Technical Report

Investigations and
Monitoring Group

Groundwater resources associated with the Rakaia riparian sub-area: assessment of technical and allocation issues

Environment Canterbury
Your regional council

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Executive summary

This report addresses four options:

- whether to formalise the current Rakaia riparian sub-area as a stand alone groundwater resource allocation zone;
- whether to enlarge the current riparian sub-area;
- whether to introduce special management criteria in the sub-area; and
- whether to adopt the status quo (do nothing).

The report also responds to concerns submitted by the Southbridge Water Users Group (SWUG), who with other consent holders in the Rakaia-Selwyn Groundwater Allocation Zone, are currently undergoing a consent review as part of the Restorative Programme for Lowland Streams.

The SWUG concerns are that the hydrogeological characteristics of the Rakaia riparian sub-area (area outlined in blue in Figure ES1) are sufficiently different from that of the Rakaia-Selwyn Groundwater Allocation Zone (RSGAZ) that consent holders there should be treated differently. SWUG are also of the view that the current riparian sub-area could be enlarged, and that adaptive management consent conditions in the sub-area should reflect the special character.

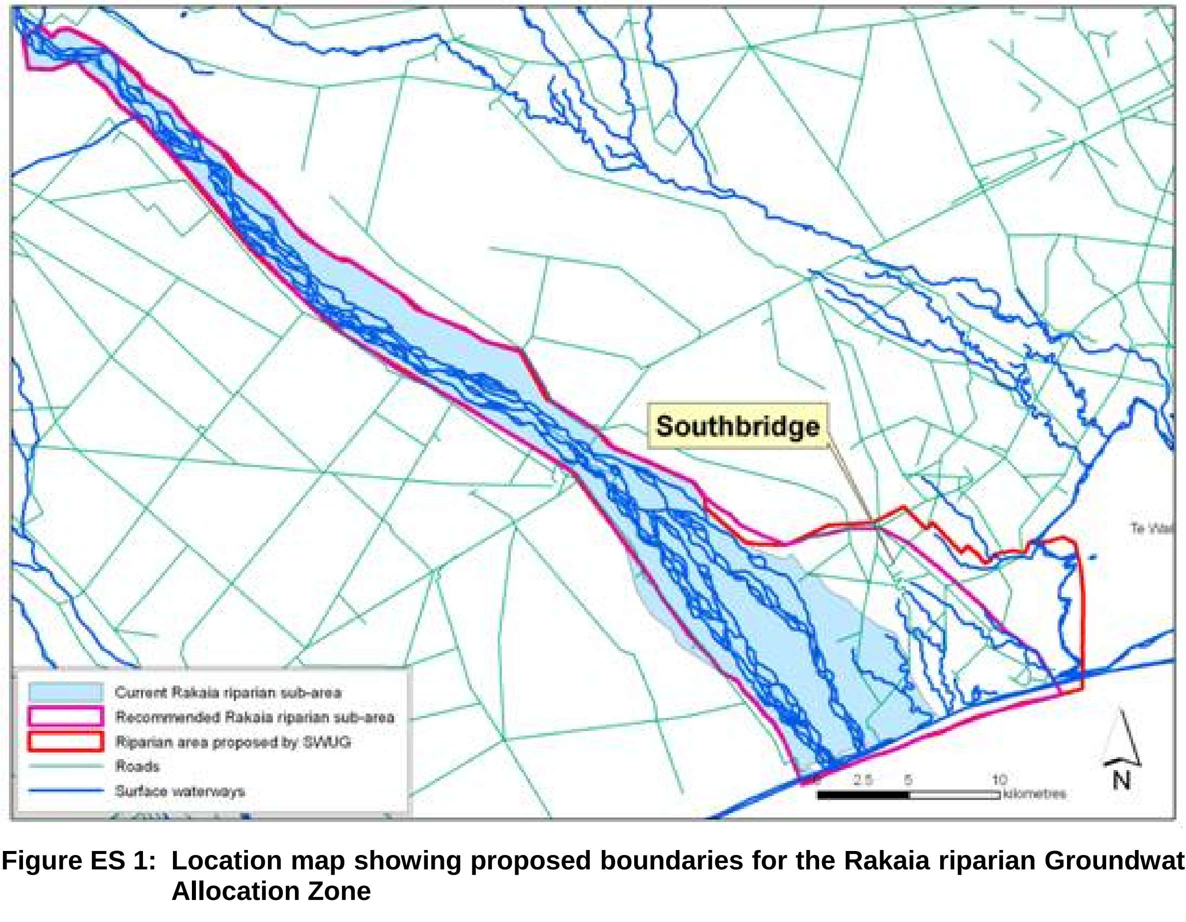

Figure ES 1: Location map showing proposed boundaries for the Rakaia riparian Groundwater Allocation Zone

The issues associated with the allocation and use of groundwater and surface water resources are discussed in this report for an area north of and adjacent to the Rakaia River especially around Southbridge. This area is currently included in the Rakaia riparian sub-area. The report contains analysis of existing and new monitoring data relating to: geology; surface water flows; groundwater levels and flow directions; assessment of recharge sources and volumes; groundwater usage; and allocation of the groundwater resource.

Evidence is presented that although the Rakaia riparian sub-area can be an allocation zone in its own right, development of a separate allocation zone for this riparian sub-area is not necessary. The current zone can be enlarged and formalised by means of the Restorative Programme for Lowland Streams consent review in which different consent conditions are attached. Both options should involve enlarging the sub-area by changing the location of the eastern boundary, this document provides data specifically supporting this modification (Figure ES 1).

Much of the current Rakaia riparian sub-area enjoys relatively high groundwater levels as a combined result of rainfall, seepage from the Rakaia River, and additional recharge derived from return water from the Northbank Irrigation Scheme and other surface water schemes. As a result of this recharge combination and geology, there is a marked contrast in the levels and variation in levels of groundwater, and the yields of wells in the riparian sub-area, when compared with the remainder of the RSGAZ to the east.

In terms of the four options, there is no advantage to any party with the status quo option. The option of creating a separate groundwater allocation zone is technically un-necessary. The option to increase the size of the sub-area has been recommended along with the option that the ‘special’ status of the Southbridge area be accommodated. It is recommended that:

- the boundary of the current sub-area be moved eastwards to incorporate more land in an enlarged sub-area (refer to area outlined in purple in Figure ES1). The recommended change to the eastern boundary is only along the southeast portion of the sub-area, the western portion, constrained by the Rakaia River terraces, is unchanged;
- no changes to allocation limits be made;
- consent conditions imposed on reviewed, renewed or new consents within the proposed enlarged sub-area should be managed adaptively;
- a consent review, currently under way, should initiate a mechanism of variable seasonal allocation in the RSGAZ. I recommend that reviewed consents in the Rakaia riparian sub-area should expect different management parameters, reflecting the different hydrogeological conditions;
- a technical assessment will be required of the number and on the quantum of groundwater abstractions deemed to be highly hydraulically-connected with the Rakaia River, and so recognised as surface water takes
- transfer of takes out of the proposed enlarged sub-area should be disallowed because the consent conditions likely to be recommended for consents within it will be site-specific.

Details of adaptive management trigger levels cannot yet be calculated until metering data become available, which is expected in the 2010-11 irrigation season. These triggers will likely be slightly less conservative than those proposed for the remainder of the RSGAZ, reflecting the special recharge sources in the proposed zone.

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1 Introduction

Southbridge is located in the Selwyn district, 40 kilometres southwest of Christchurch (Figure 1-1). The area described in this report is situated beside the Rakaia River and is currently within the Rakaia – Selwyn Groundwater Allocation Zone (RSGAZ) as defined in the Proposed Natural Resources Regional Plan (ECan 2004). Agricultural land use is mainly cropping; dairying is less common.

This report describes only land bordering the north side of the Rakaia River; it does not deal with the south bank of the Rakaia River, where there are geological, topographic and hydrogeological properties similar to those on the north bank.

1.1 The Southbridge Water Users Group issues and report scope

Members of the Southbridge Water Users Group (SWUG) which includes many of the consent holders in the Southbridge area, have over a number of years called attention to the unusual characteristics of the local groundwater system (Figure 1-1) to support their community-based proposals for groundwater management. SWUG has suggested that a separate groundwater allocation sub-zone be established.

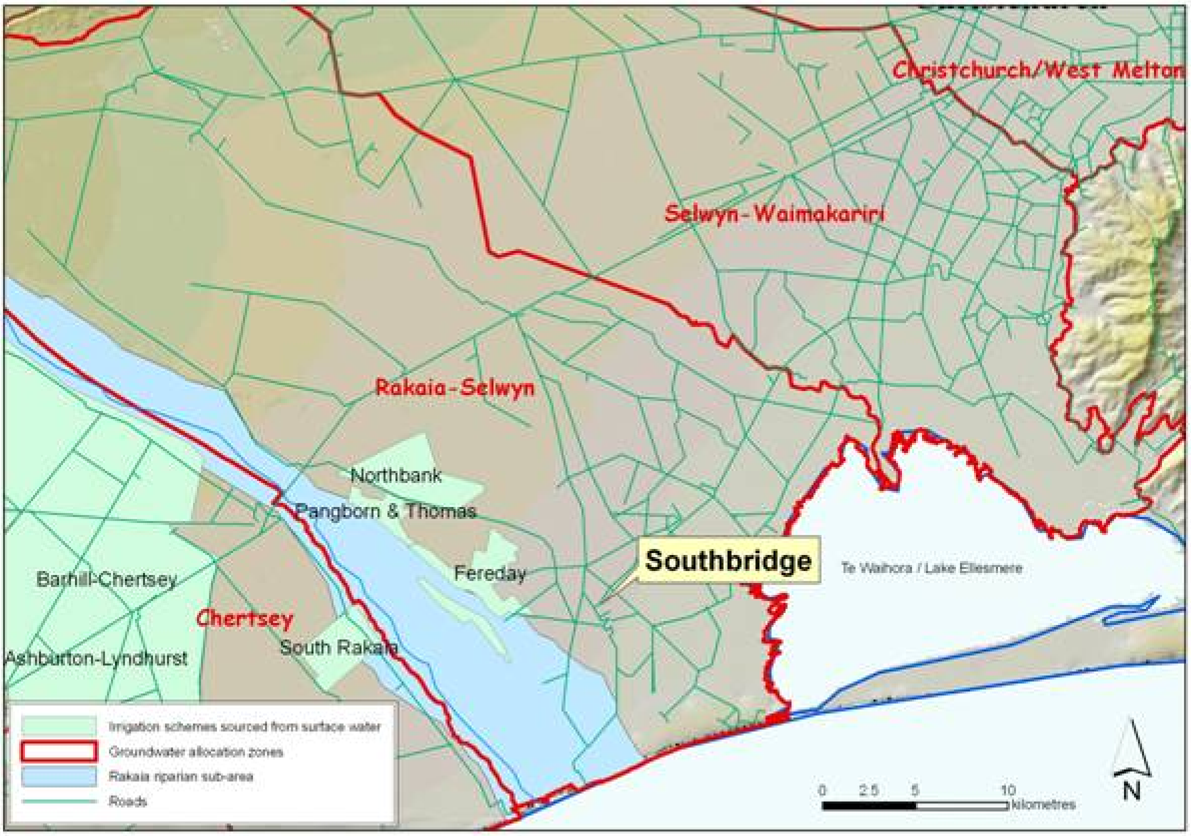

Figure 1-1: Map of the coastal portion of the current boundaries of the Rakaia riparian sub-area (blue) adjacent to the Southbridge area showing groundwater allocation zones and distribution of irrigated areas sourced from surface water (pale green)

The SWUG contends that the hydrogeological characteristics of the Rakaia riparian sub-area are sufficiently different from that of the Rakaia-Selwyn Groundwater Allocation Zone (RSGAZ), of which it forms a part, that SWUG consent holders should be treated differently. SWUG is also of the view that the current riparian sub-area could be enlarged, and that adaptive management consent conditions in the sub-area could reflect the special character. SWUG is also concerned at the imposition of stream depletion conditions. This technical report does not address this last concern because any new stream depletion assessments will be determined regardless of whether the riparian sub-area is enlarged or made into a separate allocation zone.

This report addresses these concerns associated with the allocation and use of groundwater and surface water resources in an area informally known as the Rakaia riparian sub-area (pale blue in Figure 1-1). This report assesses newly-acquired and existing data concerning the sub-area, especially in an area around Southbridge.

1.1.1 A 'special' zone

Environment Canterbury has for some time considered that at least part of this corner of the RSGAZ is 'special' and could be treated slightly differently – hence the recognition in 2005 of the Rakaia riparian sub-area (Ettema and Aitchison-Earl 2005). Currently, there are no formal or legal distinctions in the way consents or applications are treated in this sub-area. In practice, however, consent applications have been granted in this area. Seepage from the Rakaia River buffers groundwater levels and dependent-streams to the extent that a different view of allocation issues by Environment Canterbury is taken.

Figure 1-1 shows the outline of the Rakaia riparian sub-area, (pale blue), set up as a result of decisions made by hearing commissioners for applications made for groundwater by two applicants: Meadowflower, and Inch (Ettema & Aitchison-Earl, 2005, see Appendix 3 of this report). These decisions considered that the recharge geology, characteristics and groundwater resource state in the riparian zone were sufficiently different from those in the main part of the RSGAZ to the east that there was justification for treating applicants differently. However, while Environment Canterbury proposed the sub-area in 2005 it did not go as far as formalising it as a separate entity within the PNRRP (Proposed Natural Resources Regional Plan) or in its proposed variations. The current riparian sub-area has no formal allocation limit because of a lack of robust data to delineate it.

This technical report uses all currently available information, including anecdotal, to analyse the groundwater environment and its mode of recharge and discharge to assess whether it would be appropriate to develop a separate groundwater allocation zone. If such a zone were to be established, the location of the boundary with the remainder of the RSGAZ would need technical justification, as would a new allocation limit.

Views of SWUG and consultants involved in the consenting process suggest that the area centred on Southbridge, part of the Rakaia riparian sub-area and within the current boundaries of the RSGAZ, is somewhat special. Consent holders may benefit from the development of particular rules or conditions attached to groundwater consents and groundwater allocation limits. These issues can be dealt with in a consent review once the decision whether to create a separate allocation zone, or to enlarge the current riparian sub-area, has been made.

1.1.2 Restorative programme for lowland streams

The SWUG concerns stemmed from the consent review associated with the Restorative Programme for Lowland Streams (RPLS) that affects all consent holders in the RSGAZ, including those in the Rakaia riparian sub-area. There are four major 'planks' to the consent review:

- implementation of water use metering;
- re-assessment of stream depletion conditions on all consents considered to be hydraulically-connected (PNRRP Schedule WQN7: direct or high);
- implementation of an annual volume calculated by means of PNRRP Schedule WQN9, or any acceptable alternative;
- implementation of a groundwater management mechanism to reduce the risk of flows in spring-fed streams falling below their minimum flows (adaptive management).

SWUG considers that the proposed imposition of adaptive management conditions would penalise them unfairly based on the acknowledged allocation issues within the bulk of the Rakaia-Selwyn Groundwater Allocation Zone, leading to the major RPLS consent review. In this report, where it is mentioned that conditions could be changed, it should be understood that this would likely be a result of the current consent review associated with the RPLS.

1.2 Background

In this section I briefly introduce a number of parallel processes that form the background to the writing of this report.

1.2.1 The Rakaia-Selwyn Groundwater Allocation Zone Decision

In their decision on 69 consent applications in the RSGAZ, the Commissioners raised the possibility that a limited number of additional groundwater permits could be granted in the Rakaia riparian sub-area in situations where it is determined that any adverse effects on the environment will be acceptable (ECan, 2007, paragraphs 185 and 261; ECan, 2008a, paragraph 71).

1.2.2 Adaptive management proposals

A recent report (Williams *et al.,* 2008) details a technical proposal for adaptive management of groundwater in the entire RSGAZ. In light of that report there has been renewed concern from the SWUG that the riparian sub-area might be managed as if part of the RSGAZ, when in fact there may be strong arguments for the sub-area to be devolved or distinguished from the main body of the zone by means of different consent conditions.

Consent conditions are normally changed only when a consent comes up for renewal, by means of a plan change, or if it is reviewed because of adverse environmental effects such as the current RPLS consent review.

1.2.3 Rakaia River issues

Another recent report, on water allocation issues in the Rakaia River catchment (Dysart *et al*., 2008) proposed formalising the flow banding and allocation system. Proposals made in later sections of this report are informed by statements in that document. Further grants of hydraulically-connected groundwater takes adjacent to the Rakaia River "*will have a cumulative effect on instream values and the reliability of supply of existing consent holders*". Furthermore: "*some takes considered to be well connected to the Rakaia River have no low flow conditions*". One of the conclusions from the Dysart *et al*. (2008) report is that: "*hydraulically connected groundwater takes can, and should, be included in the allocation regime proposed for the Rakaia River*".

1.2.4 Minimum flows

A report on in-stream habitat and flow regime requirements for the Lee River, Harts Creek and other streams in the Southbridge area has recently been completed (Booker and Graynoth 2008). This study informs the process of determining minimum flows in the study area, which in turn affect the process of groundwater management. Stream depletion conditions have no bearing on the recommendations made in this report.

1.3 Data used to compile this report

This technical report addresses these concerns and issues voiced by the SWUG. It recommends enlargement of the riparian sub-area, use of different adaptive management conditions to those proposed for the remainder of the RSGAZ and defines the recharge sources and budget of the groundwater system, using data on the geology, groundwater levels, flows and chemistry and aquifer properties.

This technical report uses data on the recharge sources and hydrological budget of the groundwater and surface water system along with details of the geology, groundwater levels, flows and chemistry, aquifer properties and recharge sources.

Most of the data have been available in report form for some time (e.g. NCCB 1983 a and b), newly-acquired data have been critical (e.g. Hanson & Abraham 2009; Dysart *et al*. 2008; Booker and Graynoth 2008) in developing the report's recommendations.

1.4 Nomenclature used to describe the riparian sub-area in this report

Over a number of years, the area described in this report has been given a variety of names. Table 1.1 indicates which names refer to which areas. Some of these terms are introduced and explained later in this report.

Table 1.1: Relationships between different zones named in this report

Name	**Reference**	**Description**
Rakaia-Selwyn Groundwater Allocation Zone (RSGAZ)	Aitchison-Earl *et al*. (2004) and ECan (2004)	Groundwater allocation zone including all variants of the riparian zones or areas in this matrix, bounded by the Rakaia River, the Selwyn River, the foothills and the sea.
Little Rakaia Zone (LRZ)	Grant (2003)	Informal zone larger than current Rakaia riparian sub-area
Rakaia riparian sub-area	Boundaries and brief description located on Environment Canterbury website, based on report by Ettema and Aitchison-Earl (2005) and consent hearing decisions	Current area demarcated by lower terrace in northwest and a 'planning' line in southeast
Southbridge Water Users Group (SWUG) proposed zone	Letter proposals by SWUG	Reaches eastwards as far as Harts Creek, does not include upper (north-western) part of current riparian-sub-area
Recommended Rakaia riparian sub-area	This report	Smaller than the SWUG proposal, larger than the current Rakaia riparian sub-area

2 Geology and aquifer structure

In Canterbury, water-bearing strata, traditionally called ‘aquifers’, are contained in a series of coalescing gravel fans emanating from the Southern Alps, formed during successive Quaternary glacial and interglacial periods (e.g. “Q2a” in Figure 2-1). Gravel-dominated sediments up to 650 m thick were deposited by the major alpine rivers, and to a lesser extent by smaller inter-fan rivers such as the Selwyn. The Southbridge area became a small part of this complex of coalescing alluvial fans during the Quaternary glacial and inter-glacial periods. These major fan gravels are reworked by rivers such as the Rakaia and Selwyn, producing gravels containing less fine-grained matrix material (“Q1a” in Figure 2-1) commonly constrained by a topographic terrace.

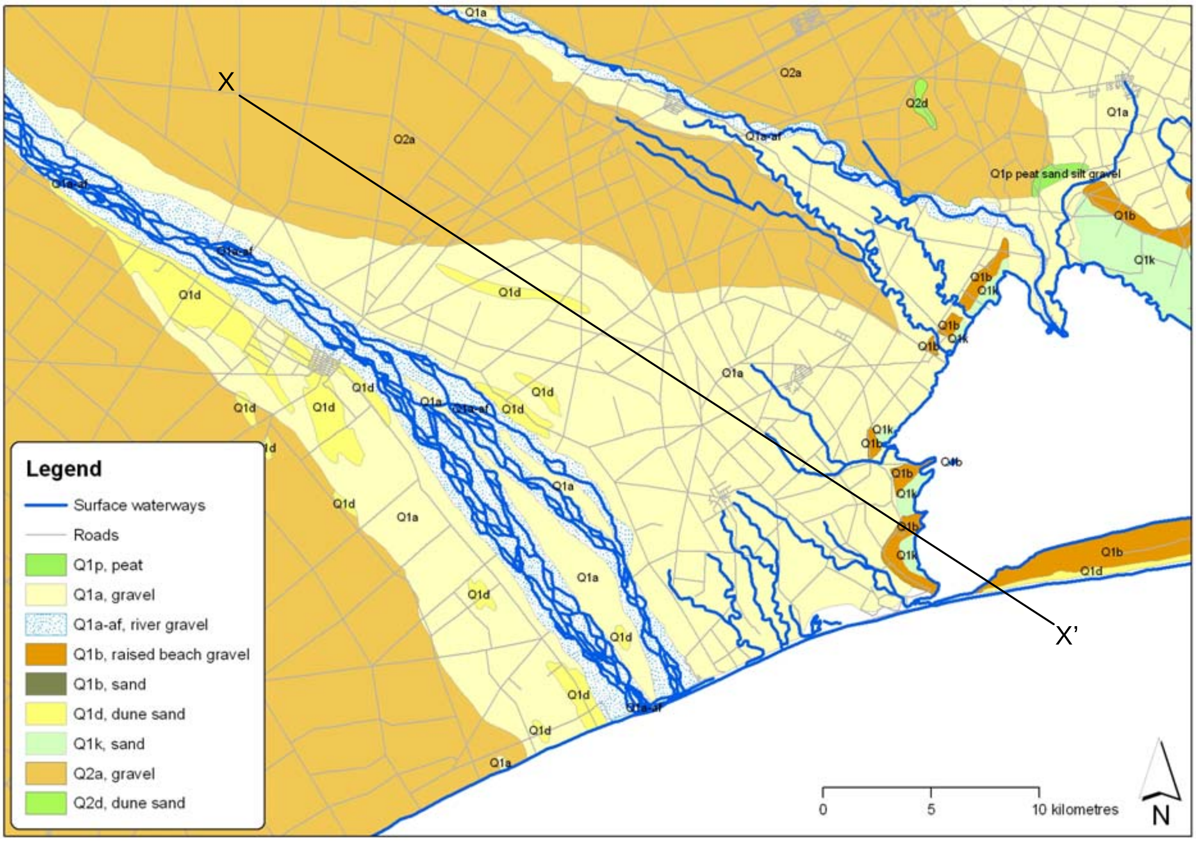

Figure 2-1: Geological map of the Southbridge area. (Source: Geological map data modified after Forsyth *et al.* (2009)) Line X-X’ denotes line of cross-section in Figure 2-2

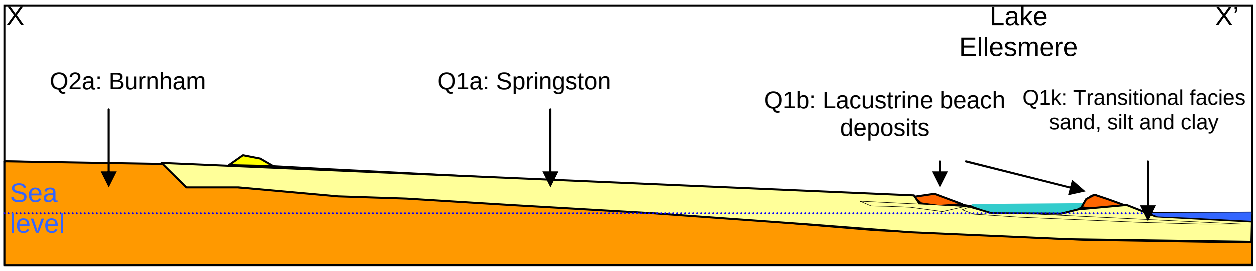

Figure 2-2: Schematic geological cross-section through the Southbridge area along line X-X’ in Figure 2-1, not to scale. (Source: Geological map data modified after Forsyth *et al.* (2009))

The geology of the Southbridge area is dominated by Quaternary alluvial gravel strata of different ages, which near the coast are interleaved with or overlain by marine and transitional facies strata such as dune sands, lacustrine beach gravels, peats, marine silts and clays.

The geology of the study area is characterised by thin surficial strata, called the Springston Formation, consisting of young, matrix-poor gravels laid down in post-glacial times by the Selwyn and Rakaia rivers (Suggate 1973, "Q1a" in Figures 2-1 and 2-2). Figures 2-1 and 2-2 are based on recently published electronic maps compiled by the Institute of Geological and Nuclear Sciences (Forsyth *et al.* 2009).

The Springston Formation gravels ("Q1a" pale yellow in Figure 2-1) may simply reflect re-worked older 'Burnham' gravels ("Q2a" orange in Figure 2-1) and are shown schematically in the geological cross-section in Figure 2-2. The Springston gravels contrast with those found at depth and elsewhere in the RSGAZ by containing less fine-grained interstitial silt and clay (matrix-material). Around Te Waihora / Lake Ellesmere, Christchurch Formation marine and transitional facies beach gravels overlie the Springston Formation gravels. Within and locally overlying the Springston Formation gravels are discontinuous layers and lenses of silt, sand, peat and clay ("Q1a", yellow and pale green in Figure 2-1), and are associated with coastline formation, or are deposits peripheral to and associated with the dynamic evolution of Te Waihora / Lake Ellesmere.

Figure 2-3 illustrates a distinction between Rakaia-sourced and Selwyn-sourced gravel strata in the area around Southbridge.

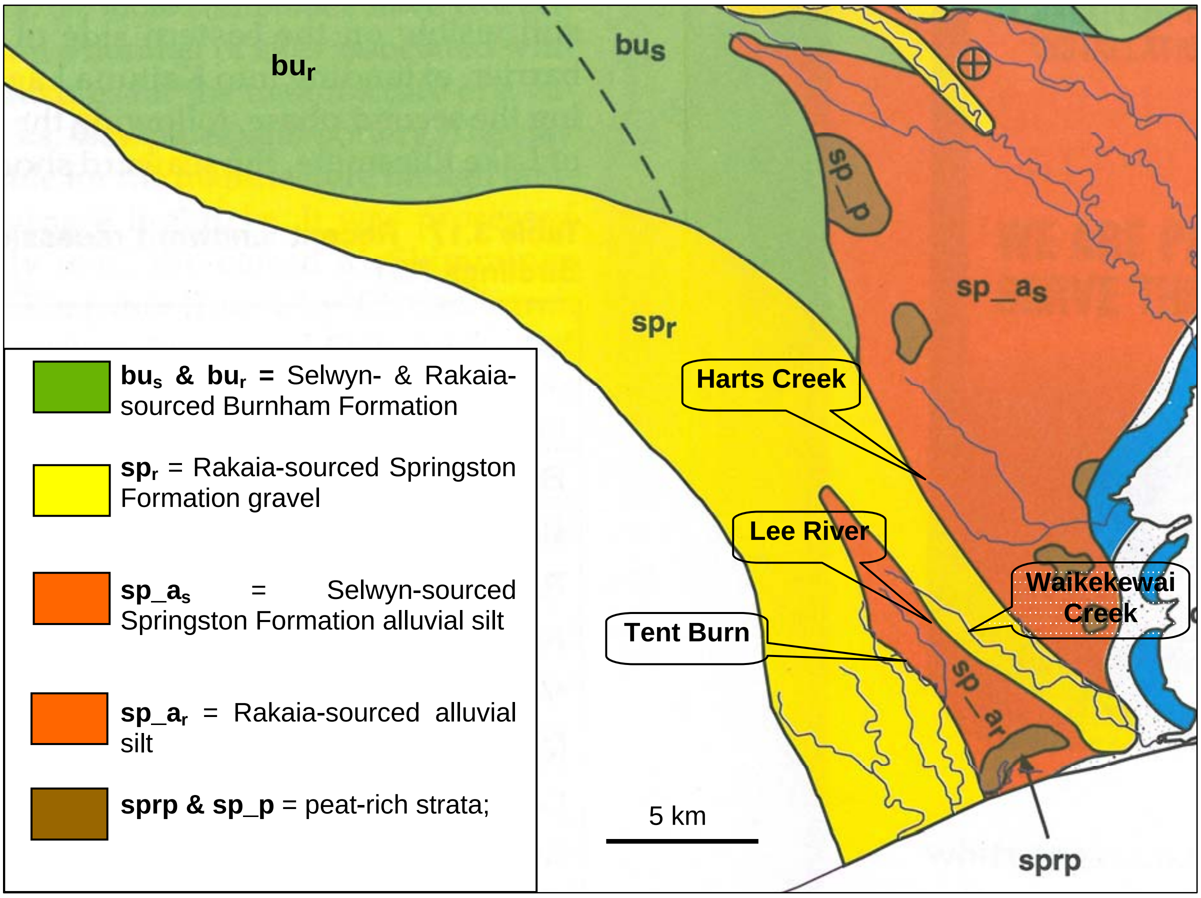

Figure 2-3: Geological map showing sources and type of sediment and distribution of spring-fed streams (modified from Figure 3.5 in Taylor (1996))

Comparison of Figures 2-1 and 2-3 indicates that the distinction of the Rakaia-sourced alluvial silt deposit (Figure 2-3: sp_ar) has not been made in the most recent GNS map (Figure 2-1). Later in this report (Figure 2-7) this silt deposit is identified as the area of relatively thick confining material between Waikekewai Creek and the Lee River. Much of the subsequent analysis in this report builds on work undertaken by Matthew Smith in 2000-1 (Smith, 2001), and Helen Grant in 2002-3 (Grant, 2003) in which they described the geological and hydrogeological features in some detail.

2.1 Geomorphology of the riparian zone

Topographic cross-sections, including the then understanding of the geology, are presented in Figures 2-4 and 2-5, modified after Bowden *et al.* (1983).

Figure 2-4 shows that the Rakaia River is elevated relative to the adjacent land in Section C-C', a coast-parallel line approximately two kilometres south of SH1. Further downstream (Section D-D'), the Rakaia River is lower than the surrounding land. Section D-D' is approximately coincident with Wabys Road, north of Southbridge. The Rakaia River is variably incised into its own deposits and is bordered on its northeast side especially, by relatively high land on which the town of Southbridge is located. These observations are consistent with the concepts advanced by Wilson (1973) and significant to the groundwater flow dynamics discussed later in this report.

Messrs Pat McEvedy and David Birkett and others in the Southbridge community refer to 'The Rise' being a subtle topographic feature whereby the elevation drops eastwards between Southbridge and Leeston. The major fall in elevation is around Pooles Road (just to east of the label "Southbridge" in D-D'). Line D-D' in Figure 2-4 indicates this change in slope and it appears coincident not only with the change from the undulating Rakaia braided fan deposits of the Springston Formation, and the underlying Burnham Formation, but also the appearance of many springs feeding the headwaters of Harts Creek and Birdlings Brook (Refer to Figure 2-7). This feature corresponds approximately with the continuation of the terrace feature to the northwest and is marked as a boundary between Rakaia-sourced and Selwyn-sourced alluvium of the Springston Formation (Taylor, 1996 - Figure 3.5, Wilson, 1973). Similar spatial relationships between springs and the peripheries of alluvial gravel fan lobes were noted in the Christchurch area by White *et al.* (2007). Unfortunately, the change in topographic expression across 'The Rise' is not discernable from the 15 metre pixel digital terrain model currently held at Environment Canterbury.

Figure 2-5 (Section E-E') shows the decline in ground elevation as the coast and Te Waihora / Lake Ellesmere are approached, with a significant reduction in the rate of decline just south of Southbridge, coincident with the post-glacial rise in sea level to a height of about one metre above current levels (Clement *et al*. 2008), a figure consistent with the maximum elevation of the base of onshore marine strata in the Te Waihora / Lake Ellesmere area.

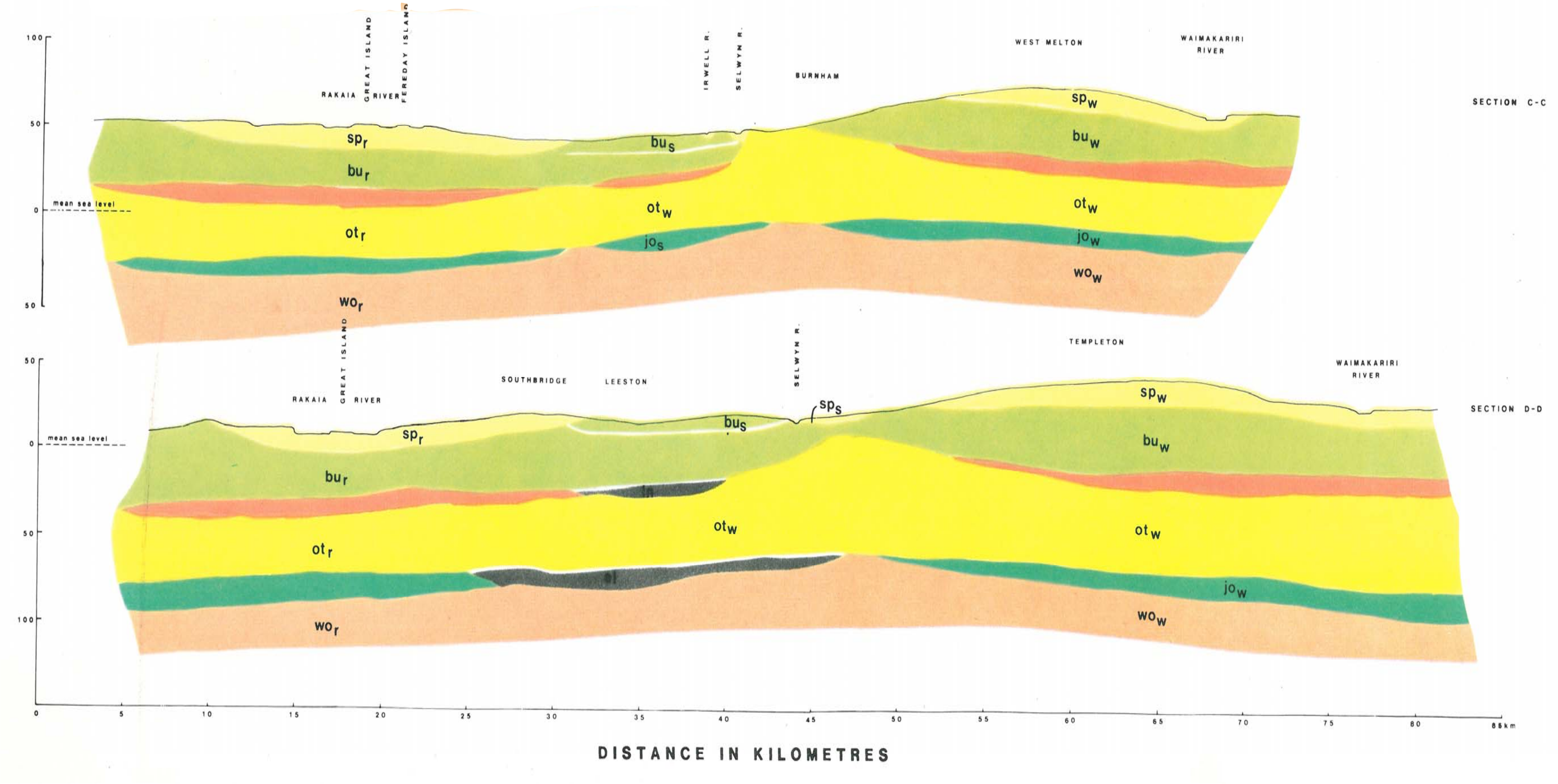

Figure 2-4: Topographic and geological cross-sections through the Southbridge area (Adapted from Bowden *et al.* 1983). Locations of sections described in text

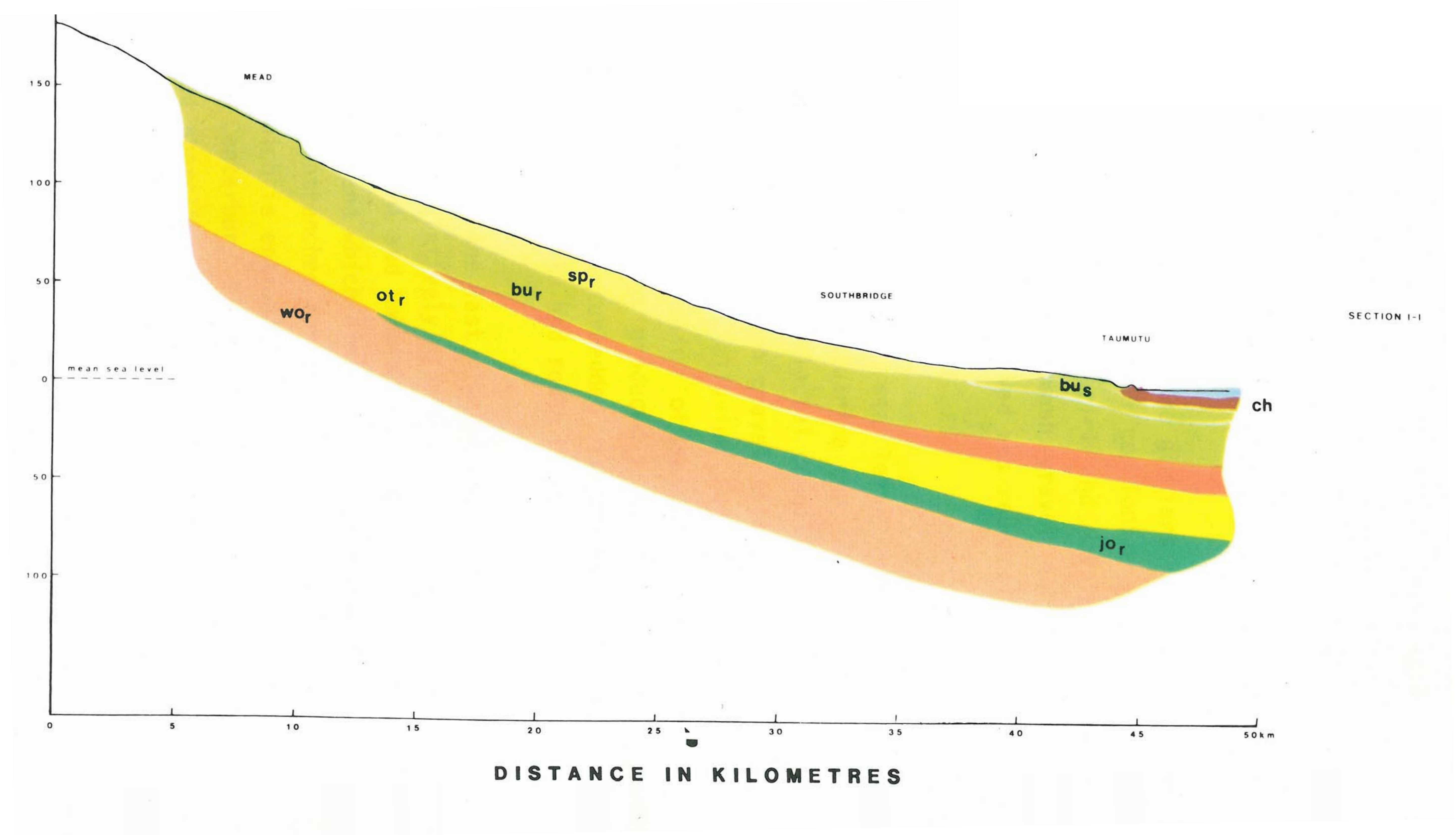

Figure 2-5: Topographic and geological long-sections through the Southbridge area (Adapted from Bowden *et al*. 1983)

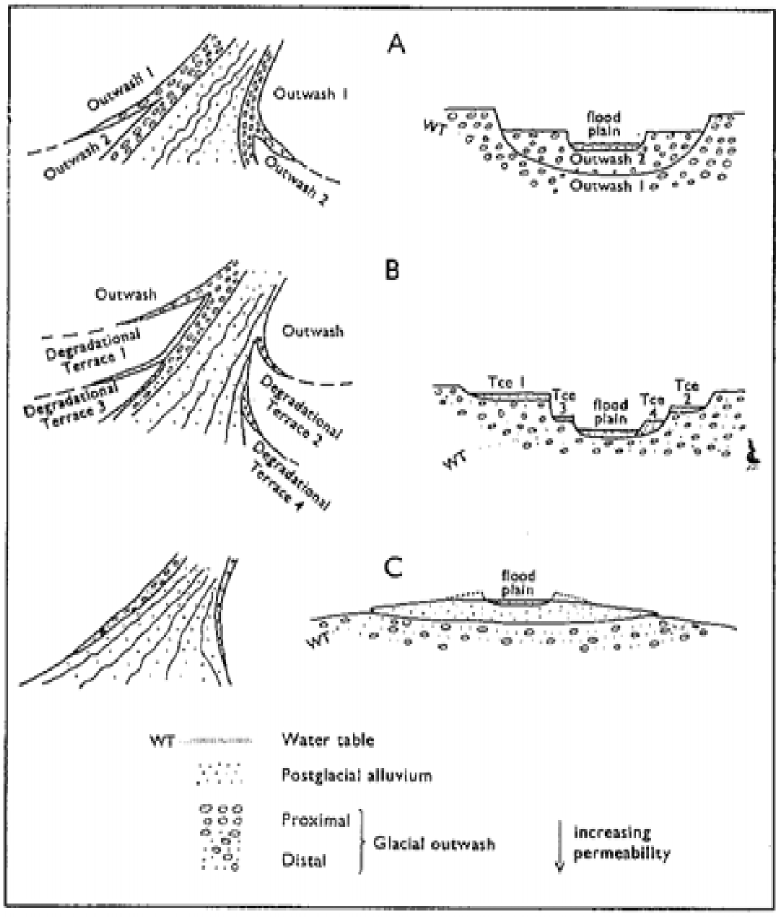

Figure 2-6: Diagrammatic representation of the relationship between terraces and aggradational fans (Wilson, 1973)

Figure 2-6 shows how terraces in an incised portion of the Rakaia River relate to the aggradational fan deposits close to the coast (Wilson, 1973; Wilson, 1985). The topographic expression of the contact between aggradational and earlier fan deposits and distinction between fans and reworked deposits as shown in Figure 2-6 (part C) can be subtle and difficult to map without techniques such as modal analysis of the compositions of gravel clasts. Wilson (1985) explained the ‘cut and fill’ relationships between terraces (cut) and aggradational fans (fill).

2.2 Geology and aquifer structure

This section assesses the aquifer structure on the basis of the geology derived from geological maps and from bore logs. The geology of the Southbridge area has been reviewed by Grant (2003), who undertook hydrological analysis and nominated a discrete area called the Little Rakaia Zone (LRZ). The LRZ appears to be contiguous with the larger groundwater system underlying the Canterbury Plains. The following description of the LRZ is largely derived from her report.

In the Southbridge area, especially close to the Rakaia River, there is a tendency for the gravels to have less matrix sand, silt and clay than elsewhere, and as a result hydraulic conductivities are greater. The reduction in fine-grained matrix material has been observed elsewhere close to major alpine rivers, and is thought to be due to the recent re-working of older gravel strata, with the winnowing out of fine material.

2.2.1 Inland aquifer structure

Inland, the regional aquifer system is characterised by thick sequences of gravel of various ages corresponding to glacial maxima. These display a poorly defined layering when exposed in river and coastal cliffs. Units demonstrated to be of widely different age commonly display different colour in outcrop, reflecting different stages of weathering. Although gravel-dominated sediment saturated with groundwater have traditionally been called 'aquifers', in fact, the calculation of leakage values from aquifer tests indicates that groundwater passes readily from shallow to deep strata, and vice-versa, over time frames of weeks and months (ECan, 2008b).

The strata are either continuous or lensoid structures (at kilometre scales) hydraulically connected through leakage, and considered integrated on a regional scale. Between these 'aquifers' there is little evidence for continuous fine-grained units; instead, fine-grained material commonly forms the matrix to the gravel strata (Davey 2006a and 2007). Therefore, in essence, these aquifers act as one anisotropic and heterogeneous hydro-stratigraphic unit (ECan 2009; Lough and Williams 2009).

2.2.2 Coastal aquifer structure

In contrast, along the coastal region, the "Q1a" gravels are variably inter-bedded with or overlain by fine interglacial marine and estuarine sediments locally forming a 'leaky' confined aquifer zone exhibiting significant vertical flow of groundwater ("Q1b" in Figure 2-1; Figure 2-2).

Note that these finer-grained layers appear to be absent or discontinuous in the area closer to the Rakaia River (within 5 km), probably because they have been partially removed by erosion associated with the northwards tracking of the Rakaia River (Figure 2-7).

Greater thicknesses of fine-grained material, causing locally semi-confined aquifer conditions in underlying strata, are visible in deep (>25 m) bore logs in the south-eastern corner of the LRZ. In the northwest portion of the Southbridge area there is no clear subdivision between gravel units; fine-grained layers are absent, delineation between gravel sediments of different age is problematic and has not been attempted. A recent review (ECan 2009) indicates that whereas the Springston and Burnham formations may be distinguished in their type sections using geological and geomorphological criteria, these formations cannot always be reliably distinguished, especially in drilling logs.

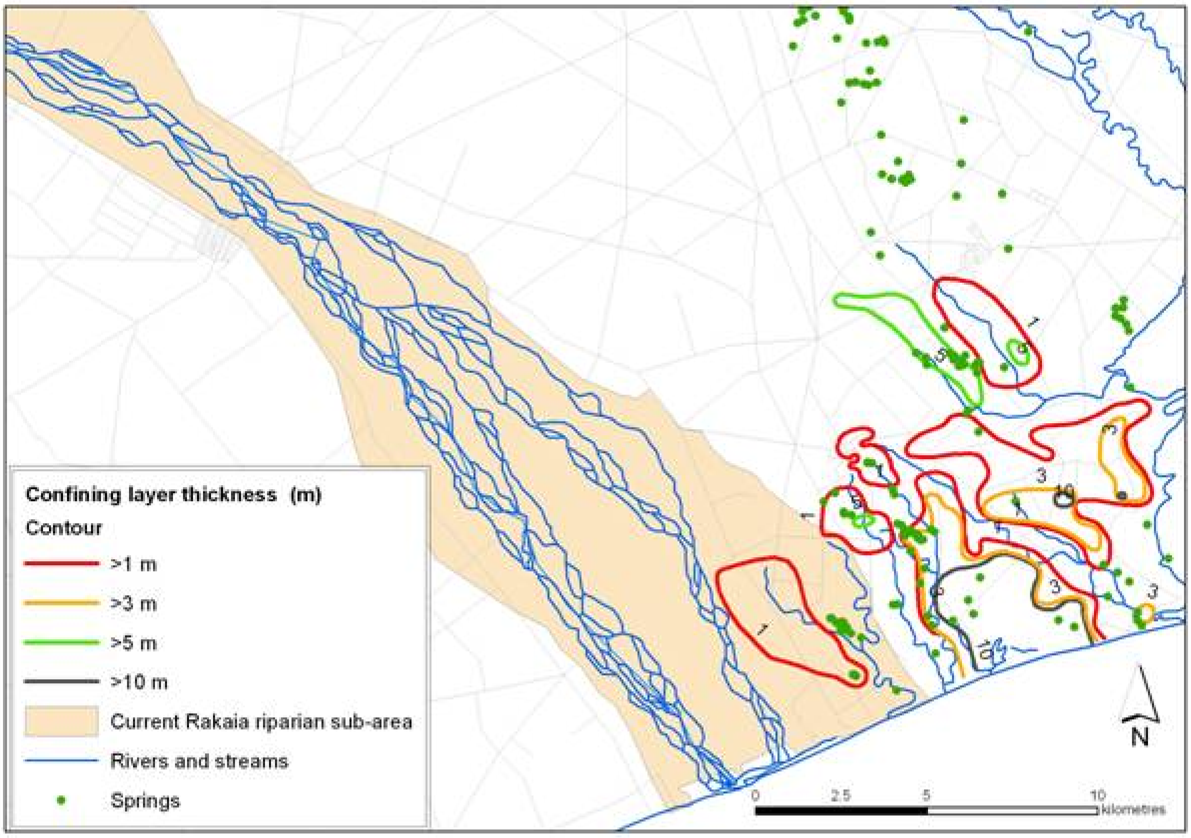

Figure 2-7: Map showing distribution of springs and uppermost confining strata in the Southbridge area

The uppermost strata present in the LRZ consist of surficial dune sand, and post-glacial alluvial sand and gravel and areas of overbank silty sediment, deposited by the Rakaia River. The silty material forms a discontinuous surface confining layer present in the LRZ and may locally be inter-bedded with estuarine/marine deposits (“Q1b” in Figure 1-1) towards the coast. Figure 2-7 illustrates the variability in thickness of this confining layer, from zero to ten metres, based on the few available cable tool bore logs.

