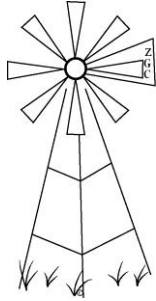


**Colfax County
Hydrogeology Project
Annual Progress Report
2016-2017**



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Introduction

This report is Zeigler Geologic Consulting, LLC's (ZGC) annual progress report for the Colfax County Hydrogeology Project, sponsored by Colfax County and the Colfax Soil and Water Conservation District (SWCD). During the 2017 calendar year, ZGC measured static water level in 25 wells in February and July of 2017, began geologic mapping around Maxwell, obtained seven trace metal chemistry samples, seven radiocarbon dating samples, and eight tritium isotope samples. Here we describe the progress in each of these tasks. We would like to thank Colfax County and the Colfax SWCD for funding this project.

Static Water Level Measurements

In February and July of 2017, depth to water was measured in 25 wells spread across the county to document maximum (July) and minimum (February) use water levels (Figure 1). A 300-foot steel tape is used for most of the wells and a 500 foot steel tape for wells deeper than 300 ft. For open casing wells, we use an e-tape (maximum length of 300 ft). The measuring point, or height of the entrance to the well above land surface, is subtracted from the total depth measurement such that the final static water level for all wells is calculated relative to the land surface. Measurements are repeated until two values that are within 0.01 ft of one another are obtained. We observed two discrete groups of water levels: very shallow water levels (10-60' depth) and deeper water levels (100-220' depth). Shallow water levels occur primarily in wells located immediately adjacent to drainages.

From February to July, 11 of the wells showed increasing water levels, nine showed decreasing water levels, and four were inconclusive. Wells with deeper water levels often show declining water levels. Wells with inconclusive results included wells that appeared to not fully recover from the time the well was turned off to when a measurement was taken and wells where the water line on the steel tape was not clear and water levels were thus an average value of uncertain measurements.

