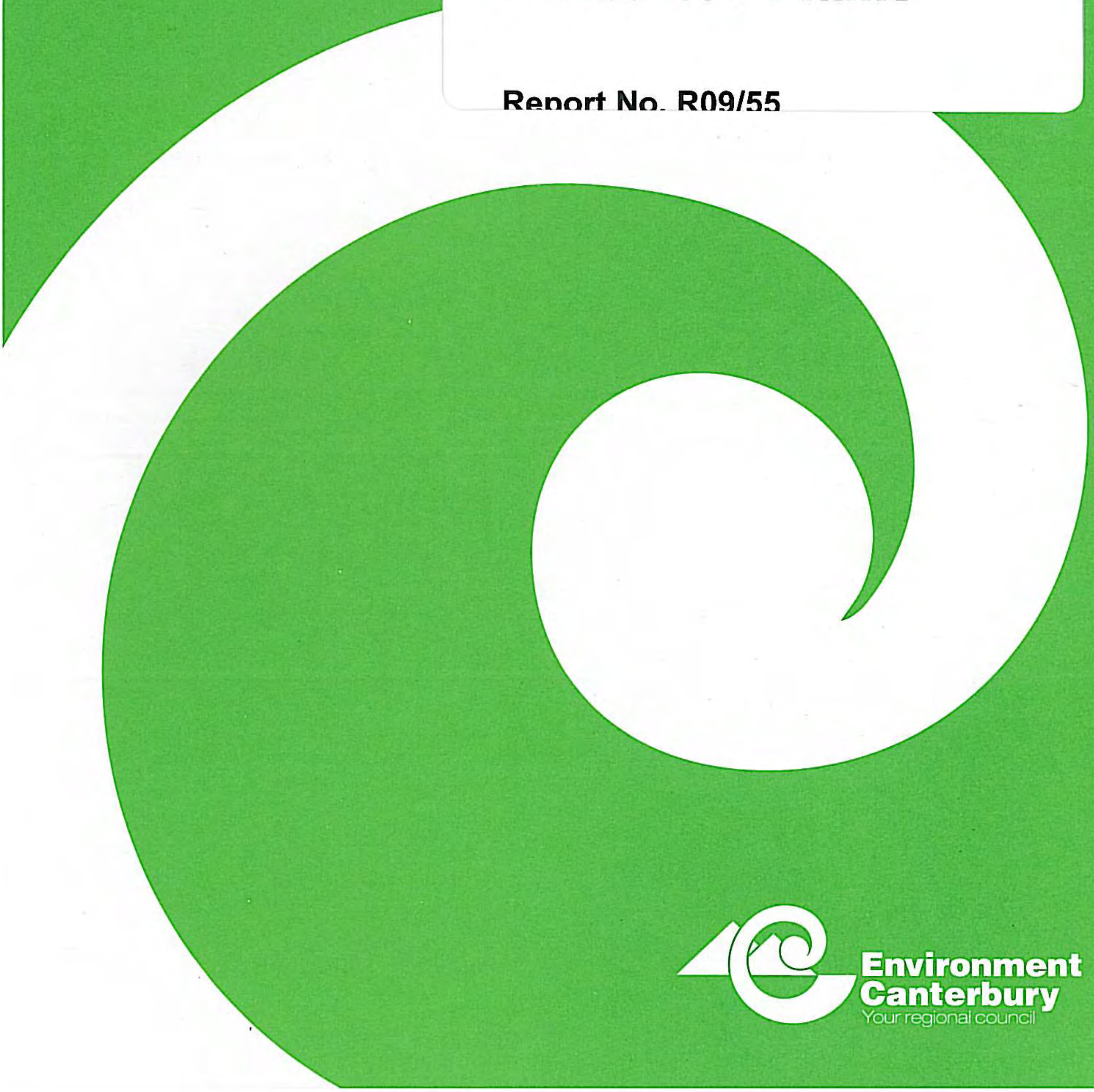
**Technical Report**

Investigations and
Monitoring Group

# Land-surface recharge and groundwater dynamics – Rakaia-Ashburton Plains

Report No. R09/55



**Environment Canterbury**
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# Land-surface recharge and groundwater dynamics – Rakaia-Ashburton Plains

**Report No. R09/55**
**ISBN 978-1-86937-995-7**

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Environment Canterbury
Your regional council

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# Executive summary

The purpose of the report is to advance the technical understanding of the groundwater system and inform resource management decisions in the Rakaia-Ashburton Plains area. The report also aims to provide information for stakeholders about possible groundwater system responses to various irrigation development scenarios. The scenarios evaluated in the report include: converting border-strip irrigation to spray irrigation across the Ashburton-Lyndhurst Irrigation Scheme (ALIS); and increasing groundwater sourced irrigation across the Rakaia-Ashburton Plains area. The report recommends resource management strategies for managing the risk of irrigation development in the area. The report has been written in the context of applications to take groundwater for irrigation beyond the current allocation limit. However, the report is not intended to provide an audit or assessment of effects of these applications.

This study describes the occurrence of groundwater across the Rakaia-Ashburton Plains, and uses an eigenmodel to explore the relationship between climate, abstraction, and dynamic groundwater behaviour. Estimates of irrigated area and land-surface recharge (LSR) are provided for sub-areas of the Rakaia-Ashburton Plains. Descriptions of groundwater occurrence and dynamics are provided in the context of local recharge sources. These datasets are subsequently correlated by calibrating the eigenmodel, and predictions of future abstraction and LSR scenarios provided using the eigenmodel.

LSR, river recharge, and groundwater abstraction are water budget components which influence the dynamic behaviour of the groundwater system. The dynamic responses of groundwater levels reflect influences such as sporadic and seasonal LSR, damped responses to LSR, steady river recharge effects and groundwater abstraction. Some groundwater level records in the Rakaia-Ashburton Plains area show long-term declining trends, others do not.

A pattern of higher piezometric head nearer the rivers and decreasing piezometric head toward the centre of the Rakaia-Ashburton Plains area was found. The increasing piezometric head around the rivers reflects significant local river recharge sources compared with LSR. Down plains of State Highway 1 piezometric heads reflect relatively low vertical hydraulic gradients compared with those up plains.

A soil moisture water balance model was used to estimate LSR under dryland and spray irrigation conditions. A modified approach was applied to estimate LSR occurring across the ALIS to represent border-strip irrigation and to take account of records of the volume of water delivered to the scheme from the Rangitata Diversion Race (RDR). Estimates of the proportions of border-strip and spray irrigation LSR over time were considered together with conveyance efficiency and by-wash flows. The additional LSR caused by the ALIS is significant when compared with other areas.

Irrigated area is an important factor when estimating LSR as rainfall recharge through the soil increases under irrigation. Very little information is currently available about irrigation water use, or about areas actually irrigated. Three sources of information have been used to estimate irrigated area: 1) areas listed as irrigated in the Environment Canterbury RMA Database; 2) land parcels associated with consents from the Environment Canterbury RMA Database; 3) remote sensing. Considerable differences were found between these three sources.

The eigenmodel method characterises an aquifer in terms of a set of conceptual groundwater reservoirs. This method quantifies the dynamic behaviour of groundwater storage and groundwater discharge in response to time-series of recharge. Recharge includes that from land surface, rivers and pumped abstraction. There is consistency between the eigenmodel method and the more conventional numerical groundwater models; however, the eigenmodel method enables significant model simplification and accessibility.

Using the eigenmodel, the recharge component from the ALIS is shown to be significantly “propping up” groundwater levels in the vicinity of and down gradient of the ALIS command area. As more efficient irrigation practices develop within the ALIS, it is likely that some groundwater users will face reduced reliability or even dry bores depending on their proximity to the ALIS. To minimise piezometric head reductions arising from more efficient irrigation, surface water supply for irrigation should be used over the widest area possible to minimise groundwater pumping demand and

maximise the additional recharge of rainfall via soil percolation. Managed aquifer recharge options could also be investigated to augment groundwater levels currently “propped up” by border-strip irrigation.

Groundwater development scenarios were tested using the eigenmodel. The scenarios looked at the change between status quo and full irrigation development. The scenario testing showed that the effect on piezometric head due to fully irrigating areas down-plains of State Highway 1 would be less than full development above SH1. This is due to a combination of system dynamics and higher levels of current irrigation sourced from groundwater coastwards of SH1.

Further groundwater development coastwards of SH1 is expected to have less of a cumulative effect on piezometric levels than development up-plains. Therefore, the preferred source for irrigation development up-plains of about SH1 should be surface water, not groundwater. Arranging irrigation supplies in this way will provide higher productivity yields whilst minimising the piezometric response in the groundwater system.

All groundwater takes will contribute to a reduction in coastal discharge from the groundwater system. Therefore, if further groundwater is developed and/or if surface water irrigation is made more efficient, additional resource management measures are recommended. Such measures could include: developing a coastal monitoring and trigger level system; managed aquifer recharge; up plains trigger levels for deep wells; improving water use and irrigated area information.

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# 1 Introduction

Land-surface recharge (LSR), river recharge and groundwater abstraction are water budget components which influence the dynamic behaviour of the groundwater system. This study describes the occurrence of groundwater across the Rakaia-Ashburton Plains, and uses an eigenmodel to explore the relationship between these drivers and the observed groundwater dynamic behaviour.

The report begins by estimating and describing irrigated area and recharge datasets in Section 2. The following section (Section 3) plots and describes groundwater occurrence and dynamics across the Rakaia-Ashburton Plains area. These datasets are subsequently correlated by calibrating the eigenmodel in Section 4. The eigenmodel analysis illustrates the behaviour of groundwater level dynamics, made up of river recharge, LSR, and abstraction. Predictions of future abstraction and LSR scenarios are also described in this section using the eigenmodel.

For background to, and general physical descriptions of the Rakaia-Ashburton groundwater system, refer to Sanders (1999); and Scott and Thorpe (1986).

Several abbreviations are used throughout the report. For ease of reference these are summarised in Table 1.1.

**Table 1.1 Table of Abbreviations**

| Abbreviation | Long form |
|---|---|
| AET | Actual evapotranspiration |
| ALIS | Ashburton-Lyndhurst Irrigation Scheme |
| GWL | Groundwater level |
| ha | hectares |
| LSR | Land-surface recharge |
| mamsl | metres above mean sea level |
| m | metres |
| mm | millimetres |
| PAW | Profile available water |
| PET | Potential evapotranspiration |
| RDR | Rangitata Diversion Race |

# 2 Land-surface recharge

## 2.1 Introduction

The major driver of groundwater system dynamics is LSR which is a function of climate and irrigation[1]. Between about September and April each year, soil moisture in Canterbury naturally declines, creating deficits that need to be met by irrigation to maintain plant growth. This section of the report introduces and describes monthly and annual estimates of LSR, under dryland and irrigated conditions, for the six areas across the Rakaia-Ashburton Plains shown in Figure 2-1. These estimates are used in the eigenmodel described subsequently in Section 4.

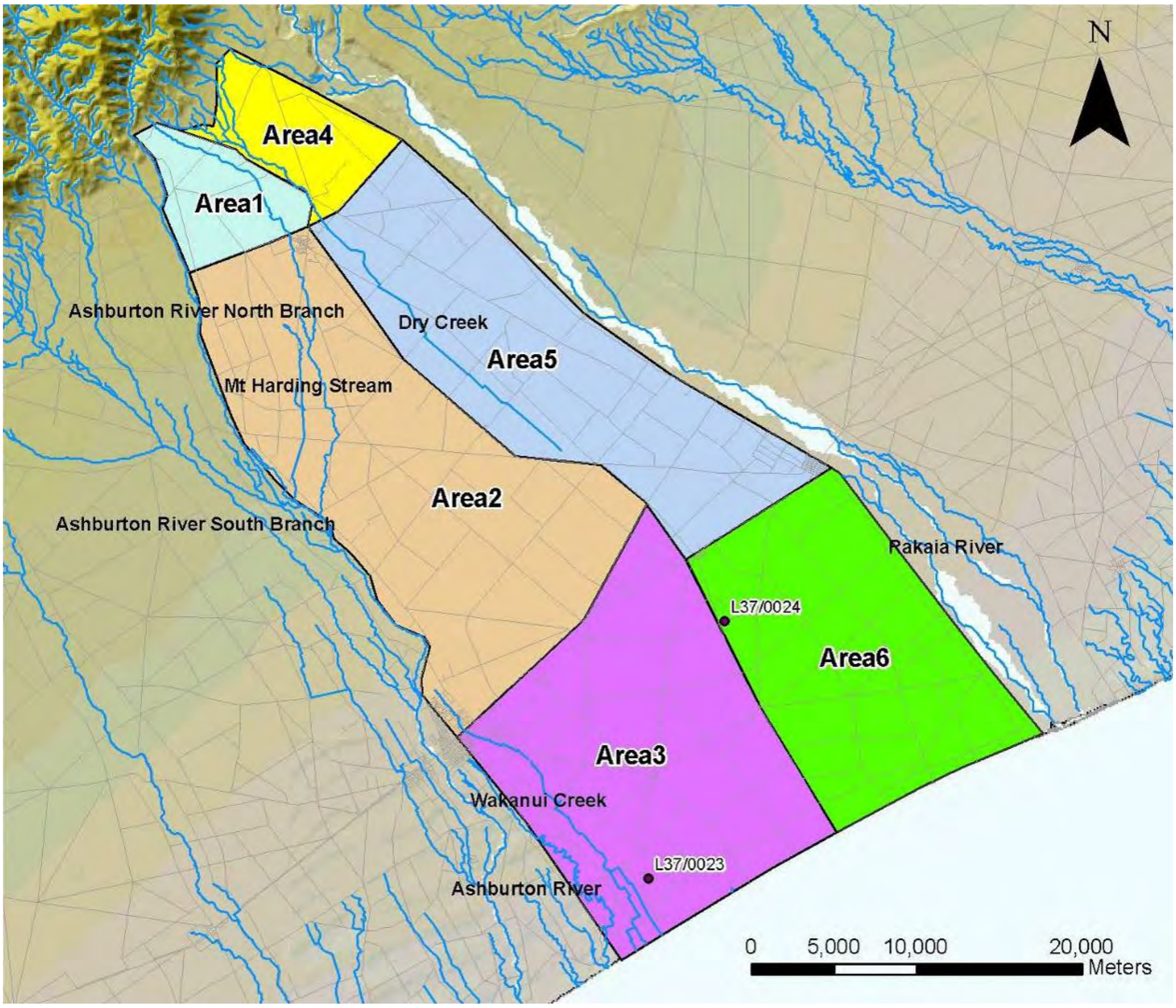

**Figure 2-1 Areas for which land-surface recharge (LSR) was estimated across the Rakaia-Ashburton Plains**

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[1] The term land-surface recharge (LSR) was used in the Canterbury Strategic Water Study (Morgan *et al.*, 2002) to refer to the process of replenishment of water to the saturated zone by downward infiltration of water from the soil caused by the interception of rainfall and the irrigation of land.

## 2.2 Method

For those areas outside the Ashburton-Lyndhurst Irrigation Scheme (ALIS), monthly irrigation demand and sub-soil drainage for the period 1960 to 2007 were calculated using the soil-water balance model described by Scott (2004). The soil-water balance model uses the NIWA Virtual Climate Network data to provide estimates of rainfall and potential evapotranspiration (PET) across the area[2]. The model simulates soil moisture conditions like a daily bank balance. The available soil-water storage is determined by the profile available water (PAW), rainfall is added, and actual evapotranspiration (AET) derived from PET, using the function from Scott (2004), is deducted from the soil storage on a daily basis. When the PAW is exceeded, the excess is considered to drain from the soil to form LSR to the groundwater system.

Irrigated conditions are represented by applying additional water within an irrigation season from October through April whenever the soil storage drops to a specified percentage of PAW (50% has been adopted for spray irrigation). The volume of irrigation water applied by the model is considered to represent irrigation demand, and is presented as such throughout the remainder of the report. Irrigation results in soil moisture levels being higher than they would be under dryland conditions. These elevated soil moisture levels result in increased drainage when rainfall closely follows an irrigation event. Inefficiencies of the irrigation application also contribute to increases in LSR, and an efficiency of 80% was assumed in this modelling[3]. Actual irrigation efficiencies will clearly vary over a considerable range depending on individual land use, soil properties and irrigation methods. Nevertheless, in the absence of detailed water use records this simplified approach has been shown (Williams *et al.,* 2008) to provide a useful estimate of the modified pattern of recharge under irrigated conditions.

The daily soil-water balance model output forms monthly time-series for areas 1, 3, 4, 5, and 6 (Figure 2-1). For the purposes of this project, areas 1, 2, and 3 (which approximate to the Ashburton Lyndhurst Groundwater Allocation Zone); and areas 4, 5, and 6 (which approximate the Chertsey Groundwater Allocation Zone) are each considered together as slices from foothills to the sea, through the aquifer system. These are referred to from here on as the Ashburton-Lyndhurst slice and the Chertsey slice.

**ALIS recharge**

For Area 2, which is dominated by the ALIS, a modified approach was taken to the estimation of LSR in order to represent the border-strip irrigation method used within the ALIS and to take account of records of water delivered to the scheme from the Rangitata Diversion Race (RDR). Because irrigation methods have progressively improved within the ALIS, estimates of the proportions of border-strip and spray irrigation over time were considered together with conveyance efficiency and by-wash flows[4]. Border-strip irrigation as commonly practised in Canterbury differs from spray irrigation in two critical ways: application depths are governed by the depth needed to flood an entire border-strip rather than the size of the soil moisture deficit, and water availability is generally dependent on a time roster. These factors require a different irrigation rule, i.e. irrigation will be applied if the deficit exceeds a specified value *and water is available*. This variation to the spray irrigation method has been simulated by dividing the scheme into many small sub-areas – each with a position in the roster - and by maintaining separate water balances for them all. The changing dryland and spray irrigated sub-areas of Area 2 are accommodated within the same simulation. Full details of the method used to determine the land-surface recharge for Area 2 are described in Appendix 1.

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[2] NIWA Virtual Climate Network data is part of New Zealand's National Climate Database and is accessible from http://cliflo.niwa.co.nz/

[3] Spray efficiency of 80% was adopted to reflect the efficiency goals of the proposed Natural Resources Regional Plan (NRRP).

[4] Conveyance efficiency is the ratio between the volume of water delivered to farms and the volume diverted from the supply source. The losses via conveyance are caused by seepage through the base and sides of the canals, evaporation, leaks in structures, and operational factors.

## 2.3 Irrigated area

Irrigated area is an important factor when estimating LSR since a higher proportion of rainfall becomes recharge under irrigated conditions. Information is limited about actual irrigation water use, or about the areas that are either consented to be irrigated or are actually irrigated.

Irrigated area in the eigenmodel is represented as the fraction of the total area that is assessed as being irrigated. This fraction is used to pro-rate the estimated irrigation demand and the estimated irrigation component of LSR. Irrigated area is important when calibrating the eigenmodel to existing conditions and predicting a change in groundwater level response to future abstraction scenarios (Section 4). To be conservative when predicting changes in groundwater levels in response to abstraction and LSR in the eigenmodel, we have used the lowest of the irrigated area estimates outlined in this section.

Three sources of information have been used to estimate irrigated area as summarised in Table 2.1; 1) irrigation areas listed in the Environment Canterbury RMA Database; 2) legal description of land parcels associated with consents from the Environment Canterbury RMA Database; 3) remote sensing data sourced from Pairman & North (2009).

**Table 2.1 Summary of irrigated and irrigable land estimates**

| | Total area (ha) | Irrigation area fraction using irrigation areas from consent database | | Irrigation area fraction using land parcels with irrigation consents[2] | Irrigation area fraction using remote sensing[3] | Potential irrigable area fraction[4] |
|---|---|---|---|---|---|---|
| | | GW | SW | | | |
| Area 1 | 5,193 | 9% | 0.1% | 6% | 14%[6] | 95% |
| Area 2 | 35,672 | 20% | 71%[1] | 71%[1] | 49% | 90% |
| Area 3 | 30,322 | 87% | 1% | 79% | 50% | 89% |
| Area 4 | 6,078 | 0 | 0 | 0 | 11%[6] | 94% |
| Area 5 | 27,208 | 49% | 0 | 45% | 23% | 90% |
| Area 6 | 23,678 | 95% | 4%[5] | 85% | 60% | 93% |

*Note:* [1] *Includes command area of ALIS (24500 ha) (Figure 2-3)*
[2] *Figure 2-2*
[3] *Figure 2-4*
[4] *Source: AgriQuality 2006*
[5] *South Rakaia Irrigation Scheme (does not include areas associated with Barrhill-Chertsey Irrigation*
[6] *Areas 1 and 4 are in the higher rainfall area of the plains and can cause the remote sensing to identify unirrigated land as irrigated*

### 2.3.1 Consented area

The areas associated with resource consents to take groundwater or surface water were queried from the Environment Canterbury RMA Database (Table 2.1). In some areas, the total area that has associated rights to water exceeds the land that could potentially be irrigated. For example, in the coastal area of the Chertsey groundwater allocation zone (Area 6), water allocation entitlements have apparently been given to 99% of the area (excluding the Barrhill-Chertsey Irrigation Scheme). We estimated only 93% of the area could be irrigated. This means that sufficient water has already been allocated within Area 6 to allow irrigation of the entire area; however, Environment Canterbury is still receiving applications to take additional water. The explanations for this are: some entitlements are short-term transfers from the upper-plains areas, errors and incomplete recording of spatial information in the Environment Canterbury RMA Database, and "double counting" on some properties.

### 2.3.2 Land parcels with consents

Another estimate of irrigated area was developed by identifying the land parcels referred to in the Environment Canterbury RMA Database as being related to consents to take surface water or groundwater for irrigation. The ArcGIS dissolve tool was applied to merge overlapping land parcels to define the "shadow" cast by all the land parcels referred to by the resource consent information as shown in Figure 2-2 and summarised in Table 2.1[5]. The area served by the Ashburton Lyndhurst Irrigation Scheme (ALIS) is described in the scheme design (Ministry of Works, 1982) (Figure 2-3 shows the sub-areas served by the scheme laterals). In some cases, the irrigation area determined from the Environment Canterbury RMA Database seems to be overstating the areas that could be irrigated.

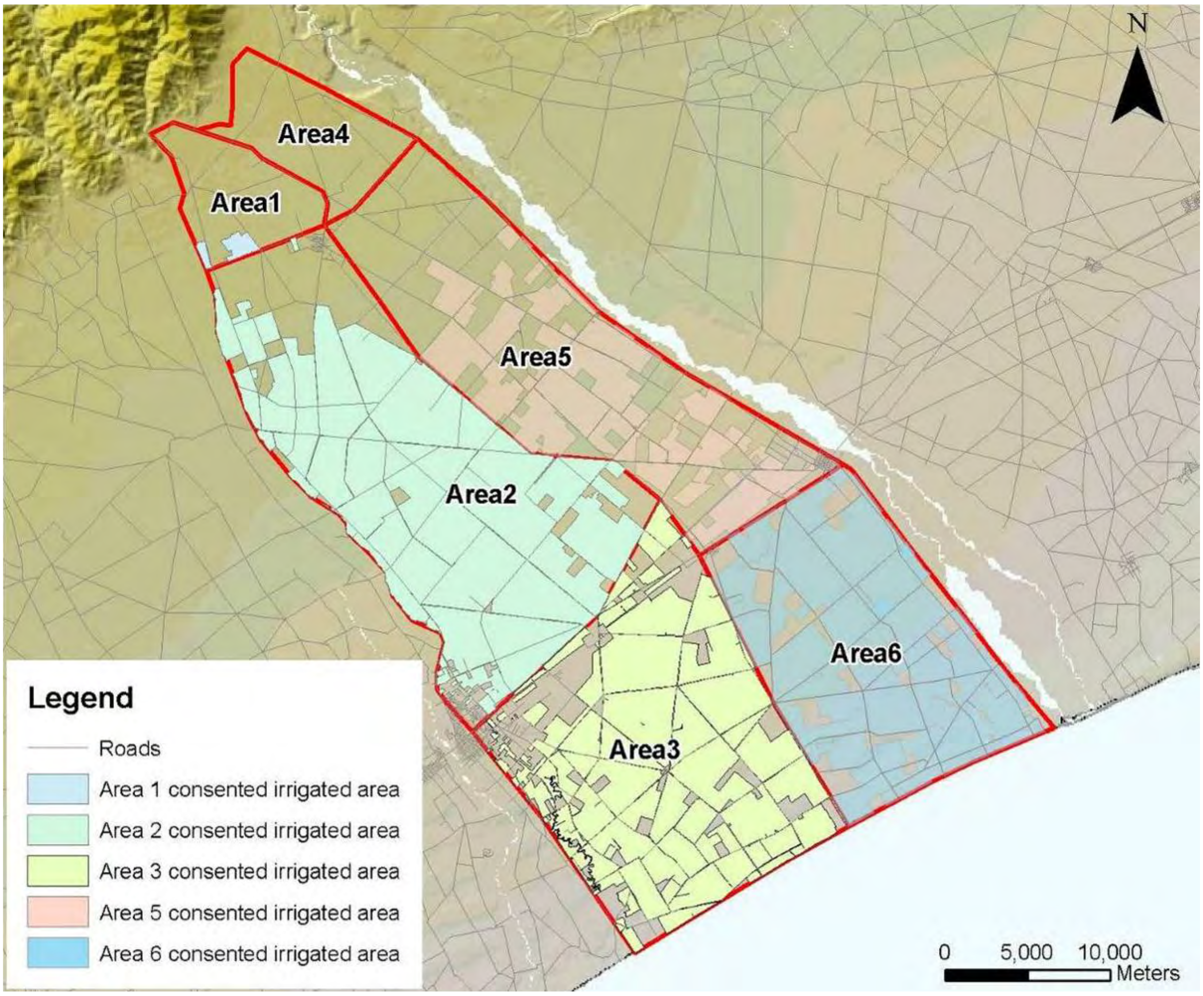

**Figure 2-2 Estimated consented irrigation land parcels**

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[5] ArcGIS is a geographic information system by ESRI www.esri.com

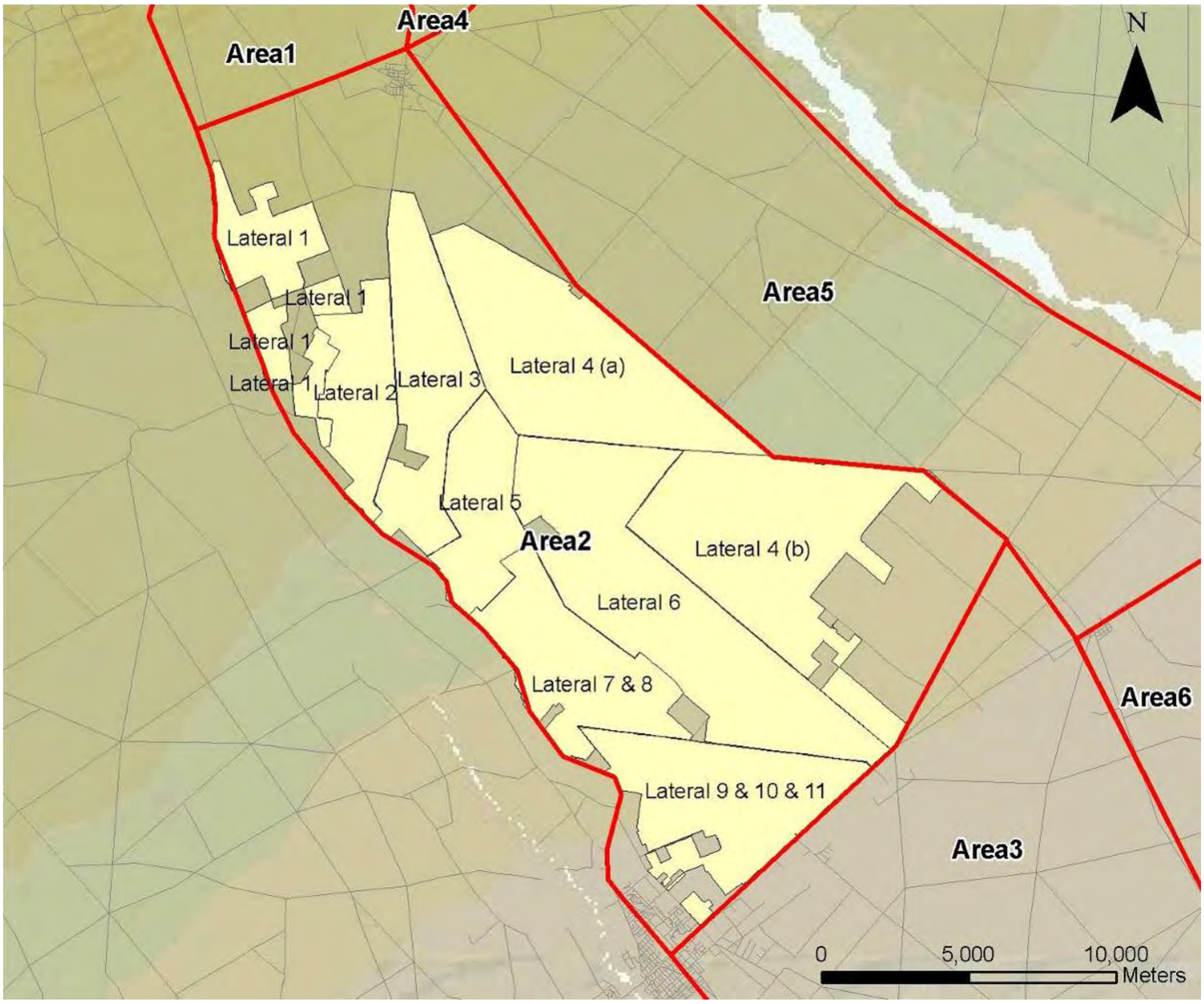

**Figure 2-3 Ashburton-Lyndhurst Irrigation Scheme (from Ministry of Works (1982))**

### 2.3.3 Remote sensing

Recent remote sensing work conducted by Landcare Research (Pairman & North 2009) provides an estimate of irrigated area over the central Canterbury Plains area (Figure 2-4). The Landcare Research analysis takes a series of images over the 2007/08 and 2008/09 irrigation seasons and identifies those areas that remained "green" throughout. Obviously this has problems associated with identifying areas containing irrigated crops which can become fallow as the season progresses. The irrigated area fraction identified by the remote sensing technique is summarised in Table 2.1.

