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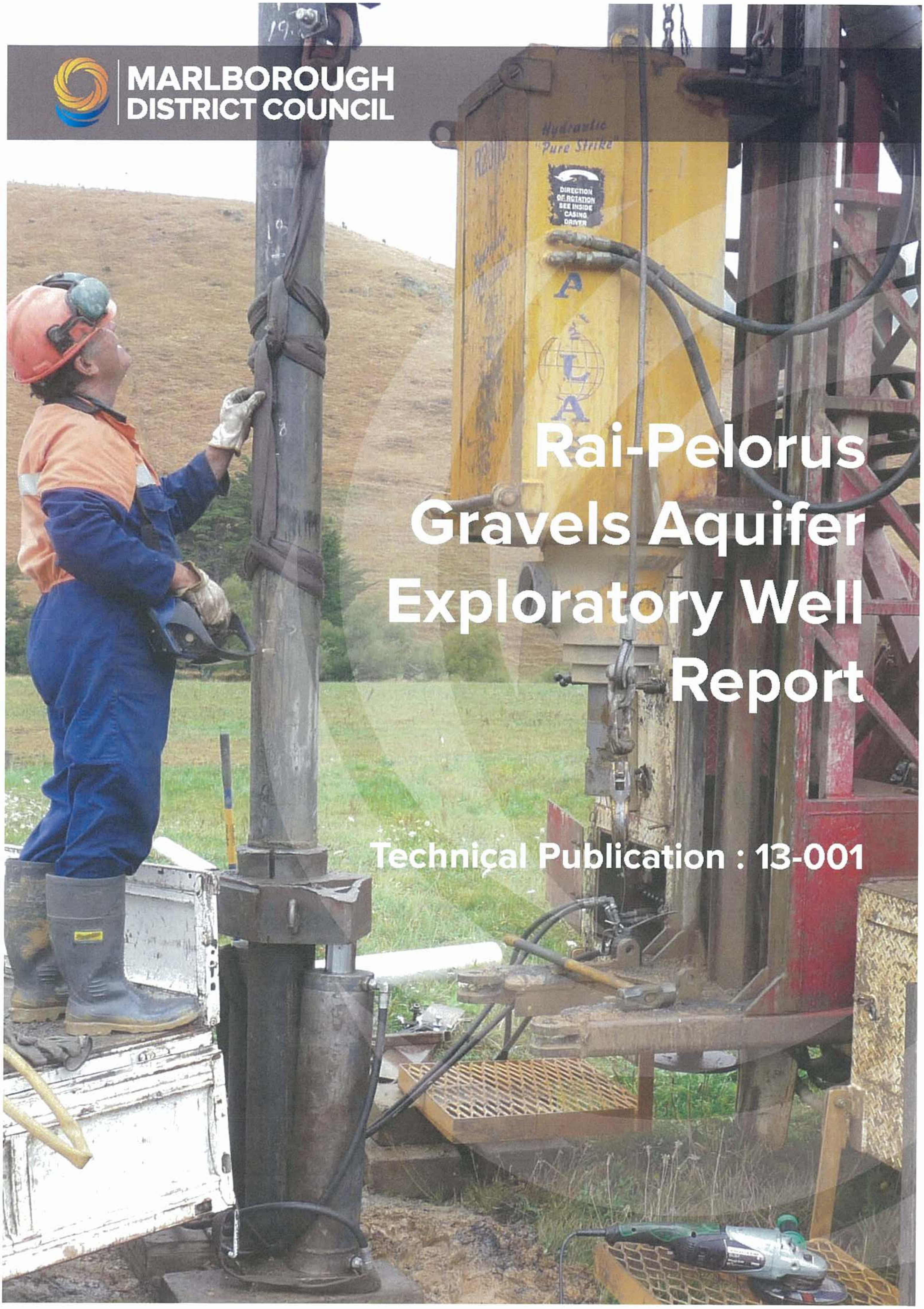

Rai-Pelorus Gravels Aquifer Exploratory Well Report

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Executive Summary

- The groundwater resources of the Rai-Pelorus River valley area are a focus of MDC investigations in 2012/2013 because relatively little is known about them relative to other parts of Marlborough

- With increasing demand for water as the township grows and land-use intensifies, an improved understanding is needed to assess the significance of groundwater storage relative to river flow for allocation purposes, the potential for aquifer contamination and modelling nutrient movement at a catchment scale

- A number of projects are scheduled by MDC to develop an improved picture of the local hydrogeology. The first was the drilling and testing of a test well near Rai Valley township in February 2012 to define the local geology

- The intention was to drill a single test well but basement rock was intercepted at very shallow depth and a second attempt closer to the Rai River struck bedrock only slightly deeper

- The aquifer forming gravels are thinner than predicted and if representative of the valley floor, then the groundwater resource underlying Rai Valley may be limited

- The western test well (10323) will form part of the permanent MDC district wide state of the environment (SOE) network and be sampled seasonally to track changes in groundwater quality over time. This record will form a baseline to track seasonal and long-term changes in relation to climate variability, river flow or human activities

- Aquifer transmissivity varied from an estimated maximum of 3,000 m^2/day at the western well (10323) to an estimated minimum of 50 m^2/day at the eastern well (O27w/0119)

- Based on initial measurements the chemistry of deeper groundwater is more evolved than shallower groundwater, but more information is needed to conclusively define interactions between shallow groundwater and local streams or the Rai River

- The residence time of groundwater varied from greater than 155 years for the deeper test well to recent water of 7.5 years in the shallow test well

Contents

1. Introduction

There is a good understanding of the nature and extent of groundwater resources beneath the Wairau Plain, but gaps exist for other parts of Marlborough district. The Rai/Pelorus River Valley is one of the last alluvial floodplains not to have been studied in any detail by MDC or its predecessors.

A baseline understanding of groundwater resources and in particular the impacts of landuses on groundwater quality was needed because the Rai township is growing in population and landuse is intensifying throughout the wider catchment. Both of these trends will increase stress on groundwater resources through higher demand and the generation of more waste that could potentially contaminate aquifers.

This information will also help define the water balance of the catchment and in particular the significance of the groundwater store relative to rainfall runoff or river flow for water allocation and nutrient budgeting purposes.

This area has been the focus of investigations into the links between landuse and the quality of rivers or runoff to the Marlborough Sounds over the past 25 years together with a focus on improving farming practices. Understanding how long runoff is held up in aquifers is a key parameter for modelling runoff processes at a catchment scale because it controls any time lags that may exist.

The first stage in improving community understanding of local groundwater resources was to determine the depth of potentially aquifer forming gravels beneath Rai Valley, their hydraulic properties, the quality of groundwater and its residence time. This started with exploratory drilling in February 2012 and will be followed up by testing of groundwater quality in 2013 at selected wells located throughout the wider catchment downstream to Pelorus Sound at Havelock.

While deeper wells have been drilled in the nearby Waikakaho Valley, Linkwater, Tuamarina River Valley, Kaituna and at Havelock by MDC or private landowners; there are few deeper wells in the Rai-Pelorus River Catchment.

Most wells are naturally enough only drilled as deep as necessary to intercept groundwater and this is often less than 10 metres below the surface, especially near perennially flowing streams or the Rai River. Because of this the full sequence of aquifer forming gravels hasn't been explored yet. It is possible that new aquifers may exist that local residents are unaware of and verifying this is one of the aims of the current MDC investigation.

2. Water Management

MDC currently manage and allocate water resources in the Ronga-Tunakino-Opouri-Rai-Wakamarina-Pelorus River system based on catchment runoff and river flow. Groundwater has been ignored because its volume is uncertain, but to be conservative it has assumed to be small by comparison with average surface water flows.

Groundwater may be a significant component of the catchment water budget under low river flow conditions and it is this type of question that will be answered over the next 2 years as part of the MDC programme.

A basic understanding of the interaction between surface water and groundwater is needed to understand any buffering effect of groundwater storage when river flows are low for both nutrient runoff management and for optimising catchment water allocation or siting wells to minimise interference effects. Because a detailed knowledge of groundwater resources hasn't been critical for water management until now, there hasn't been the need for research any sooner.

3. Regional Geology

The geology of the Marlborough Sounds catchments is dominated by narrow river valleys flanked by steep hills formed of hard-rock. The bedrock consists of sandstone (greywacke) or its metamorphosed equivalent (schist), and is unlikely to store significant amounts of groundwater or act as aquifers under normal circumstances.

The axis of the valley floors are orientated along faults in these basement rocks which in turn form depressions that become infilled with sediments deposited by local rivers or slumping hillsides, over many thousands of years.

Figure 1 is a map view showing the geologically distinct mineral belt in orange/purple, roads in red, rivers or streams in blue, faults in yellow and the land surface topography. While there are many faults, most are not currently active meaning they haven't moved in thousands of years.

The Ronga Fault runs parallel to the main road through Rai Valley and controls the deposition and thickness of the aquifer forming sediments (**Figure 1**). The map extends from the confluence of the Pelorus and Rai Rivers in the south to the Ronga saddle in the north at the top of the picture. Rai Valley township is in the centre of **Figure 1** and the catchment area of Hills Stream which is the focus of the test drilling is hatched white.

