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Hydrogeology of the Oreti Basin

REPORT PREPARED FOR ENVIRONMENT SOUTHLAND

- Final
- 27 July 2005

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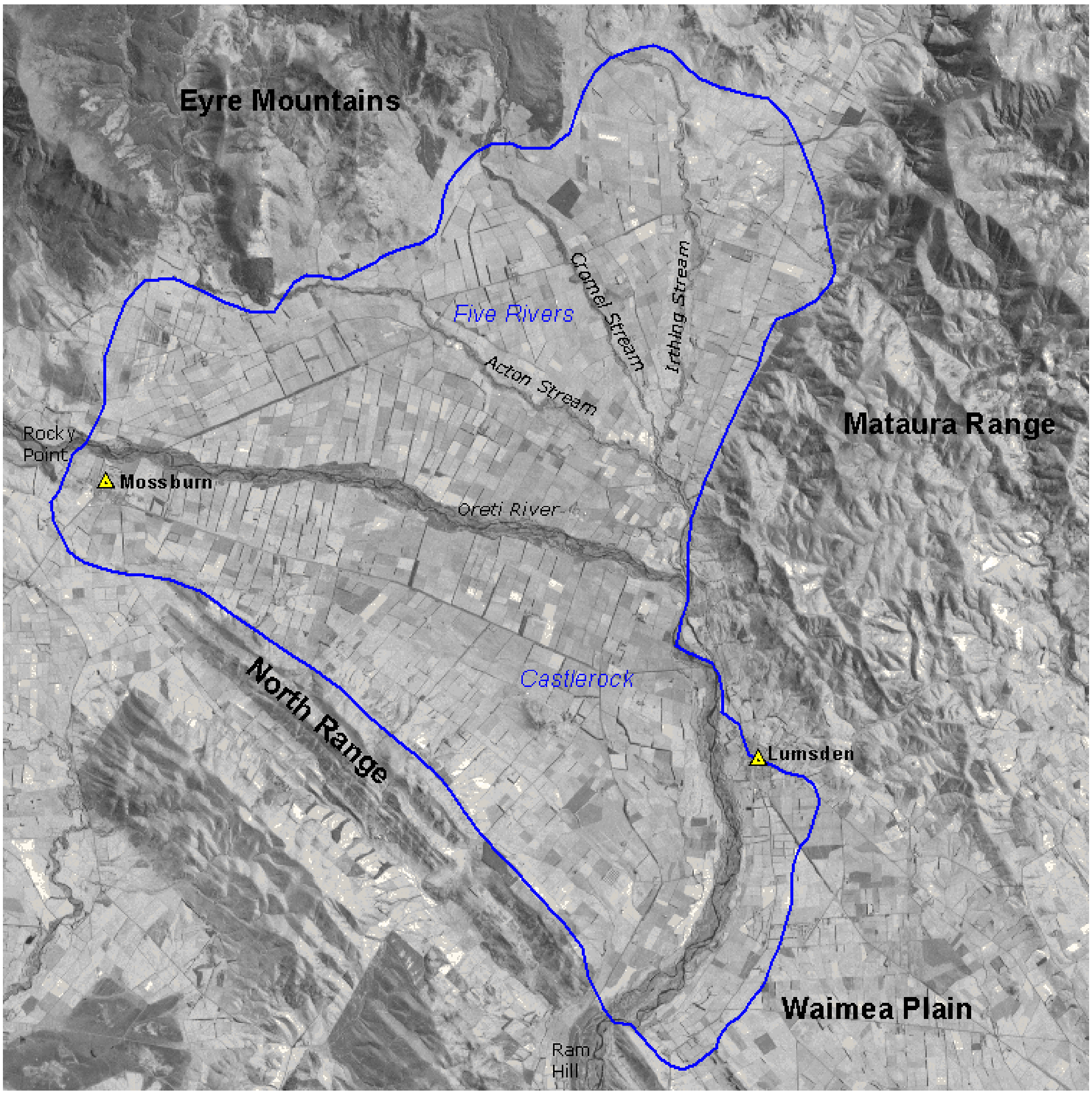
1. Introduction

1.1 Physiography

The Oreti basin encompasses a roughly triangular area of approximately 270 km^3 at the western extent of the Waimea Plain in Northern Southland (Figure 1). The area is bounded to the south by the North Range of the Hokonui Hills and to the east and west by foothills of the Mataura Range and Eyre Mountains respectively. The eastern boundary crosses the Waimea Plains approximately 2 km east of the Oreti River following the drainage divide between the Oreti River and Waimea Stream.

▪ **Figure 1. Physiography of the Oreti basin**



Large alluvial fans fringe the foothills surrounding the Oreti basin. These alluvial fans then grade onto an extensive alluvial plain that slopes to the southeast following the drainage pattern of the Oreti catchment. The alluvial plain is bisected by the Oreti River which enters the basin via a narrow, basement defined channel at Rocky Point immediately west of Mossburn. The Oreti River then flows eastward until it reaches the foothills of the Mataura Range. At this point the river turns almost 90 degrees and flows south to exit the basin via a narrow gorge through the Hokonui Hills at Ram Hill. Five major tributary streams (Acton, Cromel, Dilston, Irthing and Oswald Streams) flow from headwaters in the Eyre Mountains across the Five Rivers area and enter the Oreti River near Lumsden.

The township of Lumsden lies at the base of the Mataura Range near the point of inflection in the Oreti River. Mossburn is located at the western extent of the North Range.

1.2 Geology

The Oreti basin is a large intermountain basin formed by extensive fault movement during the Cretaceous Period. The basin is underlain by basement rocks of three geological terranes and is infilled by a sequence of Tertiary marine sediments and Quaternary fluvioglacial gravel deposits.

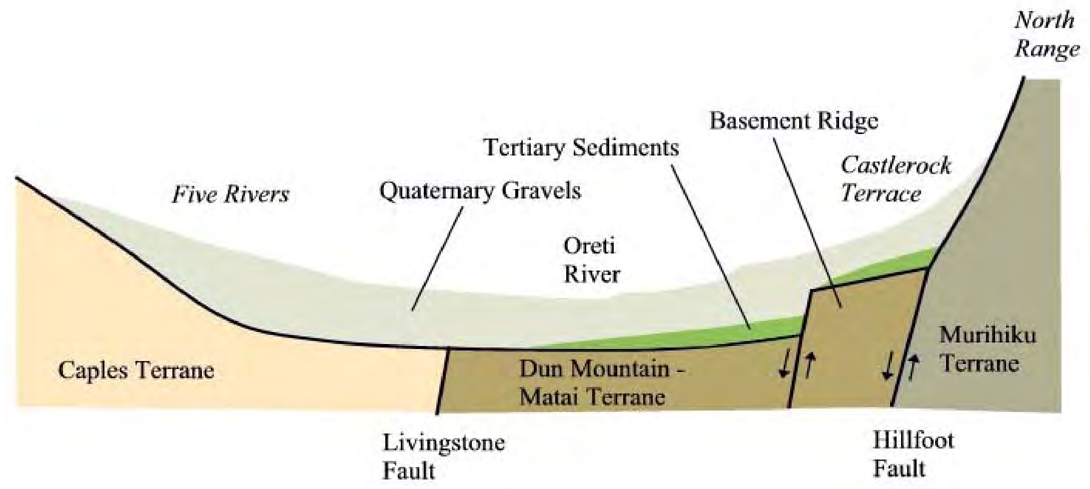
Volcanioclastic sandstone and mudstone sediments of the Caples Group underlie the northern portion of the Oreti basin. These sediments grade to the north into the semischists of the Haast Group that form the Hector and Garvie Mountains. Rocks of the Dun Mountain-Matai terrane underlie the central portion of the Oreti basin. These rocks are extensively faulted and, in part, represent remnants of a slice of Early Permian oceanic crust (gabbro and peridotite of the Dun Mountain Ultramafics Group) and associated volcanics and volcanioclastic sediments (the Livingstone Volcanics Group). Outcrop of these rocks is restricted to areas along West Dome to the north of Mossburn and along the foot of the North Range.

The Caples and Dun Mountain-Matai terranes are separated by the Livingston Fault system that extends across much of Northern Southland and South Otago. This fault system represents a zone of major displacement with strike-slip movement inferred to have occurred on the scale of hundreds of kilometres (Carwood 1986, 1987).

To the south, the steeply dipping northern limb of the Southland Syncline forms the southern boundary of the Oreti basin. Preferential erosion of the alternating mudstone and sandstone units have resulted in the formation of prominent strike ridges which can be traced along the Hokonui Hills from the North Range at Mossburn to Kaka Point on the Catlins Coast. The Hillfoot Fault system, which runs along the northern flanks of the North Range, forms the boundary between the Dun Mountain-Matai and Murihiku terranes.

Figure 2 shows a schematic cross section of the geology underlying the Oreti Basin.

- **Figure 2. Schematic geological cross section of the Oreti basin**



Basement rocks in the Oreti basin are overlain by an unknown thickness of Tertiary sediments. These sediments are interpreted as laterally equivalent to the East Southland Group sediments of the Forest Hill Formation that outcrop in downfaulted blocks within the axis of the Southland Syncline and on the Waimea Plains in the vicinity of Balfour.

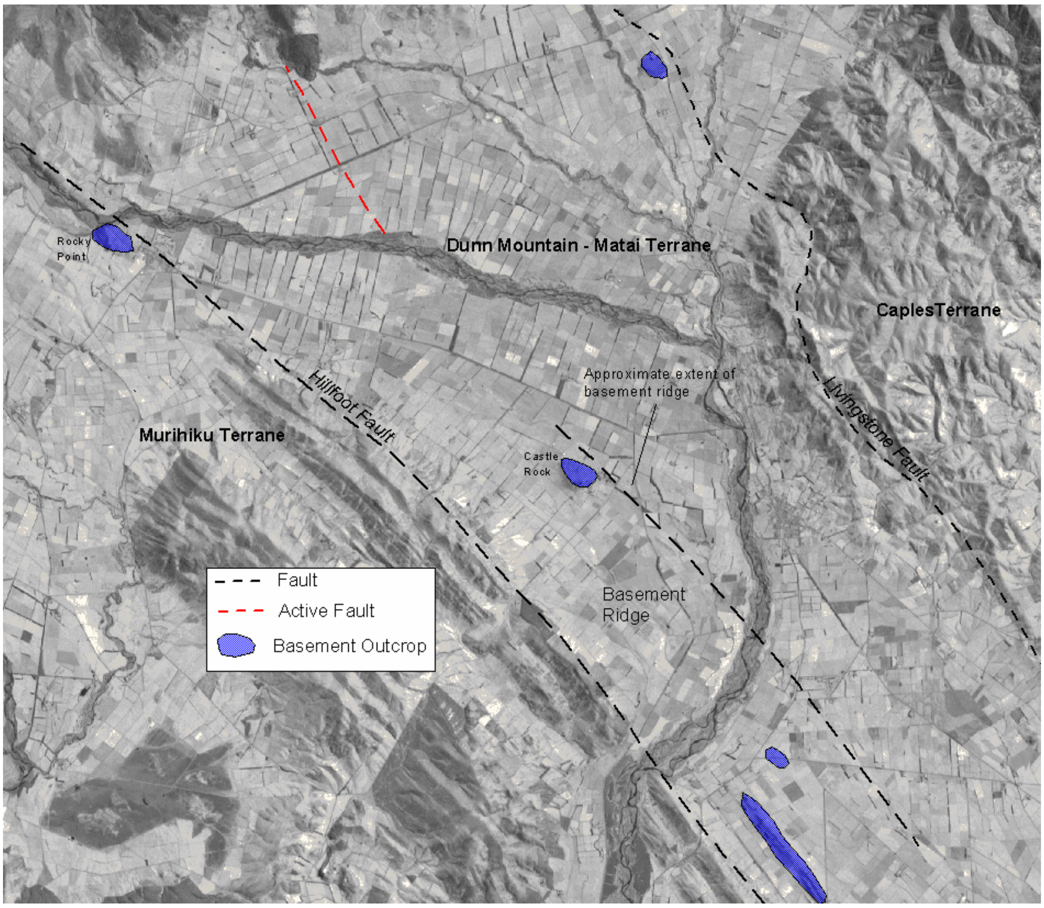
The Oreti basin contains a relatively thick accumulation of glacial and fluvioglacial outwash gravels deposited during successive Quaternary glaciations. These sediments form a sequence of tightly claybound and relatively clean gravel strata representing rapid deposition and subsequent reworking of gravel material during glacial and subsequent interglacial periods. On the Castlerock terrace these gravel deposits interfinger with a large alluvial fan accumulated on the northern slopes of the North Range. Total thickness of gravel deposits in the Oreti basin is poorly defined however recent drilling indicates at least 80 m of gravel material overlie Tertiary sediments basement in the central basin area.

1.2.1 Basement Geology

Limited information currently exists to define basement structure and topography underlying the Quaternary gravel deposits in the Oreti basin. Available information suggests both the thickness of Tertiary sediments and basement topography is highly variable across the area, particularly close to base of the Hokonui Hills. The location of relevant bores is shown in Figure 40 in Section 4.

The "Castle Rock" is a prominent basement outcrop of Dun Mountain-Matai basement to the west of the Dipton-Mossburn Highway. It appears this basement outcrop represents a continuation of the basement ridge exposed to the north of Ram Hill on the eastern side of the Oreti River. Recent drilling investigations (E44/0259 - E44/0268) indicate a significant thickness of alluvial sediments (>70 m) occur to the west of Castle Rock while, to the east, a significantly different sequence of Quaternary sediments was encountered overlying basement at a relatively shallow depth in E44/0282. These observations indicate the presence of a buried basement ridge immediately to the north of the Murihiku escarpment following the approximate boundary (dashed line) shown in Figure 3.

- **Figure 3. Interpreted basement structural control in the Oreti basin**



The extent of the basement ridge and associated fault system to the west of Castle Rock is uncertain however, the outer margin of this feature appears to align with the recent fault trace documented by Turnbull *et al* (2004) near Hillas Road. The significance of this structure on the hydrogeology of the area is further discussed in Section 2.1

Toward the northern margin of the Oreti basin a prominent outcrop of Dun Mountain-Matai basement occurs at the northern end of Lowther Road. This structure is interpreted to represent localised disruption of basement structure along the Livingstone Fault as recent drilling in this area (E44/0302, E44/0320 drilled early 2005) has shown the presence of up to 80 m of Quaternary gravels overlying basement less than 1 km to the east.

1.2.2 Tertiary Sediments

Available drill logs indicate the presence of a variable thickness of Tertiary sediments overlying basement in the Castlerock area. However, the exact distribution and structure of these sediments remains poorly defined.

Tertiary sediments of the Eastern Southland Group have been encountered along the base of the North Range. At the southern end of Edwards Road 2.5 m of mudstone was recorded in E44/0262 overlying greywacke basement at a depth of 22.5 m (~225 mRL). Approximately 1 km to the east, mudstone was recorded in E44/0266 from 32 m (~207 mRL) to a depth of 83 m (~156 mRL). Further toward the centre of the basin, mudstone was also encountered in E44/0264, located adjacent to SH94, at a depth of 77 m (~170 mRL).

Elsewhere in the Oreti basin a relatively thick sequence of Tertiary sediments including mudstone and lignite were encountered at a depth of 38 m in E44/0281 located close to Ram Hill.

1.2.3 Quaternary Geology

The alluvial sediments infilling the Oreti basin have a relatively complex depositional history reflecting both Quaternary climatic variations as well as the influence of faulting and folding on local drainage patterns. The thickness of these deposits is largely unknown however, based on available drill hole data, at least 80 m of alluvial gravels are thought to overlie basement throughout the central area of the basin.

During Quaternary glaciations large volumes of fluvioglacial outwash gravels were deposited in the Oreti basin by rivers draining the surrounding Eyre Mountains and Oreti River headwaters. During subsequent interglacial periods sediment supply was reduced and the ancestral Oreti River and tributaries entrenched into these glacial materials. Successive cycles of deposition followed by river entrenchment and reworking created a vertical sequence of claybound glacial gravels separated by coarse gravel and sand deposits. This geological succession is similar to that observed in many alluvial gravel aquifer systems elsewhere in New Zealand (e.g., Heretaunga Plains, Wairau Valley).

Complicating the deposition environment through this period were the effects of major shifts in the local drainage pattern that occurred through the middle to late Quaternary period. Turnbull and Allibone (2004) suggest that during the late middle Quaternary the Oreti River flowed south into the headwaters of the Aparima River. Due to the influence of faulting in the Mossburn area the Oreti River then shifted course to flow down the Waimea Plain to join the Mataura River (“the

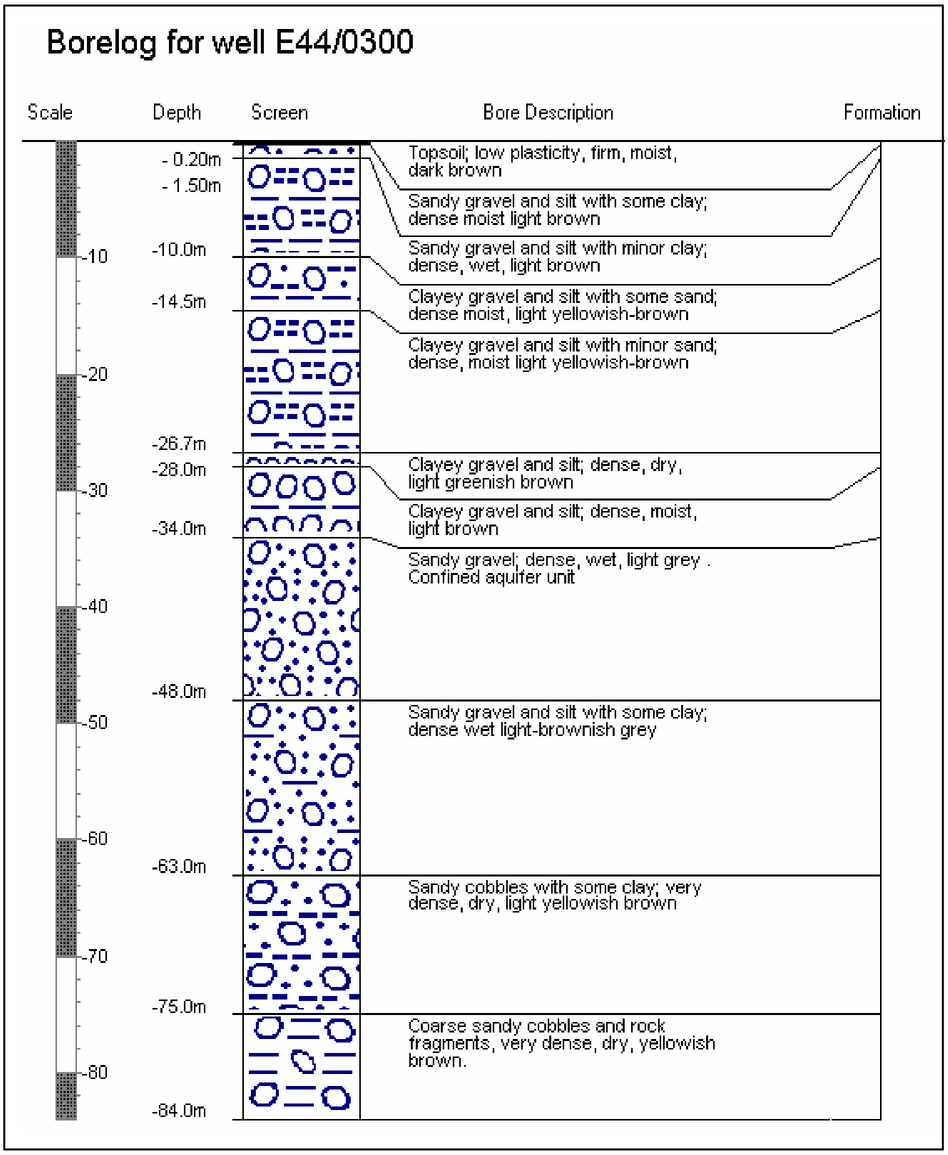
Lumsden River") before in more recent times being diverted again, either due to structural deformation and faulting or depositional processes, to its current alignment through Ram Hill. The Ram Hill "gap" being created by downfaulting within the axis of the Southland Syncline and general uplift and structural deformation across the Waimea Plain in the vicinity of Lintley.

Around the basin margins the depositional pattern is also complicated by the formation of large alluvial fans such as those along the base of the North Range. These localised deposits coalesce with the major alluvial terraces formed by the Oreti River and tributaries in central areas of the basin.

Despite the complex depositional history a consistent pattern of geology is evident within the upper 50 m of Quaternary gravels in the central portion of Oreti basin. In the Five Rivers area, layers of relatively coarse, poorly sorted waterbearing alluvial gravel and sand are separated by a laterally extensive tightly claybound gravel layer. Figure 4 shows the drillers log for E44/0300 drilled by Environment adjacent to the Oreti River north of the Castlerock saleyards. The bore log shows the presence of over 80 m of Quaternary gravel overlying basement in the central portion of the Oreti basin. The observed sequence of alluvial gravels can be differentiated into four distinct parts:

- Sandy gravels to a depth of ~10 m below ground representing sediments of the recent floodplain of the Oreti River. These sediments form a thin unconfined aquifer.
- A thick sequence of tightly claybound gravel extending from 10 - 34 m below ground representing glacial outwash gravels accumulated during the last glacial period. These gravels contain little water and form a low permeability confining layer over the deeper waterbearing gravel sediments.
- A thick sequence of sandy gravels representing alluvial sediments extensively reworked during the last interglacial period. These gravels form a confined aquifer from 34 - 63 m below ground.
- A sequence of very tight gravels and cobbles becoming increasingly coarse with depth. This layer is interpreted to represent a basal gravel sequence overlying a weathered bedrock surface.

- **Figure 4. Drillers log from E44/0300 in the central Oreti basin**

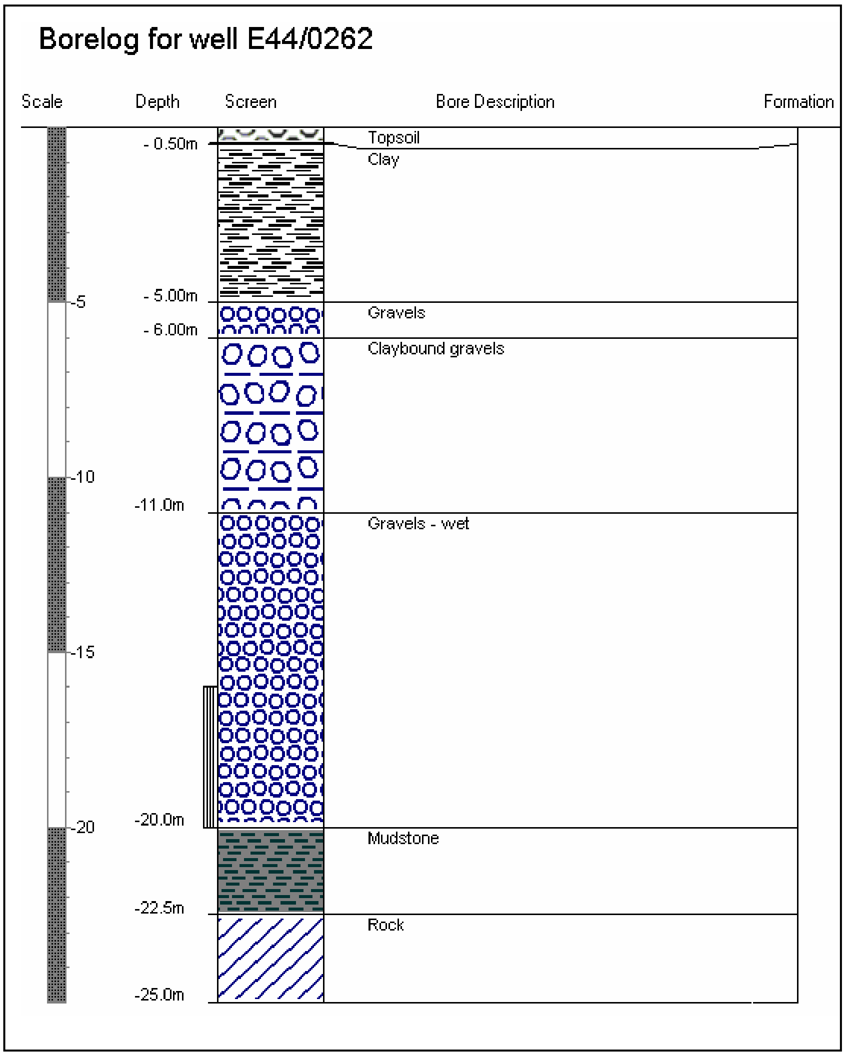


A similar pattern of subsurface geology is observed across the area from Ellis Road as far south as the Mossburn-Lumsden Highway. North of Ellis Road the thickness of the confined aquifer unit diminishes and the subsurface geology becomes a thick, relatively undifferentiated sequence of claybound gravel. An investigation bore (E44/0183) drilled by Environment Southland adjacent to the Mossburn-Five Rivers Highway near the Cromel Stream showed a sequence of relatively undifferentiated claybound gravels extending to a depth of over 50 m.

