Riverlands Aquifer Resource Review

Prepared for Marlborough District Council

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1 INTRODUCTION

1.1 Scope of this Report

This report reviews the groundwater resources of the Riverlands Aquifer. The southern margin of the confined Wairau Aquifer is also covered by this report, as the dynamics of the Riverlands Aquifer is largely dependent on conditions within the Wairau Aquifer.

All conceptual aspects of the hydrogeology of the Riverlands Aquifer are covered in this report. Aquifer inputs, outputs, and dynamics are studied as well as aquifer chemistry. Independent studies of isotopes and soil quality have been covered by other authors, and their finding are summarised here.

A companion report has also been written to document a numerical groundwater model of the area (Wilson, 2008). The groundwater model report is primarily focussed on groundwater allocation and management rather than conceptual understanding.

1.2 Background

This report is primarily concerned with the hydrogeology of the Riverlands Aquifer and the southern margin of the confined Wairau Aquifer. Increased demand in the Riverlands area over the last ten years has prompted concerns over the sustainability of existing and additional allocation in this area.

The location of the Riverlands Aquifer is shown in Figure 1.The area of primary interest is the area to the south of Dillons Point Road, southeast of Blenheim. This area is susceptible to large pumping drawdowns because the Riverlands Aquifer has a low yield that is similar to the Southern Valleys aquifers.

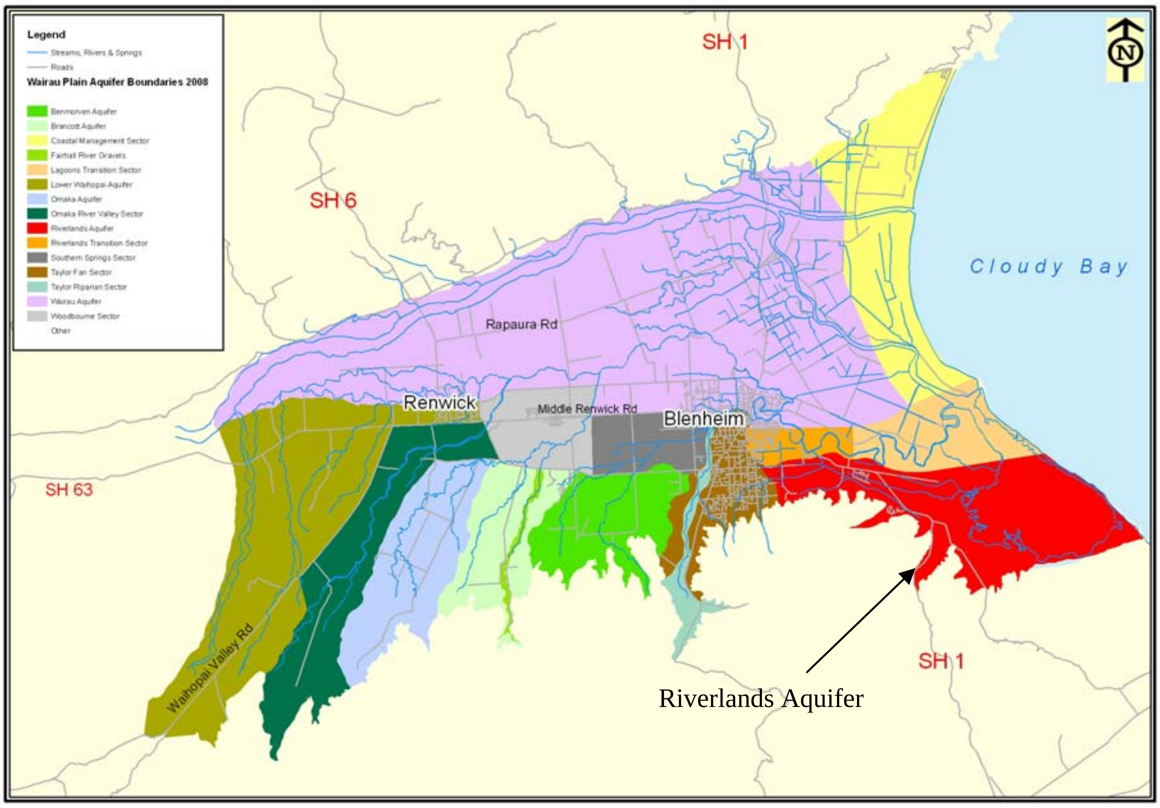

Figure 1 Map of aquifers on the Wairau Plain showing the location of the Riverlands Aquifer

The Wairau Aquifer immediately to the north of the Riverlands aquifer is also included in this report. This part of the Wairau Aquifer supplies local recharge to the Riverlands Aquifer, and the two are intimately linked. Wilson (2008) demonstrated that the southern 1km of the Wairau Aquifer is also subject to exaggerated pumping drawdown.

There are three reasons for exaggerated drawdown at the southern Wairau Aquifer margin:

1. There is a large demand for groundwater in this area
2. Regional aquifer pressure is lowered by pumping in the Riverlands Aquifer
3. The Riverlands Aquifer acts as a discharge boundary to wells in the Wairau Aquifer

With these issues in mind, a transition zone has been identified at the southern margin of the Wairau Aquifer (Figure 2). The northern extent of the transition zone is delineated by a 1km buffer within the confined-leaky part of the aquifer, west of Malthouse Road. The boundary within the fully confined part of the aquifer to the east of Malthouse Road follows the 20 mS/m conductivity contour, and is projected to cross the coast halfway between the Lagoons (P28w/0708) and Wairau Bar (P28w/1733) sentinel wells.

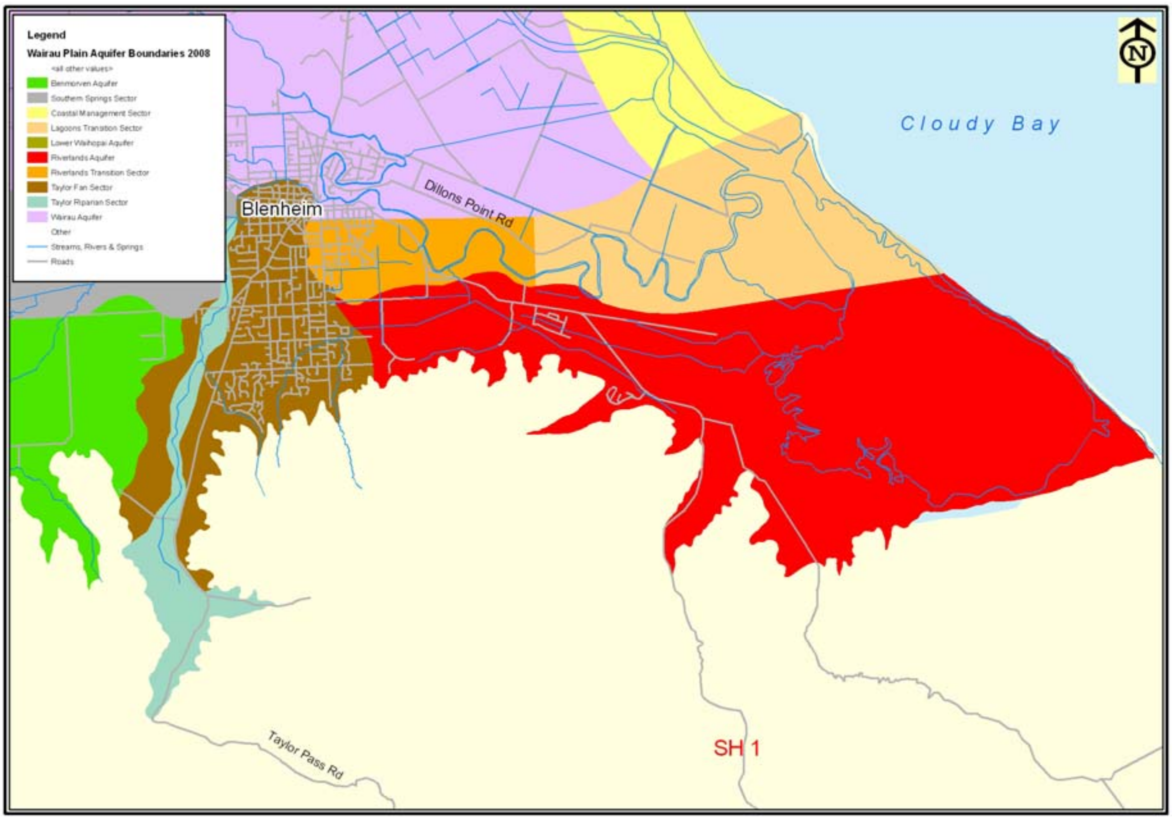

Figure 2 Map of the Riverlands-Lower Wairau area showing the boundary of the Riverlands Aquifer. Transition sectors for the confined-leaky and confined parts of the Wairau Aquifer are also shown.

1.3 Previous Work

The importance of the Riverlands Aquifer is reflected in its definition as an aquifer that is separate to the Wairau Aquifer. Until now, the Riverlands Aquifer has not been well understood. This report presents the results of the first comprehensive study on the Riverlands Aquifer to date.

The Wairau Aquifer is considered to be comparatively well understood. There have been several reports that encompass particular aspects of the Wairau Aquifer as a whole such as geology (Brown, 1981), groundwater resources (Cunliffe, 1988; Davidson and Scott, 1994), isotopes (Taylor et al.; 1992, Stewart, 2008), and chemistry (Daughney, 2004). These reports include the Riverlands area as part of their analysis, but do not specifically describe the Riverlands system.

There have also been numerous smaller reports prompted by resource consent issues. These reports usually document pumping tests performed to assess the environmental effect of groundwater abstraction. There has been one study carried out to assess the effect of irrigating with chemically evolved, saline groundwater (U030827).

1.4 Community Survey

In early 2004 a questionnaires were sent to 90 landholders in Riverlands. The purpose was to find out how many properties have wells for domestic and irrigation supply, whether there are any public concerns about water quality and availability.

Feedback was received from two thirds of the questionnaires, of which 70% (40 properties) had wells on their properties. The key results are as follows:

- 71% of the wells identified in the area are used for domestic supply
- Only 10% of all wells in use have submersible pumps
- 12% of respondents had experienced difficulty with water availability
- 28% of respondents were not happy with the water quality in their well

Many comments were received that expressed concern over the loss of artesian head. Several respondents had issues with water availability during times of low water pressure. The main reason for this that three quarters of well owners rely on surface mounted pumps. The efficiency of these pumps diminishes as head in the well drops.

2 CONCEPTUAL GROUNDWATER MODEL

2.1 Hydrogeology and Aquifer Properties

2.1.1 Hydrogeologic Setting

The Riverlands area consists of two main aquifers in hydraulic continuity. The northern of these is commonly known as the highly productive Wairau Aquifer. The southernmost aquifer is distinctly low-yielding, and is the Riverlands Aquifer.

The two aquifers are overlain by marine and lagoonal silts and clays, and marine sands of the Dillons Point Formation. These marine sediments form a confining layer, and aquifer conditions are confined or leaky-confined to the east of Bells Road, and unconfined to the west.

The base of the Wairau Aquifer is marked by the top of the Speargrass Formation. The base of the Riverlands Aquifer is marked by a layer of sticky clay or loess that marks the top of the lower member of the Speargrass Formation.

The two main aquifer bodies can be seen in a map of estimated transmissivity values for the Wairau Plain (Figure 3). Transmissivity values have been estimated by using an empirical relationship between specific capacity data, and transmissivity data obtained from pumping test results for the whole of the Wairau Plain. It is apparent from Figure 3 that the Riverlands Aquifer has similar transmissivity to the low-yielding Southern Valleys aquifers, which are located along strike to the west.

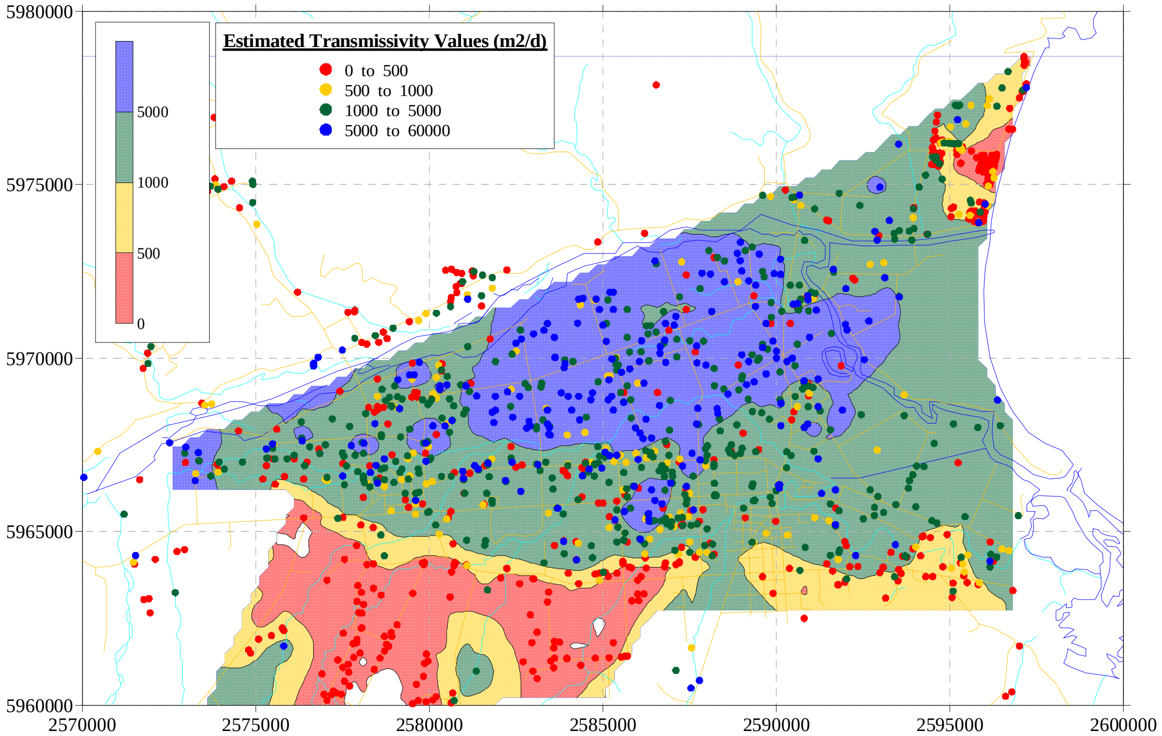

Figure 3 Map of Wairau Plain showing the estimated distribution of aquifer transmissivity (m^2/d).

2.1.2 Geological Units

The most comprehensive review of the geology of the Wairau Plain to date is by Brown (1981), who separated the sedimentary sequence into distinct stratigraphic units. MDC is currently commissioning work to revise this stratigraphy. The revision will incorporate the knowledge gained from an additional 25 years of available borehole data, and will benefit from the use of new technology such as 3-D stratigraphic modelling software.

The sedimentary sequence at Riverlands is summarised in Table 1. This sequence has been updated from Brown (1981) to include recent information about unit ages (Ota et al., 1995; Begg and Johnstone, 2000). Also, the Speargrass Formation has been divided into upper and lower members to account for the occurrence of Speargrass Formation that hosts the Riverlands Aquifer (see Section 2.1.6).

Table 1 Summary of stratigraphic units found in the Riverlands area

Stratigraphic Unit	Hydrostratigraphy	Lithology	Sediment Source	Period	Age (yrs)
Surface Deposits	Localised aquifer	Clay and gravel	Fan, river, flood and wetland deposits	Holocene	<1000
Dillons Point Formation	Aquitard	Marine silt and sand with thin gravel lenses	Passive marine and lagoonal deposits	Aranui Postglacial	<8750
Rapaura Formation	Wairau Aquifer	Alluvial gravels	River deposits, reworked Speargrass Fm	E. Aranui Postglacial	8750-14,000
Speargrass Formation (upper member)	Riverlands Aquifer	Claybound gravel	Reworked? glacial outwash	L. Otiran Glacial	14,000-30,000
Speargrass Formation (lower member)	Localised aquifer	Claybound gravel	Glacial outwash	Otiran Glacial	30,000-70000
Early marine sediments	Aquitard/local aquifer	Marine silt and sand with gravel lenses	Passive marine and lagoonal deposits	Kahini Interglacial	70,000-120,000
Wairau Conglomerate/ Hillersden Gravel	Aquitard	Cemented claybound gravel and silt	Marine mass flow/ terrestrial fan deposits	Pliocene to Early Pleistocene	1.5-5 Million

Cross sections through the Riverlands area are presented in Figure 4. The location of these sections is provided on Figure 5. Note that the vertical scale is greatly exaggerated, and is 250 times the horizontal. The cross sections are based on borehole log data provided by drillers. Knowledge limited to what the bores have intersected, and the degree of detail recorded on the logs.

The Rapaura Formation and Upper Member of the Speargrass Formation constitute the most productive gravels, and host the Wairau and Riverlands aquifers respectively. The sedimentary sequence is bound to the south by the Hillersden Gravel and Wairau Conglomerate. These gravels are fairly well cemented, and are expected to act as a bounding aquitard to the Riverlands Aquifer. The nature of the contact between the Hillersden and Wairau gravels not known, but it is expected to be at least partially faulted, as indicated by Begg and Johnstone (2000).

The cross sections also show the presence of productive gravel lenses within the Dillons Point Formation and also in the deeper marine sediments. These shape and extent of these gravel lenses is currently unknown and it is hoped that they can be mapped in the near future with 3D modelling software.

