Mora-Wagon Mound SWCD

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 Mora-Wagon Mound Hydrogeology Project, sponsored by the Mora-Wagon Mound Soil and Water Conservation District and the High Plains Grasslands Alliance. During the 2016-2017 fiscal year, ZGC measured static water level in 28 wells in August and an additional 47 wells in December of 2016, continued revisions of maps around the Turkey Mountains, began detailed mapping of the Mogote Hills-Wagon Mound area, obtained 18 trace metal chemistry samples and 17 tritium isotope samples. Here we describe the progress in each of these tasks. We would like to thank the Mora-Wagon Mound SWCD and the Soil and Water Conservation Commission for funding this project and we also thank the High Plains Grassland Alliance for additional funding and for assisting us in making contact with landowners. Fort Union Ranch has graciously agreed to release their data for inclusion in the overall project.

Static Water Level Measurements

In August and December of 2016, depth to water was measured in multiple wells spread across the county to document maximum (August) and minimum (December) use water levels (Figures 1, 2). The project began with 27 wells in January of 2015 and in December 2016, 47 additional wells were added around Wagon Mound, Watrous and Golondrinas. The project now includes over 70 individual wells and eight springs. A 300-foot steel tape is used to measure static water level for most of the wells and a 500 foot steel tape for wells deeper than 300 ft. For open casing wells, we use a well level sounder (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 three discrete groupings of water levels in the District area, a shallow zone of water levels between 10' and 40', an intermediate zone between 150' and 300' and a deeper zone with water levels greater than 350'. We hypothesize that the shallow zone is an alluvial aquifer, the intermediate zone generally corresponds to the Dakota Sandstone and that the deeper zone corresponds to the Morrison Formation or Permian rocks, depending on the well’s location. In the Turkey Mountains, a double-plunging anticline, the uplift has exposed older rocks in the central dome so these wells penetrate Triassic Dockum Group and potentially Permian Glorieta Sandstone.

For wells that have measurements from December 2015 and December 2016 and can thus be compared to determine water table behavior, eight wells showed increases in water level and 15 showed decreases. Some wells were not measured in December 2015 or 2016 due to maintenance issues, such as broken brakes on windmills, holes in internal casings, or other problems. Decreasing water levels in these areas may not reflect permanent draw-down of the water table, but most of the District had highly variable summer rains and winter snow, resulting in lack of recharge in wells that appear to receive significant modern recharge based on tritium isotope values (see below). For example, wells around Ocate usually respond quickly to precipitation in the Sangre de Cristo Mountains, but this year very little snow accumulated in the area and these wells mostly show declining water levels.

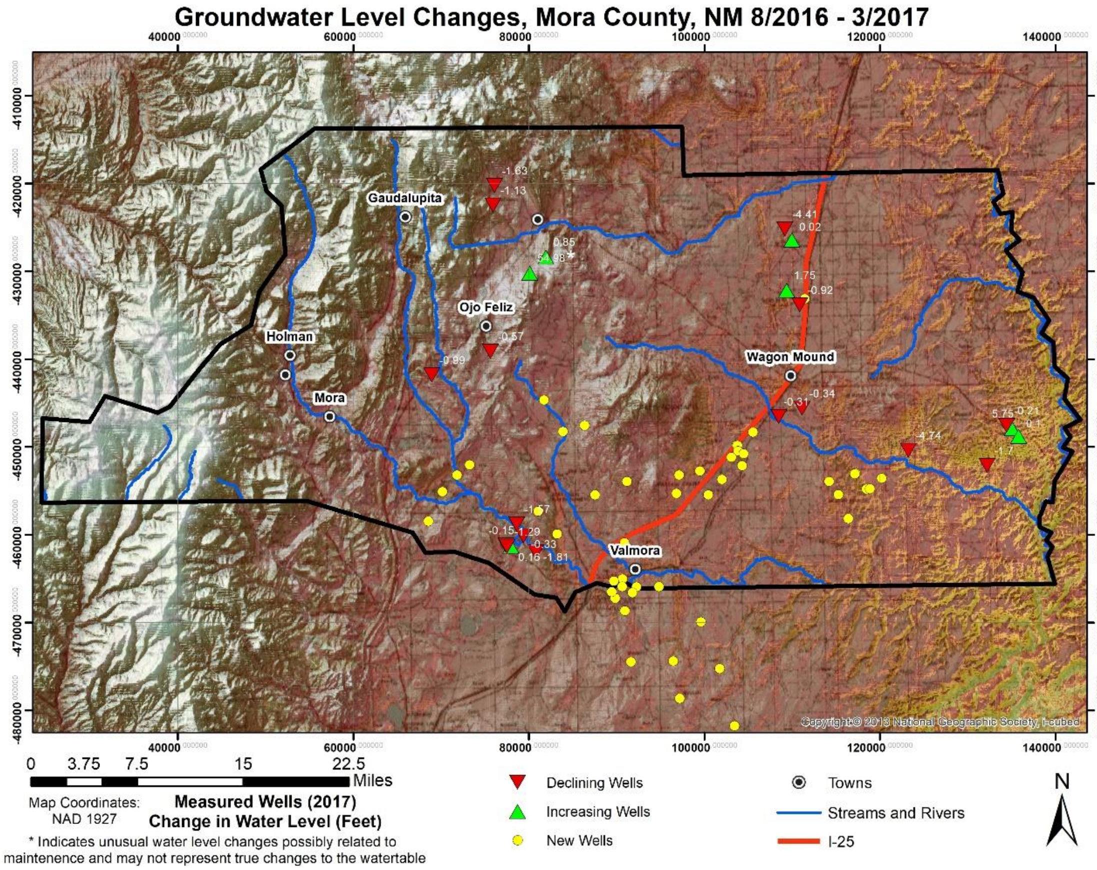


Figure 1. Rate of change in feet of static water levels in wells in the MWMSWCD network from August 2016 to February 2017.