South of the Lumsden-Mossburn Highway, a similar pattern of Quaternary gravels is observed but which is offset vertically from those to the north by approximately 25 m. In this area the gravels overlie a thick sequence of Tertiary sediments along the base of the North Range. This displacement and the presence of Tertiary sediments at a relatively shallow depth may reflect vertical displacement of Dun Mountain-Matai basement along, or associated with, the Hillfoot Fault complex.

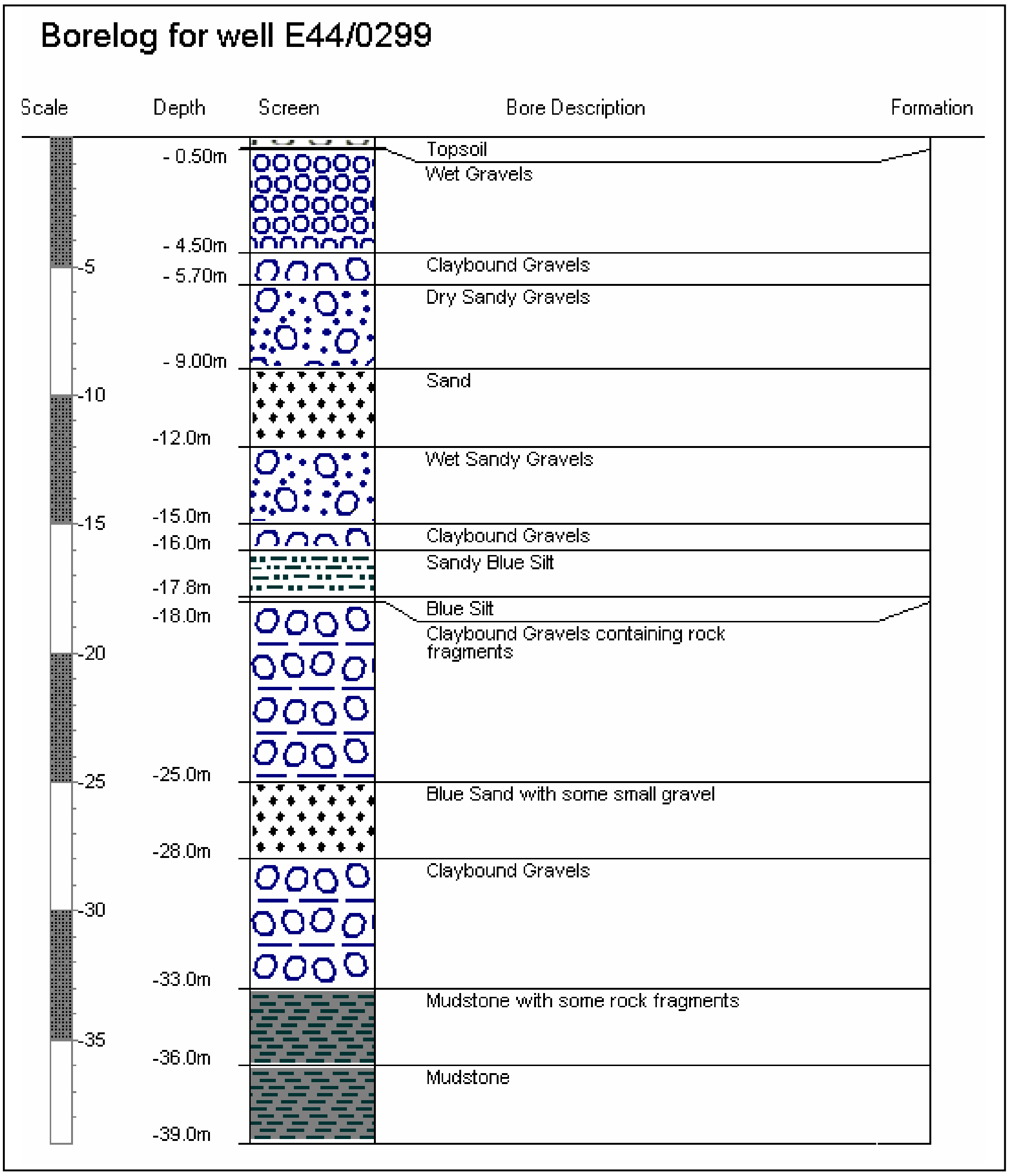
Figure 5 illustrates a typical bore log from the Castlerock area with a sequence of Quaternary gravels overlying a thin layer of Tertiary mudstone and Dun Mountain-Matai basement.

- **Figure 5. Drillers log from E44/0262, Edwards Road, Castlerock**



The pattern of subsurface geology observed in the Oreti basin does not appear to extend east of the Oreti River to any significant extent. Figure 6 shows the geological log from E44/0299 drilled in the centre of the Waimea Plain near St Patricks-Glenure Road, St Patricks. The subsurface geology at this site consists of an irregular sequence of claybound gravels, sand and silt quite distinct from the thick deposits of coarse alluvial gravel and claybound gravel layers observed in the Oreti basin.

- **Figure 6. Drillers log from E44/0229, Glenure-St Patricks Road, St Patricks.**



The subsurface geology of the Waimea Plain suggests that fluvial processes associated with the Oreti River have largely been confined to the areas west of the current river alignment with limited geological evidence to support the Oreti River flowing eastward across the Waimea Plain for any extended period in recent geological times.

1.3 Soils

Figure 7 shows the distribution of major soil types in the Oreti basin based on data collected for the Topoclimate soil survey. Riversdale, Oreti and Gore soils are the dominant soil types on the floodplain areas of the Oreti River and tributaries, covering approximately 65% of the total area. These soils are typically thin, gravelly silt-sandy loams with good internal drainage and low water holding capacity. The other major soil types present in the area are Waikoikoi, Jacobstown and Dipton soils which occur on the Castlerock terrace and in areas around the Acton and Irthing streams. These are typically heavy silt to clay loams with relatively poor internal drainage and moderate to high water holding capacity. A range of minor soil types are found around the basin margin reflecting historical drainage patterns and accumulation of windblown loess material.

- Figure 7. Distribution of major soil types in the Oreti basin

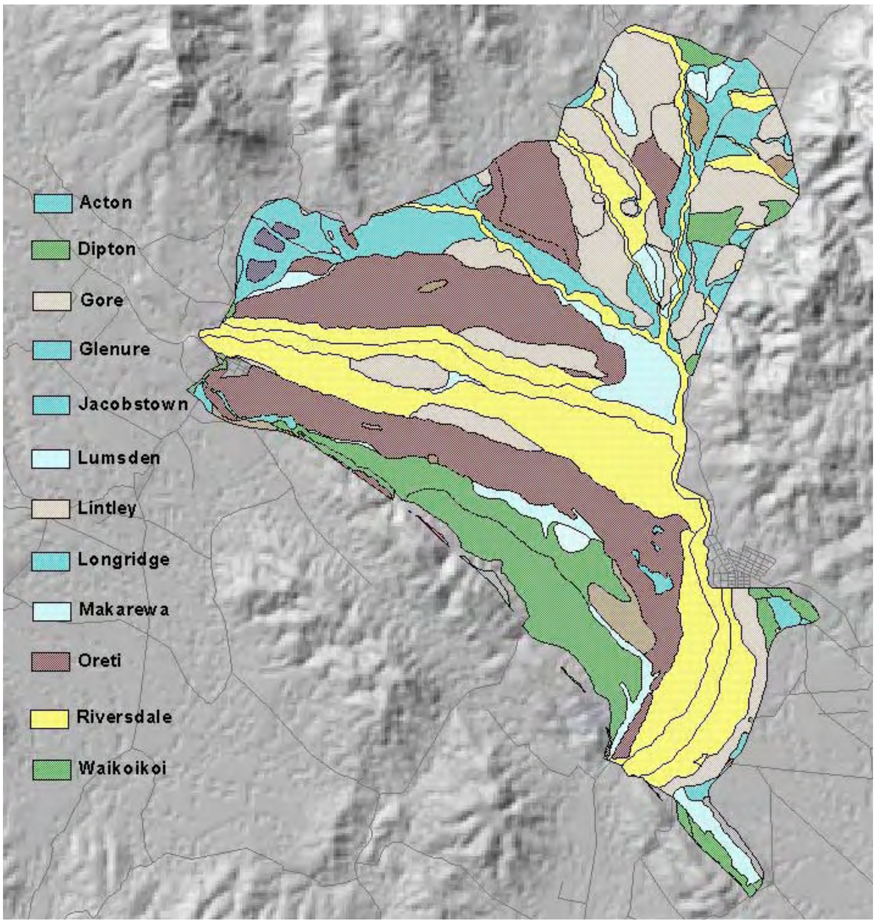


Table 1 lists the physical characteristics and extent of the major soil types present in the Oreti basin.

- **Table 1 Physical characteristics of major soil types in the Oreti basin**

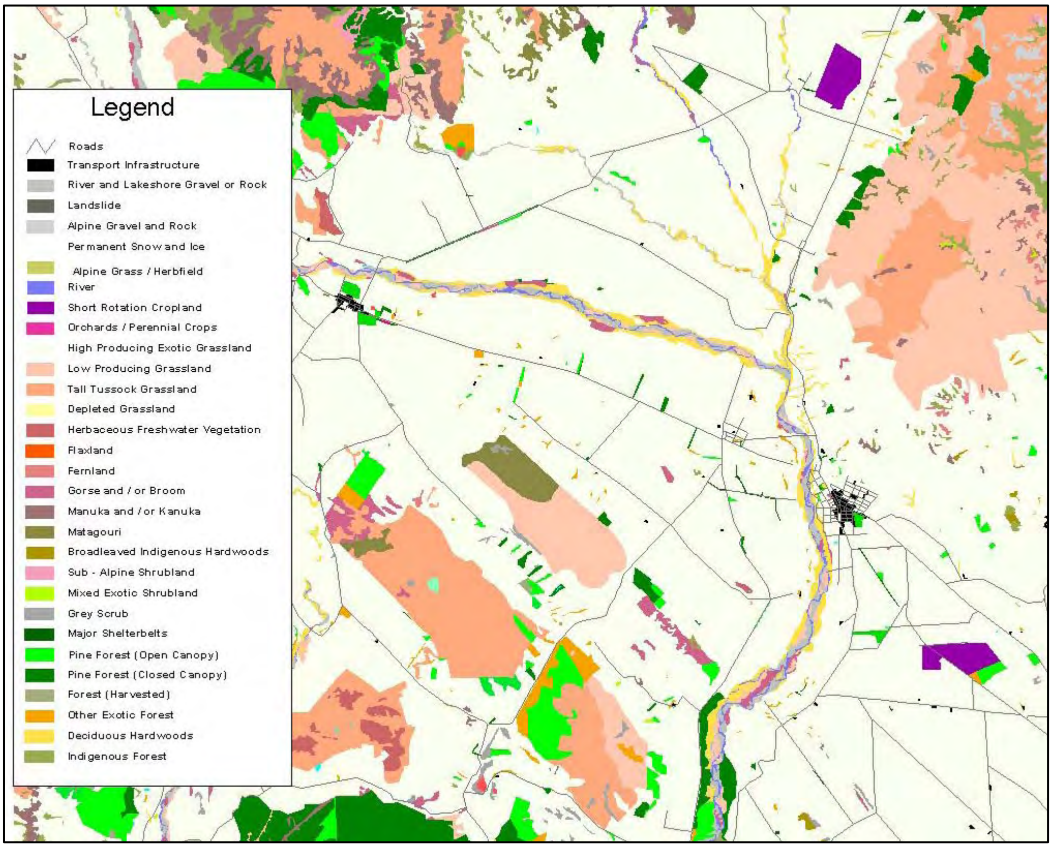
Soil Name	Order	Group	Internal Drainage	Water Holding Capacity (mm)	Total Area (Ha)	Percentage of Total Area
Riversdale	Recent	Fluvial	Well Drained	60-90	6506	26.3
Oreti	Brown	Firm	Well Drained	30-60	6246	25.2
Gore	Brown	Orthic	Well Drained	60-90	3210	13.0
Waikoikoi	Pallic	Perch-gley	Poorly Drained	90-150	1689	6.8
Jacobstown	Gley	Orthic	Poorly Drained	150-250	1117	4.5
Dipton	Pallic	Perch-gley	Poorly Drained	90-150	1037	4.2
Lumsden	Gley	Orthic	Poorly Drained	60-90	933	3.8
Lintley	Brown	Orthic	Poorly Drained	60-90	862	3.5
Longridge	Gley	Orthic	Poorly Drained	60-90	745	3.0
Acton	Gley	Orthic	Well Drained	90-150	686	2.8

1.4 Landcover

Of the total land area of 26,723 Ha in the Oreti basin, slightly over 90% (24,150 Ha) is recorded as high producing exotic grassland on the New Zealand Land Cover Database (LCDB2). The only other landcover types of any notable extent within this area are deciduous hardwoods and river and lakeshore gravel and rock classifications that extend over 2.9 and 2.0% of the total land area respectively.

Landcover in the wider Oreti area shown in Figure 8 consists largely of high producing exotic grasslands on the low-lying or flat areas, with significant areas of low producing grasslands, tall tussock grasslands, pine plantations and native forest and shrublands on the surrounding hills.

- **Figure 8. Landcover in the Oreti basin**



1.5 Climate

1.5.1 Rainfall

Average annual rainfall totals recorded in the Oreti basin vary from 800 mm along the foothills of the Mataura Range to over 1000 mm near Mossburn. Table 2 contains summary statistics for rainfall sites in the area. The spatial distribution of average annual rainfall totals is shown in Figure 9.

- **Table 2 Annual rainfall totals recorded in the Oreti basin**

Site Name	Grid Reference	Record Length	Average Annual Rainfall (mm)	Minimum Rainfall (mm)		Maximum Rainfall (mm)	
				Total	Year	Total	Year
Mossburn at Dyer Road	E44:385-917	1994-	1060	805	2003	1188	1995
Oreti at Lumsden Cableway	E44:535-908	1988-	805	586	2003	1021	1995
Five Rivers at Ellis	E44:488-956	1979-	953	692	1990	1117	1997

Site Name	Grid Reference	Record Length	Average Annual Rainfall (mm)	Minimum Rainfall (mm)		Maximum Rainfall (mm)	
				Total	Year	Total	Year
Road		2001					
Five Rivers at Five Rivers Station	E43:488-025	1980-	985	719	2003	1173	1987
Oreti River at Lumsden, Rocklands	E44:430-910	1955-1987	919	614	1966	1110	1972
Oreti at Lowther	E44:530-930	1949-1963	792	717	1959	999	1957
Lintley at Lintley District Road	E44:577-828	1977-	974	715	2003	1128	1983
Irthing at West Dome	E44:384-977	1951-1961	1035	914	1952	1165	1957
Mataura at Mid Dome	E43:591-058	1949-1986	950	708	1966	1224	1968

Figure 9. Average annual rainfall totals (mm) recorded in the Oreti basin

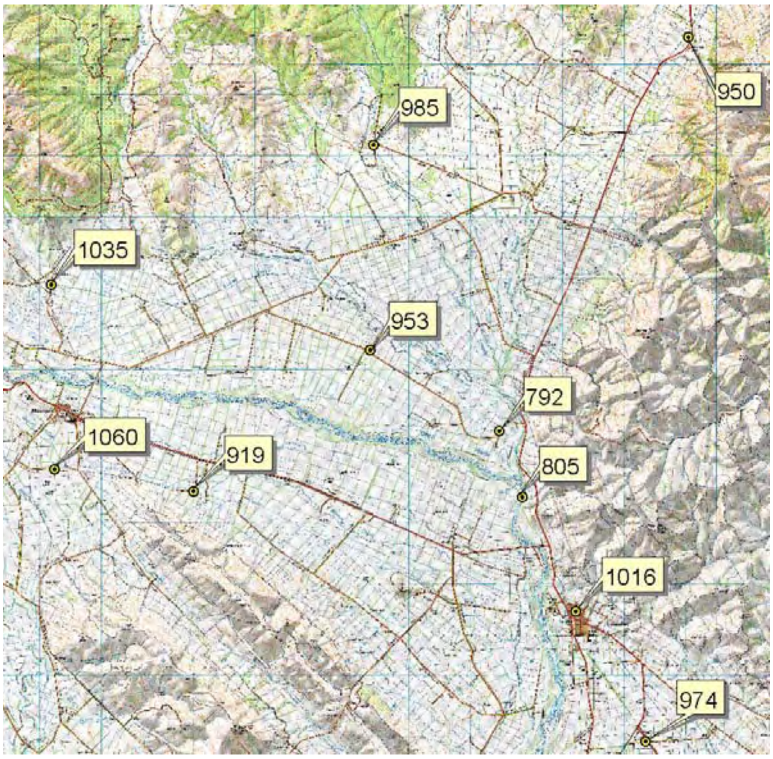


Figure 10 shows the variation in mean monthly rainfall at three sites located in the Oreti basin. All sites show a characteristic seasonal variation with the highest rainfall in early summer and lowest rainfall during the winter months.

- **Figure 10. Monthly rainfall variability in the Oreti basin**

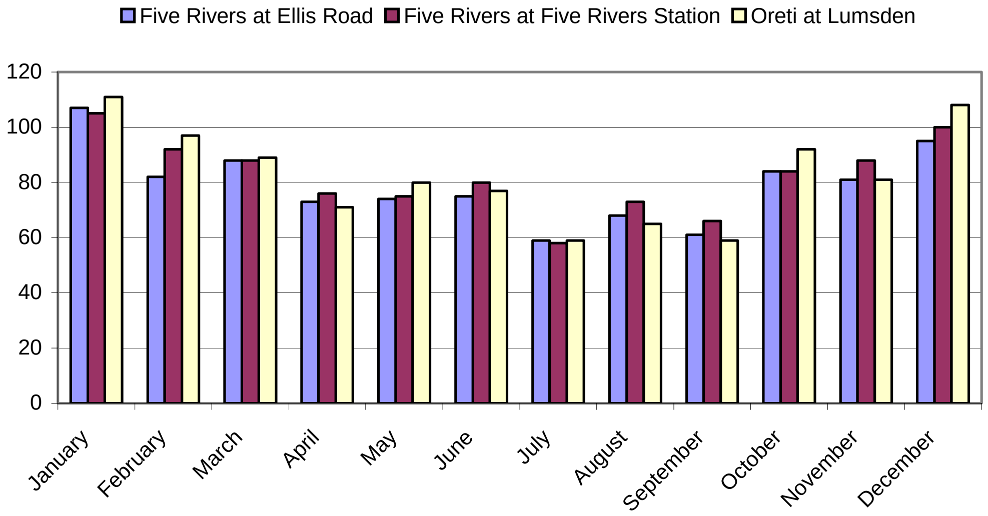
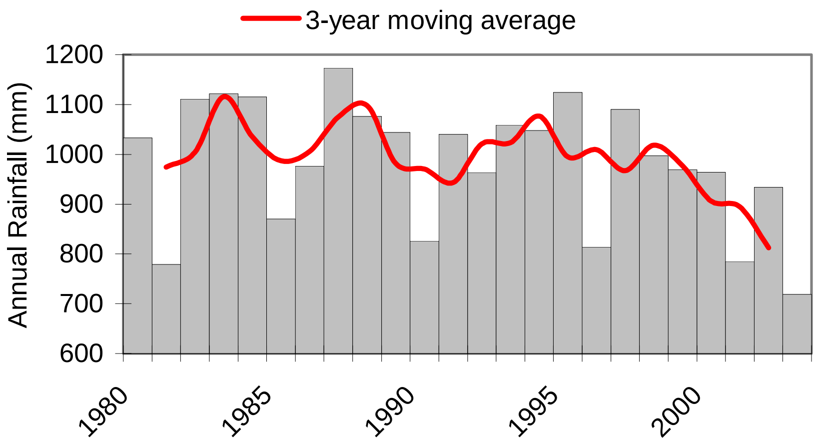


Figure 11 shows the temporal variation in annual rainfall recorded at the Five Rivers at Five Rivers Station rainfall site since 1980. Recorded totals show inter-annual variability of up to 25% of the mean. However, over the long-term, there appears to have been a consistent decline in annual rainfall totals since the late 1990's. This decline in rainfall is also illustrated in Figure 12 which shows cumulative departure from the mean for monthly rainfall totals recorded at the same site.

- **Figure 11. Long-term rainfall variation recorded at Five Rivers at Five Rivers Station**



- **Figure 12. Cumulative Rainfall Departure at Five Rivers at Five Rivers Station**

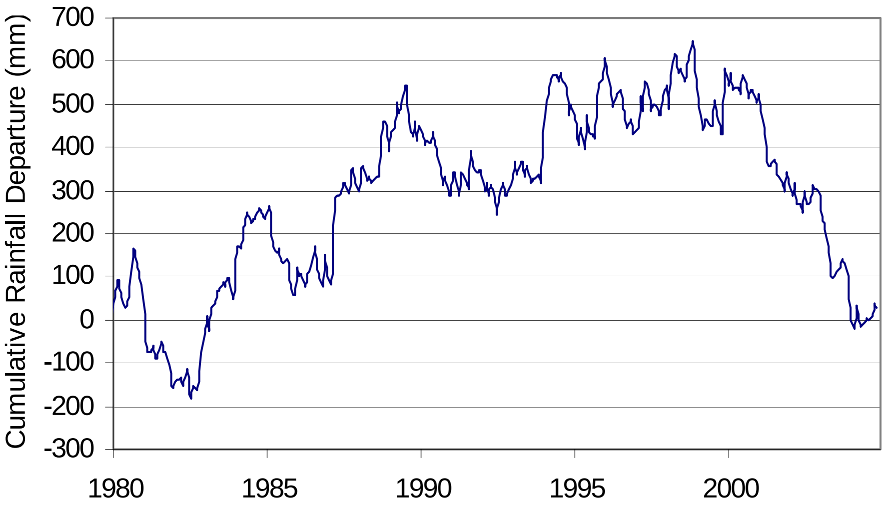


Figure 12 clearly shows rainfall totals were consistently above the long-term average from the early 1980’s to the mid-1990’s, held around the long-term average during the mid-late 1990’s before declining sharply in recent years. This long-term rainfall variability appears to be part of a cyclical pattern and is recognised in rainfall records from elsewhere in Southland (McKerchar and Henderson, 2003). The pattern appears to involve a climate cycle of 10 - 30 year duration which results in extended periods of above and below average rainfall.

This climate shift has been linked to a phenomenon termed the Interdecadal Pacific Oscillation (IPO) which results in long-terms shifts in climate due to changes in ocean-atmospheric circulation patterns. These shifts in climate tend to be associated with changes in the frequency of El Nino and La Nina events in the Pacific region. Positive phases of the IPO tend to be associated with El Nino conditions that enhance westerly airflow over southern New Zealand and commonly lead to above average rainfall totals in the west and south of the South Island. Negative phases of the IPO tend to be associated with a reduction in westerly airflow and a consequent reduction in rainfall over the same areas. Predictions indicate the current negative phase of the IPO may continue for some time with consequent effects on rainfall variability in Southland.

1.5.2 Temperature

Mean monthly minimum air temperatures recorded at the Lumsden AWS site range from 8.9^{o}C in January to -0.7^{o}C in July. Than mean annual minimum air temperature is 4.4^{o}C with the lowest temperature of -9.8^{o}C recorded on 5 July 1996.

Mean monthly maximum air temperature recorded at the Lumsden AWS site range from 18.0°C in February to 6.2°C in July. The mean annual maximum temperature is 14.8°C with the highest temperature of 31.3°C recorded on 2 February 1990.

Table 3 shows the seasonal variation in daily minimum and maximum temperatures recorded at the Lumsden AWS site.

- **Table 3. Mean daily minimum and maximum temperatures recorded at the Lumsden AWS site**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Minimum Air Temperature	8.9	8.5	6.8	4.5	2.6	0.3	-0.7	0.8	2.6	4.8	6.7	7.7	4.4
Maximum air temperature	20.6	20.3	18.0	15.3	12.3	9.0	8.5	10.6	13.3	15.3	16.9	18.7	14.8

1.5.3 Evapotranspiration

Potential Evapotranspiration (PET) calculated at Gore AWS is considered as representative of much of the Northern Southland area including the Oreti basin. Calculated PET values at this site over the period 1977 - 2002 range from 14 mm in June to 120 mm in December with an annual average of 773 mm. Table 4 illustrates monthly average PET values from long-term climate stations in the Southland Region.