Underlying any Q1b and Q1k surficial strata is gravel. Where fine-grained strata are absent, bore logs do not allow definition of geological and hydrogeological boundaries between near-surface reworked gravel strata (Q1a) and the underlying gravels (Q2a). Effectively then, the shallow gravel aquifer is comprised of gravel with some interleaved fine-grained strata, to a depth of approximately 30 m; while clean gravels in the northern and western portion of the LRZ, occur to a depth of approximately 25 m, below which are the older (Q2a bu) gravel units.

The shallow gravel aquifer in the coastal portion of the LRZ tends to be more sandy than strata further inland which contain both sand and silt as a matrix. The variable nature and presence of a fine-grained layer at or near the surface means that the shallow gravel aquifer responds in a leaky confined manner in some areas and as an unconfined system in others. Most bores in the LRZ abstract from the shallow aquifer because the strata are high-yielding.

In the area close to the Rakaia River, shown in Figure 2-7, the lack of laterally extensive confining layers in much of the Southbridge area means that most springs are of depression type[1]. Elsewhere, the marine to transitional facies confining layer (“Q1b” in Figure 2-1) induces artesian springs[2].

The presence of fine-grained layers and of clay-bound gravel at different depths in these gravel-dominated sediments means that aquifer properties vary from being unconfined to semi-confined. For example, near the coast, a two to three metre thick band of silt underlies the uppermost gravel aquifer, acting as a leaky confining layer. This silt layer can reach a thickness of up to ten metres, as shown on Figure 2-7, but is of local extent only.

Inland, the uppermost gravel strata are underlain by an approximately ten metre thickness of clay-bound gravels which retards but does not stop vertical flow of groundwater. This layer is between 24 m and 33 m below ground level, and is characterised by a notable absence of bore screens (Davey 2006b).

Near the coast and deeper than about 30 m, another gravel unit forms the second preferred zone of screening. Further inland, this screened zone starts at approximately 33 m depth, with a number of bores drawing from this aquifer between 33 m and 48 m. This deeper zone of high yielding gravel is not fully penetrated within the LRZ thus its thickness remains undetermined.

2.3 Geological cross sections

A regional scale geological cross-section has been presented as Figure 2-2, having an orientation approximately parallel with the sediment transport direction (normal to the coastline). While this section is useful to show the stratigraphic relationships between the major formations, it does not have the detail required to aid our understanding of the localised geology and aquifer structure.

Local geological cross-sections have been prepared, based on bore logs created by drillers. These illustrate the small-scale constraints on groundwater flow. Four separate geological cross sections have been created using ‘*xsect*’, an in-house program that creates bore logs from data recorded during the drilling of bores. The spatial distribution of the four sections is shown in Figure 2-8 (green lines).

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[1] Depression springs occur where the land surface and the water table intersect

[2] Artesian springs occur where pressurized groundwater issues at surface through a confining layer

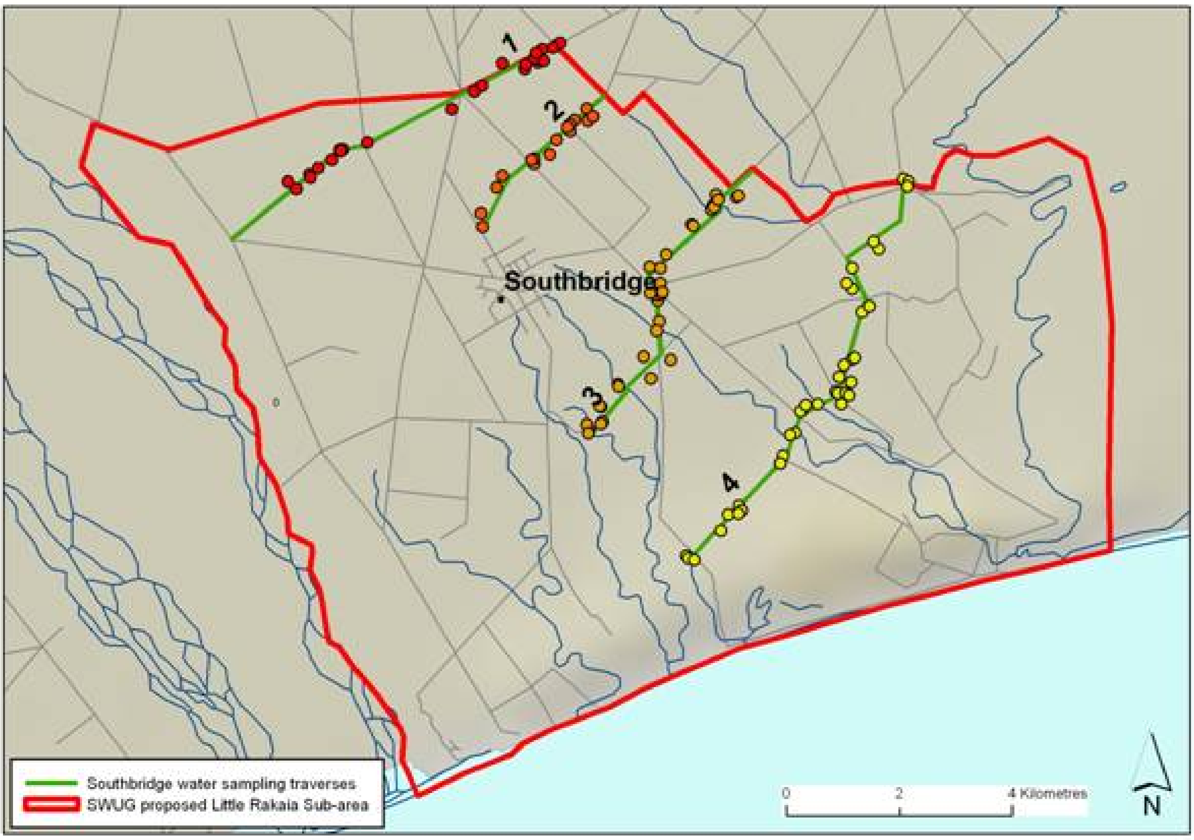


Figure 2-8: Part of the Southbridge area showing locations of traverses (green lines) used in compiling geological logs for creating cross sections and used as a basis for selecting groundwater samples (coloured dots), and the outline of the riparian area proposed by SWUG (red line)

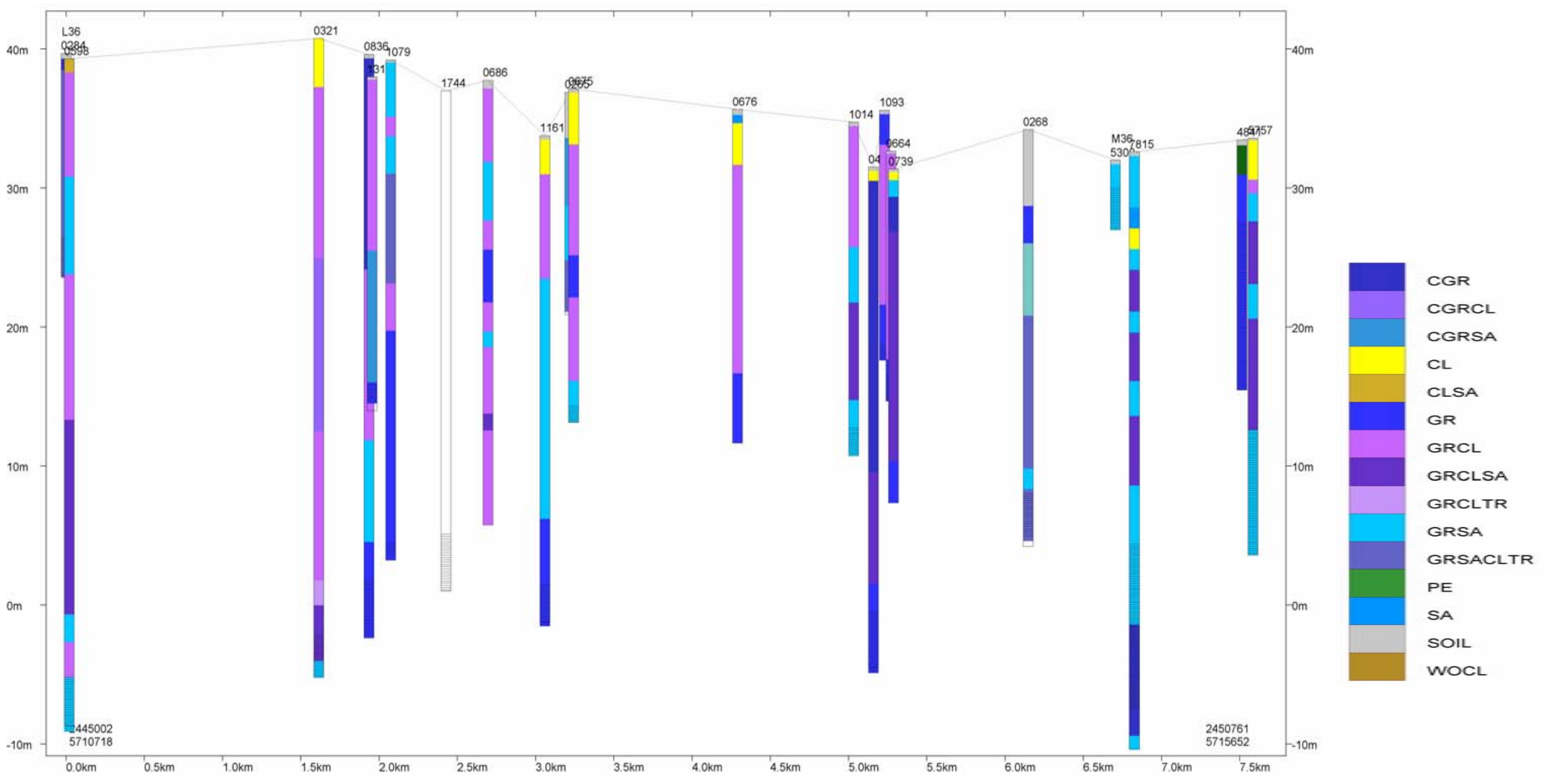


Figure 2-9: Geological cross-section Traverse 1 created from drilling logs from L36/0284 to M36/4723 (For the legend for this and following cross-sections: C=coarse; GR=gravel; SA=sand; CL=clay; TR=trace; PE=peat; WO=wood)

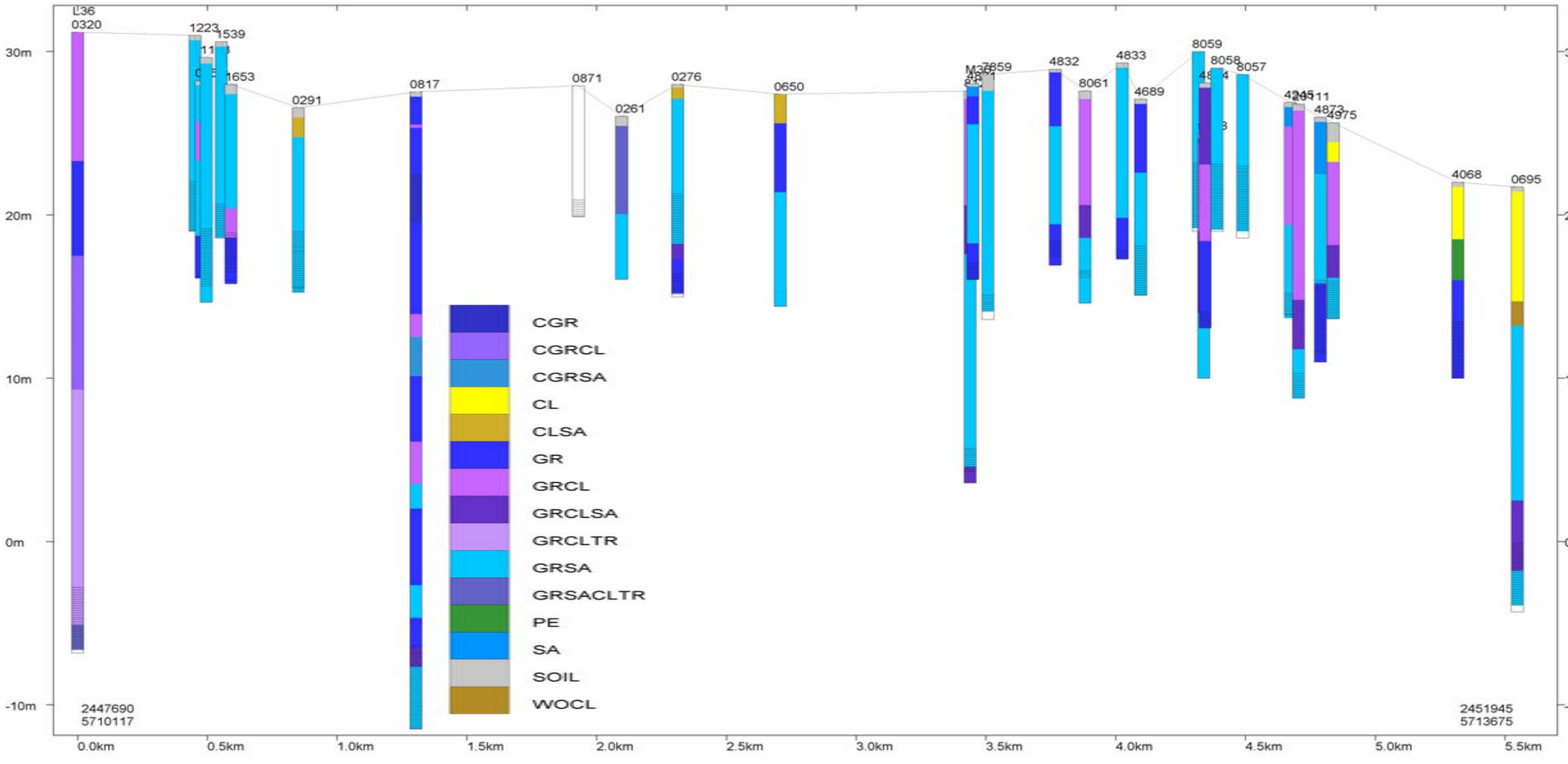


Figure 2-10: Geological cross-section Traverse 2 created from drilling logs from L36/0320 to M36/5991

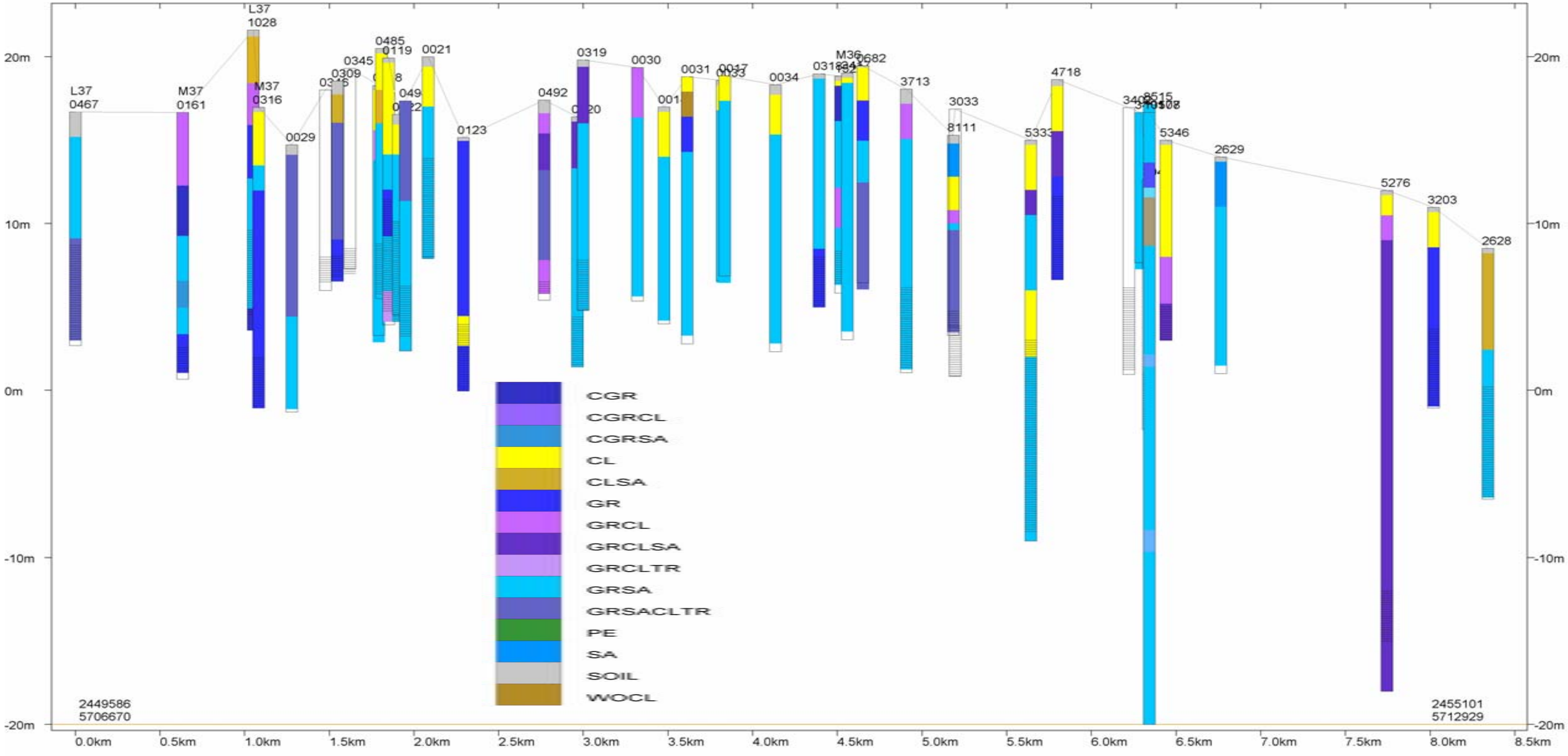


Figure 2-11: Geological cross-section Traverse 3 created from drilling logs fro L37/0467 to M36/5969

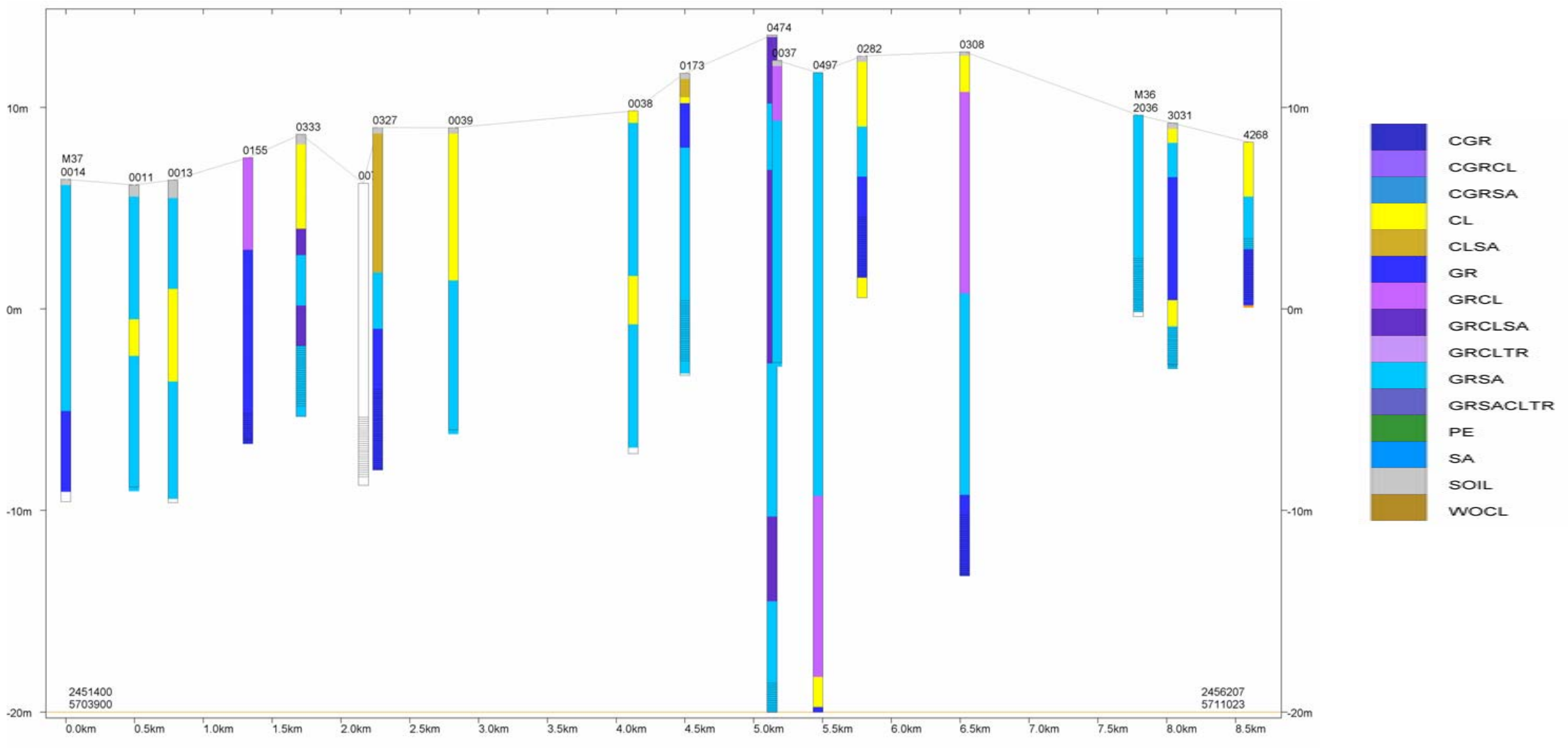


Figure 2-12: Geological cross-section Traverse 4 created from drilling logs from L37/0014 to M36/7871

The orientation of the sections was chosen to cross the boundaries marked on the geological maps (Figures 2-1 and 2-3) and illustrate what variation is apparent across the boundary between the current Rakaia riparian sub-area and the area proposed by SWUG, ending in the east within the RSGAZ. In Figures 2-9 to 2-12 the sections run from southwest (left) to northeast (right). The purpose of these cross-sections is to allow assessment of the geological controls on groundwater flow. Figures 2-9 to 2-12 are indicative of the geological variability determined from logs.

2.3.1 Bore log results

The following key observations have been noted from examination of the four cross-sections:

- There are no laterally continuous layers along any traverse. This is to be expected in a high energy fluvio-glacial to alluvial depositional environment of coalescing gravel / sand fans (Ashworth *et al.* 1999; Leckie 2003; Shulmeister 2007).
- Numerous clay layers (yellow in cross-sections) exist, exhibiting limited lateral continuity. In cross section traverse 1, the clay layers are all very thin and shallow. However, as the cross sections are traced closer to the coast more clay and silt (brown in cross-section) layers exist, and they may occur at greater depths, creating a network of leaky confined aquifers and lower-yielding sediment. These finer-grained sediments could lead to the development of artesian pressures which locally exist in the southeast of the study area.
- There is also a trend towards coarser matrix to the gravels in a southeast direction (sand rather than silt).

The cross section represented by Traverse 1 contains predominantly clay-rich gravels, whereas towards the southeast the sediments are predominantly sandy gravels. Too few data are currently available to determine whether this is a consistent change and whether it would provide a technical justification for delineating a boundary based on aquifer or geological properties. Use of an alternative data viewing tool, allowing three-dimensional imaging, is demonstrated in Section 2.6.

2.4 Correlation between strata

The drilling log data presented in Figures 2-9 to 2-12 show little tendency for sedimentary strata to be reliably correlated from bore to bore. A few bores contain strata that may be matched with strata in adjacent bores, continuous for a kilometre or two, but the general picture is one of discontinuous lenses, rather than continuous layers. This observation is important in understanding the constraints on groundwater flow. These observations are consistent with cross-sections drawn by Anderson (1994).

2.5 Confining layers

The bore log transects also show that laterally continuous confining layers of silt or clay are uncommon (yellow and pale brown colours in Figures 2-9 to 2-12). What is more, the confining layers are localised and thinner to the northwest, thicker towards the coast.

2.6 Representation of 2-D and 3-D geological data

Applied Research Associates New Zealand Ltd (ARANZ) provided Environment Canterbury with a visualisation tool (Earth Research), undergoing development. The tool enables the production of geological cross-sections, oblique views and interpolation of surfaces. These maps, cross-sections or slices through the data (Figures 2-13 to 2-16) are easier to analyse than the traditional approach shown in Figures 2-9 to 2-12.

The ARANZ visualisation tool creates interpolated volumes by joining up distributed occurrences of a specific lithological type or range. A map of the spatial distribution of silt- and clay-bearing strata, at any depth in each log, is shown as Figure 2-13. Note in Figure 2-13 that the incidence of fine-grained strata, associated with transitional or marine facies sedimentation, increases coastwards. Note also that Figure 2-13 broadly corresponds with Figure 2-7. The occurrence of silt offshore is an artefact of the process by which the computer surface was created.

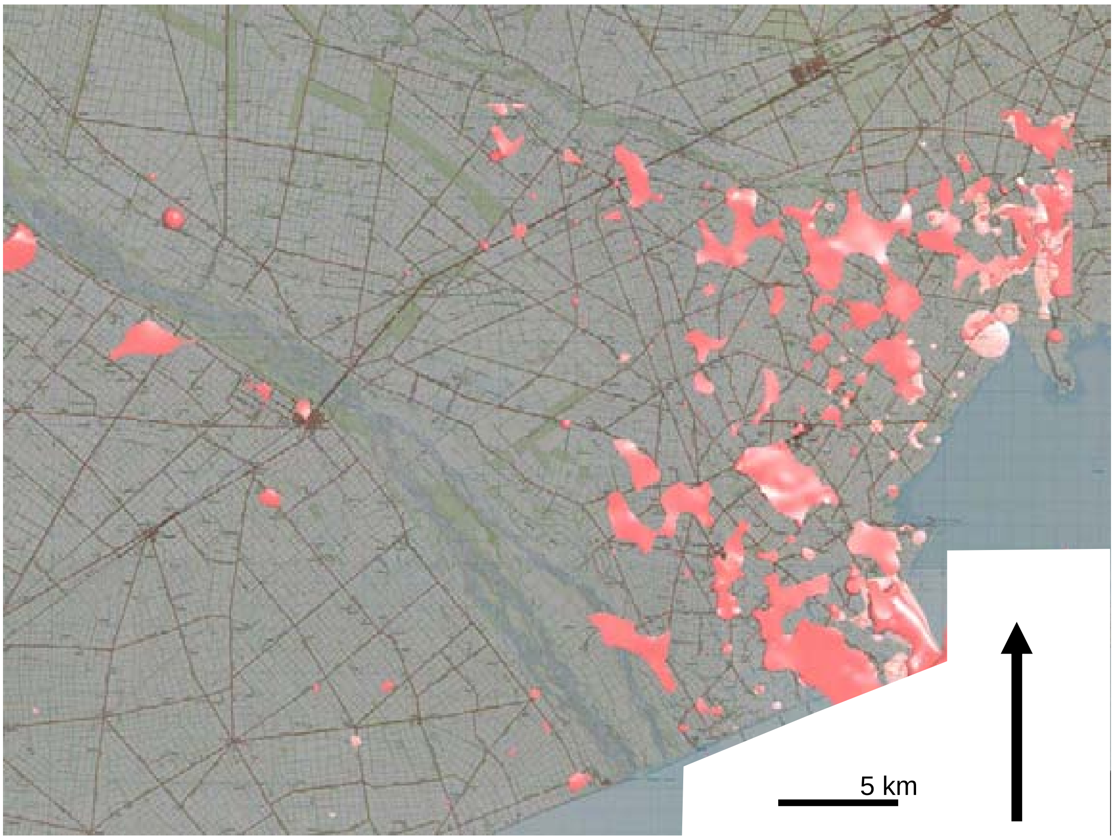


Figure 2-13: Map showing distribution of silt (pink) in bore log data for the Southbridge area

Figure 2-14 shows a cross-section of the well log data looking northeast at a slice paralleling the Rakaia River near Southbridge. Portions of the logs containing silt, clay, organic materials and silt-bound gravels are shown in shades of pink. Variation in the pink colour relates to the presence of an illumination effect to enhance the three-dimensional aspect. Note that although there is a tendency for some lateral continuity of logs close to the coast, inland, any distinction into layers becomes minimal.

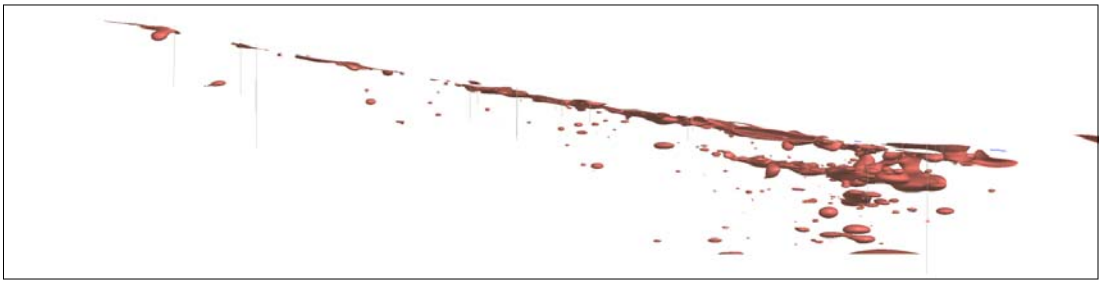


Figure 2-14: 2-D cross-sectional view of silt-bearing strata (red shapes) in the Southbridge area looking from the southwest

Figure 2-15 shows a cross-section of the well log data looking southeast at a slice paralleling the coast near Southbridge. In this figure, a larger buffer has been created around individual occurrences of silt in bore logs, with the result that a more continuous volume has been created. The red colouration indicates the outside of a volume containing silt-bearing strata, blue colours are simply the inside of a volume seen where it is cut by the section plane.

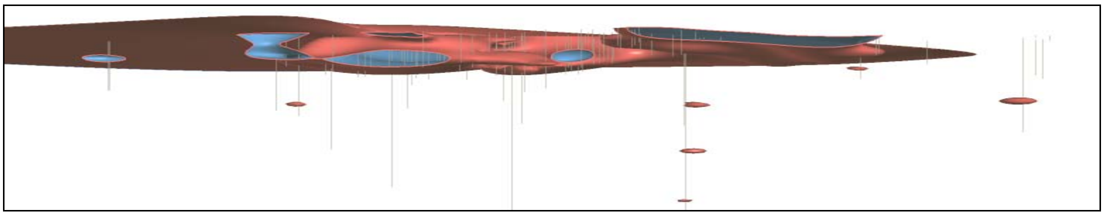


Figure 2-15: 2-D cross-sectional view of silt-bearing strata in the Southbridge area looking down the fan to the southeast

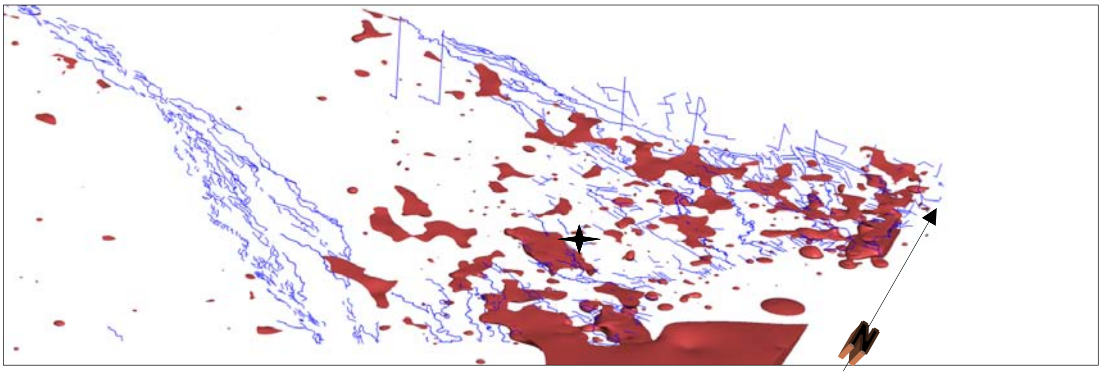


Figure 2-16: 3-D oblique view of model of the area around Southbridge (located at cross) looking down from the southeast, compare with Figure 2-12

Figure 2-16 is an oblique view of the Southbridge area, looking towards the northwest from near the coastline. Silt-bearing strata are coloured dark pink and their patchy distribution indicates the lack of lateral continuity. This means that water-bearing 'aquifer' strata are vertically well-connected. The apparent occurrence of silt extending into Te Waihora / Lake Ellesmere is based on few data and is in part an artefact of the shape-generating process.

2.7 Sedimentological conceptual model

Fieldwork and physical modelling indicate that the Canterbury Plains were constructed of gravel that was largely deposited during flood events when rivers burst their banks and spread aprons of coarse, grading to fine material as the flood developed and waned (Ashworth *et al*. 1999). Successive floods removed much of the alluvial fine-grained material prior to the deposition of gravel-dominated debris. As a result, the preservation potential for fine-grained strata on the alluvial fans is minimal. Near, or at the coast, marine or transitional facies silt and clay are preserved, but the patchy lateral extent of these units is consistent with the formation of low energy sedimentary conditions behind coastal bars or dunes, or beside 'switching' river systems. Figure 2-13 illustrates that the maximum lateral continuity of fine-grained strata is generally less than five kilometres.

Field studies also indicate that post-depositional processes, involving movement of groundwater and seepage of surface water into the groundwater system, transported fines to the extent that matrix to the gravel becomes clay rich (Davey 2006a). Cross-cutting patches of clay-rich material forming a matrix to gravel is visible in natural and man-made sections, for example along the cliffs to the west of the mouth of the Rakaia River.

Whereas the great proportion of the alluvial material is composed of gravel, there has been considerable post-depositional modification of the gravel, with infilling or clogging of pore space with clay, a process caused by the downwards infiltration of rock-flour laden surface water from the alpine rivers.

The occurrence of 'open' gravels close to the Rakaia River is in large part due to the local reworking of older Burnham gravels by the river. This reworking removes much of the interstitial silt and clay, leaving behind the coarse, open-textured material. The hydrogeological significance of this reworking will be described and explained in Section 4.

2.8 Structure of the riparian zone

Topographic and geologic evidence are consistent with the structure of the riparian sub-area as a thin sequence of recently-reworked alluvial gravel strata lying above non-reworked Burnham gravel fan strata. The coastal part of this zone also contains discontinuous fine-grained units that locally retard groundwater flow.

This distinction in topography, geological age, and lithological constitution, supports recognition of a discrete groundwater management zone for this area, bounded to the east by the small but relatively abrupt fall in land surface elevation to the east of Southbridge, representing the contrast between Rakaia-sourced gravels to the west and Selwyn-sourced alluvium to the east.

The geological and topographic distinction used as a boundary criterion by Ettema and Earl (2005), especially along the upstream portion of the riparian zone, is a well-marked terrace that decreases in height south-eastward. At Bankside, this terrace is only three metres or so in height, decreasing to one metre at Heslerton Road, southeast of which it effectively disappears. This terrace edge increasingly departs from the Rakaia River and becomes an inappropriate marker for a riparian zone. Therefore I recommend that the boundary is unchanged from its current location in the area north of Feredays Road. East of Southbridge there is a subtle distinction between aggradational gravel deposits to the west and Selwyn-sourced alluvial strata to the east (Figures 2-2, 2-3 and 2-4). I have used this distinction to delineate the eastern boundary of the riparian zone in that area.

2.9 Conclusions on geology

I have reached the following conclusions from an analysis of the geological data presented in this section:

- the eastern boundary of the riparian sub-area inland of state Highway 1, based on the locus of the lower terrace scarp, does not require change;
- on the coastal side of State Highway 1, a gradually diminishing terrace edge scarp is less easily mapped when traced to the southeast, becoming un-mappable east of Heslerton Road. This outer scarp, representing the northern limit of reworking of the Rakaia fan gravel sequence, is not an appropriate edge to the riparian sub-area; and
- from State Highway 1 south-eastwards, to east of Southbridge, the boundary of the riparian zone is coincident with a geological boundary representing the eastward margin of the most recent reworking of Rakaia-sourced gravels (Figure 2-3), locally coincident with the topographic contrast known as 'The Rise'.

3 Surface water hydrology

This section of the report describes the distribution and flow series of the Rakaia River and adjacent spring-fed streams that characterise the area around Southbridge (Waikekewai, Lee River, Tent Burn, Jollies Brook, Harts Creek, and Birdlings Brook, locations shown on Figure 3-1).

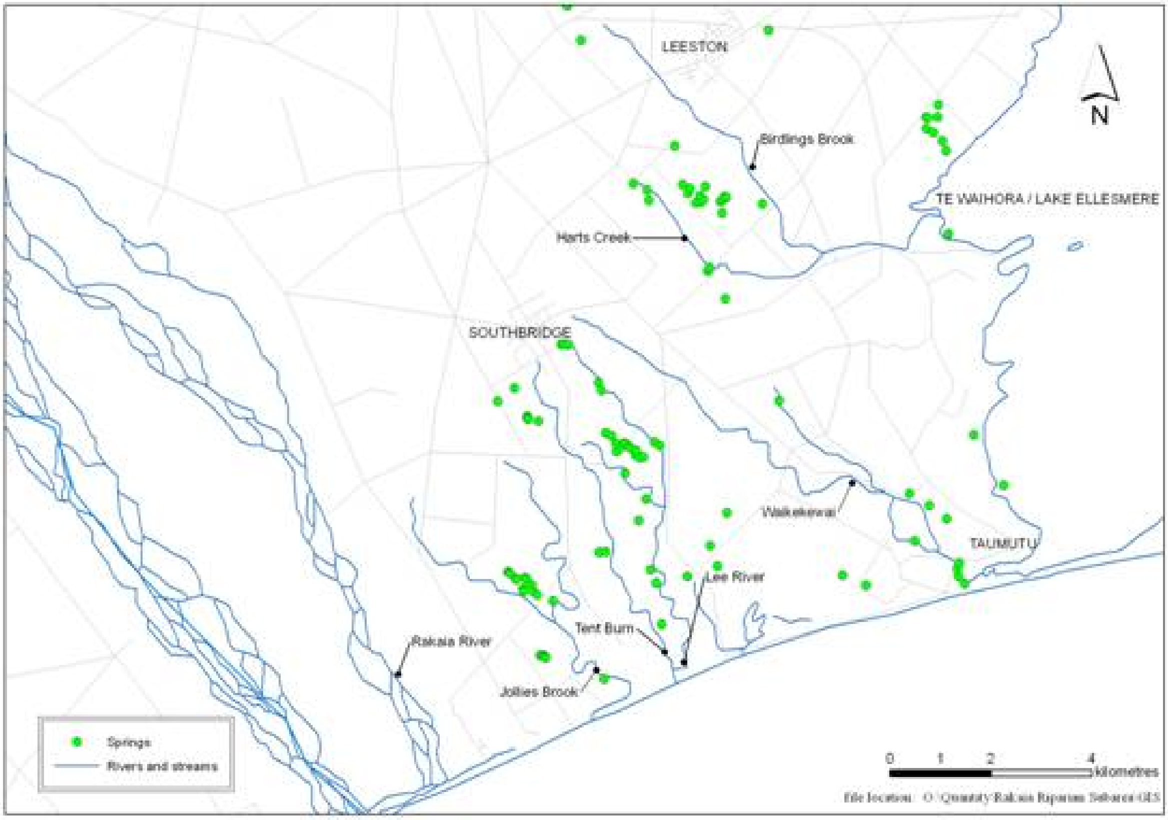


Figure 3-1: Map of the Southbridge area showing locations of streams, springs and places cited in text. Some springs occur on un-marked streams and drains

3.1 Catchment boundaries

Catchment boundaries for the surface water system are presented in Figure 3-2. These boundaries represent the topographic subdivision of the drainage system, in part controlled by artificial drains or enhancements of the natural network or stock water races (Rakaia water race system: pink). Natural or modified spring-fed lowland stream catchments are depicted in pale green. Also shown on Figure 3-2 are the surface water-sourced irrigation schemes in medium green.

Groundwater catchment boundaries, if indeed such exist in reality, are not necessarily spatially coincident with surface water catchment boundaries. The implication of this statement is significant: it means that individual streams do not necessarily source water from well-defined zones up-gradient. Even if they did, the boundaries of such zones would migrate somewhat according to the resource state.

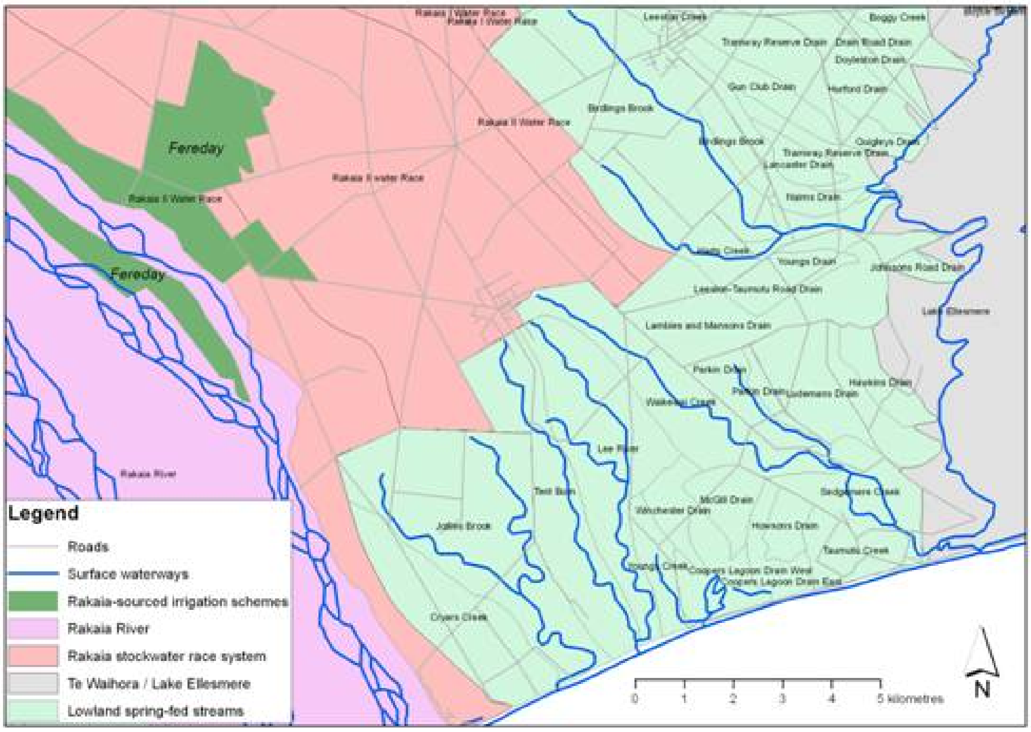


Figure 3-2: Catchment map of the Southbridge area

3.2 Analysis of surface water flow data

Surface flow data have been assessed for time series trends and seasonal variation (Figure 3-3). In Figure 3-3, for comparative purposes, the smoothed monthly dryland surface rainfall recharge volume in millions of cubic metres (green line) is also shown. Most of the flow data are simply spot gaugings, although continuous monitoring of the Lee River commenced in 2007. Flows in the Rakaia River have been continuously monitored at Fighting Hill since December 1978 and smoothed flow data are shown in Figure 3-4.

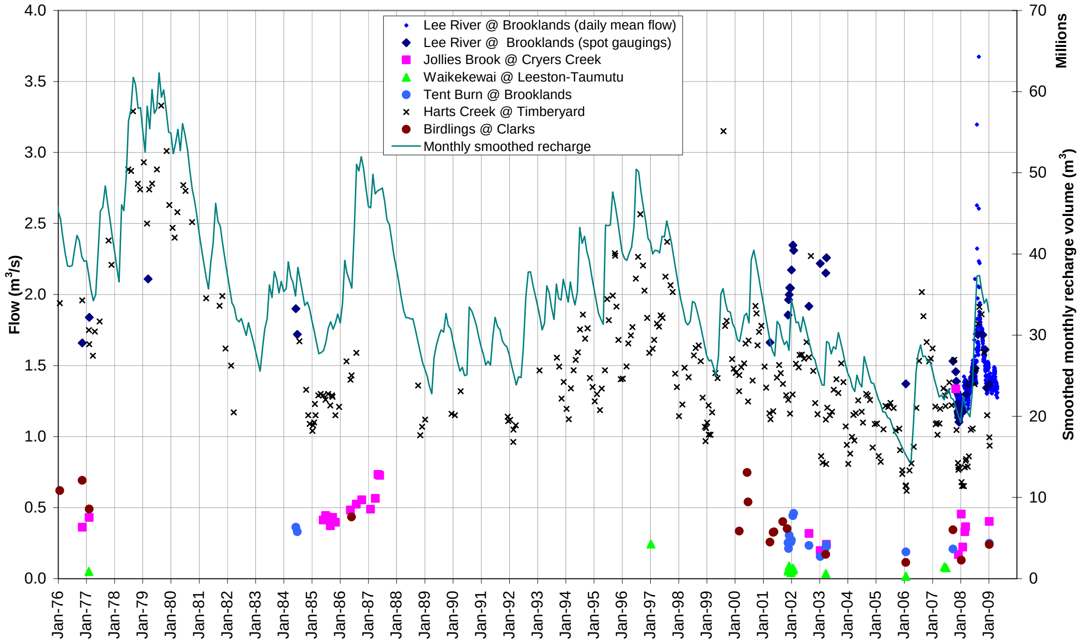


Figure 3-3: Flow plots for Harts Creek, Birdlings Brook, Waikekewai, Jollies Brook, Tent Burn, Lee River and smoothed RSGAZ monthly rainfall recharge

In Figure 3-4, the smoothed Rakaia River flow is developed from an exponentially weighted moving average whereby more weight is given to previous results than the current result. This smoothing has the effect of removing sudden peaks and troughs and gives a better indication of the general pattern of flow though it does not take into account the variability associated with the Highbank hydro-electric station discharge.

