# TE WAIHORA/LAKE ELLESMERE

## State of the Lake and Future Management

Edited by KENNETH F.D. HUGHEY and KENNETH J.W. TAYLOR

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Edited by **KENNETH F.D. HUGHEY** and **KENNETH J.W. TAYLOR**
Lincoln University Environment Canterbury



Lincoln University
Te Whare Wānaka o Aoraki



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SHELLEY McMURTRIE

SHUTTERSTOCK

# 01 INTRODUCTION

**KENNETH F.D. HUGHEY** Lincoln University **KENNETH J.W. TAYLOR** Environment Canterbury

Te Waihora/Lake Ellesmere[1] is a large coastal lake, intermittently open to the sea. It is highly regarded for its conservation and related values, some of which are of international significance. Its function as a sink for nutrients from its large predominantly agriculturally based catchment, currently undergoing accelerated intensification, is also recognised, at least implicitly. It is the resulting conflict from these value sets which is mainly responsible for the ongoing debate about the future of the lake, a debate long fuelled by rhetoric and informed by a body of science which highlights the lake's complexity as a biophysical system, but has many gaps. It is a debate that now has substantial statutory implications, arising from factors which include:

- the requirements of conservation, and indigenous needs and entitlements which are growing in prominence and statutory (including property rights based) legitimacy;
- public interest in legal processes associated with further major intensification of agriculture planned for the catchment;
- a recent Environment Court decision in which serious questions about the overall biological health of the lake were raised; and
- the consequences arising from the need for Environment Canterbury to obtain resource consents for the lake operating regime.

In addition, in recent times the Waihora Ellesmere Trust (WET), a community based group advocating for improved management of the lake, has been established. It is within these diverse contexts that this State of Te Waihora/Lake Ellesmere report has been prepared—it results from the 2007 Waihora/Ellesmere Living Lake Symposium, held from 31 October-3 November 2007 at Lincoln University, Canterbury. The symposium was initiated and organised by the WET (see www.wet.org.nz).

The Living Lake Symposium had several key objectives:

- To determine the overall state of the lake, by first defining the key value sets, and indicators that could be reported against;
- To suggest future management actions that would address key issues affecting the defined values;
- To provide a forum within which lay individuals, scientists and managers could openly debate issues; and
- To provide a launching pad for integrated and focused future management of the lake and its environs.

The programme incorporated three keynote speakers: Dr Larry Hildebrand from Environment Canada, Dr Hamish Rennie from Lincoln University, and Dr Bryan Jenkins from Environment Canterbury—their addresses made a major contribution to the symposium although none are included in this report, because it is focused primarily on the science and the management options associated with the lake.

The format of this report is designed to be readily updateable. Ten of the principal presentations in the main sessions of day two of the symposium are included in this report—two Power Point presentations (both regarding water quantity and related issues) are provided as appendices to improve completeness. Over time, however, topic areas not available as full papers for this report, e.g., surface water quantity, will be written up and included in detail. Similarly, the papers herein will themselves be updated as new and significant data become available. Each subject area will be reconsidered within the same structure and context as has been provided here. One paper, 'Te Waihora/Lake Ellesmere: An integrated view of the current state and possible futures', was presented on the final formal day of the symposium and it is included as the concluding chapter of this report.

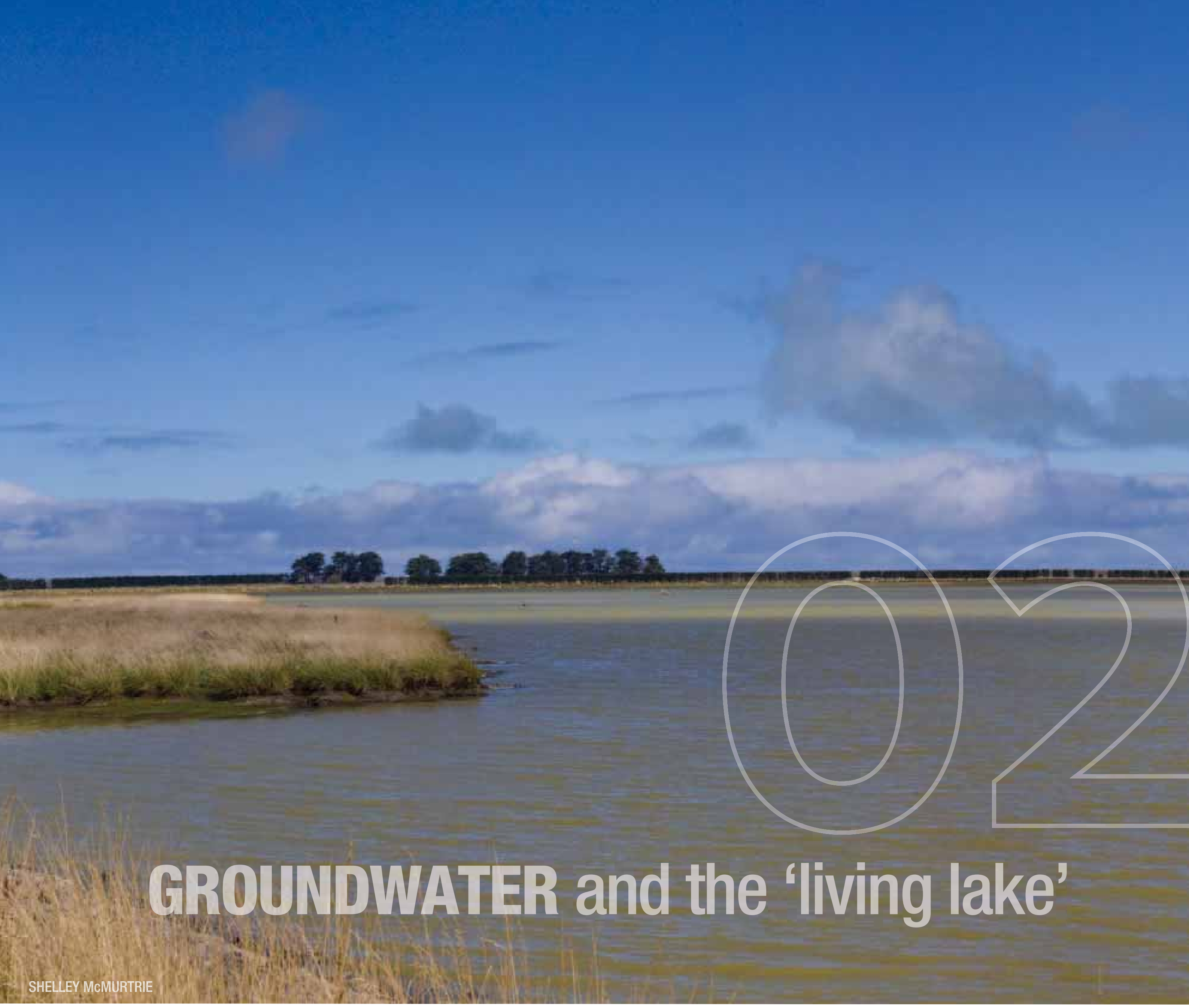
Finally, the Waihora Ellesmere Trust and many of the others attending the symposium saw merit in reconvening the event around two years after the initial symposium, to report on progress with management, indicator monitoring, scientific understanding and other matters. We support that suggestion.

