Recharge Processes in the Lower Portneuf River Valley Watershed

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ABSTRACT

In the lower Portneuf River Valley (LPRV), the Mink Creek and Gibson Jack watersheds are part of a ground water recharge corridor that supplies more than 80% of the annual recharge to the municipal aquifer system (Welhan, 2006). These watersheds also contain the majority of the more than 600 septic drain fields that contribute more than six metric tons of nitrate-nitrogen annually to the LPRV aquifer (Meehan, 2004). Past water sampling focused on ground water quality, so information on recharge sources, flow rates and flow paths within this vital recharge corridor has been unavailable until now.

In April and July, 2014, eight private water wells in this area (Figure 1) were sampled for ^{3}H, ^{14}C and stable isotopes to determine whether ground water residence times within the recharge corridor can be estimated. Sampling focused on bedrock wells deeper than 100 meters that should be minimally impacted by septic leachate: five, in the least-developed watersheds areas (representing flow systems ca. 5 to 7 km in length), and three wells in the watersheds' discharge zone (ca. 10 - 12 km flow path).

Results suggest that locally recharged ground water in these watersheds has a mean residence time of the order of < 200 to 2000 years (Figure 3), although these estimates are, at best, tentative. Such residence times indicate mean linear groundwater flow rates from the nearest recharge zone could exceed 50 meters/year. This is within the range of flow rates expected in upland fractured crystalline and carbonate bedrock but very shortest residence times could point to the involvement of known paleokarst units in the upland areas.

More importantly, the LPRV's conceptual recharge model may need to be revised if the temperature and ^{2}H / ^{18}O isotope data have been interpreted correctly: Locally recharged meteoric water (estimated at ca. 8 °C) derived from local snowpack) appears to mix with thermal water (ca. 25 °C) reflecting deep, regional-scale flow from distant (and/or fossil) recharge sources. This thermal component, postulated to rise along bedrock faults within the LPRV watershed, severely limits our ability to interpret ^{14}C in terms of ground water residence times.

The most significant result of this study is the finding that non-local recharge sources contribute to the LPRV aquifer system. If corroborated, ground water temperature variations in the LPRV will need to be evaluated to determine whether non-local recharge is volumetrically important to the aquifer's water balance and management of the municipal water supply.

GEOHYDROLOGIC SETTING

The study area is located in the lowermost part of the Mink and Gibson Jack Creek watersheds (Figure 1), situated over the LPRV aquifer system's most important recharge corridor. Previous work has shown that the area is heavily impacted by septic leachate, characterized by Cl and SO_4 enrichments (Figure 2).