- **Table 4. Potential evapotranspiration for long-term climate sites in the Southland Region**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ave
Gore AWS	118	93	72	42	24	14	16	31	55	83	104	120	773
Winton AWS	112	90	67	38	20	11	14	29	51	78	100	113	722
Invercargill AWS	123	97	74	43	25	15	17	32	57	85	109	126	801

2. Groundwater Resources of the Oreti basin

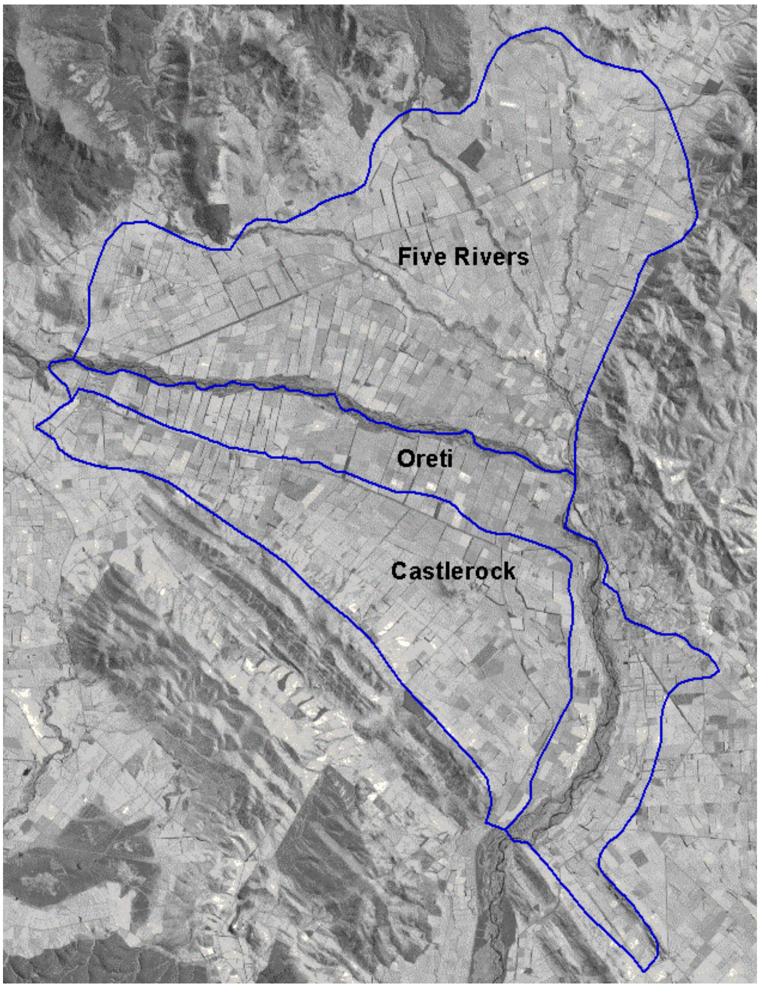
2.1 Hydrogeology

The Oreti basin contains a significant groundwater resource both in shallow unconfined and deeper confined aquifers.

2.1.1 Unconfined Aquifers

For the purposes of resource management, unconfined aquifers in the Southland Region have been subdivided into a number of discrete groundwater management areas. These areas (termed groundwater zones) delineate individual hydraulic units on the basis of geology, geomorphology, hydrogeology, and / or resource development. The three groundwater zones defined within the Oreti basin are illustrated in Figure 13.

- **Figure 13. Groundwater Management Zones in the Oreti basin**



The Castlerock groundwater zone extends across the remnant Quaternary terrace south of the Oreti River to the lower slopes of the North Range. This aquifer system is recharged by rainfall on the terrace surface as well as infiltration from small streams on the lower slopes of the North Range. Groundwater discharge occurs via a series of springs which discharge into Murray Creek at the base of the terrace along the eastern boundary.

The Oreti groundwater zone encompasses the unconfined aquifer along the southern and eastern riparian margin of the Oreti River. This unconfined gravel aquifer is hydraulically connected to the Oreti River with water being exchanged between the river and surrounding aquifer depending on the relative difference between river stage and adjacent groundwater levels.

The Five Rivers groundwater zone is a roughly triangular area, approximately 140 km^3 in extent, bounded by the Oreti River to the south, the Lintley Range to the east and the Eyre Mountains to the north. The area is crossed by a number of streams, namely the Acton, Oswald, Dillston, Cromel and Irthing Stream that drain into the Oreti River upstream of the SH94 Bridge. This shallow unconfined aquifer is recharged by rainfall infiltration and flow loss from streams around the outer basin margin. These streams in turn drain water from the unconfined aquifer over their lower reaches, upstream of the Oreti confluence.

2.1.2 Confined Aquifers

Available geological, piezometric level and aquifer test information indicate the presence of two separate confined aquifers underlying a significant portion of the Oreti basin.

The Lumsden Aquifer is encountered along the full length of Ellis Road, Five Rivers and extends under the Oreti River as far south as the Mossburn-Lumsden Highway. Geological evidence indicates the lateral extent of the Lumsden Aquifer has been influenced by historical drainage patterns and is unlikely to extend eastwards down the Waimea Plain much past the current alignment of the Oreti River. Piezometric heads over 20 m lower than that observed in the overlying unconfined aquifer indicate the well-confined nature of this aquifer system.

The North Range Aquifer extends west of Edwards Road, Castlerock as far north as Hillas Road, Five Rivers. The aquifer appears to be recharged by infiltration of rainfall and runoff on the alluvial fans on the upper slopes of the North Range. A significant head differential is apparent between the North Range Aquifer and the overlying unconfined aquifer, with the North Range Aquifer exhibiting artesian conditions Sutherland Road and Edwards Road.

Figure 14 shows the extent of the confined aquifers in the Oreti basin. The interpreted boundary between the aquifers follows the alignment of the northern margin of the basement ridge in the Castlerock area and the active fault trace near Hillas Road, Five Rivers. This observation suggests that geological structure, particularly vertical displacement of basement topography, has had a significant influence on the resulting geometry of the alluvial sediments. It is anticipated that seismic profiling project currently under way in the Oreti basin (Blakemore, *in prep*) will yield valuable information on the influence of geological structure on the hydrogeology of the area.

- **Figure 14. Interpreted extent of confined aquifers in the Oreti basin**

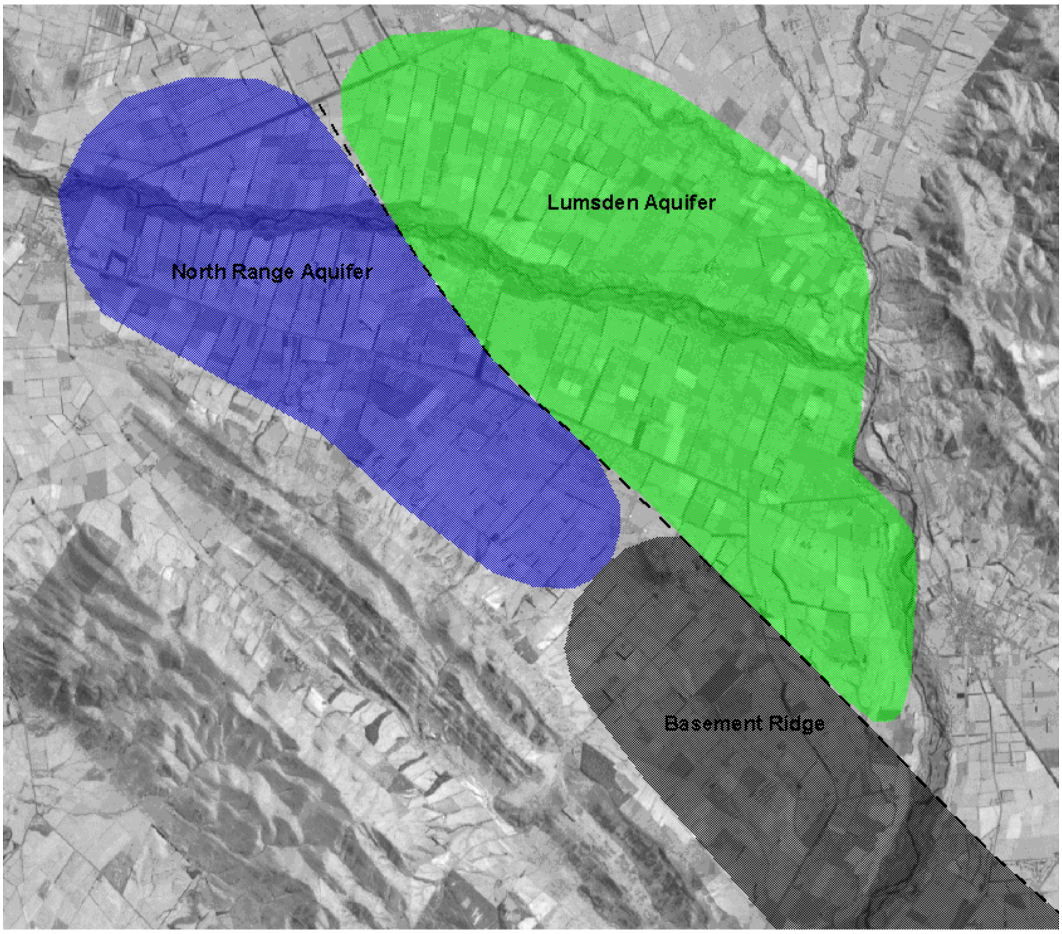


Table 5 summarises the type, extent and classification of the main groundwater resources defined in the Oreti area

- **Table 5. Classification of main groundwater resources in the Oreti basin**

Groundwater Management Unit	Confinement	Aquifer Type	Extent (Hectares)
Five Rivers groundwater zone	Unconfined	Riparian	13800
Oreti groundwater zone	Unconfined	Riparian	6130
Castlerock groundwater zone	Unconfined	Terrace	6800
Lumsden Aquifer	Confined	Confined	7200
North Range Aquifer	Confined	Confined	4270

2.2 Piezometric Levels

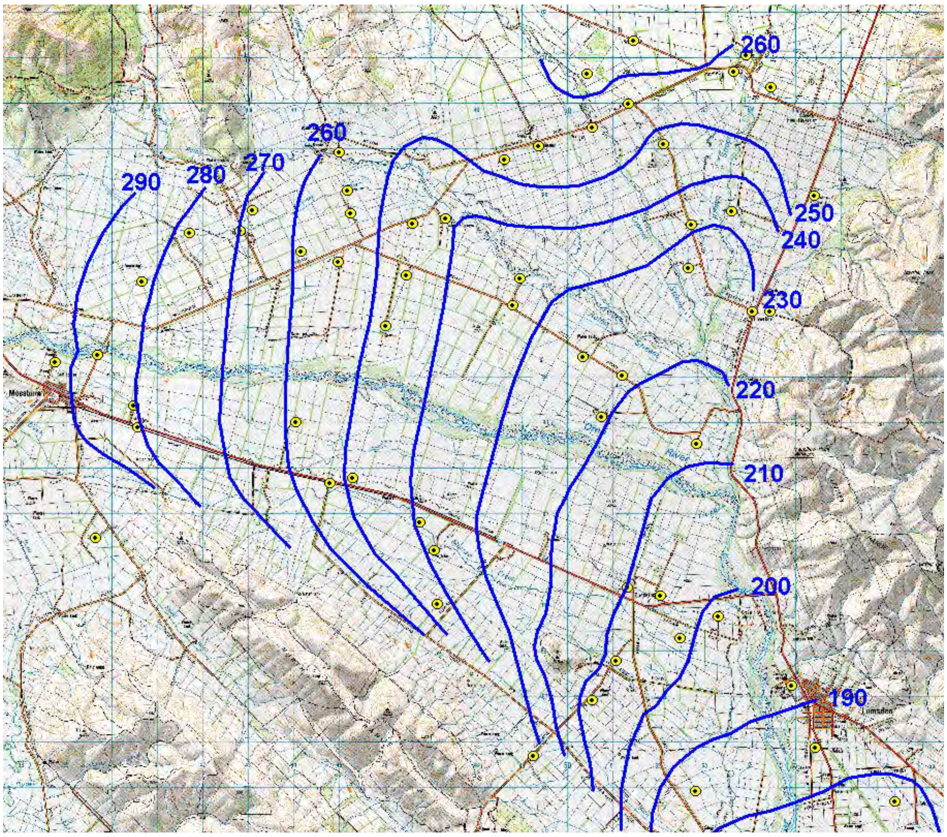
2.2.1 Unconfined Aquifers

A piezometric survey of approximately 60 bores and wells was undertaken in the Oreti basin in February 2002. A majority of the bores included in the survey were shallow (less than 10 m deep) and screened in unconfined aquifers. Wellhead elevations were surveyed using differential GPS to an accuracy of approximately 0.25 m. Groundwater levels were measured in all bores across the survey area on 12 - 13 February 2002 and reduced piezometric levels calculated from the measured wellhead elevations.

Piezometric contours interpreted from survey results are shown in Figure 15. Overall, the piezometric surface in the unconfined aquifer was observed to approximate the topographic surface with groundwater depth measured at less than 4 m below ground in a majority of the bores surveyed.

In the western portion of the Castlerock groundwater zone, groundwater flow was observed in a northeast direction on the lower slopes of the North Range swinging to a more easterly direction along the terrace marking the boundary between the Castlerock and Oreti groundwater zones. This change in flow direction was interpreted to represent recharge to the Castlerock groundwater zone along the lower slopes of the North Range and subsequent throughflow to the Oreti groundwater zone. Towards the eastern end of the Castlerock groundwater zone, the groundwater flow was observed in an east-southeast direction reflecting significant groundwater discharge from springs along the terrace margin.

- **Figure 15. Piezometric contours in unconfined aquifers in the Oreti basin, February 2002**



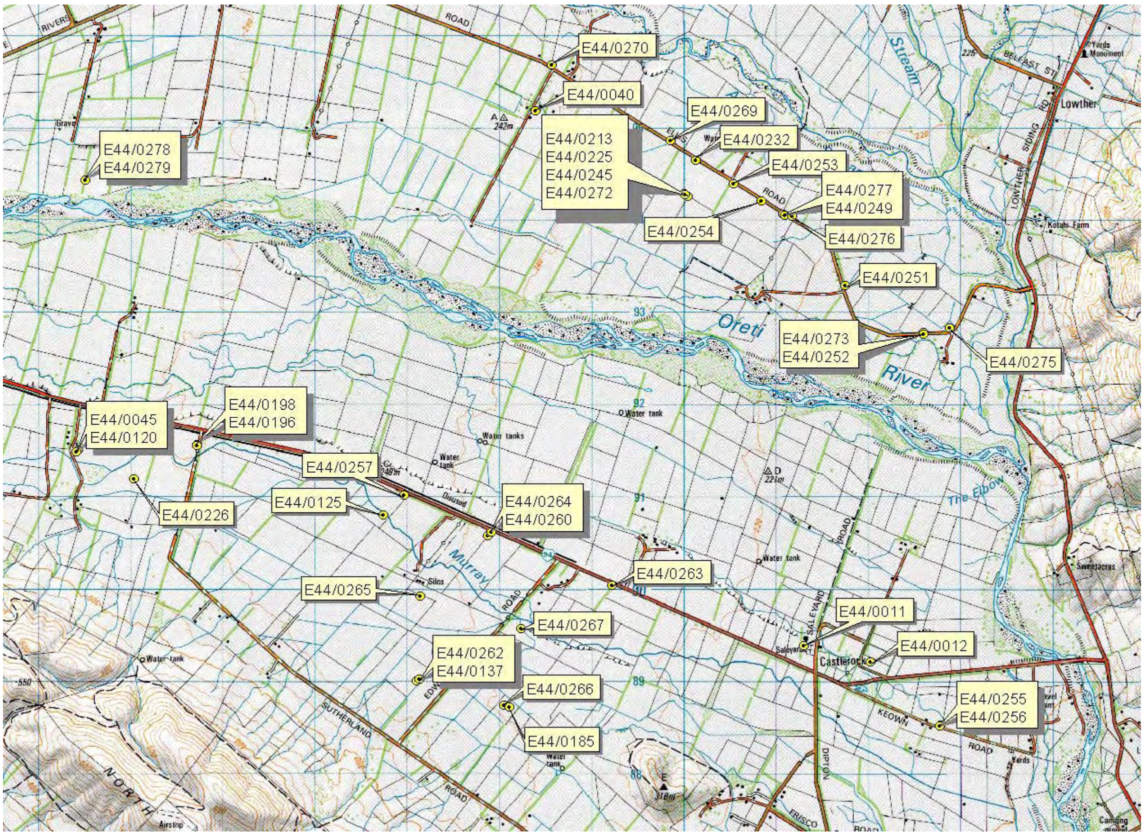
In the Five Rivers groundwater zone piezometric contours indicate an overall pattern of groundwater drainage from the surrounding hills toward the confluence of the Oreti River and Irthing Stream. Around the outer margin of the Five Rivers groundwater zone, piezometric contours are influenced by local recharge from the Acton, Cromel and Irthing Streams. Over their lower reaches these streams gain significant flow from groundwater infiltration and discharge from numerous small spring-fed tributaries. The contribution of flow loss to groundwater recharge in this area is further examined in Section 2.5.2.

2.2.2 Confined Aquifers

A piezometric survey to determine relative groundwater levels in the North Range and Lumsden Aquifers was undertaken on the 7 - 8 September 2004. This piezometric survey involved measurement of wellhead elevations and groundwater depths in all bores known to penetrate the confined aquifers. Wherever possible groundwater levels were also measured in adjacent shallow bores to enable comparison of relative piezometric heads in the confined and unconfined aquifers. Surveyed wellhead elevation and measured depth to groundwater were used to compute the relative groundwater level at each site.

Figure 16 shows bore locations included in the September 2004 piezometric survey. Of the 39 bores surveyed, 32 were screened in confined aquifers, the remainder in overlying unconfined aquifers.

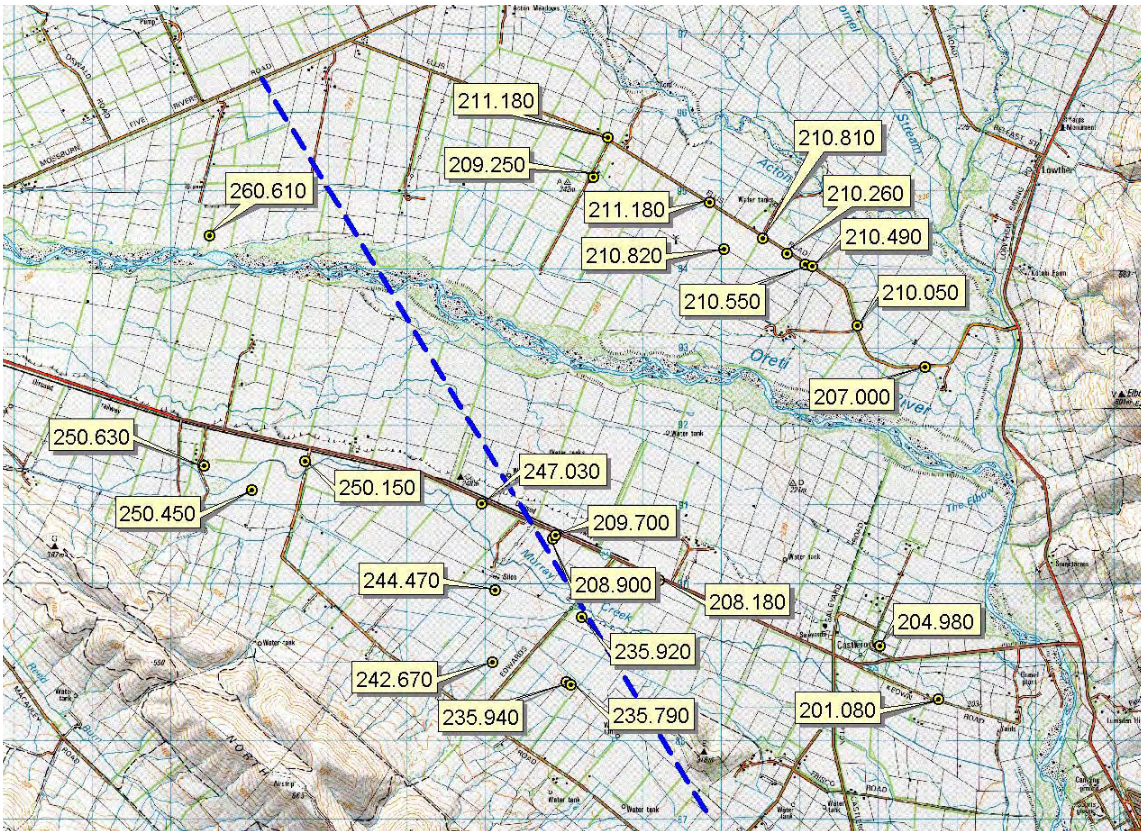
- **Figure 16. Location of bores included in the September 2004 piezometric survey**



Piezometric levels recorded in confined aquifers showed significant variation across the survey area. Relative to ground level, observed piezometric levels ranged from 2 - 4 m positive head in the North Range Aquifer east of Sutherland Road (E44/0257, E44/0265 and E44/0267) to in excess of 25 m below ground in the Lumsden Aquifer towards the western end of Ellis Road (E44/0270, E44/0040).

Figure 17 shows relative potentiometric levels recorded in confined aquifers in the Oreti basin.

- **Figure 17. Reduced piezometric levels (mamsl) recorded in the North Range and Lumsden Aquifers**



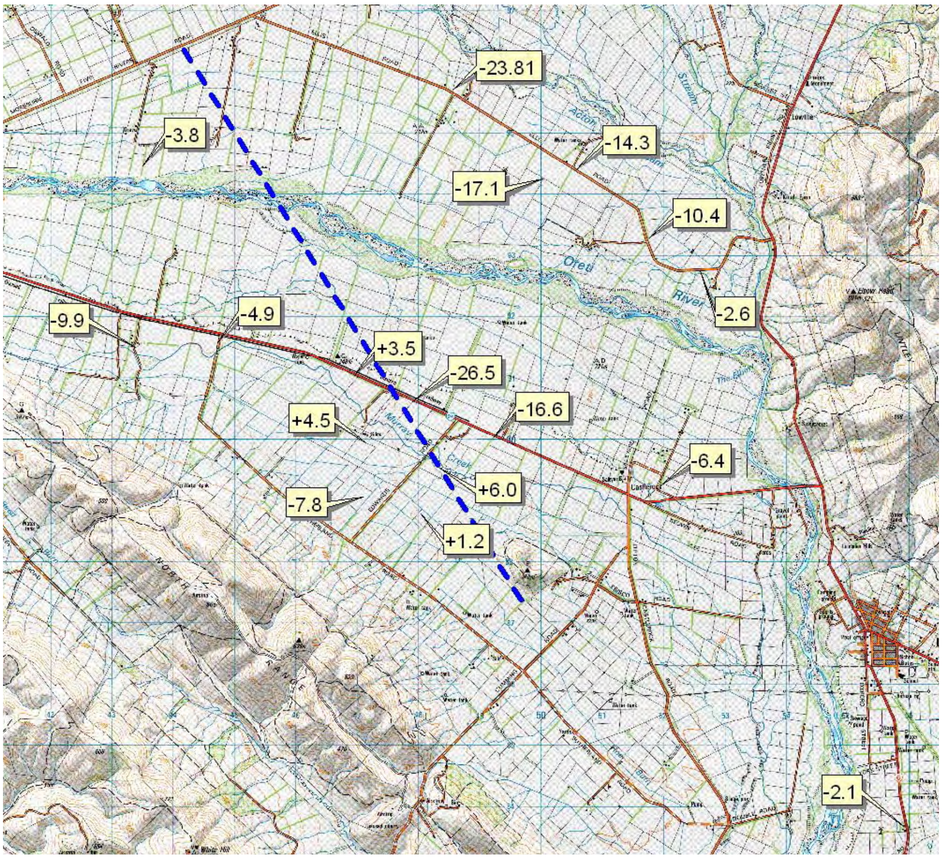
The calculated piezometric levels show an offset of 25 - 30 m between the North Range and Lumsden Aquifers over a relatively short distance in the Castlerock area along the approximate line shown in Figure 17. The piezometric level observed in E44/0279 on the northern side of the Oreti River indicates the North Range Aquifer extends under the Oreti River toward Hillas Road. These observations, combined with the consistent piezometric heads measured in the Lumsden Aquifer along Ellis Road and in the Castlerock area, indicate separation of the confined aquifers along a boundary close to the observed structural control shown in Figure 3.

2.2.3 Relative Head Difference

Figure 18 shows the measured head differential across the survey area. In the Lumsden Aquifer a negative (or downward) head gradient was observed across the whole aquifer ranging from approximately 2 m at the eastern end of Ellis Road to in excess of 20 m, 5 km to the west. In the North Range Aquifer the measured head difference ranged from a 9 m downward gradient west of Sutherland Road, to a positive gradient of 6 m at Edwards Road. The large range in observed head differential across the two aquifers is related to the relative slope of the piezometric gradient in the confined and unconfined aquifers further discussed in the following section.

The significant head differential between unconfined and confined aquifers observed across the Oreti basin reflects the well-confined nature of both the North Range and Lumsden Aquifers.