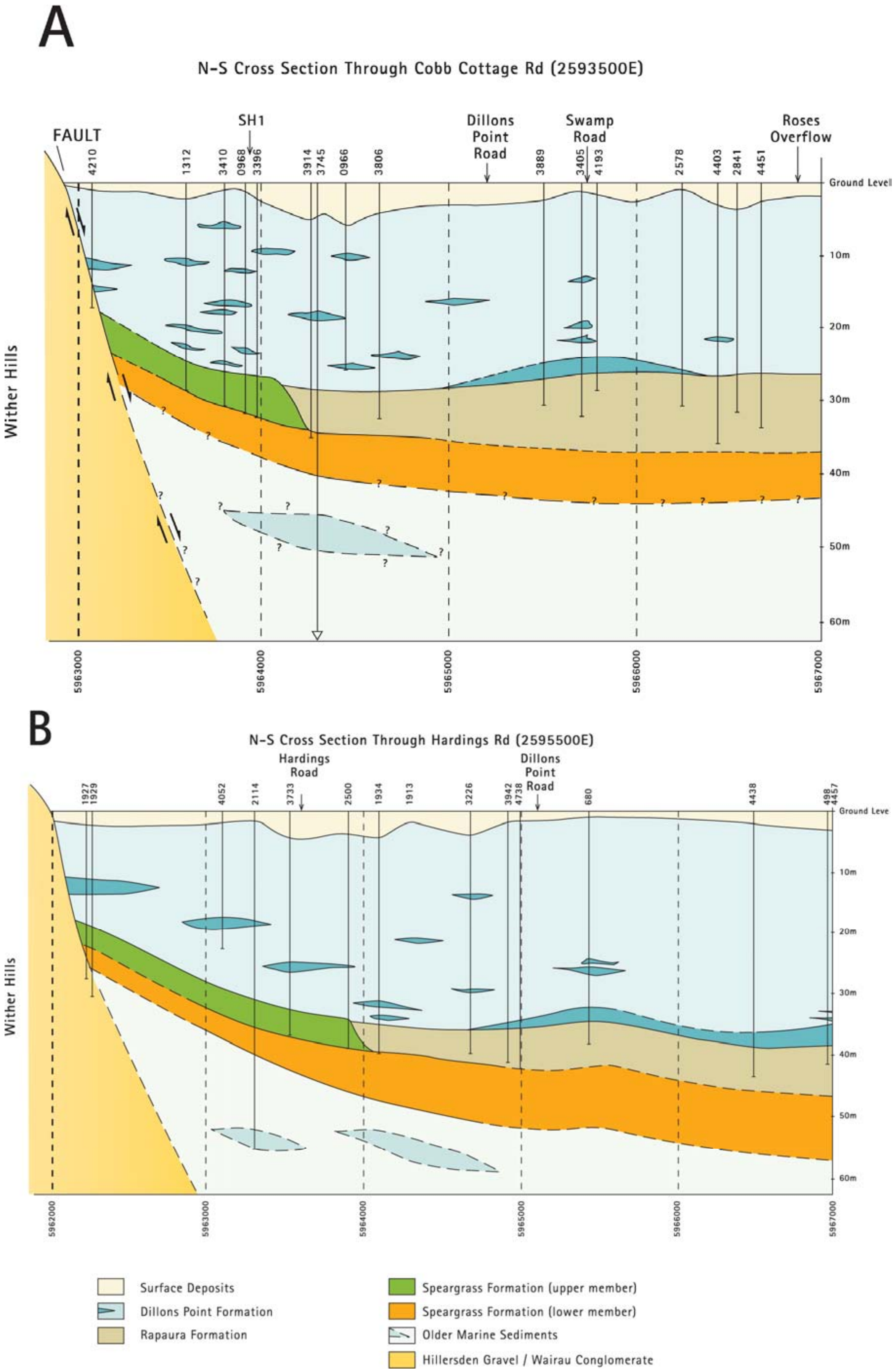

Figure 4 Representative north-south geological cross sections though the Riverlands area

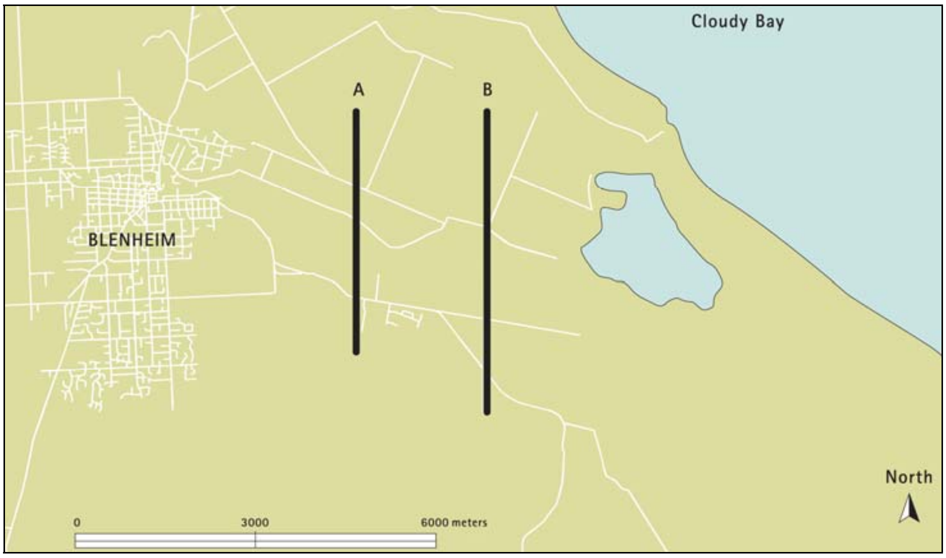

Figure 5 Location map of the two N-S Riverlands cross sections

2.1.3 Wairau Aquifer

The Wairau Aquifer is hosted by high permeability gravels of the Rapaura Formation (Brown, 1981). The Rapaura Formation is composed of alluvial gravels initially derived from the Speargrass Formation. These gravels are characterised by a high degree of alluvial reworking. This has given the Wairau Aquifer particularly high well yields, even compared to other New Zealand aquifers.

In the Riverlands area, transmissivity of the Wairau Aquifer varies from about 1,000 m^2/d to in excess of 4,000 m^2/d (Table 2). Transmissivity has been observed to generally increase towards the middle of the Wairau valley, reaching a maximum in the Lower Wairau area.

Table 2 Pumping test results for the confined Wairau Aquifer south of the Wairau River

Well	E	N	Depth	Scrn Top	Cs (m^3/d/m)	T (m2/d)	S	Source
P28w/0716	2595900	5964700				3710	1.0^{-04}	Vol 2
P28w/0739	2591800	5964400	25.3	22.3	1640	3100	5.2^{-05}	Vol 2
P28w/0742	2591500	5964300	23.5			3100	1.0^{-04}	Vol 2
P28w/0743	2596500	5964300	41.8			3160	9.7^{-05}	Vol 2
P28w/0765	2596150	5963980	38.7	34.4	1138	2450	1.0^{-04}	MDC
P28w/0786	2596200	5963800				2450	1.0^{-04}	U040191
P28w/1119	2591820	5964470	25.4	22.2	882	1700	8.0^{-05}	MDC
P28w/1678	2593731	5964273	32.0	29.0	1536	2980	2.2^{-04}	U031249
P28w/1738						1870	1.0^{-04}	Vol 2
P28w/1739						2860	7.7^{-05}	Vol 2
P28w/1741						3300	3.1^{-05}	Vol 2
P28w/1742						4000	2.8^{-05}	Vol 2
P28w/1795						2500	3.3-^{05}	Vol 2
P28w/2500	2595037	5963945	38.8	36.9	260	3400	5.0^{-04}	U020465
P28w/4191	2591550	5964318	24.3	21.7	733	970		U041758
P28w/4339	2595511	5964322	38.5	35.6	318	1673	2.0^{-04}	U041517
					Mean	2701	1.2^{-04}	
					Median	2920	1.0^{-04}	

Thickness of the Rapaura Formation is estimated to be 8m on average. The majority of wells that intersect the Wairau Aquifer are screened in the top 2-3m of water-bearing gravels. Because drillers do not consider it necessary to drill any deeper, the aquifer thickness is not known with certainty. There are some wells drilled by MDC, that have intersected a much greater thickness of water bearing gravels than this (e.g. P28w/1733 and 4403).

The Taylor River has historically dominated sediment deposition at Riverlands. There is evidence of alluvial reworking and deposition both above and below the Wairau Aquifer. A few wells in the area are screened in gravel lenses within the Dillons Point Formation (P28w/0966, 2133, 4052). Another well is screened within gravels below the Speargrass formation (P28w/3745).

2.1.4 Riverlands Aquifer

The Riverlands aquifer has not previously been distinguished as a separate aquifer to the Wairau Aquifer. The Riverlands Aquifer describes moderate to low-yielding clay-rich gravels that underlie the Dillons Point Formation along the foot of the Wither Hills. While the aquifer is found at a similar depth to the Wairau Aquifer, and the two are in hydraulic continuity, the Riverlands Aquifer is distinguished by a consistent and marked drop in aquifer yield. The gravels of the Riverlands aquifer are likely to represent Speargrass Formation gravels that have been reworked by the Taylor River.

Aquifer transmissivity within the Riverlands Aquifer is typically 300 to 350 m^2/d (Table 3). This is an order of magnitude lower than the Wairau Aquifer. At the northern edge of the Riverlands Aquifer is a narrow band of about 200m where transmissivity, is slightly higher, averaging around 425 m^2/d. Wells within this zone are still screened within the Riverlands Aquifer, and have a slightly higher specific capacity. This indicates that the aquifer margin is slightly higher yielding, and the higher transmissivity recorded from pumping tests is not solely due to the recharge effect of the Wairau Aquifer to the north.

Table 3 Pumping test results for the Riverlands Aquifer. Cs = specific capacity (m^2/d), Scrn top = depth to top of well screen, T = transmissivity (m^2/d), S = storativity

Well	E	N	Depth	Scrn Top	Cs	T	S	Source
P28w/0785	2591500	5963800	23.2			360	2.0^{-05}	U000989
P28w/1283	2591619	5963864	32.7	20.5	134	135	5.7^{-05}	Vol 2
P28w/1312	2593500	5963580	28.8	24.5	187	200	3.0^{-04}	U030920
P28w/2579	2595493	5963531	37.5	31.1	186	500	7.0^{-06}	U030074
P28w/3396	2593063	5963973	31.0	28.0	64	250	1.0^{-04}	U040691
P28w/3636	2591764	5963468	22.1	18.6	30	290	8.0^{-05}	U000989
P28w/3638	2591966	5963535	21.5	19.4	205	550	8.0^{-05}	U000989
P28w/3949	2591996	5963610	22.2	20.7	169	290	1.3^{-04}	U000989
P28w/4005	2592075	5963992	24.6	22.0	196	450	5.2^{-05}	U021132
P28w/4052	2595003	5963112	22.3	17.9	189	290	1.0^{-05}	U021199
P28w/4235	2593074	5963973	32.1	26.5	200	355	1.0^{-04}	U031313
P28w/4402	2592343	5963996	25.5	22.3	136	430	5.0^{-05}	MDC
P28w/4446	2595910	5963228	36.8	32.5	263	325	6.3^{-06}	U050668
					Mean	340	7.6^{-05}	
					Median	325	5.7^{-05}	

Despite the low yield of the Riverlands Aquifer, well productivity (step-drawdown) tests have not been required in this area. The main reason for this is that demand is typically low, with most resource consents being issued for vineyard irrigation.

2.1.5 Riverlands-Wairau Aquifer Boundary

The distribution of aquifer properties is the most accurate method for delineating the boundary between the two aquifers. The Riverlands area has more data available for aquifer properties than anywhere else in Marlborough. Despite the good availability of data, only 15% of wells in the Riverlands area have had a constant rate aquifer test performed on them.

There is considerably more data available for specific capacity, which is derived from a drillers well yield test. About 40% of wells in Riverlands have been tested for specific capacity, and this can be used as a proxy for aquifer transmissivity at a point within the aquifer.

Enough transmissivity data has been collected to derive an empirical relationship between transmissivity and specific capacity (Figure 6). Fitting a power trend curve to the two datasets allows for an estimation of transmissivity to be made for the Riverlands area:

$$T = 7.05 \text{ x } C_s{}^{0.79}, \ R^2 = 0.72$$

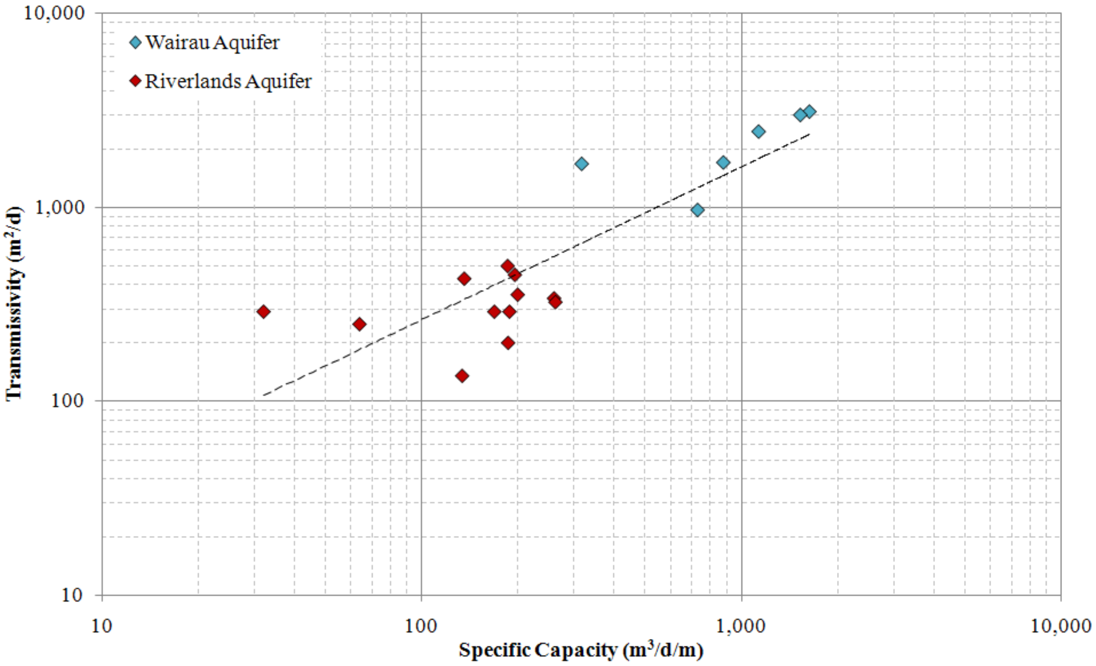

Figure 6 Relationship between transmissivity and specific capacity for the Riverlands aquifer and well screened in the Wairau Aquifer at Riverlands.

There is significant scatter in the data for lower values, and further testing in the southern Riverlands Aquifer would help to further constrain the relationship. Much of the scatter in Figure 6 derives from inaccuracies inherent in testing for specific capacity.

Specific capacity can vary widely depending on well and screen construction, development and pumping rate. However, it is the duration of the test which contributes the most error to specific capacity results. Tests are usually carried out for between one to two hours, but can be anywhere from half an hour to three hours in duration. A longer duration test tends to underestimate specific capacity, while shorter tests tend to overestimate specific capacity. This has clearly affected the accuracy of the relationship in Figure 6, as data points that lie well below the trend line have been tested for an hour (e.g. P28w/1312 and 1283). Outliers above the trend line have been tested for two and a half to three hours (e.g. P28w/3636 and 4339).

The relationship between specific capacity and transmissivity allows for the boundary between the Riverlands and Wairau aquifers to be mapped spatially. A map of the aquifer boundary for the region where it can be traced is provided in (Figure 7). The boundary has been derived by following the transition from low to high transmissivity and specific capacity values for individual wells. Note that this map also shows aquifer transmissivity data, but does not show data from specific capacity tests. The abundance of specific capacity tests carried out between Blenheim and Hardings Road allows for the boundary to be traced to within 250m in this area.

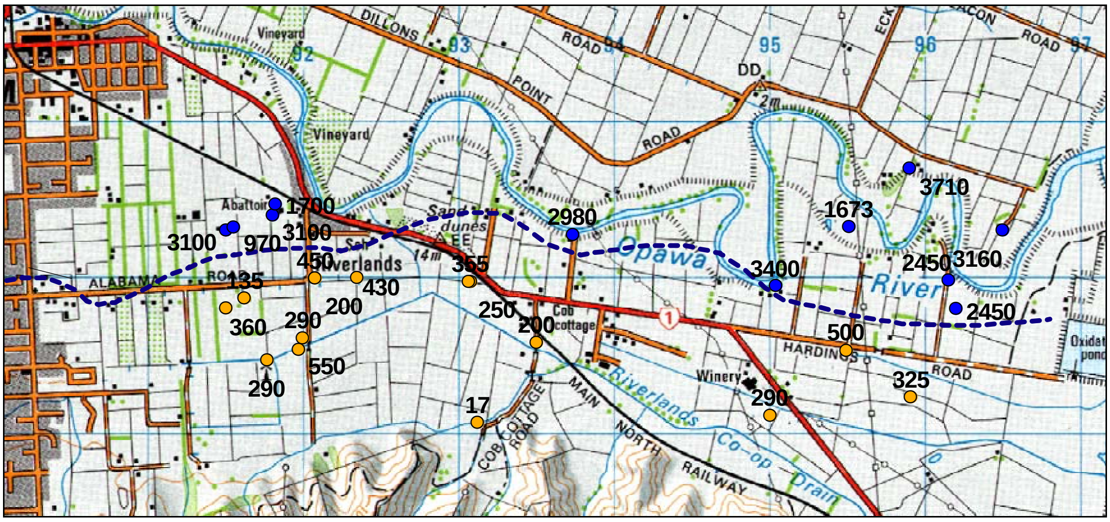

Figure 7 Map of Riverlands area showing the boundary between the Riverlands and Wairau Aquifers (dashed blue line). Aquifer transmissivity values derived from pumping tests are also shown, with Wairau Aquifer in blue and Riverlands Aquifer in orange.

2.1.6 Riverlands Aquifer Provenance

The Riverlands-Wairau aquifer boundary strikes in an east-west direction along Alabama Road, and is slightly sinuous (Figure 7). The shape of the boundary is characteristic of a river terrace escarpment.

The most likely explanation for the change in transmissivity across this boundary is that the Riverlands Aquifer sediments represent a phase of deposition that is older than the Rapaura Formation. These sediments are interpreted to be contemporaneous with the Speargrass Formation, which outcrops to the west of the present day Taylor River in the Burleigh and Ben Morven areas (Brown, 1981, 1981a). The Riverlands Aquifer sediments were most probably deposited by the Taylor River during the Otiran Glacial period. These sediments have not been reworked to the same extent as the more recent Rapaura Formation, hence their lower yield compared to the Wairau Aquifer.

The Riverlands Aquifer gravels would have formed a higher river terrace at the end of the Otiran glacial period, prior to Rapaura Formation deposition. The Rapaura gravels have subsequently infilled the river plain below the terrace at the onset of the last postglacial period. The alluvial Plain was then levelled to form a peneplain during the postglacial marine transgression, prior to deposition of the Dillons Point Formation.

2.1.7 Dillons Point Formation Aquitard

The Dillons Point Formation is the name given to the passive marine silt sequence that overlies the coastal Wairau Aquifer (Brown, 1981). Detailed stratigraphy and a depositional history of the Dillons Point Formation, including radiocarbon dates, is presented in Ota et al. (1995).Overall, the Dillons Point Formation tends to coarsen with depth from fine silt and clay near the surface to silty sand near the base. The bottom 1-2m is typically a silt, sand and shingle mix.

There is no hydraulic information available for the Dillons Point Formation. The large number of drains located east of Blenheim suggests that the unit does not act as an aquiclude, but is leaky. This is supported by the mass balance of the groundwater system (Davidson and Scott, 1994; Wilson, 2008). Aquitard leakage is also evident in potentiometric contours, which show that there is some interaction between the Wairau Aquifer and Taylor River, at least within the Blenheim area.

Aquitard leakage can be detected in the drawdown curve of aquifer tests if accurate monitoring data is available. Drawdown initially follows a typical Theis curve which gradually flattens in response to an external recharge source. This flattening is evidence of vertical leakage, most probably from the Dillons Point Formation. The leakage coefficient (K'/b') of the aquitard is difficult to estimate accurately because of tidal interference effects.

2.1.8 Speargrass Formation

The Speargrass Formation is the name given to claybound gravels found beneath the Rapaura Formation. Sediments of the Speargrass Formation are derived from glacial outwash during the Late Pleistocene. The top of the Speargrass Formation is characterised by loess and sticky claybound gravels. Beneath this layer, the unit is distinguished from the Rapaura Formation by a higher clay and silt matrix content.

2.1.9 Older Marine Sediments

Towards the coastline, some deeper bores have intersected marine sediments underlying the Speargrass Formation (e.g. P28w/1913, 3745). These sediments are similar to the Dillons Point Formation, consisting predominantly of fine marine silt and mixed blue silt and gravel. Water bearing gravel lenses are common within this deeper unit, and are typically thicker than those found in the Dillons Point Formation. These sediments are likely to be local equivalents of the Bromley Formation of Canterbury, deposited during the Kahini Interglacial period.

2.2 Aquifer Mass Balance

An aquifer mass balance characterises all the inputs and outputs to an aquifer. Input components to the Riverlands area are groundwater inflow and river flow losses. Outputs components are vertical leakage, offshore discharge to the sea, and pumping. The rate or flux of each component changes from season to season, and from year to year.

