Using stable isotopes of well water to assess contamination vulnerability in a karst aquifer, Kewaunee County, Wisconsin, USA

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Abstract

Ground water contamination has been a long-standing problem in rural northeastern Wisconsin, especially in areas with thin soils over karsted Silurian dolostone bedrock. In some counties, 20-35% of the wells exceed health standards for nitrates and/or coliform bacteria presence. One limitation of testing for bacteria and viruses is their episodic presence in well water. Here we present the results of a high-resolution time series technique using stable isotopes of oxygen and hydrogen in well water to assess well vulnerability to surface contamination from rapid recharge.

Homeowners self collected water samples from four private wells between March and October of 2015. Sampling occurred at least once per week, with more frequent sampling after large recharge events. Three wells had prior histories of contamination and vary in total depth from 74 to 240 feet, with depth to bedrock ranging from 5 feet to 42 feet. A control well with no prior record of contamination had a total depth of 364 feet, with a depth to bedrock of 79 feet. Preliminary results show average δD values ranging from -68.15‰ to -74.55‰, with average $\delta^{18}O$ values ranged from -10.06‰ to -10.80‰. Average deuterium excess (d) values ranged from 11.8 to 12.6, with the shallowest well containing the lowest d value.

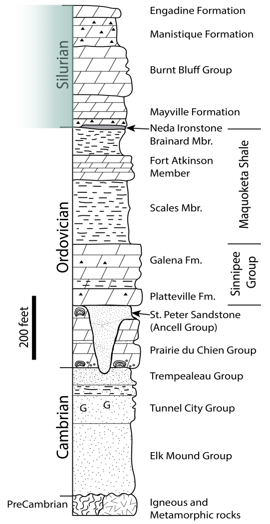
Well depth and average isotopic composition were strongly correlated ($R^2 \geq 0.88$), but a geographic influence was not ruled out. Deuterium excess did not show a strong correlation with well depth. The shallowest well had a higher standard deviation for δD and $\delta^{18}O$ than the deeper wells ($\sigma = 1.39$ vs. $\sigma = 0.31$ to 0.42). All wells showed some isotopic variation during the sampling period, but the shallowest well showed the largest responses to recharge events. A negative isotopic response occurred during the first spring melt of a thin snowpack during early March 2015 and smaller positive isotopic responses occurred after heavy rain events during summer months. As expected, the largest isotopic response occurred when the isotopic composition of recharge water was farthest from that of the average groundwater (i.e., snow melt). The shallowest well, with the shortest casing and thinnest soils showed the largest water isotope variation, suggesting the shortest travel time from surface to well. This lends support to the utility of this technique in identifying potentially vulnerable wells in karst systems.

Introduction

Ground water contamination has been a long-standing problem in rural northeastern Wisconsin, especially in areas with thin soils over karsted Silurian dolostone bedrock.

The majority of residents in Kewaunee County are dependent on private wells open to the unconfined aquifer in the Silurian strata. Stable isotopes has been used in regions with similar geology as is seen here to determine the sources of groundwater (Delbart et al. 2014, Lakey and Krothe 1996, Petrella and Celico 2013). This method has not been applied to domestic well water analysis at high temporal resolution.

An isotopic signature pattern consistent with episodic precipitation and melting events would indicate rapid recharge from surface to groundwater. Here, we present the results of a high-resolution time series technique using stable isotopes of oxygen and hydrogen in well water to assess well vulnerability to surface contamination from rapid recharge.

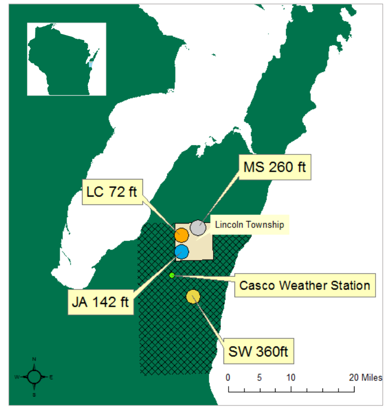


Methods

Four homeowners collected water samples in plastic bottles from their private wells beginning in March 2015. Owners were instructed to expel all air from the bottles prior to replacing the caps. Bottles were stored with electrical tape encasing the caps in order to prevent post-collection evaporation for follow-up or duplicate analyses.

Collection occurred at least once per week, with more frequent sampling after large groundwater recharge events. Sampling is ongoing. Samples were sent to University of Washington IsoLab for stable isotope analysis (δ18O and δD).