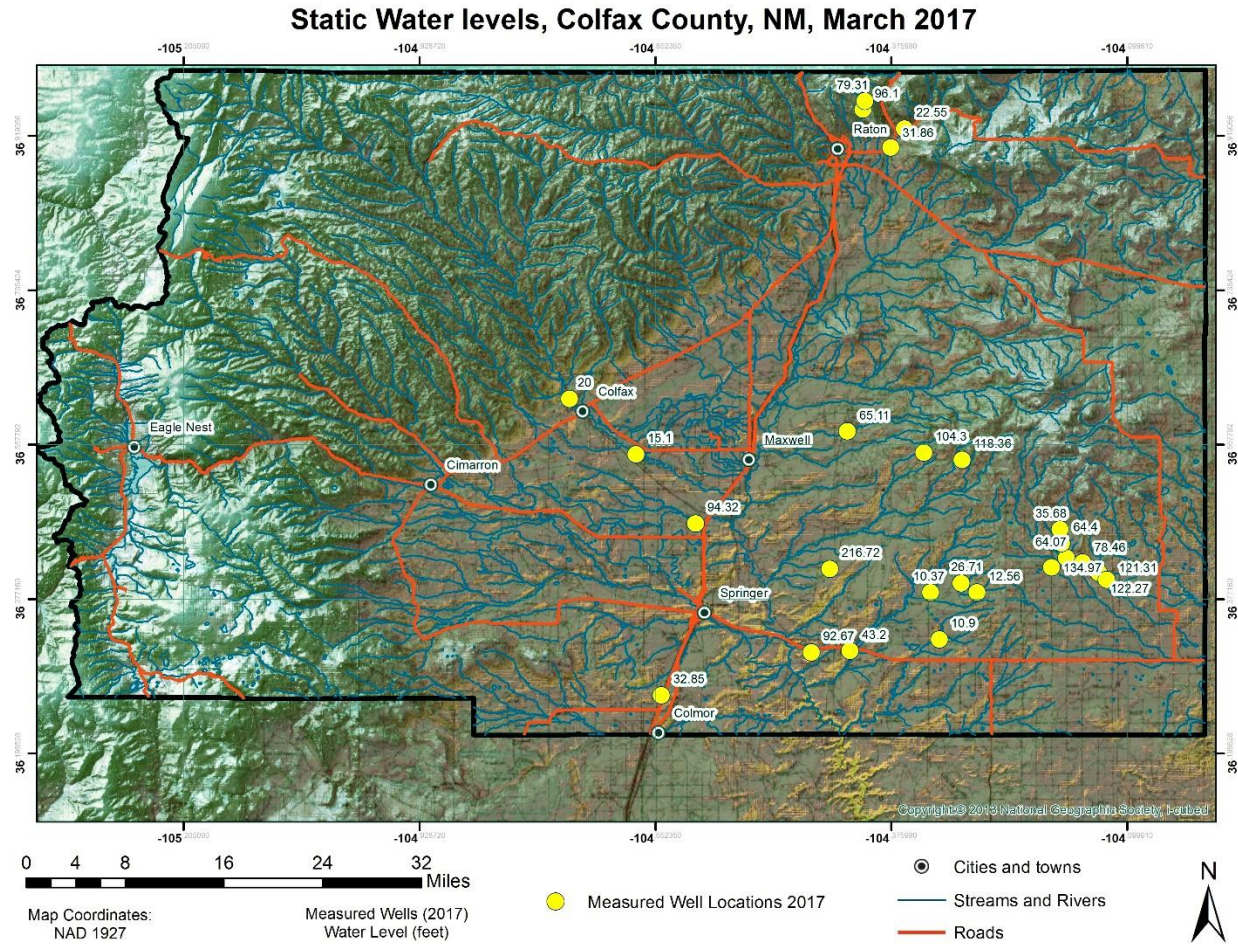


Figure 1. Location and preliminary water levels in wells in the Colfax groundwater network.

Water Chemistry

Approximately half a liter of water was collected from each of six wells distributed across the county for basic water chemistry analyses of major cations and anions as well as trace metals. Wells were allowed to flow for 10 minutes prior to collecting a sample if the well was off upon arrival. For stock tanks where the windmill was actively pumping on arrival, a sample was collected within a few minutes. The analytical work was conducted by the New Mexico Bureau of Geology and Mineral Resources in Socorro. Major cation/anion analyses included the cations calcium (Ca), sodium (Na), magnesium (Mg), and potassium (K), and the anions carbonate (CO_3), bicarbonate (HCO_3), sulfate (SO_4), and chloride (Cl). Trace metal analyses did not show

any significant concentrations of 26 different metals, ranging from aluminum and arsenic to uranium (EPA method 200.8).

Each of the ions analyzed for can provide information about groundwater-rock unit interactions. A brief overview of each ion follows here (based on Hem, 1985) and we recommend Hem's (1985) *Study and Interpretation of the Chemical Characteristics of Natural Waters* for an in-depth review of groundwater chemistry. Piper and Stiff diagrams (Figures 2 and 3) below show the concentrations of ions for each well.

Calcium is the most abundant of the alkaline-earth metals and is an important part of many igneous, metamorphic, and sedimentary rocks. In igneous rocks, the minerals pyroxene, amphibole, and the feldspar family contain calcium, but in general, groundwater that interacts with igneous rocks has relatively low concentrations of calcium due to the slow decomposition rates of most of these minerals. In sedimentary rocks, calcium occurs most commonly in carbonate rocks, such as limestone and dolomite, and in the sulfate evaporites gypsum and anhydrite. In sandstone, calcium is generally present as a cementing agent and in soils it is present as an adsorbed ion on negatively charged surfaces.

Magnesium is also an alkaline-earth metal that is important in mafic igneous rocks, occurring in minerals such as pyroxene, amphibole, and olivine. In sedimentary rocks, magnesium occurs as a carbonate (magnesite) or as a mixture with calcium (e.g., limestone and dolomite). Magnesium carbonates are more soluble than calcium carbonates. Hem (1985) notes that magnesium concentration tends to increase along groundwater flow paths. Sodium is the most abundant of the alkali metals and is an important constituent in igneous and sedimentary rocks in the feldspar mineral family. Feldspars that include a mixture of sodium and calcium tend to be more susceptible to chemical weathering. In sedimentary rocks, evaporites (e.g., rock salt) are important sources of sodium, as well as sodium occurring as part of unaltered minerals, an impurity in a cement, or as a residue left over by saline waters that interacted with sediments or sedimentary rocks after depositions. In interbedded shales and sandstones, sodium is often held in the less permeable shales and with long-term groundwater withdrawal and declining water tables, this sodium can be reintroduced into the groundwater from the shales.