Sediments forming the valley floors are a mixture of gravels, sands and clays which store water between rainfall or river flood events to form aquifers. These are in turn tapped by wells to supply water for drinking, stock supply, dairy shed washdown or pasture irrigation. What is immediately obvious is the relatively small area of the valley floors which are potentially aquifer forming compared to the surrounding hill country.

We can't be precise about the depth of the sediments underlying the Rai Valley area yet because there aren't enough deeper wells to map their base however they are thought to reach their maximum depth in the north and pinch out at Rai Falls in the south based on current well information. This concept will be discussed in more detail later in the report.

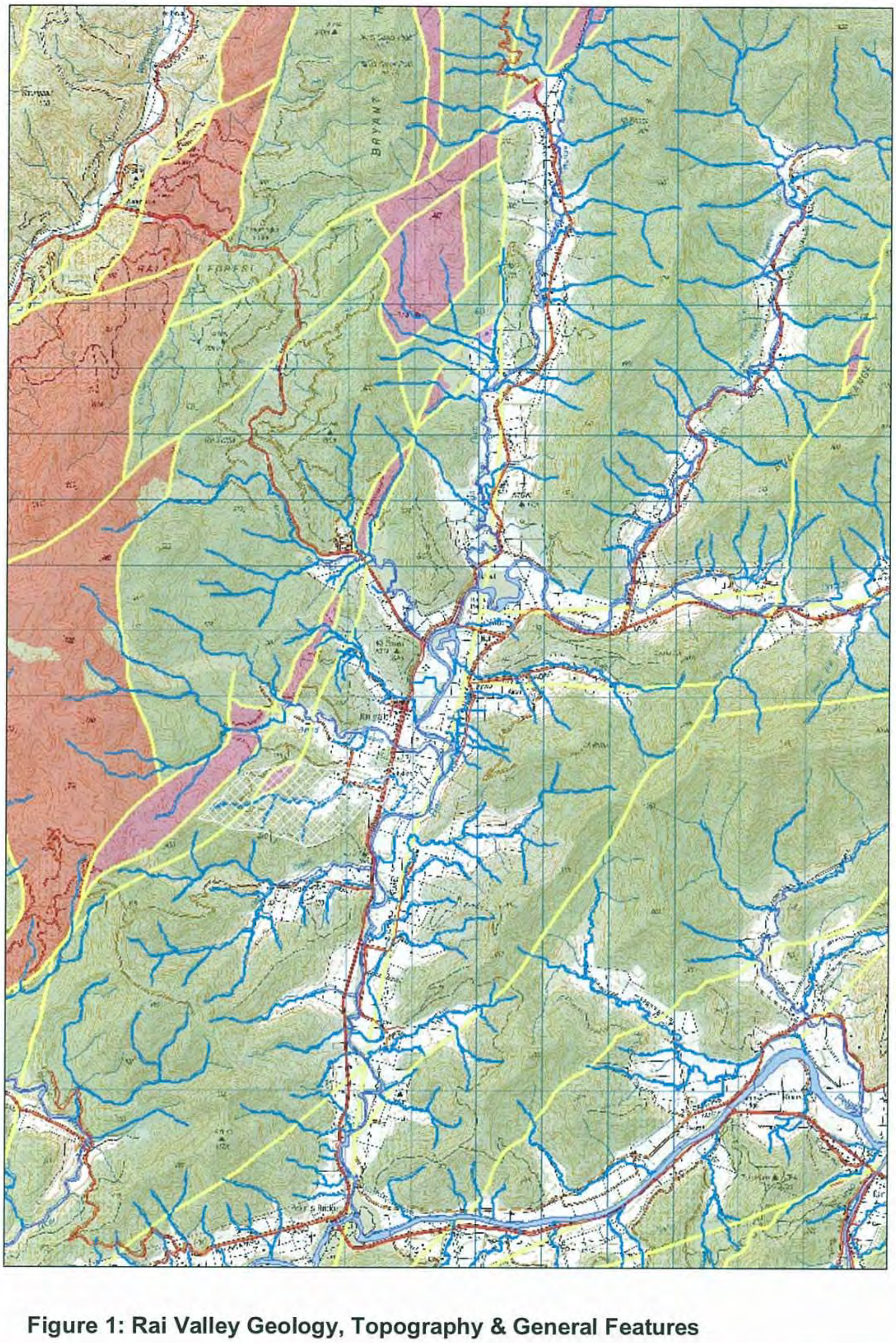


Figure 1: Rai Valley Geology, Topography & General Features

Rivers and streams draining the western and northern catchments of the Rai River come into contact with outcrops of ultramafic rock types belonging to the Dun Mountain Ophiolite Belt, Patuki Melange and Croiselles Melange geological Formations. Together these are known as the mineral belt.

Rivers and streams draining these catchments dissolve this distinctive assemblage of minerals and water typically contains higher concentrations of iron or magnesium as a result. These particular rock groups are shaded purple or pink in the geology map (**Figure 2**).

A good example of how water chemistry varies with catchment rock type is the Brown River which is a western tributary of the Rai River. MDC survey Brown River water quality regularly and it has a characteristically higher electrical conductivity compared to the Opouri River which flows from the east. Higher conductivity means the water has more dissolved solids making it easier to conduct electric current and these originate from weathering of the rocks forming the mineral belt.

Because the Rai River water sampled as part of this study will be a mix of Ronga River, Rai River, Opouri River, Brown River and Tunakino River water; it will have blend of different mineralogies influencing its water chemistry. On the other hand Hills Stream water originating from the west is likely to be influenced by the mineralogy of the ultramafic rocks (**Figure 2**).

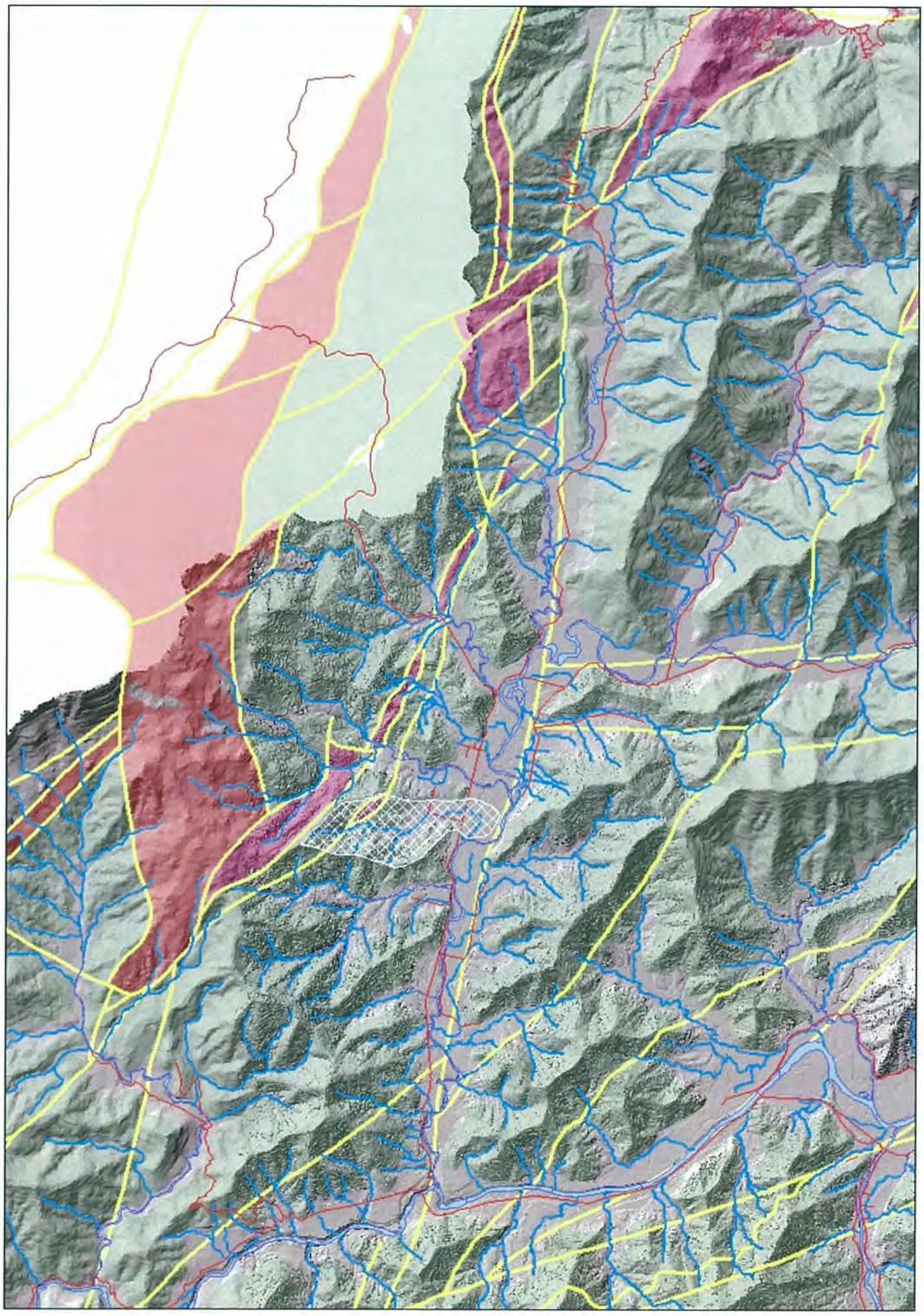


Figure 2 : Rai Valley Geology & Terrain

Figure 3 : Rai Falls Looking Upstream

4. Groundwater/Surfacewater Interaction

Experience in other Sounds catchments has shown that water moves backwards and forwards between river channels and their associated riparian aquifers. This pattern has been observed in the Waikakaho and Tuamarina River Valleys by MDC, with the direction of flow depending on the relative levels of the water bodies. A similar exchange involving shallow groundwater in the Rai-Pelorus River Valley is likely within the riparian influence of the river, but may not hold further from the channel.

