WAIRAU VALLEY EXPLORATORY DRILLING & TESTING TECHNICAL REPORT

July 2007

Environmental Science & Monitoring Group Technical Report 2007/2

MARLBOROUGH DISTRICT COUNCIL

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1. Executive Summary & Conclusions

- *Demands on freshwater at Wairau Valley continue to increase and more information is needed on these natural resources. Marlborough District Council has focused its investigation and monitoring programmes in the area to assist with water management planning*

- *The regional hydrological network has been extended to include a representative site for the Wairau Valley Aquifer. The new site will provide continuous water level record to compliment the existing flow recorder on Mill Creek*

- *Testing showed the Wairau Valley Aquifer represents a moderate yielding system, containing high quality water, with a mean residence time of only 2 years*

- *Recent research suggests the source of recharge to the most commonly utilised Wairau Valley Aquifer is the drier south-bank hill catchments, rather than the Wairau River as previously thought*

- *This has implications for water management given the observed decline in runoff due to landcover change since the 1970's, and predictions of less rainfall in these catchments from 2030 onwards*

- *Exploratory drilling by Marlborough District Council confirmed the existence of highly saline water beyond 25 metres depth, west of the township. This deeper groundwater is unlikely to represent an economic aquifer due to its poor water quality and low yield*

- *The discovery of the most saline water to date is consistent with historic observations and infers the existence of a regional scale saline wedge underlying Wairau Valley*

- *Tectonic fluids seeping from the Wairau fault which bisects Wairau Valley, is the likely source of the saline water. Widely distributed reports of saline well waters reflects the regional nature of the fault*

- *Some of the naturally occurring salts associated with fault fluids including arsenic and boron can be harmful to human health. High concentrations have been measured in Wairau Valley groundwater's and care is needed when assessing the long-term suitability of drinking supplies*

- *Marlborough District Council are working with the Ministry of Health to measure the natural variability of arsenic concentrations in Wairau valley groundwater over time*

- *The sensitivity of the saline wedge to changes in surface flow, drainage or river patterns is uncertain*

2. Introduction

Wairau Valley is the westward extension of the Wairau Plain towards the headwaters of the Wairau River and the ranges of the main divide. It has been formed by a combination of mountain building processes associated with the Wairau Fault, and the fluvial processes of the Wairau River. The front cover of the report shows the familiar braided pattern of the Wairau River channel looking downstream to the east.

The axis of the Wairau Fault runs sub-parallel to the Wairau River for much of its length, but does intercept the channel upstream of the Wye River. The Wairau Fault is an extension of the main Alpine Fault which splits into 5 in the Marlborough region to form the Awatere, Clarence and Kekerengu Faults. Faulting created a topographic depression or basin, which has subsequently been in-filled with river deposited alluvium over geological time.

Alternating glacial and interglacial cycles have caused a series of river terraces and alluvial gravel deposits to accumulate in the fault angle depression. River action has eroded or deposited alluvium, depending on the geologic cycle operating at the time. Generally speaking the alluvium is poorly sorted with a mixture of grain sizes from boulders to clay, reflecting its glacial origin near the main divide.

In addition to creating regional scale landforms, the fault has a major influence on local water flow patterns by diverting them sideways, with a good example being Walkers Stream located just west of the township. The same effect occurs in the Delta area near Renwick, where Fault Lake is symptomatic of stream flow being ponded behind the up-thrown side of the fault trace.

Figure 1 is an oblique view of the Wairau valley area showing the predominant features including the Wairau Fault in black, Wairau River channel at left and South-bank hill catchments to the right. The West Coast Road or State Highway 63 bisects the upper terrace shaded green.

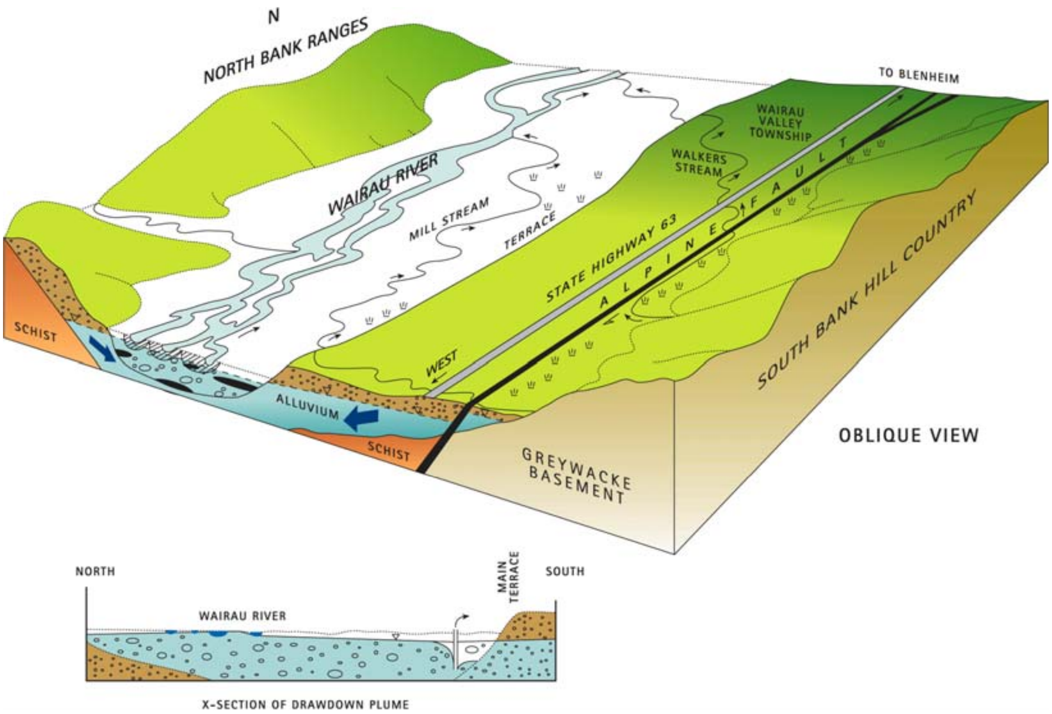

Figure 1: General Features at Wairau Valley

Wairau Valley is also an area of climatic contrasts with the 2 extremes of rainfall within the catchment represented on opposite banks of the Wairau River. Heavy orographic rain is regularly generated by north-westerly weather systems impacting on the Richmond Ranges, which results in heavy rainfall on the North-bank and low rainfall in the rain shadow area on the South-bank. The focus of this report is the South-bank where water resources are scarcer, and demand higher.

The area is rather unique for a number of reasons including the occurrence of saline flow in Walkers Stream and saline groundwater in some wells. This is not a new phenomena based on chemistry results dating from the 1980's (MC&RWB 1987). Recent investigations suggest the fault is the source of the saline water which may underlie a large area of the Wairau Valley (Taylor 2002).

Concentration of salts occurs as groundwater lies in contact with rocks in the fault zone for long periods of time and is subsequently flushed out. This has potential implications for human health because toxic substances like arsenic and boron are commonly associated with fault processes.

Demand for freshwater is increasing due to conversion of traditional dryland farms to irrigated pasture, cropping and vineyard. Lifestyle and rural residential subdivision is also becoming common near the township.

Unfortunately from a water supply perspective the majority of the flat land lies on the drier South-bank of the river channel. Groundwater is the preferred source water due mainly to the potential damage to intakes from floods. Not all demands are consumptive however as the recent application by TrustPower Ltd illustrates.

3. Background

A distinction is generally made between groundwater resources occurring above and below the main river terrace, a distinctive feature which lies between the West Coast road (SH 63) and the Wairau River. This boundary reflects the occurrence of more permeable gravels closer to the river, which in turn host higher yielding aquifers. The terrace is shown in Figure 1.

Currently the highest demands on groundwater are for crop irrigation and municipal supply. These activities are predominantly supplied from the Wairau Valley Aquifer, located within the upper 10 or 15 metres of river alluvium on the lower river terrace.

Historically this terrace was also thought to represent the southern influence of Wairau River recharge, a concept supported by the occurrence of higher producing well closer to the channel. However this idea is being reviewed in light of recent environmental isotope results suggesting the predominant source of recharge is runoff from the South-bank hill catchments, rather than a direct river link.

While a South-bank hill country source now appears most likely, the only inconsistency is whether there is sufficient summer runoff from the South-bank catchments to maintain through-flow in the lower terrace aquifer, or to account for the high productivity of many wells.

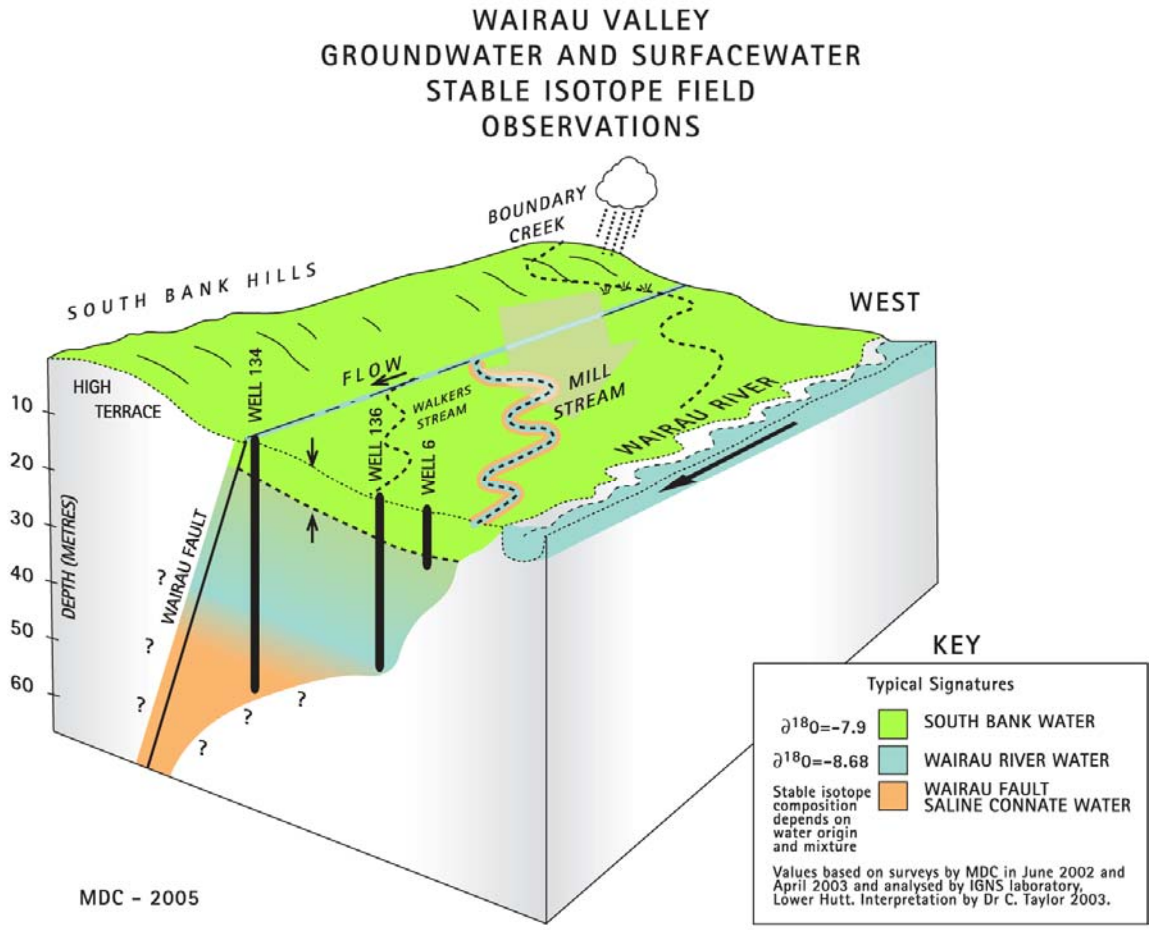

Figure 2: Wairau Valley Oxygen Isotope Signatures

This distinction is significant as these South-bank hill catchments receive relatively low rainfall and are fed by mostly ephemeral streams. Research is continuing on the relative contribution of Wairau River versus South-bank runoff, as this has implications for water management in the future given the declining trends in stream flow due to plantation forestry, and predicted effects of climate change from 2030, and particularly 2070 onwards.