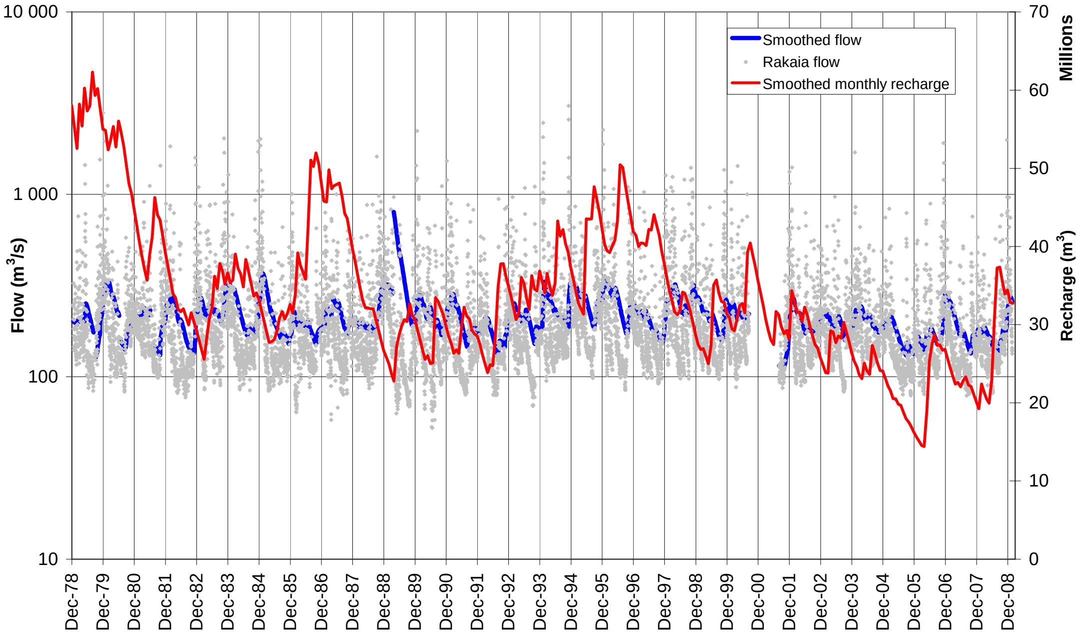


Figure 3-4: Time series plot of flow in Rakaia River (note logarithmic scale) and corresponding smoothed monthly rainfall recharge volume for the RSGAZ

Williams *et al.* (2008) demonstrated the consistent relationship between the total rainfall recharge to groundwater in the RSGAZ and the discharge from that zone in the form of flow in Harts Creek. This is a cause and effect relationship, the rainfall input to the groundwater system correlates with an output in the form of flow. If, in the Rakaia riparian sub-area, this relationship is not seen, or is weaker, then the implication might be that the recharge to that zone is less controlled by rainfall.

To this end, the recharge signature for the RSGAZ is added to the time series plots (Figures 3-3 and 3-4) for comparison. Williams *et al*. (2008) showed that there is a strong correspondence between the Harts Creek flow and the calculated smoothed monthly rainfall recharge data (Figure 3-3). There are insufficient data to show that there is a relationship between recharge and the other spring-fed streams. In contrast, there is little, if any correspondence between flow in the Rakaia River and rainfall recharge to the RSGAZ, as would be expected for an alpine river that is fed from rainfall and snowfall distant from the plains environment.

Flow in Harts Creek is largely related to groundwater levels in the area up-gradient of its headwaters (Williams and Aitchison-Earl 2006). However, at low flows, Harts Creek is remarkably persistent and this is in marked contrast to other spring-fed streams, such as the Irwell and Boggy Creek. Harts Creek may receive a small and possibly constant quantum of groundwater sourced from the Rakaia River, reducing its dependency on rainfall recharge.

Plots of flow in the Rakaia River (Figure 3-4) and in the adjacent spring-fed streams such as those in Figure 3-3 have been prepared, but no clear or consistent relationship exists between their respective flows. Streams that discharge directly into Te Waihora / Lake Ellesmere have been subject to analysis by Clausen and Horrell (2007); their mean discharge data are used in the water budget section of this report.

There is a broad similarity between the flows in Harts Creek and those in the Lee River (Figure 3-5). There is, however, a difference at low flows such that Harts Creek tends to fall further during the summer/irrigation season than the Lee River. This phenomenon is consistent with the Lee River flows being bolstered by seepage from the Rakaia and from border strip irrigation, processes less likely in

Harts Creek that is further from the Rakaia River and not directly down-gradient of the Northbank Irrigation Scheme.

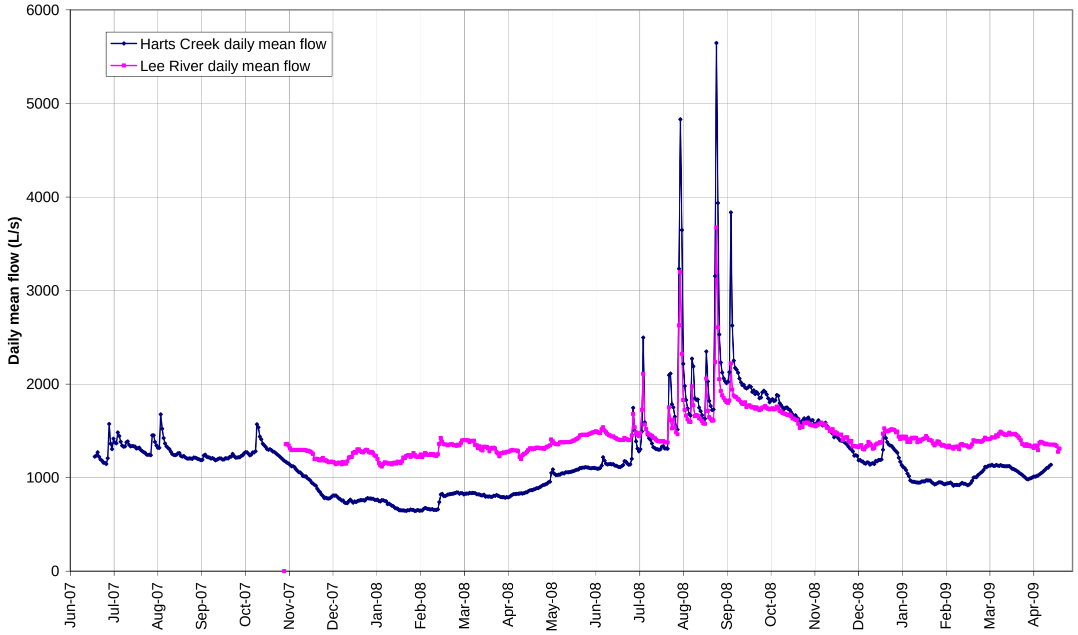


Figure 3-5: Comparison of daily mean flows in Harts Creek and Lee River

These issues will be revisited in Section 4 while looking at the relationship between groundwater levels and the recharge signature.

3.3 NIWA report on low flows – habitat assessment

A NIWA report (Booker and Graynoth 2008) identified minimum flows for a number of waterways in the Southbridge area based on fish habitat assessment alone. The report was produced without reference to existing minimum flow reviews based on an expert panel approach that considered not only habitat, but other parameters, such as cultural, traditional, landscape and aesthetic values.

The report recommended that: "*minimum residual flows in accordance with the values associated with each site and physical habitat modelling*" gave the following results as presented in Table 3.1:

- 0.3 m^3/s for Birdlings Brook at Locheads Road;
- 1.25 m^3/s for Harts Creek at Timberyard Road;
- 1.5 m^3/s for the Lee River at Brooklands.

These recommended minimum residual flows at the studied sites matched closely with estimated naturalised 7-day mean annual low flows (MALF) documented by Facer and Horrell (2002).

On the basis of the modelling, the report also recommends, in the absence of alternative methods, that minimum residual flows for similar sites, where physical habitat modelling was not applied, be set in accordance with estimates of naturalised mean annual low flow:

- 0.4 m^3/s for Jollies Brook at Bullocks Road;
- 0.1 m^3/s for Taumutu Creek at the beach; and
- 0.3 m^3/s for Tent Burn at Brooklands.

3.4 Minimum flow assessment

Minimum flows have been determined using an 'expert panel' approach for streams in the Southbridge area (Miller 2006). These flows may be compared with those recommended in the NIWA report (Table 3.1) and current minimum flows as shown on the Environment Canterbury website and proposed in Maw (2008).

Table 3.1: Minimum (residual) flows as determined from expert panel and habitat assessment methods

Waterway	NIWA residual flow (m^3/s)	Current minimum flow (m^3/s)	Proposed minimum flow (m^3/s)	7 day MALF (m^3/s)
Birdlings Brook	0.3	0.2	0.115	0.345 ± 0.062
Harts Creek	1.25	1.0	0.6	1.282 ± 0.034
Taumutu Creek (Waikekewai)	0.1	0.16	0.12	0.109 ± 0.060
Jollies Brook	0.4	0.36	0.23	0.464 ± 0.027
Tent Burn	0.3	-	0.18	0.321 ± 0.042
Lee River	1.5	0.7	1.3	1.704 ± 0.072
Source of information	*Booker & Graynoth (2008)*	*ECan website (Feb 2009)*	*(Miller 2006)*	*ECan, cited in Booker & Graynoth (2008)*

3.5 Rakaia River flow

Flows in the Rakaia River are dominated by summer snow melt and ‘northwest’ rainfall (Figure 3-4), giving rise to summer peaks in the flow regime, with winter lows (NCCB 1983b). In addition, there are short-lived variations in flow due to the activities of hydro-electric power schemes at Lake Coleridge. The Highbank power station does not have significant storage and operates as a run-of-canal system.

A plot of actual and smoothed flow is presented in Figure 3-4. Note the timing of maximum seasonal flow is generally mid-summer, representing a combined snow melt and northwest rainfall source.

According to NCCB (1983b), losses of river flow from the Rakaia River to the groundwater system are small between the gorge and SH1, increasing downstream of SH1. In some areas the loss is evident from examination of the relationship between the flow and groundwater levels in adjacent wells (see Section 4), but the primary information on this process comes from concurrent flow gaugings which separate out seepage upstream of SH1 and that downstream. NCCB (1983b, page 64) states that the seepage from the river, upstream of SH1, ranges between 10 and 25 m^3/s, with a mean loss of 22.9 m^3/s, some of which is retained within the channel gravels. Such measurements of flow loss are inherently uncertain; Scott and Thorpe (1986) state that “*it is not usually possible to directly assess whether the loss is to the left bank* (NE side)*, the right bank* (SW side) *or merely underflow within the river bed gravels*...”. Scott and Thorpe (1986) also state that it is likely that seepage from the river only occurs down-gradient of a line between Te Pirita and Barrhill. Probably half of the loss occurs upstream of SH1 (Table 3.6: Scott and Thorpe 1986).

In contrast, seepage from the river into the left bank unconfined aquifer downstream of SH1 may be less than 5 m^3/s as can be verified by groundwater monitoring and chemistry (Sections 4 and 5). Scott and Thorpe estimated that the equivalent flow across the true right bank to be 3 to 8 m^3/s. Grant (2003) reported on concurrent gaugings on the north channel of the Rakaia River, indicating losses from the river in the range of 100 L/s/km to 400 L/s/km. This could translate to a total loss from just the North Channel of between 1.5 to 6 m^3/s, which is within the range of earlier predictions. There is a significant groundwater-sourced irrigation system on Rakaia Island which, because of hydraulic connection, could account for some of the losses in the north channel.

Observations along the cliffs on the south side of the Rakaia River just downstream of the gorge indicate that the river is gaining a very small amount of water from groundwater. By analogy, not observation, it seems reasonable that a similar process occurs on the north side, but any groundwater seep is obscured by vegetation and by the absence of steep, exposed cliffs on this side of the river. However, further downstream, gauging data (NCCB 1983a & b) and the shape of groundwater contours (Figure 4-4) together indicate that the river loses water to the adjacent groundwater system.

Tracer experiments in the vicinity of Rakaia Golf Course by Scott and Thorpe (1986) indicated that the underflow is in the order of 10 to 20 m^3/s, representing a significant loss from the river, but that not all of this loss becomes actual recharge to the aquifers on each side of the river.

The range and uncertainties in these numbers are such that calculation of anything more than a conceptual water budget is unwise without further data on sub-coastal discharge and seepage flow from the Rakaia River.

3.6 Conclusions on surface water hydrology

I have reached the following conclusions from an analysis of the surface water flow data:

- the regime of Rakaia River flows bears no relationship with rainfall recharge on the adjacent Rakaia-Selwyn Groundwater Allocation Zone;
- there is a closer relationship between the Lee River and the smoothed rainfall recharge signature than with flows in the Rakaia River;
- there are currently insufficient flow data measured in the small streams such as Tent Burn and Jollies Brook to demonstrate a relationship between their flows and that of the Rakaia River;
- there is no consistent relationship between the flow in Harts Creek and the corresponding flow in the Rakaia River, although at low groundwater levels Harts Creek flow is remarkably persistent, in contrast to other spring-fed systems. This persistence may be ascribed to a flow component derived from Rakaia-based recharge;
- there is continuing uncertainty about the magnitude and location of seepage from the Rakaia River into the adjacent groundwater systems. Concurrent gauging runs have indicated that the Rakaia River may lose between 10 and 25 m^3/s, with a mean loss of 22.9 m^3/s, with slightly less than half of this amount occurring between the gorge and SH1;
- the destination of this seepage is arguable; some would say that it simply remains as underflow, occasionally re-appearing in the river or, contributing to the large-scale groundwater systems on both sides of the river;
- tracer experiments indicate that although much water is lost from the Rakaia River, by no means all of it ends up recharging aquifers; and
- concurrent gauging runs indicate that the Rakaia River probably loses between 5 and 10 m^3/s between the SH1 and the coast and that this seepage is likely lost to the general groundwater system evenly on both sides of the river.

4 Groundwater hydrology

This section of the report describes the groundwater system in terms of groundwater levels, groundwater flows, springs, the relationship between groundwater levels and stream flows, between groundwater levels and flows in the Rakaia River, and aquifer properties. The location and depth of bores is shown in Figure 4-1.

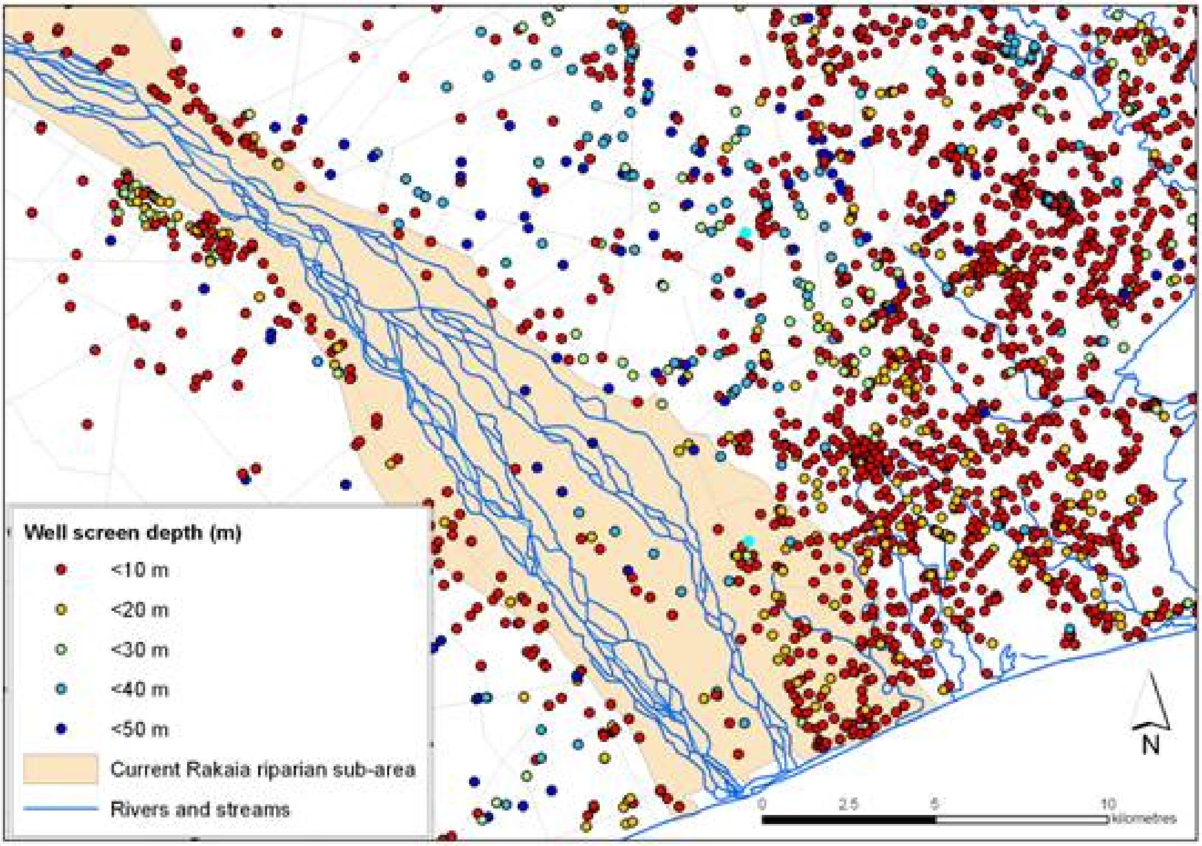


Figure 4-1: Map showing bore location and depth to topmost screen

The topmost screen depth varies greatly over the entire RSGAZ, but is generally shallow near the coast and along the Rakaia River.

4.1 Depth of bores

Bores drilled to access groundwater for domestic and irrigation use are the main source of information about groundwater levels and their variation in space and time. Figure 4-2 illustrates the contoured distribution of the topmost well screen depth for wells in the area. Note that well screens are generally shallow in the area adjacent to and north of the Rakaia River, except where deeper wells have been screened to lower the degree of hydraulic connection between the well and the river (e.g. on Fereday and Rakaia islands).

The generally shallow depths of bores within the sub-area contrasts with the depth ranges in the remainder of the RSGAZ (brown colours in Figure 4-2). The generally shallow bore screen depths (green areas) are explained as a function of the relatively high bore yields for low drawdowns (high specific capacity), and high groundwater levels. Elsewhere in the RSGAZ, yields and specific capacities are generally lower, and up-gradient, groundwater levels become increasingly deep with the result that deeper bores are required.

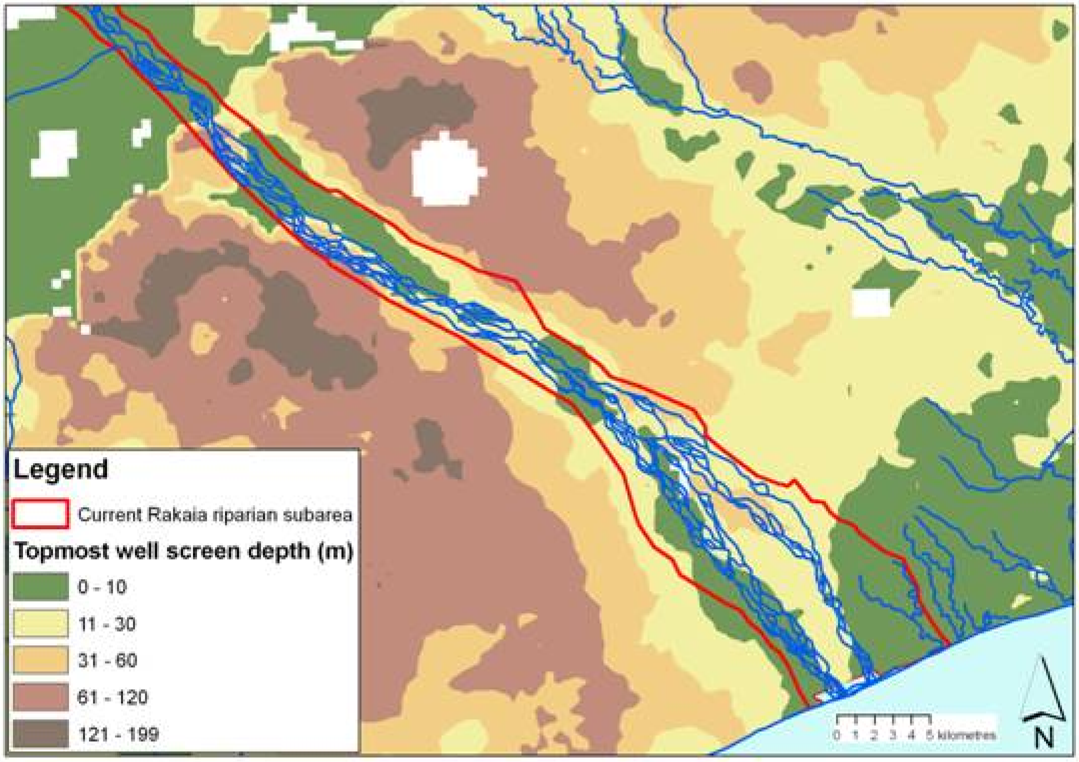


Figure 4-2: Map showing contoured topmost well screen depth and Rakaia riparian sub-area

4.2 Springs

Numerous springs in the Southbridge area also result from the shallow and unconfined nature of the groundwater (Figure 4-3).

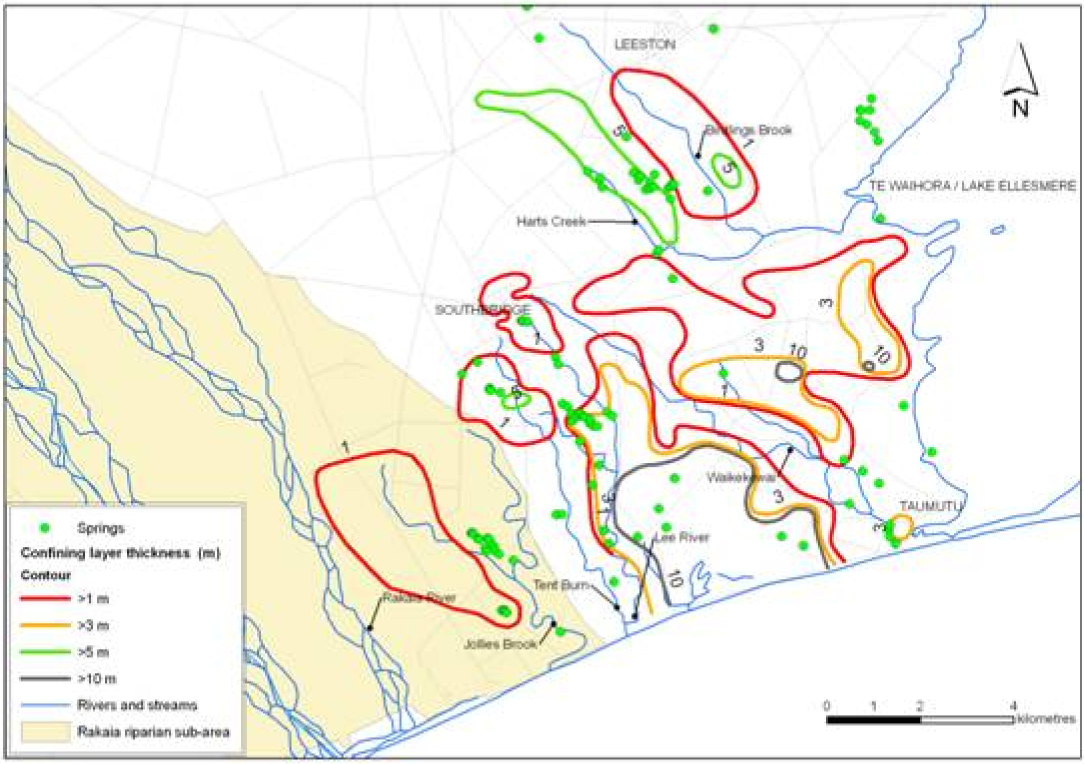


Figure 4-3: Map showing spring and confining layer distribution

Figures 2-7 & 4-3 show the distribution of confining strata and contours of its thickness (isopachytes). Many springs occur within the distribution of these mapped confining layers but most have not been defined in terms of spring type. Those springs spatially associated with Jollies Brook and the Tent Burn are probably depression springs, the remainder are more likely to be artesian springs. In many cases, springs form the headwaters of, or contribute flow to the streams.

The spatial distribution of springs with the streams and with drains that may represent small, straightened streams, signifies that the stream flows are likely to be largely dependent upon groundwater levels. This topic will be described in more detail later in this section.

4.3 Groundwater levels: spatial and temporal distribution

Contoured groundwater levels within and adjacent to the Rakaia riparian sub-area are shown in Figure 4-4. Levels are generally high close to the river, and to the coast, falling away as the distance from the Rakaia River increases, especially in the part of the sub-area greater than 8 km north of State Highway 1 (Main South Road), which is incised within the alluvial fan deposits.

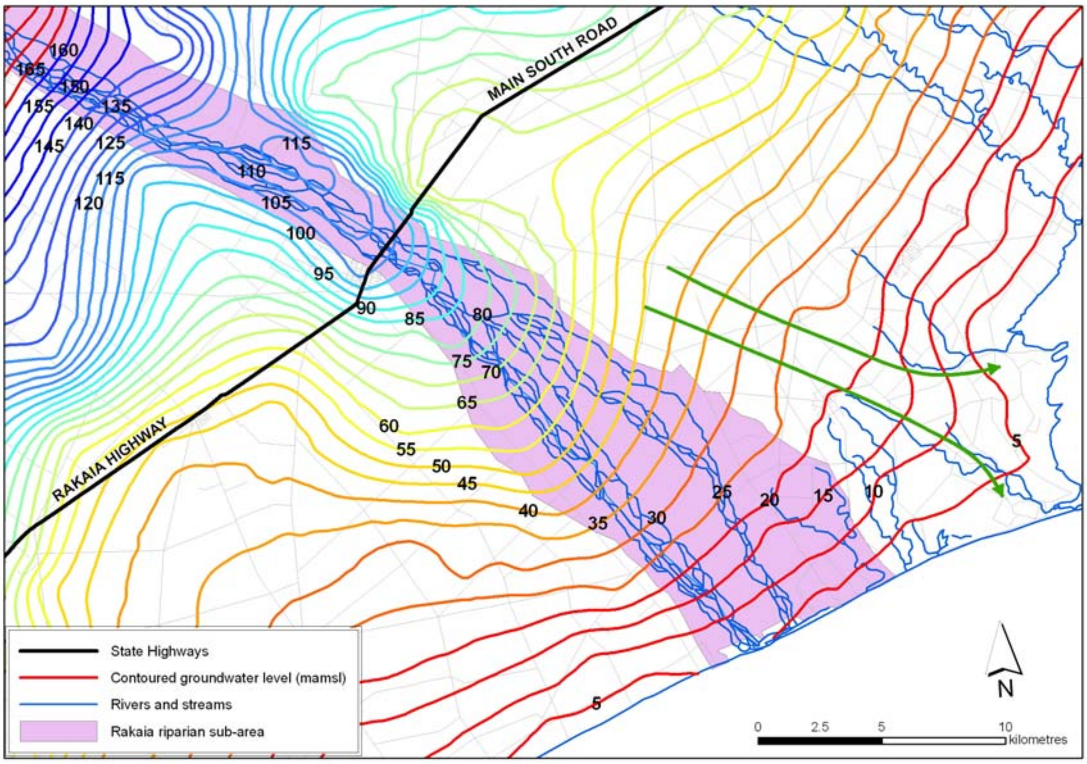


Figure 4-4: Rakaia riparian sub-area (current) coloured pale purple, showing groundwater levels contoured in metres above mean sea level recorded in wells; also shown are two indicative arrowed groundwater flow lines (green)

Figure 4-4 shows the effects of river water loss, causing the seaward bulge in the regional-scale contour pattern in the centre of the map, beginning about 8 km northwest of SH1. This bulge dissipates south-eastwards and is not apparent near the coast where piezometric pressures are controlled by sea level. It is useful to compare this figure with detailed data illustrated in Figure 4-6 and Figure 4-7. The intensity of the bulge is a measure of the magnitude of seepage loss from the river into the adjacent groundwater system. Figure 4-4 also contains two groundwater flow lines showing the groundwater divide between flow derived from rainfall recharge and that derived, at least in part, from the Rakaia River.

4.3.1 Spatial distribution of groundwater levels in the Southbridge area

More recent, and more dense monitoring data are available within the Southbridge portion of the riparian sub-area, allowing the spatial distribution of groundwater levels to be fully described by Grant

(2003), with maps showing how groundwater levels differed at two periods (Figures 4-5 and 4-6). The following is an extract from her report.

"*Two piezometric surveys were carried out over the LRZ to determine the direction of, and seasonal variations in, groundwater flow. The surveys involved the measurement of groundwater levels in 132 wells (124 shallow aquifer, eight second aquifer). ... The first survey was conducted from 27-29 August 2002, prior to irrigation abstractions, and the second from 2-4 April 2003, immediately after a period of heavy rainfall and the cessation of irrigation. The measuring point of each well was also surveyed using differential GPS to determine the elevation of groundwater above mean sea level.*

The results of the pre-irrigation season survey are shown in Figure 2.5 [Reproduced here as Figure 4-5]*. The general flow direction in the shallow aquifer is northwest to southeast, for the most part following the slope of the land, but swinging around toward the Rakaia River in the upper LRZ (although the accuracy of the contours here is decreased due to a lack of data points in the northern end of the zone). This flow pattern shows the Rakaia River as a major source of recharge for the shallow aquifer system.*

The results of the post-irrigation season survey are shown in Figure 2.6 [Reproduced here as Figure 4-6]*. Even though this survey was conducted only four days after the cessation of most irrigation there is little difference in flow patterns or groundwater levels over most of the LRZ. Figure 2.7* [Reproduced here as Figure 4-7] *shows the difference in the water levels between August and April. The most noticeable feature is the effect of irrigation recharge in the upper LRZ from upstream border-dyking."*

The results of this detailed piezometric work indicate that in the main, the Rakaia River controls groundwater flow in the area, that there is little difference between pre- and post-irrigation period levels, and what differences there are may be ascribed to the effects of surface water-sourced irrigation. Note that the third figure in this series was developed by calculating the difference between the two interpolated surfaces, along with their inherent uncertainties. Notwithstanding this, the pattern of differences is consistent with some recharge sourced from the Rakaia River and some sourced from the Northbank Irrigation Scheme.

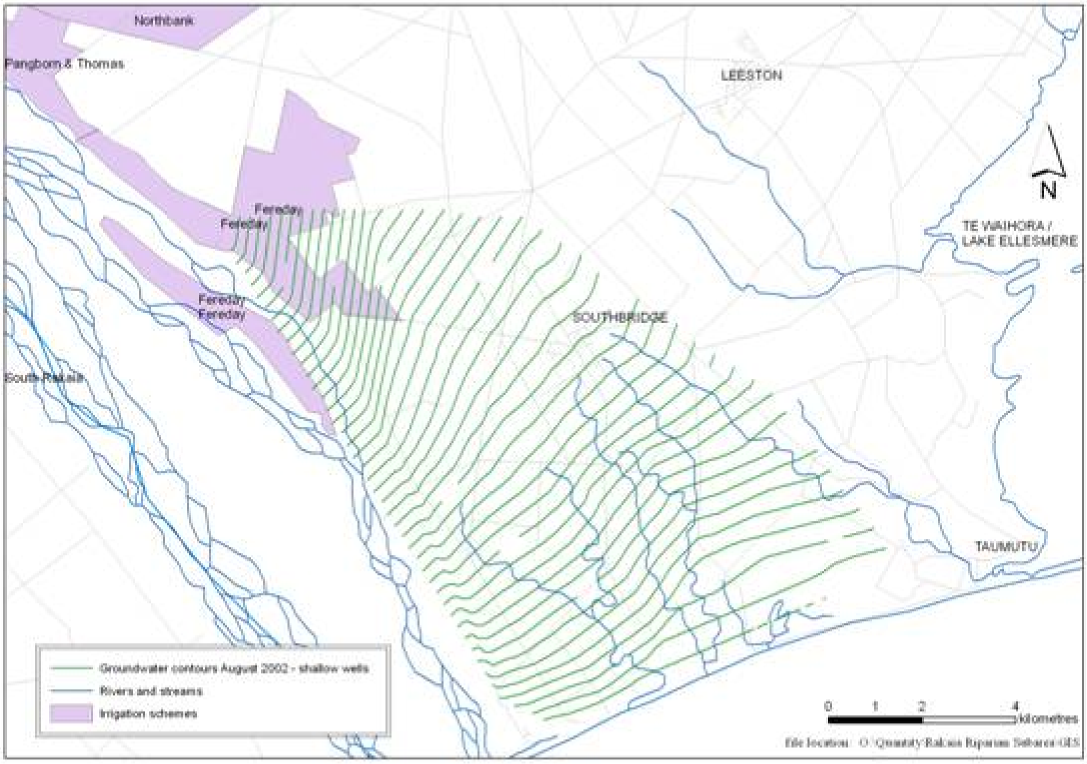


Figure 4-5: Map showing distribution of August 2002 groundwater levels at one metre intervals above mean sea level (modified from Grant 2003)

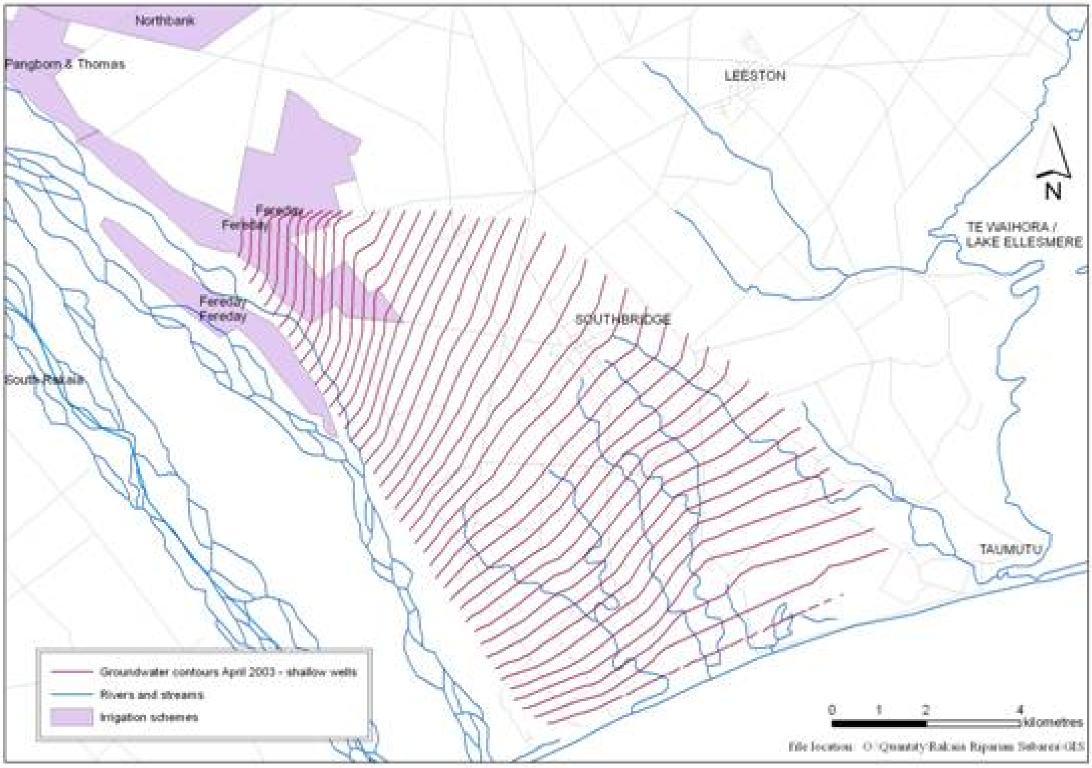


Figure 4-6: Map showing distribution of April 2003 groundwater levels at one metre intervals above mean sea level (modified from Grant 2003)

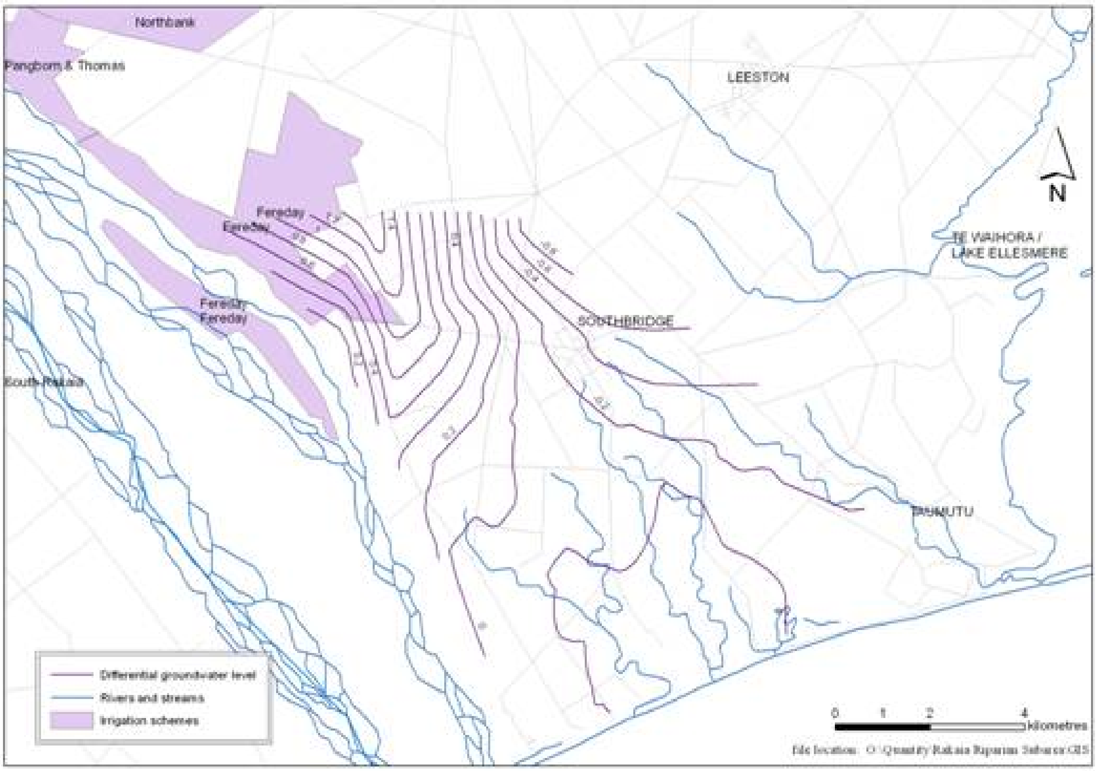


Figure 4-7: Distribution of differences between August 2002 and April 2003 levels, contoured at 0.2 metre intervals (modified from Grant 2003)

4.3.2 Temporal trends in groundwater levels

Analysis of time series of groundwater levels to May 2009, has been undertaken to produce monthly time series for a number of Environment Canterbury monitoring wells whose locations and depths are shown in Figure 4-8.

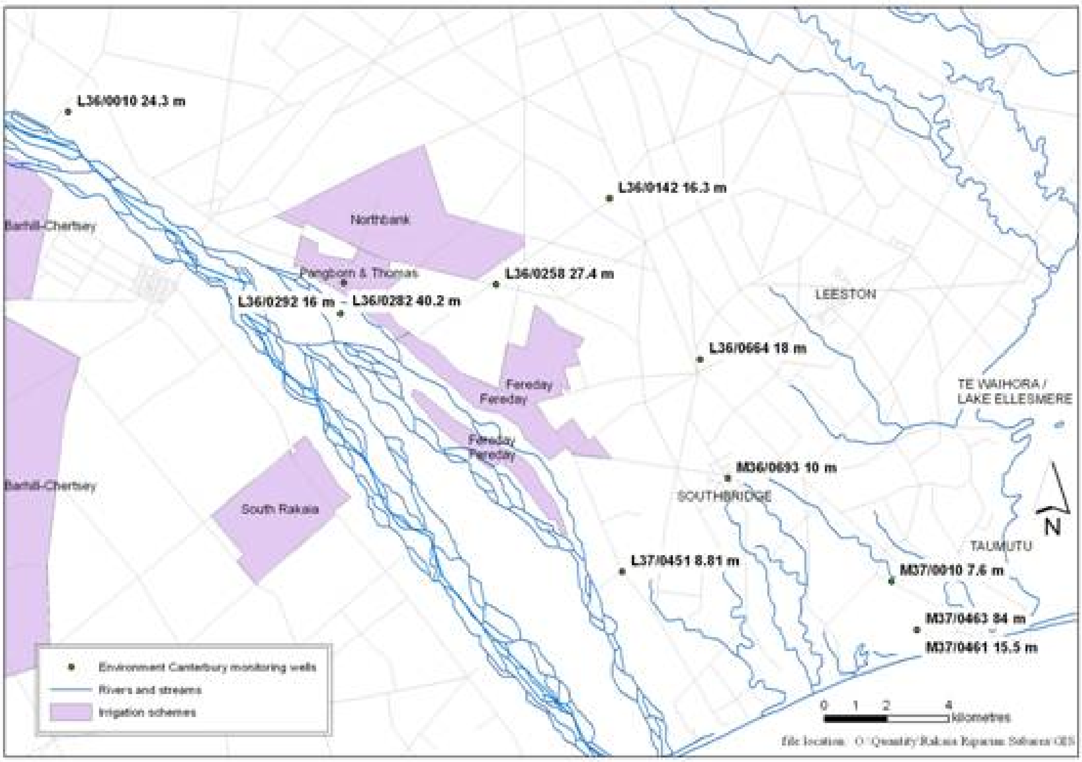


Figure 4-8: Map showing locations of Environment Canterbury monitoring wells used to determine temporal variation in groundwater levels

Time series plots of groundwater levels for ten wells are presented in Figures 4-9 and 4-10.

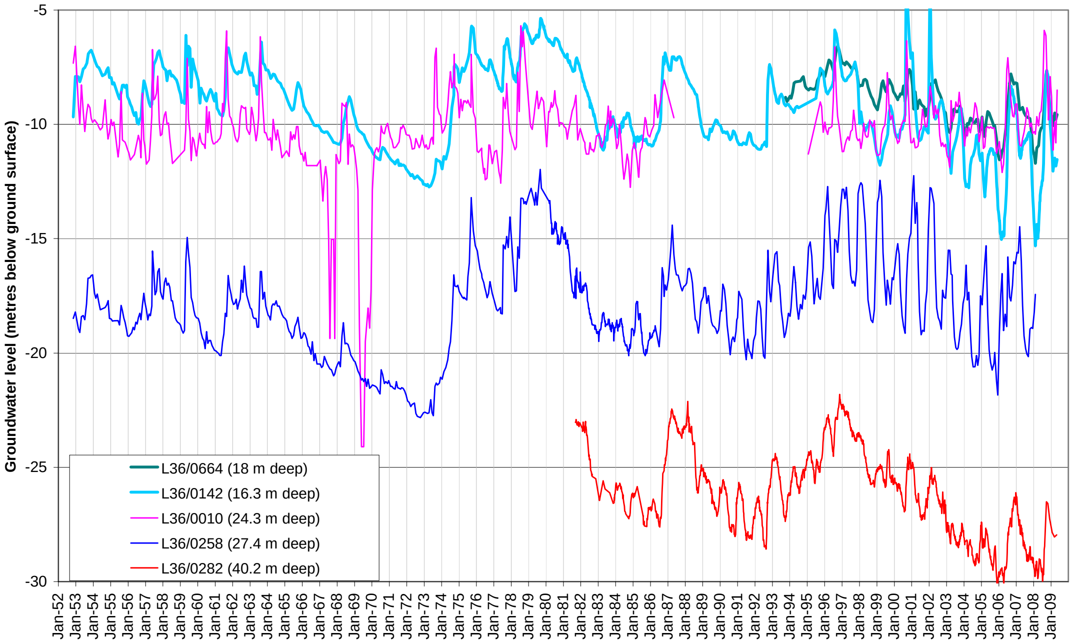


Figure 4-9: Time series plot of Environment Canterbury monitoring wells

Figures 4-9 and 4-10 show differing behaviour for wells of differing location and depth. Reviewing this variation, using the statistical relationships between the mean groundwater level and the corresponding standard deviation of levels, for each well (Table 4.1), the following points can be made:

- shallow wells close to the Rakaia display relatively constant long-term levels, with early summer maxima corresponding to river flow maxima (e.g. L36/0292);
- deeper wells close to the Rakaia display lower groundwater levels than shallower wells, and exhibit spring and summer maxima (e.g. L36/0010, L36/0282);
- wells within or down-gradient of the Northbank irrigation command area display summer to late summer peaks of groundwater levels, the result of excessive irrigation. (e.g. L36/0258)
- wells distant from the Rakaia River and the coast, shallow or deep, exhibit marked winter-spring peaks, summer troughs related to abstraction and discharge, and strong inter-seasonal variation (e.g. L36/0142);
- wells close to the coast, buffered by a constant head boundary (the sea), exhibit small variation in level, with winter peaks (e.g. M37/0010); and
- wells in shallow confined strata are flowing artesian (e.g. M37/0461).

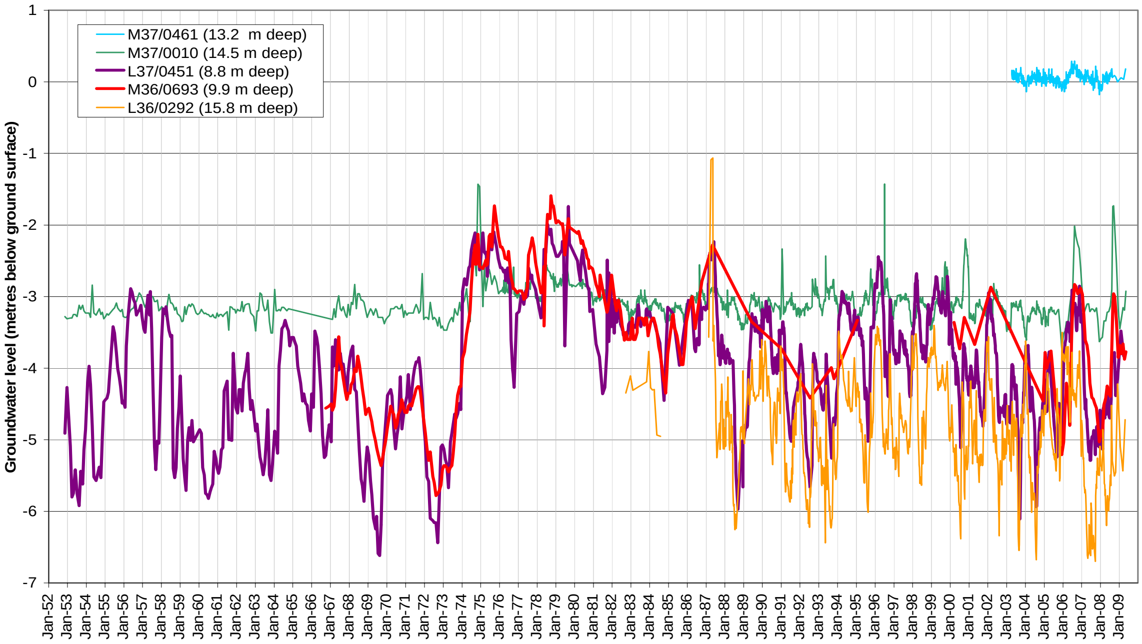


Figure 4-10: Time series plot of shallow depth Environment Canterbury monitoring wells

Table 4.1: Mean groundwater levels for selected Environment Canterbury monitoring wells, with standard deviations

Well	Well depth (m)	Mean groundwater level (mamsl)	Standard deviation (SD) (m)	SD/Mean	Time of groundwater level maximum	Comments
M37/0461	13.2	0.05	0.08	1.6	winter	Coastal
M37/0010	14.5	3.08	0.21	0.07	winter	Coastal
L36/0292	15.8	4.84	0.72	0.15	summer	River
L37/0451	8.8	3.93	0.81	0.21	summer	River
M36/0693	9.9	3.62	0.99	0.27	summer	Southbridge
L36/0664	18	8.94	1.06	0.12	winter	Raceway
L36/0282	40.2	26.1	1.89	0.07	summer	River
L36/0010	24.3	10.4	1.91	0.18	spring	River
L36/0142	16.3	9.14	1.98	0.22	winter	R-S (outside riparian sub-area)
L36/0258	27.4	17.9	2.05	0.11	summer	Northbank

Figure 4-11 shows the linear relationship between mean groundwater level in metres above mean sea level and the standard deviation of variation in groundwater level for each of ten wells. This generally linear relationship reflects the fact that shallow water levels tend not to vary much, and vice-versa. Four wells (black squares in Figure 4-11) exhibit water levels that plot to the right of the correlation line (L39/0292, L36/0010, L37/0451 and L36/0282). In Figure 4-11, all other wells, more distant from the river, exhibit a consistent linear trend of increasing standard deviation in their water levels with increasing water level. Wells M37/0010 and M37/0461, both close to the coast, exhibit the smallest variation and the shallowest water levels, and plot near the origin.

