2. Hydrogeological Setting

2.1. Hydrogeology of the Central Plains area

The Central Plains comprise a broad alluvial fan surface which extends between the Rakaia and Waimakariri rivers, extending from the foothills in the west to the coast south of Banks Peninsula. The subsurface geology of this area comprises alluvial gravel materials deposited and reworked by the braided alpine rivers in response to climatic variation associated with glacial and interglacial cycles during the late Pleistocene (Brown and Webber, 2001). These alluvial materials host an extensive aquifer system which is extensively utilised for domestic, public and municipal water supplies and which also provides baseflow to rivers and streams in lowland areas.

Along the coastal margin, the aquifer system comprises a sequence of permeable gravel layers separated by fine-grained marine and estuarine silt deposits accumulated during periods of sea level highstand during late Pleistocene interglacial periods. These silt layers form low permeability aquitards which limit the upward flow of water resulting in flowing artesian conditions in coastal areas. Further inland, the aquifer system comprises a thick sequence of heterogeneous alluvial materials containing layers of relatively coarse, well sorted gravels interspersed with lower permeability gravel materials containing variable amounts of silt and sand. Various investigations (e.g. Davey, 2006) have attempted to group water-bearing units encountered at similar depths in individual wells into discrete 'aquifers' based on well screen depths (as a proxy for permeability) separated by less permeable silt-bound gravel aquitards. However, evaluation of aquifer test data from the Central Plains area indicates a degree of vertical leakage between individual water-bearing zones suggesting the entire aquifer system is hydraulically connected, at least to some degree (SKM, 2008, Williams and Lough, 2009).

Recharge to the aquifer system consists of a base, relatively constant recharge derived from the alpine rivers, coupled with a more variable recharge component derived from rainfall, foothills rivers (including those inland and mid-plains reaches of rivers that exhibit intermittent flow) and irrigation water (including stock water races). Rainfall and foothills recharge occurs mostly across the upper and mid plains while alpine river recharge occurs mainly in the mid and lower plains (Williams and Gabities, 2010).

Across the upper section of the plains both the Rakaia and Waimakariri Rivers are incised into the surrounding alluvial fan materials by as much as 50 metres and appear to be perched above the surrounding water table. However, significant flow losses are observed from their middle reaches to the coast. These losses are estimated at up to 15 m^3/sec for the Rakaia River and 10 m^3/sec from the Waimakariri River (Scott and Thorley, 2009), a portion of which flows through the coastal section of the Central Plains aquifer system. The Selwyn River and tributaries (e.g. Hawkins River, Hororata River and Waianiwaniwa River) are observed to lose water to the surrounding unconfined aquifer downstream of their emergence onto the upper plains and frequently dry up through their middle reaches during the summer months.

Land surface recharge to the Central Plains aquifer system occurs via infiltration of rainfall and seepage losses from the water race network. In recent years natural rainfall recharge has become increasingly augmented by irrigation as, although good irrigation practice does not in itself result in direct recharge, the higher soil moisture levels maintained by irrigation result in an increased volume of soil moisture drainage during the winter months. Due to natural climate variability the timing and depth of rainfall

recharge varies considerably over time. This variability can exert a significant influence on groundwater levels across the Central Plains area both in terms of large, episodic recharge events associated with high rainfall events or more subtle variation in long-term recharge rates associated with extended periods of above average rainfall occurring on a decadal scale.

As illustrated in **Figure 2** below, groundwater flow occurs in a south-easterly direction across the central plains area following the overall topographic gradient toward the coast. Some departures from the general flow direction are observed along the major river systems reflecting their recharge contribution to the groundwater system (discussed in more detail in following sections).

