Lake and Groundwater Interaction at Clear Lake in Clear Lake, Iowa

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1. Objective

The objective of this project was to understand lake/groundwater interaction at Clear Lake in Clear Lake, Iowa using a combination of stable isotopes of oxygen and hydrogen, hydraulic head measurements, tritium activities, and chloride concentration data in groundwater. In particular, we hypothesized that enriched $\delta^{18}O$ values in evaporated lake water could be used as a tracer into groundwater adjacent to the lake. The results provide evidence that isotope data can be useful in groundwater/lake interaction studies, specifically to define areas of groundwater inflow and outflow.

2. Methods

Simpkins (2006) installed 33 monitoring well nests at 11 well nests around the lake (Figure 1). At each nest, wells were installed at 5, 15, and 30 ft. Those wells were used to obtain water samples and hydraulic head measurements from the groundwater (and lake) in June and November of 2012 and in May and October of 2013. Stable isotope ($\delta^{18}O$, $\delta^{2}H$) samples were analyzed on a Picarro L1102-i isotopic liquid water analyzer in the Dept. of Geological and Atmospheric Sciences (SIPERG). Results were reported in standard delta notation in per mil. Cl concentrations were determined using a Hach Chloride Test Kit model 8-P (range: 5-400mg/L). Hydraulic head measurements were made using an electric water-level tape and recorded to the nearest 0.01 ft. Tritium and hydraulic conductivity data were taken from Simpkins (2006). Hydraulic gradients were calculated and used to estimate average linear velocities and groundwater residence times. Data ($\delta^{18}O$, $\delta^{2}H$) were plotted on a Local Meteoric Water Line (Simpkins, unpublished).

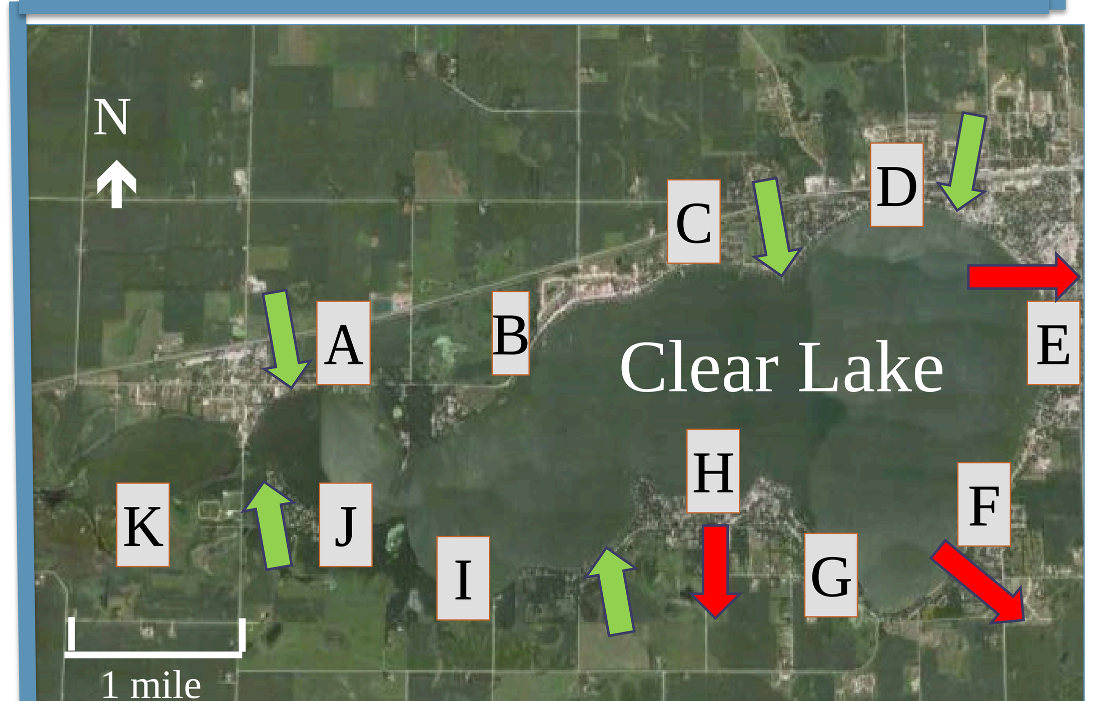

Figure 1: Monitoring well nest locations. Arrows indicate groundwater flow direction.

3. Results

Isotope Data

The Local Meteoric Water Line (LMWL; Figure 2) shows the isotopic composition of incoming precipitation, and lake water and groundwater originating from precipitation recharge. When lake water is exposed to sunlight and heat during the summer (or in a drought), lighter isotopes ^{16}O and ^{1}H are evaporated preferentially. With fewer light isotopes, the remaining lake water is enriched in ^{18}O and ^{2}H, causing isotopic composition of that water to show more positive $\delta^{18}O$ and $\delta^{2}H$ values and to plot on an evaporation trend line. Isotope values that plot along a slope between 4-6 indicate evaporated lake water or a mixture of lake water and groundwater.