Figure 2 illustrates the pattern of stable isotope signatures for Wairau Valley waters observed as part of Marlborough District Council surveys since 2002. Water originating from the Wairau River has a typical value of around -8.5 or less, while water sourced locally normally exhibits a value of -8.00 or more. The difference in the ratio reflects the altitude difference between the higher elevation catchments feeding the Wairau River, compared to the lower South-bank ranges and its effect on concentration of one isotope relative to the other during fractionation.

Recent work by Marlborough District Council has focused on the local influence of Wairau River channel flow and its interaction with nearby wells. While it is generally accepted that in regional terms recharge originates from the south-west, are there periods when Wairau River flow could dominate Wairau Valley wells near the channel, for example in spring or winter.

Relatively little is known about the extent of deep groundwater resources beneath Wairau Valley, however there are now sufficient domestic wells with good records available to describe the shallower layers. Drilling records indicate a low to moderate yielding aquifer of around 10-15 metres thickness exists near the surface on the lower terrace, associated with fluvially reworked Wairau River alluvium. It is referred to in this report as the Wairau Valley Aquifer, or upper aquifer to distinguish it from deeper saline aquifers.

A similar, but lower yielding aquifer appears to exist beneath the upper terrace, or in other words the land to the south of State Highway 63. The reason for the poorer yield is probably the lower permeability of the gravels deposited by the South-bank hill streams, which have higher proportion of fines.

Only a small number of deeper wells exist in the area, with the deepest being drilled by Marlborough District Council to 50 metres at Mill Road in 2007. This probably demonstrates the ability of the shallower layers or direct takes from the Wairau River channel to meet the current demands of water users.

The occurrence of saline groundwater has now become more than of academic interest. It is providing clues on the deep circulation of groundwater flow, and is an indicator of potability, which is of increasing interest from a human health perspective.

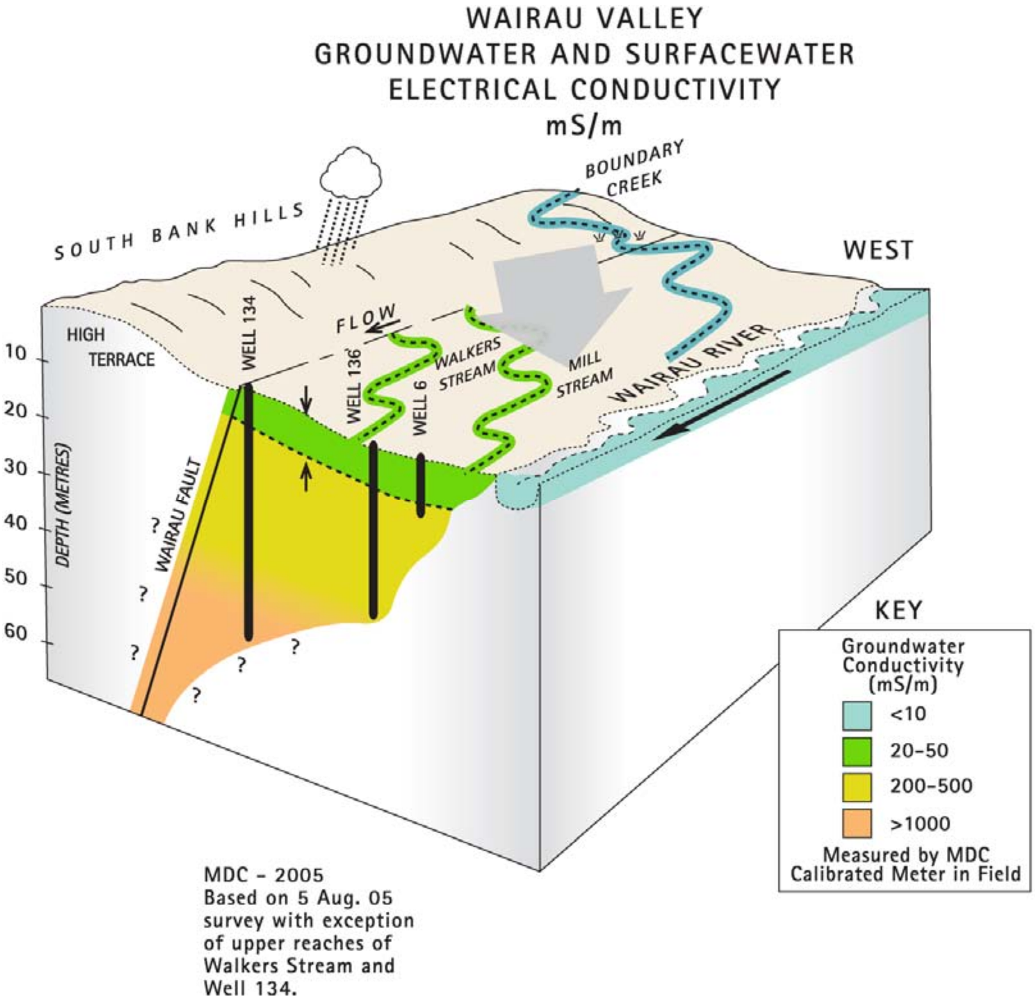

Figure 3: Wairau Valley Groundwater Electrical Conductance

Figure 3 is an oblique view of Wairau Valley landforms showing the general classes of groundwater electrical conductance observed by Marlborough District Council since 2002. While this is a simplification, it does provide a conceptual understanding of the regional scale hydrology and particularly the stratification of flow.

The youngest water flowing in the South-bank streams and Wairau River also have the lowest observed electrical conductivity values. The exception is Walkers Stream which interacts with the Wairau Fault and has slightly saline channel flows. This process will be described in more detail shortly. Electrical conductance is a quick measure of the dissolved salts in water.

The upper or shallower aquifer water within 20 metres of the surface has low to moderate conductivity values, but again there are exceptions such as north of the township in the vicinity of the Wairau Fault, where conductivity is higher, and in other places where it is slightly lower. A real contrast occurs at depth where highly saline water has been measured in wells of 40 to 50 metres depth, and this is attributed to the seepage of tectonic fluids.

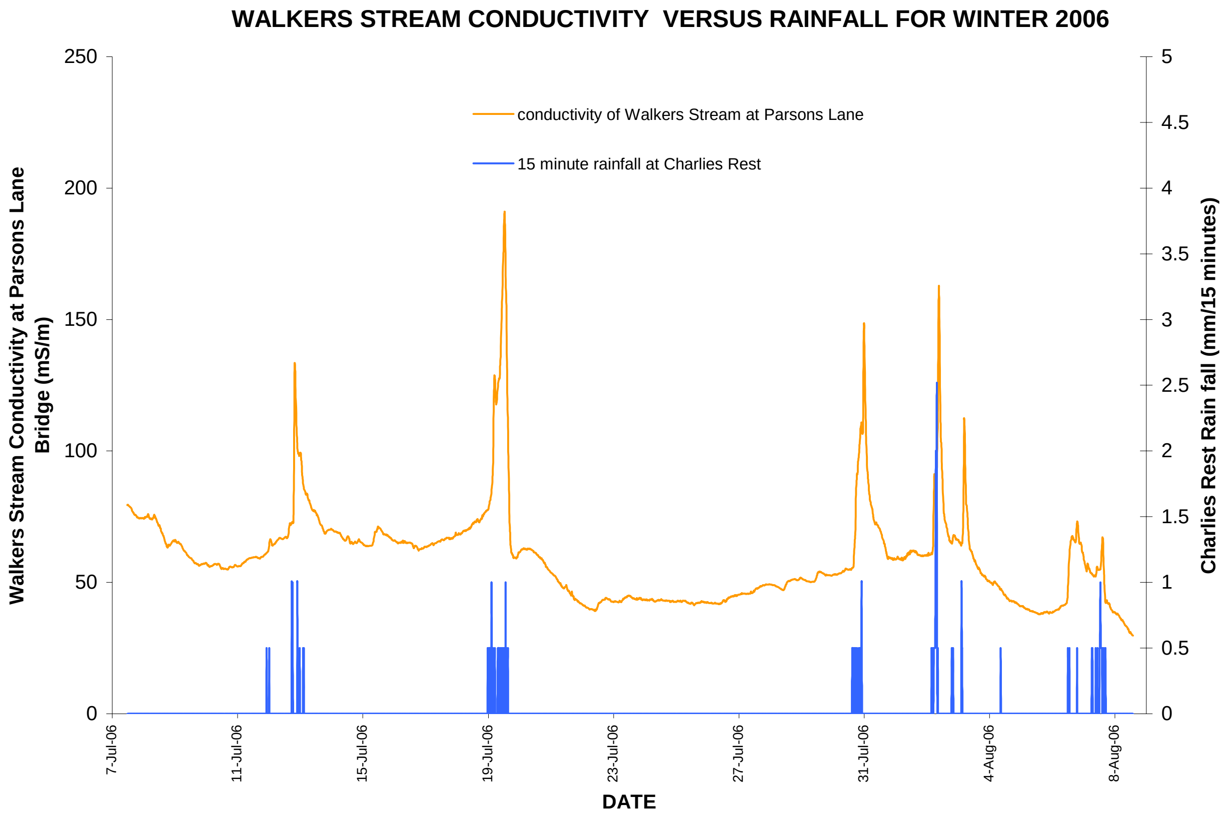

Figure 4: Response of Walkers Stream Salinity to Rainfall

Figure 4 is a comparison of the variation in the salinity of Walkers Stream flow with rainfall events during 2006. Rainfall at 15 minute intervals at the Charlies Rest recorder is shown on the right hand vertical axis, with electrical conductance of water flowing in Walkers Stream channel on the left hand vertical axis. There is a close correlation between rainfall as shown by the blue vertical bars, and a rise in the conductivity of Walkers stream water shown by the orange trace.

