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Attention: Zeb Etheridge

Dear Zeb

Tritium results and residence time interpretations for spring-fed streams in the Waimakariri Water Management Zone

This report has been prepared as part of a collaborative project between GNS Science and Environment Canterbury aimed at contributing towards an understanding of nitrogen loads from groundwater reaching spring-fed streams in the Waimakariri Water Management Zone (WMZ). The report presents the results of laboratory analyses of tritium concentrations in samples from nine spring-fed stream, drain and river sites in the Waimakariri WMZ (Table 1), and provides an interpretation of mean residence times (MRT) for water in the streams (Table 2). A comparison of MRT of groundwater from previously sampled nearby wells is included. Site locations are shown in Figure 1.

Springs and spring-fed streams are assumed to integrate flow paths from a large catchment area resulting in a wide range of travel times for water reaching the sampling point, with the majority of the water being of a younger age. Manga (2001) has suggested the well-mixed model, also known as the exponential model (EM), as being an appropriate model to describe the residence time distribution of water emanating from springs. However, as the samples in this study were collected during a time of low-flow conditions, water with the youngest residence times in the aquifer, i.e., near zero, is not expected to be present (Morgenstern et al., 2010). Therefore, to calculate the mean residence times (MRT), an exponential piston flow model (EPM) with 80% exponential flow (20% piston flow) has been used (Table 2). In essence, the EPM is an EM delayed by a period of time, defined by the amount of piston flow assumed in the system (Maloszewski and Zuber, 1982). It should be noted that the EM and EPM are idealised residence time distributions for a catchment. In reality, the residence time distribution would not be as smooth as that represented by the models, due to varying flow contributions from different parts of the drainage system, with accompanying different residence times, as well as other factors such as the size and geology of the catchment and prevailing weather patterns.

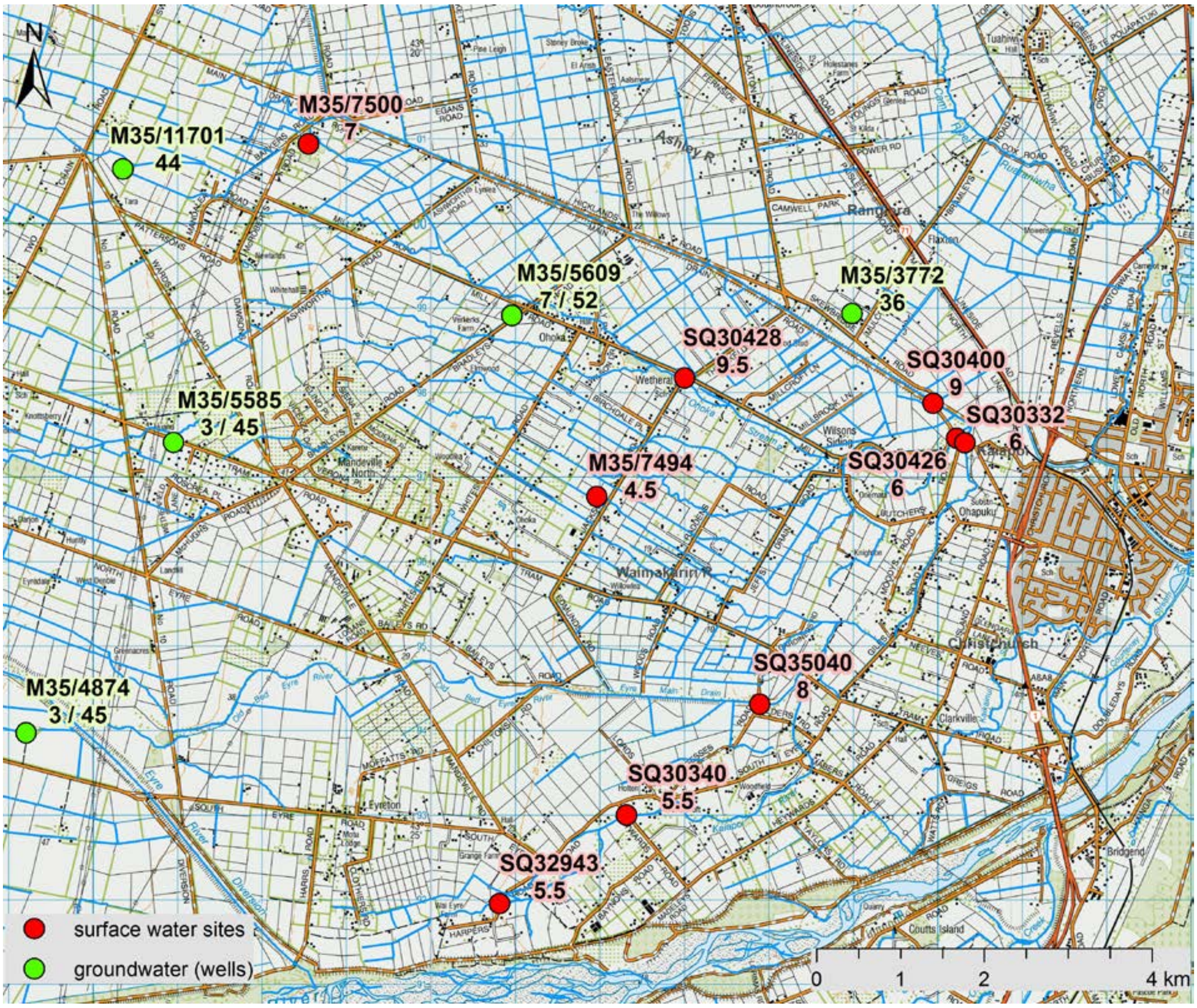

Figure 1 Map showing location and MRT (years) of sampled surface water sites and nearby wells.