Potassium goes into solution less readily than does sodium and tends to be incorporated back into solid weathering products during chemical weathering. It is an important ion in many igneous rock minerals, including the feldspar family and micas. In sedimentary rocks, potassium

is a constituent of unaltered feldspar grains, micas, clays minerals, and some evaporites. Because it is less soluble than sodium, potassium concentrations tend to be relatively low. Carbonate and bicarbonate are produced as part of the interactions of water and carbonates (e.g., limestone and dolomite). Bicarbonate concentrations are higher in more acidic waters and carbonate concentrations are higher in more basic waters.

Sulfate occurs as a result of the chemical weathering of sulfide minerals with aerated waters. In this reaction, sulfur is oxidized to form sulfate ions. In sedimentary rocks, pyrite is a common mineral host for sulfur that occurs in association with biogenic deposits, such as coal. The most important contributors for sulfate are the evaporite rocks gypsum and anhydrite.

Chloride is the most abundant halogen, but conversely has one of the lowest concentrations in rocks. It is generally most common in sodalite (a feldspathoid) and apatite (a calcium phosphate), as well as occurring as an impurity in other minerals. In sedimentary rocks, chloride occurs as inclusions in brine deposits, in cements, or as incompletely leached deposits that formed in ocean or closed basins. Chloride tends to be moved through the hydrologic cycle by physical processes, as opposed to chemical processes (Hem, 1985). Generally, where sodium is the dominant cation present, chloride will be the dominant anion (primarily due to the relationship of sodium and chloride ionically bound together as halite, or rock salt).

The chemistry of the water in each well primarily reflects the bedrock unit(s) that the well is drawing water from. These wells appear to be screened along most of their length, such that wells that penetrate more than one geologic unit will have mixed waters. Dakota Group sandstones are cemented with calcite, which can dissolve to provide carbonate, calcium, and magnesium. Black shales, which are commonly interbedded with sandstone in the Dakota Group and constitute the primary lithology of the Graneros Shale, contain gypsum, a calcium sulfate, which provides sulfate. Deeper wells completed in the black shale units, such as BLC and NY1, have higher proportions of Na+K. Wells completed partly in black shale, but adjacent to drainages, do not show as high a proportion of Na+K, which may result from flushing of the aquifer unit when the drainages contain significant surface flow. FG4 and FG7 are deeper wells east of Springer that have low proportions of major ions, suggesting these wells are drawing the majority of their water from the Dakota Group.