Environment Canterbury holds no records of irrigation permits in Area 4 yet the remote sensing identifies 11% of Area 4 as irrigated. Pairman & North (2009) acknowledge that identifying "green" irrigated land across the upper plains is difficult due to the naturally higher rainfall. Because of this the remote sensing analysis excluded areas within areas 1 and 4 above a specified altitude. Some validation of the results is presented in Pairman & North (2009).

The large difference in Area 5 between the irrigated areas estimated from remote sensing and inferred from the consent information is likely to be due to the greater occurrence of cropping activities in this area, for which irrigation ceases early to allow crops to ripen.

In Area 2 the remote sensing technique is suspected to provide a lower-end estimate of the areas that have been irrigated over the last couple of irrigation seasons based on feedback from ALIS staff.

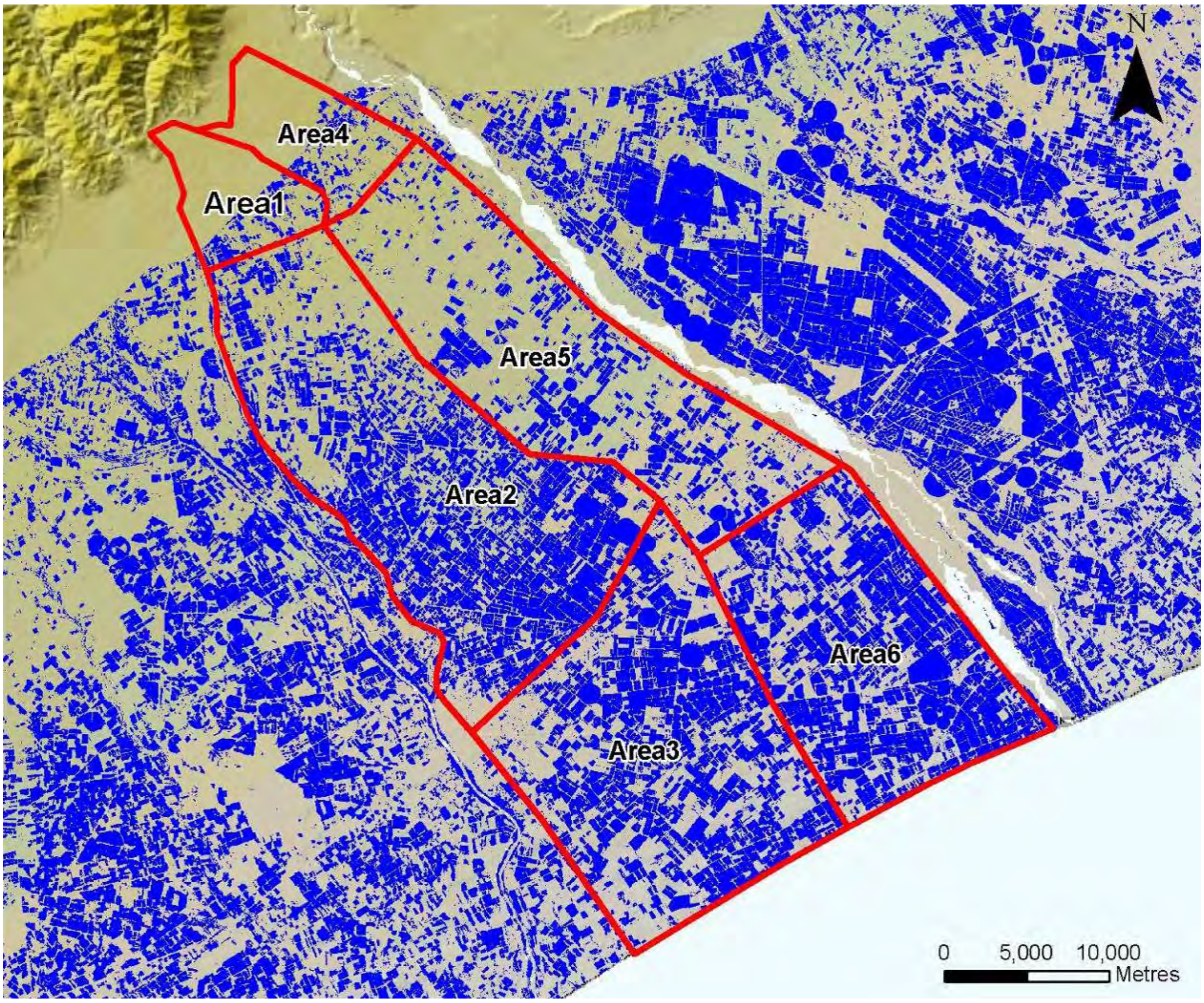

**Figure 2-4 Irrigated area identified by remote sensing (in blue) (Pairman & North 2009)**

## 2.4 Estimates of land-surface recharge (LSR)

This section outlines the results of the soil-water balance modelling, presents the data and provides an estimate of how LSR occurs in time and space under dryland and irrigated conditions.

### 2.4.1 Dryland LSR

Table 2.2 presents descriptive statistics of the estimated annual LSR under dryland conditions. The important point to note is the substantial difference in all statistics of estimated LSR for the upper-most areas of the plains (areas 1 and 4) compared with those further down the plains. The mean and median values of areas 1 and 4 are approximately double those in other areas. The maximum estimated annual dryland LSR exceeded 1 metre in areas 1 and 4 in 1978 and 1986. The lowest estimated annual dryland LSR occurs in the coastal area represented by areas 3 and 6 with only 4 mm and 1 mm respectively. This was a result of a very dry winter in 2005 (refer Figure 2-5 and Figure 2-6).

**Table 2.2 Descriptive statistics of estimated annual dryland LSR**

| | Minimum (mm) | Maximum (mm) | Standard deviation (mm) | Mean (mm) | Median (mm) |
|---|---|---|---|---|---|
| Area 1 | 240 | 1152 | 203 | 616 | 570 |
| Area 2 | 60 | 762 | 146 | 308 | 281 |
| Area 3 | 4 | 645 | 135 | 238 | 213 |
| Area 4 | 142 | 1102 | 2063 | 545 | 531 |
| Area 5 | 33 | 761 | 150 | 288 | 265 |
| Area 6 | 1 | 588 | 133 | 216 | 188 |

Figure 2-5 presents the estimated annual dryland LSR within areas 1, 2 and 3 (January to December). Figure 2-6 provides the equivalent results for areas 4, 5 and 6. The annual recharge rate is greatest in areas 1 and 4 and lowest in areas 3 and 6, reflecting the spatial distribution of rainfall and PET (i.e. more rain and cloud at the top of the plains plus lower temperatures). Estimated dryland LSR is slightly higher on the Ashburton River side of the area of interest (areas 1 to 3) due to spatial variations in climate and soils.

In several years the estimated dryland LSR in some of the areas is less than 100 mm including: 1964; 1969; 1982; 1988; 2001; 2004; 2005; 2007. These periods of low estimated dryland LSR are largely the result of dry winter climate conditions.

In general, the estimates of average LSR compare well with those of Scott (2004) for the Chertsey and Ashburton-Lyndhurst groundwater allocation zones.

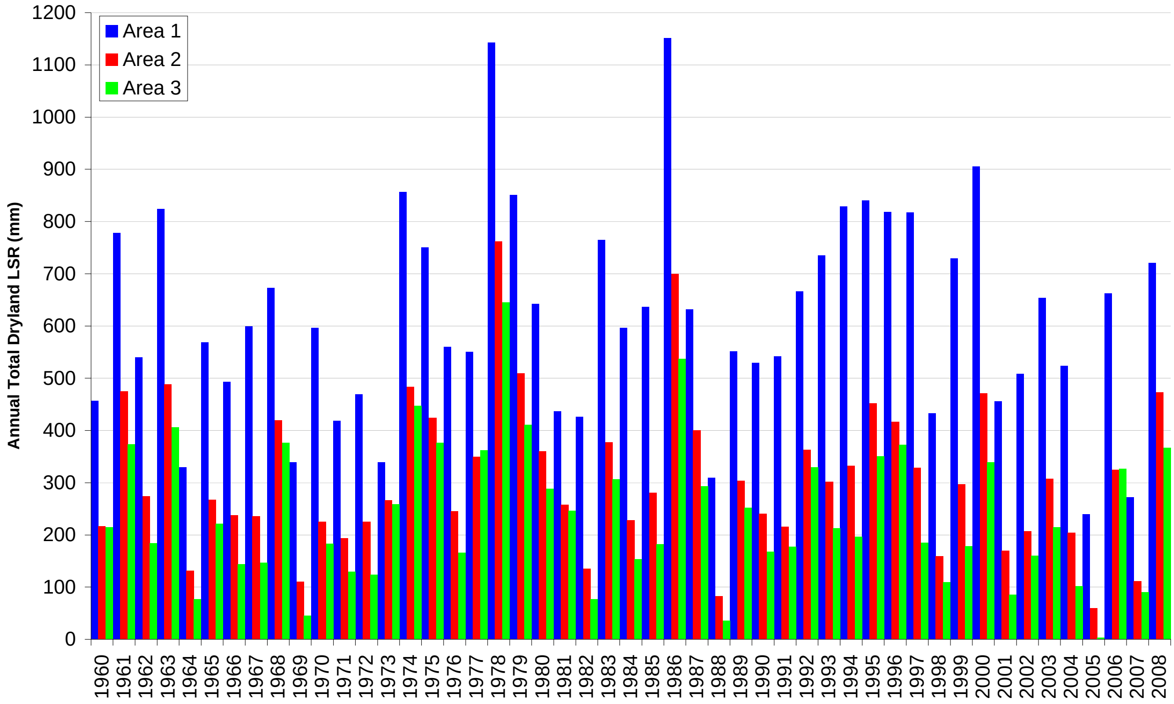

**Figure 2-5** Estimates of annual dryland LSR for areas 1, 2 and 3 (Ashburton-Lyndhurst slice)

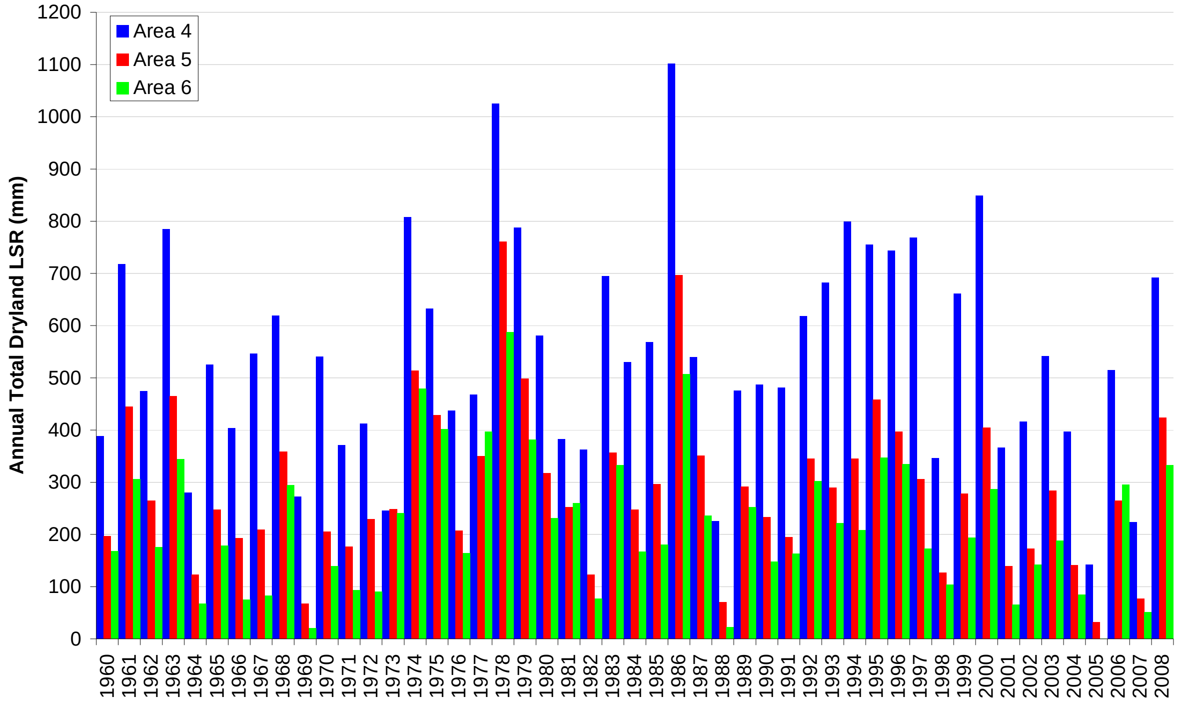

**Figure 2-6** Estimates of annual dryland LSR for areas 4, 5 and 6 (Chertsey slice)

### 2.4.2 Irrigated LSR

Normally, seasonal changes in climate drive the annual cycle of rise and fall in groundwater levels, high in spring and low in autumn. Irrigation adds a complication, making a positive contribution to the groundwater balance through enhanced recharge and a negative one where irrigation water is abstracted from groundwater.

The estimates of irrigated LSR described in the following sections take account of irrigated area in order to represent the volume of recharge and irrigation demand in terms of effective depths. The effective irrigation depths are applied over areas 1 through 6, as displayed in Figure 2-1. This representation of recharge and demand is effectively a sub-catchment water balance, used as input in the eigenmodel analysis of groundwater dynamics (Section 4).

#### Annual irrigated LSR

Table 2.3 presents descriptive statistics of the estimated annual irrigated LSR. The important point to note is the difference between the statistics in Table 2.2 and Table 2.3 as this represents the effect of additional LSR caused by irrigation. The more widespread and less efficient the irrigation, the greater the increase in LSR. Area 2 shows a substantial increase in recharge compared with dryland conditions due to the extent of the irrigated area but also reflecting the lower efficiency of border-strip irrigation in the ALIS.

**Table 2.3 Descriptive statistics of estimated annual irrigated LSR (includes dryland LSR and effective irrigation increment)**

| | Minimum (mm) | Maximum (mm) | Standard deviation (mm) | Mean (mm) | Median (mm) |
|---|---|---|---|---|---|
| Area 1 | 251 | 1160 | 202 | 626 | 607 |
| Area 2 | 280 | 962 | 136 | 510 | 518 |
| Area 3 | 106 | 763 | 136 | 335 | 297 |
| Area 4 | 142 | 1102 | 206 | 545 | 531 |
| Area 5 | 75 | 805 | 148 | 330 | 318 |
| Area 6 | 107 | 722 | 133 | 332 | 307 |

## Monthly irrigated LSR

Seasonality can be analysed at a monthly scale to show how LSR and irrigation demand vary throughout the year. Figure 2-7 plots the estimated average monthly LSR and irrigation demand (soil moisture deficit met by irrigation) for each of the six areas shown in Figure 2-1.

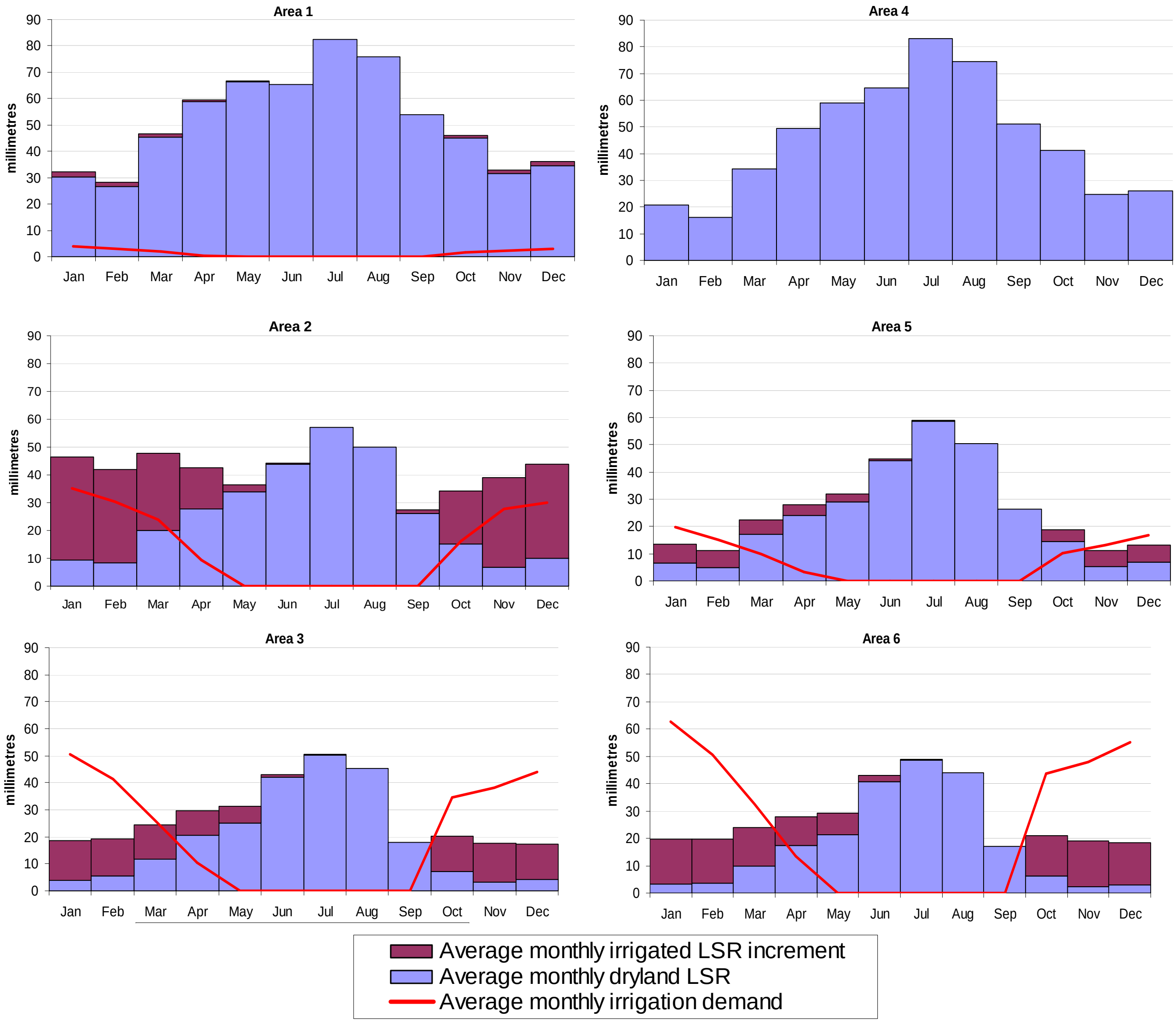

**Figure 2-7** **Plots of average (monthly) effective depth equivalents of LSR under dryland and irrigated conditions, and irrigation demand met by irrigation across six areas of the Rakaia-Ashburton Plains (Figure 2-1)[6].**

On average, dryland recharge peaks in July and is lowest around January of each year. The additional LSR caused by irrigation comes through additional rainfall drainage due to the soil moisture levels being higher than otherwise would have occurred naturally, and as a result of irrigation inefficiency. The increased recharge of rainfall continues after the irrigation season has ceased until about June (on average), after which LSR is effectively the same under irrigated and dryland conditions.

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[6] For Area 2 the analysis takes account of the ALIS development over time. For the other areas the estimate of the currently irrigated land was used throughout the simulation period.

We have used irrigation demand or the average monthly deficit met by irrigation as a proxy for groundwater abstraction. In the absence of water use records (for those areas outside Area 2) this is considered the best available estimate of historic water use and we believe it is appropriate for the purposes of this study. The nominal increment of LSR due to irrigation and irrigation demand was pro-rated according to the estimates of irrigated area shown in Table 2.1. Not surprisingly, increases in LSR due to irrigation are greatest in those areas with more irrigation coverage, and where less efficient irrigation practices are predominant.

Areas 3 and 6 have the highest irrigation demand reflecting more extensive irrigation development but also lower rainfall than areas 1 and 4. On average, estimated demand for irrigation water exceeds estimates of dryland and irrigated LSR between October and March. Where irrigation water is supplied from groundwater the increase in LSR is more than outweighed by the groundwater abstraction required to meet the soil moisture deficits. On the other hand, irrigation water abstracted from surface water bodies will result in a net import of water to the groundwater system.

### 2.4.3 ALIS scenario – estimates of LSR for Area 2 using spray irrigation only

One of the important issues in water management for the Rakaia-Ashburton Plains is the effect on LSR from increasing water use efficiency within the ALIS. The results for Area 2 shown in Figure 2-7 incorporate our estimate of LSR from the scheme. The additional LSR from the ALIS largely results from border-strip irrigation, where relatively large application depths are applied compared with more efficient spray irrigation methods. Conveyance losses from canal leakage also account for increased LSR across the ALIS. This is consistent with the estimated average monthly LSR being in excess of the soil moisture deficit. The additional LSR caused by the ALIS is significant when compared with neighbouring Area 5. A more detailed description of the methodology used to estimate LSR across the ALIS is included in Appendix 1. The results compare well with previous estimates of LSR across the ALIS which are summarised in Dommisse (2005).

Two scenarios of ALIS irrigation development have been considered to illustrate the reduction in LSR resulting from potential efficiency gains from the present move towards spray irrigation. The irrigation rules for these scenarios use 80% efficiency and an unconstrained water supply and no conveyance losses. The response of the groundwater system to a change in LSR under the Area 2 spray development scenario will be simulated using the eigenmodel in Section 4.

**i) ALIS LSR under spray irrigation scenario – 80% irrigated area**

Figure 2-8 shows what might happen if 80% of Area 2 was converted to spray irrigation from the "status quo" conditions shown in Figure 2-7 (Area 2). Status quo reflects our estimate of developments that have occurred within the ALIS (Appendix 1).

The spray scenario reflects changes in estimated average monthly LSR of +10% to -33%. Increases in irrigated LSR would occur predominantly in the winter months due to the late season soil moisture deficits being more fully met. Decreases would occur predominantly during the irrigation season as a result of increased irrigation efficiency (compared to border-strip) and the reduction of conveyance losses (assuming a piped distribution system). Underlying the change in LSR from current irrigation practice to spray is an increase in irrigated area of 31%, or approximately 11 000 ha. If the ALIS stayed within its current spatial extent but converted to more efficient delivery and application systems, then LSR would decrease more than outlined in this scenario.

Under this scenario, the estimated average January irrigation demand is approximately 9.5 $m^3$/s, and 12.8 $m^3$/s at the 80th percentile. This means that the soil moisture demands across 60% of the currently un-irrigated area in Area 2 could potentially be irrigated using the water currently allocated to the ALIS. The highest proportion of ALIS irrigated land within the mapped areas of the supply laterals identified by remote sensing is 70% (Section 2.3).

Figure 2-10 shows the estimated annual LSR if the area of spray is developed to 80%. Under this scenario the mean LSR is 397.8 mm which is 78% of the estimated mean annual LSR of the status quo scenario. LSR could be even further reduced due to constrained availability of surface water supply and a more limited system capacity than that modelled.

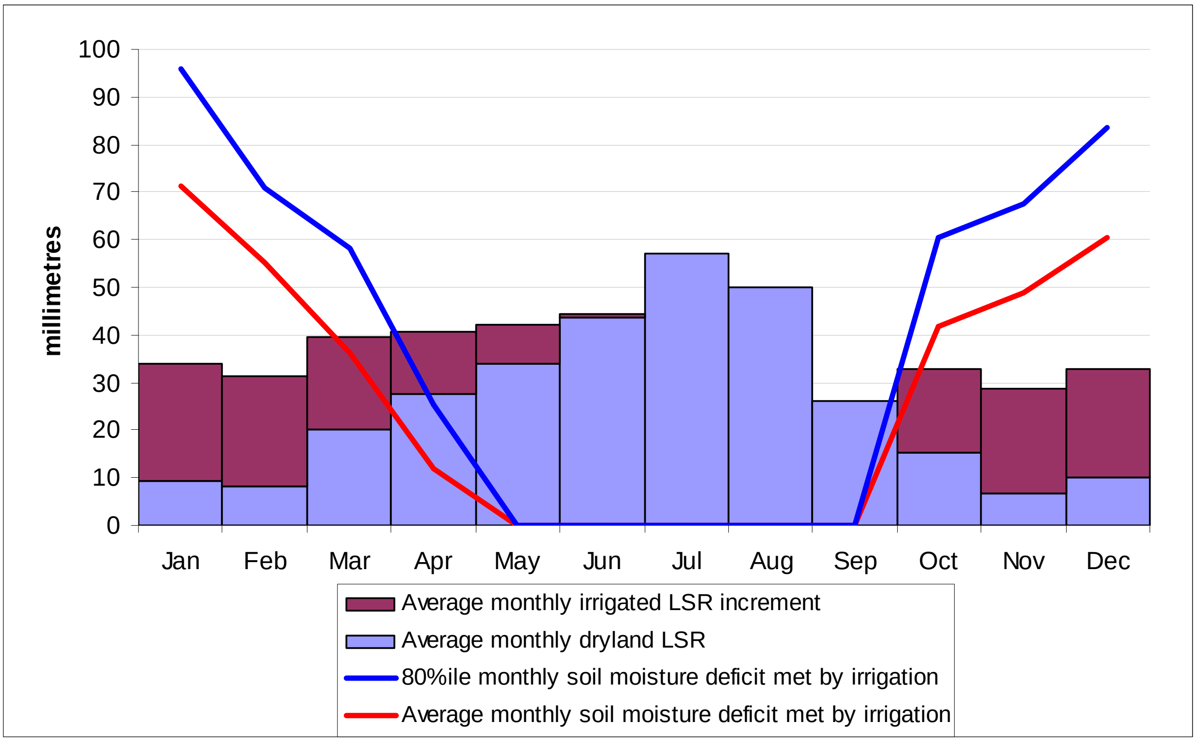

**Figure 2-8 Estimated average monthly LSR and irrigation demand for Area 2 assuming 80% irrigation efficiency, 80% area coverage and with no conveyance loss**

### <u>ii) ALIS LSR under spray irrigation scenario – 100% irrigated area</u>

Figure 2-11 shows the estimated mean annual LSR if 100% of Area 2 was converted to spray irrigation. The estimated annual LSR for Area 2 under “status quo” conditions is presented in Figure 2-9. The 100% irrigated area scenario is only included here to highlight the importance of irrigated area when evaluating water budget changes with changing irrigation practice. This scenario is not used in the eigenmodel scenarios in Section 4.

The 100% irrigated area spray development scenario shows an estimated mean annual LSR of 497.3 mm. This is 98% of the estimated mean annual LSR for the status quo scenario (509.5 mm), which is consistent with the work of Bright (2008) for the Valetta Irrigation Scheme. The extra recharge from the greater area irrigated is largely offset by the lower losses through higher irrigation efficiency.