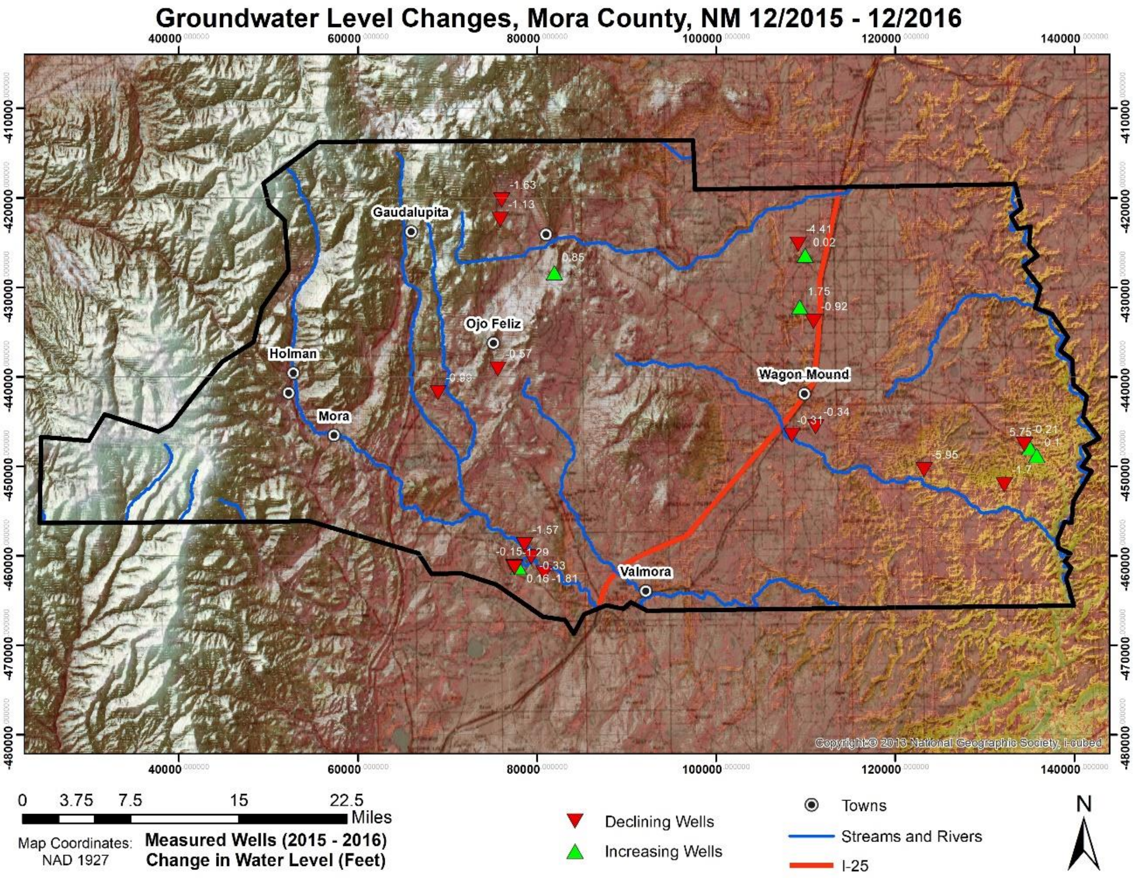


Figure 2. Rate of change in feet of static water levels in wells in the MWMSWCD network from December 2015 to December 2016.

Water Chemistry

Approximately one liter of water was collected from each of 14 wells and four springs around the District for analyses of major cations and anions as well as trace metals (Figure 3). 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 Analytical Chemistry Laboratory at 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) (Figure 3).