Being in a high rainfall zone, these shallow aquifers are recharged frequently and are likely to be hydraulically connected with the Rai River to some extent. However in a significant drought like the 2001 event, aquifers are unlikely to store large volumes of water, especially downstream of the Rai Valley township where the latest drilling show the sediments appear to thin out.

Based on the elevation of the Rai River it is postulated that in its upper reaches channel flow is lost to the sediments whereas the direction of flow is probably reversed at the Rai Falls with groundwater draining back towards the river. The Rai River passes over bedrock at the Rai Falls making it an ideal flow measurement site as all flow can be accounted for and not lost to the sediments (**Figure 3**).

Flow patterns involving deeper groundwater are likely to be more complex and will rely on deeper wells being drilled in the future to define them. Older groundwater could potentially be trapped in deeper sediments and confirming this was one of the original objectives of the exploration programme, although as it turned out the sediments near the test well site were too shallow to resolve this question.

5. MDC Exploratory Drilling

The initial MDC test well was located approximately 1 kilometre south of the township on the eastern side of SH6 (**Figure 4**). The site was chosen so samples of groundwater would detect any long-term impacts on quality associated with upstream changes in catchment landuse or township growth. The second drill site is marked by the red arrow closer to the bottom of **Figure 4**.

Based on the geological information available at the time of planning the location of the test well, it was thought to overlie the maximum thickness of aquifer hosting gravels. A geophysical survey was considered to help target the deepest sequence of gravels but there was insufficient budget for this. Other criteria used for siting the well included its accessibility for MDC staff to sample while not interfering with farming operations, and being above the lower lying areas affected by Rai River floods.

Figure 4 : Aerial View Of Rai Valley Looking North-West Showing MDC Test Wells

The preferred site for MDC long-term monitoring wells is on public land such as road reserve so there is guaranteed security of tenure and fewer interruptions to sampling. In this case the main road was too far west to intercept the deepest sequence of gravels and both test wells were sited on paper road within the farm owned by Mr Mervyn Prattley. The property had been a dairy farm in the past and is currently used to fatten beef cattle.

Figure 5 : Well 10323 With Rai River & Second Test Well Under Construction In Background (February 2012)

The near finished well-head of the first test well drilled (10323) is shown looking east towards the Rai River (**Figure 5**). Well 10323 is located on top of a 3 metre high terrace and a small stream referred to as Hills Stream runs along its base from left to right.

Claybound gravels were intercepted down to a depth of just over 8 metres followed by a thin layer of clay before hard rock at 9 metres depth (**Figure 6**). The gravels were sandstone or mudstone derived from the Pelorus Group. Drilling continued to 16 metres depth to check this material wasn't just a series of boulders which it wasn't. The bedrock was described as shale and slate.

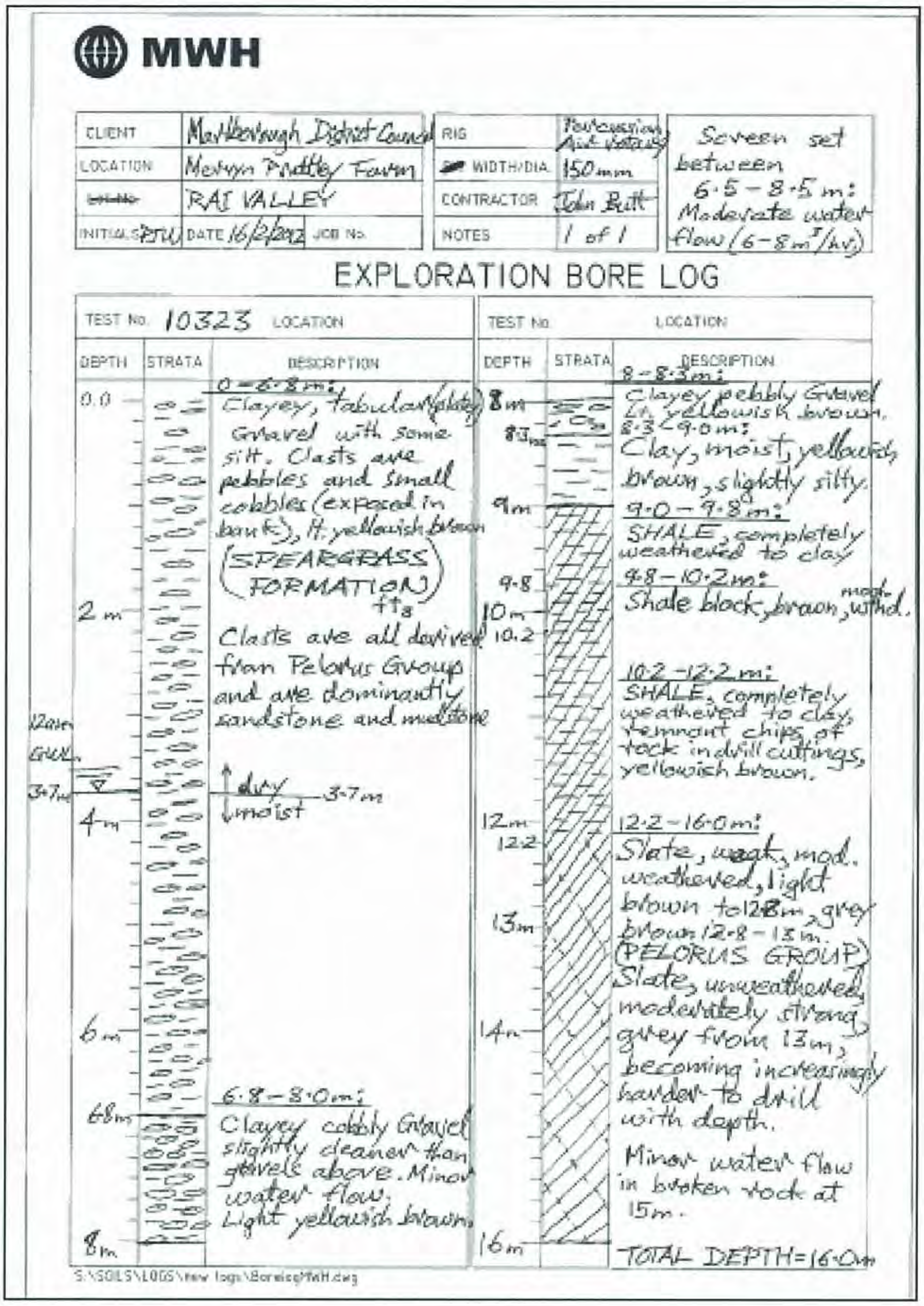


Figure 6 : Initial Test Well (10323) Field Log

Paul Wopereis, an engineering geologist from MWH Ltd in Nelson was on site to log the drill cuttings from both wells as they arrived at the surface and identify the geological formation they were associated with. Paul Wopereis was chosen because of his wide experience interpreting the geology of the Marlborough Sounds and Rai-Pelorus area.

The claybound gravel material was attributed to the equivalent of the Speargrass Formation which is the predominant low permeability layer forming most of the flats in the Southern Valleys Catchments south-west of Blenheim and extends beneath the more permeable Wairau Aquifer across the northern Wairau Plain. The water table was encountered at a depth of 3.7 metres below the surface and at the time was thought to match the level of Hills Stream.

After the first well intercepted basement at the shallower than expected depth of 9 metres, a second well (O27w/0119) was drilled further east and closer to the Rai River in an attempt to find a deeper sequence of aquifer forming sediments.