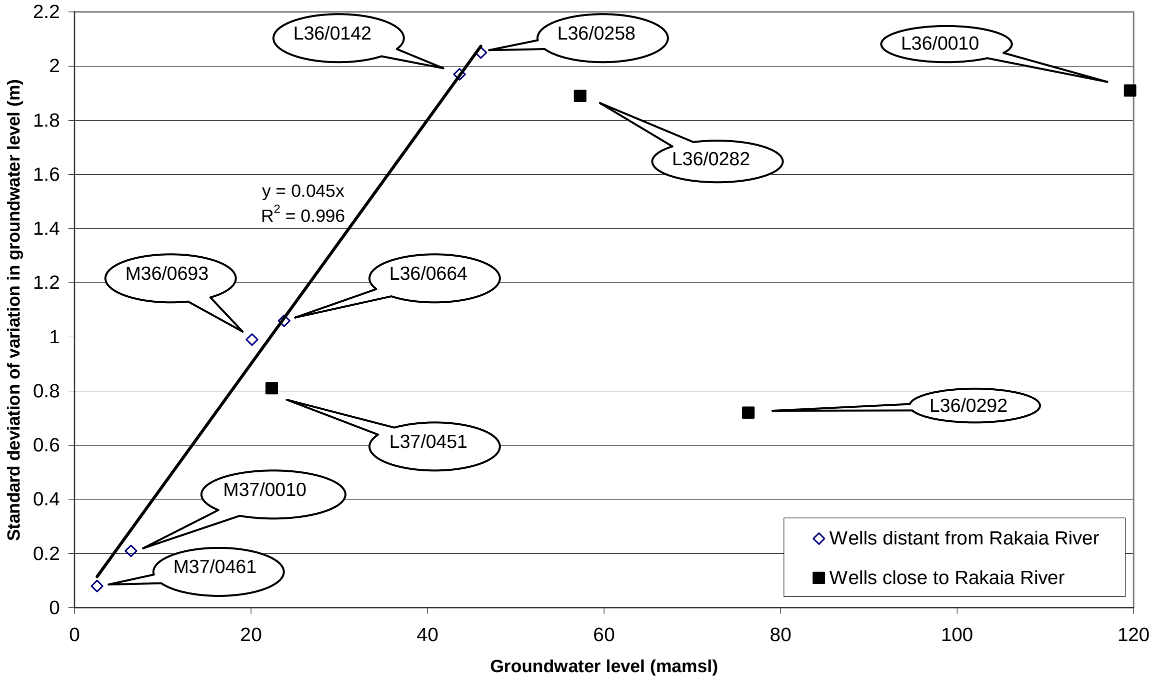


Figure 4-11: Plot of mean groundwater level versus standard deviation of the variation in groundwater level for a selection of Environment Canterbury monitoring wells in and adjacent to the Rakaia riparian sub-area

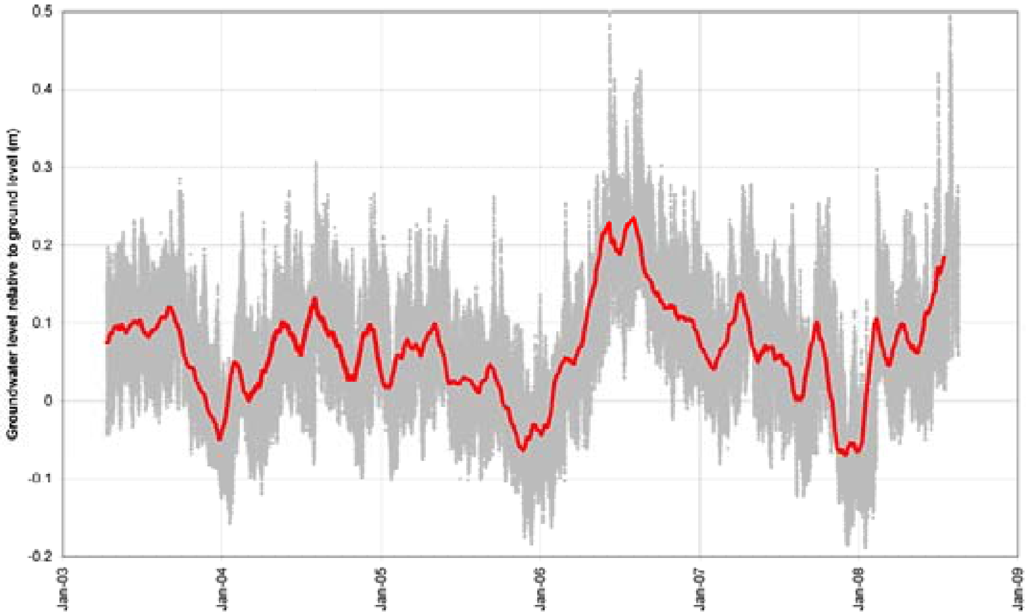


Figure 4-12 Time series plot of Environment Canterbury monitoring well M37/0461 (13.2 m deep) at McLachlans Road. Grey points are tidally-influenced levels; red line represents smoothed data with tidal effect removed

Figures 4-10 and 4-12 show the time series plot of groundwater level in monitoring well M37/0461, a tidally-influenced, sometimes flowing-artesian well (13.2 m deep). In Figure 4-10, manually measured un-smoothed data are presented for comparison with other wells. In Figure 4-12, the smoothed data (red line) shows seasonal variation of 0.3 m and the 6-year record does not exhibit any overall trend with the mean groundwater level close to the land surface.

4.4 Groundwater flow: spatial and temporal variation

The distribution of groundwater contours in figures 4-5, 4-5 and 4-7 may indicate the recharge flow from the Rakaia River. The August 2002 contours in Figure 4-5 and the April 2003 contours in Figure 4-6 both show a slight, poorly-constrained tendency to bend clockwise close to the river near its mouth. I infer from the contours in Figure 4-5 and Figure 4-6 that there is a slight tendency for groundwater to flow back into the river in the reach close to the coast (cf. Waimakariri River, north of Christchurch).

As a result of the local geology, groundwater flow velocities in near-surface strata are thought to be rapid, yields from shallow bores are generally good, and groundwater levels are generally quite high. These clean (open-textured) gravels facilitate seepage to groundwater from and perhaps back to the Rakaia River. This natural seepage benefits the Rakaia riparian sub-area by providing a reliable and reasonably constant source of recharge in addition to that provided by rainfall.

In addition, the rises in groundwater level during the summer season, as shown in the time series plots (Figure 4-9 and Figure 4-10) and the map (Figure 4-4), indicate the mounding of groundwater beneath and down-gradient of the Northbank Irrigation Scheme that was commissioned in 1990. Mounding of groundwater levels as much as nine kilometres down-gradient of the Northbank scheme has been thought to cause difficulties with the working of land (Thorpe 1999). The perceived local abundance of groundwater in the riparian sub-area is likely caused in part by the operation of the Northbank Irrigation and other schemes in which water from the Rakaia River is used for irrigation, largely by border strip methods, though these are progressively being replaced by spray. Davey (2006c), amongst others, has documented the reduction in mounding associated with conversion of border strip irrigation to spray. This relationship is important when considering the source and reliability of recharge to the sub-area (Section 6).

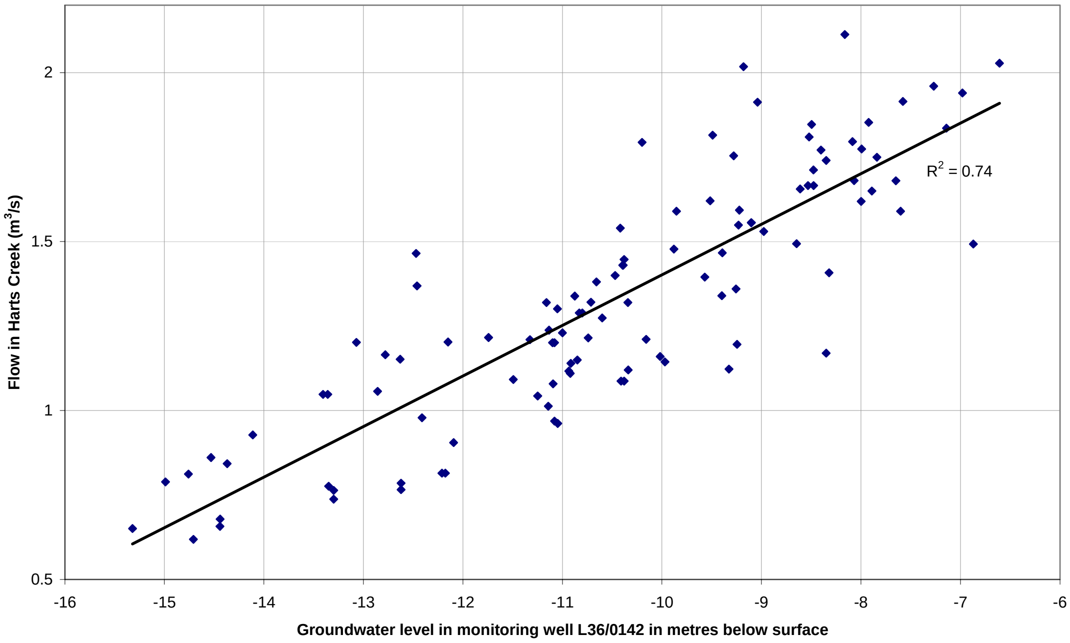
The major difference between the Rakaia riparian sub-area and the remainder of the RSGAZ is one of degree: the Rakaia riparian sub-area appears to receive a greater proportion of Rakaia River recharge water than elsewhere in the RSGAZ as shown by the bulge in the contoured groundwater levels in Figure 4-4[3]. However, this recharge from the Rakaia River is vital as a base recharge to the allocation zone as a whole and is deliberately not included in the calculation of the allocation limit (ECan 2004, Aitchison-Earl *et al.* 2004, and Scott 2004) in order for the discharge to sustain stream flows and to minimise the potential for saltwater intrusion.

4.5 Relationship between surface water flows in streams and groundwater levels

Many of the spring-fed streams in the lower part of the Central Plains catchment typically show a relationship between flow and groundwater levels in adjacent wells (Williams and Aitchison-Earl 2006; Clausen and Horrell 2007). The following sections describe what is known about these relationships within the Rakaia riparian sub-area and adjacent land and how that relationship may be used to inform our knowledge of the sub-area recharge sources.

4.5.1 Harts Creek

The relationship between groundwater levels and stream flows provides a measure of the sensitivity of stream flows to changes in groundwater level. This may be approached using two different styles of plot. A simple plot of level versus flow for a number of specific time observations provides an indication of the general relationship, as shown in Figure 4-13 for Harts Creek.



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[3] 'Appears to' because much of the river seepage losses north of the State Highway 1 may not be confined as underflow, but are probably infiltrating to great depth in the adjacent RSGAZ, consistent with the steep vertical groundwater gradients monitored in wells down to depths of 100 m in the Te Pirita area and with geochemical work undertaken by Hanson and Abraham (2009).

Figure 4-13: Plot of groundwater levels in Environment Canterbury monitoring well L36/0142 versus monitored flow at Harts Creek as measured at the Timberyard Point Road site within 1 day of the monitored level

Well L36/0142 is about 13 km from the Harts Creek flow monitoring point. Preliminary data indicate that piezometer nest M36/20108 at Locheads Road, only 3 km from the flow monitoring point at Timberyard Point Road, correlates even better with flow in Harts Creek.

The associated groundwater levels and flow monitoring data shown in Figure 4-13 were measured within a day of each other and indicate that there is a correlation between flow and level, but there is scatter. This scatter could be due to local drawdown interference on bore L36/0142, quick flow within, and surface water takes from Harts Creek upstream of the monitoring site, or all three. Until all surface and groundwater takes are monitored, such distortion of the natural flow and groundwater level record cannot be assessed.

Another method of plotting this information is as a time series, that allows recognition of similar patterns of flow and level over a period of time, as shown in Figure 4-14. Spot gaugings for Harts Creek are illustrated in Figure 4-14 as medium blue triangles, daily means as small pale blue triangles, and L36/0142 groundwater levels as dark blue lozenges.

Smoothing of the flow data is useful to illustrate trends with less noise. In Figure 4-15, the peaks and troughs illustrated by the smoothed Harts Creek flow (green line) are removed slightly in time from the original data (blue spots) because of the smoothing process. A smoothing variable (alpha=0.98) for the calculation of the exponential weighted average, provides the best match of flow and groundwater level, both in timing and in smoothness.

Time series plots, shown in Figure 4-14 and Figure 4-15, indicate that there is a general correspondence between the maxima and minima of flows and levels in L36/0142, reflecting decadal climatic variation as described in Williams *et al.* (2008).

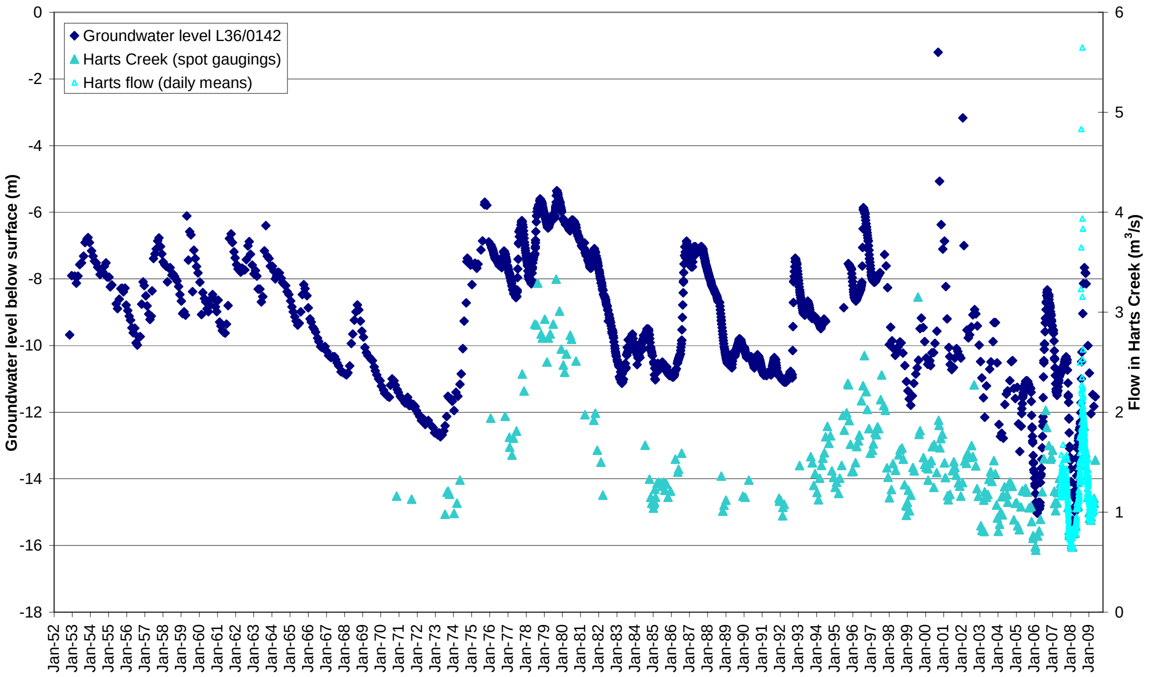

Figure 4-14: Time series plot of Environment Canterbury monitoring well L36/0142 versus spot gaugings and daily mean flows at Harts Creek as measured at the Timberyard Point Road site

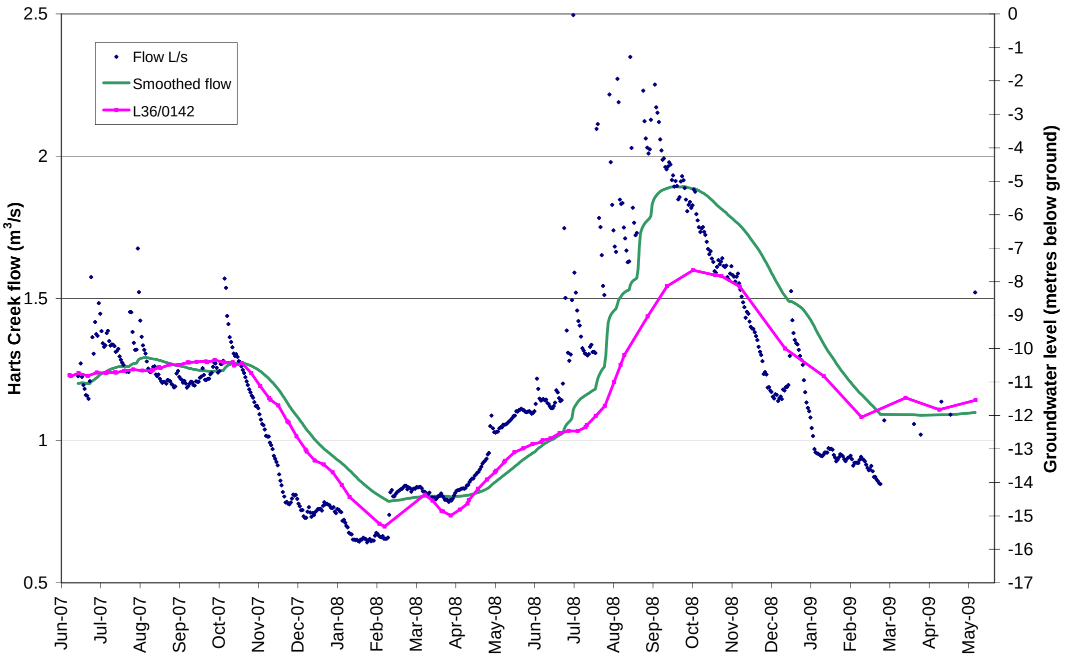

Figure 4-15: Relationship between groundwater levels in monitoring well L36/0142 and flows in Harts Creek

4.5.2 Waikekewai Creek (Parkin Drain)

A groundwater level versus flow analysis was undertaken by Smith (2001) for flows in Waikekewai Creek and groundwater levels in a nearby shallow monitoring well M37/0010. Using groundwater data gathered weekly, and occasional spot flow gaugings, the relationship was found to be only poorly correlated, indicating that factors other than groundwater level variation (such as by-wash discharge and localised groundwater abstraction) may be contributing to flows in the creek and distorting local groundwater levels. Smith (2001) suggested that the weak correlation between flow across a weir on Parkin Drain, the main part of the Waikekewai, and levels in M37/0010 could have been improved had the groundwater level data been corrected for diurnal tidal variation of the order of five centimetres.

4.5.3 Tent Burn

Grant (2003) cites earlier work by Facer and Horrell (2002) and Smith (2001) that illustrated a good correlation between groundwater levels in M37/0010 and flows in Tent Burn.

4.5.4 Jollies Brook

Groundwater levels are also correlated with stream flows for Jollies Brook as in Figure 4-16.

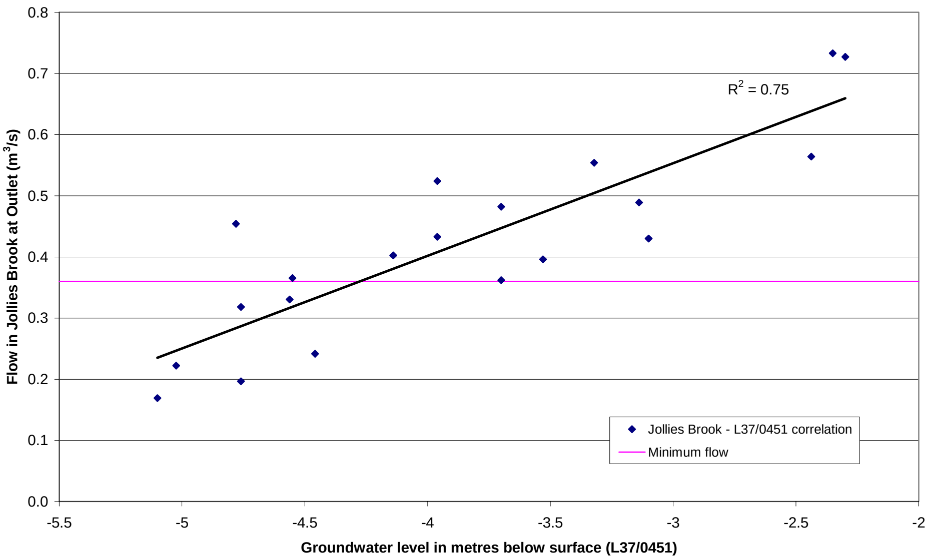

Figure 4-16: Plot showing correlation of Jollies Brook with monitored groundwater levels in well L37/0451

Examination of the data indicates that, in general, the lower flows corresponding with low groundwater levels, are from measurements made over the last decade. This relationship corresponds with that determined by Grant (2003). Grant concluded that while Jollies Brook correlated with groundwater levels in L37/0451, and thus with flow in the north channel of the Rakaia River, it did not correlate well with flows in Parkin Drain, Tent Burn, or the Lee River.

It has been suggested (Grant 2003) that Jollies Brook correlates well with the Rakaia because it occupies an old channel of that river, and there is little evidence for confining layers along much of its length (Figure 2-7). Greater thicknesses of fine-grained material, causing locally semi-confined aquifer conditions in underlying strata, are visible in deep (>25 m) bore logs in the south-eastern corner of the LRZ. In the northwest portion of the Southbridge area there is no clear subdivision between gravel units, fine-grained layers are absent, and delineation between gravel sediments of different age is problematic and has not been attempted. A recent review (ECan 2009) indicates that whilst the Springston and Burnham formations may be distinguished in their type sections using geological and geomorphological criteria, these formations cannot always be reliably distinguished, especially in drilling logs.

Observations by Grant (2003), Smith (2001) and Facer and Horrell (2002), showing that flows in the Lee River, Tent Burn and the Waikekewai correlate well together and with groundwater in M37/0010 and with L36/0142, suggest that these streams are susceptible to rainfall recharge and groundwater levels in wells distant from the Rakaia River, rather than showing a correlation with flows in the Rakaia River. This is a conclusion that has groundwater management implications, to be discussed later in this report.

4.6 Relationship between groundwater levels and Rakaia River flow

Oborn and Collins (1950, cited in NCCB 1983b) and Oborn (1955, page 67) reported that some land owners recognised that groundwater levels immediately north of the Rakaia River responded to the magnitude of the flow and also to the location of the flow in the river. If the north channel (between the true left bank and Rakaia Island) was not being occupied by the river, then groundwater levels along the north bank of the river were not as high as when it did occupy that channel.

Plots of flow in the Rakaia River and an adjacent groundwater level (L37/0451) are shown in Figure 4-17. In this figure, note the smoothed flow data (magenta line) and the prolonged low flow period during the period mid-2005 to mid-2006.

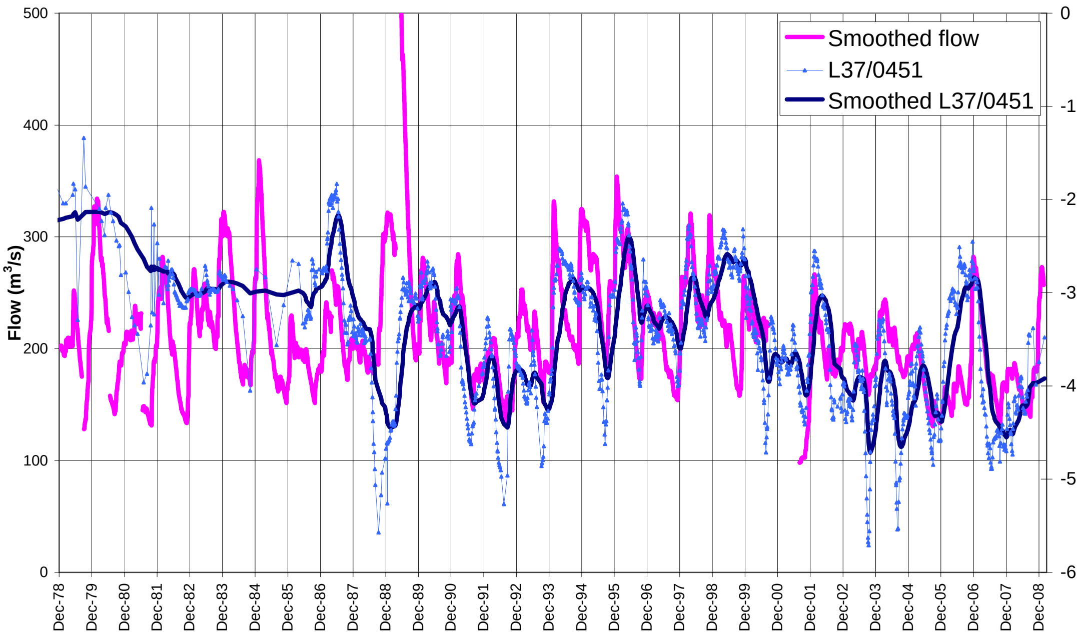

Figure 4-17: Smoothed plot of NIWA flow data in the Rakaia River at Fighting Hill (magenta, derived from Figure 3-4), plotted with corresponding groundwater levels and smoothed data from monitoring well L37/0451

In Figure 4-17, there is a weak and not consistent correlation between groundwater level in L37/0451 and flow in the Rakaia River. While some peaks and troughs in the smoothed flow and groundwater level do coincide, there are other times when such a correspondence is absent (e.g. late 1998, early 2003) and Figure 4-18 shows details of the weak relationship.

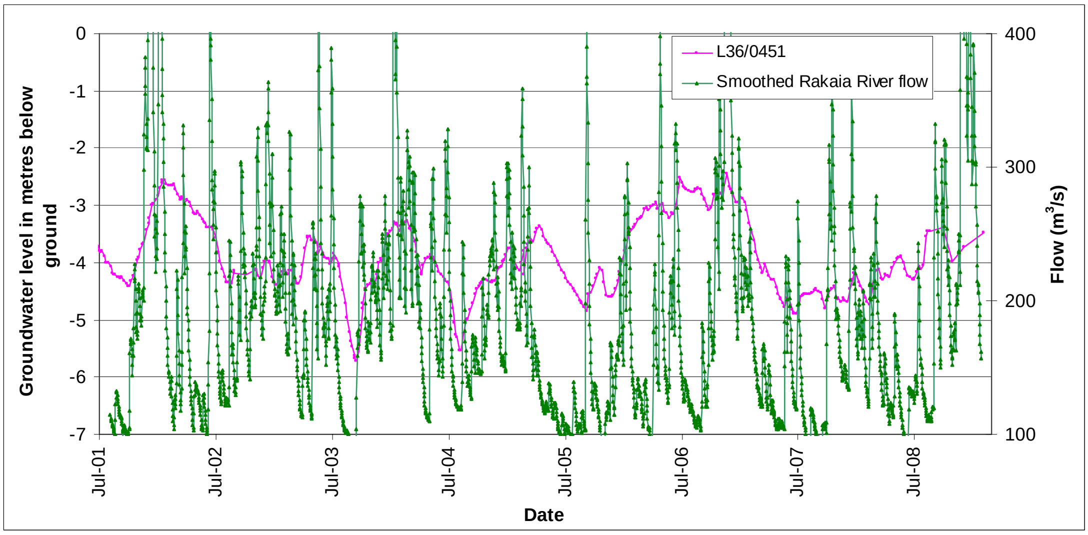

Figure 4-18: Detail of Figure 4-17, showing smoothed plot of NIWA flow data in the Rakaia River at Fighting Hill plotted with corresponding groundwater levels from monitoring well L37/0451

I conclude from Figure 4-17 and Figure 4-18 that during lengthy periods of lowered flows, groundwater levels fall in correspondence (e.g. early 2005 and 2007).

Plotting of synchronous smoothed daily flow and groundwater level data from well L37/0451 illustrates just how weak this relationship is (Figure 4-19).

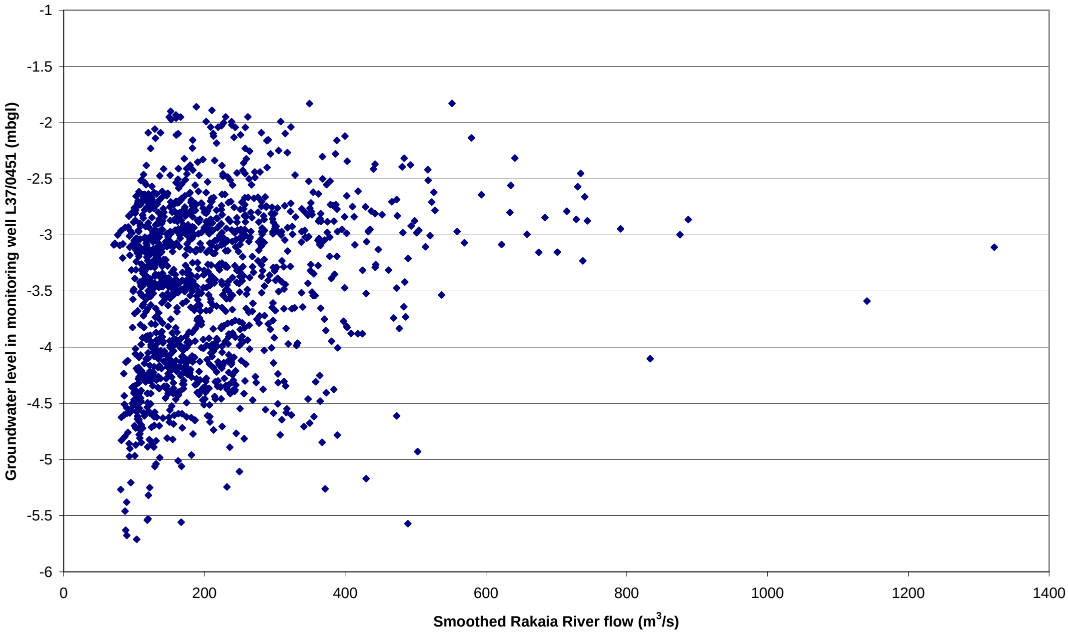

Figure 4-19: Plot of smoothed NIWA flow data for the Rakaia River at Fighting Hill plotted with corresponding groundwater levels from monitoring well L37/0451

Plotting of groundwater levels in well L36/0292 (15.8 m deep) and smoothed Rakaia River flow also shows inconsistent relationships (Figure 4-20). Note the poor correlation between flow in spring 2006 through fall 2007, and again, in mid-2008. Plotting of synchronous smoothed daily flow and groundwater level data illustrate just how weak this relationship is (Figure 4-21).

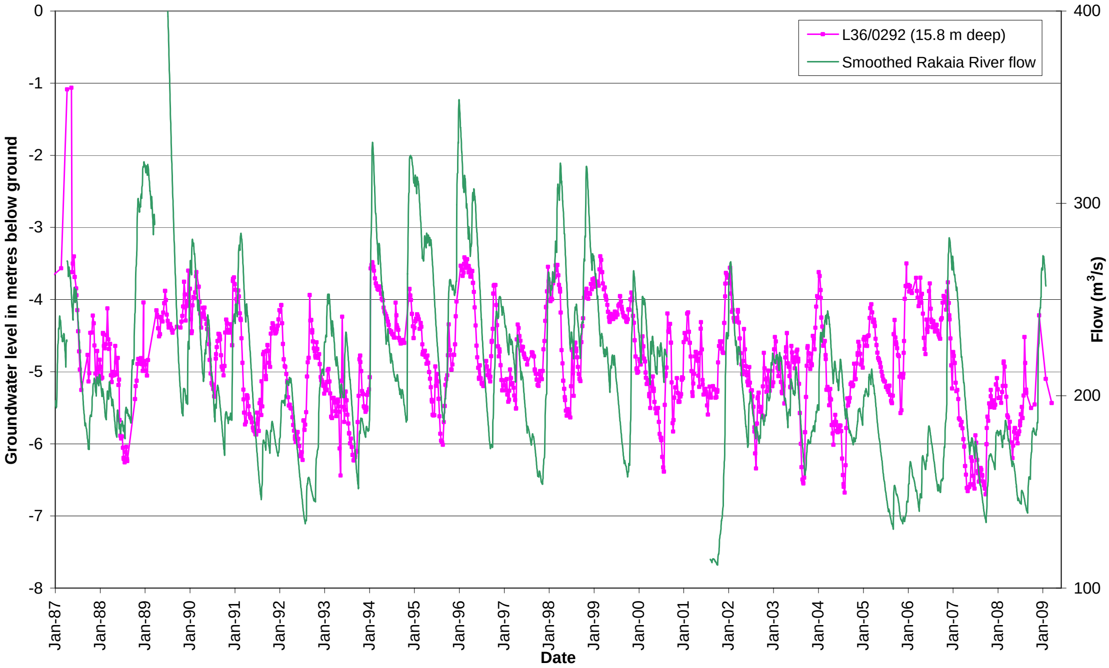

Figure 4-20: Time series plot of monitored groundwater levels in L36/0292 and smoothed Rakaia River flow

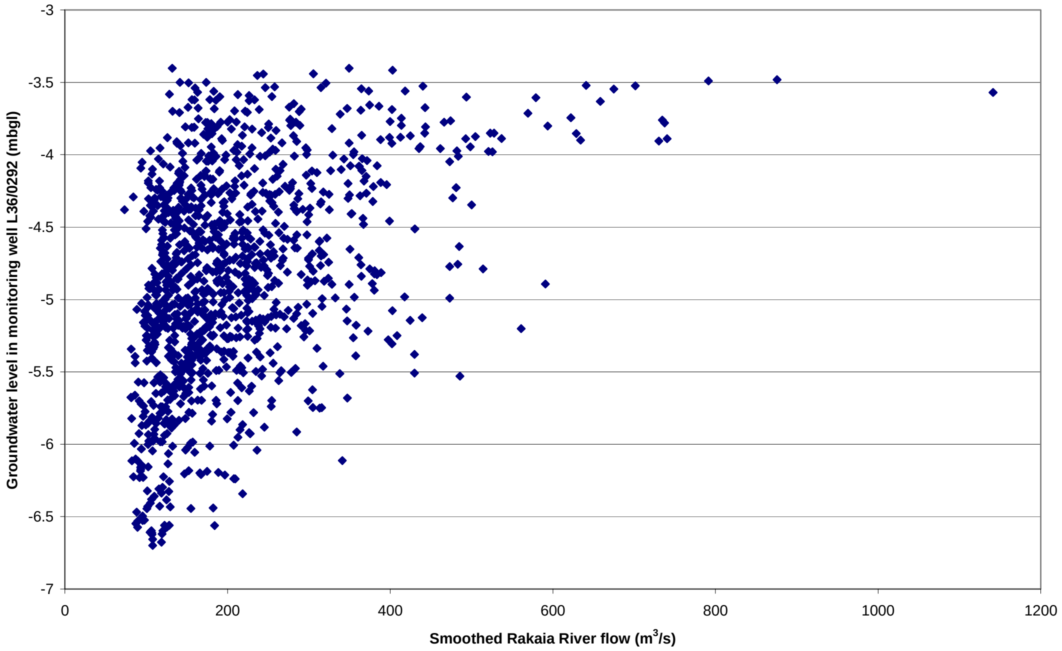

Figure 4-21: Plot of smoothed NIWA flow data for the Rakaia River at Fighting Hill plotted with corresponding groundwater levels from monitoring well L36/0292

Finally, plotting of groundwater levels in well L36/0282 (40 m deep) and smoothed Rakaia River flow also shows an inconsistent relationship (Figure 4-22). Note the poor relationship between flow for the following periods: early 2004, winter 1996, and winter 1987-88.

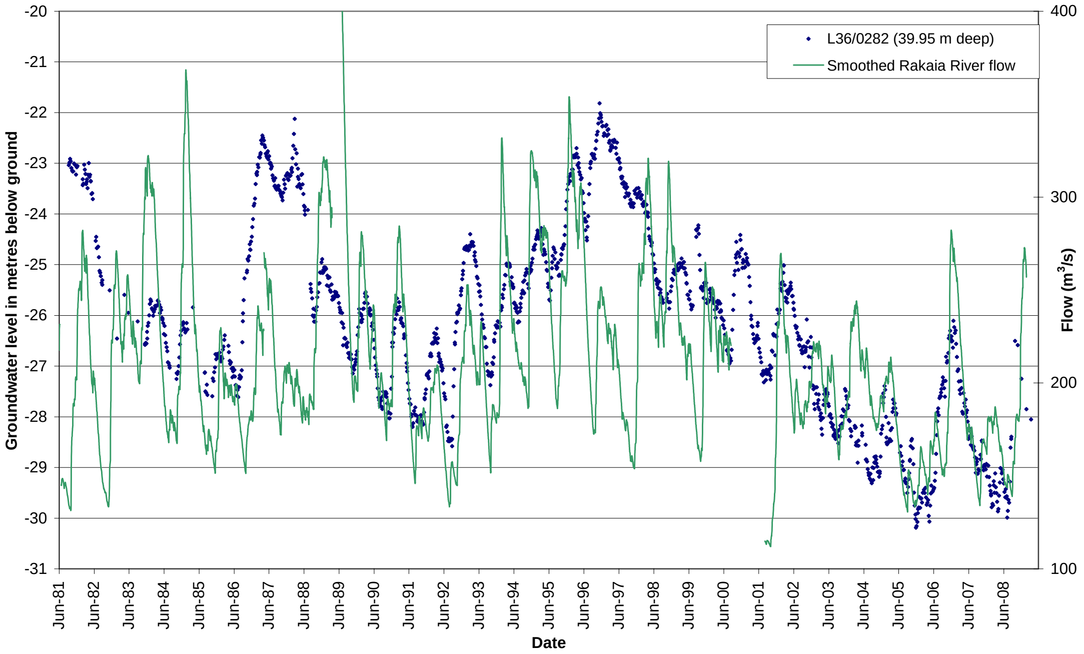

Figure 4-22: Time series plot of monitored groundwater levels in L36/0282 and smoothed Rakaia River flow

Plotting of synchronous smoothed daily flow and groundwater level data illustrate just how weak this relationship is (Figure 4-23).

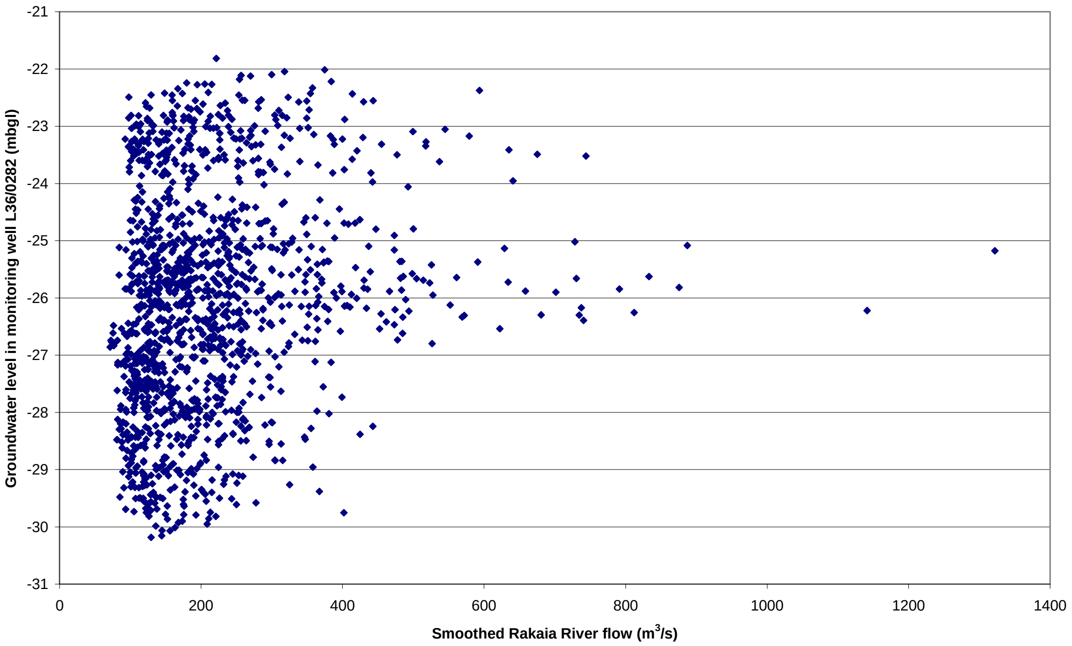

Figure 4-23: Plot of smoothed NIWA flow data for the Rakaia River at Fighting Hill plotted with corresponding groundwater levels from monitoring well L36/0282

An explanation for these absences of strong relationships is that large flows in the river do not always involve much change in head (stage), only changes in the width or number of braids occupied by flowing water. It is for this reason that the information supplied by local residents is useful, because it reinforces the observation that stage and location, rather than flow by itself, influence adjacent groundwater levels. Unfortunately, data relating to the timing and degree of the occupation of a specific channel of the Rakaia River is almost non-existent, so this relationship has yet to be tested. Even qualitative assessments of flow in the north channel would be useful to relate to groundwater levels.

The significance of this weak and inconsistent relationship is that although it is generally recognised that the Rakaia River locally affects groundwater levels in a gross sense, making them less susceptible to rainfall recharge variation, the river flow does not exert a consistent short-term temporal control on groundwater levels and the flow regime should not be used as a management tool to modify the groundwater allocation limit.

4.7 Causes of variation in groundwater flows and levels

Variation in the direction of groundwater flow and groundwater levels in the area adjacent to the Rakaia River is likely caused by proximity of seepage sources lying within the Rakaia River, mounding associated with surface water-sourced irrigation, and rainfall-fed recharge.

As described in Section 4.3.1, Grant (2003) showed that groundwater flow in the Southbridge area is generally towards the coast, slight divergent, down-gradient, from the Rakaia River (i.e. flow trending away from the river). This observation is the same as from earlier studies such as Bowden *et al.* (1983), and NCCB (1983b), or from more recent regional piezometric surveys. Grant (2003) showed that there was little temporal variation in groundwater flow direction, and what variation was evident could be ascribed to variation in recharge associated with the Northbank Irrigation Scheme.

There is qualitative evidence of changes in groundwater levels and surface water flows in small streams associated with the change in relative flow in the two channels of the Rakaia, north and south of Rakaia Island. In Appendix 5 of Grant (2003), this anecdotal evidence from local residents is cited. For example, when in the 1950s the north channel of the river was not active, groundwater levels dropped and corresponding surface flows ceased in rivers such as the Tent Burn. These observations that are generally consistent, one with another, are also consistent with monitoring data collected by Environment Canterbury, for flows in the Rakaia River and associated groundwater levels. These anecdotal observations are significant because they suggest that one of the main controls on groundwater level and stream flow is the proximity of the active (flowing) braid of the Rakaia River. In some years when it is flowing strongly in the north channel, there is an abundance of groundwater and surface water, and vice-versa, as has been the case.

This conclusion is problematic for it implies that management of the resource would not be entirely dependent upon the quantum of rainfall recharge, but might also be variant on the state and location of the Rakaia River. The corollary to this conclusion is that groundwater could reasonably be tied to flows in the Rakaia River as long as the location of the river channel was static. This statement will be revisited in later parts of this report when water budgets and allocation issues are described. The generally weak relationship between groundwater levels and Rakaia River flow is largely due to the channel occupancy effect, coupled with the variation in rainfall recharge on the land surface, that has little relationship with flows in that river.

4.8 Aquifer properties

This short section describing aquifer properties is included here only to set the scene for interpretation of the geochemistry results and the proposal that the groundwater-bearing strata in the riparian sub-area are treated as one management unit. Based on pumping tests carried out sporadically within the Canterbury Plains, the gravel sequences in the Central Plains form an aquifer system displaying great variability in horizontal and vertical hydraulic conductivity and groundwater in deep strata is connected to that in shallower strata i.e. there is leakage between the water bearing strata. (ECan 2008b; Lough and Williams 2009).

Transmissivity, storativity and leakage values in the Southbridge area are illustrated by the range of values in Table 4.2.

Table 4.2: Details of constant rate aquifer tests performed in the Southbridge area

Bore #	Easting	Northing	Depth (m)	Transmissivity (m^2/day)	Storativity	Leakage (m)	Test reliability[4]
M37/0242	2452365	5703627	19.6	10920	0.00007	690	B
M36/6019	2450680	5714535	12.0	1428	-	-	B
M36/0699	2450365	5710486	13.5	31 400	0.0001	-	B
L37/0885	**2444008**	**5707562**	**41.0**	**2600**	**0.0003**	**800**	**A**
M37/0237	2454723	5708250	13.7	18150	0.0003	2000	C
L36/1022	2436173	5717857	94.8	5700	0.0007	35425	B
M37/0077	2452999	5705429	15.0	17 250	0.00013	900	C
M37/0044	2452113	5708252	15.8	15 500	0.008	1200	D
M36/0616	2450958	5710436	14.8	***22 970***	0.0025	1450	C
M37/0076	2450306	5706409	13.1	26 500	0.0004	79	D

The revised edition of aquifer test guidelines (Aitchison-Earl and Smith 2008) modified the Brooks (1998) reliability rating (Table 4.2) with specific criteria to assess the robustness of the data and the method used to audit an aquifer test. In Table 4.2, only the aquifer test performed on Rakaia Island (L37/0885) is considered to be reliable (ECan 2008b), using the new letter grading system. The original high Brooks rating of 1 for other tests relate to data collected, not the analysis. This new rating system generally downgrades earlier ratings (Aitchison-Earl & Smith 2008). The test for well L37/0885 exhibits a high degree of leakage between strata as might be expected at this location.

Aquifer tests with reliabilities of B, C and D should not be used in any resource assessment or technical report because the data, or their analysis are insufficiently robust to produce a reliable assessment of the aquifer parameters.

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[4] See ECan (2008b) for details.

The remaining tests indicate a number of features in the Southbridge area:

- many transmissivities are high and are consistent with 'open' rather than silt-bound gravels at shallow depths;
- despite these high transmissivities, the storativity values are generally quite low, usually less than 0.0005, meaning that the water-bearing strata are reacting, in the short term, as semi-confined units. Most of these low storativity values were developed from short-term pumping tests. Longer tests might produce more reliable values (ECan 2008b); and
- leakage values (L) in metres, are low, meaning that there is little impediment to vertical flow from one set of high-yielding strata to another; or there may be unrecognised stream depletion.

Notwithstanding, aquifer parameters derived from test data, do, with one exception show that the strata are not only highly conductive but the low leakage (L) values indicate the potential for efficient vertical passage of water from the Rakaia River into the surrounding strata.

A similar inventory of aquifer tests for the entire Central Plains shows that leakage of groundwater between strata is the norm, rather than the exception (ECan 2008b). This observation is significant because it refutes any argument that deep abstractions should be treated differently from shallow abstractions from a resource management perspective (Lough and Williams 2009).

4.9 Groundwater age and isotope determinations

The Stewart *et al.* (2002) report on groundwater age determinations and isotope chemistry presents the latest information for the Southbridge area. Subsequent work by Environment Canterbury (Vincent 2007) provides data for an adjacent area, around the upper Selwyn River, useful for this report.

4.9.1 Oxygen isotope data ($\delta^{18}O$)

Stewart *et al.* (2002) quote a figure for $\delta^{18}O$ of –7.6 to –8.4‰ for lowland to mid-plains rainfall, and a corresponding figure of -9.5‰ for the Rakaia River. These two pieces of information are significant for any discussion on the relative contributions to groundwater from alpine river and rainfall sources. Oxygen isotope data from the nearest lysimeter site, Lincoln, give a mean of $\delta^{18}O$ -7.38‰ for water discharged into the lysimeter from unimproved pasture (Stewart 2005, unpublished GNS report). These values and ranges are pertinent to the discussion of results in the following sections.

