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Identifying hydrologic recharge connections in the Moscow sub-basin using isotopic and caffeine tracers

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This report describes progress made toward identification of hydrologic recharge connections within the Moscow Sub-basin using light stable isotopes. As described in the proposal, seasonal and event-based variability in $\delta^{18}O$ and $\delta^{2}H$ (also referred to as 18O and 2H in this report) isotopic ratios in rain and snowmelt provide a unique signal which can be traced in streamflow from a watershed and can be observed in groundwater wells. If a hydrologic connection exists between two sources of water then it is expected that the down-gradient water source would have a similar but damped isotopic signal which is lagged in time relatively to up-gradient source. The variability in the 18O and 2H is caused by fractionation which occurs whenever there is a change of phase in the water with more enriched (larger magnitude) 18O in water which has been exposed to evaporation.

In this project we are extending the work of an ongoing PhD project to investigate connections between precipitation and streamflow by testing groundwater in 22 wells and 2 springs throughout the Moscow Sub-basin (see Figure 1 and Table 1 for a map and description of each sampling location). Ricardo Sanchez-Murillo has measured event-based 18O and 2H in precipitation (N=203) and streamflow in Crumarine Creek (N=244)and the South Fork of the Palouse River (N=195) since June 2011. This record provides the isotopic baseline necessary to investigate hydrologic connections to groundwater similar to the approach of Moxley (2012). With the exception of the IDWR-3 (well number 60 in Figure 1) which is sampled monthly, each of the wells and springs are sampled once every two weeks. In total 352 samples have been analyzed for 18O, 2H, electrical conductivity, and temperature since the start of the project (see Tables 2a and 2b). Wells were selected based on geology and soil type (e.g., basalt, granite, sediments of Bovill, loess), well depth (see Figure 2), proximity to streams, landowner cooperation, and with the intention to have distributed samples throughout the Moscow sub-basin. Water samples are taken directly from outdoor spigots after allowing the system to flush for 2 to 10 minutes depending on the temperature of the water. Water samples are collected in sealed vials which are additionally wrapped in parafilm as a secondary precaution.

In isotopic analysis it is critical that water samples are preserved such that evaporation of the water samples is avoided. Comparing the relationship between 18O and 2H in collected water samples (i.e. Local Meteorc Water Line LMWL) to the Global Meteoric Water Line (GMWL: $\delta^2H=\delta^{18}O+10$) can indicate if water samples have experienced evaporation suggesting improper preservation (departure from the meteoric water line also named evaporation slope). As seen in Figure 3, the observed 18O and 2H water line is very close to the LMWL for the Palouse region, indicating the proper preservation has occurred. As expected from previous studies(Carey 2011; Moxley 2012; Larson 2000) in the region, 18O decreases with depth below the soil surface such that 18O of deep groundwater is often less than -16.0 and 18O of near surface water is often greater than -15.0, see Figure 4.

Variability in the 18O signature with time in the data collected to date suggests that groundwater recharge is occurring in some of the wells. The variability in 18O for some of the wells is significant and consistent across many of the locations. Figure 5 shows highly dynamic 18O fluctuations at four well locations in the study. The Picarro instrument used to analyze 18O is accurate to ±0.1 and therefore fluctuations of greater than 0.1 are significant. In contrast, 18O in other wells are relatively stable, see Figure 6.

If the fluctuations in 18O are occurring due to recharge, then the source water should have a similar peak which occurs earlier in time. The 18O in precipitation measured during this same time period has been added in Figures 7 and 8. As seen in Figure 7, the peak 18O in the dynamic wells often occurs two to three weeks following a peak in 18O in precipitation. It is interesting to note that wells which have the greatest fluctuations in 18O normally have a much more depleted 18O signature between recharge events (Figure 7) in comparison to the well with more stable wells (Figure 8). It is also interesting to see the wells which do not respond dynamically still have a dampened signal suggesting a slower connection or smaller amount of recharge may be occurring in these wells.

As expected with a surface water system, the 18O signal from Crumarine Creek is much more closely related to the signal in precipitation, see Figure 9. There is a general trend of increasing 18O (i.e., enriching) throughout the summer and fall period in the streamflow, and a drop in 18O in the precipitation with the onset of snowmelt in early December. These preliminary data suggest that there is not a clear connection between the surface water in Crumarine Creek and the groundwater in the wells. Differences in LMWL slopes can also be used to determine potential enrichment or surface and groundwater connectivity. The slopes of precipitation and groundwater samples exhibited similar slopes (7.48 and 7.20, respectively), indicating that infiltration may occur rapidly, preserving the isotopic input characteristics. On the other hand, Crumarine Creek slope (5.34) indicates clear evaporation enrichment, especially during the summer season. The fluctuations in 18O in the surface water appear to be lagged even further behind the precipitation signal than observed in the well data. A longer dataset will help resolve the timing and connection between the fluctuations in precipitation, streamflow and groundwater.

One outcome of the project will be a map which identifies the wells which appear to be actively recharged. We have observed high spatial variability in 18O and electrical conductivity (EC), see Figures 10 and 11. As mentioned previously, much of the variability in 18O is explained by the depth of the wells and therefore interpreting these patterns on a two dimensional map is difficult. One indication of the relative proportions of 18O and 2H contained in the soil water is the deuterium-excess (d-excess), which is plotted for all the wells in Figure 12. The d-excess value is the intercept of the LMWL for the particular source of water. As seen in Figure 12, the wells nearest the forested uplands in the Moscow Sub-basin have a unique d-excess value near 9, indicating a small deviation from the LMWL (d-excess=10) or minimum evaporation enrichment (i.e., the smaller the d-excess the greater the evaporation loss). . Potentially this parameter could be a good indicator of water passing through the upper forested environments off Moscow Mountain.   Interestingly, the wells which have a dynamic 18O signal (see the list of wells plotted in Figure 5) are located closer to the forest margin in the major tributaries coming off of Moscow Mountain, see the large red dots in Figure 13. In contrast, the wells with the most stable 18O signals occur farther away from the forest near the city of Moscow. Both these patterns suggest that the hydrologic response of a well is related to the proximity of the well to the upper forested margin of the basin. These initial speculative conclusions will be tested and further developed as more data is collected over the next year and a half.

References

Carey, LR, 2011. *Evaluation of oxygen and hydrogen isotopes in groundwater of the Palouse basin and Moscow sub-basin.* MSc. thesis report Hydrology, University of Idaho.

Larson, K.R., Keller, C.K., Larson, P.B., Allen-King, R.A., 2000. Water resource implications of 18O and 2H distributions in a basalt aquifer system. Ground Water 38, 947–953.

Moxley, N, 2012. *Stable isotope analysis of surface water and precipitation in the Palouse basin: hydrologic tracers of aquifer recharge.* MSc. thesis report Geology, Washington state University.