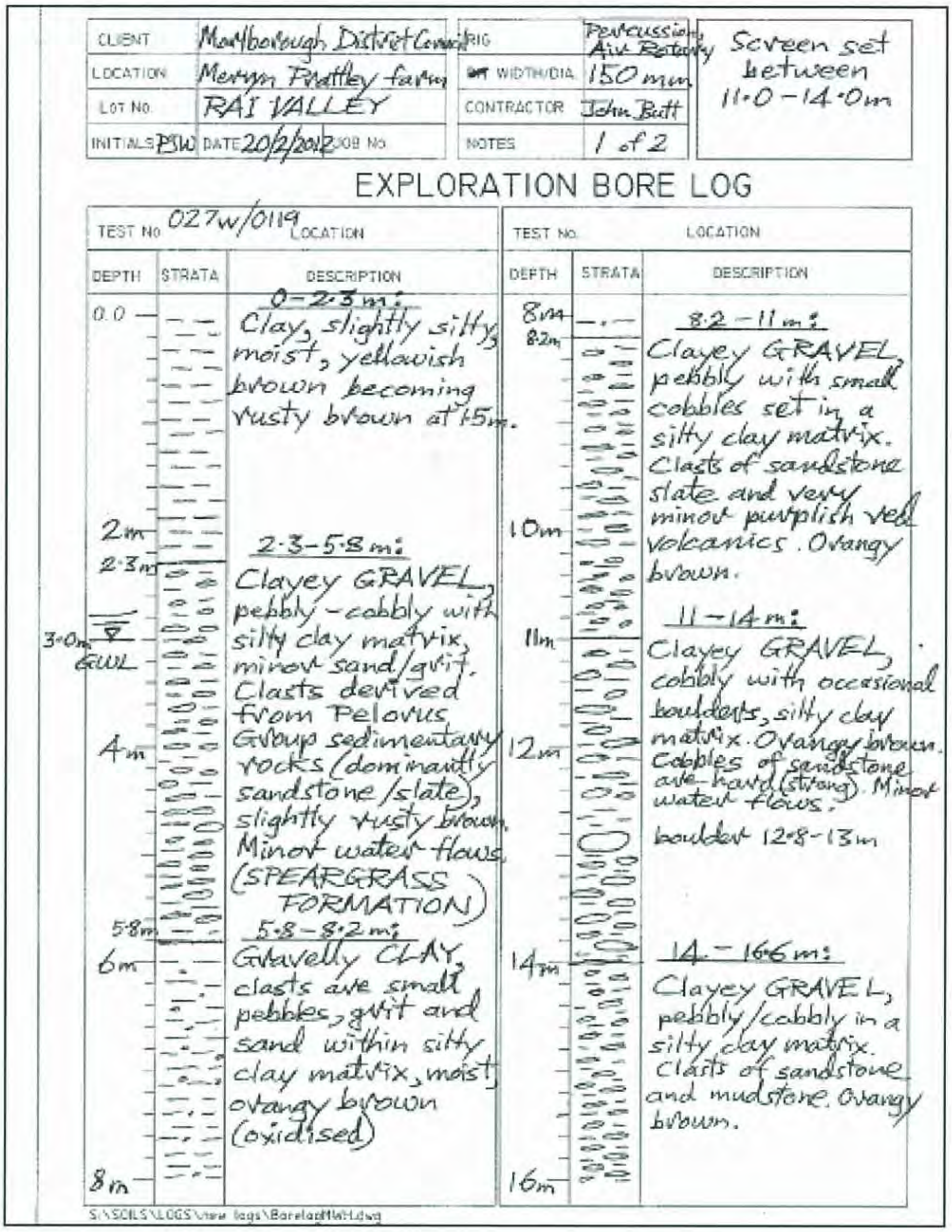
The second well under construction is shown with the Rai River in the background (**Figure 7**). The lithology of the material intercepted by the second well was similar to the first attempt except for the occasional boulder with bedrock being intercepted at a depth of about 17 metres (**Figure 8**).

Figure 7 : Fitting Screen In Second Test Well (O27w/0119) February 2012

The second well was very low yielding compared to the first which demonstrates the variable nature of the gravels over short distances across the Rai Valley flats at the exploratory drilling site. This is contrary to the feedback from well owners and drillers over the years that gave MDC staff the impression that local gravels were relatively uniform and high producing.

Another surprising feature of the aquifer forming gravels is how shallow they are at this site. More work is needed to determine if this is representative of the wider Rai-Pelorus River system riparian aquifers however.

The productivity of local wells will be a function of not just the permeability of the gravels forming the aquifer but also the proximity to a stream or river recharge source. It is likely that wells drilled close to the Rai River or a stream will be hydraulically connected and as a consequence their capacity will reflect channel flow at a particular time. Having a reliable source of recharge assumes greater importance if the aquifer forming gravels are thin with limited storage to buffer well levels during dry spells.



CLIENT	Marlborough District Council	RIG	Percussion Air Rotary
LOCATION	Mervyn Prattley farm	WIDTH/DIA	150 mm
LOT No.	RAI VALLEY	CONTRACTOR	John Butt
INITIALS PSW	DATE 20/2/2012 JOB No.	NOTES	1 of 2

Screen set between 11·0 – 14·0m

EXPLORATION BORE LOG

TEST No 027w/0119 LOCATION

DEPTH	STRATA	DESCRIPTION
0.0		**0 – 2·3 m:** Clay, slightly silty, moist, yellowish brown becoming rusty brown at 1·5m.
2m, 2·3m		**2·3 – 5·8 m:** Clayey GRAVEL, pebbly – cobbly with silty clay matrix, minor sand/grit. Clasts derived from Pelorus Group sedimentary rocks (dominantly sandstone/slate), slightly rusty brown. Minor water flows. (SPEARGRASS FORMATION)
3·0m GWL		
4m		
5·8m, 6m		**5·8 – 8·2 m:** Gravelly CLAY, clasts are small pebbles, grit and sand within silty clay matrix, moist, orangy brown (oxidised)
8m		

TEST No. LOCATION

DEPTH	STRATA	DESCRIPTION
8m, 8·2m		**8·2 – 11 m:** Clayey GRAVEL, pebbly with small cobbles set in a silty clay matrix. Clasts of sandstone, slate and very minor purplish red volcanics. Orangy brown.
10m		
11m		**11 – 14 m:** Clayey GRAVEL, cobbly with occasional boulders, silty clay matrix. Orangy brown. Cobbles of sandstone are hard (strong). Minor water flows.
12m		boulder 12·8 – 13m
14m		**14 – 16·6 m:** Clayey GRAVEL, pebbly/cobbly in a silty clay matrix. Clasts of sandstone and mudstone. Orangy brown.
16m		

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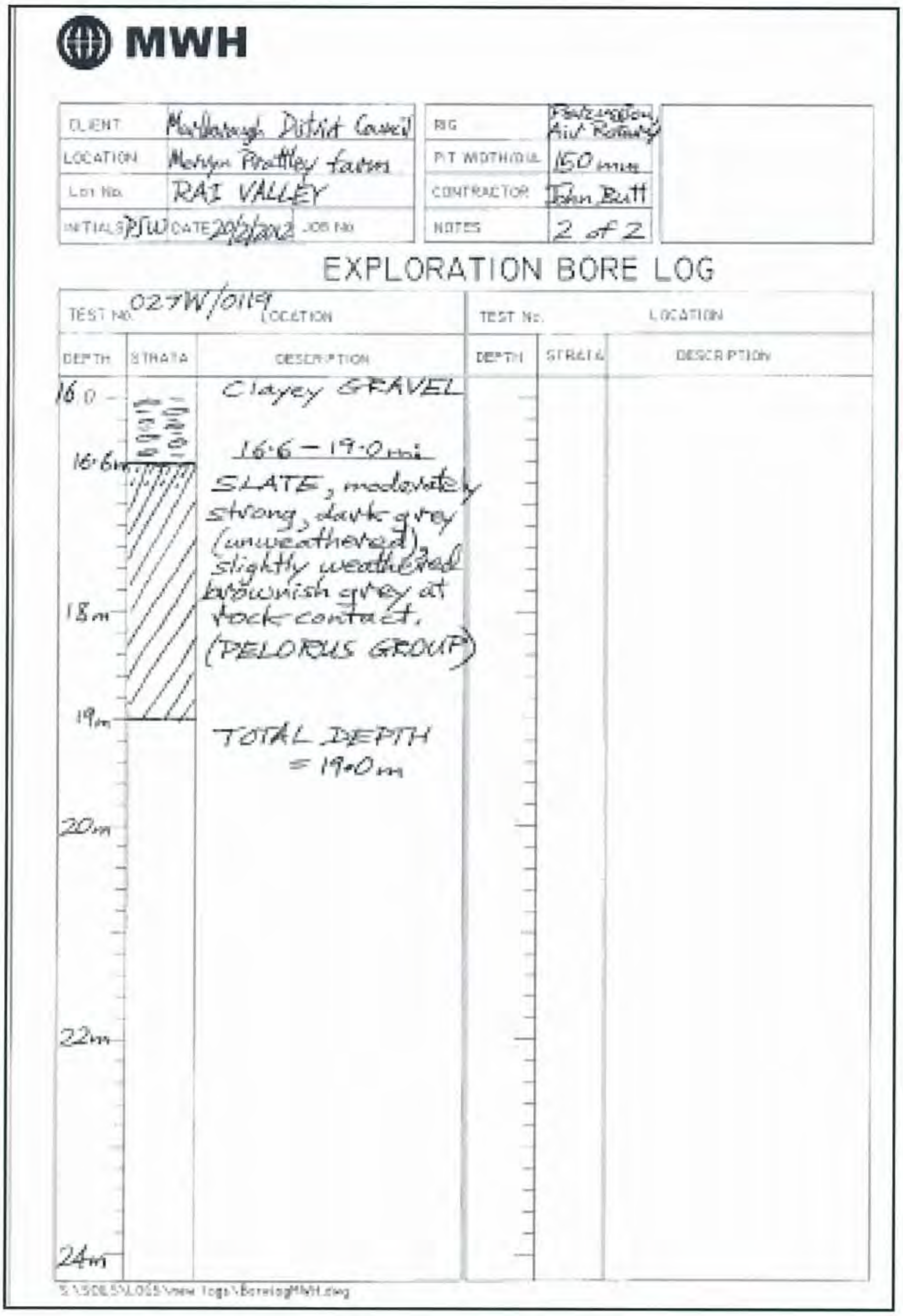
MWH