In terms of report format it is important that readers note the following:

- All authors were provided with 'briefs of work' and were requested to contextualise their work with that contained within the Taylor (1996) report on the lake—this was more easily achievable for some than others. Given some lack of consistency between symposium presentations and final papers it is our intention that a revised set of agreed indicators will be considered and included in any follow-up symposium and associated reports—some considerable work will be required in some areas to achieve this objective;
- Only the wildlife and integration papers included in this report have been formally peer reviewed; and
- All other papers have been standardised and style edited-some changes have been suggested by the report editors and made by the paper authors.

Finally, an attempt has been made to present the papers in a logical sequence of 11 chapters: chapter 1 sets the scene; chapters 2-7 cover the biophysical science dimensions (groundwater, water quality, native vegetation, native fisheries, trout, wildlife); chapters 8-10 deal with the human dimensions (Ngāi Tahu, recreation, economics); and chapter 11 deals with integration of the findings from the previous chapters and setting the scene for future management.

[1] Note that the Geographic Place Names Board has defined the name as Lake Ellesmere (Te Waihora). It is not our intention to debate the nomenclature, but rather to put the focus where we consider it should lie, within the lake's initial historical and cultural context for indigenous Maori.



SHELLEY McMURTRIE

# 02 GROUNDWATER and the ‘living lake’

**HOWARD R. WILLIAMS** Environment Canterbury

Surface water inflow to Te Waihora/Lake Ellesmere is largely sourced from groundwater flowing into its catchment. In turn, this groundwater is sourced from both rainfall recharge and seepage from rivers. A marked decrease in groundwater levels over the last decade has been caused by drier than average conditions, in combination with large increases in groundwater abstraction. The decrease in groundwater levels induced a corresponding decrease in spring-fed stream flows that enter the lake. Planned adaptive management of the groundwater resources in the Te Waihora/Lake Ellesmere catchment aims to balance the needs of the lake with intense groundwater development and potential adverse effects of climate change.

## 2.1 Introduction

At least a millennium ago, the un-named body of water later to be called 'Te Waihora/Lake Ellesmere', had variously been: a major discharge point for the Waimakariri River; a relatively quiet tidal estuary; and a freshwater lake. Such major changes in its character were caused by the chaotic migration of the Waimakariri River across its braid plain. Sometimes the river discharged south of Banks Peninsula, sometimes north. Currently, Te Waihora/Lake Ellesmere is a brackish bar-type lagoon: it has not always been so.

Over the last few thousand years at least, the lake has been largely fed by water that has spent much of its time underground-groundwater. Figure 1 depicts a schematic view of the catchment water inputs and outputs that provide water to Te Waihora/Lake Ellesmere.

Except during periods of persistent rain such as occurred during the winters of 2006 and 2008, or during the wet periods of the mid-1990s, nearly all of the water entering Waihora/Ellesmere is derived from the groundwater system that underlies the gravel-dominated strata of the Central Plains. The groundwater system is fed from two sources of recharge: rainfall incident on the plains; and subterranean seepage from the Rakaia and Waimakariri rivers. For short bursts, generally during winter, discharge into Te Waihora/Lake Ellesmere is supplemented by surface flow derived from the foothills distributed north of a line from the Rakaia Gorge to Darfield (Figure 1).
This brief review of recent research describes how and why Te Waihora/Lake Ellesmere is so dependent upon groundwater, and what is being done to ensure that this dependency is fed sustainably. To aid in an under-

*Photo* ***A general view of the lake, looking south.*** *Photography* ***Shelley McMurtrie.***

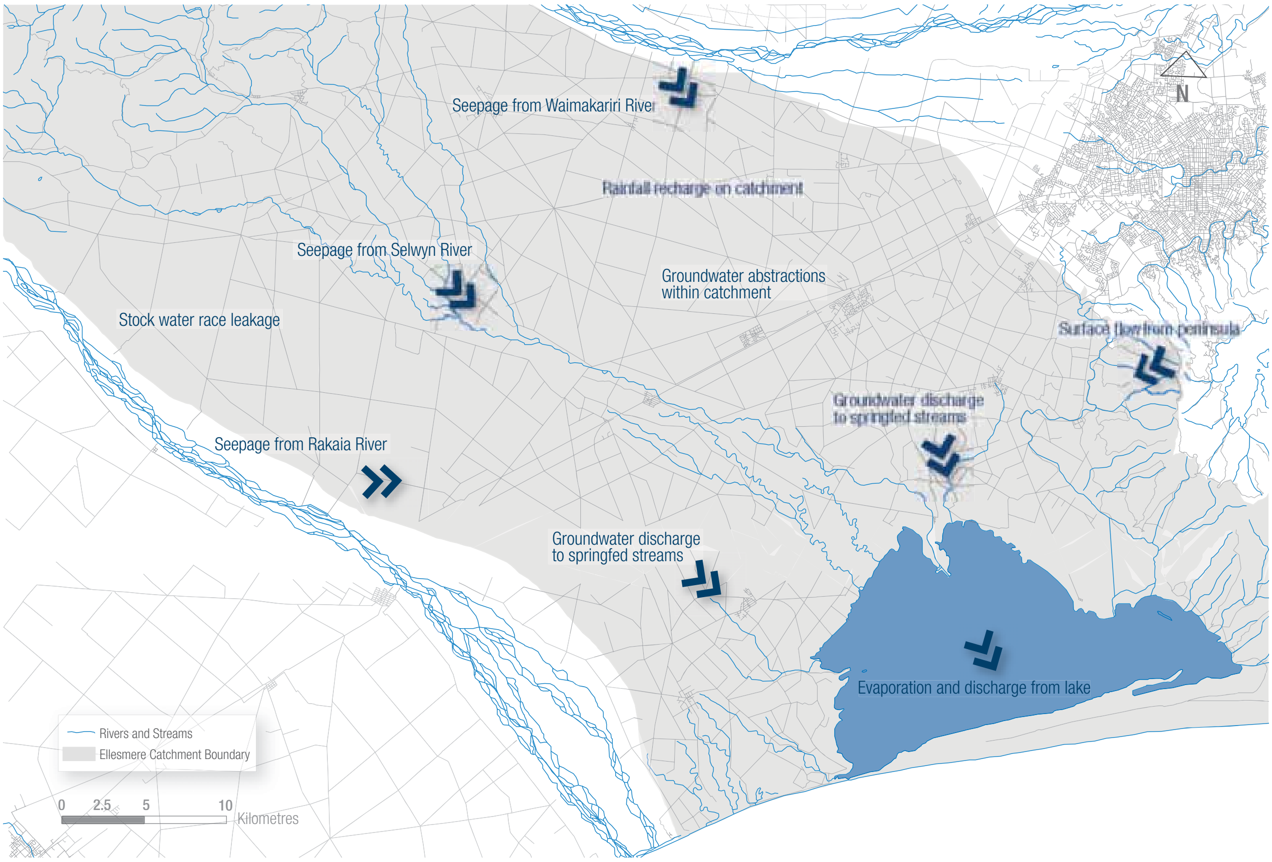



**FIGURE 1.** The Te Waihora/Lake Ellesmere catchment, showing schematic water inputs and outputs (Modified from Figure 6.17 in Taylor 1996).

standing of this groundwater system, I first briefly describe the last two million years of inter-related climate and geology.