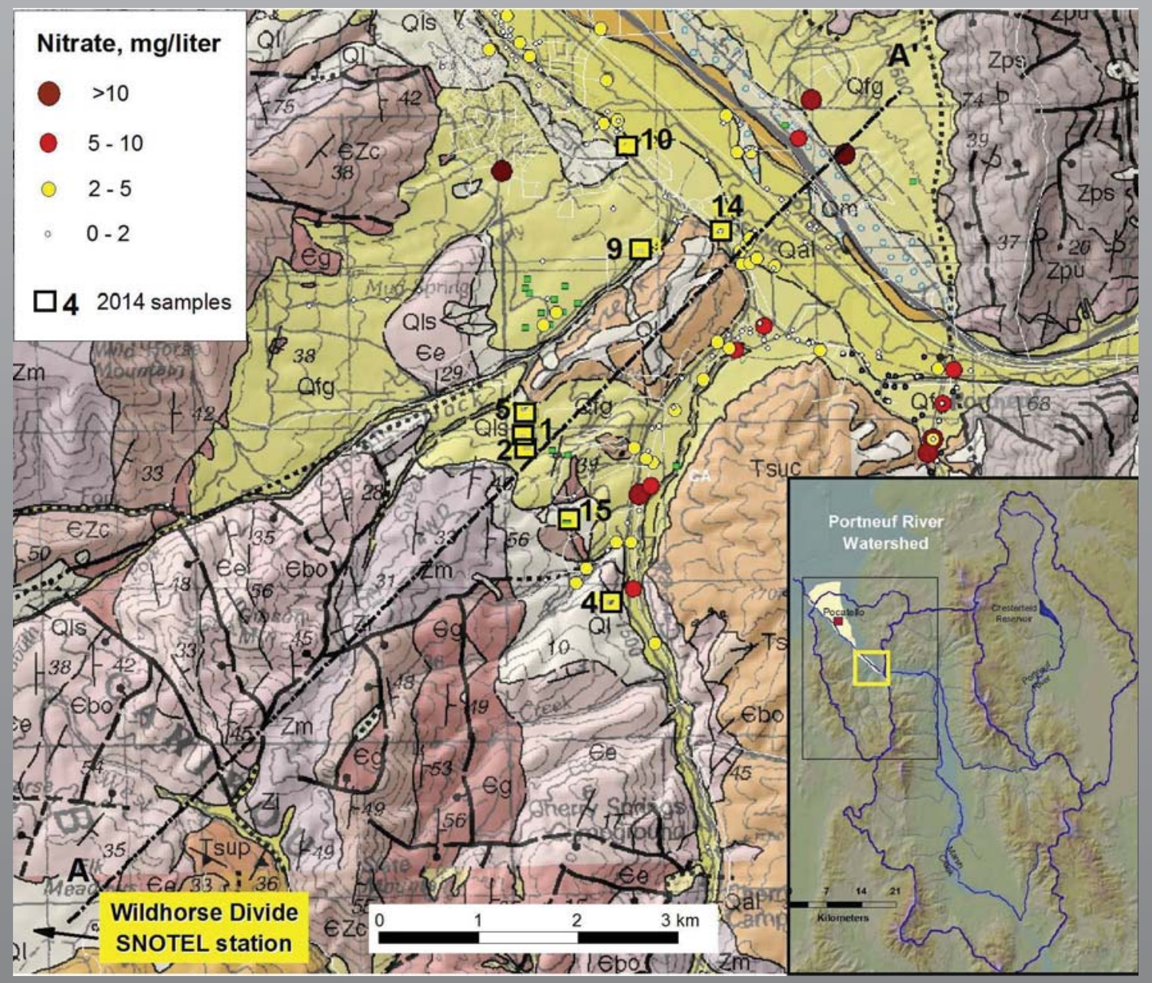

Figure 1 – Study area showing 2014 sample locations, geologic units and historic septic-derived nitrate impacts (Meehan, 2004). Nearest recharge area is the Wild Horse Divide / Elk Meadows basin, ca. 10 km SW of the municipal aquifer. Presumed ground water flow direction is to the north.

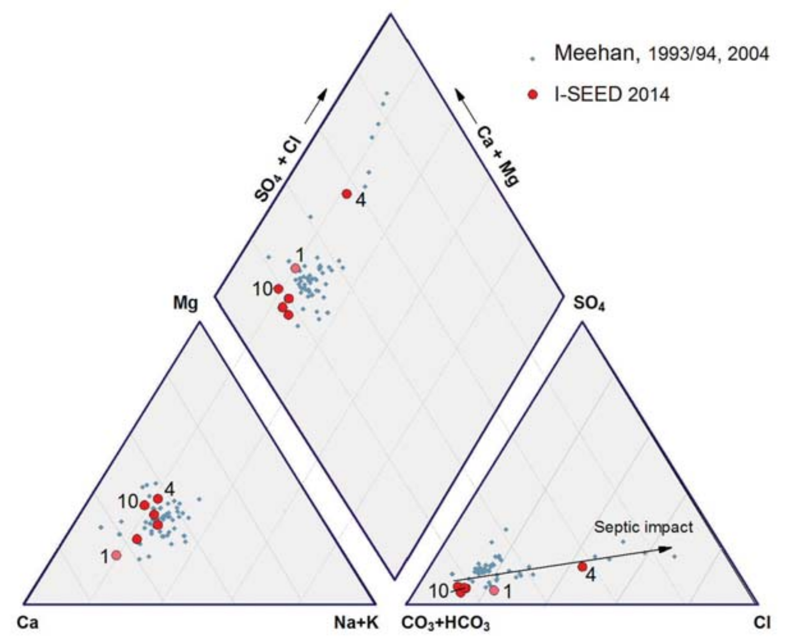

Figure 2 – Major ion composition of some of the 2014 samples (red) relative to data from Meehan (2004), in blue.

INTERPRETATION OF RESULTS

Sampling sites for this study were selected to minimize septic influence, but only three of eight wells proved to be free of septic influence (i.e., < 0.2 mg/l NO_3-N) and could be evaluated for approximate ^{14}C "ages" (Figure 3).

