Age and Source of Wairau Plains Groundwater

M. K. Stewart

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M K Stewart, GNS Science, P O Box 30 368, Lower Hutt 5040, New Zealand

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ABSTRACT

Isotopic measurements are interpreted to reveal the ages (i.e. mean residence times) and (recharge) sources of groundwater in the Wairau Plains. The information is presented in maps to give a quick visual impression of the important flow processes in the groundwater in each area.

The main Wairau Aquifer contains groundwater sourced mainly from the Wairau River, to which is added rainfall infiltration (average 19%) as the water flows eastwards in the unconfined Rapaura Gravel aquifer. The water is young (with less than six years residence time) and eventually reaches the coast in a central east-west band beneath the confining layer. Older groundwater from the Wairau River (at least sixty years old) rises from the underlying Speargrass Formation in the north and south of the coastal region, and mixes with the young water in the central zone.

The Southern Valley Aquifers comprise the aquifers in the valley fans which protrude onto the plain and contain young (less than ten years old) groundwater sourced from approximately equal proportions of rainfall (surface recharge) and streamflow infiltration, and the aquifers in the tributary valleys themselves containing old (greater than sixty years old) water sourced from stream infiltration. The Rarangi Shallow Aquifer groundwater is sourced from rainfall on the plains or from the hills to the north.

Future work could include a survey of oxygen-18 and tritium measurements on previously sampled wells in five years time to improve the estimates of ages and sources (i.e. the proportions of the different waters), and to look for changes in flow patterns. More detailed work could also be carried out to estimate ages for individual wells that have been resampled and where there is a long sequence of tritium measurements.

KEYWORDS

Groundwater recharge; groundwater residence times; oxygen-18; tritium; Wairau Plains

1.0 INTRODUCTION

During the past 50 years, human activities have released a number of chemical substances into the environment in sufficient quantities to allow their use as tracers. The substances, such as tritium or CFCs, dissolve in precipitation and become incorporated into the hydrologic cycle. They are found in groundwater recharged in the last 60 years. Their concentrations give valuable information on the subsurface residence times of groundwaters.

Other naturally distributed substances, such as oxygen-18 or chloride, can be used to give information on the sources of recharge to groundwater systems. Such information supplements that obtainable (at greater cost) from hydrometric methods.

This report applies these hydrochemical measurements to determine the ages and sources of groundwater in relation to their locations and depths in the Wairau Valley. Much data had been reported by Taylor et al. (1992), this report includes those and subsequent measurements. The information is presented in dual maps, one showing well locations and depths, the other water ages and sources. The intention is to give a quick impression of how the systems “work”. The results reveal the flow patterns of the groundwater systems, and will assist development and implementation of management strategies for protection and use of the groundwater.

2.0 HYDROGEOLOGICAL SETTING

The coastal plain of the Wairau River covers an area of 170 km^2. Permeable gravel is 30 m thick at the head of the plain (west of Renwick) and thickens towards the coast where it reaches a depth of 90 m. The aquifer becomes confined in the coastal region, where marine sediments overlie the gravels. Fans from tributary valleys on the south protrude into the Plain, and host minor groundwater systems that also contribute groundwater to the Plain.

The following stratigraphy is from Brown (1981). The lower boundary of active groundwater circulation is considered to be the Wairau Gravels, which are tight deposits of undifferentiated Quaternary gravel, sand, silt and clay under the plain and southern area. Above these is the Speargrass Formation, composed of glacial outwash laid down during the last glaciation. Its permeability increases markedly towards the coast. Speargrass Formation outcrops over wide areas in the southern valleys, but is covered by Rapaura Formation north of Renwick. Rapaura Formation contains postglacial, highly permeable, fluvial gravels (reworked Speargrass Formation) and has lower and upper layers (Early and Late Rapaura). Early Rapaura gravels extend to the coast and are tapped by wells in the confined region. Late Rapaura gravels merge and interfinger with the low-permeability Dillons Point Formation, composed of postglacial marine deposits, in the area between Tuamarina and Blenheim. Dillons Point Formation confines the underlying aquifers and thickens rapidly towards the coast.

The groundwater aquifers of the Wairau Plains are geographically divided into two major parts because of their hydrogeological characteristics (Figure 1). The Marlborough District Council has designated these the Wairau Aquifer (covering the northern and central parts of the plains) and the Southern Valley Aquifers (the southern parts of the plains and southern valleys). These are treated separately below. Individual Southern Valley aquifers and the Rarangi Shallow Aquifer are shown in Figure 1. The MDC are currently refining historical aquifer boundaries as part of the review of the district plan based on information included in this report along with other sources.

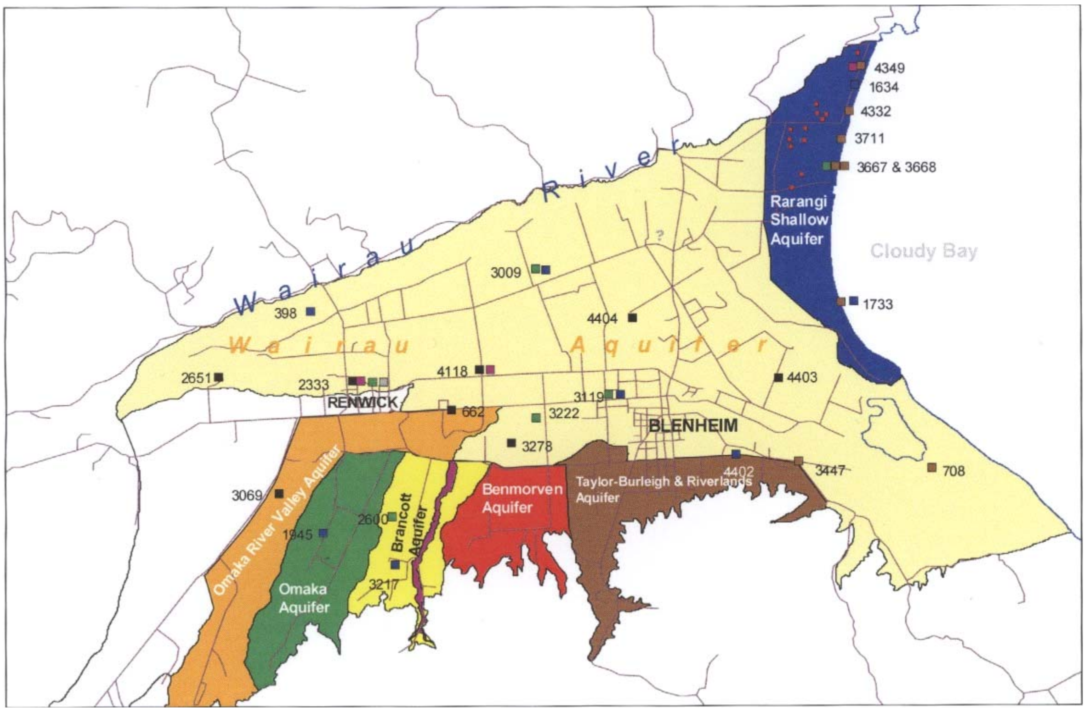

Figure 1. Map showing the groundwater aquifers of the Wairau Plains.

3.0 METHODS

Both oxygen-18 and tritium are nearly ideal tracers for water because they are part of the water molecule. Oxygen-18 is useful as a tracer of water sources, because natural processes produce variations in its concentration in different waters. Oxygen-18 concentrations are expressed as $\delta^{18}O$ values in parts per thousand (‰), where:

$$\delta^{18}O = [\frac{(^{18}O/^{16}O)_{sample}}{(^{18}O/^{16}O)_{VSMOW}} - 1].1000 . \qquad (1)$$

VSMOW (Vienna Standard Mean Ocean Water) is the international standard. Sea water (having the same concentration as VSMOW) has $\delta^{18}O$ ~ 0‰, and freshwaters generally have negative values, because they usually contain less ^{18}O than sea water.

Tritum undergoes radioactive decay and therefore is useful for determining the mean residence time of water underground (termed the groundwater age). The radioactive half-life of tritium is 12.32 years (i.e. half of the tritium present will have decayed in 12.32 years). Tritium concentrations are expressed in Tritium Units (TU), where 1 TU denotes a tritium/hydrogen (i.e. $^{3}H/^{1}H$) ratio of 1 x 10^{-18}.

4.0 WAIRAU AQUIFER

The Wairau Aquifer makes up the larger part of the plains. Wairau Aquifer wells are listed in approximate order from west to east in Appendix 1, as the aquifer changes from being unconfined in the west to confined in the east. (A transition zone between them is classed as semiconfined.) Some of the wells on the southern border of the aquifer could be affected by water from the southern tributary valleys. Judgment has been applied based on the geology and the hydrochemistry of the well in association with the $\delta^{18}O$ value to assign these wells to either the Wairau Aquifer (fed mainly by the Wairau River) or to the Southern Valleys Aquifers (fed mainly by tributary streams).

The well waters in the Wairau Aquifer were divided into Groups A, B and C by Taylor et al. (1992). They made the grouping based on the type of aquifer and the age of the water. Group A wells are within the unconfined area of the aquifer and have very young water, Group B wells are in the confined area with ages dominated by a young water component, and Group C wells are in the confined area with ages dominated by an old water component.

We have retained this classification, but extended it in the light of the data presented below. Group A1 wells draw very young water from the Rapaura Formation in the unconfined region, while Group A2 wells draw older water from the underlying Speargrass Formation. Group B1 wells draw from Rapaura Formation in the confined region, and have very young water (i.e. water showing no perceptible ageing compared with the Wairau River water and Group A1 wells). Group B2 wells contain mixed age water (i.e. water older than A1 and B1 water, but still containing a young component). Group C waters are dominated by an old water component (C1 is in the northeast area of the plain, C2 in the southeast area).

These groupings have a geographical basis (related to the geological character of the region). Boundaries between the groups are shown in Figures 2 and 3. The southern boundary separates wells drawing from the Wairau Aquifer from wells drawing from Southern Valley Aquifers; the boundary lies to the north of the surface contact between Speargrass Formation outcropping in the Southern Valleys and Rapaura Formation outcropping in the Wairau Valley. Likewise the boundary between groups A and B marks approximately the surface contact between the Rapaura Formation and the low-permeability Dillons Point Formation. The boundaries between groups B and C separate older waters to the northeast and southeast from the central zone of group B waters extending through to the coast.

