The use of $^{18}0$ as a groundwater tracer in the Marlborough Region

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ABSTRACT

The usefulness of ^{18}O for monitoring groundwater wells in the Wairau River coastal plain has been investigated by conducting a survey of the wells used for monitoring.

The $\delta^{18}O$ values of the Wairau Aquifer well waters show trends along the lines of flow depending on distance and depth. Near the head of the valley and close to the river, the groundwater has $\delta^{18}O$ values like that of the Wairau River. With distance from the river and towards the coast, the $\delta^{18}O$ values of shallow groundwater in the unconfined aquifer become more positive as land surface infiltrating recharge with higher $\delta^{18}O$ values contributes to the flow. The infiltrating water also carries nitrate and other chemicals to the groundwater. At deeper levels, the groundwater is not affected by water infiltrating through the surface, and retains its Wairau River $\delta^{18}O$ signature when it rises towards the surface near the coast. However, this conclusion is regarded as preliminary because of the possible temporal variability of the groundwater $\delta^{18}O$ values. Regular 3-monthly ^{18}O measurements should be carried out on 8 key wells (listed below) to substantiate this conclusion.

The $\delta^{18}O$ values of the southern valley aquifer waters indicate that they are sourced from local streams and surface recharge. The Rarangi and Tuamarina Aquifers are sourced from local rainfall with $\delta^{18}O$ of -6.2‰.

KEYWORDS

Groundwater; ^{18}O; nitrate; river recharge; surface recharge; alluvial plains aquifers

1.0 INTRODUCTION

As part of the National Groundwater Monitoring Project (NGMP), a survey of wells in the Marlborough region was undertaken to demonstrate the usefulness of ^{18}O measurements in association with the regular chemical measurements.

The coastal plain of the Wairau River covers an area of 170 km^2. Permeable gravel is about 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 Wairau Aquifer becomes confined in the coastal region, where marine sediments overlie the early Rapaura Gravels. The Wairau River is a major source of recharge, along with lesser amounts of rainfall on the Plain. Fans from tributary valleys on the north and south protrude into the Plain, and host minor groundwater systems that also contribute groundwater to the Plain.

A comprehensive compilation of ^{18}O measurements up to 1988, along with tritium measurements, was published by Taylor et al. (1992). Since then, ^{18}O results have been collected sporadically along with tritium and CFC/SF_6 results, and reported in unpublished reports. The present survey of ^{18}O was conducted on wells used for monitoring by the Marlborough District Council (MDC) Regional Groundwater Monitoring Network and the National Groundwater Monitoring Programme (NGMP) of GNS Science in 2005.

2.0 SAMPLING

Most of the wells sampled were described in the "Regional groundwater monitoring network manual" produced by the Marlborough District Council in 2005. The $\delta^{18}O$ results are listed in Table 1, along with other details of the wells. The well locations are plotted in Figure 1.