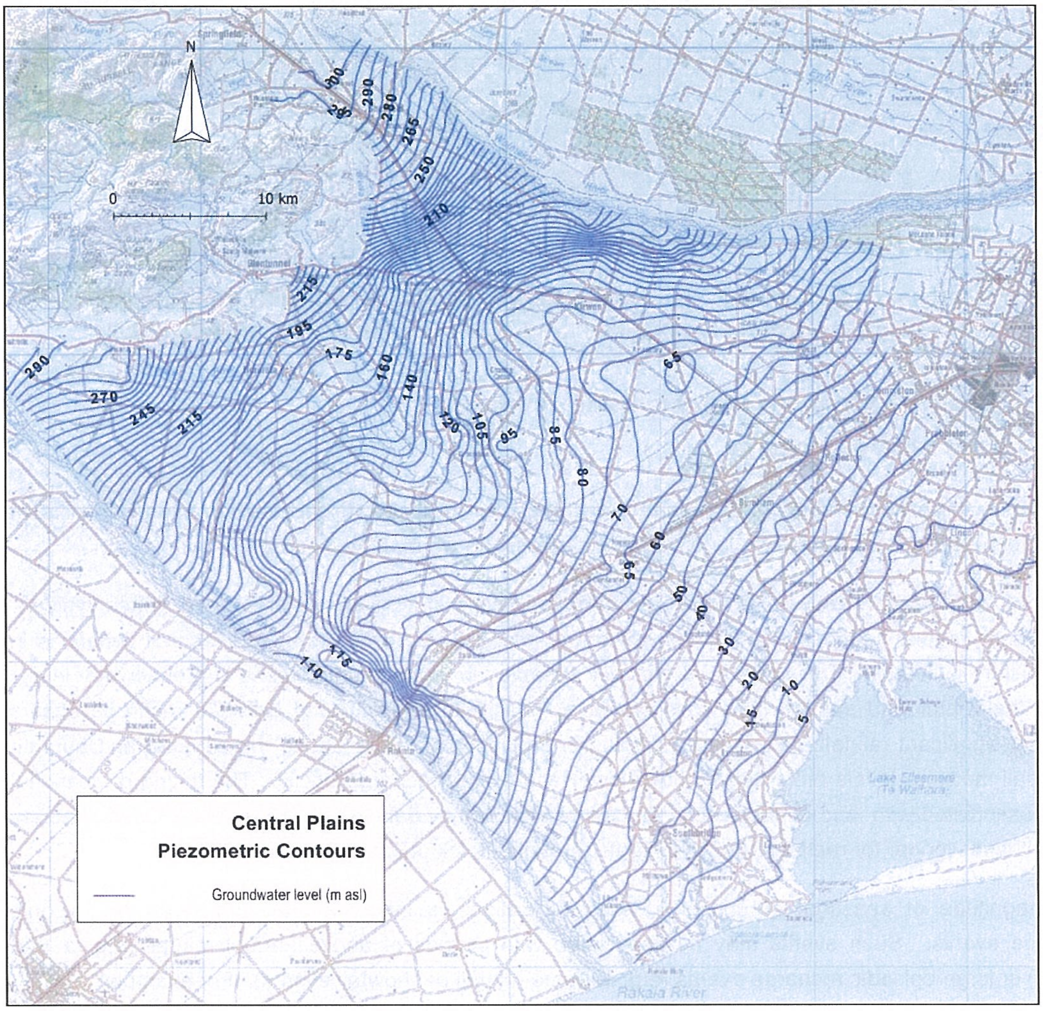

Figure 2. Generalised piezometric contours across the Central Plains area (data sourced from the Environment Canterbury GIS system)

Discharge from the Central Plains groundwater system primarily occurs through abstraction and discharge from springs and lowland streams, with a relatively poorly quantified volume of water discharge via diffuse leakage of the coast.

Figure 3 shows a simple conceptual hydrogeological cross section through the northern sector of the Central Plains aquifer system.

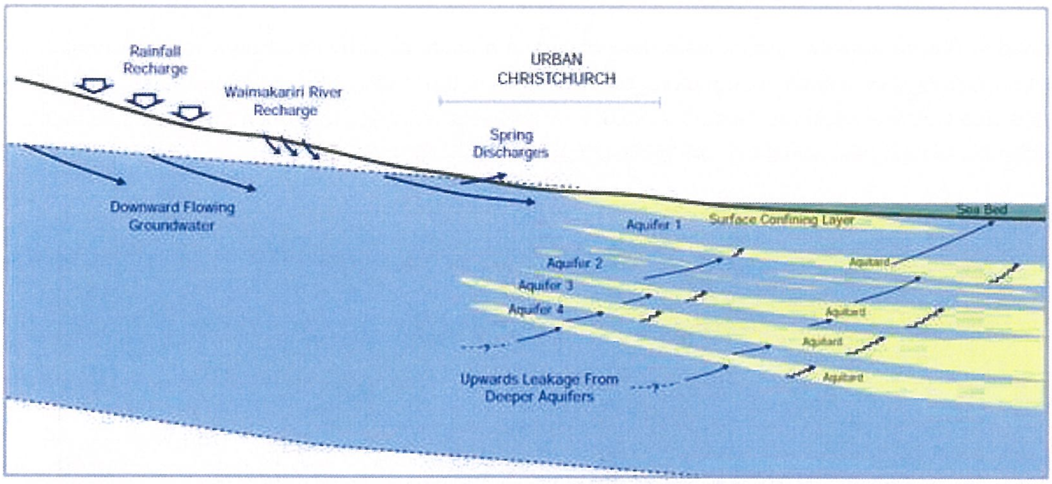

Figure 3. Conceptual hydrogeological cross section through the northern (Waimakariri-Christchurch) sector of the Central Plains aquifer system (from Callander, 2008)

2.2. Temporal variations in groundwater levels

2.2.1. Land surface recharge

As noted in the previous section, land surface recharge and groundwater abstraction exert a significant influence on temporal groundwater level variations across the Central Plains area.

