environment
SOUTHLAND
Te Taiao Tonga

Riversdale Groundwater Management Zone

Technical Report

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20th October 2011

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1. Executive Summary

Groundwater is one of the Southland region's most important natural resources and is used for a variety of purposes including domestic, stock, irrigation and community supply as well as playing a crucial role in sustaining stream flows, particularly during droughts and other low-flow periods. This report summarises the current state of knowledge about groundwater resources in the Riversdale groundwater management zone and assesses where future monitoring and investigation should be focused to best address emerging issues or information gaps.

The Riversdale groundwater zone is hosted in the Quaternary alluvial gravel deposits which occupy the recent floodplain of the Mataura River between Ardlussa and the Otamita Bridge in the mid-Mataura basin. The system contains an extensive groundwater resource which is utilised for domestic, farm, irrigation and industrial water supplies as well as a receiving environment for discharges associated with agricultural landuse and industrial wastes. Current allocation for consumptive groundwater use totals a maximum of approximately 80,000 m^3/day, of which over 95 percent is for the purpose of irrigation.

The aquifer system is primarily recharged from infiltration of local rainfall and flow loss from the Mataura River. Groundwater level monitoring shows the influence of the two major components of aquifer recharge with flow loss from the Mataura River providing a "base" aquifer level which modulates groundwater level variations to a one metre annual range. Rainfall recharge provides an "active" storage component which results in short-term variations in aquifer storage. Modelling results indicate the Riversdale groundwater zone has a hydraulic residence time of approximately 134 days. As river recharge to the aquifer system is relatively constant year-round, this means that storage added to the aquifer system from rainfall recharge is rapidly discharged from the aquifer system during summer. As a result, there is effectively no carry-over of groundwater storage from one winter recharge period to the following year which limits the potential for groundwater abstractions to adversely impact on long-term aquifer sustainability. However, the groundwater level monitoring data indicates that in recent years the seasonal decline in groundwater levels may be occurring more rapidly with a reduction in the seasonal minimum level which does not appear to be correlated with rainfall or river flow variability.

Piezometric contours indicate groundwater generally flows parallel to the Mataura River. Downstream of Ardlussa, data shows flow is lost from the river to the aquifer while downstream of Pyramid, the relative gradient is reserved and groundwater is discharged to the river. Groundwater is also discharged via a series of spring-fed streams in the lower portion of the groundwater zone with the total volume of aquifer discharge via these springs estimated to be in excess of 20 million cubic metres per year.

Groundwater quality monitoring results illustrate the significant influence recharge source has on groundwater chemistry and the vulnerability of aquifer discharge areas to potential impacts from overlying land use activities. In particular, areas of the aquifer which are dominated by riparian recharge show more dilute nitrate-nitrogen concentrations. Overall, groundwater quality in the Riversdale groundwater zone is generally high and is suitable for potable supply without treatment

2. Introduction

Groundwater is one of the Southland region's most important natural resources. It is estimated groundwater is the main source of drinking water to more than a third of Southland's total population (ES and TAMI, 2010) and is used for domestic purposes by more than 60 percent of rural properties (Hamill, 1998). In some areas, groundwater is the only reliable source of water suitable to meet domestic, stock, irrigation and community needs. Groundwater also plays a crucial role in sustaining stream flows, particularly during droughts and other low-flow periods.

In response to increasing pressure on groundwater resources, Environment Southland formally began a state of the environment (SOE) groundwater monitoring programme in 2000. The purpose of the program was to provide a regional perspective to:

- quantify the current state of the groundwater resources;
- identify trends in the ambient condition of groundwater resources;
- determine the cumulative effect of pressures including those from human activities;
- provide a basis for assessing environmental effects;
- identify resource management issues; and
- assist in monitoring the effectiveness of regional plans.

In addition to the long-term SOE monitoring program, Environment Southland also developed a groundwater investigations programme designed to improve definition of the hydrogeological characteristics of the regions aquifer systems to enable the effective and sustainable management of quantity and quality of the groundwater resource. Applications of this work include the establishment of sustainable allocation limits, improved understanding of the inter-relationship between groundwater and surface water resources and characterisation of potential linkages between land use change and impacts on groundwater quality. As a result of these programmes, knowledge and understanding of Southland's groundwater resources has increased considerably over the past ten years, particularly in those areas which have experienced higher levels of resource development.

In order to assist resource management of the region's groundwater resources, Southland was divided into 29 groundwater management zones in 2003. These zones were an integral part of a groundwater variation to the Proposed Regional Freshwater Plan (as it was then called) in 2004. Due to the limited information available at the time to describe the nature and extent of various aquifer systems, especially those in Tertiary period and basement deposits, the groundwater management zones were delineated on the basis of topographic gradient, geology, geomorphology, observed groundwater quality, groundwater level fluctuations and resource development (Hughes, 2003a). As a result, they are generally only relevant for unconfined aquifer systems. The groundwater zones were then further classified according to aquifer type based on the hydraulic properties and recharge/discharge characteristics and this formed the basis of the groundwater allocation framework which is used in the Regional Water Plan for Southland, 2010 (RWPS).

The basic premise of the management framework was the concept of adaptive management whereby the level of information and assessment required to support an individual resource consent application escalate as the level of groundwater use increases. As a consequence, the groundwater framework does not establish definitive allocation limits, rather it recognises that the establishment of limits will, in a practical sense, only be determined through an iterative process involving further investigations, monitoring and resource development. The overall philosophy being to establish a management framework which enables information derived from progressive resource development to inform the resource consent decision-making process as a groundwater resource is progressively developed.

2.1 Objectives

The purpose of this report is to document the current state of knowledge of the groundwater resource in the Riversdale groundwater management zone and to assess where future monitoring and investigation should be focused to best address emerging issues or information gaps.

It is intended that over time similar technical reports will be produced for all of Southland's groundwater management zones and that these reports will be updated periodically as understanding of groundwater resources grows. It is intended that the information contained within these reports will provide a point of reference to assist the effective and sustainable management of groundwater resources in Southland.

2.2 Geology

The geology of the mid-Mataura basin has been described in detail in many previous reports (e.g. Isaac and Lindqvist, 1990; Williamson, 2005; Gyopari, 2007 and Wilson, 2010a). The following provides a brief summary of current understanding of the geological setting. The surficial spatial distribution of the geological units described are illustrated in Figure 1.

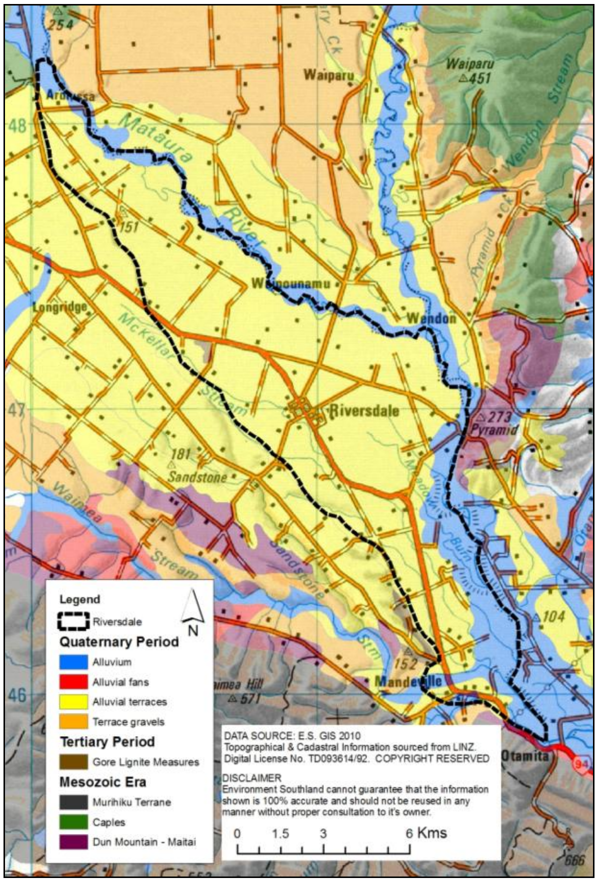

Figure 1: Map of the surface geology of the Riversdale area
[source: Turnbull and Alibone, 2003]

The geological setting of the mid-Mataura catchment presents a relatively complex assemblage of at least three distinct geological terranes (Caples, Dun Mountain - Matai and Murihiku) that were laterally displaced along large fault systems during the Mesozoic period. This displacement formed large structural features such as the Southland Syncline (also termed the Murihiku escarpment) which dominate the local landscape and can be traced from Nugget Point on the east coast through to the North Range near Mossburn.

During the Tertiary period relative sea levels were significantly higher than at present resulting in the deposition of marginal marine and marine sediments across much of the lower-lying areas of what is now the Southland region. The predominantly sandstone and mudstone sediments of the Tertiary aged East Southland Group underlie large areas of Southland including the Waimea Plains from Gore through to Mossburn.

Extensive Quaternary gravel deposits overly Tertiary and Mesozoic basement rocks across the Waimea Plains and in the upper and mid Mataura basins. These deposits were formed during successive Quaternary glaciations when the ancestral Mataura River (including for a time the present-day upper Oreti catchment) deposited an extensive glacial outwash gravel sequence across the respective inter-montaine basins. River entrenchment over the subsequent interglacial period formed the broad river valley containing a sequence of progressively older alluvial terraces along the valley margins evident today, as illustrated in Figure 2.

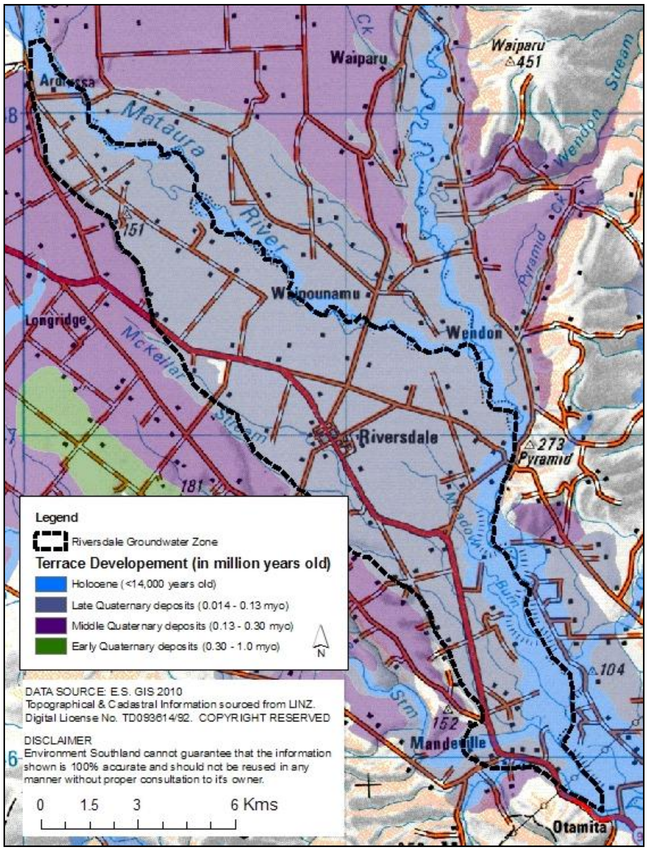

Figure 2: Map of the terrace sediments ages for the Riversdale area
[source: Turnbull and Alibone, 2003]

In summary, the subsurface geology of the Riversdale groundwater zone consists of a sequence of heterogeneous alluvial gravels associated with a moderate to large braided river. The gravel deposits are comprised of moderately to poorly sorted gravel, claybound gravel, sand and silt which extends to a depth of up to 30 metres below ground to the west of Riversdale thinning to less than 10 metres thick towards Mandeville. Tertiary sediments of the East Southland Group comprising of mudstone, sandstone and lignite underlie the gravel deposits to an unknown depth.

2.3 Aquifer Extent

The Riversdale groundwater zone is a riparian aquifer system which underlies the recent floodplain on the true right bank of the Mataura River between Ardlussa and the Otamita Bridge. The Riversdale groundwater zone is bounded to the north and east by the Mataura River which forms a hydraulic divide with the Waipounamu and Knapdale groundwater zones that occupy the Mataura floodplain on the true left bank. The western boundary follows the prominent alluvial terrace which separates the Riversdale groundwater zone from the elevated alluvial terrace which forms the Waimea Plains groundwater zone.

The up-stream Cattle Flat groundwater zone is separated from the Riversdale groundwater zone by channelling of the Matura River between two basement outcrops (assumed to be Caples Terrane) immediately upstream of Ardlussa.