Lake water sampled in summer/fall of 2012 during a drought deviates the most from the LMWL (green points on Figure 2). The lake samples from the summer/fall of 2013 which are representative of a more "normal" summer rainfall also align on the evaporation trend line, but are closer to the meteoric water line (orange points). In addition, groundwater samples from May 2013, which were heavily influenced by snow and rain recharge, plot very closely to the meteoric water line (blue points). Groundwater samples that plot along the evaporation trend line suggest they contain evaporated surface water. This implies that surface water is moving out of the lake and into the groundwater at these locations. Throughout the study, isotopic data show lake water entering the groundwater at well locations E, F, and H and groundwater entering the lake at all other locations (Figure 1). Therefore, with lake water flowing into the groundwater on the eastern side and groundwater entering the lake everywhere else, Clear Lake can be classified as a flow-through lake. Tritium data also show that groundwater under influence of surface water contains higher tritium concentrations than that influenced only by meteoric water with groundwater residence times greater than 55 years. Figures 3 and 4 show how lake water infiltration to groundwater varies with depth. In Figure 3, the $\delta^{18}O$ composition of the lake and shallow groundwater in well F5 is shown where lake water is exiting the lake, suggesting a direct relationship. In Figure 4, there is no relationship between the groundwater in well F30 and the lake water isotopes.

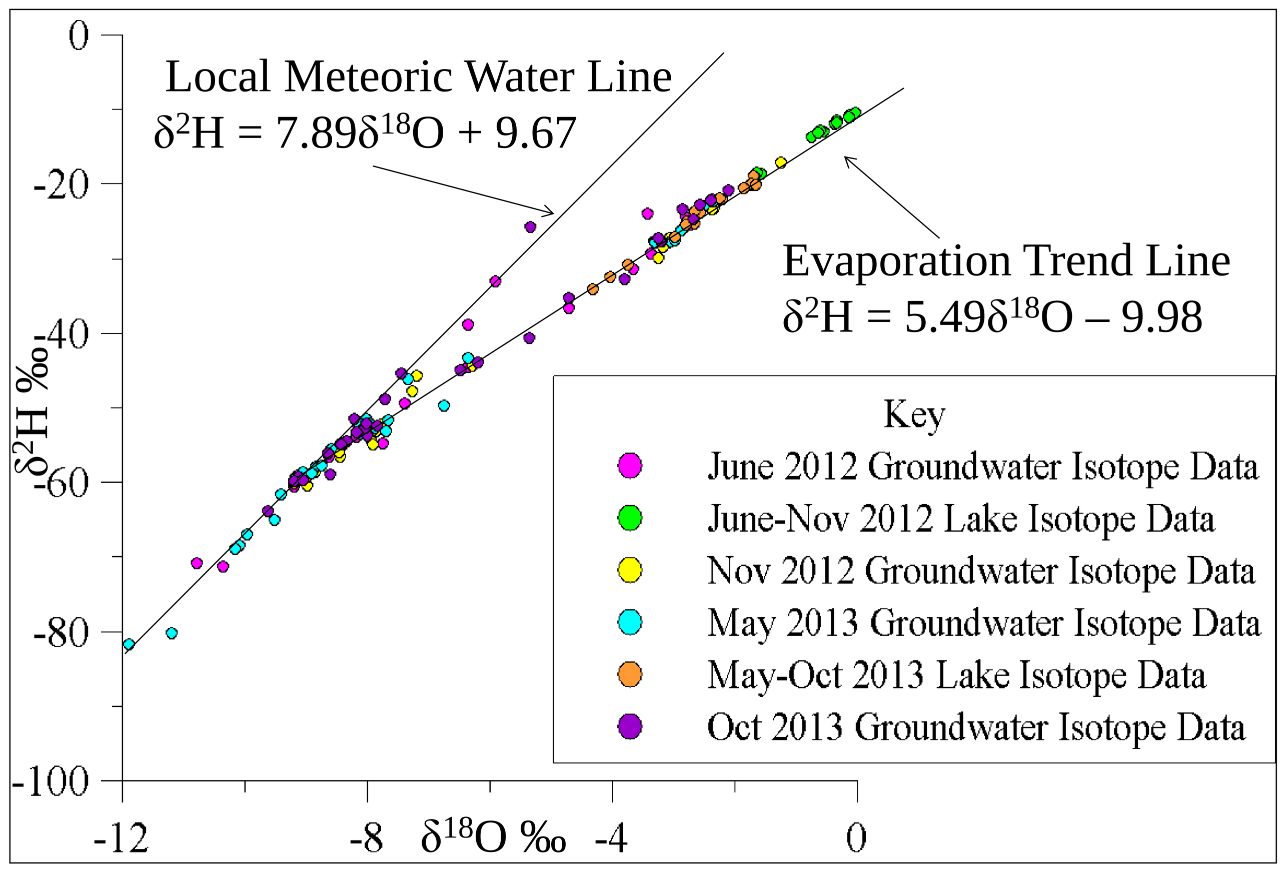

Figure 2: Isotope data from the study.