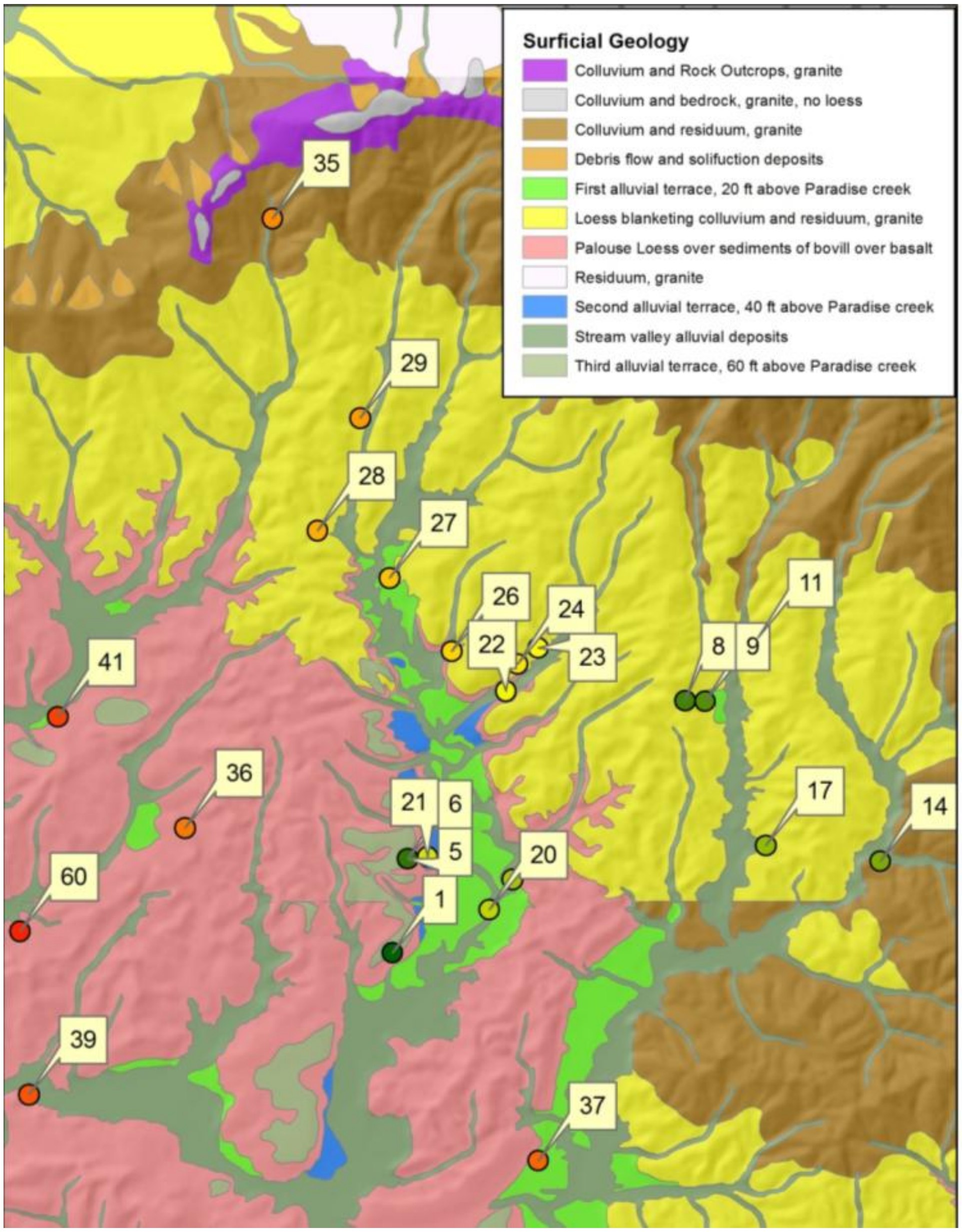

Figure 1. Sample locations within the Moscow sub-basin over the surficial geology map.

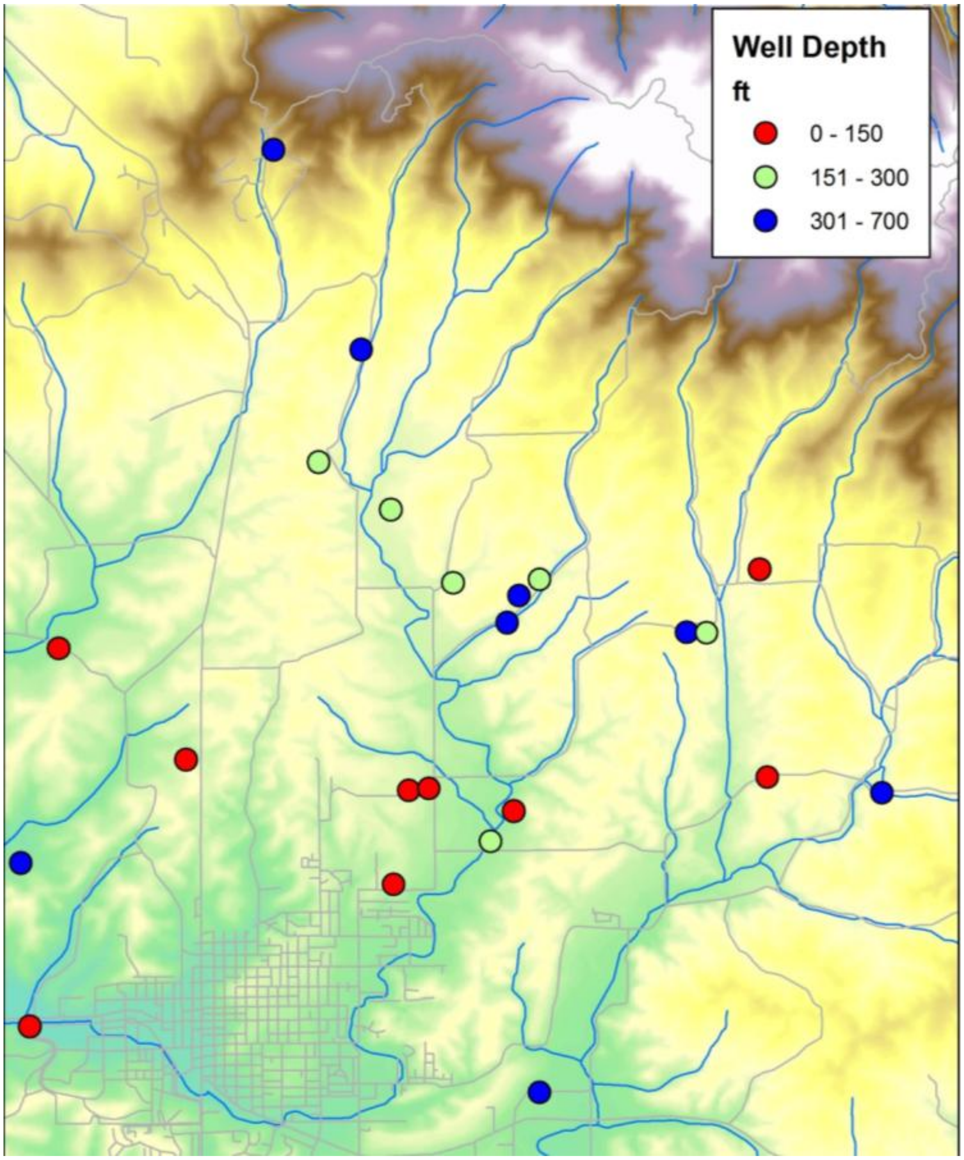

Figure 2. Well depth for each of the sampling locations overlaid over the elevation map and roads layer of the basin.