Over the short-term (weeks to months) groundwater levels in shallow water-bearing zones typically exhibit semi-regular seasonal fluctuations which are influenced by corresponding seasonal variations in soil moisture infiltration. This variation is typically observed in terms of an increase in groundwater levels during the winter and spring when soils are at or near field capacity and episodic recharge occurs following significant rainfall events and a decline in groundwater levels during the summer and autumn when soil moisture levels are typically much lower and limited recharge occurs. The timing of seasonal peaks associated with land surface recharge can be significantly delayed in deeper water-bearing zones where it takes longer for recharge flux to infiltrate through a thick unsaturated zone.

The magnitude of seasonal groundwater level fluctuations is influenced by short-term or episodic recharge events. Such events may be associated with periods of above normal rainfall (e.g. a 'wet winter') or large episodic recharge events (e.g. extreme rainfall or snowfall events). For example,

Figure 4 shows a plot of calculated land surface (rainfall) recharge[1] in the West Melton area and corresponding variations in groundwater levels in a shallow (33 m deep) monitoring well between 2000 and 2013. The data show relatively minor seasonal variations between 2000 and 2005 during a sequence of dry winters but exhibit significant increases during 2006, 2008, 2010 and 2013 in response to periods of significant land surface recharge.

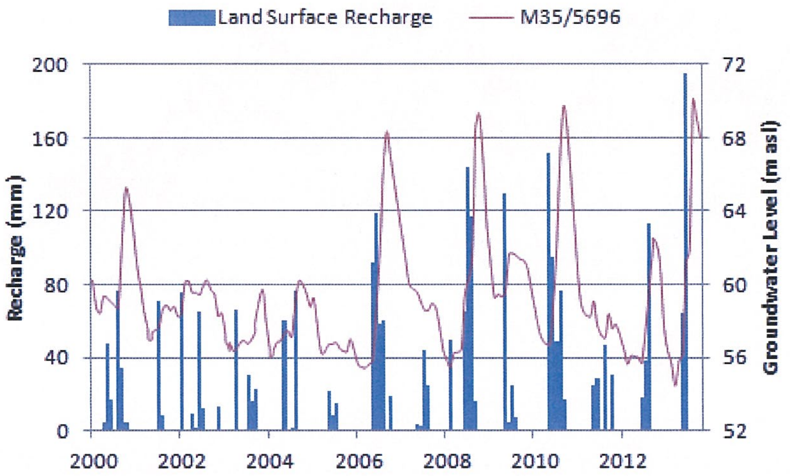

Figure 4. Plot of calculated land surface recharge and groundwater levels in the West Melton area, 2000 to 2013

On a longer timescale, groundwater levels across a majority of the Central Plains area (aside from areas located near constant head (river, spring or coastal) boundaries) are influenced by variations in long-term rainfall. **Figure 5** shows a plot of cumulative rainfall departure calculated for 5 rainfall sites distributed across the Central Plains area (or just outside in the case of Winchmore). The data exhibit a relatively consistent pattern of rainfall pattern across the entire plains and show:

- Rainfall was generally close to, or slightly above normal during the 1950's and 60's;
- A period of significantly below normal rainfall from the late 1960's through to the mid-1970's;
- Significantly above normal rainfall from the mid-1970's to the early 1980's;
- Generally below normal rainfall from the early-1980's to the mid-2000's (with a period of slightly above average rainfall during the mid-1990's); and
- Average to above average rainfall over recent years (i.e. post-2005)

[1] Estimated land surface recharge derived from Environment Canterbury calculations