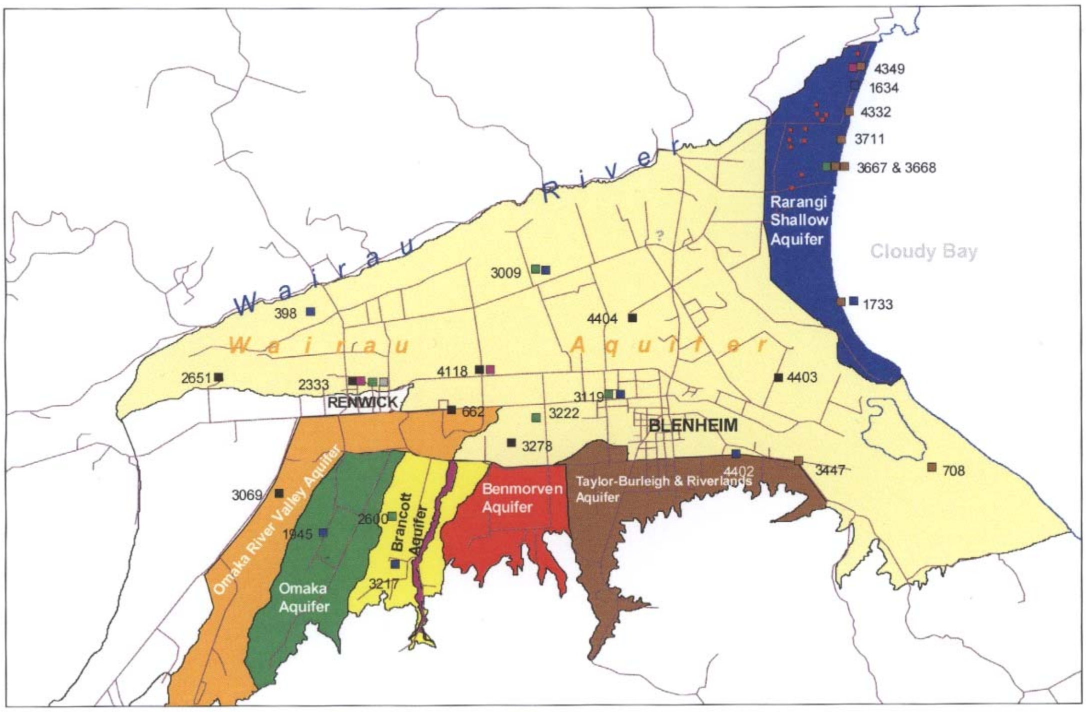

Figure 1. Map showing well locations.

3.0 RESULTS

Wairau River and other streams

The mean of three $\delta^{18}O$ measurements on the river is -8.78‰ (Table 1), in good agreement with the value of -8.79 ± 0.14‰ (standard deviation 0.44‰) given by Taylor et al. (1992) (Table 2). The (flow) weighted mean value was -8.86‰.

The other streams had $\delta^{18}O$ in the range -7.69 to -8.41‰, the more positive values showing lesser altitudes of precipitation than for the Wairau River.

Wairau Aquifer

Wairau Aquifer wells are listed in approximate order from west to east in Table 1, as the aquifer changes from being unconfined on the west to confined in the east. A transition zone between them is classed as semiconfined. Some of the wells are on the southern border of the aquifer, where they are likely to be affected by water from the southern tributary valleys.

Well P28w/2651 is the easternmost well in the Wairau Aquifer Group (Table 1). Its $\delta^{18}O$ value, as well as its location on the south side of the valley, suggests that it gains recharge from the south. Well P28w/0398 is close to the Wairau River and has a $\delta^{18}O$ value (-8.54‰),

Table 1. Information and $\delta^{18}O$ results for monitoring wells in the Marlbororough region.