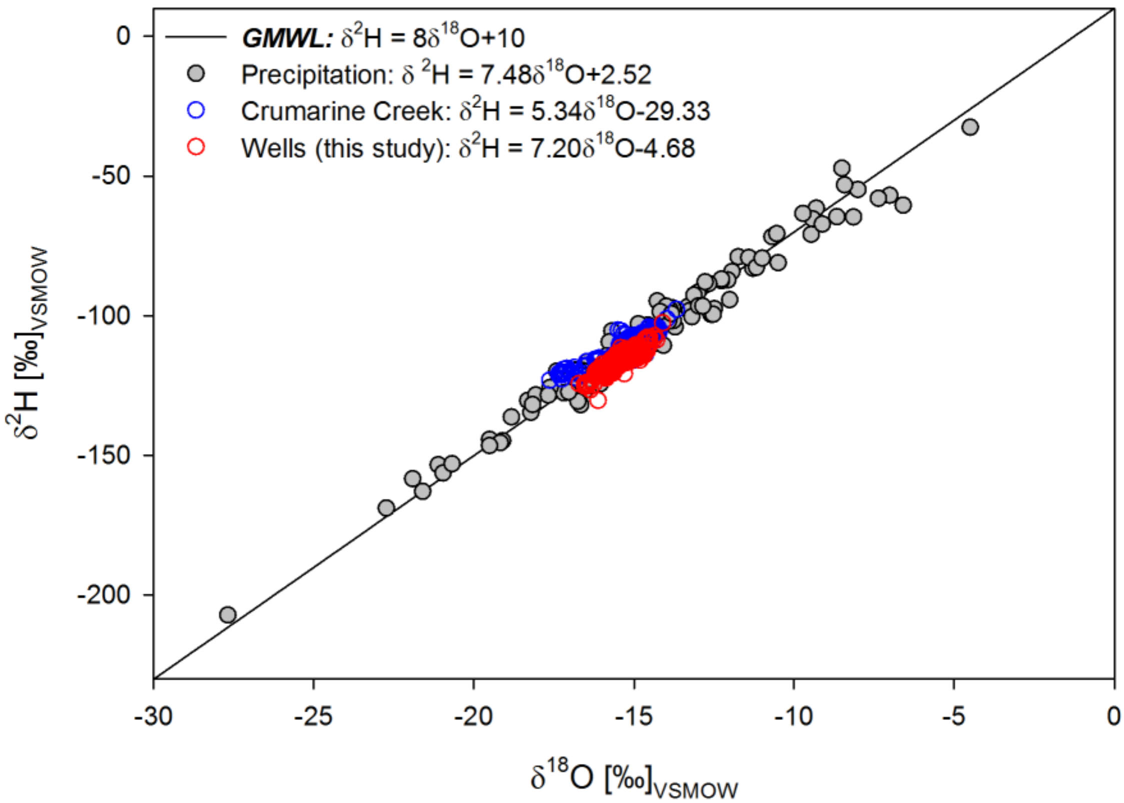

Figure 3. Local Meteoric Water Lines for various water sources collected in this study in comparison to the Global Meteoric Water Line (GMWL).

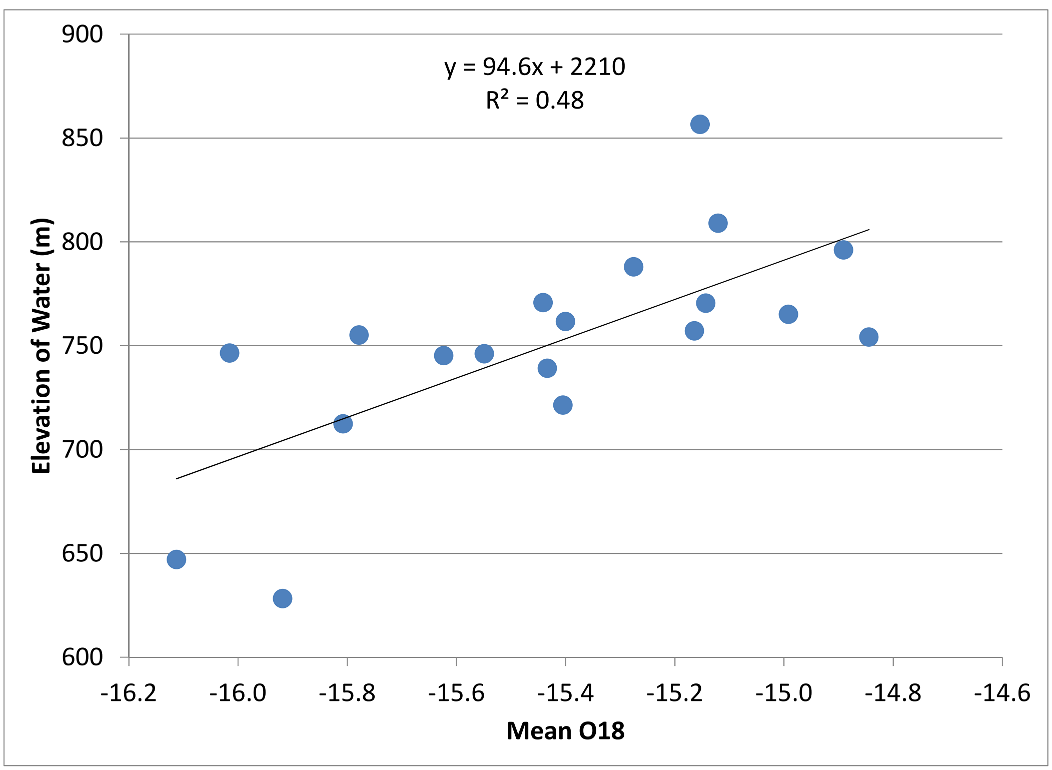

Figure 4. Relationship between average 18O and elevation of the bottom of the well.

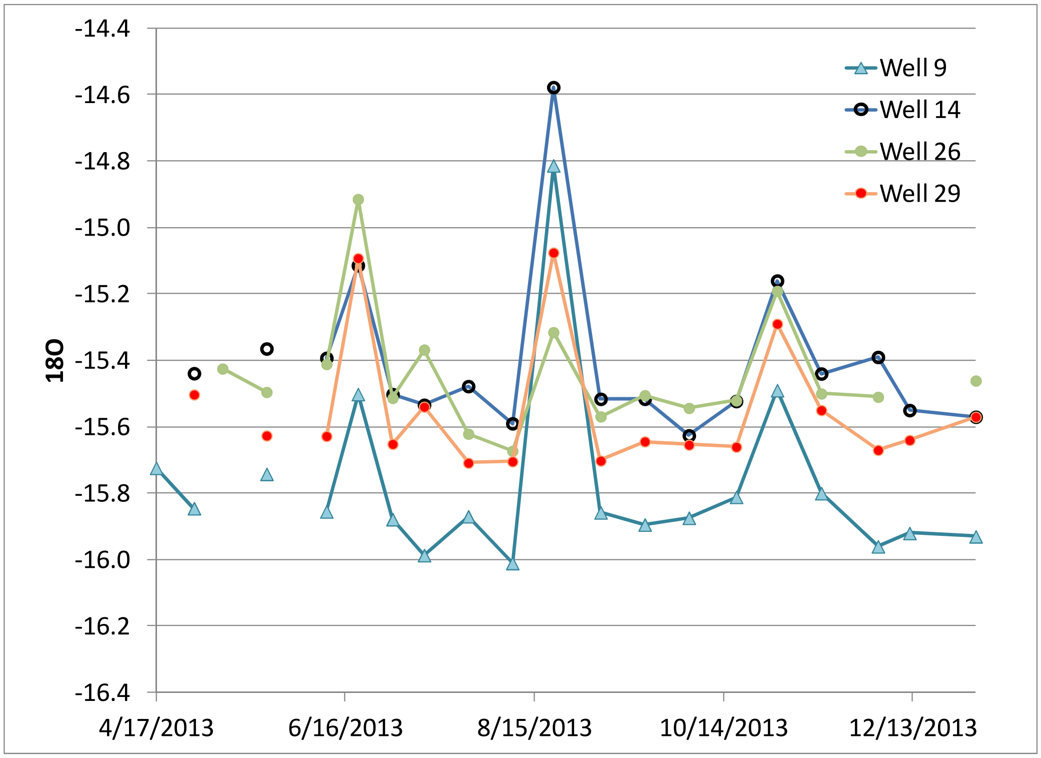

Figure 5. O18 readings for the four most dynamic wells in the study.

