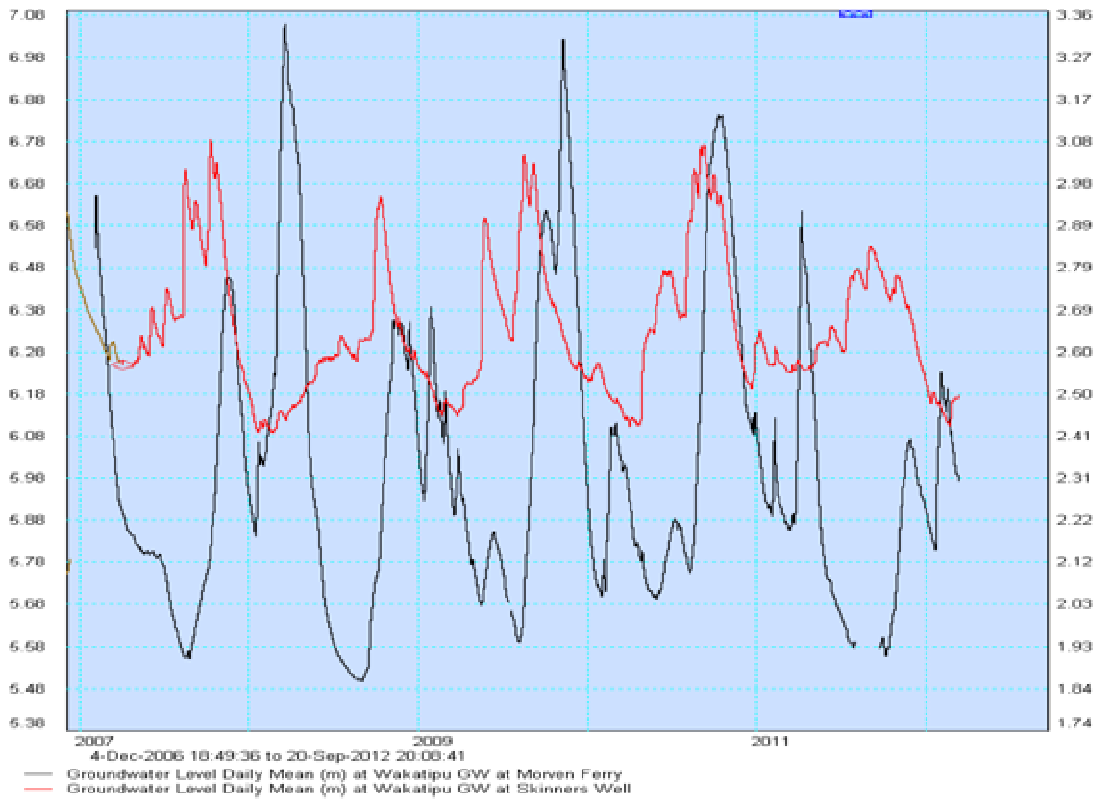


**Figure 18** **Comparison of Skinner well and Moonlight Stables (Morven) groundwater level**

The other matter to consider when monitoring groundwater level is the difference between the results generated by automated, continuous records and manual records. Figure 19 is a comparison of adjacent bores monitored by continuous recorder and manual means, and it illustrates the loss of significant groundwater information as a result of relying on quarterly manual level measurements alone.