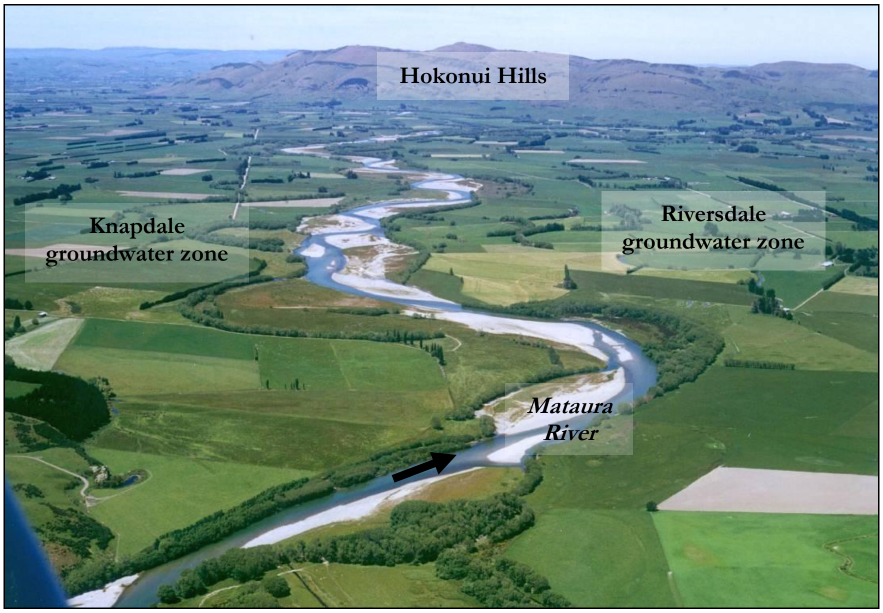

Figure 3: Aerial photograph of the lower portion of the Riversdale groundwater zone looking south towards the Hokonui Hills
[Source: L McGraw, date taken unknown]

2.4 Soils

Figure 4 shows the distribution of the major soil types in the Riversdale groundwater zone based on data collected for the Topoclimate South soil survey. Gore and Ardlussa (brown) and Mataura and Riversdale (recent) soils are the dominant soil types covering over 95 percent of the land area.

Gore and Ardlussa soils are typically well drained with good plant rooting depth although the subsoils are commonly very to extremely gravelly. Mataura and Riversdale soils are shallow, free-draining soils which are occasionally flooded. The versatility of the soils in the Riversdale groundwater zone are limited by their stoniness which increases their susceptibility to drought due to their rapid drainage characteristics and low water holding capacity. As a result, irrigation can be required to offset soil water deficits in order to enable intensive farming in the area.

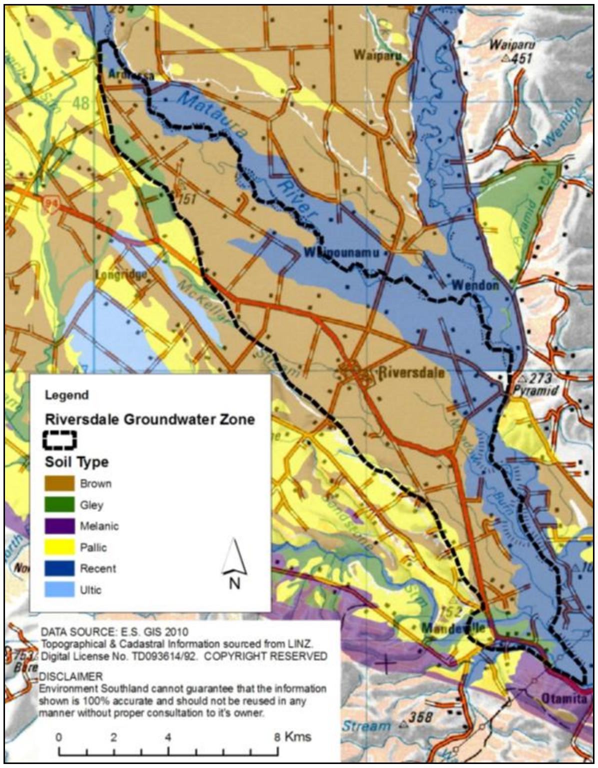

Figure 4: Map of the soils of the Riversdale groundwater zone

2.5 Hydrogeology

Groundwater is found pervasively throughout the glacial outwash and alluvial gravel deposits that mantle the Waimea Plains and Upper Mataura Valley. These sediments host a series of unconfined and, in places, deeper semi-confined/confined aquifers. The spatial extent of these aquifer systems reflects the geology and geomorphology of the gravel deposits. A limited groundwater resource also occurs in coarser-grained gravel and sand layers within the Tertiary East Southland Group sediments and in areas where bedrock of the Murihiku and Caples Terranes have sufficient secondary permeability due to jointing and fracturing within the rock mass. A diagram of the conceptual hydrogeology of the Riversdale groundwater zone is summarised in Figure 5.

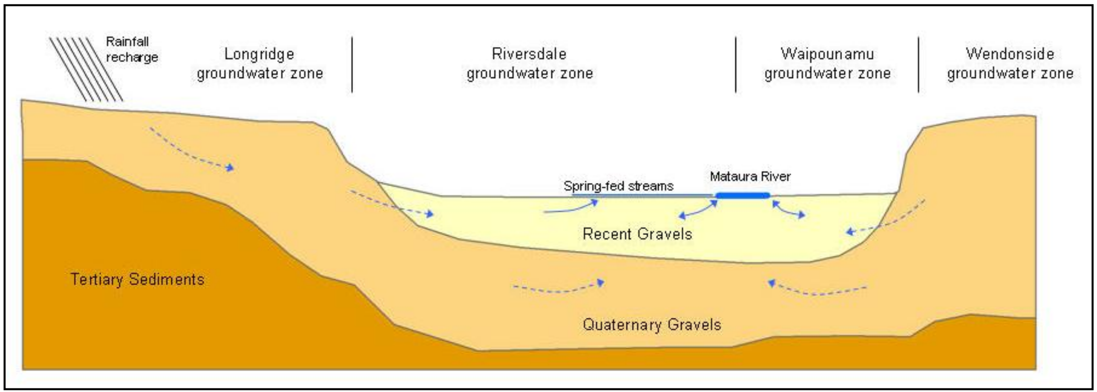

Figure 5: Schematic cross-section of the Riversdale groundwater zone

The Riversdale groundwater zone is classified as a riparian aquifer (ES, 2010). This aquifer type primarily occurs in the recent Quaternary deposits that form alluvial floodplains. As shown in Figure 6, riparian aquifers are in direct hydraulic connection with major surface water ways. Commonly flow is lost from the river to the aquifer system near the upstream margin and returns to the river in the downstream section either via direct infiltration to the river channel and/or spring-fed stream discharge. Riparian aquifers are typically narrow and elongate following the river channel and are bounded by either basement lithology or higher, less permeable alluvial terraces.

The Riversdale groundwater zone consists of a shallow unconfined riparian aquifer which exhibits significant hydraulic connection with the Mataura River and local spring-fed streams. The water table generally occurs at shallow depths (less than 4 metres below ground) across much of the Riversdale groundwater zone and exhibits limited seasonal variation reflecting the permeability of the alluvial gravel materials as well as the nature and extent of the hydraulic connection to surface water which essentially provides a constant head for the aquifer system.

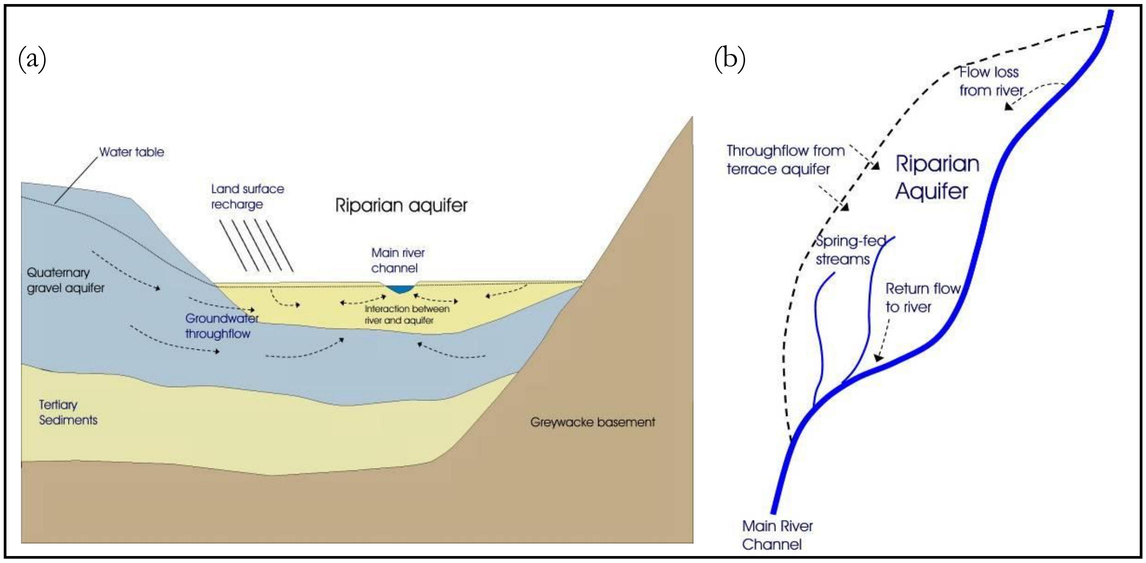

Figure 6: Schematic representation of a (a) cross-section and (b) plan view of a riparian aquifer system

In addition to flow loss from rivers, riparian aquifers also receive recharge from direct rainfall infiltration and well as throughflow from terrace aquifers located along the valley margins. Due to their high permeability and interconnection with surface water, riparian aquifers are typically high yielding.

Aquifer pump tests are used to determine an aquifer's basic hydraulic parameters and are a standard information requirement in applications for large-scale groundwater takes in Southland. To date, about twelve aquifer pump tests of varying size and quality have been undertaken in the Riversdale groundwater zone. In order to improve spatial resolution, specific capacities have also been used to roughly estimate transmissivity values for other areas of the aquifer. This data is summarised in Figure 7. The results generally show relatively high aquifer transmissivity in the order of 1,000 to 5,000 m^2/day. However, aquifer test results do exhibit some variability which is interpreted, in part, to reflect the overall heterogeneity of the alluvial gravel materials. In general, aquifer transmissivity increases with proximity to the Mataura River which is assumed to reflect depositional processes with greater reworking and fine sediment removal in central areas of the Mataura floodplain which have been occupied by river channel for the longest duration.

In summary, the alluvial gravel materials hosting the unconfined aquifer are highly permeable and aquifer yields are more than sufficient for domestic, stock and dairy-shed scale water takes and most areas of the aquifer are able to support larger-scale abstraction for industry, irrigation and community supply.

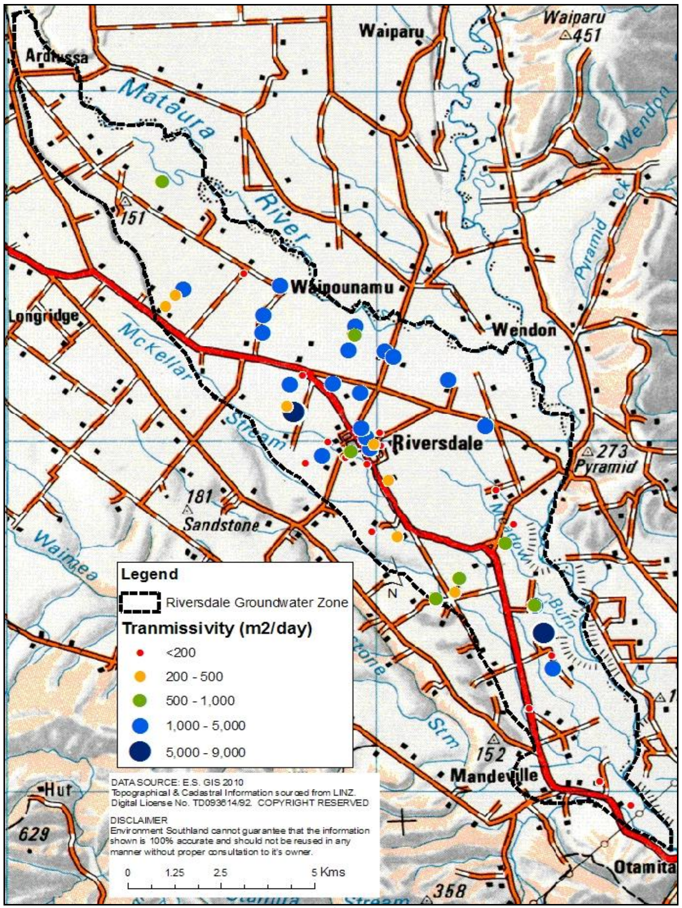

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Figure 7: Map of transmissivity estimates[1] for the Riversdale groundwater zone

2.6 Groundwater Hydrology

There have been several piezometric (or water table) surveys of the Riversdale groundwater zone however the most comprehensive survey was undertaken by Environment Southland between the 18th to 25th March 2004 and covered the area from Cattle Flat to Gore. The results from the Riversdale area, illustrated in Figure 8, show the general groundwater flow direction is roughly parallel to the Mataura River channel. Downstream of Ardlussa piezometric contours reflect flow loss from the river to the Riversdale groundwater zone,

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[1] Transmissivity values determined from aquifer pump test analysis and calculated from specific capacity values (using Driscoll, 1986).

while downstream of Pyramid the relative gradient is reversed and contours indicate groundwater discharge to the river. The piezometric contours also illustrate throughflow of groundwater from the Longridge groundwater zone along the alluvial terrace which forms the boundary with the Riversdale groundwater zone however this is considered to constitute a minor part of the overall water balance (Wilson, 2008 and Williamson, 2005).