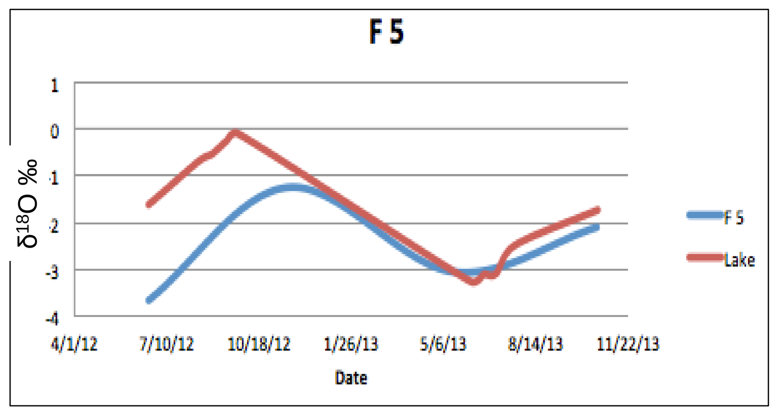

Figure 3: Groundwater (well F5) and lake isotope comparison.

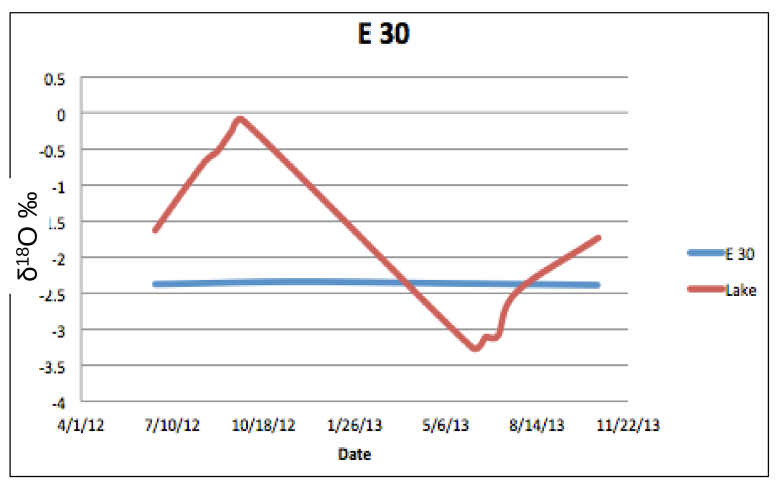

Figure 4: Groundwater (well E30) and lake isotope comparison.

Hydraulic Head Data

Table 1 shows the number of monitoring well sites where groundwater is flowing into the lake and where lake water is flowing into the groundwater. Each hydraulic head measurement was used to calculate the hydraulic gradient at the site, which was then utilized to calculate groundwater residence time. Table 2 shows the groundwater residence times in wells F5 and E30. The groundwater in F5 influenced by lake water recharge has a much shorter residence time than groundwater in E30 which is not influenced by the lake. Therefore, the groundwater in E30 is moving very slowly. Groundwater residence times also decrease when the aquifer/lake is being recharged by snow or rain, as evidenced by the May 2013 values.

Table 1: Hydraulic head and mean gradient results from June 2012-Oct. 2013

Date	Number of Well Sites with Groundwater Flowing into the Lake	Number of Well Sites with Lake Water Flowing Out of the Lake	Mean Hydraulic Gradient of Water Moving Out of the Lake
June 2012	6	5	0.0506
Nov. 2012	2	10	0.0579
May 2013	3	22	0.0707
Oct. 2013	3	4	0.0745

Table 2: Groundwater residence times (years)

Well	June 2012	Nov. 2012	May 2013	Oct. 2013
F5	1.59	1.49	0.40	1.25
E30	2491	2494	2263	2484

4. Conclusions

- Stable isotope data indicate lake water is moving out of the east and southeastern parts of the lake and into groundwater to depths of 30 ft (wells E30, F5, F15, F30, G15, H5, H15, and H30).
- Stable isotope data, tritium data and residence time calculations suggest that groundwater in wells A30, B15, B30, C30, E30, J30, and K30 are meteoric in origin and that groundwater moves slowly with little interaction with the lake.
- Tritium data and residence time calculations indicate that groundwater in wells C5, C15, G5, H5, H15, and I5 have both groundwater and lake water.
- High Cl concentrations (>100 mg/L) in groundwater in wells C5 and C15 likely indicate road salt contamination.
- The water table adjacent to the lake is more responsive to drought and precipitation than is the lake surface elevation.
- Stable isotopes of oxygen and hydrogen are excellent tracers of surface water flowing into groundwater.

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References: Simpkins, W.W. 2006. A Multiscale Investigation of Groundwater Flow at Clear Lake, Iowa. *Ground Water* 44(1): 35-46.

Photo of Clear Lake courtesy of Google Earth.