Figure 4 summarizes stable isotope tracer data on precipitation and shallow ground water in the watershed (IGS, unpublished data). The 2014 well water samples revealed a surprisingly large range of correlated isotopic variability that cannot be due solely to seasonal temperature or elevation differences among local recharge areas and therefore must reflect mixing with ground water from outside the watershed.

Figure 5 shows that most sampled wells have surprisingly warm temperatures. Waters that are strongly influenced by septic leachate appear to have T > ambient (ca. 8 °C), and at least one mixing relationship with a thermal component is suggested. The hypothesized mixing relationship was tested with an iterative two-component mixing analysis which indicated that T-^{18}O and other ionic relationships (Figure 6) are consistent with mixing of a local, dilute component and a thermal water whose DIC is -14.7 ‰ (Figure 7).

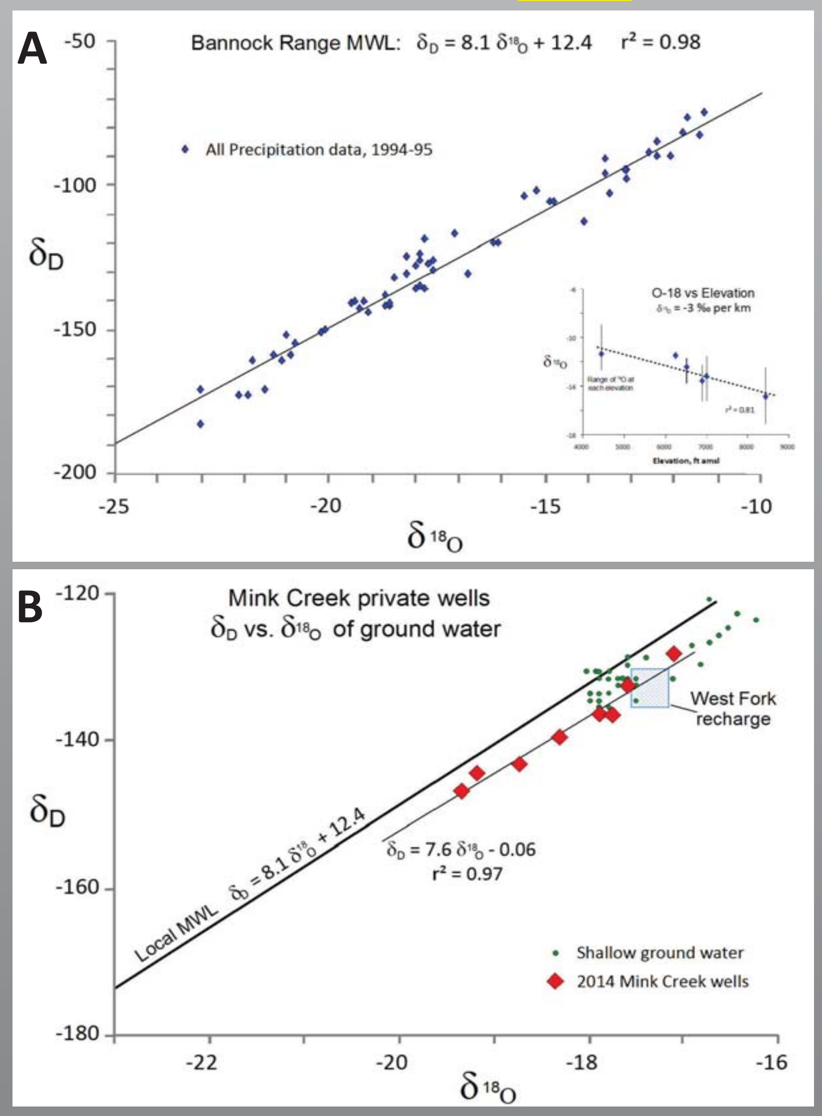

Figure 4 – Available stable isotope data for precipitation (A) and ground water (B) in the study area. Shallow ground water samples in (B) were collected ~600 m (2000 ft) higher in elevation than the 2014 well waters in the lower Mink Creek drainage.