The age of groundwater gives an indication of how the groundwater flux varies throughout the aquifer. Groundwater in the Riverlands area is shown by isotopic dating to be over 60 years old (Stewart, 2008). This is considerably older than the unconfined Wairau Aquifer, and also the confined aquifer in the central plain. This implies that groundwater flux in the Riverlands area is considerably less than in the unconfined aquifer. This is not because aquifer transmissivity is less, but because flux is controlled by the way the aquifer discharges.

The hydraulic gradient of the confined aquifers is very low. Also, there does not appear to be a large component of offshore discharge at the southern margin of Cloudy Bay. As a result of these two factors, the principle direction of flow is upward rather than towards the coast. The rate of upward flow is controlled by the conductance of the Dillons Point Formation aquitard. The aquitard becomes thicker towards the coast, which restricts the rate of vertical leakage from the aquifer. In other words, the aquifer becomes more confined eastward, and hydraulic gradient increases to the extent that aquifer pressure is artesian near the coast.

The most important implication of pressure driven flow is that aquifer head is controlled by discharge rather than recharge. The relationship between recharge and discharge can be studied by plotting the relative change in fluxes over the course of a year. A transient mass balance of Riverlands groundwater has been produced as an output of the transient numerical model (Wilson, 2008). The results of the mass balance in terms of percentage flux are shown in Figure 8.

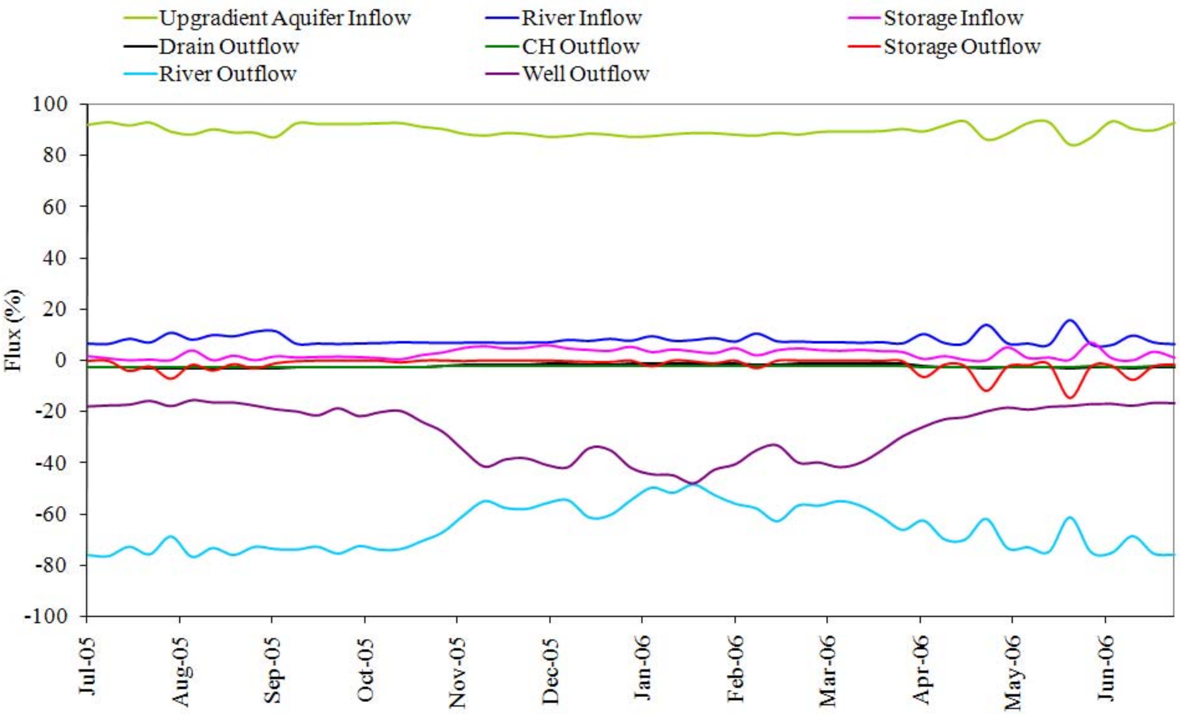

Figure 8. Water budget for Riverlands area groundwater as predicted by numerical modelling. The budget is for one year, as is presented as percentage of groundwater outflow and inflow

The mass balance shows that aquifer recharge is dominated by upgradient inflow, with an additional 10% coming from Taylor River losses. Aquifer discharge occurs mainly as losses to Taylor and Opawa rivers (via the aquitard), and as groundwater pumping. Changes in aquifer storage only have a minor contribution to the water balance.

The greatest seasonal change in the mass balance is a loss of river recharge in response to pumping. This occurs because the upward hydraulic gradient is reduced, and locally reversed, in response to pumping (Wilson, 2008). Pumping also increases the rate of upgradient groundwater inflow slightly.

A detailed review of each of the principle recharge and discharge components is covered in the following two sections.

2.3 Aquifer Recharge

2.3.1 Upgradient Aquifer Inflow

The majority of recharge to Riverlands groundwater is sourced from upgradient aquifer flow from the unconfined Wairau, Taylor Riparian, and Benmorven aquifers. Oxygen isotope data shows that this recharge water is a mixture of Southern Valleys stream water and local rainfall. This recharge is supplemented by flow losses from the Taylor River in the vicinity of Burleigh Bridge. It’s possible that there is additional recharge from meteoric seepage below the Wither Hills, although there is no clear chemical or isotopic evidence for this. The meteoric signature evident in oxygen isotope studies (Stewart, 2008) is more likely to be derived from land surface recharge to unconfined aquifers.

The mass balance for the Riverlands numerical groundwater model shows that the upgradient influx to the Wairau Aquifer changes little throughout the year (Wilson, 2008). The Wairau Aquifer south of Middle Renwick Road has approximately 9,000 m^3/d of groundwater flowing through its gravels. To put this into context, the groundwater flux is similar to discharge from the Doctors Creek spring system during periods of low flow. Note that while the flow in Doctors Creek may be typically over five times this volume during winter, the groundwater flux within the confined aquifer does not increase. The reason for this is that the springs represent the discharge of excess pressure within the confined aquifer.

By contrast, upgradient flow to the Riverlands aquifer is only 1,900 to 2,300 m^3/d. This is equivalent to approximately 0.5 m^3/d per metre, which is less than 10% of the Wairau Aquifer flux.

2.3.2 Taylor River

The mass balance shows that losses from the Taylor River account for 5-10% of groundwater inflow to the Riverlands area. The remaining inflow is groundwater throughflow from the Burleigh-Southern Springs area.

Taylor River water is sourced from rainfall, mostly at higher altitudes in the catchment. Below the Taylor Dam, the river is ephemeral, with the bed drying up for 4-5 months each year from Athletic Park southwards. The reason the river goes dry is that the Taylor riparian gravels are discharging to the Taylor Fan, Riverlands, and Wairau Aquifers at a faster rate than they can be recharged by the river. During winter when flow in the Taylor River increases, recharge to the Taylor riparian gravels increases and they eventually become fully saturated. When this occurs, there is continuous flow between the Taylor Dam and Athletic Park.

River recharge to the Riverlands area can be detected as changes in head at MDC's Athletic Park monitoring well (P28w/0949). Figure 9 shows how groundwater levels in the southern Wairau Aquifer respond to an increase in Taylor River flow. MDC wells situated close to the Taylor River at Athletic Park (P28w/0949) and Eltham Road (P28w/1313) show a rapid response to rising river levels. While this response could be due to loading of the aquitard by the river, the aquifer does maintain high pressures after river stage has subsided. These signatures suggest that the aquifer has actually been recharged by river losses.

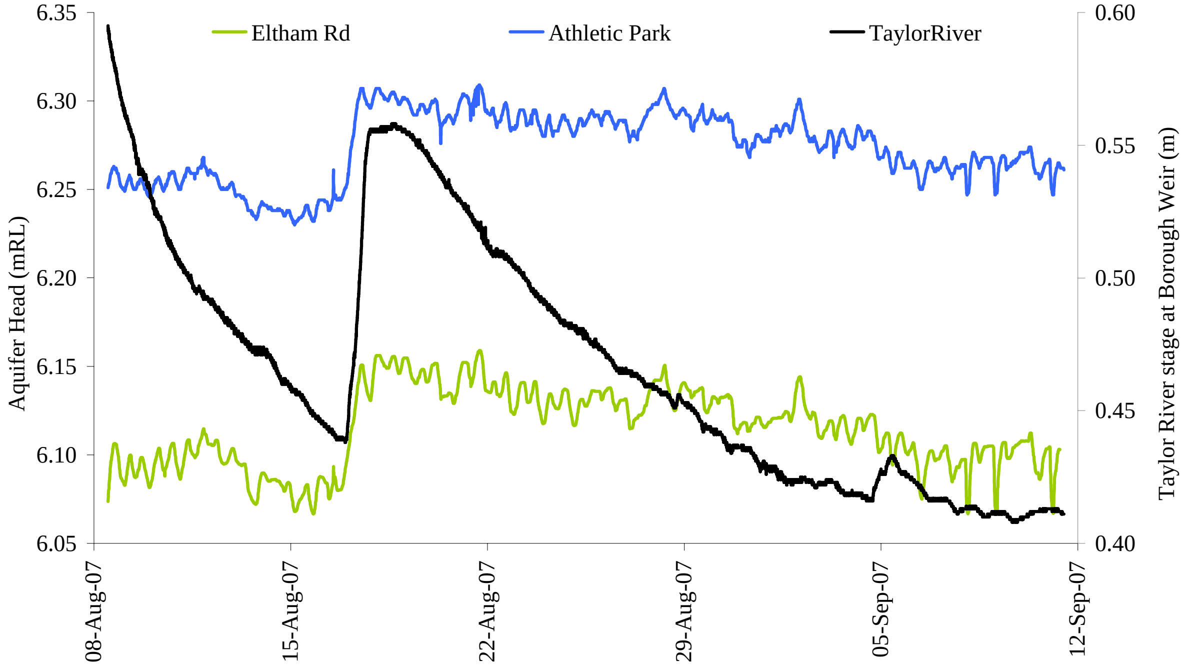

Figure 9 Hydrograph of groundwater levels at Athletic Park and Eltham Road plotted with Taylor River stage

Water levels in the Athletic Park well show a clear relationship with flow in the Taylor River. The relationship is particularly clear if the baseflow component of the stream hydrograph is plotted to remove quickflow events. Baseflow has been removed from the Taylor River record by applying a low-pass filter to the hydrograph. This removes the runoff or quickflow component of the stream hydrograph which has no bearing on groundwater levels, and creates too much scatter in the relationship.

The adjusted flow record for the Taylor River and groundwater at Athletic Park is shown in Figure 10. The baseflow separation technique used follows that described by Eckhardt (2005), using a maximum baseflow index of 0.5. The recession constant for the Taylor River recorder site is 0.992, which was derived using the matching strip method.

The Taylor River is ephemeral between the Taylor Dam and Doctors Creek confluence. There is only continuous flow above Doctors Creek confluence for 4-5 months of the year, when water levels in the Athletic Park well are above approximately 6.1m. At times when the Taylor River is dry, all of the flow below the Taylor Dam is discharged to shallow riparian gravels. During this time, the groundwater influx from the Taylor River ranges from 5 l/s to 80 l/s (Figure 11).

The rate of recharge increases at a lower rate once the riverbed is fully wetted, reaching an estimated maximum of 150 l/s during higher flow events. Concurrent flow gaugings carried out in July 2007 showed a loss of about 120 l/s between Meadowbank and Athletic Park. Over 70% of this flow loss occurred downstream of Burleigh Bridge.

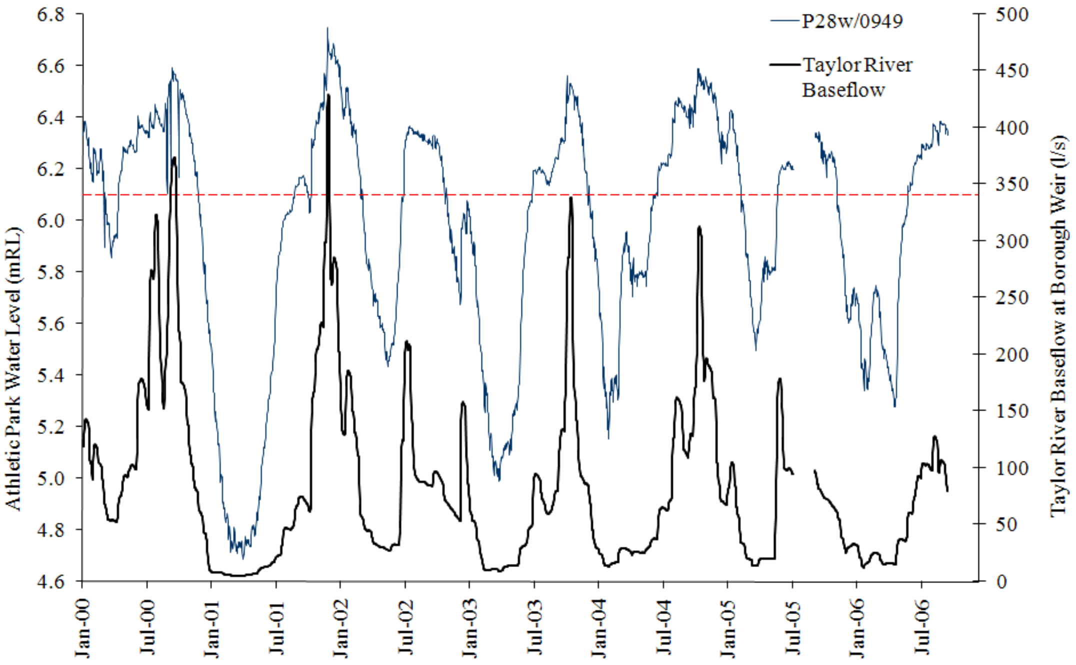

Figure 10 Head at Athletic Park P28w/0949 compared with Taylor River baseflow. The water level at which the Taylor River flows continuously past Athletic Park is also shown. The Taylor River monitoring site is located approximately 3km upstream of the Taylor Dam. Peak flow events within this period range from 2 to 9 cumec.

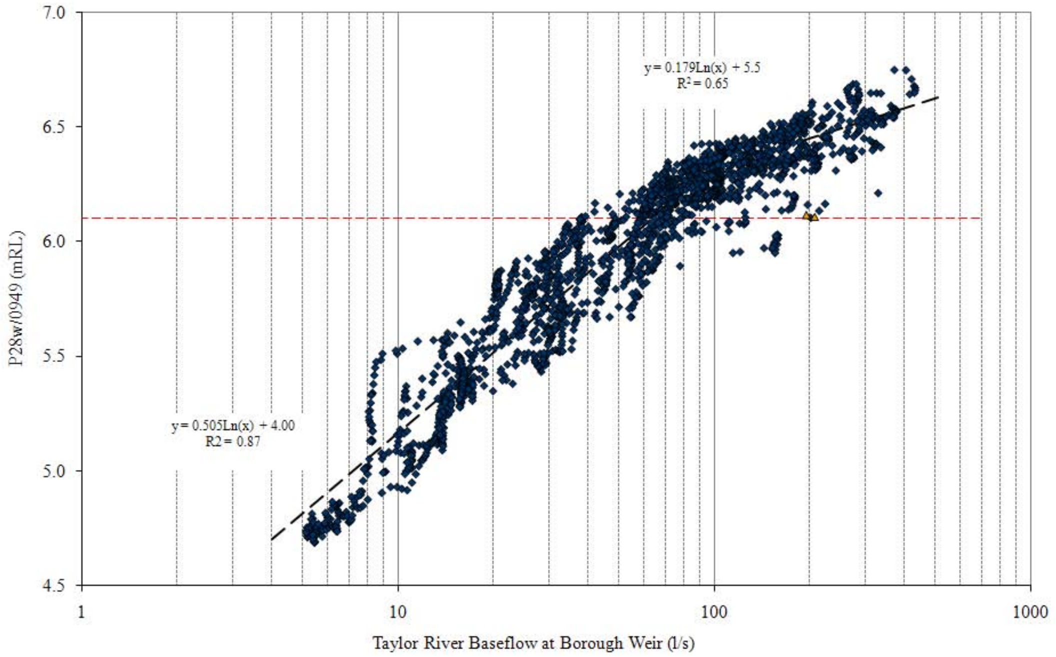

Figure 11 Relationship between Athletic Park monitoring well and Taylor River baseflow. The inflexion of the relationship marks the transition to continuous river flow, when head at Athletic Park is above approximately 6.1m.

2.3.3 Land Surface Recharge

Land surface recharge (rainfall recharge) to the confined Riverlands and Wairau aquifers does not occur in the Riverlands area due to the confining effect of the Dillons Point Formation. A minor volume of land surface recharge does enter the Dillons Point Formation, although its contribution can be assumed to be negligible.

To test this assumption, a daily soil moisture balance using the method of Rushton et al. (2006) was run from January 2000 to June 2007 on the major Riverlands soil types. Land use was assumed to be pasture with a 500mm rooting depth. The Motukarara and Temuka soils only allowed 9mm of drainage through the soil profile, while the Kaiapoi soils allowed 32mm. As a result of this calculation, land surface recharge was not included as a component in the numerical groundwater model (Wilson, 2008).

2.3.4 Upwelling of deeper groundwater

Another possible source of recharge is from upwelling of groundwater from deeper sediments in the Speargrass Formation. Taylor et al. (1992) proposed this mechanism as the reason for highly negative ^{18}O isotope values in the Riverlands area. However, if upwelling does occur, it does not cause any obvious change in groundwater chemistry. This suggests that the contribution of upwelling to the mass balance is only minor. The exception may be in areas of the Riverlands Aquifer where mixing with more highly evolved groundwater is observed. This phenomenon is covered further in the chemistry section of this report (4.1.1).

2.4 Aquifer Discharge

2.4.1 Vertical Leakage

The mass balance for Riverlands groundwater shows that recharge is drawn into the aquifer in response to an increase in aquifer discharge or loss of pressure. Loss of pressure may derive from three mechanisms:

1. Offshore discharge
2. Pumping
3. Vertical leakage through the aquitard

Thus, during late winter when aquifer pressure is high, aquifer discharge is partitioned between aquitard leakage and, to a much lesser extent, offshore discharge. The mass balance is changed considerably during summer, when additional discharge occurs in the form of pumping.

Numerical modelling has predicted that aquifer discharge in the Riverlands area mainly occurs by leakage through the aquitard (Wilson, 2008). During summer, when groundwater demand is high, most of the pumping demand is met by a reduction in vertical aquifer flow to the aquitard (Figure 12). There is also a significant loss of aquitard pressure, and a very slight increase in flux across the western boundary. The reduction in flux across the western boundary is largely met by a reduction in groundwater discharge to rivers and springs via the aquitard.