Wells sampled include three with prior histories of contamination and vary in total depth from 74 to 240 feet, with depth to bedrock ranging from 5 feet to 42 feet. A control well with no prior record of contamination had a total depth of 364 feet, with a depth to bedrock of 79 feet.



Results

Preliminary results show average δD values ranging from -68.15‰ to -74.55‰, with average $\delta^{18}O$ values ranging from -10.06‰ to -10.80‰. Average deuterium excess values ranged from 11.8 to 12.6‰, with the shallowest well containing the lowest value.

As expected, the shallowest well showed the greatest variation in isotopic composition. The shallowest well had a higher standard deviation for δD and $\delta^{18}O$ than the deeper wells ($\sigma = 1.39$ vs. $\sigma = 0.31$ to 0.42).

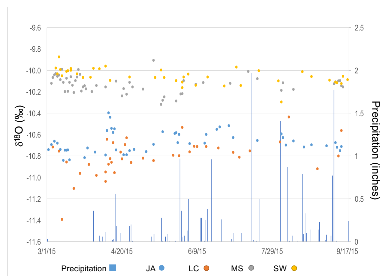
Well depth and average isotopic composition were strongly correlated ($R^2 \geq 0.88$) (Figure 6), but a geographic influence was not ruled out. Deuterium excess did not show a strong correlation with well depth.

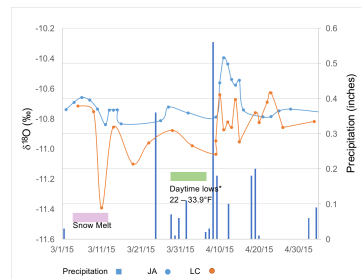
All wells showed some isotopic variation during the sampling period. However, the shallowest well showed the largest responses to recharge events. Negative isotopic responses occurred during the first spring melt of a thin snowpack during early March 2015 and one rain event while frost was in the ground (Figure 5). Smaller positive isotopic responses occurred after heavy rain events during summer months.

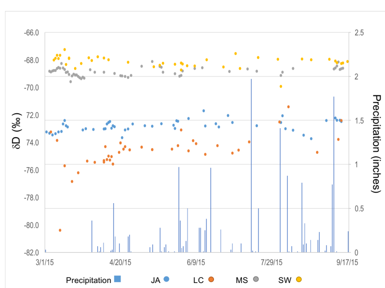
As expected, the largest isotopic response occurred when the isotopic composition of recharge water was farthest from that of the average groundwater (i.e., snow melt). The shallowest well also showed a response while frost may have been present when runoff is expected rather than infiltration. The second shallowest well show a smaller response to snow melt. The second event (rainfall with frost present) from March 29 to April 2 produced a positive response in both of the shallow wells.

Conclusion

The shallowest well, with the shortest casing and thinnest soils showed the largest isotope variation, suggesting the shortest travel time from surface to well. From data presented here, it appears that well depth and isotopic composition are highly correlated. However, geographic influences or lake-effect precipitation cannot be ruled out. Nevertheless, these results lend support to the utility of this technique in identifying potentially vulnerable wells in karst systems.







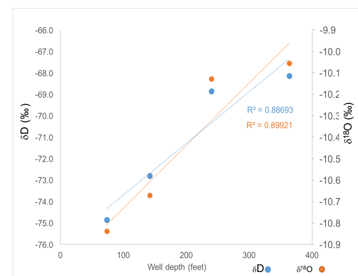


Figure 1 (top left): Stratigraphic column of northeastern Wisconsin (Luczaj 2013). All wells in this study are open to the Silurian strata (highlighted).
Figure 2 (top): Map of study wells. Depth of wells is listed with identification. Also shown the University of Michigan Automated Weather Network.
Figure 3 and 4 (above): Precipitation, δD and $\delta^{18}O$ plotted as time series. The two shallowest wells have an isotopic composition more similar than the two deeper wells despite geographic locations (see map). Values also appear to show responses in isotopic composition following large recharge events. *After April 1, 2015, the daytime low temperatures are generally well above freezing.

Figure 5 (top at left): Enlargement of March and April $\delta^{18}O$ values and precipitation events. Approximate periods of snow melt and higher than average daytime temperatures are highlighted. The changes in isotopic signatures of well water show large responses to snow melt (pink) and rainfall (green) on frozen ground.
Figure 6 (bottom at left): Graphic representation of the average δD and $\delta^{18}O$ vs. well depth. Isotopic composition appears to be highly correlated with well depth.

References

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Acknowledgements

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