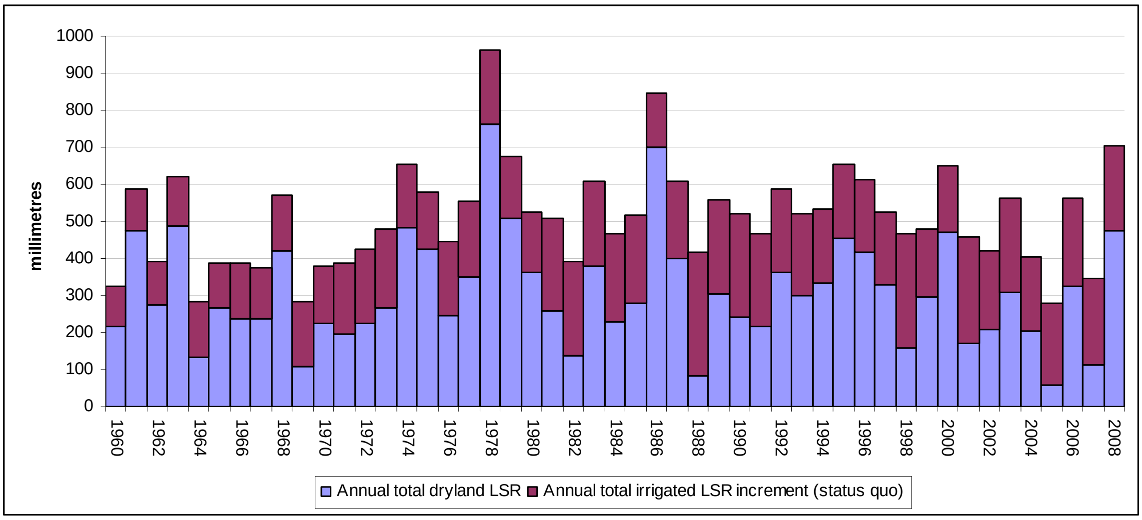

**Figure 2-9** **Estimated annual LSR for Area 2 under status quo**[7]

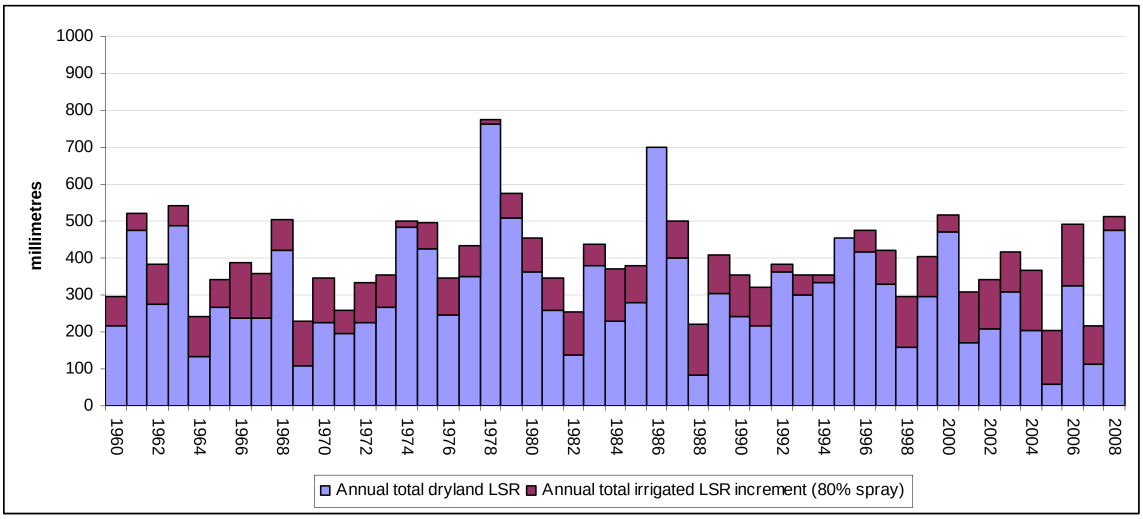

**Figure 2-10** **Estimated annual LSR for Area 2 if spray irrigation was developed across 80% of the area at 80% efficiency throughout the time series record of estimated LSR**

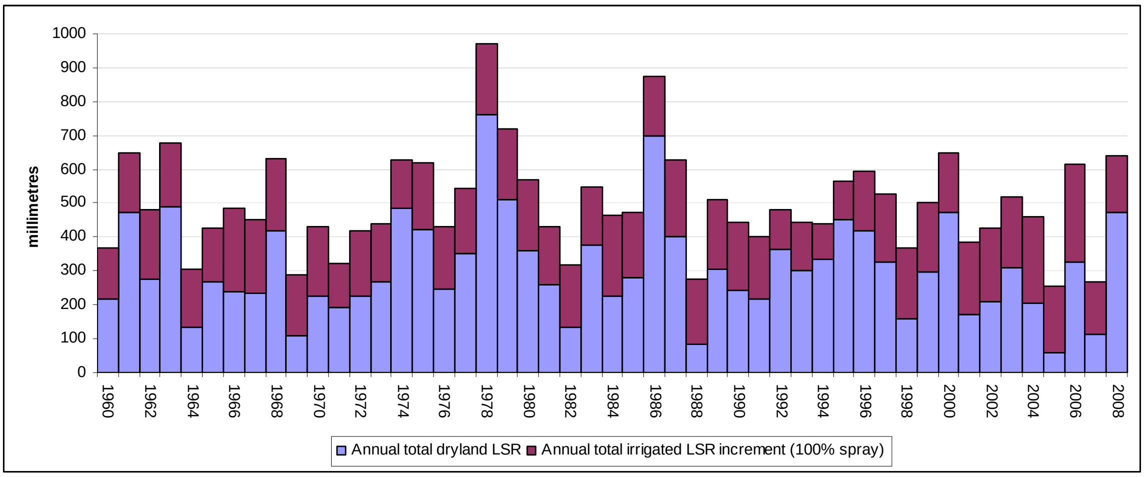

**Figure 2-11** **Estimated annual LSR for Area 2 if spray irrigation was developed across 100% of the area at 80% efficiency throughout the time series record of estimated LSR**

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[7] Irrigation area increased over time

# 3 Groundwater dynamics

Groundwater occurrence and dynamics are described in this section. Groundwater level patterns are described using time-series of piezometric head in order to relate these to local recharge sources. The purpose of this section is to develop a conceptual description of the groundwater hydrology and provide a context for considering the components of groundwater behaviour using the eigenmodel (Section 4).

## 3.1 Time series plots of groundwater levels

Environment Canterbury currently regularly monitors thirty wells across the Rakaia-Ashburton Plains area as shown in Figure 3-1. The recorded groundwater levels, plotted in Figure 3-2 and Figure 3-3, reflect a wide range of short-term dynamic behaviours and long-term trends across the area. The dynamic responses of groundwater levels reflect influences such as:

- sporadic and seasonal rainfall recharge in areas of shallower water table;
- damped responses to rainfall recharge in areas of deeper groundwater;
- “steady” river recharge effects and seasonal groundwater abstraction; and

Note that some records show declining trends, while others do not.

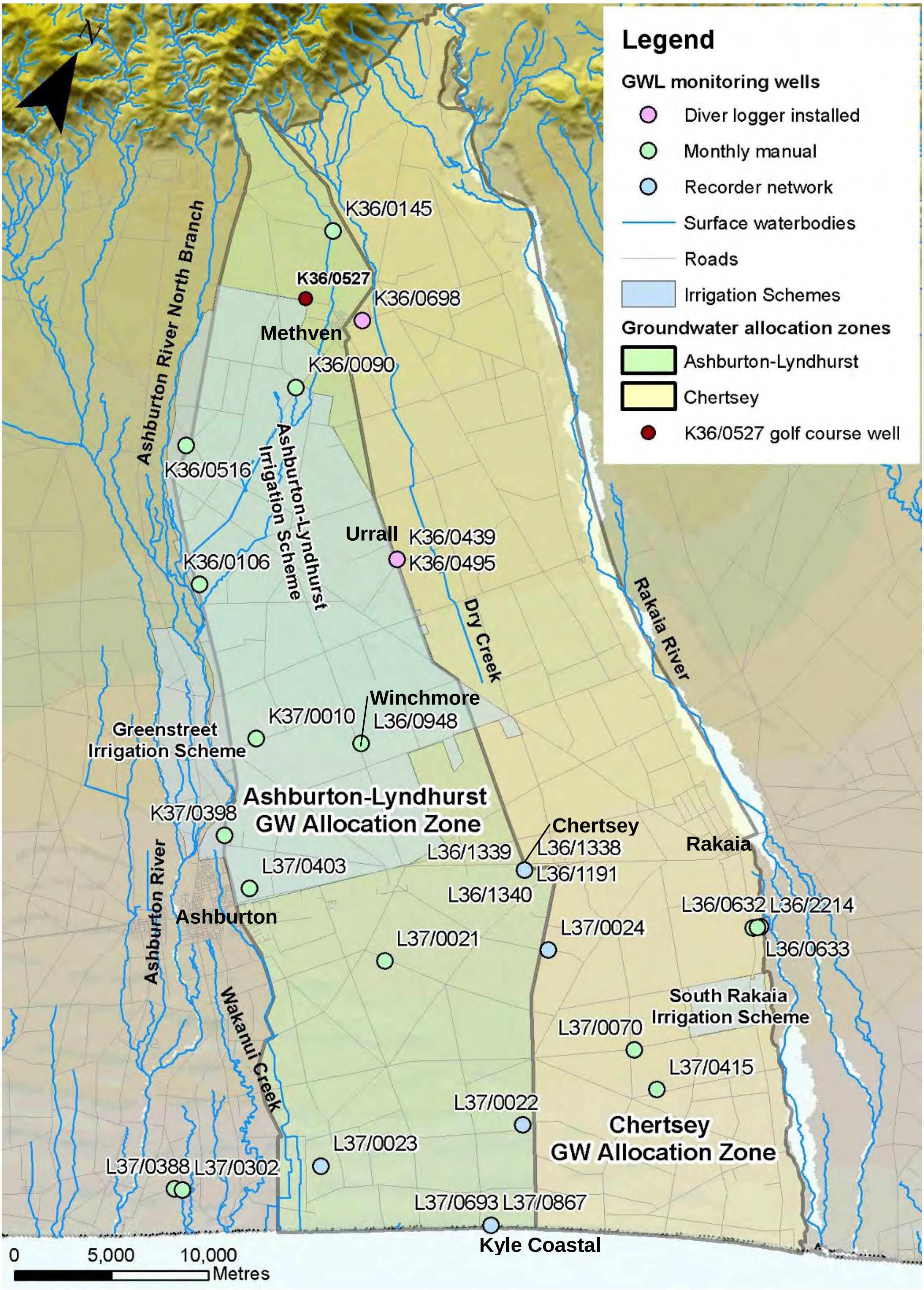

Figure 3-1 Environment Canterbury groundwater level monitoring sites across the Rakaia-Ashburton Plains

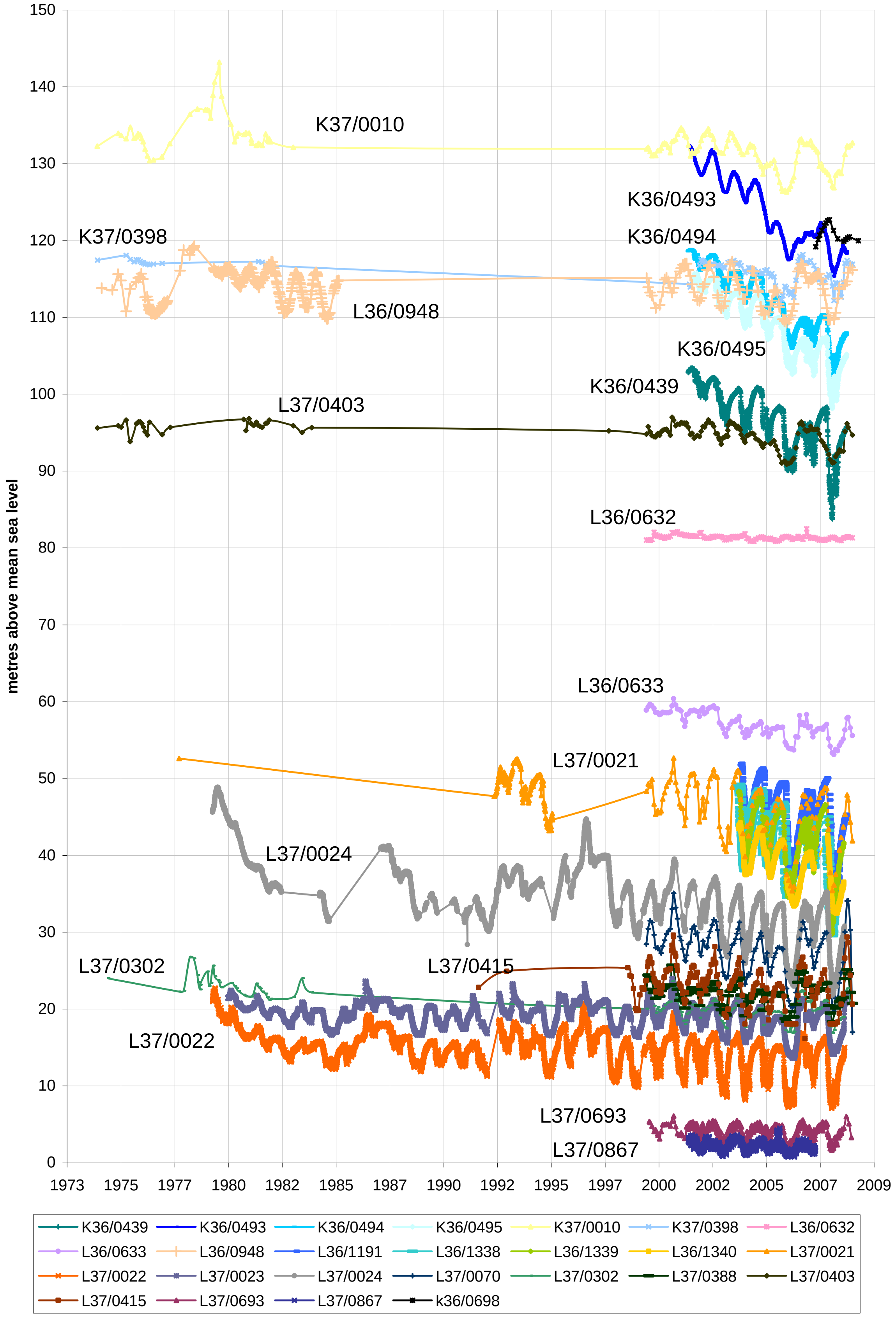

**Figure 3-2** Groundwater levels between 0 and 150 metres above mean sea level measured at those sites identified in Figure 3-1

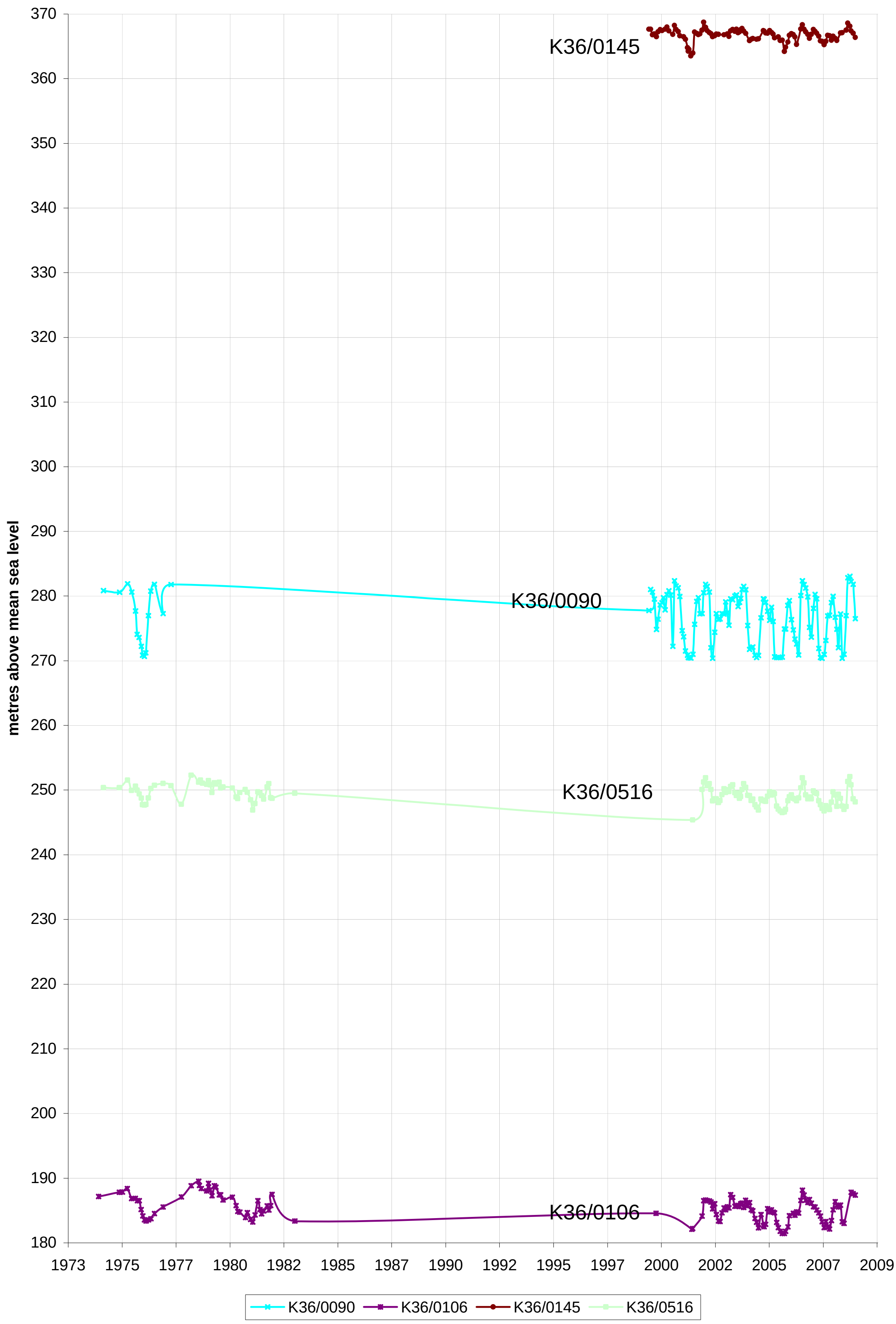

**Figure 3-3** **Groundwater levels between 150 and 370 metres above mean sea level measured at those sites identified in Figure 3-1**

## 3.2 Standardised plot assessment

Groundwater level records for five observation wells were selected for an assessment of longer term trends. In order of increasing distance from the foothills. The wells are: K36/0145, K36/0495, L36/0948, L36/1340, and L37/0024. These records were selected as they represent the range of long-term trends observed across the study area.

It is helpful for comparison of groundwater level records for a number of wells to plot them in standardised form. Standardisation involves subtracting the mean level for that well from the groundwater level and dividing this result by the standard deviation of the data for that well. This enables the same plot scale to be used for several records. For example, comparison of these standardised series shows more clearly which well records are particularly affected by pumped abstraction.

Figure 3-4(a) shows the standardised time-series plot of five wells for the period of record from 1/1/1974, and Figure 3-4(b) shows the period from 1/1/2000.

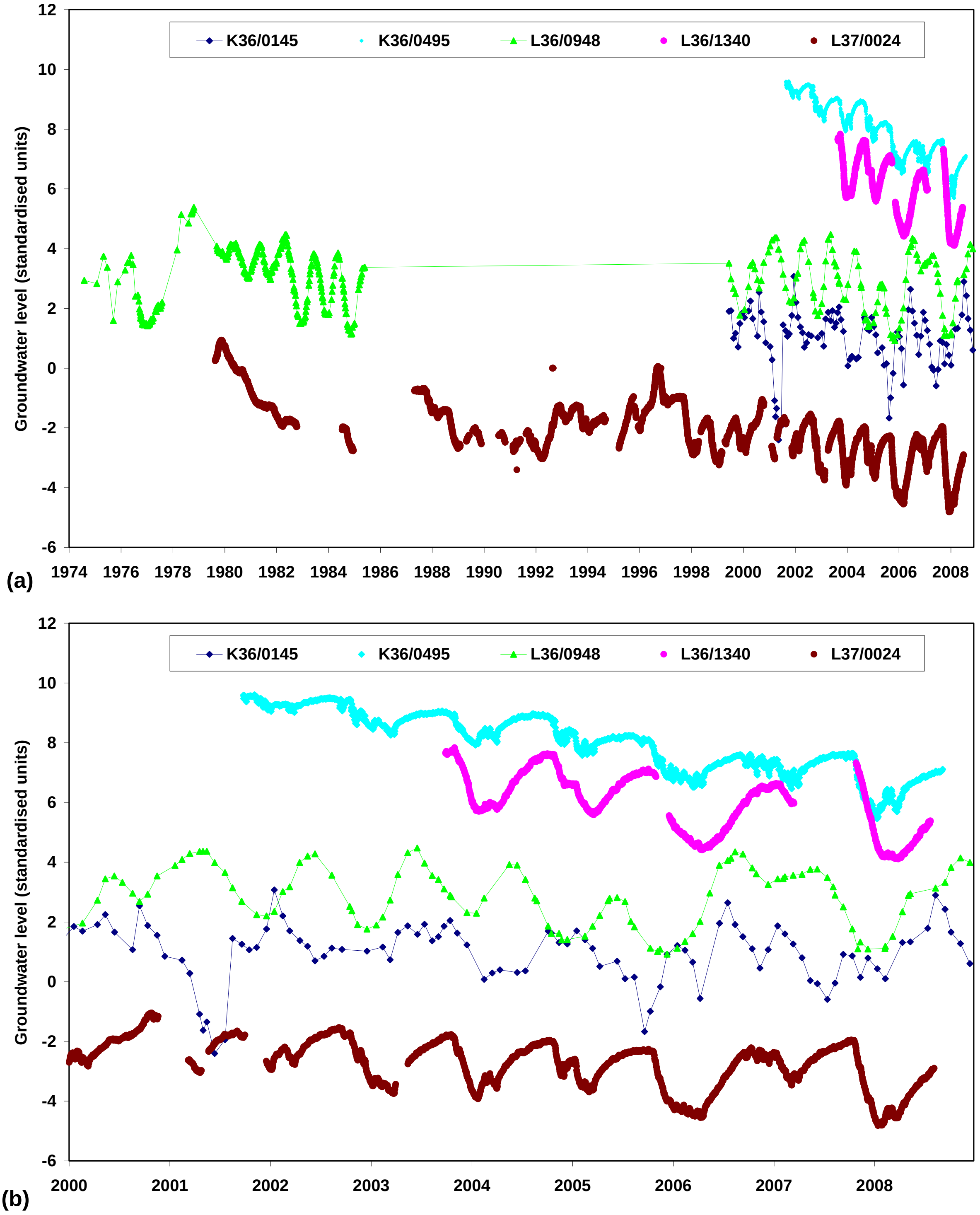

**Figure 3-4** **Standardised plots of groundwater level observations for (a) 1974-2008 and (b) 2000-2008. Note, the standardised levels have been offset for display purposes**

Figure 3-4 suggests that the groundwater level time series in this area can generally be divided into two sets:

1. Group 1: Those which show a relatively stable trend;
2. Group 2: Those which show greater effects of pumped abstraction in terms of decline in level and dynamic recovery effects since 2001.

## 3.3 Piezometric head assessment

### 3.3.1 Scatter plots

Scatter plots of well head elevation versus well bottom elevation, and well head elevation versus average piezometric head from 30 groundwater level monitoring sites are shown in Figure 3-5 and Figure 3-6 respectively. These sites are currently monitored and have the longest time-series records.

The distribution of well depths (Figure 3-5) is consistent with the analysis of Davey (2006) and, when compared with the plot of average piezometric head (Figure 3-6), shows that the distribution of the piezometric head and well bottom is consistently downwards up-plains of about Winchmore (L36/0948); however, this pattern has reversed at Chertsey showing an upward hydraulic gradient in deep wells. The direction of the vertical gradient can be determined by comparing the relative screen position and piezometric position. For example, at the multi-piezometer monitoring site at Urrall (K36/0439, K36/0493, K36/0494, and K36/0495), the lower the screen elevation the lower the piezometric head, which reflects downward hydraulic gradients (shown by the red arrows in Figure 3-6). At the multi-piezometer monitoring site at Chertsey (L36/1191, L36/1338, L36/1339, and L36/1340), the piezometric head reflects upward hydraulic gradients (shown by the red arrows in Figure 3-6).

These upwards hydraulic gradients are not as pronounced as the downward gradients found across the upper plains. The vertical range in piezometric head increases away from the coast to a maximum difference recorded at Methven of ~201 m (K36/0698: – mean GWL 124 mamsl; and K36/0527: mean GWL 325 mamsl). K36/0698 is located on the northern side of Methven while K36/0527 is located on the southern side. The head differential between these wells is likely caused by horizontal spatially variable occurrences of shallow groundwater.

Figure 3-7 shows average piezometric head from 82 wells for all available groundwater level data in the area and reproduces the pattern presented in Figure 3-6.

Figure 3-5, Figure 3-6, and Figure 3-7 are essentially cross-sections without horizontal scaling and largely reflect the control that river recharge has on the piezometric head across the plains; but also reflect geologic influences on vertical hydraulic gradients; and an apparent bottom-line for groundwater levels in deeper wells. The bottom-line below which deep groundwater levels appear not to drop, may indicate a hydraulic gradient that is controlled by regional-scale hydraulic resistance and discharge from the system.