Maximum Age

Sample	Tritium, TU	^{3}H age	$\delta^{13}C$, ‰	^{14}C, pmc	Corr'd ^{14}C Age, years $\delta^{13}C_{LS}$ = 0	+4
1	< 1.00	> 50	-13.4	83.6	(septic influence?)	
2	< 1.00	> 50	-11.1	47.2	-	-
4	1.05	(65)	-9.2	43.7	(^{3}H "age" ~ 65 yrs)	
5	< 1.00	> 50	-10.9	29.3	120	2400
9	< 1.00	> 50	-11.8	32.3	60	500
10	< 1.00	> 50	-8.9	31.2	100	1100
14	n.a.	-	-11.5	78.0	-	-
15	n.a.	-	-12.8	62.4	-	-

Figure 3 – Radioisotope data and best estimates ground water residence times, based on a Pearson-type correction for a thermal water component.

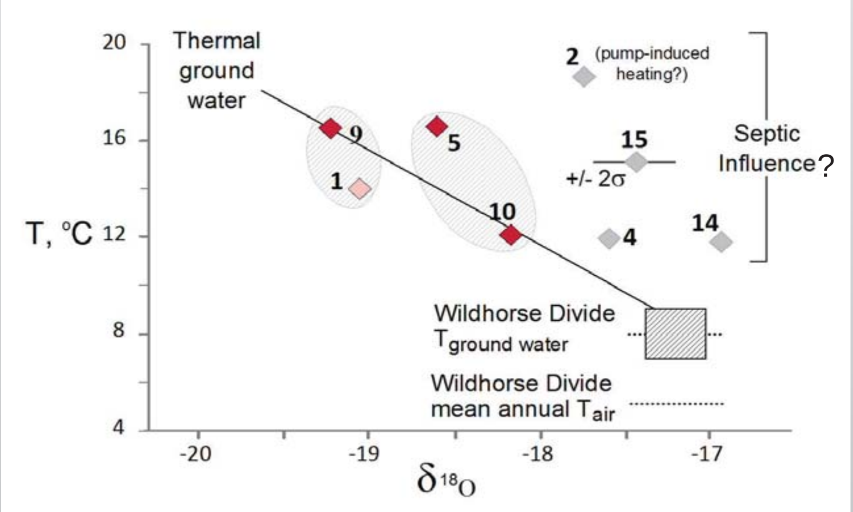

Figure 5 – Temperature variations relative to ^{18}O are assumed to reflect mixing of local ground water recharged at Wild Horse Divide (ca. 8 °C) and a warm, isotopically light ground water. A two-component mixing analysis explains the observed ionic variations in Figure 6 and constrains the thermal component's T at approximately 24 ± 3 °C (Figure 7).

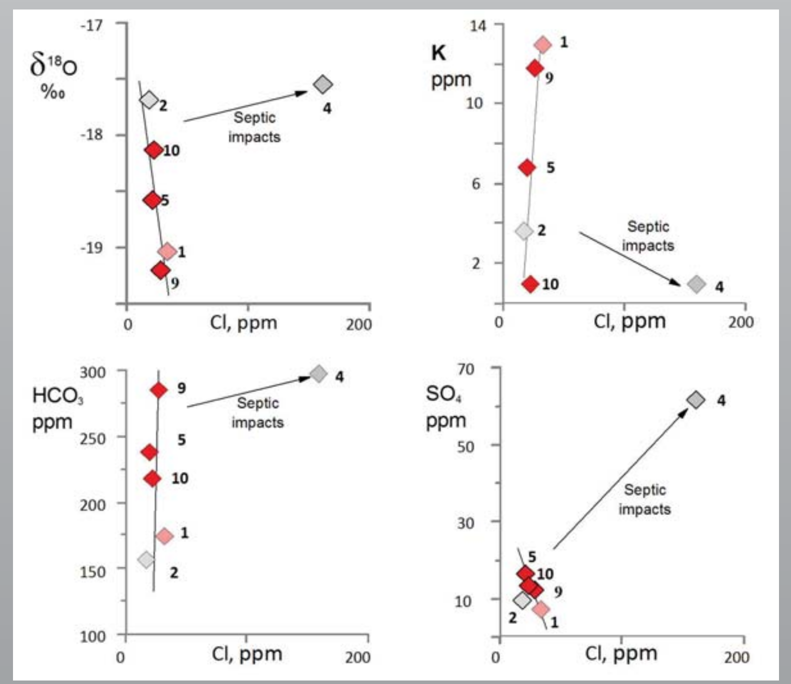

Figure 6 – Examples of correlated chemical variations in samples that are least affected by septic effluent. As in previous sampling of the Mink Creek area (Meehan, 2004), strong Cl and SO_4 enrichments characterize ground waters that are impacted by septic contamination (Figure 2).