4.9.2 Groundwater age determinations

Stewart *et al.* (2002) provide the following description of wells sampled along the arrowed flow lines 5 and 6 with well sampling numbers and depths shown in Figure 4-24 and chemistry in Figure 4-25.

"*Flow line 5 starts in the Te Pirita area and ends at the southwest edge of Lake Ellesmere. L36/1313* (120 m deep) *is sourced from either the Rakaia River or from inland rainfall, the $\delta^{18}O$ value is not diagnostic (and no chemical data is available). The Rakaia River may be more probable; the point is shown as light green* (Figure 4-24). *$\delta^{18}O$ shows that L36/1055, L36/1139 and L36/1401 are from inland rainfall, and chloride and nitrate values concur (deep pink).*

L36/0472 and L36/0473 are near L36/0725 (flow line 4) and have similar values, an inland rainfall source is indicated (Figure 4-25: deep pink). The three Leeston wells (M36/4700, M36/0670 and M36/2746) have similar depths (about 70 m), $\delta^{18}O$ about –9.1‰, and old ages (>61 years). The source is likely to be inland rainfall because of the location of the wells, although the Rakaia River cannot be ruled out. No chemical data are available for the wells (the points are given as deep pink). M37/0106 has similar $\delta^{18}O$ and age, but has low chloride content and is therefore likely to be mainly from Rakaia River. The point is light blue.....Flow line 6 runs alongside the lower Rakaia River. L36/1203, L36/0598 and L37/0545 are clearly sourced from the Rakaia River; $\delta^{18}O$ values are –9.12 to –9.24‰, and chloride and nitrate contents are very low (Figure 4-25: deep blue). L36/0424 and L36/1224 just as clearly are from inland rainfall; $\delta^{18}O$ is –8.73 and –8.54‰, and chloride and nitrate values are elevated (points deep pink). L36/0835, L36/0421, L36/0698 and M37/0325 have values *showing Rakaia River water with minor rainfall input; δ^{18}O is –8.95‰, and chloride and nitrate values are intermediate between the other two groups (Figure 4-25: light green).*"

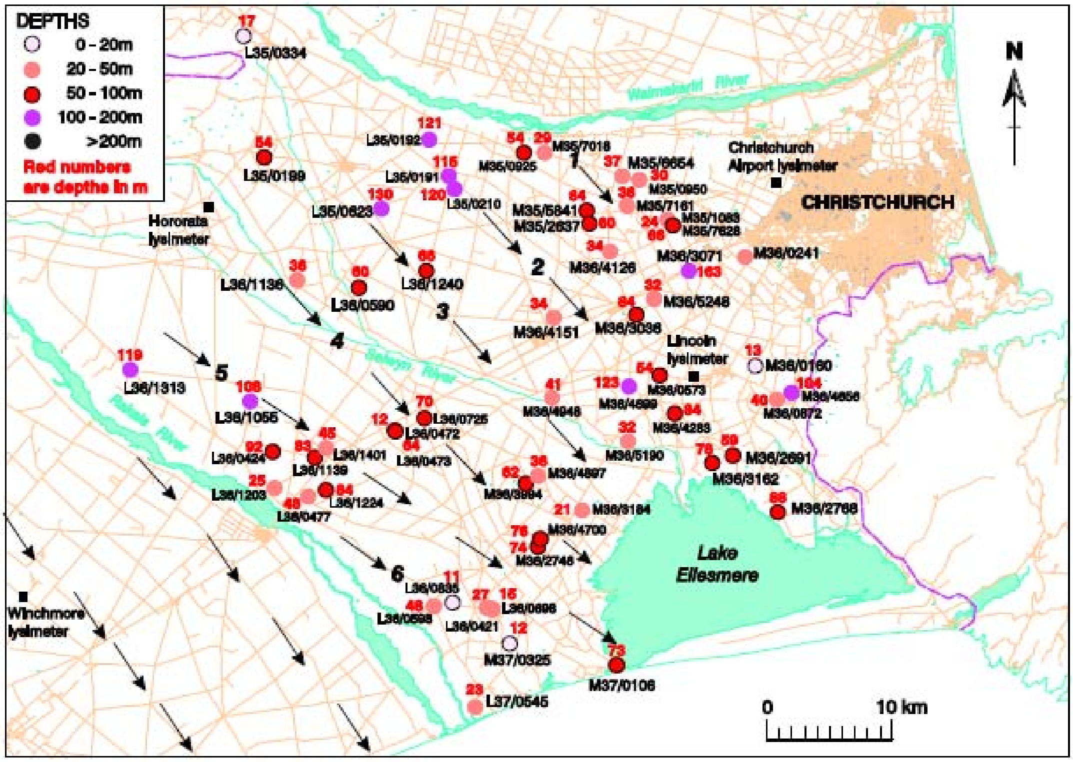

Figure 4-24: Central Plains showing locations and screen depths of sampled wells (source: Stewart *et al.* 2002)

The results presented in Figure 4-25 show that the groundwater near the Rakaia River receives water from the Rakaia (blue and pale green dots), representing relatively unadulterated alpine river water and river water mixed with rainfall recharge respectively. While the isotope results show the dominance, or not, of alpine water, there is no indication of the pathway by which it travelled to the sampled bore.

It is significant to this report that Stewart *et al.* (2002) state: "*three Leeston wells on flow line 4 (M36/4700, M36/0670 and M36/2746) have similar depths (about 70 m), δ^{18}O about –9.1‰, and old ages (>61 years, Figure 4-25).*" The Stewart report apparently did not consider that the 'alpine' water indicated by the isotope results was directly derived from the Rakaia (which would involve significant distortion of the flow lines shown in Figure 4-25). It could, alternatively, represent deep upwelling of alpine water that had previously infiltrated to deep levels near the head of the plains and moved down-gradient along flow lines 4 and 5. The Stewart *et al*. (2002) report implies such an upwelling in Figure 4-25, where line 1 ends with an 'alpine' sample beside Banks Peninsula. This result is consistent with the analysis of deep groundwater sourced from the Waimakariri River by Hanson and Abraham (2009).

Note that in Figure 4-25, the ages of groundwater in the riparian zone are significantly less than those exhibited to the northeast, in predominantly rainfall-recharged groundwater. Nonetheless, even the groundwater representing alpine water (dark blue in Figure 4-25) still exhibits ages in the order of tens of years, increasing coastwards. The 56 year-old sample taken at the shore of Te Waihora / Lake Ellesmere is approximately 30 km from the Rakaia River between flow lines 5 and 6. Water of this age may indicate that the groundwater is moving at least 500 metres per year[5] using a piston flow model.

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[5] Assuming a Darcy average linear velocity of 1.7E-5 m/s, with an average head difference of 100 m over a distance of 30 km, a porosity of 0.1 and an aquifer thickness of 20 m, then a realistic transmissivity of 880 m^2/day may be calculated.

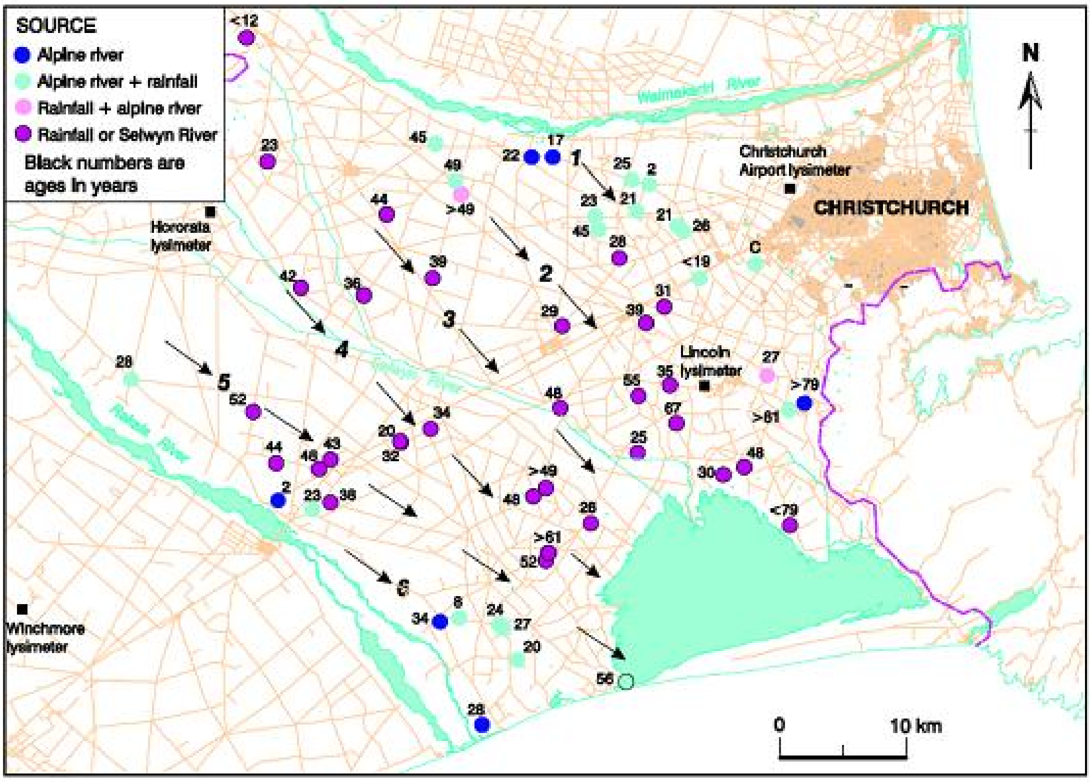

Figure 4-25: Central Plains showing age and recharge source of groundwater (Source: Stewart *et al.* 2002)

While the isotopic data show that alpine water is present in the Southbridge area as far east as Leeston, the data do not show how that water travelled to the sampling points and, therefore, not all of the alpine water need be a result of direct, local, lateral seepage from the Rakaia River; some could also be sourced from the Northbank or other irrigation schemes, and the remainder from coastal upwelling of deep groundwater flow of alpine water sourced from the Rakaia River far up-gradient (Hanson and Abraham 2009).

4.10 Conclusions - groundwater issues

The following conclusions from this section are:

- groundwater flow changes direction across the study area; a groundwater divide occurs south of Harts Creek;
- there is a change in the seasonal variation in groundwater levels across the study area;
- groundwater close to the Rakaia River is influenced by the river but not in a consistent way; and
- groundwater age determinations illustrate a change in recharge source across the study area.

5 Water chemistry

In 2007, geochemical analytical work undertaken by a visiting researcher, Alexandra Servais, culminated in geochemical analysis of existing surface water and groundwater composition data for the Central Plains (Williams and Servais 2007). That study also included spot samples of surface water whose chemical composition resembled local groundwater composition. Williams and Servais showed that significant variation in ratios of chemical determinands, especially the Ca/Mg ratio, suggested that there were two different types of recharge to the groundwater system (Figure 5-1). High ratios appeared to correspond with areas close to alpine rivers, while low ratios corresponded to areas dominated by rainfall recharge.

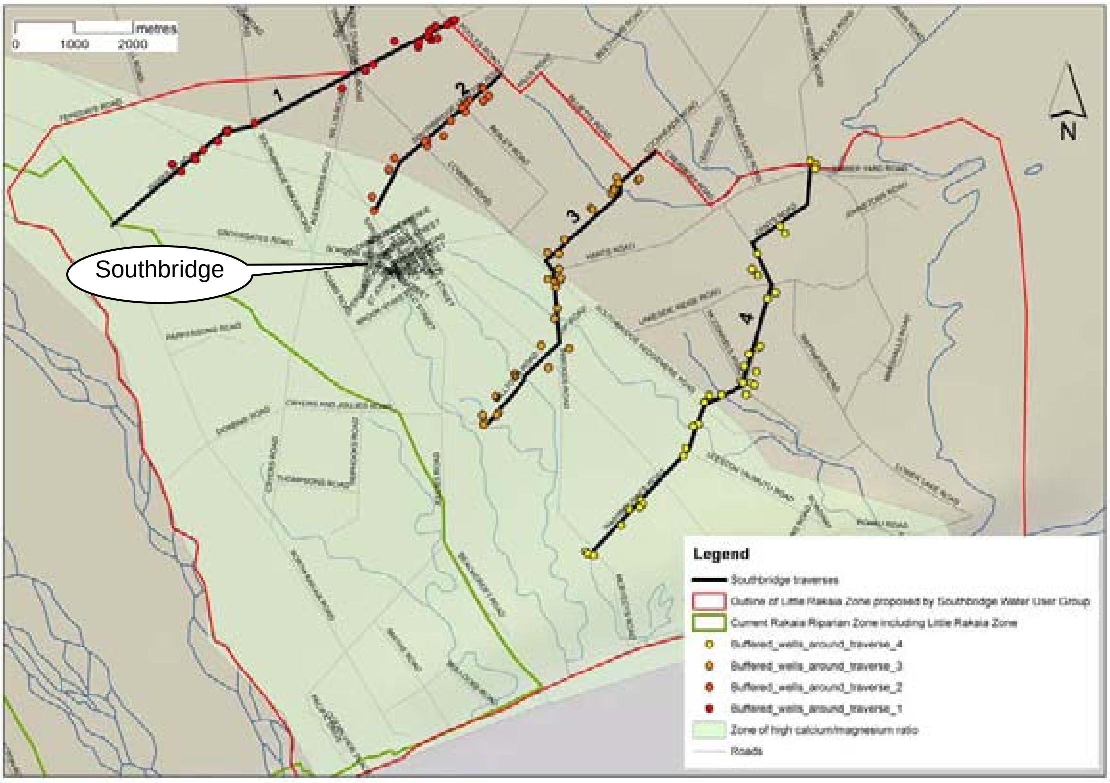

Figure 5-1: Groundwater sample transects in the Southbridge area (Williams and Hedley 2008); green wash is the provisional area of high Ca/Mg ratio values (Williams and Servais 2007)

Follow-up groundwater chemical sampling and analysis was undertaken during the 2007-08 summer period by Paul Hedley. This work concentrated on the Southbridge area and was written up as an Environment Canterbury internal memorandum (Williams and Hedley 2008) and is appended to this report as appendices 1 & 2. This section of the report reviews that internal memorandum, describing groundwater sampling and chemical analysis undertaken specifically in the Southbridge area (‘Southbridge study’).

Further groundwater sampling in the Central Plains was then undertaken by Hanson and Abraham (2009), concentrating on two transects entirely within the main portion of the Central Plains, showing the depth relationships between alpine river and rainfall recharge.

All three of these studies have contributed to our understanding of recharge characteristics in the Southbridge area.

5.1 Southbridge study

An initial bore quality assurance study determined which bores were appropriate for groundwater sampling. Bore characteristics such as depth, diameter, screen depth, and updated contact details necessary for efficient sampling were confirmed. Sampling of groundwater from forty one bores was undertaken over three periods, starting with a broad spread of samples. Subsequent sampling filled in gaps where further information was considered necessary, and data were collected from neighbouring bores of different depths (Figure 5-1).

Analysis of the samples indicates a wide spread of groundwater chemistry, with the ratio of dissolved calcium and magnesium (Ca/Mg, as shown in Figure 5-2), and concentrations of chloride, sulphate and nitrate used to determine recharge sources.

Water derived from the Rakaia River displays a high Ca/Mg ratio (generally greater than 5); groundwater derived from rainfall recharge displays a lower Ca/Mg ratio (generally less than 5). Groundwater at depth is generally poor in dissolved chloride, sulphate and nitrate whereas shallow groundwater tends to contain higher concentrations of these determinands.

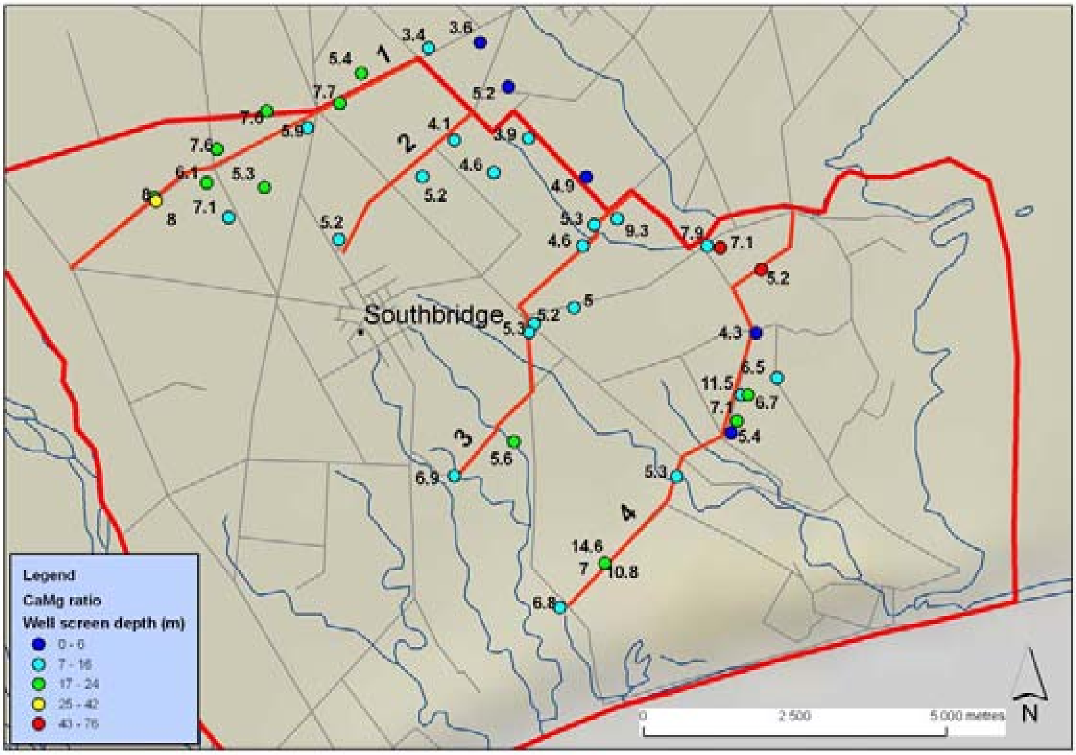

Figure 5-2: **Distribution of Ca/Mg ratios in groundwater sampled in 2007-08. Also shown are coloured spots showing well screen depth (modified from Williams and Hedley 2008)**

For example, wells sampled for groundwater within the topographic constraint of the terrace, generally up-gradient of State Highway 1, displayed high Ca/Mg ratios indicative of an ‘alpine’ source. The Ca/Mg ratio in well L36/0393 is 8.2, in L36/0023 is 6.9, in L36/0323 is 11.3, in L36/1203 is 6.3, in L36/0477 is 6.3, all ‘alpine’.

The conclusions reached from the geochemical analysis of groundwater in the Southbridge area are that:

- there is a tendency for decline of the calcium/magnesium ratio of groundwater with increasing distance from the Rakaia River;
- there is no consistent variation in Ca/Mg ratio with depth, although ions such as chloride, sulphate and nitrate-nitrogen all decrease with increasing depth;
- there are two sources of recharge water identified in the groundwater system;
- while two recharge sources are identified, the Southbridge study was unable to distinguish the pathway of that water to the sampling points;

- the water geochemistry boundary between these two sources of recharge lies to the east of the current boundary of the Rakaia riparian sub-area but is quite diffuse; and
- the shape and orientation of the boundary zone between groundwater recharged from rainfall and that recharged from the Rakaia is variable and probably occurs over a transition zone, both laterally and vertically. The distribution of 'alpine' water is further described in section 5.3.

5.2 Nitrate distribution

During the course of the geochemical study it became apparent that nitrate concentrations in groundwater and surface water were elevated above natural values in some parts of the Southbridge area (Figure 5-3). The current Rakaia riparian sub-area exhibits low nitrate, largely because of the input of fresh alpine seepage from the Rakaia River, this seepage gradually declines eastwards, with the result that nitrate concentrations gradually increase to values between half the Maximum Allowable Value (MAV, MoH 2005) and the MAV (red symbols in Figure 5-3).

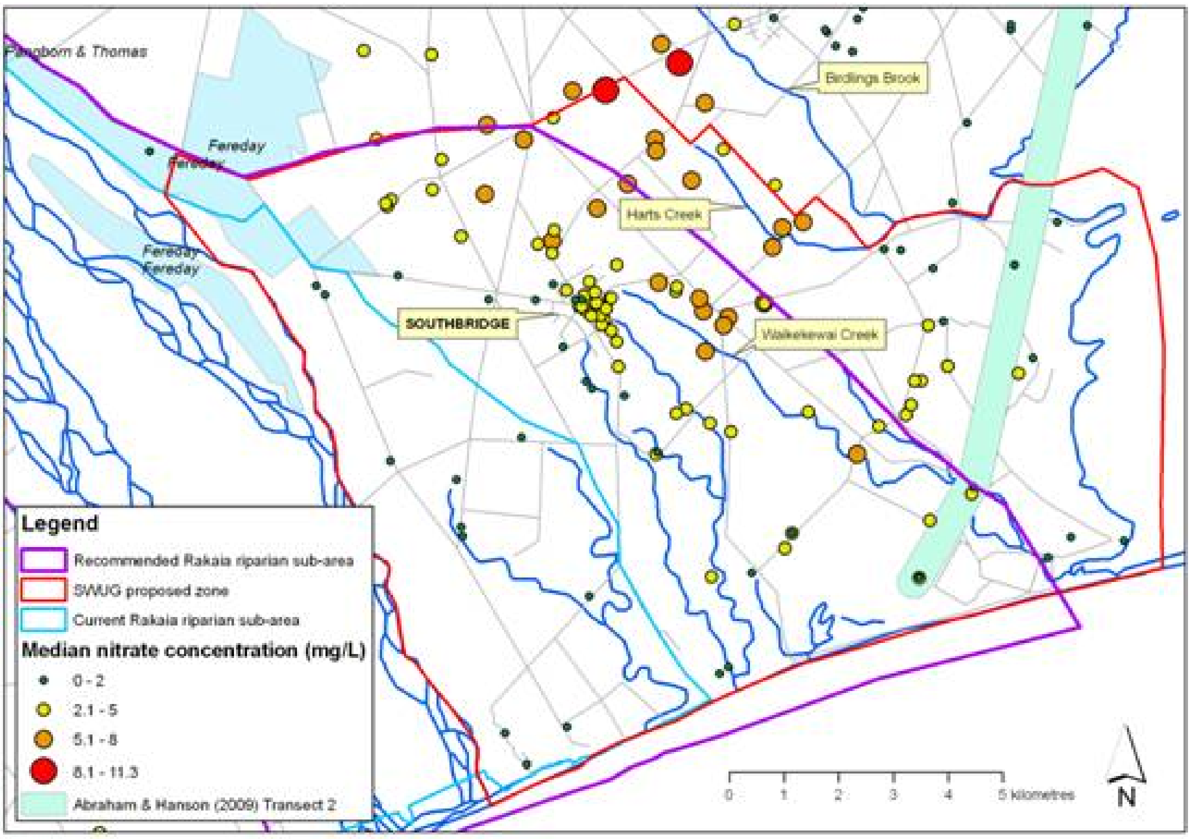

Figure 5-3: Median nitrate concentrations in groundwater samples

Note also in Figure 5-3 that nitrate concentrations decline sharply in the vicinity of Te Waihora / Lake Ellesmere (east of Birdlings Brook), where there is isotope evidence for 'alpine' signature water upwelling from depth, keeping nitrate levels low (Abraham and Hanson 2009, Stewart *et al.* 2002). The location of Transect 2 of Abraham & Hanson is shown in Figure 5-3.

There is also a marked increase in nitrate concentration east of the town of Southbridge. This change is probably due to the combined effects of seepage from the Rakaia River and border strip irrigation, maintaining low nitrate concentrations to the west of Southbridge.

To conclude, the Ca/Mg ratio and nitrate concentrations provide slightly differing locations for the locus of the contrast in groundwater composition.

5.3 Further geochemical work and stable isotope analysis

Further groundwater sampling in the Central Plains was undertaken by Hanson and Abraham (2009). Their study area did not include the Southbridge area, but concentrated on two transects, one parallel with a groundwater flow stream line starting from the Waimakariri River in the upper plains and ending at Te Waihora / Lake Ellesmere, and one at right angles to regional flow lines, starting west of Christchurch and ending at the Rakaia River, entirely within the main portion of the Central Plains.

Their analysis of stable isotope and regional chemical data produced conclusions that were broadly consistent with the earlier work of Williams and Hedley (2008) and Williams and Servais (2007), recognising two sources of recharge: rainfall, and seepage from alpine rivers. Their analysis generally corroborated the presence of depth variation in groundwater chemistry in the Central Plains, recognising the occurrence of alpine recharge water at depth. Their data were also consistent with the hypothesis that to some extent groundwater with an alpine river signature returns to near surface (upwelling) in the vicinity of the spring-fed streams around Te Waihora / Lake Ellesmere.

5.4 Conclusions from water chemistry

Groundwater isotope and chemical data are generally consistent with a zone of mixing of rainfall-dominated and alpine river-dominated recharge in the Southbridge area. The alpine signature water may be transported to wells in the Southbridge area by one or more of the following processes:

- direct local seepage from the Rakaia River in the Southbridge area;
- indirect seepage from the river to deep strata in the area up-gradient of State Highway 1, and transport along flow lines 5 and 6 (Figure 4-24), upwelling in the vicinity, or coastwards, of the lowland stream springs; and
- direct local infiltration of surface water-sourced irrigation in the vicinity of the Northbank and Fereday schemes.

Further sampling and analysis by Williams and Hedley (2008) indicated that a complex three-dimensional relationship between alpine and rainfall recharge sources probably occurs, with evidence for more than just a simple transition zone developed between them that would shift with changes in groundwater recharge rates and levels. It may be expected that the composition, thickness and extent of the transition zone will change, relating to variation in the individual components of dominant recharge listed above.

Northbank irrigation scheme water, a source of high Ca/Mg ratio and highly negative $\delta^{18}O$ values, derived directly from the Rakaia River, potentially distorts the natural rainfall recharge signature.

From water chemistry, it appears that seepage derived from the Rakaia River outlines a larger area than that currently demarcated by the eastern boundary of the Rakaia riparian sub-area. Spatial and depth variation of Rakaia riparian seepage, is complicated not only by the recharge related to the Northbank irrigation scheme, but also the rise and natural discharge of previously deep groundwater displaying the characteristics of relatively ‘clean’ water derived from alpine river recharge.

Chemical and isotopic data do not by themselves allow unequivocal support for a change in the eastern boundary of the riparian sub-area, but when taken in combination with geological, surface and groundwater hydrological data are consistent with such a change.

6 Water budget

A water budget is a quantitative attempt to estimate the contributions to, and the discharges from, a hydrological system. Inputs to the RSGAZ consist of rainfall recharge, river recharge, losses from irrigation systems, and return water (excess irrigation infiltrating into the groundwater). Outputs or discharges from the system include evapotranspiration, surface water flows direct to the ocean or indirectly through Te Waihora / Lake Ellesmere, abstractions, and groundwater flow discharging beneath the coastline. These inputs and outputs are described in this section and attempts made to quantify them.

The analysis provides evidence informing a proposal that groundwater management in the Rakaia riparian sub-area should be distinct from management of the bulk of the RSGAZ to the east and that different management criteria may be necessary. The area of the LRZ as defined by Grant (2003) and the Rakaia riparian sub-area defined in this report are similar.

6.1 Inputs

This section draws conclusions about the spatial and temporal variation of recharge and irrigation inputs flowing into and developed within the Southbridge area. Grant (2003), White in ECan (2009) and Evans (1999) have produced or compiled data on recharge and their work is reviewed. White (ECan 2009) assessed the water balance of Central Plains (Table 6.1), mostly from published sources, including the geographic areas of what he called the Little Rakaia Zone, Te Waihora / Lake Ellesmere catchment (Waihora catchment in Table 6.1 and Table 6), the Christchurch West Melton catchment and the entire Central Plains area. His tabulation appears to be based on work listed in Taylor (1996), Evans (1999), Grant (2003) and Horrell (cited in ECan 2009). In Table 6.1 and Table 6, Te Waihora / Lake Ellesmere is called the 'lake'.

Table 6.1: **Water budget components for Little Rakaia Zone, Waihora catchment, Christchurch-West Melton area (CHWM) and entire Central Plains (modified from ECan 2009)**

Component	**Little Rakaia Zone (m^3/s)**	**Waihora catchment (m^3/s)**	**CHWM (m^3/s)**	**Central Plains (m^3/s)**
Land surface recharge (A)	0.3	23.8	1.6 to 3.4	25.7 to 27.5
Rainfall on lake (B)	-	3.6	-	3.6
Recharge from rivers (C1) Rakaia	3 to 4	3 to 11	-	6 to 15
Recharge from rivers (C2) Selwyn	-	1.5 to 3.5	-	1.5 to 3.5
Recharge from rivers (C3) Waimakariri	-	3.5 to 4	6 to 7	9.5 to 11
Surface water Banks Peninsula to lake (D)	-	0.3	-	0.3
Sea water inflow to lake (E)	-	3.5	-	3.5
Stock race leakage (F)	-	1.0	0.5	1.5
Inter-zone transfer: inflow from Waihora catchment (G)	2.1 to 2.8	-	1	n.a.
Evaporation on lake (H)	-	6.1	-	6.1
Surface water discharge to sea (I)	3	12.9	6.1	22
Discharge across Kaitorete Barrier (J)	-	1 to 5.6	-	1.0 to 5.6
Use - groundwater (K)	0.4	11.3	1.7	13.4
Use - surface water (L)	not determined	0.3	-	0.3
Inter-zone transfer: outflow from Waihora catchment to Little Rakaia Zone (M)	-	2.1 to 2.8	-	n.a.
Inter-zone transfer: outflow from Waihora catchment to Christchurch – West Melton area (N)	-	1	-	n.a.

Table 6.1 (continued): Water budget components Little Rakaia Zone, Waihora catchment, Christchurch-West Melton area and entire Central Plains (modified from ECan 2009)

Component	Little Rakaia Zone (m^3/s)	Waihora catchment (m^3/s)	CHWM (m^3/s)	Central Plains (m^3/s)
Sum of inflows (A+B+C+D+E+F+G)	5.4 to 7.1	40.2 to 50.7	8.9 to 11.7	51.6 to 65.9
Sum of outflows excluding off-shore groundwater (H+I+J+K+L+M+ N)	3.4	34.7 to 40	7.8	42.8 to 47.4
Off-shore groundwater outflow (sum of inflows – sum of outflows)	2 to 3.7	0.2 to 16	1.3 to 4.1	4.2 to 23.1
Water balance (sum of inflows – sum of outflows – estimated off-shore groundwater outflow)	0	0	0	0
Intra-zone transfer groundwater discharge to streams flowing to lake	-	12	-	12
Intra-zone transfer groundwater discharge direct to lake	-	0.1	-	0.1

Table 6.2: Revised water budget components for the Rakaia riparian sub-area (modified from ECan 2009, Grant 2003, Taylor 1996)

Component	Rakaia riparian sub-area (m^3/s)
Dryland surface recharge from rainfall (1)	0.7
Recharge from Rakaia river (3)	3 to 4
Border-strip irrigation recharge (4)	1.4 to 2.0
Stock race leakage (5)	0.2
Groundwater inflow from Waihora catchment (6)	0.4
Surface water discharge to sea (I)	3.1
Use – groundwater (K)	0.4
Use - surface water from Lee River & Jollies Brook (L)	0.02
Sum of inflows (A+B+C+D+E+F+G)	5.4 to 7.1
Sum of outflows excluding off-shore groundwater (H+I+J+K+L+M)	3.4
Off-shore groundwater outflow (sum of inflows – sum of outflows)	2 to 3.7
Water balance (sum of inflows – sum of outflows – estimated off-shore groundwater outflow)	0
Intra-zone transfer groundwater discharge to Waihora streams	-
Intra-zone transfer groundwater discharge direct to lake	-

What is clear from the various water budget estimates used in the compilation of Tables 6.1 and 6.2 is the gross uncertainty in the inputs and outputs that are sub-surface. Seepage from the Rakaia River (Table 6.1: '(C1)' and Table 6.2: '(3)') is likely to be in the range of 3 to 4 m^3/s. In Section 3.5, it was acknowledged that while seepage upstream of SH1 is considerable, some of it stays within the terraced zone.

Arguments in favour of seepage remaining within the confines of the river channel seem to be at variance with assessments of seepage from the river into the groundwater system using modelling. This modelling shows a need for a substantial 'base' river-related recharge to maintain groundwater levels in the mid- to upper plains (Scott and Thorley 2009). The strong relationship between rainfall recharge and groundwater levels, and isotopic data (Stewart e*t al.* 2002), together support the conclusion that the Rakaia River loses significant flow into the adjacent groundwater system.

Based on a standard rainfall - soil moisture calculation (Scott 2004), assessment of the dryland rainfall recharge to the current riparian sub-area is approximately 58.3 GL/year (Table 6.3). This value translates into an annualised flow of about 1.8 m^3/s, very different from the modest value of 0.7 m^3/s in Table 6.1 & Table 6.2. This higher figure for rainfall recharge is preferred for this analysis because its calculation is consistent with that for the neighbouring RSGAZ (~13 m^3/s), and for the Central Plains as a whole, ~25 m^3/s (Table 6.1). Note, however, that the difference between these two figures (0.3 and 0.7 m^3/s) derived from Table 6.1 (line A) and Table 6.2 (line 1) respectively, is insignificant in terms of the uncertainty within other water budget components. Rainfall recharge would likely increase due to the operation of irrigation (Scott 2004) so these recharge estimates should be treated as minimum values.

Actual surface water use cannot be included as a precise quantum in the water budget calculations as volumes for the Northbank Irrigation Scheme and other schemes are not available

6.1.1 Spatial variation of recharge

Anecdotal information supports the hypothesis that there is spatial and temporal variation in the recharge from the Rakaia River. Groundwater levels are affected by the state of the Rakaia River and whether or not its north channel is occupied. The upper reaches of the Rakaia River, for five kilometres south of the gorge bridge, are gaining a small amount of water from the surrounding terraces, as determined from the visible line of seeps on the true right bank.

In addition, there is spatial variation in the recharge onto the land surface. Continued operation of the surface water-sourced irrigation schemes means that there is more than rainfall recharge in these irrigated areas. Yet, there is variation within the schemes, dependent upon whether irrigators use spray (spray: ~60% efficient) or border strip methods (10-20% efficient). Currently there are no data indicating the use ratio of these two methods, nor whether there is a gradual change to more efficient methods (Evans 1999). There are data on land use available that would allow recognition of irrigated and non-irrigated land but the data are preliminary in nature and do not cover the entire study area (Figure 6-1).

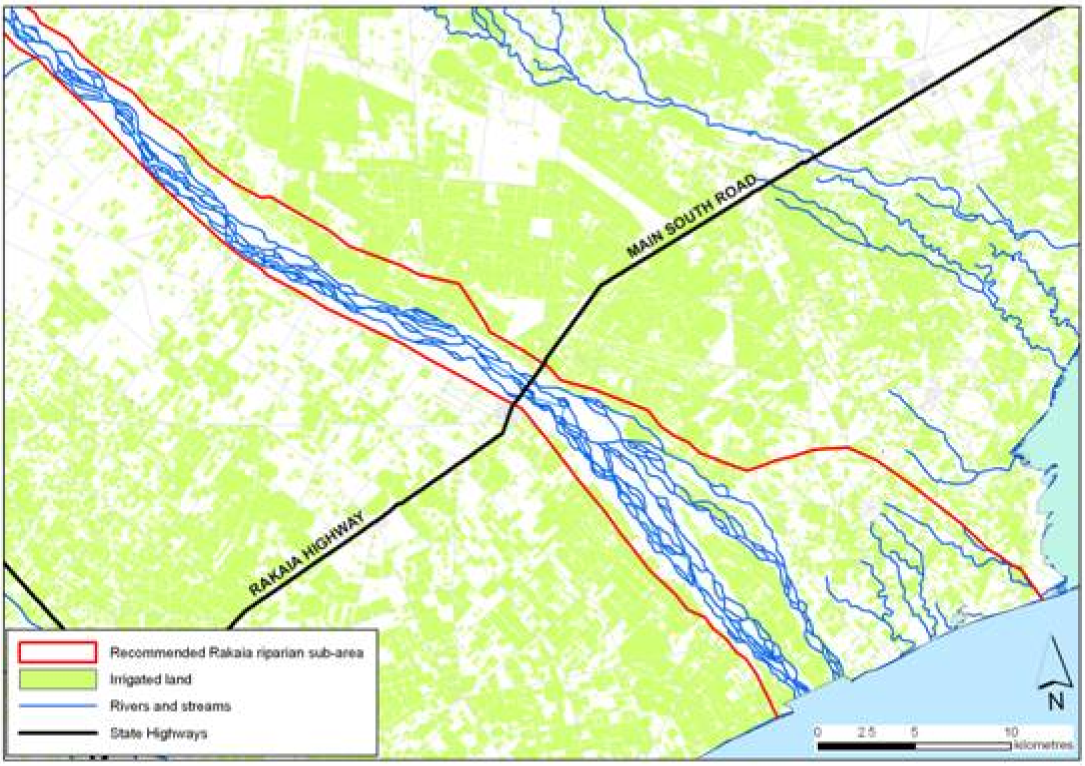

Figure 6-1: Provisional map showing location of irrigated areas determined from remote sending data

Figure 6-1 was generated from spectral analysis of remote sensing data provided by David Pairman of Landcare Research Ltd and it shows that a large proportion of land within the proposed Rakaia riparian sub-area is already irrigated.

Agricultural data indicate that of total pasture and cropland in the current Rakaia riparian sub-area, 70% is high-producing pasture (probably irrigated), 11% is low-producing pasture (non-irrigated), and 19% consists of short rotation cropland (irrigated and non-irrigated). A preliminary estimate of the proportion of irrigated land in the total land area is 25%, probably not that dissimilar from that portrayed in Figure 6-1. This proportion would be larger for the proposed and SWUG riparian land areas because of the larger proportion of intensively farmed land in the whole, which includes a significant area of ‘natural’ riparian land (native and exotic scrub (gorse & broom) associated with the Rakaia River).

6.1.2 Temporal variation of recharge

Time series analysis of the quantum of flow in the Rakaia River, coupled with anecdotal evidence of shifts in the use by the river of the northern or southern channels around Rakaia Island, indicates that there is considerable temporal variation in river recharge to the zone. Groundwater levels appear to be affected by the flow state and channel occupation of the Rakaia. Therefore, only a proportion of the recharge from the river can be relied upon. For this reason, quantifying that proportion has not been attempted and it should not be included in any recharge assessment.

6.1.3 Analysis of recharge data

If recognition of the riparian sub-area was to change to a separate allocation zone, then new recharge estimates would be required. Recharge to groundwater resulting from rainfall incident on the land can be calculated from a combination of rainfall and evapotranspiration data in combination with soil properties. Recharge to groundwater can be calculated for any specific land area. This process has been undertaken for the entire Rakaia-Selwyn Groundwater Allocation Zone, and three areas reflecting three management options have been chosen:

- The current Rakaia riparian sub-area (RRSA);
- Southbridge Water User Group proposal;
- Recommended enlarged Rakaia riparian sub-area.

The outlines of these areas are shown in Figure 6-2 and in several other figures in this report. Note that the SWUG proposal, which included the downstream (eastern) portion of the RRSA has been modified to include also the upstream (western or incised) portion of the current RRSA. Dryland rainfall recharge estimates for the three proposed riparian zones and for the corresponding remainder of the RSGAZ have been calculated and the data are presented in Table 6.3.

Table 6.3: Dryland rainfall recharge to groundwater for the three proposed management options (refer to Figure 6-2 for option areas)

Management option	Area of riparian zone (ha)	Mean recharge to entire current RSGAZ over 128 547 ha (GL/year)	Mean recharge to riparian zone (GL/year)	Recharge to remaining RSGAZ (GL/year)	Percentage of total RSGAZ recharge represented by riparian zone
Current riparian zone (formalise the status quo)	19 072	397.1	58.3	338.8	14.7
SWUG proposal	28 817	397.1	71.5	325.6	18.0
Recommended riparian zone	25 663	397.1	67.9	329.2	17.1

The indicative dry land rainfall recharge data in Table 6.3 indicate the range of variation in the recharge calculated for the three options. Further variations can be modelled, including allowance of additional recharge resulting from irrigation, a quantum dependent upon the irrigated area within each option.

While the additional recharge associated with rainfall incident upon irrigated land will change the absolute values of recharge (see paragraph below), it is not expected to change the relative proportions of recharge in the three suggested areas significantly.

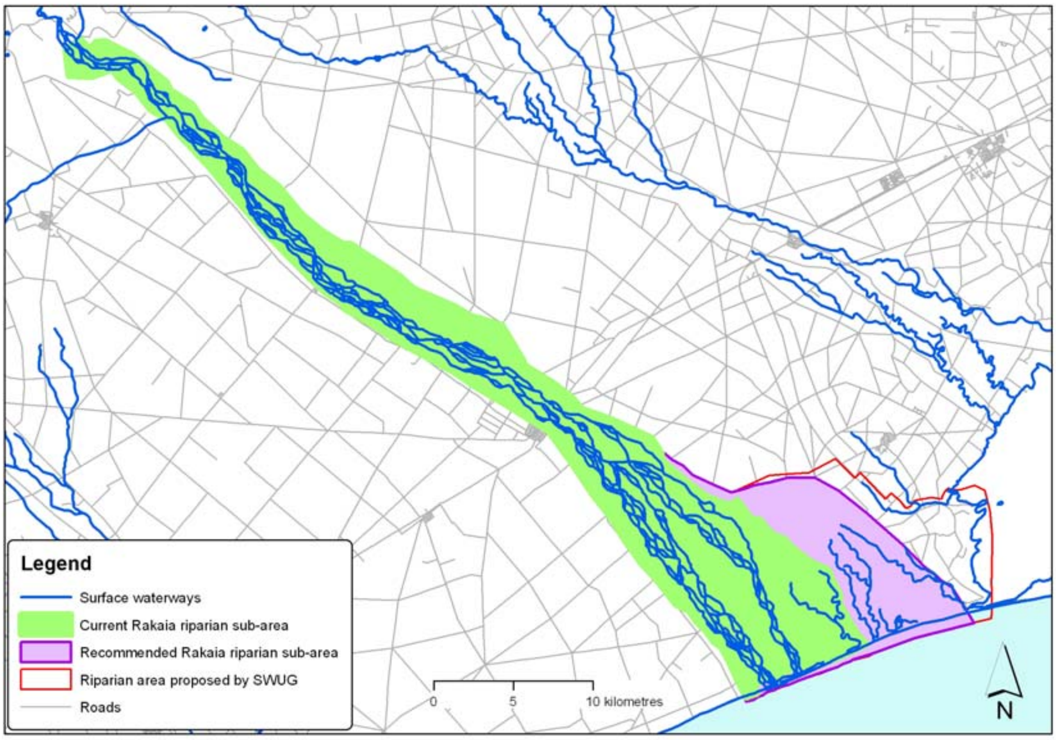

Figure 6-2: Map showing extent of the three management area options

Time series analysis of rainfall incident on the zone also indicates that there is temporal variation in the recharge derived from rainfall. This recharge is not only dependent upon the incident rainfall and corresponding evapotranspiration, but also on the area of irrigated land. This last variable determines how much of the rainfall, falling on already wet land, is able to discharge into the groundwater system. Preliminary estimates of the irrigated land area indicate that the average monthly rainfall recharge should increase from 22 mm/month to 25.6 mm/month. This would increase the annualised recharge rate in Table 6.2 from 0.7 m^3/s to approximately 0.8 m^3/s.

6.2 Outputs

Outputs from the three Rakaia riparian sub-area options consist of monitored surface water flows, an unknown flow of groundwater through the coastline, an unknown flow of groundwater back into the Rakaia River, and estimated abstraction. Estimates of these values are listed in Table 6.2.

6.2.1 Discharge of groundwater to streams and to the Rakaia River

Streams discharging from the current and proposed riparian sub-areas include Jollies Brook, Tent Burn, Lee River, and Waikekewai Creek. Mean flows from these streams are still uncertain; the total mean discharge being in the order of 3 m^3/s (Grant 2003: Figure 6.1). The mean flows reported by Booker and Graynoth (2008) for these four waterways amount to 2.1 m^3/s.

6.2.2 Discharge of groundwater under coastline

The hidden discharge via groundwater to the marine environment from the Little Rakaia area is unknown. Indeed, it can only be estimated as the mismatch of inputs and outputs. Since these are themselves all approximations, rather than fixed values, the ocean discharge is highly uncertain to the extent that it is only known to an order of magnitude. It was estimated by Grant (2003) to be a groundwater flow of up to 3.5 m^3/s for the coastline contained within the Rakaia riparian sub-area.

Direct groundwater discharge to the ocean is unlikely to be seasonally variable to any great extent because the groundwater level variation close to the coast is not likely to be more than 15% of the mean value according to preliminary work by Williams (2007). The implication of this observation is that the offshore discharge can be treated as a constant within the water budget.

6.2.3 Consented water use

Table 6.4 presents estimates of actual steady state water use as a continuous rate, by taking current status consents estimated allocation, factoring by 60% to reduce it to a mean annual volume, and converting to an annualised flow.

Table 6.4: Table showing calculation of estimated abstraction as a continuous rate

Area	60% of estimated allocation (GL)	Abstraction rate as an annualised flow (m^3/s)
Current riparian sub-area	14.6	0.5
SWUG proposal	28.3	0.9
Recommended riparian zone	23.8	0.7

Depending on the area of each riparian zone option, the abstraction discharge is in the order of 0.5 to 0.9 m^3/s for the three options in Table 6.4 and Figure 6-2. It is important to understand that these are means of ranges of annual values, and that the range for each would be about +/- 50% of the mean value. For example, the dry year use for the current riparian sub-area might be as high as 0.75 m^3/s while a wet year use might be as low as 0.25 m^3/s. As in previous sections it is worthwhile recognising this uncertainty and comparing it with the very much larger variability and uncertainties involved with inputs such as rainfall recharge and seepage from the Rakaia River.

6.2.4 Effects of water use on surface water flows

The effects on stream flows of groundwater use are both positive and negative. Abstraction of groundwater can induce stream depletion (lowered flows) where the abstracted water is in hydraulic connection with a stream (Aitchison-Earl 2006). Monitoring and modelling shows that some of the water abstracted has been induced to flow vertically through the water-saturated strata from overlying strata in direct connection with a stream. Some of that uppermost groundwater would originally have discharged to spring-fed streams. Abstractions close to spring-fed streams induce measureable stream depletion within a short time period (hours/days); more distant abstractions induce depletion over weeks and months and is a more subtle, cumulative effect.

Irrigation discharges water onto land to grow crops. Irrigation keeps soil damp to enhance crop growth. Rainfall recharge on irrigated land is therefore increased over that on dry land because less of the rainfall is required to maintain soil moisture content. Calculation of rainfall sourced recharge should, therefore, contain an adjustment for the proportion of the land that is irrigated. The proportion of the recommended riparian zone that is irrigated is approximately 25%. The proportion of irrigated land on the SWUG proposal is larger, for the current riparian sub-area it is smaller, mainly stemming from the relative influence of the undeveloped riparian Rakaia River land on the ratio.

6.3 Storage

In the section of this report dealing with groundwater levels and their spatial and temporal variation, the topic of storage was barely mentioned. Storage of groundwater changes with location, depth and time.

Storage of groundwater in the gravel-dominated strata is vital to the management of the resource. It is held in the innumerable pores of the saturated thickness of strata. Storage can be active or passive, active being that located within the normal range of maximum and minimum groundwater levels. Passive storage lies beneath the minimum groundwater levels and is usually not accessed.

Considerable seepage enters the riparian sub-area from the Rakaia River when the north channel is occupied, as that condition raises the water table locally and increases storage. Rivers and the sea control piezometric levels to a small range, so in the RRGAZ storage changes near the coast, and close to the Rakaia River, are less than in the upper plains distant from these large open-water bodies.