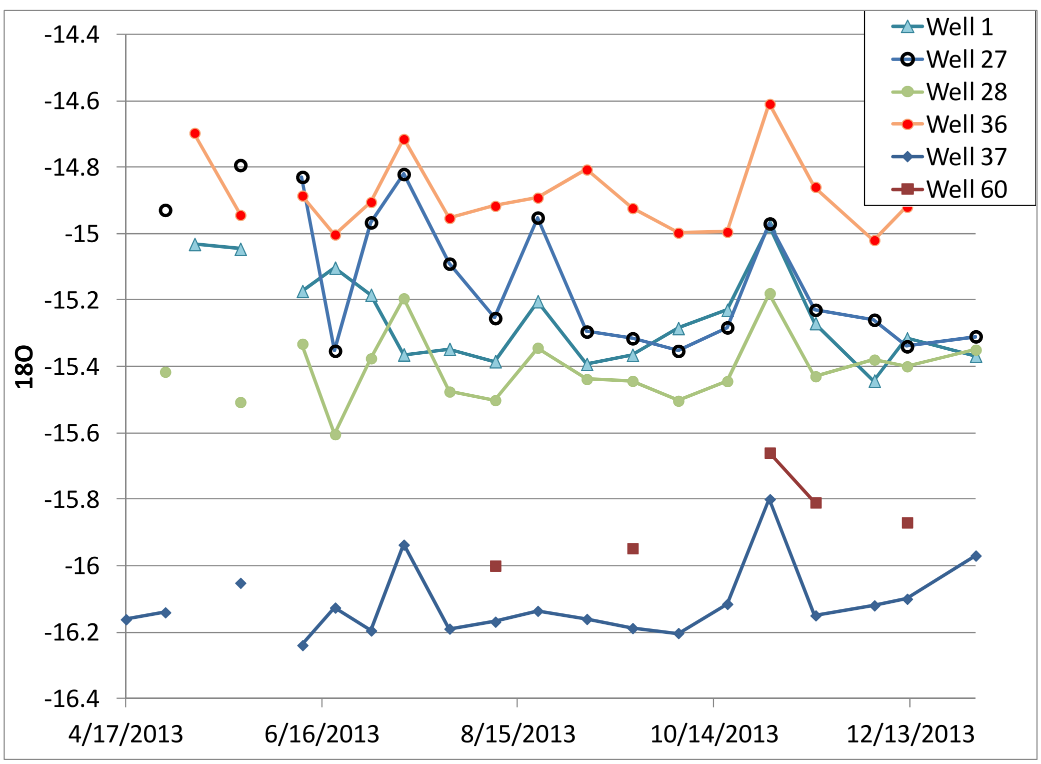

Figure 6. O18 readings for the six most stable wells in the study.

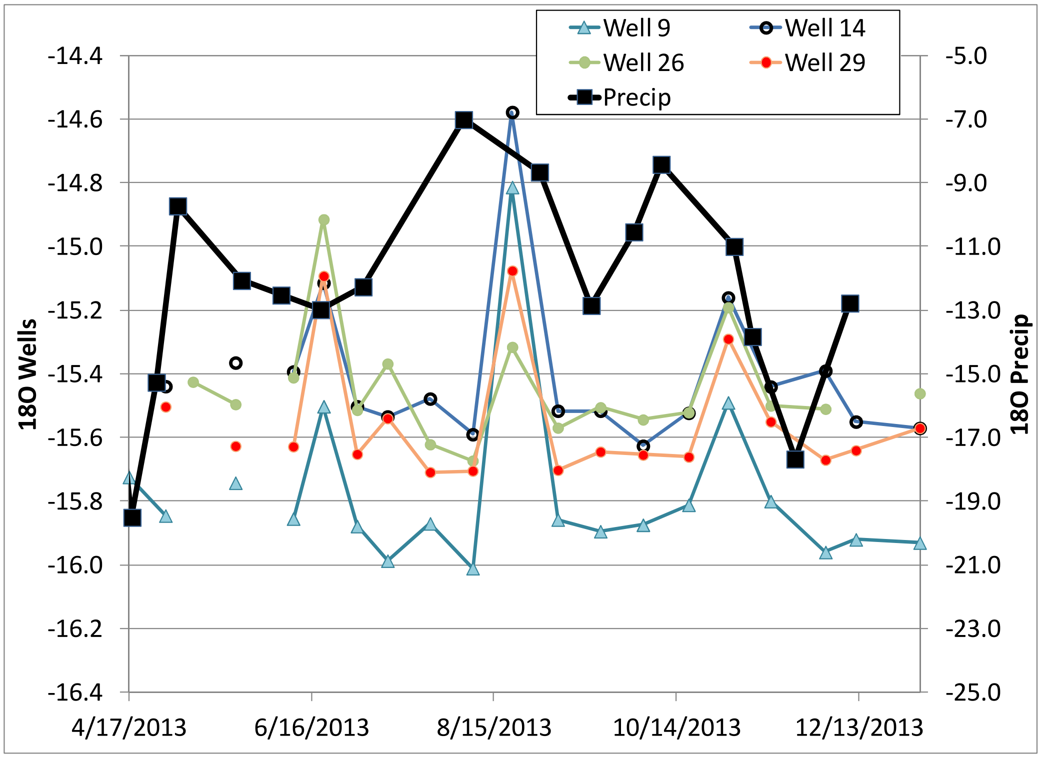

Figure 7. O18 readings for the four most dynamic wells in the study with the precipitation signal.