## 2.2 Past climate of the catchment

The Canterbury Plains were formed during cold and generally wet stages alternating with warmer and drier periods typical of the Pleistocene glaciations world-wide. To the west of what is now Te Waihora/ Lake Ellesmere, a rapidly rising land mass, the Southern Alps, stored much snow and caused much rain to fall. During periods of melting, huge masses of water were released, bringing with it in the order of 10,000 cubic kilometres of gravel, mixed with sand and silt. The Canterbury Plains comprise material that can only have been transported and deposited during major flood events such as are not, fortunately, experienced today. In these wet periods, not only were the plains decorated with a tracery of laterally migrating braided rivers, but groundwater levels were near surface.

As the glacial conditions gradually ameliorated to our dry and warm current climate, far less rain and snow fell, with the result that the major rivers ceased to transport large quantities of material, and groundwater levels gradually dropped. The reduction in gravel transport and deposition meant that lateral migration of the braided rivers became less common, and the coastline ceased to be eastward-prograding. Currently at the coastline, processes of long shore drift, and recession of the coastline have become important (Leckie 2003), while inland, rivers have cut down into their deposits.

## 2.3 Geology of the catchment

The Canterbury Plains comprise a series of large coalescing fluvio-glacial fans built by the main stem rivers (Rangitata, Ashburton, Rakaia and Waimakariri). During successive glaciations when glaciers partly occupied the inland valleys and extended to the eastern foothills, great quantities of detritus eroded from rapidly rising mountains. Gravel, with sand and silt material, was transported eastwards and literally dumped, without sorting, to form the fans of gravel-dominated strata that extend beyond the present day coastline (Figure 2).

Superimposed on the regional architecture of the coalescing fans created by the major rivers, are inter-fan depressions occupied by smaller-scale fans of reworked gravels. The inter-fan Selwyn River occupies the depression between the major overlapping fans of the Rakaia and Waimakariri rivers and consists of reworked gravels exhibiting a more open texture than the fluvio-glacial gravels associated with the adjacent fans (Anderson 1994; Brown 2001; Brown and Wilson 1988; Wilson 1989).

The thickness of gravels is variable, ranging from over 300 m to greater than 600 m (Figure 2). These gravels contain a finite though renewable resource of groundwater which is utilised by means of wells, with a maximum well depth currently at 240 m in the Te Pirita area.

It is probable that groundwater in the uppermost gravel strata discharges into the marine environment, all others are probably pinched out laterally. The significance of this is that groundwater discharge from the groundwater system to the marine environment is likely to be only through these uppermost strata (Figure 2). Gravel-dominated strata in the coastal zone are separated by fine-grained sediment such as silt as shown in Figure 2.

Although there has been a tradition of separating out the various gravel strata in the coastal zone into 'aquifers', inland, these are not discrete entities but are zones of preferred well screening reflecting the interplay of a number of geological characteristics. Over most of the Canterbury plains, the gravels cannot be divided up into true aquifers because they cannot be geologically mapped as such and are not separated by discrete lithological zones of contrasting material 'aquitards'. Well logs do not indicate long-distance correlation of strata from well to well. Indeed, away from the coastal portion of the zone, the concept of a layered stratigraphy is unsupported by drilling records. The groundwater system is simply contained in a large set of overlapping and interconnected, elongate lens-shaped structures of relatively permeable gravel set in a matrix of less permeable gravel, sand and silt. Modelling of braid-plain gravel fans has shown that the build up and preservation of the gravel-dominated layers results in a heterogeneous and anisotropic mass that is variably saturated with groundwater.

## 2.4 Groundwater hydrology of the catchment

In this section the sources of recharge to groundwater, its passage through the gravels, and its eventual discharge are described.

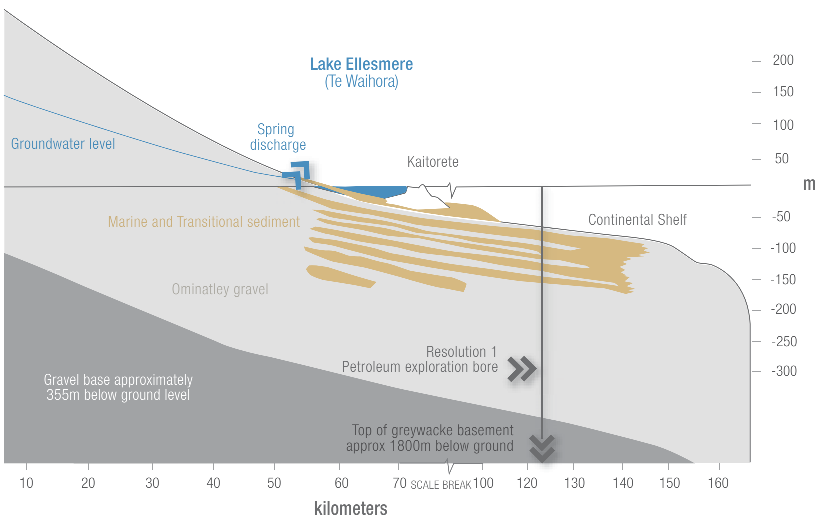



**FIGURE 2.** Geological cross-section showing the schematic relationships between strata, spring discharge, Te Waihora/Lake Ellesmere and Kaitorete barrier (based on Ettema 2005).