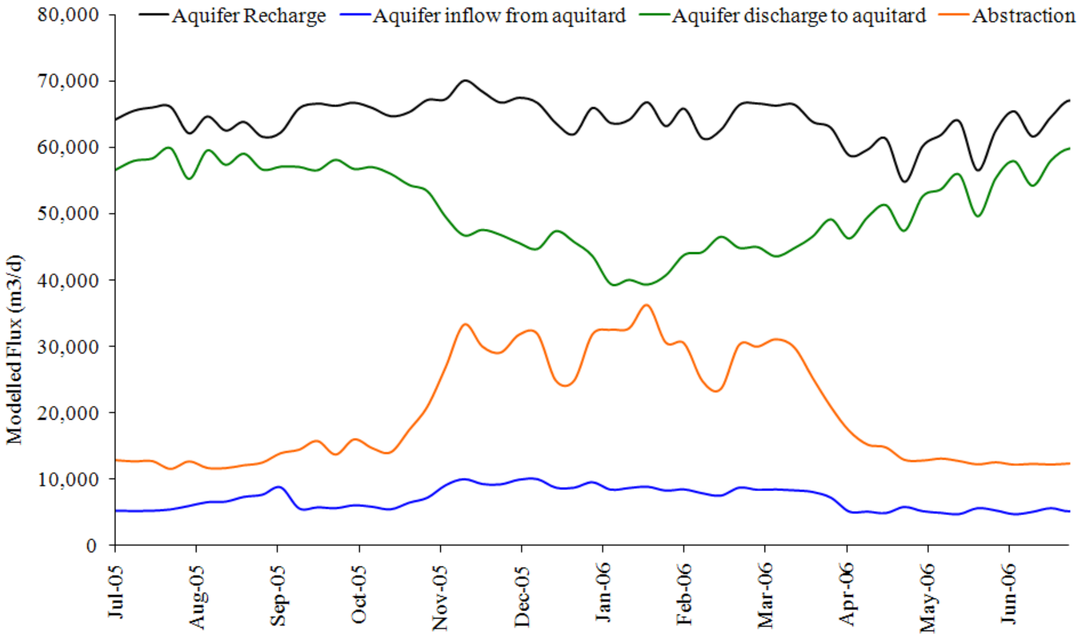

Figure 12 Graph of change in flux between aquifer and aquitard throughout the year as predicted by the Riverlands numerical model.

This conceptual model of aquifer discharge is supported by tritium isotope data, which shows a sharp increase in groundwater age between Butter Factory corner and Malthouse road. Wells situated from Butter Factory corner westward intersect young groundwater, with ages less than 10 years. By contrast, wells from Malthouse Road east intersect much older groundwater, ranging from 28 to over 60 years.

The younger ages found west of Butter Factory corner indicate that the aquifer in this area is fairly dynamic, with continual replenishment of groundwater storage. The reason for the higher turnover west of Malthouse Road is that there is more discharge from the aquifer in this area, which induces more aquifer recharge through river and spring losses. The increase in discharge is caused by a combination of vertical leakage through the Dillons Point Formation aquitard, and well abstractions.

Water chemistry results also support the concept that vertical leakage does occur within the Dillon Point Formation. Where hydraulic conductivity of the Wairau Aquifer is low, we would expect the water to be enriched in Na. However, these areas are relatively enriched in Ca. This suggests that some water is sourced from storage in the overlying carbonate-rich silts upon pumping. This is covered in more detail in the Chemistry section of this report.

The rate of leakage though the Dillons Point Formation at Riverlands has not yet been empirically measured. The main reason for this is that there is a lack of concurrent river and drain flow gauging data in the Riverlands area.

An estimation of leakage could be made from the analysis of pumping test data. However, historical pumping test results in the Lower Wairau and Riverlands area are difficult to analyse with accuracy because of pumping interference and tidal fluctuations. Carefully planned and directed pumping tests would be required to obtain data suitable for analysis of vertical leakage.

Piezometric contours indicate that leakage is most active in the vicinity of the Taylor River to the east of High Street Bridge. This suggests that the Taylor River is draining the Dillons Point Formation, which in turn is lowering pressures within the Wairau Aquifer. Unfortunately, flow gains in the Taylor River cannot be quantified. Proliferation of oxygen weed within the Taylor makes it impossible to accurately gauge river flow.

2.4.2 Offshore discharge

A potentiometric surface of the entire Wairau Plain for March 1978 was provided by Cunliffe (Figure 9, 1988). The potentiometric contours represent the distribution of pressure across the aquifer, which is largely controlled by aquifer discharge. The pattern of equipotential contours suggests that an area of increased aquifer discharge occurs offshore in Cloudy Bay, to the northeast of Wairau Bar. However, this offshore discharge from the Wairau Aquifer has not yet been detected as seafloor springs.

A region of lowered potential extends inland from Cloudy Bay toward Marukoko and Roberts Drains. This suggests that either the area of increased offshore discharge extends landward and contributes flow to these drains, or that aquifer transmissivity is significantly higher in the mid Plains area.

The rate of offshore discharge from the Wairau Aquifer is not possible to measure, and can only be realistically measured from a groundwater model mass balance. It is unlikely that there is any significant offshore groundwater discharge from the Riverlands Aquifer.

2.5 Aquifer Abstraction

2.5.1 Consented Allocation

Over 18,000 m^3/d or groundwater has been allocated from the Riverlands area (Table 4). This area includes the Riverlands Aquifer, and the southernmost kilometre of the Wairau Aquifer to 5965000 N (Figure 13). Of this allocated volume 9,550 m^3/d is allocated to MDC, and 1,200 m^3/d is allocated to Canterbury Meats Ltd (CMP).

MDC is the consent holder with the greatest allocation, with just over 50% of the total allocation. This allocation comes from two wells, at Malthouse Road, and Hardings Road, and is split between community, industrial and irrigation supply.

Table 4 Summary of water allocation and use for the Riverlands area

	Allocation (m^3/d)	**Summer Demand (m^3/d)**	**% Use**
MDC	9,550	3,200	34
CMP	1,200	750	63
Irrigation	7,400	2,960	40
Total	18,150	6,910	38

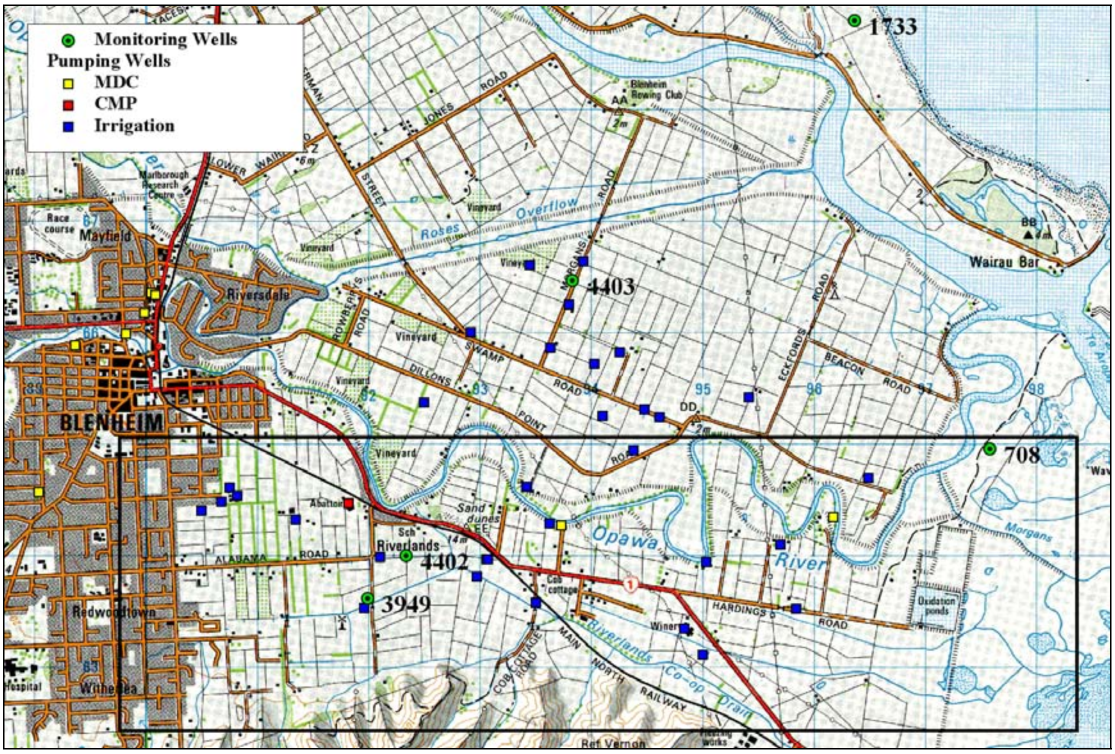

Figure 13 Are covered by the groundwater allocation study (indicated by a black box). Also shown are monitoring wells (labelled) and pumping wells with over 100 m^3/d allocation

A breakdown of water allocation by consented use is provided in Figure 14. The dominant water use in the Riverlands area is for irrigation purposes. Irrigation consents comprise 12,800 m^3/d or 70% total of the allocation volume. Viticulture is the dominant land use in the area. While vineyards use relative small volumes of water per hectare, vineyard allocation comprises 41% of the total allocated groundwater volume.

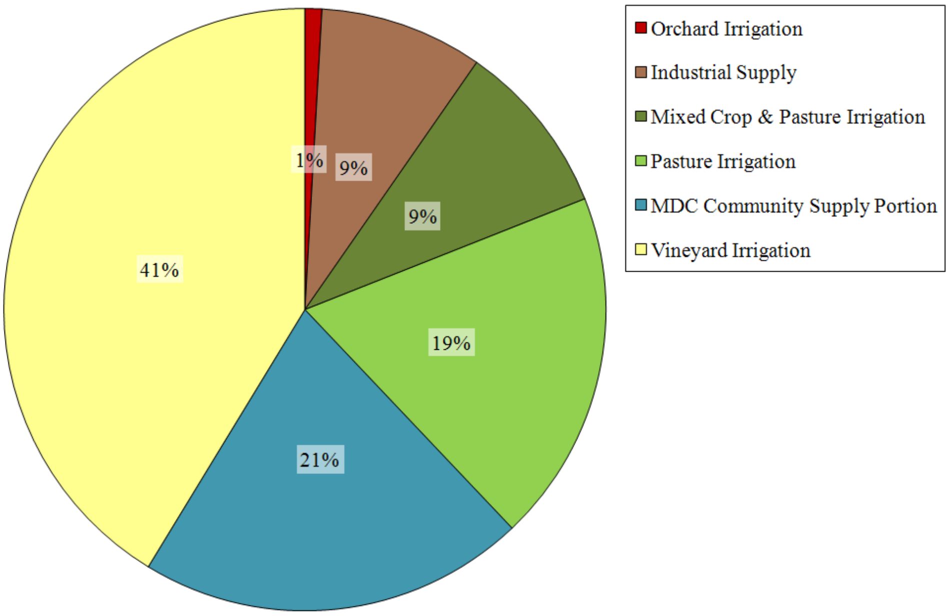

Figure 14 Pie chart of Riverlands water allocation by consented use as a percentage of total allocation volume

2.5.2 *Water Use*

Continuous water abstraction data is available for all MDC community supply wells. Water use from the two MDC wells in Riverlands, Malthouse Road (P28w/1678) and Hardings Road (P28w/1147/1148) is shown in Figure 15. Malthouse Road shows a steady increase in demand over time, peaking during April 2008 with up to 80% of allocation used. The Hardings Road well has hardly been used, mainly because the water quality is not as good as it is at Malthouse Road.

Also shown in Figure 15 is the abstraction record for the CMP wellfield. CMP records weekly water use, which is typically 50-60% of allocation to recorded maximum of 750 m^3/d. The record shows that daily demand from CMP has been fairly stable throughout the eight years of monitoring.

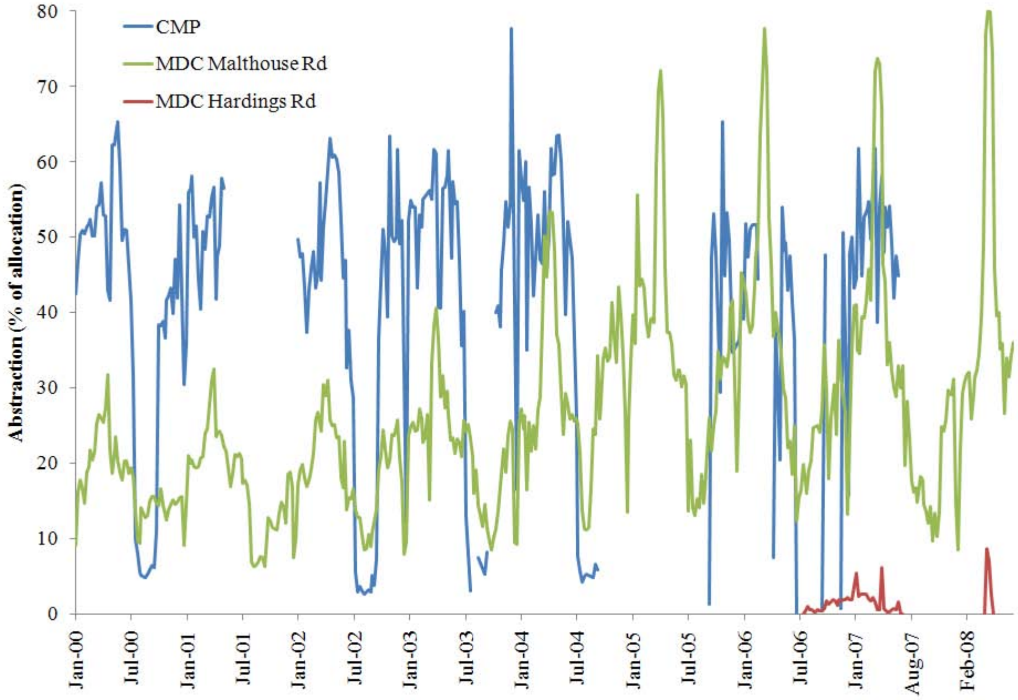

Figure 15 Abstraction rates as a percentage of allocation for wells with continuous flow records. Allocation limits are CMP 1,200 m^3/d; Malthouse Rd 3,900 m^3/d; PPCS 5,650 m^3/d

There is much less certainty in the actual volume used by irrigation consent holders. While the majority of wells have water meters installed as a requirement of their consent conditions, the water meter information is rarely recorded except during MDC surveys.

A summary of the available water meter data for irrigation wells is provided in Table 5. Abstraction volume between different consent holders varies markedly. Also, the seasonal abstraction volume for each consent holder also varies from year to year. The high variability of use shows that it is difficult to predict seasonal abstraction rates for any single well in the Riverlands area unless the meter data has been recorded.

Assuming a 120-day irrigation season, the available data suggests that irrigators tend to only use about 35-40% of their allocation. The exception appears to be during vineyard development, when irrigators may apply greater volumes to get the plants established.

Table 5 Water meter data of abstractions with long term use records assuming a 120-day irrigation season. Use codes are C-cropping, P-pasture, V-vineyard, O-orchard

Well	Use Type	Allocation (m^3/d/Ha)	Average use (%)	Percentage of allocation used over season					
				2002/03	2003/04	2005/06	2006/07	2007/08	Other
1312	P	21	20				0	30	31
2500	V	18	43				47	39	
2558	V	22	3				3		
3396	V	12	60					83	38
3405	P	40	62	86				39	
3447	V	22	60				60	69	53
3745	O	14	30	100			0	1	18
3806	V, P	17	16				15	18	
3944	V	13	40	63	19		60	0	60
4005	V	18	64		28	130	54	42	65
4029	P	50	12	1			8	13	26
		Average	37	62			27	33	41

Water use also seems to vary between each summer season. Of the irrigation seasons listed in Table 5, 2002-2003 was the driest overall, followed by 2006-2007. February-March 2007 was a particularly dry period, but preceding rainfall was normal. While data availability is limited, the observed water use during these drier seasons does not significantly increase.

A summary of allocation and peak demand for Riverlands during the 2007-2008 irrigation season is shown in Table 6. Several water meter surveys were carried out during this season, and a request was made by MDC for irrigators to voluntarily submit water meter data. As a result, there is data for larger number of users for the 2007-2008 summer.

Table 6 Riverlands groundwater use as measured during the 2007/2008 irrigation season. The daily useage assumes a 120-day irrigation season. Use codes are C-cropping, P-pasture, V-vineyard, O-orchard

Well P28w/	Use	120-day abstraction (m^3/d)	Allocation (m^3/d)	Area (Ha)	Allocation (m^3/d/Ha)	% Use
0680	C, P, V	2,282	3,055	116.5	26	75
1208	C, P	72	600	13	46	12
1285	V	98	668	12.5	53	15
1312	P	89	300	14	21	30
1322	V	485	1,494	36.7	41	32
1451	P	0	136	8	17	0
1708	V	52	319	14.5	22	16
2500	V	209	540	30	18	39
2578	V, P	222	697	21.5	32	32
2579	O	177	350	7	50	51
2881	V	618	1,658	83	20	37
3396	V	216	260	22	12	83
3405	P	155	400	10	40	39
3447	V	1,180	1,700	76.5	22	69
3745	O	2	164	11.5	14	1
3806	V, P	89	483	29	17	18
3889	V	625	1,659	83	20	38
3944	V	0	110	8.2	13	0
4005	V	98	234	13	18	42
4029	V	59	450	9	50	13
4106	V	39	1,590	31.8	50	2
4240	V	319	416	26	16	77
				Average Use	**27**	**40**

Average demand was 40% for the season, but varies considerably between users, from 0 to 83% of allocation. Furthermore, there is no clear relationship between water use, and crop type, location and soil type. It appears that water use is dependent on the perception of the irrigator rather than climatic or soil factors.

3 AQUIFER DYNAMICS

3.1 Hydrographs

3.1.1 P28w/0708, MDC at Lagoons

Aquifer dynamics can be assessed by studying hydrographs of strategically placed monitoring wells. The MDC coastal monitoring well at the Wairau Lagoons has the longest record of observations in the Riverlands area. This well is screened within the extreme southeast corner of the Wairau Aquifer. The well is an indicator of head at the furthest point from the Wairau Aquifers main source of recharge, the Wairau River.

The hydrograph of mean daily head for the Lagoon well is shown in Figure 16. Mean daily head has been plotted, as there well is strongly affected by tidal fluctuations, and these obscure the overall hydrograph trend. The tidal range in the Lagoons well is typically 200 to 320 mm, depending on the actual tidal range.

Head in the Lagoons well is drawn down rapidly each year in response to pumping, but also recovers fully during each winter. Historically, water levels have fluctuated between about 2.3 and 3.3m above mean sea level annually. 2008 shows a marked departure from this trend, with head reaching a record low of 1.9m.

This additional drawdown is a response to increased demand from irrigation wells. The MDC wells had very little influence on drawdown at the Lagoon well despite higher than ever abstraction rates. During April 2008, the MDC Hardings Road wellfield pumped at an average rate of 400 m^3/d, and Malthouse Road pumped at 3,000 m^3/d, which is up to 80% of allocation (Figure 15). However, the high MDC pumping rates occurred after the irrigation season when water pressures were rapidly recovering. The additional drawdown must therefore reflect new irrigation demand coming online in the Riverlands-Lower Wairau area.