6.3.1 Temporal, spatial and depth variation in storage

Active storage can be estimated from knowledge of the storage characteristics and saturated thickness of the strata involved.

Depth is a factor in the ability of an aquifer to store water (storativity) because there are changes with depth in the proportion of space capable of participating in elastic storage processes in the gravel-dominated strata. In general, storativity decreases with depth as the pores between the gravels are progressively in-filled with fine-grained material. The storativity parameter may be calculated from groundwater response when stressed by an aquifer pumping test.

Moderate to deep strata are characterised by low storativity values (~0.0001). Changes in storage in deep saturated ‘semi-confined’ strata are accompanied by correspondingly large changes in groundwater (piezometric) level, as much as 30 m between winter and summer levels. Such large changes are typical of deep strata and those distant from recharge sources.

When storativity is high (~0.1), as in unconfined strata, slight changes in groundwater level may release or take up large volumes of stored water, reflecting drainage or filling of pore space. This behaviour is typical of shallow strata and those close to recharge sources.

Time series plots described in this report show how the range of groundwater levels (active storage) changes with location and time. Storage change close to the Rakaia River is small but increases with distance from it.

Therefore, by itself, a change in groundwater (piezometric) level is not a reliable indicator of change in the volume of stored groundwater. However, taken in conjunction with measured storage coefficients, change in stored volumes can be assessed. For example, in the Central Plains overall, the typical seasonal change in water levels is estimated to represent less than ten percent of the entire stored groundwater, reflecting ‘active’ storage. Were the underlying ‘passive’ storage to be accessed on a continual basis by takes, then groundwater levels as a whole would decline, with adverse effects on spring-fed streams (the natural discharge), and on wells accessing the resource.

6.4 Water budget and allocation discussion

This section uses conclusions concerning the water budget, reached earlier in the report, and discusses how they may impact on allocation.

6.4.1 Should seasonal variation in allocation of groundwater in any proposed allocation zone be linked to flow in the Rakaia River?

The information and analysis presented in this report leads to the conclusion that if groundwater levels adjacent to the Rakaia River are not consistently related to flows in the Rakaia River, then allocation should be linked instead to rainfall recharge. While it is recognised that the presence of the river in the north channel of the Rakaia promotes higher groundwater levels in the riparian zone, these higher levels have not consistently responded to all changes in river flow in the short term. Further from the river, groundwater levels become increasingly related with rainfall recharge. There is a slight long-term relationship between flows and levels but it is not certain to what extent channel proximity plays a part in this also. It may be useful to attempt to subdivide river flow and groundwater level data into periods when flow is likely in the north channel, such as during the spring melt, in order to determine whether there is a stronger relationship during specific times of year. Until such work is done, seasonal variation in allocation should not be related to flow in the Rakaia River.

6.4.2 To what extent should budget variables other than rainfall recharge be involved in the allocation calculation?

Unlike the bulk of the RSGAZ to the east, response of riparian zone groundwater levels to rainfall recharge is complex. This complexity is caused by the introduction of additional recharge from the Northbank and similar surface water-sourced irrigation schemes. In addition, the flow, stage and channel proximity in the adjacent Rakaia River plays a small part in the variability of groundwater levels.

There is an unquantified groundwater discharge to ocean that is likely to be related with groundwater levels which, near the coast, are fairly constant. Regardless of its magnitude, provided this quantum is also relatively constant, it need not play an active part in any allocation calculation providing the water budget stays in ‘credit’.

Stream flows are measured and may be used as environmental indicators of the success, or otherwise, of any allocation mechanism and management of use. Were surface water chemistry in the spring-fed streams to change significantly from alpine river-dominated to rainfall recharge-dominated, then this, too, could be used as a monitoring tool.

Monitored groundwater and surface water use is some time away, probably not until the 2010-11 season. Prior to final decision on the values of any triggers to modify allocation on a seasonal basis, an improved estimate of water use and irrigated area is required.

Given the current high level of uncertainty in river and irrigation scheme recharge, it seems reasonable that, for the meantime, no variables other than rainfall recharge should be involved in the calculation of the allocation limit. As experience is gained the allocation may be increased or decreased adaptively.

6.4.3 Is the recommended change in the riparian zone boundary consistent with the recently-proposed planning options on Rakaia allocation issues?

In a recent report on water allocation issues in the Rakaia River catchment (Dysart *et al*. 2008) it has been proposed to formalize the banding and allocation system, making it consistent and transparent. The data used in the Dysart *et al*. (2008) report was based on analysis undertaken by Aitchison-Earl (2006).

In that report it was stated that further grants of hydraulically-connected groundwater takes adjacent to the Rakaia River “*will have a cumulative effect on instream values and the reliability of supply of existing consent holders*”. Furthermore: “*some takes considered to be well connected to the Rakaia River have no low flow conditions*”. One of the conclusions from the Dysart *et al*. (2008) report is that: “*hydraulically connected groundwater takes can, and should, be included in the allocation regime proposed for the Rakaia River*”.

These three statements all indicate that there is concern that in an inconsistent manner, some groundwater takes adjacent to the Rakaia have been subject to minimum flow restrictions and, therefore, have become part of the banding mechanism. Other high hydraulically-connected takes for a number of reasons do not yet have these restrictions and may be incorporated into the surface water allocation in the future.

Altering the boundary of the Rakaia riparian sub-area does not change the degree of hydraulic connection between takes and the river. Takes within two kilometres of the Rakaia River may have all or part of their allocation associated with the river and deemed a surface water take, not a groundwater take from within the riparian sub-area. Once the review of takes adjacent to the Rakaia River is complete, any change in the ratio of surface water to groundwater allocation should become clear.

Groundwater takes greater than 2 km distance from the Rakaia River, but within the current or recommended riparian sub-area, would generally be treated as strictly groundwater takes for allocation purposes (unless there were specific aquifer parameter reasons for not doing so). Removal of these takes and the accompanying land surface area from the main part of the RSGAZ would reduce its allocation limit and correspondingly increase that in the riparian sub-area.

6.4.4 Should part of the Rakaia River surface water allocation block be linked to the Rakaia riparian sub-area?

Currently, the Rakaia River surface water allocation block is at or close to being fully allocated, especially as the Ashburton Community Water Trust application has been granted and there is legal activity concerning the availability of remaining water to other consent holders. The Dysart *et al*. (2008) report proposes that a more formal and rigorous allocation mechanism should be implemented. In their recommendation concerning hydraulically connected groundwater takes, Dysart *et al*. (2008), in Section 3.3.3.b: state the following:

"(i) Following on from recommendation (a), groundwater takes with a 'direct' degree of hydraulic connection to the Rakaia River (or tributary), would be treated exactly as though they were surface water takes, i.e. they would be subject to the monthly minimum flow associated with the relevant allocation block, and 1 for 1 sharing), with 100% of the average daily rate of take being counted towards the 70 cumec concurrent allocation limit.

(ii) Groundwater takes with a 'high' degree of connection would be subject to the same restrictions as 'direct' takes, except that they could carry on taking water when low flow restrictions are imposed, if they can reduce their theoretical stream depletion effect below the threshold established in the Rakaia Schedule. The estimated stream depletion effect (and not the average rate of take as for direct takes), would be counted towards the surface water allocation block, in accordance with Schedule WQN7.

(iii) Groundwater takes with a 'moderate' degree of hydraulic connection would not be subject to any Rakaia River low flow regime, given the relatively poor connection with the Rakaia River, i.e. restricting them will have little, if any, effect on river flows, given the significant time lag between the cessation of pumping (weeks to months), and when the effect on the river would cease (refer to Figure WQN5 of Appendix 5). However the estimated stream depletion effect, where this exceeds a specified cut-off, would be included in the 70 cumec allocation limit, as for takes with a 'high' degree of connection.

(iv) Groundwater takes with a low degree of connection would not be subject to any Rakaia low flow regime, nor would any stream depletion effect be counted towards the 70 cumec allocation limit."

Were these proposals to be implemented, then some of the groundwater allocation in the recommended riparian sub-area may become part of the surface water block of the Rakaia River.

6.4.5 What are the potential effects of the proposed Central Plains Water scheme and how might they affect calculation of an allocation limit?

The Central Plains Water Enhancement Scheme (CPW) is an application to discharge surface water, derived from the Rakaia and Waimakariri rivers, onto 60 000 hectares of land. Some of that land is already irrigated with groundwater, nevertheless, an effect of the proposed scheme would be to recharge more water into the aquifers which is likely to cause mounding of the groundwater system.

At the CPW hearing (August 2008 and May 2009), considerable analysis and modelling were described. Discussions ensued that attempted to clarify the timing and magnitude of expected mounding effects resulting from the Central Plains Water scheme. An interim decision in the form of a Commissioners' minute[6] has indicated that the scheme storage and dam would likely be declined.

The significance of that minute to this report is that if the CPW scheme were to proceed as run of river, then the regional groundwater mounding effects especially in the area south of State Highway 1, would be less than forecast at the hearing. Further down-gradient, for example, peripheral to Te Waihora / Lake Ellesmere, the mounding effects would be lesser in magnitude still and later in time relative to the seasonal discharge.

Will the scheme impact on groundwater levels within all or some parts of the riparian sub-area? The answer is probably 'no' for the riparian sub-area that lies north of State Highway 1 because this area exhibits groundwater levels higher than those produced by mounding. However, the answer is 'yes' for the riparian zone south of State Highway 1, but the extent of the effects, their timing and magnitude are arguable and probably considerably less than that originally predicted at the CPW hearing because of the lack of irrigation water storage resulting in less water used overall.

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[6] Commissioners' minute dated 1st April 2009. http://www.ecan.govt.nz/NR/rdonlyres/B8197B52-39E8-4376-8914-960D3C2A5FF6/0/MinuteCommissioners01Apr2009.pdf

Unlike many previous surface water-sourced irrigation schemes, this proposed scheme will require spray irrigation, not border strip. Consequently, the efficiency of water use will be much higher, and the mounding effects beneath and down-gradient of the scheme will be smaller. The corollary to this is that although the irrigation will in effect act as a further source of recharge, much of the benefit of that additional recharge will be felt merely as raised groundwater levels in the main part of the RSGAZ. Mounding developed in the riparian sub-area will take some time to develop and stabilise because it is distant from and not directly down-gradient of the area of enhanced recharge located within the entire CPW command area up-gradient of State Highway 1.

Environment Canterbury policy so far in the PNRRP has been cautious at including the increased recharge resulting from irrigation schemes as recharge inputs into allocation zones for a number of reasons:

- the variability in source river flows means that there is no guarantee that the scheme will be a reliable seasonal source of recharge and in the event that it goes ahead without storage, it is no more reliable than rainfall;
- while the increased area of irrigated land will increase the overall rainfall recharge, this will only occur if irrigation persists; and
- leakage from infrastructure will increase recharge to the groundwater system overall but this would likely be minimised by the use of pipes rather than open channels.

It is reasonable to exclude the effects of the CPW scheme on the recharge calculation for the meantime. If an adaptive management style is to be used, then the management constraints on use can be varied, in real time, depending on the recharge from the scheme.

6.4.6 What technical issues arise from the two options: separate allocation zone, or enlarged sub-area?

Formalising a separate groundwater allocation for the recommended Rakaia riparian sub-area would require updated information regarding the water use and irrigated area, in order that the rainfall recharge estimate used to calculate any new allocation limit is based on the correct ratio of irrigated to non-irrigated land (Scott 2004). Simply enlarging the current riparian sub-area does not require this technical step because the allocation limit set in Variation 4 of the PNRRP need not change.

Furthermore, in this report, modification of the southern boundary of the current riparian zone has not been addressed, lying as it does close to the southern (true right) bank of the Rakaia River. Were a separate allocation zone to be developed, then this southern boundary might also need to be modified for sake of consistency.

Enlarging the Rakaia riparian sub-area does not require a new allocation limit.

7 Discussion, conclusions and recommendations

In this report, conclusions have been reached regarding the state of the water resource and its dynamics. While it has been clear from the outset that the Rakaia riparian sub-area has characteristics that render it distinct from the remainder of the RSGAZ, the boundary between this ‘daughter’ sub-area and the ‘parent’ RSGAZ can be drawn in different ways, using different criteria.

For the purposes of this report, the Southbridge portion of the sub-area is freshly defined, substantiated by topographic and geological data.

This section addresses whether there are reasons to treat abstractions differently according to their location within the current riparian sub-area and in an enlarged riparian sub-area.

Section 7.1 details the criteria used to extend the recommended riparian zone. Topographic and/or geological criteria were detailed in Section 2. Surface water and groundwater criteria were detailed in sections 3 and 4. Water chemistry criteria were used to delineate the overall riparian zone in Section 5.

An analysis of all the data in this report indicates that there is a case for treating consent holders’ abstractions close to the Rakaia River differently and this can be done through stream depletion or hydraulic connection assessments.

7.1 Criteria used in boundary definition

Table 7.1 indicates the criteria used to define the boundary between the Rakaia riparian sub-area and the remainder of the RSGAZ. These criteria are described below:

- topography and geology are considered together because the two are related by physical process; geological boundaries are typically placed on maps as a result of topographic analysis.
- groundwater flow direction and recharge source are also related. The direction of groundwater flow lines are a useful means of sub-dividing zones but have no particular weight over other criteria.
- groundwater level and its variation are together a useful means of subdividing the riparian zone from the remainder of the RSGAZ. Measured aquifer parameters may also provide a basis for distinguishing the riparian sub-area from the remainder of the RSGAZ. The evidence presented in Section 4 illustrated how the recharge effect of the Rakaia River reduces eastwards.
- groundwater chemical composition has been used to distinguish different recharge sources. Notwithstanding the complexities of the groundwater flow, especially the evidence of upwelling of deep groundwater at the coastal zone (Hanson and Abraham 2009), there is a change in the groundwater chemistry consistent with increased recharge from the Rakaia River. East of the recommended riparian zone, such chemistry indicating river recharge is absent, or has different characteristics. Surface water composition is such that some streams in the recommended riparian area display ‘alpine’ type chemistry consistent with underlying groundwater. As the riparian area is traced eastwards, the alpine signature in surface water bodies weakens, and rainfall recharge signature strengthens.
- hydraulic connection with the Rakaia River would be expected, on theoretical grounds, to reduce eastwards, connection being largely a function of hydraulic conductivity and distance.

Table 7.1: Criteria used for determining the location of the proposed boundary of a new riparian sub-area (both western and eastern portions)

Criteria	Upstream or incised (western) portion	Downstream, aggradational area around Southbridge (eastern)	Comments
Topography, geology and soils	Within youngest (lowest) terrace	Boundary of Rakaia re-worked gravel sourced from the Rakaia fan coincides with change in elevation east of Southbridge 'The Rise'	While the incised section is a highly visible boundary, it becomes much less so coastward and is poorly constrained 5 km east of Bankside. 'The Rise', close to the boundary proposed by SWUG, may mark the eastern side of Rakaia alluvial re-working of older fan gravels , representing the most recent Rakaia River lobe of the aggradational fan system
Groundwater flow direction and recharge source	Surficial flow in channel probably river-parallel, with seepage from that channel downwards	Surficial flow slightly away from river, becoming normal to the coast as the coast is approached	No distinct boundary visible on basis of flow direction. Reasonable to choose a boundary parallel to a flow line, or along the flow divide illustrated in Figure 4-2. There is potential for un-quantified minor flow towards the river within 5 to 10 km of coast
Groundwater level and variation	Level broadly related to river stage rather than flow, little variation seasonally, slight spring-summer maximum corresponding with river flow maxima. Groundwater level drops off sharply at or near boundary terrace	Potential for distinction on basis of variation timing and amplitude of change in groundwater level. Eastern part of the downstream portion has time series plots showing strong rainfall recharge-based groundwater level signature	Logical to keep riparian sub-area outside zone exhibiting strong seasonal groundwater change reflecting rainfall recharge variation
Groundwater chemical composition	Not studied	Preliminary Ca/Mg and isotope chemical distinction confirmed but complicated by recharge of Northbank scheme water and natural alpine water discharging upwards from deeper strata near coast	Geochemistry consistent with recharge effects from the Rakaia River, but does not allow creation of a defensible boundary
Surface water composition	Not studied	Preliminary data indicate consistent with groundwater variation	Stream geochemistry reflects underlying groundwater. Geochemistry of some streams consistent with recharge from the Rakaia River, creation of a defensible boundary uncertain
Hydraulic connection with Rakaia River	Not determined and locally variable dependent upon depth of screen and localised aquifer parameters. Boundary between high and moderate connection would be a convenient criterion but insufficient data available	Not determined and locally variable dependent upon depth of screen and localised aquifer parameters. Boundary between high and moderate connection would be a convenient criterion but insufficient data available	Without aquifer tests for each groundwater abstraction point the hydraulic connection can only be estimated Hydraulic connection variable, probably dependent upon occupation by the river of specific channels

7.2 Uncertainties

Uncertainties associated with the criteria used to define the boundary between the Rakaia riparian sub-area and the remainder of the RSGAZ are listed in Table 7.2. In Table 7.2, note that having high confidence in the data corresponds to 'low uncertainty'.

Table 7.2: Criteria uncertainty

Criteria	Data availability and uncertainty (western incised portion)	Data availability and uncertainty (Southbridge area)
Topography, geology and soils	Low to moderate, constrained by mappable topographic feature	Poorly constrained 5 km east of Bankside, reliant on known topographic feature and geological compilation (Taylor 1996)
Groundwater flow direction and recharge source	Low to moderate, constrained by geology and topography	Boundary parallel with flow direction constrained by regional and local studies (e.g. Grant 2003)
Groundwater level and variation	Low to moderate, constrained by small number of monitoring wells	Poorly constrained by potential for distinction on basis of dynamics of groundwater level timing and variation in amplitude
Groundwater chemical composition	Low uncertainty, shallow to moderate depth groundwater within the riparian sub-area displays 'alpine' characteristics of high Ca/Mg ratio	Ca/Mg and isotope distinction, complicated by Northbank and allied schemes' excess water and natural alpine water discharging upwards from deeper strata near coast
Surface water composition	Not studied	Preliminary work consistent with groundwater level variation
Hydraulic connection with Rakaia River	Not determined so poorly constrained, perhaps boundary between high and moderate	Highly uncertain because based on unknown stream depletion (hydraulic connection) parameters

7.3 Review and discussion of the implications of change in the sub-area

Implications from any change in the status, size and shape of the riparian sub-area such as the following, need to be addressed:

- Should consent conditions be related to Rakaia River flows? Answer, probably no, because there is a poor relationship between levels and flows. However, hydraulic-connection issues suggest that at least part of the consented groundwater allocation contained within the sub-area should be included in a Rakaia River surface water allocation block (Dysart *et al.* 2008).
- The zone inherently has a higher supply reliability than the neighbouring RSGAZ due to the buffering effect of Rakaia River seepage on groundwater levels and associated spring discharges.
- Management of the resource should be with lower level triggers to reflect this greater reliability that is correlated with the health of the spring-fed streams in this area.
- Stream flows in the proposed zone should continue to have protection by means of minimum flow conditions on consents.

7.3.1 Will all consent holders need to have minimum flow conditions?

In their report, Dysart *et al*. (2008) use the revised version of Policy WQN8 of the PNRRP Chapter 5 concerning the implementation of rules to manage the effects of groundwater takes hydraulically-connected to surface water. In general, takes further than three kilometres from a stream, and with well screens greater than 50 m deep are unlikely to be 'direct', 'high' or 'moderately' connected.

Change in the location of the eastern boundary of the Rakaia riparian sub-area, and even the upgrading of its status to an allocation zone, if this were decided, will not affect hydraulic connection. What may change is the allocation of a hydraulically-connected take to the Rakaia River surface water rather than from the groundwater allocation, but this process would not occur as a result of this report, but of the consent review associated with the RPLS. Large takes close to the Rakaia River, and those other takes that are defined as highly-connected, are likely candidates for inclusion in the Rakaia River allocation. It is expected that all other takes would remain part of a groundwater allocation but with possible constraints dependent upon lowland stream flows.

Of more significance to the existing consent holders in the existing or future riparian sub-area will be constraints imposed by minimum flow conditions relating to the spring-fed streams. This imposition of conditions is one part of the RPLS consent review.

7.3.2 What changes might a consent holder expect if a new groundwater allocation zone replaced the existing riparian sub-area?

What stays the same :

- there is no change in stream depletion conditions;
- there would be no change in the consented annual volume determined by Schedule WQN9v3 or any subsequent variant; and
- groundwater take metering requirements would be identical;

What might change:

- an allocation limit would need to be determined, with concurrent modification of the ‘parent’ RSGAZ allocation limit; and
- adaptive management conditions, representing the final ‘plank’ of the consent review, though not yet formalised, could be implemented regardless of any change in status from riparian sub-area to allocation zone. Adaptive management conditions and associated trigger levels would likely be less onerous in the riparian zone because groundwater levels and associated stream discharge in the zone are less susceptible to the variation in rainfall recharge than in the remainder of the RSGAZ.

7.3.3 What changes might a consent holder expect if the current riparian sub-area was simply enlarged and formalised?

What stays the same :

- there is no change in stream depletion conditions;
- there would be no change in the consented annual volume determined by Schedule WQN9v3 or any subsequent variant; and
- groundwater take metering requirements would be identical;

What might change:

- adaptive management conditions, representing the final ‘plank’ of the consent review, though not yet formalised, could be implemented regardless of any enlargement of the riparian sub-area. Separate adaptive management conditions and associated trigger levels could be developed for it and would likely be less onerous in the riparian sub-area because groundwater levels and associated stream discharge in the riparian sub-area are less susceptible to the variation in rainfall recharge to groundwater than the remainder of the RSGAZ.

7.3.4 Bore depth

Data presented in Section 4 indicated that there is a range of bore depths within the current riparian sub-area. I see no reason to exclude deep bores from the sub-area, the strata they screen and the groundwater they abstract benefit by seepage from the Rakaia River. Deep bores will likely display different (lower) degrees of hydraulic connection than shallow bores.

7.4 Potential outcomes from this report

Two potential outcomes could result from this report:

- change to the shape and size of the RSGAZ plus the elevation of the riparian sub-area to groundwater allocation zone status. This would involve formal recognition of a riparian zone with its own allocation limit and adaptive management conditions; and the complementary change in the allocation limit and conditions for the remainder of the RSGAZ; or
- simple change to the shape and size of the current riparian sub-area with the development of discrete adaptive management conditions for consent holders in this sub-area and complementary changes to the remainder of the RSGAZ.

These two potential outcomes are described in more detail below followed by a final recommendation.

7.4.1 Formal recognition of a riparian zone with its own groundwater allocation and management mechanism

The recognition of a 'new' or 'daughter' allocation zone from within an existing 'parent' allocation zone requires change to the allocation limit for its parent, and perhaps, changes to any proposed adaptive management conditions.

Change in groundwater allocation limit is a straightforward exercise, based on change in land area, incident rainfall, determination of irrigated area and resultant rainfall recharge. Some of these have been undertaken in a previous section of this report to indicate how it can be done.

Change in adaptive management conditions may not be required in the parent allocation zone. However, there may be a change in the corresponding conditions in any newly developed "daughter " zone. Any such change in adaptive management conditions would need to recognise the special recharge conditions relating to the proximity of the Rakaia River.

However, there is a 'down' side. When the Rakaia River flows along its northern channel, groundwater levels are higher than when it is not flowing there. In the alternative state, where the river flows mainly in its southern channel, groundwater levels in the riparian zone decline, as has been observed from time to time by the community and confirmed by Environment Canterbury monitoring. It might be appropriate for a further management condition to be imposed in the newly-developed riparian zone relating to the seepage from the Rakaia River. If, for example, this seepage is reduced by a 'permanent' southward change in location of active braids, then a review clause in the management condition might be required to accommodate the change in the water budget.

In Table 6.3, the numerical effect of subdividing the RSGAZ allocation zone into a formal 'daughter' riparian zone and a bereft 'parent' zone, is that the allocation limit in the parent zone would be reduced by about 16% according to the location of the new boundary.

Specific details of this change in allocation could only be finalised once the boundary of the new allocation zone was confirmed, such as through a planning mechanism. The recommended allocation zone boundary is largely along roads that parallel both the topographic / geological boundary and the groundwater flow lines.

7.4.2 Enlargement of the current riparian sub-area with a discrete adaptive management mechanism

The recognition of an enlarged riparian sub-area is technically easier than the creation of a new allocation zone because it requires only changes to any proposed adaptive management conditions.

Any change in the adaptive management conditions in an enlarged riparian sub-area can be developed once the irrigated area, water use data and any updating of the rainfall recharge calculations for the entire RSGAZ have been undertaken. Details of adaptive management conditions for the enlarged riparian sub-area can be developed but only finalised once these data have been taken into account.

7.5 Recommendations

On the basis of the preceding analysis and discussion I recommend that the 'special' status of the Southbridge area and the concerns of the Southbridge Water Users Group can be accommodated by enlarging the riparian sub-area:

- the enlargement is simply undertaken by moving the boundary of the current sub-area eastwards to incorporate more land (refer to area outlined in purple in Figure 1);
- no changes to allocation limits would be necessary;
- consent conditions imposed on renewed, reviewed or new consents within the recommended enlarged sub-area should be managed adaptively, as is expected to be the case in the current RSGAZ, but with different management parameters, reflecting the different hydrogeological conditions;
- new estimates of allocation of groundwater and surface water would not be necessary;
- any change in the riparian sub-area is also an opportunity for a routine technical assessment of the number and quantum of groundwater abstractions deemed to be highly hydraulically-connected with the Rakaia River, and so recognised as surface water takes.

This technical report recommends that consent conditions for abstractions of groundwater in the Rakaia riparian sub-area should include adaptive management but with trigger levels differing from those likely to be imposed in the neighbouring part of the Rakaia-Selwyn Groundwater Allocation Zone. Details of these triggers are currently beyond the scope of this report and can be finalised when data on water use is available (2010-2011). I would expect that these triggers will be slightly less conservative than those proposed for the remainder of the RSGAZ, reflecting the special recharge sources in the proposed zone. The trigger levels would be set primarily to preserve ecosystem health in the spring-fed streams within the riparian zone.

7.6 Further work

The following describes further work that would facilitate the implementation of the recommendation put forward in this report and allow monitoring and assessment of expected environmental outcomes:

- analysis of metered water usage data in the RSGAZ (expected to be available in 2010-11);
- update of the proportion of irrigated land area in the RSGAZ;
- confirmation of hydraulic-connection status for consent holders in the recommended enlarged riparian sub-area;
- continued monitoring and analysis of stream flows and groundwater levels within and adjacent to the recommended riparian allocation zone;
- regular qualitative or semi-quantitative monitoring of flows in the north channel in order to determine what relationship may exist between them and groundwater levels close to the Rakaia River;
- use of the monitoring data to recommend details of adaptive management triggers (Williams *et al*. 2008), which are currently beyond the scope of this report. They could be finalised when water use data become available; and
- following a review by the Groundwater Resources Section into its monitoring network, assess the need for further installation of monitoring wells.

8 Acknowledgements

This report was initiated by proposals from the Southbridge Water Users Group (SWUG), a community of water users and concerned residents. SWUG has helped in the planning and implementation of fieldwork, provided documents and information on the water resource.

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This report has been internally reviewed by: Kathleen Crisley, Manager of the Groundwater Resources Section; by Mike Thorley, Matt Smith and Lee Burbery, my colleagues in the Groundwater Resources Section; by Suzanne Gabites of the Surface Water Resources and Ecosystems Section; by Marie Dysart, Environment Canterbury solicitor; and by Tania Harris, Manager of Consent Reviews. The report has also been externally peer-reviewed by Dr. Hugh Thorpe.

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Appendix 1: Water quality data (Source Williams and Hedley 2008)

WELL_NO	DEPTH	DIAMETER	OWNER	QUALARC_SI	GRID_EAST	GRID_NORTH	Ca_Mg_ratio	Alkalinity	Calcium	Chloride	Conductivity	Conductivity_field	Magnesium	Nitrate_Nitrogen	pH_field	Potassium	Sodium	Sulphate	Total_Hardness	Water_Temp	pH_CHEM
L36/0617	18.2	150	ELLESMERE GOLF CLUB	CRC305257	2449687	5714285	5.37	56	22	16	22	22.9	4.1	7.4	7	1.3	9.7	7.5	72	13.2	0
L36/0739	24	150	MCLEOD .M.	CRC305269	2449333	5713788	7.67	69	23	8	18	19.3	3	4.9	7.8	1.3	8.5	5	70	0	0
L36/0862	14.32	100	BISHOP, G.F.	CRC305266	2448800	5713390	5.90	74	23	9	20	21	3.9	5.2	7.6	1.3	11	7.1	73	13.8	0
L36/0286	17.4	80	Moorhead (Dave)	CRC301200	2447303	5713029	7.57	78	28	8	21	22.4	3.7	5.6	7	1.4	9.2	8.2	85	12.8	0
L36/1311	23.5	150	MILLER, FJ & MW	CRC305273	2446280	5712230	8.00	62	20	5	15	15.1	2.5	2.5	6.7	1.1	5.2	7	60	14.1	0
L36/0625	9	50	HESLOP C.J.	CRC303189	2449320	5711540	5.20	77	26	11	23	23.5	5	6.4	6.8	1.4	11	11	86	12.5	0
L36/0676	24.1	125	BISHOP .A.	CRC305360	2448130	5713660	7.57	93	28	7.4	23	23.7	3.7	5.2	7.4	1.3	12	9.5	85	12.5	7.7
L36/0836	42	300	Lowery, I D	CRC305274	2446303	5712173	8.00	68	20	5.4	16	0	2.5	3.1	0	1.3	6.1	7.2	60	0	0
L36/2273	21.8	100	Moorehead, N	CRC305365	2447135	5712475	6.11	72	22	8.3	19	20	3.6	4.2	6.8	1.1	7.2	9.2	70	13.1	0
L36/0278	15.8	150	Moorehead, N	CRC305366	2447500	5711900	7.14	62	20	7.2	17	17.6	2.8	3.6	6.8	1	6	8.6	61	13.1	7
L36/0260	18.5	150	Lemon, W S & C M	CRC305357	2448090	5712400	5.33	74	24	9.9	22	23.1	4.5	6.1	7.2	1.2	9.6	12	78	13.5	0
M36/4245	13.2	100	MCCARTIN P.J.	CRC305286	2451216	5713182	4.13	50	19	13	19	19.4	4.6	6.3	6.8	1.2	9.7	7.4	66	11.9	0
M36/8061	13	150	MR & MS AM & PT REID & EASTGATE	CRC305322	2450690	5712580	5.22	63	24	14	21	22.3	4.6	6.1	6.8	1.3	10	8.2	79	13.1	0
M36/2629	12.5	152	CHAMBERLAIN T	CRC305308	2453900	5711882	9.25	53	7.4	12	17	17.4	0.8	5.1	7.5	8.8	6.3	3.7	22	12.3	0
M36/2496	13	152	CROFT R.N.	CRC305307	2453340	5711433	4.58	54	22	16	21	21.6	4.8	7	7	1.4	11	7.9	75	13	0
M36/3417	12.2	100	LILLEY, R.W.& SONS	CRC305306	2452535	5710147	5.21	74	25	12	23	22.8	4.8	6.2	6.81	1.4	12	10	82	12.1	0
M36/3412	12	50	CARTER DJ	CRC305351	2455389	5711432	7.89	44	15	5.2	11	0	1.9	1.3	0	1.1	5.8	2.5	45	0	7.9
M36/0677	76.2	50	COLLIER. A.	CRC305347	2455600	5711400	7.14	45	15	5.2	11	0	2.1	1.4	0	1.2	5.9	2.3	46	0	7.9
M36/8111	11.55	100	MR & MS CL & CJ CROFT & WAUGH	CRC305367	2453190	5710410	5.00	62	21	14	21	22.4	4.2	6.4	7.1	1.3	11	8.2	70	12.5	7.3
M36/5346	12	100	O'CALLAGHAN, M.K.R.	CRC305359	2453525	5711781	5.26	58	20	13	20	19.8	3.8	5.9	7.4	1.2	9.2	5.8	66	13	7.7
M36/2271	60.9	50	FORD A.B.	CRC305319	2456278	5711041	5.22	46	24	6	11	11.4	4.6	1.4	7.8	1.4	11	2.2	79	12.7	0
M37/0318	14	150	REESE, A.F	CRC305305	2452450	5710000	5.31	77	26	12	23	24.1	4.9	5.8	6.8	1.4	12	11	85	12.4	0
M37/0417	17	100	MR R L INWOOD	CRC305321	2452200	5708210	5.58	71	24	9	20	20.7	4.3	4.1	6.8	1.2	8.5	10	78	12.3	0
M37/0481	11.6	150	MR ROBIN OAKLEY	CRC305302	2451218	5707645	6.92	54	18	5	14	14.4	2.6	2.2	6.8	1.1	5.6	8.6	56	12.4	0
M37/0196	12.1	50	MCCORMICK K.J.	CRC305317	2455940	5708980	11.54	53	15	11	16	17.1	1.3	3.4	7.2	1.1	4.9	5.3	43	12.1	0
M37/0372	8.5	80	CHURCH PROPERTY TRUSTEES	CRC305313	2454885	5707639	5.28	61	19	14	22	22.8	3.6	6.1	6.7	1.2	8.3	11	62	11.7	0
M37/0244	73	55	WINCHESTER, D. J. & A. K.	CRC305311	2453699	5706199	10.77	51	14	4	11	11.2	1.3	1.2	8	1	4.9	2.9	40	12.8	0
M37/0244	73	55	WINCHESTER, D. J. & A. K.	CRC305311	2453699	5706199	14.62	52	19	3.6	11	11.1	1.3	1.2	7.5	1.2	5.3	3	53	13	8
M37/0239	9.1	50	BAXTER I.D.	CRC305320	2452960	5705473	6.79	54	19	5	13	13.6	2.8	1.7	7	1.3	8.4	6.5	59	13.9	0
M37/0243	19	50	WINCHESTER, D. J. & A..K.	CRC305337	2453699	5706198	7.00	72	28	8.9	20	20.3	4	4.2	7.1	1.5	11	8.3	86	12.5	7.3
M37/0349	18	150	ND & SJ McCormack	CRC305361	2456060	5708980	6.67	50	16	10	15	0	2.4	3.7	0	1.2	8.2	5.2	50	0	7.5
M37/0157	15.2	100	CROFT L.A.	CRC305358	2456540	5709250	6.52	52	15	9.7	15	15.1	2.3	3.1	7.3	1.1	7.7	4.5	47	13.1	0
M37/0190	6	100	PARNHAM, L.S.	CRC305341	2455778	5708355	5.38	61	28	18	23	0	5.2	4.7	0	2.1	14	15	91	0	7.2
M37/0193	16.5	150	PARNHAM ,L.S.	CRC305316	2455877	5708550	7.14	52	20	9.6	16	0	2.8	3.6	0	1.3	9.1	4.9	61	0	0
M37/0188	4.8	50	MCPHERSON A.W.	CRC305318	2456188	5709993	4.29	64	24	21	26	28.9	5.6	4.8	7	1.4	16	27	83	12.3	0
M36/5974		50	GARDINER HJ AND TM	CRC305393	2453391	5712567	4.87	54	19	9.8	16	16.8	3.9	4.6	6.9	1.2	8.6	3.2	64	12.6	0
M36/0715	7.6	50	MCLACHLAN SI	CRC302168	2452444	5713210	3.93	66	24	16	24	25.3	6.1	6.8	7	1.5	14	8.6	85	14.5	0
M36/5673	12.89	150	MCLACHLAN, SI	CRC305398	2451868	5712649	4.57	52	21	13	20	0	4.6	6.5	0	1.3	11	7.9	71	0	7.4
M36/8621		50	W.N & D.A Sheddan	CRC305394	2452107	5714057	5.24	55	22	13	19	20	4.2	5.9	7.3	1.3	9.8	4.9	72	14.8	0
M36/8202	12	150	MR PETER GEOFFREY LOWERY	CRC305395	2450796	5714706	3.41	60	29	22	30	31.8	8.5	11.7	6.5	1.7	18	18	107	13.4	6.7
M36/6007	3.4		LOWERY P	CRC305396	2451645	5714792	3.56	71	31	22	31	0	8.7	8.7	0	1.8	17	26	113	0	6.5

Appendix 2: Water quality section of Environment Canterbury internal memorandum (Williams and Hedley 2008)

Water sampling

The groundwater sampling process was undertaken as a staged approach in order to maximise opportunity to focus effort on sampling and analytical issues as they arose.

Stage One: Desk study/preparation

Initially, four traverses were identified along which sampling was to be undertaken. The traverses were aligned approximately perpendicular to the Rakaia River in order to assess whether there is lateral variation in the geochemical signature of the groundwater as had been indicated by Williams and Servais (2007). The traverses also intersect the current boundary between the Little Rakaia sub-area and the main body of the RSGAZ. Selection of bores from the Environment Canterbury Wells database (Ettema 2005) was conducted in ArcGIS 9 by use of a 100 m buffer around each traverse line (Figure A2-1, bores listed in Appendix 1).

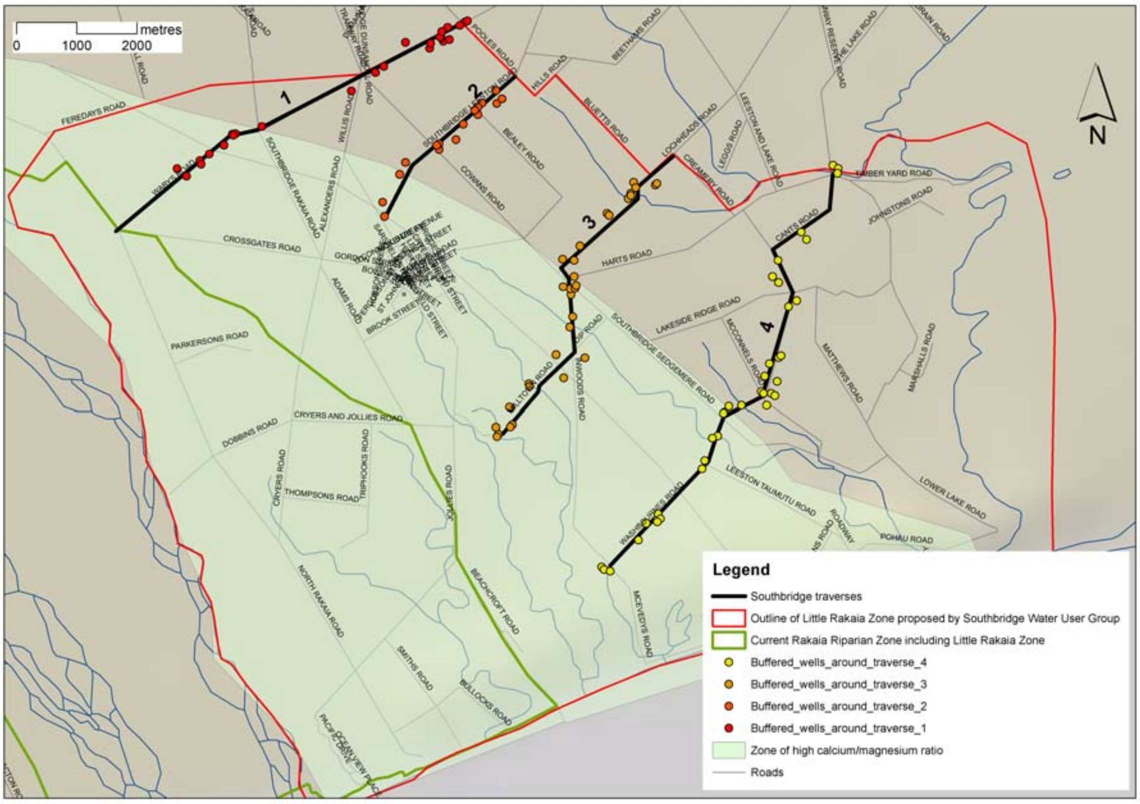


Figure A2-9-1: Map showing traverses 1 to 4 with the bores initially selected for analysis

Stage Two: Bore quality assurance

A quality assurance survey of the bores was undertaken from 20-23rd November 2007 on all of the bores identified in Stage one. This involved visiting each of the bores and performing the following actions.

- Identify whether it was possible to collect an uncontaminated water sample from the wellhead or adjacent tap;
- Obtain a location with five metre precision using a handheld GPS;
- Photograph the bore head and bore surroundings;

- Confirm the bore dimensions and depth;
- Meeting bore owners / landowners and obtaining contact and access details;
- Surveying any bores that were previously not in the Environment Canterbury WELLS database

This information was used to update the Environment Canterbury WELLS database. After completion of this stage the following bores (Appendix 2: Tables A2-1a to 1d) were identified as locations where water samples could be obtained (under various conditions).

Stage Three: Initial groundwater sampling

Initially, water samples were collected during the period 26th-29th Nov. The samples (Table A2-1) were collected in a broad spatial distribution to give an overview of the groundwater geochemistry throughout the area outlined by the traverses (Figures 10 & 11). (Note: two extra sites were subsequently added from outside the 100 m buffer to fill in gaps). All samples were taken in accord with the Environment Canterbury procedure EMG - G002 – 02.

Table A2-9.1: Bores sampled during first stage

Traverse 1	Bore L36/0617 Bore L36/0739 Bore L36/0862 Bore L36/0286 Bore L36/1744 Bore L36/1311
Traverse 2	Bore M36/4245 Bore M36/8061 Bore L36/0625
Traverse 3	Bore M36/2629 Bore M36/2496 Bore M36/3417 Bore M37/0318 Bore M37/0417 Bore M37/0481
Traverse 4	Bore M36/2271 Bore M37/0196 Bore M37/0372 Bore M37/0244 Bore M37/0239

At each location the following field measurements were recorded:

- pH
- Water temperature (degrees Celsius)
- Conductivity (temperature corrected).

These were collected with the use of a YSI 63 pH/Conductivity field meter with flow cell which provided non-turbulent and non-aerated flow.

Before final measurements were recorded the bore was purged for a time sufficient to ensure that physical measurements had stabilised. Through communication with the landowner, the usage of the bore (volume/frequency) was determined and taken into consideration for purging times. This assured that the sample was fresh and therefore the water chemistry was representative of the aquifer and not that residing in the bore casing.

Water samples were collected for laboratory analysis of major ions. They were collected in two different bottles (125 mL and 500 mL). The samples were analysed for pH, calcium, magnesium, alkalinity, chloride, conductivity, nitrate-nitrogen, potassium, sodium, sulphate, and total hardness.

The 125 mL bottle was used to collect the cation samples. The water was filtered in the field to remove suspended solids and the bottle contained a drop of acid as a preservative.

The 500 mL bottle was used to collect the anion samples, plus pH and conductivity, and was filled directly from the sample point. Care was taken to assure there was no air in the bottle which could affect the pH of the sample. All samples were stored on ice and were delivered to the laboratory for analysis within six hours of sampling. Sampled bores are listed in Table A2-1 and results are presented in Table A2-2.The results obtained during the initial (first stage) water sampling are presented in Figure A2-3 to show the distribution of calcium/magnesium ratios (Ca/Mg). It became apparent that further sampling was necessary to fill in gaps and to indicate whether there was a variation in chemistry with depth.

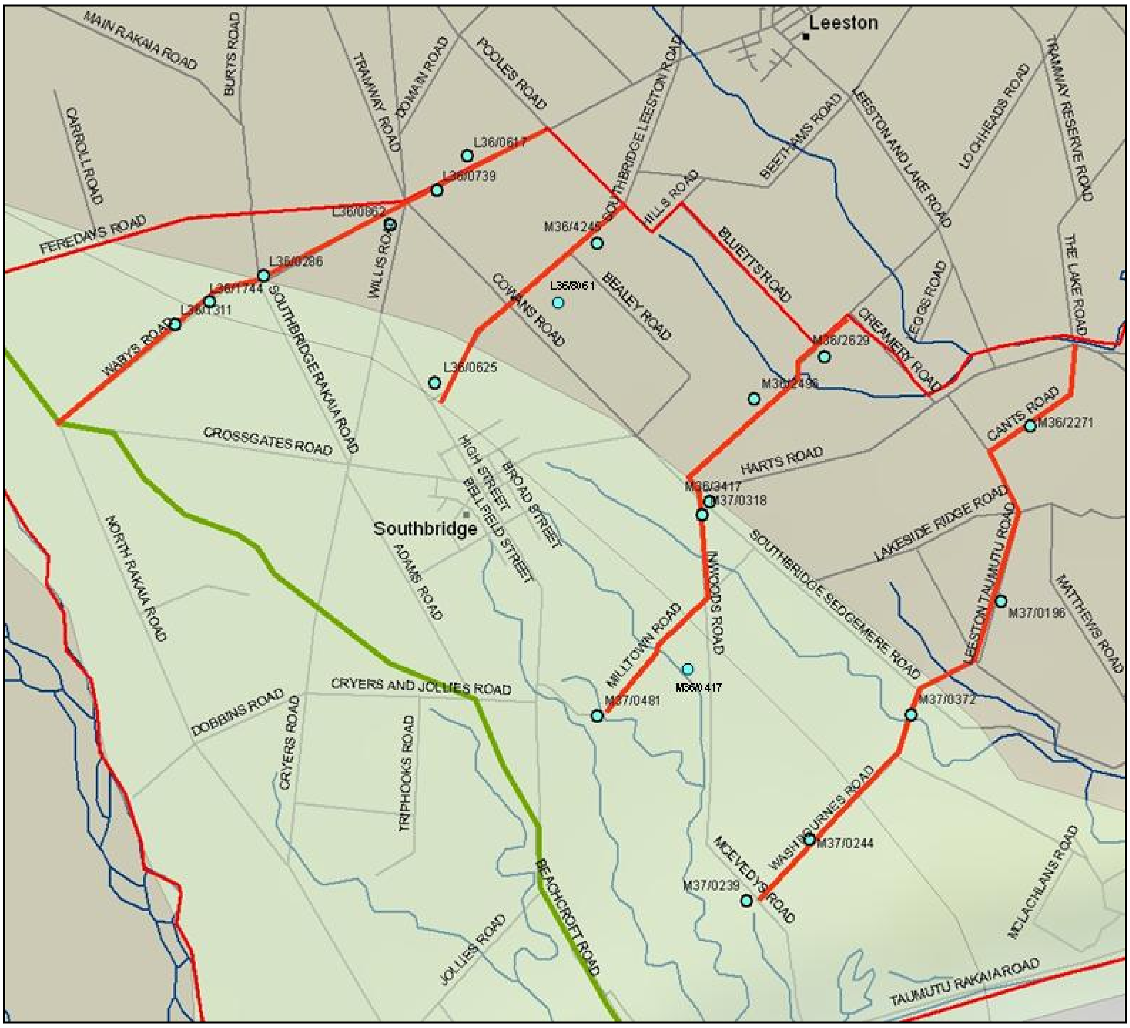


Figure A2-9-2: Location of the sampled bores sampled during period 26TH - 29TH Nov

Stage Four: Follow up groundwater sampling
The initial results revealed certain aspects that needed to be investigated with further sampling in target areas:

- Understanding the relationship between the Ca/Mg ratio and depth;
- Investigating anomalous values;
- Sampling areas where a perceived need for additional data.

To investigate the relationship between the Ca/Mg ratio and depth, deep bores were identified which were in close proximity to shallow bores. Both bores were sampled to reveal any variation. Follow-up sampling was undertaken from 16 bores as shown in Figure A2-4.

A table containing the results of this second round of sampling is presented in Table A2-3.

Final water sampling

In late January 2008, six more water samples were taken at the edge and outside (east) of the border of the Little Rakaia sub-area. These samples were taken along Bluetts, Bethams and Feredays roads (Figure A2-5 and inset). These samples were intended to tie the traverses together (NW-NE) and also to gain a better understanding of the geochemistry in this area originally outside the initial area of interest.

An existing bore of unknown depth was discovered, given an Environment Canterbury number (M36/8621), and its record entered into the database.