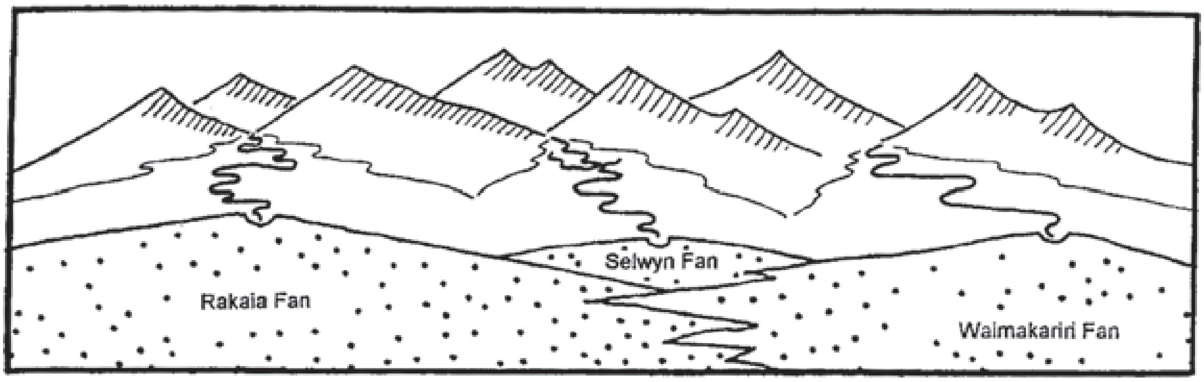



**FIGURE 3.** A simplified and schematic oblique view of the fan deposits associated with the three rivers in and bordering the catchment, looking towards the foothills to the northeast.

## Recharge sources

Groundwater in much of the catchment represents recharge from rainfall, and seepage from the Rakaia and Waimakariri rivers, from irrigation races, and return water from irrigated land. Rainfall falling on the plains portion of the catchment largely disappears and forms groundwater. Rainfall falling in the foothills discharges to the Selwyn and Hororata rivers.

Observations in the upper Selwyn River area indicate that the groundwater and surface water resources interact (Taylor 1996). There is a partitioning of the entire water resource between the Selwyn River and its tributaries, and the groundwater system. Water may be lost from one watercourse by seepage into groundwater, that then emerges in an adjacent tributary. For example, flow is lost from the upper reaches of the Selwyn River, but flow lines determined from detailed water levels, and water chemistry, indicate that this water emerges as springs feeding into the Hororata River (Vincent 2005). In turn, both these rivers lose flow into the groundwater system further south, reappearing again in the spring-fed streams (Gabites and Williams 2007; McKerchar & Schmidt 2007). In effect, the quantum of losses in the upper part of the Selwyn catchment is approximately the same as the gains (spring discharges) at the bottom of the catchment.

Along the centre of the catchment, the Selwyn River provides recharge to groundwater with the result that surface flow in that river generally disappears. Significantly, most, if not all of this groundwater reappears in spring-fed streams near to the coast.

Along the south-western and northern boundaries of the catchment, the major alpine rives allow seepage of part of their flow into the groundwater system. For example, in the Little Rakaia area and the elongate riparian zone adjacent to the Rakaia River, a major proportion of the groundwater is derived by seepage from the Rakaia River. Similarly, seepage from the Waimakariri River flows east towards Christchurch and south, around the western margin of Banks Peninsula, towards the lake.

## Hydrogeology of the catchment

This section describes the groundwater flow directions in the catchment. Within the catchment, groundwater flow is from the higher ground in the northwest, towards the coast. A map of groundwater contours measured in the uppermost strata is presented in Figure 4.

Groundwater flow moves at right angles to piezometric contours. The groundwater piezometric contours also indicate that losses from surface water flow to groundwater are evident from the Rakaia River into the Little Rakaia area. In contrast, groundwater flow resulting from rainfall recharge results in groundwater contours that are generally parallel with topographic contours, and with the coast. South west of Te Waihora/ Lake Ellesmere, groundwater flows either towards the lake, or towards the sea.

In addition to groundwater flow within the gravel strata, there is evidence of vertical flow between strata of differing depths. For example, in the inland plains such as in the Te Pirita, and Dunsandel areas, a downward piezometric gradient exists, with the result that groundwater flows downwards, from gravel into underlying gravel. Measurements of water pressures in wells indicates that groundwater levels (pressures) become progressively deeper (lower) with depth, though this variation in pressure seems to disappear below about 100 m. Downwards groundwater flow, from overlying strata into underlying ones, represents the mechanism whereby infiltrated rainfall and river recharge penetrate into the deeper strata.

Towards the coast, at the inland margin of where spring-fed streams appear, the vertical groundwater pressure gradient becomes upwards, with higher pressures in deeper strata. As a result, groundwater flow is both seaward and upwards, towards the land surface. The presence of thin and discontinuous confining layers overlying and between the gravels in this coastal zone, and the seawards pinching out of deeper gravel strata, help maintain this pressure gradient.

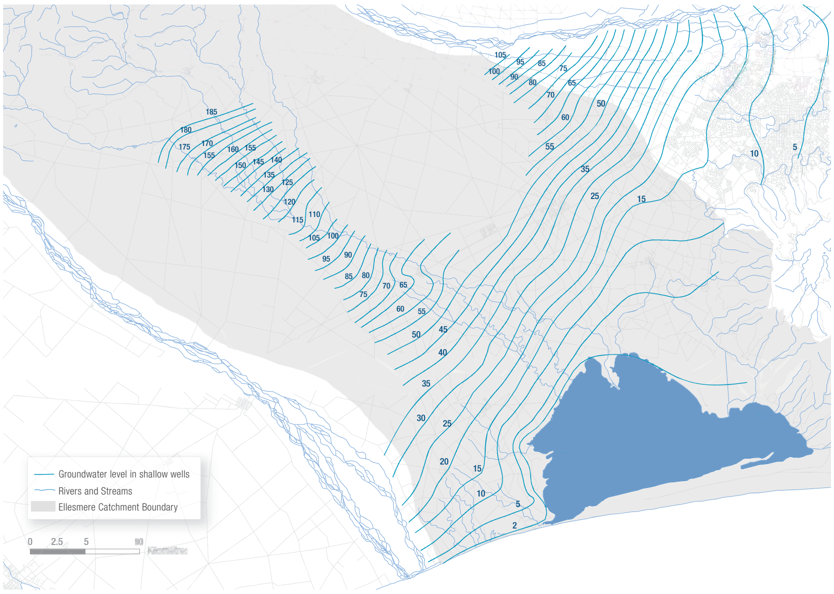



**FIGURE 4.** Groundwater contours (metres above mean sea level) within the shallowest water-bearing strata in the catchment.