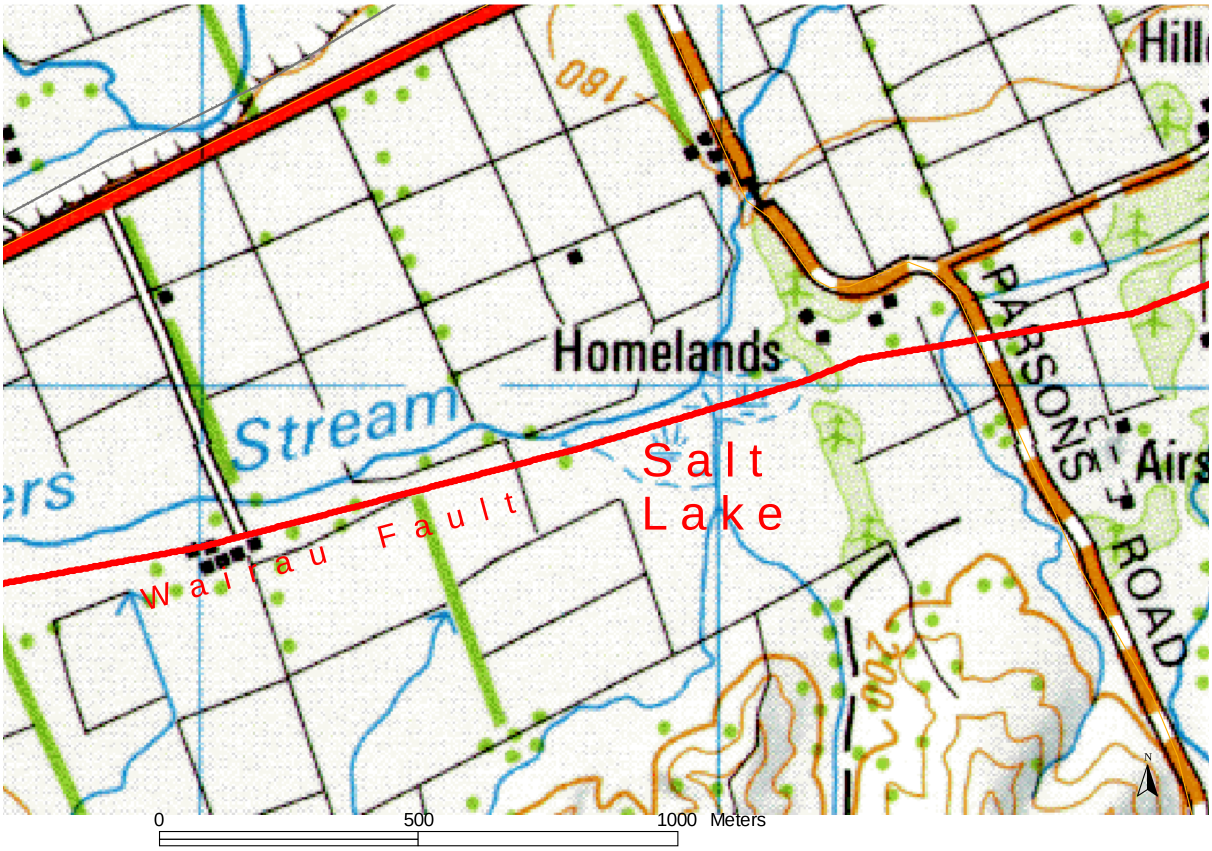

Figure 5: Source of Walkers Stream Salinity

The explanation for this phenomenon lies first of all with fluid seepage from the Wairau Fault accumulating at the surface in a salt lake near the foot-hills, west of Parsons Road (Figure 5). Evaporation over a succession of summers results in a build-up of concentrated salt species in the soil.

Marlborough District Council staff postulate that rainfall running off the South-bank hills and contributing to Walkers Stream flow, leaches salts as it passes through the lake basin. Figure 5 shows Walkers Stream channel flowing from west to north-east, as it is initially captured behind the up-thrown side of the fault, and subsequently breaks out near the kink in Parsons Road.

While the existence of groundwater at Wairau Valley has been common knowledge for generations, a recent focus of attention has been the origin and nature of freshwater springs. Interestingly these springs are some of the most highly valued examples of their type outside of the Wairau Plain by virtue of their constant flow of clear, cool water. The most notable examples rise near Mill Road, several kilometres west of the township, but occur elsewhere also. Figures 6 and 7 show Mill Creek; a tributary of the Wairau River and the best known example of the Wairau Valley springs.

Figure 6: Mill Creek Main Branch at Mill Road December 2006

They represent up-welling groundwater induced by changes in the permeability of their host formation. For example at Mill Road groundwater is likely to be forced to the surface as aquifer flow converges due to the narrowing of the lower terrace gravels, between the Wairau River and the main terrace.

Effectively these gravels form flow tubes and because less water can be conveyed as they narrow, water is forced upwards as shown in the aerial photograph in Figure 8. Historically it was assumed that because they emerged on the lower terrace they must be hydraulically linked to the Wairau River, but they are now thought to receive recharge from the South-bank hill country catchments. However, it is likely that there is an influence on groundwater flow very close to the Wairau River channel, based on very recent stable isotope measurements made by Marlborough District Council in conjunction with GNS Science Ltd.

Figure 7: Mill Creek South Branch at Mill Road December 2006

Figure 8: Convergence of Groundwater Flow at Mill Road

Maintaining acceptable flow in Mill Creek is important for many reasons. Marlborough District Council established a flow recorder site upstream of Ormond Aquaculture to collect long-term information for water management purposes and to manage seasonal water allocation (Figure 9).

Figure 9: MDC Mill Creek Flow Recorder at Ormond Aquaculture

Figure 10 shows the newly installed water level recorder representing the Wairau Valley Aquifer, and rain gauge station at Mill Road. This new addition to the regional monitoring network will compliment the existing flow recorder and allow analysis of the local relationship between groundwater flow, stream flow, rainfall and Wairau River flows.

Figure 10: MDC Wairau Valley Aquifer Level Recorder at Mill Road

What is becoming increasingly evident from a number of data sources is the likely existence of an extensive wedge of denser, saline groundwater beneath Wairau Valley. Figure 11 shows the location while Table 1 summarises the details of the 11 known occurrences from near the Wye River, east to Loddon.

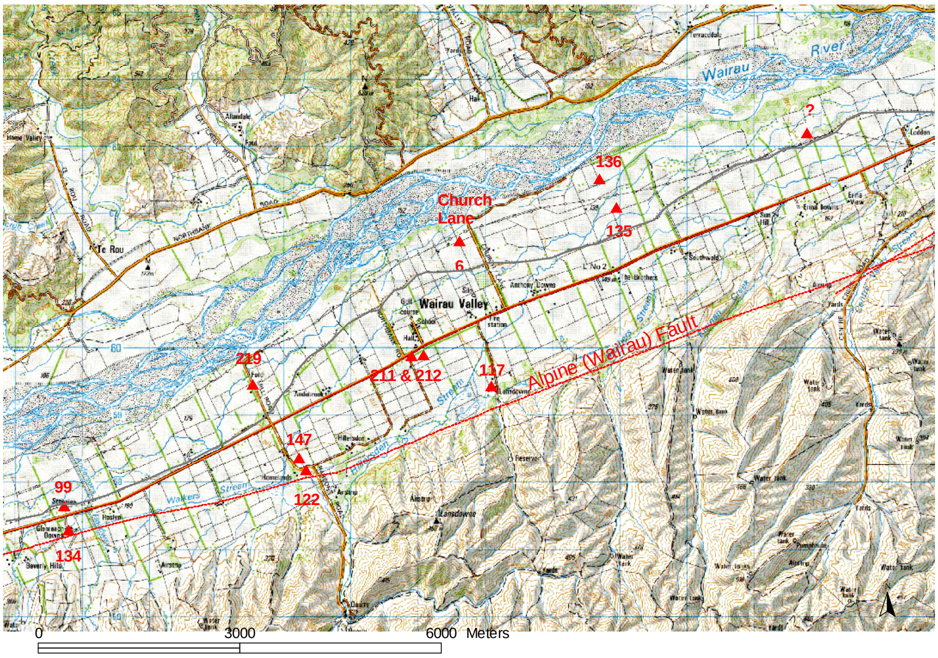

Figure 11: Known Occurrences of Saline Water Wells

While the salinity of groundwater may have limited relevance while current land or water use practices continue, it has implications for activities associated with a recent power generation proposal, including excavations and changes in natural recharge or drainage patterns.

It is of importance to quantify the chemistry of known saline water bodies and map their distribution for 3 reasons. Firstly, to provide a baseline record for measuring the impact of future water management or landuse activities on inducing changes to groundwater quality. Secondly, to learn about the significance of tectonic controls on regional aquifer flow patterns, particularly at depth. The appearance of saline groundwater at a depth of around 15 metres depth has effectively defined the base of the freshwater aquifer and constrained the screened depth of wells.

Well details	Electrical conductance of well water (mS/m)	Well depth (metres)	Origin of information on saline groundwater	Comments
134 Clifford Near fault on upper terrace	**1600**	47.2	Personal discussion with owner & sampling of well by MDC	Measurements showed well had highest concentration of salts of any groundwater s sampled in area until recent MDC test well in Mill Road
99 Jerrett Near main terrace, north of fault	no measurements available	40.9	Personal discussion with owner 2005	Saltwater following extension of well from 23 to 40.9 metres depth
147 Ex-Wadsworth stock well North of fault on upper terrace	**700**	Shallow	MDC field meter & laboratory results. Chloride concentration of 1,980 g/m^3 measured March 1984 (W & SRW Vol. 2 – 1987)	Long standing salinity issue
122 Ex-Wadsworth new domestic North of fault on upper terrace	**70**	10.5	Field meter & laboratory results	
6 Ex Newhaven Salmon on lower terrace near river	**-**		References on well record	Well originally drilled to 27 metres depth & casing subsequently shortened & screened at 10 metres to avoid saline water
136 Parkes North of fault on lower terrace near river	**409**	Measured depth of 27 in 2005	MDC field meter & laboratory results	Apparently 35 metres depth originally but casing shortened presumably to avoid saline water
135 Parkes North of fault on lower terrace	**-**		References on well record	Well no longer exists
219 MDC North of fault on lower terrace near Mill Creek	**4900**	50	MDC test well meter field measurements & laboratory results	Gradual increase in salinity from a depth of around 15 metres peaking after 25 metres depth with concentration of chloride equivalent to that of seawater
Loddon/Erina Downs	**-**	Saline water encountered at 47 feet or 14.3 metres	Based on community knowledge	A new well drilled at Erina school early in the 20th century was reported to be salty but exact location uncertain.
212 Field North of fault near SH63	**-**		Reference to saline water on well record. Low yielding	Initial depth of 38.2 metres. But eventually screened from 20-22 metres depth after encountering saline water
211 Field North of fault near SH63	**142**	14 metres	Landowners laboratory results. Low yielding	
117 Senior Near fault trace on upper terrace	**203**	10.7 metres overall depth	Common knowledge & 1999 laboratory report	

Table 1: Details of Saline Groundwater beneath Wairau Valley

Thirdly, from a public health perspective the community needs to be aware of the risks associated with poor quality drinking water supplies and its distribution. Because of the natural occurrence of arsenic and boron, it is likely have existed for generations. The seasonal variability will be assessed as part of a survey planned for later in 2007 by Marlborough District Council in conjunction with the Ministry of Health.