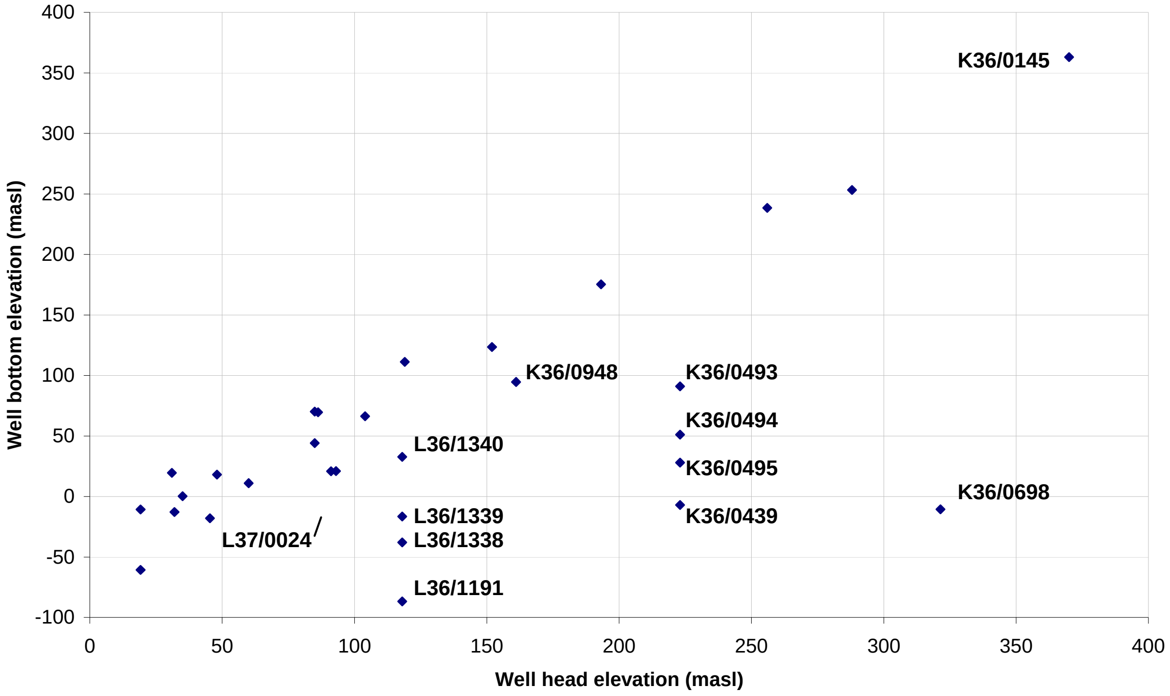

**Figure 3-5** Plot of well depth elevation versus well head elevation. Wells were selected if they have had more than 60 groundwater level readings. K36/0698 had only 16 readings useable but was included due to its depth and inland location

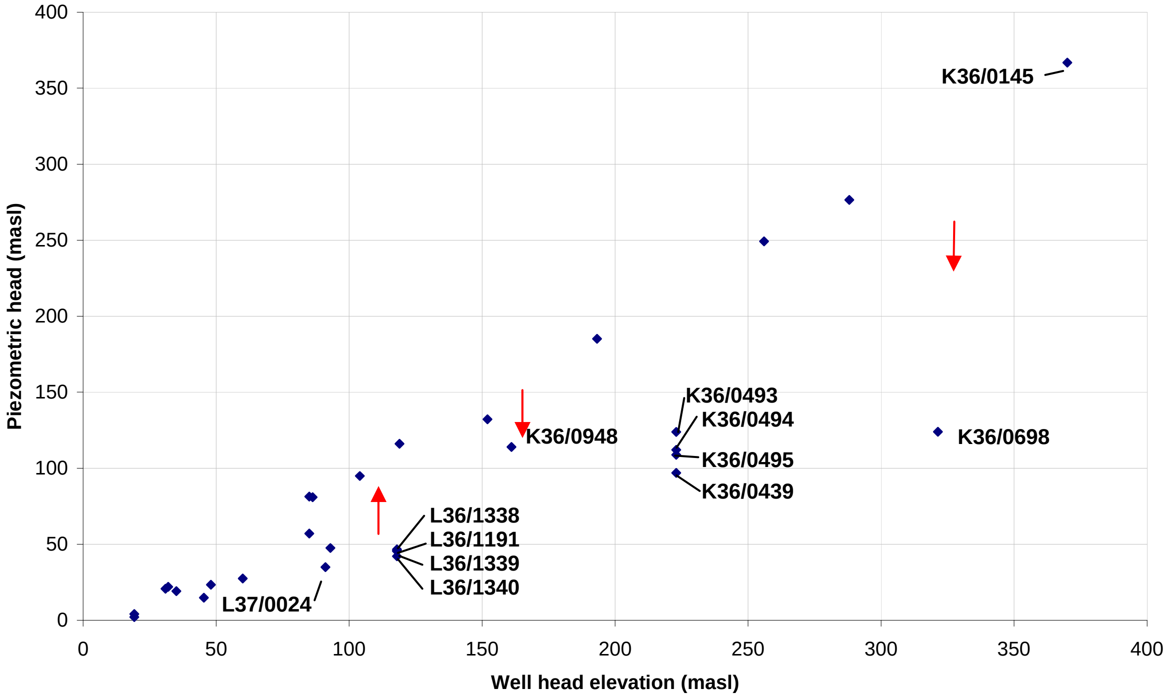

**Figure 3-6** Plot of average piezometric head versus well head elevation. Wells were selected if they have had more than 60 groundwater level readings. K36/0698 had only 16 readings usable but was included due to its depth and inland location. Red arrows indicate the vertical direction of hydraulic gradient

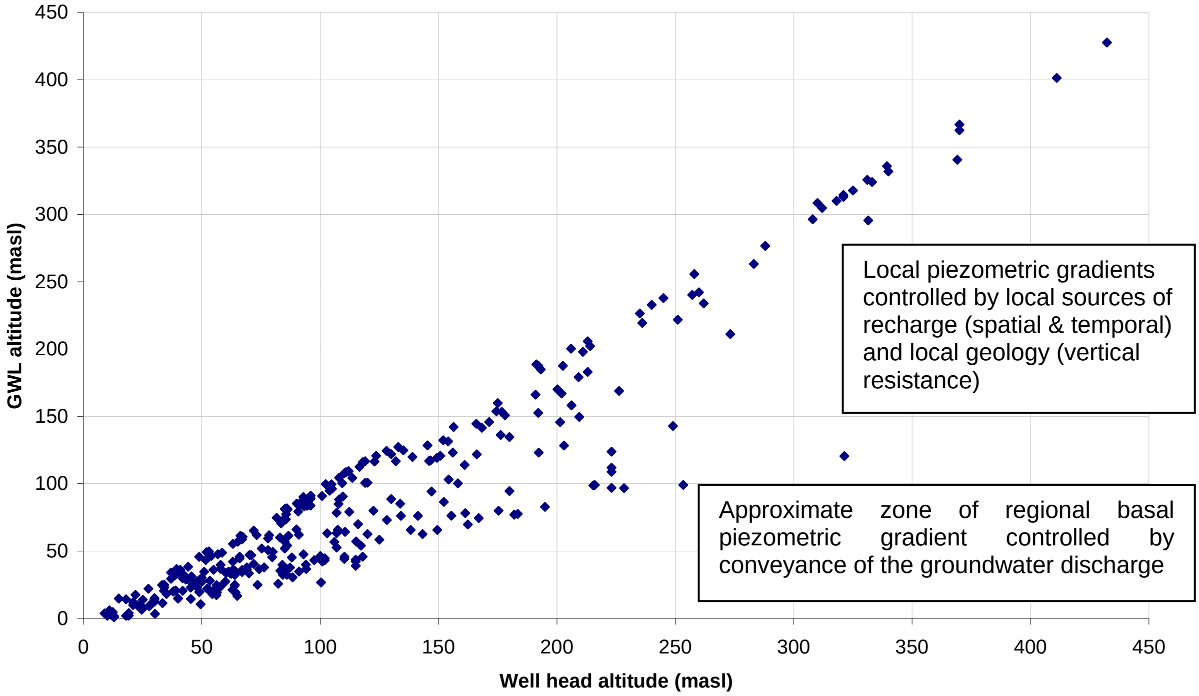

**Figure 3-7 Plot of average piezometric head distribution using well head altitude versus groundwater level altitude using data from 82 wells and not limited to the sites with more than 60 readings**

Figure 3-8 presents in map form the same information shown in Figure 3-6 and Figure 3-7. The map allows an evaluation of how the vertical distribution of average piezometric head varies spatially across the groundwater system. The vertical range in piezometric head is more pronounced across the upper plains in contrast to the lower vertical differences in piezometric heads across the lower plains.

The influence of the Ashburton River on piezometric head is apparent in Figure 3-8 from a comparison of the topographic elevation of the river and nearby groundwater levels.

The upper Rakaia River topographic elevations plot distinctly higher than piezometric head northwest of State Highway 1, shown in Figure 3-8. The piezometric head drops away rapidly on the south side of the river within about 500-1000 m of the river. Up gradient of the State Highway 1 Bridge, deeper groundwater levels are at much lower elevations than the Rakaia River elevation which supports the suggestion that leakage from the Rakaia River in its upper reaches is limited and/or relatively steady.

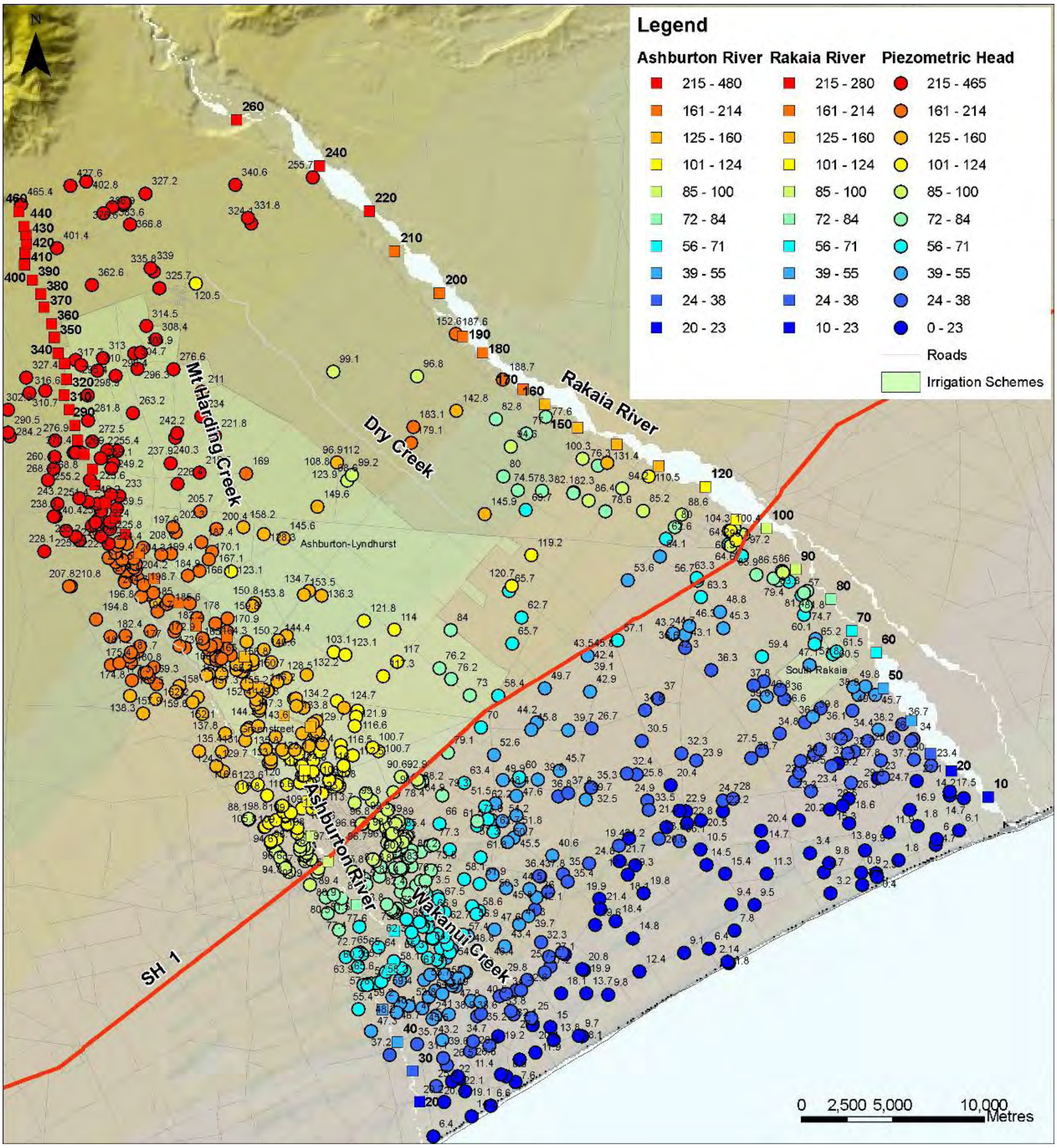

**Figure 3-8** Map of average piezometric head (masl) across the Rakaia-Ashburton Plains. Piezometric head (mamsl) is represented by the circles, and the topographic elevation of the Ashburton River (including the North Branch) and the Rakaia River (mamsl) are represented by the squares. The colouring intervals are the same across the three features

### 3.3.2 Cross-sections

A further perspective on piezometric head and screen elevation distributions is provided in a series of cross-sections, the locations of which are shown in Figure 3-9. The data were plotted in three dimensions using a software package recently developed by ARANZ (2009). Cross-section images were exported from the three-dimensional model at 15 km intervals across the plains and show how spatial variability in local recharge sources affects the vertical distributions of piezometric head. This reflects the patterns described earlier in this section. However, the cross-sections more clearly reveal the locations of high vertical hydraulic gradients. There is a consistent pattern throughout of higher piezometric head nearer the rivers and lower piezometric head toward the centre of the Rakaia-Ashburton Plains area. The higher piezometric head around the rivers reflect significant local river recharge sources compared with LSR. The cross-sections down plains of State Highway 1 reflect relatively low vertical hydraulic gradients compared with those up-plains.

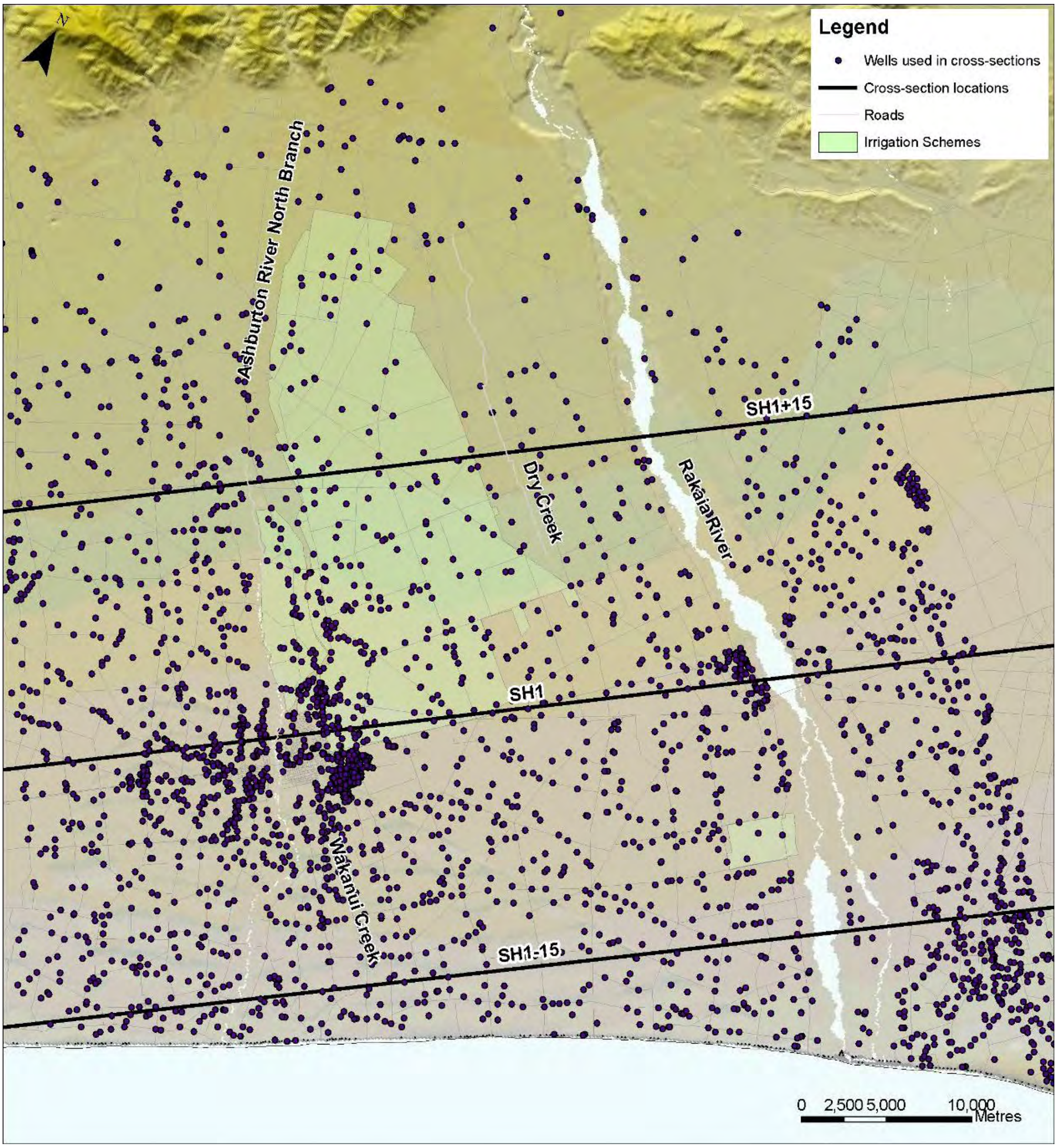

**Figure 3-9** **Location of cross-sections shown in Figure 3-10 (Wells within 2.5 km of the line are represented in the cross-sections)**[8]

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[8] SH1 runs approximately along State Highway 1. SH1-15 and SH1+15 are located 15 km coastward and landward respectively from SH1.

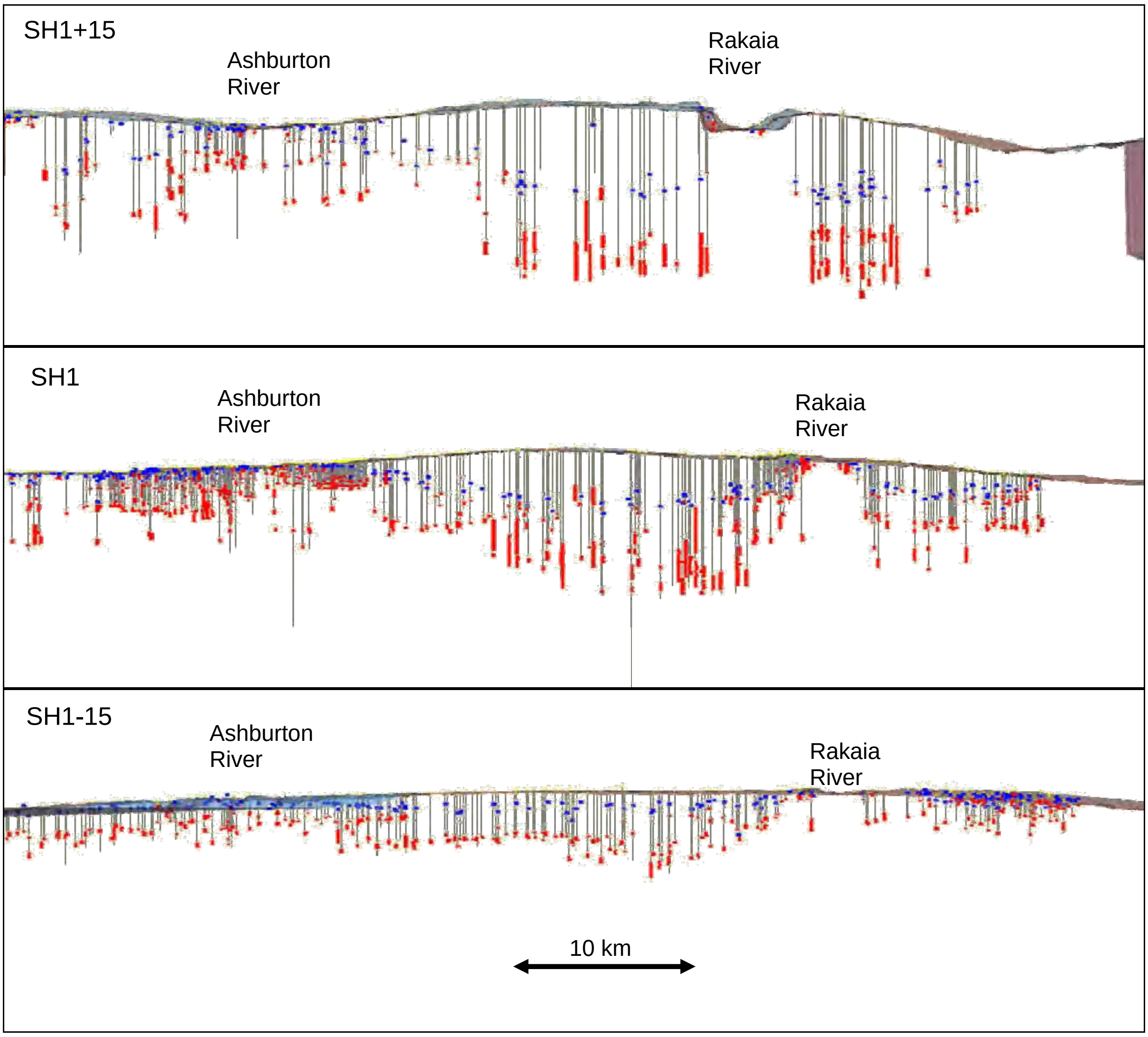

**Figure 3-10** **Cross-sections made using Hydro (ARANZ, 2009) showing representative distributions of piezometric head (blue) and well screens (red) with 50x vertical exaggeration**

## 3.4 Classification

The two broad groups of groundwater level behaviour described in the previous section are identifiable in a larger number of groundwater level monitoring sites across the Rakaia-Ashburton Plains. Table 3.1 summarises a comparison between groundwater levels, their standard deviation, and well screen/depth elevations together with a classification into either group. The two groups of wells are shown in Figure 3-11, which reflects the spatial distribution. Group 1 wells tend to lie in shallower parts of the system nearer the rivers and the ALIS. Group 2 wells tend to occur in deeper parts of the system and away from the rivers and the ALIS.

**Table 3.1 Groundwater level statistics and well screen or depth elevation in metres above sea level (mamsl)**

| Well | Mean piezometric head (mamsl) | Standard deviation (m) | Screen or depth (mamsl) | Comments |
|---|---|---|---|---|
| | | | | |
| L37/0302 | 20.6 | 1.9 | 19.4 | Group 1 (relatively stable trend) |
| L37/0388 | 22.0 | 1.5 | -10.0 | |
| L36/0632 | 81.4 | 0.3 | 70.0 | |
| L36/2214 | 81.2 | 0.3 | 72.8 | |
| L37/0403 | 94.8 | 1.5 | 77.5 | |
| L36/0948 | 114.0 | 2.2 | 94.6 | |
| K37/0398 | 116.0 | 1.5 | 111.1 | |
| K37/0010 | 132.2 | 2.7 | 123.4 | |
| K36/0106 | 185.1 | 1.8 | 175.2 | |
| K36/0516 | 249.2 | 1.4 | 238.5 | |
| K36/0090 | 276.6 | 3.9 | 253.3 | |
| K36/0145 | 366.8 | 1.0 | 363.0 | |
| L37/0693 | 4.02 | 0.9 | -58.8 | Group 2 (apparent declining trend) |
| L37/0867 | 2.12 | 0.7 | -8.81 | |
| L37/0022 | 14.9 | 2.4 | -15.0 | |
| L37/0023 | 19.2 | 1.7 | 6.1 | |
| L37/0415 | 23.3 | 2.3 | 18.0 | |
| L37/0070 | 27.4 | 3.4 | 15.9 | |
| L37/0024 | 34.9 | 4.6 | 30.1 | |
| L36/1340[1] | 39.3 | 3.4 | 33.7 | |
| L36/1339[1] | 42.7 | 4.2 | -15.5 | |
| L36/1338[1] | 43.7 | 4.5 | -35.2 | |
| L36/1191[1] | 46.0 | 4.5 | -79.0 | |
| L37/0021 | 47.6 | 3.5 | 25.6 | |
| L36/0633 | 57.0 | 1.7 | 44.0 | |
| K36/0439[2] | 96.9 | 4.0 | -5.0 | |
| K36/0495[2] | 108.8 | 4.4 | 30.0 | |
| K36/0494[2] | 112.0 | 4.3 | 53.0 | |
| K36/0493[2] | 123.9 | 4.6 | 93.0 | |
| K36/0698 | 124.0 | 1.3 | 321.4 | |

*Note:* [1] *Monitoring well cluster at Chertsey*
[2] *Monitoring well cluster at Urrall*

Classification into two broad sets is supported by the groundwater level statistics and well characteristics listed in Table 3.1 and the time series plots shown in Figure 3-2, Figure 3-3 and Figure 3-4. The two groups are shown in Figure 3-11. The groups can be characterised in the following way:

1. Group 1 groundwater levels are more closely associated with river levels and localised runoff causing piezometric head to reach greater elevations than Group 2. Standard deviations are also generally lower across the Group 1 set but depend on the proximity to the surface water recharge source and border-strip irrigation in the area. L36/0948 shows an average piezometric head, standard deviation and screen level mid-way between those across Group 1 and Group 2, and is considered to be near the edge of the shallow aquifer system supported directly by surface water recharge and border-strip irrigation. The L36/0948 well screen is at 94.6 metres above mean sea level (mamsl), in comparison with the ~30 mamsl of K36/0495, L36/1340, and L37/0024;
2. Group 2 groundwater levels are generally at lower piezometric levels than those in Group 1. There is also a tendency toward higher standard deviations likely indicating lower storativity, but may also be accounted for by pumping effects being comparatively larger than the climatic effect. Some wells such as L37/0023 and L36/0633 are nearer surface water recharge source reflecting standard deviations more like Group 1. However the piezometric head is significantly lower. L37/0693 and L37/0867 are at the coast and these wells reflect strong pumping signatures in their records, although the lower piezometric head and standard deviation in these wells is influenced by the coastal “constant” head boundary. K36/0698 has not been monitored for very long and was included in Group 2 due to the similarity in piezometric head to K36/0493 at Urrall.

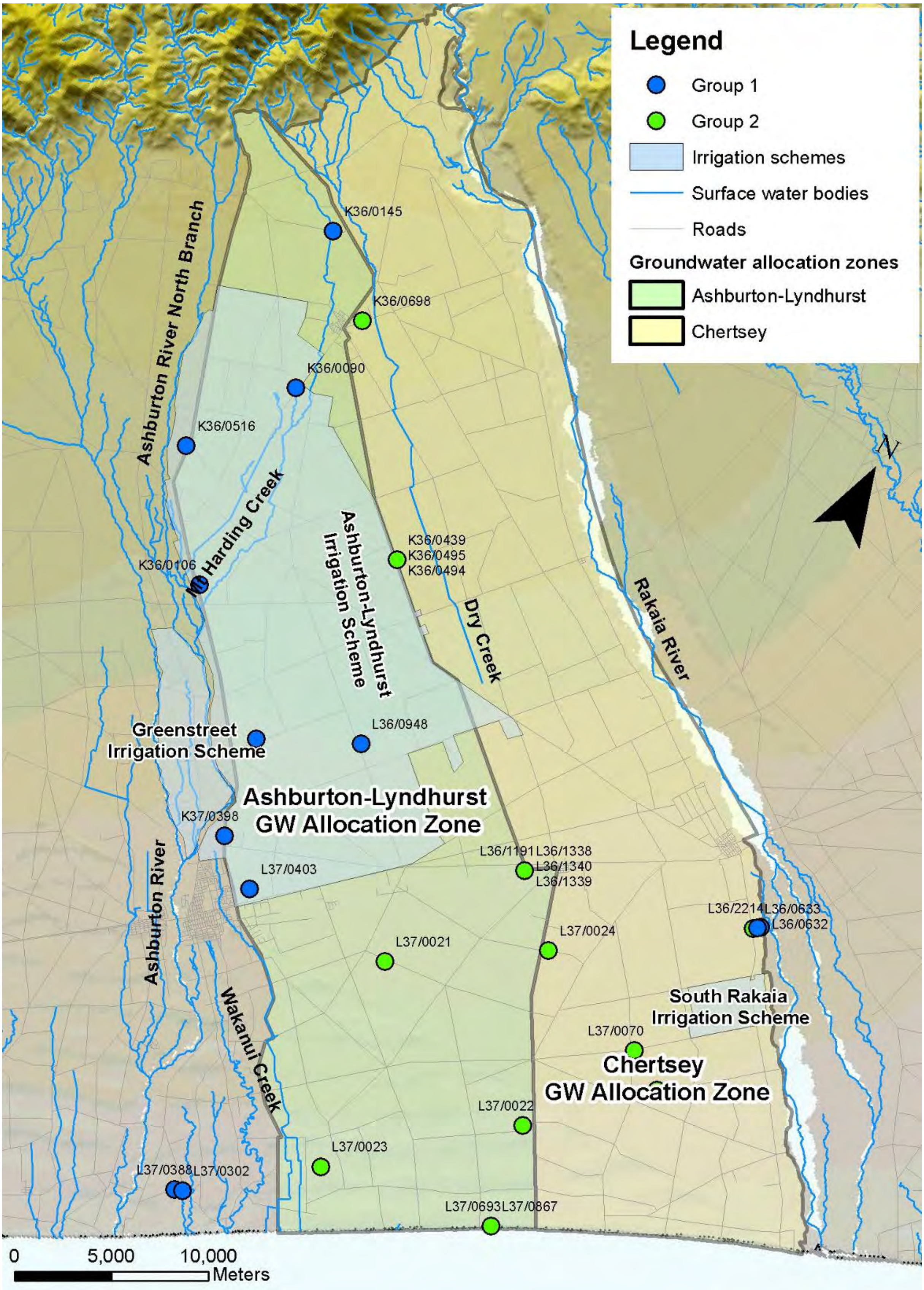

**Figure 3-11** Map showing the two groupings of groundwater level monitoring sites as summarised in Table 3.1

## 3.5 Discussion and summary

The distribution of piezometric head across the upper plains area can be interpreted in terms of the combined effects of LSR, local river recharge and spatial variability of hydraulic conductivity. Higher hydraulic conductivity within inter-glacial deposits adjacent to the large alpine rivers results in an asymmetric piezometric surface, with deep groundwater levels reflecting the relatively low hydraulic gradient required to convey the groundwater discharge. Local river recharge maintains comparatively elevated piezometric head in the remaining lower hydraulic conductivity areas, such as in the vicinity of the Ashburton River (Aitchison-Earl, 2000).

The spatial variation in groundwater level response to the cumulative effects of pumping also reflects spatial variability in hydraulic conductivity (including horizontal and vertical anisotropy); however, the high vertical gradients in some areas of the upper plains may limit the observed response to cumulative pumping effects. Furthermore, the response to cumulative pumping in shallow wells near rivers and irrigation schemes is likely to be less than in deep wells due to the buffering effect of local recharge sources and possibly higher storativity.

It is possible that localised perching may occur in some areas (this implies the existence of unsaturated conditions below saturated zones). If this condition does occur then there may be implications for groundwater management in affected sub-areas. Further detailed field investigations would be required to establish the presence of unsaturated zones.

The groundwater system is considered to be fully vertically connected in the lower plains area, especially where upwards vertical hydraulic head gradients have developed. Therefore abstraction from both the shallow and deep aquifers across the upper plains will have cumulative effects on all depth ranges of the groundwater system across the lower plains, although to varying degrees and time scales.