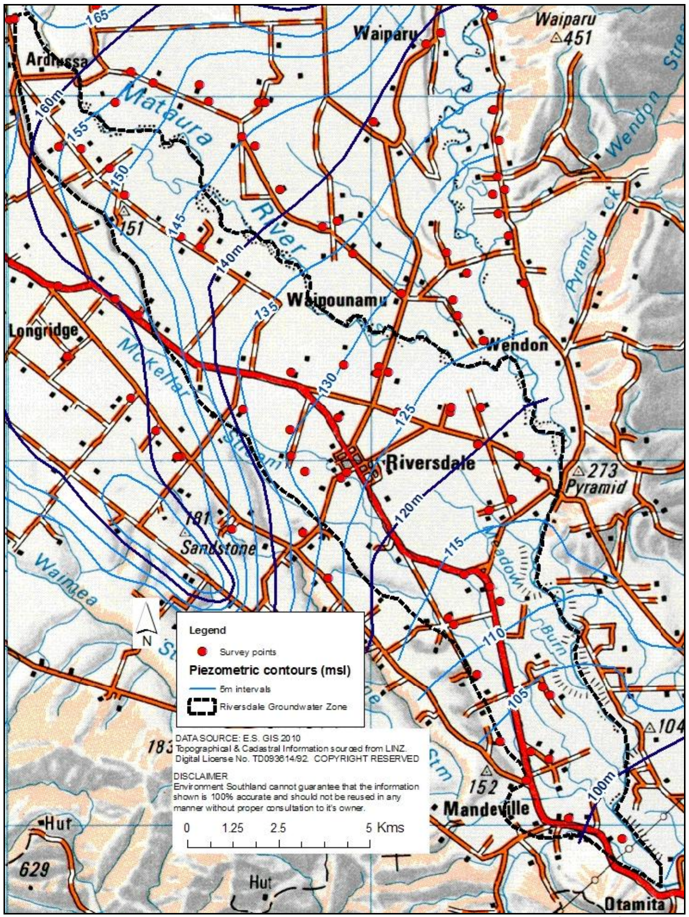

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Figure 8: Map of piezometric surveying results for March 2004[2]

Assuming an average saturated thickness of 15 metres (estimated from bore log and groundwater level monitoring data), an average aquifer transmissivity of 2,000 m^2/day (based on data shown in Figure 7), an interpolated hydraulic gradient of 0.0028 (based on data shown in Figure 8) and an assumed porosity of 0.2, the average bulk seepage velocity through the aquifer was calculated using Darcy's Law at 1.87 metres per day or approximately 700 metres per year. This is a relatively rapid bulk flow rate and is consistent with estimates for other aquifers in Southland. For example, the bulk groundwater seepage velocity for the Balfour area has been calculated at 480 metres per year (Wilson, 2010b) and 700 metres per year for the Edendale aquifer (Wilson, 2010c). It is important to remember estimates of bulk aquifer flow rate are indicative only and do not necessarily reflect the flow rate at all points in a given aquifer system which may exhibit considerable variability due to geological heterogeneity.

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[2] Contours were mapped using a regularised spline method in ArcGIS (ESRI software)

2.7 Recharge and Discharge

The Riversdale groundwater zone is a riparian aquifer and is recharged via a combination of seepage losses from the Mataura River, land surface recharge (predominately as a result of rainfall infiltration) and throughflow from aquifers underlying the Waimea Plains. In response to large-scale irrigation, an unknown component of irrigation drainage will also contribute to the aquifer water budget.

Concurrent gauging data show the Mataura River loses a significant proportion of flow to groundwater recharge between Ardlussa and the Riversdale-Waikaia Road Bridge during summer low flows. Measured flow losses across this reach are generally in the range of 1.2 to 2.0 m^3/s (104,000 to 173,000 m^3/day). However the observed flow losses across the upstream section of the Riversdale groundwater zone are poorly correlated with river discharge which suggests river recharge to the aquifer is relatively constant. As a result, it is inferred that the Mataura River provides a relatively constant volume of 'base' recharge to the Riversdale groundwater zone which, at least away from the margins of the Mataura River, is relatively insensitive to variations in river flow. Overall, the Mataura River constitutes a major recharge source for the Riversdale groundwater zone. Modelling results indicate river losses constitute between 55 to 65 percent of the average annual recharge to the Riversdale groundwater zone (Morgan and Evans, 2003 and Gyopari, 2007).

A significant proportion of the remaining recharge to the Riversdale groundwater zone is derived from land surface recharge which occurs predominately as direct rainfall infiltration. Various estimates of rainfall recharge from soil drainage modelling exercises indicate that between 23 to 33 percent of the mean annual rainfall recharges the aquifer (see Table 1). The highest estimate (i.e. Morgan and Evans, 2003) has been used to establish aquifer allocation thresholds in the RWPS.

Table 1: Estimates of rainfall recharge to the Riversdale groundwater zone

Reference	Model	Rainfall Recharge (mm/year)	% of Mean Annual Rainfall
Morgan and Evans (2003)	LEL Irrigation Model	281	33%
Williamson (2005)	SMWBM	192	23%
Gyopari (2007)	Rushton	201 - 227	25 - 28%
Average:		**229**	**28%**

Groundwater is discharged from the Riversdale groundwater zone via a combination of direct seepage into the bed of the Mataura River downstream of the Riversdale Bridge and a series of spring-fed streams which originate across the downstream section of the aquifer system.

Concurrent gauging data shows that the Mataura River gains flow over the reach between the Riversdale Bridge and the Otamita Bridge in excess of tributary inputs and is interpreted to reflect groundwater seepage into the river channel. The observed flow gains are approximately 25 percent higher than the observed flow losses from the Mataura River in the upstream reach between Ardlussa and the Riversdale Bridge. This demonstrates the gradual discharge of aquifer storage to the river system which is reflected in the gradual recession of groundwater levels observed during the summer months.

Recent modelling by Bidwell (2009) suggests the Riversdale groundwater zone has a hydraulic residence time[3] of approximately 134 days. As river recharge to the aquifer system is relatively constant year-round, this means that storage added to the aquifer system from rainfall recharge is rapidly discharged from the aquifer system during summer. As a result, there is effectively no carry-over of groundwater storage from one winter recharge period to the following year.

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[3] Residence time describes an exponential decay function which describes the time required for 69% of groundwater storage to discharge from the groundwater system, assuming there is no further recharge.

3. Groundwater Quantity

Regular monitoring of groundwater levels and spring discharge began in the Riversdale groundwater zone in 2000 when Environment Southland established its groundwater SOE monitoring program.

3.1 Groundwater Levels

Environment Southland has been monitoring groundwater levels in the Riversdale groundwater zone on a monthly basis since September 2000. In December 2002, a reference monitoring site was installed at Liverpool Street on the northeast boundary of the Riversdale township. The site installation included instrumentation to automatically record rainfall, soil moisture and groundwater levels as shown in Figure 9. Data from this site is telemetered to Environment Southland on an hourly basis and is immediately available on our website.

Figure 9: Photograph of the Riversdale monitoring site at Liverpool Street
[Source: K Wilson, 25th February 2003]

Due to irresolvable onsite issues, the soil moisture probe was shifted to York Road (approximately 600 metres southeast) in July 2008. In October 2010, a climate monitoring station was also installed at the York Road site to enable real-time monitoring of potential evapotranspiration (PET).

Currently, Environment Southland regularly monitors eleven bores in the Riversdale groundwater zone; one bore is dipped quarterly, six are dipped monthly and four are monitored continuously using dataloggers. The locations of the groundwater level monitoring sites are shown in Figure 10.

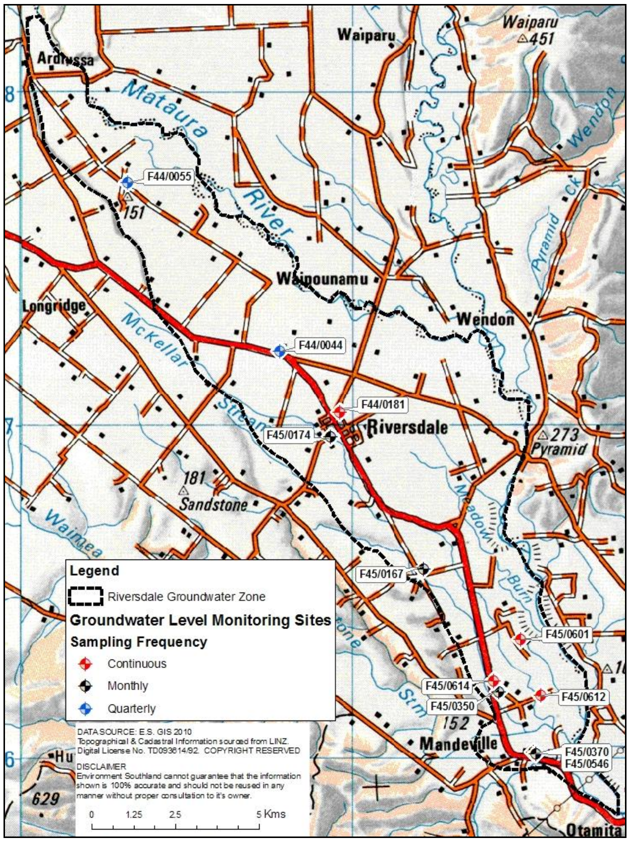

Figure 10: Environment Southland groundwater level monitoring sites in the Riversdale groundwater zone

The reference groundwater level monitoring site (F44/0181) was situated to provide a representative record of groundwater levels at a central point in the aquifer system close to the point where the hydraulic gradient changes away from the Mataura River across the upstream reach to back towards the river downstream of Pyramid. There is a good correlation between groundwater levels in the Liverpool Street bore (F44/0181) and other manual groundwater level monitoring sites elsewhere in the Riversdale groundwater zone which indicate this site is not significantly impacted by drawdown from localised pumping.

Following discussions with the Riversdale Water Users Group and in response to growing concern regarding spring flows, it was identified that a second reference site would be desirable for the Riversdale groundwater zone. In order to improve correlation with spring discharge in the downstream extent of the aquifer and in order to better understand changes in hydraulic gradients across the aquifer in response to pumping regimes, an unused bore in the lower aquifer extent was identified as being potentially suitable (F45/0601). Unfortunately monitoring data from this bore shows groundwater levels are affected by localised pumping from both irrigation and dairy supplies so in June 2011, Environment Southland drilled two new bores (F45/0612 and F45/0614) in order to establish a second reference site. Once some data overlap has been established between the new bores and existing monitoring sites, one of the new bores will be selected as the second reference site.

A summary of the groundwater level monitoring data is summarised in Appendix 1 and shown in Figure 11.

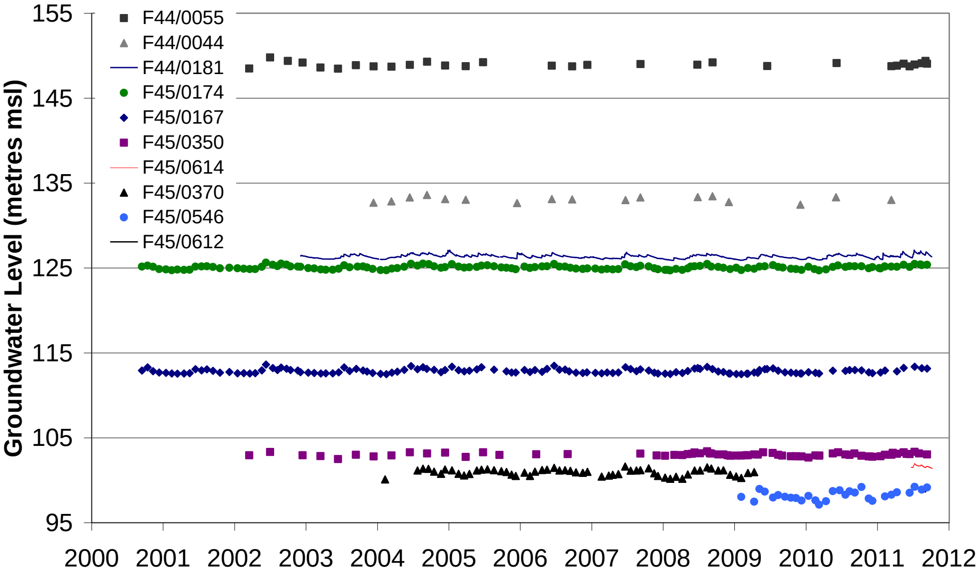

Figure 11: Groundwater level monitoring data from the Riversdale groundwater zone

Riparian aquifers are by definition hydraulically connected to surface water bodies. This relationship, which allows water to flow into or out of the aquifer system depending on the relative head difference, acts to modulate groundwater level variations. Figure 12 shows that although groundwater variability is small, there is a decreasing trend in the mean annual groundwater level between 2005 to 2009 which is interpreted to reflect lower than normal rainfall over the same time period.

The Mataura River effectively provides a constant head boundary recharging the aquifer so it is unlikely groundwater abstraction will adversely affect long-term aquifer storage volumes.

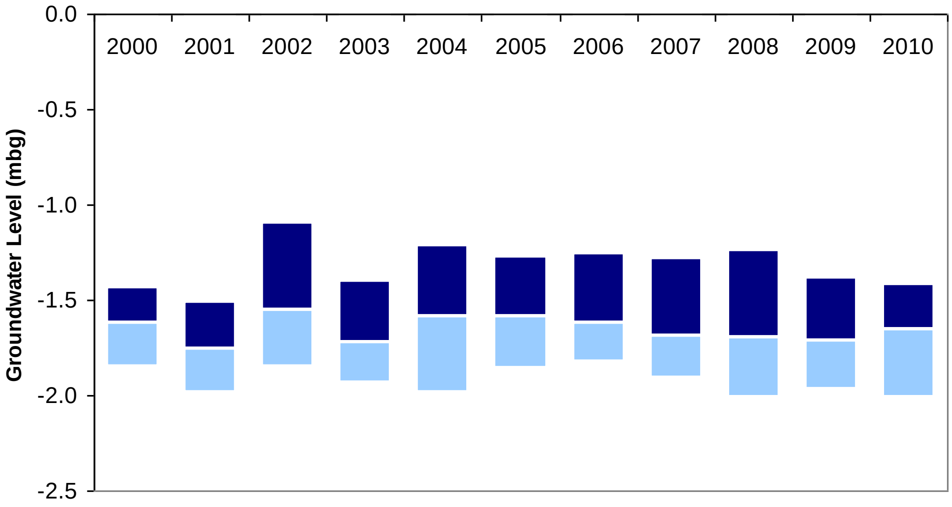

Figure 12: Annual minimum, average and maximum groundwater level for monitoring bore F45/0174 (York Road, Riversdale)

Measured flow losses across the upstream section of the Riversdale groundwater zone (between Ardlussa and the Riversdale – Waikaia Road Bridge) are poorly correlated with river discharge which suggests that river recharge to the aquifer is relatively constant[4]. The Mataura River therefore appears to provide a relatively constant volume of 'base' recharge to the aquifer which, at least away from the margins of the Mataura River, is relatively insensitive to variations in river flow. As a result, groundwater level variations tend to match rainfall events rather than river flow despite the fact that overall, the Mataura River constitutes a major recharge source for the Riversdale groundwater zone.