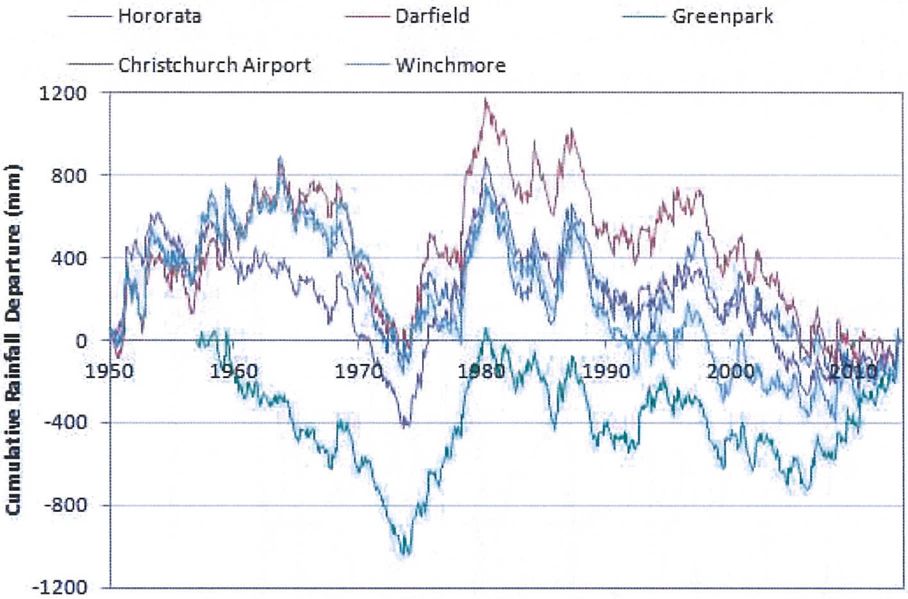

Figure 5. Cumulative rainfall departure from normal across the Central Plains area, 1950 to 2013 (data sourced from NIWA CliFlo)

Long-term variations in rainfall and associated fluctuations soil moisture drainage are reflected in temporal groundwater levels across the Central Plains area. For example, **Figure 6** shows a plot of 3-year moving average land surface recharge and groundwater levels recorded in an 18 metre deep bore near Broadfield. The data illustrate that temporal variations in rainfall recharge are the primary driver of groundwater levels at this location. A similar pattern is evident in groundwater across a majority of the Central Plains area (although the magnitude varies between different locations and at depths) indicating inter-seasonal variations in rainfall are the major factor influencing long-term groundwater levels across a majority of the Central Plains area.

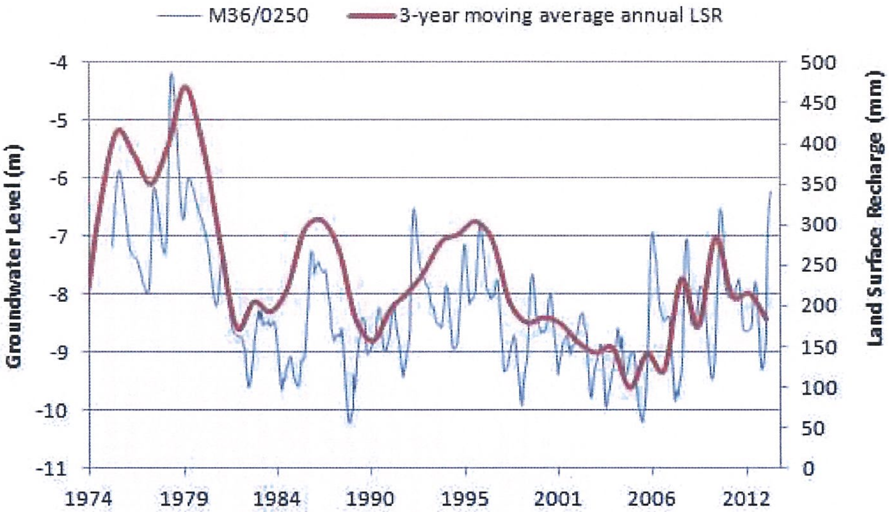

Figure 6. Long-term variations in land surface recharge and groundwater levels in the Broadfield area, 1974 to 2013

2.2.2. Groundwater Abstraction

Short-term variations in groundwater levels in the Central Plains area are also influenced by ground water abstraction, particularly on a local scale. Although limited historical water use data is available, estimates of potential water use have been made based on modelling of irrigated area and climate. **Figure 7** shows a plot of estimated actual water use in the Central Plains area from 1971/72 through to 2009/10. The data indicate an ongoing increase in the volume of abstraction from the late-1980's, accelerating post-2000.

Figure 8 shows a plot of groundwater levels recorded in a 75 metre deep monitoring bore (L36/0181) in the Dunsandel area. The figure shows a significant increase in pumping interference from the mid-1990's, increasing in magnitude through the mid-2000's. Although likely to largely reflect local pumping interference, the increase in observed seasonal variation tracks estimated variations in cumulative groundwater abstraction across the Central Plains. A similar pattern of increasing seasonal variation (i.e. summer drawdown) is observed in many parts of the Central Plains groundwater system, particularly in deeper or confined parts of the aquifer system where groundwater storage (expressed in terms of storativity) is typically lower than in shallow unconfined aquifers.