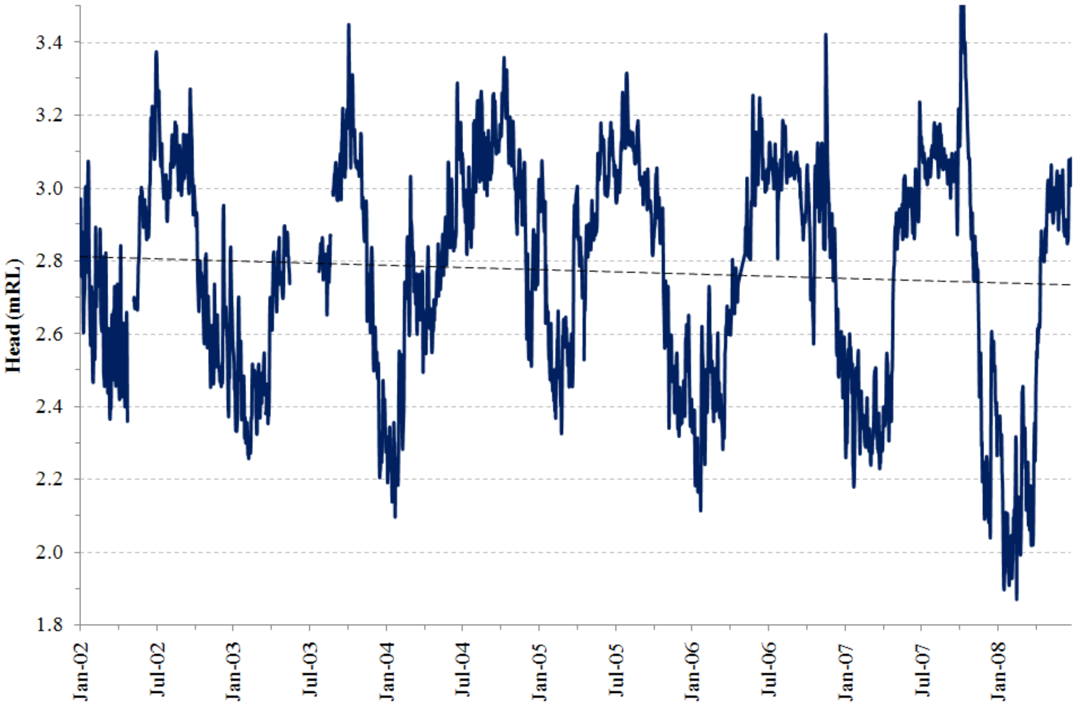

Figure 16 Hydrograph for MDC coastal monitoring well at Wairau Lagoons (P28w/0708).

3.1.2 P28w/4402, MDC at Huia Vineyard

The MDC well at Huia vineyard was installed to observe water levels within the Riverlands Aquifer. The well is screened within the Riverlands Aquifer at a depth of 22.3-25m. Continuous records for this well started in October 2006, (Figure 17). Head fluctuates on an annual basis by over a meter, from about 1.7m during the summer to 2.8m during the winter. High river flow events are met by a rapid and large increase in head, which rapidly subsides when flow recedes. This indicates that freshes in the river increase the loading pressure on the aquifer, causing aquifer head to briefly increase.

Water levels start to fall after the onset of the irrigation season in November to December, with irrigators gradually coming online over the course of the summer. Unless there are significant flows in the Taylor River, head remains at low levels until late March to early April when vineyard irrigators turn off before harvesting. The response in the Huia well to a reduction in pumping is rapid, with 0.8m rebound during April, and over half a meter rebound in the course of a single week. The rate of rebound is rapid because harvest occurs over a very short period.

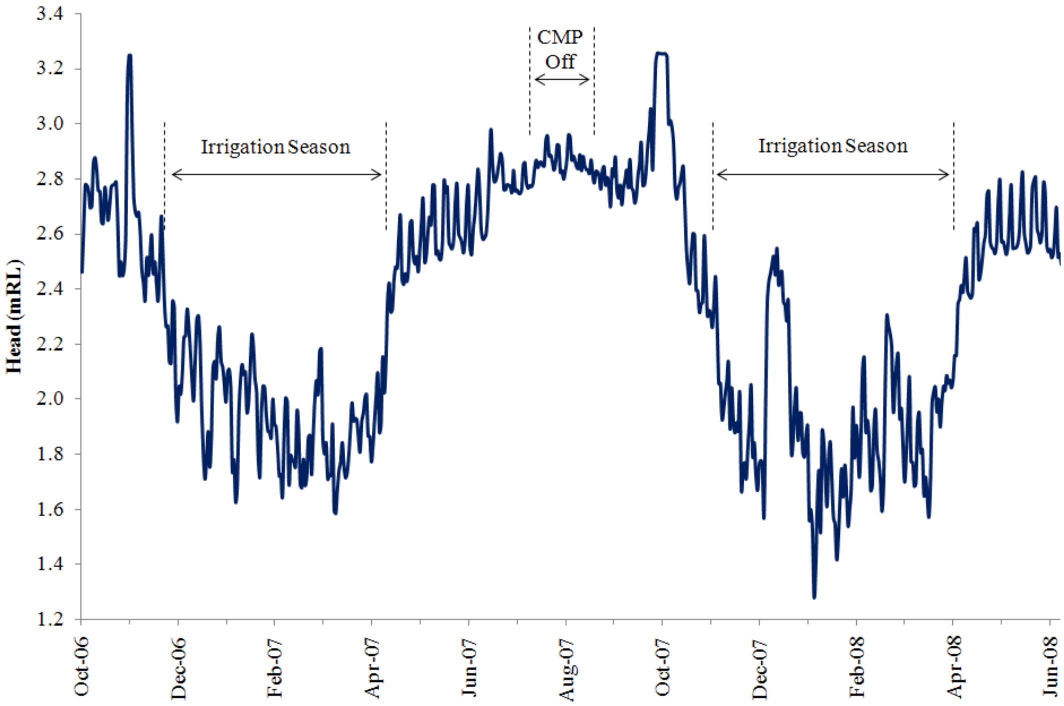

Figure 17 Hydrograph of MDC monitoring well P28w/4402 at Huia Vineyard

There is very little period of record available when the Huia well is not affected by pumping interference, even outside of the irrigation season. Abstraction from the MDC community supply well at Malthouse Road creates the most obvious interference effect in the Huia well hydrograph (Figure 18). While the Malthouse Road well draws from the Wairau Aquifer, and is 1,400m away, its drawdown at Huia is about 400mm when pumping at 1,600 m^3/d (40% of allocation). Its effect on the hydrograph is so pronounced that it is difficult to discern drawdown from the CMP plant, or any tidal fluctuations. The CMP well, also screened in the Wairau Aquifer, is only 850m away, and 600 m^3/d is typically used during production. The Theis equation predicts a pumping response of 150 mm to be apparent at the Huia well. The observed response to a seasonal shutdown is about 100mm. The difference is due to heterogeneity and uncertainties in aquifer properties, which make precise drawdown predictions difficult, particularly across the Riverlands Aquifer boundary.

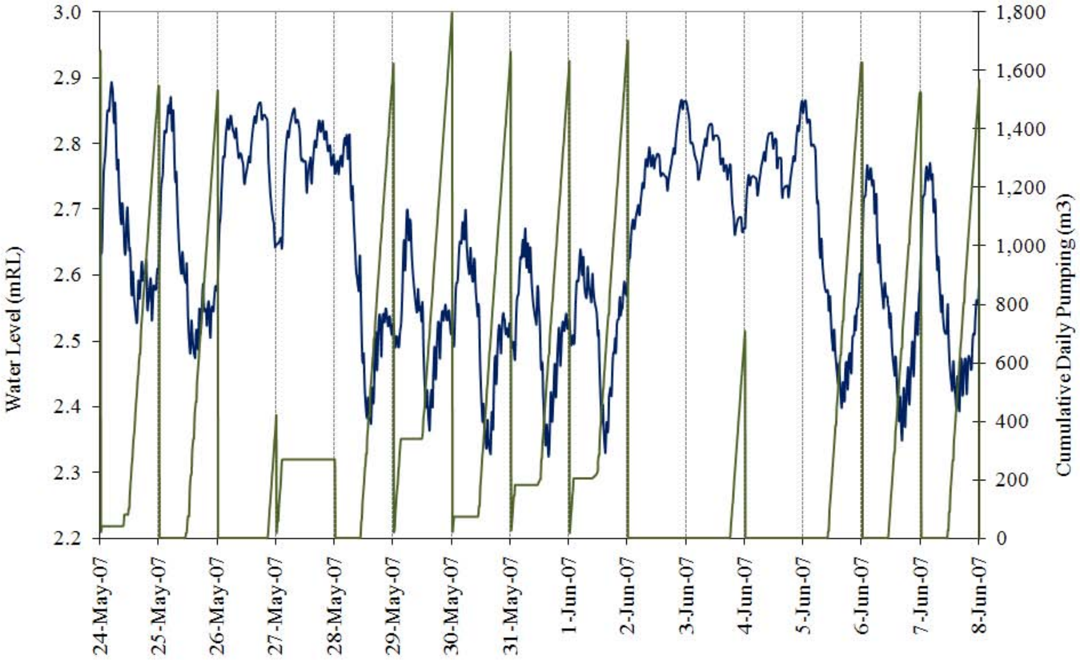

Figure 18 Hydrograph of MDC monitoring well P28w/4402 outside of irrigation season, compared with daily cumulative abstraction at Malthouse Road

During July to September the CMP plant closes down and the drawdown effect of the Malthouse Road well can be seen more clearly in the Huia well hydrograph (Figure 19). A tidal range of 95mm (40 to 45mm amplitude) can also be seen in the hydrograph when the Malthouse Road well is not operating

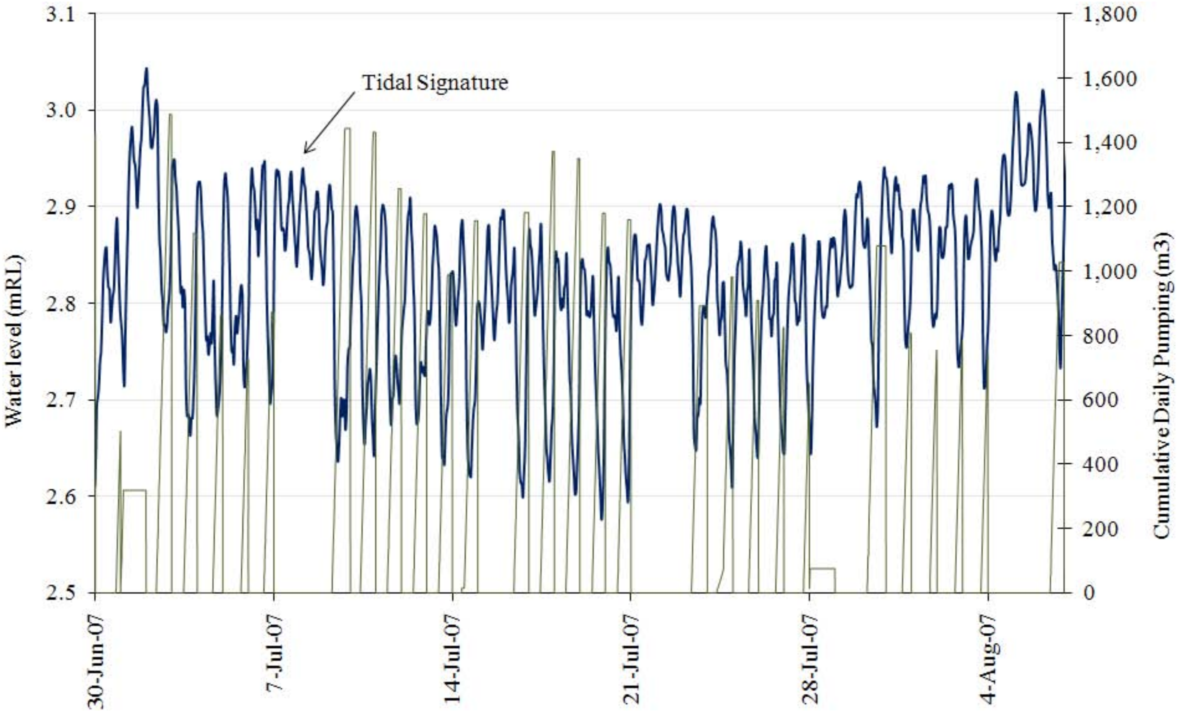

Figure 19 Hydrograph of MDC monitoring well P28w/4402 when CMP plant is not in operation, and daily cumulative abstraction at Malthouse Road

3.1.3 P28w/3949 at Diamond

The Diamond well is a private domestic well in the Riverlands Aquifer at the end of Alabama Road. This well was manually monitored on a regular basis by MDC from October 2003 to May 2005 (Figure 20). Further monitoring was carried out from July to November 2007 in order to clarify the relationship between the Diamond and Huia wells.

Several consents in the vicinity of the Diamond well have conditions to reduce or cease pumping when head reaches 6m below ground level (-4.94 mRL). The reason for this is that the Diamond well is used for domestic purposes, and a 5m drawdown threshold was considered to provide protection for this well to continue operating with a surface mounted pump. The monitoring record shows that water levels have remained well above the recommended threshold.

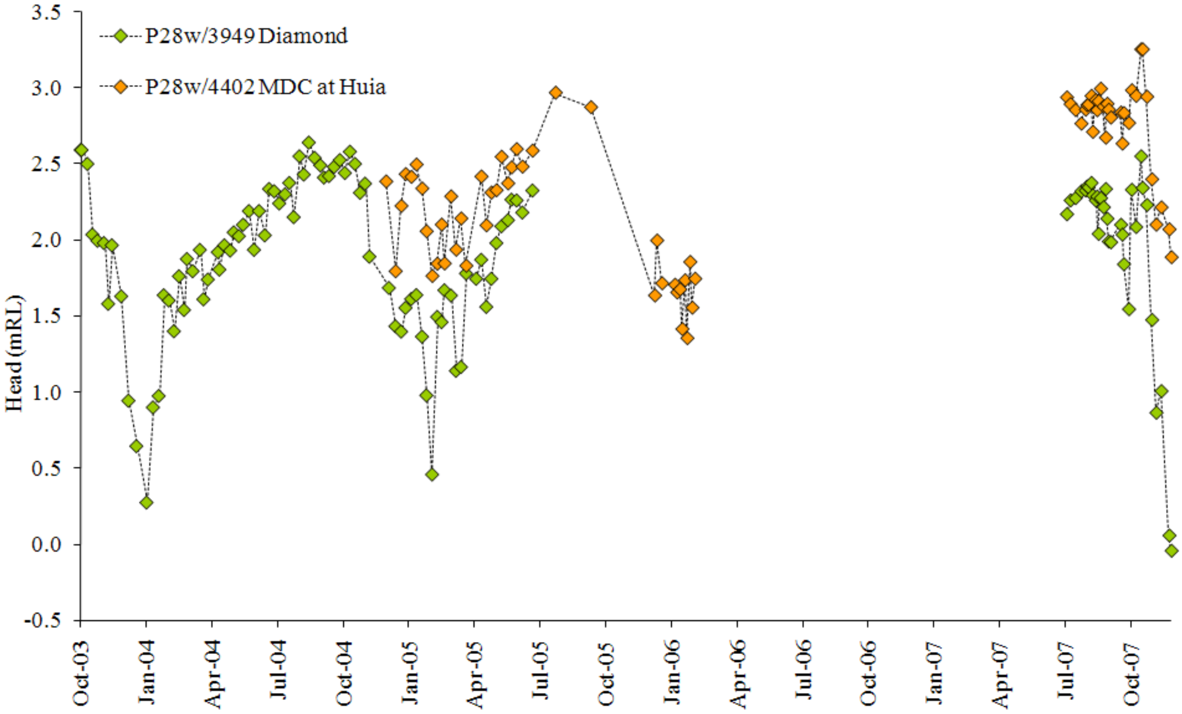

Figure 20 Manual monitoring record for the Huia and Diamond wells.

Water levels in the Diamond well are affected by the operation of the surface mounted pump. Because of this interference, the Huia well was drilled in 2004 as a monitoring well specifically for the Riverlands Aquifer. Manual monitoring of both wells continued until May 2007, when regular monitoring of the Diamond well ceased. Monitoring was continued again for five months in 2007 to increase confidence in the relationship between the Diamond and Huia wells.

Sufficient records have been collected for a relationship between the Huia and Diamond wells to be made (Figure 21). The relationship includes all available data for the Diamond well from 2003 to 2007. Interference effects at the two sites have required that some outlying data points be removed. Interference is particularly pronounced at Diamond which is affected by pumping for domestic use. The relationship is as follows:

$$\text{Diamond} = 1.37 \times \text{Huia} - 1.71, \quad R^2 = 0.69$$

This relationship predicts that the -4.94 mRL threshold at Diamond is equivalent to a water level of -0.83mRL at Huia.

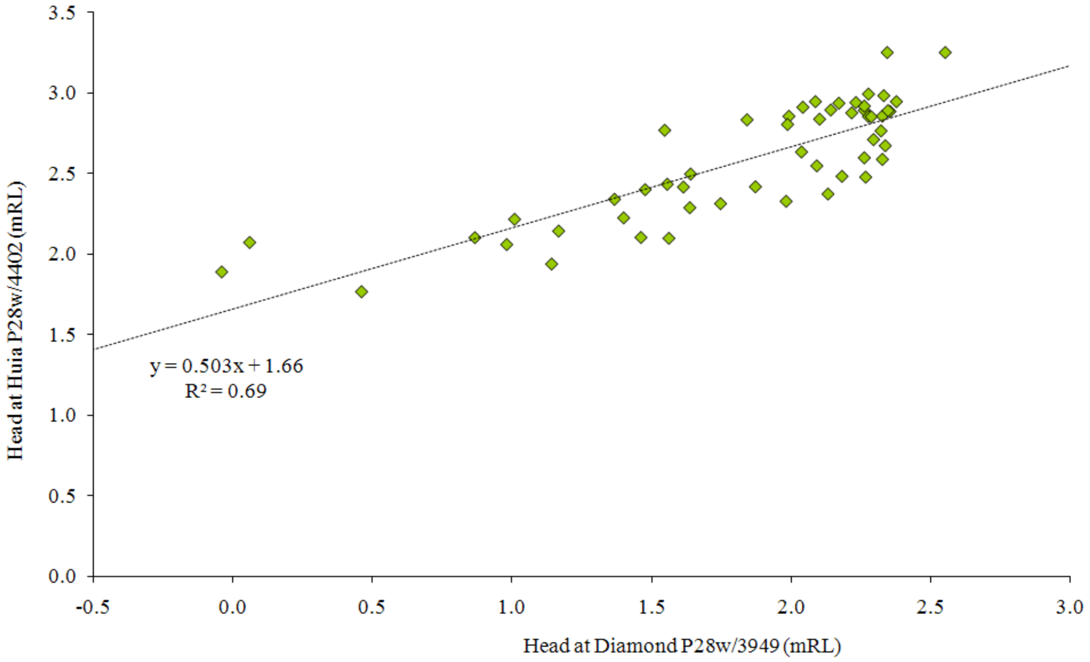

Figure 21 Relationship between the Huia and Diamond monitoring wells

3.1.4 Comparative Hydrographs

Figure 22 is a comparative plot of the hydrographs at Huia, Lagoons and Athletic Park monitoring wells. The Head at Huia is the lowest of the three wells. This reflects the well's relative topographic height, but also its position at the transition between leaky and more fully confined conditions.

Aquifer conditions at Huia are more effectively confined compared to Athletic Park. The increase in confined is manifest in a smaller value of storativity at Huia. The lower storativity is immediately apparent in the Huia well's response to a 3 cumec fresh in the Taylor River on 18 November 2006. The fresh produced a 0.16m rise in head at Athletic Park, whereas the response at Huia was over 0.8m with head flowing over the well standpipe. The effect of increasing aquifer confinement between Huia and the coast is manifest in a 350mm increase in head between Huia and the Lagoons well.

The Huia well shows more pumping drawdown effects than the other wells. This is mainly due to the high concentration of demand in the near vicinity of this well. Water levels in the Athletic Park well have a large annual variation, but very little pumping interference. The reason for this is that head in this well is closely related to flow in the Taylor River, which is ephemeral.

The Huia and Lagoons wells start to recover at the end of the irrigation season, towards the end of April. The Athletic Park well does not recover again until a week after irrigation ceases, when there is a 1.35 cumec fresh in the Taylor River.