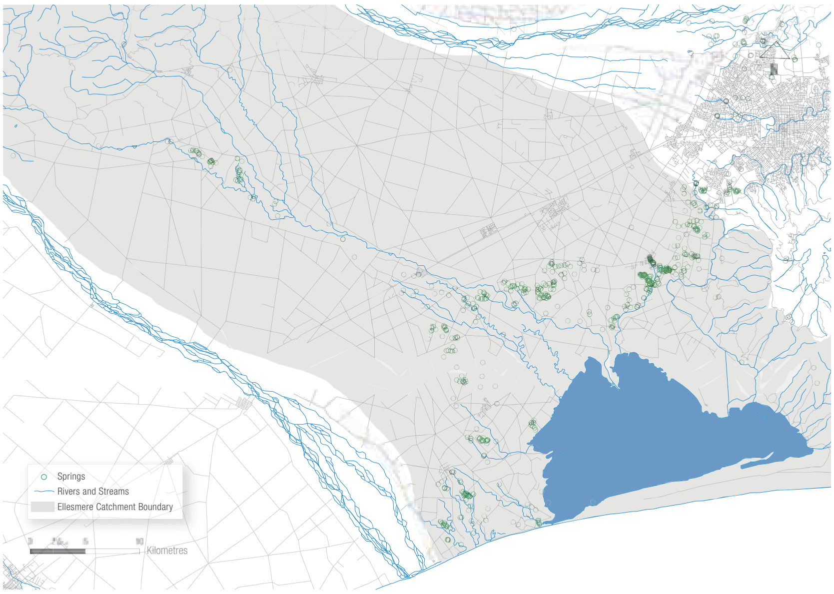



**FIGURE 5.** Spring distribution in the catchment.

*Photo* ***Lake flats taken at low water level, showing deposition of fine-grained sediment and encroaching vegetation.*** *Photography* ***Shelley McMurtrie.***

This pressure difference, driving groundwater flow and maintaining groundwater levels, explains the distribution of discrete artesian and depression springs that feed many of the lowland streams. The spatial distribution of artesian and depression springs is shown in Figure 5.

Flow discharges from both artesian and depression springs are sensitive to groundwater levels. Springs and dispersed seepage of groundwater occur also within the lake (Ettema & Moore 1995).

The artesian nature of the coastal portion of the groundwater system is illustratevd by the occurrence of flowing artesian wells in the areas around the lake, and of springs in the lake. Maintenance of this artesian pressure is significant in keeping the marine saltwater / groundwater interface at bay. Temporal variation in this hydraulic pressure controls flow in the spring-fed streams.

## 2.5 Water budget

The most recent estimates of the input and outputs of water to the catchment are those produced by White (2008), using data largely derived from Horrell (2006), and updating those in Taylor (1996). The water budget in Table 1 serves to illustrate the general magnitude and uncertainty of these variables.

Although some terms in the water budget such as long-term means of rainfall recharge and use can be estimated reasonably, the discharge from the major alpine rivers is not well quantified, nor is the groundwater discharge direct to the ocean.

Obtaining better estimates of the major inflows from the alpine rivers, and the outflow of groundwater direct to the ocean are necessary to advance understanding of the hydrogeology of the catchment.

## 2.6 Groundwater levels and trends

In this review I briefly describe groundwater levels from three geographical areas: inland plains; mid-plains; and the coastal area. These three areas reflect broad topographic, rainfall and groundwater characteristics. Similar descriptions are to be found in the

TABLE 1. **Te Waihora/Lake Ellesmere catchment water budget (based on Table 5.10 in White 2008).**

| Component | Te Waihora/Lake Ellesmere catchment ($m^3/s$) |
|---|---|
| Land surface recharge | 23.8 |
| Rainfall on Te Waihora/Lake Ellesmere | 3.6 |
| Recharge from Rakaia River | 3 to 11 |
| Recharge from Selwyn River | 1.5 to 3.5 |
| Recharge from Waimakariri River | 3.5 to 4 |
| Recharge from Banks Peninsula streams | 0.3 |
| Sea water inflow to lake | 3.5 |
| Stock race leakage | 1 |
| Evaporation from Te Waihora/Lake Ellesmere | 6.1 |
| Surface water discharge to sea | 12.9 |
| Discharge across spit | 1 to 5.6 |
| Groundwater use | 11.3 |
| Surface water use | 0.3 |
| Outflow from catchment to Little Rakaia zone | 2.1 to 2.8 |
| Outflow from catchment to Christchurch-West Melton zone | 1 |
| Sum of inflows | 40.2 to 50.7 |
| Sum of outflows | 34.7 to 40 |
| Off-shore groundwater discharge | 0.2 to 16 |
| Groundwater discharge to spring-fed streams | 12 |
| Groundwater discharge direct to Te Waihora/Lake Ellesmere | 0.1 |

annual reports entitled: 'State of the water resources at the end of winter' regularly published by Environment Canterbury (e.g. Martin and Williams 2007).

## Inland plains

Groundwater levels in wells in the inland plains area are close to or at minimum levels. Figure 6 presents details of water levels from six wells reflecting different strata and well depths. Groundwater levels below seasonal and annual means are evident in all of these wells, as they are in other wells in this area.

Few inland plains wells have relatively long periods of data available. Groundwater levels in these wells were high during the relatively wet years of the 1970s, and low in the dry mid-1980s. A seasonal pattern is evident since 1997, an increasing summer irrigation-induced groundwater drawdown (saw-tooth pattern). This is particularly evident, not only in the pumped well L36/0023, and but also in the Te Pirita observation bores L36/1157 and L36/1226 (Figure 6). The declining saw-tooth pattern shows that over the last 12 years, seasonal (winter) recovery has been insufficient to allow recovery of groundwater levels. In contrast, the Darfield well L35/0163 shows less of a declining trend, perhaps due to its proximity to the Waimakariri River.

The Te Pirita wells have a relatively short length of record, only being installed in the late 1990s when irrigation first developed in the area. These wells have previously been compared to a well at Greendale, L36/0092, which has a record dating back to the early 1950s. Figure 6 compares groundwater levels in the Te Pirita wells to L36/0092, a well whose water levels originally responded to climate change stresses, but are now increasingly affected by the cumulative effects of groundwater abstraction. Note in Figure 6 that deeper wells generally have lower groundwater levels.

There is a general correspondence in groundwater levels between the two Te Pirita wells (L36/1226 and L36/1157) and those in L36/0092. The two Te Pirita wells show marked progressively lower summer groundwater levels. In addition, winter levels are also lower each year, especially over the last six years.

Results from rainfall-evapo-transpiration-soil moisture models to calculate rainfall recharge, in association with eigen modelling (Bidwell 2003), indicate that the low winter recharge is in large part responsible for these low groundwater levels but that abstraction is compounding the problem. The eigen modelling has allowed robust simulation of groundwater levels and discharges based on a combination of climatic input and estimated groundwater abstraction data (Williams et al. 2008).

## Mid plains

Groundwater levels from four wells located within the mid-plains area are displayed in Figure 7. Note in Figure 7 that there is less variation in general groundwater levels between wells of different depth.

Two of these wells have a monitoring record dating back to the early 1950s. Three wells, M36/0255, M36/0183 and L36/0142 illustrate similar trends from the 1970s. The pattern of groundwater levels in these wells progressively changes from about 1987, becoming more seasonally variable, especially in well L36/0181.