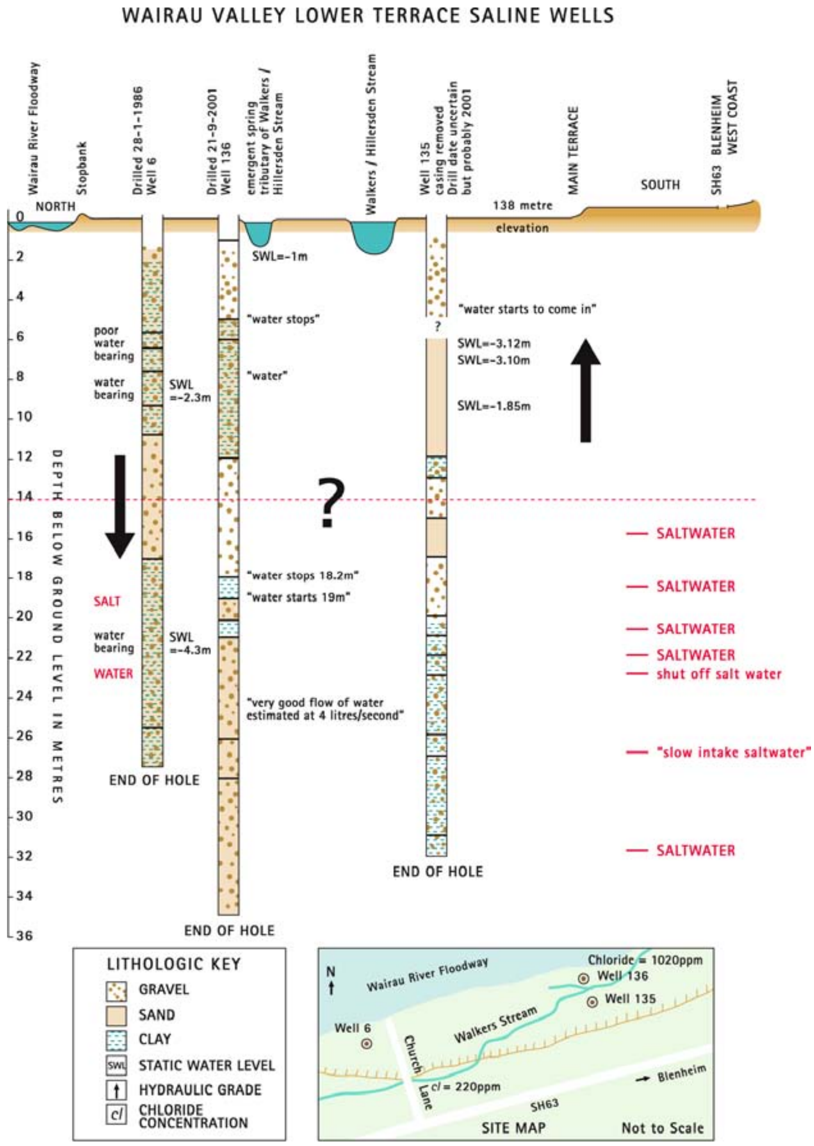

Figure 12: Depth Distribution of Saline Water

Well drilling information is beginning to identify several patterns about the distribution of saline water. Not only is it widespread but as Figure 12 shows, it consistently occurs at a depth of 15 metres or more below the surface. Figure 12 is a cross-section showing wells 6, 135 and 136, all of which have intercepted saline water in the area east of the Wairau Valley township, on the lower terrace.

Putting aside the human health effects of saline water, the most significant potential groundwater management issues for Wairau Valley are sustainable use of South-bank Hill country runoff and maintaining aquifer fed spring flows. Spring flows appear to be at acceptable levels but several years of record is needed to adequately describe their behaviour.

Potential growth in water demand from many sectors including plantation forestry, hydroelectric power generation, dairy industry and rural residential development are on the horizon. Added to this demand will be the likelihood of increasing variability in natural recharge in the South-bank hill catchments in particular.

4. 2006-07 Investigation & Methodology

Gaps in community understanding of the water resources in general and underground water in particular, sparked a series of investigations by Marlborough District Council from 2002 onwards. The focus of this report is the results of the exploratory drilling and testing programme, but in the context of recent findings from other research. The specific aims of the recent investigation programme were to:

- *Measure the hydraulic properties of the Wairau Valley Aquifer (upper aquifer) which represents the principal source for current consented water takes. This will allow for more accurate predictions of aquifer behaviour and assessments of safe yield*
- *Evaluate the structure and hydraulic properties of any deeper, newly discovered aquifer layers*
- *Measure and document the chemical nature of groundwater from the Wairau Valley Aquifer (upper aquifer) and in particular any saline waters*
- *Compare the water bodies on the lower terrace at Mill Road to determine if they represent a single interconnected water resource, or whether the freshwater springs are independent of the aquifer*
- *Establish a permanent Wairau Valley Aquifer level recorder to provide continuous information to the local community, regulators, water planners and the public*
- *Provide a representative section describing the sediments encountered at the Marlborough District Council exploratory bore 219 in Mill Road*

5. Initial Exploratory Drilling

The focus of the Marlborough District Council investigation was the construction of 2 new wells at Mill Road, 2.5 kilometres west of Wairau Valley township on the lower terrace, and approximately 600 metres south of the Wairau River channel. Both wells are located on road reserve with their casings standing 1 metre above ground-level.

The more northerly well known as 220, will be used by Marlborough District Council to expand the regional groundwater monitoring network and accommodate the water level recording instruments. It will represent the Wairau Valley Aquifer or upper aquifer, currently the main source of groundwater for larger water users at Wairau Valley, such as crop irrigation and municipal supply.

The smaller diameter well known as 219 is located 16 metres to the south and its role was to explore to a depth of 50 metres below the surface. It won’t be screened, but its casing will be left in the ground permanently to allow for future testing or sampling. Figure 13 shows the layout of the wells in relation to State Highway 63, Mill Road, Wairau River, both branches of Mill Creek and the main river terrace.

Figure 13: Plan View of Mill Road Well Sites

Well construction began in mid 2006 with both wells being drilled to the target depth of 10 metres by spring. This represented the final depth for the monitoring well 220, which was then screened from 9.73 to 12 metres depth below the surface, and developed in preparation for its role as a permanent monitoring site. The exploratory well 219 was temporarily left at a similar depth for observation purposes during aquifer testing. It would subsequently be extended to its final target depth of 50 metres.

As expected the material encountered in the upper sections of both wells consisted of river derived alluvium of varying permeability. Figure 14 shows that the upper 15 metres was dominated by gravel and clay with a series of water bearing layers denoted by the double arrows. A change occurred below a depth of 15 to 20 metres, with increasing sand content, tighter drilling conditions and less productive water bearing layers.

Details of the deeper drilling down to the end of the exploratory hole at 50 metres will be described in a later section of the report. Effectively the so-called Wairau Valley Aquifer or upper aquifer on the lower terrace is hosted by the top 15 metres or less of alluvium.