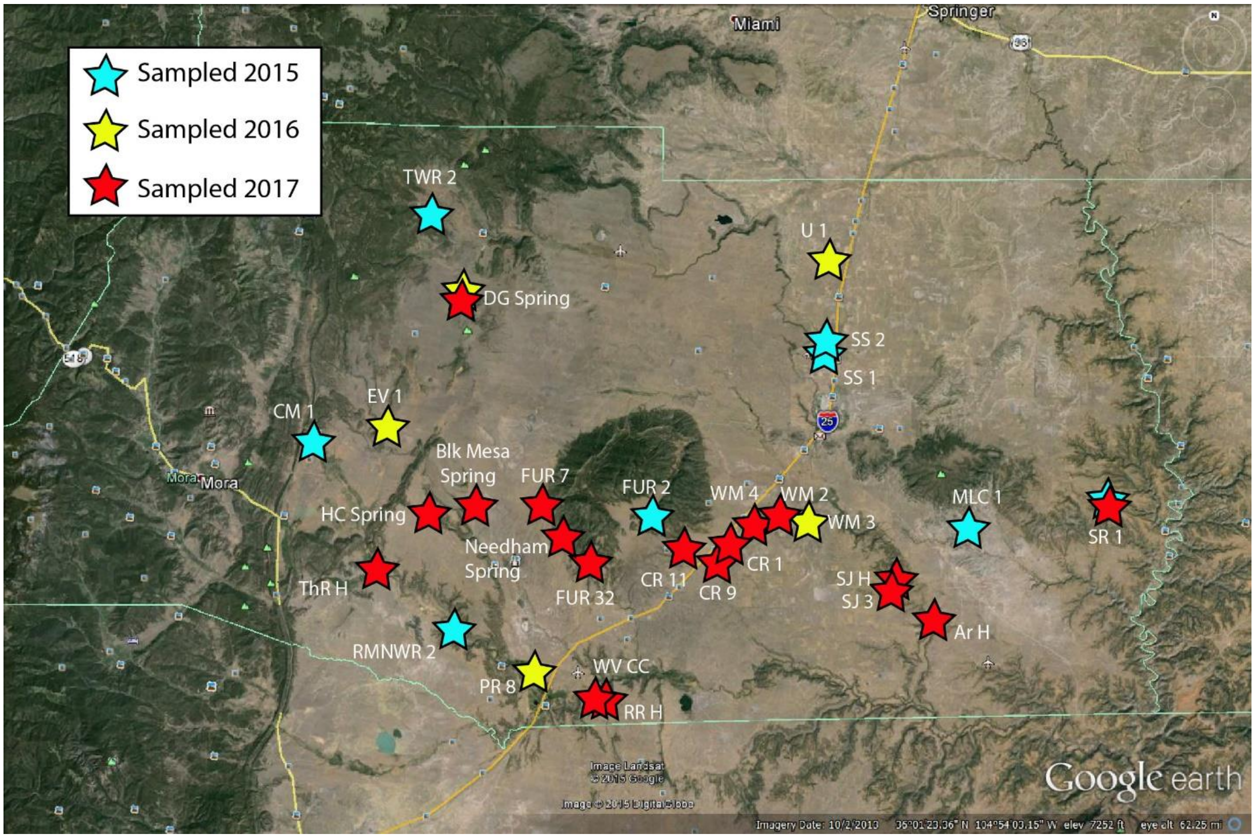


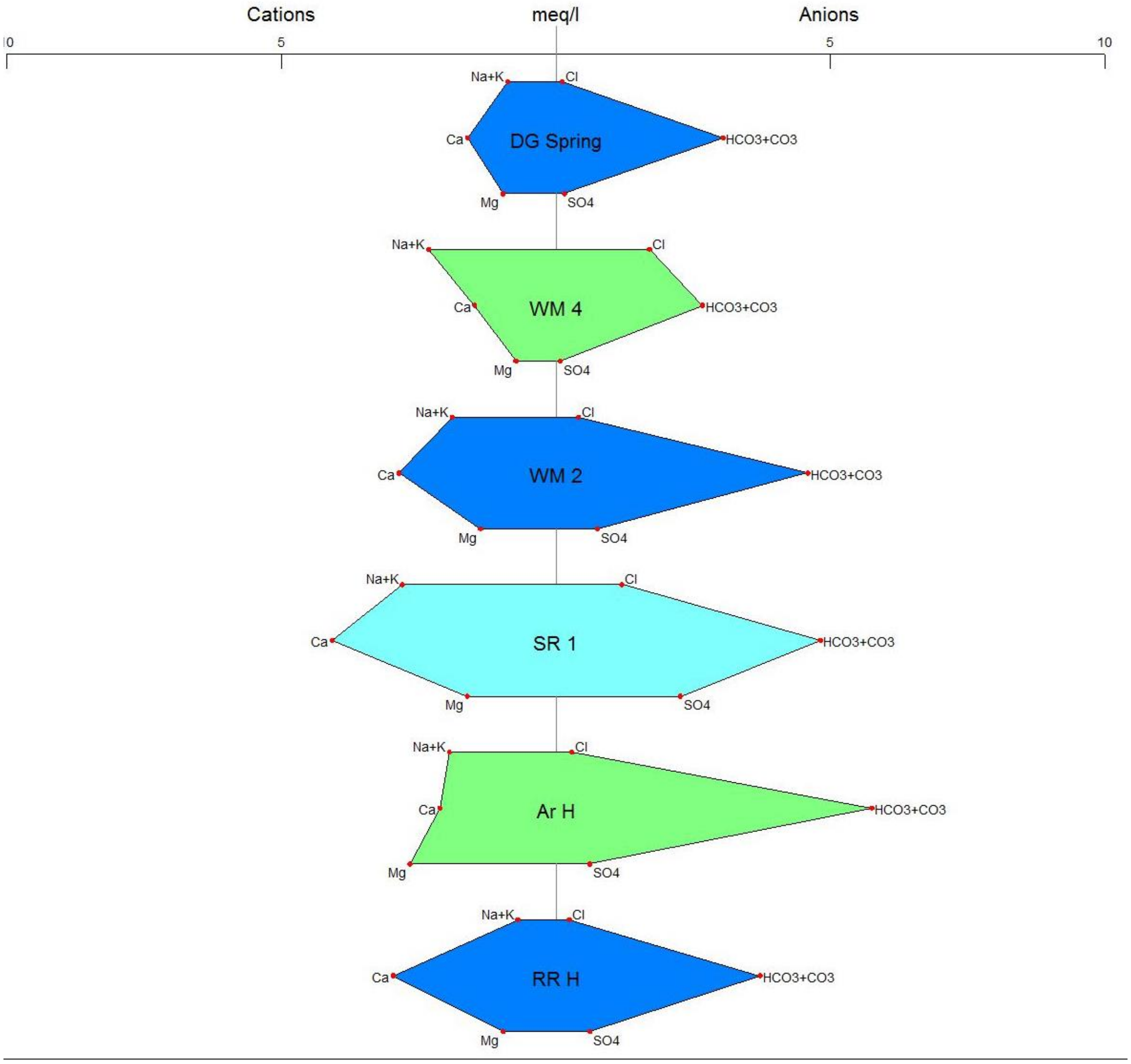
Figure 3. Well locations with water chemistry samples taken. Stiff and Piper diagrams are below for the 2017 samples. Analytical results for 2015 and 2016 samples are in Zeigler et al. 2015 and 2016.