4.1 IDENTIFICATION OF GROUNDWATER SOURCES

Identification of the groundwater sources was made using $\delta^{18}O$ value as the main indicator of source; the $\delta^{18}O$ values of the possible source waters are given below. These were supplemented by other information (well location and depth, chemical information) where available.

The $\delta^{18}O$ value of the Wairau River shows considerable variation in time and has a mean value of -8.79 ± 0.14‰ (standard error) from Taylor et al. (1992). (The standard deviation of the measurements was ±0.44‰.) The flow-weighted mean value of -8.86‰ is used below. The relatively negative value is due to the high altitude of the Wairau River catchment.

The $\delta^{18}O$ values in rainfall on the plains (and therefore at close to sea level in altitude) vary considerably in time and are best assessed from aquifers known to be recharged by rainfall. For Rarangi wells, this is $\delta^{18}O$ = -6.87 ± 0.13‰ (sd ±0.38‰); Taylor et al. (1992) gave the value of -7.08‰ for plains rainfall-derived groundwater. We use the value -7‰ for surface recharge to groundwater in the Wairau Aquifer area (this is assumed to include rainfall and irrigation water).

Negligible contributions are expected from Southern Valley-sourced waters to Wairau Aquifer wells, because of the selection process for wells near the southern boundary of the Wairau Aquifer.

The $\delta^{18}O$ values are used to assign recharge sources for each well in Figure 3, according to a four part colour scale based on the $\delta^{18}O$ values of the possible source waters, as follows:

Mid-blue	–8.6 to –9.2‰	Predominantly Wairau River recharge
Orange	–8.0 to –8.6‰	Wairau River and rainfall recharge, river dominant

Light green	–7.4 to –8.0‰	Rainfall and Wairau River recharge, rain dominant
Dark green	–6.8 to –7.4‰	Predominantly rainfall recharge

Figure 2 shows the locations and depths of the wells sampled.

The points in the Wairau Aquifer are either mid-blue or orange showing that they are dominated by recharge from the Wairau River. There are no light or dark green points (except within the overlying shallow Rarangi Aquifer near the coast, which is discussed in the Southern Valleys section below).

The Wairau River point in Figure 3 is mid-blue, based on the weighted average $\delta^{18}O$ value, but its value varies considerably in time (see the high standard deviation above). Wells near the Wairau River in the recharge area would also be expected to show moderate variability, because of the variability in the river. Hence we prefer to rely on average $\delta^{18}O$ values. As the groundwater travels further from the river, we expect a smoothing of the $\delta^{18}O$ values and possible augmentation by surface recharge. The fraction (x) of surface recharge can be determined from the equation (Stewart, 2007):

$$x = \frac{(\delta g - \delta r)}{(\delta s - \delta r)} \qquad (2)$$

where δg, δs and δr are the $\delta^{18}O$ values of the groundwater, surface recharge (-7.0‰) and Wairau River (-8.86‰), respectively, provided average values are used for the groundwater $\delta^{18}O$ values (δg). Table 1 gives average $\delta^{18}O$ values for wells sampled more than once, and the average values for the well groupings described above. Values of x with the standard error (i.e. the standard deviation of the mean) are given.

4.2 INTERPRETATION OF GROUNDWATER AGES

Having established that the Wairau River is the predominant source of water in the Wairau Aquifer section of the plains, we need to determine how the tritium concentration in the river changes in order to be able to use tritium to date the groundwater. Tritium measurements for the Wairau River are given in Appendix 1. The river tritium concentrations have been fitted using the flow model derived by Taylor et al., 1992 (Figure 4). (Explanation of the methods are given in Taylor et al., 1992; Stewart and Morgenstern, 2001.) This model involves two water components; 60% very young water (0.2 yr) representing water that reaches the river quickly, and 40% water with moderate residence time (8 yr) representing water which Taylor et al., 1992, identified as being held in the scree deposits in the Wairau River catchment. The rainfall tritium concentration is estimated using a scale factor of 1.35 applied to Kaitoke rainfall (Taylor et al. 1992).

In order to determine the mean residence times of the groundwaters, their tritium concentrations are compared with that of the Wairau River at the time of sampling (Figure 5). Points that lie on the Wairau River curve (i.e. within ± 10% of it taking account of measurement errors) are considered to show zero tritium decay since infiltration into the aquifer and thus to have zero age. Considering possible errors this means an age of <6 years since recharge. Almost all samples from Groups A1 and B1 are in this category (see Figure 3).

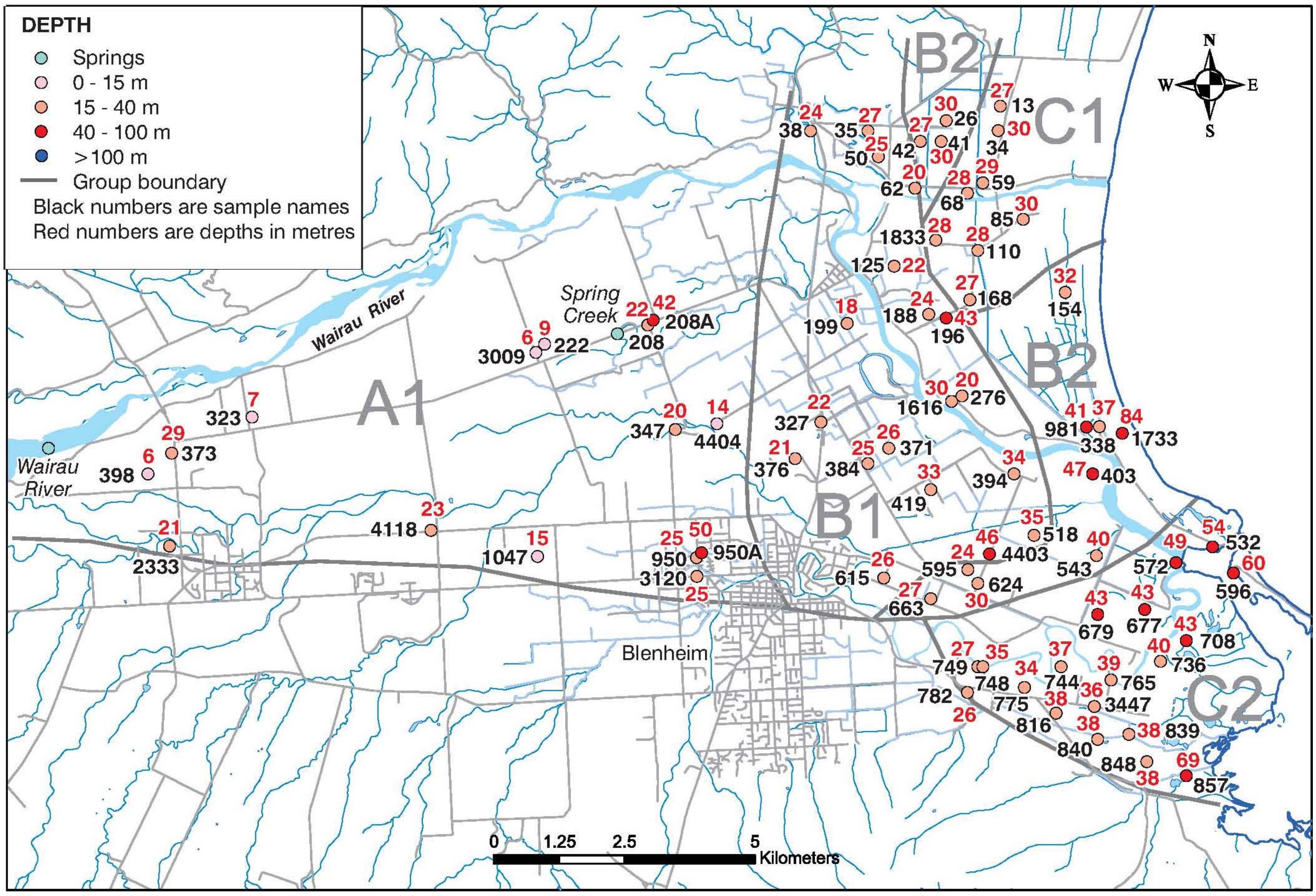

Figure 2. Locations and depths of wells for the Wairau Aquifer.