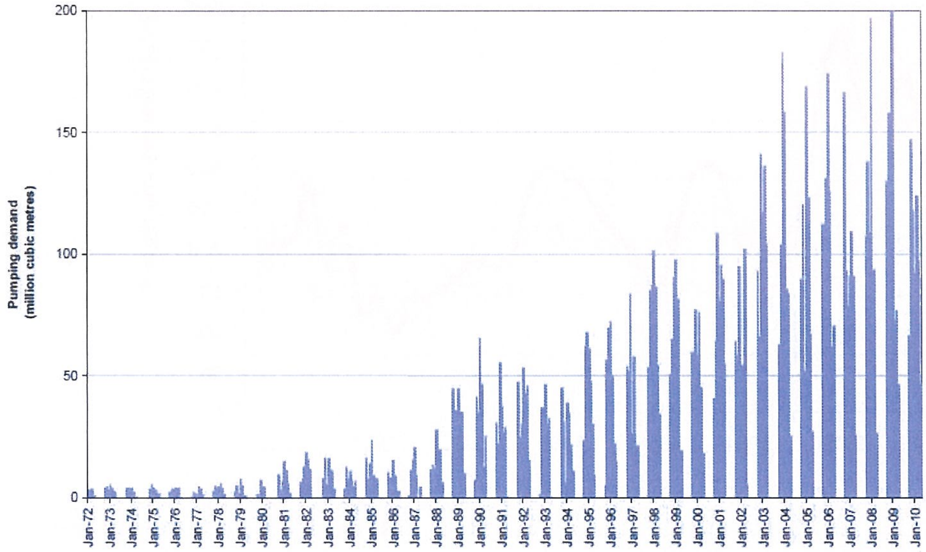

Figure 7. Groundwater abstraction in the Central Plains area, 1971/72 to 2009/10 (from Scott and Thorley, 2010)

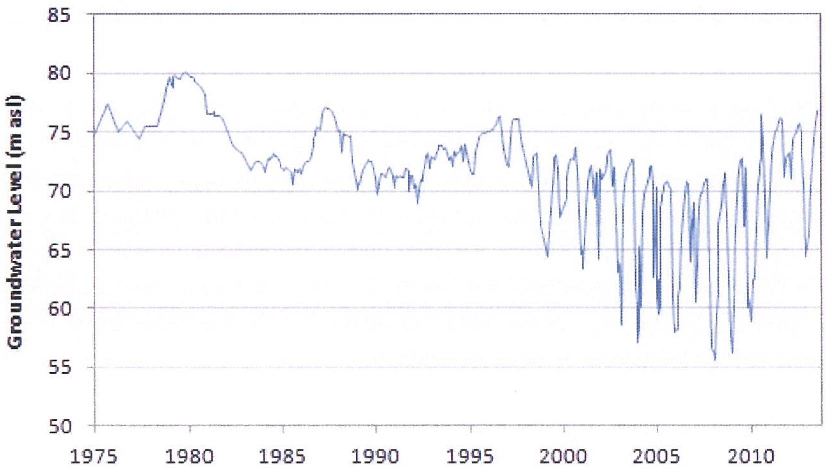

Figure 8. Effects of groundwater abstraction on water levels recorded in a 75 metre deep monitoring well (L36/0181) in the Dunsandel area, 1975 to 2013

2.3. Spatial variations in groundwater levels

The Central Plains groundwater system comprises multiple, discrete water-bearing zones within a complex geological environment. In general, the distribution of these water-bearing zones reflect portions of the alluvial gravel deposits which have been subject to greater reworking during or subsequent to deposition, resulting in greater removal (winnowing) of fine-grained materials (sand and silt) compared to the surrounding materials. The coarse texture of these deposits results in significantly higher permeability than the surrounding materials. Spatial variations in groundwater levels across the Central Plains area are, to a large extent, a product of the interaction between this hydrogeological setting and the overlying hydrological environment.

As illustrated in **Figure 9**, groundwater levels along the margins of the major perennial flowing river systems (at least over their mid to lower reaches) tend to be shallow and exhibit relatively limited (<0.5 metre) seasonal variation. In these areas temporal groundwater level variations typically follow variations in stage height in the adjacent river channels and obvious longer-term variations are generally related to changes in bed levels.