Type*	Sample	Aquifer/Stream	Map Ref	Screen Depth m	Sample Date	NO_3-N mg/L	$\delta^{18}O_{VSMOW}$ ‰	x** %
Wairau River								
	WRR-4	Wairau R @ Mill Rd			05/08/05		-8.75	
	WRR-24	Wairau R @ Church Lane			05/08/05		-8.79	
	WRR-33	Wairau R @ Onamalutu			05/08/05		-8.80	
Other streams								
	MST-25	Mill Stream opp MDC			05/08/05		-8.01	
	WST-3	Walkers Stream @ Church Lane			05/08/05		-7.69	
	BND-2	Boundary Creek @ Hill country ford			05/08/05		-8.38	
	--	Walkers/Hillersden Streams @ Parkes Ford			05/08/05		-8.41	
Wairau Aquifer								
MDC	P28w/2651	Wairau Aq (unconf)	7391766711	12.1 - 14.1	19/04/05	2.0	-8.12	--
NGMP	P28w/0398	Wairau Aq (unconf)	7769668035	6	18/04/05	0.12	-8.54	--
MDC	P28w/2333	Wairau Aq (unconf)	7811566613	14 - 18	27/07/05	0.67	-8.59	--
MDC	P28w/4118	Wairau Aq (unconf)	8312966923	19.4 - 22.4	20/04/05	1.1	-8.23	34
"	"	"	"	"	27/07/05	0.7	-8.28	31
NGMP	P28w/3009	Wairau Aq (unconf)	8513270342	5 - 6	18/04/05	0.21	-8.31	30
MDC	P28w/0662	Wairau Aq (semi)	8277065607	24	27/07/05	1.7	-7.82	--
NGMP	P28w/3120	Wairau Aq (semi)	8822166037	19.8-25	18/04/05	1.7	-8.15	38
MDC	P28w/4404	Wairau Aq (semi)	8860068968	11 - 14	19/04/05	0.44	-8.41	24
"	"	"	"	"	26/07/05	0.30	-8.36	27
NGMP	P28w/4402	Wairau Aq (conf)	9235363999	22.25 - 25.5	18/04/05	0.06	-7.61	--
MDC	P28w/4403	Wairau Aq (conf)	9383066465	34.2 - 37.0	19/04/05	0.70	-8.24	33
"	"	"	"	"	26/07/05	0.68	-8.28	31
	P28w/3439	Wairau Aq (conf)	9429275274		20/04/05	<0.02	-8.71	8
	"	"	"		27/07/05	<0.02	-8.75	6
MDC	P28w/3447	Wairau Aq (conf)	9583363531	32.6 - 35.6	19/04/05	<0.02	-8.62	13
NGMP	P28w/1733	Wairau Aq (conf)	9636868789	45.5-49.5	18/04/05	<0.002	-8.62	13
MDC	P28w/0708	Wairau Aq (conf)	9754764982	43	19/04/05	0.04	-8.83	2
MDC	P28w/3278	Deep Wairau Aq	8394764363	100 - 189	20/04/05	<0.02	-8.58	--
Southern valley aquifers								
MDC	O28w/0015	MDC water supply well	5354361370	8.1 - 10.1	19/04/05	0.97	-8.13	
"	"	"	"	"	26/07/05	1.8	-8.06	
"	"	"	"	"	05/08/05		-8.13	
MDC	P28w/3069	Omaka R. V. Aq	7583962765	5.8 - 7.8	19/04/05	4.5	-7.83	
"	"	"	"	"	26/07/05	5.0	-7.65	
NGMP	P28w/1945	Omaka Aq (semi to conf)	7751361087	15 - 60	18/04/05	0.054	-8.34	
NGMP	P28w/3217	Brancott Aq (semi to conf)	8056660400	55-141	18/04/05	<0.002	-8.22	
Northern valley aquifer								
MDC	P27w/0448	Tuamarina (schist alluv.)	8948182976	6.6 - 9.6	20/04/05	1.5	-6.22	
"	"	"	"	"	27/07/05	1.5	-5.82	
Rarangi Aquifer								
	P28w/4442	Rarangi shallow	9446375501		20/04/05	<0.02	-6.40	
	"	"	"		27/07/05	<0.02	-6.47	
	P28w/3242	Rarangi shallow	9502874077		20/04/05		-6.54	
NGMP	P28w/1634	Rarangi Aq (unconf)	9680277695	6	18/04/05	0.63	-5.97	
Other aquifers								
	O28w/0136	Parkes Well			05/08/05		-8.79	
		P28w/1652			20/04/05	1.4	-8.20	
		P28w/3447			26/07/05	<0.02	-8.62	
		P28w/3242			27/07/05	4.0	-6.42	
		P28w/3010			20/04/05	1.1	-8.11	
MDC	P29w/0169	Ward (unconf gravel aq)	0462631218	4.3	19/04/05	0.58	-6.34	
"	"	"	"	"	26/07/05	4.3	-6.26	

*Type indicates wells in the Marlborough District Council Regional Groundwater Monitoring Network (MDC), and the National Groundwater Monitoring Programme (NGMP).
**x is the fraction of land surface infiltrating recharge (see text).

Table 2. Average $\delta^{18}O$ results from Taylor et al. (1992).