A table containing the results of this final round of sampling is presented in Table A2-3.

Data analysis

This section of this memorandum describes some of the variation in the groundwater quality data and makes some conclusions.

Calcium magnesium relationships

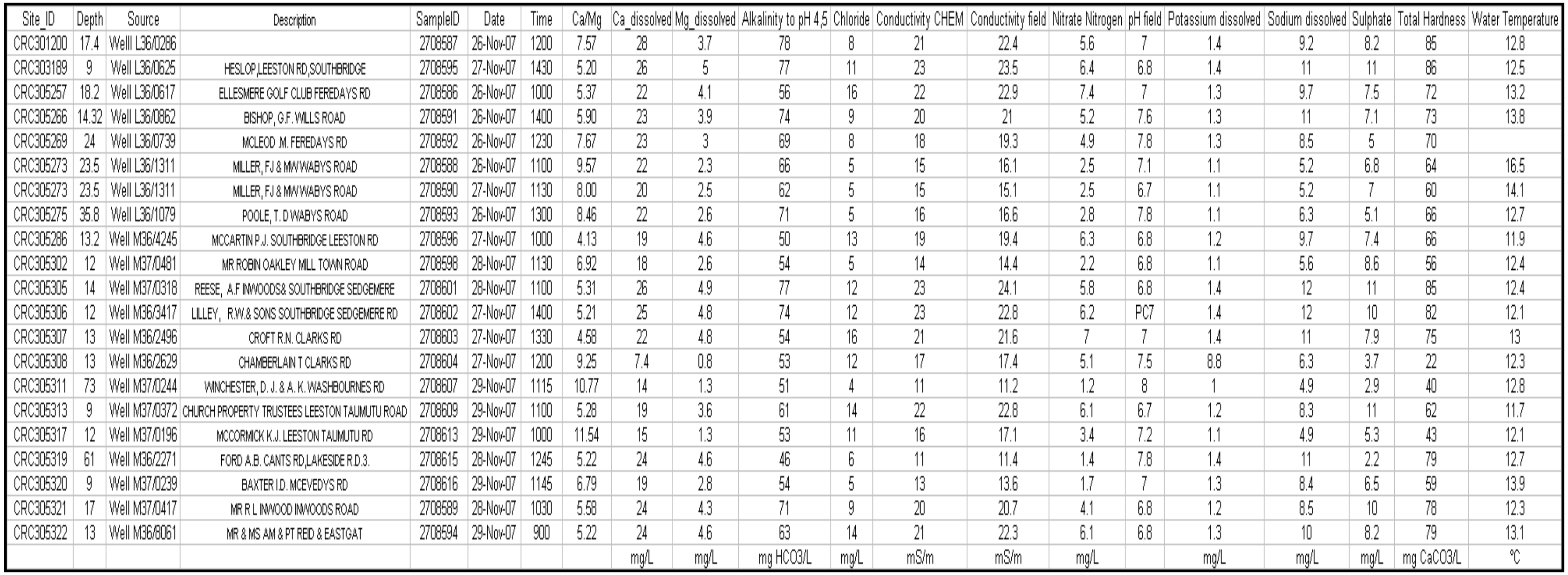
Previous work

Exploratory sampling of groundwater and surface water in the Southbridge area, undertaken by Williams and Servais (2007), indicated that the calcium magnesium ratio (Ca/Mg) might be a useful tool to delineate the source of groundwater. Further work in the Southbridge area in 2007 investigated in more detail the spatial variation of the Ca/Mg ratio, and determined depth variation and other characteristics. Williams and Servais (2007) showed that groundwater that had been sourced from rainfall had percolated through and interacted with the soil profile, altering the calcium magnesium ratio. In general, this interaction increases the concentration of calcium and magnesium in the percolating water and resulted in a generally low Ca/Mg ratio. Alpine river water seeps through river gravels to enter the aquifer system and therefore displays lower concentrations of these metals and is characterised by a higher Ca/Mg ratio.

Workers in other areas, such as Scott and Thorpe (1986), Close (1987), and Close *et al.* (1995), recognised the varying chemical composition of groundwater adjacent to major rivers but did not specifically attribute the variation in chemistry to soil-water interaction processes. Without purpose-designed experiments, it is unlikely that soil-water interaction processes will be sufficiently understood to determine if these are the likely cause of the differences in chemistry between groundwater sourced from rainfall and that sourced from alpine river seepage. Notwithstanding this caution, groundwater chemistry adjacent to the Ashburton, Rakaia and Waimakariri (M. Thorley, Environment Canterbury internal memorandum, July 2008) rivers illustrate contrasts in composition that may be most simply explained by this process.

It would appear that as rainfall moves down through the soil, both magnesium and calcium concentrations increase, but at different rates with the result that the Ca/Mg ratio becomes smaller.

Table A2-9.2: The results from the chemical analysis of the water samples collected during November 2007



Site_ID	Depth	Source	Description	SampleID	Date	Time	Ca/Mg	Ca_dissolved	Mg_dissolved	Alkalinity to pH 4,5	Chloride	Conductivity CHEM	Conductivity field	Nitrate Nitrogen	pH field	Potassium dissolved	Sodium dissolved	Sulphate	Total Hardness	Water Temperature
CRC301200	17.4	Welll L36/0286		2708587	26-Nov-07	1200	7.57	28	3.7	78	8	21	22.4	5.6	7	1.4	9.2	8.2	85	12.8
CRC303189	9	Well L36/0625	HESLOP,LEESTON RD,SOUTHBRIDGE	2708595	27-Nov-07	1430	5.20	26	5	77	11	23	23.5	6.4	6.8	1.4	11	11	86	12.5
CRC305257	18.2	Well L36/0617	ELLESMERE GOLF CLUB FEREDAYS RD	2708586	26-Nov-07	1000	5.37	22	4.1	56	16	22	22.9	7.4	7	1.3	9.7	7.5	72	13.2
CRC305266	14.32	Well L36/0862	BISHOP, G.F. WILLS ROAD	2708591	26-Nov-07	1400	5.90	23	3.9	74	9	20	21	5.2	7.6	1.3	11	7.1	73	13.8
CRC305269	24	Well L36/0739	MCLEOD .M. FEREDAYS RD	2708592	26-Nov-07	1230	7.67	23	3	69	8	18	19.3	4.9	7.8	1.3	8.5	5	70	
CRC305273	23.5	Well L36/1311	MILLER, FJ & MW WABYS ROAD	2708588	26-Nov-07	1100	9.57	22	2.3	66	5	15	16.1	2.5	7.1	1.1	5.2	6.8	64	16.5
CRC305273	23.5	Well L36/1311	MILLER, FJ & MW WABYS ROAD	2708590	27-Nov-07	1130	8.00	20	2.5	62	5	15	15.1	2.5	6.7	1.1	5.2	7	60	14.1
CRC305275	35.8	Well L36/1079	POOLE, T. D WABYS ROAD	2708593	26-Nov-07	1300	8.46	22	2.6	71	5	16	16.6	2.8	7.8	1.1	6.3	5.1	66	12.7
CRC305286	13.2	Well M36/4245	MCCARTIN P.J. SOUTHBRIDGE LEESTON RD	2708596	27-Nov-07	1000	4.13	19	4.6	50	13	19	19.4	6.3	6.8	1.2	9.7	7.4	66	11.9
CRC305302	12	Well M37/0481	MR ROBIN OAKLEY MILL TOWN ROAD	2708598	28-Nov-07	1130	6.92	18	2.6	54	5	14	14.4	2.2	6.8	1.1	5.6	8.6	56	12.4
CRC305305	14	Well M37/0318	REESE, A.F INWOODS& SOUTHBRIDGE SEDGEMERE	2708601	28-Nov-07	1100	5.31	26	4.9	77	12	23	24.1	5.8	6.8	1.4	12	11	85	12.4
CRC305306	12	Well M36/3417	LILLEY, R.W.& SONS SOUTHBRIDGE SEDGEMERE RD	2708602	27-Nov-07	1400	5.21	25	4.8	74	12	23	22.8	6.2	PC7	1.4	12	10	82	12.1
CRC305307	13	Well M36/2496	CROFT R.N. CLARKS RD	2708603	27-Nov-07	1330	4.58	22	4.8	54	16	21	21.6	7	7	1.4	11	7.9	75	13
CRC305308	13	Well M36/2629	CHAMBERLAIN T CLARKS RD	2708604	27-Nov-07	1200	9.25	7.4	0.8	53	12	17	17.4	5.1	7.5	8.8	6.3	3.7	22	12.3
CRC305311	73	Well M37/0244	WINCHESTER, D. J. & A. K. WASHBOURNES RD	2708607	29-Nov-07	1115	10.77	14	1.3	51	4	11	11.2	1.2	8	1	4.9	2.9	40	12.8
CRC305313	9	Well M37/0372	CHURCH PROPERTY TRUSTEES LEESTON TAUMUTU ROAD	2708609	29-Nov-07	1100	5.28	19	3.6	61	14	22	22.8	6.1	6.7	1.2	8.3	11	62	11.7
CRC305317	12	Well M37/0196	MCCORMICK K.J. LEESTON TAUMUTU RD	2708613	29-Nov-07	1000	11.54	15	1.3	53	11	16	17.1	3.4	7.2	1.1	4.9	5.3	43	12.1
CRC305319	61	Well M36/2271	FORD A.B. CANTS RD,LAKESIDE R.D.3.	2708615	28-Nov-07	1245	5.22	24	4.6	46	6	11	11.4	1.4	7.8	1.4	11	2.2	79	12.7
CRC305320	9	Well M37/0239	BAXTER I.D. MCEVEDYS RD	2708616	29-Nov-07	1145	6.79	19	2.8	54	5	13	13.6	1.7	7	1.3	8.4	6.5	59	13.9
CRC305321	17	Well M37/0417	MR R L INWOOD INWOODS ROAD	2708589	28-Nov-07	1030	5.58	24	4.3	71	9	20	20.7	4.1	6.8	1.2	8.5	10	78	12.3
CRC305322	13	Well M36/8061	MR & MS AM & PT REID & EASTGAT	2708594	29-Nov-07	900	5.22	24	4.6	63	14	21	22.3	6.1	6.8	1.3	10	8.2	79	13.1
								mg/L	mg/L	mg HCO3/L	mg/L	mS/m	mS/m	mg/L		mg/L	mg/L	mg/L	mg CaCO3/L	°C

Table A2-9.3: The results from the chemical analysis of the water samples collected during January 2008

WELL_NO	DEPTH	DIAMETER	OWNER	QUALARC_SI	GRID_EAST	GRID_NORTH	Ca_Mg_ratio	Alkalinity	Calcium	Chloride	Conductivity	Conductivity_field	Magnesium	Nitrate_Nitrogen	pH_field	Potassium	Sodium	Sulphate	Total_Hardness	Water_Temp	pH_CHEM
L36/0617	18.2	150	ELLESMERE GOLF CLUB	CRC305257	2449687	5714285	5.37	56	22	16	22	22.9	4.1	7.4	7	1.3	9.7	7.5	72	13.2	0
L36/0739	24	150	MCLEOD .M.	CRC305269	2449333	5713788	7.67	69	23	8	18	19.3	3	4.9	7.8	1.3	8.5	5	70	0	0
L36/0862	14.32	100	BISHOP, G.F.	CRC305266	2448800	5713390	5.90	74	23	9	20	21	3.9	5.2	7.6	1.3	11	7.1	73	13.8	0
L36/0286	17.4	80	Moorhead (Dave)	CRC301200	2447303	5713029	7.57	78	28	8	21	22.4	3.7	5.6	7	1.4	9.2	8.2	85	12.8	0
L36/1311	23.5	150	MILLER, FJ & MW	CRC305273	2446280	5712230	8.00	62	20	5	15	15.1	2.5	2.5	6.7	1.1	5.2	7	60	14.1	0
L36/0625	9	50	HESLOP C.J.	CRC303189	2449320	5711540	5.20	77	26	11	23	23.5	5	6.4	6.8	1.4	11	11	86	12.5	0
L36/0676	24.1	125	BISHOP .A.	CRC305360	2448130	5713660	7.57	93	28	7.4	23	23.7	3.7	5.2	7.4	1.3	12	9.5	85	12.5	7.7
L36/0836	42	300	Lowery, I D	CRC305274	2446303	5712173	8.00	68	20	5.4	16	0	2.5	3.1	0	1.3	6.1	7.2	60	0	0
L36/2273	21.8	100	Moorehead, N	CRC305365	2447135	5712475	6.11	72	22	8.3	19	20	3.6	4.2	6.8	1.1	7.2	9.2	70	13.1	0
L36/0278	15.8	150	Moorehead, N	CRC305366	2447500	5711900	7.14	62	20	7.2	17	17.6	2.8	3.6	6.8	1	6	8.6	61	13.1	7
L36/0260	18.5	150	Lemon, W S & C M	CRC305357	2448090	5712400	5.33	74	24	9.9	22	23.1	4.5	6.1	7.2	1.2	9.6	12	78	13.5	0
M36/4245	13.2	100	MCCARTIN P.J.	CRC305286	2451216	5713182	4.13	50	19	13	19	19.4	4.6	6.3	6.8	1.2	9.7	7.4	66	11.9	0
M36/8061	13	150	MR & MS AM & PT REID & EASTGATE	CRC305322	2450690	5712580	5.22	63	24	14	21	22.3	4.6	6.1	6.8	1.3	10	8.2	79	13.1	0
M36/2629	12.5	152	CHAMBERLAIN T	CRC305308	2453900	5711882	9.25	53	7.4	12	17	17.4	0.8	5.1	7.5	8.8	6.3	3.7	22	12.3	0
M36/2496	13	152	CROFT R.N.	CRC305307	2453340	5711433	4.58	54	22	16	21	21.6	4.8	7	7	1.4	11	7.9	75	13	0
M36/3417	12.2	100	LILLEY, R.W.& SONS	CRC305306	2452535	5710147	5.21	74	25	12	23	22.8	4.8	6.2	6.81	1.4	12	10	82	12.1	0
M36/3412	12	50	CARTER DJ	CRC305351	2455389	5711432	7.89	44	15	5.2	11	0	1.9	1.3	0	1.1	5.8	2.5	45	0	7.9
M36/0677	76.2	50	COLLIER. A.	CRC305347	2455600	5711400	7.14	45	15	5.2	11	0	2.1	1.4	0	1.2	5.9	2.3	46	0	7.9
M36/8111	11.55	100	MR & MS CL & CJ CROFT & WAUGH	CRC305367	2453190	5710410	5.00	62	21	14	21	22.4	4.2	6.4	7.1	1.3	11	8.2	70	12.5	7.3
M36/5346	12	100	O'CALLAGHAN, M.K.R.	CRC305359	2453525	5711781	5.26	58	20	13	20	19.8	3.8	5.9	7.4	1.2	9.2	5.8	66	13	7.7
M36/2271	60.9	50	FORD A.B.	CRC305319	2456278	5711041	5.22	46	24	6	11	11.4	4.6	1.4	7.8	1.4	11	2.2	79	12.7	0
M37/0318	14	150	REESE, A.F	CRC305305	2452450	5710000	5.31	77	26	12	23	24.1	4.9	5.8	6.8	1.4	12	11	85	12.4	0
M37/0417	17	100	MR R L INWOOD	CRC305321	2452200	5708210	5.58	71	24	9	20	20.7	4.3	4.1	6.8	1.2	8.5	10	78	12.3	0
M37/0481	11.6	150	MR ROBIN OAKLEY	CRC305302	2451218	5707645	6.92	54	18	5	14	14.4	2.6	2.2	6.8	1.1	5.6	8.6	56	12.4	0
M37/0196	12.1	50	MCCORMICK K.J.	CRC305317	2455940	5708980	11.54	53	15	11	16	17.1	1.3	3.4	7.2	1.1	4.9	5.3	43	12.1	0
M37/0372	8.5	80	CHURCH PROPERTY TRUSTEES	CRC305313	2454885	5707639	5.28	61	19	14	22	22.8	3.6	6.1	6.7	1.2	8.3	11	62	11.7	0
M37/0244	73	55	WINCHESTER, D. J. & A. K.	CRC305311	2453699	5706199	10.77	51	14	4	11	11.2	1.3	1.2	8	1	4.9	2.9	40	12.8	0
M37/0244	73	55	WINCHESTER, D. J. & A. K.	CRC305311	2453699	5706199	14.62	52	19	3.6	11	11.1	1.3	1.2	7.5	1.2	5.3	3	53	13	8
M37/0239	9.1	50	BAXTER I.D.	CRC305320	2452960	5705473	6.79	54	19	5	13	13.6	2.8	1.7	7	1.3	8.4	6.5	59	13.9	0
M37/0243	19	50	WINCHESTER, D. J. & A..K.	CRC305337	2453699	5706198	7.00	72	28	8.9	20	20.3	4	4.2	7.1	1.5	11	8.3	86	12.5	7.3
M37/0349	18	150	ND & SJ McCormack	CRC305361	2456060	5708980	6.67	50	16	10	15	0	2.4	3.7	0	1.2	8.2	5.2	50	0	7.5
M37/0157	15.2	100	CROFT L.A.	CRC305358	2456540	5709250	6.52	52	15	9.7	15	15.1	2.3	3.1	7.3	1.1	7.7	4.5	47	13.1	0
M37/0190	6	100	PARNHAM, L.S.	CRC305341	2455778	5708355	5.38	61	28	18	23	0	5.2	4.7	0	2.1	14	15	91	0	7.2
M37/0193	16.5	150	PARNHAM ,L.S.	CRC305316	2455877	5708550	7.14	52	20	9.6	16	0	2.8	3.6	0	1.3	9.1	4.9	61	0	0
M37/0188	4.8	50	MCPHERSON A.W.	CRC305318	2456188	5709993	4.29	64	24	21	26	28.9	5.6	4.8	7	1.4	16	27	83	12.3	0
M36/5974		50	GARDINER HJ AND TM	CRC305393	2453391	5712567	4.87	54	19	9.8	16	16.8	3.9	4.6	6.9	1.2	8.6	3.2	64	12.6	0
M36/0715	7.6	50	MCLACHLAN SI	CRC302168	2452444	5713210	3.93	66	24	16	24	25.3	6.1	6.8	7	1.5	14	8.6	85	14.5	0
M36/5673	12.89	150	MCLACHLAN, SI	CRC305398	2451868	5712649	4.57	52	21	13	20	0	4.6	6.5	0	1.3	11	7.9	71	0	7.4
M36/8621		50	W.N & D.A Sheddan	CRC305394	2452107	5714057	5.24	55	22	13	19	20	4.2	5.9	7.3	1.3	9.8	4.9	72	14.8	0
M36/8202	12	150	MR PETER GEOFFREY LOWERY	CRC305395	2450796	5714706	3.41	60	29	22	30	31.8	8.5	11.7	6.5	1.7	18	18	107	13.4	6.7
M36/6007	3.4		LOWERY P	CRC305396	2451645	5714792	3.56	71	31	22	31	0	8.7	8.7	0	1.8	17	26	113	0	6.5

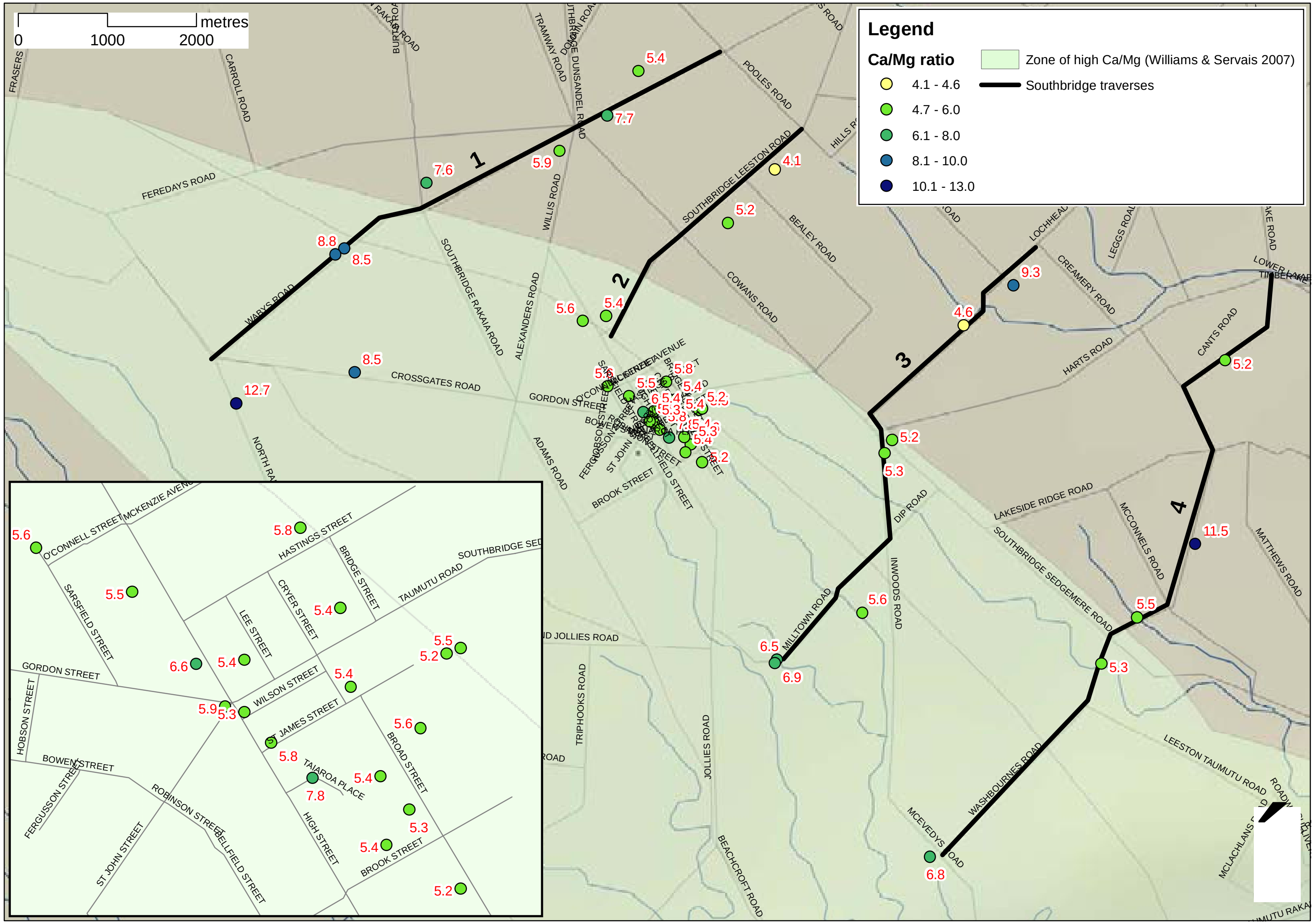


Figure A2-9-3: Map showing results of Ca/Mg ratio derived from first sampling round (Numbered black lines are traverses)

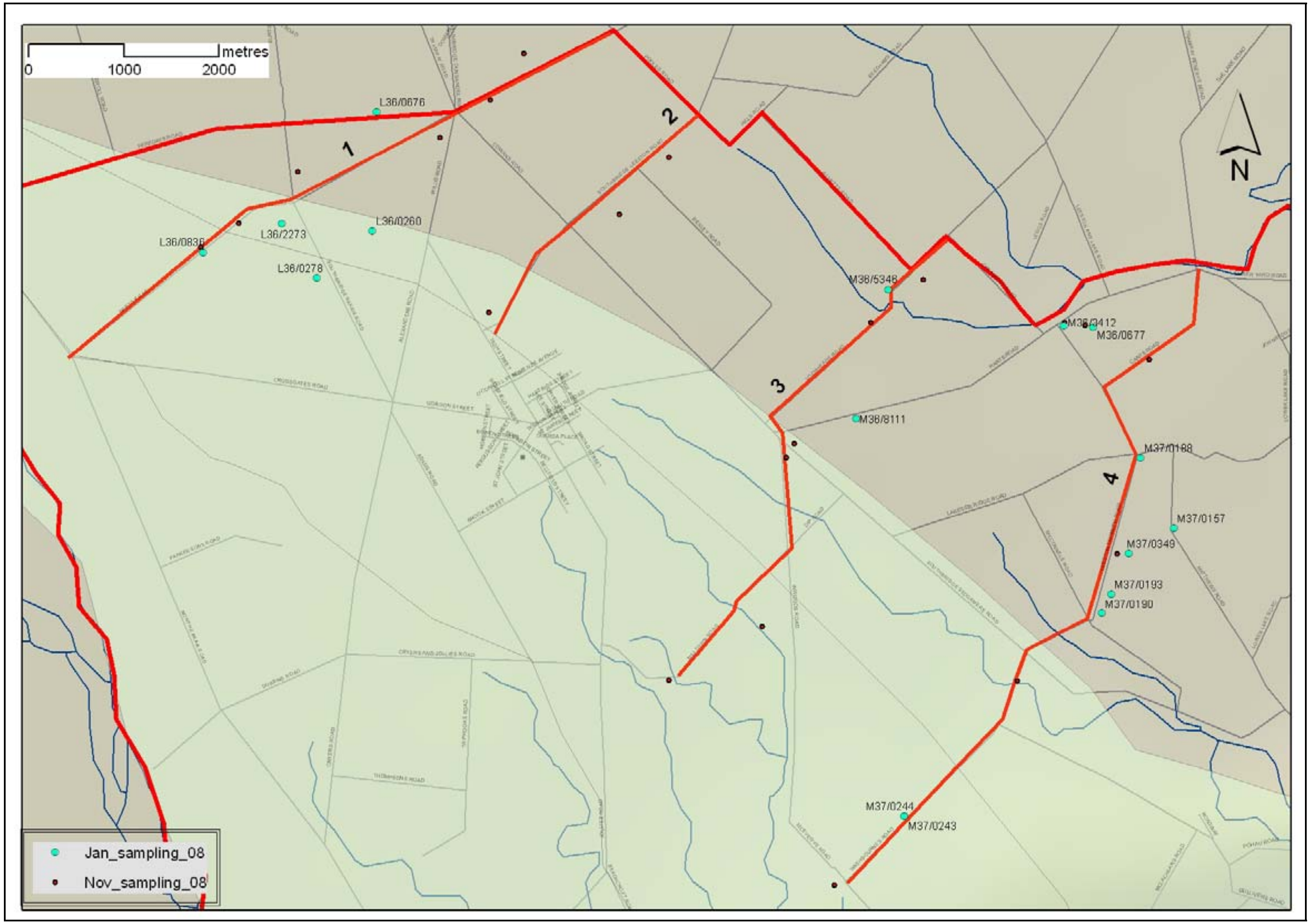


Figure A2-9-4: Bores that were sampled during January 2008 (L36/0260, L36/0278, L36/0836, L36/2273, L36/0676, M36/0677, M36/3412, M36/5346, M36/8111, M37/0157, M37/0188, M37/0190, M37/0193, M37/0243, M37/0244, M37/0349) Numbered red lines are traverses

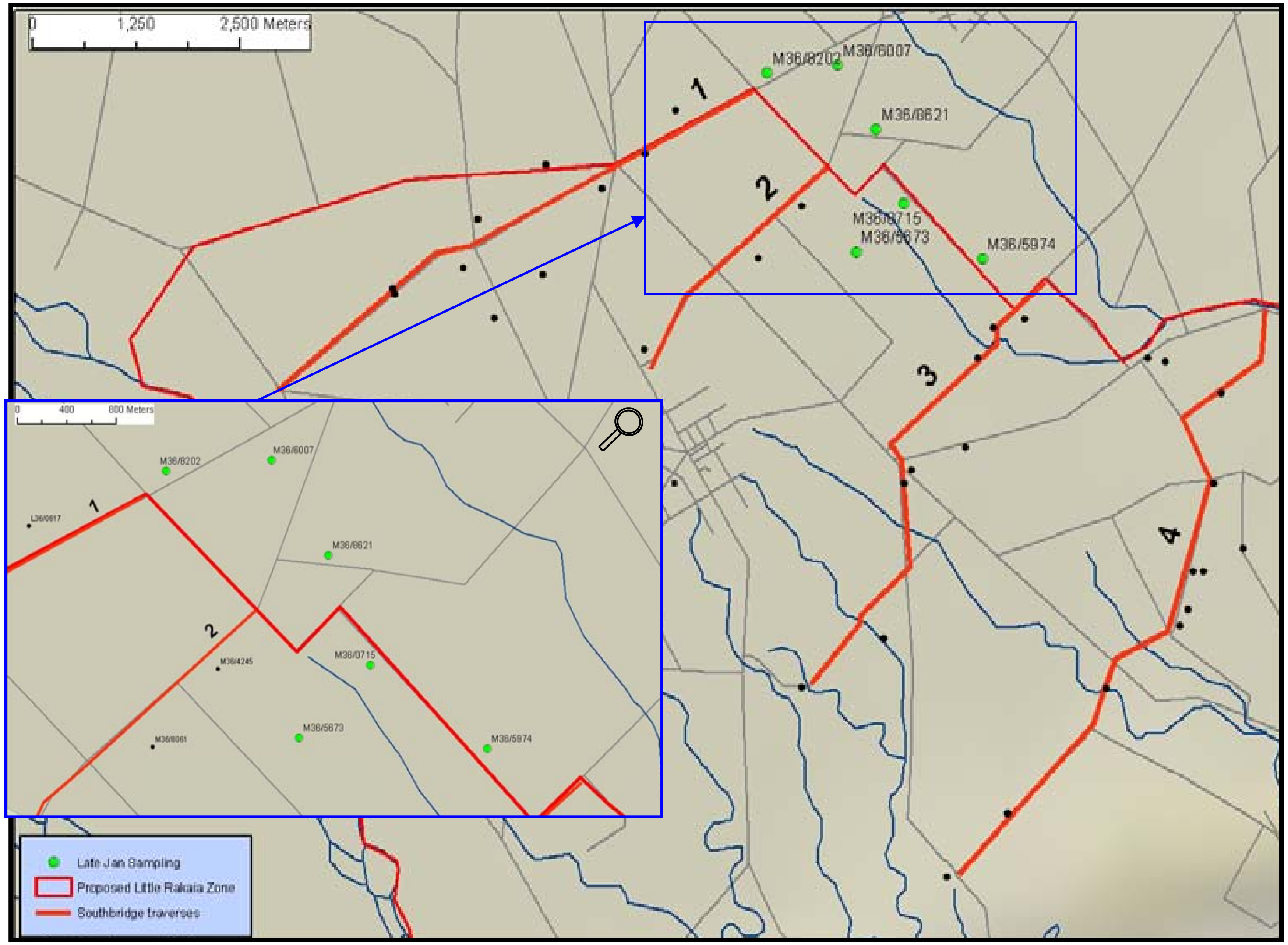


Figure A2-9-5: Bores sampled in Late January. Numbered red lines are traverses

Current work

The Southbridge samples were subjected to this type of analysis by plotting the Ca/Mg ratio against Ca and Mg respectively. Figure A2-6 shows that the Ca/Mg ratio is high when both Ca and Mg are relatively low and *vice versa*.

Samples of river water from the Rakaia are also plotted on Figure A2-6. Both have low concentrations of Ca and Mg, but exhibit a high ratio. This lends credence to the interpretation that the magnitude of the Ca/Mg ratio is indicative of the groundwater flow history and is related to the materials through which it has been flowing. Rainfall water quality data are not yet available.

The trend line in Figure A2-6 has no statistical significance and is drawn simply to illustrate the lack of well-defined trend.

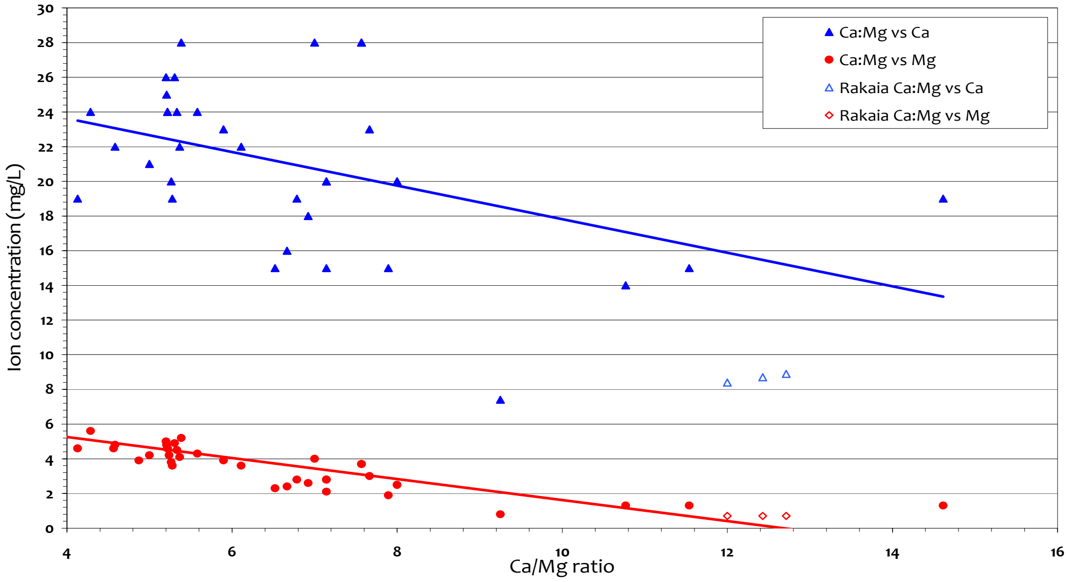


Figure A2-9-6: Plot Ca/Mg ratio versus calcium and magnesium for groundwater and river water samples taken from the Southbridge area

Ca/Mg ratio versus bore screen depth

Although spatial variation of Ca/Mg ratio was the primary objective of this study, it became apparent that there was a depth control on the Ca/Mg ratio and so depth variation in the Ca/Mg ratio was also investigated using a scatter plot of Ca/Mg *vs*. Depth (Figure A2-7). The plot reveals a tendency for the Ca/Mg ratio to be lower in groundwater sampled from bores with screens at shallow depths. Other than relatively young and high capacity wells, most older, domestic wells in this area do not have information regarding the depths of screens. This is primarily an issue for the older, deeper wells where the screened depth has the greatest uncertainty. We have assumed the depth of the well is generally the same as the depth of the screen.

However, this relationship between Ca/Mg ratio and well depth is very poorly correlated: some samples from deep bores (>30 m) appear to behave independently to the cluster of data from shallow bores; there is a distinct possibility in Figure A2-7 that there are two separate populations of data. The values for depth and Ca/Mg Ratio at each bore are presented in Figure A2-7 while data presented in Table A2-4 shows a depth *vs*. Ca/Mg ratio for bores relatively close to each other. The data in Table A2-4 are not always consistent with an increase in Ca/Mg ratio with increasing depth.

Table A2-9.4: Depth vs. Ca/Mg Comparison

Bore depth (m)	Ca/Mg ratio	Bore separation: horizontal (m)
73	11	0.2
19	7	
76	***7.1***	200
12	7.9	
23	8	30
42	8	
16.5	7.1	220
6	5.4	

There is a distinct possibility that two processes are acting here to effect differences in the Ca/Mg ratio: location and depth.

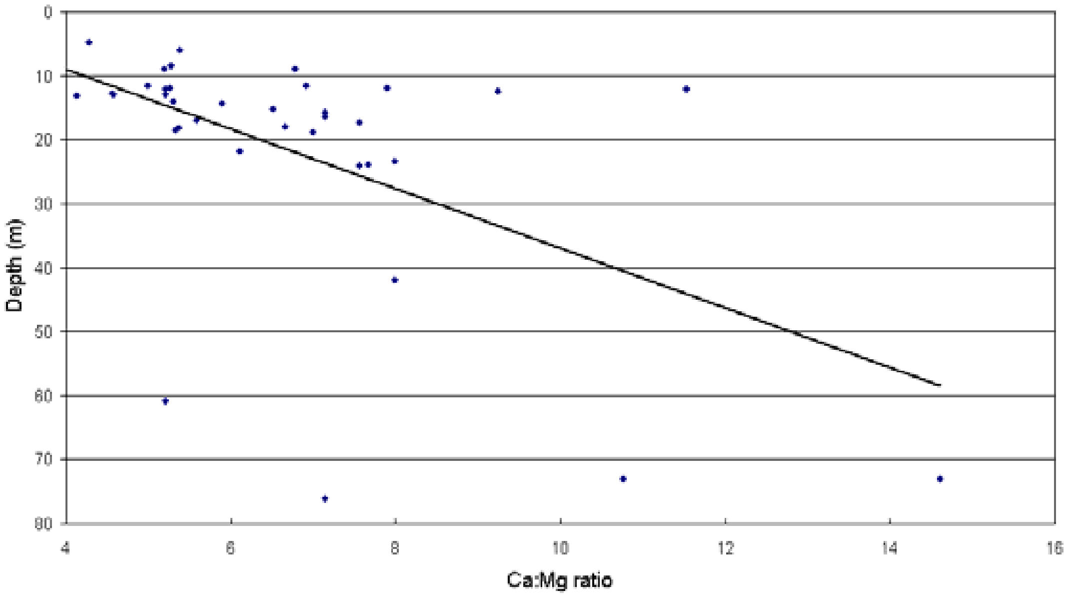


Figure A2-9-7: Calcium magnesium ratio versus depth for groundwater samples taken from the Southbridge area

Similar plots of chloride (Figure A2-8) and nitrate-nitrogen (Figure A2-9) and sulphate (Figure A2-10) versus depth show patterns of variation unlike the Ca/Mg ratio pattern, with ionic concentrations generally being lower in deeper bores. Caution should be taken in regard to the concentrations of nitrate-nitrogen and sulphate in the confined portions of the aquifer system because these species are prone to variation with oxidation state (Eh).

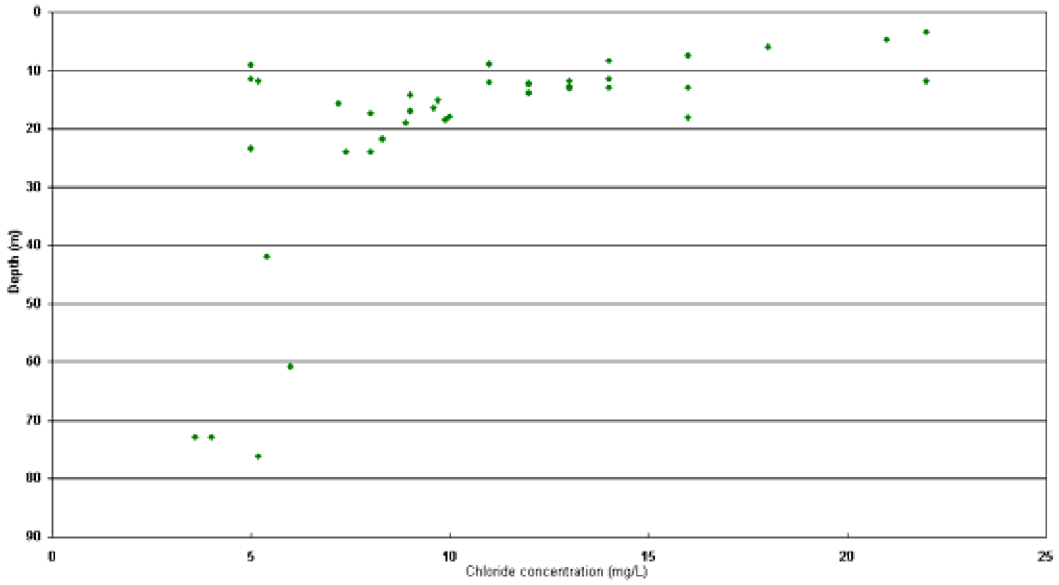


Figure A2-9-8: Plot of chloride concentration in groundwater and bore depth for groundwater samples taken from the Southbridge area

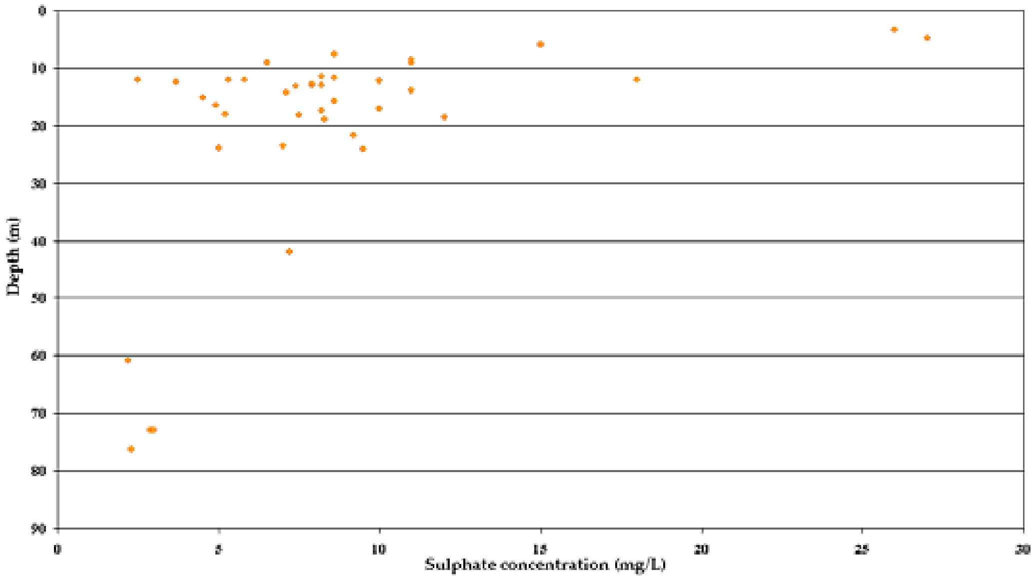


Figure A2-9-9: Plot of nitrate-nitrogen concentration in groundwater versus bore depth for groundwater samples taken from the Southbridge area

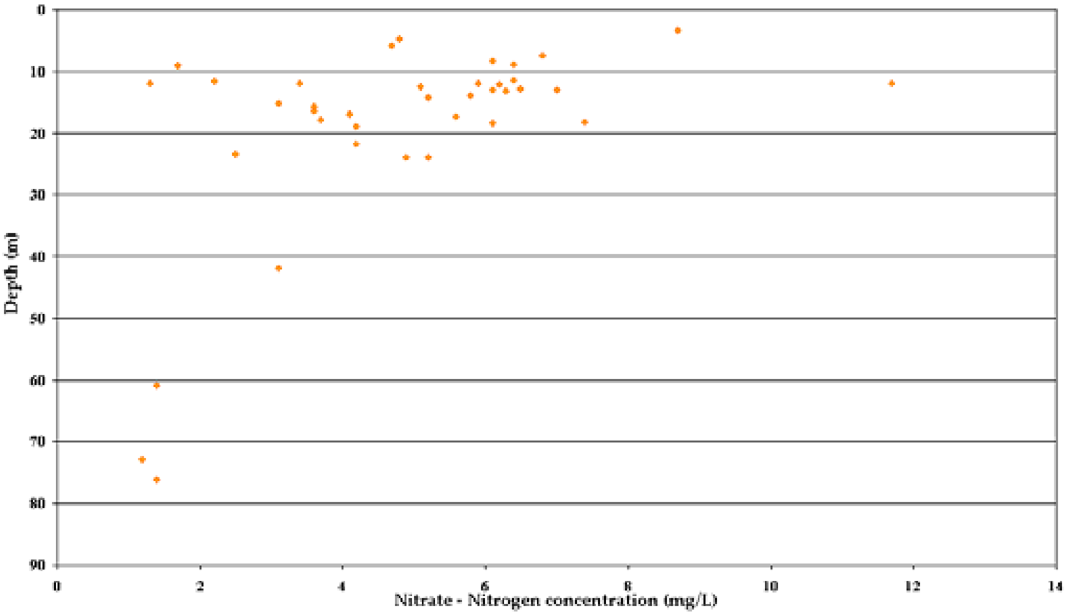


Figure A2-9-10: Plot of sulphate concentration in groundwater versus bore depth for groundwater samples taken from the Southbridge area

Scott and Thorpe (1986) showed in a geochemical study that the groundwater resource at depth between the Rakaia and Ashburton rivers displayed a different chemical signature compared with water sampled at or near the water table. This could be either attributed to age or a different recharge source (river recharge). In particular, significant variations were noted in the chloride ion (decrease with depth) and the HCO_3 (increase with depth).

Spatial interpretation of Ca/Mg Ratio

Although previous workers did not specifically identify the Ca/Mg ratio as an indicator of recharge source, subsequent analysis of water quality data derived from those studies, by Close (1987), Close *et al.* (1995), Close and Woods (1986), and Scott and Thorpe (1986), also showed the contrast in Ca/Mg ratio between rainfall-fed groundwater and river water and, their Ca/Mg data have been found to be consistent with those of Williams and Servais (2007).

The study by Close *et al.* (1995) investigated 12 years of groundwater quality data from bores that were adjacent to the Ashburton and Rakaia rivers. The groundwater samples showed that a decrease in metal ion concentration coincided with low rainfall. This observation suggests that during low rainfall periods, groundwater recharge from rainfall is low, and groundwater would then be primarily sourced from river water. This was based on the assumption that river water generally has a lower concentration of ions than water that has percolated through the soil profile. In addition, river water is generally a more constant resource than rainfall. Where groundwater is being recharged dominantly by river water, the resource is less susceptible to seasonal variation associated with rainfall recharge.

Williams and Servais (2007) showed that significant portions of land adjacent to the alpine rivers was underlain by groundwater whose Ca/Mg ratio contrasted with that underlying the areas distant from alpine rivers. The ratio can therefore be used to ascertain the influence of alpine river water within the groundwater system. However, the effects of bore screen depth also need to be assessed.

The results reported here reveal a trend of decreasing Ca/Mg ratio away from the Rakaia River. There are however a few anomalies which have proven difficult to explain.

The maps depicted in the following Figures A2-11, A2-12 and A2-13 illustrate the spatial variability of bore depths, the Ca/Mg ratio, and the Ca/Mg ratio related to bore depth respectively. In these maps the area coloured pale green represents the original area delineated by Williams and Servais as dominated by recharge from the Rakaia River, based on initial geochemistry results.

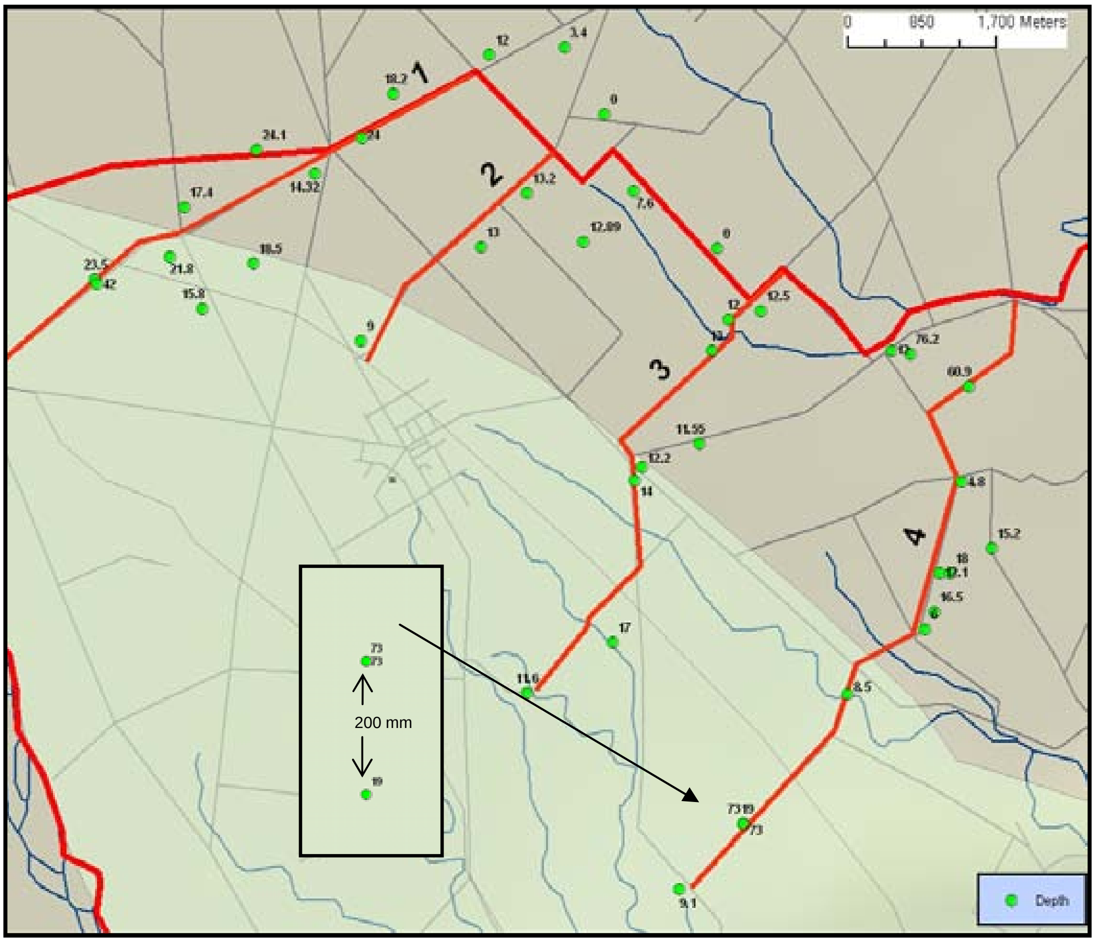


Figure A2-9-11: **Map showing depths of all bores sampled**

In Figure A2-12, a map showing the spatial distribution of Ca/Mg ratios, there is a general tendency for the ratios to decrease eastwards towards Lake Ellesmere. On the map there is a broad division, represented by the separation into pale green and brown areas, between high and low Ca/Mg ratios as proposed by Williams and Servais (2007).