# 4 Eigenmodel

## 4.1 Conceptual model

The eigenmodel is a method for quantifying the dynamic behaviour of groundwater storage and groundwater discharge in response to time-series of recharge. Recharge includes that from land surface, rivers and pumped abstraction. There is consistency between the eigenmodel method and the more conventional numerical groundwater models, in that the latter are capable of conversion to an eigenmodel format. Experience has shown (Andreu and Sahuquillo, 1987) that this form enables significant model simplification when describing dynamic behaviour and is the principal purpose of the model.

The eigenmodel of a complex aquifer system has a reduced set of model parameters that characterise an aquifer in terms of a set of conceptual groundwater reservoirs. The storage time of these conceptual reservoirs decreases rapidly as more reservoirs are included in the model. The dominant reservoir, with the largest storage time, defines the dynamic behaviour during drought (long period of zero land surface recharge) and accounts for most of the useful groundwater storage in the model. The other reservoirs are relatively less important in volumetric terms but contribute to the details of dynamic response.

The eigenmodel method used for the present study has even fewer parameters to be calibrated because it represents a simple aquifer for which there is an analytical solution. Previous experience in Canterbury (e.g. Williams *et al.,* 2008) demonstrates the useful predictive performance of this model for dynamic analysis of groundwater resources.

The eigenmodel used for the analysis in this report is an accurate mathematical representation of a simple conceptual groundwater model of the Rakaia-Ashburton Plains aquifer system, as illustrated in Figure 4-1. The model represents a slice across the plains from mountains to the coast. The mountains are represented as a “no-flow” aquifer boundary, and the coastal discharge area (including springs, drains and streams) is represented as a “specified head” boundary.

Time-varying recharge and abstraction can be specified separately for each of the recharge zones, described in Section 2. The locations of the boundaries of the recharge zones are specified in terms of their distance from the upstream “no-flow” boundary. Since this is a one-dimensional model, the spatial variation of recharge and abstraction is also along the direction of dominant groundwater flow from mountains to sea. Parallel model slices can be taken through other locations to obtain a more comprehensive picture, but this is still a simplification in comparison to a full spatially-distributed numerical model.

One consequence of this parallel-slice approximation is that the piezometric influence of river recharge is expected to vary with slice location. For a particular slice, the influence of river recharge can be quantified by a steady recharge term that is distributed over each or any of the specified zones, usually as a calibrated parameter value.

In each of the zones the eigenmodel can have an additional component that simulates the dynamic effect on land surface recharge of water storage in the vadose zone, especially in the form of a perched aquifer. In model studies of the Central Canterbury aquifer system this vadose zone storage effect has a mean residence time of up to about five months. A perched aquifer has the effect of smoothing the recharge input to the main aquifer system below, but the piezometric effect of abstraction from the main aquifer is decoupled from the perched aquifer.

Groundwater abstraction can be specified as a negative recharge distributed uniformly over any of the recharge zones.

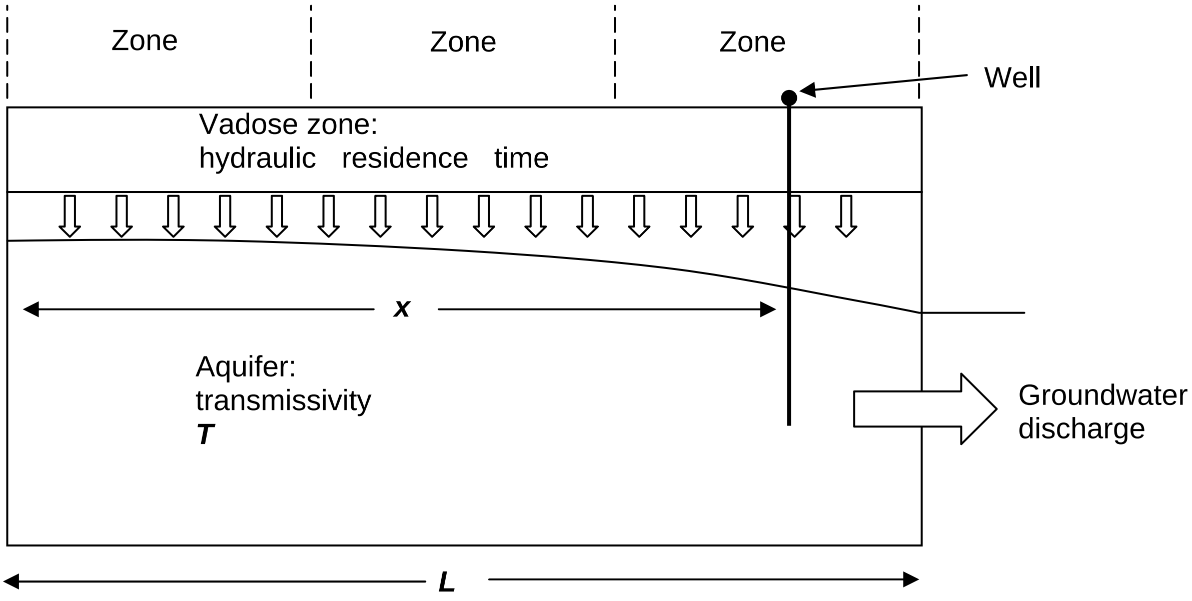

**Figure 4-1** **Concepts of the multi-zone eigenmodel for groundwater level response to recharge on Rakaia-Ashburton Plains**

## 4.2 Model setup

The model was applied as a slice through areas 1, 2 and 3 which is referred to as the Ashburton-Lyndhurst slice; and areas 4, 5 and 6 which is referred to as the Chertsey slice (Figure 2-1). The eigenmodel uses the LSR, irrigated area fractions and groundwater water demand data described earlier in this report (Section 2). The calibration of the eigenmodel is to groundwater levels from two monitoring sites, well L37/0023 for the Ashburton Lyndhurst slice, and well L37/0024 for the Chertsey slice. These wells were chosen because of their length of record and proximity to the discharge end of the aquifer system.

## 4.3 Model parameters

The dynamic response of this conceptual aquifer to a specified pattern of recharge and abstraction can be predicted as the piezometric change at location *x km* from the upstream boundary (Figure 4-1). There are three fundamental model parameters that completely determine this response: the relative location $x/L$ (where $L$ is the total length of the system); the dynamic parameter $T/SL^2$, for which $T$ and $S$ are the bulk values of aquifer transmissivity and storativity respectively; and storativity $S$ itself.

For the purposes of practical model calibration the value of steady piezometric effect controlled by river recharge $R$ is also unknown, so there are a total of four fundamental model parameters to be considered. River recharge is not assumed to be steady; rather it is the piezometric effect that is steady because of the damping effect of the aquifer for this kind of boundary condition.

The fundamental parameters are rearranged so that the components $x$, $L$, $S$, and $T$ can be entered separately as physically realistic values. River recharge $R$ is calibrated as the ratio $R/T$, to avoid parametric non-uniqueness that occurs with steady flow models (river recharge effect is assumed to be steady). Hence, as the value of $T$ is calibrated the value of $R$ is automatically updated.

Initial values of $x$ and $L$ can be scaled from a topographic map. Although the exact locations of the effective upstream boundary and downstream discharge are not known, the estimation error of these dimensions is typically only about 10%.

The eigenmodel was calibrated to the groundwater level record for wells L37/0023 and L37/0024 with land surface recharge distribution estimated as outlined in Section 2.4, the associated pumped irrigation demand (outlined in Section 2.4) and irrigated area fraction using the lowest of the results from Section 2.3 and Table 2.1. Well L37/0024 has the longest record of the three deep aquifer wells (Figure 3-2). Calibration was done manually in two stages to achieve a satisfactory simulation of dynamic behaviour of the groundwater system. Firstly, the calibration minimised residuals between modelled and measured groundwater levels during the period prior to 1990 using the estimates of dryland LSR with no pumping. Secondly, the calibration minimised residuals between modelled and measured groundwater levels during the period after ~1990 using the estimates of dryland and irrigated LSR with groundwater abstraction.

## 4.4 Results – Ashburton-Lyndhurst slice

Plots of measured and simulated groundwater levels are shown in Figure 4-2 and Figure 4-3.

The characteristic length of the deep aquifer is $L$ = 52 km, and the well is $x$ = 47.8 km from the upstream boundary, so that $x/L$ = 0.92. The calibrated aquifer properties of transmissivity $T$ = 30,000 $m^2$/d and storativity $S$ = 0.02 and vadose zone storage 1 month are generally similar to values obtained for eigenmodel analyses of data for Central Canterbury (e.g., Weir, 2009; Table 3)[9]. The calibrated value of *River1/T* = 0.0016 results in a river recharge of 48 mm being applied to all three zones, in this example.

Figure 4-3 shows the relatively good fit of the observed and simulated levels over the post-1990 period as the simulation includes pumping and irrigation recharge. Figure 4-2 shows the relatively good fit of the observed and simulated levels over the pre-1990 period because the simulation did not include pumping and irrigation recharge from groundwater abstraction, but did include recharge from the ALIS. This reflects the presence of pumping and additional recharge from the ALIS over the early and later parts of the groundwater level monitoring record.

Figure 4-4 shows the response at well L37/0023 to dryland and ALIS LSR (i.e. without pumping demand) and the piezometric effect (or component) of the river alone. The purpose of this plot is to show the relative importance of pumping demand compared to the sources of recharge. Groundwater level observations (brown circles) for the last few years have values above the river recharge effect (blue line). This suggests that pumping has a smaller piezometric effect than total LSR (dryland plus irrigated LSR). This also suggests that observed groundwater levels (brown circles) are affected by pumping as they plot up to ~3.6 m below the levels simulated under dryland conditions +ALIS (green line).

A better representation of the comparison between pumping demand and the various recharges is shown in Figure 4-5. The independent effects predicted by the eigenmodel of various components of recharge can be compared by reversing the sign of the pumping. Figure 4-5 shows that the piezometric effect of pumping is less than dryland and irrigated LSR but that it does contribute to the seasonal dynamic changes and, to a lesser degree, the longer-term trend in groundwater levels. The LSR simulation (as a component of total recharge) shows the aquifer response to climate and surface water irrigation across the ALIS.

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[9] The calibrated parameter values were derived from the following "Model" worksheets: Eigenprofile multizone_MidCant Areas 1 2 3_dryland.xls; Eigenprofile multizone_MidCant Areas 1 2 3_irrigated.xls .

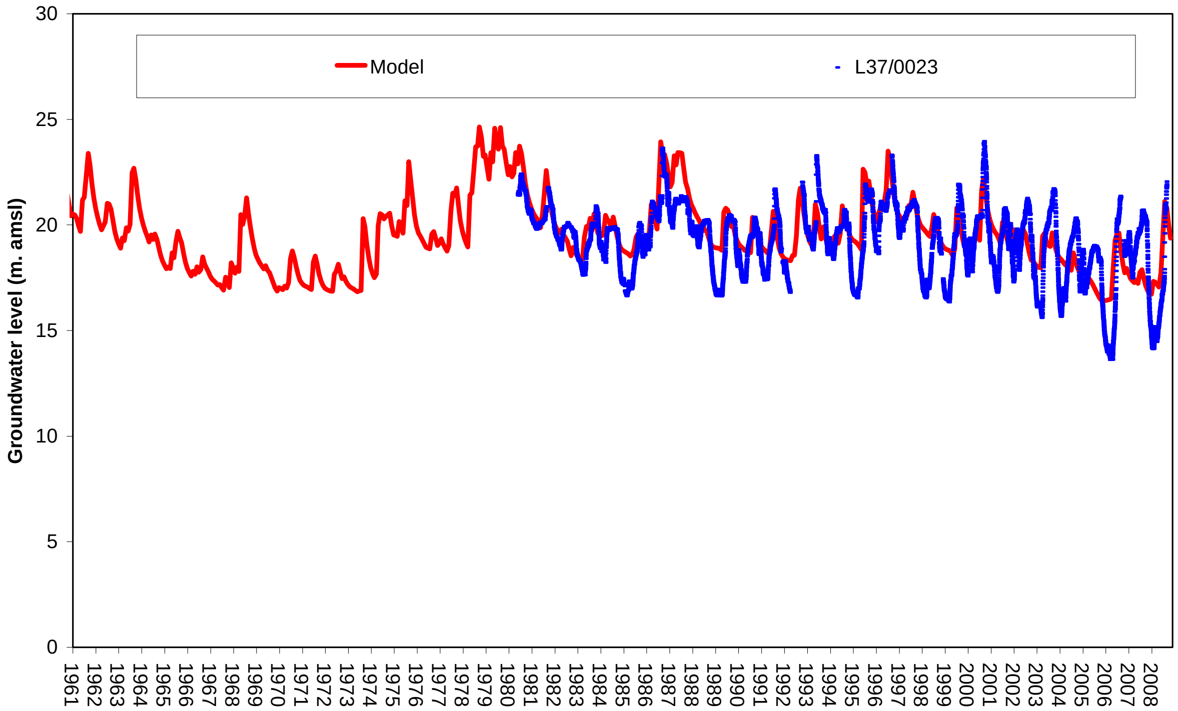

**Figure 4-2** Model prediction of groundwater level at well L37/0023. The model was calibrated using dryland recharge conditions without pumping and was matched to early-time groundwater level data (pre-1990)

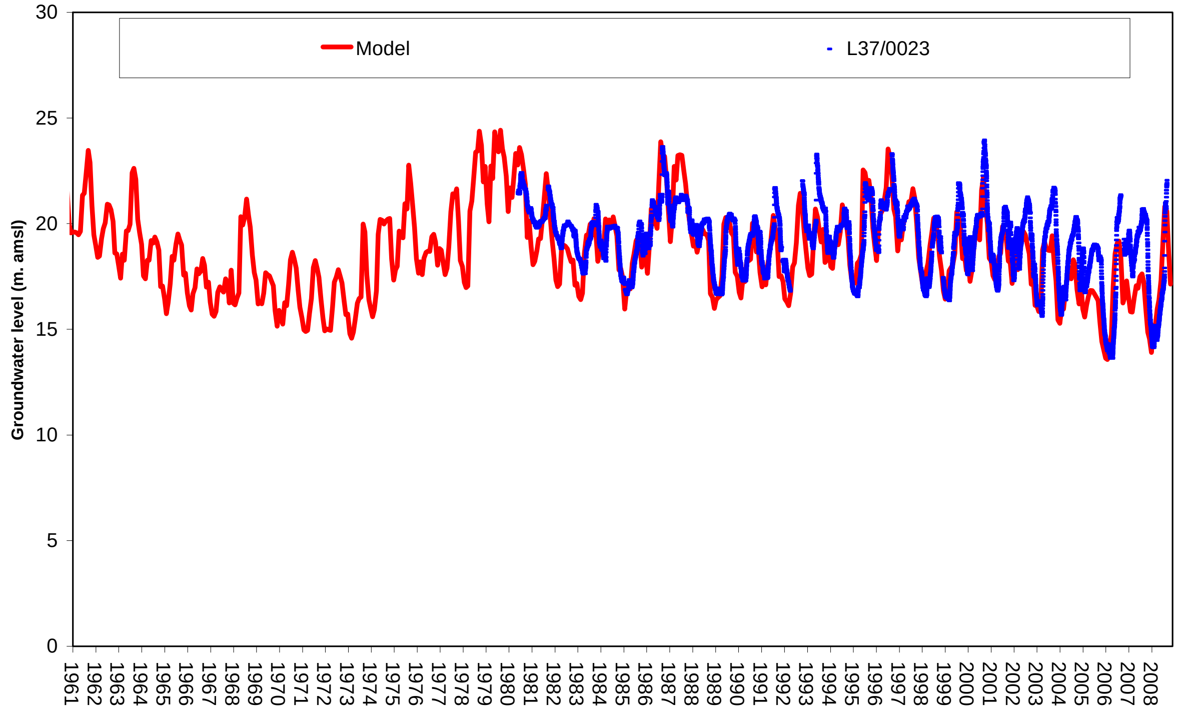

**Figure 4-3** Model prediction of groundwater level at well L37/0023. The model was calibrated using irrigated recharge conditions with pumping over the entire simulation period, and was matched to later-time groundwater level data (post-1990)

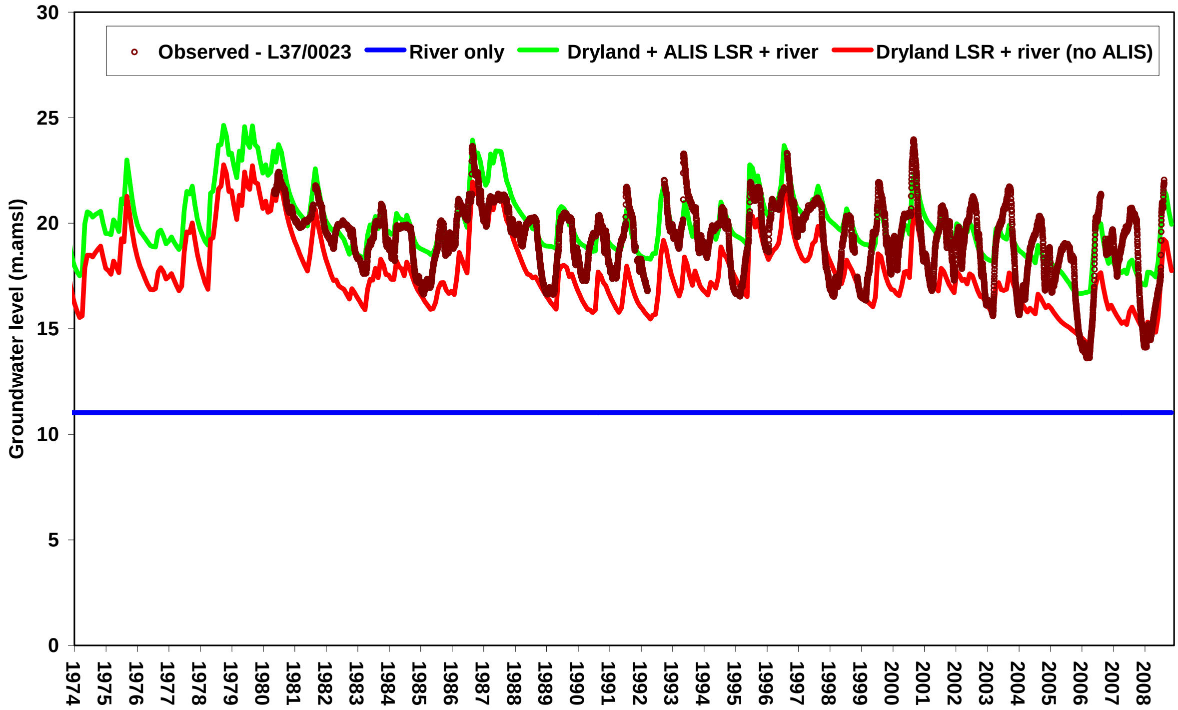

**Figure 4-4** Model predictions of independent piezometric components of dryland and ALIS LSR and river recharge at well L37/0023

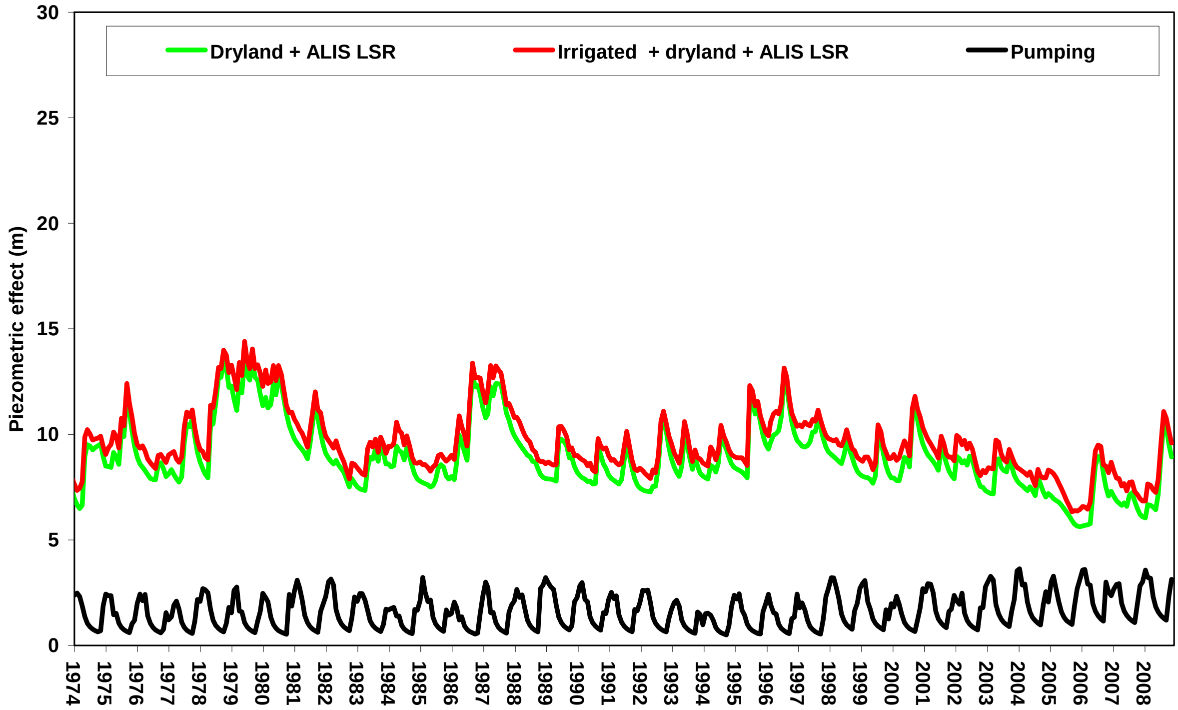

**Figure 4-5** Model predictions of the effects of various components of recharge and pumping at well L37/0023. The negative effect of pumping is reversed to better enable comparison with recharge effects

### 4.4.1 ALIS spray and groundwater development scenarios

The following scenarios illustrate the effects on the groundwater system of moving to more “efficient” irrigation systems across the ALIS and increased pumped demand in Area 3. A scenario exploring the significance of changes associated with further groundwater development in Area 3 is also considered. The lowest of the estimates of irrigated area (Table 2.1) was adopted as the “status quo” in order to provide a conservative prediction of piezometric changes resulting from increased abstraction.

Figure 4-6 shows the downstream change (in Area 3) in the predicted groundwater level at well L37/0023 if spray irrigation replaced border-strip irrigation throughout ALIS.

Table 4.1 summarises the change in groundwater levels from the status quo irrigation configuration across the ALIS to all spray-type irrigation and no change in irrigated area fraction. The 80% spray area development scenario assumes that the spray irrigated area in Area 2 increases from 49% to 80%. The ALIS spray scenarios assume spray-type irrigation rules (as opposed to border-strip), the delivery system is 100% efficient, and the source is 100% reliable. The simulation assumes only 20% of Area 2 is supplied from groundwater (a 2% increase on the current status quo) with the remaining coming from surface water.

The scenarios were considered at two locations (x/L = 0.92 and 0.5) in the eigenmodel with the predicted change derived against a base case (ALIS status quo & Area 3 status quo). The scenarios are summarised by the following:

1. ALIS converting from status quo (i.e. 49% irrigated area) to spray irrigation over 49% of Area 2;
2. ALIS converting from status quo (i.e. 49% irrigated area) to spray irrigation over 80% of Area 2;
3. Area 3 changes from status quo (i.e. 50% irrigated area) to 89% irrigated area whilst keeping ALIS at status quo;
4. Area 3 changes from status quo (i.e. 50% irrigated area) to 89% irrigated area whilst ALIS converts from status quo (49% irrigated area) to spray irrigation over 49% of Area 2;
5. Area 3 changes from status quo (i.e. 50% irrigated area) to 89% irrigated area whilst ALIS converts from status quo (49% irrigated area) to spray irrigation over 80% of Area 2.

**Table 4.1 Statistics describing the change in predicted groundwater levels at x/L = 0.92 and 0.5 if spray-type irrigation replaced current irrigation practices across the ALIS, the irrigation area fraction is increased, and groundwater is developed to its full potential in Area 3. The predictions at x/L = 0.5 represent cumulative effects in Area 2 and x/L = 0.92 represent cumulative effects in Area 3**

| Scenario | Change in predicted groundwater level (m) | | | | | |
|---|---|---|---|---|---|---|
| **x/L = 0.92** | **minimum** | **20%ile** | **median** | **average** | **80%ile** | **maximum** |
| (1) ALIS spray = 49% | -0.94 | -1.42 | -1.77 | -1.77 | -2.10 | -2.81 |
| (2) ALIS spray = 80% | -0.41 | -0.90 | -1.25 | -1.26 | -1.62 | -2.31 |
| (3) ALIS status quo, Area 3 = 89% | 0.01 | -0.22 | -0.49 | -0.67 | -1.16 | -2.15 |
| (4) ALIS spray = 49%, Area3 = 89% | -1.16 | -1.87 | -2.39 | -2.44 | -2.98 | -4.28 |
| (5) ALIS spray = 80%, Area3 = 89% | -0.40 | -1.15 | -1.68 | -1.74 | -2.30 | -3.55 |
| **x/L = 0.5** | **minimum** | **20%ile** | **median** | **average** | **80%ile** | **maximum** |
| (1) ALIS spray = 49% | -5.34 | -8.14 | -10.25 | -10.30 | -12.31 | -16.94 |
| (2) ALIS spray = 80% | -2.06 | -5.12 | -7.25 | -7.31 | -9.43 | -14.07 |
| (3) ALIS status quo, Area 3 = 89% | -0.17 | -1.20 | -1.53 | -1.56 | -1.94 | -2.71 |
| (4) ALIS spray = 49%, Area3 = 89% | -6.13 | -9.40 | -11.85 | -11.86 | -14.12 | -19.54 |
| (5) ALIS spray = 80%, Area3 = 89% | -3.18 | -6.46 | -8.73 | -8.87 | -11.21 | -16.40 |

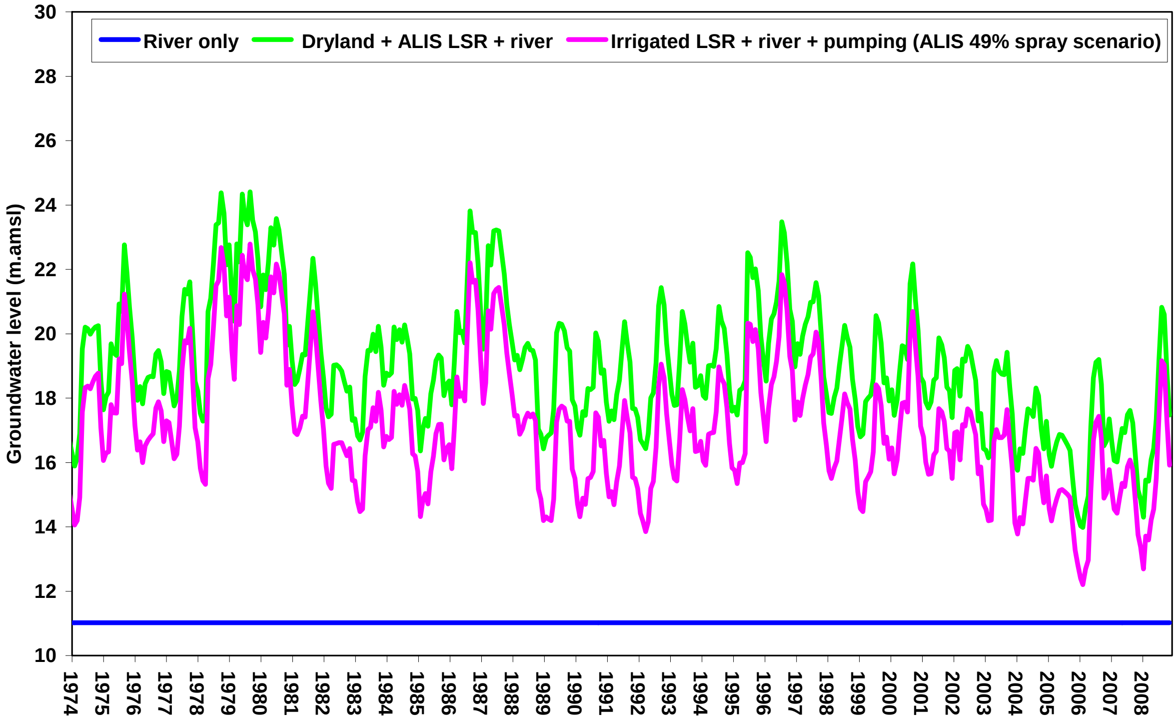

**Figure 4-6** **Model prediction at x/L 0.92 (well L37/0023 in Area 3) for a spray development scenario in Area 2 (the irrigation component of recharge from the ALIS has been entirely converted to spray, maintaining the status quo irrigated area fraction of 49%)**

The spray development scenarios reflect the positive effect on groundwater levels that the ALIS has in areas 2 and 3 because of drainage of excess irrigation water. More efficient spray irrigation means less drainage and so the ALIS spray development scenario (scenario 1) shows a maximum decrease in predicted groundwater levels of 2.8 m and an average decrease of 1.8 m using the existing area of 49%. If the area fraction under spray irrigation increases to 80% of Area 2 (scenario 2), the maximum reduction in predicted groundwater levels is 2.3 m and 1.3 m on average. These changes in predicted groundwater level are at a position in the eigenmodel (x/L) of 0.92 (the position of monitoring well L37/0023, 4.2 km from the coast, which is used to calibrate the eigenmodel). Predicted changes are greater at an "observation" position corresponding to x/L = 0.5 (half way down the slice of areas 1, 2, and 3). Using the status quo area fraction of 49% (scenario 1), the maximum decrease is 16.9 m and 10.3 m on average. Under an area fraction of 80% (scenario 2), the maximum decrease is up to 14.1 m and 7.3 m on average.