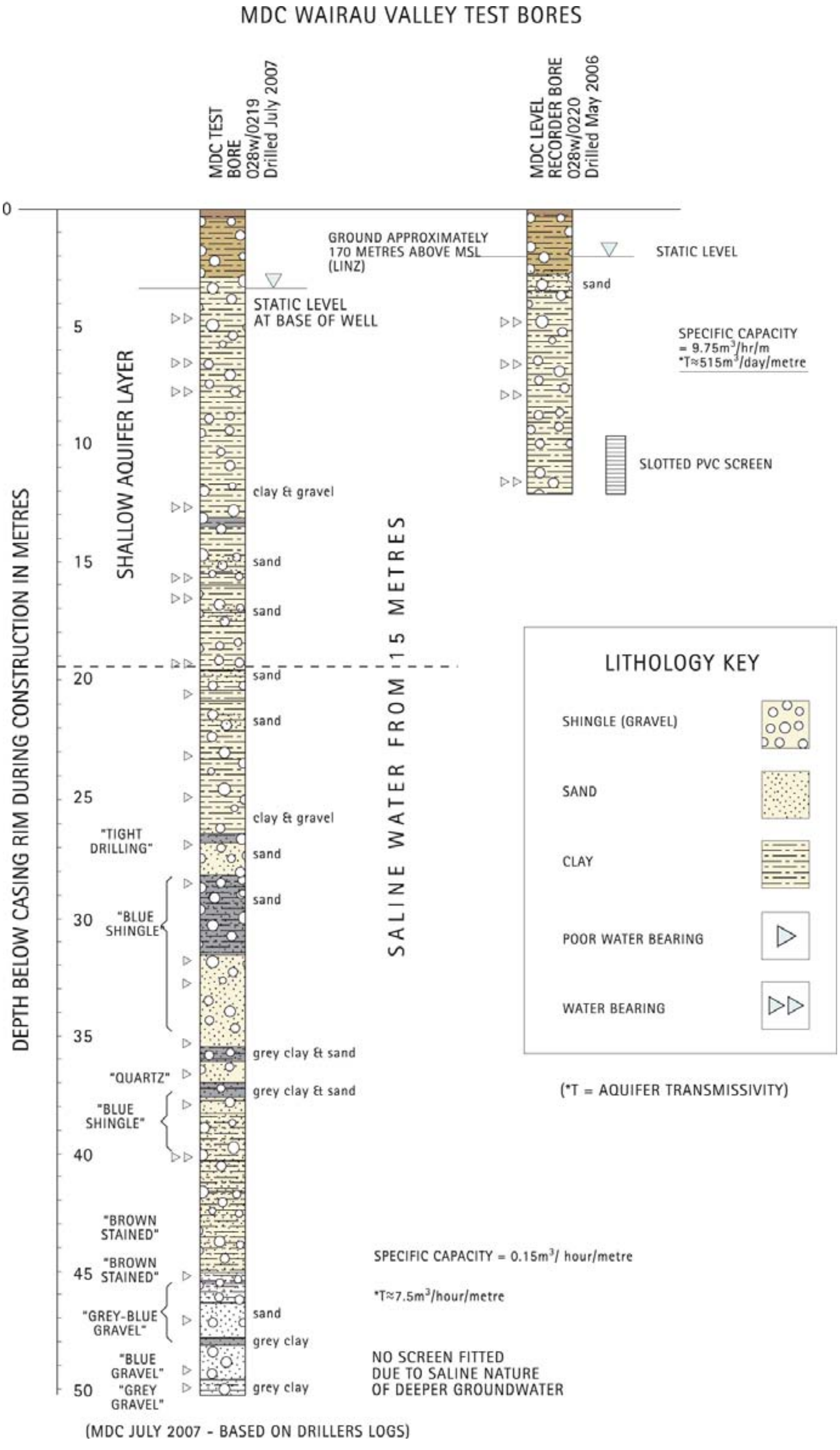

Figure 14: Lithologic Section for MDC Wells 219 & 220

Initial indications of aquifer yield based on the driller's short term tests for well 220 were of a relatively low yielding groundwater system by Wairau Plain standards. A well specific capacity of 9.75 m^3/hour/metre of drawdown corresponds to an aquifer transmissivity value of around 500 m^3/day/metre. Subsequent testing showed this figure underestimated the true aquifer permeability.

6. Aquifer testing

Aquifer testing is a standard procedure for assessing the extent, hydraulic properties and structure of an aquifer. In practical terms it involves pumping a well at a known rate while observing the response at neighbouring wells, and other water features such as streams or springs. Of particular interest in this case was the existence of any link between the Wairau Valley Aquifer and flow in either branch of Mill Creek. In other words were they a common water body or independent.

Figure 15: Observation Well 219

Mill Creek is recognised as an important waterway with low flows protected by restrictions on the water permits of some nearby aquifer users. Another objective of the aquifer test was to verify the appropriateness of these restrictions and their benefits.

Figures 15 to 17 are photographs of the test set-up. Figure 15 shows the observation well 219 with a manual dipping instrument and Trutrak water level recorder in the Wairau Valley Aquifer. Figure 16 shows the pumped well 220 with the gate valve used for controlling flow and the electric cable delivering generator power to the submersible pump fitted at the base of the well. The pipe and hoses connect the well to the orifice flow meter about 150 metres north. Figure 17 shows the test water discharging to the main or northern branch of Mill Creek. The vertical piezometer tube for measuring flow is attached to the left side of the meter.

Figure 16: Pumped Well 220

Figure 17: Orifice Flow Meter

Figure 18 shows the variation in drawdown during the aquifer test at the pumped well 220 in light blue, and at the observation well 219 in darker blue. Drawdown is defined as the change in aquifer water level minus the initial level, before pumping started. In other words zero drawdown indicates aquifer level prior to pumping.

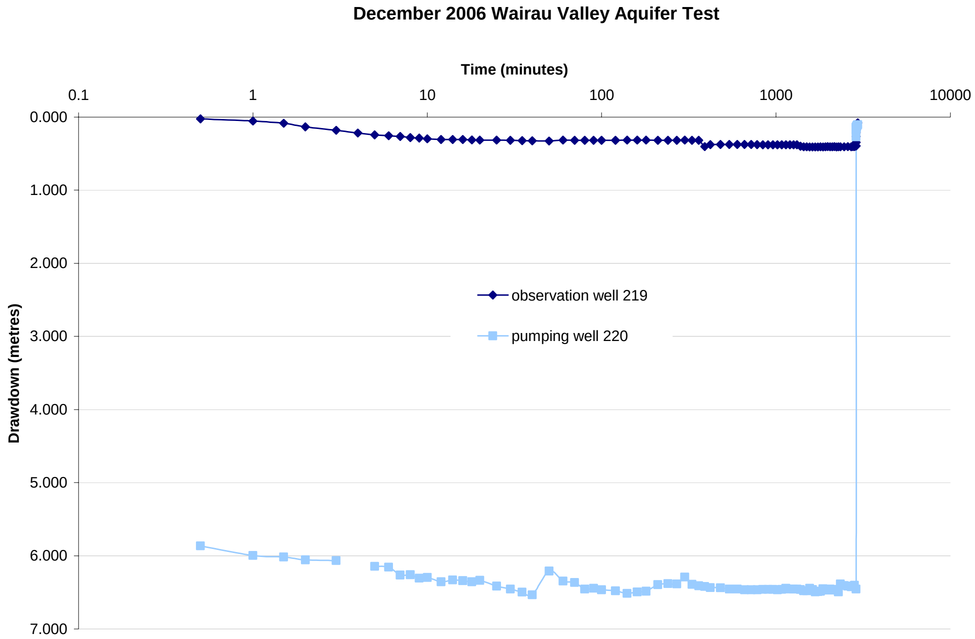

Figure 18: Observed Drawdown at Pumped well 220 and Observation Well 219

Testing was conducted over the 12th and 13th of December 2006, however conditions weren't ideal with more rainfall than was typical of a normal summer.

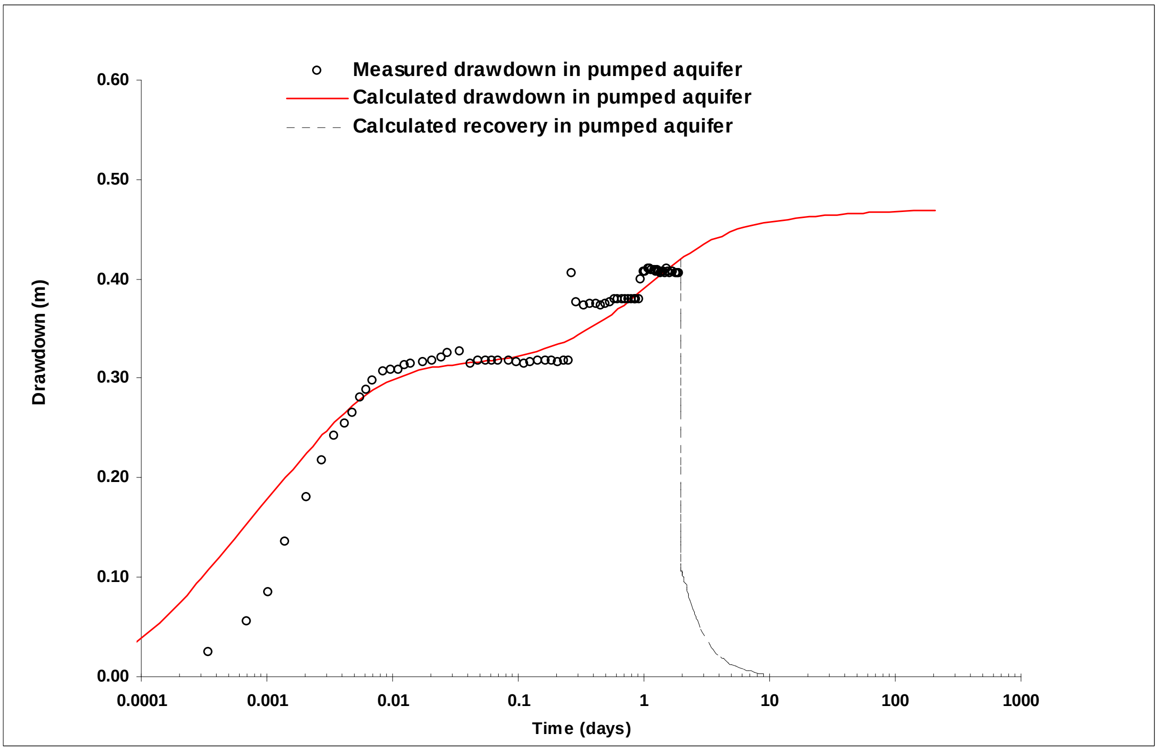

Figure 19: Drawdown Observations at Well 219 versus Hunt Type Curve

Pumping continued for 47 hours with flow being measured using the well drilling contractors orifice flow meter. It was positioned 160 metres to the north of well 220 to allow test water to be discharged into Mill Creek, avoiding recirculation. The flow in Mill Creek during testing was about 390 litres per second and stable. It was important to maintain a constant pumping rate so any hydraulic boundary effects could be isolated and identified.

The black circle symbols in Figure 19 shows the observed drawdown at the observation well 219 during the test. The red line represents the theoretical response of the aquifer for the given boundary conditions, using the Hunt 2003 solution. It is useful to describe the variation in drawdown throughout the duration of the test in relation to the type curve, as it tells us a lot about the aquifer.

Initially the rate of drawdown is rapid, and fits the standard response of a confined aquifer releasing water from storage. The imprecise fit to the red type curve earlier on probably reflects problems with establishing the correct flow rate. At around 20 minutes the rate of drawdown flattens due to the arrival of delayed yield draining downwards from higher in the aquifer and this continues through until about the first hour of pumping.

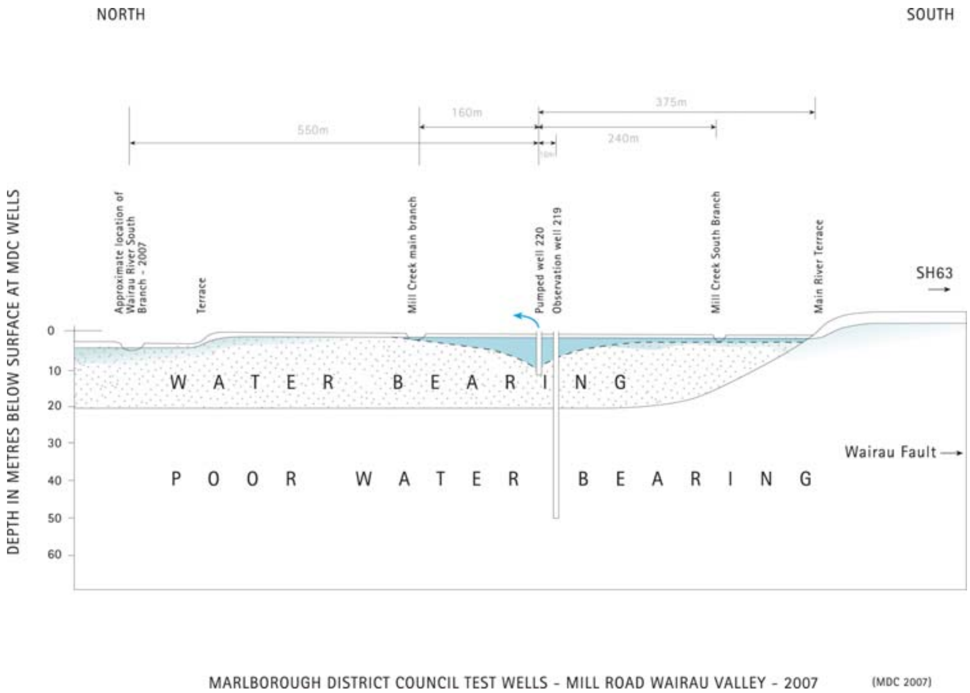

Figure 20: West to East Section along Mill Road

Between 1 hour and approximately 300 minutes, drawdown stabilises with the rate at which water is being pumped from well 220, being matched by recharge to the aquifer. In physical terms this probably represents the interception of the cone of depression with channel flow in the closest branch of Mill Creek, 160 metres to the north. This is illustrated in Figure 20 where the cone of depression is denoted by the dashed line.