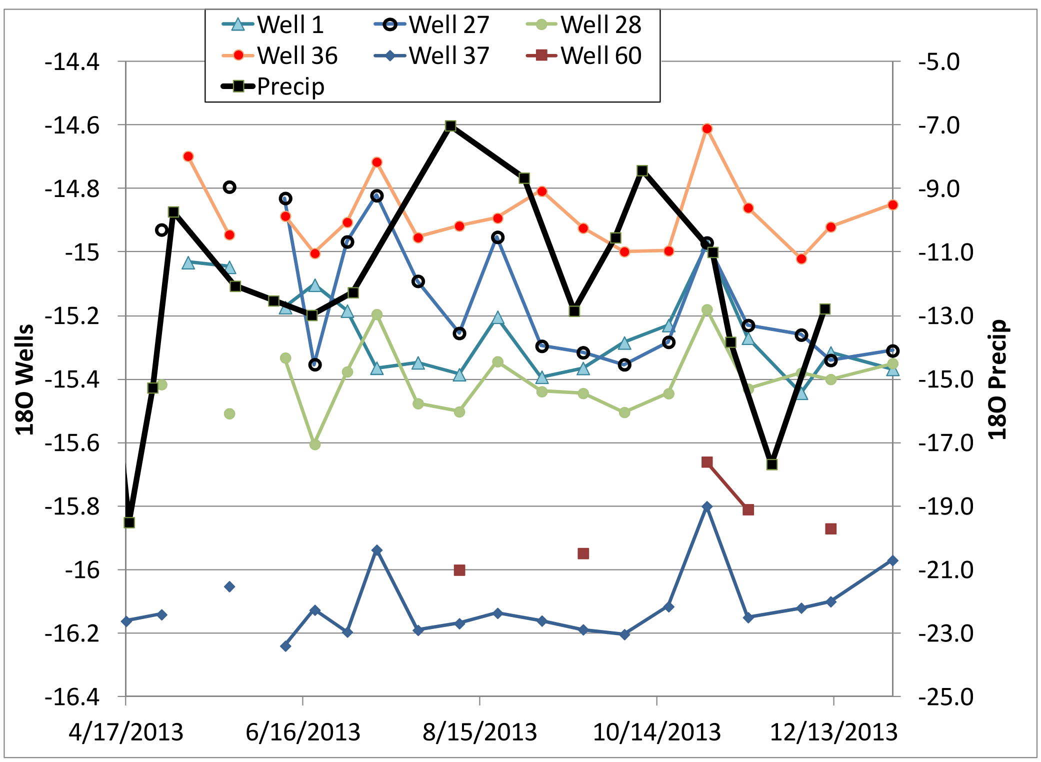

Figure 8. O18 readings for the six most stable wells in the study with the precipitation signal.

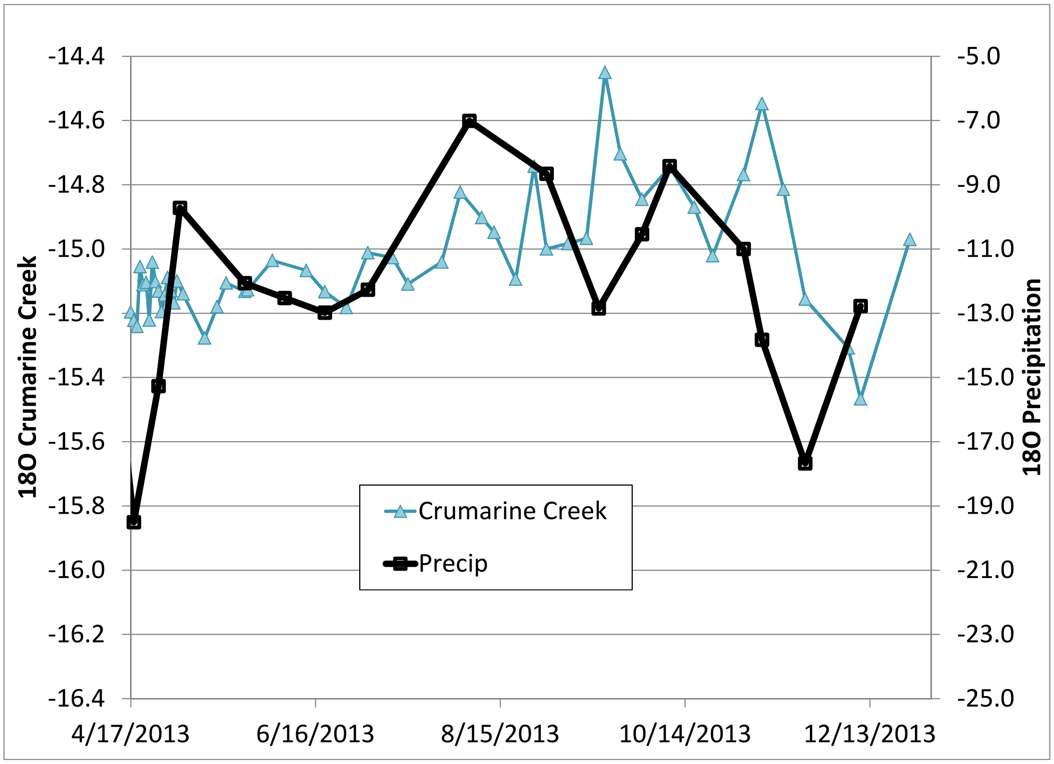

Figure 9. O18 readings for precipitation and Crumarine Creek samples.

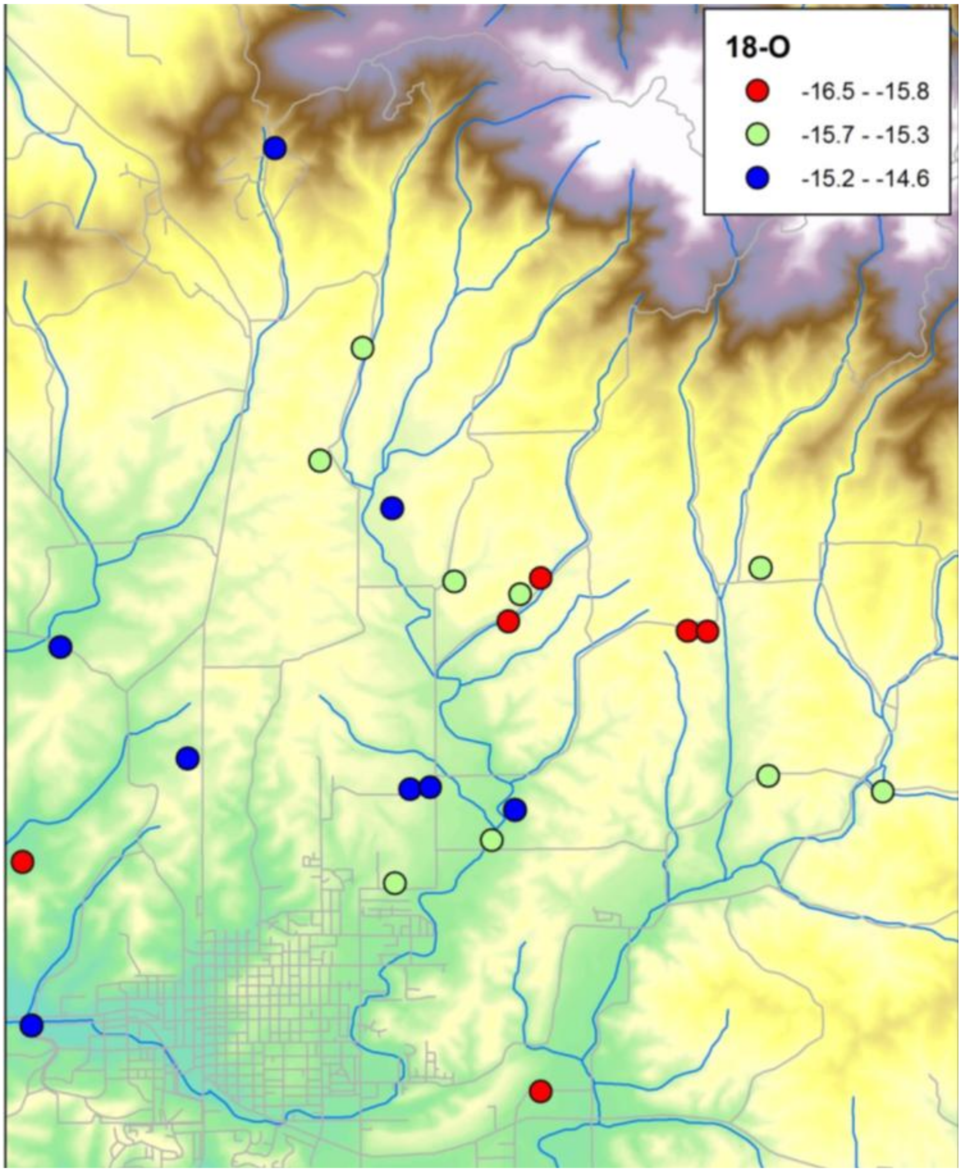

Figure 10. Average 18O for all samples analyzed between April 2013 and January 2014. Lower (more negative) 18O readings suggest water was recharged during relatively cooler conditions with relatively little enrichment due to evaporation.