The seasonal pattern of groundwater levels in wells within and down-gradient of the North Bank irrigation scheme, such as L36/0258, changes radically from about 1987 as a result of irrigation discharges in the scheme. Groundwater in the vicinity of this well now enjoys extra recharge in summer from border dyke irrigation, leading to higher summer groundwater levels than those in winter. This effect is illustrated by the relatively high levels in the last few years, as well as the seasonal 'saw-tooth' nature of the variation in water levels, even in wells not showing localised drawdown interference effects.

Groundwater levels in the vicinity of well L36/0181 have become increasingly affected by irrigation pumping, representing an interference effect, with increasing summer drawdowns evident in the record since the late 1990s, combined with a decline in winter levels. Well L36/0142 does not indicate any clear-cut direct interference effect but there is an indication of progressively lower groundwater levels in summer in recent years.

## Coastal groundwater levels

The seasonal range of groundwater levels in wells in the coastal area is much less than in wells elsewhere in the allocation zone due to its proximity to the coast, which provides a constant head boundary that moderates seasonal and climatic changes in water level. Note in Figure 8 that deeper wells tend to have higher groundwater levels. For example, some wells in the confined part of the zone exhibit positive artesian pressures (e.g. well M36/0355 in Figure 8).

In the coastal Te Waihora/Lake Ellesmere region, there is no consistent pattern of groundwater level (Figure 7) even though groundwater monitoring records for wells L37/0451, M36/0338 and M37/0010 extend back to the early 1950s.

Groundwater levels in well M36/0338 at Brookside, adjacent to the Irwell River, are strongly correlated with flows in that river. The seasonal range of water levels has increased in this well in recent years, from around 1 m to over 3 m. Prior to 1999, groundwater levels in M36/0338 were rarely lower than 3 m below ground (occurrences in the early 1970s and mid 1980s), but since then have regularly been lower. These low groundwater levels occur in late summer to early autumn and reflect increased abstraction locally and regionally.

Well L37/0451 is located within the Little Rakaia riparian area, adjacent to the north bank of the Rakaia River. Groundwater in this well is influenced by recharge from the Rakaia River, and particularly by the position of actively flowing braids within the Rakaia River. If the North Branch of the Rakaia River is active, groundwater levels will be higher in this well, and vice versa. This well illustrates the effects of the Rakaia River on the groundwater system adjacent to it.

Well M36/0355 is located at Doyleston, and is screened in a relatively deep aquifer. This well has a shorter period of monitoring record, and shows that the magnitude of summer seasonal drawdowns, caused by groundwater abstraction, is increasing each year, so that the range between summer and winter is now around 6 m, compared to around 2 m in the early 1990s. In the winter months this is a flowing artesian well, as shown by a water level above ground level.

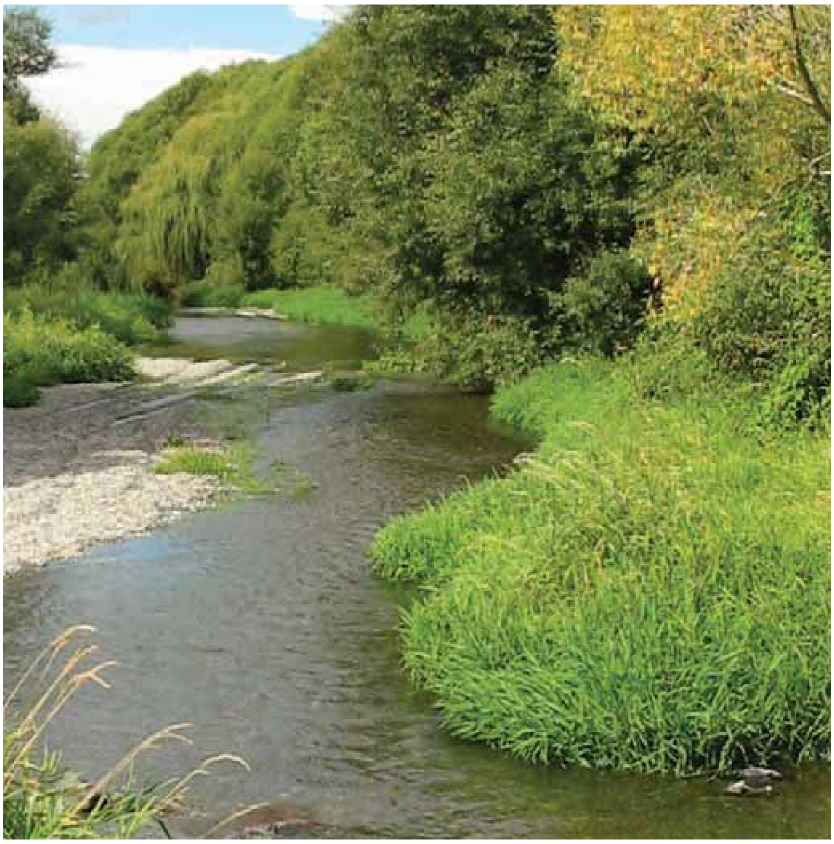


*Photo* ***Selwyn River at Coes Ford, looking upstream in March 2009, flow 300 L/s, half minimum flow.***
*Photography* ***Howard Williams.***

However, it ceases to flow in the summer when irrigation induces a regional lowering of groundwater level.

Well M37/0010, near Taumutu, has a very small range of water levels because it is close to the coast. Levels generally range from 2.5 m to 3.5 m below ground. While recent groundwater levels (since 2001) have been low, they are not lower than they have been historically.

Coastal wells, like those described in the inland and mid-plains areas, show evidence of the 'saw-tooth' seasonal decline and recovery of groundwater levels.

To conclude this section, it is clear that whilst many ECan observation wells are illustrating larger summer season declines than historically, in many wells the winter recovery levels are also declining. The only part of the catchment where this is not occurring is in the costal zone, where winter levels have remained relatively constant due to the fact that groundwater levels cannot rise further without inducing increased spring activity. In effect, the winter levels are capped, with the excess released as discharge to the lake.

## 2.7 Groundwater surface water interaction

Hydrogeologists generally acknowledge a relationship between local groundwater levels and spring flows. When groundwater levels or artesian pressures are high, spring flows are at a maximum, and vice versa. Such a relationship has been observed in this part of Canterbury and is continually monitored (Williams and Aitchison-Earl 2006). This section describes examples of this relationship for two spring-fed streams that occur along the northern edge of Te Waihora/Lake Ellesmere.

Springs cluster around the headwaters of many of the lowland streams around the lake. Except during protracted wet weather, these streams are generally fed by these springs. Along with groundwater abstraction, these streams form a major component of discharge from the groundwater system as a whole.