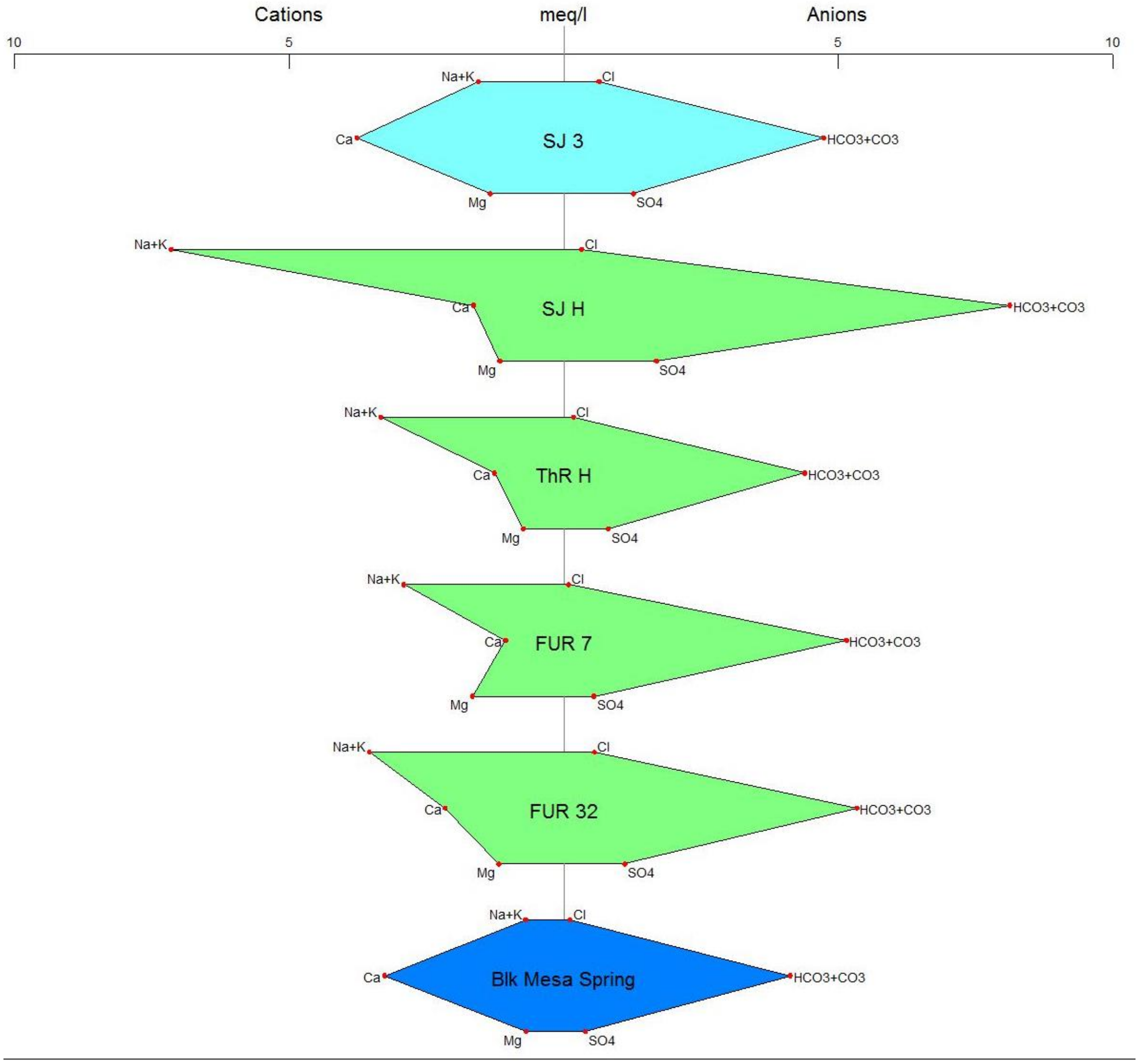
Each of the ions analyzed for can provide information about groundwater-rock unit interactions. A brief overview of each ion was noted in the 2014-2015 progress report (Zeigler et al., 2015) and we recommend Hem's (1985) *Study and Interpretation of the Chemical Characteristics of Natural Waters* for an in-depth review of groundwater chemistry. The chemistry of the water in each well reflects primarily the bedrock unit(s) that the well is drawing water from (Figures 4, 5). 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. These differences in chemistry reflect the differences in mineralogy among these bedrock units. Dakota Group sandstones are mostly composed of quartz cemented with calcite, which can dissolve to provide carbonate, calcium and some magnesium. Locally, however, the Dakota Group sandstones are cemented with silica cement. Black shales, which are commonly interbedded with sandstone in the Dakota Group, and constitute the primary lithology of the Graneros Shale, Greenhorn

Limestone and Carlisle Shale, contain gypsum, a calcium sulfate, which provides sulfate. Sandstones in the Morrison Formation are rich in feldspars, which can contain sodium and potassium, providing these two cations. Sandstones in the Triassic Dockum Group are locally rich in feldspar grains, but tend overall to be less rich in feldspar when compared to Morrison Formation sandstones.

Wells that include a mixture of waters from the Dakota Group and the Morrison will thus include some proportion of all the ions expected for those waters. The presence of higher proportions of sodium and potassium in several wells suggests that these wells may penetrate at least some part of Morrison Formation strata, even if the local terrain exposes only Dakota Group. The presence of Morrison Formation strata based on water chemistry from wells can be used to help constrain what the subsurface geology looks like, in addition to the geologic mapping and examination of petroleum and water well log information. Several wells also show high concentrations of sulfate, indicating some influence by gypsum-bearing units.