Concurrent gauging data shows that Mataura River gains flow over the reach between the Riversdale Bridge and Otamita in excess of tributary inputs, as illustrated in Figure 13. The observed flow gains are approximately 25 percent higher than the observed flow losses from the Mataura River in the upstream reach between Ardlussa and the Riversdale Bridge and are interpreted to reflect groundwater seepage into the river channel. This demonstrates the gradual discharge of aquifer storage to the river system which is reflected in the gradual recession of groundwater levels observed during the summer months.

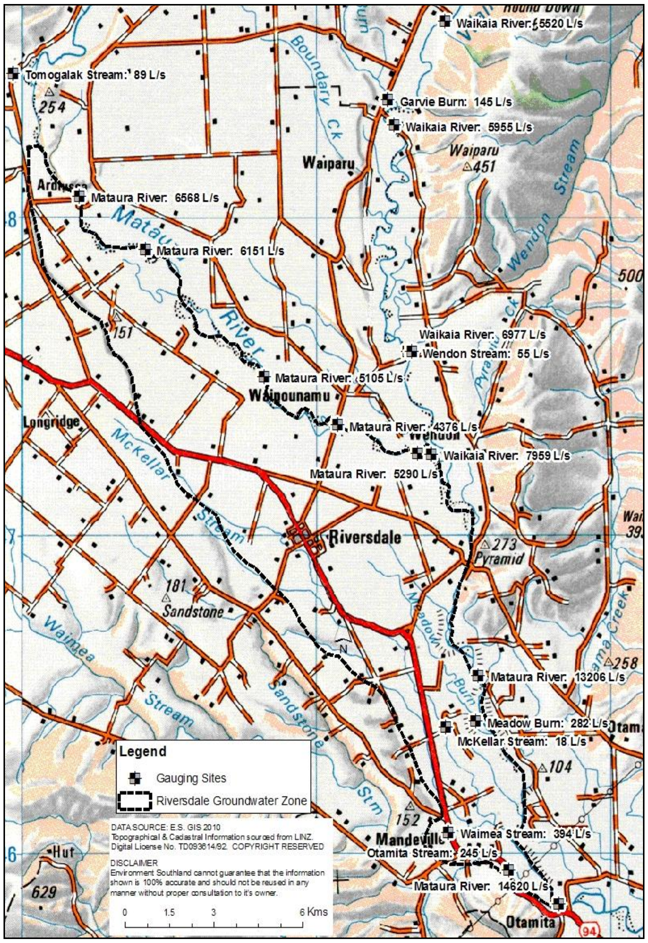

Figure 13: Map of 20th February 2007 concurrent gauging results for the mid-Mataura[5]

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[4] It is acknowledged river recharge may be affected by high stage events, particularly in terms of bank storage.

[5] Note: Mataura River at Gore flow was 16,375 l/s. Gore has a 7-day mean annual low flow of 17,572 l/s.

Based on this observed relationship groundwater levels in the Riversdale groundwater zone can be considered as being influenced by two separate components:

- Relatively constant *base level* recharge from the Mataura River, and
- An *active storage* component from rainfall recharge

Prior to large-scale groundwater development groundwater levels generally receded relatively quickly during late winter and spring before levelling off in late summer and autumn. This pattern, also characteristic of riparian aquifers elsewhere in Southland, is interpreted to reflect the progressive drainage of winter rainfall recharge during late spring with the slower rate of groundwater level decline reflecting groundwater levels equilibrating with the relatively constant river recharge.

However, in recent years, groundwater level monitoring data from F44/0181 indicate that the seasonal decline in groundwater levels may have occurred more rapidly with an on going reduction in the seasonal minimum (see Figure 14). This observed change in the groundwater hydrograph is interpreted to reflect the effects of increased groundwater abstraction over the corresponding period as it does not appear to be correlated with rainfall or river flow variability. Due to the relatively high permeability of the aquifer system a similar pattern is also observed in the manual dipping sites elsewhere in the Riversdale groundwater zone.

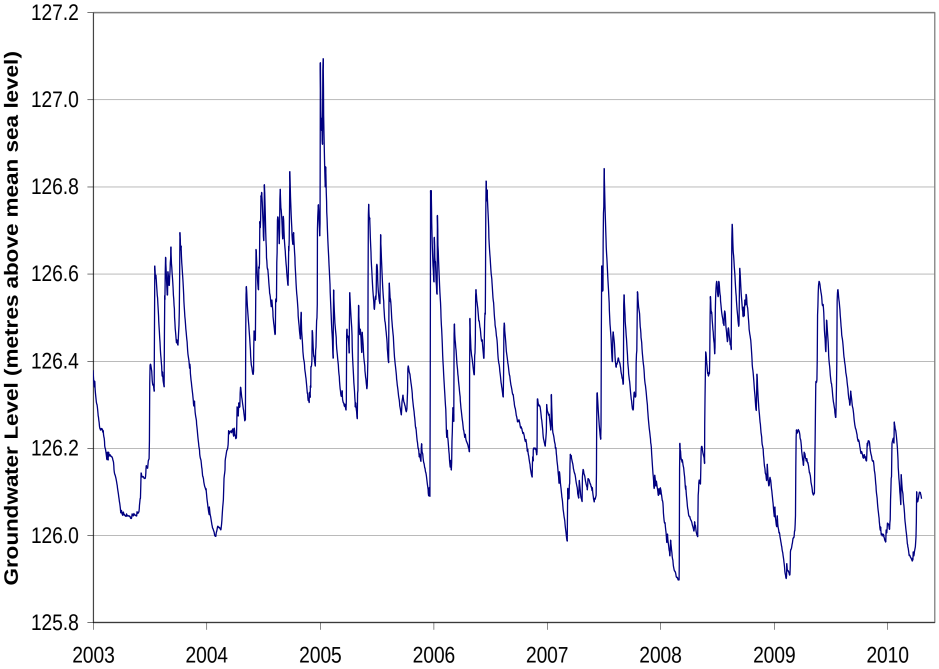

Figure 14: Time-series data from monitoring bore F44/0181

The complex inter-relationship between the relatively constant recharge/discharge to and from the Mataura River and episodic rainfall recharge events which result in short-term variation in aquifer storage means that it is difficult to detect the influence of long-term rainfall patterns on groundwater levels, as shown in Figure 15.

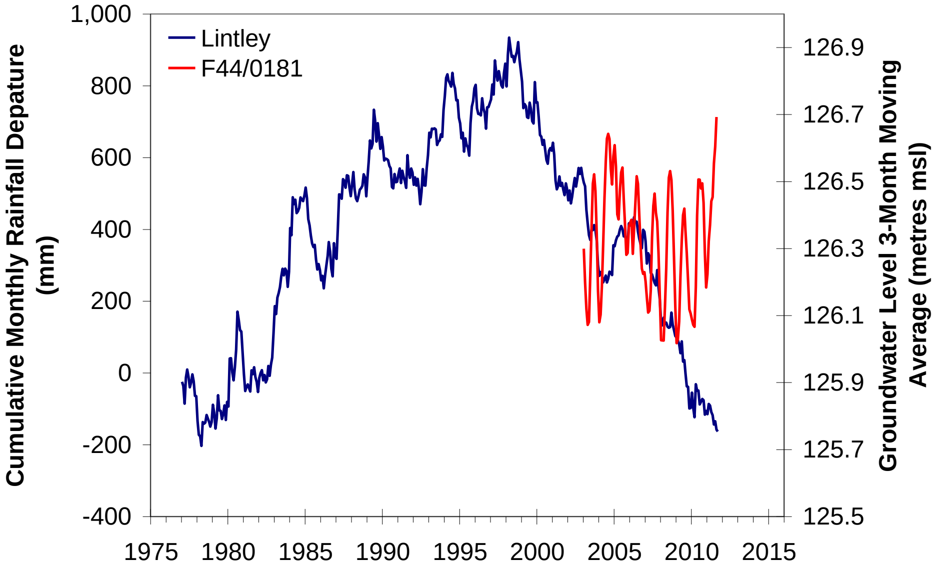

Figure 15: Long-term rainfall patterns and groundwater level trends for Riversdale

3.2 Spring Discharge Monitoring

A number of spring-fed streams flow across the Riversdale groundwater zone before discharging into either the Mataura River or Waimea Stream near Mandeville. Regular flow gaugings have been undertaken on six spring-fed streams in the Riversdale groundwater zone since 2001.

3.2.1 Meadow Burn

The Meadow Burn is the largest of several spring-fed streams that drain the downstream section of the Riversdale groundwater zone and originates northeast of the Riversdale township in an area where the land surface and water table intersect (i.e. the Meadow Burn is a depression spring). It flows in an east-southeasterly direction across the Mataura River floodplain for approximately 11 kilometers before entering the Mataura River about 6.5 kilometers downstream of Pyramid.

The total discharge from all spring-fed streams in the Riversdale groundwater zone has been measured twice; 716 l/s on the 17th January 2003 and 570 l/s on the 10th March 2010 for a groundwater level in bore F44/0181 of 126.270 and 125.960 metres above mean sea level respectively. Discharge in the Meadow Burn accounted for approximately 50 to 65 percent of the total spring discharge on these occasions. The Meadow Burn is therefore used as a reference spring for groundwater discharge from the Riversdale groundwater zone because it contains the largest component of total spring discharge, it is the most suitable for flow gauging and it is representative of the relationship between discharge in the spring-fed streams and surrounding groundwater levels.

Figure 16: Photograph of the Meadow Burn 500 metres downstream of Fingerpost Pyramid Road with in-stream piezometer
[source: K Wilson, 21st June 2006]

The Meadow Burn has been regularly gauged since 2001. Efforts to establish a rated flow site in three separate locations in the lower reaches have been unsuccessful due to the impact of extensive macrophyte growth on the stage/discharge relationship. The lower reaches of the Meadow Burn may also be influenced by high levels in the Mataura River which can inhibit discharge into the Mataura River.

Discharge in the Meadow Burn increases down its length due to drainage of the surrounding aquifer. Flow gauging results show the median gauged flow increases from approximately 30 litres per second (l/s) in the headwaters at York Road to 200 l/s at Fingerpost-Pyramid Road and 610 l/s at Round Hill Road (immediately above the Mataura River confluence), as summarised in Table 2. The gauging results indicate greater groundwater inflow per unit length in the lower reaches of the Meadow Burn which likely reflects the increased hydraulic gradient in downstream section of the Riversdale groundwater zone.

Table 2: Flow statistics from spot gaugings of the Meadow Burn

Site	Record Period	Number of Gaugings	Min Gauged Flow (l/s)	Mean Gauged Flow (l/s)	Median Gauged Flow (l/s)	Max Gauged Flow (l/s)	Linear Regression[1] (r^2)	SEE[2] (l/s)
York Road	2006 - 2010	40	6	37	30	98	0.7867	11
Fingerpost Pyramid Rd	2001 – 2009	57	89	238	199	588	0.7808	54
Stock Bridge	2004 - 2010	35	111	244	244	432	0.8340	36
Round Hill Road	2003 – 2010	64	206	625	610	1,216	0.8736	97

[1] Linear regression between flow and groundwater levels in F44/0181. The co-efficient of determination (r^2) is an estimate of the "goodness of fit" of the regression. It measures the exact percentage of variation shared by two variables.

[2] Standard error of the estimate (SEE) is a measure of the accuracy of the predictions. It measures the dispersion of the actual Y values about the regression line.

Flows measured in the Meadow Burn show a relatively good correlation with the Liverpool Street monitoring site (F44/0181). This relationship, shown in Figure 17, suggests that discharge in the Meadow Burn is sensitive to relatively small changes in groundwater level. For example, the observed correlation at Round Hill Road suggests a decline in discharge of approximately 250 l/s in the lower reaches of the Meadow Burn for a groundwater level decline of 0.2 metres at F44/0181.