- **Figure 18. Relative head differential (m) between unconfined and confined aquifers in the Oreti basin**



2.2.4 Piezometric Gradient

Data from piezometric surveys undertaken in the Oreti basin has been utilised to estimate the piezometric gradients in the unconfined and confined aquifers along the section lines shown in Figure 19. These were selected on the basis of available data and interpreted groundwater flow direction and hydraulic gradients estimated by transferring data from relevant bores to each section line.

- **Figure 19. Lines of section used to compare relative hydraulic gradient in the Lumsden and North Range Aquifers**

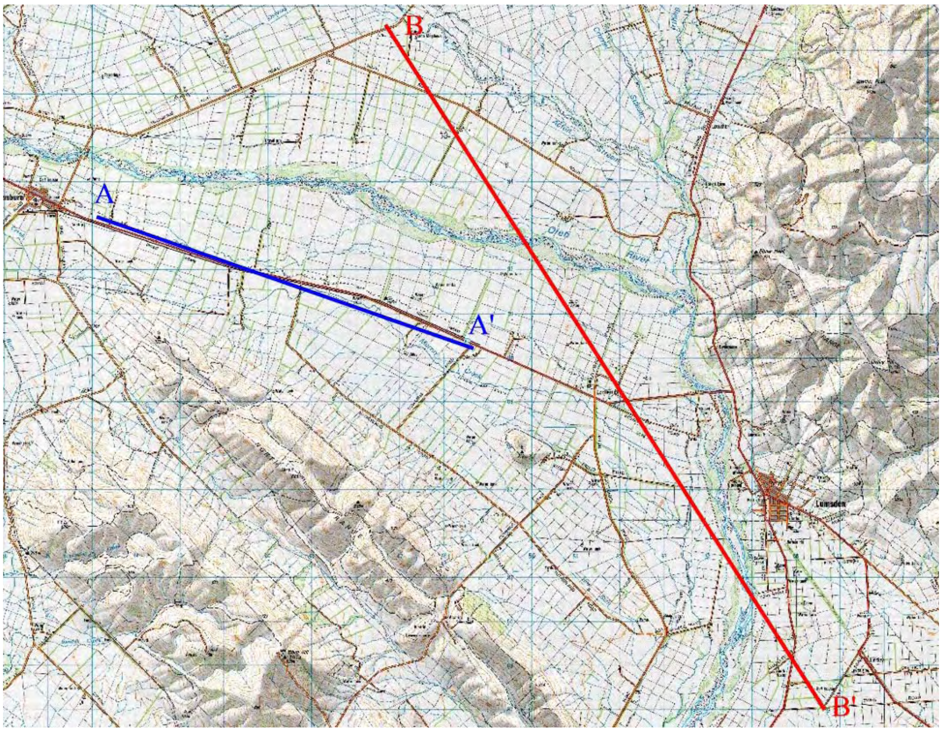


Figure 20 shows the calculated piezometric gradient for the Castlerock groundwater zone and the North Range Aquifer along section A-A’. The gradient of 0.0055 in the unconfined aquifer in Castlerock groundwater zone roughly approximates the topographic gradient while a much flatter gradient of 0.001 is observed in the underlying North Range Aquifer. The intersection of the relative gradients defines the point where the North Range Aquifer is estimated to become artesian, approximately 1 - 1.5 km east of Sutherland Road.

- **Figure 20. Observed piezometric gradient along section A-A’**

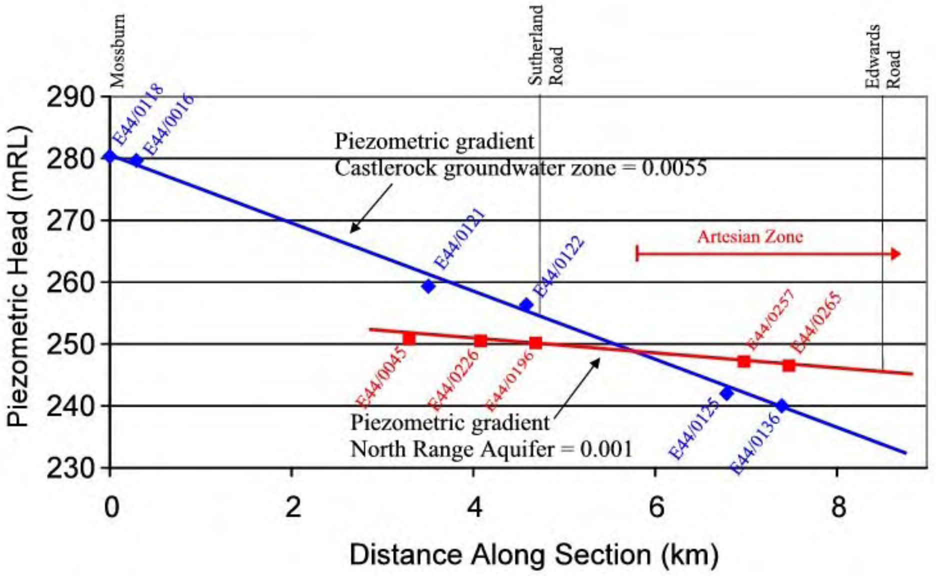
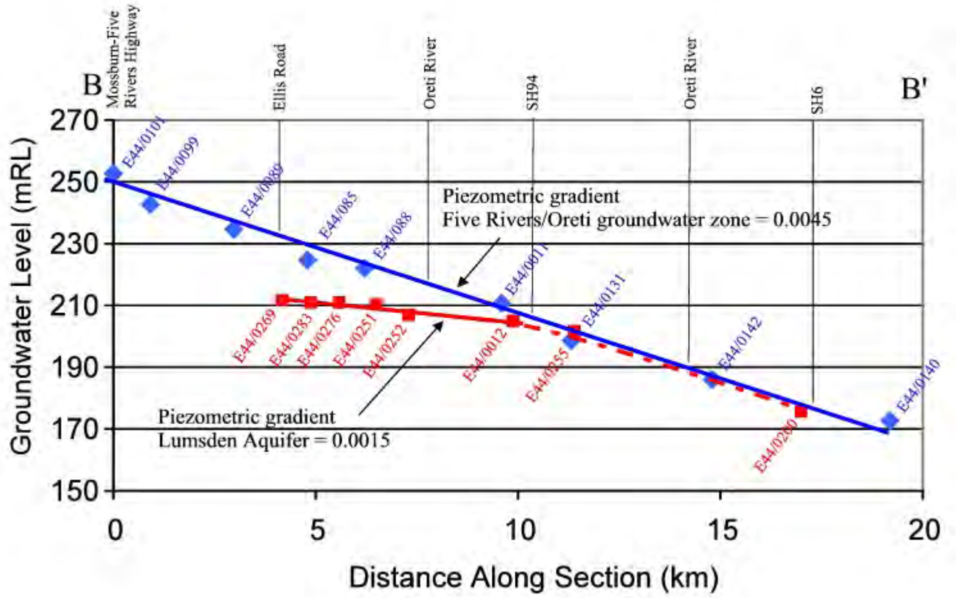


Figure 21 illustrates a comparison of measured piezometric head in the Lumsden Aquifer with levels measured in the overlying Five Rivers and Oreti groundwater zones. The figure shows a relatively constant piezometric gradient of 0.0045 across the unconfined aquifers with a gradient of 0.0015 estimated in the area of the Lumsden Aquifer underlying the Five Rivers groundwater zone.

- **Figure 21. Observed piezometric gradient along section B-B’**



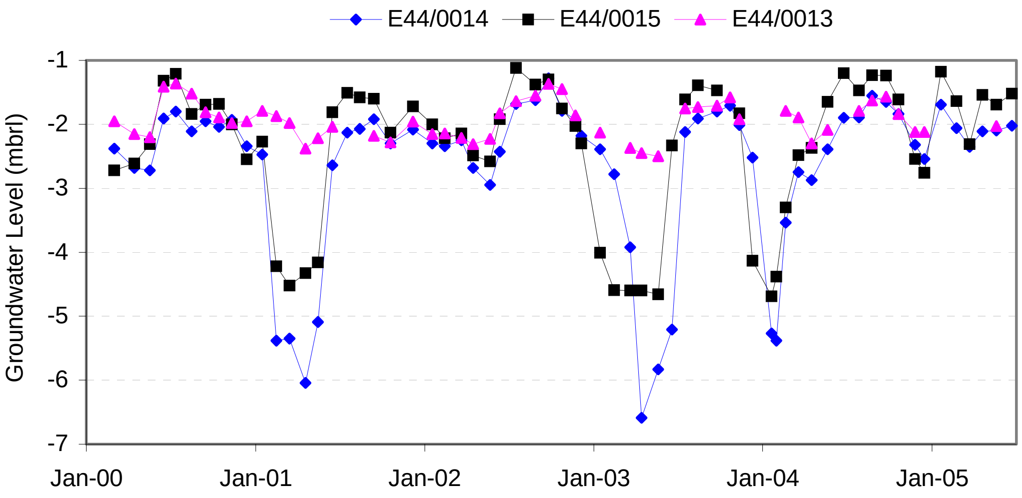
Extrapolation of measured piezometric heads in the Lumsden Aquifer from E44/0012 and E44/0255 at Castlerock to E44/0200, located on the eastern side of the Oreti River, (marked by the dotted red line on Figure 19) is tentative. The significant depressurisation required to produce the observed difference in relative heads between these sites would, due to the high aquifer permeability, result in a steeper hydraulic gradient elsewhere in the Lumsden Aquifer than that observed. Therefore it appears the confined aquifer intercepted at E44/0200 is hydraulically separate from the Lumsden Aquifer and may form part of a localised aquifer system.

2.3 Groundwater Level Variations

2.3.1 Five Rivers Groundwater Zone

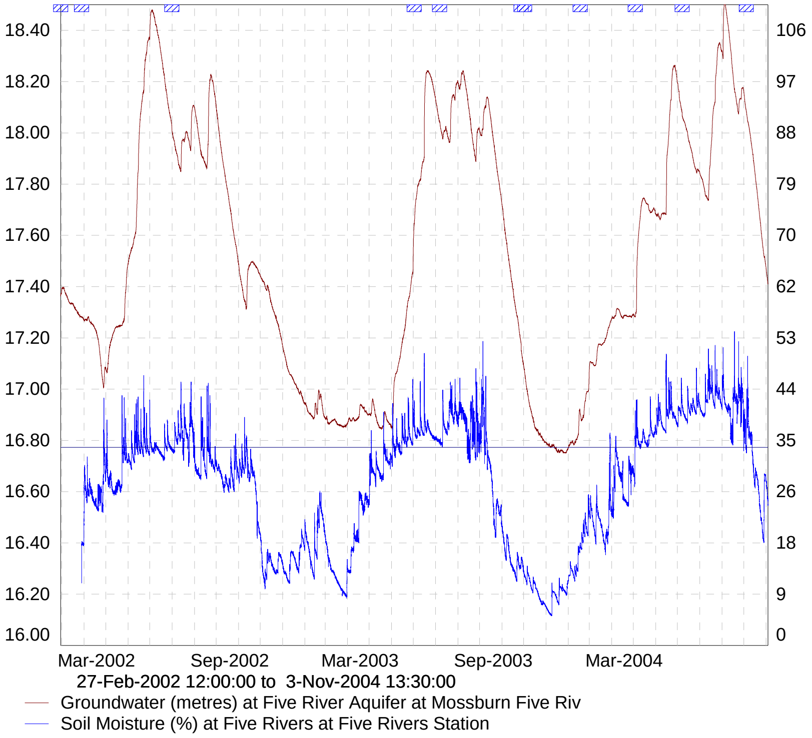
Figure 22 shows seasonal hydrographs from three bores in the Five Rivers groundwater zone over the period 2000 to 2005. The figure shows measured depths to groundwater range seasonally from a maximum in early winter to a minimum in late summer / autumn. The magnitude of seasonal fluctuation ranges from up to 5 m at the western end of Ellis Road (E44/0014) to less than 1 m in at the eastern end of Ellis Road (E44/0013).

- **Figure 22 Seasonal hydrographs from the Five Rivers groundwater zone (metres below reference level)**



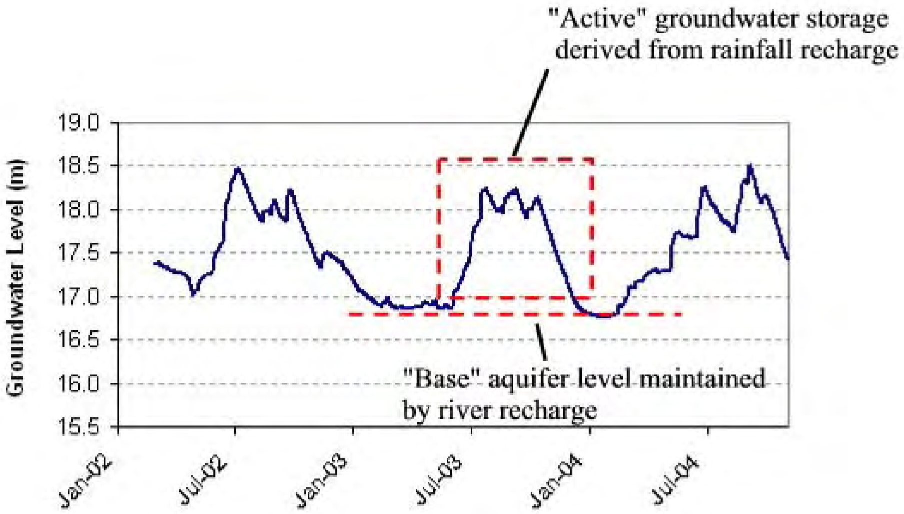
Seasonal groundwater levels in the Five Rivers groundwater zone vary in response to input from both rainfall recharge as well as stream/aquifer interaction. Figure 23 shows the groundwater hydrograph measured at E44/0183, adjacent to the Mossburn-Five Rivers Highway and soil moisture levels measured nearby at Five Rivers Station. The graph shows rapid groundwater level recovery once soil moisture levels reach field capacity in autumn. Groundwater levels then respond to rainfall recharge events during winter and early spring until soil moisture falls below field capacity in late spring and groundwater levels decline rapidly before levelling off in late summer / autumn.

- **Figure 23. Soil moisture and groundwater level response recorded E44/0183 in the Five Rivers groundwater zone**



The observed pattern of seasonal groundwater variation in the Five Rivers groundwater zone is similar to that observed in riparian aquifers elsewhere in Southland (Environment Southland, 2003). The hydrograph can be considered to consist of two components: "active" groundwater storage derived from rainfall recharge and a "base" aquifer level maintained by recharge from nearby streams. The two components of groundwater recharge are illustrated in Figure 24.

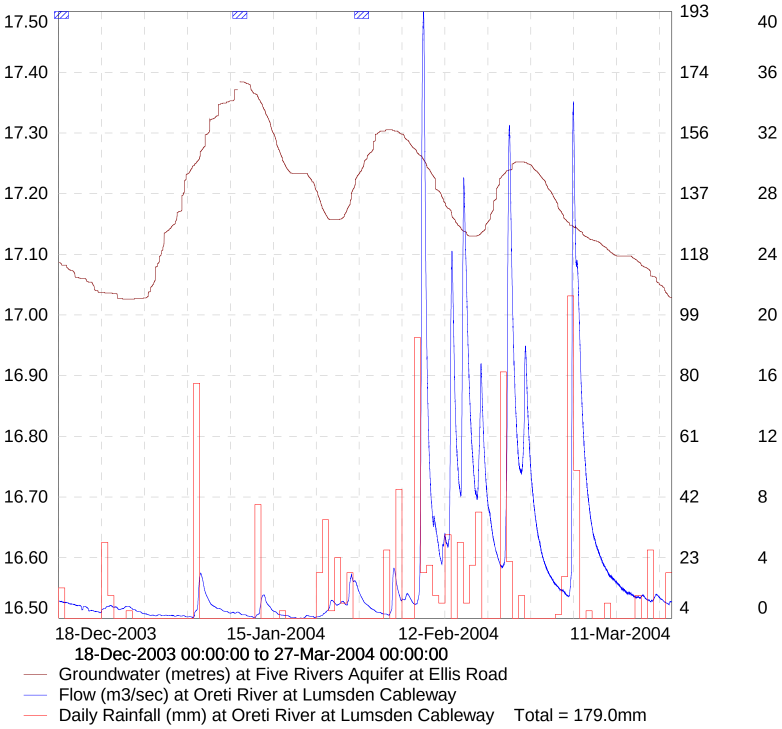
- **Figure 24. Hydrograph from E44/0183 illustrating "active" and "base" components of groundwater recharge in the Five Rivers groundwater zone**



The observed inter-annual variation in minimum groundwater levels illustrated in Figure 22 can be explained by these recharge processes. Years when groundwater levels decline markedly occur in summer / autumn periods when limited rainfall recharge occurs and the active groundwater storage component is drained from the aquifer system. This results in groundwater levels rapidly declining to the level maintained by river recharge. Years when limited groundwater level variation occurs in summer / autumn reflect seasons when soil moisture levels remain sufficiently high for rainfall recharge to maintain active storage throughout the year.

The sensitivity of the unconfined aquifer in the Five Rivers groundwater zone to land surface recharge is also illustrated by groundwater level fluctuations recorded in E44/0232 located adjacent to Ellis Road. Figure 25 shows an increase in groundwater level in the unconfined aquifer of up to 0.35 m over the December 2003-March 2004. The observed aquifer response, occurring during a period of low rainfall and river flow recession, coincides with the operation of a nearby border dyke irrigation system.

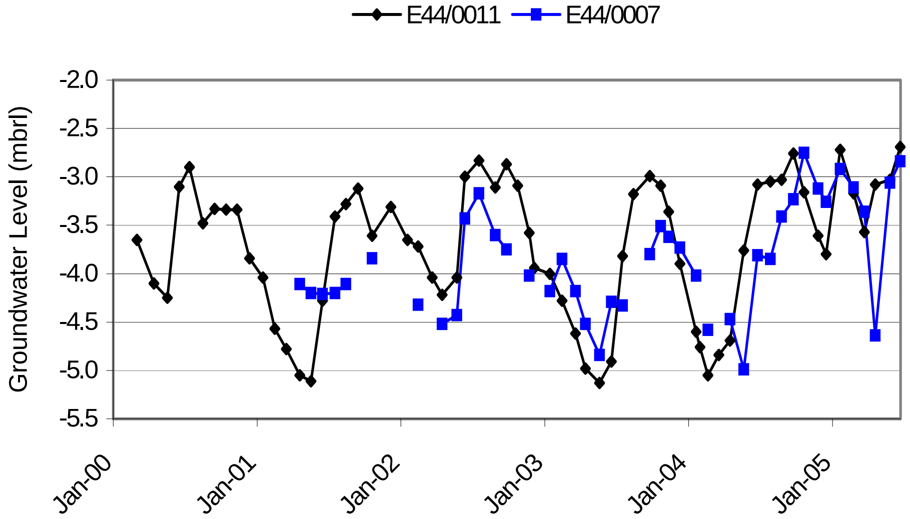
- **Figure 25. Rainfall, river flow and groundwater level response recorded at Ellis Road, Five Rivers, summer 2003-04**



2.3.2 Oreti groundwater zone

Figure 26 shows hydrographs from two bores located within the Oreti Groundwater Zone. Both show a cyclical pattern of seasonal fluctuation with an amplitude of up to 2 m corresponding to seasonal rainfall recharge.

- **Figure 26 Groundwater levels (mbrl) recorded in the Oreti groundwater zone**



2.3.3 Castlerock groundwater zone

Figure 27 shows the hydrograph from E44/0198 screened in unconfined aquifer at a depth of 6 m near the corner of Sutherland Road and Mossburn-Lumsden Highway.

The magnitude and timing of groundwater level fluctuations at this site vary in response to the seasonal occurrence of rainfall recharge events. Temporal variation of soil moisture levels generally results in groundwater recharge during late autumn and winter when soils are at or near field capacity and a decline in levels through summer and autumn when recharge is limited due to lower soil moisture. The pattern of seasonal groundwater level response can vary significantly between individual seasons depending on climatic variability.

- **Figure 27 Groundwater Levels recorded in E44/0196 in the Castlerock groundwater zone**

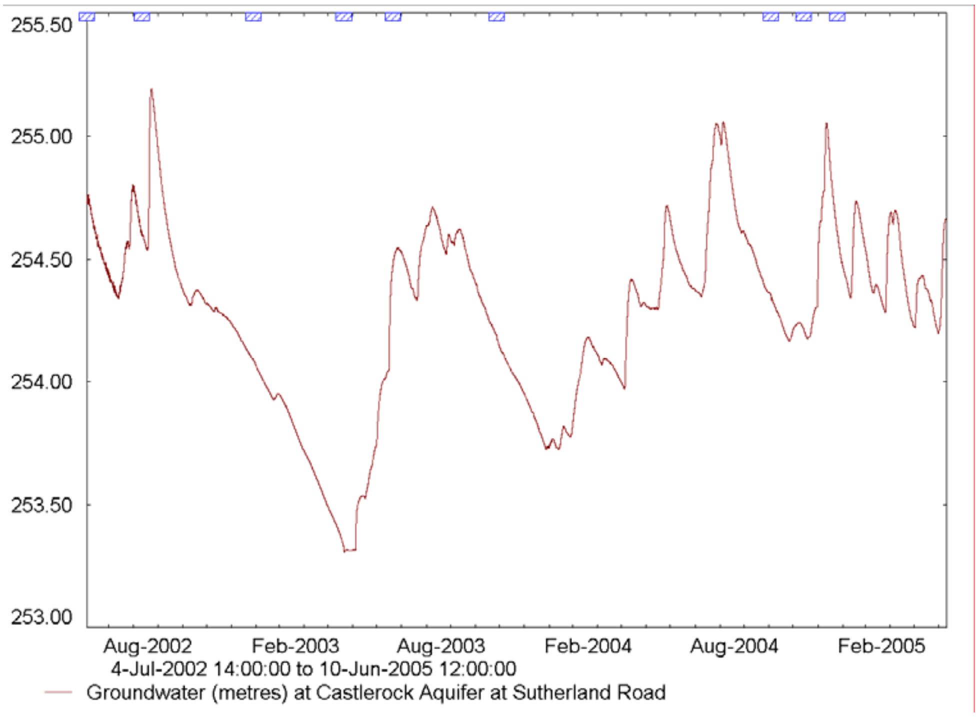
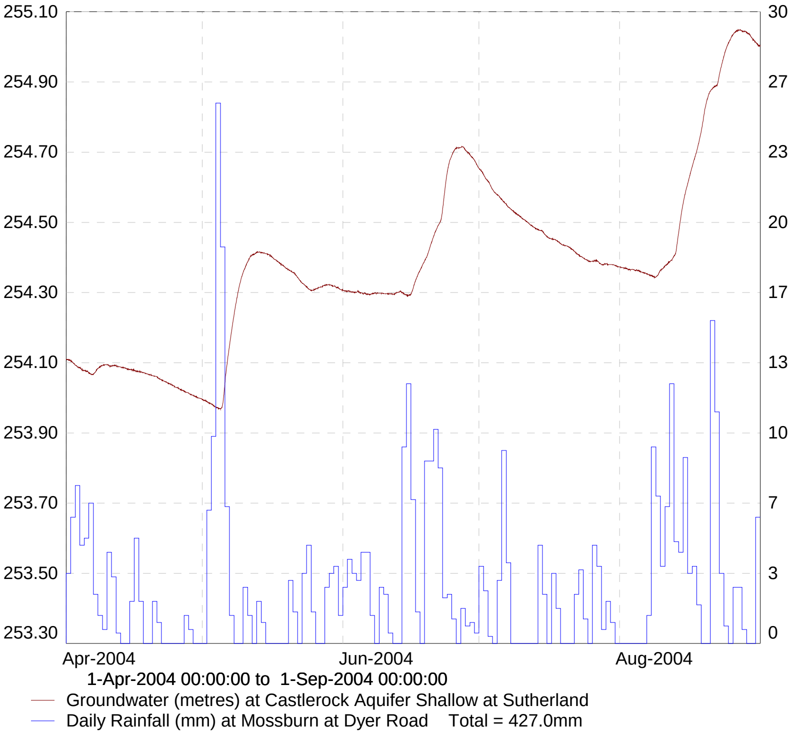


Figure 28 shows the response of groundwater levels in the Castlerock groundwater zone to individual recharge events. The figure shows large spikes in groundwater level corresponding to periods of significant rainfall. Groundwater level peaks lag the observed rainfall reflecting the time taken for soils to reach field capacity and soil moisture to drain to the water table.

- **Figure 28. Daily Rainfall and groundwater level response in the Castlerock groundwater zone**



2.3.4 Confined Aquifers

Potentiometric heads recorded in the North Range and Lumsden Aquifers show a pattern of seasonal variation similar in frequency to that observed in overlying unconfined aquifers but with significantly reduced magnitude. Piezometric levels in the confined aquifers also show limited evidence of abrupt changes in response to individual recharge events.