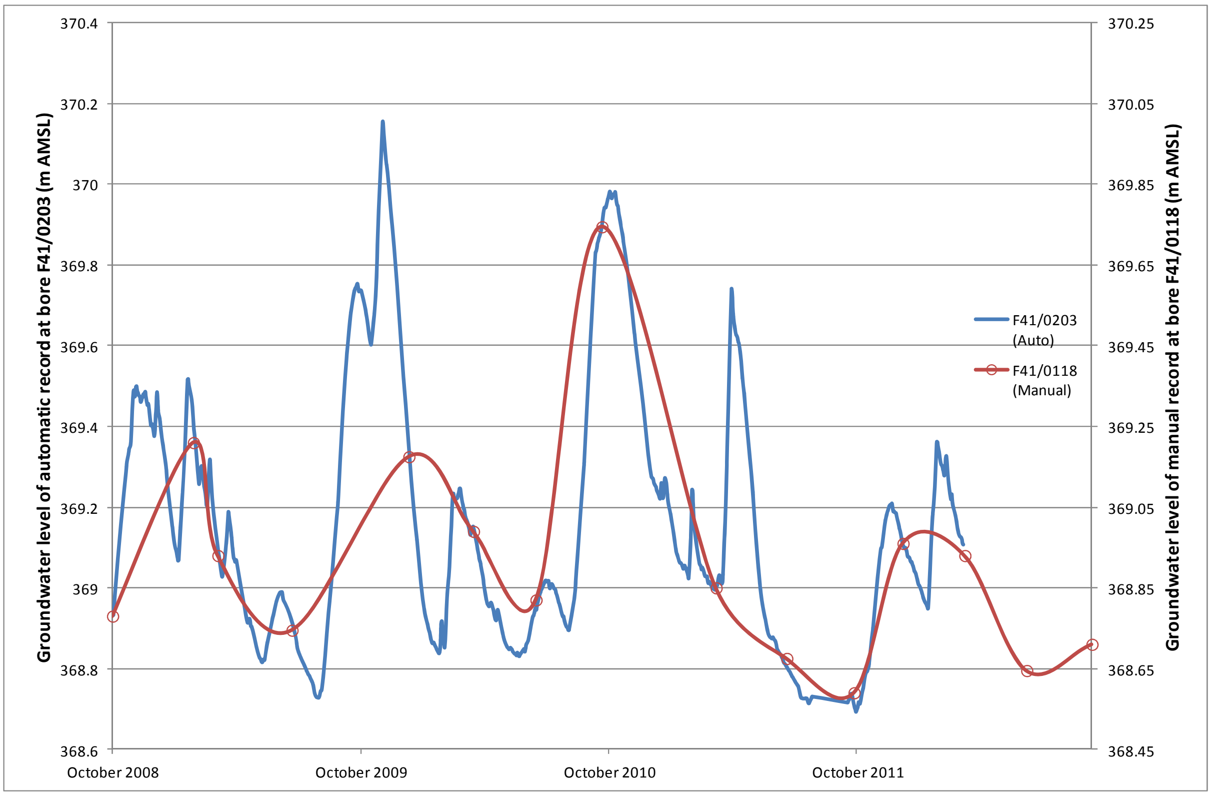


**Figure 19** **Comparison of automated and manual groundwater level records for the same location in the Morven Aquifer**

The quality and usefulness of information contained in automated, continuous level records is substantially better than for infrequent manual records. Therefore, we suggest that manual groundwater level monitoring be phased out in favour of automated level logging. ORC also has a policy of making the transition from using private bores to ORC-owned and customised monitoring bores. We propose that wherever ORC installs custom monitoring bores in the Wakatipu Basin, automated level monitoring is installed at the same time, as a means of improving the quality of the level record.

## 6.3 Conclusions

The following conclusions could be drawn from this investigation.

### 6.3.1 Groundwater allocation

We propose that glacial outwash and alluvial aquifers be allocated at 50% of MAR, as defined in the tables below.

| | Hawthorn-Speargrass Aquifer (Figure 6) ($Mm^3/y$) | Morven Aquifer (Figure 7) ($Mm^3/y$) | Windemeer aquifer (Figure 5) ($Mm^3/y$) |
|---|---|---|---|
| Mean annual recharge | 0.46 | 0.27 | 0.48 |
| 50% of mean annual recharge | 0.23 | 0.135 | 0.24 |
| Consented allocation | 0.023 | 0.006 | 0.055 |
| Remaining allocation volume [in accordance with Policy 6.4.10A(a)(ii)(1)] | 0.207 | 0.129 | 0.185 |

| | Upper Mill Creek Aquifer (Figure 3) ($Mm^3/y$) | Mid-Mill Creek Aquifer (Figure 4) ($Mm^3/y$) | Frankton Flats Aquifer (Figure 8) ($Mm^3/y$) |
|---|---|---|---|
| Mean annual recharge | 1.19 | 1.02 | 0.42 |
| 50% of mean annual recharge | 0.6 | 0.51 | 0.21 |
| Consented allocation | 0.022 | 0.843 | 0 |
| Remaining allocation volume | 0.57 | Over-allocated (by 0.33 $Mm^3/y$) | Undetermined, aquifer to be managed as surface water |

We propose that remaining undifferentiated glacial-deposit groundwater and fractured-rock groundwater systems in the Wakatipu Basin continue to be managed under the default groundwater-allocation provisions of the Water Plan (i.e. 50% of MAR) and that the Shotover and Kawarau alluvial ribbon aquifers are allocated as surface water by inclusion in the Water Plan, Schedule 2C.

### 6.3.2 The protection of groundwater quality

We suggest that the outwash and alluvial aquifers within the Wakatipu Basin (Figure 3 to Figure 7) are defined as GPZs within the Water Plan. In view of the importance of these aquifers for communal drinking-water supply, we suggest that the grade of GPZs for these aquifers is set at GPZ-A. The NSZs affecting the Wakatipu Basin should also be retained.

### 6.3.3 Groundwater monitoring

We suggest that the site of ORC groundwater-level monitoring at Skinner well in the upper Mill Creek Aquifer be discontinued. The continuous level monitoring should be relocated to the mid-Mill Creek Aquifer or the Windemeer Aquifer.