CLIENT	Marlborough District Council	RIG	Air Rotary
LOCATION	Mervyn Prattley farm	PIT WIDTH/DIA	150 mm
Lot No.	RAI VALLEY	CONTRACTOR	John Butt
INITIALS PJW	DATE 20/2/2012 JOB No	NOTES	2 of 2

EXPLORATION BORE LOG

TEST No. O27W/0119 LOCATION

DEPTH	STRATA	DESCRIPTION
16.0		Clayey GRAVEL
16.6m		16.6 – 19.0m: SLATE, moderately strong, dark grey (unweathered), slightly weathered brownish grey at rock contact. (PELORUS GROUP)
18m		
19m		TOTAL DEPTH = 19.0m
20m		
22m		
24m		

Figure 8 : Second Test Well Field Log (O27w0119)

6. Drilling Process And Well Construction

The first well (10323 closest to SH6) was drilled to a maximum depth of 16 metres and screened between 6.7 and 8.7 metres. The second well (O27w/0119 closest to Rai River) was drilled to 19 metres depth and screened at between 11.7 to 14.7 metres. In both cases the screen location corresponded with the most promising water bearing material based on the drillers and geologists interpretation of the lithology.

The screens were made of slotted PVC pipe to make them inert for water quality sampling purposes. Both wells were developed using surges of compressed air released below the water table and activated by an automatic timer over the space of about a day.

The development of well 10323 was relatively straightforward but well O27w/0119 retained its discoloured water and intercepts less transmissive and lower yielding sediments. The depth of well 10323 is shallow by Wairau Plain standards.

The wells were cased throughout the drilling process because experience had shown that the local alluvial material isn't self-supporting and would collapse otherwise. Ideally a cable tool rig would have been used so the drill cuttings were less altered and the geological strata could be more accurately described, but this method was too slow and costly for the potential depth of the well of up to 75 metres.

Because the more eastern well is close to the Rai River on a low lying floodplain subject to flooding, the finished casing was built-up above general groundlevel and both wells have water-tight seals and caps to stop contamination.

Groundwater level will not be measured by MDC at this stage but may be needed in the future for managing local aquifer issues, or for long-term water resources planning in the Marlborough Sounds catchments.

7. Aquifer Hydraulic Properties

Very few measurements of hydraulic properties exist for aquifers in the Marlborough Sounds catchments because so few wells have been properly tested. The reason for this is that until recently there was little demand for this type of information apart from some larger irrigators needing to predict well drawdowns and for selecting pump capacity.

The situation has now changed due to increased pressure on water resources and improved knowledge of how these aquifers transmit and store water is required by Marlborough District Council for catchment scale management purposes.

Through its monitoring and own research MDC is developing a better understanding of general aquifer processes, groundwater travel times, likely interference effects between wells and how long water is held up in aquifers.

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WATER WELL ENGINEERS TO MARLBOROUGH

Rai Valley test bore details. Both 150mm steel casing.

1st well (nearest state highway 10323
Grid ref 2558852-5996213
Static water level 5.45Mtr
Total depth 9.89 Mtrs
Total screen (125mm Pvc) length 3.66mtr (Sump 1.16Mtr, Screen 2Mtr, leader .5Mtr)
Flanged 410mm above ground level.
Pumped at 2.66 l/sec for 1 hour with a drawdown of 0.12Mtrs

2nd well (nearest river)
Grid ref 2559093-5996154 O27w/0119
Static water level 3.71Mtr
Total depth 14.71 Mtrs
Total screen (125mm Pvc) length 3.33mtr (Sump 0, Screen 3Mtr, leader .33Mtr)
Flanged 1.12Mtr above ground level.

Figure 9 : Drillers Well Productivity Measurements

Well O27w/0119 was too low yielding to sustain a useful flow of groundwater and its productivity wasn't tested, but the transmissivity of the aquifer is likely to be of the order of 50 m^2/day or less. This is similar to the low yields of wells tapping the Southern Valleys Aquifer systems.

Unfortunately well 10323 was unable to be properly tested because the casing diameter was too small to accommodate a pump large enough to drawdown the well level significantly. Based on the short term test carried out by the driller soon after the well was developed however, aquifer transmissivity is estimated to be around 3,000 m^2/day. This is high considering the relatively impermeable sediments and may indicate a recharge influence from Hills Stream.

8. Groundwater-Surfacewater Interaction

A cross-section of the land surface, depth to bedrock basement and river or groundwater levels was prepared to compare the relative elevation of the different water bodies. This was based on the drilling results in conjunction with a precise survey by Ayson and Partners Ltd on the 13th of June 2012 (**Figure 10**). The brown line marks the ground surface elevation in terms of the LINZ datum. Also shown are the positions of river terraces, the Rai River and SH6.

The 2 black cylinders represent the total drilled depth of the MDC test wells. The dashed pattern shows the location of their screen or finished depth. The screens were set as close to the base of the sediments as possible to maximise the available drawdown for testing purposes.

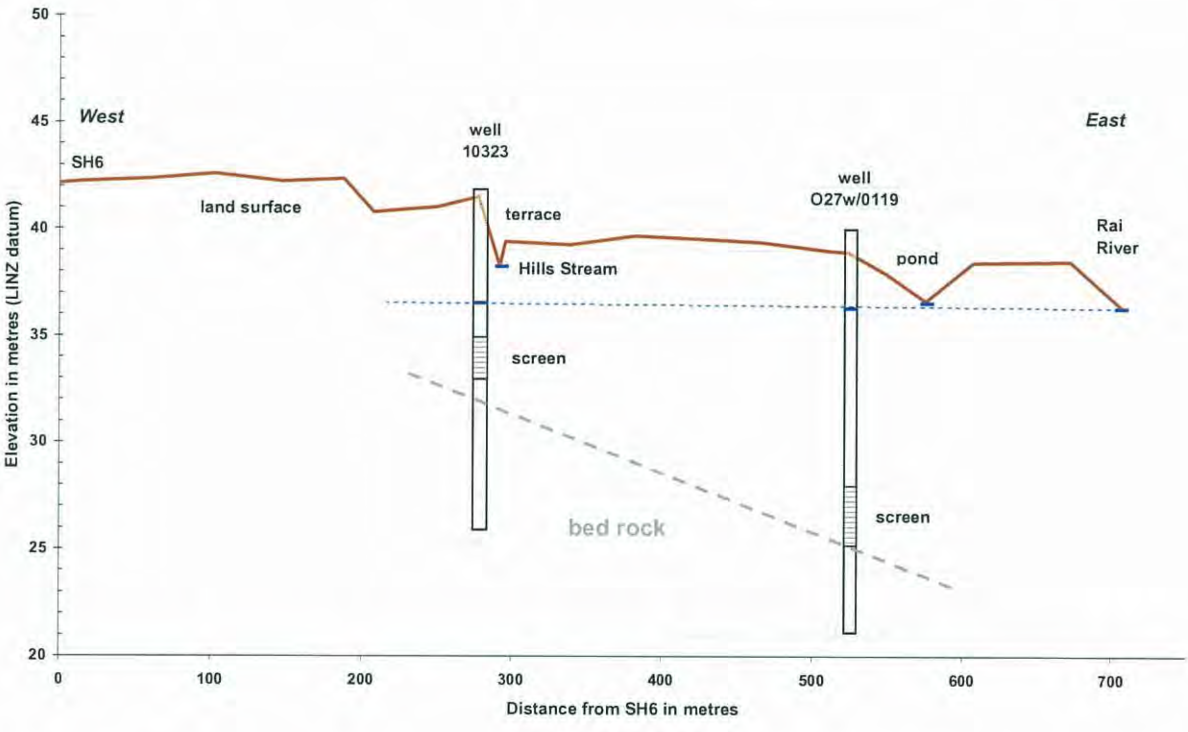


Figure 10 : 13th June 2012 Water Level And Land Surface Survey Cross-section

During the 13th of June 2012 survey the water level in Hills Stream was 1.76 metres higher than the water table in the nearby well 10323, implying separate water bodies. At the time of the level survey there was a moderate flow in the Rai River at the Falls of around 7 m^3/second receding from a peak flow of 45 m^3/second meaning it could have been backed up slightly in the main channel (**Figure 11**). This is above the median flow but less than the mean flow.