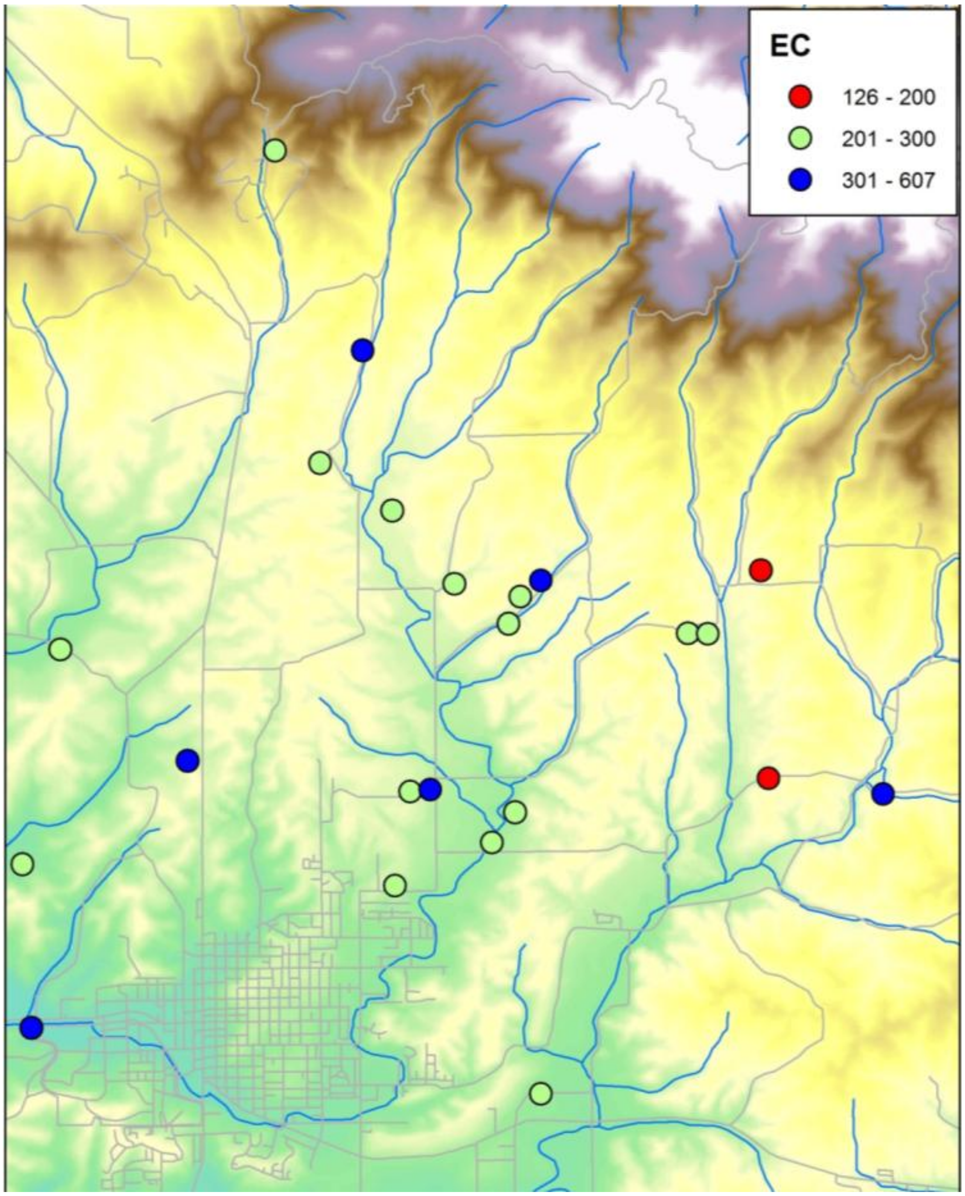

Figure 11. Average electrical conductivity (uS/cm) for all samples analyzed from April 2013 through January 2014. Higher EC values suggest older water or water high in solute or ion concentrations.