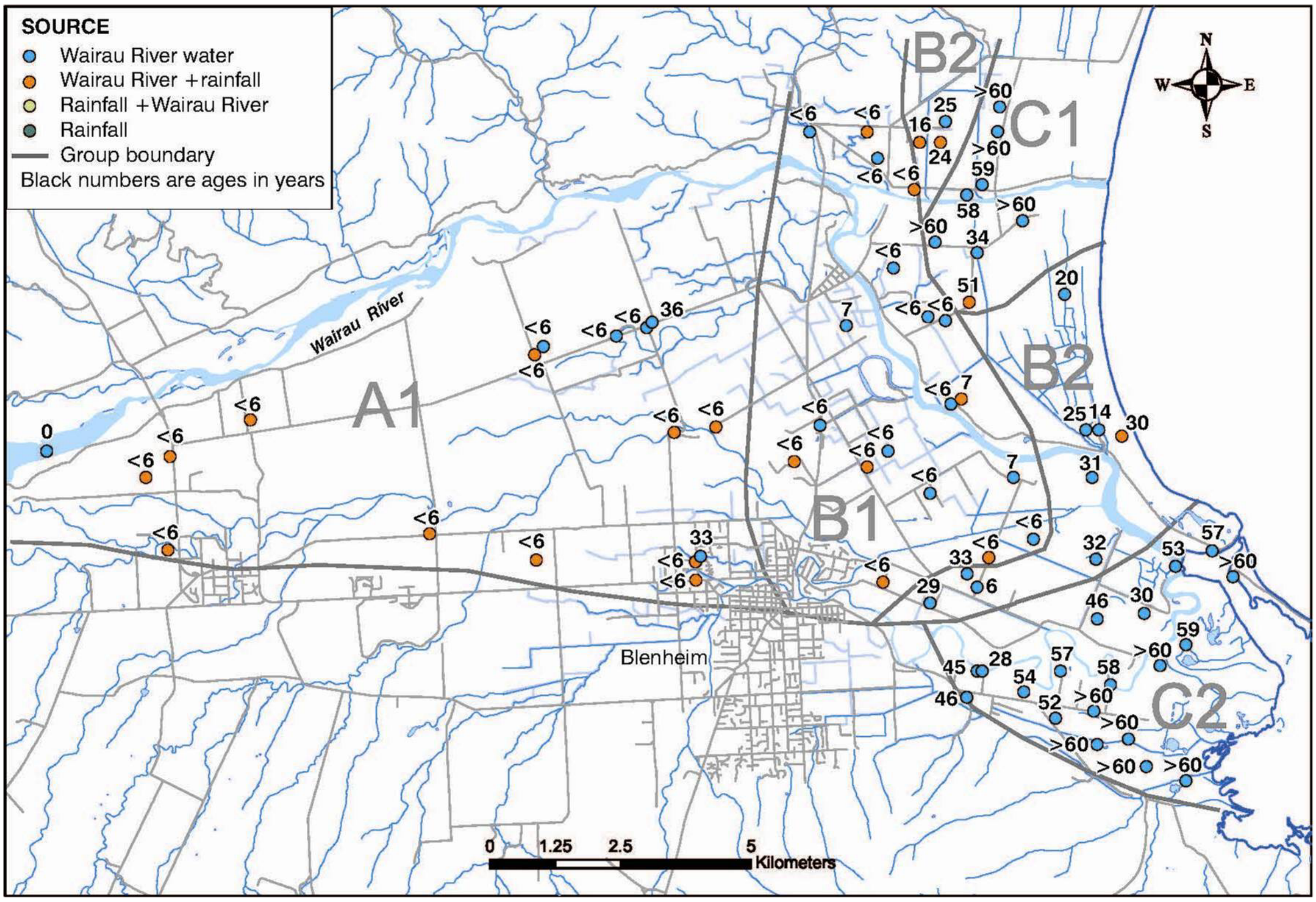

Figure 3. Ages and sources of groundwater in the Wairau Aquifer.

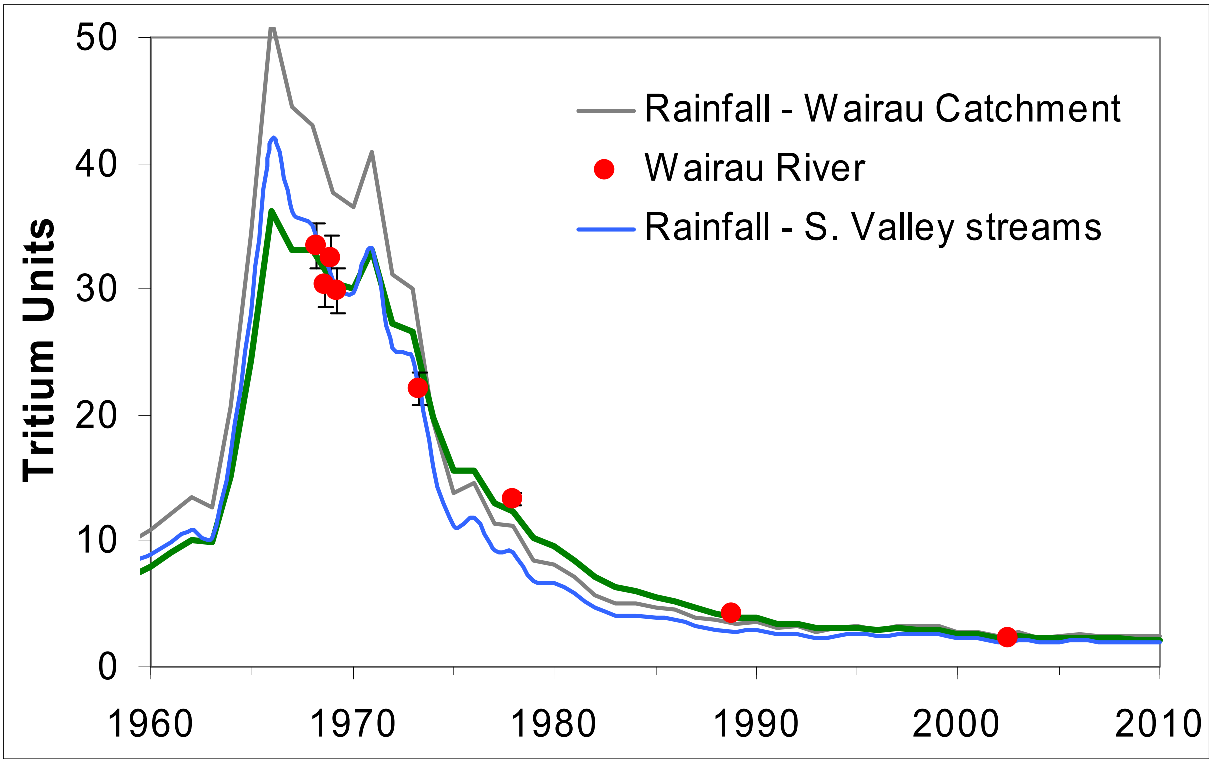

Figure 4. Tritium concentrations in the Wairau River, and monthly rainfall in the Wairau River and Southern Valley stream catchments. The green curve is fitted to the Wairau River measurements.

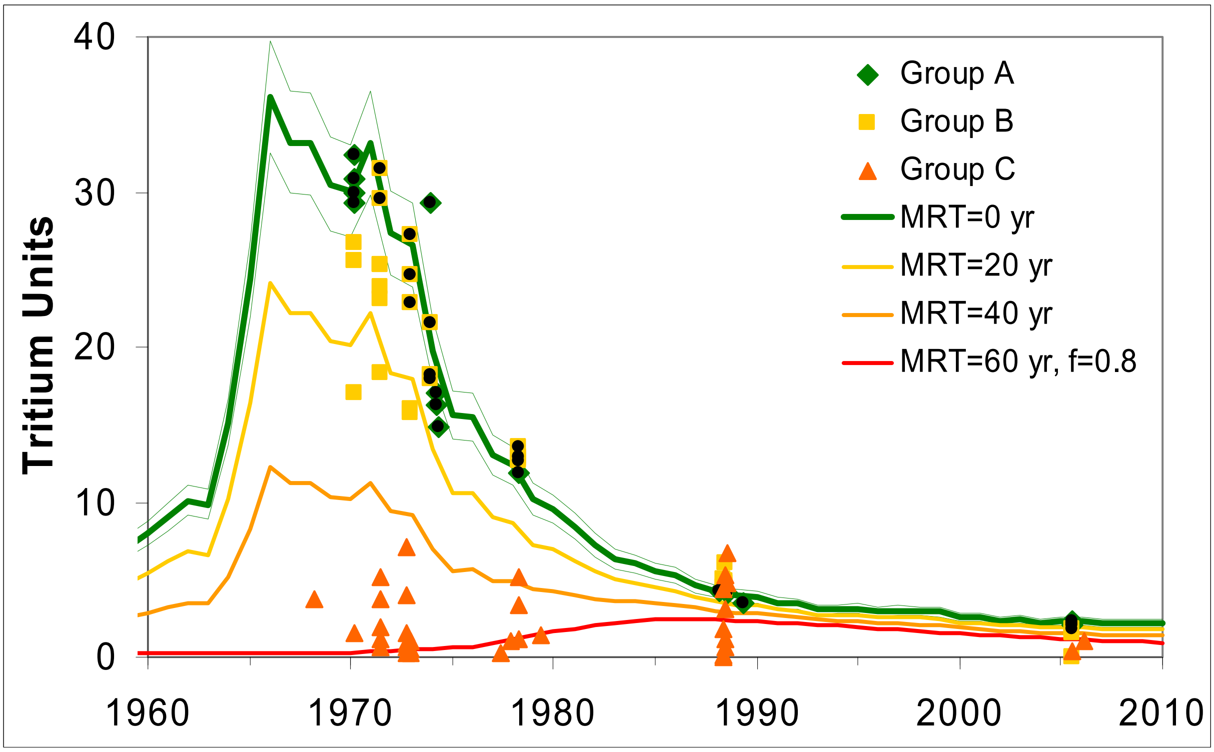

Figure 5. Tritium concentrations in well waters. Simulations for the Wairau River (green) and the 60-year old water component (red) are shown. 20-year (yellow) and 40-year (orange) mixing curves are shown.

Results for Groups B2, C1 and C2 show the presence of older water. Taylor et al. (1992) used several lines of reasoning to show that this results from upward flow of older water from depth near the coast (i.e. upward flow from the underlying Speargrass Formation) rather than being due to decreasing permeability in the Rapaura Formation leading to ageing towards the east. The evidence includes (1) the pattern of $\delta^{18}O$ values (which have the most negative values in the Speargrass Formation (area A2) and in areas C1 and C2), (2) the pattern of piezometric levels (with lowest piezometric levels in the B2 area at the coast and higher levels in areas C1 and C2), and (3) the pattern of ages (with the oldest ages in areas C1 and C2).

Accepting the evidence for two water components with different ages in the aquifers near the coast, we estimate the tritium ages for each well assuming they are mixtures of the two components. The young component has age <6 years and its tritium concentration is shown by the green curve in Figure 5. The old component was assumed to be 60 years old (model parameters: MRT = 60 years, exponential fraction = 80%) and its tritium concentration is shown by the red curve in Figure 5. Groundwater with tritium values between those of the young and old components are given ages determined by mixing; 20 and 40-year mixing curves are shown in the figure. Tritium concentrations less than that of the old component indicate ages greater than 60 years. The results are given in Appendix 1 and are plotted in Figure 3.

4.3 AGE AND SOURCE OF WAIRAU AQUIFER GROUNDWATERS

Points in area A1 in Figure 2 are mostly orange showing that infiltration of surface recharge affects the groundwater (Table 1). Wells P28/398, 4118 and 4404 have seven measurements each and surface recharge fractions of 15, 26 and 19% respectively, with small errors. The other wells in Table 1 have similar values of x, but some have large errors. Spring Creek with only three measurements gives an indeterminate result (because of the large error), but probably has a small surface recharge fraction because of the relatively large flow of water through the groundwater system at this location. The overall group average for x (using data from Appendix 1) is 19 ± 2%. This indicates that a substantial fraction of the groundwater derives from surface recharge. Surface recharge would be expected to cause increases in some chemicals (particularly nitrate) in groundwater; and Group A1 wells have up to 2 mg/L NO_3-N (see Appendix.). The groundwater ages of wells in Group A1 are consistently less than 6 years (the lower limit estimatable with tritium), showing that flow through the aquifer is rapid in this area. Most of the waters probably have ages closer to zero than 6 years.

Table 1. Average $\delta^{18}O$ values, surface recharge fractions (x) and ages for groups and wells sampled more than once in the Wairau Aquifer. (n is the number of measurements, se the standard error.)