Sample/Group	Quantity	n	$\delta^{18}O_{VSMOW}$ ‰	sd ‰
Rainfall-derived groundwater	Mean		-7.08 ± 0.05	
Wairau River	Mean	10	-8.79 ± 0.14	0.44
	Weighted mean	10	-8.86	
Wairau Aquifer (unconf) (Group A)	Mean	?	-8.69 ± 0.10	0.37
		17	(-8.60 ± 0.10)*	0.40
Wairau Aquifer (conf) (Group B)	Mean	33	-8.69 ± 0.04	0.23
Wairau Aquifer (conf, older component) (Group C)	Mean	39	-8.89 ± 0.03	0.16

*Mean using all data listed in this group.

which is typical of values measured for the river. Wells near the river would be expected to show almost as much variability in $\delta^{18}O$ as the river itself. Well P28w/2333 also has a $\delta^{18}O$ value (-8.59‰) like that of the river, although it may also contain water derived from the south.

As the groundwater travels further from the river, we expect less temporal variability of the $\delta^{18}O$ values (also identified by Taylor et al. 1992 in the overall Wairau Aquifer system) and possible augmentation by water from other sources. Well P28w/4118 has a more positive $\delta^{18}O$ of -8.25‰ (mean of two values) than the river suggesting that input of rainfall &/or irrigation water (collectively called land surface infiltration recharge or surface recharge for short) in the area between the river and the well affects the $\delta^{18}O$ value. The fraction of surface recharge (x) is given by the equation

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

where δ_s, δ_g, and δ_r are the $\delta^{18}O$ values of the surface recharge, groundwater sample and Wairau River, respectively. The mean $\delta^{18}O$ of the surface recharge (δ_s) is assumed to be about -7.0‰ (see below), and the Wairau River recharge (δ_r) is taken as -8.86‰ (the weighted mean). For well P28w/4118, the fraction of surface recharge estimated by the equation is 33%. Fractions for some other wells are given in Table 1.

However, there may be considerable error in applying this equation because of the temporal variability of the $\delta^{18}O$ values of the groundwater (δ_g) (highlighted by Taylor et al. 1992). Average $\delta^{18}O$ values (derived from regular monitoring of wells) should really be used with the equation. Wells close to the river and with high flows (e.g. P28w/3009) would be expected to show much the same $\delta^{18}O$ variability as the river. The single $\delta^{18}O$ measurement for well P28w/3009 gave a fraction (x) of 30%, but more measurements would give more confidence in the result. Taylor et al. (1992) considered that Spring Creek and nearby wells are not affected much by input of surface recharge because of their high flows and relative proximity to the river. Larger effects would be expected further away from the river and where flows are less.

Surface recharge would be expected to cause increases in some chemicals (particularly nitrate in oxidising conditions) in the groundwater. A generally increasing trend is seen in the nitrate-N concentrations in agreement with the increasing surface recharge fraction (x) in Table 1. Fig. 2 shows that there is an approximately linear relationship between $\delta^{18}O$ and nitrate-N in the Wairau Aquifer.

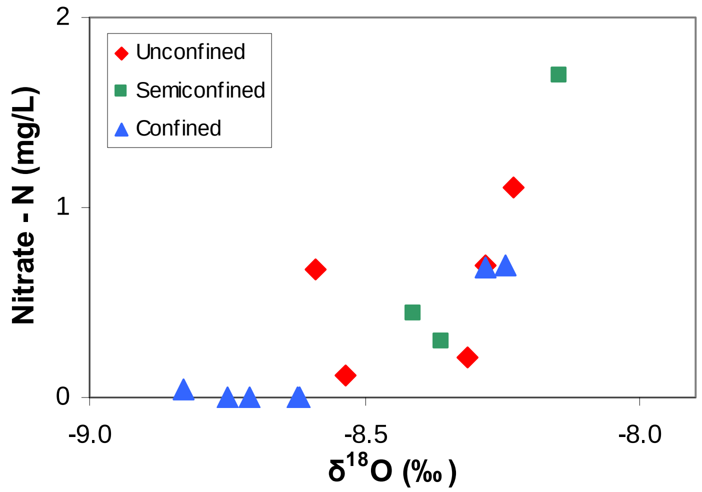

Figure 2. Plot of $\delta^{18}O$ versus nitrate-N concentrations for the Wairau Aquifer.