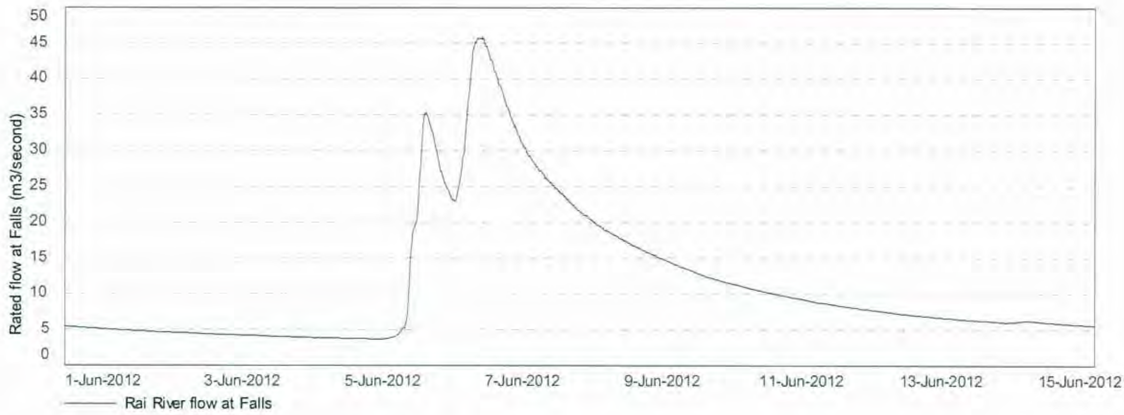


Figure 11 : June 2012 Rai River Flow At Rai Falls

The water table of the wells and the Rai River channel level opposite Hills Road forms a flat surface sloping very slightly to the east. It is thought that upstream of this point the Rai River channel is elevated above the groundwater table while downstream the reverse situation occurs (**Figure 12**).

This pattern is supported by the situation on the 13th of June where the flow direction is almost neutral in the middle reaches of the river opposite the test wells. There is likely to be localised variations depending on seasonal weather conditions and the state of the Rai River or groundwater.

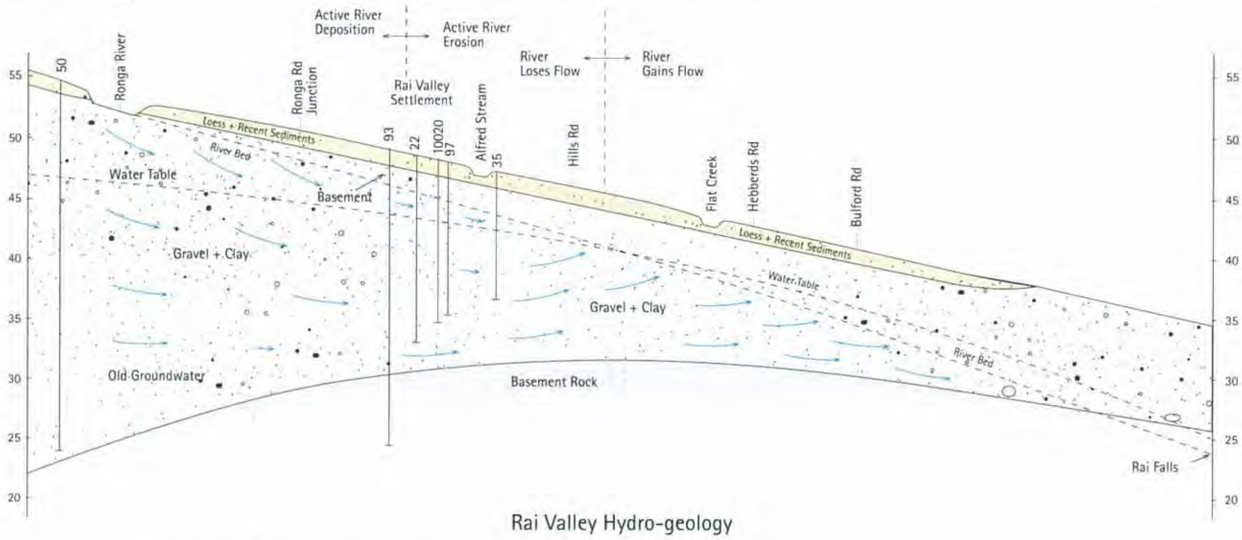


Figure 12 : General Flow Pattern

9. Groundwater Quality & Isotope Chemistry

One off samples of groundwater from the 2 wells, the Rai River and Hills Stream were taken by MDC staff for the analysis of its age (CFC11-12, SF_6, tritium), recharge source (^{18}O) and the full suite of chemical parameters in 2012. The western test well will be sampled seasonally into the future by MDC as part of the state of the environment survey (SOE) programme.

A sample was collected from well O27w/0119 on the 7th of March 2012 and analysed for the standard set of chemical parameters and isotope tracers to determine the age and origin of local groundwater. The results are summarised in Table 1. Rai River flow at Rai Falls on the day of sampling was around 6 m^3/second having receded from a peak flow of 20 m^3/second (**Figure 13**). Groundwater from this well is likely to be reasonably isolated from river flows meaning its chemistry is possibly independent of variations in Rai River flow.

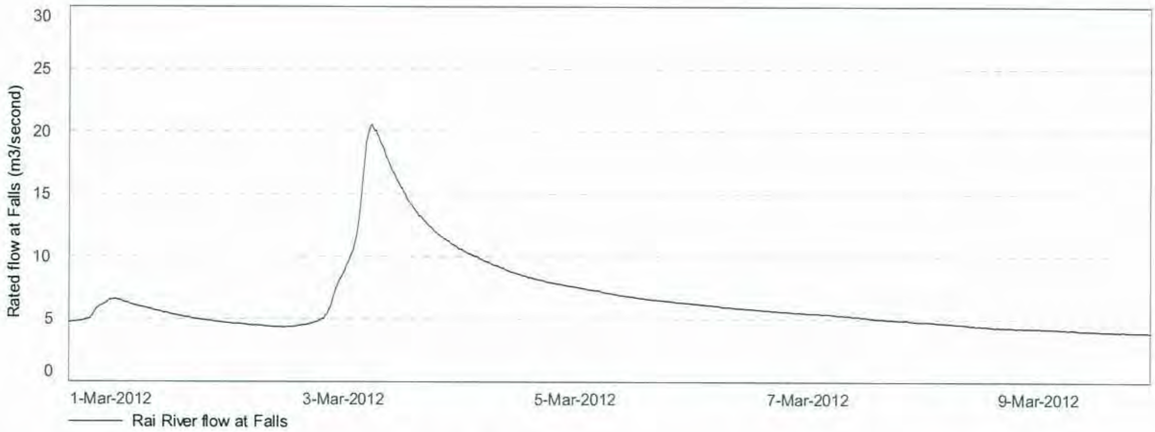


Figure 13 : 7th March 2012 Rai River Flow At Rai Falls

Well 10323, Hills Stream and the Rai River were sampled as part of the MDC seasonal state of the environment autumn 2012 survey on the 28th of May 2012. Rai River flow at the Rai Falls automatic recorder on the day of the sampling was reasonably high at about 15 m^3/second, receding from a small flood of 41 m^3/second (**Figure 14**). Fifty millimetres of rain fell at the Rai Falls rain gauge on the 26th of May which would have contributed to higher Hills Stream flows.

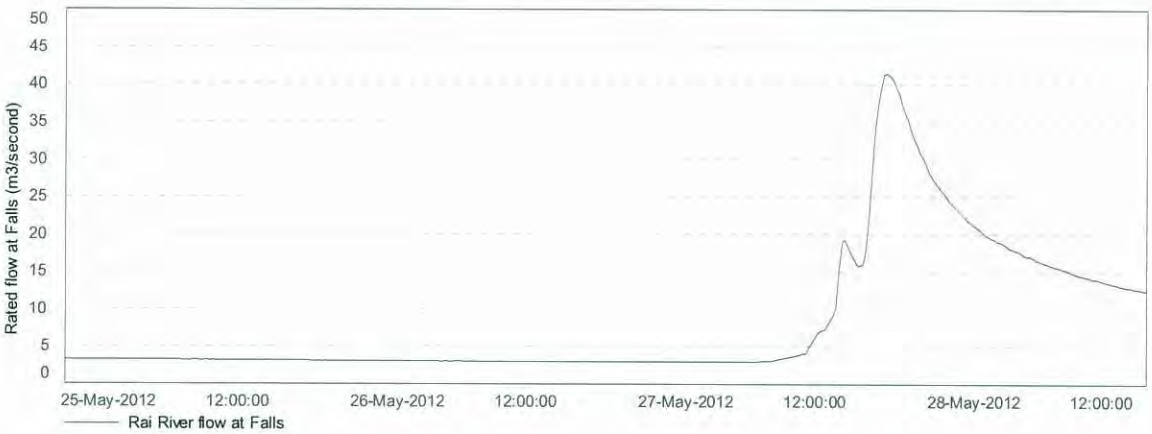


Figure 14 : 28th May 2012 Rai River Flow At Falls

The laboratory results for the 4 water samples are summarised in Table 1 expressed as concentrations in terms of weight per volume. Field measurements and isotope results are listed at the bottom of the table in various units.