		Local Recharge	Deep Recharge	
$\delta^{18}O$, ‰		-17.1	-21.0	
T, °C		8.0	24	± 3
K	mg/l	0.4	19	1
Ba	mg/l	0.1	0.5	.1
Fe	mg/l	0.8	3.6	.5
SO_4	mg/l	27.0	0.0	0
Cl	mg/l	19.0	36	6
DIC	mg/l	130.0	288	15
$\delta^{13}C$, ‰		-8.8	-14.7	.3

Figure 7 – Results of two-component mixing analysis on samples # 5, 9 and 10, which do not show any septic influence (i.e., NO_3-N < 0.2 mg/l), and sample # 1, which is minimally impacted (NO_3-N = 1.1 mg/).

DISCUSSION

Approximate ^{14}C corrections were developed for the three samples with NO_3-N < 0.2 mg/l based on the mixing fraction of the high- dissolved inorganic carbon (DIC) thermal end-member determined in Figure 7. A fourth sample, with ^{3}H activity just above detection, indicates a mean residence time of approximately 60-70 years in septic-impacted water.

The corrected ^{14}C mean residence times for a range of possible ^{13}C compositions of Cambrian and Proterozoic carbonates in the study area represent maximum estimates because the dilution correction for the thermal DIC source (assumed to be ^{14}C-dead) provides an estimate of ^{14}C activity in local DIC prior to mixing, but this DIC is itself a mixture of soil zone and carbonate-derived DIC within the local flow system, for which an independent correction cannot be derived.

These tentative ^{14}C residence time estimates suggest that local ground water flow rates in the Mink Creek watershed may greatly exceed 50 meters / year depending on the dilution fraction of locally derived carbonate DIC and the ^{13}C composition of these carbonates. If corroborated, such high ground water flow rates could implicate paleokarst units in the uplands area of the watershed.

Figure 8 shows all available ground water temperature data in the study area (Meehan, 2004) and Figure 9 depicts hypothetical ground water flow paths that could explain the spatial distribution of elevated temperatures. The possibility that water from as deep as 1 km rises along bedrock faults and unconformities in the Mink and Gibson Jack Creek watersheds begs the question of whether it represents a significant source of recharge to the LPRV aquifer and the municipal water-supply system.

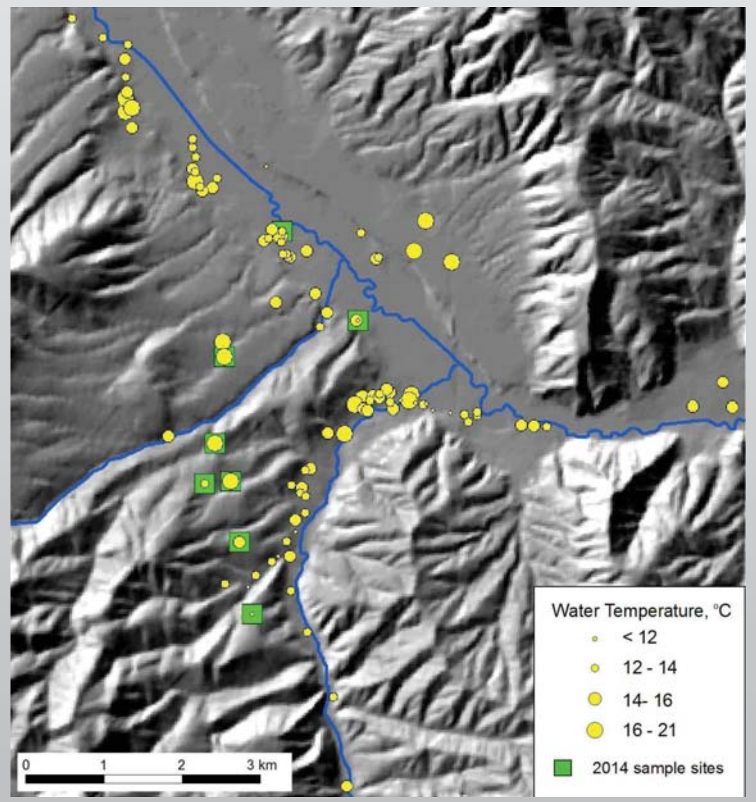

Figure 8 – All available temperature data showing spatial distribution of warm well water in the study area.