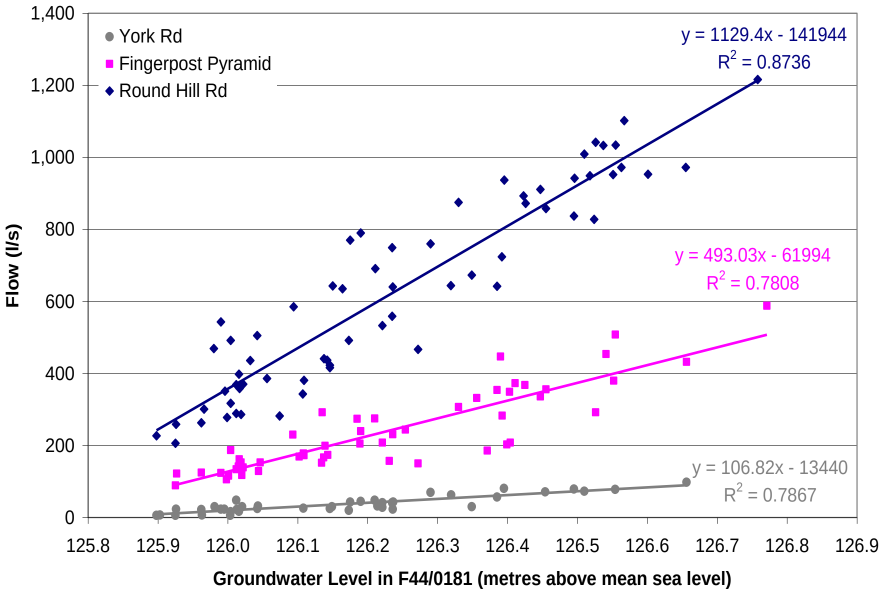

Figure 17: Scatter-plot of groundwater levels in F44/0181 and discharge in the Meadow Burn

The Meadow Burn is ecologically significant. It supports populations of two threatened fish species – the longfin eel and Gollum galaxias (Allibone, 2010) in addition to providing a refugee for adult brown trout during times of high flow in the Mataura River (Ledington, 2010). During a recent Environment Court case[6], ecologists agreed aquatic life in the Meadow Burn is stressed for a variety of reasons including impacts from landuse and abstractions. As a result, Environment Southland is currently in the process of developing ecological minimum flows for the Meadow Burn (for example Young and Hay, 2011) in order to protect all critical species in the stream.

3.2.2 McKellar Stream

The McKellar Stream is sourced from a series of contact springs which originate at the base of the Longridge terrace west of Dunn and Cody Road. The main branch of the McKellar Stream flows for approximately 15 kilometres across the floodplain before discharging into the Waimea Stream near its confluence with the Mataura River.

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[6] Environment Court case: South Otago Holdings Limited v Environment Southland (ENV 2009 – CH 102)

Figure 18: Photograph of the McKellar Stream at Dunn and Cody Road
[source: D Elliotte, 21st September 2006]

Gauging data collected between 2006 and 2009 show a relatively constant discharge of 25 to 35 l/s at the base of the Longridge terrace in the headwaters of McKellar Stream (at O'Conner Road). During dry periods, gauging results show the reach between O'Conner Road and the Riversdale township (at Nine Mile Road) loses up to 85 percent of the flow to the underlying aquifer. During dry periods, flow downstream of the Riversdale township to the Waimea Stream confluence remains relatively constant indicating limited interaction with the underlying aquifer.

Field measurements using in-stream piezometers confirm the McKellar Stream is perched above the underlying aquifer upstream of the Riversdale township. These measurements show spring discharge is unrelated to groundwater levels in the underlying aquifer (shown in Table 3).

Table 3: Flow statistics from spot gaugings of the McKellar Stream

Site	Record Period	Number of Gaugings	Min Gauged Flow (l/s)	Mean Gauged Flow (l/s)	Median Gauged Flow (l/s)	Max Gauged Flow (l/s)	Linear Regression[1] (r^2)	SEE[2] (l/s)
O'Conner Road	2006 – 2009	9	24	31	31	39	0.0289	5
Dunn and Cody Road	2001 – 2008	11	24	38	34	68	0.2487	13
Nine Mile Road	2004 – 2009	14	3	23	18	65	0.7665	10
Fortune Road	2003 - 2009	15	13	33	25	83	0.5082	14

[1] Linear regression between flow and groundwater levels in F44/0181. The co-efficient of determination (r^2) is an estimate of the "goodness of fit" of the regression. It measures the exact percentage of variation shared by two variables.
[2] Standard error of the estimate (SEE) is a measure of the accuracy of the predictions. It measures the dispersion of the actual Y values about the regression line.

While no specific piezometric investigations have been undertaken downstream of Nine Mile Road, the limited change in flow during periods of low groundwater levels suggests there is a very poor hydraulic connection between the stream and underlying aquifer most likely due to streambed clogging. This is illustrated in Figure 19 where changes in flow in the downstream reach of McKellar Stream are unrelated to the underlying aquifer level.

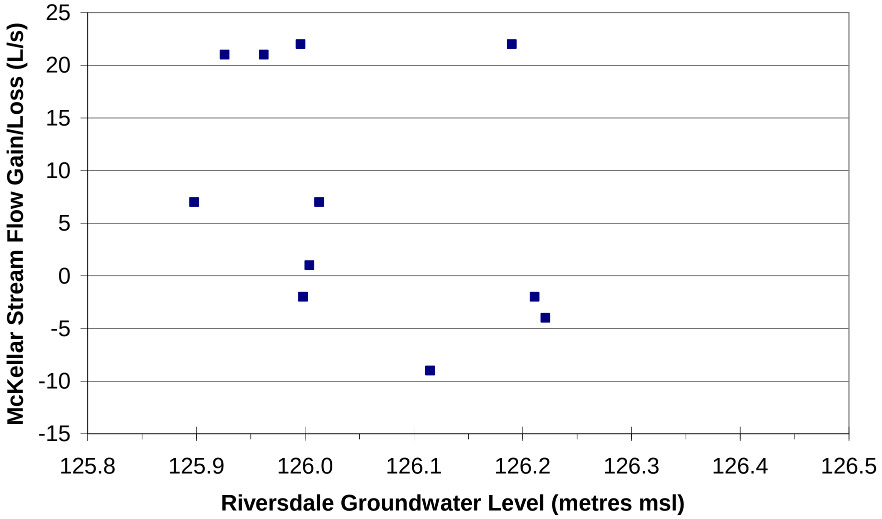

Figure 19: Scatter-plot of McKellar Stream flow gain/loss between Riversdale and Fortune Road and groundwater levels at bore F44/0181

3.2.3 Un-named Spring-fed Streams

In addition to the Meadow Burn, there are a number of smaller un-named depression spring-fed streams which originate south of the Riverdale township and flow across the Mataura River floodplain. Two of these streams cross Fingerpost Pyramid Road and progressively drain groundwater from the surrounding aquifer down their reach. These streams were regularly monitored from 2001 to 2007 however due to their size and extensive macrophyton growth, these streams were not ideally suited for flow gaugings and have only been sporadically gauged since. The better gauging site (Fingerpost Pyramid Road) has a correlation similar to the Meadow Burn with groundwater levels in the Liverpool Street monitoring bore however the Tayles and Fingerpost Pyramid Road spring discharge shows greater variability which could reflect greater gauging errors. Combined with the Meadow Burn, these three springs drain a gauged average of 900 l/s of groundwater (Wilson, 2008).

In addition to McKellar Stream, there are a number of smaller un-named contact spring-fed streams which originate at the southern tip of the Longridge terrace and drain into the Waimea Stream near its confluence with the Mataura River. Two of these streams which cross the Mandeville – Riversdale Highway were gauged regularly from 2002 to 2006 and have been gauged sporadically since. The un-named spring which crosses the Kingston Crossing – Mandeville Road has a fairly constant discharge of approximately 60 l/s indicating it is almost entirely sourced from drainage of the Longridge terrace. The un-named spring which crosses the Mandeville – Riversdale Highway originates further north towards Pyramid – Siding Road and has a much more variable discharge. This is interpreted to reflect a combination of discharge from the Longridge terrace and groundwater drainage from the Riversdale groundwater zone as it crosses the floodplain towards Mandeville (Wilson, 2008). This spring-fed stream shows a stronger correlation to groundwater levels in the Riversdale groundwater zone as summarised in Table 4. The combined gauged discharge of these two springs averages 200 l/s.

Table 4: Flow statistics from spot gaugings of the Un-named Springs

Site	Record Period	Number of Gaugings	Min Gauged Flow (l/s)	Mean Gauged Flow (l/s)	Median Gauged Flow (l/s)	Max Gauged Flow (l/s)	Linear Regression[1] (r^2)	SEE[2] (l/s)
Fingerpost Pyramid Rd	2001 – 2009	32	26	73	62	198	0.8673	24
Tayles and Fingerpost Pyramid Rd	2000 - 2007	26	72	132	130	240	0.4147	25
Mandeville – Riversdale Hwy	2001 - 2009	24	21	132	124	461	0.7057	55
Kingston Crossing – Mandeville Rd	2002 - 2009	24	31	65	54	182	0.5180	27

[1] Linear regression between flow and groundwater levels in F44/0181. The co-efficient of determination (r^2) is an estimate of the "goodness of fit" of the regression. It measures the exact percentage of variation shared by two variables.
[2] Standard error of the estimate (SEE) is a measure of the accuracy of the predictions. It measures the dispersion of the actual Y values about the regression line.

4. Groundwater Allocation

4.1 Groundwater Demand

The Riversdale groundwater zone has been utilised as a source of domestic and stock water since the area was first settled in the 1800s. Environment Southland's WELLS database shows there are currently 167 bores operative in the Riversdale groundwater zone, of which over half are used for drinking water supply (stock or domestic), as shown in Figure 20. The drinking water supply bores have a median depth of 6.0 metres[7], so are generally very shallow and only penetrate about 30 percent of the average aquifer thickness. Environment Southland recommends bores fully penetrate an aquifer to obtain the greatest supply reliability and to minimise the potential of sourcing poorer water quality.

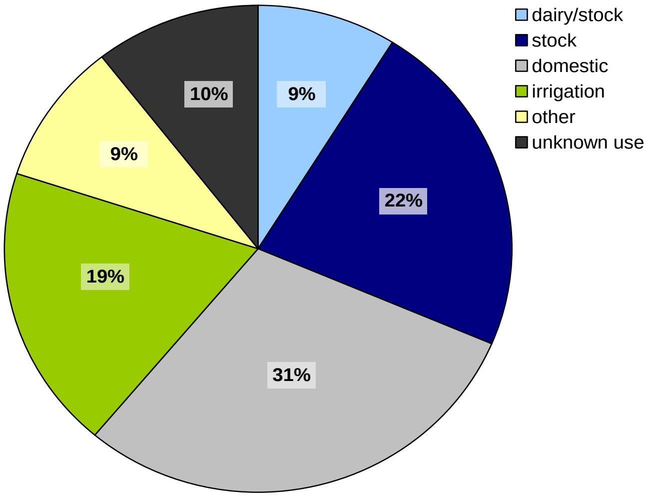

Figure 20: Pie-graph of use of bores in the Riversdale groundwater zone

If we assume there are approximately 60 bores in the Riversdale groundwater zone which are used as the sole water supply for a single dwelling, and that the dwellings contain an average of three people (average sourced from Statistics New Zealand website), and domestic water use is on average 250 litres per person per day (sourced from Environment Canterbury website), then the total volume of water used for domestic purposes in the Riversdale Aquifer is 45 m^3/day. This equates to less than 0.1 percent of the total consented groundwater allocation. This difference of several orders of magnitude between permitted use and consented allocation is assumed to apply to all types of permitted use across the region, however this assumption will be ground-truthed in 2011 as part of a Mataura catchment non-consented water use survey.

The Riversdale groundwater zone is known to have provided water for some relatively small-scale pasture irrigation during the 1970s following a series of dry years, however a majority of these water permits lapsed in the 1980s due to a combination of economic conditions and

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[7] Average depth is 7.7 metres with n = 78

an extended period of above average rainfall. By the mid-1990s only one consent for pasture irrigation remained active in the Riversdale area.

The first large-scale water permit for pasture irrigation was issued in December 2001. Over the subsequent period a further 13 consents for pasture irrigation have been granted by Environment Southland bringing total allocation from the aquifer system to 72,400 m^3/day, as shown in Figure 21. Today, irrigation accounts for 98 percent of the maximum daily consented groundwater allocation from the Riversdale groundwater zone while the majority of the remainder of allocation is used for dairy shed wash-down.

In early 2009 two applications for further resource consents for pasture irrigation were declined by Environment Southland on the grounds of the potential for cumulative effects of abstraction to result in adverse effects on both spring-fed streams and the Mataura River (Wilson, 2010). This decision was upheld by the Environment Court in 2011.

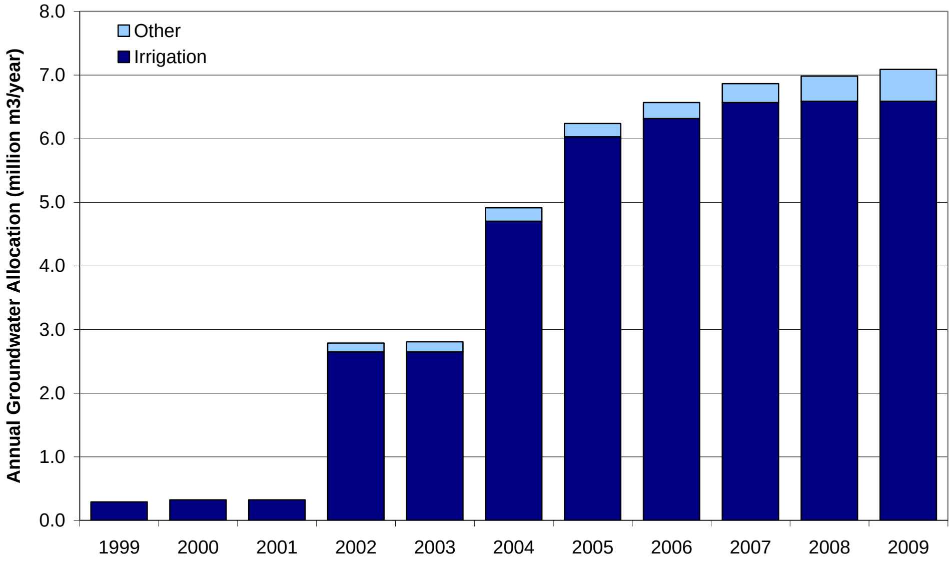


Figure 21: Plot of daily consented groundwater allocation for the Riversdale groundwater zone from 1999 to 2009

4.2 Groundwater Use

Figure 22 shows that, although allocation has remained relatively static over the past four years, reported water use has increased. In 2009/10 reported water use was 42 percent of the total allocation for the Riversdale groundwater zone. Patterns in water use in the Riversdale groundwater zone will be discussed in greater detail in a technical report on irrigation water use currently *in prep*.