Table 1 : Groundwater & Surface Water Chemistry/Isotope Results

Chemical Parameter	**Deep MDC well O27w/0119**	**Shallow MDC well 10323**	**Hills Stream**	**Rai River**	**Comments**
Appearance of sampled water from well	Discoloured and this will partly explain the ion imbalance	clear	-	-	
Alkalinity as HCO_3 (g/m^3)	114	51	24	19.6	Large range in values with highest similar to Southern Valleys Aquifers. Distinct split between surface & ground waters with higher values subsurface suggesting different chemical environment
Arsenic (g/m^3)	<0.001	<0.001	<0.001	<0.001	All low suggesting absence of advanced reducing

					conditions or lack of a local mineral source
Boron (g/m^3)	0.081	0.04	0.013	0.015	Distinct split between surface & groundwaters with highest values associated with deeper groundwater supporting concept of an isolated aquifer. Surface waters identical showing flow processes dominate
Calcium (g/m^3)	18.3	9.9	5.2	3.7	Distinct split between surface & groundwaters with highest values associated with deeper groundwater & similar to Southern Valleys Aquifers
Iron (g/m^3)	0.006	0.009	0.068	0.049	Lower concentrations in older groundwater which is unusual & may reflect mineralisation or dilution processes
Magnesium (g/m^3)	7.2	7.6	1.85	1.43	Distinct split between surface & ground waters. Groundwater values similar to Southern Valleys Aquifers
Manganese (g/m^3)	0.2	0.001	0.0058	0.0023	Highest concentration for deeper groundwater due to water-rock interaction. Next highest values in surface waters which is unexpected
Potassium (g/m^3)	0.88	0.65	0.97	1.07	Highest concentrations in surface waters which is unexpected from a natural mineral point of view
Sodium (g/m^3)	39	6.2	5.5	5.0	Lower values in surface waters & shallow groundwater. Significantly higher value at deeper well similar to Southern Valleys Aquifers due to longer water rock action or mineralogy
Bromide (g/m^3)	0.12	<0.05	<0.05	0.06	Significantly higher values in deeper well & variable elsewhere
Chloride (g/m^3)	58	7.8	5.5	5.7	Similar pattern to sodium which is normal
Fluoride (g/m^3)	<0.05	0.07	0.06	0.05	Lower values in surface waters than shallow groundwater but deeper groundwater anomalously low
Ammoniacal nitrogen (g/m^3)	<0.01	<0.01	0.014	<0.01	Less than 0.1 showing absence of advanced reducing conditions with slightly higher level in Hills Stream
Nitrate-nitrogen (g/m^3)	0.3	2.8	1.3	0.41	Very low in deep groundwater supporting idea of reducing aquifer conditions. Large difference in surfacewater values
Dissolved reactive phosphorous (g/m^3)	0.008	0.011	0.008	0.01	Similar concentrations
Reactive silica (g/m^3)	19.2	17.7	15.4	11.0	Higher concentrations in groundwater implying older age & consistent with electrical conductivity
Sulphate (g/m^3)	3.1	7.6	2.9	2.0	Surface water values lower than shallow ground water concentrations suggesting flow dilution. Older groundwater has lower value due to natural reduction processes
pH	7.46	6.22	6.73	7.11	Highest in deeper groundwater presumably due to byproducts of reactions in moderate reducing conditions. Doesn't match HCO_3 concentrations however
Dissolved oxygen (%)	4.1	32.8	96.5	92.1	Significantly lower in groundwaters, particularly from deeper well indicating isolation from atmosphere compared to surfacewaters
Electrical conductivity (mS/m)	32.4	14.8	7.64	6.15	Moderately high for groundwaters and consistent with higher concentrations of most dissolved salts
Mean residence time (years) based on various isotope dating methods	155	7.5	-	-	Groundwater age increases with depth below surface
Temperature (degrees C)	14.8 Flow = 6 m^3/sec. March 2012	14.6 Flow = 15 m^3/sec. May 2012	11.2 Flow = 15 m^3/sec. May 2012	11.8 Flow = 15 m^3/sec. May 2012	Sample from the deeper well taken at different date to other 3 samples & can't be directly compared. Groundwater temperature elsewhere in Marlborough is generally around 14 degrees Celsius & values are close to this temperature. Surfacewater significantly cooler based on the May sampling

Based on the current single set of samples it appears there are 3 distinct water bodies: deeper groundwater, shallow groundwater and surface waters. However there are several anomalies that should be resolved through a longer length of monitoring record as part of the SOE programme.

There is a consistent pattern across the 4 waters provided by measurements of: temperature, electrical conductivity, dissolved oxygen, sulphate, reactive silica, nitrate-nitrogen, chloride, sodium, magnesium, calcium, boron and alkalinity. However levels of potassium, manganese and iron are higher in surface waters than would be expected. Groundwaters generally have higher levels of dissolved solids in the same catchment because of the diluting effect of river flow on the one hand and the groundwater-rock interaction effect on the other.

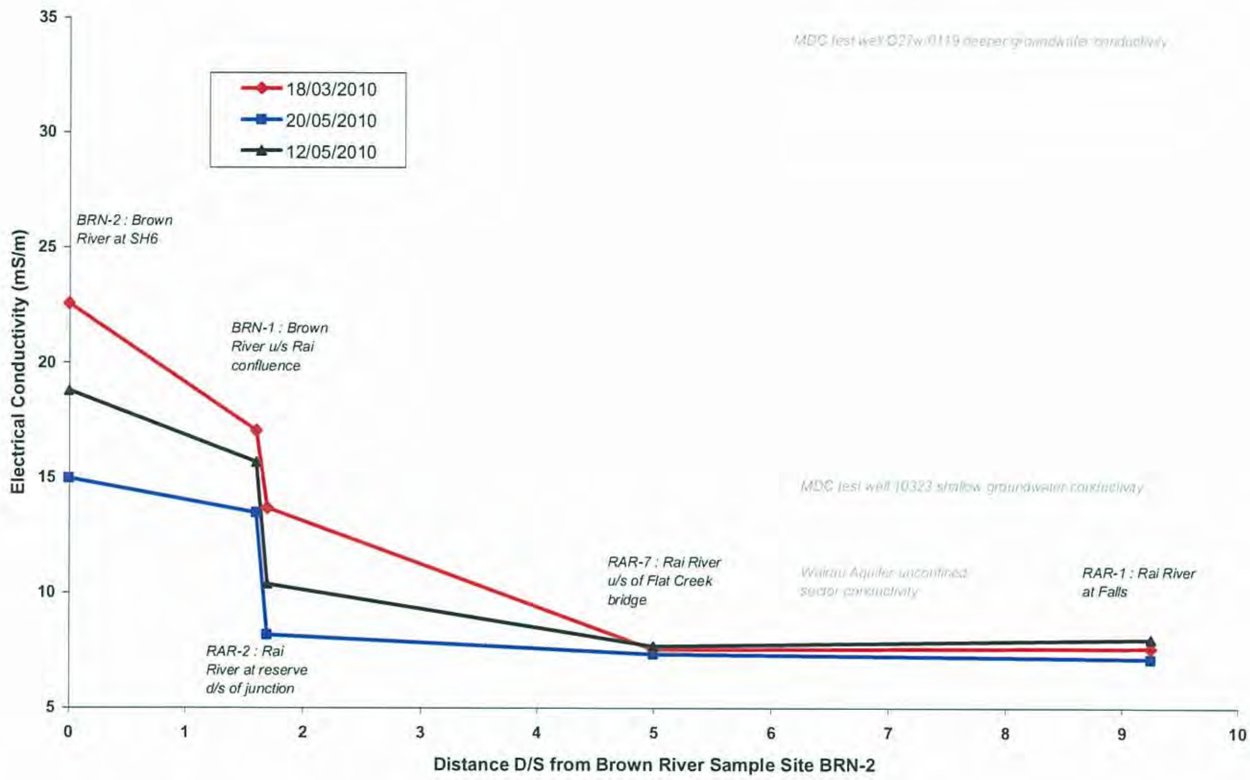


Figure 15 : Rai River Electrical Conductivity Profile

Rivers draining the eastern catchments of the mineral belt forming the Wangamoa ranges and the Brown River in particular, have higher electrical conductivity compared to the Ronga, Opouri and Tunakino Rivers which aggregate together to form the Rai River (**Figure 1**). This reflects the ultramafic (ferro-magnesium) type minerals forming these rocks.

Because MDC have limited record of the individual ionic makeup of these waters and in particular how much potassium, magnesium, manganese or iron they typically contain; electrical conductivity was used as an indicator to compare differences in dissolved salts between waterways.

Historical measurements show the electrical conductivity of Brown River water varies between 15 and about 23 mS/m which is relatively high compared to the Opouri River or other eastern rivers and reflects the mineral belt influence (**Figure 15**).

The rapid decline in electrical conductivity where the Ronga, Tunakino and Opouri Rivers join to form the Rai River is also due to the diluting effect of the higher flows from these catchments with less than 50% of flow at the Falls originating from the Brown River and Hills or Alfred Streams.