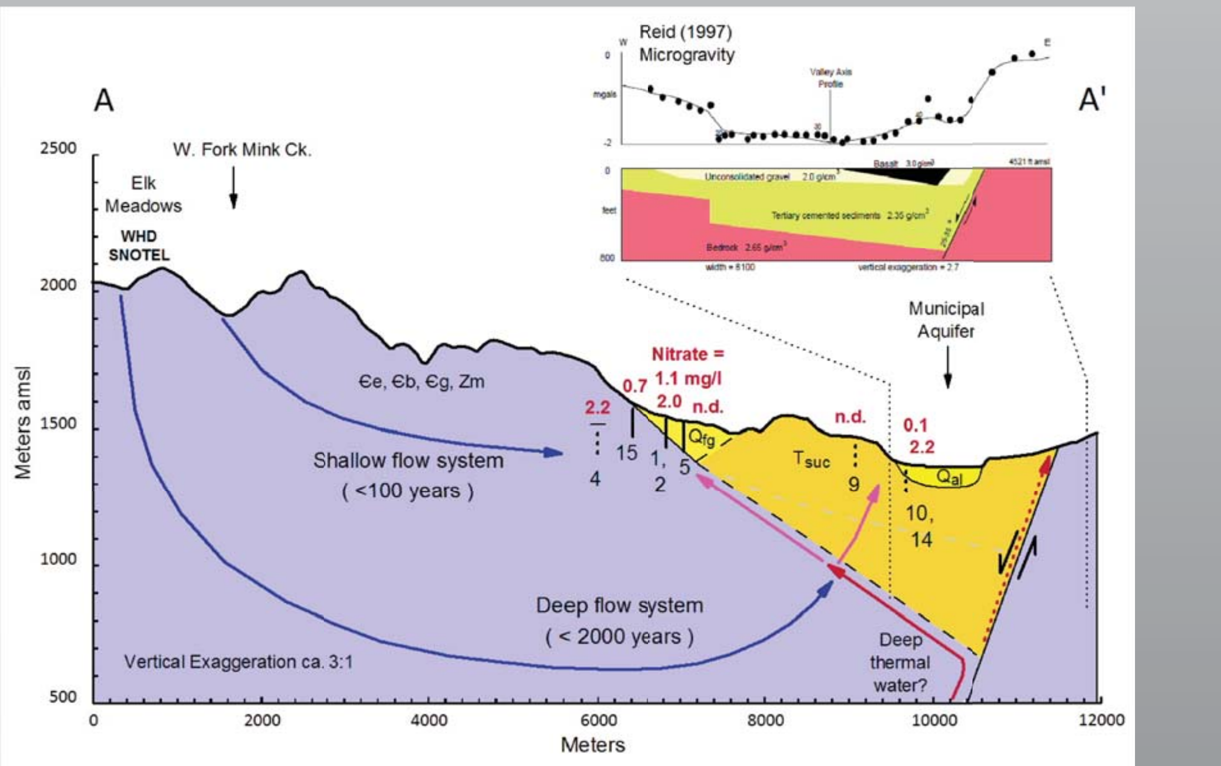

Figure 9 – Subsurface hydrogeology along cross section A-A' (Figure 1) as constrained by the modeled bedrock geometry and Tertiary basin fill after Reid's (1997). Possible deep thermal water and local meteoric water flow paths are indicated with colored arrows. Sampled wells and depths are plotted to scale.

CONCLUSIONS

The outcomes of this study are by no means conclusive, the results being dependent on various assumptions, hypotheses and minimally constrained interpretations. Chief among these is the source of warm water observed in many of the sampled wells in this and previous studies. If warm ground water enters the local flow system from the graben-bounding fault east of the LPRV (where thermal wells are known to occur), then future ^{14}C dating is not recommended. However, if the residence time estimates determined in this study prove to be reasonably accurate, it suggests that snowpack-derived recharge may travel quite rapidly from the uplands, possibly through upland paleokarst bedrock units.