Lumsden Aquifer

Figure 29 shows a plot of piezometric levels recorded in the unconfined aquifer (E44/0011) and the underlying Lumsden Aquifer (E44/0012) at Castlerock over the period 2000 to 2005. The plot shows relative piezometric levels in the Lumsden Aquifer are consistently 5 - 6 m lower than the unconfined aquifer and the magnitude of seasonal variation in the Lumsden Aquifer is much less than that observed in the unconfined aquifer.

- **Figure 29. Piezometric level variations (mRL) in the Castlerock groundwater zone and Lumsden Aquifer at Castlerock**

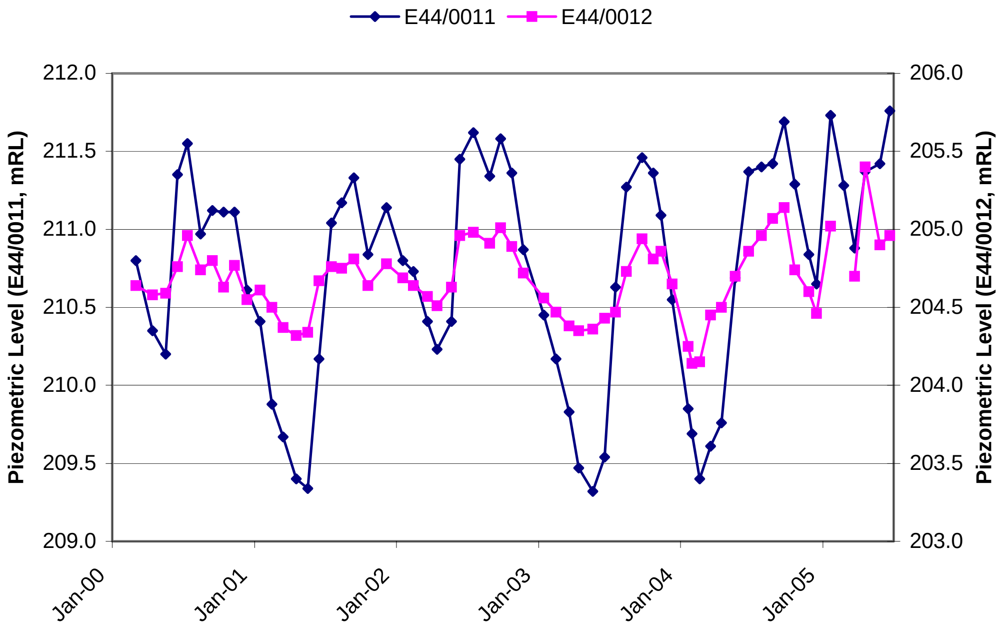
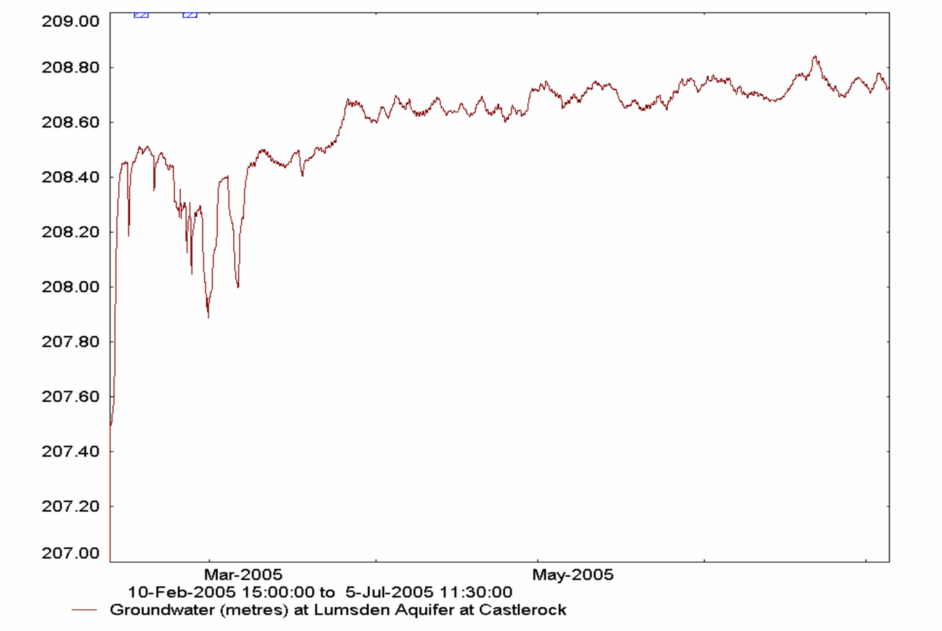


Figure 30 shows a plot of piezometric levels in the Lumsden Aquifer over the period February to July 2005 recorded at E44/0300 located adjacent to the Oreti River approximately 2 km north of the Castlerock saleyards.

The plot shows piezometric levels were affected by drawdown, resulting from abstraction in the vicinity of Ellis Road, during February and early March. Following cessation of abstraction piezometric levels recovered rapidly reaching pre-pumping levels by late March. Over the period April to July 2005 piezometric levels underwent a gradual increase of approximately 0.2 m. This rise is attributed to normal seasonal recovery and is, to a large extent, somewhat obscured by short-term variations in piezometric level resulting from barometric pressure variations.

Piezometric levels observed in E44/0300 show no response to rainfall or high stage events in the Oreti River over this period. Both the lack of response to potential recharge events and the variations in piezometric levels caused by barometric pressure fluctuations indicate the limited hydraulic connection between the Lumsden Aquifer and overlying unconfined aquifer.

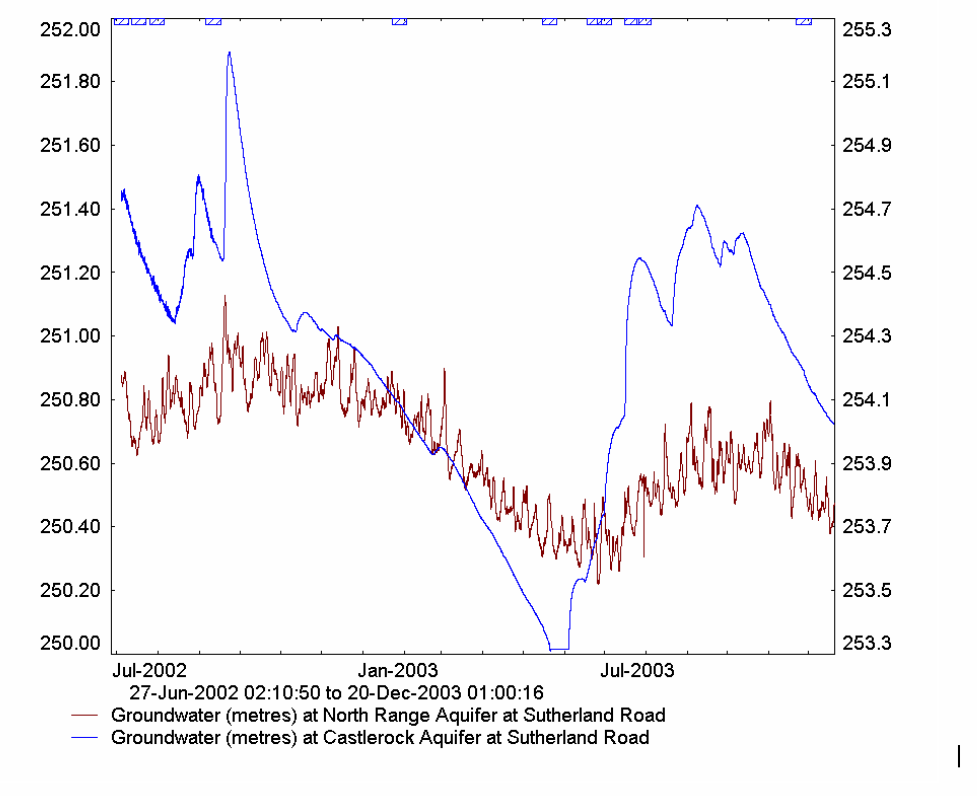
- **Figure 30. Piezometric levels in E44/0300, February to July 2005**



North Range Aquifer

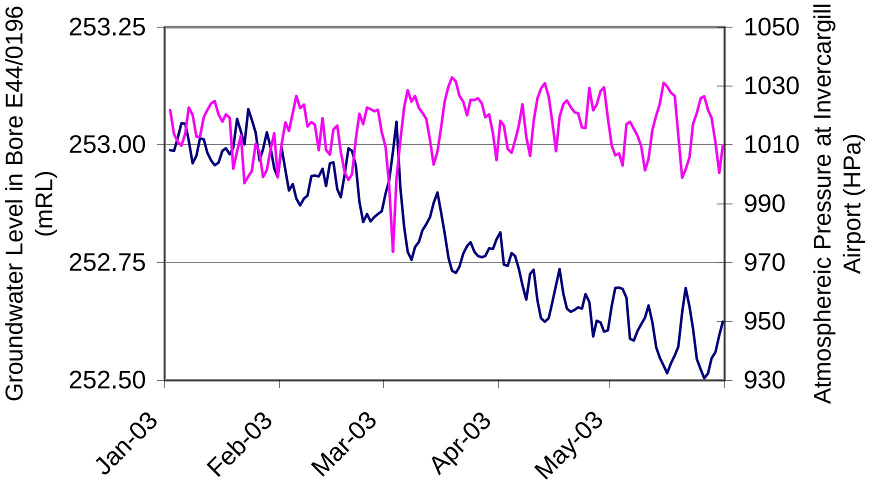
Figure 31 compares the seasonal variation in piezometric levels recorded in the North Range Aquifer near the intersection of Sutherland Road and SH94 (E44/0196) with those recorded in the overlying Castlerock groundwater zone (E44/0198) at the same location. The plot shows a consistent downward hydraulic gradient of between 3 - 4 m with significantly reduced magnitude of seasonal variation and no obvious response to individual recharge events in the North Range Aquifer.

- **Figure 31. Piezometric levels in the Castlerock groundwater zone and North Range Aquifer, July 2002-December 2003**



Short-term fluctuations in groundwater level observed in the North Range Aquifer correlate well with measured variations in atmospheric pressure. This relationship, illustrated in Figure 32, indicates the North Range Aquifer has a barometric efficiency of approximately 90%, indicative of a well-confined aquifer.

- **Figure 32. Mean daily groundwater levels in the North Range Aquifer and atmospheric pressure at Invercargill Airport**



2.4 Hydraulic Characteristics

2.4.1 Unconfined Aquifers

Limited aquifer test data are available from unconfined aquifers in the Oreti basin. Results from an aquifer test conducted on E44/0067 indicated an aquifer transmissivity of 920 m^3/day in the Castlerock groundwater zone near Ram Hill (Consent Number 201052). Subsequent attempts to establish an irrigation supply from the unconfined aquifer at this location for pasture irrigation indicate this test may have overestimated aquifer permeability.

Elsewhere in the Oreti basin aquifer transmissivity in unconfined aquifers estimated from specific capacity data from drillers logs ranges between 5 - 150 m^2/day. The reliability of this data is uncertain given issues with historical drilling practice including adequate screening and development, as well as the accuracy of discharge rate measurement.

Anecdotal information (J Engel, *pers comm.*) suggests that during the 1970’s several small-scale pastoral irrigation schemes were established in the Five Rivers groundwater zone utilising large diameter, shallow wells. The ability of these systems to meet demand was limited with many able to pump for less than 12 hours continuously before requiring an equal period of recovery. This observation likely reflects the moderate to low permeability and limited saturated thickness of the unconfined aquifer.

2.4.2 Confined Aquifers

A number of large-scale aquifer tests have been undertaken in confined aquifers in the Oreti basin as part of resource consent applications received by Environment Southland since 2002. Table 6 summarises calculated aquifer test results. These results include analyses derived from tests of up to 72 hours duration undertaken at rates of up to 7500 m^3/day.

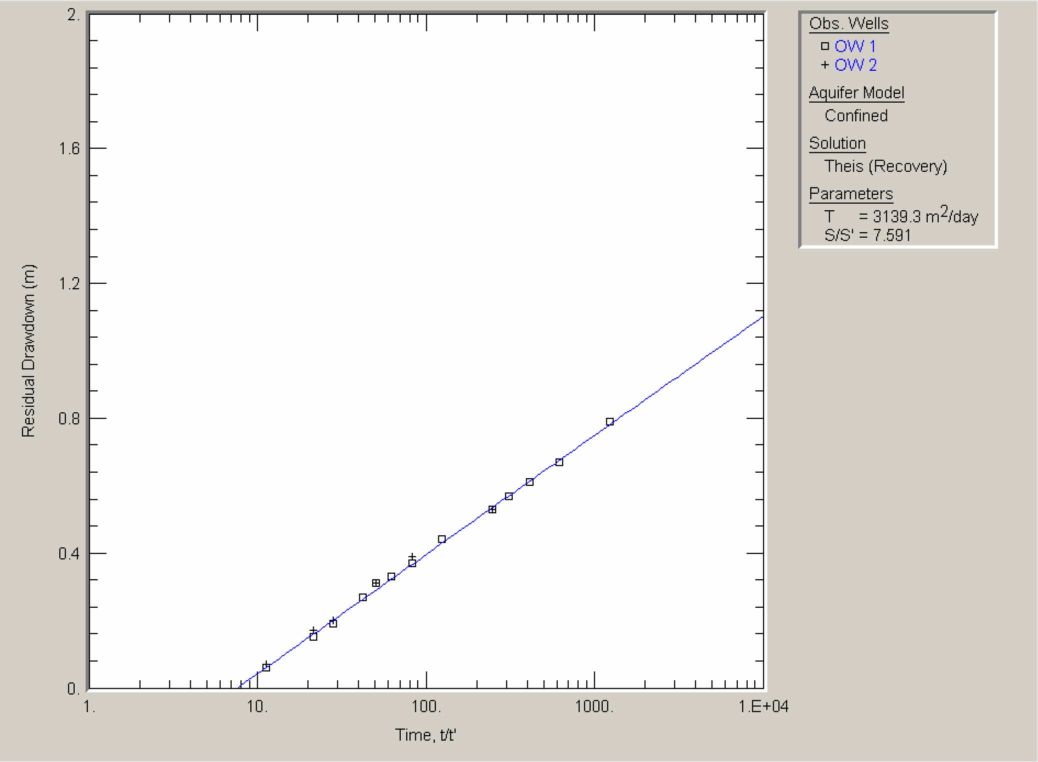
- **Table 6. Aquifer test results from confined aquifers in the Oreti basin**

Well Number	Hydraulic Conductivity (m/day)	Transmissivity (m^2/day)	Storativity
North Range Aquifer			
E44/0226	80	790	0.009
E44/0258	200	1700	0.00005
E44/0262	45	560	0.0001
E44/0265	300	1700	0.0001
E44/0266	101	700	0.00001
E44/0267	156	630	0.00001
Lumsden Aquifer			
E44/0200	70	600	0.00007
E44/0225	100	2330	0.0008
E44/0251	125	1850	0.003
E44/0252	100	2300	0.003
E44/0263	24	670	0.001
E44/0264	80	640	0.00001
E44/0269	335	3700	0.001

Aquifer test results show the heterogeneity characteristic of many alluvial gravel aquifer systems. Calculated aquifer transmissivity ranges from 560 - 1700 m^2/day in the North Range Aquifer and 600 - 3700 m^2/day in the Lumsden Aquifer. Aquifer storativity in both aquifers range from 0.009 - 0.00001.

Analysis of aquifer tests in the Lumsden Aquifer consistently show the presence of a recharge boundary. Figure 33 shows a typical recovery curve derived from aquifer testing undertaken on E44/0269, located toward the western end of Ellis Road, Five Rivers. The plot clearly shows positive displacement of the recovery curve from the observation and pumping wells indicating the resulting drawdown cone has intercepted a recharge boundary.

Figure 33. Typical residual drawdown plot from the Lumsden Aquifer



Given other hydrogeological evidence showing the well-confined nature of the Lumsden Aquifer, MWH (2004) interpreted the observed recharge boundary to represent a paleochannel within the alluvial gravel deposits in the central area of the Lumsden Aquifer.

Analysis using the Stallman method indicated an influence associated with the presence of the paleochannel close to the current alignment of the Oreti River. This hypothesis is supported by results of exploratory drilling undertaken for Environment Southland near the Oreti River, north of Castlerock (E44/0300). Drilling at this site indicated the waterbearing gravels comprising the Lumsden aquifer were approximately 30 m thick in the centre of the basin compared to less than 10 m along Ellis Road to the north, and Mossburn-Lumsden Highway to the south.

2.5 Aquifer Water Balance

2.5.1 Rainfall Recharge

The following section contains estimates of rainfall recharge for unconfined aquifers in the Oreti basin. Calculation of rainfall recharge is based on typical soil moisture capacity and rainfall totals for each groundwater zone and uses daily values of potential evapotranspiration calculated at the

Gore AWS site. The calculation assumes all rainfall in excess of that required to replenish soil moisture drains to groundwater.

Castlerock Groundwater zone

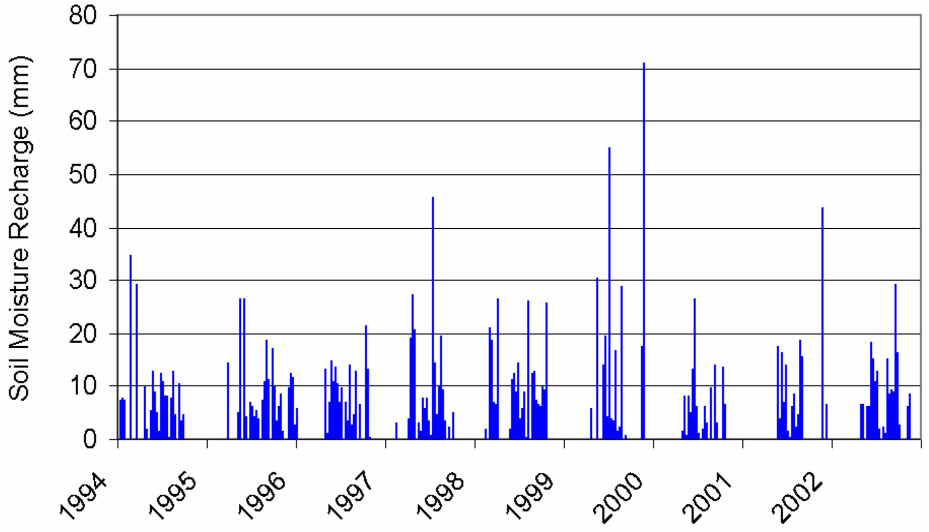
The extent and estimated soil moisture water holding capacity of the main soil types in the Castlerock groundwater zone are listed in Table 7. Well drained Oreti soils cover approximately 40 percent of the total area, predominantly on the flat-lying areas of the Castlerock Terrace. Poorly drained Waikoikoi and Dipton soils are found on the alluvial fan on the northern slopes of the North Range.

- **Table 7. Main soil types in the Castlerock groundwater zone**

Soil type	% Area	Water Holding Capacity (mm)
Oreti	41.3	30-60
Waikoikoi	21.2	90-150
Dipton	14.1	90-150
Makarewa	5.2	60-90
Stony Creek	5.2	60-90

A daily soil moisture water balance calculated for the Castlerock groundwater zone is shown in Figure 34. This calculation is based on average soil moisture capacity of 90 mm and rainfall recorded at the Mossburn at Dyer Road site.

- **Figure 34. Calculated soil moisture water balance for the Castlerock groundwater zone**



Due to the change in altitude across the Castlerock groundwater zone (~350 mm) it is likely there is a degree of orographic enhancement of rainfall on the upper slopes of the North Range. The selection of Mossburn at Dyer Road as a representative rainfall site is based on an assumption that average rainfall in the Castlerock groundwater zone is likely to be higher than that recorded in the central area of the Oreti basin.

Based on the soil water moisture balance calculation an annual rainfall recharge of 360 mm is calculated for the Castlerock groundwater zone. Over the 6,800 Ha surface area, this equates to an annual volume of rainfall recharge of 24.5 Mm^2 (775 L/s).

2.6 Oreti groundwater zone

The extent and estimated soil moisture water holding capacity of the main soil types in the Castlerock groundwater zone are listed in Table 8. Well drained Oreti and Gore soils predominate on the recent floodplain of the Oreti River covering approximately 85 percent of the total area.

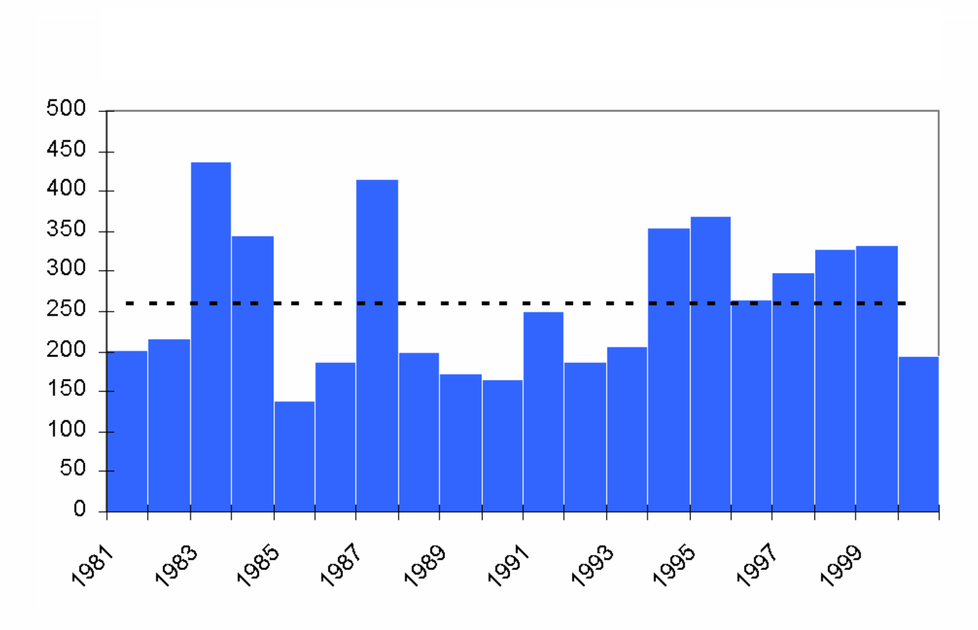
- **Table 8. Main soil types in the Oreti groundwater zone**

Soil type	% Area	Water Holding Capacity (mm)
Riversdale	70.5	60-90
Gore	15.5	60-90
Waikoikoi	4.2	90-150
Makarewa	3.2	60-90

Annual rainfall recharge for the Oreti groundwater zone, calculated from daily potential evapotranspiration values at Gore AWS and rainfall at Five Rivers at Ellis Road assuming an average soil moisture water holding capacity of 75 mm, is shown in Figure 35.

Based on the soil water moisture balance calculation the annual surface recharge for the Oreti groundwater zone is calculated as 263 mm. Over the total area of 6,130 Ha this equates to an average annual rainfall recharge volume of 16.1 Mm^2 (511 L/s).

- **Figure 35. Temporal variation in calculated rainfall recharge (mm) in the Oreti groundwater zone (1981-2002)**



Five Rivers groundwater zone

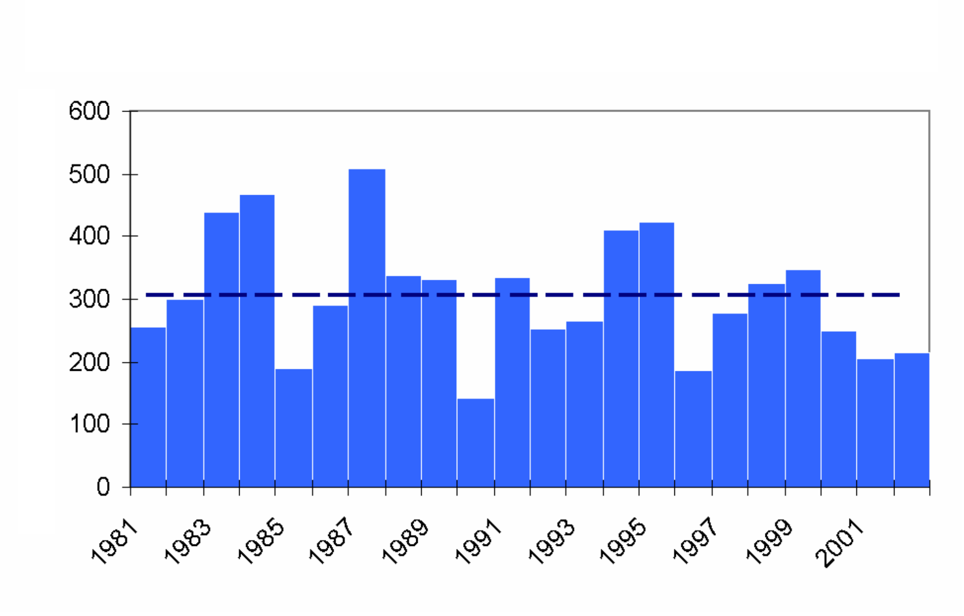
The extent and estimated soil moisture water holding capacity of the main soil types in the Five Rivers groundwater zone are listed in Table 9. In this area, well drained Oreti, Gore and Riversdale soils are found extensively across the Five Rivers area with less extensive areas of poorly drained soils around the basin margin.