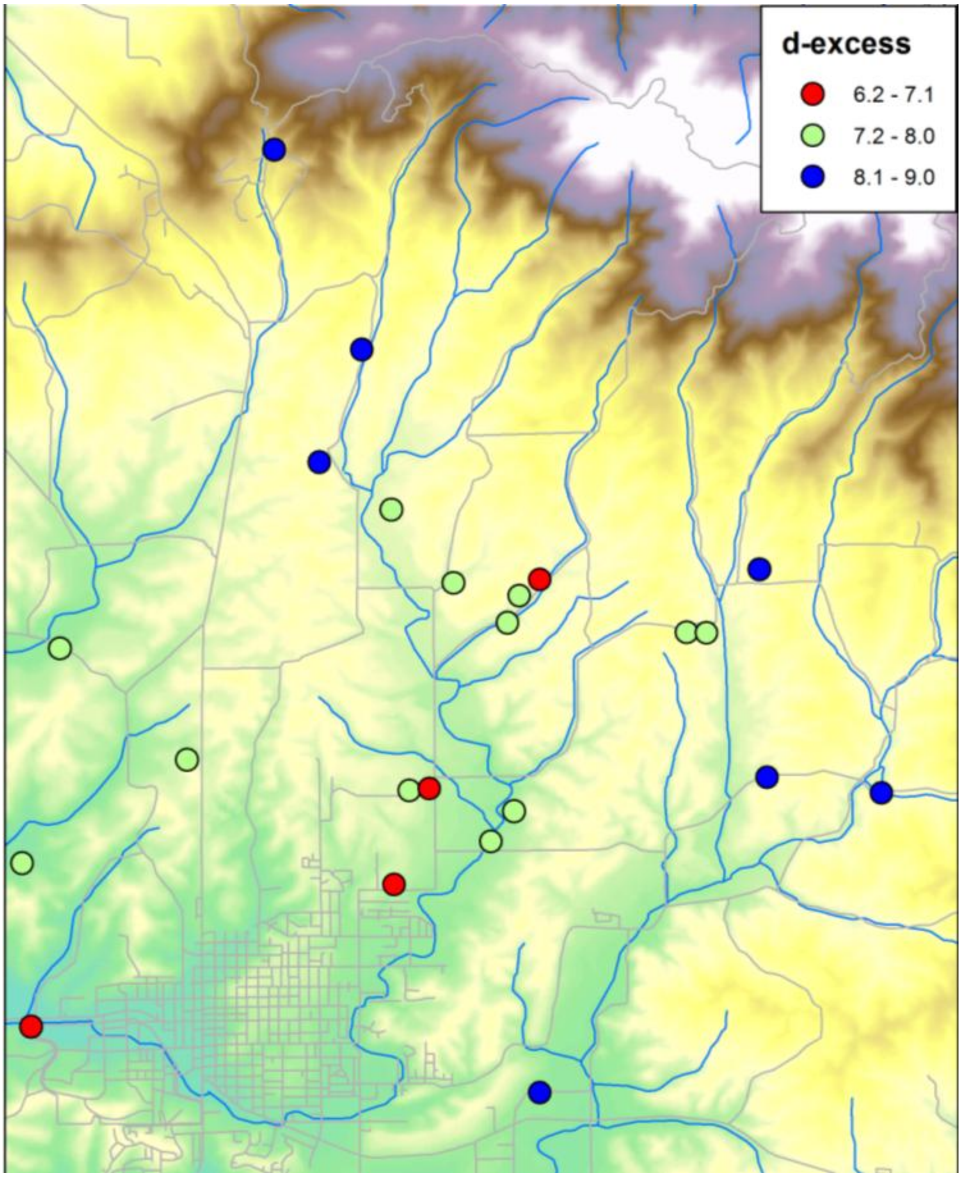

Figure 12. Average deuterium excess for all samples analyzed from April 2013 to January 2014. Average deuterium excess is a measure of the relative proportions of 18O and 2H contained in water, and can be used as an index of deviation from the global meteoric water line (GMWL; d=10).

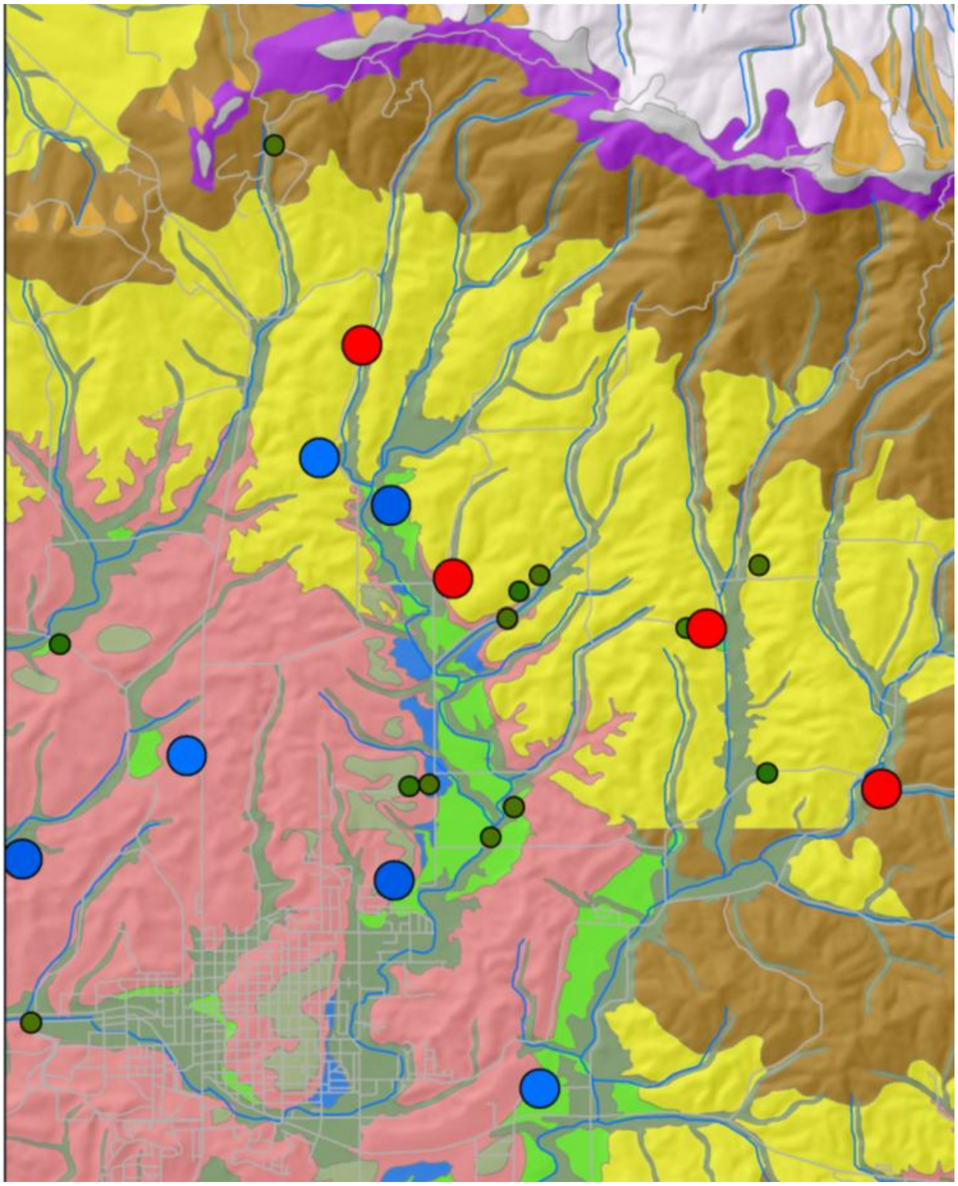

Figure 13. Red dots represent well locations where 18O has responded dynamically suggesting recharge may be occurring intermittently. Blue dots indicate well locations with relatively stable 18O readings indicating either constant recharge or no recharge.

Table 1. Description of each well location and average 18O readings from 4/17/2013-1/2/2014.

Well ID	Address	Top of Well (meters)	Bottom of Well (meters)	Longitude	Latitude	Number of Samples	Average 18O	Stdev 18O	min 18O	max 18O
1	1275 Mountain view Road	811.7	787.9	-116.975	46.745	16	-15.28	0.12	-15.44	-14.98
5	2350 Trail Road	818.1	746.5	-116.973	46.754	16	-16.02	0.22	-16.17	-15.30
6	2350 Trail Road	818.1	818.1	-116.973	46.754	10	-14.67	0.46	-15.93	-14.29
8	3715 Moscow Mountain Road	841.6	628.2	-116.935	46.769	16	-15.92	0.18	-16.15	-15.47
9	3727 Moscow Mountain Road	832.2	755.1	-116.933	46.769	16	-15.78	0.30	-16.01	-14.81
11	Frink Road	848.6	821.4	-116.925	46.775	14	-15.36	0.12	-15.56	-15.02
14	5168 Robinson Park Road	823.5	721.4	-116.908	46.754	16	-15.40	0.26	-15.63	-14.58
17	3919 Darby Road	828.9	785.6	-116.924	46.755	11	-15.41	0.09	-15.54	-15.25
19	2080 Darby Road	809.0	809.0	-116.959	46.752	15	-15.12	0.16	-15.34	-14.76
20	2077 Darby Road	800.1	745.2	-116.962	46.749	16	-15.62	0.11	-15.79	-15.36
21	2175 Mountain View Road	810.8	765.1	-116.971	46.754	16	-14.99	0.17	-15.17	-14.54
22	3116 W Twin Road	817.5	712.3	-116.960	46.770	16	-15.81	0.12	-15.99	-15.49
23	3129 W Twin Road	827.4	764.9	-116.955	46.774	11	-16.47	0.12	-16.71	-16.30
24	3109 W Twin Road	832.1	739.1	-116.958	46.772	16	-15.43	0.24	-15.93	-15.13
26	End of Mountain view RD	817.4	770.7	-116.967	46.774	15	-15.44	0.19	-15.67	-14.91
27	3200 Foothill Road	824.2	757.1	-116.976	46.781	16	-15.16	0.19	-15.35	-14.82
28	3281 Foothill Road	834.1	761.6	-116.986	46.785	16	-15.40	0.11	-15.60	-15.18
29	3355 Foothill Road	839.0	746.1	-116.980	46.796	16	-15.55	0.21	-15.71	-15.08
35	1066 Nearing Road	950.1	856.5	-116.992	46.814	16	-15.15	0.11	-15.29	-14.85
36	Highway95	815.0	796.1	-117.004	46.757	16	-14.89	0.11	-15.02	-14.61
37	Plant Science Farm	797.0	647.0	-116.955	46.726	16	-16.11	0.12	-16.24	-15.80
39	Groundwater Research Site	775.1	754.1	-117.025	46.732	16	-14.84	0.23	-15.07	-14.10
41	Ordonell Rd	797.9	770.4	-117.021	46.767	15	-15.14	0.12	-15.29	-14.85
60	IDWR 3	800.1	691.9	-117.027	46.747	5	-15.86	0.13	-16.00	-15.66