The relationships between groundwater levels and surface flows in the spring-fed

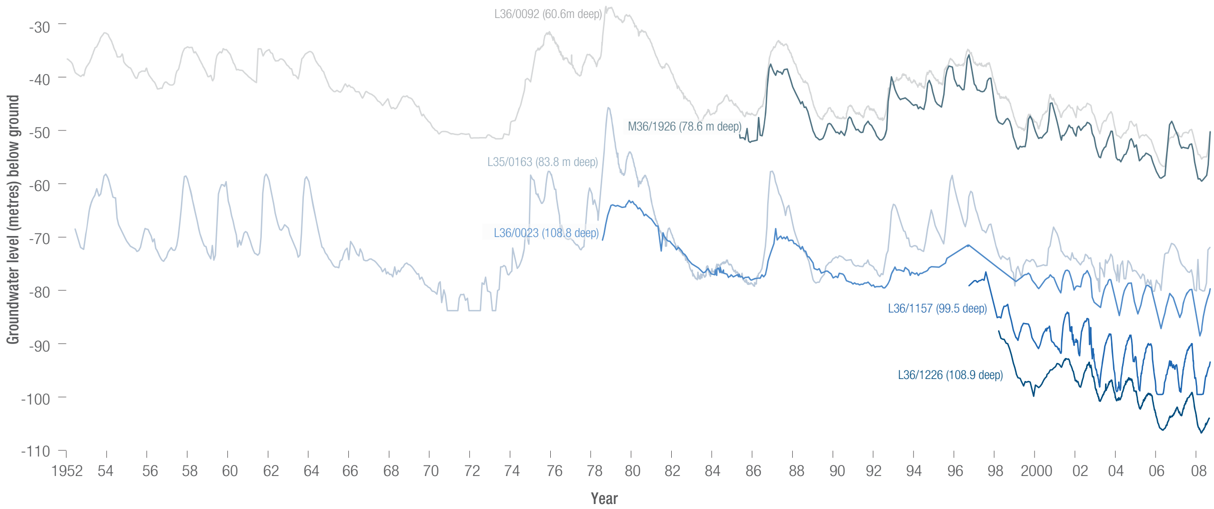



**FIGURE 6.** Groundwater levels and trends in six inland plains wells.

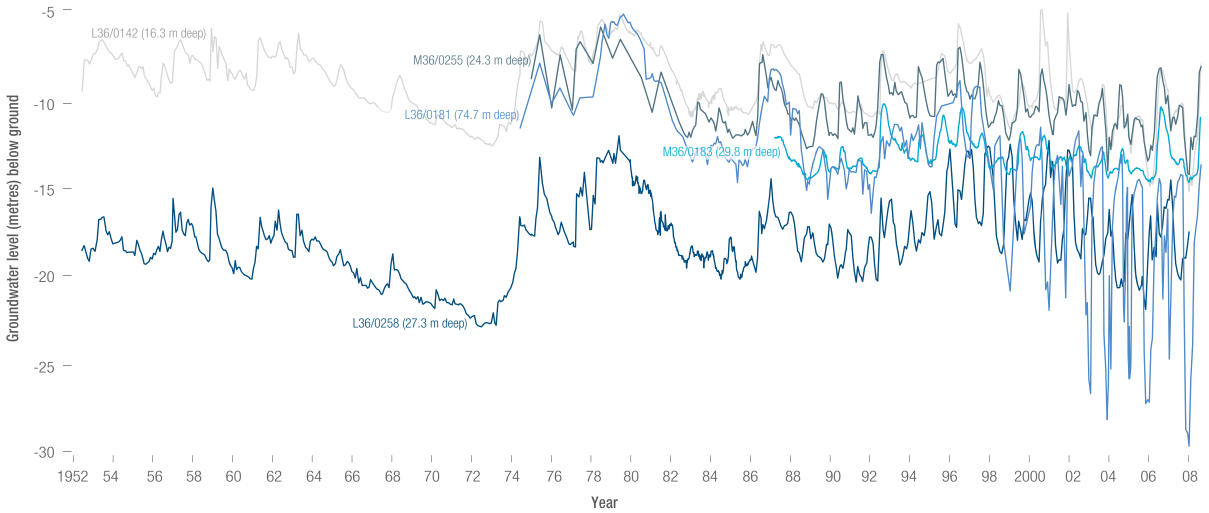



**FIGURE 7.** Groundwater levels and trends in mid-plains wells.

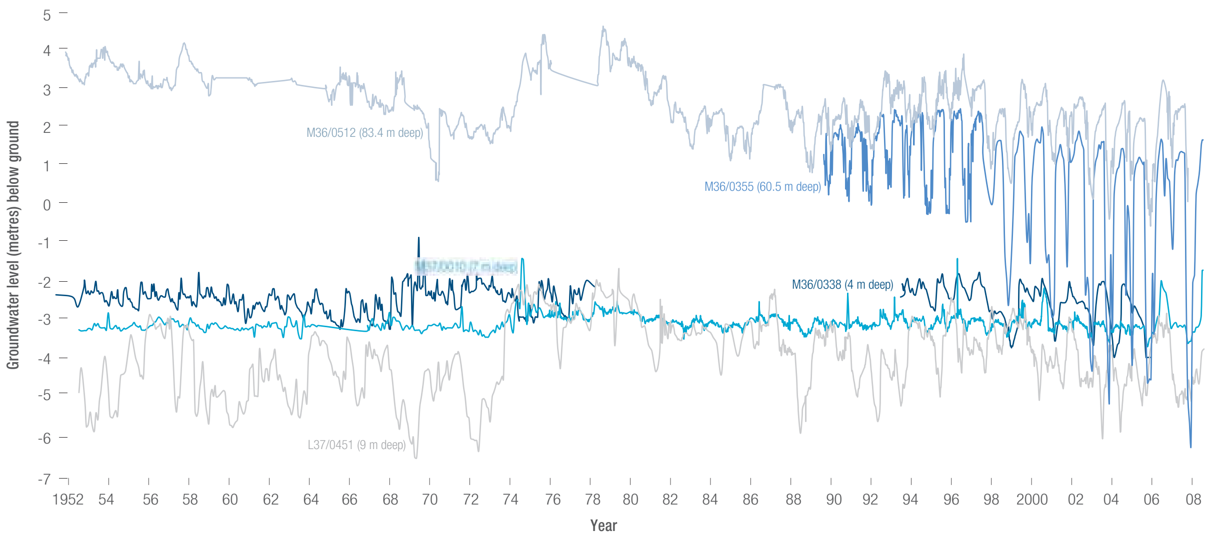



**FIGURE 8.** Groundwater levels and trends in coastal plains wells.

streams has been analysed by Williams and Aitchison-Earl (2006). They found that there was a good correlation between the flow in a spring-fed stream and the local groundwater levels in wells (Figures 9 & 10).

Monitoring has shown that the Irwell River can be expected to be dry when groundwater levels are deeper than 3 m below ground level in well M36/0338 (Figure 9). The frequency of the Irwell being dry at The Lake Road has increased in recent years, with the river dry for extended periods in 1998, 1999, 2001, 2003 to 2008. Groundwater levels in M36/0338 display a decreasing trend, with levels becoming lower in late summer since 1998.