- **Table 9. Main soil types in the Five Rivers groundwater zone.**

Soil type	% Area	Water Holding Capacity (mm)
Oreti	25.6	30-60
Gore	17.1	60-90
Riversdale	16.2	60-90
Jacobstown	7.0	150-250
Lumsden	6.6	60-90

Using rainfall recorded at Five Rivers at Five Rivers Station and assuming and average soil water holding capacity of 75 mm average annual rainfall recharge across the Five Rivers groundwater zone is calculated as 307 mm/year. Figure 36 shows the temporal variation in calculated annual land surface recharge over the period 1981 to 2002.

- **Figure 36. Temporal variation in calculated rainfall recharge in the Five Rivers groundwater zone (1981-2002)**



Based on the soil water moisture balance calculation the annual rainfall recharge for the Five Rivers groundwater zone is calculated as 307 mm. Over the total area of 13,800 Ha this equates to an average annual land surface recharge volume of 42.37 Mm^2 (1,340 L/s).

2.6.1 River Recharge

River recharge of groundwater in the Oreti basin is derived from flow loss from the Oreti River as well as smaller tributary streams that enter the basin from the surrounding foothills. Available concurrent stream gauging data as well as observed groundwater level variations and groundwater isotopic composition support the inference that river recharge makes a significant contribution to overall groundwater recharge in the Five Rivers and Oreti groundwater zones and the underlying Lumsden Aquifer.

Five Rivers Groundwater Zone

Anecdotal evidence suggests many of the small streams that drain from the surrounding foothills into the Oreti basin lose a considerable portion of flow when they reach the alluvial plains. The only stream with suitable concurrent gauging data currently available to confirm this effect is the Cromel Stream. Table 10 contains concurrent gauging data for the Cromel Stream showing a significant degree of interaction between this stream and surrounding unconfined aquifer.

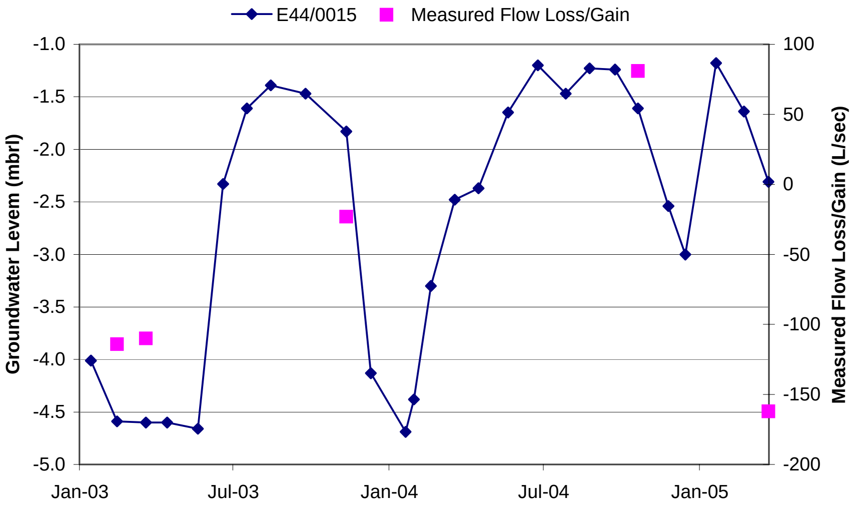
- **Table 10 Concurrent gauging data from the Cromel Stream**

Date	Cromel Stream at Selbie Road (L/s)	Cromel Stream at Mossburn-Five Rivers Highway (L/s)	Measured Flow Loss/Gain (L/s)
31 January 2003	312	198	-114
19 March 2003	276	166	-110
20 November 2003	1370	1347	-23
16 November 2004	1723	1804	+81
7 December 2004	4077	4839	+762
4 February 2005	600	438	-162

Figure 37 compares the measured flow loss from the Cromel Stream between Selbie Road and Mossburn-Five Rivers Highway with groundwater levels measured in E44/0014 located approximately 1250 m to the south. Clearly significant flow loss from the Cromel Stream occurs over this reach during periods of low aquifer levels. The measured flow of approximately 110 L/s during summer 2003 equates to recharge of 9,500 m^3/day to the surrounding unconfined aquifer.

During periods of high aquifer levels the Cromel Stream acts as a drain removing water from the unconfined aquifer. This type of stream-aquifer response is characteristic of riparian aquifers.

- **Figure 37. Groundwater levels and measured flow loss from the Cromel Stream**



Anecdotal evidence supports similar stream-aquifer interaction occurring in other small streams which enter the Oreti basin such as Irthing Stream, Acton Stream, Oswald Stream, Tank Creek and Dome Burn. Further gauging work is required on these streams to better quantify the degree and nature of stream / aquifer interaction.

Castlerock Groundwater Zone

Some local interaction is likely between streams that drain the North Range and the underlying unconfined aquifer. However, no gauging data is available to define the magnitude of flow loss from these streams which are generally ephemeral in character. Available flow measurements in the section of Murray Creek that crosses the Castlerock Terrace indicate this stream is largely influent over a majority of its length with flows virtually ceasing during summer when runoff from the North Range is limited and groundwater levels in the unconfined aquifer are low.

Observed groundwater level fluctuations in the unconfined aquifer of the Castlerock groundwater zone indicate that recharge to this aquifer system is primarily derived from local rainfall on the Castlerock terrace.

Oreti Groundwater Zone

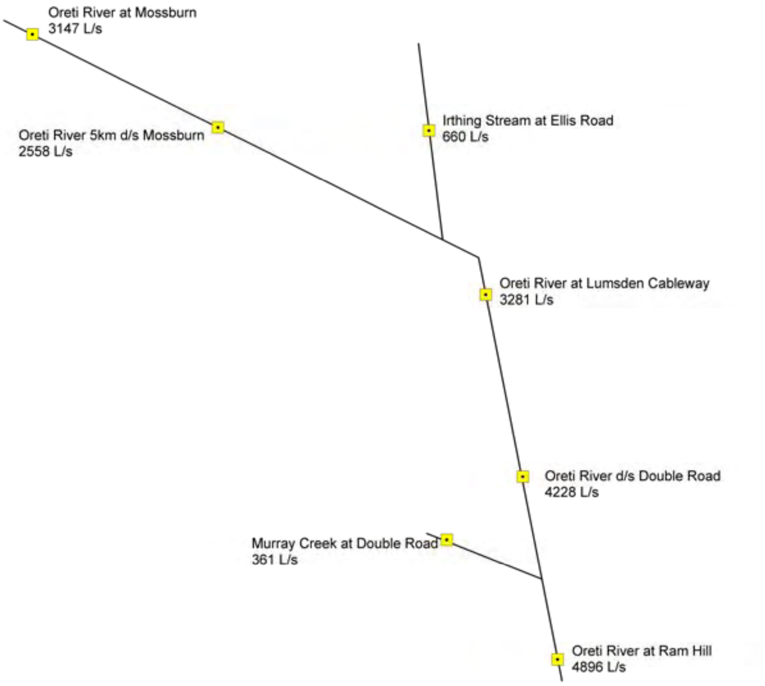
Available concurrent gauging data suggest significant flow exchange between the Oreti River and surrounding riparian aquifer across the Oreti basin. Results of gauging runs indicate significant flow loss from the Oreti River in the reach downstream from Mossburn and significant flow gain in the reach between Double Road and Ram Hill (Table 11). Figure 38 shows a schematic illustration of results from the 30 April 2003 gauging run.

- **Table 11. Concurrent gaugings in the Oreti River between Mossburn and Ram Hill**

Date	Oreti River at Mossburn (m^3/s)	Oreti River 5 km d/s Mossburn (m^3/s)	Oreti River 7.25 km d/s Mossburn (m^3/s)	Irthing Stream At Ellis Road (m^3/s)	Oreti at Lumsden Cableway (m^3/s)	Murray Creek at Oreti confluence (m^3/s)	Oreti River d/s Double Road (m^3/s)	Oreti River at Ram Hill (m^3/s)
28/01/2001	3.825	2.769		2.264	4.229	0.380	4.495	5.303
30/04/2003	3.147	2.558		0.660	3.281	0.361	4.228	4.896
04/02/2005	5.403		4.414	2.411	7.318	0.466	7.936	8.400*
08/02/2005	5.294	4.890		2.319	6.996	0.438		8.388

* Flow estimated from incomplete gauging

- **Figure 38. Concurrent Gauging Results on the Oreti River and tributaries, 30 April 2003**



The gauging results show a flow loss from the Oreti River of 5 - 600 L/s between Mossburn and Lumsden Cableway, allowing for Irthing Stream input. This indicates recharge to the surrounding unconfined aquifer across this reach of approximately 50,000 m^3/day.

Between Lumsden Cableway and Ram Hill gauging results indicate a flow increase in the Oreti River of between 1,100 - 1,600 L/s, approximately 400 L/s of which is derived from flow input from Murray Creek. This indicates discharge to the river from the surrounding unconfined aquifer during low flow conditions of between 95,000 - 138,000 m^3/day.

Overall, gauging results, with the exception of the January 2001 run, indicate a net flow increase in the Oreti River of between 620-1090 L/s (53,000 - 94,000 m^3/day) within the Oreti basin. This increase represents groundwater drainage from the surrounding unconfined aquifer.

2.6.2 Groundwater Discharge

Groundwater discharge via spring flow or drainage by influent streams makes a significant contribution to baseflow in the Oreti River and tributaries in the Oreti basin.

Five Rivers groundwater zone

Available gauging information suggest that streams crossing the Five Rivers groundwater zone remove significant quantities of water from the surrounding unconfined aquifer. Across the central portion of the Five Rivers Plain significant flow gains are observed in the cumulative discharge of the Acton, Cromel and Irthing Streams reflecting flow inputs from numerous spring-fed tributaries as well as direct groundwater discharge to the stream bed. Table 12 contains relevant gauging results which show a consistent flow gain of between 0.5 and 1.5 m^3/s in the combined discharge of the Acton, Cromel and Irthing Streams between Mossburn-Five Rivers Highway and the Irthing Stream at Ellis Road.

- **Table 12. Measured flow and calculated flow gains in the combined discharge of the Acton, Cromel and Irthing Streams below Mossburn-Five Rivers Highway (m^3/s)**

Date	Irthing Stream at Mossburn-Five Rivers Highway (m3/s)	Acton Stream at Mossburn-Five Rivers Highway (m3/s)	Cromel Stream at Mossburn-Five Rivers Highway (m3/s)	Combined Discharge at Five Rivers-Mossburn Highway (m3/s)	Irthing Stream at Ellis Road (m3/s)	Flow gain below Five Rivers-Mossburn Highway (m3/s)
09/01/1976	0.316	0.279	0.591	1.186	2.028	0.842
06/07/1981	0.801	1.881	0.601	3.283	4.637	1.354
17/12/1981	0.803	2.187	1.727	4.717	5.72	1.003
06/12/1982	1.906	1.946	2.107	5.959	7.511	1.552
23/03/1983	0.461	0.562	0.475	1.498	3.041	1.543
12/07/1983	1.187	0.654	1.856	3.697	4.278	0.581
21/08/1984	2.038	4.19	2.514	8.742	11.531	2.789
22/11/1984	1.113	0.799	1.668	3.58	4.884	1.304
31/03/2002	0.172	0.18	0.198	0.55	1.423	0.873
20/03/2003	0.143	0.138	0.166	0.447	0.883	0.436
30/04/2003	0.262	0.275	0.32	0.857	1.412	0.555

A significant number of small spring-fed streams also originate in downgradient portion of the Five Rivers groundwater zone. At the current time no gauging information is available to quantify the magnitude of discharge from these springs.

Oreti Groundwater Zone

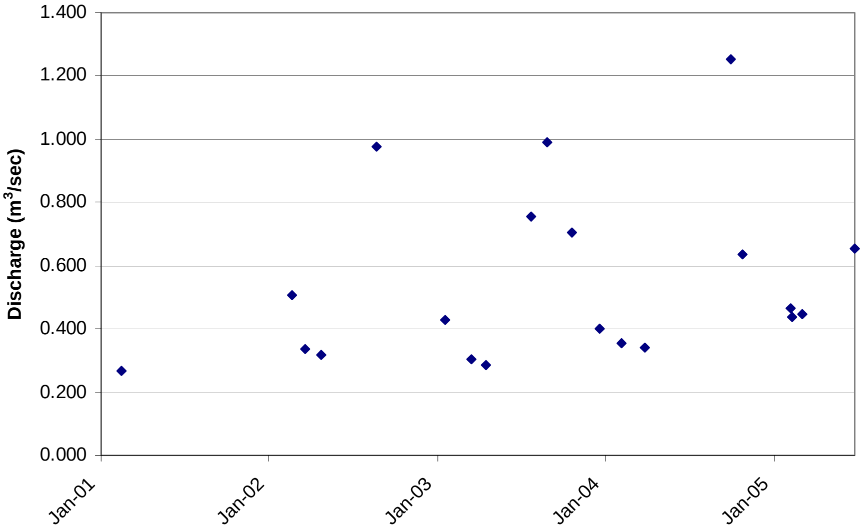
Significant interaction between the Oreti River and surrounding riparian aquifers is illustrated by the results of concurrent flow gaugings outlined in Section 2.5.2. In addition to direct inflow exchange with the Oreti main stem, many of the spring fed streams originating along the Castlerock Terrace margin appear to gain significant flow as they cross the Oreti groundwater zone before joining the Oreti River. For example, gauging results indicate an increase in flow of up to 100 L/s in Murray Creek between Double Road and the Oreti River confluence.

Castlerock groundwater zone

Groundwater discharge from the Castlerock groundwater zone occurs via numerous spring-fed streams that occur around the outer terrace margin as well as by direct throughflow into the alluvial gravels of the Oreti groundwater zone.

Significant spring discharge occurs in the Murray Creek catchment along the base of the alluvial terrace the marks the eastern extent of the Castlerock groundwater zone. During periods of high rainfall Murray Creek drains runoff from the North Range and the Castlerock Terrace as far west as Mossburn. However, during extended periods of low rainfall runoff from these areas is negligible and the major source of flow is a series of springs which occur immediately upstream of Double Road. Figure 39 shows the temporal variability of measured stream discharge in Murray Creek at Double Road. During late summer the measured discharge is consistently between 250 - 350 L/s, exclusively derived from spring discharge upstream of Double Road.

- Figure 39. Murray Creek discharge at Double Road

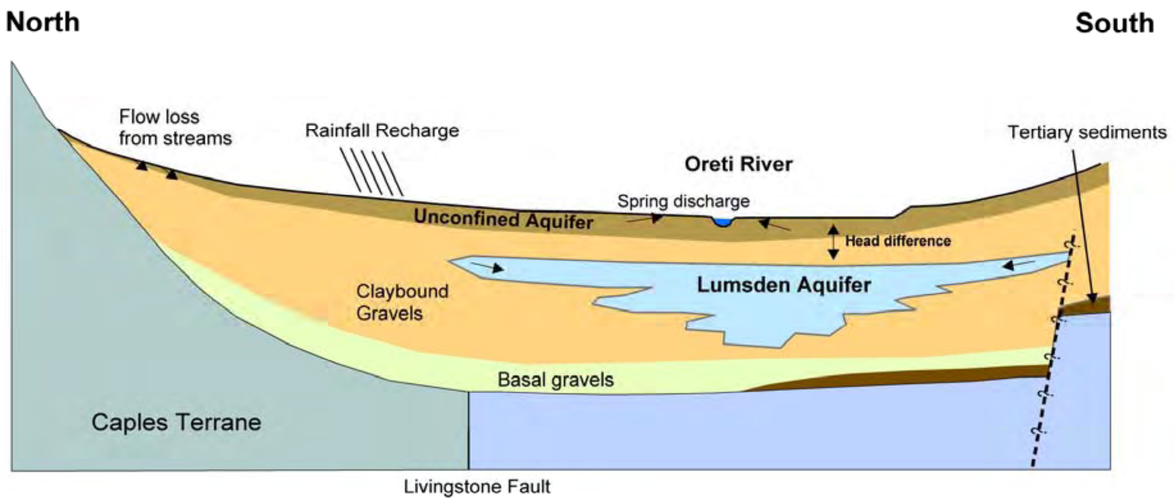


Other smaller springs which drain the Castlerock groundwater zone include the Row Burn which crosses the Castlerock-Dipton Road approximately 1 km south of Sutherland Road. This stream has similar discharge characteristics Murray Creek with a measured summer discharge of between 10 - 20 L/s. Other un-named springs of similar magnitude occur along the northern margin of the Castlerock Terrace near Edwards Road.

2.7 Conceptual Aquifer Model

Figure 40 illustrates the conceptual model of the Five Rivers and Oreti groundwater zones and the underlying Lumsden Aquifer.

- **Figure 40. Conceptual model of the Lumsden Aquifer**



The Oreti basin is infilled by a sequence of fluvioglacial gravels up to 80 m thick. These gravels overlie an unknown thickness of Tertiary lignite measure sediments which in turn rest on basement rocks of the Dun Mountain-Matai Terrane.

The upper 10 m of the gravel deposits have been locally reworked by the Oreti River and tributaries over the post-glacial period, forming a thin unconfined aquifer which is hydraulically connected to adjacent rivers and streams. The remainder of the gravel deposits infilling the Oreti basin consist largely of very poorly sorted, tightly claybound gravels except in the central area where extensive reworking of the gravel deposits occurred during the last interglacial period. These reworked gravels form the Lumsden Aquifer. This aquifer is confined beneath by a layer of tightly claybound, low permeability gravels deposited during the last glaciation. The gravels forming the Lumsden Aquifer thicken towards the centre of Oreti basin reflecting the extent of fluvial reworking by the Oreti River during the last interglacial period.

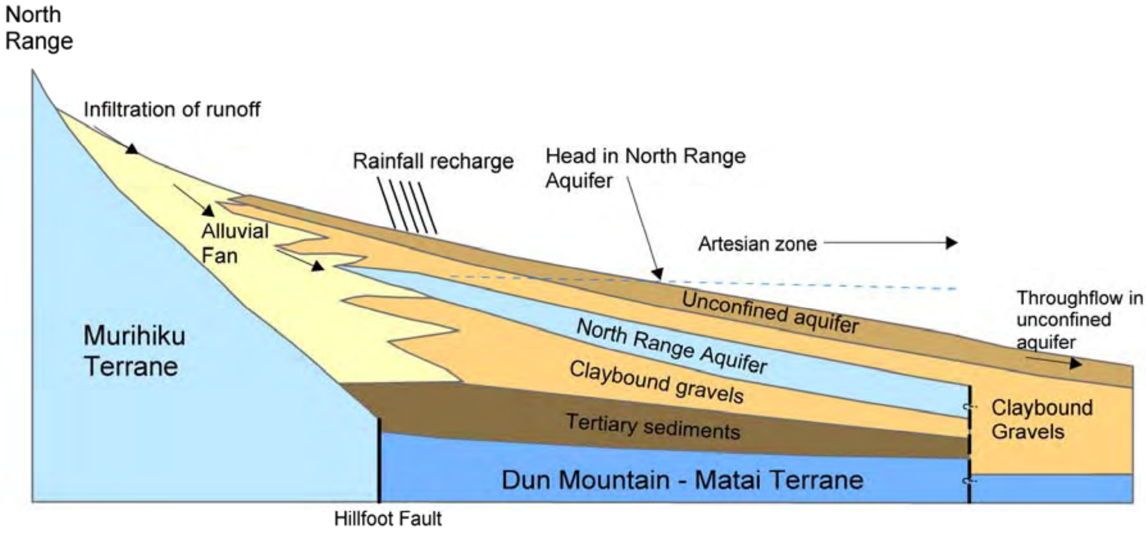
The unconfined aquifer is recharged by flow loss from streams around the outer margin of the basin as well as direct rainfall recharge. Groundwater discharge occurs via spring discharge and direct seepage into streams along the riparian margin of the Oreti River. Recharge to the Lumsden Aquifer occurs via limited throughflow from the surrounding claybound gravel deposits.

The large head differential evident throughout much of the Lumsden Aquifer reflects the well-confined nature of this Aquifer. Due to the limited hydraulic connection with the unconfined aquifer groundwater throughflow in the Lumsden Aquifer is limited, with no obvious recharge or discharge areas. Tritium analysis indicates a mean residence time in excess of 80 years in the Lumsden Aquifer.

The spatial extent of the Lumsden Aquifer appears to be limited by the underlying geological structure. The southern boundary occurring along the alignment of structural control and possible fault displacement in the underlying basement.

Figure 41 illustrates a conceptual model of the Castlerock groundwater zone and underlying North Range Aquifer.

- **Figure 41. Conceptual model of the North Range Aquifer**



In the Castlerock area the large alluvial fan on the northern slopes of the North Range interfingers with the alluvial sediments infilling the Oreti Basin. These alluvial deposits overlie Tertiary lignite measure sediments and basement rocks of the Dun Mountain-Matai and Murihiku Terranes. Basement structure has been significantly disrupted by movement along, and associated with, the Hillfoot Fault which runs along the base of the North Range.

A shallow unconfined aquifer extends across the area to a depth of approximately 10 m. This aquifer is underlain by a sequence of tightly claybound gravels which form a confining layer over the reworked alluvial gravels which form the North Range Aquifer. The North Range Aquifer extends from the base of the North Range to the west of Edwards Road. The northern boundary of the aquifer appears to follow basement structure along an alignment between Castle Rock and Hillas Road, Five Rivers.

Groundwater recharge to the unconfined aquifer occurs via direct rainfall recharge to the terrace surface as well as infiltration from streams which drain the North Range. The North Range Aquifer is recharged by infiltration through the alluvial fan at the base of the North Range and becomes artesian between Sutherland Road and Edwards road due to the intersection of the relatively flat piezometric gradient and the topographic surface.

Groundwater discharge from the Castlerock groundwater zone occurs via springs which originate around the outer margin of the alluvial terrace. The largest of these springs discharge into Murray Creek along the eastern margin at a rate of 250 - 350 L/s during extended periods of low rainfall.

3. Groundwater Quality

3.1 Major Ion Chemistry

Three bores in the in the Oreti basin are currently sampled on a quarterly basis as part of the Environment Southland baseline groundwater quality monitoring program. One-off samples have also been collected from seven bores screened in the Lumsden Aquifer and one bore screened in the North Range Aquifer. Table 13 contains summary results of major ion chemistry for groundwater samples collected in the area.

- Table 13. Summary groundwater quality in the Oreti basin

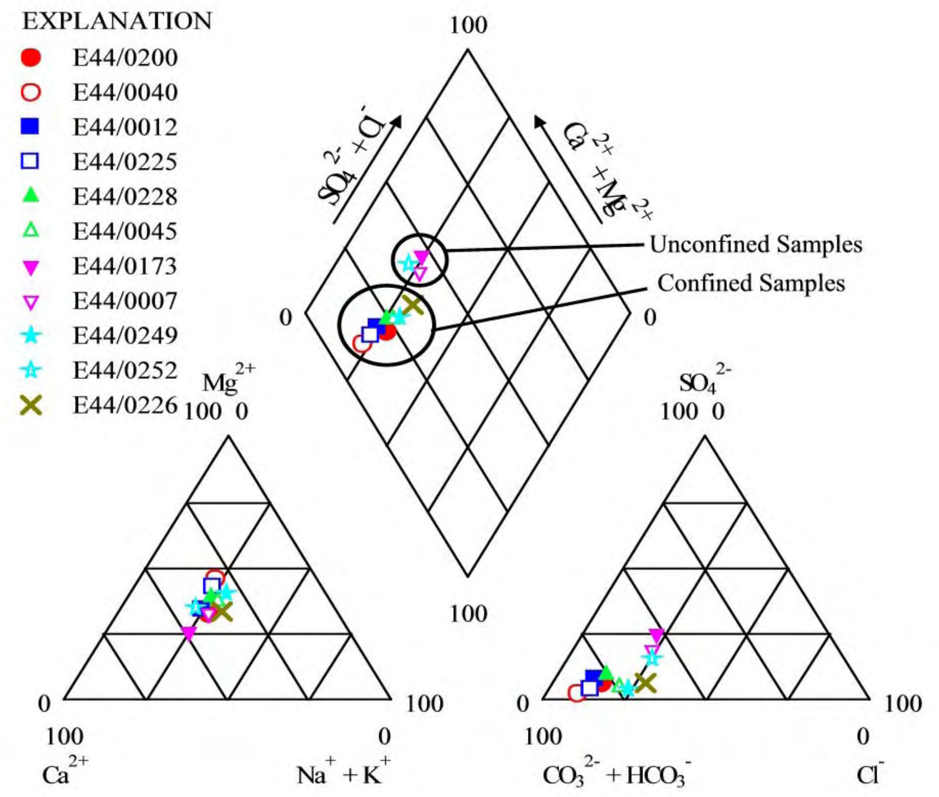
Site Number	Electrical Conductivity	PH	Total Alkalinity	Chloride	Sulphate	Nitrate-N	DRP	Calcium	Magnesium	Potassium	Sodium	Total Iron
Lumsden Aquifer												
E44/0012	99	7.3	38	3.5	2.9	1.0	0.032	7.6	3.9	0.5	5.2	0.089
E44/0040	131	7.5	55	3.5	1.3	0.9	0.034	8.1	7.2	0.5	6.8	<0.005
E44/0200	113	7.4	40	4.5	2.5	1.5	0.028	8.2	4.1	0.5	6.5	<0.005
E44/0225	112	7.3	45	4.0	1.6	0.9	0.030	7.3	5.7	0.5	6.0	0.021
E44/0228	131	6.8	40	4.5	3.8	2.6	0.020	8.5	5.6	0.5	6.9	0.427
E44/0249	98	7.3	33	6.5	1.5	1.4	0.011	5.2	4.3	0.6	5.7	<0.05
E44/0252	98	6.5	24	6.0	5.0		0.048	6.9	3.4	0.6	3.8	0.47
North Range Aquifer												
E44/0045*	140	6.8	43	7.0	2.0	2.7	0.023	9.4	6.1	0.8	8.3	0.02
E44/0226	148	6.7	38	9.7	3.0		0.012	9.2	5.3	1.0	9.0	<0.005
Unconfined Aquifers												
E44/0173*	108	6.3	19	4.7	6.9	3.5	0.008	9.6	3.0	1.1	5.0	0.01
E44/0007*	164	6.7	37	9.4	9.8	4.4	0.027	12.3	6.3	1.1	9.5	0.06

*Median values from multiple samples

Sample results indicate groundwater quality in the Oreti basin is high. All samples exhibit major ion concentrations well within New Zealand Drinking Water Standard MAV's. The relatively low major ion concentrations reflect limited water-rock interaction indicative of the relatively inert aquifer media. However, a clear differentiation in major ion chemistry is observed between unconfined and confined aquifer samples. Samples from unconfined aquifers tend to have slightly higher chloride, sulphate, nitrate calcium and potassium concentrations possibly indicative of the influence of land use activities on shallow groundwater. Samples from confined aquifers tend to have higher pH and alkalinity values reflecting longer residence times.