Trace metal analyses on these samples did not show significant concentrations of 26 different metals, ranging from aluminum and arsenic to uranium (EPA method 200.8). No potential health hazards were identified for trace metals concentrations.


Cations
meq/l
Anions
10
5
5
10
Na+K
Cl
Ca
HCO3+CO3
Mg
SO4
DG Spring
WM 4
WM 2
SR 1
Ar H
RR H


Cations
meq/l
Anions
10
5
5
10
Na+K
Cl
Ca
HCO3+CO3
Mg
SO4
SJ 3
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ThR H
FUR 7
FUR 32
Blk Mesa Spring

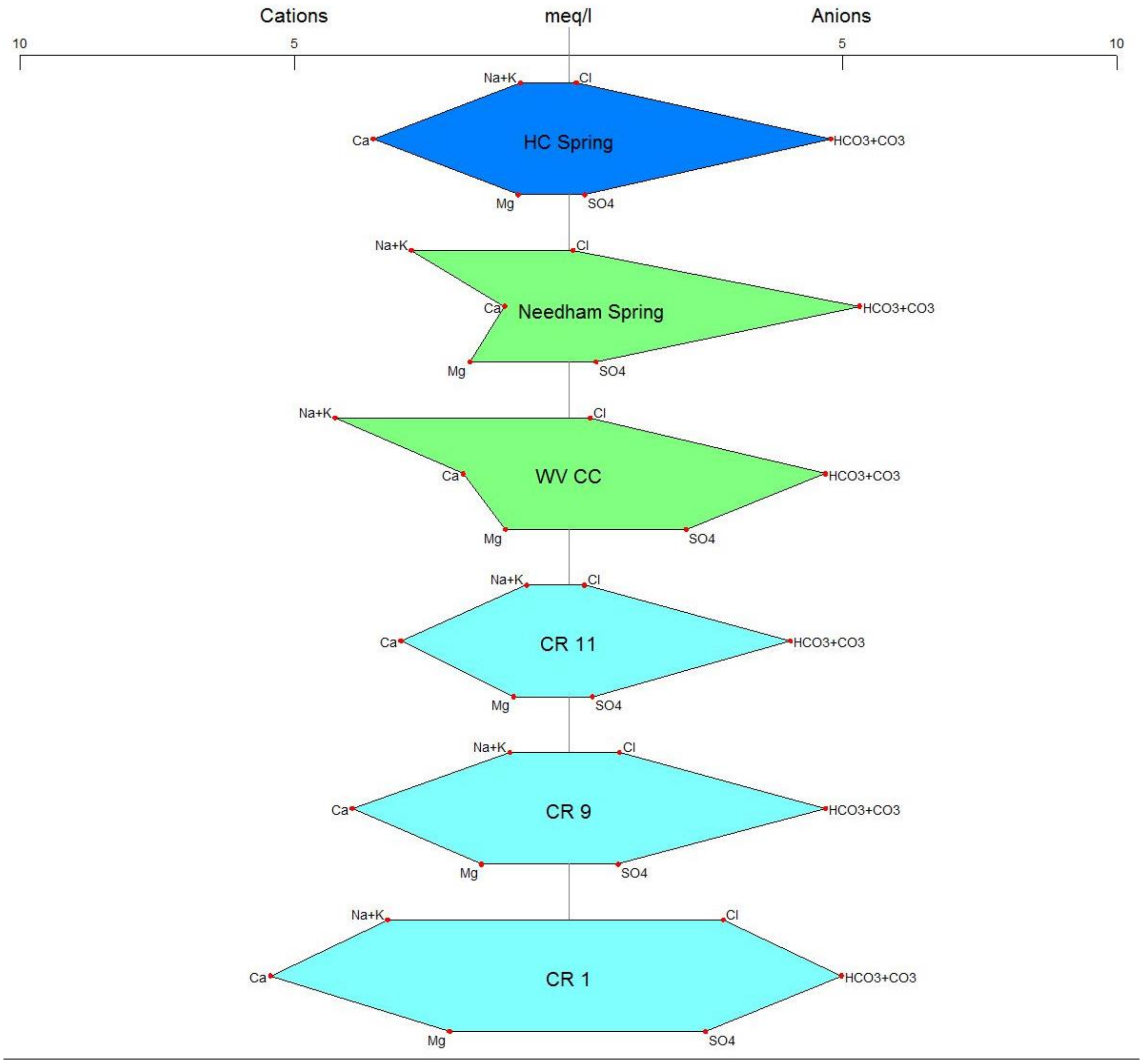

Figure 4. Stiff diagrams for samples collected in 2016-2017. The shape of each polygon reflects proportions of major cation/anion concentrations. Higher proportions of Na+K appear to correlate to interaction of groundwater with arkosic sandstones in the Morrison Formation. Higher SO_4 concentrations reflect interaction with gypsum-bearing horizons, predominantly black shale units.