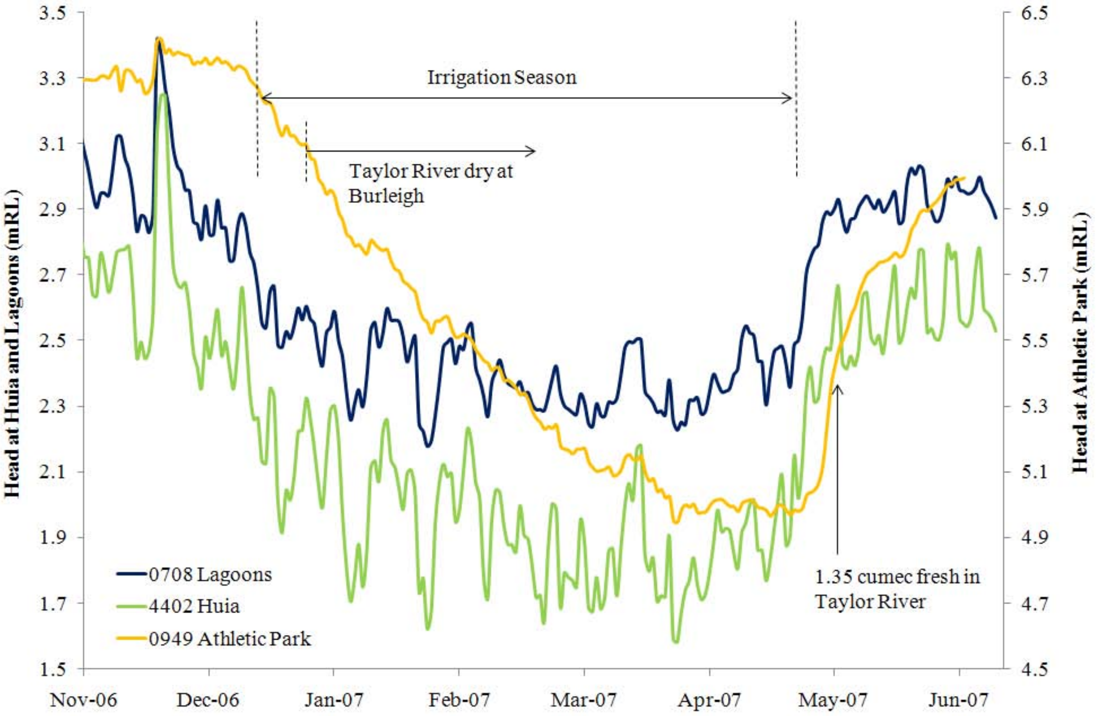

Figure 22 Comparative hydrographs of mean daily head at the Huia, Lagoons and Athletic Park monitoring wells

3.2 Potentiometric Surveys

The first piezometric survey of the Lower Wairau area was carried out in March 1978. This survey is plotted in Figure 9 of Cunliffe (1988), and the data is provided in Appendix 5 of the same report.

The 1978 survey has been re-plotted in Figure 23, as there were some data points included in Cunliffe (1988) that are not representative of the aquifer. The results show a regional pattern of Wairau Aquifer discharge towards the Marshlands/Lower Wairau area. At the southern margin of the Wairau Plain there is a groundwater divide, with contours to the south of Swamp Road dipping towards the Wither Hills. This results in the coastal head at the Lagoons well (P28w/0708) being lower than the Wairau Bar well (P28w/1733).

In Blenheim, the contours inflect around the Taylor River indicating that aquifer Discharge is occurring in around the river. There is very little definition at Riverlands, as few wells in this area were included in the survey.

Recently, five detailed potentiometric surveys have been carried out in the Riverlands-Lower Wairau area. Contour plots of the surveys are presented in Figure 24 to Figure 28. The resulting potentiometric surfaces are consistent with results of the 1978 survey, but show more definition of the Riverlands Aquifer.

The recent potentiometric surveys show a rapid drop in head from the Southern Springs area to the west of Blenheim, with the potentiometric gradient flattening from Blenheim toward the coastline. Within Blenheim, an embayment in the contours occurs around the Taylor River, representing loss of head due to seepage losses to the river. The influence of the Taylor River appears to diminish at the eastern edge of Blenheim.

Figure 23 Potentiometric Survey of March 1978. Measured wells are shown as blue dots

Plots for the winter period can be considered to portray the distribution of aquifer losses to the aquitard. Plots for summer plots can be considered to be more representative of head losses caused by pumping. The regional pattern of head distribution in the Riverlands-Lower Wairau area remains fairly consistent throughout the year. The major seasonal changes that do occur are changes in the magnitude of the head. Seasonal changes in head become more prominent towards the coast, particularly in the Hardings Road area where loss of aquifer pressure is greatest during the irrigation season. Pumping can also create large local interference effects that distort the regional head distribution (e.g. at Alabama Road, Dec 2007, Figure 26).

The new survey plots show that there is a steep pressure gradient within the Riverlands Aquifer, with low heads occurring along the edge of the Wither Hills. During summer, this pressure gradient becomes much steeper than during winter. The pressure gradient occurs because aquifer yield in the Riverlands Aquifer is much lower than the Wairau Aquifer. So when the Riverlands aquifer is pumped, aquifer head is lowered to a relatively large degree. Furthermore, the potential for winter recharge is also less in the Riverlands Aquifer than in the Wairau Aquifer. The low transmissivity of the Riverlands Aquifer means that it doesn’t recover to the same extent.

The steepening of the pressure gradient towards the Riverlands Aquifer is most pronounced in the Hardings Road area (compare plots for the 2007-2008 summer, Figure 26, Figure 27 and Figure 28). This is a response to a higher demand in the Hardings Road area during the summer period. It is also apparent in April 2008 (Figure 28) that lower pressures also occur within the Wairau Aquifer adjacent to the Riverlands Aquifer boundary. The reason for this is that there is a high transmissivity contrast between the two aquifers, with the Riverlands Aquifer acting as a discharge boundary for the Wairau Aquifer.

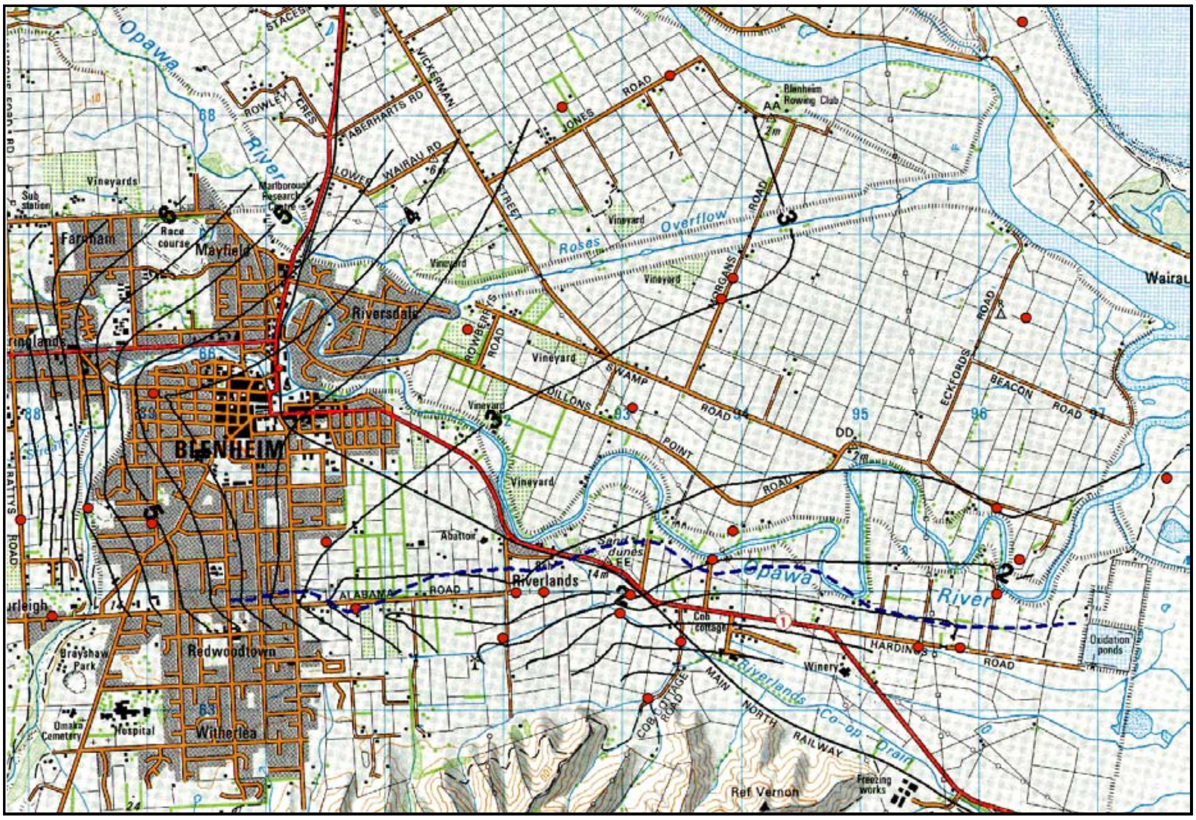

Figure 24 Potentiometric contours from survey 15 April 2004. Measurement sites and the Riverlands Aquifer boundary (blue line) are also shown

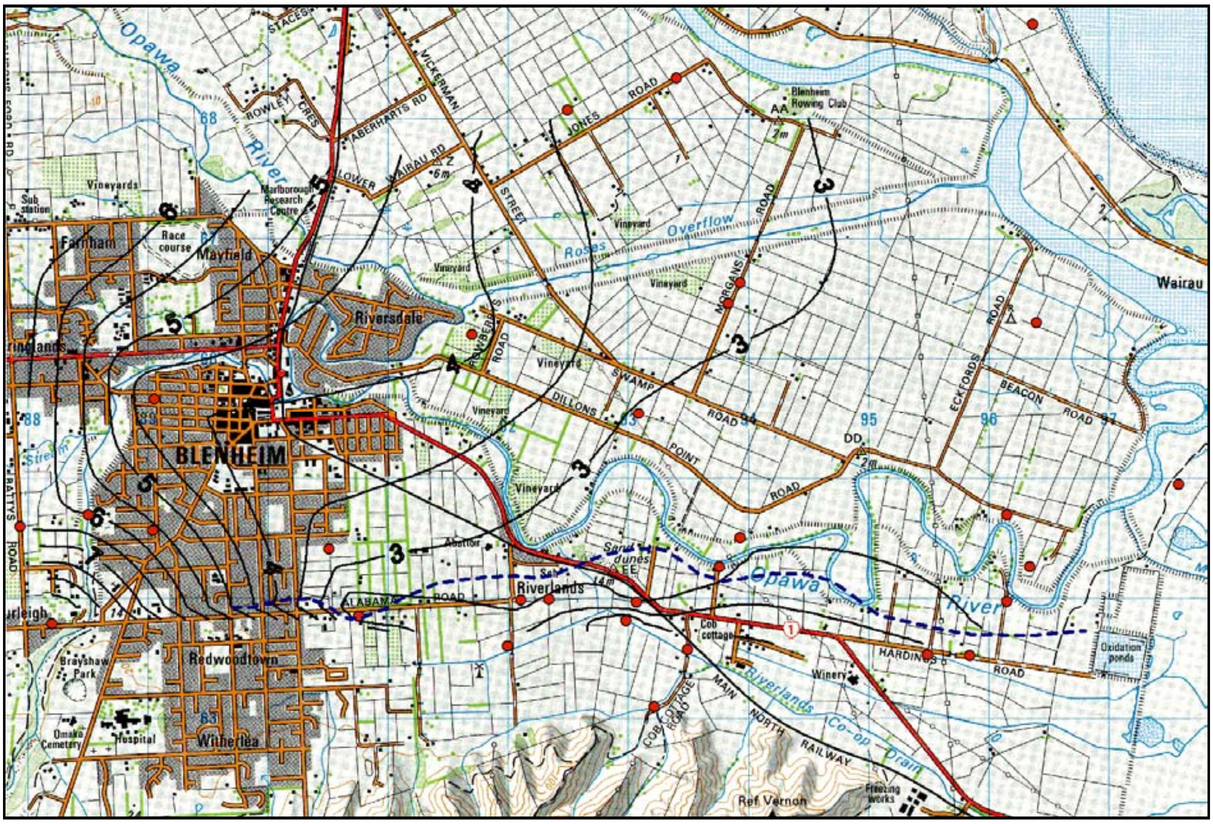

Figure 25 Potentiometric contours from survey 13 June 2007. Measurement sites and the Riverlands Aquifer boundary (blue line) are also shown

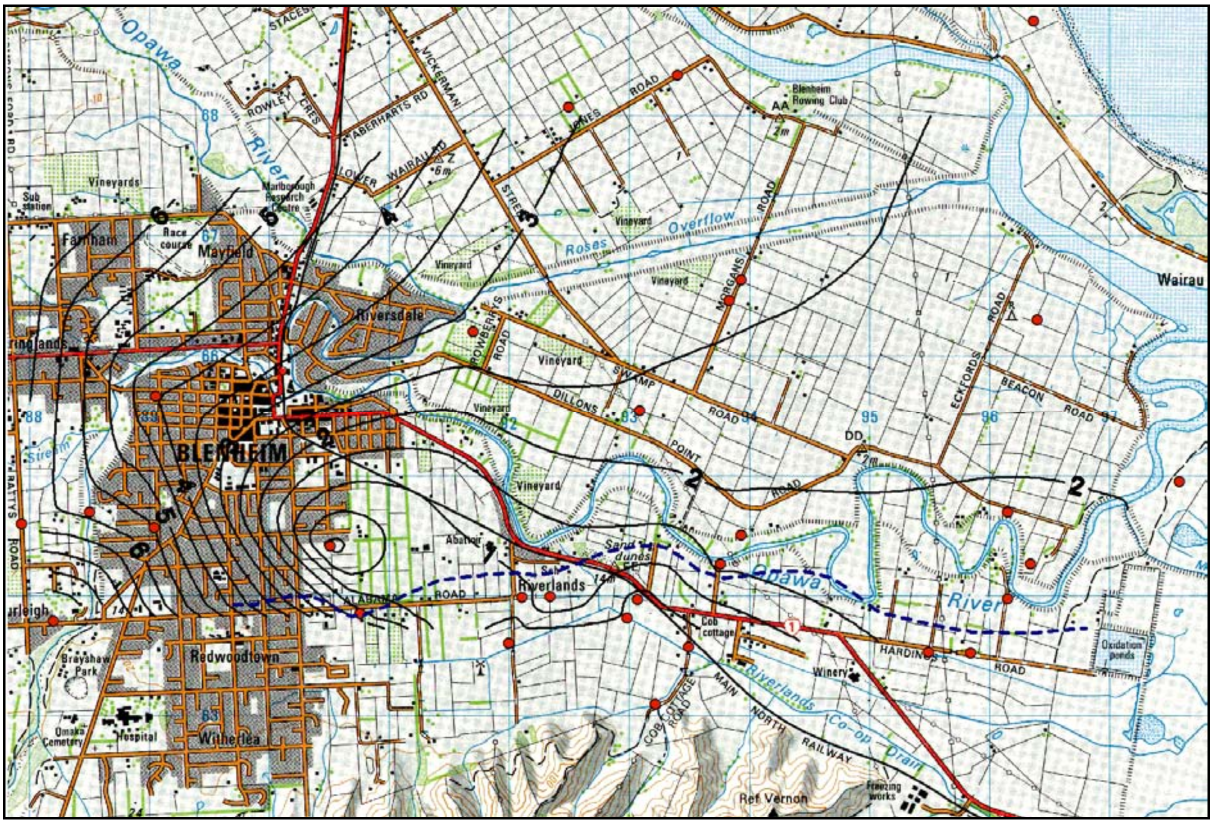

Figure 26 Potentiometric contours from survey 7 December 2007. Measurement sites and the Riverlands Aquifer boundary (blue line) are also shown

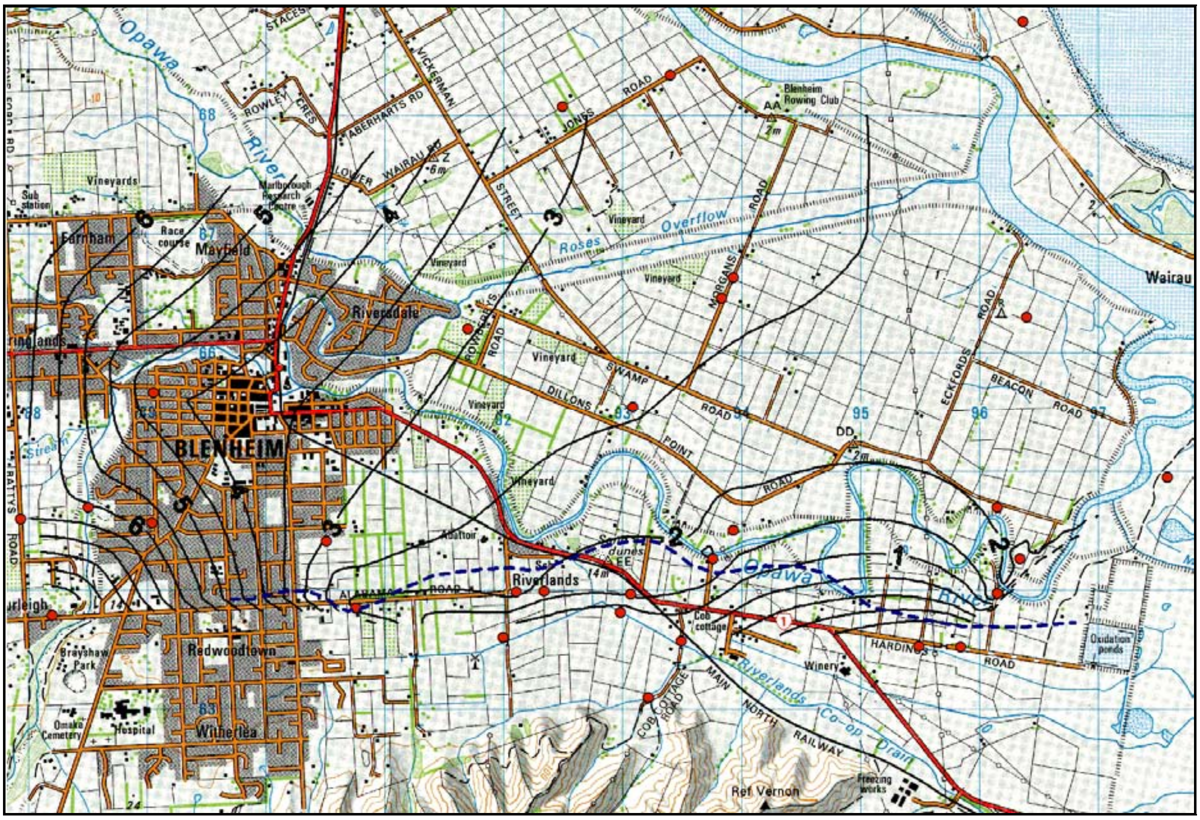

Figure 27 Potentiometric contours from survey 9 January 2008. Measurement sites and the Riverlands Aquifer boundary (blue line) are also shown