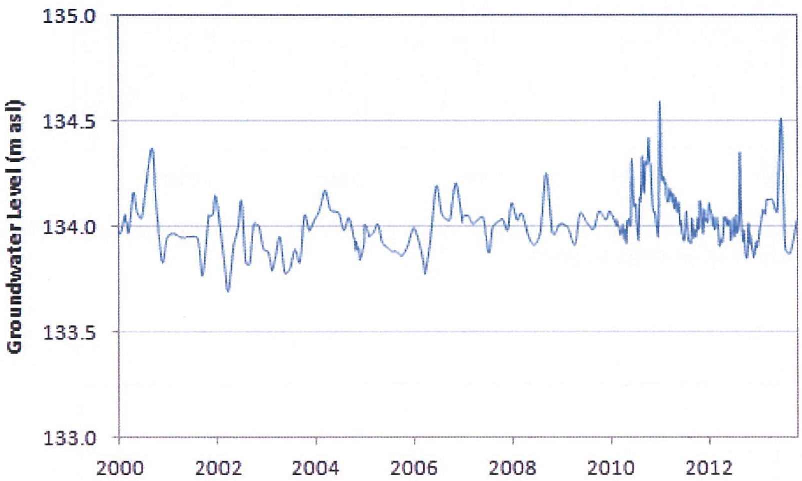

Figure 9. Groundwater levels recorded in M35/8379, a 6 metre deep monitoring well adjacent to the Waimakariri River near Courtenay, 2000 to 2013

As previously noted, shallow groundwater levels away from the major rivers tend to be dominated by seasonal land surface recharge flux. **Figure 10** shows the hydrograph from M35/5696 a 33 metre monitoring bore located approximately 7 kilometres south of the Waimakariri River. This bore exhibits an appreciably different hydrograph to M35/8379 (located approximately 11 kilometres to the north-west) dominated by episodic land surface recharge with an overall magnitude of seasonal variation up to 15 metres. Broadly similar hydrographs are observed in a majority of shallow water-bearing zones between the Waimakariri and Rakaia rivers.

In deeper water-bearing zones in inland areas, seasonal variations in recharge flux tend to be dampened by the thick unsaturated zone meaning groundwater hydrographs tend to track longer-term variations in

land surface recharge. **Figure 11** shows a hydrograph from L36/1226, a 109 metre deep bore in the Te Pirita area. Water levels at this site exhibit a seasonal variation of around 5 metres (possibly related to localised pumping effects) which is superimposed on a larger trend which tracks long-term variations in land surface recharge. It is noted that the apparent water level recovery in this well commencing in 2008 lags the corresponding increase in estimated land surface recharge by around 2 years, providing an indication of the response time in many deeper water-bearing zones.

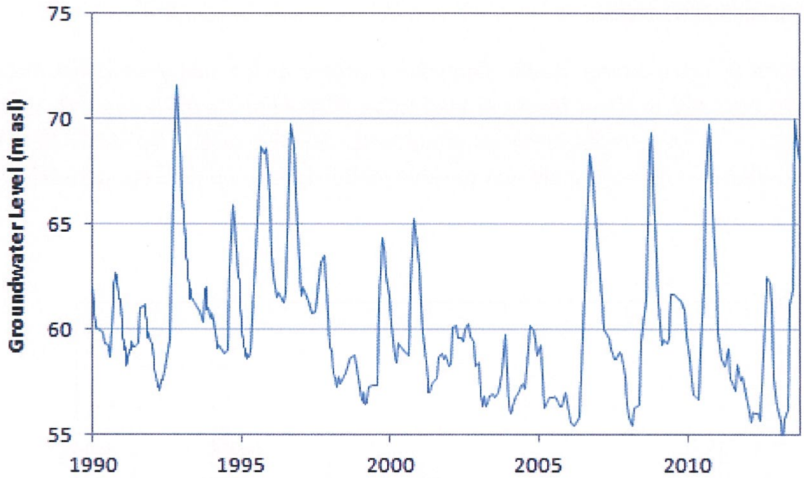

Figure 10. Groundwater levels recorded in M35/5696, a 33 metre deep monitoring well in the West Melton area, 1990 to 2013