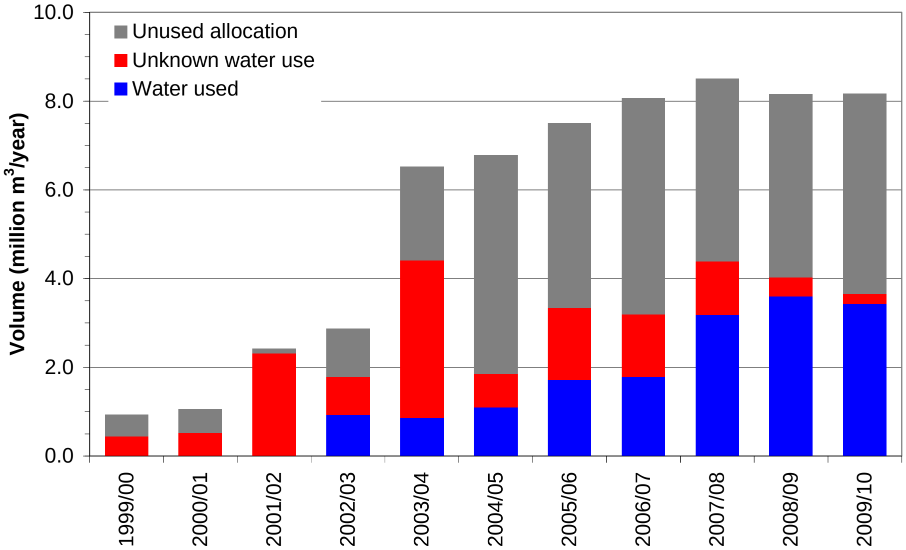


Figure 22: Time-series plot of groundwater use in the Riversdale groundwater zone (Wilson, 2011).

5. Groundwater Quality

All water contains dissolved constituents and of all freshwater sources, groundwater generally contains the largest amounts of dissolved solids. The range and relative concentration of the dissolved constituents reflect a range of factors including the nature and source of aquifer recharge, the rate and characteristics of groundwater flow through an aquifer system, the interaction of groundwaters with aquifer materials as well as geochemical processes resulting from the interaction between groundwater and the physical environment. Human (or anthropogenic) influences on groundwater quality include the introduction of contaminants associated with land use activities and wastewater discharges as well as alterations to the natural flow of groundwater as a result of groundwater abstraction.

Groundwater is extensively used for drinking supply throughout the Southland region with over 60 percent of rural properties reliant on groundwater to some extent for domestic and/or stock supply (Hamill, 1999). The widespread use of groundwater for potable supply reflects its relative abundance and ease of access, as well as an expectation within the community that groundwater is generally suitable for both human and stock consumption without the need for treatment. The importance of groundwater as a source of drinking water supply is reflected in Objective 8 in the RWPS which states groundwater quality should be maintained for aquifers which already meet the Drinking Water Standards for New Zealand (DWSNZ) and enhanced to a drinkable quality for aquifers which have been degraded due to land use and discharge activities (excepting situations where groundwater quality naturally exceeds relevant standards).

Environment Southland currently undertakes a range of groundwater quality monitoring throughout the Southland region to characterise spatial variability across the region, identify trends in the condition of groundwater resources and to better understand the source, behaviour and effect of contaminants. All available data from these monitoring programs collected in the Riversdale area have been used in the following section to characterise groundwater quality. The baseline environmental monitoring data is supplemented by sampling results from resource consent compliance monitoring and water resource investigations.

5.1 Water Quality Characterisation

Nearly all groundwater originates as either rainfall or snowmelt that infiltrates through the soil into underlying geological materials either directly from rainfall or infiltration of runoff. While both rainfall and runoff generally contain relatively low concentrations of dissolved ions, concentrations of minerals and nutrients may increase in water infiltrating into underlying groundwater as a result of natural chemical and biological processes in the soil zone. These processes typically result in an increase in the total concentration of dissolved ions which is reflected in a shift in the dominant ions from sodium and chloride (naturally present in rainfall) to calcium and bicarbonate ions reflecting the preferential dissolution of carbonate relative to other minerals present (Daughney and Wall, 2007). Due to isolation from the atmosphere, it is common (but not universal) for natural microbiological and chemical processes to deplete oxygen from deeper groundwater (groundwater with low concentrations of dissolved oxygen is commonly referred to as *reduced*). In some instances, the degree of oxygen depletion can be used as a guide to the relative age of groundwater (Freeze and Cherry, 1979). The occurrence of reduced conditions in an aquifer is commonly accompanied by an increase in concentrations of elements only soluble in low-oxygen conditions (e.g. iron, manganese, arsenic and ammonia).

The occurrence and relative concentrations of dissolved ions resulting from geochemical processes within an aquifer system can be used to characterise groundwater quality into water 'types' (called *facies*). This classification allows inferences to be made with regard the source and nature of groundwater flow through an aquifer system.

The major groundwater ion concentrations for monitoring sites in the Riversdale groundwater zone and the Southland region are shown in Figure 23 where the ion concentrations are represented as percentages of the total equivalents per litre (meq/l). Triliner diagrams like the piper plot used in Figure 23 are useful for visually demonstrating differences in major-ion chemistry as similar groundwater types will cluster together (because the plot is based on the relative ratio between the major ions). The facies classification diagram for piper plots is included in Appendix 2.

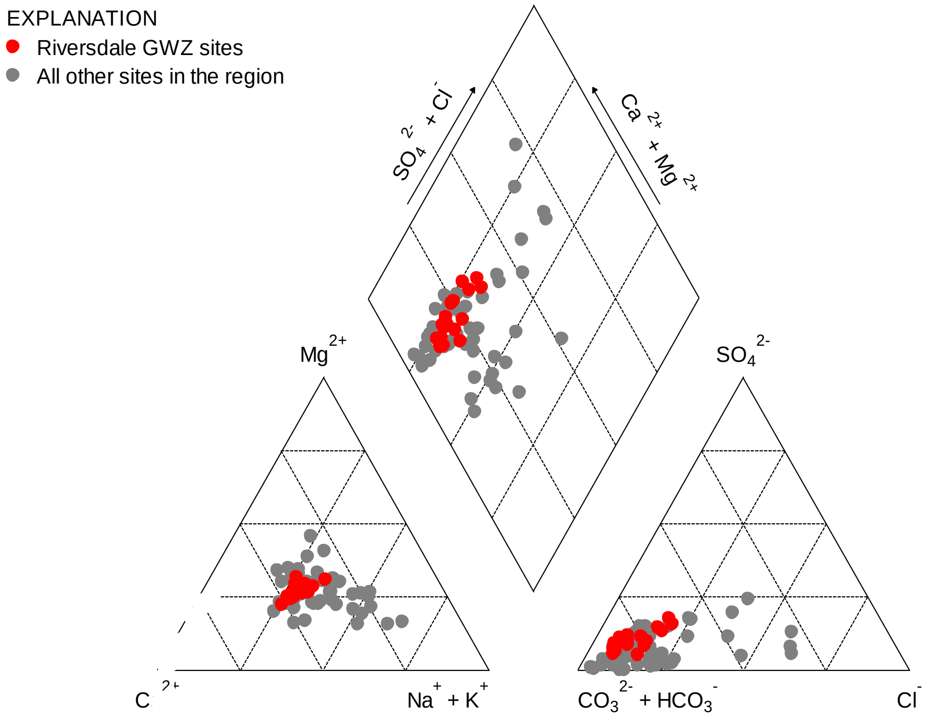
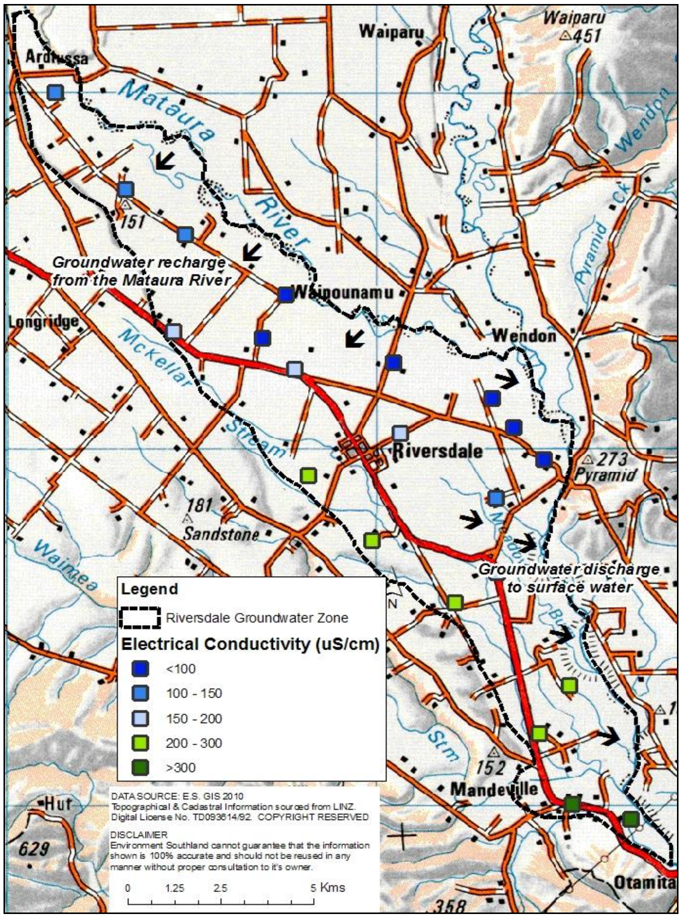


Figure 23: Piper-plot of the median value of the major ion chemistry from the Riversdale groundwater zone (red data points) and other Southland monitoring sites (grey data points)

The concentrations of major ions in the Riversdale groundwater zone monitoring sites are relatively low and are typical of other riparian aquifer systems. In general, Figure 23 shows that groundwater can be characterised as calcium-bicarbonate facies which is typical of groundwater with a low residence time flowing through relatively inert aquifer media. It is noted that the Riversdale groundwater zone sites do not all cluster together. Although cation concentrations plot in a relatively tight cluster (i.e. the bottom left triangle) the relative anion concentrations exhibit some spread (i.e. the bottom right triangle). This discrepancy is interpreted to reflect the influence of different recharge sources.

The influence of recharge source on groundwater chemistry in the Riversdale groundwater zone can be observed spatially in the electrical conductivity measurements taken in the May 2009 snapshot survey. Electrical conductivity is a measure of how well a material accommodates the movement of an electric charge and it is used to estimate the amount of total dissolved salts in water. In groundwater, electrical conductivity reflects the influence of geology, groundwater residence time, recharge processes and anthropogenic impacts. Figure 24 shows the spatial distribution of electrical conductivity in the Riversdale groundwater zone. It can be seen that in general, electrical conductivity increases with distance from the Mataura River (i.e. westwards) and increases in a downgradient direction (i.e. southwards).



DATA SOURCE: E.S. GIS 2010
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Figure 24: Map of May 2009 snapshot survey of electrical conductivity

As discussed in Section 2.7, the Riversdale groundwater zone recharge sources include flow loss from the Mataura River between Ardlussa and Riversdale, land surface recharge from rainfall and irrigation water draining through the soil profile and groundwater throughflow from the adjacent Longridge terrace. Typically, surface waters have a much lower electrical conductivity than groundwater because groundwater receive significant recharge from water infiltrating through the soil zone where chemical and physical reactions between rocks, minerals and organic material result in larger concentrations of salts. Once waters from the soil zone have reached the underlying aquifer further interaction with aquifer materials may result in additional contributions of dissolved solutes. The Mataura River discharges flow into the aquifer between Ardlussa and Riversdale and consequently lowers the electrical conductivity of the groundwater in this area. From Figure 24 it is interpreted that the riparian recharge mixing zone extends across most of the northern portion of the aquifer. Down-gradient of the Riversdale township, groundwater is discharged into surface waterways via numerous springs and the Mataura River. The higher electrical conductivity in groundwater in the southern portion of the aquifer is interpreted to reflect the dominance of land surface recharge and cumulative effects from landuse activities.

5.2 Drinking Water Standards

Access to good quality drinking water is essential for public health. Groundwater from the Riversdale groundwater zone is used for stock and domestic purposes including being the dominant water supply for residents in the Riversdale township. Groundwater is also used for dairy shed wash down and pasture irrigation. These supplies rely on groundwater in the Riversdale groundwater zone being of a suitable standard to meet the DWSNZ and relevant industry guidelines.

The DWSNZ were first published in 2000 and subsequently updated in 2005 and 2008 and establish maximum acceptable values (MAV) for a range of potential contaminants including microbial, chemical and radiological parameters. Consumption of water containing concentrations of parameters exceeding MAV are considered to present a significant risk to human health.