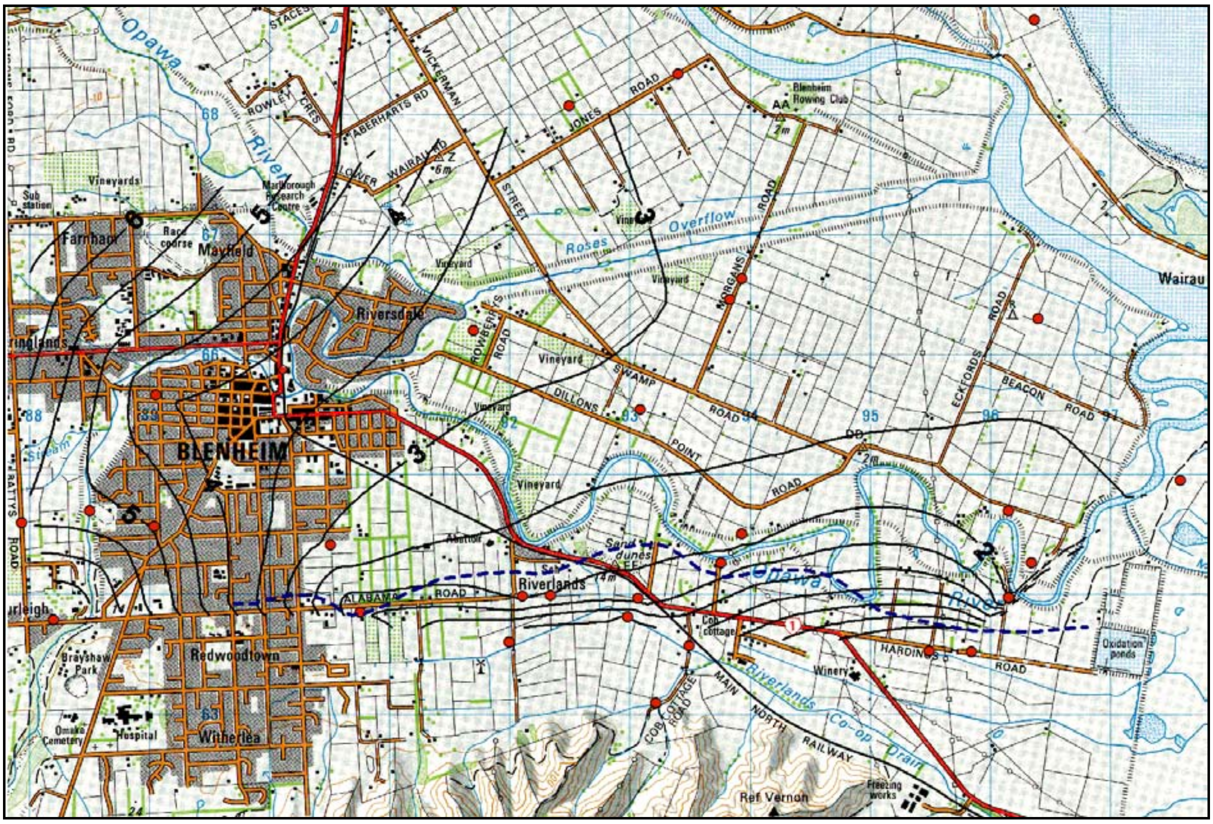

Figure 28 Potentiometric contours from survey 8 April 2008. Measurement sites and the Riverlands Aquifer boundary (blue line) are also shown

4 GROUNDWATER CHEMISTRY

4.1 Major Element Chemistry

4.1.1 Groundwater Character and Evolution

A useful way to study groundwater chemistry is to plot the major cations and anions on a Piper diagram (Figure 29). This allows us to see how the relative proportions of the major ions change throughout the aquifer, so we can determine how groundwater evolves. Three main trends in aquifer evolution are apparent in the Piper diagram:

1. Immature groundwater (Class 1B)
2. Evolved groundwater (Class 1B to 2A)
3. High TDS groundwater (Class 2B)

The above classes refer to water categories developed for the National Groundwater Monitoring Program (Daughney, 2004). All samples plotted on the Piper Diagram have mass balances of less than ±2.5%.

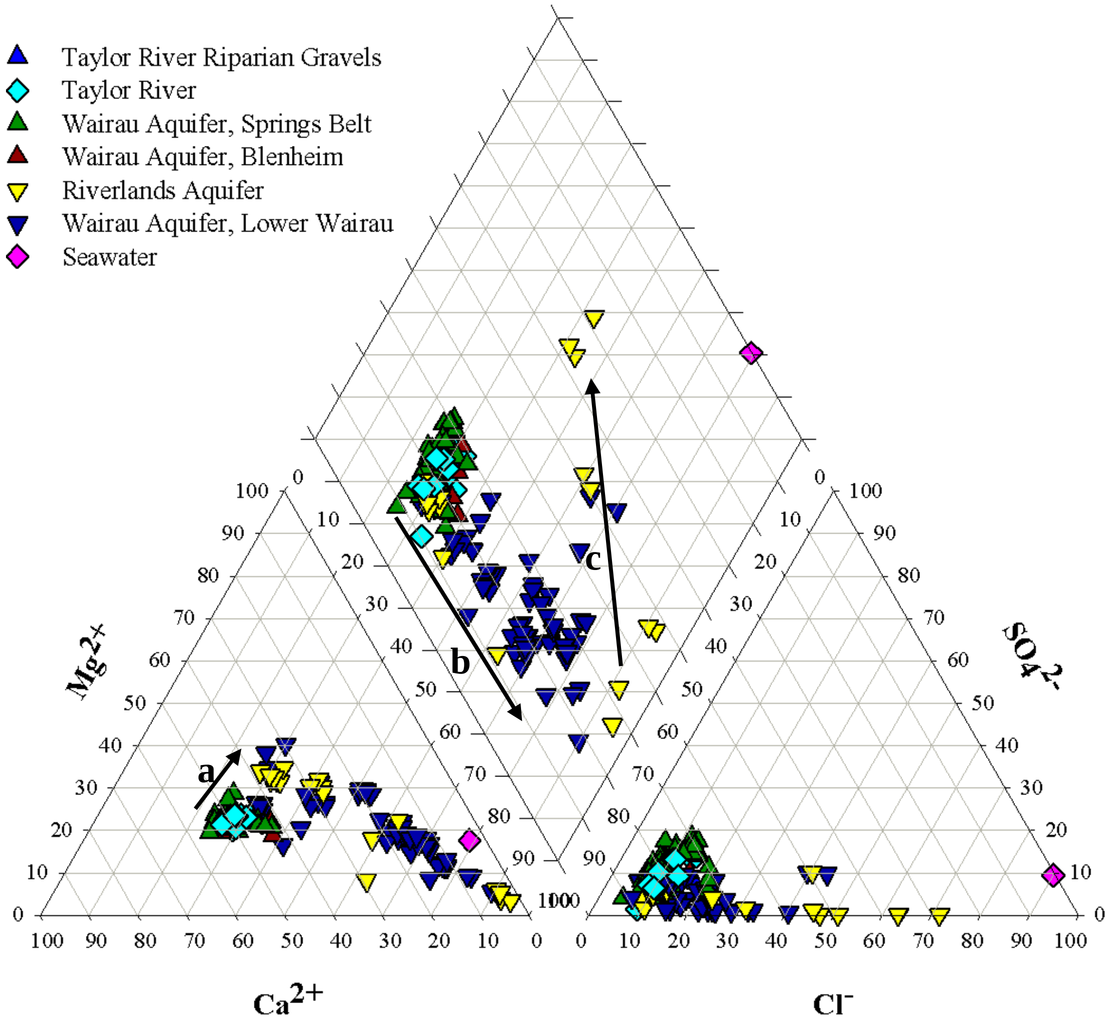

Figure 29 Piper diagram of major ion chemistry for the southeastern Wairau Plain

Immature Groundwater

Groundwater in the vicinity of Blenheim has a chemical signature that differs very little from its recharge source, which is the Wairau River, Taylor River and upgradient groundwater in the Southern Springs area. This water is characterised as Ca-Na-Mg-HCO_3 type water, and is typical of groundwater within the unconfined Wairau Aquifer. Immature groundwater is oxidised and has had little interaction with host sediments, so total dissolved solid (TDS) content is low.

Evolved Groundwater

East of the spring discharge belt the aquifer shifts from oxidised to reduced conditions as confining conditions prevail. As leakage through the aquitard decreases eastward, aquifer flux or velocity also decreases. The slowing down of groundwater flow increases the residence time of the groundwater, allowing for more interaction between groundwater and the host sediments. Groundwater chemistry evolves as its residence time increases. These chemical changes are primarily the result of cation exchange with clay minerals, which increases sodium concentrations and TDS.

The initial response to a lower aquifer flux is marked by a slight enrichment of magnesium (path “a” in Figure 29). This occurs when the groundwater is still less than 10 years old (Stewart, 2008).

As it moves further away from its recharge source, the groundwater composition evolves along a path of sodium and potassium enrichment, exchanging these cations with calcium and magnesium. As the groundwater becomes progressively reduced, its sulphate concentration also decreases. Chloride concentrations of evolved type water are typically low, and constitute less than a third of the total anion composition.

The change in chemistry with increasing residence time is recorded in the Piper plot as a shift in cation composition away from the recharge signature towards Na-K-HCO_3 type water at the bottom of the Piper diamond (“b”). Thus, chemistry which falls on this trend line can be used as an estimate of confined aquifer flux or aquitard leakage.

The evolution of groundwater in both the Riverlands and Wairau aquifers follows the cation exchange trend. The geology of the two aquifers is very similar, so chemical changes are determined by redox conditions, residence time and groundwater mixing.

High TDS Groundwater

Some of the more evolved water in the coastal Riverlands and Wairau Aquifer makes a further shift in composition towards chloride and calcium enrichment. The chemistry of this type of groundwater is unusual, has an anion composition of over 60% chloride, and plots as Cl-Ca-Mg type water at the top of the Piper diamond. Water of this composition has high TDS, with elevated concentrations of most major ions, including sodium.

Many coastal groundwater samples from both the Riverlands and Wairau aquifers show a range of compositions between evolved-type water and high TDS water (trend ‘c’ in Figure 29). This suggests that mixing is occurring between the two water types.

The shift from evolved type groundwater to high TDS groundwater is quite abrupt and occurs within the eastern Riverlands Aquifer. The transition is apparent when sodium and calcium are plotted with distance east of the edge of the confining layer (Figure 30).

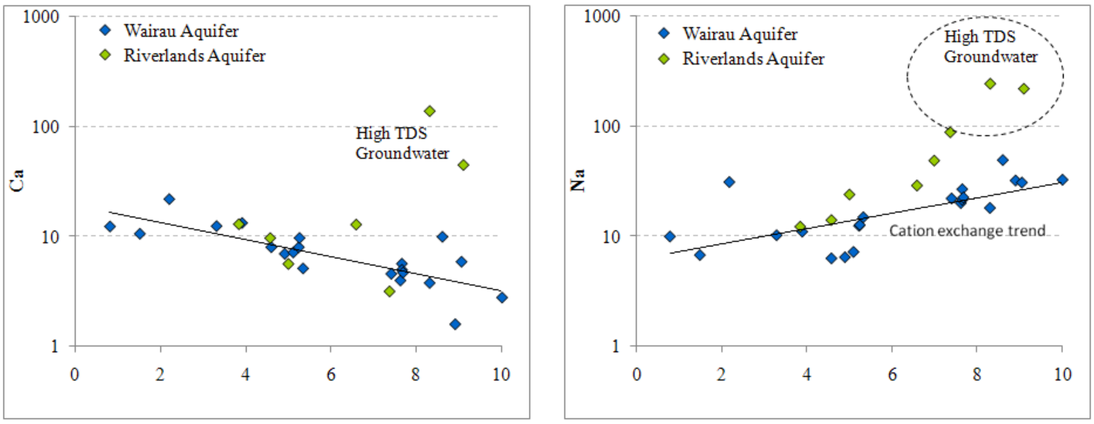

Figure 30 Plots of change in calcium and sodium concentration with distance from Athletic Park

It appears that chloride and calcium enrichment is the result of mixing with connate groundwater rather than seawater, as the trend is towards a composition that is relatively enriched in calcium. This connate water is situated around the margins of the Wairau and Riverlands aquifers, where the groundwater flux is extremely low or negligible.

It is also possible that the high TDS groundwater represents a mixing of aquifer water with water from the overlying Dillons Point Formation. The aquitard sediments have a passive marine origin, and as such are rich in calcium (from shells), chloride and sodium. So, the composition of this final phase could be caused by an increase in vertical leakage. In this scenario, water is directly drawn into the pumped well from the Dillons Point Formation in response to pumping. In areas where aquifer transmissivity is lower, a higher proportion of pumped water would be sourced from leakage.

If the high TDS groundwater composition does represent mixing with aquitard water, we should see a relationship between calcium concentration and aquifer yield, and this is what the available data shows (Figure 31). The sampling of more wells that are screened within the Dillons Point Formation (e.g. P28w/0966, 2133, 4052) would help to confirm the source of these evolved type waters.

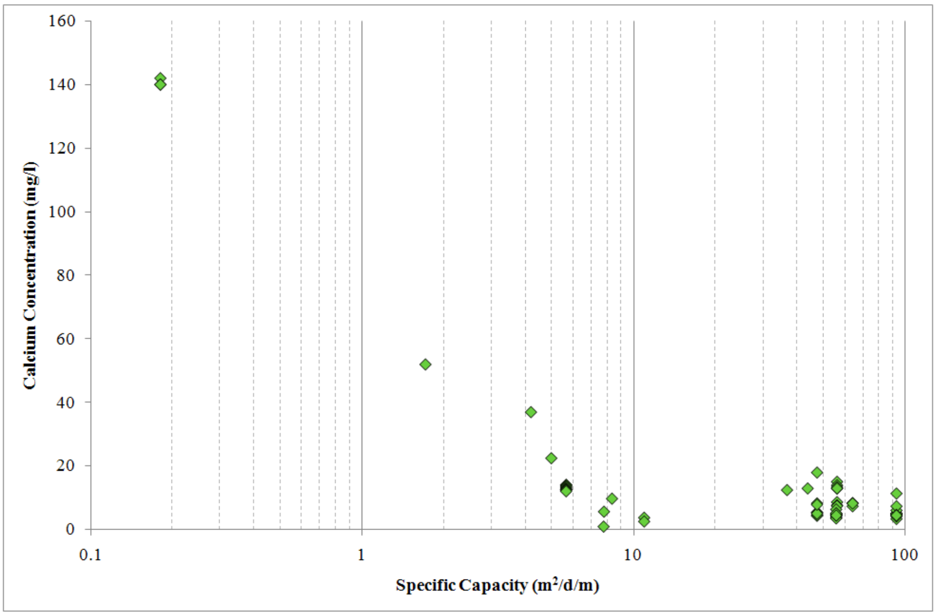

Figure 31 Relationship between well specific capacity and calcium concentration

Wells that show evidence of high TDS type groundwater are P28w/3606, 4210, 0857, 1147, 0736, and 0708. All of these wells are situated in the vicinity of the Wairau Lagoons. Tritium dating shows that groundwater in these wells is at least 60 years old (Stewart, 2008).

Samples from deeper groundwater also lie along this trend. These samples have not been plotted on Figure 29 in order to keep the Piper diagram simple enough to illustrate major trends. Well P28w/0980 at Wairau Hospital is screened at 87m depth in the Speargrass Formation and its chemistry plots towards just left of the centre of the piper diamond. This is suggestive of recharge water that is evolving towards a Cl-Ca-Mg type composition without passing through the evolved groundwater trend of sodium enrichment.

Well 3745 at Malthouse Road is screened at 75m depth in gravels well below the Wairau Aquifer. These gravels are a lens lying within deeper marine silts (Figure 4). The chemistry of this well plots in the position of the ‘c’ on Figure 29. This is representative of water that has evolved right though the cation exchange trend of sodium enrichment. This groundwater has subsequently mixed with, or is evolving towards, Cl-Ca-Mg type water.

4.1.2 Distribution of evolved groundwater

The spatial distribution of high TDS type groundwater can be mapped using specific conductance, or conductivity, values. Conductivity is measured with a hand-held field meter, hence the MDC water quality database has more conductivity values than chemistry samples. Samples with high conductivity values have a higher concentration of dissolved ions, so the method is a useful proxy for water salinity.

The distribution of conductivity values in the Riverlands area is shown in Figure 32. Sites which have had multiple conductivity readings recorded over time have had the values averaged. Conductivity values change very little between immature and evolved phases, so the approach is only useful for identifying areas of more evolved groundwater.

The conductivity of the Riverlands Aquifer is typically over 20 mS/m. Values less than 50 mS/m are expected to be still within the cation exchange phase of chemical evolution. Conductivity values of over 100 mS/m represent high TDS groundwater that is clearly trending towards Cl-Ca-Mg type water. Thus, conductivity can be used as a useful measure of aquifer flux, or the ability of the aquifer to respond to a loss of pressure due to pumping.

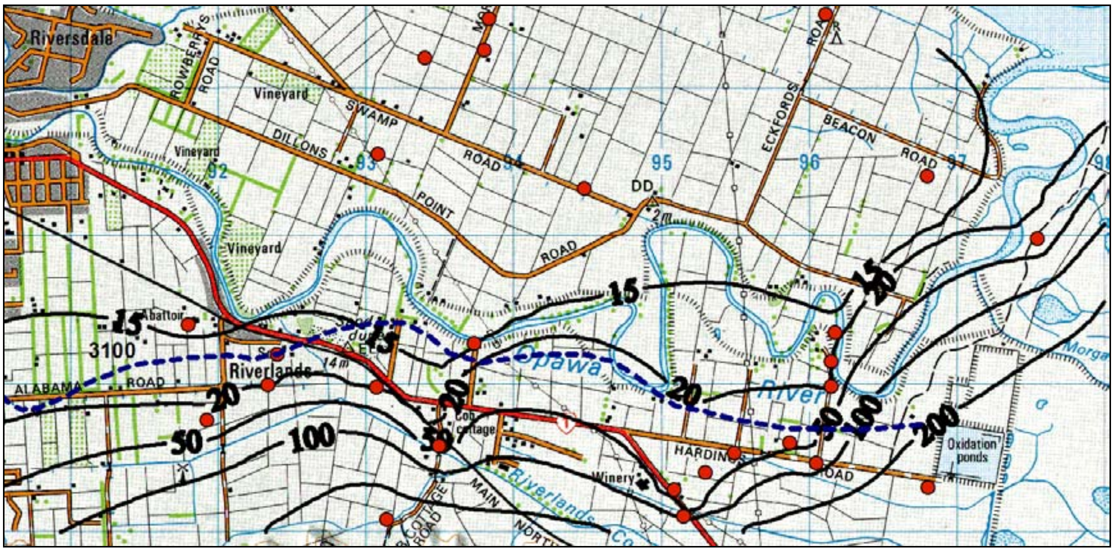

Figure 32 Contours of specific conductivity (mS/m). Data points are indicated by red points, the Riverlands-Wairau Aquifer boundary is shown with a blue dashed line.

4.1.3 *Trends in major ion chemistry*

The characterisation of major groundwater ions has shown that calcium-sodium exchange is the most useful indicator of groundwater flux and evolution. Also, initial departures away from recharge chemistry are recorded by an increase in magnesium concentration. A marked increase in chloride concentration is the most useful indicator of mixing between evolved groundwater and high TDS type water. These four ions should always be collected in the future when sampling the confined Wairau or Riverlands aquifers.

We can use these indicator ions to assess how the aquifer responds to pumping seasonally, and over long periods of time. The Lagoons (P28w/0708) and Huia (P28w/4402) wells are included within the MDC water quality monitoring network, and have the best records of water chemistry in the Riverlands area.

The Lagoons well has the longest record of water quality results, but has frequent gaps in the dataset. The Huia well has been sampled seasonally (quarterly) since it was installed in June 2004). Plots of ion concentration and aquifer head are plotted in Figure 33 and Figure 34 for the Lagoons and Huia wells respectively.

Groundwater composition in the Lagoons well is Na-K-HCO_3 type water. On the Piper diagram, samples from the Lagoons well plot towards the end of the 'evolved' trend, close to the sodium apex (Figure 29). It is difficult to detect any long term changes in chemical compositional at Lagoons. Large gaps in the dataset also make seasonal trends difficult to detect.