Table 1 Site details and measured tritium concentration.

Site ID	Site name	E	N [1]	Tritium TR [2]	± 1SD TR
SQ32943	Silverstream @ Harpers Rd	1564806	5191960	1.709	0.032
SQ30340	Kaiapoi River @ Heywards Rd	1566309	5193008	1.731	0.032
SQ30426	Ohoka River @ Island Rd	1570219	5197464	1.687	0.036
SQ30332	Kaiapoi River @ Island Rd	1570316	5197412	1.685	0.033
SQ30400	Cust River @ Skewbridge Rd	1569938	5197879	1.528	0.028
M35/7494	Ohoka Stream tile drain – Dalleys Weir	1565959	5196778	1.814	0.035
SQ30428	Ohoka River @ Jacksons Rd	1567000	5198181	1.489	0.031
M35/7500	Ohoka River tile drain	1562542	5200950	1.603	0.038
SQ35040	Eyre Main Drain	1567890	5194322	1.572	0.033

1. Coordinates are NZTM

2. Tritium concentrations are expressed as $^{3}H:^{1}H$ ratios, where 1 tritium unit (TR) signifies a ratio of $1:1\times10^{18}$.

Table 2 Mean residence times.

Site name	EPM mean residence time (years)	EPM Uncertainty range for mean residence time[1] (years)
Silverstream @ Harpers Rd	5.5	4.5 – 6.5
Kaiapoi River @ Heywards Rd	5.5	4.5 – 6.5
Ohoka River @ Island Rd	6	5 – 7
Kaiapoi River @ Island Rd	6	5 – 7
Cust River @ Skewbridge Rd	9	8 – 10
Ohoka Stream tile drain – Dalleys Weir	4.5	3.5 – 5.5
Ohoka River @ Jacksons Rd	9.5	8.5 – 11
Ohoka River tile drain	7	6 – 9
Eyre Main Drain	8	7 – 9

1. The stated model age ranges result from the 95% confidence interval based on the uncertainty in analytical measurements only and do not account for the uncertainty in model selection.

The calculated MRT for the nine sites range from 4.5 years to 9.5 years. Previous measurements of the two tile drains M35/7494 and M35/7500, taken in 2012 (van der Raaij, 2013), combined with the recent measurements, indicate that proportions of exponential flow above 70% are appropriate for these sites. Varying the exponential flow component between 70% and 90 % has no significant effect on calculated MRT for both these sites and the other sites. At 100% exponential flow, i.e., the EM, MRTs are approximately 0.5 years older than reported in Table 2. Note that under the EPM (and EM), roughly 68% of the total flow has a residence time younger then the MRT.

Previous work by Morgenstern et al. (2010) has shown that the age distribution of stream baseflow, and therefore the MRT of the water, varies continuously with flow rate. Morgenstern et al. (2010) reported older MRTs in stream baseflow at lower flow rates. Because it is not presently known if the streams and springs sampled in the present investigation display a similar variation of MRT with flow rate, the MRT values reported in Table 2 should be considered conditional of the flow rate at the time of sampling.

Figure 2 shows the residence time distributions of three of the sites at the time of sampling. The Eyre Main Drain and the Kaiapoi River at Heywards Road are presented as components of the total flow of the Kaiapoi River measured at Island Road, based on flow data provided by Environment Canterbury. The Kaiapoi River at Heywards Road has an MRT of 5.5 years, while the Eyre Main Drain has a slightly older MRT of 8 years. Overall, water reaching the Island Road sampling site has an MRT of 6 years. By removing the flow contributions of the Kaiapoi River at Heywards Road and the Eyre Main Drain, we find that other contributions to the flow at Island Road also have a MRT of 6 years.