The differentiation in groundwater chemistry between unconfined and confined aquifers in the Oreti basin is illustrated in Figure 42. With the exception of E44/0252, a 48 m production well located at the eastern end of Ellis Road, a clear differentiation in terms of major ion concentrations can be seen between samples from the confined and unconfined aquifers.

- **Figure 42. Piper Diagram of major ions (meq/L) in the Oreti basin**



The water quality sample result from E44/0252 is slightly anomalous given this bore has a similar pattern of subsurface geology to other bores situated along Ellis Road, and aquifer testing confirmed the well-confined nature of the Lumsden Aquifer at this point. One possible explanation for the difference in observed water quality at E44/0252, aside from it resulting from sample variance, may be the proximity of this bore to recharge areas along the foot of the Mataura Range approximately 1 km to the east. The observed water quality at this site is consistent with the conceptual aquifer model of recharge to the Lumsden Aquifer occurring via infiltration around the basin margin.

3.1.1 Temporal Variability

Figure 43 shows the temporal variation in groundwater quality observed at E44/0007. This bore is screened a depth of 9 m in the Oreti groundwater zone approximately 1 km from the true left bank of the Oreti River. The plot shows concentrations of sodium, magnesium, potassium, chloride and nitrate remained relatively stable over the period 2000 to 2004. Concentrations of other major ions with the exception of sulphate and calcium were also relatively stable over this period. The reason for the observed variability in sulphate and calcium results is uncertain but may be related to local factors such as land use in the vicinity of the bore and the adequacy of wellhead protection.

- **Figure 43. Temporal groundwater quality measured at E44/0007**

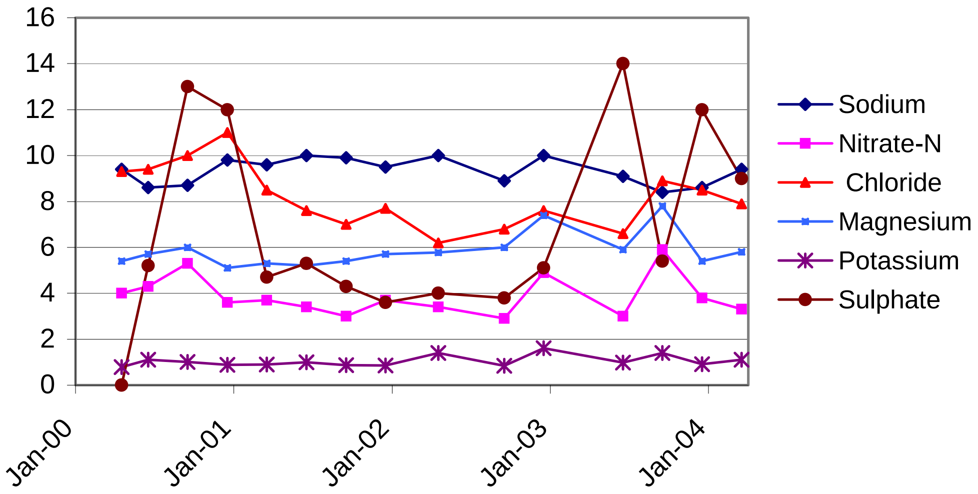


Figure 44 shows temporal variability of groundwater quality at E44/0173. This shallow bore (<5 m deep) is located in the Five Rivers groundwater zone adjacent to Lowther Road, approximately 500 m from the Cromel Stream. Groundwater quality at this site shows significant seasonal variation with parameter concentrations highest in spring and lowest in autumn. The significant temporal variability in groundwater quality observed at this site is likely to reflect the seasonal contaminant loading introduced into this shallow aquifer system during winter rainfall recharge. The subsequent improvement in groundwater quality during the summer and autumn reflecting the greater contribution of stream recharge to aquifer water balance during this period.

- **Figure 44. Temporal groundwater quality measured at E44/0173**

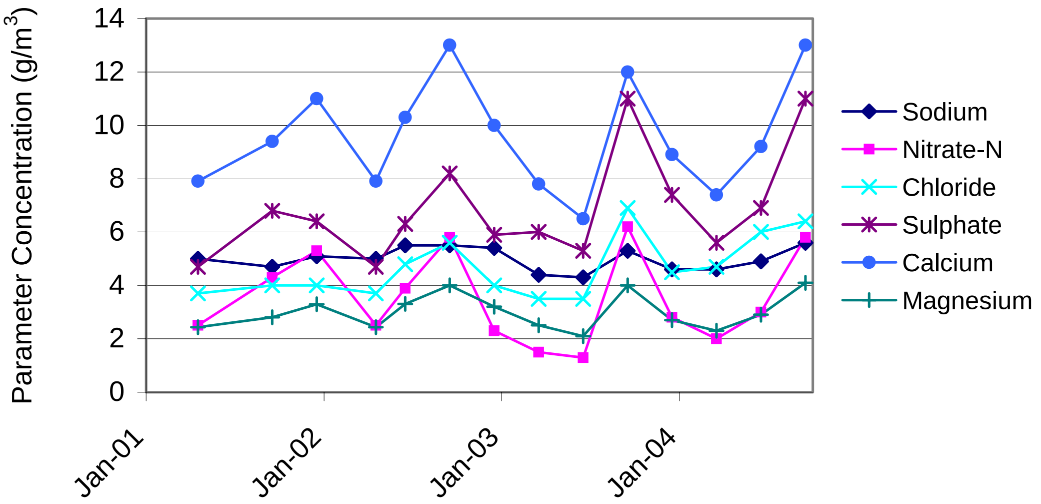
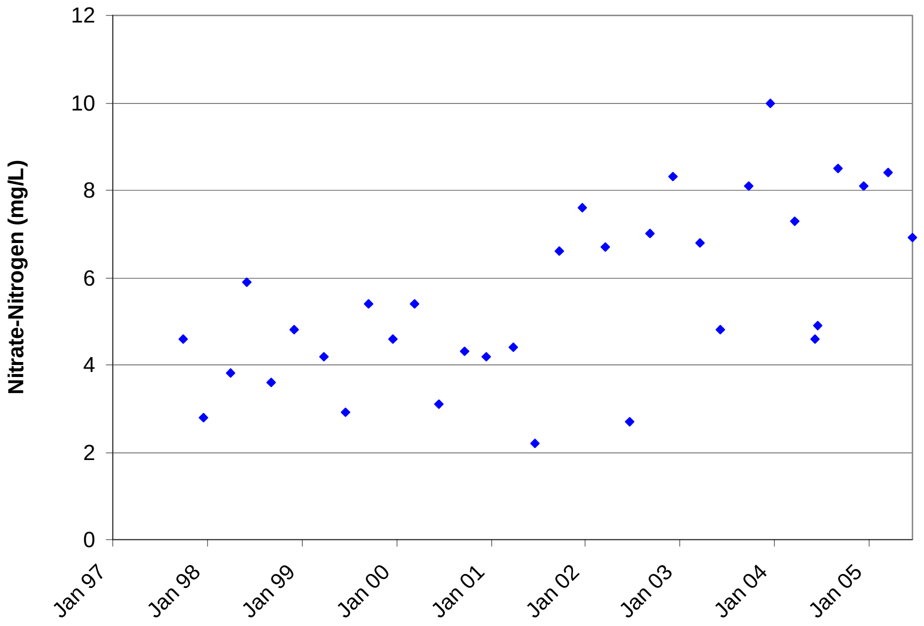


Figure 45 shows nitrate-nitrogen concentrations recorded in E44/0014 adjacent to Mossburn-Five Rivers Highway at the western end of Ellis Road. This site has been monitored on a quarterly basis over the period 1997 to 2005 as part of compliance monitoring for a nearby dairy conversion. The graph shows an apparent increase in nitrate concentration since 2001. Distinct seasonality is also obvious in the data with nitrate concentrations varying up to 50% between a peak in December and a minimum in June.

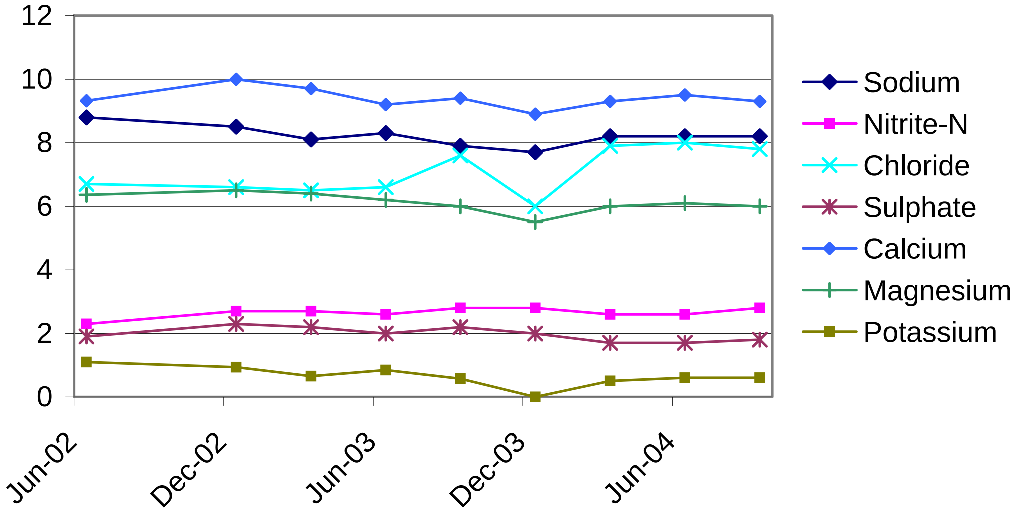
Some caution is required in directly attributing a cause to the observed changes in groundwater quality at this site as samples are derived from a large diameter dug well with very poor wellhead protection. Also, a synoptic survey undertaken in the area in June 2004 indicated elevated nutrient concentrations in the local area not immediately downgradient of the dairy conversion. As a result, it is not possible to establish a definitive cause-effect relationship from the water quality changes observed at this site. However, these monitoring data highlight the vulnerability of shallow unconfined aquifers that underlie well drained soils to impacts from land use intensification.

- **Figure 45. Nitrate-nitrogen concentrations recorded in E44/0014 over the period 1997-2005**



In contrast to the significant temporal variation in groundwater quality observed in unconfined aquifers, samples from E44/0045, screened at a depth of 28 m in the North Range Aquifer, show relatively limited variation in major ion concentrations. Figure 46 shows temporal variation in measured groundwater quality at this site. Aside from some variability in chloride ion concentration, groundwater quality has remained relatively constant over the period of measurement reflecting the isolation of this confined aquifer from the influences of seasonal recharge and local land use effects.

- **Figure 46. Temporal groundwater quality measured at E44/0045**



3.2 Hydrochemical Analysis

3.2.1 Oxygen-18

Oxygen occurs naturally in two stable isotopic forms; Oxygen-16 and Oxygen-18. Both isotopic forms occur naturally as constituents of water molecules however the ratio of the two isotopes varies according to the degree of atmospheric fractionation of the water vapour during precipitation. The degree of fractionation is to a large degree controlled by atmospheric temperature which in-turn is strongly influenced by altitude. As a result the ratio (expressed as δ18O) of the two oxygen isotopes can be used to distinguish precipitation from different altitudes. Thus δ18O is widely utilised as a natural tracer in hydrogeological studies to assist identification of groundwater recharge sources.

Stewart and Morgernstern (2001) report that δ18O values typically decrease by approximately 0.21‰ for each 100 m increase in altitude in New Zealand. In the Southland Region observed δ18O values range from -7.3 in shallow groundwater near the south coast to a value of -14.3 in rainfall at McKellars Flat situated at an altitude of approximately 670 m in the upper Oreti catchment.

In general, δ18O values in groundwater in Southland range from -7.3 to -8.0 in the area from the south coast to the Hokonui Hills, and lie in the range of -8.0 to -9.0 across the Waimea Plain from Gore to Mossburn with a steady increase observed with increasing elevation to the west. Samples from the major rivers in Southland show δ18O values between -9.5 to -10 reflecting the contribution of alpine runoff to streamflow. As δ18O values in locally recharged groundwater are relatively tightly constrained, values greater than -9.0 are inferred to indicate groundwater recharge derived from alpine rivers or high altitude precipitation. Insufficient information currently exists to define temporal variation in δ18O values in the Southland Region.

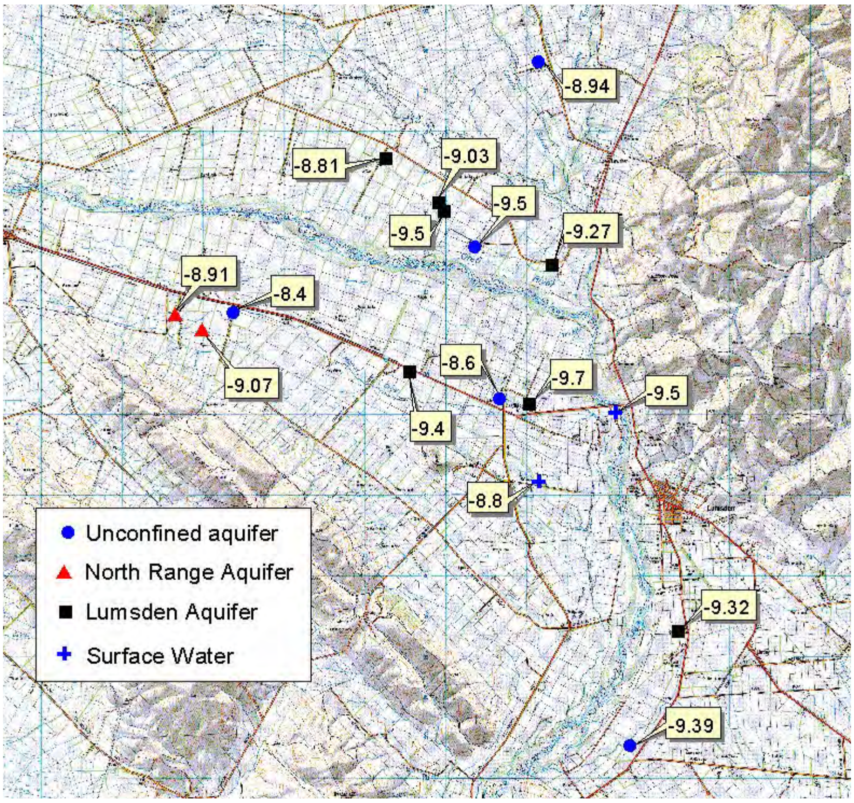
Samples from 15 sites in the Oreti basin have been analysed for δ18O. Sample sites include the Oreti River and Murray Creek, five unconfined bores and eight bores screened in the underlying confined aquifers. Sample results are listed in Table 14 and the spatial distribution of sample results is shown in Figure 47.

- **Table 14. δ18O sample results from the Oreti basin**

Well Number	Site Name	Aquifer/Groundwater Zone	δ18O	Interpreted Recharge Source
E44/0173	Kirker	Five Rivers	-8.94	Local Rainfall – some river influence
E44/0087	Southland Ostrich Export	Five Rivers	-9.5	River recharge
E44/0007	Reichmuth	Oreti	-9.39	River recharge
E44/0011	Castlerock Saleyards	Castlerock	-8.6	Local rainfall
E44/0122	Lott	Castlerock	-8.4	Local rainfall
E44/0045	MacInnes	North Range	-8.91	Rainfall Recharge – North Range
E44/0226	MacInnes PW1	North Range	-9.07	Rainfall Recharge – North Range
E44/0213	Southland Ostrich Export TW3	Lumsden	-9.5	River Recharge
E44/0225	Southland Ostrich Export PW1	Lumsden	-9.03	River/Rainfall
E44/0012	Stewart	Lumsden	-9.66	River Recharge
E44/0012	Stewart	Lumsden	-9.7	River Recharge
E44/0228	Van Leeuwen TW1	Lumsden	-9.4	River Recharge
E44/0200	Patterson	Lumsden	-9.32	River Recharge
E44/0040	Hamilton	Lumsden	-8.81	River/Rainfall
	Murray Creek at Double Road	Surface water	-8.8	Local rainfall/drainage from Castlerock groundwater zone
	Oreti River at SH94 Bridge	Surface water	-9.5	Alpine Rainfall

The δ18O results showed a more negative value in the Oreti River (-9.5) in comparison with Murray Creek (-8.8). This reflects the contribution of high altitude precipitation in the Oreti River headwaters compared to Murray Creek which is sourced from a combination of rainfall on the North Range and spring discharge from the Castlerock Terrace.

- **Figure 47. Results of Oxygen-18 isotope analysis in the Oreti basin**



In general, unconfined aquifer samples show less negative δ18O values reflecting a greater contribution of locally derived rainfall recharge. However, unconfined samples from E44/0007 and E44/0087 show relatively negative δ18O values indicating the contribution of river recharge to groundwater in riparian areas. The sample from E44/0173 shows a δ18O value of -8.9 reflecting a combination of river and rainfall recharge to this bore located approximately 500 m from the Cromel Stream in the Five Rivers groundwater zone.

Samples from bores screened in confined aquifers generally show δ18O values greater than -9. The samples from the North Range Aquifer (E44/0045 and E44/0226) show δ18O values of between -8.9 and -9.07. In light of the known geology and groundwater flow direction in this area, the observed δ18O value is likely to reflect groundwater recharge from rainfall at higher elevations on the North Range.

In the Lumsden Aquifer δ18O values range from -9.03 to -9.7 with the more negative values occurring in the central and southern portions of the aquifer. The observed variability is interpreted to reflect the range of δ18O concentrations in throughflow from the Five Rivers groundwater zone. Recharged derived from areas close to rivers and streams having more negative δ18O values while recharge from intervening areas having less negative δ18O values reflecting the greater contribution of rainfall recharge.

3.2.2 Groundwater Residence Time

Table 15 shows results of tritium analysis on samples from five bores screened in Lumsden Aquifer. Calculated mean groundwater residence times range from 130 ± 20 years in E44/0040 located toward the western end of Ellis Road to 61 ± 7 years in E44/0200 located on the eastern side of the Oreti River approximately 2.5 km south of the Lumsden township.

The calculated residence time for E44/0200 was slightly anomalous yielding two possible interpretations of mean residence time (61 or 14 years respectively). Even adopting the longer residence time, the result from this site is slightly anomalous when compared to other bores screened in the Lumsden Aquifer. Given that this bore is located along the eastern margin of the Oreti basin, the calculated residence time may support the inference that this bore is screened in a localised confined aquifer as discussed in Section 2.2.4.

Groundwater residence times calculated for bores elsewhere in the Lumsden Aquifer indicate limited throughflow in the Lumsden Aquifer. The calculated residence times in excess of 80 years are is consistent with observations of the well-confined nature of this aquifer and low piezometric gradient.

- **Table 15. Calculated groundwater residence time in the Lumsden Aquifer**

Well Number	Site Name	Depth	Tritium (TU)[1]	Mean Age (years)[2]
E44/0012	Stewart	28	0.880 ± 0.031	80 ± 10
E44/0040	Hamilton	21	0.016 ± 0.021	130 ± 20
E44/0200	Patterson	26	1.36 ± 0.04	61 ± 7*
E44/0225	Southland Ostrich Export PW1	43	0.191 ± 0.022	97 ± 15
E44/0228	Van Leeuwen TWI	65	0.866 ± 0.034	80 ± 10

[1] Tritium concentrations are expressed as tritium/hydrogen ratios in tritium unity (TU); 1 TU signifies a ratio of 1 x 10^{-8}

[2] Mean age (i.e. mean residence time) estimate based on an exponential piston flow mixing model with 60 ± 10% mixing (i.e. with exponential volume 60% of the total volume in the groundwater system).

* Some ambiguity in age estimate (Mike Stewart *pers comm*.) - 2 alternatives for mean residence time of either 61 or 14 years

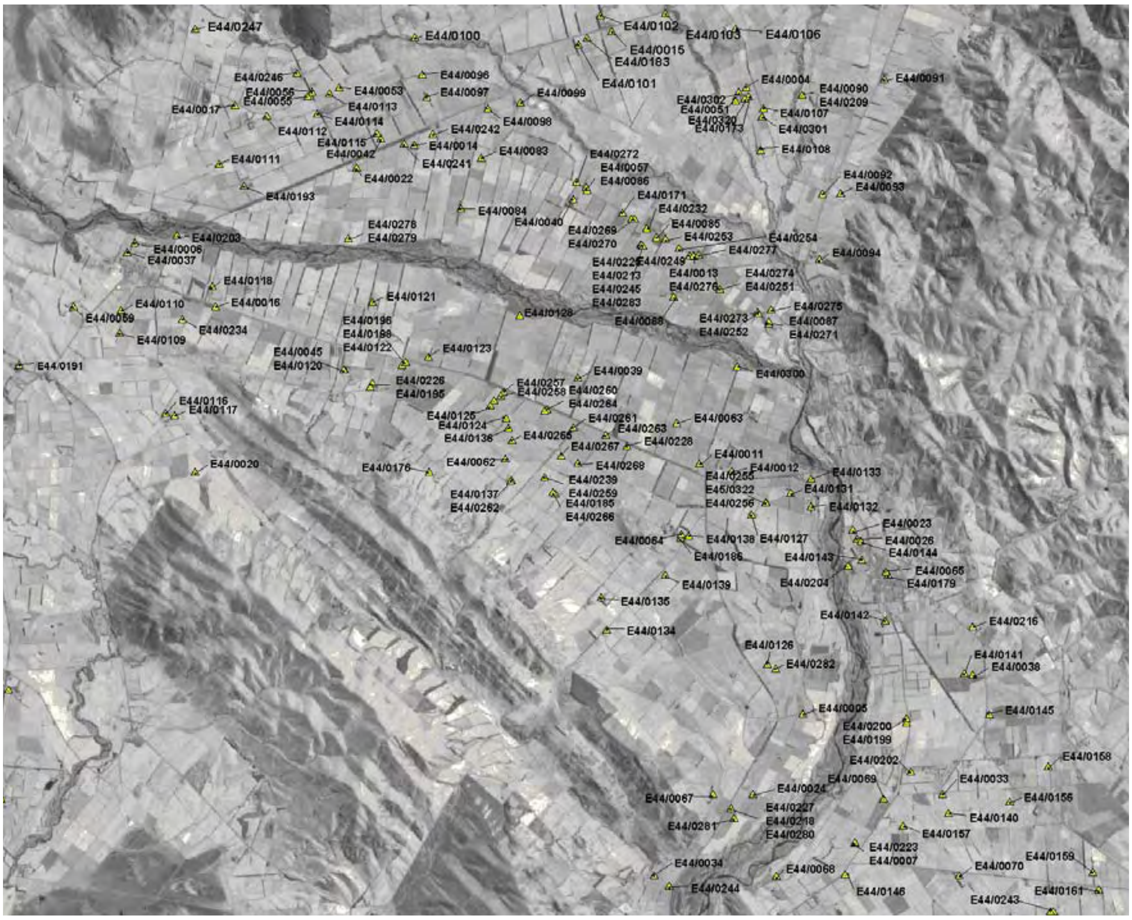
Groundwater residence time was also measured in the Oreti groundwater zone at E44/0007 in May 2002 using a combination of CFC-11/CFC-12 and SF_6 methods. These methods utilise the varying atmospheric concentrations of these compounds to create a unique “signature” in aquifer recharge. Groundwater residence time is then calculated by measuring the concentration if each compound the groundwater making allowance for the effects of dilution caused by groundwater flow. The calculated mean groundwater residence time from this analysis was 28 years.