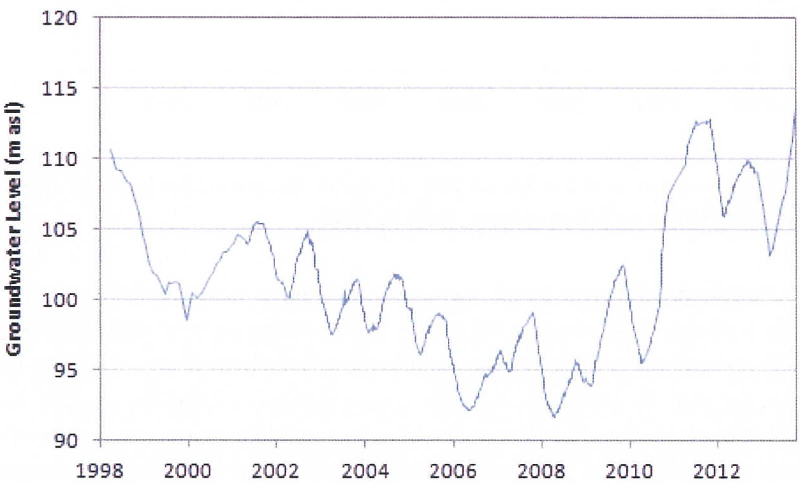

Figure 11. Groundwater levels recorded in L36/1226, a 109 metre deep monitoring well in the Te Parita area, 1998 to 2013

Figure 12 shows a plot of groundwater levels recorded in two monitoring wells in the Doyleston area between 1989 and 2013. Prior to 1995 the deeper well (M36/0355, 60m deep) exhibited a slight upward gradient compared to the shallower well (M36/0424, 12.8m deep). However, after 1995 increased abstraction from the deeper (semi-confined) water-bearing layer resulted in significant seasonal drawdown of up to 8 metres which is not observed (at least to anywhere near the same extent) in the shallower well. This illustrates the significant drawdown in response to pumping observed in many confined aquifers (due to their low storativity) in lowland areas and the differing response observed in overlying unconfined aquifers (due to a combination of limited vertical leakage through intervening aquitards and the higher specific yields in unconfined aquifers).

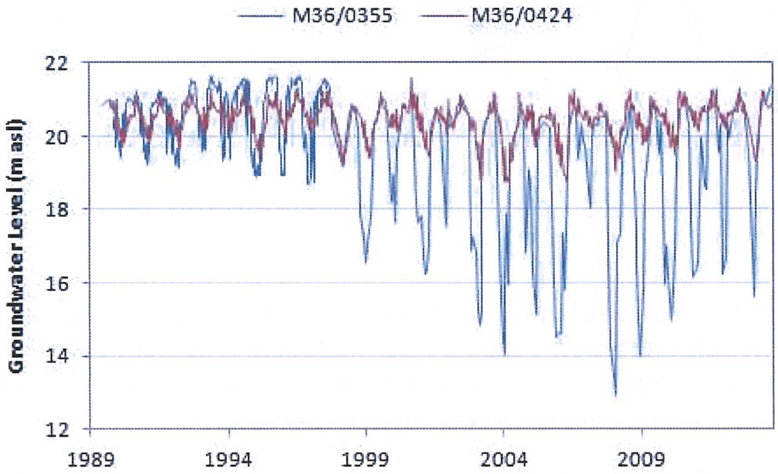

Figure 12. Groundwater levels recorded in M36/0355 (61 m deep) and M36/0424 (12.8 m deep) in the Doyleston area, 1989 to 2013

2.4. Vertical hydraulic gradients

As noted in the previous section, the hydrogeological setting of the Central Plains comprises multiple, discrete water-bearing zones in a complex geological environment. Due to the contrasting hydraulic properties (particularly in terms of vertical permeability) between the primary water-bearing units and intervening alluvial sediments it is not uncommon to observe relatively significant vertical hydraulic gradients in the Central Plains area. In general, relatively significant vertical gradients tend to be restricted to inland areas which reduce across the mid-plains toward the coast where upwards hydraulic gradients are observed (at least in places) indicating potential discharge from deeper aquifers to the surface environment (either to spring-fed streams via overlying unconfined aquifers or the offshore environment via diffuse leakage through confining layer materials).

Figure 13 shows a plot of groundwater levels recorded in a cluster well in the Te Pirita area. The data show a downward hydraulic gradient of around 2.5 metres between the two shallowest wells (L36/1157, 100m deep and L36/2266, 121m deep). This gradient increases to around 10 metres between L36/1157 and the two deeper wells (L36/2267, 160m deep and L36/2210, 254m deep).