These stable conditions continue until around 300 minutes after pumping started, when there is an abrupt increase in drawdown. This is likely to represent the cone of depression encountering the main river terrace, situated a distance of 375 metres to the south of well 220 (Figure 20). A fall in level occurs under these circumstances because the terrace represents the edge of the Wairau Valley Aquifer and acts in the same way as the wall of a swimming pool. Because the cone of depression can’t derive any recharge from that direction, it acts as a barrier boundary, which induces a drop in levels in wells 219 and slightly later at 220. Figures 21 and 22 are close-ups of drawdown versus time for the pumped and observation wells respectively.

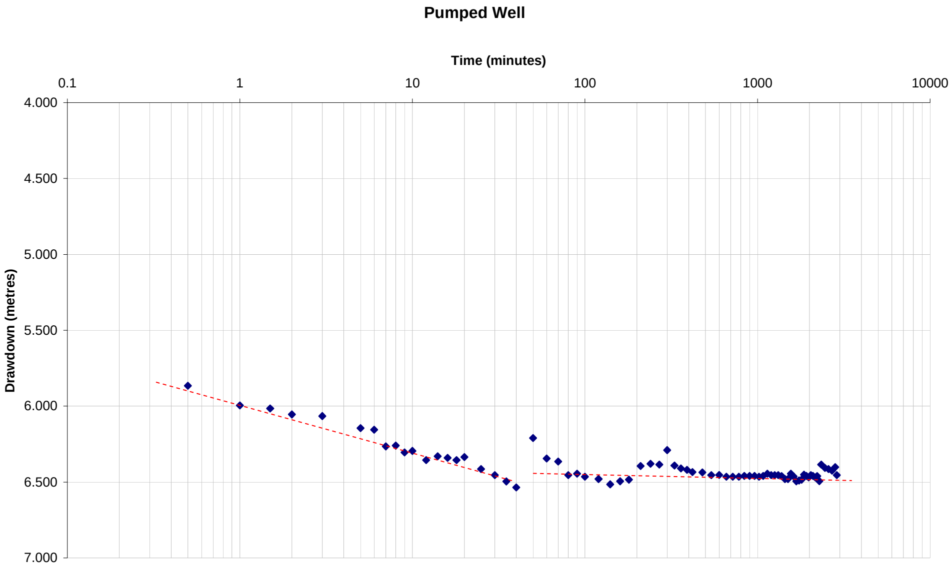

Figure 21: Pumped Well 220 Drawdown versus Time

After the rapid fall in level of around 75 millimetres, drawdown once again stabilises through until about 1 day of pumping has elapsed. This flat lining is a repetition of the earlier record, and represents the contribution of Mill Creek flow from both branches. After 1 day there is a second abrupt increase in drawdown due to the effect of another barrier boundary, maybe a pinching out of a water bearing layer. This is followed by a further stabilisation of drawdown reflecting induced stream flow which lasts through to the end of the test.

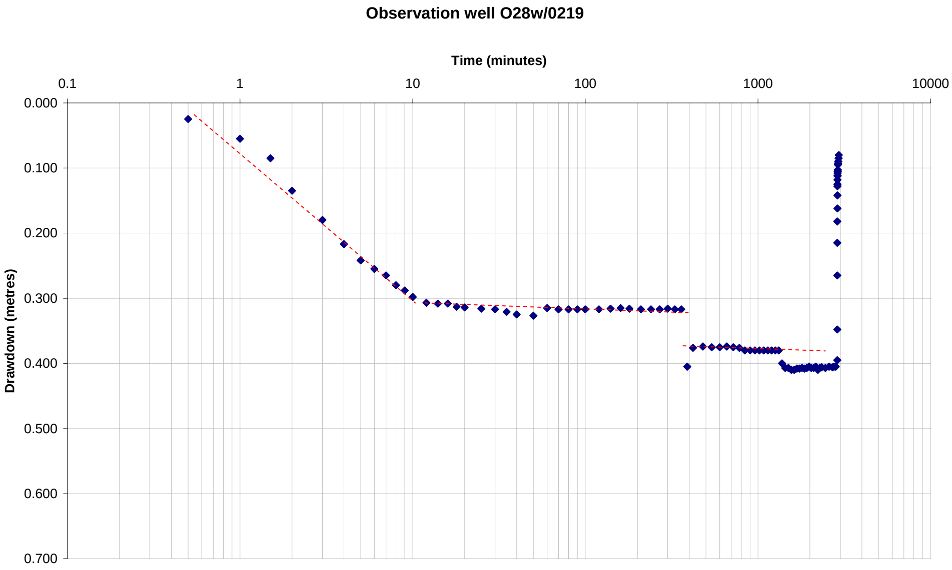

Figure 22: Close-up of Monitoring Well 219 Drawdown versus Time

Figure 23 shows that over the 2 day duration of the test, the Hunt equation predicted around 50% of water pumped from well 220 originated from Mill Creek or represented groundwater that would otherwise have ended up there.

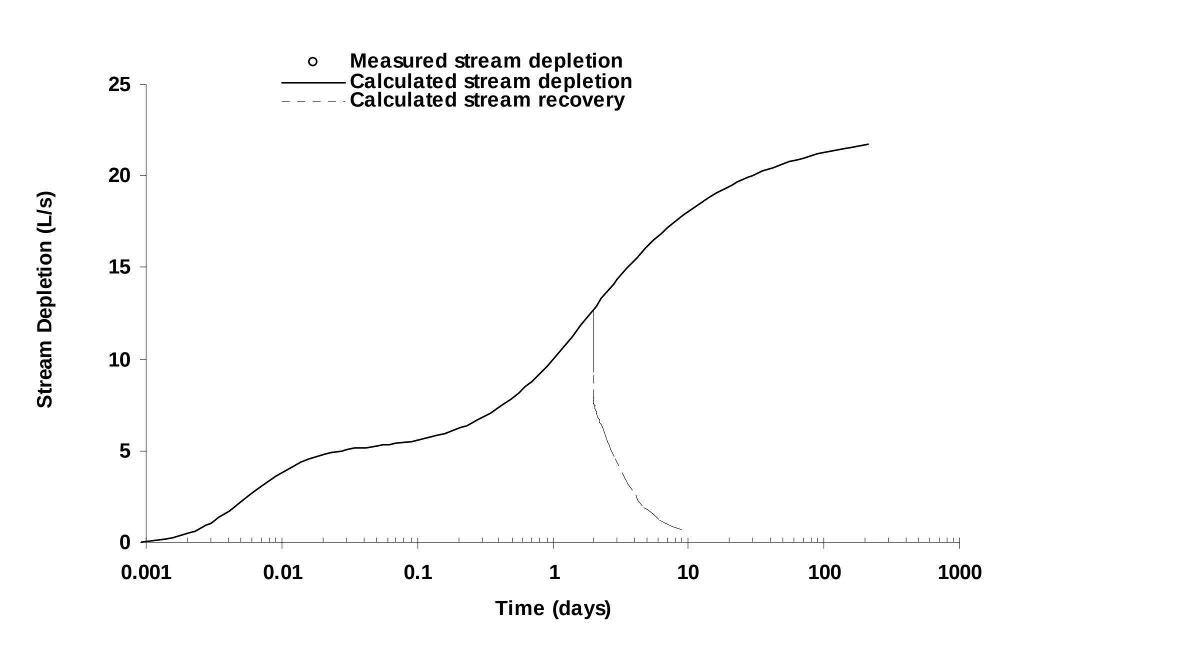

Figure 23: Calculated Stream Depletion

The rate at which an aquifer transmits water is described by its transmissivity rate. Values of transmissivity measured via testing of the Wairau Valley or upper aquifer, varied from 1,030 to 2,000 m^3/day per metre per width of aquifer, as shown in Table 2. This is relatively high given the formation hosting the aquifer is only 10-20 metres thick, indicating reasonably permeable gravels.

Method of Analysis	Aquifer Transmissivity (m^3/day/metre)	Aquifer Storativity	Data source
Hunt stream depletion equation type curve fitting	**2000**	**0.002**	Observation well 219
Theis type curve fitting	**1050-1987**	**0.002-0.007**	Observation well 219
Cooper Jacob line of best fit	**1030**	**-**	Pumped well 220
Cooper Jacob line of best fit	**1590-1799**	**0.0035-0.005**	Observation well 219

Table 2: Measured Aquifer Properties from 2006 Test

Another method of assessing aquifer transmissivity is via drillers well test results. Table 3 shows the specific capacity value derived from the contractors post construction test was 7 m^3/hour/metre for the Wairau Valley Aquifer and less than 1 m^3/hour/metre for the deeper aquifer as represented by well 219. These translate into transmissivity values of 468 m^3/day/metre and 7 m^3/hour/metre respectively. Obviously the upper aquifer represents a viable source of water, but the very low yield of the deeper aquifer shows it is a poor reservoir.

Another hydraulic property useful for predicting the effects of future use is storativity or the way in which an aquifer stores and releases water. In the case of the Wairau Valley Aquifer on the lower terrace, the storage coefficient is relatively low indicating a semi-confined to confined aquifer structure. In other words a relatively small volume of water is released from storage for each metre the aquifer level falls. Table 2 shows there is a small range in storativity values with an average of $4x10^{-3}$.

Well	219 (Deep Aquifer)	220 (Wairau valley or upper Aquifer)
Well specific capacity (m^3/hour/metre)	**0.14**	**9.75**
Aquifer transmissivity (m^3/day/metre)	**7**	**468**

Table 3: Well Specific Capacity

At the end of testing water samples were collected for laboratory analysis to measure the concentration of a range of chemical parameters and environmental isotopes. This information was used to assess groundwater potability, origin and flow-path.