Electrical conductivity readings of Hills Stream and Rai River water during the 2012 survey were 7.64 and 6.15 mS/m respectively which is similar to historic readings, and lower than the 14.8 mS/m for shallower groundwater on the same day. The values are shaded yellow in Table 1.

It was expected that Hills Stream water and groundwater from the nearby well (10323) would have similar values because they are located together and water drains the same catchment with supposedly higher mineral contents or conductivity levels to match those of the Brown River. But this is not the case and dilution may be the explanation with higher flows in Hills Stream due to recent rain. Despite electrical conductivity being lower, the concentrations of manganese, potassium and iron are higher in the 2 surface waters than groundwater.

To try and explain differences in water chemistry the results were plotted using Stiff diagrams. Each sample is graphed in terms of their major ion concentrations expressed in milliequivalents/litre (**Figure 16**). Anions are plotted on the right hand axis and cations on the left.

The shape of the plot indicates the dominant anion and cation for each water sample. The concentration is shown along the horizontal axis with groundwater samples having higher dissolved solid contents than the surface water samples.

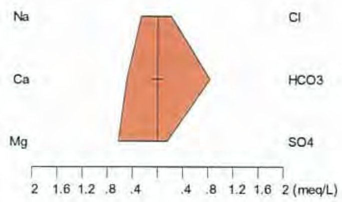
Bicarbonate (HCO_3) is the major anion of all 4 waters which is commonly the case in Marlborough and reflects the mineralogy of local rocks that waters pass over or flow through. However the dominant anion varies from sample to sample (**Figure 16**).

Magnesium is dominant in shallow groundwater (well 10323) and sodium is dominant in deeper groundwater (well O27w/0119). The dominance of magnesium in shallow groundwater is consistent with its catchment mineralogy. On this basis, Hills Stream should show a similar signature but doesn't based on this single sample.

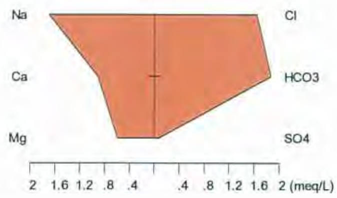
Calcium and sodium are the main cations for Hills Stream and the Rai River respectively, but aren't dominant. Water from well O27w/0119 is dominated by sodium and has higher concentrations of dissolved solids and is referred to as being more evolved.

This is also reflected in distinctively higher pH and electrical conductivity of deeper groundwater (Table 1). The makeup of the 2 groundwaters is chemically different from surface water and from each other in terms of the ions present and their concentration. Overall however there is little difference between the waters chemically except for deeper groundwater.

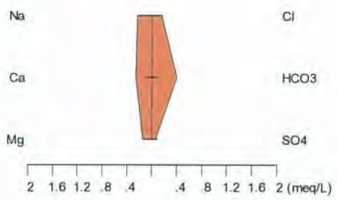
10323



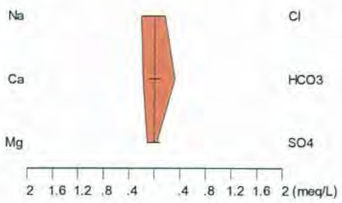
o27w0119



Hills Stream



Rai River



The chemical composition of Hills Stream and Rai River water is identical which probably reflects the dominant influence of rainfall/runoff or dilution processes.

Figure 16 : 2012 Sample Water Composition

Stiff diagrams describe the chemical composition of the 4 waters, but not how they may have evolved or whether they are a mixture of different waters. The Piper diagram is a method of plotting multiple sites in terms of their major ions to see how they are related (**Figure 17**).

Cations are plotted in the left hand bottom triangle and anions in the right hand bottom triangle. Proportions are then projected into the upper diamond based on their plotting position to provide an overall summary with units of milliequivalents per litre. What the Piper plot doesn't do is provide information on differences in the concentration of the salts dissolved in the 4 waters.

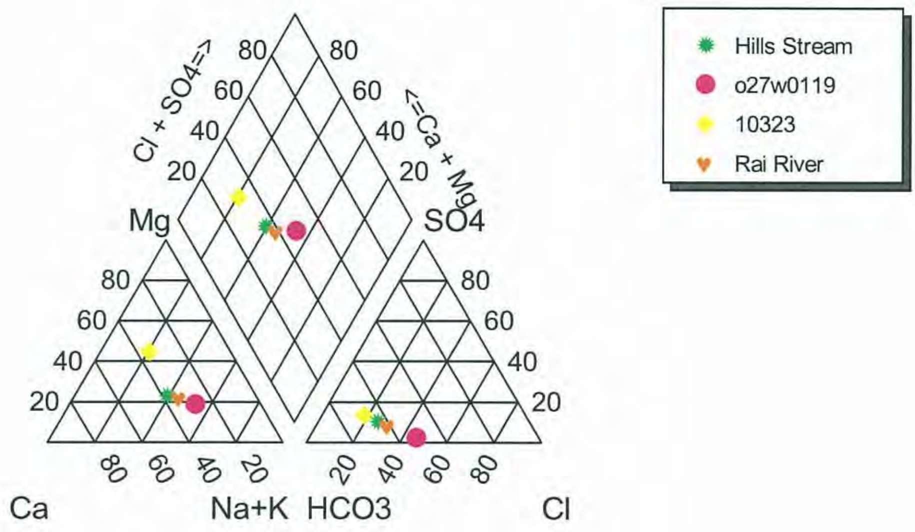


Figure 17 : Piper Diagram

In terms of anions, all 4 samples are dominated by bicarbonate as they lie within the left-bottom corner of the right hand triangle (**Figure 17**). The cluster of samples in the centre of the left hand triangle shows there is no really dominant cation, except for the deeper groundwater sample from well O27w/0119 which is higher in sodium and potassium.

Projecting these points into the diamond sector at the top of the diagram provides an overall summary of the chemical makeup of each water sample. The closer the samples are grouped together the more likely they are related either through mixing, or a common source of recharge.

The 2 surface waters marked green and orange have the same composition and are more closely related in turn to shallow groundwater from well 10323 because all 3 could fall on a line parallel to the grid. On the other hand deeper groundwater plots separately from the other 3 samples and this tells us it is distinct, probably due to its relative isolation from surface processes which has caused it to evolve separately through longer water-rock interaction.

10. Conceptual Groundwater Flow & Discussion

On the basis of its older age, higher dissolved solids and low nitrate levels, we can be reasonably sure that older groundwater tapped by well O27w/0119 is distinct from local surface waters or shallower groundwater.

The dynamics of shallow groundwater and its links with streams or rivers are less clear cut however. There may be slightly different water types, or alternatively it may be a short term difference and more results under different flow or climate conditions are needed to clarify aquifer behaviour.

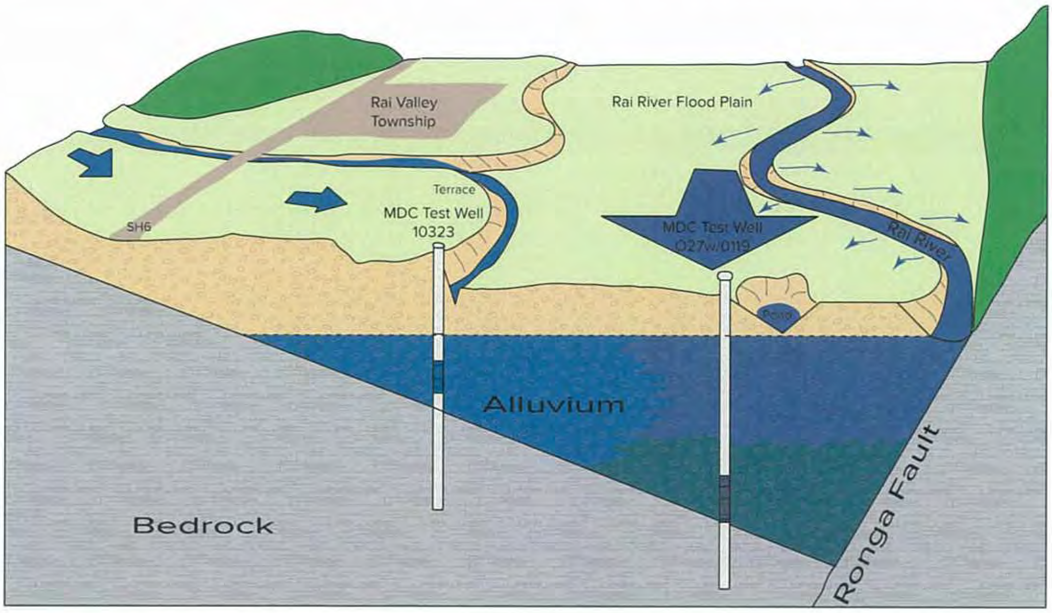


Figure 18 : Conceptual Model

Water quality information from local rivers will be extended to help refine the conceptual understanding of the aquifer.

11. References

Johnson, M.R; 1993: Geology Of The Rai Valley Area

Marlborough District Council; 2011: Groundwaters of Marlborough