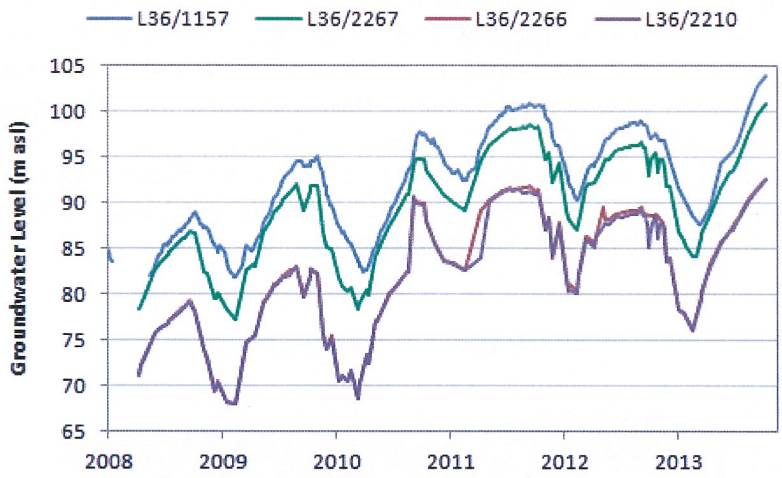

Figure 13. Relative groundwater levels observed in a cluster well (L36/1157, L36/2266, L36/2267 and L36/2210) in the Te Pirita area

Further toward the coast, a downward vertical gradient of less than 2 metres is observed in a cluster well installation (comprising L36/2320 (66m deep), L36/2256 (92m), L36/2255 (119m) and L36/2254 (139m)) near Killinchy. As illustrated in **Figure 14** vertical hydraulic gradients at this site remain downward but with a reduced magnitude compared to those observed in the Te Pirita area.

As previously illustrated in **Figure 12**, groundwater levels around the margin of Te Waihora/Lake Ellesmere tend to exhibit an upward hydraulic gradient in the absence of significant pumping effects and in some areas this gradient can be relatively significant. For example, as illustrated in **Figure 15**, an upwards gradient of 6 metres is observed in the Ladbrooks area.

Overall, vertical hydraulic gradients observed across the Central Plains area tend to reflect circulation of groundwater through deeper water-bearing layers. These layers are recharged from the land surface in inland areas and discharge via upward leakage toward the coastal margin where aquifers become confined by intervening layers of marine silt. This upward leakage from these deeper water-bearing layers contributes to baseflow in spring-fed streams occurring around the margins of Te Waihora/Lake Ellesmere.

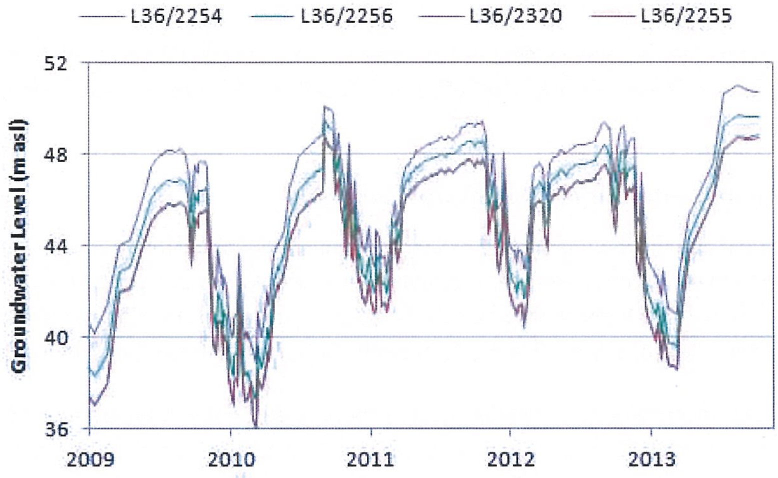

Figure 14. Relative groundwater levels recorded in a cluster well (L36/2254, L36/2255, L36/2256 and L36/2320) in the Killinchy area

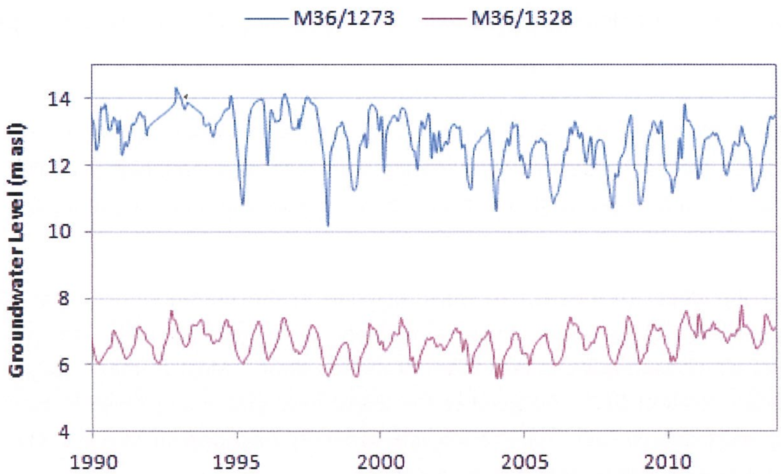

Figure 15. Relative groundwater levels recorded in the Ladbrooks area (L36/1273 41.9 m deep and L36/1328 19.6 m deep)