Group	Well	n	$\delta^{18}O$ (‰)	x ± se (%)	n	Age (yr)
Surface recharge			-7.0	100		--
Wairau River		8	-8.86*	0 ± 10	8	--
A1	398	7	-8.58	15 ± 5	2	<6
	4118	7	-8.38	26 ± 3	1	<6
	3009	4	-8.48	20 ± 9	1	<6
	222	3	-8.78	4 ± 22	1	<6
	Spring Creek	3	-8.60	14 ± 20	1	<6
	208	3	-8.73	7 ± 4	2	<6
	3120	4	-8.33	28 ± 4	1	<6
	4404	7	-8.50	19 ± 3	1	<6
Group A1 average		44	-8.51	19 ± 2	18	<6

Group	Well	n	$\delta^{18}O$ (‰)	x ± se (%)	n	Age (yr)
A2	208A	2	-9.31	-24 ± 8	2	37
	950A	2	-9.01	-8 ± 4	3	45
Group A2 average		4	-9.16	--	--	--
B1	38	2	-8.76	6 ± 7	1	<6
	384	2	-8.58	15 ± 3	2	<6
	4403	7	-8.35	27 ± 2	1	<6
	394	2	-8.83	2 ± 11	1	7
	518	2	-8.70	9 ± 0	2	<6
Group B1 average		30	-8.56	16 ± 4	19	<6
B2	624	2	-8.83	2 ± 9	2	6
	403	2	-8.93	-4 ± 0	2	31
	338	2	-8.76	6 ± 9	2	14
	1733	7	-8.56	16 ± 4	2	30
Group B2 average		20	-8.70	9 ± 2	12	24
C1	34	2	-9.10	-13 ± 9	2	>60
	13	2	-8.76	6 ± 4	1	>60
Group C1 average		12	-8.83	1 ± 3	8	>60
C2	749	2	-8.83	2 ± 9	1	45
	679	2	-8.95	-5 ± 5	1	46
	765	2	-8.95	-5 ± 8	2	58
	736	2	-8.89	-2 ± 0	2	>60
	572	2	-8.87	-1 ± 2	2	53
	857	2	-8.88	-1 ± 1	2	>60
	708	2	-8.97	-6 ± 8	2	59
	532	2	-8.78	4 ± 1	2	57
Group C2 average		28	-8.89	-1 ± 1	19	54

*Weighted average

Only two wells drawing from the Speargrass Formation (Group A2) were sampled. Samples were taken from both the Rapaura and Speargrass Gravels for these wells; the latter samples are marked 208A and 950A to distinguish them from the samples drawn from the Rapaura Gravels. The Speargrass points are mid-blue, but are too few to yield a valid average. Nevertheless, their negative x values can be taken as indicating that there is no surface recharge contributing to them. The ages observed are 37 and 45 years respectively, markedly older than the ages within the Rapaura Formation.

Area B1 contains slightly more mid-blue points than orange points in Figure 3. Well P28/4403, with seven measurements, has a large surface recharge fraction (27 ± 2%). The average surface recharge fraction for the group is 16 ± 4% (Table 1). This is a smaller percentage than for Group A1, but still substantial. It is good evidence that groundwater flows from area A1 to B1 in the Rapaura gravels. The slightly smaller surface recharge fraction is taken to mean that the flowpaths of groundwater tapped in area B1 are deeper on average than those tapped in A1 and therefore more protected from surface recharge. The mean ages are all <6 years (except for a few marginally higher ones at 7 years).

Area B2 contains mostly mid-blue points (Figure 3). The average surface recharge fraction for the group is 9 ± 2% (Table 1). Well P28/1733, with seven measurements, has a surface fraction of 16 ± 4%. The waters have moderate ages ranging from 14 to 33 years; the average age of the group is 24 years (Table 1). As noted in Section 4.2, this indicates input of a third water component. The three components are young Wairau River water and surface recharge water, which together make up the A1/B1 type water flowing in the Early Rapaura gravels (with age <6 years), and old Wairau River water from greater depth most probably flowing in the Speargrass Formation (with age = or >60 years). The mixture would comprise 60% young Rapaura water and 40% old Speargrass water on average (based on the Group B2 average age).

Areas C1 and C2 have almost entirely mid-blue points (Figure 3). Their average surface recharge fractions in Table 1 are 1 ± 3% and -1 ± 1% respectively, giving a net surface recharge of precisely zero. This shows that they contain only old Wairau River-sourced water (i.e. the old component); almost no young Rapaura water is present at all. The individual $\delta^{18}O$ measurements from the different wells show very little variation. Average ages for the groups are >60 years for C1 and 54 years for C2 (Table 1). (The average ages for Groups B2, C1 and C2 were obtained by averaging the tritium measurements at each sampling date and fitting a curve to them assuming the exponential fraction is 80% (Stewart and Morgenstern, 2002).) One or two points have ages that suggest they belong with Group B2 (e.g. P28w/110 in C1 (age 34 years), P28w/748 and 677 in C2 (ages 28 and 30 years). Nevertheless, the areal separation of the different groups is quite clear in general.

In summary, the pattern of ages shows rapid groundwater flow eastwards within the Rapaura Formation towards and past the unconfined/confined boundary where Spring Creek and other springs emerge. The young component (with ages less than 6 years) flows further towards the east and south within the Early Rapaura Formation, only showing a moderate ageing in the central part of the plain near the coast when the older component from depth begins to affect the ages. The groundwaters in the northeast and southeast are much older (ages are mostly greater than 60 years) and are sourced only from the old component, which rises from the underlying Speargrass Formation

5.0 SOUTHERN VALLEY AND RARANGI AQUIFERS

Most of the tributary aquifer systems lie on the south side of the Wairau Plain. They are important for supplying water for local viticulture. Figure 1 shows the names and locations of the various aquifers.

5.1 IDENTIFICATION OF WATER SOURCES AND AGE INTERPRETATION

The locations and depths of the wells sampled are given in Figure 6. The same four-part scale of $\delta^{18}O$ values is used, but with different indicated water sources as follows (Figure 7):

Mid-blue	–8.6 to –9.2‰	Wairau River*, Southern Valley stream recharge
Orange	–8.0 to –8.6‰	Southern Valley stream recharge
Light green	–7.4 to –8.0‰	Stream/rainfall recharge mixtures
Deep green	–6.8 to –7.4‰	Predominantly rainfall recharge

The average $\delta^{18}O$ values for rainfall depend on altitude, at the rate of about -0.21‰ for each 100m rise in altitude (Stewart and Morgenstern, 2002). At sea level (i.e. on the plains), we have estimated the $\delta^{18}O$ of surface recharge to be -7.0‰ (section 4.1). Rainfall in the hills south of the plains will have more negative values; rainfall from sea level up to 200m is likely to have $\delta^{18}O$ values in the deep green point classification in the scale above. Southern Valley streams will have more negative values because they are derived from rainfall falling at higher altitudes.

The average $\delta^{18}O$ values measured in Southern Valley streams are in the range -8.49 to -8.17‰, and become more positive from west to east reflecting lower altitude and/or increasing proximity to the coast. Average values for individual streams are: Omaka River -8.44±0.23‰, Fairhall River -8.49‰, Doctors Creek -8.25‰, Taylor River -8.17±0.13‰. Points representing stream water will be orange, but could occasionally be mid-blue because of the secular variation in the $\delta^{18}O$ values of the streams. The Wairau Deep Aquifer (see below) has mid-blue points indicating Wairau River water as the source, but climatic conditions would have been very different then.

To use tritium for age determination requires the tritium input to the system to be known. Tritium comes into the Southern Valley Aquifer system via the streams and rainfall. The tritium concentration in rainfall in the Southern Valley stream catchments has been estimated using a scale factor of 1.1 applied to Kaitoke rainfall tritium concentrations (Taylor et al., 1992). This curve (shown in Figure 4) is used as the input for the Southern Valley Aquifers; the groundwater ages are simulated using this input and assuming an exponential fraction of 80% (Stewart and Morgenstern, 2002). Tritium results which are not distinguishable from those of the input are given ages <10 years, because of the tritium measurement error and because many of the samples were collected in 1988 and later. Samples collected in 1988 and later are more ambiguous to interpret, because older samples can have tritium values either higher or lower than the input water (see Figure 5).

5.2 AGE AND SOURCE OF SOUTHERN VALLEY AND RARANGI AQUIFER GROUNDWATERS

Southern Valley Aquifers

The immediate visual impression of Figure 7 shows mainly light green with some orange points in the valley fan aquifers that protrude onto the plain (Omaka River Valley Aquifer (top part) and Taylor-Burleigh & Riverlands Aquifer) indicating approximately equal proportions of rainfall (surface recharge) and streamflow infiltration in these areas. On the other hand, the southern tributary valley aquifers (Omaka River Valley Aquifer, etc.) have mostly orange points indicating that groundwater is sourced from stream infiltration in these valleys.

Omaka River Valley Aquifer: Wells P28w/1154 and 922 have orange points in Figure 8 like that for Omaka River, indicating recharge from the river. The ages are relatively young; 20 and <6 years, respectively. P28w/3069 has a light green point showing a stream/rainfall mixture and age <6 years.

Omaka River Valley Aquifer (top part): Well P28w/683 (dark green point) is recharged mainly by local rainfall and has a young age (<10 years). Wells P28w/972 and 681 have light green points showing stream/rainfall mixtures. Their ages reflect their depths (<10 years for 3m depth, and >60 years for 15m). Wells P28w/1000, 678, 1651, 634 (depths 20-36m) have a variety of sources. In order they are expected to be: 1000 and 678 - mainly stream-sourced water, 1651 – stream-sourced or Wairau River-sourced water, 634 – stream/rainfall mixture. They all have young ages (<10 years). Wells P28w/662, 642, 1829 have light green, light green and orange points, but their $\delta^{18}O$ values are very similar (all near -8.0‰) showing mainly stream-sourced water. Their ages are young. Wells P28w/990, 1681, 1731 have orange points showing mainly stream-sourced water, and young ages.

Omaka Aquifer: Wells P28w/1945, 1863, 1366, 955 are deeper (19-60m) and draw from the Speargrass Formation. They have orange points (Figure 8) suggesting a source from the nearby Mill Stream. Their ages are greater than 60 years.