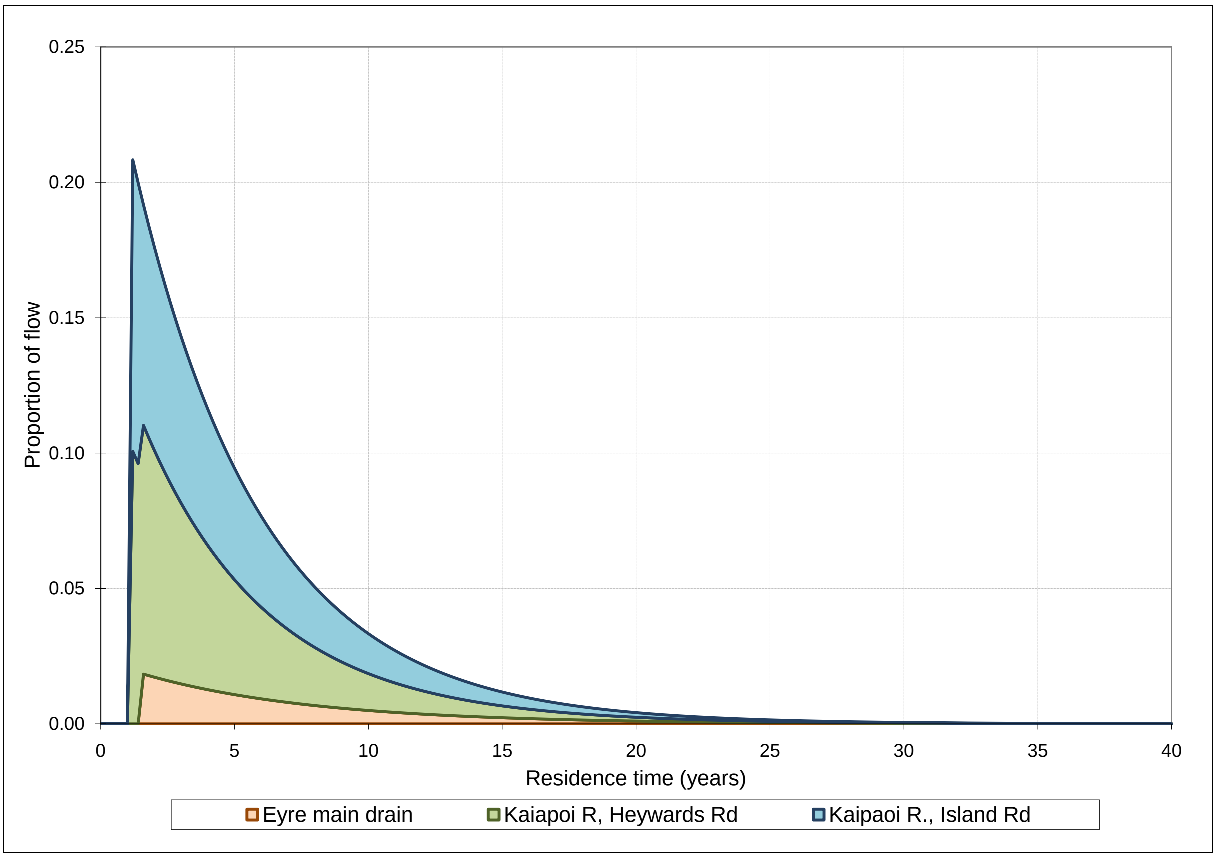

Figure 2 Residence time distribution of the Kaiapoi River at Island Road and contributions of sampled sub-catchments, using an EPM with 80% exponential flow. The area under the curve encompasses the entire flow volume at the sampling site, while the y-axis indicates the proportion of the total flow volume which has any specific age.

Similarly, the Ohoka River at Jacksons Rd has an MRT of 9.5 years, while at Island Road the MRT has decreased to 6 years. By removing the flow contribution of the Ohoka River at Jacksons Road, we find that other contributions to the flow at Island Road have an MRT of 5.5 years.

Upwards hydraulic gradients, observed by Etheridge (2016), imply that deeper inland groundwater could contribute to the flow and water quality of the streams sampled in this study. With this in mind, the MRT of several nearby wells was examined (Figure 1). Wells M35/3772, M35/4874, M35/5585 and M35/5609 have depths of 16 m to 23 m, while well M35/11701 is deeper at 59 m. Well M35/3772, sampled in 1985, had a tritium concentration indicating an MRT of 36 years at 40% exponential flow (van der Raaij, 2011). Well M35/11701, sampled in 2006 and 2010, had tritium and gas tracer (CFC and SF_6) concentrations indicating an MRT of 44 years at 32% exponential flow. Given the MRT of groundwater at these two wells, it seems unlikely that groundwater from these depths and locations contributes a significant proportion of the flow in the sampled streams.

The remaining three wells, all sampled in 2010, had tritium concentrations which are ambiguous, and could indicate either younger (MRT 3 to 7 years) or older (MRT 45 to 52 years) water. The possibility of groundwater at these shallow depths contributing to the flow of the sampled streams depends on the MRT. If the younger MRTs are correct, then contributions to the stream flow from groundwater at these depths and locations are possible; if the older MRTs are correct, then flow contributions would be minimal or unlikely. The ambiguity in the tritium data might be resolved by resampling of these wells.

SUMMARY

MRT for the nine surface water sites range from 4.5 years to 9.5 years under an EPM with 80% exponential flow. Unsampled contributions of flow to the downstream sites at Island Road for the Kaiapoi and Ohoka Rivers appear to have an MRT of about 6 years. Groundwater contributions to the flow from nearby wells cannot currently be qualified on the basis of groundwater MRT.

The water age interpretations provide information that can be used by Environment Canterbury to gain a better understanding of the time-lags of nitrogen loads from groundwater reaching spring-fed streams in the Waimakariri Water Management Zone**.**

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Yours sincerely

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