Table 2a. 18O data for each well for all sampling dates

Well ID Number

Date	1	5	6	8	9	11	14	17	19	20	21	22
4/17/2013				-15.831	-15.724	-15.372		-15.42	-14.945			
4/29/2013		-16.101	-14.631	-15.637	-15.845	-15.233	-15.439	-15.334	-14.678		-15.087	
5/8/2013	-15.032	-15.866	-14.352						-15.246			-15.608
5/22/2013	-15.047	-15.885	-14.514	-15.619	-15.742	-15.246	-15.365	-15.176	-15.023	-15.507	-14.935	-15.607
5/31/2013			-14.561						-15.132			
6/10/2013	-15.173	-16.061	-14.621	-15.871	-15.855	-15.348	-15.393	-15.544	-15.001	-15.663	-15.142	-15.914
6/20/2013	-15.103	-15.823	-14.359	-15.473	-15.502		-15.114	-15.267	-14.949	-15.428	-14.539	-15.679
7/1/2013	-15.185	-16.048	-14.505	-16.037	-15.878		-15.502	-15.247	-15.096	-15.558	-15.012	-15.775
7/11/2013	-15.364	-16.117	-14.602	-16.147	-15.987	-15.407	-15.534	-15.448	-15.251	-15.709	-14.86	-15.638
7/25/2013	-15.348	-16.091	-14.571	-15.845	-15.87	-15.358	-15.478	-15.392	-15.249	-15.655	-15.068	-15.889
8/8/2013	-15.385	-16.166		-16.092	-16.01	-15.564	-15.59	-15.512	-15.337	-15.792	-15.168	-15.985
8/21/2013	-15.204	-16.054		-16.053	-14.813	-15.213	-14.577	-15.401	-14.948	-15.569	-15.033	-15.874
9/5/2013	-15.393	-16.129		-15.931	-15.858	-15.422	-15.516	-15.464	-15.314	-15.726	-15.115	-15.888
9/19/2013	-15.365	-16.127	-14.574	-15.976	-15.894	-15.419	-15.516	-15.409		-15.666	-15.06	-15.824
10/3/2013	-15.285	-16.094		-16.014	-15.874	-15.433	-15.626	-15.435	-15.155	-15.685	-15.006	-15.852
10/18/2013	-15.23	-16.085	-14.592	-15.923	-15.811	-15.366	-15.523	-15.396	-15.188	-15.661	-15.075	-15.81
10/31/2013	-14.976	-15.82	-14.29	-15.54	-15.49	-15.02	-15.16		-14.76	-15.36	-14.72	-15.49
11/14/2013	-15.27	-15.296		-15.98	-15.8	-15.38	-15.44		-15.02	-15.61	-14.94	-15.8
12/2/2013	-15.443	-16.113	-15.93	-15.93	-15.96	-15.42	-15.39		-15.22	-15.63	-15.11	-15.92
12/12/2013	-15.316	-16.11	-14.66	-15.93	-15.92	-15.35	-15.55		-15.18	-15.6	-15.07	-15.81
1/2/2014	-15.368	-16.11		-15.95	-15.93	-15.32	-15.57		-15.14	-15.659	-14.95	-15.77

Table 2b. 18O data for each well for all sampling dates

Well ID Number

Date	23	24	26	27	28	29	35	36	37	39	41	60
4/17/2013									-16.162			
4/29/2013				-14.929	-15.416	-15.503			-16.141			
5/8/2013	-16.475	-15.184	-15.425					-14.697			-15.168	
5/22/2013	-16.255	-15.263	-15.495	-14.794	-15.508	-15.626	-15.406	-14.944	-16.052			
5/31/2013										-15.002	-15.125	
6/10/2013	-16.423	-15.133	-15.411	-14.83	-15.332	-15.628	-15.157	-14.886	-16.24	-14.899	-15.292	
6/20/2013	-16.302	-15.491	-14.915	-15.353	-15.605	-15.092	-15.081	-15.003	-16.127	-14.104	-14.852	
7/1/2013	-16.468	-15.21	-15.513	-14.967	-15.376	-15.652	-15.248	-14.905	-16.196	-15.015	-15.245	
7/11/2013	-16.36	-15.185	-15.368	-14.821	-15.195	-15.54	-15.061	-14.716	-15.937	-14.771	-15.022	
7/25/2013	-16.542	-15.346	-15.621	-15.091	-15.476	-15.709	-15.16	-14.954	-16.19	-14.932		
8/8/2013	-16.714	-15.454	-15.673	-15.255	-15.502	-15.704	-15.243	-14.917	-16.169	-15.05	-15.185	-16
8/21/2013	-16.331	-15.296	-15.315	-14.952	-15.344	-15.076	-15.119	-14.892	-16.136	-15.067	-15.225	
9/5/2013	-16.532	-15.934	-15.569	-15.295	-15.438	-15.702	-15.239	-14.807	-16.161	-14.868	-15.215	
9/19/2013	-16.522	-15.846	-15.505	-15.316	-15.444	-15.644	-15.171	-14.924	-16.188	-14.96	-15.057	-15.948
10/3/2013	-16.536	-15.381	-15.543	-15.354	-15.504	-15.654	-15.291	-14.998	-16.203	-14.986	-15.205	
10/18/2013	-16.487	-15.408	-15.521	-15.283	-15.445	-15.66	-15.239	-14.995	-16.116	-14.969	-15.248	
10/31/2013		-15.28	-15.191	-14.97	-15.18	-15.29	-14.854	-14.61	-15.8	-14.61	-15.01	-15.66
11/14/2013		-15.63	-15.5	-15.23	-15.43	-15.55	-15.18	-14.86	-16.15	-14.84	-15.12	-15.81
12/2/2013		-15.31	-15.51	-15.26	-15.38	-15.67	-15.19	-15.02	-16.12	-14.8	-15.19	
12/12/2013		-15.77		-15.34	-15.4	-15.64	-15.165	-14.92	-16.1	-14.85	-15.19	-15.87
1/2/2014		-15.26	-15.461	-15.31	-15.35	-15.57	-15.061	-14.85	-15.97	-14.79	-15.09	