Brancott Aquifer: Wells P28w/1895, 773 are deeper and have orange points showing stream recharge. They draw from Speargrass Formation and have ages greater than 60 years. Further downstream, well P28w/770 is sourced from stream water and has a younger age (about eight years).

Benmorven Aquifer: These artesian wells (P28w/864, 2096, 875, 865) are 31-47 m deep and have three orange and one mid-blue point. However, they are all likely to derive from the same stream source as their $\delta^{18}O$ values have only a small range. Taylor et al. (1992) suggested they could be from an extension of the Brancott Aquifer "flowing slowly in Wairau Gravel below the intervening (Tophouse-Manuka Deposit) ridges" based on their relatively negative $\delta^{18}O$ values and old ages (>60 years). In contrast, Chapman Spring, in the same area, has a light green point and age of >60 years indicating rainfall recharge and long-term storage within the Tophouse Formation. The downstream well (P28w/874) has similar depth, $\delta^{18}O$ value and age to the other wells and may also draw from the Wairau Gravel.

Taylor-Burleigh & Riverlands Aquifer: All of these wells (P28w/1477, 703, 1830, 785, 1283, 1119, 4402) have light green points showing they are sourced from rainfall and streamflow. All but one (785) have young ages (<10 years). There are seven $\delta^{18}O$ measurements for P28w/4402 and they show very little variation (sd = 0.03‰).

Rarangi Aquifer

Wells tapping the shallow Rarangi Aquifer in the northeast corner of the plains (P28w/ 47, 1831, 4442, 1396, 205, 3242, 982) all have dark green points showing that they are sourced from local rainfall either on the plain or draining from the hills to the north. Ages are variable ranging from <10 to 38 years reflecting the moderate permeability of the aquifer.

Wairau Deep Aquifer

Four deep wells in the Southern Valleys region (P28w/3217, 3333, 3287, 3278) draw from a different, much deeper aquifer, which contains much older water. The aquifer is completely disconnected from the overlying aquifers. Carbon-14 measurements have established the pre-Holocene age of this water (Taylor, 2004). The points are easily located in Figure 6 by their blue colour showing depth greater than 100m. Their ages are given as >60 years, but the waters are really thousands of years old.

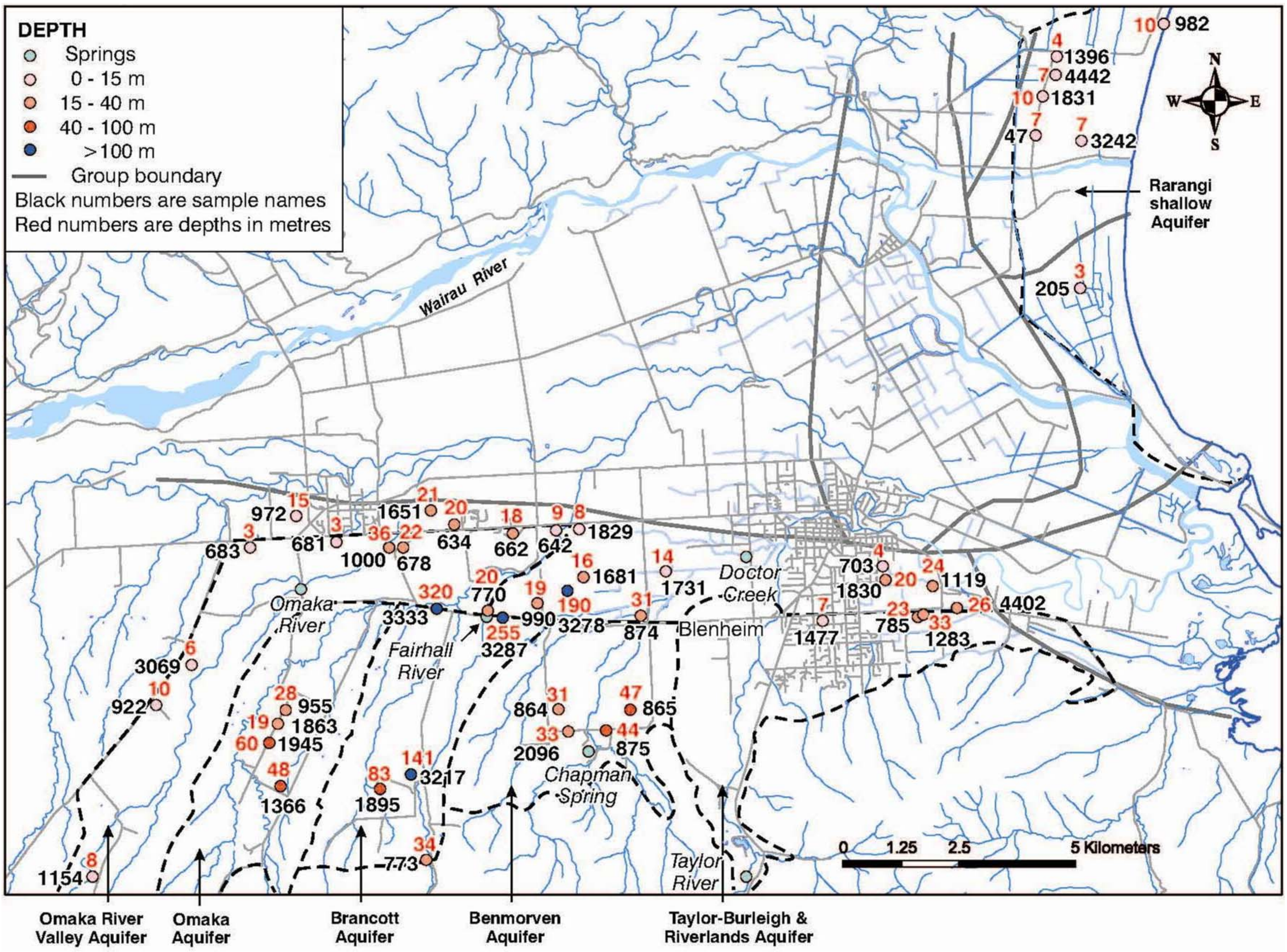

Figure 6. Locations and depths of wells for the Southern Valley and Rarangi Aquifers.

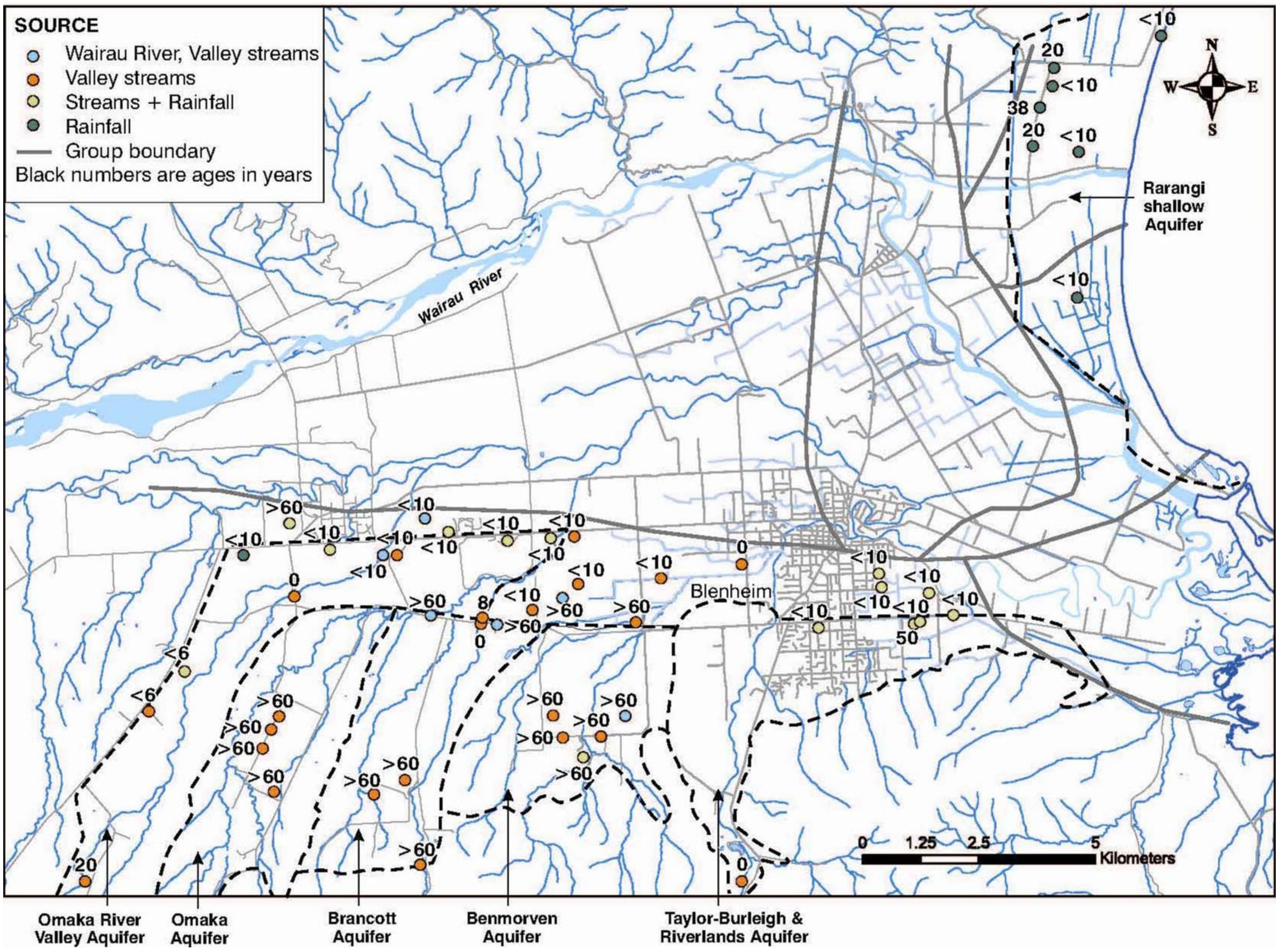

Figure 7. Ages and sources of groundwater in the Southern Valley and Rarangi Aquifers.

6.0 CONCLUSIONS

Figures 3 and 7 give visual impressions of the ages and sources of the groundwater in the Wairau Aquifer and the Southern Valley Aquifers, and show the different water types present. The disposition of water types observed is consistent with that shown by hydrochemistry (C. Daughney, pers. comm., 2004). The ages and sources reveal the flow patterns and processes in each area.