5.2.1 Micro-organisms

Micro-organisms, including bacteria, viruses and protozoa, can result in short-term acute impacts on human and animal health through a variety of diseases which range from mild gastroenteritis to severe, potentially fatal illnesses. Numerous studies undertaken both within New Zealand and overseas (e.g. Pang 2009; Wall et al 2008; Pang et al 2005) show that natural processes of filtration, adsorption and die-off reduce microbe concentrations in groundwater so that contamination tends to be localised near the contaminant source. The exception occurs where groundwater flow rates are particularly rapid or when viruses attach themselves to colloids. As a consequence, the majority of instances of micro-organism contamination in groundwater can be attributed to localised impacts downgradient of a point source discharge (e.g. septic tank, effluent pond) or where the bore or wellhead is poorly constructed or maintained allowing contamination of the abstraction point.

Although there are a wide range of micro-organisms that may result in waterborne illnesses, the presence of micro-organisms in groundwater is generally measured in terms of the presence/absence of the bacteria species Escherichia coli (referred to as *E. coli*). This bacteria is commonly found in large numbers in the lower intestine of warm blooded animals and is utilised as an indicator of potential faecal contamination due to their persistence outside of the body (Hughes, 2010). The DWSNZ specify that *E. coli* should not be present in water used for potable supply to minimise the potential for adverse health effects.

Figure 25 shows the number of sites at which indicator bacteria have been detected for groundwater samples taken from the Riversdale groundwater zone between 2001 and 2010. These data indicate the *E. coli* detection rate has gone from 63 percent of sites in 2005 to less than 20 percent of sites in the past four years. This is consistent with regional observations reported in recent SOE reports (ES and TAMI, 2010 and Hughes, 2010) which noted the incidence of faecal contamination had reduced from 55 percent of groundwater sites sampled across the Southland region in 2003 to 22 percent of sites in 2009. The high number of exceedances in 2005 likely reflects the influence of a very wet year and is a pattern observed in data from other Southland aquifers (e.g. Wilson, 2010c).

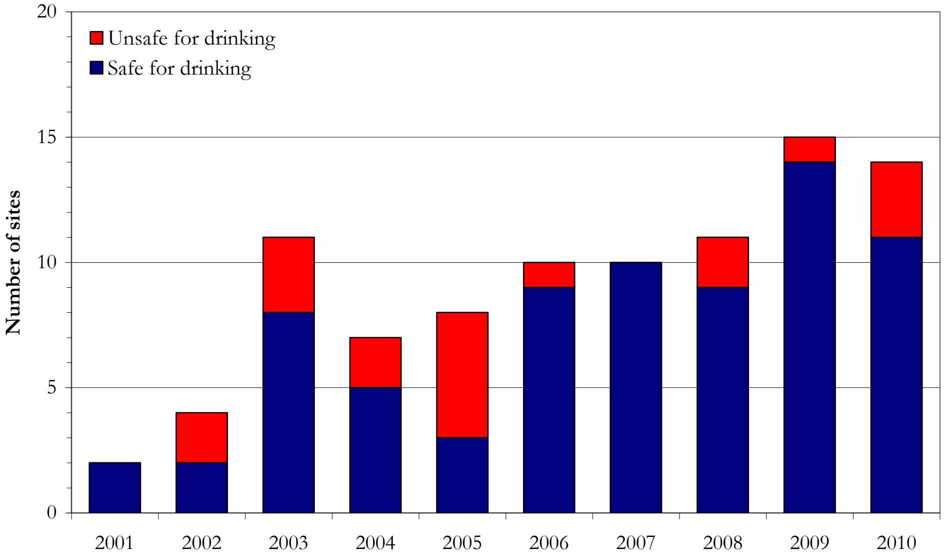

Figure 25: Plot of *E. coli* exceedances of the DWSNZ for all groundwater sites sampled in the Edendale groundwater zone between 2001 and 2010

5.2.2 Nitrogen

Nitrogen can exist in the environment in many forms and is a key element required to support plant growth and biological activity. Nitrate (or ammonia/ ammonium depending on geochemical conditions) is soluble in water and can be lost from the soil profile and accumulate in groundwater or surface water receiving environments. This can affect the potability of water and/or the aquatic ecology of surface waters due to the promotion of aquatic plant growth. Nitrate and ammonia can be toxic in elevated concentrations.

In New Zealand, the Ministry of Heath has set a MAV for (nitrate + nitrite) – nitrogen (henceforth called nitrate-nitrogen) of 11.3 mg/l for drinking water (MoH, 2008). This is based on World Health Organisation recommendations and is established to protect for short-term exposure against methaemoglobinaemia (or '*blue baby syndrome*') in bottle fed infants.

Figure 26 shows a map of nitrate-nitrogen concentrations for bores sampled in the May 2009 snapshot survey. These data show no sites exceed the MAV. Spatially, the distribution of nitrate-nitrogen in groundwater matches the pattern observed in the electrical conductivity data where elevated nitrate-nitrogen results coincide with areas which are interpreted to be dominated by land surface recharge source. As surface waters typically have much lower nitrate-nitrogen concentrations than groundwater, areas of the aquifer which are dominated by riparian recharge show more dilute nitrate-nitrogen concentrations. The two most southern sites (near Mandeville) show very low levels of nitrate-nitrogen which is interpreted to reflect groundwater denitrification processes influenced by the presence of East Southland Group sediments observed near the surface in this area.

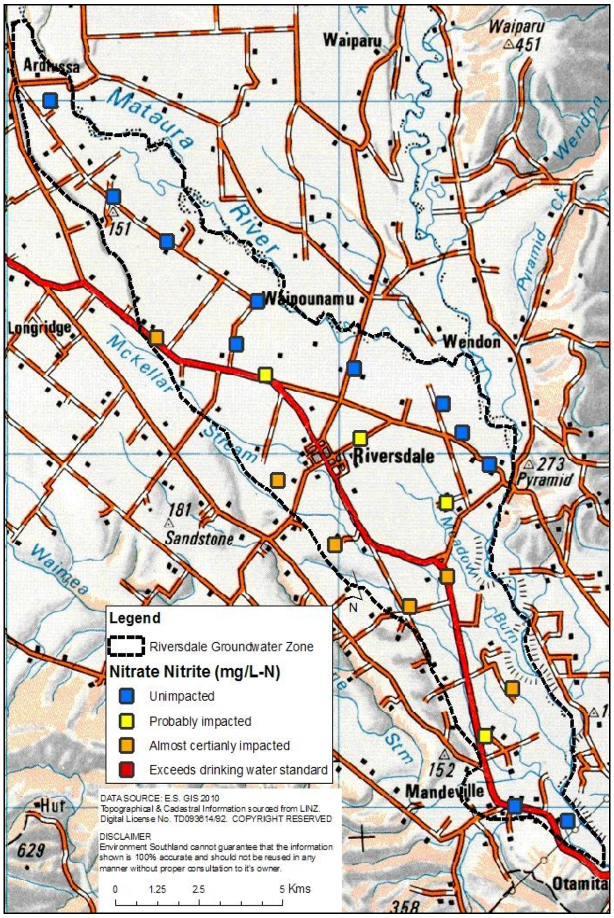

Figure 26: Map of the May 2009 snapshot survey nitrate-nitrogen concentrations

Figure 27 shows the number of sites which have exceeded the DWSNZ nitrate-nitrogen MAV since sampling began in 1997. At the current time it is observed that only one sample from the Riversdale groundwater zone has ever exceeded the MAV and it is noted that this sample was likely affected by a combination of sub-standard wellhead protection combined with a very heavy rainfall event immediately prior to sampling.

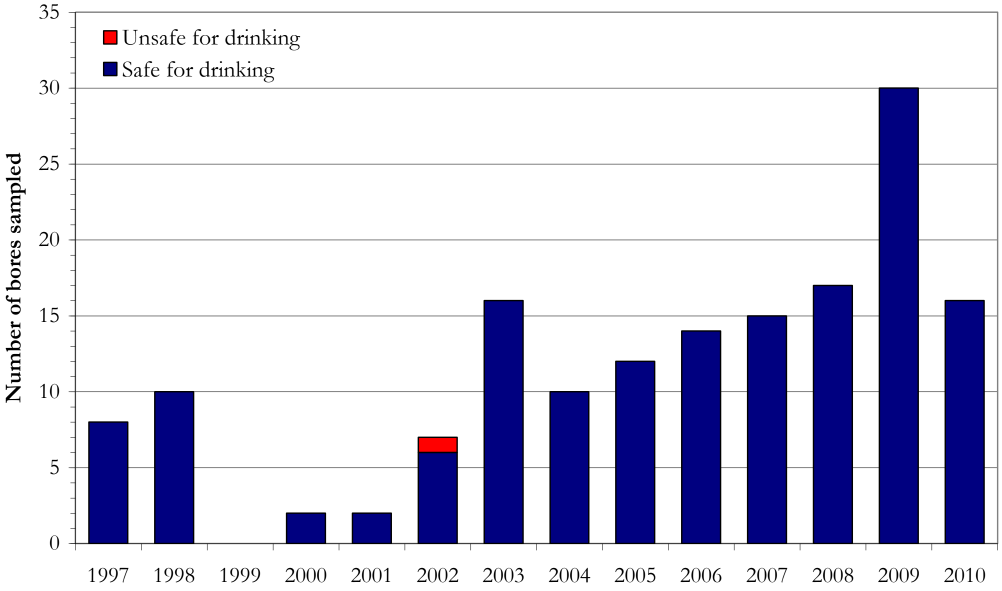

Figure 27: Exceedances of DWSNZ nitrate-nitrogen MAV from 1997 to 2010

In terms of temporal trends, Figure 28 shows a plot of nitrate-nitrogen concentrations at five SOE monitoring sites and one dairy compliance monitoring site (F45/0353) in the Riversdale groundwater zone. The plot shows nitrate-nitrogen concentrations are increasing at a rate of 0.08 to 0.20 mg/l/year in five of the six sites. The site which does not show a statistically significant trend (F45/0055) is located in the northern extent of the aquifer and is likely dominated by riparian recharge from the Mataura River.

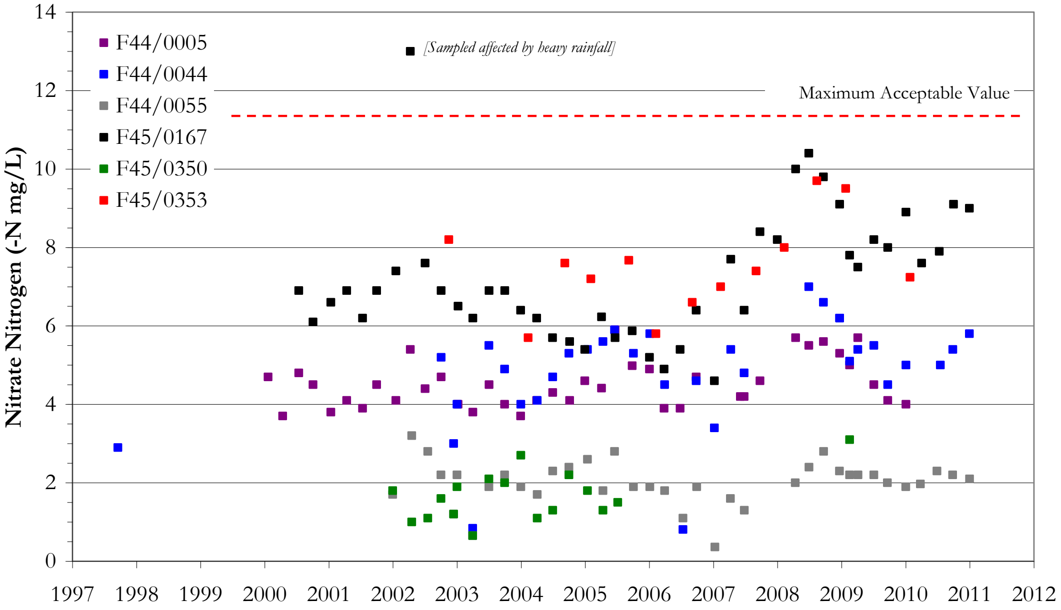

Figure 28: Nitrate-nitrogen results from monitoring bores

5.2.3 Pesticides

Two bores in the Riversdale groundwater zone have been sampled for pesticides as part of the on-going national groundwater survey. No pesticides were detected in F44/0005 (Gaw et al, 2006) and low concentrations of pesticide residue were detected in F44/0055 at concentrations less than one percent of MAV (Close and Skinner, 2010). These results indicate that existing pesticide practices in the Riversdale groundwater zone do not pose a risk to groundwater quality.

5.3 Stable Isotopes and Environmental Tracers

An isotope is an element which is of the same chemical form but which has a slightly different mass (atomic mass) due to either a greater or less number of neutrons. A stable isotope is one that does not decay whereas a radioactive isotope both decays and emits radiation. Radioactive isotopes are commonly used for age dating whereas stable isotopes are valuable for understanding physical, chemical and biological processes. The slight differences in atomic mass between the various isotopes of an element result in the discrimination (or fractionation) of the different isotopes during physical, chemical and biological processes which is what allows us to use them for a number of measurements relating to understanding past conditions and source characterisation[8]. Since the early 1950s, naturally occurring isotopes have been used in investigations of groundwater and surface water systems (Freeze and Cherry, 1979). The stable isotopes of oxygen (^{18}O, ^{17}O and ^{16}O) and hydrogen (^{1}H and ^{2}H) are mainly used as indicators of groundwater recharge source while the radioactive isotopes tritium (^{3}H) and carbon 14 (^{14}C) in conjunction with human sourced organic chemicals (sulphur hexafluoride (SF_6) and chlorofluorocarbons (CFC)) serve mainly as indicators of groundwater age. Stable (or nonradioactive) isotope ratios can also be used to help determine the source of an element as in the case of nitrogen (e.g. ^{15}N:^{14}N ratio).