The decreases occur mostly as a result of reduced summer recharge from spray compared with border-strip irrigation. This shows that the recharge component from border-strip irrigation is "propping up" groundwater levels down gradient of the ALIS. If such scenarios eventuated (which is unlikely in the next decade based on discussions with ALIS staff), it is likely that some groundwater users would face reduced reliability and even dry bores depending on their proximity to the ALIS. If the goal is to minimise piezometric changes when converting to more efficient irrigation practices, then surface water supply for irrigation should be used over the widest area possible in order to minimise groundwater pumping demand and maximise the additional recharge of rainfall via soil percolation. Alternative managed aquifer recharge options could also be investigated as border-strip irrigation is replaced. Whilst these changes are likely to significantly affect shallow bores, piezometric levels are likely to remain above those that would be sustained by river recharge alone.

The scenario testing also looked at increasing the groundwater abstraction, mostly in Area 3, because of the surface scheme supplies already available in Area 2. The change in predicted groundwater levels due to increasing the area fraction from 60% to 89% in the Area 3 (scenario 3) results in a maximum decrease of 2.7 m and an average of 1.6 m using status quo conditions for the ALIS. This reflects the lesser potential effect from further groundwater development in Area 3 compared with the relatively large effects of the ALIS moving to spray irrigation.

Scenarios 4 and 5 predict the changes associated with increased irrigation area in Area 3 and the spray development scenarios across the ALIS in Area 2.

## 4.5 Results – Chertsey slice

Plots of measured and simulated groundwater levels are shown in Figure 4-7 and Figure 4-8.

The characteristic length of the deep aquifer is $L$ = 52 km, and the well is $x$ = 42.6 km from the upstream boundary, so that $x/L$ = 0.82. The calibrated aquifer properties were the same as those found for L37/0023 (Section 4.4)[10].

Figure 4-7 shows simulated groundwater levels assuming no pumping. The observed groundwater response to the climatic trend is predicted quite well from the start of the record during the relatively wet late 1970s through to the distinctly drier climate of the past decades. The observed lows from the mid 1990s onwards are not simulated very well because pumping was not included in the simulation.

Figure 4-8 shows simulated groundwater levels with status quo pumping in areas 5 and 6. In this case the model predictions provide relatively good fit to observed levels during the last decade when pumping has had the most effect.

Figure 4-9 shows the model predictions for L37/0024 at a more exaggerated scale, as well as the response at that well to the other recharge component – dryland LSR (without pumping demand) and the river effect (or component) alone. The purpose of this plot is to show the significance of observed pumping demand on piezometric levels relative to the sources of recharge. Model predictions and observations for the last few years have values close to the river recharge effect (blue line). Comparison of the observed level (brown circles) and the river recharge effect (blue line) suggests that the piezometric effect of pumping is at times about equivalent to LSR. This plot also indicates that groundwater levels are ~5.5 m below what would be expected under dryland conditions (green line).

A better representation of the comparison between pumping demand and recharge is shown in Figure 4-10. The independent piezometric effect (or component) of pumping, predicted by the eigenmodel, can be compared by reversing the sign of the pumping effect. Figure 4-10 shows that in April 2003, pumping demand is approximately equal to recharge from dryland LSR. Since 2003, pumping has at times increased beyond the level of irrigated LSR. These periods of relatively high pumping demand coincide with periods of low dryland LSR (due to climate). The expected coincidence of increased pumping and decreased recharge within the study area has resulted in the recent record low groundwater levels.

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[10] The calibrated parameter values were derived from the following “Model” worksheets: *Multizone eigenmodel_MidCant Areas456_dryland.xls; Multizone eigenmodel_MidCant Areas456_irrigated.xls.*

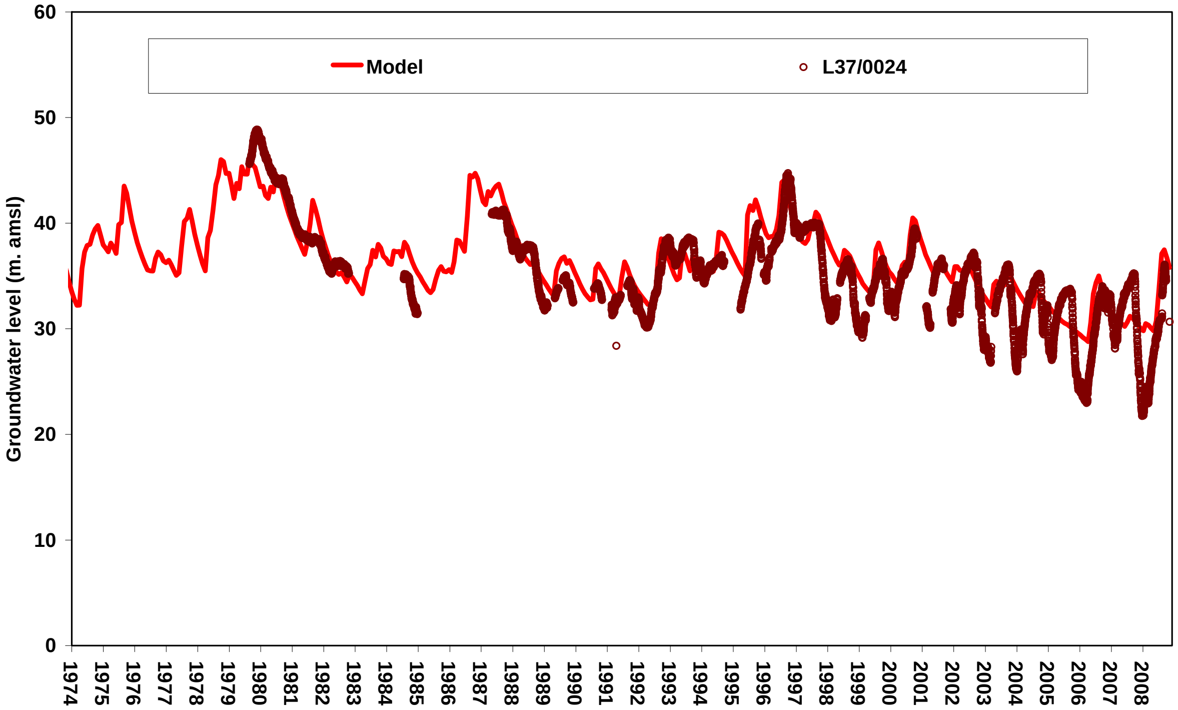

**Figure 4-7** Model prediction of groundwater level at well L37/0024. The model was calibrated using dryland recharge conditions without pumping and was matched to early-time groundwater level data (pre-1990)

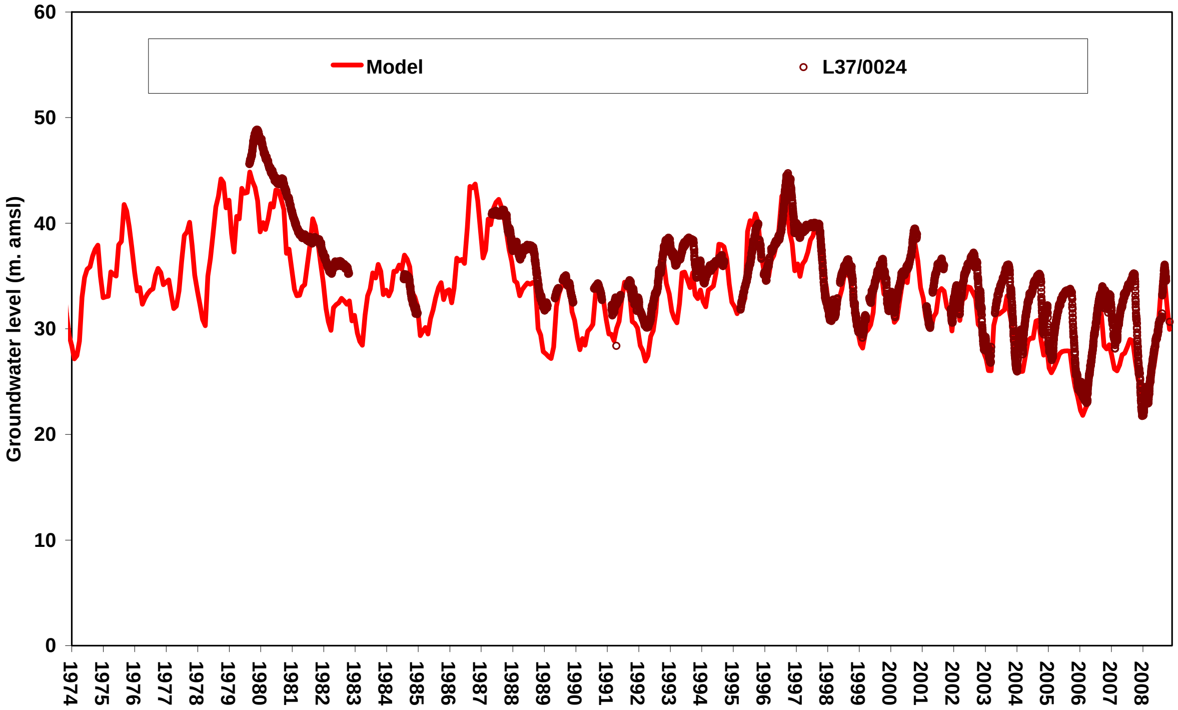

**Figure 4-8** Model prediction of groundwater level at well L37/0024. The model was calibrated using irrigated recharge conditions with pumping and was matched to later-time groundwater level data (post-1990)

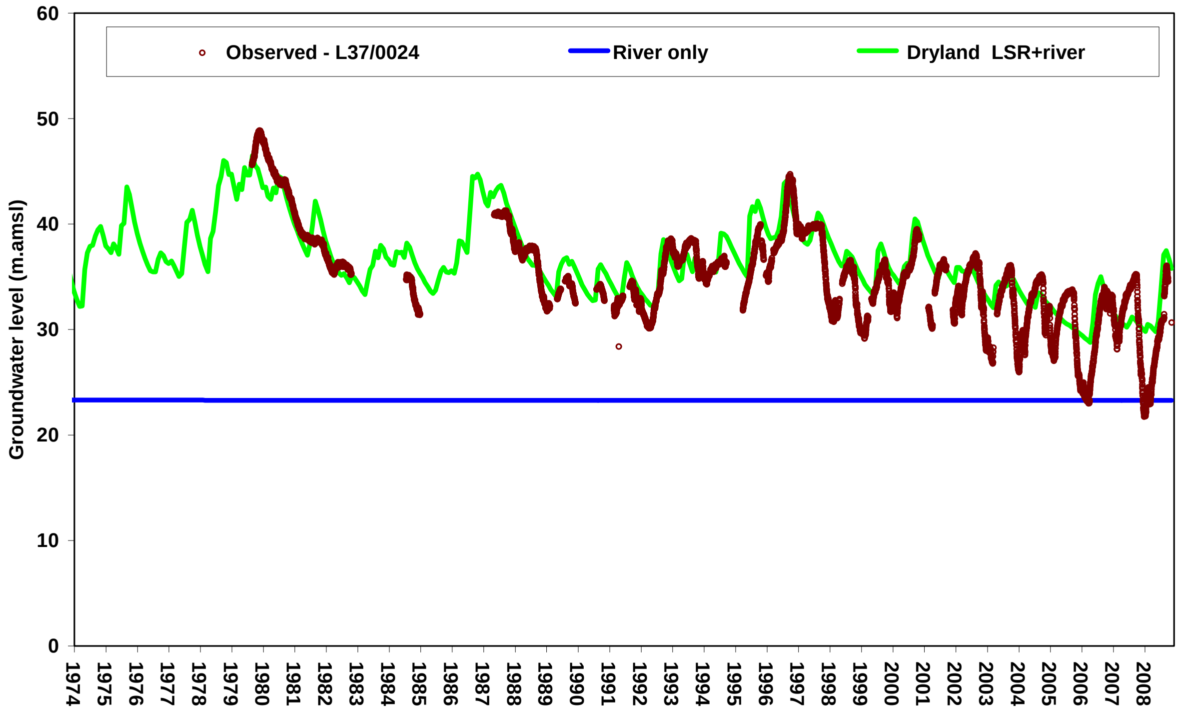

**Figure 4-9** **Model predictions of groundwater level response at well L37/0024 to various combinations of recharge**

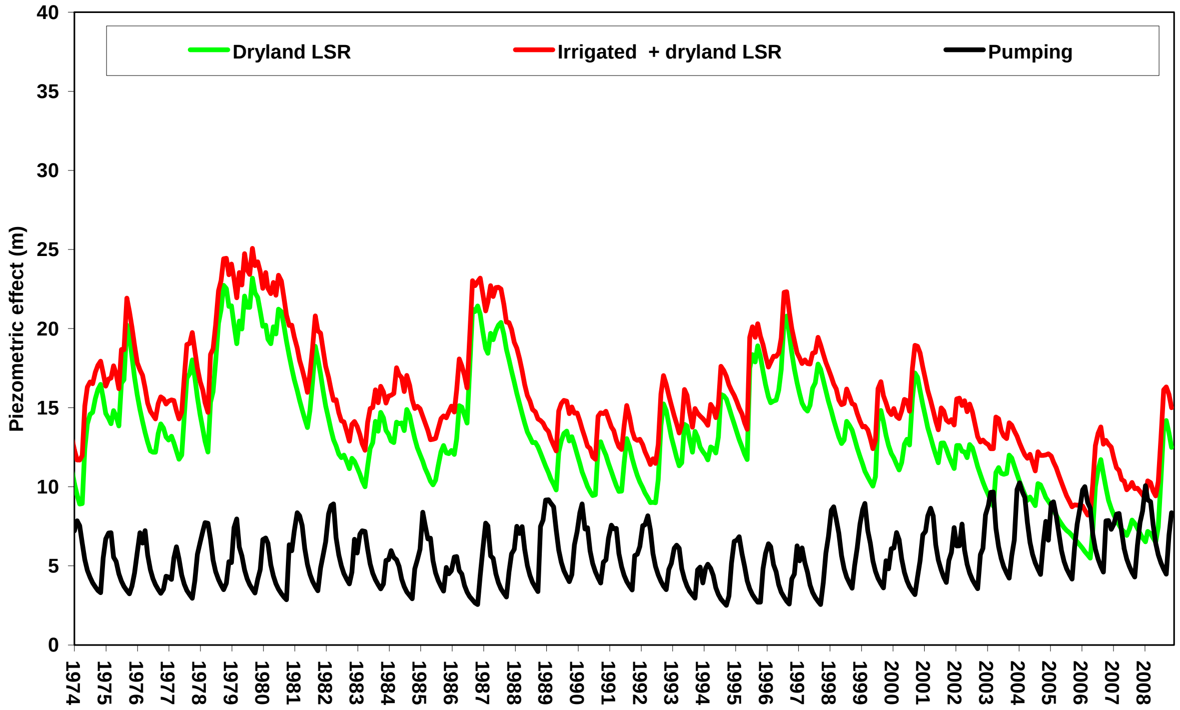

**Figure 4-10** **Model predictions of the independent piezometric effects of recharge and pumping at well L37/0024. The negative effect of pumping is reversed to better enable comparison with recharge effects**

### 4.5.1 Groundwater development scenarios

The scenarios considered in this section attempt to illustrate the effect of pumping groundwater to fully spray irrigate areas 5 and 6 combined and then Area 6 alone. The lowest of the estimated irrigated areas was adopted as the status quo (Table 2.1) in order to provide a conservative prediction of piezometric changes resulting from increased abstraction.

Figure 4-11 shows the predicted groundwater levels under status quo conditions and full development of areas 5 and 6[11]. Statistics describing the change in predicted groundwater levels for all scenarios are provided in Table 4.2. The first scenario of irrigating areas 5 and 6 to the full potential is predicted at x/L = 0.82 (equivalent position of well L37/0024) and at x/L = 0.5. The maximum reduction in predicted groundwater level is greatest at x/L = 0.5, being up to 18.0 m and 9.2 m on average. At x/L = 0.82, the maximum reduction in predicted groundwater level is 7.9 m and 3.9 m on average.

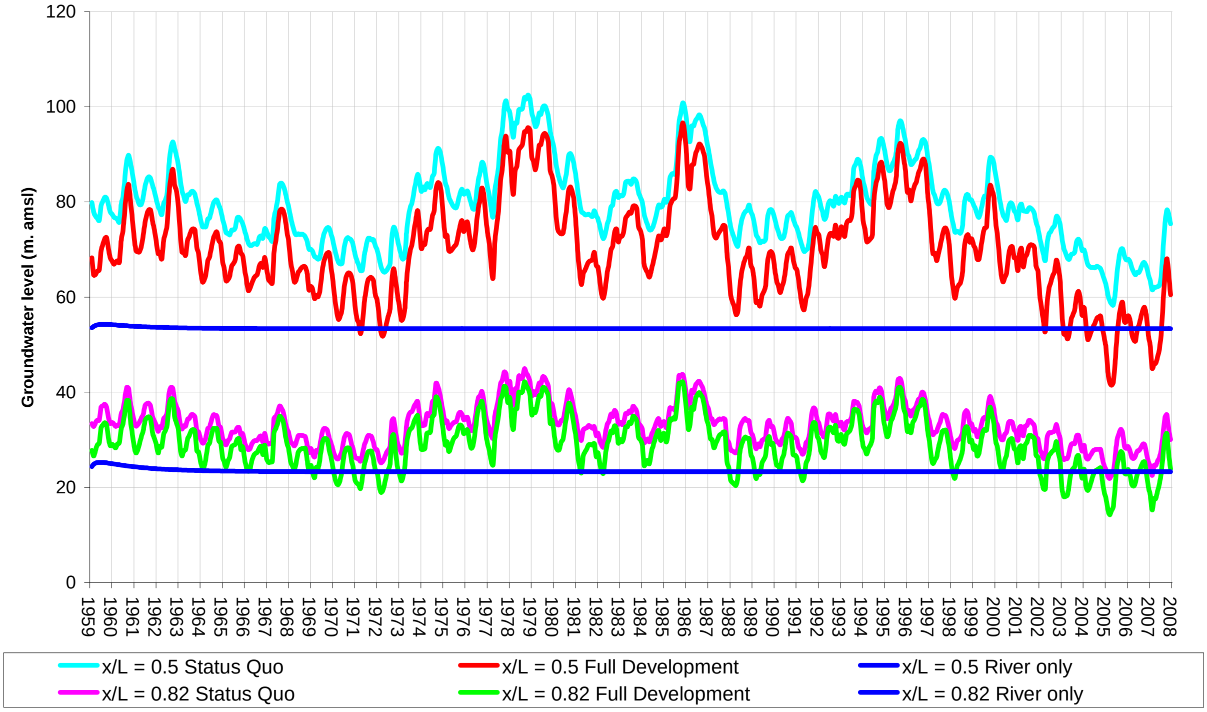

**Figure 4-11 Model prediction at x/L 0.82 (well L37/0024) for a spray development scenario in areas 5 and 6. The predictions at x/L = 0.5 represent cumulative effects in Area 5 and x/L = 0.82 represent cumulative effects in Area 6**

The second scenario looks at potential changes if Area 6 only is fully developed with the irrigated area fraction increasing from 60% to 93% (89% from groundwater to account for South Rakaia Irrigation Scheme). The reduction in predicted groundwater level at x/L = 0.82 is up to a maximum of 2.8 m and 0.9 m on average. At x/L = 0.5, the reduction is up to 2.6 m and 1.4 m on average. These results suggest that the effects of further irrigation development supplied from groundwater are likely to be greatest in Area 5, especially from any further development within that area. The predicted piezometric effects from further development in Area 6 are relatively smaller than development in Area 5, but still affect the up-plains areas.

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[11] The small perturbation at the beginning of the river only plots reflects the initial value in 1960 being slightly above the long-term value.

**Table 4.2 Statistics describing the change in predicted groundwater levels at x/L = 0.82 and 0.5 if irrigation was developed from groundwater to its full potential in areas 5 and 6 (South Rakaia scheme area is excluded from groundwater abstraction). The predictions at x/L = 0.5 represent cumulative effects in Area 5 and x/L = 0.82 represent cumulative effects in Area 6**

| **Scenario** | **Change in predicted groundwater levels (m)** | | | | | |
|---|---|---|---|---|---|---|
| **x/L=0.82** | **min** | **20%ile** | **median** | **average** | **80%ile** | **max** |
| Areas 5 & 6 Fully Irrigated | -1.50 | -2.75 | -3.74 | -3.86 | -4.88 | -7.89 |
| Areas 6 Fully Irrigated | -0.01 | -0.34 | -0.73 | -0.91 | -1.51 | -2.84 |
| **x/L=0.5** | **min** | **20%ile** | **median** | **average** | **80%ile** | **max** |
| Areas 5 & 6 Fully Irrigated | -4.06 | -6.82 | -8.83 | -9.15 | -11.39 | -17.97 |
| Areas 6 Fully Irrigated | -0.17 | -1.07 | -1.39 | -1.42 | -1.77 | -2.64 |

# 5 Conclusions

The major characteristic of groundwater levels is the seasonal cycle driven by LSR. Dryland LSR increases with elevation across the Rakaia-Ashburton Plains and is increased by irrigation. Groundwater abstraction is, however, becoming a significant component in seasonal groundwater level variation.

The distribution of piezometric head across the upper plains area can be interpreted in terms of the combined effects of local river recharge, and spatial variability of hydraulic conductivity and storativity. Local river recharge maintains comparatively elevated piezometric head in the vicinity of the rivers due to surface water recharge. The more laterally extensive presence of elevated piezometric head in shallow bores around the upper Ashburton River may indicate lower hydraulic conductivity material when compared to the distribution of piezometric head in the vicinity of the Rakaia River.

The spatial variations in groundwater level response to the cumulative effects of pumping are believed to reflect anisotropic hydraulic conductivity. However the high vertical hydraulic gradients in some areas of the upper plains may limit the observable response to cumulative pumping effects. Furthermore, the groundwater level response to cumulative pumping in shallow wells near rivers and irrigation schemes appears to be less than the response in deep groundwater levels, probably due to the buffering effect of local recharge sources, vertical hydraulic head gradients and variations in aquifer properties, including hydraulic conductivity and storativity.

It is possible that localised perching may occur in some areas (this would imply the existence of unsaturated conditions below fully saturated zones). If this condition does occur then there may be implications for groundwater management in affected subareas. Further detailed field investigations would be required to establish the presence of unsaturated conditions beneath saturated zones.

The groundwater system is considered to be fully connected in the lower plains area. Therefore abstraction from shallow and deep aquifers across the upper plains will ultimately affect groundwater discharge from the lower plains.

In the Ashburton-Lyndhurst slice, the supply of surface water to the ALIS adds additional recharge to the system and lessens demand from the groundwater system. The eigenmodel was calibrated to well L37/0023 which demonstrated that the piezometric effect (or component) of pumping demand at this well location remains less than the LSR component. This is mostly due to the additional recharge from border-strip irrigation and the relatively lower demand for groundwater since irrigation requirements are largely met from a surface water supply. If the ALIS area was converted to spray irrigation, recharge would decrease and could cause significant reduction in groundwater levels in the vicinity of the ALIS. This could be partially counter-balanced by increasing the area over which the ALIS supplies surface water for irrigation. The predicted changes in groundwater levels due to increasing irrigation from groundwater across Area 3 are significantly less than the changes associated with more efficient irrigation across the ALIS.

The groundwater level records indicate that the pumping demand is primarily from deep groundwater in the Chertsey slice. Well L37/0024, with the longest record, was analysed with a multiple recharge zone version of the eigenmodel. The results demonstrate that the piezometric effect (or component) caused by pumping demand at this well location is likely to have increased in the last decade, having been equivalent to dryland recharge and now being equivalent to irrigated recharge. This change is the result of the climate trend during the last decade causing reduced recharge and the increased irrigation demand. Increasing groundwater-supplied irrigation to full development levels in Area 5 is likely to cause the greater changes in groundwater levels compared with increases in Area 6, although both are likely to affect discharge including to the coast.

# 6 Recommendations for groundwater management

**Further groundwater development**

Scenario testing using the eigenmodel shows that fully developing irrigation from groundwater coastward of about State Highway 1 (Area 3 of the Ashburton-Lyndhurst slice and Area 6 of the Chertsey slice) will have less effect on piezometric head compared with increasing groundwater sourced irrigation development up-plains of about State Highway 1 (in areas 2 and 5). Groundwater abstraction could be increased from the status quo coastward of State Highway 1 on the condition that further irrigation development above about State Highway 1 is primarily sourced from surface water and LSR across the upper-plains area does not decrease significantly from historical volumes, particularly in the Chertsey slice.

**Managed aquifer recharge**

LSR from the ALIS is likely to decrease as more efficient irrigation is developed, and this could cause significant reductions in groundwater levels, particularly within the scheme. To minimise the impact on groundwater levels, reductions in LSR may need to be counter-balanced by increasing the irrigated area supplied from surface water, and/or using managed aquifer recharge (perhaps via Dry Creek and/or injection systems).

**Water use and irrigated area**

Improving water use data collection and developing administrative systems for capturing irrigated areas is crucial to effective management planning and informed decision making. There are significant differences in the irrigated area identified by remote sensing, the areas listed in the Environment Canterbury RMA Database, and those areas identified through land-parcels containing irrigation permits. The uncertainties associated with unused groundwater allocation makes understanding the relationship between volumes allocated and groundwater level response very difficult. The likelihood that unused consented allocation will eventually be used means that effects will also increase even without any further allocation. Overall, there is inadequate information about the spatial distribution of irrigation permits and it is recommended that a geo-spatial accounting system for water allocation be implemented.

**Groundwater levels**

The following are important factors in relation to accessing groundwater in the upper Rakaia-Ashburton Plains:

- Seasonal groundwater amplitude increases in deep bores with distance from the coast;
- Groundwater becomes deeper inland due to natural deep hydraulic gradients;
- There are physical limits on drilling deep production bores;
- Shallow bores in the vicinity of the ALIS rely on recharge from border-strip irrigation.

The seasonal amplitude of groundwater levels is greatest in deep bores across the upper plains. This is reflected in the greater seasonal variation in deep groundwater levels with distance away from the coastal boundary - due to the “hinge” effect.

Available drawdown in deep bores decreases naturally as deep groundwater levels are found at lower levels below land surface with distance from the coast. Furthermore, the depth to which a particular diameter well casing can be driven can constrain the depth to which the larger submersible pumps can be installed below the groundwater level. Near Urrall, well K36/0687 shows the lowest static groundwater level measured, at ~160 m below ground level and the pump is set at 193 m below ground level, leaving approximately 30 m available drawdown. The available drawdown is much less than deep wells further down-plains like L36/1677 (between Winchmore and Rakaia), which has approximately 65 m available drawdown. Therefore the greatest risk of reduced yield due to declining groundwater levels is in deep bores across the upper plains.

Shallow groundwater levels in the vicinity of the ALIS are also prone to decline if more efficient methods replace less efficient irrigation and conveyance. Shallow groundwater users within and downstream of the ALIS are likely to have to drill deeper wells to maintain reliable access to groundwater supplies in the future.

More permanent groundwater level monitoring sites will be needed and an investigation of a trigger level management system could look at options for maintaining piezometric head and protecting well yields.

### Saltwater intrusion

A trigger level system at the coast is recommended if further groundwater development is to occur anywhere in the study area. This could comprise a set of piezometric levels and salinity thresholds that would trigger restrictions if breached.

The existing monitoring bores at the Kyle coastal monitoring site (L37/0693, L37/0867, and L37/1713) are located mid-way between the Rakaia River and Ashburton River where piezometric levels are lowest. These wells penetrate both shallow and deep strata and could be part of a coastal trigger system. However two additional multi-level groundwater monitoring sites part-way between the Kyle coastal site and the Rakaia and Ashburton rivers would enable more complete management of the risk of salt-water intrusion.