7. Exploratory Drilling Phase

Once testing of the upper aquifer was complete, the depth of the exploratory well 219 was extended to 50 metres during winter 2007. The cable tool drilling process was used and provided undisturbed samples of the drill-hole material.

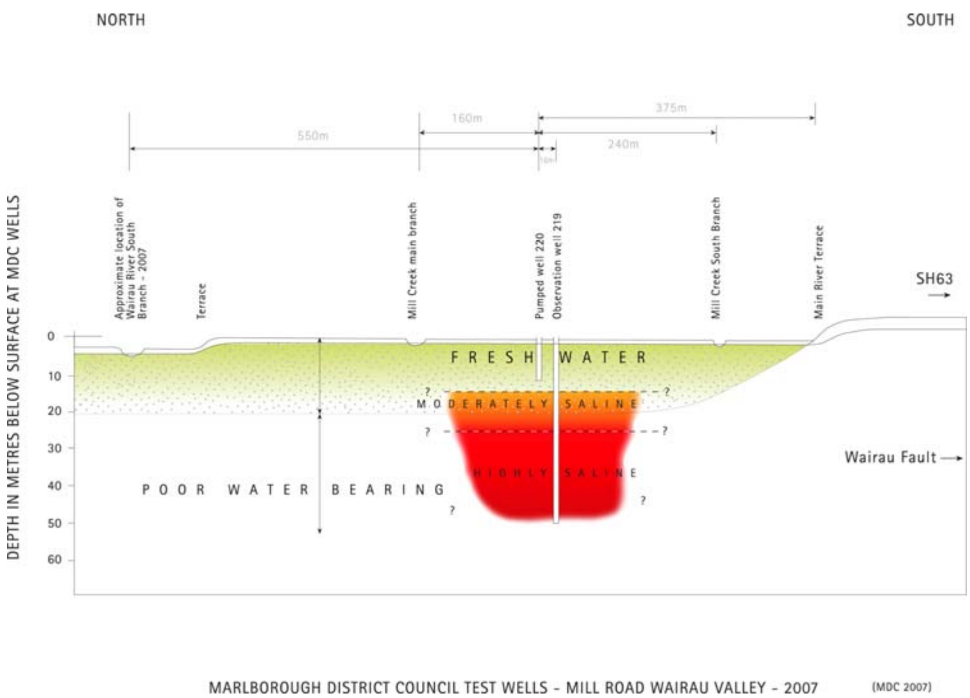

Figure 24: West to East Section along Mill Road

The drilling process demonstrated the existence of a layered series of groundwaters of different densities, from freshwater near the surface through to moderately saline groundwater from around 15 metres downwards, and highly saline water beyond 50 metres depth. This pattern is illustrated in Figure 24. Of particular interest was the electrical conductivity of the saline waters which at around 5,000 mS/metre, were equivalent to that of seawater.

The increasing trend in groundwater electrical conductivity with depth is shown in Figure 25 where the red vertical line represents the value for seawater. Figure 24 shows the saline water discovered at Mill Road in the context of the terrace and Wairau River. The regional extent of this water is uncertain but geophysical surveys planned for later in 2007 will map its local extent in the Mill Road area.

It is likely based on the drillers descriptions of tighter drilling conditions with increasing depth for well 219, that aquifer yield also declines. Certainly the yield of well 219 at its final depth of 50 metres supported these observations. This implies a sluggish groundwater flow environment beyond a depth of 25 metres, with limited flushing and no means for the highly saline groundwater to dissipate or be diluted.

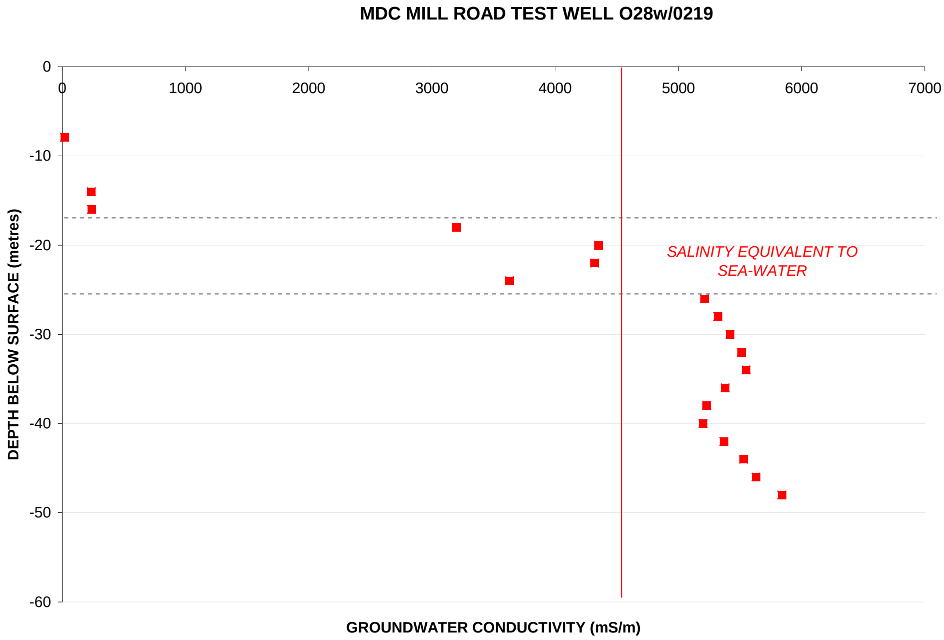

Figure 25: Well 219 Electrical Conductivity versus Depth

Also of interest in identifying the direction of groundwater flow is the relativity in groundwater pressures with depth. Figure 26 shows the variation in static level in well 219 from the start of drilling through to the end of well construction at 50 metres depth, based on well drillers daily observations. Static levels fell from an average of around 2.5 metres depth in the upper 15 metres, to 3.25 metres during the lower 30 metres of drilling. In other words a downward flow gradient naturally exists, inducing gravity drainage of water.

The well drilling process identified the stratigraphic and aquifer sequence beneath Wairau Valley at Mill Road to the maximum explored depth of 50 metres. While the series is likely to be representative of the Wairau Valley Aquifer (upper aquifer) beneath the lower terrace area of Wairau Valley, it remains to be seen whether the deeper sequence applies universally. In other words, local depositional patterns may vary.

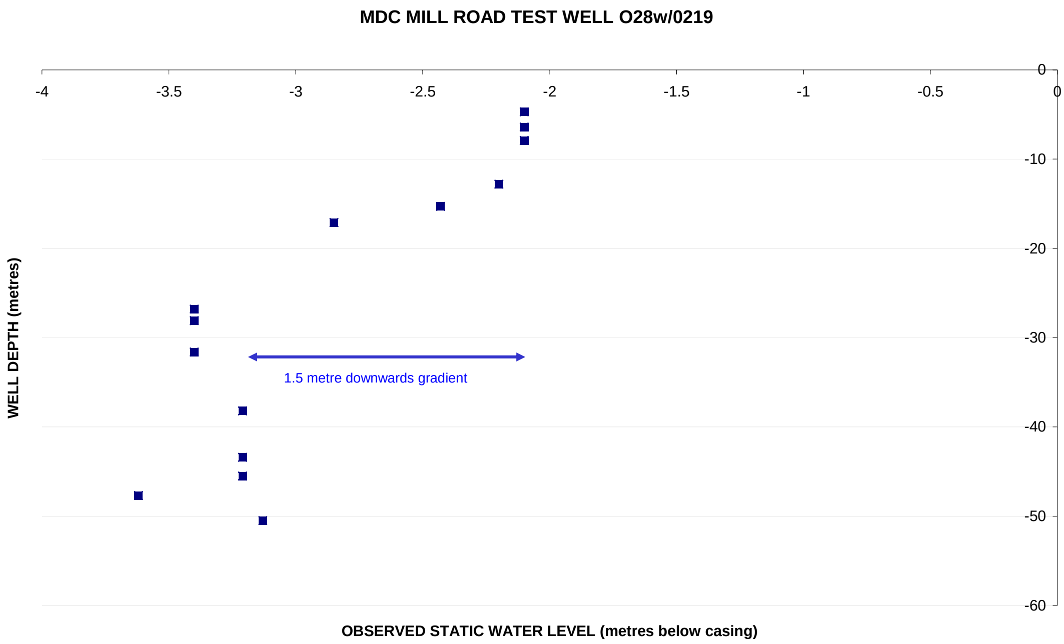

Figure 26: Well 219 Static Level versus Depth

8. Groundwater Chemistry

The chemical fingerprint of a particular groundwater can be a powerful tool for identifying its origin, evolution and flowpath. It is also an index of land-use impacts on aquifer quality and a direct measure of the potability of water, or in other words its suitability for human consumption.

It is particularly relevant tool for understanding the Wairau Valley groundwater hydrology, where distinctive water types occur due to differences in fluid density. The presence of highly saline water associated with tectonic seepage is relatively unique in Marlborough, and an ideal marker.

The salinity is naturally occurring and a function of an extended period of water-rock interaction in a particular chemical environment associated with the Wairau Fault. The most highly saline groundwater discovered to date was encountered at depths of between 25 and 50 metres in the Marlborough District Council exploratory well 219 in mid 2007. It is similar in composition and concentration to seawater. Drilling to deeper depths in the future may identify even more saline waters.

In 2002 Dr Claude Taylor, a research hydrologist, was commissioned by Marlborough District Council to assess the origin of the saline water at Wairau Valley using isotope techniques. He identified the saline water as old connate water associated with the Wairau Fault.

Table 4 lists the concentration of dissolved salts in groundwater from the deeper aquifer based on the sample collected at well 219 in May 2007. It contains high concentrations of: arsenic, ammoniacal-nitrogen, boron, iron, manganese, potassium, sodium, chloride and calcium. A low redox potential is commonly associated with fault processes, and this is consistent with the observed low levels of sulphate and nitrate-nitrogen (Table 4.) Well 219 sources water from the deeper aquifer, while the neighbouring Marlborough District Council well 220 draws water from the Wairau Valley Aquifer or upper aquifer.