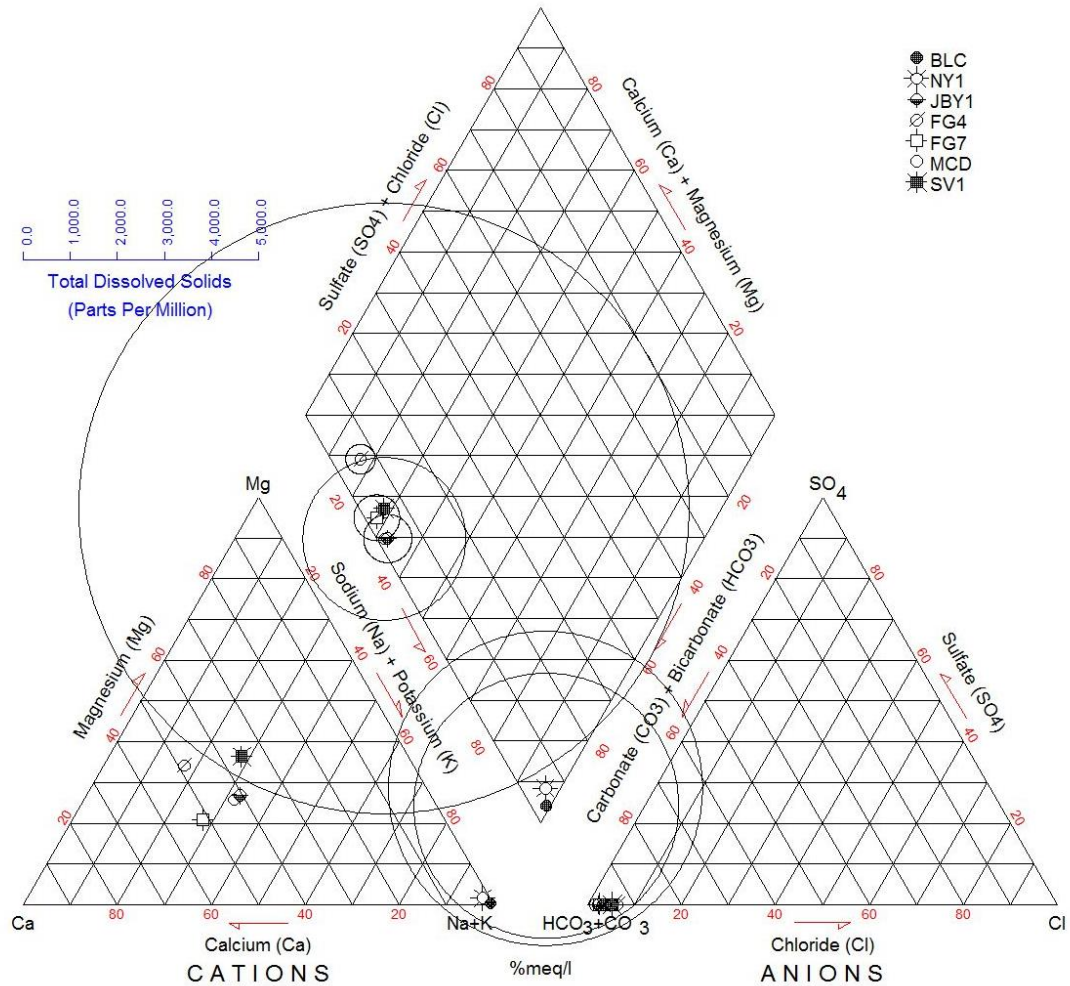


Figure 2. Piper diagram for water chemistry samples collected in 2017 from Colfax County. Circles indicate total dissolved solids for each well – larger circles indicate higher TDS.