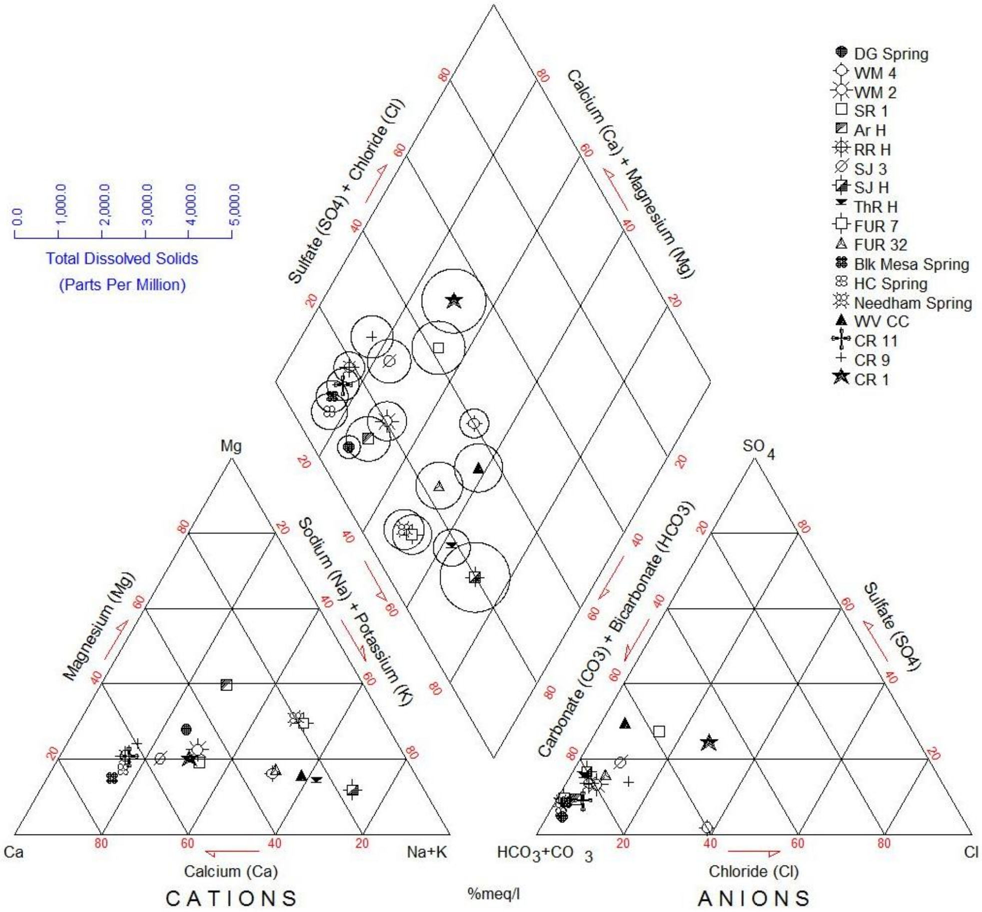

Figure 5. Piper diagram for water chemistry samples collected in 2016-2017 from the Mora-Wagon Mound area. Circles indicate total dissolved solids for each well – larger circles indicate higher TDS.

Tritium Isotopes

We collected one liter of water from three springs and 14 wells for analysis for tritium isotopes (Figure 6). These samples are in the process of analysis at the Tritium Laboratory at the University of Miami. Results will be released as a report addendum later this summer. 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).

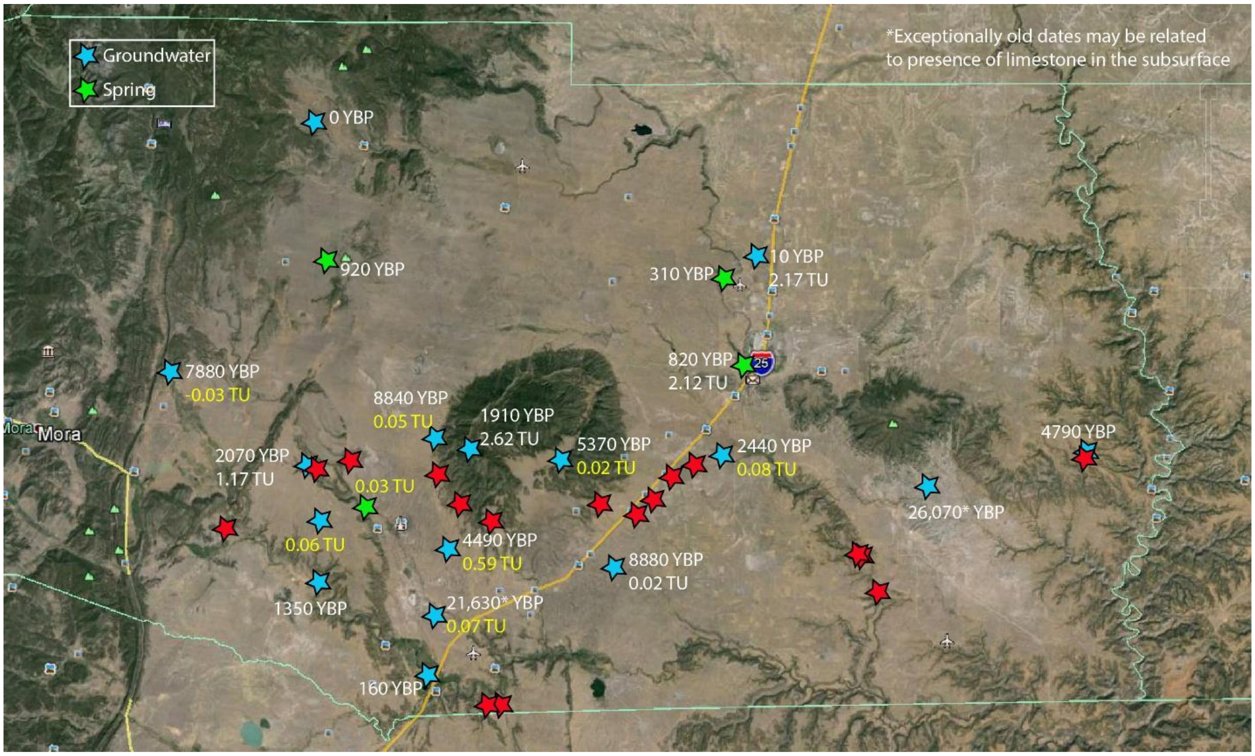

Figure 6. Wells sampled for tritium. Green and blue stars indicate samples collected in 2014-2015 and 2015-2016. Red stars indicate wells sampled 2016-2017 with results pending. Number followed by "YBP" is the 14-carbon result for previously sampled wells, used here as an indicator of *average residence time*. Number followed by "TU" is the tritium result. YBP = years before present, TU = tritium unit.