Limited stable isotope and environmental tracer data is available to characterise the potential origin and residence time of groundwater in the Riversdale groundwater zone.

5.3.1 Recharge source

Oxygen in the atmosphere occurs in three naturally occurring isotopic forms; oxygen 18 (^{18}O), oxygen 17 (^{17}O) and oxygen 16 (^{16}O) - ^{17}O is seldom used due to its low abundance. The relative abundance of ^{18}O and ^{16}O changes according to well documented temperature-related effects (termed *fractionation*) during evaporation and condensation (Stewart and Morgenstern, 2001). As a consequence, the ratio between ^{18}O and ^{16}O can be utilised to provide an indication of likely recharge source for an aquifer system with recharge from lowland rainfall being enriched with respect to ^{18}O compared to that occurring in alpine precipitation (the major source of flow in larger river systems).

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[8] Isotope definition sourced from www.tuition.com.hk/geography/i.htm

The stable isotope ratios of oxygen in water ($H_2{}^{18}O/H_2{}^{16}O$) have been analysed in two bores in the Riversdale groundwater zone (F44/0005 and F45/0167). These sites showed values with a range of of $\delta^{18}O$ = -8.3 to -9.7 ‰ (per mil or per thousand) relative to a known standard, which is consistent with recharge from a mixture of local rainfall and river flow. (The greek symbol del (δ) indicates the difference in the ratio of ^{18}O:^{16}O isotopes relative to a known standard). A more comprehensive oxygen isotope survey of the Riversdale groundwater zone is planned for the 2011/12 summer.

5.3.2 Age-dating

Available age dating results from three sites in the Riversdale groundwater zone indicate an average groundwater residence time in the range of 10 to 20 years. At the current time it is uncertain if these results are representative of actual residence time or are more a reflection of the sampling techniques utilised (CFC's and tritium) and associated uncertainty with application of the associated mixing models.

Despite the uncertainty of existing age estimates, given the potential importance of an understanding of groundwater age to interpretation of both observed groundwater quality variations and the potential nature of aquifer recharge sources it is recommended that further age-dating investigations be undertaken once techniques are considered sufficiently robust to yield unambiguous age estimates.

5.3.3 Nitrate source

Similar to oxygen, nitrogen also naturally occurs in two isotopic forms; nitrogen-14 (^{14}N) and nitrogen-15 (^{15}N) and the ratio between these forms can be used as a general indicator to distinguish nitrogen source. As a general rule, $\delta^{15}N$ values in groundwater less than 5‰ reflect input from artificial fertiliser while values between 5‰ to 10‰ reflect soil mineralisation (breakdown of organic material within the soil zone) and values greater than 10‰ indicate an animal effluent source.

Nitrogen-15 results are currently available from two sites in the Riversdale groundwater zone (F44/0005 and F45/0167). At both sites $\delta^{15}N$ values were approximately 5‰ which suggests soil mineralisation as the primary nitrate-nitrogen source. The dual analysis of both the stable isotope ratios of nitrogen and oxygen of groundwater nitrate (NO_3) provide a more definitive measure of the nitrate source and it is recommended this method be used in future.

5.4 Summary

Groundwater quality in the Riversdale groundwater zone is generally high with groundwater being suitable for potable supply without treatment.

Overall, groundwater quality is strongly influenced by the recharge source. Areas dominated by riparian recharge from the Mataura River show lesser concentrations of major ions (including nitrate-nitrogen) compared to areas which are dominated by land surface recharge.

Groundwater quality in the Riversdale groundwater zone is generally high with a majority of groundwater being suitable for potable supply without treatment. However, temporal and spatial variations in groundwater quality illustrate the significant influence recharge source has on groundwater chemistry and the vulnerability of aquifer discharge areas to potential impacts from overlying land use activities. Available monitoring data provide a good illustration of the diluting effect riparian recharge has within the aquifer system and the water quality impacts associated with land use activities in the lower portion of the aquifer.

6. Summary and Recommendations

The Riversdale groundwater zone occupies the recent floodplain terrace on the true right bank of the Mataura River between Ardlussa and the Otamita Bridge. The northern and eastern boundary follows the main channel of the Mataura River while the southern and western boundary follows the prominent alluvial terrace which marks the outer boundary of the Mataura floodplain.

The subsurface geology of the Riversdale groundwater zone consists of a typical sequence of heterogeneous alluvial gravels associated with a moderate to large braided river. The gravel deposits, comprising of moderately to poorly sorted gravel, claybound gravel, sand and silt, extends to a depth of up to 30 metres below ground to the west of the Riversdale township and reduces to a thickness of less than 10 metres towards Mandeville. Tertiary sediments of the East Southland Group comprising of mudstone and sandstone underlie the gravel deposits to an unknown depth.

The Quaternary gravels generally have very high permeability, as evident by the large scale irrigation in this zone, although there is some variability which reflects the heterogeneous nature of the gravels. In general, hydraulic conductivity reduces away from the Mataura River. This is assumed to reflect depositional processes with greater reworking and fine sediment removal in the area adjacent to the current river channel where the river.

Surveying in the Riversdale groundwater zone show groundwater tends to flow roughly parallel to the main river channel. Downstream of Ardlussa piezometric contours reflect flow loss from the river to the Riversdale groundwater zone, while downstream of Pyramid the relative gradient is reversed and contours indicate groundwater discharge to the river. The piezometric contours also illustrate throughflow of groundwater from the Longridge groundwater zone along the alluvial terrace which forms the boundary with the Riversdale groundwater zone however modeling work indicates this likely forms a minor component to the aquifer water budget.

Recharge to the Riversdale groundwater zone occurs from a combination of rainfall recharge, river recharge, throughflow from the Longridge groundwater zone and more recently, an unknown component from irrigation drainage. Generally the water table in the Riversdale groundwater zone is less than three metres below ground level and varies within a one metre range.

Groundwater level fluctuations reflect the two major components of aquifer recharge. Flow loss from the Mataura River provides a "base" aquifer level to which groundwater levels fall during extended periods of low rainfall, while rainfall recharge provides an "active" storage component. The limited amplitude of the observed groundwater level seasonal fluctuations reflects the constant head provided by river recharge.

The Riversdale groundwater zone is hydraulically linked to the Mataura River over a majority of the 50 kilometre reach between Ardulssa and Otamita. The river recharges the aquifer system upstream of the Riversdale – Waikaia Road Bridge and in turn, groundwater is discharged from the Riversdale groundwater zone back to the river via direct infiltration downstream of Pyramid. Groundwater is also discharged through a series of spring-fed streams which drain groundwater from the lower half of the aquifer. The largest of the spring-fed streams is the Meadow Burn which originates near the Riversdale township and progressively gains flow from groundwater discharge to its confluence with the Mataura River approximately 11 kilometres downstream. The Meadow Burn accounts for 50 to 65 percent of the total spring discharge from the Riversdale groundwater zone and is an ecologically significant waterway supporting two threatened fish species.

Groundwater quality in the Riversdale groundwater zone is generally high with a majority of groundwater being suitable for potable supply without treatment. However, temporal and spatial variations in groundwater quality illustrate the significant influence recharge source has on groundwater chemistry and the vulnerability of aquifer discharge areas to potential impacts from overlying land use activities.

Recommendations for future monitoring and investigations in the Riversdale groundwater zone include:

- continuation of existing groundwater level monitoring including the installation of a permanent second groundwater level reference site in the downstream extent of the aquifer;
- continuation of the existing current spring-fed stream gauging programme at representative sites in the Meadow Burn, McKellar Stream and other un-named springs;
- refinement of estimates of the aquifer water balance including estimates of aquifer recharge/discharge;
- a comprehensive oxygen isotope survey (and/or alternative sourcing methods) to improve current understanding of recharge/discharge sources and mixing zones;
- additional tritium sampling (and/or alternative age dating methods) to improve current understanding of the spatial and depth distribution of groundwater residence time across the Riversdale groundwater zone;
- recording of land use across the Riverdale groundwater zone at regular intervals to improve the ability to attribute observed variations in groundwater quality with potential causative factors; and
- investigations to improve knowledge of the influence groundwater discharge has on surface water quality particularly with respect to nitrate-nitrogen.

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8. Appendices

Appendix 1

Groundwater level monitoring sites summary (in metres below top of casing and n/a stands for insufficient data)

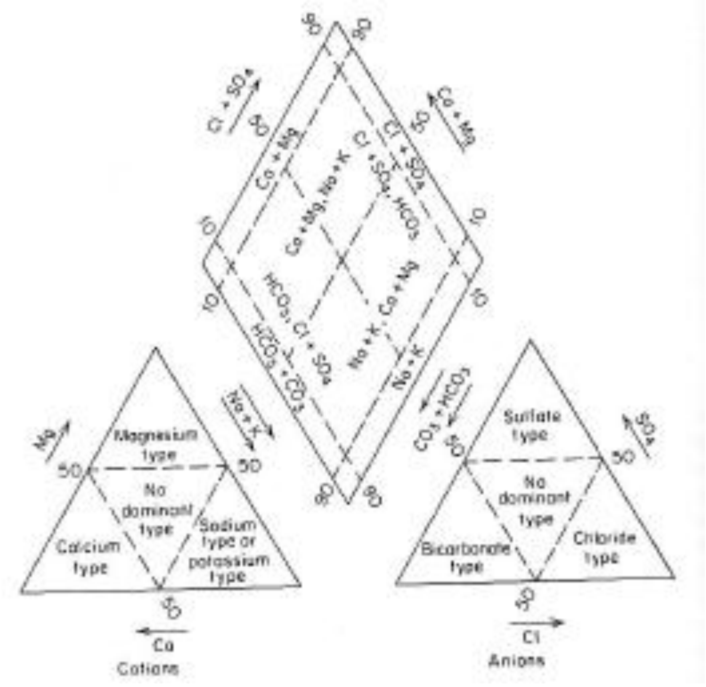
Site	Easting	Northing	Record Period	Elevation (m msl*)	Current Monitoring Frequency	Min Reading	Max Reading	Median Level	Mean Annual Range (m)
F44/0044	2177776	5472239	Dec-03-	135	Quarterly	-2.54 (Dec 09)	-1.40 (Sep 04)	-1.92	n/a
F44/0055	2173205	5477288	Mar-02-	151.772	Monthly	-3.31 (Jun 03)	-1.98 (Jul 02)	-2.87	n/a
F44/0181	2179575	5470413	Dec-02	128.086	10 minutes	-2.19	-0.92	-1.78	0.84
F45/0167	2182092	5465690	Sep-00-	115.107	Monthly	-2.62 (Feb 09)	-1.48 (Jun 02)	-2.29	0.75
F45/0174	2179319	5469672	Sep-00-	126.710	Monthly	-2.01 (Mar 10)	-1.09 (Jun 02)	-1.62	0.63
F45/0350	2184361	5462028	Mar-02-	105.254	Monthly	-2.77 (Jun 03)	-1.85 (Aug 08)	-2.25	0.41
F45/0370	2185408	5460216	Feb-04-Mar-09	103.193	Monthly	-3.09 (Feb 04)	-1.58 (Jun 07)	-2.18	1.07
F45/0546	2185478	5460153	Feb-09-	100	Monthly	-2.88 (Mar 10)	-0.77 (Jul 11)	-1.76	0.79
F45/0601	2185026	5463586	Oct-10-Feb-12	106	10 minutes	n/a	n/a	n/a	n/a
F45/0612	2185640	5461915	Aug-11-	100	10 minutes	n/a	n/a	n/a	n/a
F45/0614	2184211	5462343	Jun-11-	104	10 minutes	n/a	n/a	n/a	n/a

*Metres above mean sea level using Bluff 1949 datum (source: Digital Elevation Model) or where more precise than 1 metre, the top of casing has been measured using RTK GPS surveying equipment.

Appendix 2

Classification diagram for anion and cation facies in terms of major-ion percentages.

Water types are designated according to the domain in which they occur on the diagram segments (source Freeze and Cherry, 1979).



Appendix 3

Groundwater quality monitoring data summary

Median concentration in mg/l

Site	n	EC	pH	Na	Ca	Mg	K	Fe	Mn	Cl	SO_4	HCO_3	NO_3	DRP	NH_3
F44/0005	42	141	6.5	6.7	12	4.3	1.7	0.013	0.002	7.3	9.9	28	4.4	0.011	<0.01
F44/0044	35	160											5.2		
F44/0055	37	103											2.0		
F45/0167	46	223	6.3	11	19	7.9	1.8	0.02	0.001	15	17	30	6.9	0.01	<0.01
F45/0350	38	196	6.5	14	13	7.1	0.87	0.08	0.110	18	8.7	62	1.6	0.015	<0.01
F45/0353	13	222											7.4		

Index:

n number of samples

EC electrical conductivity

Na sodium

Ca calcium

Mg magnesium

K potassium

Fe iron

Mn manganese

Cl chloride

SO_4 sulphate

HCO_3 bicarbonate alkalinity

NO_3 nitrate + nitrite - nitrogen

DRP dissolved reactive phosphorous

NH_3 ammoniacal nitrogen