We propose that wherever ORC installs custom monitoring bores in the Wakatipu Basin, continuous level monitoring is installed at the same time, as a means of improving the quality of the level record.

# Glossary

***Ablation till***

Loose, clayey gravel or sandy gravel, deposited by melting ice

***Alluvium***

Sediments deposited by a river

***Aquifer***

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

***Basal till***

Un-stratified, compact, gravelly, sandy and silt/clay, deposited at the base of the glacier

***Basement rock***

Solid rock, such as schist or greywacke, which underlies younger unconsolidated rocks

***Confined aquifer***

An aquifer in which water is stored under elastic pressure, and which tends to be found at depths below the ground surface where permeable sediments such as gravels have been overlain by low permeability mud, silt or clay

***Cumec***

A measure of flow rate, literally cubic metres per second ($m^3/s$) (one cumec is 1000 l/s)

***Drawdown***

The lowering of water levels in response to pumping

***Fan and delta deposits***

Well-graded, sandy gravel deposited into lakes near a fan or delta

***Flux***

Flow through a unit of aquifer, or the rate of exchange with a hydraulically connected surface-water body

***Formation***

A distinctive unit of rock that can be mapped

***Geohydrology***

The study of aquifers and groundwater with a hydrological emphasis (see hydrogeology)

***Hydraulic conductivity***

The rate at which water can pass through a permeable medium in meters per day (m/day)

***Hydraulic gradient***

The slope of the water table or piezometric surface

***Hydrogeology***

The study of aquifers and groundwater with a geological emphasis (see geohydrology)

***Lake deposits***

Layered/bedded, micaceous silt, sometimes referred to as 'pro-glacial till' where deposited against the moraine of a pro-glacial lake, or as 'varved lake beds' where the bedding patterns are particularly well developed

***Permeability***

The ability of a rock or sediment to transmit water; highly permeable gravel will allow water to flow quite freely

***Piezometer***

A small-diameter observation well used to monitor water levels only; often abbreviated to 'Piezo'

***Porosity***

A measure of the void or pore space within a sediment or rock (e.g. sand typically consists of 30% total pore space, which is a porosity of 0.3)

'Effective porosity' is the pore space that is effective in conducting water through the sediment or rock. Given the number of blind pores, 'effective porosity' is a fraction of 'total porosity'.

***Quaternary***

The most recent geological period from 2.6 million years ago to the present day, comprising the Pleistocene of about 2.6 million years, and the Holocene, the last 10,000 years, during which global sea levels stabilised

***Recent floodplain and lake-beach deposits***

Coarse-grained alluvial deposits, in accordance with their modern depositional environments

***Roche moutonnée***

Rock formation formed by the passing of a glacier over underlying bedrock, resulting in asymmetric erosion with smooth abrasion on the up-ice side of the rock and plucking on the down side

***Schist***

A type of metamorphic rock in which the individual mineral grains have been elongated or flattened (e.g. the fabric of a schist rock is usually planar or foliated

Schist is the distinctive basement rock found throughout most of Otago.

***Screen***

A filter installed at the end of bore casing to keep sediment from entering a borehole

***Specific capacity***

Used to describe well productivity and is determined by pumping a well at a constant rate for a specified duration, usually 30 minutes to two hours

The specific capacity of the pumped well is the rate of discharge divided by the drawdown.

***Storativity***

A measure of the storage characteristic of an aquifer

In confined aquifers, 'storativity' refers to elastic storage (contraction and expansion of water and aquifer matrix). In unconfined aquifers, it is a measure of the water released from the pores between grains as a result of flow under gravity (specific yield).

***Structure***

Refers to a particular structural feature, or related series of features within a rock or region ('Structural geology' is the study of the faults, folds, fabrics and bedding of rocks.)

***Terrace***

A flat topographic feature formed by erosion or deposition of sediments by a river

***Terrane***

A shorthand term for a 'tectono-stratigraphic terrane', which is a fragment of crustal material formed on, or broken off from, one tectonic plate and accreted or 'sutured' to crust lying on another plate

***Terrace alluvium***

Layered, sandy gravel with minor layers of silt and sand deposited as glacial outwash downstream of terminal moraines, primarily as aggradation surfaces (terraces)

***Transmissivity***

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

***Unconfined aquifer***

Tends to be shallow and recharged directly from rainfall infiltration onto the ground surface or from water flowing from surface-water bodies

(Streams, lakes and wetlands are usually the surface expression of an unconfined aquifer.)