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 and 15 TU indicate waters that are modern (5-10 years old).

As noted in previous reports, the young average residence times derived from 14-carbon isotopic data and higher proportions of tritium in many of the previously analyzed samples suggest some degree of interaction with younger waters infiltrating from the surface. However, the majority of the water samples analyzed indicate very little or no modern recharge is making its way into the aquifer units. The apparent lack of a trend of younger waters to the west suggest that the bedrock aquifer units (as opposed to alluvial aquifers) are more internally partitioned than might otherwise be expected. In addition, structural features such as folds and faults, as well as potential paleotopography in the subsurface bring older rocks (and possibly older waters) closer to the surface. This suggests that the hypothesis that aquifer units in northeastern New Mexico receive recharge from summer rains and/or snowpack in the Sangre de Cristo Mountains is not correct and that only either very shallow wells (alluvial aquifers), wells located immediately adjacent to perennial streams or wells located in the front range have the potential to receive significant modern recharge.

Geologic Mapping and Cross Sections

We have mapped some or all of the following 1:24,000 quadrangles: Mogote Hills, Optimo, Maxson Crater, Fort Union and Loma Parda, which will be compiled and digitized over the coming year along with previous mapping on the northern half of Watrous quadrangle, Wagon Mound and Colmor quadrangles. This area was chosen for initial mapping efforts in order to incorporate areas with known groundwater issues, such as declining water tables, declines in rate of flow from existing wells as reported by producers, and water quality problems. Bedrock outcrops include (in age order) the Permian Yeso Formation and Glorieta Sandstone, Triassic Dockum Group, Jurassic Exeter (?Entrada) Sandstone and Morrison Formation, Cretaceous Dakota Sandstone, Graneros Shale, Greenhorn Limestone, and Carlisle Shale, Miocene-Pliocene gravels (?Ogallala Formation) and Quaternary volcanic deposits as well as Recent eolian sand and alluvial deposits.

Features observed during mapping efforts include north-south trending fracture sets (discussed in Zeigler et al., 2015), northwest-southeast trending faults that have a wide range of offset and local folds. Two prominent folds in the Watrous-Wagon Mound area are the double-plunging anticlines that form the Turkey Mountains and the lower-relief Mogote Hills. Numerous faults cross-cut these features, mostly trending north-south to northwest-southeast. In general, most of these faults have less than 20 feet of offset, but some exhibit much greater structural relief. The hinge of the Turkey Mountains anticline trends northeast-southwest whereas the hingeline of the Mogote Hills anticline is approximately north-south and the structure plunges relatively steeply towards the Wagon Mound volcanic features and more gently to the south towards the Rio Mora valley. Mapping of the Turkey Mountains (Optimo and Maxson Crater quadrangles) has led to significant revisions to the pre-existing geologic map (Boyd, 1983) which will greatly clarify variations in local hydrostratigraphy.

In addition to the surface geologic mapping, we have reviewed well log information for water wells and petroleum wells around the Turkey Mountains to Las Mesas del Conjelon area. Below are two cross-sections, one oriented north-south from the edge of the basalt-capped mesa north of Wagon Mound to the southwestern flank of the Mogote Hills, and the other oriented west-east from the hogback of the eastern Turkey Mountains across Las Mesas del Conjelon to just west of the Canadian River drainage. These two cross-sections highlight a few key features that probably control the vertical distribution of aquifer units in the Wagon Mound area. Structural features, such as the anticlines that form the Turkey Mountains and the Mogote Hills, and some large-scale faults cause significant vertical differences in depth to aquifer units. In addition, paleotopography developed on top of the Jurassic Morrison Formation is likely also a factor in vertical position of aquifer units, as is the case in Union County to the northeast. However, further work is needed to determine the degree of influence on vertical distribution related to structural features versus paleotopography.