The main Wairau Aquifer draws most of its water from infiltration from the Wairau River, but surface recharge (from rainfall on the plains) contributes an average of about 19% to groundwater in the unconfined zone of the Rapaura Gravel (Group A1 wells), and 16% in the confined zone (Group B1 wells). The proportion of surface recharge in the groundwater is expected to vary with depth. Surface recharge contributes nitrate and other chemicals to the groundwater.

Groundwater flow rates are very rapid in the Rapaura Gravel, ages being less than six years in the unconfined (Group A1) and confined (Group B1) areas (based on the tritium levels in the groundwater being the same (i.e. not distinguishable because of the measurement error) as those of the Wairau River). Flow rates are much slower in the underlying Speargrass Formation (Group A2).

In the central part of the plains, a considerable proportion of the young Rapaura water reaches the coast (average 60% in Group B2 wells), showing that the aquifer has good permeability and offshore flow is likely. In contrast, the aquifer permeability decreases markedly near the coast in the north and south (Groups C1 and C2), and older groundwater rises from the Speargrass Formation into the Rapaura Gravel in these areas. This water has a tendency to flow towards the central zone.

South of the Wairau Aquifer (Omaka River Valley Aquifer (top part) and Taylor-Burleigh & Riverlands Aquifer) fan deposits emerge from the southern tributary valleys onto the plain. The young groundwater here (with age usually less than 10 years) is sourced from approximately equal proportions of rainfall (surface recharge) and streamflow infiltration.

Unconfined groundwater in the southern tributary valleys comes mainly from stream infiltration. The water is slow-moving, with old ages mostly greater than 60 years, showing that permeabilities are moderate to low. Inter-valley flow may occur from the Brancott to the Benmorven Aquifer through the underlying Wairau Gravel.

7.0 ACKNOWLEDGEMENTS

I thank Peter Davidson (Marlborough District Council) for contributing his support, knowledge of the district and groundwater information to the project, Julie Lee and Carolyn Hume for preparing the GIS diagrams (Figures 2-3 and 6-7) and Rob van der Raaij for compiling the database (Appendix 1). Chris Daughney and Vanessa Trompetter are thanked for their comments on the manuscript.

8.0 REFERENCES

Brown, L.J. 1981: Late Quaternary geology of the Wairau Plain, Marlborough, New Zealand. *New Zealand Journal of Geology and Geophysics, 24*, 477-490.

Stewart, M.K. 2006: The use of ^{18}O as a groundwater tracer in the Marlborough Region. *GNS Science Report 2006/3*, 12 p.

Stewart, M.K., Morgenstern, U. 2001: Age and source of groundwater from isotope tracers. Chapter 7 *in* Groundwaters of New Zealand. Eds: M.R. Rosen & P.A. White. 24 p.

Stewart, M.K., Trompetter, V., van der Raaij, R 2002: Age and source of Canterbury Plains groundwater. *Environment Canterbury Technical Report No. U02/30*. 46 p.

Taylor, C.B. 2004: Time-dependent factors inherent in the age equation for determining residence times of groundwater using 14C: A procedure to compensate for the past variability of 14C in atmospheric carbon dioxide, with application to the Wairau Deep Aquifer, Marlborough, New Zealand. *Radiocarbon, 46*(2), 501-515.

Taylor, C.B., Brown, L.J., Cunliffe, J.J., Davidson, P.W. 1992: Environmental isotope and ^{18}O applied in a hydrological study of the Wairau Plain and its contributing mountain catchments, Marlborough, New Zealand. *Journal of Hydrology, 138*, 269-319.

Taylor, C.B.; Wilson, D.D.; Brown, L.J.; Stewart, M.K.; Burden, R.J.; Brailsford, G.W. 1989: Sources and flow of North Canterbury Plains groundwater, New Zealand. *Journal of Hydrology 106*, 311-340.

APPENDIX 1: MEASUREMENTS OF TRITIUM AND OXYGEN-18 CONCENTRATIONS, AND ESTIMATES OF AGES AND SOURCES OF GROUNDWATERS

Sample Identity	Sampling Date	Grid Reference Map	E	N	Depth (m)	Tritium No.	TU	sd	Age yr	$d^{18}O$ ‰	$d^{18}O_{mean}$ ‰	Source No.	Cl mg/l	SO_4 mg/l	NO_3-N mg/l
Wairau Aquifer															
Wairau River															
Wairau River	21.03.68	P28	2575800	5968500	0	TM25	33.2	2.0		-7.96					
Wairau River	23.08.68	P28	2575800	5968500	0	TM29	30.0	1.8		-8.87					
Wairau River	6.12.68	P28	2575800	5968500	0	TM30	32.2	2.0		-8.96					
Wairau River	10.03.69	P28	2575800	5968500	0	TM31	29.6	1.8		-8.33					
Wairau River	11.04.73	P28	2577900	5969300	0	TM118	21.9	1.3		-8.71					
Wairau River	1.12.77	P28	2575100	5967800	0	TM178	13.1	0.5		-9.56					
Wairau River	21.10.88	P28	2576500	5968500	0	TM447	4.18	0.20		-8.79					
Wairau River	25.06.02	O28	2554500	5922200	0	TMB14	2.33	0.05		-8.21	-8.86*	1			
Group A1 (Groundwater from Rapaura Formation in unconfined zone)										10					
999	8.12.80	P28	2577500	5966600	16.5					-8.37		2			
398	15.07.88	P28	2577696	5968035	6.1	TM431	4.06	0.18	<6	-8.95					
398	25.07.05	P28	2577696	5968035	6.1	TMB33	2.11	0.04	<6	-8.54			3.15	4.16	0.34
398	13.11.06	P28	2577696	5968035	6.1					-8.87					
398	26.02.07	P28	2577696	5968035	6.1					-8.25					
398	19.06.07	P28	2577696	5968035	6.1					-8.37					
398	10.10.07	P28	2577696	5968035	6.1					-8.43					
398	20.11.07	P28	2577696	5968035	6.1					-8.63	-8.58	2			
2333	27.07.05	P28	2578115	5966613	21.0	TMB19	2.29	0.06	<6	-8.59		2	3.01	5.84	1.97
373	11.05.89	P28	2578160	5968400	29.3	TM472	3.40	0.18	<6						
323	26.02.70	P28	2579700	5969100	7.3	TM32	29.6	1.8	<6	-8.06		2			
4118	20.04.05	P28	2583129	5966923	22.6					-8.23					
4118	27.07.05	P28	2583129	5966923	22.6	TMB17	2.26	0.07	<6	-8.28			3.27	5.73	1.31
4118	15.11.06	P28	2583129	5966923	22.6					-8.72					
4118	22.02.07	P28	2583129	5966923	22.6					-8.48					
4118	9.05.07	P28	2583129	5966923	22.6					-8.29					
4118	22.08.07	P28	2583129	5966923	22.6					-8.36					
4118	21.11.07	P28	2583129	5966923	22.6					-8.32	-8.38	2			
3009	25.07.05	P28	2585136	5970344	6.0	TMB32	2.19	0.05	<6	-8.31			3.19	3.07	0.40
3009	13.11.06	P28	2585136	5970344	6.0					-8.92					
3009	20.06.07	P28	2585136	5970344	6.0					-8.18					
3009	20.11.07	P28	2585136	5970344	6.0					-8.51	-8.48	2			
1047	9.06.88	P28	2585169	5966418	15	TM413	4.12	0.21	<6	-8.48		2	2.98	4.64	1.93
222	26.02.70	P28	2585300	5970500	9.1	TM34	30.7	1.9	<6	-7.95					
222	12.04.78	P28	2585300	5970500	9.1	TM190	11.8	0.5	<6	-9.21					
222	7.12.78	P29	2585300	5970500	9.1					-9.17	-8.78	1			
Spring Creek	26.02.70	P28	2586700	5970700	0	TM35	32.1	1.9	<6	-8.05					
Spring Creek	11.04.73	P29	2586700	5970700	0					-8.43					
Spring Creek	7.12.78	P30	2586700	5970700	0					-9.31	-8.60	1			
208	21.11.73	P28	2587283	5970865	22.0	TM123	18.9	1.5	<6	-8.60					
208	19.11.73	P28	2587283	5970865	22.0					-8.88					
208	20.03.74	P28	2587300	5970800	22.0	TM127	16.0	0.7	<6	-8.70	-8.73	1			
347	27.09.74	P28	2587810	5968859	103.6	TM137	16.8	0.6	<6	-8.57		2			
950	29.10.74	P28	2588210	5966390	25.3	TM133	14.6	0.5	<6	-8.53		2			
3120	25.07.05	P28	2588221	5966037	24.9	TMB36	2.09	0.05	<6	-8.15			4.05	6.77	1.98
3120	13.11.06	P28	2588221	5966037	24.9					-8.52					
3120	20.06.07	P28	2588221	5966037	24.9					-8.30					
3120	20.11.07	P28	2588221	5966037	24.9					-8.36	-8.33	2			
4404	19.04.05	P28	2588600	5968968	14.0					-8.41					
4404	26.07.05	P28	2588600	5968968	14.0	TMB22	2.17	0.06	<6	-8.36			3.52	3.72	0.42
4404	14.11.06	P28	2588600	5968968	14.0					-8.76					
4404	26.02.07	P28	2588600	5968968	14.0					-8.61					
4404	10.05.07	P28	2588600	5968968	14.0					-8.48					
4404	23.08.07	P28	2588600	5968968	14.0					-8.39					
4404	22.11.07	P28	2588600	5968968	14.0					-8.51	-8.50	2			
Group A2 (Groundwater from Speargrass Formation in unconfined zone)										2					
208A	23.11.73	P28	2587283	5970865	39.6	TM124	8.9	0.5	36	-9.45					
208A	26.11.73	P28	2587283	5970865	45.1	TM125	8.2	0.5	39	-9.17	-9.31	1			
950A	29.10.74	P28	2588210	5966390	39.6	TM134	7.6	0.3	33						
950A	29.10.74	P28	2588210	5966390	45.7	TM135	3.6	0.3	46	-8.93					
950A	29.10.74	P28	2588210	5966390	55.6	TM136	1.2	0.1	57	-9.09	-9.01	1			
Group B1 (Groundwater from Rapaura Formation in confined zone - young water)										6					
376	26.06.71	P28	2590100	5968300	21.4	TM56	25.0	1.50	<6	-8.21		2			
38	7.12.78	P28	2590400	5974600	24.1					-8.63		1			
38	8.05.73	P28	2590400	5974600	24.1					-8.88	-8.76	1			
32	26.02.70	P28	2590524	5974697	27.5	TM36	25.3	1.5	9	-8.54		2			