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Kathleen Crisley (Groundwater Resources Manager) and Ken Taylor (Director Investigations & Monitoring) have both reviewed and approved the report for publication.

# 8 Reference list

AgriQuality 2006: AgriBase$^{TM}$; AgriQuality Ltd, Palmerston North.

Andreu, J, and A Sahuquillo 1987: Efficient aquifer simulation in complex systems; Journal of Water Resources Planning and Management 113, pp 110-128.

ARANZ (Applied Research Associates New Zealand Ltd) 2009: HYDRO; Geospatial and groundwater modelling software and can be found at the website address: http://www.aranzgeology.com/

Aitchison-Earl, PL 2000: Springs of the Ashburton Catchment; Environment Canterbury technical report U00/25.

Bright, JC 2008: In the matter of the Resource Management Act 1991 and applications for water permits to take and use groundwater in the Valetta and Ashburton groundwater allocation zones; Evidence provided to Environment Canterbury hearing panel.

Davey, G 2006: Definition of the Canterbury Plains Aquifers; Environment Canterbury unpublished technical report U06/10.

Dommisse, J 2005: A review of surface water irrigation schemes in Canterbury. Their development, changes with time & impacts on the groundwater resource; Environment Canterbury unpublished technical report U05/07.

Ministry of Works 1982: Water & Soil Ashburton – Lyndhurst Irrigation Scheme Water Distribution Layout; approved by A. W. Gibson, Director of Water & Soil.

Pairman, D and H North 2009: Detecting and Mapping Irrigation in Canterbury; Landcare Research, Lincoln. Prepared for Environment Canterbury under Landcare Research Contract: LC0910/072.

Sanders, RA 1999: Groundwater in the coastal Ashburton-Rakaia plains area: A recent perspective; Environment Canterbury technical report U99/31.

Scott, D 2004: Groundwater Allocation Limits: land-based recharge estimates; Environment Canterbury unpublished technical report U04/97.

Scott, DM, and HR Thorpe 1986: Ground water resources between the Rakaia and Ashburton Rivers; Publication No 6, Hydrology Centre, Christchurch.

Weir, J 2009: Supplementary Evidence for Central Plains Water Hearing Resumption October 2009.

Williams, H, Scott, DM, and VJ Bidwell 2008: Adaptive management of groundwater in the Rakaia-Selwyn Groundwater Zone: technical and implementation issues; Environment Canterbury technical report R08/64.

# Appendix 1 – Estimation of ALIS LSR

This appendix describes the method developed to estimate the history of land-surface recharge (LSR) over the period January 1960 to April 2009 for the Ashburton-Lyndhurst Irrigation Scheme (ALIS) and adjacent area (i.e. the area shown as Area 2 in Figure 2-9). The method is an adaptation of the simple soil-moisture budget modelling used to estimate LSR elsewhere in the Rakaia-Ashburton Plains. Two factors require this more complex analysis:

- the range of irrigation methods now employed within the ALIS which requires simulation of alternative irrigation strategies, and
- the availability of some ALIS water delivery data which has been used to constrain the extent to which climate driven irrigation demand is able to be met[12].

The ALIS is able to supply water to a substantial proportion (~ 80%) of Area 2 (see Figure 2-10). The extent and type of irrigation within the area has changed over time with a progression from the initial border-strip irrigation to spray irrigation, sometimes with supplementary use of groundwater. The following four water-use strategies have been adopted to represent this range:

- **dryland** (i.e. unirrigated),
- **border** (fixed application depth of 130 mm, 21-day water supply roster, daily application constrained by recorded water use data),
- **spray** (supplied from ALIS, variable application depth, irrigation applied to restore soil moisture to field capacity when deficit reaches 50% of profile available water (PAW), irrigation efficiency of 80%, daily application constrained by recorded water use data), and
- **supplementary spray** (as for spray, but pumped from groundwater and thus without the constraint imposed by recorded water use).

Eleven separate water budget calculations have been carried out for Area 2 – nine representing sub-areas within the ALIS and two representing the balance of the area as shown in Figure 2-10. The codes used to identify the sub-areas and the corresponding areas are tabulated in Table A1-1.

**Table A1-1 Details of ALIS sub-areas**

| Code | Description | Area (ha) |
|---|---|---|
| 0 | Area upslope of ALIS | 6000 |
| 1 | Lateral 1 | 1822 |
| 2 | Lateral 2 | 1464 |
| 3 | Lateral 3 | 2423 |
| 4a | Lateral 4a | 4008 |
| 4b | Lateral 4b | 4438 |
| 5 | Lateral 5 | 1528 |
| 6 | Lateral 6 | 4997 |
| 7&8 | Laterals 7 & 8 | 2350 |
| 9&10&11 | Laterals 9, 10 & 11 | 2911 |
| 99 | Area down slope of ALIS | 3732 |

The dryland and spray strategies have been simulated using the same algorithm as applied to the other five areas in the Rakaia-Ashburton Plains (areas 1, 3, 4, 5 & 6 in Figure 2-9) following the approach described by Scott (2004). The one exception is the way in which ALIS water use data is applied in the simulation – on those days when the recorded water use (as inferred from delivery records) has been less than the simulated total demand the application depth for the spray strategy has been reduced on a pro-rata basis. The reduction has not been applied for the supplementary spray component since that is independent of the ALIS supply.

The border strategy differs from the spray strategies in two significant ways. A fixed application depth is applied if the soil moisture deficit exceeds 50% of (PAW) and if the roster makes water available. A pro-rata reduction is applied to the border application on those days when the recorded water use has

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[12] Measured (or estimated) bywash flows have been subtracted from ALIS water delivery data and a conveyance loss of 20% assumed to generate an estimate of water available within the scheme on a daily basis.

been less than the simulated total demand, in the same way as applied to ALIS supplied spray irrigation. To take account of the rostered nature of the water supply each of the sub-areas within the ALIS has been sub-divided into 21 equal sub-sub-areas each with their own water budgets and roster day. The FORTRAN code developed to undertake the recharge calculations for dryland, spray and border irrigation is listed in Table A1-2.

The history of irrigation development for each of the sub-areas listed in Table A1-1 has been described by specifying, on an annual basis, the proportion of each sub-area which had been developed for irrigation and the relative proportions developed for spray and for supplementary spray. These proportions have been estimated by considering the current status and the time periods over which particular irrigation upgrades were in train. The resulting time profiles of development of the different categories of irrigation are shown in Figures A1-1 to A1-11.