The $\delta^{18}O$ value of surface recharge is expected to depend on its composition (i.e. proportion of rainfall and irrigation water) as well as on the processes affecting it during infiltration (such as evaporation and preferential selection of winter rainfall with lower $\delta^{18}O$ values). The relative dryness of the Wairau Plain means that there is considerable scope for alteration of the $\delta^{18}O$ value during infiltration. If the mean δ_s is taken as more negative than -7.0‰ (e.g. because there is more irrigation water in the surface recharge) then the x values derived would be larger. On the other hand, if δ_s is taken as less negative then x values would be smaller. (Taylor et al. 1992, gave the value of -7.08‰ for plains rainfall-derived groundwater (Table 2).)

Well P28w/0662 is on the south side of the Wairau Aquifer, and the fact that it is semiconfined relates to the effect of the fan of the Omaka River Valley protruding from the south rather than to it being in the transition zone of the Wairau Aquifer. The $\delta^{18}O$ value (-7.82‰) suggests that the groundwater is sourced mainly from the south. P28w/3120 and P28w/4404 are both in the transition zone, and their $\delta^{18}O$ values give fractions of 38 and 26% of surface recharge respectively, similar to the fractions in the unconfined shallow aquifer to the west.

Of wells in the confined zone, P28w/4402 is on the border between the Wairau Aquifer and the Taylor-Burleigh & Riverlands Aquifer. Its $\delta^{18}O$ value (-7.61‰) indicates input of water from the latter aquifer. Well P28w/4403 has $\delta^{18}O$ value of -8.26‰, giving a fraction of 32%. This well appears to have the same mixture of recharge sources as wells P28w/3120 and 4404. All of these wells contain relatively young water, which has flowed through the upper layers of the Wairau Aquifer and gained surface recharge. Taylor et al. (1992) identified these as Groups A (unconfined) and B (young confined) groundwaters (Table 2).

The other confined wells are part of the group identified by Taylor et al. (1992) as Group C waters, which contain a proportion of older water from depth. These waters have had a deeper travel path (probably involving the Speargrass Formation) which has protected them from receiving surface recharge. Hence their $\delta^{18}O$ values are similar to Wairau River $\delta^{18}O$ (and their x values much less). P28w/3439 is located at Rarangi, but from the confined Wairau Aquifer not the unconfined Rarangi Aquifer. The $\delta^{18}O$ value gives a surface recharge fraction of 7%. Wells P28w/3447, 1733 and 0708 have fractions in the range 0-13%. Although consistent with low surface recharge, the very low nitrate-N concentrations are also likely to have been affected by reducing conditions in the deep aquifers and near the coast.

Well P28w/3278 is from a different deeper aquifer, with water which is much older and quite disconnected from the overlying aquifers. Carbon-14 measurements have established the pre-Holocene age of this water (Taylor 2004).

Southern Valley Aquifers
Most of the tributary aquifer systems lie on the south side of the Wairau Plain. They are important for supplying water for local cropping (horticultural, vinicultural and agrarian). The $\delta^{18}O$ data (with a range of -7.65 to -8.34‰) indicate that groundwater recharge is from local streams and surface recharge. There is quite a number of individual valley systems with not much variation in $\delta^{18}O$ between them, so the limited $\delta^{18}O$ data does not give detailed information on the systems.

Northern Valley and Rarangi Aquifers
The Tuamarina and Rarangi Aquifer waters are derived from rainfall on the coastal northern hills and Wairau Plain. The results show that the mean $\delta^{18}O$ of rainfall in this area is about -6.2‰ (the mean of the six samples is -6.24 ± 0.12‰). Rainfall further inland and at higher altitudes is expected to have more negative $\delta^{18}O$ values.

Other aquifers
Insufficient information is available to discuss these values.