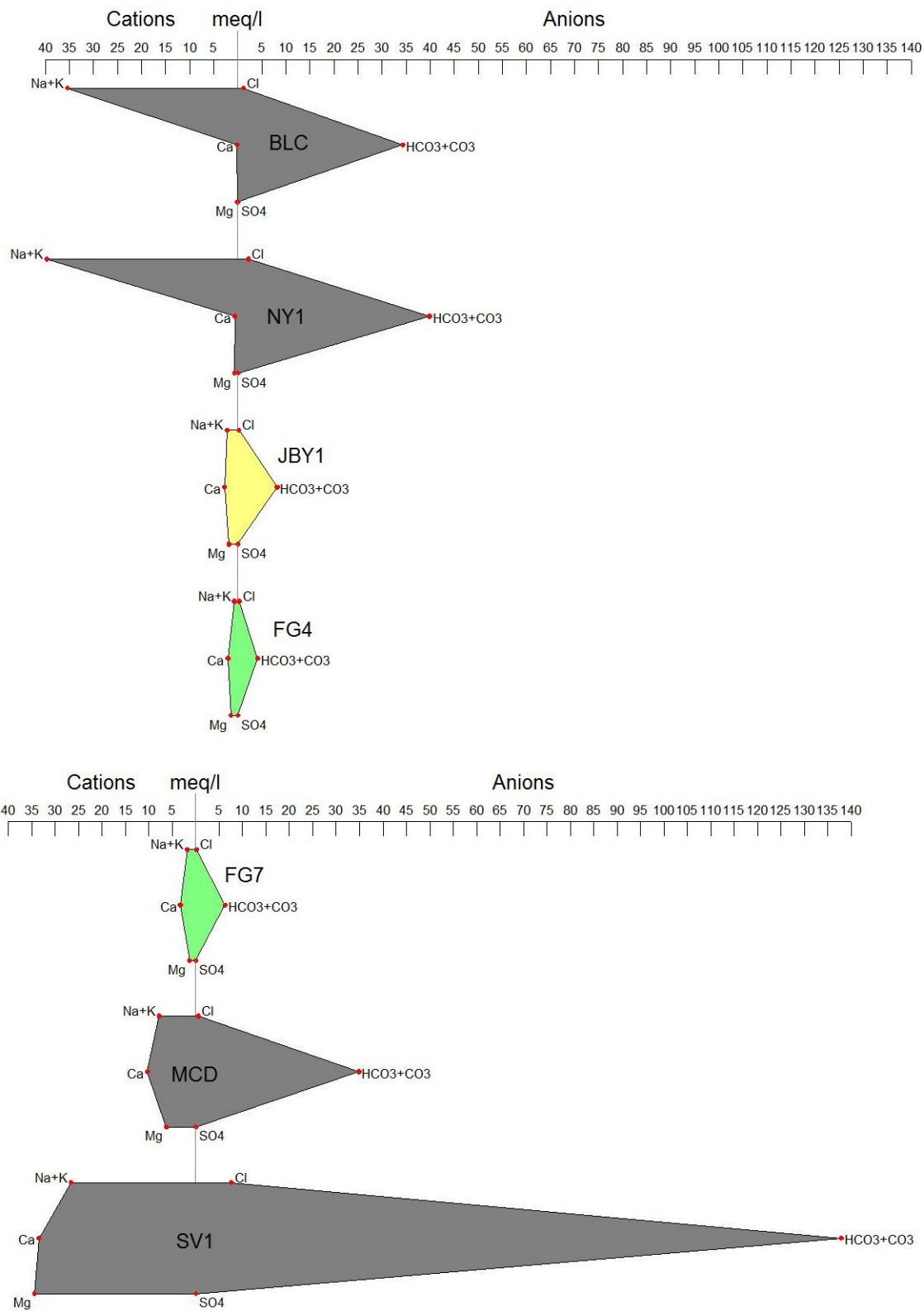


Figure 3. Stiff diagrams for sampled wells. Gray corresponds to black shale (note exceptions for MCD and SV1 in the text above), green to Dakota Group, and yellow to alluvial aquifers respectively.

Carbon-14 and Tritium Dates

One liter of water was collected from seven wells for carbon-14 isotope analysis (Figure 4) and the samples were analyzed by Beta Analytic, Inc. in Miami, Florida. Groundwater age is related to the rate at which water migrates through the subsurface. It is important to remember that water molecules may enter and leave the system via cross-formational flow and that any given mass of groundwater will exchange water molecules with masses of water on all sides of it (Bethke and Johnson, 2008). Hence, a mass of water that entered the groundwater and had a single age associated with it will end up with many of those particles dispersed, rather than traveling entirely as a discrete package. A groundwater sample, therefore, is an average of the ages of all of the molecules of water contained in that sample (Bethke and Johnson, 2008). The distribution of these ages for each sample may include much older molecules and much younger molecules, and may be heavily skewed in one direction or the other. One complication for the ^{14}C method is that the oxidation of ancient organic matter or the dissolution of carbonates (e.g., limestone) will add ^{14}C -depleted carbon (also called “dead” carbon) into the groundwater (Bethke and Johnson, 2008). This process will create an erroneously old age and so ages of water extracted from systems that are suspected of including carbonate interactions should be corrected for this depleted carbon addition.

For this study, geochemical interactions with the host rocks in the Dakota Group or the shallow alluvial aquifers are unlikely to contribute significant amounts of “dead” carbon due to a lack of significant quantities of carbonate rocks. However, wells drawing water from the black shale units above the Dakota Group, including the Graneros Shale, Greenhorn Limestone, and overlying units, will probably have skewed age results due to the presence of limestone beds within these units. For example, the significantly older 14-carbon result from the well east of Springer is probably an artificially older result given that this well is completed through tens of feet of limestone-bearing shale.

Seven samples were analyzed by the Tritium Laboratory at the University of Miami. Tritium is a radioactive isotope that has a very short half-life of just 12.3 years. It is most commonly used to determine relative age of waters that are less than fifty years old (Clark and Fritz, 1997). Tritium is produced both as a natural byproduct of interaction of cosmic radiation with the stratosphere and comes into the water cycle by precipitation, but also was produced

anthropogenically in large volumes during testing of thermonuclear bombs in the 1950s. The majority of the bomb-produced tritium has decreased significantly such that most modern dating is reflecting the natural tritium signal (Clark and Fritz, 1997). Generally, a tritium value (in tritium units or TU) less than 0.8 TU indicates pre-1952 or no modern recharge. Tritium values between 0.8 TU and 4.0 TU indicate a mixture of modern recharge and pre-1952 recharge and values between 5 TU and 15 TU indicate waters that are modern (5-10 years old).