Surface flow in Harts Creek also demonstrates a relationship with groundwater in the upstream well L36/0142, as shown in Figure 10. Since 2002, when groundwater levels in L36/0142 have been consistently low, surface flow in Harts Creek has regularly fallen below the statutory minimum flow of 1000 L/s.

Lowered flows in spring-fed streams correlate with observations on the progressive drying up of springs and seeps, and the regional lowering of groundwater levels. As a consequence, monitored wetted length and breadth of rivers has also decreased, with consequent ecological effects.

To conclude this section, it is worthwhile stating that the intimate relationship between groundwater levels and spring-fed stream flows, means that in order to protect the inflows to the lake, management of groundwater levels is required.

## 2.8 State of the water resource

The preceding sections on groundwater levels and trends, and the relationship between groundwater and surface water allow the following statements.

Whilst climate is the main driver for the time-series variation in groundwater levels, and as a consequence, the discharge from the aquifer system, intensification of existing groundwater abstraction without appropriate management of groundwater abstraction will likely lower groundwater levels and stream discharges.

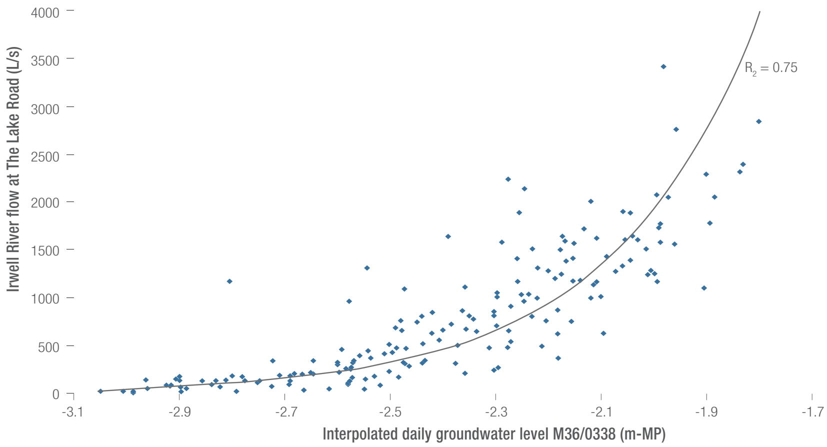



**FIGURE 9.** Relationship between groundwater level in well and flow in the Irwell River.

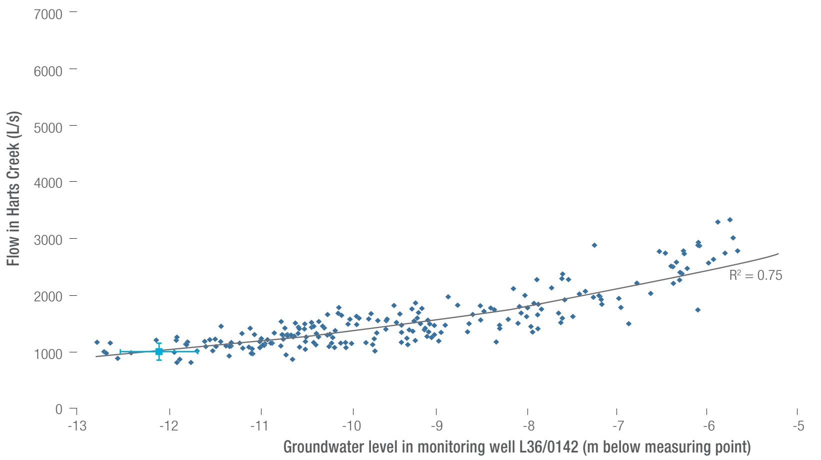



**FIGURE 10.** Relationship between groundwater level in well L36/0142 and flow in Harts Creek (blue cross is standard error).

*Photo* ***Harts Creek at the Environment Canterbury flow monitoring station, Timberyard Point Road bridge, March 2009, at about minimum flow of 1000 L/s.*** *Photography* ***Howard Williams.***

Abstracted volumes of groundwater by consent holders is largely unmanaged at present. The institution of metering of takes in the Rakaia-Selwyn allocation zone will aid understanding of the water budget that in turn will inform a groundwater management method.

## 2.9 Groundwater management

In 2004, Environment Canterbury instituted groundwater allocation zones with specific allocation limits (Aitchison-Earl et al. 2004). Within each groundwater allocation zone a groundwater budget was prepared. The allocation limits largely related to the quantum of dryland surface recharge in each zone. The limits and the boundaries of zones underwent some change as new data were forthcoming, until the limits were set more formally in Variation 4 of the Proposed Canterbury Natural Resources Regional Plan.

The Te Waihora/Lake Ellesmere catchment lies within the greater part of two allocation zones: Rakaia-Selwyn and Selwyn-Waimakariri. The dependency of Te Waihora/Lake Ellesmere on groundwater-sourced input has resulted in Environment Canterbury implementing a 'Restorative Programme for Lowland Streams' (RPLS). The RPLS involves review of over 600 consents in the Rakaia-Selwyn zone (ECan 2007). The programme resulted from recognition that the combination of climate and abstraction was causing adverse effects on groundwater levels that in turn adversely affected the spring-fed stream discharge. The review is on-going, and one of its aspects is the introduction of adaptive management of groundwater resources (Williams et al. 2008) whereby consented abstraction of groundwater will be tailored to supply, as determined from knowledge of the recharge to the aquifer system.

Whilst the dependency of the lake on the groundwater system in its catchment cannot be reduced, it is to be hoped that by managing groundwater abstractions during times when the inputs to the aquifer system are low, the output from the system to the lake will be maintained at a level that ensures protection of Te Waihora/Lake Ellesmere.

## 2.10 References

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*Photo* **Groundwater being used to irrigate pasture. "Whilst there are significant economic and social benefits accruing from irrigated agriculture, a balance needs to be maintained between these and the complementary adverse environmental effects of abstraction on the hydrological system, including Te Waihora".** *Photography* **Shutterstock.**

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Te Waihora/Lake Ellesmere is a large coastal lake, intermittently open to the sea. It is highly regarded for its conservation and related values, some of which are of international significance. Its function as a sink for nutrients from its large predominantly agriculturally based catchment, currently undergoing accelerated intensification, is also recognised, at least implicitly. It is the resulting conflict from these value sets which is mainly responsible for the ongoing debate about the future of the lake.

This book serves to quantify the nature of this debate by documenting changes to lake values, both over time and spatially. It provides a standardised approach to reporting these changes, set against indicators that are value-specific. Ultimately, it provides a template for thinking about future management scenarios for the lake and its environs. Given this approach the book ultimately serves as a resource for helping understand the ever-changing and current and possible future states of the lake, under a variety of management requirements and implications.