Parameter	Well 219 (deep layer) *May 2007*	Well 220 (shallow layer)		Units
		25/7/2006	*14/12/2006*	
Electrical conductivity @ 25 degrees	4870	18.3	16.1	mS/m
pH	6.83	6.7	7.2	
Alkalinity	69	Bicarbonate 33 g/m^3 HCO_3	Alkalinity 33 g/m^3 $CaCO_3$ Bicarbonate 40 g/m^3 HCO_3	g/m^3 HCO_3
Bromide	28		0.15	g/m^3
Chloride	**19000**	27	23	g/m^3
Fluoride	0.05	0.11	0.088	g/m^3
Sulphate	0.15	5.4	5	g/m^3
Ammoniacal-Nitrogen	5.8	0.006	0.005	g/m^3
Nitrate-Nitrogen	0.004	3.1	1.7	g/m^3
Silica	14	14	15	g/m^3 SiO_2
Boron	**18**	0.08	0.07	g/m^3
Calcium	**3200**	12	10	g/m^3
Iron	**6**	0.015	0.006	g/m^3
Magnesium	47	2.8	2.4	g/m^3
Manganese	**5.8**	0.004	0.002	g/m^3
Potassium	19	1	1	g/m^3
Sodium	**8300**	16	15	g/m^3
Arsenic	**0.023**	<0.001	<0.001	g/m^3

Table 4: Groundwater Chemistry Results

For comparison with the unique saline water, the analyses of 2 samples of water from Marlborough District Council well 220 are listed in Table 4. It is useful to compare the concentration of each parameter individually to identify possible indicators for distinguishing between old and newly recharged groundwaters, or risk factors to human health.

The pH value for the deeper aquifer sample is suspiciously low for what is likely to represent older water. It is also different to a pH value of 8.26 for a sample taken on the 4th July 2007. In both cases measurements were made using a field meter. As expected, groundwater from the Wairau Valley Aquifer or upper aquifer has a low pH reflecting its young age. This was confirmed by GNS Science isotope measurements in 2007, which assessed the age of the water as juvenile with a mean residence time of less than 2 years.

Electrical conductivity is very low for the Wairau Valley Aquifer (upper aquifer) water reflecting the low concentrations of dissolved salts. Values are correspondingly high in the deeper aquifer at around 5,000 mS/m, the highest recorded to date for a Marlborough groundwater. Alkalinity is significantly higher in deeper aquifer water, but of the same order as that from the upper aquifer.

Bromide, sodium and calcium levels are 2 orders of magnitude higher in the deeper aquifer water compared to the Wairau Valley Aquifer (upper aquifer) water. Likewise the concentrations of chloride, ammoniacal-nitrogen, boron, iron and manganese are all 3 orders of magnitude higher. Concentrations of arsenic, potassium, magnesium are all an order of magnitude greater in the deeper aquifer, compared to the Wairau Valley Aquifer (upper aquifer).

Conversely, sulphate and nitrate-nitrogen concentrations are very low at 0.15 and 0.004 g/m^3 respectively in the deeper aquifer sample, reflecting the anaerobic aquifer conditions and relative isolation from land-use or surface activities. Interestingly, silica concentrations are similar for both aquifer waters, whereas higher levels would be expected in the deeper aquifer with the older water. The other apparent anomaly is the low concentration of fluoride in deeper groundwater.

The next step is to review the upper aquifer chemistry data to see if they support the current conceptual model of groundwater flow at Wairau Valley, and in particular a South-bank hill country source of recharge for the Wairau Valley Aquifer (upper aquifer) on the lower terrace.

The first step was to analyse the ratios of cations and anions for 5 Wairau Valley waters using a Piper Trilinear type plot. Samples included: Wairau River opposite Church Lane, Mill Creek at Mill Road, Mill Creek southern tributary at Mill Road, Marlborough District Council exploratory well 219 and monitoring well 220.

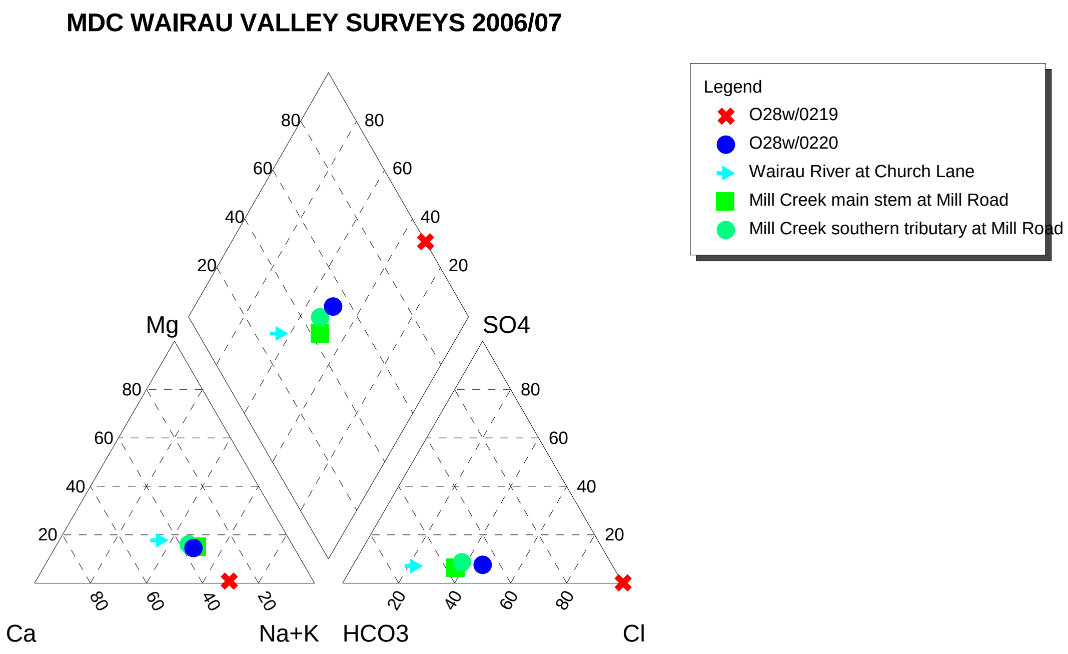

Figure 27: Piper Trilinear Diagram

Figure 27 shows the samples plotted as ratios of the major ions in milliequivalents to determine if they represent the same or related water types. The red dot represents the highly saline sample from the deeper aquifer at exploratory well 219, and is obviously quite distinct to the other 4 waters. It is effectively seawater both in terms of its concentration of salts, and ratio of sodium to chloride.

Groundwater from well 220 (dark blue) representing the upper or Wairau Valley Aquifer, and the 2 Mill Creek samples in green are similar and can be described as sodium-calcium-bicarbonate-chloride type waters. There is subtle difference between this group and Wairau River channel flow, which is described as calcium-sodium-bicarbonate-chloride type water. Table 5 lists the data used to derive Figure 27.

This analysis supports the concept of a common body of water for Mill Creek and the upper or Wairau Valley Aquifer. Furthermore, that the source of replenishment originates from the South-Bank hill catchments rather than a Wairau River source.

Those parameters not included in the Piper analysis such as the stable isotope ratios, pH and electrical conductance are also consistent with this conclusion. Generally speaking there is also a closer affinity between Wairau Valley Aquifer water (well 220) and the southern rather than the main stem of Mill Creek. There doesn’t appear to be much evidence of the deeper aquifer influencing the chemistry of Wairau Valley Aquifer water (well 220), suggesting limited mixing and discrete layers or stratification of groundwater due to density.

Because Mill Creek and Wairau Valley Aquifer water (well 220) receive recharge from a common source to the south, Mill Creek and shallow groundwater aren’t independent as they are both affected by flow through the Wairau Fault zone.

Parameter	Wairau River at Church Lane	Mill Creek main stem at Mill Road	Mill Creek south tributary at Mill Road	MDC well 220 (Wairau Valley -upper Aquifer)	Units
$^{18}O/^{16}O$	-8.49	-7.82	-8.01	-8.06	
Electrical conductivity @ 25 degrees	7.5	15.2	14.0	16.1	mS/m
pH	7.7	7.1	6.7	7.2	
Alkalinity	28	43	34	33	g/m^3 $CaCO_3$
Bromide	<0.15	<0.15	<0.15	<0.15	g/m^3
Chloride	6	20	17	23	g/m^3
Fluoride	0.056	0.12	0.1	0.088	g/m^3
Sulphate	2.6	4.5	5.1	5	g/m^3
Ammoniacal-Nitrogen	0.005	0.007	0.015	<0.005	g/m^3
Nitrate-Nitrogen	0.22	0.43	1.3	1.7	g/m^3
Silica	9	12	16	15	g/m^3 SiO_2
Boron	0.04	0.16	0.07	0.07	g/m^3
Calcium	6.6	9.2	9.3	10	g/m^3
Iron	0.033	0.13	0.041	0.006	g/m^3
Magnesium	1.5	2.4	2.4	2.4	g/m^3
Manganese	0.003	0.006	0.003	0.002	g/m^3
Potassium	0.6	0.6	0.7	1	g/m^3
Sodium	5.4	15	13	15	g/m^3
Arsenic	<0.001	<0.001	<0.001	<0.001	g/m^3

Table 5: December 2006 Survey Chemistry

Finally, what do the water chemistry results tell us about the suitability of local groundwaters for domestic water supply, and the impacts of current land-use or farming activities on water quality at Wairau Valley. Levels of boron, manganese and arsenic from the deeper aquifer are of health significance with guidelines values in the Drinking Water Standards for New Zealand 2005 (DWSNZ 2005) of 1.4 g/m^3 , 0.4 g/m^3 and 0.01 g/m^3 respectively. Their concentrations transgressed the health thresholds by 1300% for boron, 1450% for manganese and 230% for arsenic. It is not known if these represent the maximum values to occur at Wairau Valley.

Because a potential risk to human health exists from deep groundwaters, it would be prudent to measure the seasonal variability of arsenic levels in particular, to check the representativeness of one off samples used to support land subdivision applications.

Agricultural products are most likely to end up in shallow groundwater. Results from the Marlborough District Council shallow well 220 on the lower terrace are representative due to its location at the end of the travel path from the South-bank hill country catchments. Table 5 shows levels of nutrients including nitrate-nitrogen and sulphate are relatively low for the Wairau Valley Aquifer (upper aquifer), suggesting minimal impacts from agriculture on this particular occasion, however further data are needed to identify any seasonal variability. Potentially, shallow groundwater is unlikely to represent a secure water supply for human drinking purposes.

Further sampling of water from well 219 was carried out on the 4^{th} of July 2007 to measure the residence time of groundwater from this deeper aquifer (Figure 28). It is expected that this water will be relatively old, but the results weren't available for inclusion in this report.

Figure 28: Radioisotope Sampling of Well 219

9. Future Work Programme

The Geological Sciences Department of the University of Canterbury will geophysically survey the sub-surface terrain along an axis from Mill Road to Parsons Road, mapping the wider extent of the highly saline groundwater. This is likely to involve the electric resistivity and seismic reflection methods.

At the time of writing the laboratory analyses to determine the residence time and likely recharge source of groundwater from the deeper aquifer hadn't been completed. There was also insufficient aquifer water level record available to describe any trends or to correlate with flow in Mill Creek or the Wairau River for example.

Given uncertainty over the stability of arsenic concentrations in Wairau Valley groundwaters and continuing rural residential development, Marlborough District Council will institute a programme of monthly measurements at a representative site with a previous record of elevated levels.

10. **References**

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