Sample ID	Tritium (in TU)	¹⁴ C Date (YBP)	Age Interpretation
JBY #1	5.65	300	Modern
SV #1	5.14	0	Modern
FG #4	0.89	3300	Pre-1952
BLC	-0.07	33,570	Pre-1952
NY#1	0.03	37,370	Pre-1952
FG #7	-0.02	16,240	Pre-1952
MCD	5.4	280	Modern

*TU = tritium units. YBP = Years before present.

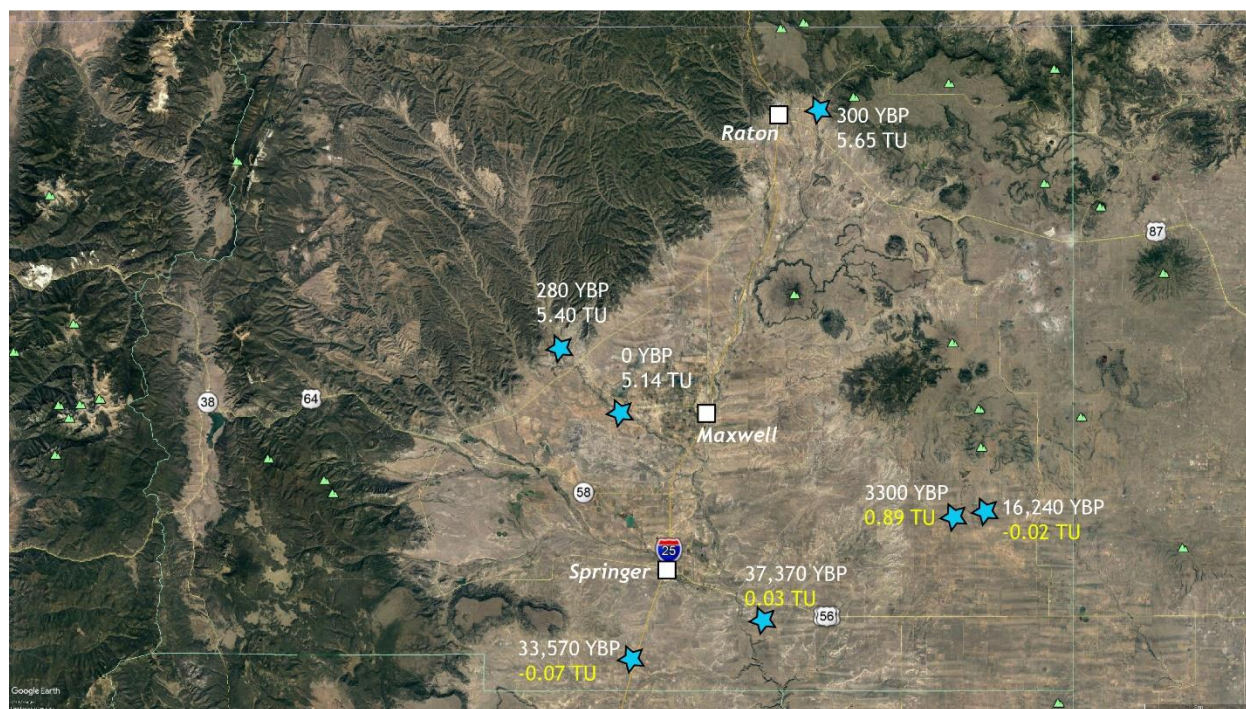


Figure 4. ¹⁴-carbon and tritium isotopic results for the Colfax area. YBP = years before present, TU = tritium units.

Wells showing significant tritium levels and younger average residence times are all located close to drainages and have shallow water levels. Wells with little to no measurable tritium and older average residence times generally have deeper water levels and do not seem to be receiving significant modern recharge.

Geologic Mapping

We are currently mapping two 1:24,000 scale quadrangles around the village of Maxwell: Maxwell and Loco Arroyo quadrangles. Locally, the geology includes significant surficial deposits of Quaternary alluvium along drainages and young sheetwash and eolian sheet sand deposits in the intervening space between drainages. Bedrock exposures include Tertiary igneous rocks and Cretaceous sedimentary rocks. In addition, there may be thin relict deposits of the Ogallala Formation, but these deposits need further review.