4. Groundwater Use and Development

Until recently abstraction of groundwater in the Oreti basin was generally limited to small-scale takes for domestic, stock and dairy supply. As discussed in section 2.4.1, some utilisation of groundwater for pasture irrigation took place in the early 1970's however this was generally limited by the low yields available from the unconfined aquifer.

Since 2002 significant development of the groundwater resource for large-scale pasture irrigation has occurred in the Oreti basin. This development was spurred by investigation drilling that indicated the presence of confined aquifers capable of yielding significantly greater volumes of water than available from the unconfined aquifer. As a result of the drilling and associated investigations undertaken, a significant amount of information has become available to describe the hydrogeology of the confined aquifers. Figure 48 shows the location of bores and wells currently recorded in the Oreti basin.

- Figure 48. Bore locations in the Oreti basin



4.1 Current Allocation

Unconfined Aquifers

Table 16 lists current allocation from unconfined aquifers in the Castlerock, Oreti and Five Rivers groundwater zones. Current allocation from these aquifers is relatively, limited representing a small proportion of the calculated aquifer recharge (see sections 2.5.1 and 2.5.2)

Of note is Consent Number 201052 issued for a take of 6,000 m^3/day from the Castlerock groundwater zone. To date this consent, granted in 2002, has not been exercised as drilling investigations on the site adjacent to Castlerock-Dipton Road near Ram Hill have to date failed to identify a sufficiently high yielding aquifer either within Quaternary gravels or underlying Tertiary sediments.

As would be expected from the relatively limited level of current allocation groundwater level monitoring in unconfined aquifers since 2000 does not show any evidence of significant effects on groundwater levels as a result of abstraction.

- **Table 16 Consented groundwater abstraction from unconfined aquifers in the Oreti basin**

Consent Number	Holder	Well Number	Grid Reference	Maximum Abstraction Rate (m^3/day)	Seasonal Allocation (m^3/year)
Oreti groundwater zone					
200343	NC & N Ruygrok	E44/0038	E44:572-847	84	-
93780	Southland District Council	E44/0204	E44:546-871	2480	-
96406	Northern Southland Transport Limited	E44/0142	E44:554-809	21	-
200152	A & MC Reichmuth	E44/0223	E44:548-809	240	-
202822A	A Macdonald	n/a	E44:401-944	160	-
Castlerock groundwater zone					
201052	W McMeeken[1]	n/a	E44:520-817	6,000	900,000
202044	The Pines Dairy Farm	E44/0126	E44:528-849	160	-
Five Rivers groundwater zone					
200635	MD & DW Heenan	E44/0056	E44:427-977	126	-
99350	E & D Marsh	E44/0193	E44:412-956	20	-

[1] Consent yet to be exercised

Lumsden Aquifer

Table 17 lists current consents in the Lumsden Aquifer. At present there are 6 consents issued for a total of 47,542 m^3/day (annual allocation 4,257,650 m^3) from this aquifer with a further application pending.

- **Table 17. Consented groundwater abstraction from the Lumsden Aquifer**

Consent Number	Holder	Well Number	Grid Reference	Maximum Abstraction Rate (m^3/day)	Seasonal Allocation (m^3/year)
201912	Southland Ostrich Export Limited	E44/0225 E44/0249	E44:500-943 E44:511-940	15,000	1,237,500
202623	Ellis Road Farming Limited	E44/0251 E44/0254	E44:518-933 E44:526-928	17,280	1,426,000
202706	A & W Van Leeuwen	E44/0264	E44:499-949	2,000	195,000
202622	D Day	E44/0269	E44:499-949	8,467	699,000
202926[a]	WEG Menlove	E44/0256	E44:528-885	2,160	210,150
200853[b]	Timbertops Farm Limited	E44/0200	E44:555-840	2,635	490,000
Total				**47,542**	**4,257,650**
202786[c]	A & W Van Leeuwen	E44/0263	E44:492-900	1,820	177,450

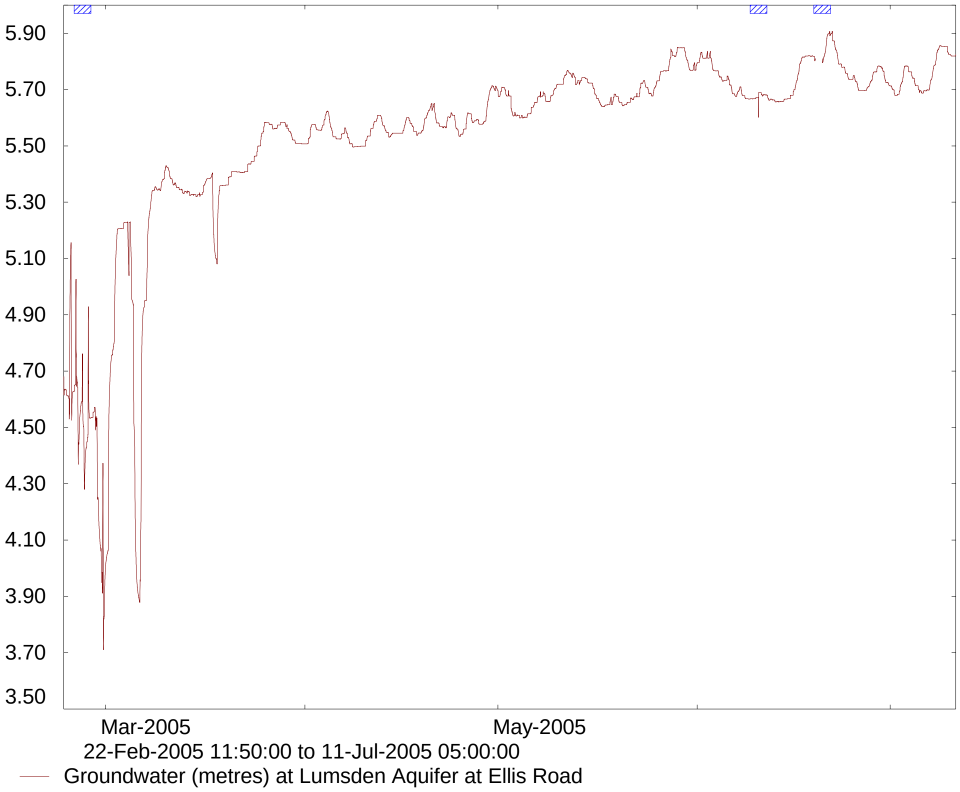
[a] Consent granted but yet to commence operation.

[b] Uncertain if source aquifer is Lumsden Aquifer.

[c] Current Application.

Figure 49 shows a plot of piezometric levels recorded in bore E44/0254 over the period February to July 2005. This monitoring bore is located approximately 300 and 800 m respectively from the production bores (E44/0225, E44/0249) for Consent No. 201912. Due to the proximity to the pumping bores the piezometric level at this site shows a relatively significant drawdown of the order of 1.5 m due abstraction during February and March 2005. However, once abstraction ceased in early march piezometric levels in the Lumsden Aquifer rapidly recovered to pre-pumping levels.

- **Figure 49. Piezometric level in the Lumsden Aquifer at E44/0254, Ellis Road, Five Rivers**



In the absence of long-term monitoring data to confirm the sustainability of abstraction from the Lumsden Aquifer recent consents 202623 and 202622 have been issued subject to a condition requiring abstraction to be reduced, and ultimately cease, if piezometric levels in E44/0254 fall below prescribed levels. Consent 202926 has a similar condition linked to levels recorded in the recently installed Environment Southland monitoring bore E44/0300. All three consents also have a condition triggering a consent review if the recovery of piezometric levels between consecutive irrigation seasons is not adequate to ensure sustainability of abstraction.

North Range Aquifer

Table 17 lists current allocation from the North Range Aquifer. At present there are 4 consents issued for a total of 21,030 m^3/day (annual allocation 2,328,750 m^3) from this aquifer with a further application pending.

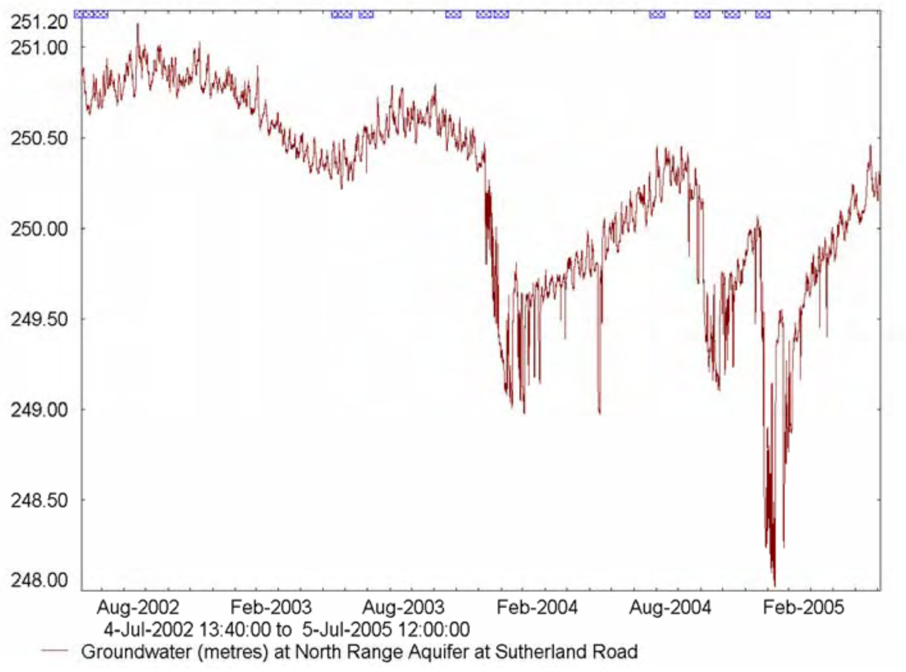
- **Table 18. Consented groundwater abstraction from the North Range Aquifer**

Consent Number	Holder	Well Number	Grid Reference	Maximum Abstraction Rate (m^3/day)	Seasonal Allocation (m^3/year)
201333	A & W van Leeuwen	E44/0186	E44:509-877	250	-
201447	RP & CM MacInnes	E44/0226	E44:440-912	5,800	870,000
202708	Kokura Holdings Ltd	E44/0258	E44:469-909	6,480	630,000
202706	A & W Van Leeuwen	E44/0265 E44/0262	E44:471-899 E44:471-890	8,500	828,750
Total				**21,030**	**2,328,750**
202786*	A & W Van Leeuwen	E44/0266 E44/0267	E44:480-887 E44:482-896	6,000	585,000

*Current Application.

Figure 50 shows a plot of piezometric levels in the North Range Aquifer measured at the Environment Southland monitoring bore (E44/0196) located near the corner of Sutherland Road and Mossburn-Lumsden Highway. The plot shows significant drawdown of aquifer levels in response to abstraction during the 2003-04 and 2004-05 irrigation seasons. This drawdown is followed by an extended period of gradual recovery throughout the following winter.

- **Figure 50 Piezometric levels in the North Range Aquifer 2002 to 2005**



In order to address the issue of aquifer sustainability the two most recent consents issued to take water from the North Range Aquifer (202708 and 202706) are issued subject to conditions specifying:

- Abstraction to be reduced to 50% of maximum if piezometric levels in the Environment Southland monitoring bore E44/0196 fall to 246 mamsl.
- Abstraction to cease if piezometric levels in E44/0196 fall to 245 mamsl.
- That the consent will be reviewed if water level recovery between successive irrigation seasons is not sufficient to ensure sustainability.

4.2 Future Allocation

Unconfined Aquifers

Current allocation from the Castlerock, Oreti and Five Rivers groundwater zones is listed in Table 19 in comparison to preliminary allocation limits for these aquifers specified in Appendix H of the Variation No. 2 (Groundwater) to the Draft Regional Freshwater Plan.

- **Table 19 Current allocation and preliminary allocation limits for unconfined aquifers in the Oreti basin**

Groundwater Zone	Current Allocation ($m^3 \times 10^6$)	Preliminary Allocation ($m^3 \times 10^6$)	Percentage of Preliminary Allocation (%)
Castlerock	0.946	6.1	15
Oreti	0.871	3.9	22
Five Rivers	0.043	13.2	0.3

This comparison shows current allocation is relatively low and at the current time applications to abstract groundwater will have restricted discretionary status under Rule 19. Under this classification, matters which Environment Southland will limit its discretion to include effects on existing users and the potential for localised and cumulative stream depletion effects. The potential for stream depletion effects being a major consideration in the Oreti and Five Rivers groundwater zones given the degree of hydraulic connection between ground and surface water evident along the riparian margins of the Oreti River and tributaries.

Lumsden Aquifer

All available geological, hydrogeological and monitoring data indicate that the Lumsden Aquifer is well-confined with a limited, indirect hydraulic connection to overlying unconfined aquifers and surface waterways. As a result, the major consideration for future allocation from this aquifer are the potential effects of abstraction on the reliability of supply for existing users and the overall sustainability of abstraction.

At the present time monitoring indicates that abstraction from the Lumsden Aquifer falls within the restricted discretionary category specified in Rule 19 of Variation No. 2 to the Proposed Regional Freshwater Plan for Southland. Under this category, defined as where abstraction reduces piezometric head in the surrounding aquifer by less than 25%, the major information requirements for resource consent applications include:

- Bore construction standards.
- Analysis of aquifer leakage.
- Interference effects.
- Radius of influence.

In conjunction with results of environmental monitoring.

To ensure ongoing sustainability of abstraction it is recommended that future allocation from the Lumsden Aquifer be considered in terms of the criteria specified in Rule 19 and issued subject to conditions specifying minimum aquifer levels and adequacy of piezometric level recovery similar to those on recent consents granted.

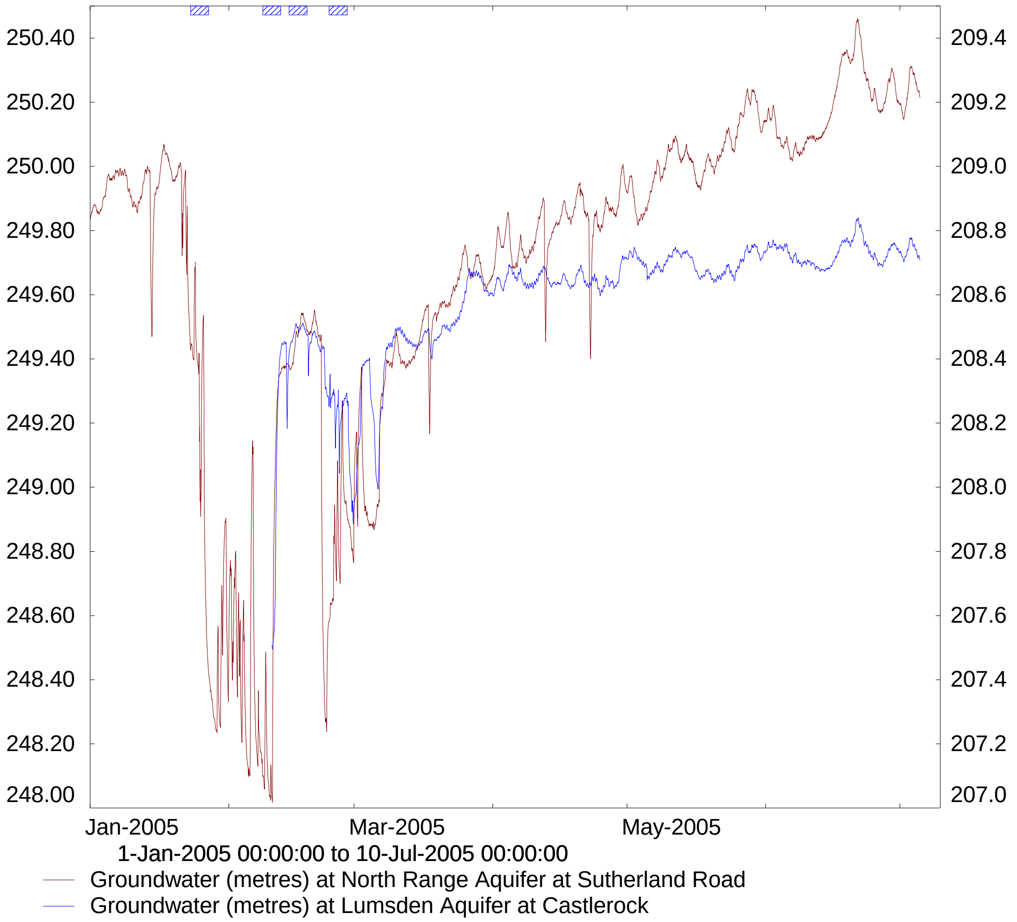
North Range Aquifer

Although demonstrating a similar degree of confinement as the Lumsden Aquifer, the potential for future allocation from the North Range Aquifer may be significantly limited by the overall sustainability of the resource.

The difference in aquifer recovery following abstraction between the North Range and Lumsden Aquifers is illustrated in Figure 51. This figure, showing data recorded over the period January to July 2005 illustrates a number of significant differences in the response to abstraction between these aquifers including:

- The magnitude of drawdown in the Lumsden Aquifer was lower for a significantly higher overall abstraction rate.
- Piezometric levels recovered rapidly in the Lumsden Aquifer to near pre-pumping levels following cessation of abstraction in mid February and early March.
- The rate of recovery in piezometric levels in the North Range Aquifer was slow, occurring over a four month period at a rate of approximately 6 mm per day.

- **Figure 51. Piezometric levels in the North Range and Lumsden Aquifers over the period January to July 2005**



Overall, piezometric levels in the North Range Aquifer in July 2005 were approximately 0.5 m lower than initially recorded during 2002 with a downward trend evident in the maximum seasonal recovery observed over the period 2002 to 2004 (shown in Figure 50). Piezometric levels in July 2005 were approximately 0.2 m higher than at the corresponding period in 2004. This may be due to abstraction ceasing approximately one month earlier in the 2004/05 season than in the pervious year.

Given the observed response in piezometric levels in the North Range Aquifer, and the fact that current consents to abstract water from this aquifer are yet to be fully exercised, there is currently insufficient information available to confirm the ability of this aquifer to sustain higher levels of allocation on an ongoing basis. As a result, it is recommended that no further allocation be granted from the North Range Aquifer until monitoring indicates that current levels of allocation are sustainable and future allocation will not adversely impact on the reliability of supply for existing users.

5. Summary

The Oreti basin is infilled with a sequence of Quaternary gravel deposits and Tertiary sediments that overlie basement rocks of the Dun Mountain-Matai and Murihiku Terranes. These sediments contain a significant groundwater resource hosted in both unconfined and confined aquifers.

Unconfined aquifers are found extensively across the Oreti basin within the upper 10 m of the Quaternary gravels that have been locally reworked by rivers and streams since the last glaciation. Two separate confined aquifers have been identified within the underlying gravel deposits. These aquifers represent alluvial gravels extensively reworked by the ancestral Oreti River. Overall, the hydrogeology of these confined aquifers appears to be significantly influenced by structural deformation of the basement rocks and consequent effects on subsurface geology and historical drainage patterns.

Until recently groundwater development in the Oreti basin was limited to relatively small-scale domestic, stock and farm supply. However, over the past two to three years a significant volume of water has been allocated for large-scale pasture irrigation, a majority of which is derived from the confined aquifers.

5.1 Unconfined Aquifers

For the purposes of resource management the unconfined aquifers in the Oreti basin have been subdivided into three groundwater zones, each describing an area of similar hydrogeological characteristics. The groundwater zones defined in the Oreti basin are:

- **Castlerock groundwater zone:** This unconfined aquifer system underlies the elevated alluvial terrace between the Oreti River and the North Range of the Hokonui Hills. The aquifer is recharged by incident rainfall and infiltration of runoff on the lower slopes of the North Range. Groundwater flows in an east-southeast direction following the topographic gradient. Groundwater discharge occurs via throughflow into the Oreti groundwater zone and discharge from a series of springs along the eastern margin.
- **Oreti groundwater zone:** The Oreti groundwater zone follows the floodplain of the Oreti River from Mossburn to Ram Hill. This riparian aquifer is recharged by flow loss from the Oreti River between Mossburn and the Irthing confluence, throughflow from the Castlerock groundwater zone as well as direct rainfall recharge. Groundwater discharge occurs via direct seepage to the Oreti River and springs that originate over the reach between Lumsden and Ram Hill.
- **Five Rivers groundwater zone:** This aquifer system extends north from the Oreti River across the Five Rivers area to the foothills of the surrounding Eyre Mountains and Mataura Range. Groundwater recharge occurs via direct rainfall infiltration as well as flow loss from tributary

streams around the basin margin. Groundwater flows in a south-easterly direction under the Five Rivers plain and is discharged via springs and direct infiltration to rivers and streams towards the confluence of the Irthing Stream and Oreti River.

Groundwater level fluctuations in unconfined aquifers in the Oreti basin are largely driven by climate with seasonal fluctuations reflecting the temporal variability of rainfall and river flow. In the Five Rivers area, significant inter-annual variations in groundwater levels reflect the relative contribution of rainfall and river recharge to groundwater storage.

In general unconfined aquifers in the Oreti basin contain groundwater of very high quality containing low concentrations of dissolved ions. Seasonal fluctuations in groundwater quality observed in the Five Rivers area reflect variations in the relative contribution of rainfall and river recharge. Elsewhere, monitoring data show some evidence of localised groundwater quality impacts resulting from land use.

5.2 Confined Aquifers

Two separate confined aquifers have been identified in the Oreti basin. Piezometric survey data indicate these aquifers are separated along an approximate boundary extending between the Castle Rock and Hillas Road. This boundary runs close to the alignment of an uplifted basement shelf that runs along the base of the North Range and an active fault trace evident in the Hillas Road area. This observation indicates that basement structure has had a significant influence on the hydrogeology of the confined aquifers due to vertical and/or horizontal displacement as well as through influence on historic drainage patterns.

Due to the high yields available, confined aquifers in the Oreti basin have been extensively developed over the past two to three years for large-scale pasture irrigation.

- **Lumsden Aquifer:** The Lumsden Aquifer has been identified as extending from Ellis Road, Five Rivers as far south as the Mossburn-Lumsden Highway. Piezometric levels in this aquifer are in excess of 25 m lower than in the overlying unconfined aquifer towards the western end of Ellis Road and show a relatively flat gradient of 0.0015 to the southeast. Investigation drilling indicates a considerable increase in the saturated thickness of the Lumsden Aquifer near the centre of the Oreti basin possibly reflecting historical alignment of the Oreti River during the last interglacial period.
- **North Range Aquifer:** The North Range Aquifer extends west of Edwards Road along the base of the North Range as far north as Hillas Road, Five Rivers. This aquifer exhibits a piezometric gradient of less than 0.001 becoming artesian between Sutherland and Edwards Roads.

Piezometric levels in both confined aquifers show seasonal variations of much smaller magnitude than observed in the overlying unconfined aquifer with no evidence of response to individual river or rainfall recharge events. This observation, combined with observed differences in relative piezometric levels and response to aquifer testing confirms the well-confined nature of both aquifers.

Hydrochemical sampling indicates recharge to the North Range Aquifer is predominantly sourced from infiltration of rainfall and / or runoff on the upper slopes of the North Range. A majority of the water in the Lumsden Aquifer appears to be derived from river recharge around the basin margins. Groundwater residence time in the Lumsden Aquifer is estimated in excess of 80 years reflecting the limited throughflow in this aquifer due to the limited hydraulic connection with the overlying unconfined aquifer.

5.3 Monitoring and Investigations

It is likely that both the quality and quantity of groundwater the groundwater resource in the Oreti Basin will come under increasing pressure due to the ongoing growth of pasture irrigation and the overall intensification of land use. As a result, it is recommended that Environment Southland establish and maintain a groundwater monitoring and investigation program in the Oreti basin that is adequate to address potential resource management issues. This program should include:

- Ongoing monitoring of groundwater quality, groundwater levels and spring discharge.
- Ongoing collation of drilling records and aquifer test results.
- Further concurrent gauging runs in the Oreti River at low to mid-stage to better quantify flow loss/gain over individual reaches.
- Concurrent gaugings of tributary streams particularly around the basin margin in the Five Rivers area.
- Synoptic groundwater quality surveys to characterise groundwater quality and identify land use impacts in the unconfined aquifer.
- Hydrochemical sampling, particularly in confined aquifers, to improve definition of recharge source(s) and groundwater residence times.

6. References

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