The data determined from this current study is broadly comparable with the earlier one, but spatial details of the ratio emerge. For example, using the ratio value of five derived from Williams and Servais (2007) the location of the dividing line between high and low ratios might be more accurately drawn slightly to the east of the original line perhaps even including some properties around the lower reaches of Harts Creek.

The map exhibited as Figure A2-13 illustrates the Ca/Mg ratio concurrently with depth of the bore which is indicated by a colour. The map uses the same data as presented in Figure A2-3 which did not reveal a consistent pattern of ratio with depth. We conclude that localised groundwater flow paths may be responsible for these anomalies. In addition, the variable recharge sources of contrasting composition are likely to mix both laterally and vertically, producing one or more complex transition zones.

In Figure A2-13, where both bore depth and Ca/Mg ratio are plotted it may be seen that there are several locations where shallow groundwater tends to display a rainfall recharge ratio (<5), whilst deeper water at the same or similar location displays a higher ratio (>5).

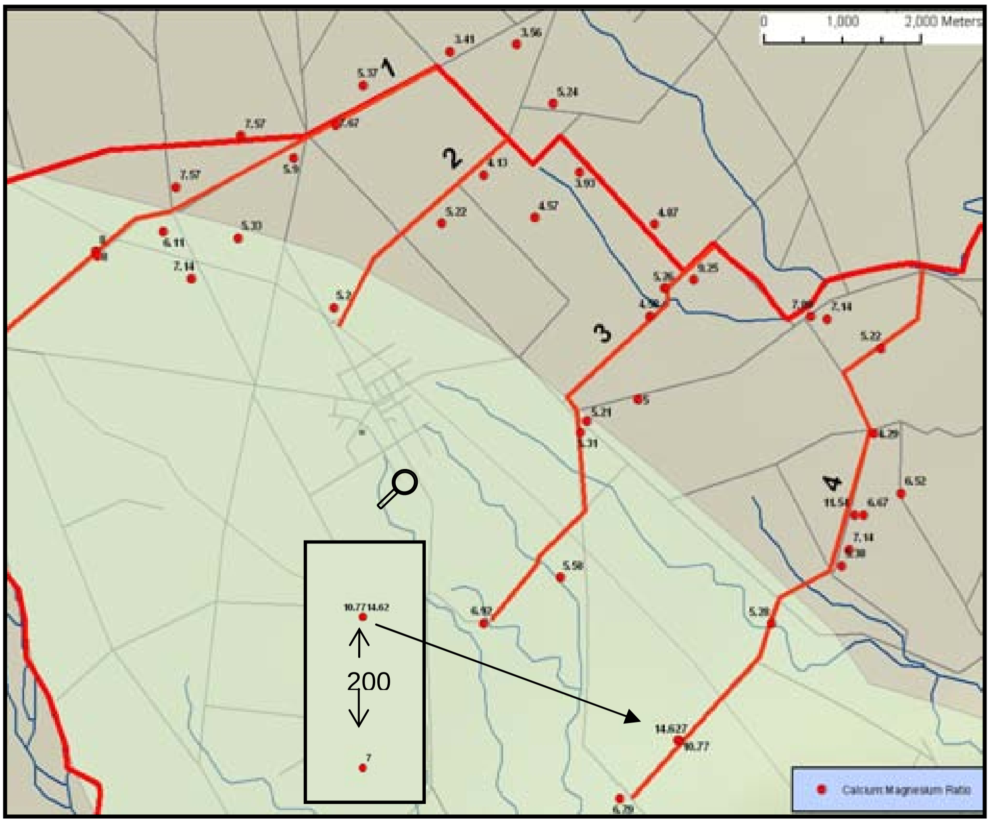


Figure A2-9-12: Ca/Mg Ratio of all the bores that were sampled Note inset showing closely adjacent bores of different depths as listed in Table A2-4

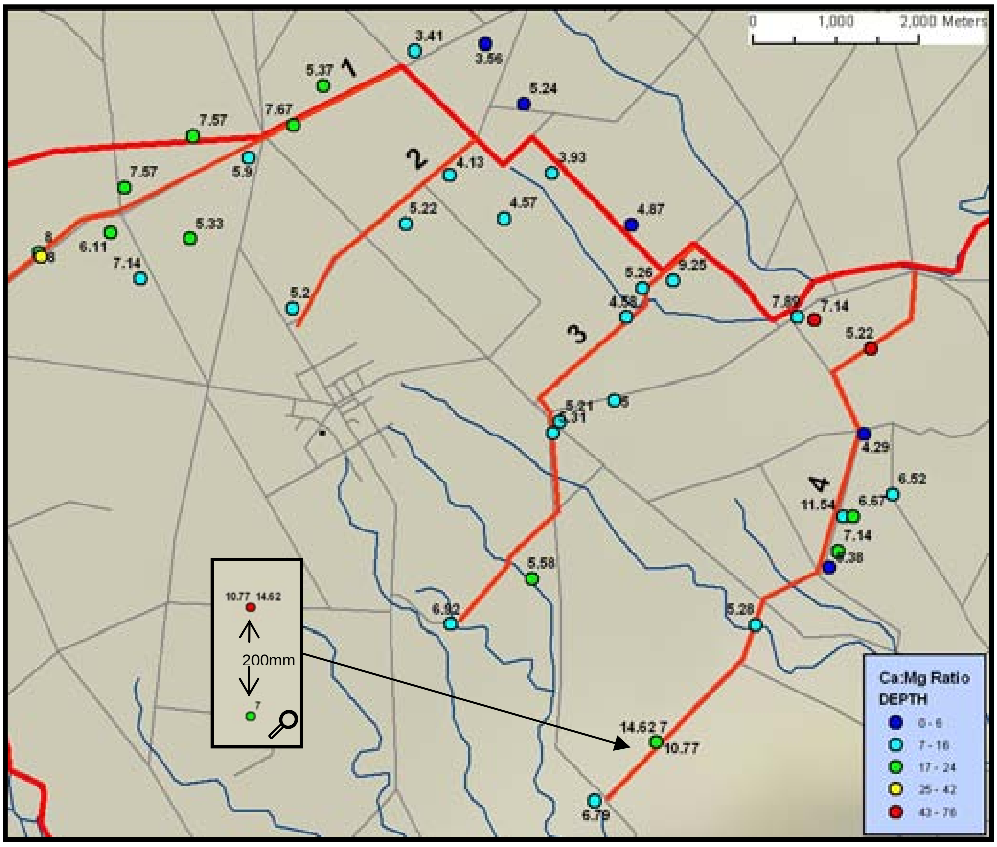


Figure A2-9-13: Ca/Mg ratio related to depth of the bore

Discussion

This section discusses the significance of the reported geochemical results in light of the proposed outcome of this work: a decision on whether to develop a discrete groundwater allocation zone in the Southbridge area.

Spatial distribution of chemistry

The work reported here indicates that the Ca/Mg ratio generally decreases with distance from the Rakaia River. This interim conclusion is consistent with the indicative assessment provided by Williams and Servais (2007) that much of the groundwater in the Little Rakaia sub-area is sourced from or influenced by the Rakaia River.

The location of the diffuse or transitional boundary proposed by Williams and Servais (2007), between the two hydro-chemical components: Rakaia River water and rainfall-sourced water is largely unaffected by these new data. However, the geochemical evidence suggests some support for moving the southern part of the boundary towards Lake Ellesmere, on the basis of the transition between the two waters at a Ca/Mg ratio of five as shown in Figure A2-14. There has yet to be an analysis of the potential environmental effects of moving the boundary of the Little Rakaia sub-area on the basis of that figure.

The frequency histogram plot in Figure A2-14 represents the 41 samples analysed for this memorandum. The figure shows a general tendency for two populations of data. The mean of all the Ca/Mg ratio data is 6.4, the median is 5.6, and these values serve to hide the fact that the data are clearly not normally distributed so mean and median of the population should not be used.

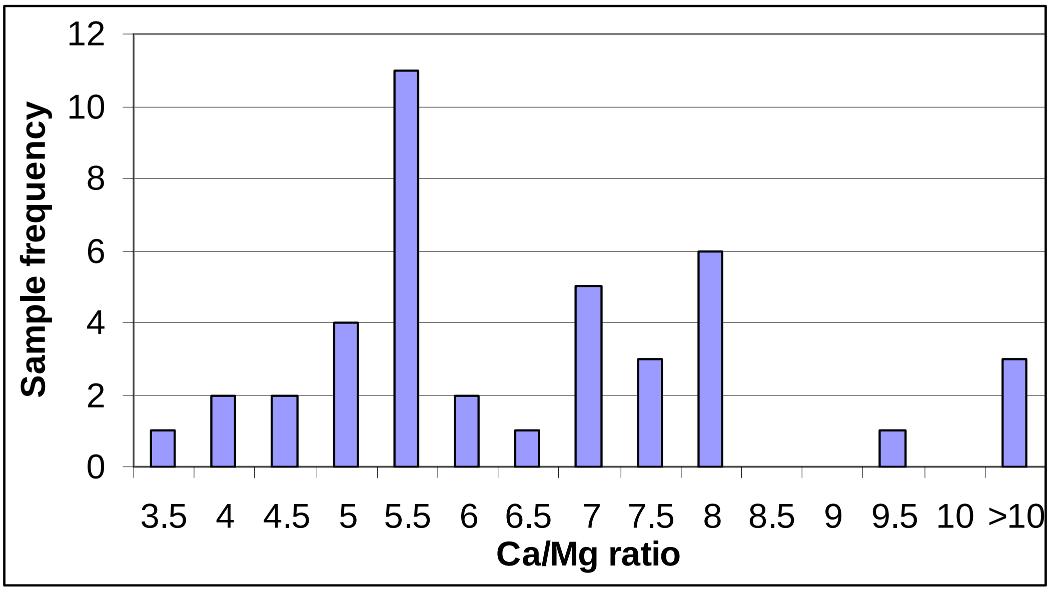


Figure A2-9-14: Frequency histogram of Ca/Mg ratio of all samples

Examination of Figure A2-14 indicates a natural division of the Ca/Mg ratio between 5 and 7 divides the data into two populations but even this division does not account for the significant gaps in the data. These gaps in the data may simply reflect the small number of samples used in the analysis, but they might also point towards uneven mixing of the two water recharge sources. Ideally, further sampling is required to discriminate between the two populations, but this discrimination may not be possible because of the mixing.

Effect of Northbank scheme

The study does not distinguish between Rakaia River water imported into the area for irrigation purposes as part of the Northbank scheme and Rakaia River water naturally seeping into the groundwater system.

Work by Dommisse (2007) indicates that highly negative $\delta^{18}O$ values in Rangitata River water used for irrigation are maintained after infiltration into the underlying groundwater but the ionic chemical signature of the infiltrating water is overwritten by passage through the soil. This observation by Dommisse is highly significant to the Rakaia River sub-area because it ought to be possible to distinguish, on the basis of ionic content, between groundwater sourced directly from the river and groundwater sourced through one of the surface water irrigation schemes. The latter should, after passage through soil illustrate a chemical signature more like that of rainfall recharge and would maintain its oxygen signature. In this respect a number of $\delta^{18}O$ analyses would allow determination of the effects, if any, of irrigation schemes such as the Northbank.

Effect of depth

There is conflicting evidence about the relationship between the Ca/Mg ratio and the depth of water sampled for analysis (Table A2-4 and Figure A2-12). In some bores, the water has a higher Ca/Mg ratio with depth, in others, lower. However, nitrate-nitrogen, sulphate and chloride concentrations all decrease with increasing depth of the sampled bore. It would appear that at a depth of 70 m in the Little Rakaia sub-area, there is some chemical evidence for Rakaia-sourced groundwater. Analysis of shallow and deep groundwater elsewhere in the region around Lake Ellesmere does not indicate any trend in Ca/Mg ratio with depth. Preliminary results from elsewhere in the Rakaia-Selwyn Groundwater Allocation Zone indicate that Rakaia-River sourced groundwater is present at great depth, beneath rainfall-recharged water (Williams & Servais 2007).

Geochemical effects of changing flow in the Rakaia River

Inter-seasonal and intra-seasonal changes in flow in the Rakaia River can lead to variation in the mounding effect that results in discharge from the river to groundwater. Over the long term, this variation is smoothed, with the result that a dynamic equilibrium develops.

A detailed groundwater flow map, similar to that illustrated in Grant (2003), has been used to show how groundwater flow directions change with time. Although these subtle variations in flow direction and magnitude of contribution from each recharge source might create measurable changes in chemistry of the groundwater, they could also serve to increase the width of any mixing zone displaying transitional chemistry.

However, should there be a large increase or decrease in the flow regime, then a change in the dynamic equilibrium would be expected, and chemistry could be used to monitor the new regime.

Appendix 3: Rakaia riparian memorandum to Water Allocation Group (with minor corrections)

8 February 2005 Ref :

MEMORANDUM

FROM : MARC ETTEMA, PHILIPPA AITCHISON-EARL
TO : GROUNDWATER SECTION
CC
SUBJECT : RAKAIA RIPARIAN GROUNDWATER ALLOCATION SUB-ZONE

1. Proposal

a) That a shallow groundwater sub-zone, the Rakaia riparian (Figure 1), be created to assist in management of groundwater allocation. This is to recognise unique aquifer conditions in this area where the allocation of additional groundwater is not envisaged to adversely affect the environment. Deep groundwater resources should still be dealt with within the current Groundwater Allocation Zone policy.

b) That the allocation limits for these sub-zones be based on allowing the entire **land area to be irrigated**, not on an allocation volume limit.

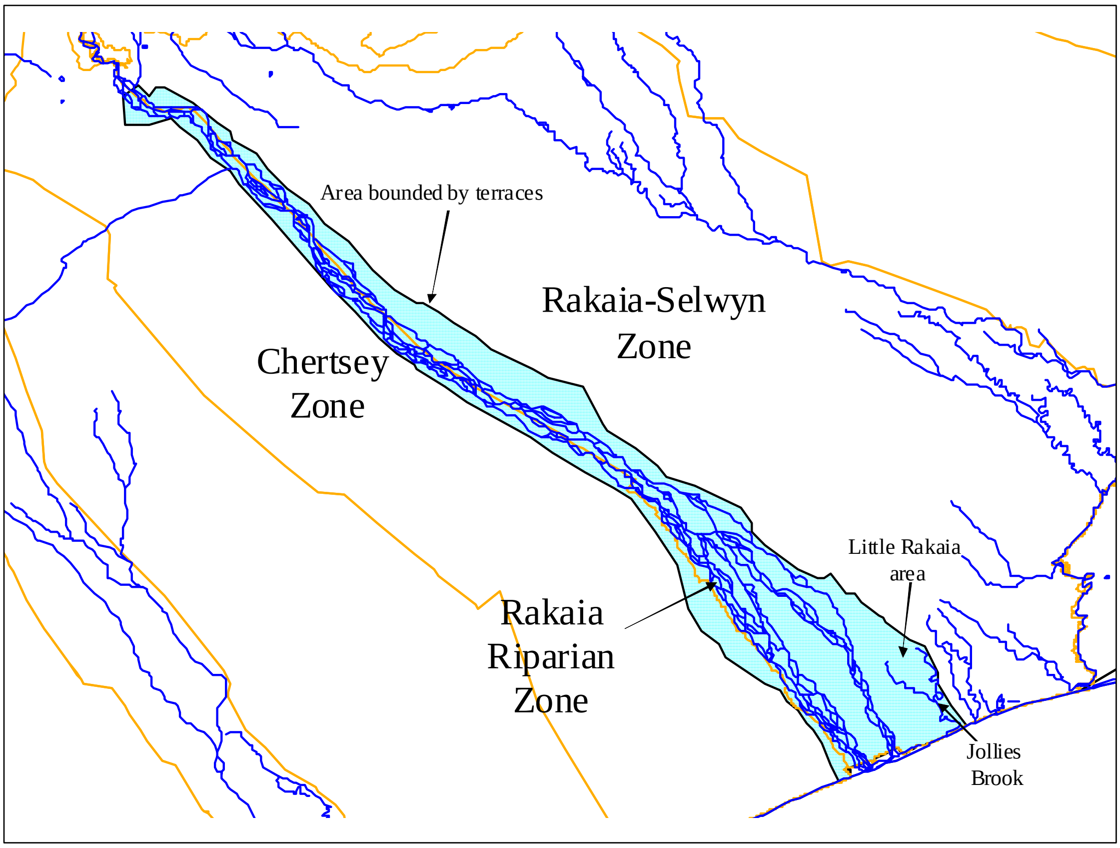


Figure 1: Rakaia riparian sub-zone

2) Justification for creation of a sub-zone

2.1) Extent of Zone

The Rakaia riparian Zone is made up of two parts:

a) shallow groundwater bound by river terraces in the mid-upper Rakaia reaches
b) shallow groundwater in the coastal Little Rakaia area that is predominately fed by Rakaia River water.

2.1.1 Mid-Upper river terrace bound reaches

Shallow groundwater (generally < 20m) occurs in a narrow band adjacent to the Rakaia River, in the riparian margin, below river terraces. Outside of this terrace-bound zone, groundwater occurs at significantly greater depths. The shallow groundwater within the river-cut terraces is primarily recharged by the river flow, and is likely to be hydraulically connected to the river itself. On this basis, we believe it is appropriate to create a riparian sub-zone where shallow groundwater intimately linked to the Rakaia River is considered separately to groundwater in the Rakaia-Selwyn and Chertsey Zones.

Decisions for Inch and Meadowflower have already adopted the riparian aquifer sub-zone approach, with the commissioner recognising the shallow aquifer as a distinct aquifer with little interaction with the deeper aquifers of the adjacent groundwater allocation zones (text from the decisions is detailed below).

Meadowflower:
'we consider that the particular riparian aquifer from which this applicant wishes to take water is distinct from other aquifers in the Rakaia-Selwyn groundwater zone and because of the hydraulic connection to the river the "red" classification in the NRRP does not, in our opinion, apply. This may not be the case further downstream where the river is known to be naturally losing water to the riparian aquifers.'

Inch:
'In this respect we consider that the particular riparian aquifer from which this applicant (and Meadowflower) wishes to take water is distinct from other aquifers in the Rakaia-Selwyn groundwater zone and because of the hydraulic connection to the river the "red" classification in the NRRP does not, in our opinion, apply. We acknowledge that this may not be the case further downstream where the river is known to be naturally losing water to the riparian aquifers.'

2.1.2 Lower Little Rakaia area

At the coastal end of the Rakaia riparian Zone, is an area of land that has previously been referred to as the 'Little Rakaia Zone', and is summarised in Grant, (2003). Groundwater is predominantly sourced from aquifers < 50m thick. There appear to be two aquifer zones (based on screen distribution – Figure 2), from 5-25 m and >35 m, however water levels in the two aquifer are similar (especially in the middle and lower parts of the Little Rakaia Zone) and well logs often show continuous 'free' gravels, and water bearing zones throughout the first 50 m. It is therefore assumed that the two aquifers (Riccarton and Linwood Gravels) are highly connected, and should be treated as one resource.

The aquifer is highly transmissive, in excess of 10 000 m^2/day based on aquifer testing. This may be related to the thickness of the aquifer (Riccarton and Linwood Gravels combined), and also to the constant recharge source of the Rakaia River.

Grant (2003) shows through piezometric contours (Figure 3), low nitrate nitrogen concentrations (Figure 4) and isotope analysis (Figure 5) that the Rakaia River is a major source of recharge for the Little Rakaia area (estimates 260 000 to 345 000 m^3/day). The area closest to the Rakaia River has the greatest amount of Rakaia recharge, with the percentage of Rakaia water versus rainfall decreasing with distance (eastward) from the river.

This continuum makes defining an area where Rakaia River water is the dominant recharge source very difficult. An assessment has been made to only include the groundwater in the Jollies Brook vicinity as having a dominant Rakaia River recharge source. The Lee River and Tent Burn have been *excluded from consideration in the Rakaia riparian zone due to the greater proportion of rainfall recharge in these zones.*

Figure 2-4 illustrates the correlation of groundwater levels at L37/0451 (Dobbins Road) and the Rakaia River flow (Gorge). Groundwater levels appear to bottom out at some occasions when river flow is not at it slowest. This is likely to be related to whether or not the Rakaia River North Branch is flowing.

Irrigation return water from surface water schemes (North Bank Rakaia) is also shown in Grant, (2003), to have an impact on the northern part of Little Rakaia area, with groundwater levels higher at the end of the irrigation season than at the beginning (Figure 2-5).

Discharge from the groundwater system occurs to springs feeding Jollies Brook. Natural values for Jollies Brook are described in Maw, (2005):
'The native fish habitat and mahinga kai values have been identified as highly significant…. Trout, natural character, indigenous vegetation and amenity values are moderately significant'

The Jollies Brook appears to be in good health, and to have sustained flows along the length compared to other lowland streams further east towards the Selwyn River, such as the Irwell and Doyleston Drain. Springs at the inland head of the Brook may go dry in periods of low groundwater levels, but further downstream flow resumes.

2.2: Environmental effects of current abstraction.

Current levels of abstraction in the Rakaia riparian sub-zone (based on 60% of 150 days) are estimated at 32 million m^3/year. A 2nd Order Allocation Limit calculated for the Rakaia riparian sub-zone using the methodology in Scott (2004) accounting for rainfall and irrigation recharge is 38.5 million m^3/year.

Current abstraction does not exceed rainfall and irrigation recharge in the Rakaia riparian, and in addition, heavy depletion of the Rakaia River or the spring-fed Jollies Brook is not observed. Recharge provided from the Rakaia River has a dominant influence on groundwater recharge, and provides a base level of groundwater to maintain spring-fed stream flow.

The model put forward in the Groundwater Allocation Limits (Aitchison-Earl, et. al, 2004), is that alpine river recharge (Waimakariri, Rakaia and Rangitata) is assumed to provide a base level constant source of recharge to the groundwater system and that rainfall recharge creates the fluctuations in groundwater level measured, by adding a non-constant recharge source. The NRRP proposes that half of this non-constant recharge is required to maintain the flow in lowland spring-fed streams such as the Irwell River. For the Rakaia riparian sub-zone this model is not appropriate, as the Rakaia River flow is the dominant source of recharge to the groundwater system and hence spring flow. Observations made by farmers (Facer and Horrell, 2003) (Grant, 2003) indicate that the presence of a flowing North Branch Rakaia has a far more dominant impact on flows in Jollies Creek than overall climatic conditions (i.e rainfall recharge).

In addition, the highly transmissive nature of the Little Rakaia area means that cumulative drawdown over an irrigation season remains low (maximum of 0.4m measured in 2002-2003, and Farmers report < 1m variance (Grant, 2003)). Based on the correlation of Jollies Brook with well L37/0415 (Facer, 2004) a drop in groundwater level of around 1m would lead to a reduction in stream flow of 140 L/s (MALF is 464 L/s).

It is therefore proposed that recharge from the Rakaia River be accounted for in allocating water within the Rakaia riparian sub-zone, and that further allocation be allowed within this zone even though the Rakaia-Selwyn Groundwater Allocation Zone is currently 'red'. Provided that Rakaia River recharge remains constant (which may rely whether the North Branch is flowing) further groundwater allocation should not compromise groundwater levels or spring-fed creek flow.

3) Zone Boundaries

The inland part of the Rakaia riparian Zone boundary is based on the extent of river terraces, and the occurrence of shallow wells. In the inland part of the plains there are a series of terraces leading down to the River, however shallow groundwater (recharged by the river) is only available in the lower terraces. Coastward of SH1 on the South Bank, the southern extent of the zone has been extrapolated from some evidence of terraces on topographic maps, and the existence of shallow wells but the actual position of the line is less exact. This upper part of the sub-zone should only encompass shallow aquifers that are directly recharged by the Rakaia River (which tend to be less than 20m deep).

The Little Rakaia part of the Rakaia riparian zone (the coastal northern bank of the Rakaia) has a boundary that is smaller than the ‘Little Rakaia Zone’ of Grant, (2003). Only groundwater that feeds Jollies Brook has been included. Land further to the north-east has not been included as the rainfall becomes more of an important recharge contribution compared to river flow (refer to Section 2). In this part of the Rakaia riparian Zone, the shallow aquifers are slightly deeper due to the connection of Riccarton and Linwood gravels, and may encompass aquifers of up to 50 m depth.

4. Groundwater Allocation Limits

4.1 Recommended Allocation Limits for sub-zones

It is recommended that no allocation limit is set for the Rakaia riparian sub-zone, but we would simply allow the total land area within the zone to be irrigated from shallow groundwater. At present around 43 % (10673 ha) of the area is irrigated but a large proportion of the area consists of riverbed. Consents should be issued to use groundwater for an area within the sub-zone only. Any other type of use (other than irrigation) or deeper well would be counted against the total allocation in the main zone (Rakaia-Selwyn or Chertsey).

4.2 Implications for whole zone Groundwater Allocation Limits

If abstractions within the Rakaia riparian sub-zone are not affecting the rest of the zone, they should not be counted against the total allocated volume. For the same reason the (rainfall) recharge to the sub-zone area needs to be subtracted from the total allocatable amount in the zone. The calculations for this case have been completed by David Scott, with the results summarised in Table 1.

Table 1: 2nd Order allocation calculations for the parts of the Chertsey and Rakaia-Selwyn Zone which are in the Rakaia riparian sub-zone.

Zone	Method of Calculation	sub-zone area (ha)	Surface water scheme supplied area (ha)	Assessed groundwater irrigation area (ha)	Rainfall recharge (m^3/yr x 10^6)	Recharge increment from surface water irrigation (m^3/yr x 10^6)	Recharge increment from groundwater irrigation (m^3/yr x 10^6)	Total land-surface recharge (m^3/yr x 10^6)[1]	Total as equivalent depth (mm)
Chertsey	2nd Order	6163	0	590.7	17.6	0	1	18.6	286.3
Rakaia Selwyn	1st Order[2]	18540.9	-	-	41.1	-	-	41.1	221
Rakaia Selwyn	2nd Order	18540.9	553	4339.6	50.4	1	7.5	58.9	272

[1] NB, 50% of this figure may be allocated

[2] The 1st order estimate was undertaken for the sub-zone using the same method as described in Aitchison-Earl 2t. al., (2004).

Applying the proposal will lead to a decrease in the total allocation limit to the Rakaia Selwyn and Chertsey Zones, as well as a reduction in effective allocation, as illustrated in Table 2. Chertsey will remain a ‘yellow’ zone, but increases from 87% to 90.3% allocated. Rakaia Selwyn remains a ‘red’ zone under the first order approach with 100.1% allocation (compared to 104% currently)[7]. If a 2nd

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[7] NB Rakaia Selwyn effective allocation is based on the ‘live read’ of the consents database. This figure differs from the official figure currently on the web-site of 234.8 Mm^3/year, or 112% allocated.

order approach is applied to the Rakaia-Selwyn Zone, the allocation limit will be 185.55 m3/yr x 10^6 (215 – 29.45), which is slightly lower than the 1st Order limit in Table 2 of 187.9 m3/yr x 10^6.

Table 2: Changes to Allocation Limits and Effective Allocation with creation of the Rakaia riparian (RR) sub-Zone (m3/yr x 10^6)**.**

	Chertsey		Rakaia-Selwyn		***Rakaia riparian***
	Current	Proposed (minus RR)	Current	Proposed (minus RR)	
Allocation Limit	112.4	112.4 – 9.3 = **103.1**	208.5	208.5 – 20.56 = **187.94**	Limit based on land-area irrigated
Effective Allocation[1]	97.7	97.7 – 4.6 = **93.1**	216.1	216.1 – 28.0 = **188.1**	32.6
Percentage allocation	87%	90%	104%	100.1%	

[1] Figures current as of 21/2/2005

5. Consents Process

5.1: Groundwater Allocation

1. The lines defining the sub-zones have no status under the NRRP, and thus are more 'fuzzy' than the Groundwater Allocation Zones. Consents thus have discretion to consider properties that are cut by the lines, or wells that they consider should be part of the sub-zone. Consents should always seek advice from the GW Section before any special case decision is made.
2. Managing groundwater allocation of sub-zones will require consents to make sure that they 'untick' the box for 'Include in Zone allocation'. Since there is no limit for the sub-zone there is no need to account for the total. The update of unticking the existing takes in the sub-zone and updating the total allocation limit should occur simultaneously.
3. Updated maps of the area currently irrigated within each zone will have to be kept to prevent double counting
4. Only groundwater use for irrigation of land should be considered within the sub-zones, abstraction for other uses will have to be assessed within the larger Groundwater Allocation Zone.

5.2: Other Environmental Effects

We consider that all other environmental effects within sub-zones can be handled by applying the relevant NRRP Policy. Thus stream depletion and well interference assessments would be conducted as normal within the sub-zone.

6. Action Points

The following action points will be required to progress on sub-zoning if approved by SGAIG:

1. Input may be required from the surface water / water quality sections regarding potential effects on the Rakaia River and Jollies Brook.
2. To define the area currently irrigated under the Rakaia riparian sub-zone: This is presently being undertaken by Quintin Eggleton of GW section
3. Other zones such as the Ashburton River allocation zone may need to be treated as a riparian 'sub zone' too with the deep wells counting against the neighbouring larger zone's.
4. Decide on a communications strategy. Currently the GW allocation zones are displayed on the website. As the sub-zones are an informal management measure, and not defined within the NRRP, a decision is needed on how to best display the information on the website. Thought will also have to be given as to how the sub-zones should be communicated to the media and public

References:

Decision of the Hearing Commissioners, Mr & Mrs S R & R C Inch, CRC042040

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Facer-Gabites, S,2004, 'Lee River Mean Annual Low Flow – revised' Internal Environment Canterbury memorandum

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Maw, R, 2004, Draft Minimum Flow Recommendations for Lake Ellesmere Catchment and Coopers Lagoon Catchment, June 2004.

PDP, 2004., 'Report on Little Rakaia Allocation Zone in support of Application for Resource Consent CRC042397'File CO6C/21882.

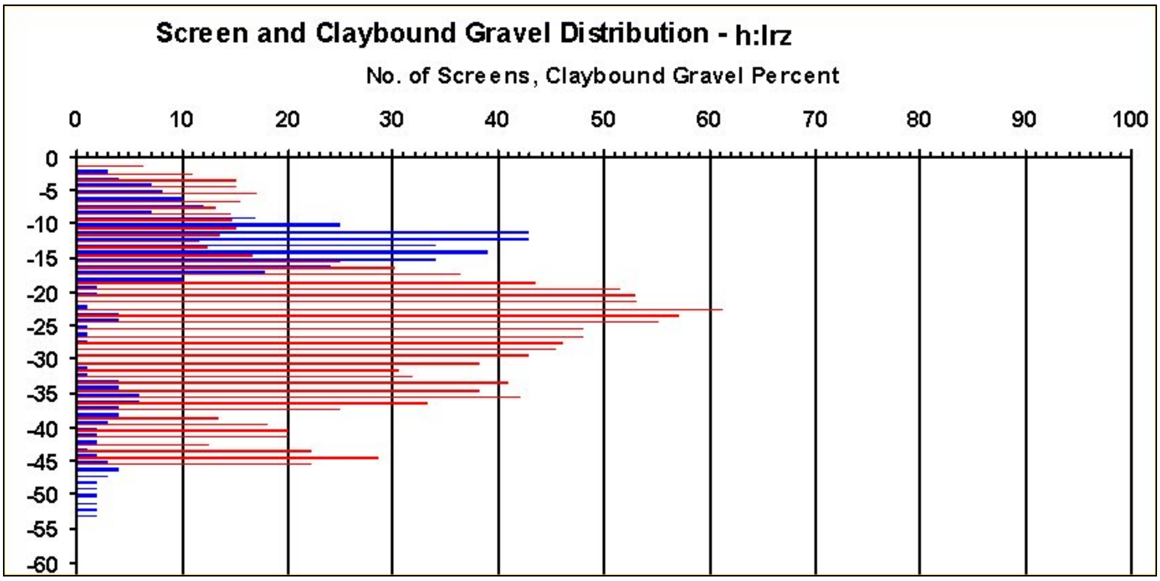

Figure 2: Screen and clay-bound gravel distribution in Little Rakaia Zone. Note two populations of screens

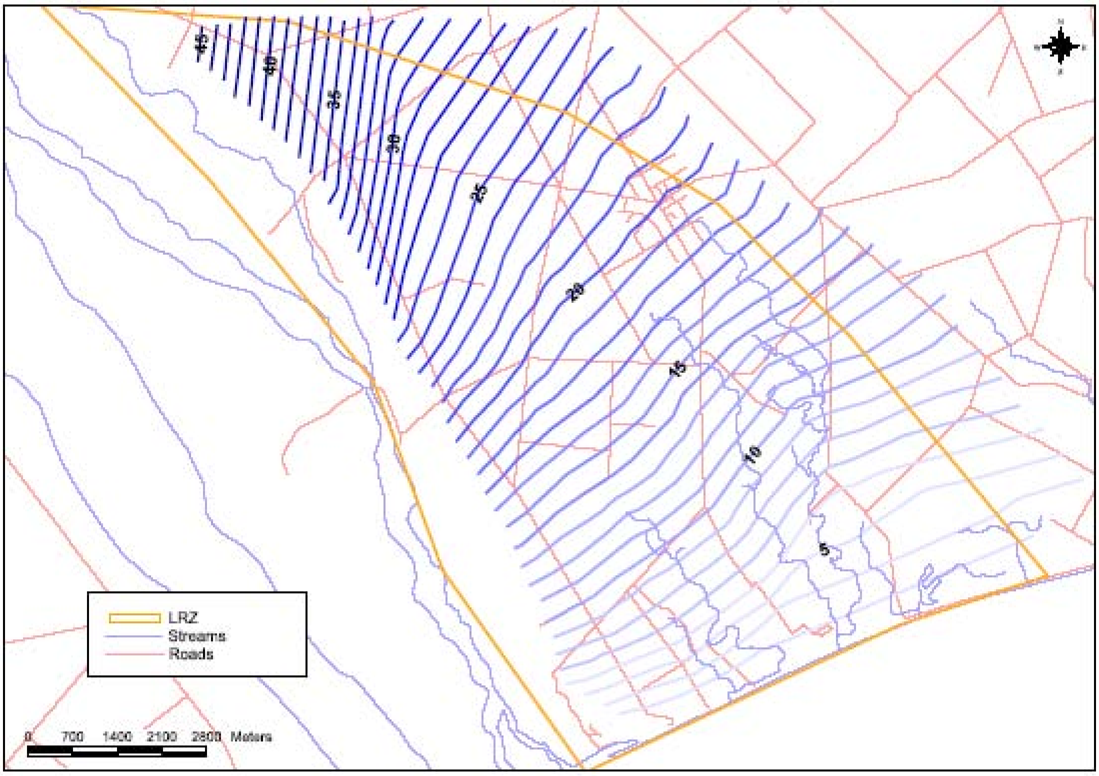

Figure 3: Piezometric contours August 2002 (from Grant, 2003) NB LRZ (Little Rakaia Zone) as shown in Grant (2003) has a different boundary to that proposed for the Rakaia riparian zone

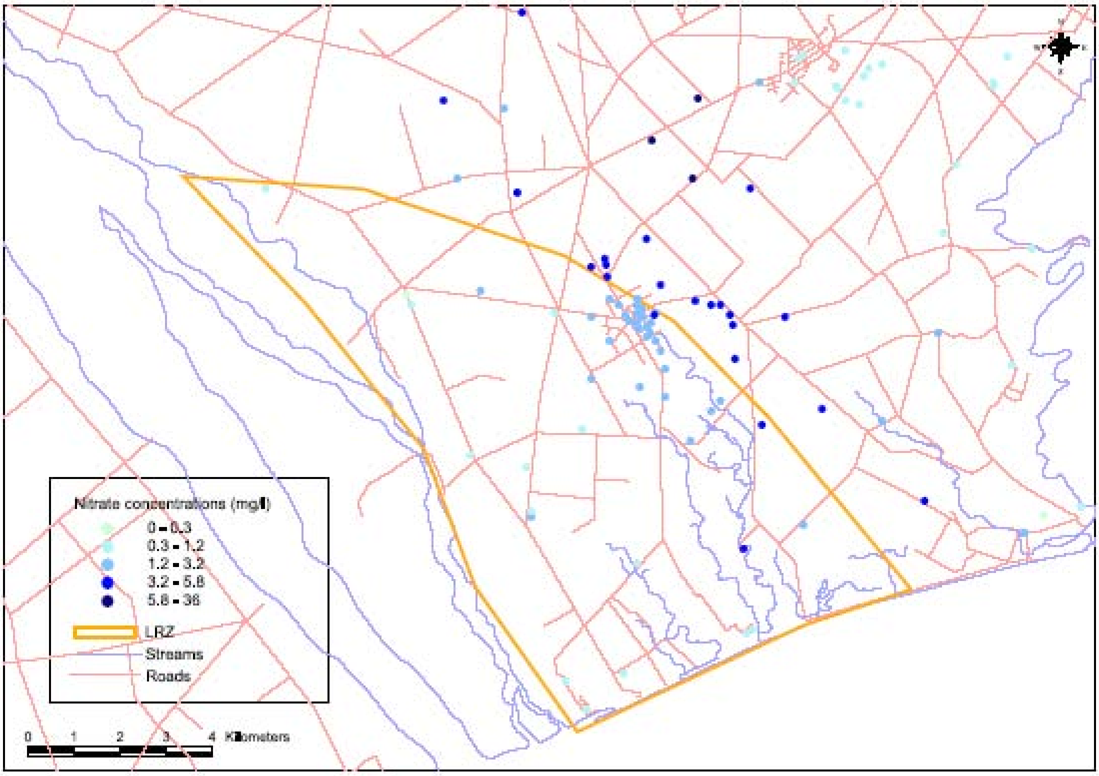

Figure 4: Nitrate concentrations of groundwater within the Little Rakaia area (from Grant, 2003)

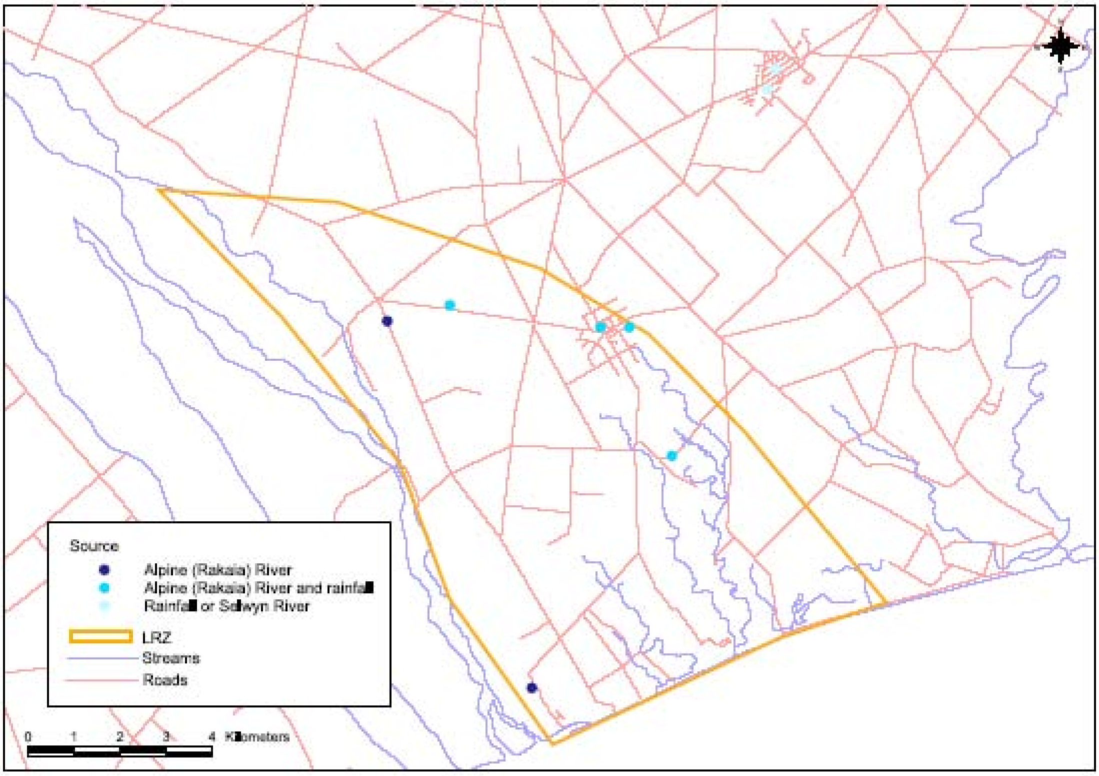

Figure 5: Oxygen isotope values for groundwater within the Little Rakaia area (from Grant, 2003)

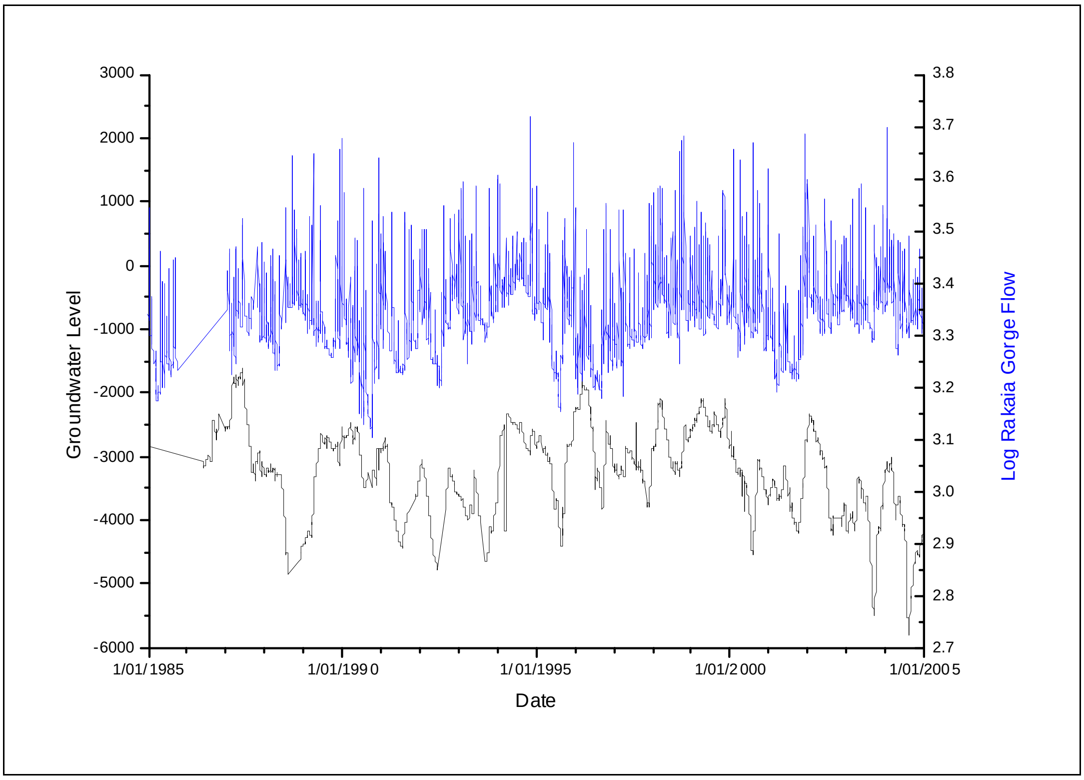

Figure 6: Correlation of Dobbins Road (L37/0451) and Rakaia River at the Gorge

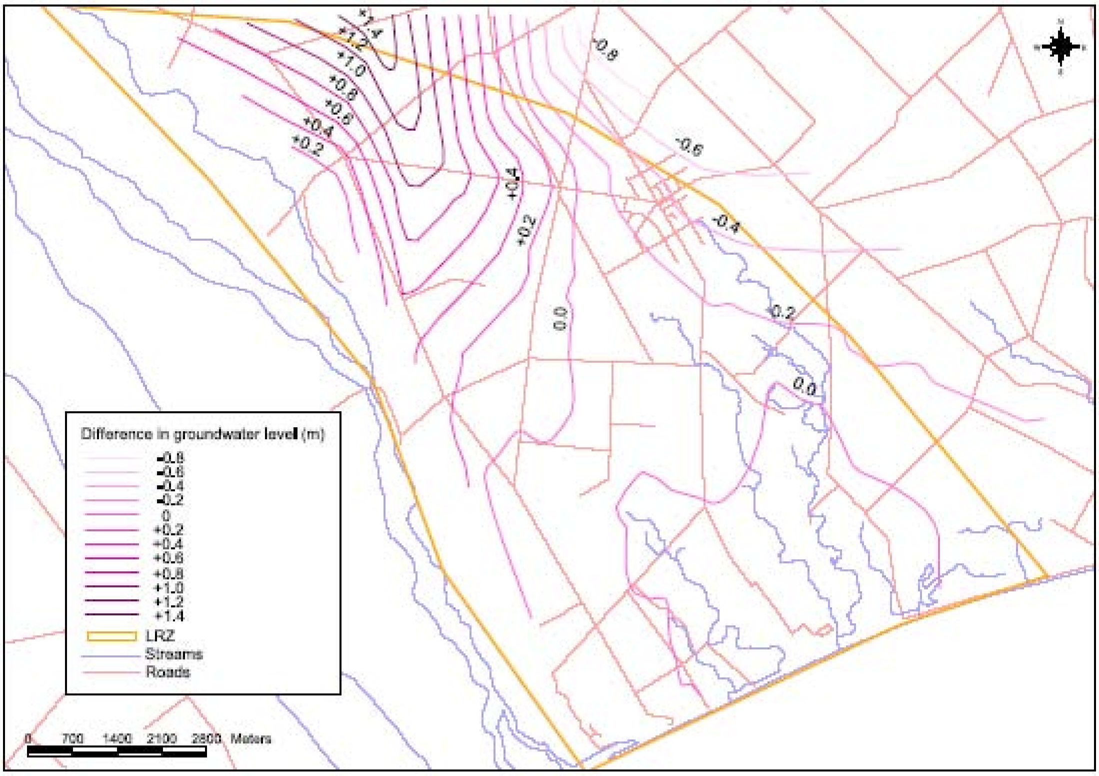

Figure 7: Difference between August 2002 and April 2003 piezometric contours (difference in 0.2 metres)

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