4.0 DISCUSSION

Continuing geochemical and modelling studies of alluvial plains in New Zealand have shown that rivers are usually major sources of water to groundwater systems in the plains, particularly at deep levels, and that land surface-derived recharge plays an increasing role with distance from the seepage zones of the rivers (Taylor et al. 1989, Stewart et al. 2002, Bidwell 2005). Interfaces can often develop in these aquifers between river-derived water underneath and land surface-derived water on top. Figure 3 illustrates this 2-tier system for the Central Canterbury Plains aquifer (Bidwell 2005). Groundwater wells can draw from either or both of these layers depending on the position of the well screen relative to the groundwater layers. If both layers are being accessed, the $\delta^{18}O$ values and nitrate concentrations will be intermediate between those of the two layers.

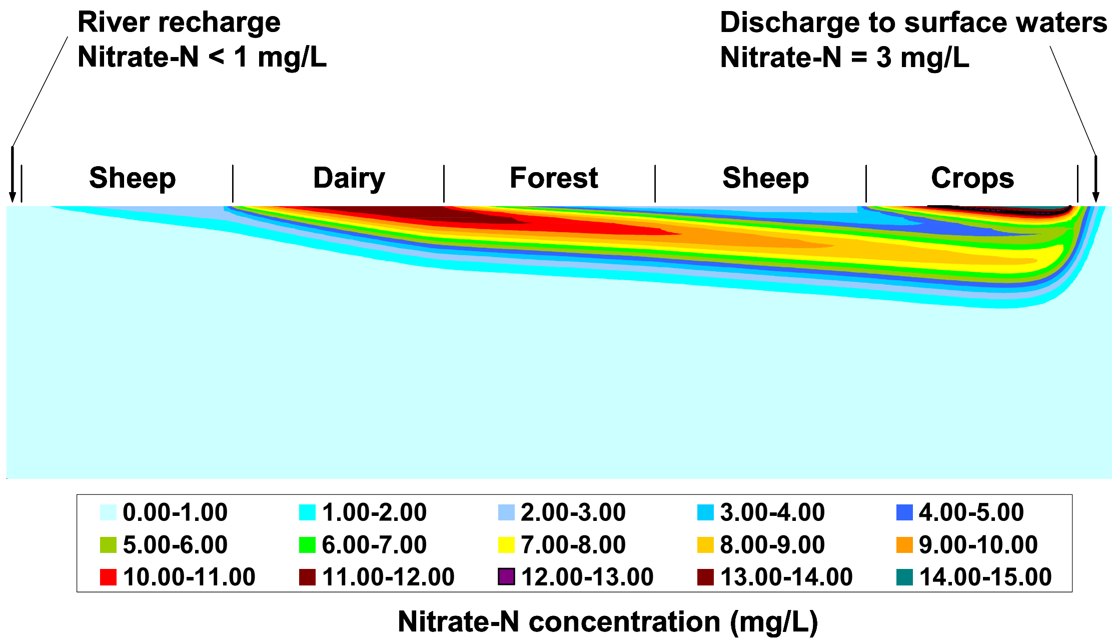

Figure 3. Conceptual figure illustrating the separation of river-derived and land surface-derived waters in alluvial plains by means of their nitrate-N concentrations. (Figure from Bidwell, 2005.)

Canterbury Plains has about 500 m of permeable gravel, whereas the Wairau Plains only has about 30-90 m. In addition, nitrate is persistent in Canterbury aquifers because of oxidising conditions, whereas it is more prone to denitrification at deep levels and near the coast at Wairau. Nevertheless, similar processes are likely to be operating, as shown by the present $\delta^{18}O$ values, the relationship shown in Fig. 2. However, the probable variability of the ^{18}O data in time, particularly for wells near the river, is likely to cause problems with determination of the surface recharge fraction (x). Hence it is recommended that some key wells be resampled at 3-monthly intervals for about two years to derive reliable average values. Key wells would include the following 4 MDC (M) and 4 NGMP (N) wells: P28w/0398 (N), 4118 (M), 3009 (N), 3120 (N), 4404 (M), 4403 (M), 1733 (N), 0708 (M). Fewer samples would be required for P28w/1733 and 0708 because these are not expected to vary much.

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