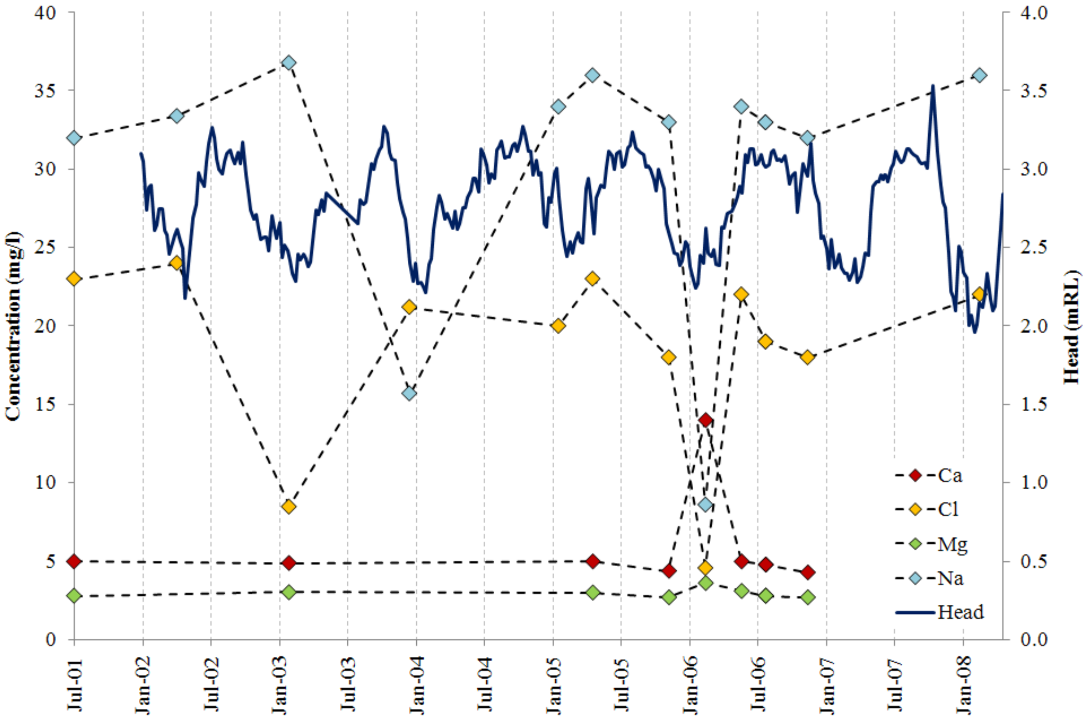

Figure 33 Trends for Ca, Na, Mg and Cl plotted with aquifer head at well P28w/0708, Lagoons

A decrease in sodium and chloride concentration coupled with an increase in calcium concentrations does occur in February 2006 when aquifer pressures are low. This indicates that fresher water has been drawn towards the coast from further inland in response to pumping. This is a movement back along the cation exchange evolutionary path ‘b’ in the Piper diagram (Figure 29). It is uncertain which well or wells may have triggered this change in chemistry, although it cannot be attributed to the MDC Malthouse Road wellfield, as this well was not operational at the time.

Samples from the Huia well are characteristic of groundwater that is at the early stages of the ‘evolved’ trend. Its composition is similar to its recharge source, but there has been a clear shift towards magnesium enrichment.

There is insufficient data available to determine any long term water quality trends at Huia with confidence. Calcium concentrations do appear to be increasing over time, with an increase of over 1 mg/l apparent over three and a half years of monitoring (Figure 34). Continued sampling will verify if this trend is real or apparent.

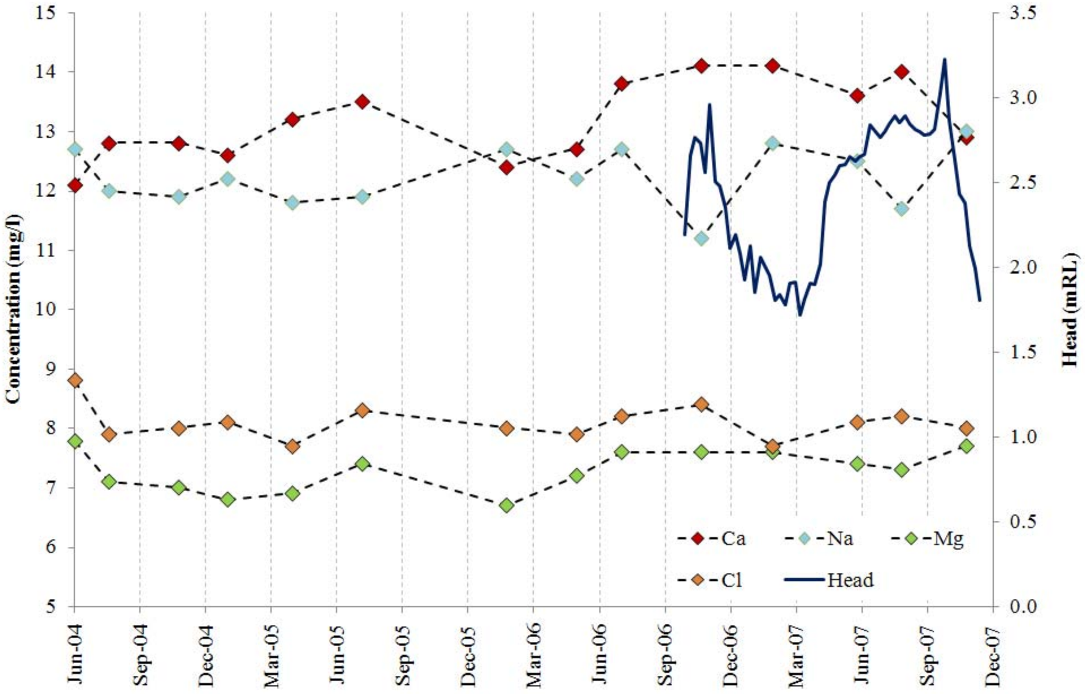

Figure 34 Trends for Ca, Na, Mg and Cl plotted with aquifer head at well P28w/4402, Huia Vineyard

The Huia well has been sampled on a seasonal basis. Subtle cyclic patterns in water chemistry are apparent throughout the year in response to changes in groundwater head. During winter when water pressures are high, sodium concentrations are low, and calcium and chloride concentrations are slightly higher. During the summer the opposite occurs, sodium concentrations increase, and calcium and chloride concentrations are lower. This cyclic pattern of calcium-sodium cation exchange is more clearly illustrated when plotted as a ratio (Figure 35).

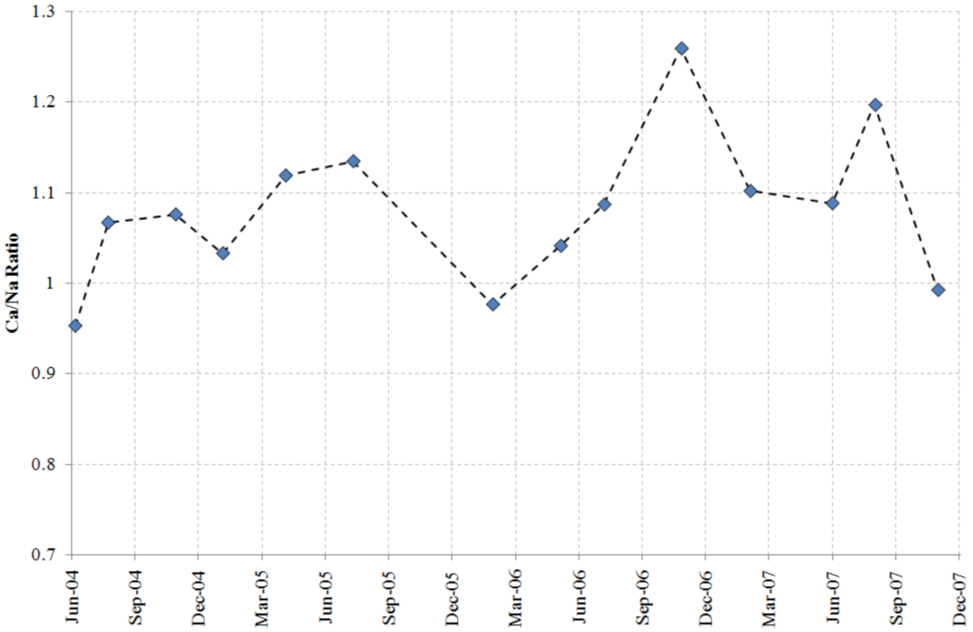

Figure 35 Trend of Ca/Na ratio through time at P28w/4402, Huia vineyard

During times of pumping stress, the Riverlands Aquifer is sourcing a higher proportion of fresher groundwater. This water is enriched in sodium, and is most likely drawn from the Wairau Aquifer to the north. During winter when water pressures recover, the composition returns to its ambient composition, which is relatively enriched in calcium and chloride.

The Huia well has also been sampled regularly for oxygen isotopes, and subtle various can be seen throughout the year. During winter, ^{18}O values are between -7.6 and -7.7, and become more negative during summer to less than -7.8. This also indicates that Wairau Aquifer water is being drawn into the Riverlands Aquifer during times of low pressure. Oxygen isotopes are covered in more detailed in Section 4.4.

4.2 Water Potability

The Riverlands and confined Wairau aquifers are considered to be ‘secure’ water sources in that they are not liable to contamination from land surface activities. However, because these aquifers are confined, reduced conditions prevail. As a result, high concentrations of naturally occurring metals can be found in some wells. Some of the more evolved groundwater also has concentrations of major ions that render that water unsuitable for drinking.

The 2004 community questionnaire found that about a third of well owners are experiencing problems with water quality. This is a concern because over 70% of wells in the area are used for domestic supply. The 2004 survey supported what MDC predicted from water quality testing in the Riverlands area. Wells in the Riverlands Aquifer in particular are often high in Mn, Fe, H_2S, and occasionally salinity.

Most water quality problems in the Riverlands area are due to high concentrations of manganese or iron. High concentrations of these elements cause staining of whitewear when above 0.04 mg/l and 0.2 mg/l respectively. Most wells in the Riverlands aquifer, and some wells in the southern Wairau Aquifer have manganese or iron concentrations that exceed the aesthetic levels for staining recommended by the Ministry of Health (2005). Most wells in the Riverlands Aquifer also have manganese concentrations above the taste threshold of 0.1 mg/l.

In wells that tap evolved groundwater in the Riverlands and Wairau aquifers where the composition is at or close to Cl-Ca-Mg type, the water is typically unpotable. Water in these wells exceeds the MAV for sodium and chloride, and the GV for manganese.

The major environmental risk to Riverlands water quality is seawater intrusion, or a migration of connate, highly evolved groundwater inland. MDC maintains a coastal monitoring network to indicate if seawater or connate water intrusion is occurring. In the Riverlands area, water specific electrical conductance, or conductivity, is recorded at the Lagoons well, P28w/0708. Conductivity is a proxy for water salinity, and is measured because continuous readings can be made through time. This is more satisfactory than taking individual samples for sodium and chloride.

The conductivity record at the Lagoons is shown in Figure 36. So far, conductivity values have remained well below levels where water quality may be compromised. To put these values into context, conductivity would have to be 200 mS/m or greater in order to exceed the MAV for sodium or chloride.

Conductivity values do appear to be decreasing overall through time, which does suggest that water quality is improving. This may be because pumping in the aquifer is inducing fresh water into the aquifer, improving overall water quality through time. Or, it may be that higher conductivity levels earlier in the record are residual values remaining from when the PPCS wells were in operation. The PPCS wells ceased pumping in the late 1990's, and were taken over by MDC. The wells are now consented for community supply use, but have been effectively unused.

Figure 36 Groundwater conductivity at Lagoons well P28w/0708

Figure 36 shows no clear relationship between conductivity and groundwater head. This is confirmed when the two are plotted against each other Figure 37. The lack of an observed relationship implies that head has not yet reached the critical level where we will expect to see an increase in conductivity. Note that while we see seasonal cation exchange between calcium and sodium, the change in total ion concentration is not significant enough to make a detectible change in conductivity.

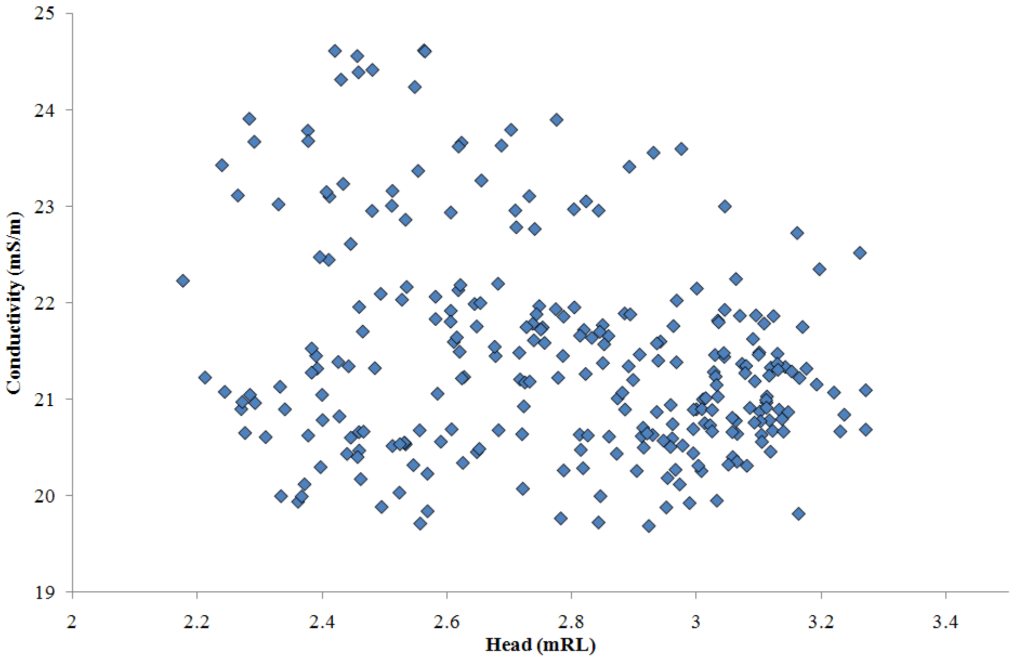

Figure 37 Relationship between groundwater conductivity and head at Lagoons well P28w/0708

4.3 Impact of water quality on soils

In 2005 MDC commissioned a report to assess the effect of applying chemically evolved groundwater to soils in Riverlands and the Lower Wairau area (Neal, 2005). The soils in these areas are silt loams with a high water holding capacity and slow drainage characteristics (Table 7).

One of the main findings of the report is that there is little information available regarding the nature of the soils in the Riverlands and Lower Wairau areas. Further work is required to determine soil hydraulic and salinity characteristics in these areas.

Table 7 Dominant soil types in the Riverlands-Lower Wairau area and their drainage classes and estimated available water capacities (AWC=PWP-FC, mm)

Name	Soil type	Drainage	AWC	Distribution
Motukarara	Heavy and peaty silt loam	Slow	175	From Malthouse and Cobb Cottage roads east to the coast
Temuka	Heavy and peaty silt loam	Slow	200	Immediately east of Blenheim and south of SH1 to the bottom of the Wither Hills detrital fans
Kaipoi	Silt loam	Mod Slow	175	Immediately east of Blenheim and north of the Opawa River

The Neal report found that there are two main issues regarding soil salinisation in the lower Wairau and Riverlands areas; irrigation with saline water, and the application of non-saline water to saline soil. In both cases, land drainage and sprinkler rather than drip irrigation is recommended to avoid salt accumulation in the soil and breakdown of soil structure. The main points of the report are as follows:

4.3.1 Irrigation with saline water

For saline soils there will be no significant alteration of soil structure by the application of saline water. However, there may be issues of plant tolerance if irrigation water has a conductivity greater than 75 mS/m. This would apply to groundwater at the end of Hardings Road, and adjacent to the Wither Hills (Figure 32).

If the soil is non-saline, there will be a gradual accumulation of salt in the soil. This is the issue that has caused so much trouble in Australia, where groundwater is typically quite evolved, having high ion concentrations. The Neal report recommended that water should not be used for irrigation if its conductivity is greater than 75 mS/m. The report also recommended that applications to irrigate water of conductivities between 25 and 75 mS/m should be reviewed on a case by case basis. This would apply to most abstractions from the Riverlands Aquifer.

4.3.2 Application of clean (non-saline) water to saline soil

The application of clean water to saline soils can result in the dissolution of sodium from clay particles into groundwater. This can results in a rapid loss of soil structure, which leads to a drying of the soil, making irrigation difficult. Loss of soil structure also makes the soil susceptible to compaction.

Application of clean water to saline soil is a potential issue for the irrigation of Wairau Aquifer water on Motukarara soils, which cover most of the Lower Wairau area. Loss of soil structure can be mitigated by the use of sprinkler irrigation, effective land drainage, and application of gypsum.

4.4 Isotope Studies

4.4.1 Stable Isotopes

Oxygen-18 is a useful tracer for determining the source of groundwater because natural processes control its concentration in different environments. Two comprehensive isotope studies have been carried out on the Wairau Plain. Initial stable isotope work was reported in Taylor et al. (1992), and this was recently revised by Stewart (2008) to incorporate more recent sampling data.

Enough ^{18}O samples have been taken from different water sources to enable their signatures to be characterised (Table 8). In general, river and stream values become more positive from west to east, which reflects a lower altitude or closer proximity to the coast.

Wairau Aquifer water is mainly sourced from the Wairau River and has a more negative ^{18}O signature than the Riverlands Aquifer. Land surface recharge typically comprises less than 20% of unconfined Wairau Aquifer storage on the Plain. The Riverlands Aquifer in its more dynamic, leaky area west of Malthouse Road has ^{18}O values characteristic of a mixture of low altitude rainfall and Taylor River recharge. The mean flow and flow losses of the Wither Hills rivers and streams are considerably less than those of the Wairau River. As a result, land surface recharge contributes a higher proportion of the groundwater composition in the southern Wairau Plain than it does in the north.

Oxygen-18 values become more negative with confinement for both the Riverlands and Wairau aquifers. Taylor et al. (1992) suggested that this is caused by vertical leakage and upwelling of more negative groundwater from the Speargrass Formation. This seems to be the only plausible explanation to derive ^{18}O values that are more negative than any of the observed surface recharge sources. If this is the case, the evolution of major ion chemistry followed by ‘evolved’ composition groundwater may be the result of an increasing proportion of Speargrass Formation water with confinement.

Table 8 Observed Oxygen-18 values for different groundwaters and surface sources

Water Source	^{18}O (‰)	Error (±)
Wairau River	-8.86	0.3
Wairau Plain Rainfall	-7	0.2
Taylor River	-8.17	0.15
Riverlands Aquifer, confined-leaky	-7.7	0.2
Wairau Aquifer, confined-leaky	-8.56	0.25
Riverlands and south Wairau aquifers, confined	-8.89	0.1
Speargrass Formation	-9.16	0.15

4.4.2 Isotopic dating

Radioactive decay of Tritium has been used by Taylor et al. (1992) and Stewart (2008) to determine the age of groundwaters on the Wairau Plain. Tritium has a radioactive half-life of 12.3 years, so is ideal for dating the Wairau Aquifer.

The confined-leaky Riverlands and Wairau aquifers typically have groundwater ages of less than ten years. In the confined part of the aquifers, east of Malthouse Road, groundwaters are typically over thirty years in age. In general, ages within the confined Wairau aquifer increase towards the valley margins. The more chemically evolved groundwaters have ages greater than sixty years.

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