Sample Identity	Sampling Date	Map	Grid Reference E	N	Depth (m)	No.	Tritium TU	sd	Age yr	$d^{18}O$ ‰	$d^{18}O_{mean}$ ‰	Source No.	Cl mg/l	SO_4 mg/l	NO_3-N mg/l
327	26.02.70	P28	2590600	5969000	22.0	TM38	29.0	1.8	<6	-8.60		1			
199	26.02.70	P28	2591100	5970900	18.3	TM37	26.4	1.6	7	-8.66		1			
35	19.12.72	P28	2591500	5974600	26.8	TM103	26.9	1.6	<6	-8.20		2			
384	26.06.71	P28	2591500	5968200	25.0	TM54	31.2	1.9	<6	-8.52		2			
384	12.04.78	P28	2591500	5968200	25.0	TM188	13.4	0.6	<6	-8.64	-8.58	1			
50	19.12.72	P28	2591700	5974100	?	TM104	24.3	1.4	<6	-8.78		1			
615	26.06.71	P28	2591800	5966000	25.9	TM51	29.3	1.8	<6	-8.50		2			
371	10.06.88	P28	2591900	5968500	26.2	TM407	4.21	0.19	<6	-8.73		1	2.86	3.40	0.73
125	23.05.88	P28	2592000	5972000	21.6	TM418	4.25	0.21	<6	-8.81		1			
62	19.12.72	P28	2592400	5973500	19.8	TM105	22.7	1.3	<6	-8.13		2			
188	9.06.88	P28	2592660	5971071	24.4	TM410	4.33	0.22	<6	-8.88		1	3.12	2.91	0.30
419	27.11.73	P28	2592700	5967700	32.6	TM131	21.4	0.8	<6	-8.74		1			
196	23.05.88	P28	2593000	5971000	42.7	TM417	4.49	0.33	<6	-8.80		1			
1616	10.06.88	P28	2593100	5969400	30	TM409	4.61	0.22	<6	-8.74		1	2.70	4.00	0.95
276	26.06.71	P28	2593300	5969500	20.0		25.3	1.50	7	-8.21		2			
4403	19.04.05	P28	2593830	5966465	45.5					-8.24		2	5.34	4.24	0.70
4403	26.07.05	P28	2593830	5966465	45.5	TMB23	1.79	0.07	<6	-8.28					
4403	14.11.06	P28	2593830	5966465	45.5					-8.53					
4403	26.02.07	P28	2593830	5966465	45.5					-8.28					
4403	10.05.07	P28	2593830	5966465	45.5					-8.36					
4403	23.08.07	P28	2593830	5966465	45.5					-8.40					
4403	22.11.07	P28	2593830	5966465	45.5					-8.39	-8.35	2			
394	26.06.71	P28	2594300	5968000	34.2	TM53	25.0	1.5	7	-8.63					
394	12.04.78	P29	2594300	5968000	34.2					-9.03	-8.83	1	3.10	4.50	0.83
518	27.11.73	P28	2594678	5966823	34.8	TM126	17.7	1.1	6	-8.70					
518	12.04.78	P28	2594678	5966823	34.8	TM182	12.5	0.5	<6	-8.70	-8.70	1	3.80	7.40	0.16
Group B2 (Groundwater from Rapaura Formation in confined zone - mixed water)										4					
42	27.06.71	P28	2592500	5974400	27.5	TM59	22.9	1.4	16	-8.44		2	10.00	5.10	0.001
663	26.02.70	P28	2592700	5965600	27.5	TM40	16.8	1.0	29	-8.84		1			
41	19.12.72	P28	2592900	5974400	30.5	TM106	15.8	0.9	24	-8.47		2			
25	20.12.72	P28	2593000	5974800	30	TM108	15.5	0.9	25	-8.72		1			
595	9.06.88	P28	2593410	5966160	24.4	TM408	4.64	0.20	33	-8.72		1	2.37	4.14	0.99
624	26.06.71	P28	2593600	5965900	30	TM52	23.7	1.4	9	-9.00					
624	12.04.78	P28	2593600	5965900	30	TM181	12.8	0.5	<6	-8.65	-8.83	1	3.50	4.60	0.22
154	14.07.88	P28	2595280	5971500	32.3	TM429	6.57	0.30	20	-8.86		1	3.35	6.08	0.002
981	22.06.88	P28	2595686	5968907	41.5	TM415	5.93	0.29	25	-8.62		1	3.50	6.60	0.31
403	26.06.71	P28	2595800	5968000	46.6	TM57	5.1	0.3	31	-8.93					
403	23.05.88	P28	2595800	5968000	46.6	TM422	5.01	0.22	31	-8.93	-8.93	1			
543	15.07.88	P28	2595872	5966436	39.7	TM432	4.70	0.20	32	-8.87		1			
338	12.04.78	P28	2595900	5969100	36.6	TM183	12.7	0.5	0-6	-8.59					
338	26.06.71	P28	2595930	5968909	36.6	TM55	18.1	1.1	25	-8.92	-8.76	1			
1733	13.06.88	P28	2596368	5968789	83.5	TM406	4.86	0.21	29	-8.83					
1733	18.04.05	P28	2596368	5968789	83.5					-8.62					
1733	25.07.05	P28	2596368	5968789	83.5	TMB30	1.58	0.05	31				7.24	3.83	0.04
1733	13.11.06	P28	2596368	5968789	83.5					-8.62					
1733	19.06.07	P28	2596368	5968789	83.5					-8.38					
1733	21.08.07	P28	2596368	5968789	83.5					-8.46					
1733	20.11.07	P28	2596368	5968789	83.5					-8.43	-8.56	2			
Group C1 (Groundwater in confined zone with dominant older component - northern group)										2					
1833	23.05.88	P28	2592800	5972500	28	TM423	1.73	0.10	>60	-8.83		1			
68	26.02.70	P28	2593400	5973400	28.4	TM39	1.6	0.1	58	-8.65		1	37.00	3.90	<0.005
168	26.06.71	P28	2593450	5971350	27.4		5.10	0.30	51	-8.57		2			
110	23.05.88	P28	2593600	5972300	28.4	TM416	4.33	0.22	34	-8.80		1			
59	19.12.72	P28	2593700	5973600	29.0	TM107	1.0	0.1	59	-8.91		1			
34	20.12.72	P28	2593994	5974609	29.6	TM111	0.46	0.04	>60	-8.94					
34	23.05.88	P28	2594000	5974600	29.6	TM426	0.16	0.07	>60	-9.26	-9.10	1	76.00	0.004	1.00
13	23.05.88	P28	2594030	5975080	27.5	TM419	-0.01	0.07	>60	-8.83					
13	8.05.73	P28	2594030	5975080	27.5					-8.68	-8.76	1			
14	20.12.72	P28	2594125	5975073	27.5	TM110	0.21	0.03	>60	-8.91		1			
3439	27.07.05	P28	2594283	5975275	27.9	TMB27	0.05	0.022	>60	-8.75		1	131.77	0.10	0.01
85	10.06.88	P28	2594473	5972901	30.5	TM411	0.61	0.07	>60	-8.87		1	10.48	3.96	0.03
Group C2 (Groundwater in confined zone with dominant older component - southern group)										3					
782	3.10.72	P28	2593400	5963800	25.6	TM92	6.8	0.4	46	-8.77		1			
749	3.10.72	P28	2593600	5964300	27.5	TM91	7.1	0.4	45	-9.00					
749	8.05.73	P29	2593600	5964300	27.5					-8.66	-8.83	1			
748	14.07.88	P28	2593700	5964300	35.1	TM433	4.95	0.20	28	-8.70		1	5.79	4.30	0.06
775	25.06.71	P28	2594500	5963900	33.6	TM48	3.3	0.2	54	-8.86		1			
816	3.10.72	P28	2595100	5963400	38.1	TM90	3.9	0.2	52	-9.00		1			
744	3.10.72	P28	2595200	5964300	36.6	TM89	1.8	0.1	57	-9.02		1			
3447	26.07.05	P28	2595833	5963531	35.7	TMB29	0.35	0.026	>60	-8.62		1	39.09	2.25	<0.02
840	25.06.71	P28	2595900	5962900	38.1	TM46	0.6	0.1	>60	-9.10		1			
679	26.06.71	P28	2595900	5965300	43.3	TM50	3.7	0.2	53	-9.14			6.60	4.30	0.002