***Water table***

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

# Appendix 1 – Consented groundwater extractions

| Consent no. | Wakatipu aquifer | Well no. | Instant. (l/s) | Daily ($m^3$/d) | Weekly ($m^3$/wk) | Monthly ($m^3$/mth) | Annually ($m^3$/a) | Water use |
|---|---|---|---|---|---|---|---|---|
| 2000.057 | Hawthorne-Speargrass | F41/0186 | 4 | 225 | | | 20,250 | Comm dom, Irr |
| 2001.685.V1 | Hawthorne-Speargrass | F41/0043 | 1.5 | 36 | | | 3,240 | Comm dom |
| 2000.457 | Mid-Mill Creek | F41/0060 | 3.9 | 182 | | | 16,380 | Irr., dom |
| 2001.201 | Mid-Mill Creek | F41/0266 | 1.8 | 35 | | | 3,150 | PWS |
| 2001.822 | Mid-Mill Creek | F41/0257 | 40 | 2200 | 15400 | | 800,800 | PWS |
| 2004.252 | Mid-Mill Creek | F41/0220 | 1.1 | 30 | 210 | 912 | 10,950 | Irr |
| 97614 | Mid-Mill Creek | F41/0054 | 1.25 | 84 | | | 7,560 | Comm dom, Irr, Ind |
| 97620 | Mid-Mill Creek | _ | 0.8 | 20 | | | 1,800 | Comm dom |
| 97752 | Mid-Mill Creek | F41/0193 | 1 | 30 | | 930 | 2,700 | Comm dom |
| 2006.127 | Morven | F41/0333 | 0.5 | 16.8 | | | 1,512 | Comm dom |
| 97251 | Morven | F41/0118 | 0.97 | 10 | | | 900 | Comm dom |
| 99023 | Morven | F41/0072 | 0.97 | 10.5 | | | 945 | Comm dom |
| 99402 | Morven | Spring | 1.5 | 28 | | | 2,520 | Comm dom, Irr |
| 98505 | Schist rock | F41/0237 | 1 | 9 | | | 810 | Comm dom |
| 2000.324 | Shotover alluvial ribbon | F41/0041 | | 43 | | | 3,870 | Comm dom, Irr |
| 2002.666 | Shotover alluvial ribbon | F41/0219 | 2.8 | 240 | 1680 | 7,440 | 21,600 | Comm dom |
| 2002.727 | Shotover alluvial ribbon | F41/0111 | 2.22 | 150 | | | 13,500 | Comm dom |
| 2002.728 | Shotover alluvial ribbon | _ | 5.94 | 400 | | | 36,000 | Comm dom |
| 2003.099 | Shotover alluvial ribbon | _ | 0.3 | 12 | 84 | 372 | 1,080 | Comm dom |

| Consent no. | Wakatipu aquifer | Well no. | Instant. (l/s) | Daily ($m^3$/d) | Weekly ($m^3$/wk) | Monthly ($m^3$/mth) | Annually ($m^3$/a) | Water use |
|---|---|---|---|---|---|---|---|---|
| 2003.957 | Shotover alluvial ribbon | F41/0038 | 6.1 | 300 | | 9,150 | 27,000 | Comm dom |
| 99444 | Shotover alluvial ribbon | F41/0236 | 1.4 | 100 | | | 9,000 | Comm dom, Irr |
| 2006.478 | Kawarau alluvial ribbon | F41/0331 | 6 | 334 | | | 121,910 | PWS |
| 2006.338 | Undefined glacial | F41/0166 | 0.55 | | | 868 | 10,220 | Comm dom, St |
| 2007.242 | Undefined glacial | F41/0341 | 1.2 | 51 | | | 12,500 | Comm dom, Irr |
| 2008.613 | Undefined glacial | F41/0250 | 1 | 20.8 | | 649 | 5,396 | Comm dom |
| 97407 | Undefined glacial | F41/0204 | 0.152 | 5 | | | 450 | Comm dom |
| 2006.344.V1 | Undefined glacial | F41/0160 | 0.8 | 16.8 | 504 | | 6,048 | Comm dom |
| 2004.932 | Upper Mill Creek | F41/0102 | 2.22 | | | 953 | 7,061 | Comm dom, St |
| 99266 | Upper Mill Creek | F41/0244 | 1.5 | 50 | | | 4,500 | Comm dom, Irr |
| 2001.752.V1 | Upper Mill Creek | F41/0270 | 1.4 | | | 3,360 | 10,080 | Irr |
| 99565 | Windemeer | F41/0239 | 1.5 | 30 | | | 2,700 | Comm dom, Irr |
| 2003.355.V1 | Windemeer | F41/0134 | 0.88 | 76 | 532 | 2,128 | 25,546 | Comm dom |
| 2004.966.V1 | Windemeer | F41/0310 | 6.94 | 300 | | | 27,000 | Comm dom |

Note:

Instant = Instantaneous rate

PWS = Public water supply

Comm dom = Communal domestic

Irr = Irrigation

St = Stock water

Ind = Industrial (winery)

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