Igneous rocks include a localized outcrop of dacite in the far southeast corner of the Loco Arroyo quadrangle. This intermediate volcanic rock is very pale gray, and fine grained with black needle-shaped crystals of hornblende. Cretaceous sedimentary rocks are predominantly part of the Smoky Hill Shale of the Niobrara Formation, which has two informal units: a lower shale and an upper sandstone (Staatz, 1987). The lower shale unit is gray and includes some thin dark limestone beds. The upper sandstone is a brown sandstone with thin, irregularly bedded units, significant bioturbation locally, and can include the fossil oyster *Pseudoperna*.

The possible Ogallala Formation deposits are thin lags of gravel capping local high spots on the Loco Arroyo quadrangle. They consist of pebble to cobble gravels of rounded limestone, sandstone, fine-grained igneous rocks, and rare pieces of quartzite. Ogallala gravels include similar clasts, but it is not yet clear if these are original Ogallala Formation deposits or old terrace deposits related to Vermejo Creek.

Conclusions

Preliminary results suggest two discrete zones of water levels: shallow water tables in wells located adjacent to drainages and deeper water levels in wells completed in bedrock aquifers. A greater density of wells is needed to determine if this pattern holds for the eastern half of the county. Wells in the Sangre de Cristos Mountains will reflect an entirely different

geologic regime and future work will include incorporating wells in the mountain front. Initial water chemistry shows a strong relationship between bedrock a well is completed in, as well as influence from nearby surface water for shallow wells. Tritium and 14-carbon data indicate that shallow wells near drainages appear to receive fairly significant modern recharge, but deeper wells completed in bedrock aquifers generally do not appear to receive significant recharge. In addition, the presence of abundant limestone locally has resulted in artificially older 14-carbon residence times.

Future work includes continued monitoring of static water level measurements to continue tracking rates of changes between minimum and maximum use seasons as well as changes over an annual basis. Further sampling for tritium and 14-carbon isotopes will help us continue to refine our understanding of where modern recharge is occurring on the landscape. Water chemistry analyses are useful not only for documenting current water quality in these wells, but assist with tying together the geologic maps and the subsurface geology. Continued geologic mapping and petroleum well log analyses will also help with developing a better picture of the complexities of the subsurface.

References

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- Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural waters: U.S. Geological Society Water-Supply Paper 2254, 264 p.
- Staatz, M.H., 1987, Geologic map of the Tres Hermanos Peak quadrangle: U.S. Geological Survey GQ-1605, 1:24,000 scale.

Appendices

Appendix I: Static Water Level Measurements

Individual well static water level measurements, corrected to land surface. *indicates measurement that may not be correct.

Well ID	Date Measured	Depth to Water Below Land Surface (ft)
MK #1	03/07/17	96.1
	07/27/2017	162.38
MK #2	03/07/17	79.31
	7/27/2017	77.94
SV #1	03/07/17	15.1
	07/27/2017	13.26
FG #1	03/07/17	122.27
	07/31/2017	122.69
FG #2	03/07/17	121.31
	07/31/2017	122.35
FG #3	03/07/17	64.07
	07/31/2017	68.8
FG #4	03/07/17	134.97
	07/31/2017	138.69
FG #5	03/07/17	64.4
	07/31/2017	63.3
FG #6	03/07/17	35.68
	07/31/2017	37.99
FG #7	03/07/17	78.46
	07/31/2017	73.66
BLC	03/16/17	32.85
	7/26/2017	32.75

BLFT	03/16/17	43.2
	7/26/2017	11.45
BLCC	03/16/17	94.32
	7/26/2017	115.96
NY#1	03/16/17	92.67
	7/27/2017	92.03
BG #1	03/17/17	10.37
	7/25/2017	13.52
BG #2	03/17/17	26.71
	7/25/2017	18.88
BG #3	03/17/17	12.56
	7/25/2017	20.9
BG #4	03/17/17	10.9
	7/25/2017	13.54
JBY #1	03/17/17	31.86
	7/28/2017	23.92
JBY #2	03/17/17	22.55
	7/28/2017	20.24
MV6A	7/28/2017	21.32