Sample Identity	Sampling Date	Map	Grid Reference E	N	Depth (m)	No.	Tritium TU	sd	Age yr	$d^{18}O$ ‰	$d^{18}O_{mean}$ ‰	Source No.	Cl mg/l	SO_4 mg/l	NO_3-N mg/l
679	12.04.78	P28	2595900	5965300	43.3	TM185	5.2	0.2	39	-8.84					
679	26.02.70	P28	2595900	5965300	43.3					-8.86	-8.95	1			
765	3.10.72	P28	2596157	5964037	38.7	TM88	1.5	0.1	58	-9.10					
765	8.06.88	P28	2596200	5964000	38.7	TM403	3.09	0.15	47	-8.79	-8.95	1	10.68	3.07	0.01
839	3.10.72	P28	2596500	5963000	38.1	TM86	0.21	0.03	>60	-9.04		1			
677	9.06.88	P28	2596800	5965400	43	TM404	5.18	0.23	30	-8.79		1	4.80	3.15	0.003
848	3.10.72	P28	2596840	5962473	38.1	TM87	0.63	0.05	>60	-8.93		1			
736	3.10.72	P28	2597100	5964400	40.0	TM85	0.87	0.06	>60	-8.89					
736	12.04.78	P28	2597100	5964400	40.0	TM187	1.12	0.15	>60	-8.89	-8.89	1	48.00	<0.15	<0.002
572	27.06.71	P28	2597400	5966300	48.8	TM58	2.0	0.1	57	-8.91					
572	12.04.78	P28	2597400	5966300	48.8	TM186	3.3	0.2	48	-8.83	-8.87	1	9.00	2.40	0.003
708	25.06.71	P28	2597585	5964954	42.7	TM45	1.1	0.1	59	-9.11					
708	23.02.06	P28	2597585	5964954	43.0	TMB38	0.97	0.03	>60	-8.83	-8.97	1	18.36	1.30	0.20
857	18.05.77	P28	2597490	5962199	69.0	TM154	0.20	0.10	>60	-8.89					
857	31.05.79	P28	2597490	5962199	69.0	TM247	1.37	0.18	>60				344.60	1.50	0.004
857	7.12.78	P28	2597490	5962199	69.0					-8.87	-8.88	1			
532	21.03.68	P28	2598100	5966600	54.3	TM26	3.7	0.2	54	-8.79					
532	30.11.77	P28	2598100	5966600	54.3	TM172	1.00	0.18	>60	-8.77	-8.78	1			
596	15.06.88	P28	2598500	5966100	60.4	TM405	1.10	0.08	>60	-8.84		1	15.70	0.002	<1
Southern Valley & Rarangi Aquifers															
Omaka River, Valley and Fan Area (Omaka River Valley Aquifer)															
1154	10.06.88	P28	2573700	5958200	?	TM399	4.84	0.22	20	-8.47		2	6.40	13.05	0.004
922	22.06.88	P28	2575075	5961900	10.4	TM425	4.83	0.20	<6	-8.43		2	2.33	5.51	0.81
3069	26.07.05	P28	2575839	5962765	5.8	TMB21	2.08	0.05	<6	-7.65		3	3.92	19.58	5.03
Omaka R.	17.05.88	P29	2578200	5964400	0					-8.46					
Omaka R.	17.08.81	P28	2578200	5964400	0					-8.82					
Omaka R.	31.03.89	P30	2578200	5964400	0					-8.03	-8.44	2			
Southern Plain: Renwick eastwards to Taylor River (Top part of Omaka River Valley Aquifer)															
1105	8.12.80	P28	2577100	5965200	?					-7.69		3			
683	17.05.88	P28	2577100	5965300	3.1	TM381	4.02	0.25	<10	-6.82		4			
1104	8.12.80	P28	2577400	5965800	33.0					-7.81		3			
972	17.05.88	P28	2578093	5965984	14.6	TM382	1.41	0.12	>60	-7.67		3	6.45	3.70	0.85
1421	17.5.88	P28	2578100	5964900	?					-8.24		2			
681	17.05.88	P28	2578960	5965420	3.4	TM383	4.55	0.26	<10	-7.87		3			
1090	8.12.80	P28	2579400	5965200	3.4					-8.67		1			
1000	8.12.80	P28	2580100	5965300	36.0					-8.85		1			
678	17.05.88	P28	2580400	5965300	21.6	TM384	4.03	0.25	<10	-8.16		2			
1651	17.08.81	P28	2581000	5966100	21.5					-8.78		1			
634	26.02.70	P28	2581500	5965800	19.5	TM33	28.4	1.7	<10	-7.42		3			
662	22.06.88	P28	2582770	5965607	18.3	TM414	3.99	0.21	<10	-7.98					
662	27.07.05	P28	2582770	5965607	18.3	TMB20	2.14	0.05	<10	-7.82	-7.90	3	4.14	7.43	1.88
990	18.05.88	P28	2583300	5964100	18.7	TM390	4.10	0.24	<10	-8.09		2			
642	18.05.88	P28	2583700	5965670	9.2	TM389	4.73	0.26	<10	-8.00		3	4.60	7.90	1.46
1829	18.05.88	P28	2584200	5965700	8.0	TM388	4.80	0.27	<10	-8.04		2			
1681	18.05.88	P28	2584289	5964663	15.7	TM387	4.74	0.29	<10	-8.15		2	4.10	10.10	1.22
1731	18.05.88	P28	2586061	5964791	14.3	TM386	4.65	0.27	<10	-8.05		2			
Mill Stream Valley (Omaka Aquifer)															
1945	25.07.05	P28	2577513	5961087	60.0	TMB35	0.059	0.022	>60	-8.34		2	8.53	4.34	0.04
1863	26.10.88	P28	2577700	5961500	19.0	TM448	0.77	0.07	>60	-8.34		2	4.92	3.60	0.04
1366	17.05.88	P28	2577755	5960150	48.0	TM380	0.04	0.07	>60	-8.49		2			
955	14.06.88	P28	2577864	5961792	28.0	TM400	0.61	0.07	>60	-8.55		2	4.94	8.64	0.55
Fairhall River, Valley and Fan(Brancott Aquifer)															
1895	8.02.89	P28	2579904	5960089	83.0	TM471	0.10	0.08	>60				42.25	12.50	0.01
773	14.04.78	P28	2580900	5958560	33.5	TM193	0.16	0.14	>60	-8.25		2			
Fairhall R.	17.08.81	P28	2582200	5963800	0					-8.49		2			
770	13.04.78	P28	2582231	5963937	20.4	TM192	9.4	0.4	8.0	-8.30		2			
Ben Morven area (Benmorven Aquifer)															
864	18.10.74	P28	2583750	5961810	30.5	TM139	-0.01	0.10	>60	-8.32					
864	30.11.77	P28	2583750	5961810	30.5	TM170	0.40	0.09	>60	-8.20	-8.26	2		3.10	<0.001
2096	29.11.90	P28	2583960	5961330	33.0	TM508	-0.06	0.07	>60	-8.25		2		5.20	0.04
Chapman Spring	12.04.78	P28	2584400	5960900	0	TM191	0.47	0.17	>60	-7.45		3			
875	30.11.77	P28	2584778	5961351	44.2	TM189	0.24	0.22	>60	-8.24					
875	5.11.74	P28	2584778	5961351	44.2	TM169	0.18	0.10	>60	-8.42	-8.33	2			
865	21.03.74	P28	2585300	5961800	47.2	TM128	0.18	0.11	>60	-8.73		1	19.66	2.40	0.03
874	25.10.74	P28	2585526	5963830	31.4	TM138	0.04	0.10	>60	-8.33					
874	17.06.88	P28	2585600	5963830	31.4	TM401	0.10	0.07	>60	-8.13	-8.23	2	191.00	1.30	0.04
Doctors Creek	17.08.81	P28	2587800	5965100	0					-8.25		2			
Taylor River															
Taylor River	30.11.77	P28	2587800	5958200						-8.02					
Taylor River	11.04.78	P29	2587800	5958200		TM180	8.5	0.4		-8.33					
Taylor River	7.12.78	P30	2587800	5958200						-7.88					

Sample Identity	Sampling Date	Grid Reference Map	E	N	Depth (m)	Tritium No.	TU	sd	Age yr	$d^{18}O$ ‰	$d^{18}O_{mean}$ ‰	Source No.	Cl mg/l	SO_4 mg/l	NO_3-N mg/l
Taylor River	17.08.81	P31	2587800	5958200						-8.44	-8.17	2			
Southern Plain: Taylor River eastwards to Riverlands (Taylor-Burleigh & Riverlands Aquifer)															
1477	8.06.88	P28	2589446	5963715	7.2	TM402	5.13	0.23	<10	-7.58		3	21.53	12.94	3.97
703	18.05.88	P28	2590744	5964894	4.3	TM428	4.42	0.19	<10	-7.75		3			
1830	18.05.88	P28	2590800	5964600	~20	TM391	4.02	0.24	<10	-7.90		3			
785	25.06.71	P28	2591500	5963800	23.2	TM47	3.3	0.2	50	-7.99		3			
1283	14.07.88	P28	2591621	5963854	32.7	TM434	4.50	0.19	<10	-7.97		3			
1119	19.05.88	P28	2591820	5964470	24.4	TM427	4.15	0.18	<10	-7.84		3			
4402	18.04.05	P28	2592340	5963993	25.5					-7.61		3	8.09	5.16	0.08
4402	25.07.05	P28	2592340	5963993	25.5	TMB37	1.67	0.05	<10						
4402	3.09.07	P28	2592340	5963993	25.5					-7.69					
4402	1.10.07	P28	2592340	5963993	25.5					-7.63					
4402	2.11.07	P28	2592340	5963993	25.5					-7.59					
4402	3.12.07	P28	2592340	5963993	25.5					-7.63					
4402	25.01.08	P28	2592340	5963993	25.5					-7.64					
4402	5.02.08	P28	2592340	5963993	25.5						-7.63	3			
Rarangi Shallow Aquifer															
47	19.12.72	P28	2594046	5974196	6.7	TM112	14.0	0.8	20	-6.92					
47	24.05.88	P28	2594046	5974196	6.7	TM424	4.85	0.20	20	-7.04	-6.98	4	8.80	14.00	0.003
1831	23.05.88	P28	2594196	5975039	10.0	TM420	3.09	0.16	38	-7.13		4	14.70	8.40	0.09
5	9.06.88	P28	2594400	5975945	30.2	TM412	0.05	0.06	>60	-7.38		4	182.75	9.80	0.01
4442	27.07.05	P28	2594471	5975503	7.2	TMB26	1.80	0.06	<10	-6.47		4	9.18	13.66	0.01
1396	23.05.88	P28	2594500	5975900	4.0	TM421	3.57	0.16	20	-6.32		4	10.60	12.84	0.05
205	14.07.88	P28	2595000	5970900	2.5	TM430	3.04	0.17	<10	-7.20		4			
3242	27.07.05	P28	2595028	5974077	6.7	TMB28	1.98	0.05	<10	-6.42		4	21.60	26.35	2.21
982	7.06.79	P28	2596800	5976600	10.0				<10	-7.01		4			
Wairau Deep Aquifer															
3217	25.07.05	P28	2580566	5960400	141.0	TMB34	0.004	0.024	>60	-8.22		2	32.30	10.93	0.04
3333	20.08.98	P28	2581124	5963982	320.0	TMB3	0.021	0.015	>60	-8.63		1	56.00	5.10	0.08
3287	21.06.98	P28	2582547	5963785	255.0	TMB2	-0.036	-0.016	>60	-8.78		1	28.10	3.76	0.10
3278	13.05.98	P28	2583947	5964363	190.0	TMB1	0.027	0.018	>60	-8.76		1	100.60	2.16	0.01

www.gns.cri.nz

Principal Location

1 Fairway Drive
Avalon
PO Box 30368
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4600

Other Locations

Dunedin Research Centre
764 Cumberland Street
Private Bag 1930
Dunedin
New Zealand
T +64-3-477 4050
F +64-3-477 5232

Wairakei Research Centre
114 Karetoto Road
Wairakei
Private Bag 2000, Taupo
New Zealand
T +64-7-374 8211
F +64-7-374 8199

National Isotope Centre
30 Gracefield Road
PO Box 31312
Lower Hutt
New Zealand
T +64-4-570 1444
F +64-4-570 4657