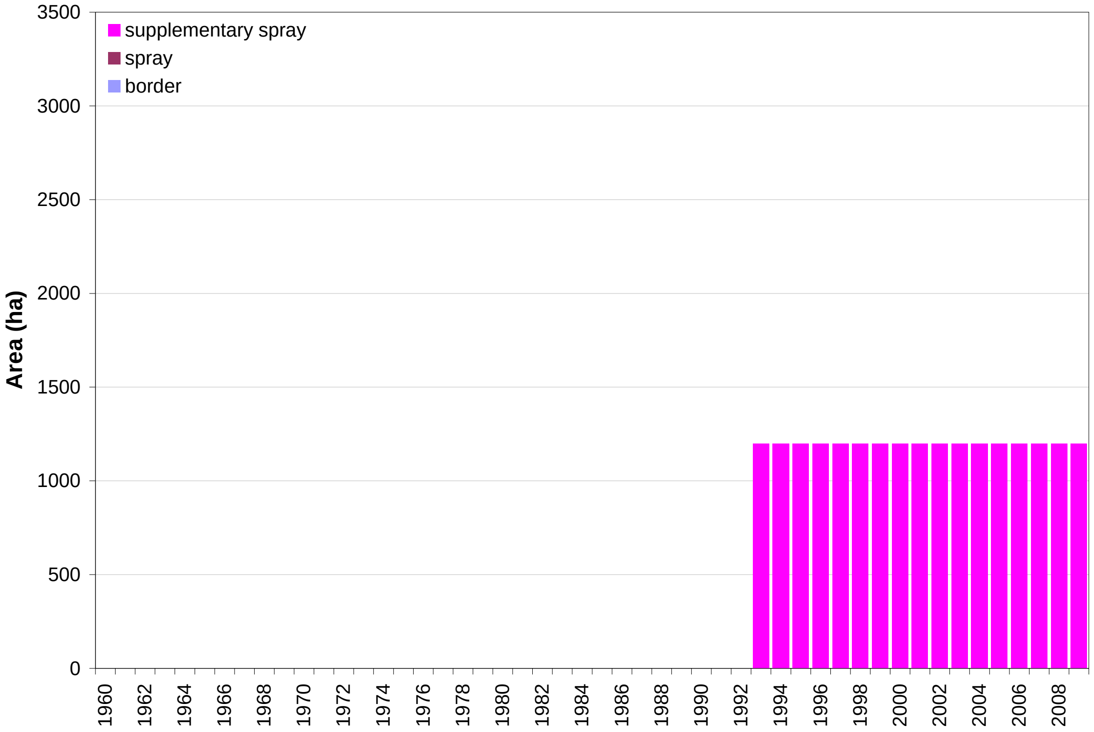

**Figure A1-1 Estimated development of irrigation for sub-area 0**

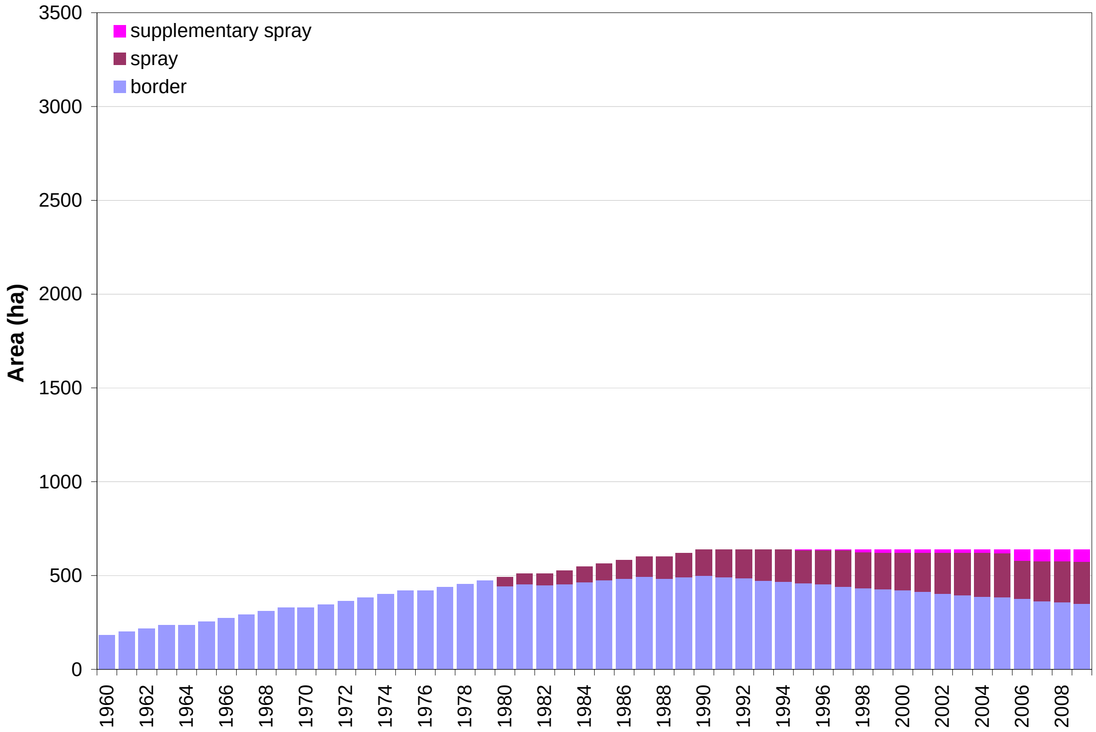

**Figure A1- 2 Estimated development of irrigation for sub-area 1**

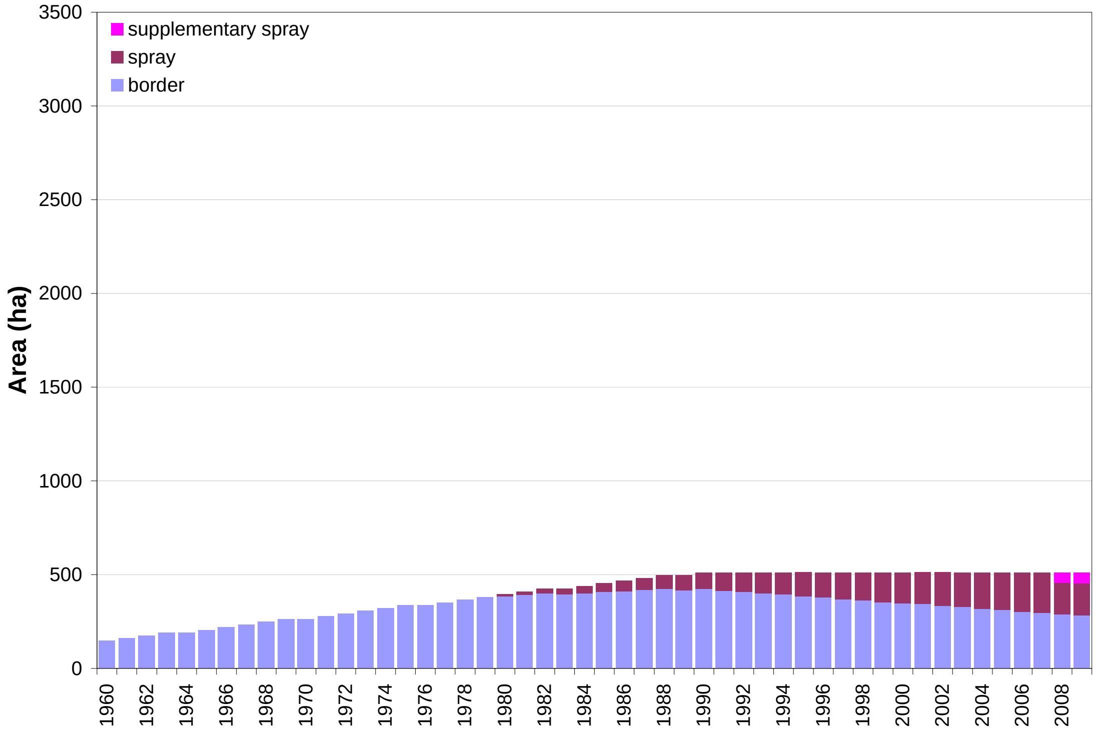

**Figure A1- 3 Estimated development of irrigation for sub-area 2**

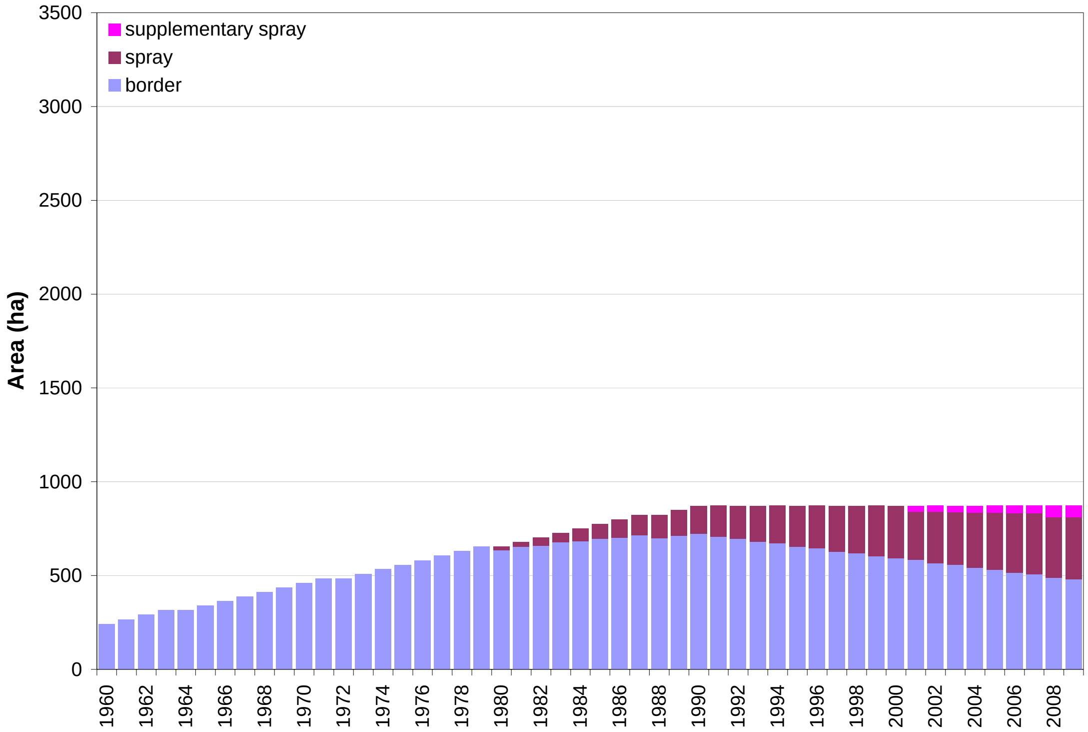

**Figure A1- 4 Estimated development of irrigation for sub-area 3**

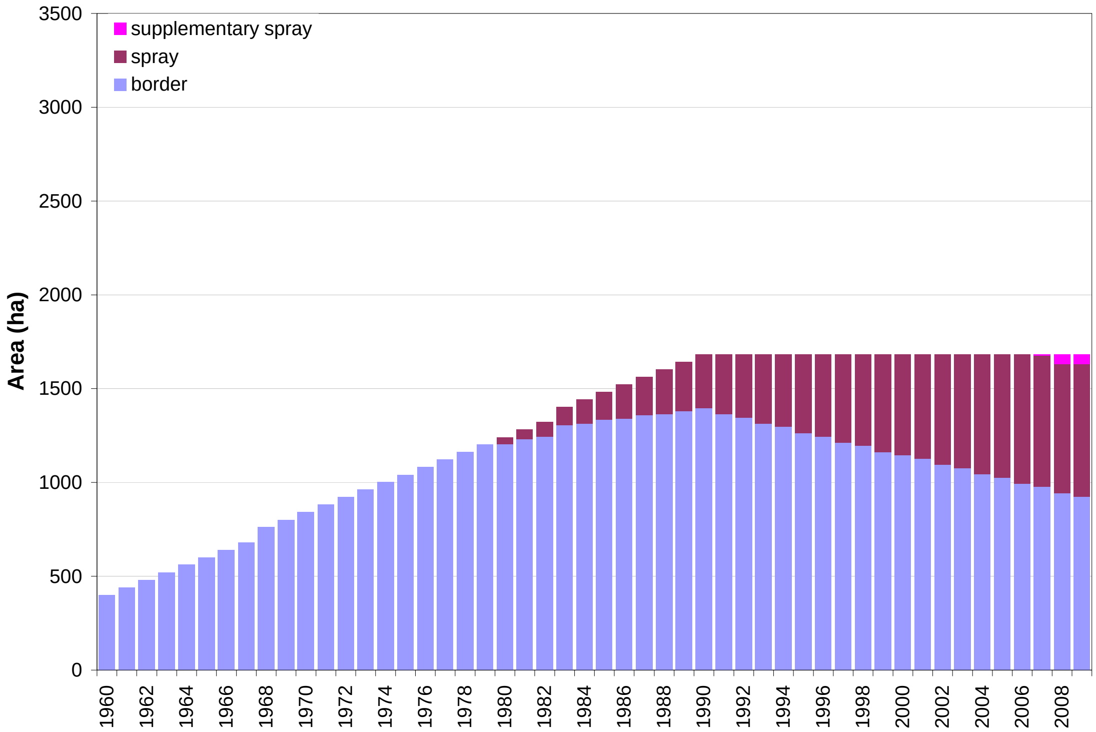

**Figure A1- 5 Estimated development of irrigation for sub-area 4a**

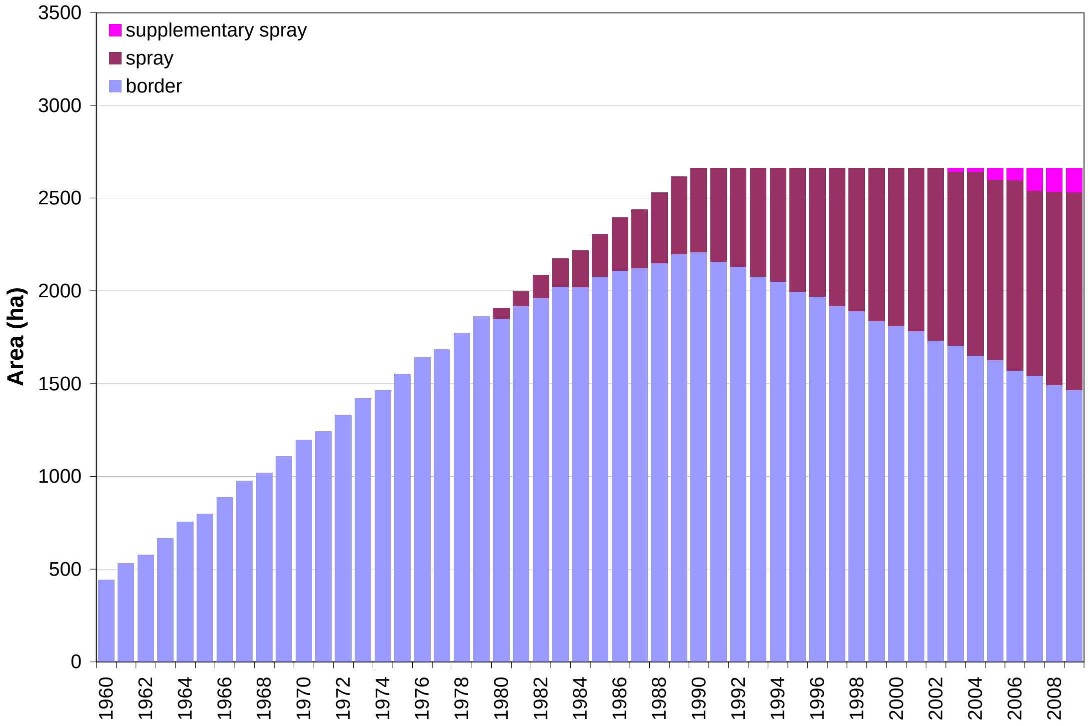

**Figure A1- 6  Estimated development of irrigation for sub-area 4b**

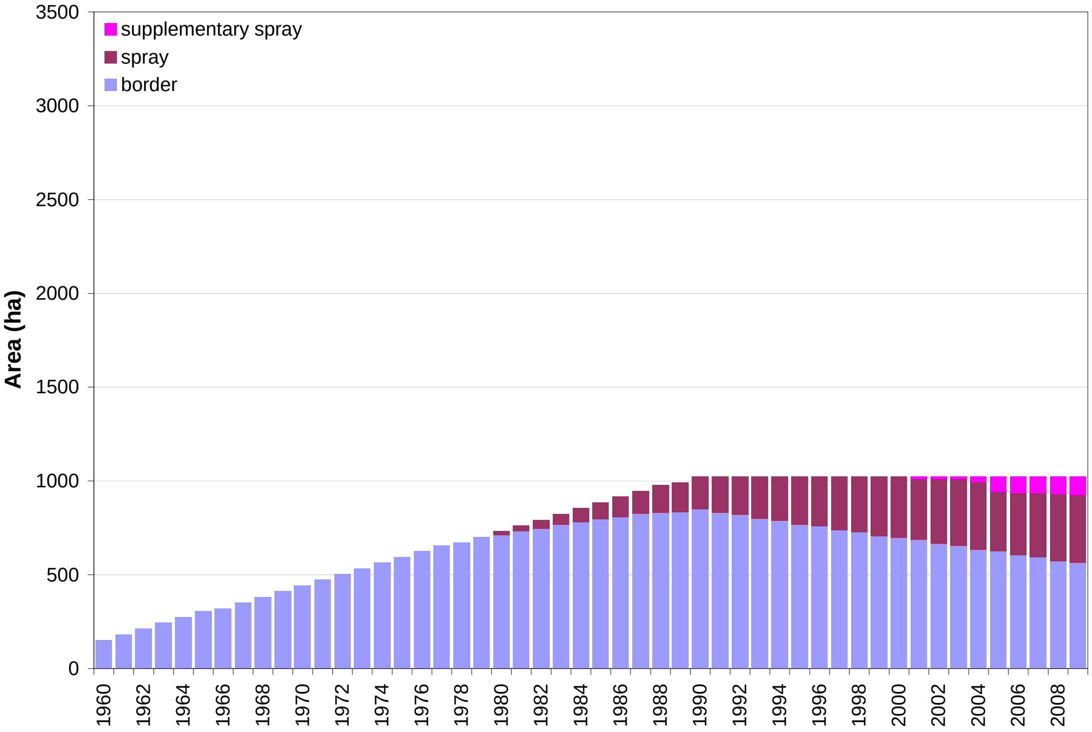

**Figure A1- 7  Estimated development of irrigation for sub-area 5**

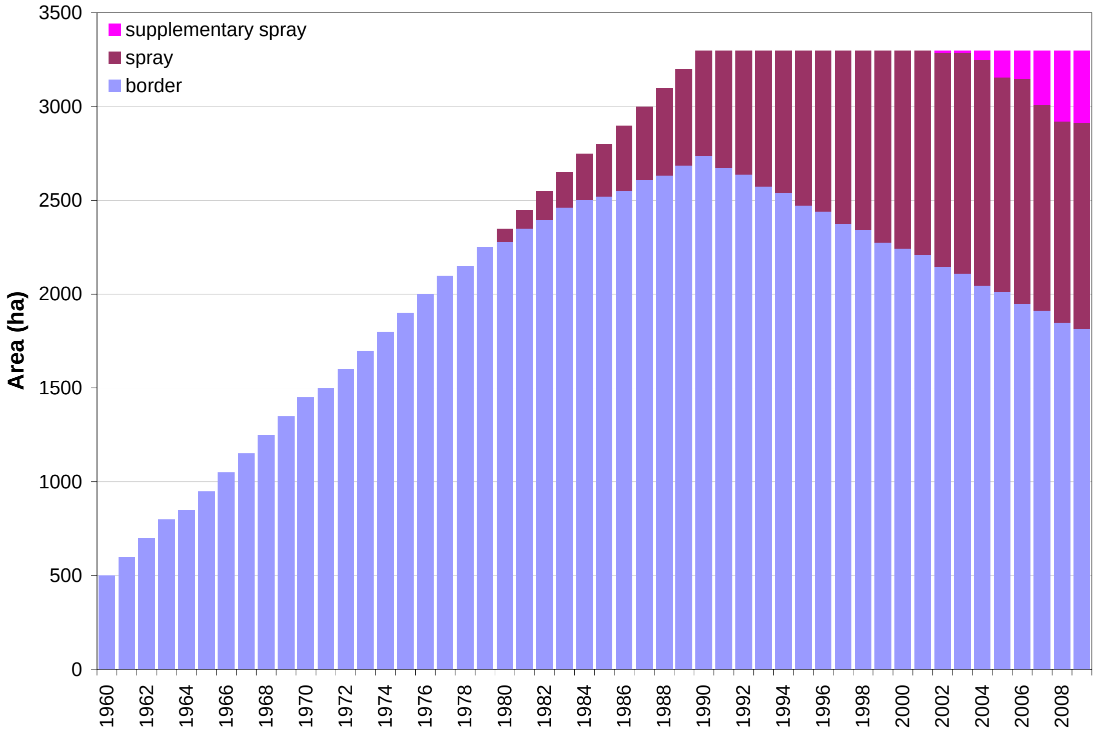

**Figure A1- 8 Estimated development of irrigation for sub-area 6**

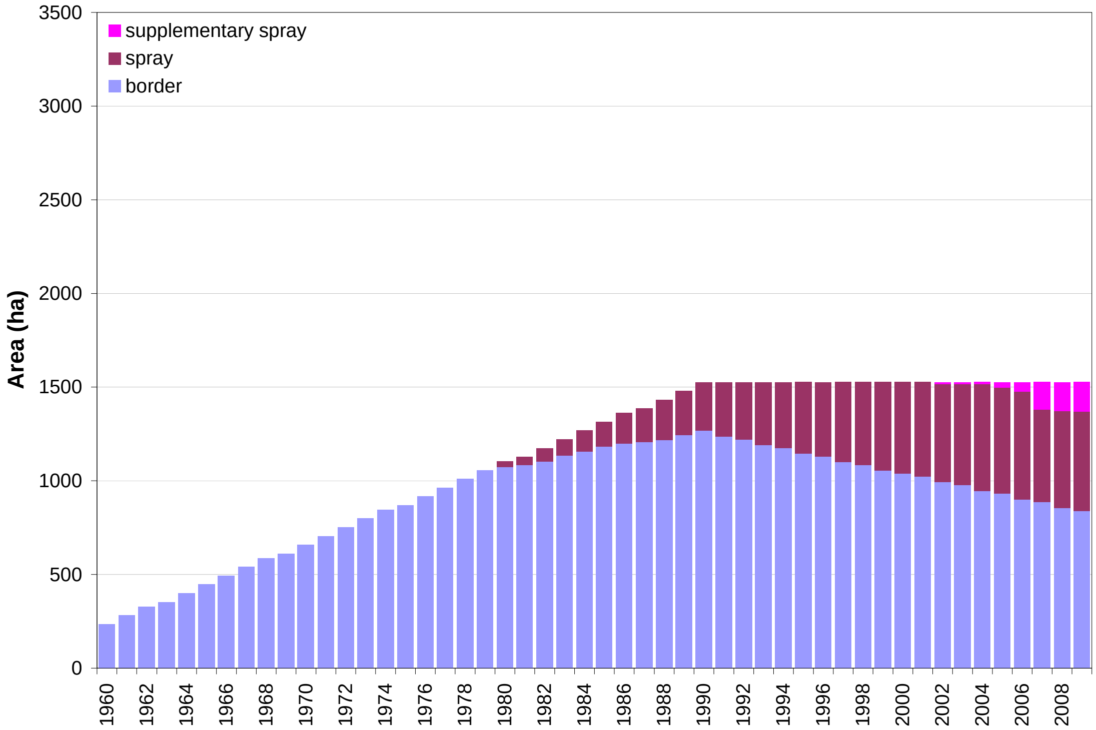

**Figure A1- 9 Estimated development of irrigation for sub-area 7 & 8**

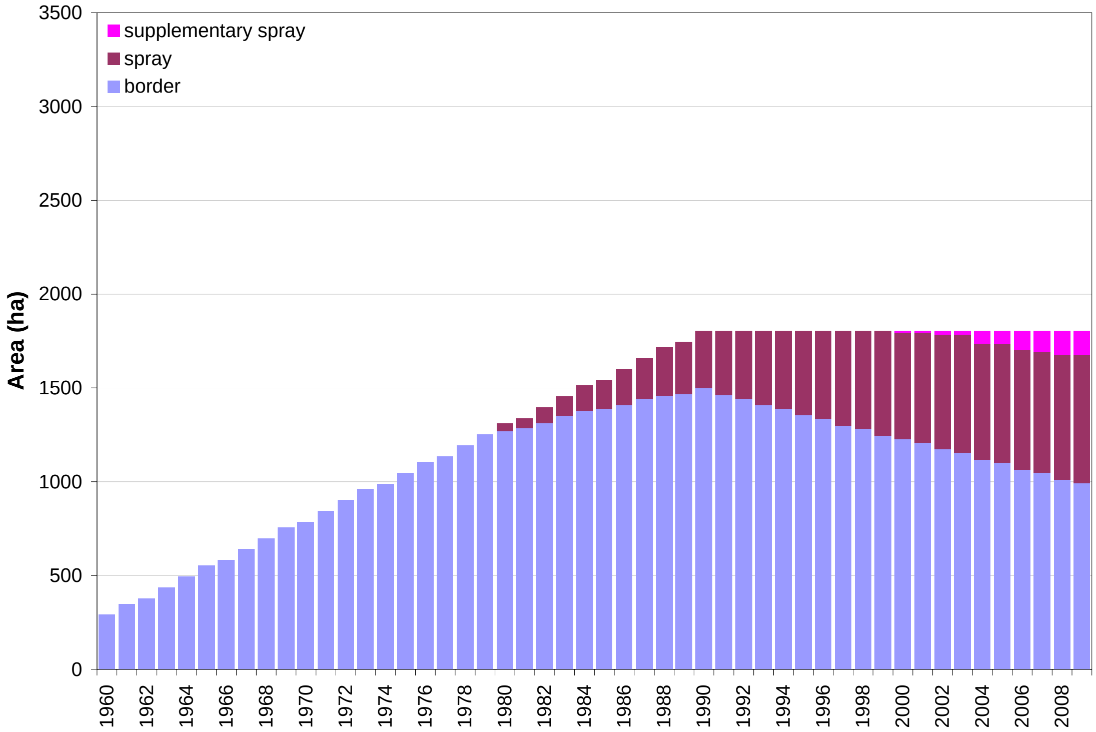

**Figure A1- 10** Estimated development of irrigation for sub-area 9, 10 & 11

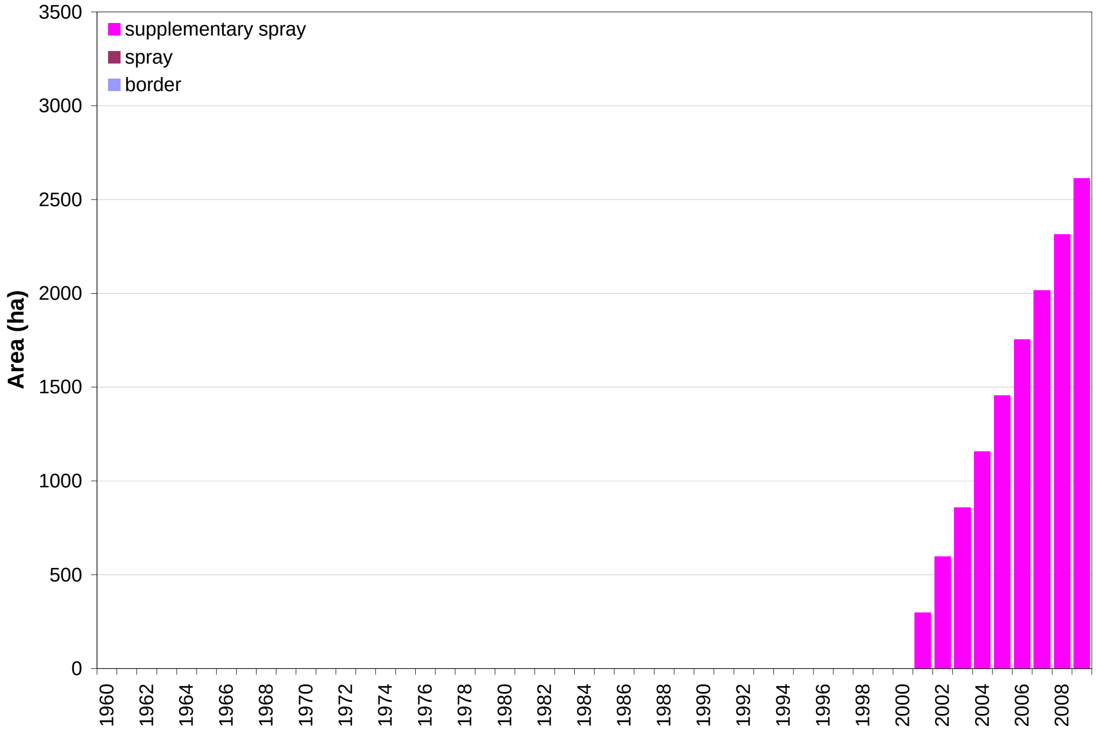

**Figure A1- 11** Estimated development of irrigation for sub-area 99

## Table A1-2 FORTRAN source code for LSR calculation

```
c     Multiple irrigation type version for ALIS analysis
c     Changes:
c     - add representation of border-dyke including a return period & sub-areas

c     This is an adaptation of the soil moisture budget method that was applied to the calculation of
c     the land-surface recharge figures used to establish interim allocation limits for groundwater
c     allocation zones (as described in Environment Canterbury report U04/97).
c
c     It has been adapted to be used for the periodic update of monthly recharge totals and assumes
c     the following:
c     - the program will be run within a folder containing the following files:
c           coords.prn (defines the location of the NIWA virtual climate sites)
c           grid_cell.prn (defines the soil property, location and sub-area for grid cells within the zone of interest)
c     - daily rainfall and pet will be read from files stored in O:\Data\NIWA Virtual Climate Station Network\Virtual Climate
data\
c     - for the period prior to 1972 daily pet will be estimated from the average monthly totals calculated for 1972 to July
2007
c           stored in O:\Data\NIWA Virtual Climate Station Network\Analysis\Mean PET\

      implicit real*8 (a-h,o-z)
      dimension    rain_t(1200), drain_dry_t(1200), drain_irr_t(1200),
     *             drain_border_t(1200), w_border(100,30),
     *             demand_irr_t(1200), demand_border_t(1200),
     *             develop(50,100,3), rain(50), pet(50), paw(100),
     *             area(100), w_rain(100), w_irrig(100), w_suppl(100),
     *             drain_suppl(100), drain_suppl_t(1200),
     *             demand_suppl_t(1200), conv_loss_t(1200)
      integer      year, month, day, year_old, month_old, month_num(12),
     *             jsite(50), ksite(50), index_site(50), id(100)
      character*80 line, data_directory, pet_directory, file_in
      character*7  climate
      real*8       lat, long, month_pet(50,12)
      integer*4    date, dates(1200), return_period, roster_day,
     *             flow_date
      logical      irrig, exists, first, no_restriction

      data month_num/31,28,31,30,31,30,31,31,30,31,30,31/
      data_directory = "O:\Data\NIWA Virtual Climate Station Network\Vir
     *tual Climate data\"
      pet_directory  = "O:\Data\NIWA Virtual Climate Station Network\Ana
     *lysis\Mean PET\"

      write(*,*) '**************************************************'
      write(*,*) 'Multiple irrigation type version for ALIS analysis'
      write(*,*) '**************************************************'
      return_period  = 21
      appl_border    = 130.0
      eff_spray      = 0.8
      eff_border     = 1.0
      roster_day     = 0
      flow_threshold = 1.0

      open(7,'debug7.out')
      write(7,*) 'date, flow_rec, total_demand, ration'

      open(8,'debug8.out')
      write(8,*) 'date, i, w_rain, w_irrig, w_suppl, mnth, rain_t'

c.......clear monthly recharge arrays
      do i = 1,1200
         dates(i)           = 0
         rain_t(i)          = 0.0
         drain_dry_t(i)     = 0.0
         drain_irr_t(i)     = 0.0
         drain_border_t(i)  = 0.0
         drain_suppl_t(i)   = 0.0
         demand_irr_t(i)    = 0.0
         demand_border_t(i) = 0.0
         demand_suppl_t(i)  = 0.0
         conv_loss_t(i)     = 0.0
      end do
      total_area = 0.0
      mnth_max   = 0

c.......read development history
      open(10,'development.prn',action='read')
      read(10,*) ncell
      if(ncell .gt. 100) then
         write(*,*) 'ncell > 100'
         go to 50
      endif
      do i = 1,50
         read(10,*) iyear, (develop(i,j,1),j=1,ncell)       ! proportion irrigated
         read(10,*) iyear, (develop(i,j,2),j=1,ncell)       ! proportion irrigated in spray
         read(10,*) iyear, (develop(i,j,3),j=1,ncell)       ! proportion spray with supplemental supply
      end do
      close(10)
      write(*,*) 'Development history read for ', ncell, ' units'

c.......read the grid cell details & relate to climate records
      num_sites = 0
      open(10,'input_areas.prn',action='read')
      read(10,*) line
      do n = 1,ncell
         read(10,*,end=40) id(n), paw(n), x0, y0, area(n)
         paw(n)     = 0.67*paw(n)                           ! limit paw to 2/3rds PAWavg value
```

```
         total_area = total_area + area(n)

c.......identify closest synthetic climate station (file 11)
         j0 = 0
         k0 = 0
         open(9,'coords.prn',action='read')
         distance = 1e12
   10    read(9,*,end=20) x, y, j, k
         write(climate,22) j, k
         file_in = charnb(data_directory)//charnb(climate)//'.lst'
c         file_in = charnb(climate)//'.lst'
         inquire(file=file_in,exist=exists)
         if( .not. exists ) go to 10
         r = ((x - x0)/1000.0)**2 + ((y - y0)/1000.0)**2
         if(r .lt. distance) then
            distance = r
            j0       = j
            k0       = k
         endif
         go to 10
   20    close(9)
         if(j0 .eq. 0 .or. k0 .eq. 0) then                  ! no station identified
            write(*,*) 'No climate station for unit ', id(n)
            go to 50
         endif
         if(num_sites .gt. 0) then                          ! look to see if station has already been selected
            do i = 1,num_sites
               if(j0 .eq. jsite(i) .and. k0 .eq. ksite(i)) then                 ! use already selected station
                  index_site(n) = i
                  go to 21
               endif
            end do
         endif
         num_sites = num_sites + 1                          ! assign new station
         if(num_sites .gt. 50) then
            write(*,*) 'num_sites > 50'
            go to 50
         endif
         jsite(num_sites) = j0
         ksite(num_sites) = k0
         index_site(n)    = num_sites
   21    write(*,23) n, id(n), paw(n), x0, y0, area(n), index_site(n),
     *              jsite(index_site(n)), ksite(index_site(n))
   23    format(2i5,f5.1,3f10.0,3i5)

c..........open climate station record (unit_no = num_sites)
         write(climate,22) j0, k0
   22    format('P',2i3.3)
         file_in = charnb(data_directory)//charnb(climate)//'.lst'
c         file_in = charnb(climate)//'.lst'
         nunit = 10 + num_sites
         open(nunit,charnb(file_in),status='old',action='read')

c..........read average monthly pet values - to use prior to 1972
         file_in = charnb(pet_directory)//charnb(climate)//'.pet'
c         file_in = charnb(climate)//'.pet'
         open(9,charnb(file_in),status='old',action='read')
         do i = 1,12
            read(9,*) month_pet(num_sites,i)
         end do
         close(9)
      end do

   40 write(*,*) 'Details input for ', ncell, ' areas'
      write(*,*) num_sites, ' climate sites identified'

c........initialise parameters
      do i = 1,ncell
         w_rain(i)  = paw(i)
         w_irrig(i) = paw(i)
         w_suppl(i) = paw(i)
         do j = 1,return_period
            w_border(i,j) = paw(i)
         end do
      end do
      mnth      = 1
      year_old  = 0
      month_old = 0
      open(10,'use_data.prn',action='read')
      write(*,*) 'use_data.prn opened'

c.......now do the water budget calculations

c.......first load the daily climate data from the selected num_sites
   31 do i = 1,num_sites
         nunit = 10 + i
         read(nunit,32,end=45) line
   32    format(a)
         read(line(11:80),*) lat, long, date
         year  = date/10000
         month = (date - 10000*year)/100
         day   = date - 10000*year - 100*month

         if(year .lt. 1972) then
            read(line(11:80),*) lat, long, date, rain(i)
            if(month .eq. 2 .and. mod(year,4) .eq. 0) then
               pet(i) = month_pet(i,month)/29
            else
               pet(i) = month_pet(i,month)/month_num(month)
            endif
         else
```

```
            read(line(11:80),*) lat, long, date, rain(i), pet(i)
         endif

         rain(i) = 1.1*rain(i)                              ! apply ground-level gauge correction
         if(pet(i) .lt. 0.0) then
            pet(i) = 0.0                                    ! correct negative pet estimates
         end if
      end do

      if(month .eq. 10 .and. day .eq. 1) then               ! reset day count for border roster
         roster_day = 0
      endif

      if(month .ge. 5 .and. month .le. 9) then              ! irrigation season october thru april
         irrig = .false.
      else
         irrig = .true.
         roster_day = roster_day + 1
         if(roster_day .gt. return_period) then             ! reset to 1
            roster_day = 1
         endif
      endif

      if(day .eq. 1) then                                   ! start a new month
         dates(mnth) = 100*year_old + month_old             ! store year/month date
         year_old    = year
         month_old   = month
         mnth        = mnth + 1
         if(mnth .gt. 1200) then
            write(*,*) 'month count exceeds 1200'
            go to 50
         endif
      endif

c.......read daily flow record
      read(10,*,end=2) flow_date, flow_rec, conv_loss
      go to 3
    2 write(*,*) 'premature end of flow record'
      go to 50

    3 continue

c.......assess demand for the day
      total_demand = 0.0
      do i = 1,ncell

c........area unit irrigation details
         j              = year - 1959
         irrigated_area = develop(j,i,1)*area(i)
         spray_area     = develop(j,i,2)*irrigated_area
         suppl_area     = develop(j,i,3)*spray_area
         border_area    = irrigated_area - spray_area
         dry_area       = area(i) - irrigated_area
         sub_area       = border_area/real(return_period)

c........generic (spray)
         appl = 0.0
         if( irrig ) then
            if(w_irrig(i) .lt. 0.5*paw(i)) then
               appl = (paw(i) - w_irrig(i))/eff_spray       ! appl to restore to field capacity with eff_spray efficiency
            endif
         endif
         total_demand = total_demand +
     *                  appl*(spray_area - suppl_area)/1000.0

c........border irrigation
         do j = 1,return_period
            appl = 0.0
            if( irrig .and. j .eq. roster_day) then
               if(w_border(i,j) .lt. 0.5*paw(i)) then
                  appl = appl_border/eff_border             ! appl of fixed depth with eff_border efficiency
               endif
            endif
            total_demand = total_demand + appl*sub_area/1000.0
         end do
      end do

      ration = 1.0
      if(total_demand .gt. 0.0) then
         ration = flow_rec*86400.0/total_demand             ! daily inflow in cubic metres/total_demand
         if(ration .gt. 1.0) then
            ration = 1.0
         endif
      endif
      write(7,*) date, flow_rec, total_demand, ration

      do i = 1,ncell

c.......irrigation details
         j              = year - 1959
         irrigated_area = develop(j,i,1)*area(i)
         spray_area     = develop(j,i,2)*irrigated_area
         suppl_area     = develop(j,i,3)*spray_area
         border_area    = irrigated_area - spray_area
         dry_area       = area(i) - irrigated_area
         sub_area       = border_area/real(return_period)

         rain_t(mnth)   = rain_t(mnth) + rain(i)*area(i)/1000.0       ! volume in cubic metres

c........dryland
         appl = 0.0                                                   ! zero application depth for dryland option
```

```
         call budget(paw(i),rain(i),pet(i),aet,w_rain(i),appl,drainage)
         drain_dry_t(mnth) = drain_dry_t(mnth) +
     *                       drainage*dry_area/1000.0

c........supplementary spray
         appl = 0.0
         if( irrig ) then
            if(w_suppl(i) .lt. 0.5*paw(i)) then
               appl = (paw(i) - w_suppl(i))/eff_spray       ! appl to restore to field capacity with eff_spray efficiency
            endif
         endif
         call budget(paw(i),rain(i),pet(i),aet,w_suppl(i),appl,drainage)
         drain_suppl_t(mnth)  = drain_suppl_t(mnth) +
     *                          drainage*suppl_area/1000.0
         demand_suppl_t(mnth) = demand_suppl_t(mnth) +
     *                          appl*suppl_area/1000.0
         appl_supl = appl

c........generic (spray)
         appl = 0.0
         if( irrig ) then
            if(w_irrig(i) .lt. 0.5*paw(i)) then
               appl = (paw(i) - w_irrig(i))/eff_spray       ! appl to restore to field capacity with eff_spray efficiency
            endif
         endif
         call budget(paw(i),rain(i),pet(i),aet,w_irrig(i),appl,drainage)
         drain_irr_t(mnth)  = drain_irr_t(mnth) +
     *                        ration*drainage*(spray_area - suppl_area)/
     *                        1000.0
         demand_irr_t(mnth) = demand_irr_t(mnth) +
     *                        ration*appl*(spray_area -  suppl_area)/
     *                        1000.0
         appl_spray = appl

c........border irrigation
         do j = 1,return_period
            appl = 0.0
            if( irrig .and. j .eq. roster_day) then
               if(w_border(i,j) .lt. 0.5*paw(i)) then
                  appl = appl_border/eff_border             ! appl of fixed depth with eff_border efficiency
               endif
            endif
            call budget(paw(i),rain(i),pet(i),aet,w_border(i,j),appl,
     *                  drainage)
            drain_border_t(mnth)  = drain_border_t(mnth) +
     *                              ration*drainage*sub_area/1000.0
            demand_border_t(mnth) = demand_border_t(mnth) +
     *                              ration*appl*sub_area/1000.0
         end do
         write(8,4) date, i, w_rain(i), w_irrig(i), w_suppl(i), mnth,
     *              rain_t(mnth)
    4    format(i10,i5,3f8.2,i5,f12.0)
       end do

c........conveyance loss
       conv_loss_t(mnth) = conv_loss_t(mnth) + conv_loss*86400.0

      go to 31

c........write the monthly recharge series
   45 write(*,*) 'total area = ', total_area
      open(14,'recharge.csv')
      write(14,*) 'date, rain, drain_dry, demand_irr, drain_irr, demand
     *_border, drain_border, demand_suppl, drain_suppl, conv_loss'
      write(*,*) mnth_max
      do i = 1,1200
         write(14,41) dates(i), rain_t(i), drain_dry_t(i),
     *                demand_irr_t(i), drain_irr_t(i),
     *                demand_border_t(i), drain_border_t(i),
     *                demand_suppl_t(i), drain_suppl_t(i),
     *                conv_loss_t(i)
   41    format(i6,9(',',g12.6))
      end do

   50 stop
      end

      subroutine budget(paw,rain,pet,aet,w,appl,drainage)
      implicit real*8 (a-h,o-z)
      a        = 6.0                                        ! constant in aet/pet vs w/paw relationship
      smfac    = (1.0 - exp(-a*w/paw))/
     *           (1.0 - 2.0*exp(-a) + exp(-a*w/paw))
      aet      = smfac*pet
      w        = w + rain + appl - aet
      drainage = 0.0
      if(w .gt. paw) then
         drainage = w - paw
         w        = paw
      elseif(w .lt. 0.0) then
         w = 0.0
      endif
c      write(14,*) paw, rain, pet, w, appl, drainage
      return
      end
```

# Appendix 2 – Groundwater level data

| Well | Well Head Altitude | Well Depth Altitude | Average GWL Altitude | Standard Deviation |
|---|---|---|---|---|
| L37/0867 | 19.19 | -10.81 | 2.12 | 0.65 |
| L37/0693 | 19.22 | -60.78 | 4.02 | 0.95 |
| L37/0302 | 31.00 | 19.42 | 20.65 | 1.92 |
| L37/0388 | 32.00 | -13.00 | 22.02 | 1.51 |
| L37/0023 | 35.09 | 0.09 | 19.17 | 1.73 |
| L37/0022 | 45.43 | -18.07 | 14.89 | 2.36 |
| L37/0832 | 45.70 | 24.40 | 31.28 | 2.30 |
| L37/0415 | 48.03 | 18.03 | 23.31 | 2.26 |
| L37/0828 | 53.43 | 26.43 | 28.45 | 1.40 |
| L37/0070 | 60.00 | 11.00 | 27.44 | 3.40 |
| L37/1015 | 64.00 | 34.00 | 35.37 | 1.41 |
| L37/0025 | 66.00 | 29.31 | 45.76 | 2.76 |
| K37/0146 | 83.69 | 77.60 | 80.46 | 0.46 |
| L36/0633 | 85.00 | 44.00 | 56.98 | 1.67 |
| L36/0632 | 85.00 | 70.00 | 81.35 | 0.30 |
| L37/0016 | 85.80 | 14.20 | 36.77 | 2.41 |
| L37/0274 | 91.00 | 60.52 | 62.17 | 0.66 |
| L37/0024 | 91.10 | 20.86 | 34.87 | 4.63 |
| K37/0028 | 92.73 | 87.62 | 89.59 | 0.32 |
| L37/0021 | 93.00 | 21.00 | 47.56 | 3.55 |
| K37/0170 | 99.45 | 96.89 | 98.14 | 0.39 |
| L37/0403 | 104.00 | 66.21 | 94.80 | 1.46 |
| L36/0947 | 109.36 | 90.16 | 100.39 | 0.17 |
| K37/1424 | 110.97 | 105.97 | 108.56 | 1.28 |
| L36/1338 | 115.00 | -41.00 | 43.75 | 4.55 |
| L36/1339 | 115.00 | -19.50 | 42.66 | 4.24 |
| L36/1340 | 115.00 | 29.70 | 39.30 | 3.35 |
| L37/0173 | 116.00 | 46.20 | 69.96 | 3.49 |
| L36/1191 | 118.00 | -86.70 | 46.00 | 4.46 |
| K37/0398 | 119.00 | 111.10 | 116.02 | 1.50 |
| K37/0396 | 121.18 | 110.68 | 117.35 | 0.80 |
| K37/0131 | 122.00 | 119.66 | 120.84 | 0.22 |
| K37/0209 | 128.10 | 119.43 | 124.42 | 0.81 |
| L37/0831 | 146.00 | 115.00 | 117.33 | 1.14 |
| K37/0132 | 147.00 | 142.00 | 144.29 | 0.64 |
| L36/1360 | 149.30 | 118.30 | 119.49 | 0.39 |
| K37/0010 | 152.00 | 123.35 | 132.20 | 2.65 |
| K37/0213 | 159.02 | 156.11 | 157.78 | 0.09 |
| K37/0133 | 160.31 | 154.22 | 157.18 | 0.56 |
| L36/0948 | 161.00 | 94.55 | 114.00 | 2.24 |

| Well | Well Head Altitude | Well Depth Altitude | Average GWL Altitude | Standard Deviation |
|---|---|---|---|---|
| L36/1677 | 161.30 | -28.70 | 78.49 | 2.39 |
| K36/0041 | 167.00 | 162.20 | 165.19 | 0.77 |
| K36/0039 | 167.34 | 161.25 | 164.47 | 0.54 |
| K36/0040 | 175.00 | 172.00 | 172.86 | 0.82 |
| K36/0497 | 176.70 | 151.70 | 153.84 | 0.72 |
| K36/0042 | 188.64 | 182.30 | 185.56 | 0.47 |
| K36/0106 | 193.20 | 175.22 | 185.12 | 1.83 |
| K36/0043 | 210.36 | 202.36 | 207.89 | 0.18 |
| K36/0439 | 223.00 | -7.00 | 96.94 | 4.02 |
| K36/0495 | 223.00 | 28.00 | 108.79 | 4.36 |
| K36/0494 | 223.00 | 51.00 | 111.98 | 4.33 |
| K36/0493 | 223.00 | 91.00 | 123.86 | 4.60 |
| K36/0044 | 234.00 | 229.16 | 232.37 | 0.29 |
| K36/0278 | 251.00 | 217.00 | 222.27 | 1.08 |
| K36/0516 | 256.00 | 238.50 | 249.23 | 1.37 |
| K36/0519 | 262.00 | 231.52 | 233.95 | 0.63 |
| K36/0001 | 265.00 | 250.37 | 256.79 | 1.38 |
| K36/0045 | 274.00 | 262.50 | 268.78 | 1.28 |
| K36/0090 | 288.00 | 253.25 | 276.57 | 3.89 |
| K36/0009 | 288.50 | 270.22 | 277.77 | 2.34 |
| K36/0046 | 289.00 | 280.42 | 284.18 | 1.88 |
| K36/0031 | 294.30 | 289.66 | 291.82 | 0.26 |
| K36/0032 | 307.96 | 306.42 | 307.56 | 0.22 |
| K36/0033 | 309.00 | 300.77 | 302.53 | 1.18 |
| K36/0270 | 312.00 | 302.90 | 304.72 | 1.67 |
| K36/0047 | 312.00 | 303.10 | 307.23 | 1.89 |
| K36/0049 | 314.00 | 306.70 | 310.70 | 1.76 |
| K36/0067 | 319.09 | 300.49 | 308.42 | 2.69 |
| K36/0269 | 320.96 | 311.96 | 313.04 | 1.63 |
| K36/0271 | 321.00 | 311.00 | 314.48 | 1.64 |
| K36/0048 | 321.00 | 313.00 | 316.60 | 1.64 |
| K36/0698 | 321.40 | -10.67 | 124.04 | 12.67 |
| K36/0034 | 331.86 | 308.10 | 320.85 | 2.78 |
| K36/0266 | 333.00 | 323.00 | 324.06 | 0.58 |
| K36/0051 | 334.06 | 325.45 | 329.32 | 1.07 |
| K36/0037 | 340.28 | 335.71 | 337.02 | 0.52 |
| K36/0038 | 343.14 | 333.99 | 339.82 | 0.84 |
| K36/0554 | 369.08 | 339.04 | 340.67 | 1.79 |
| K36/0553 | 370.00 | 351.70 | 362.55 | 1.06 |
| K36/0145 | 370.00 | 363.00 | 366.76 | 0.96 |
| K36/0273 | 380.15 | 367.45 | 371.34 | 2.09 |
| K36/0272 | 380.17 | 364.37 | 377.30 | 0.53 |

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**Fax:** 03 365 3194

**Customer services:** 03 353 9007
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**Timaru**
75 Church Street, PO Box 550, Timaru

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