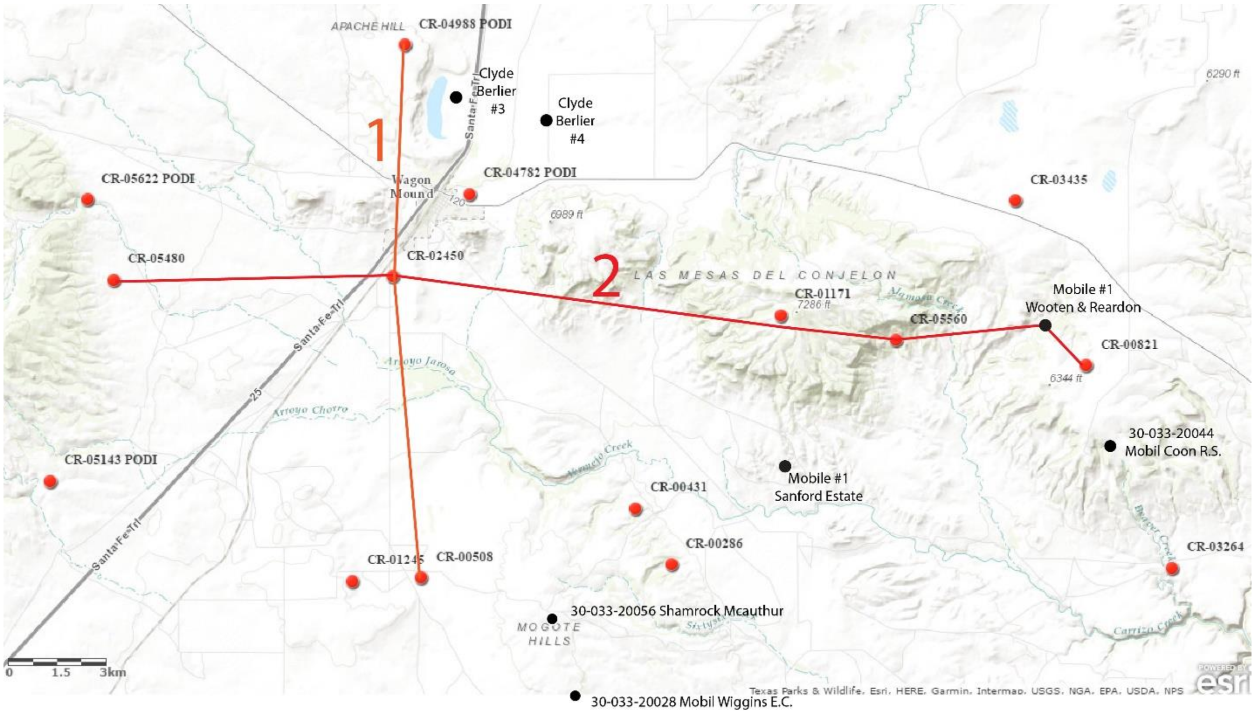

Figure 7. Lines of cross-section for the Wagon Mound area using wells with reasonable quality well log data.

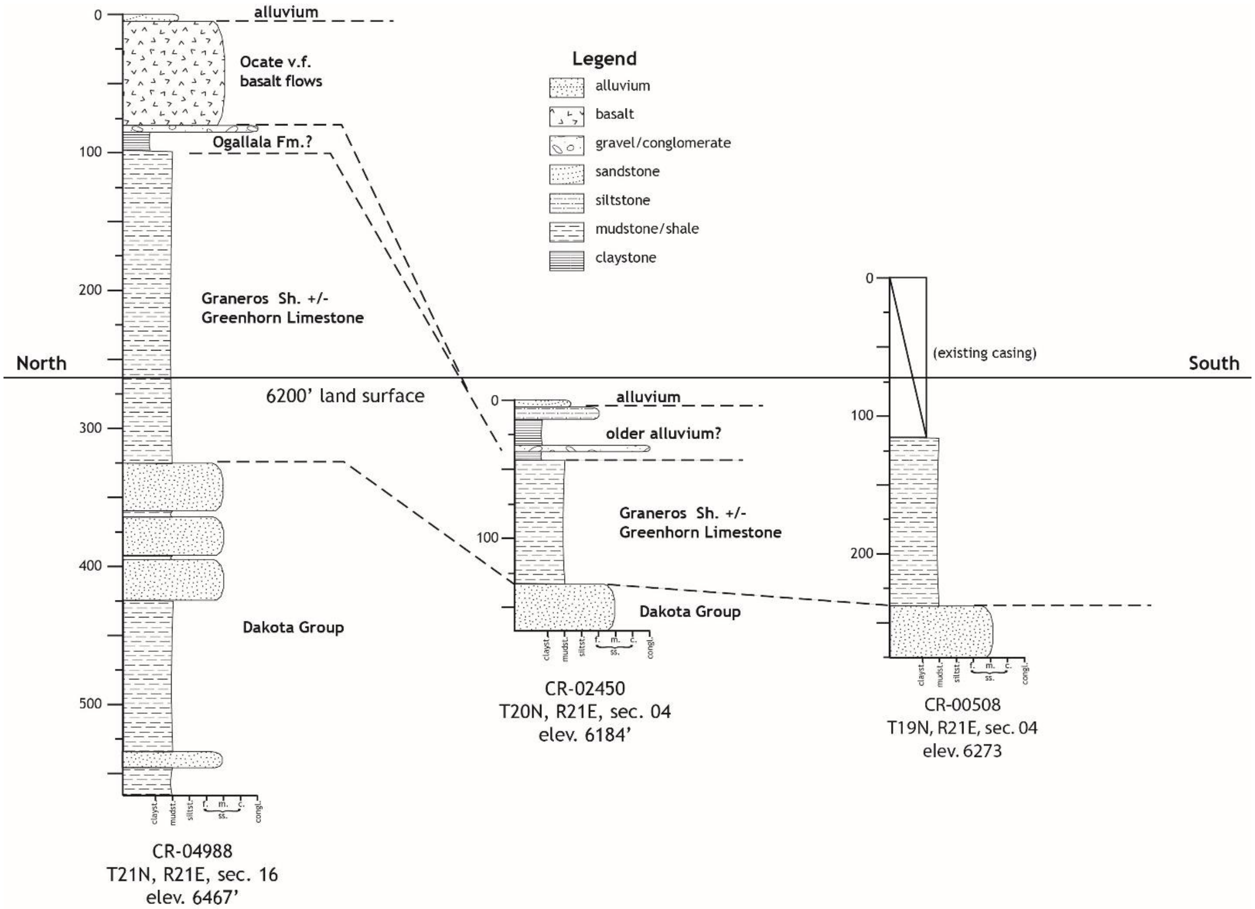

Figure 8. Cross-section 1, oriented north -south. Wells are hung from an arbitrary elevation to emphasize differences in depth to aquifer units.

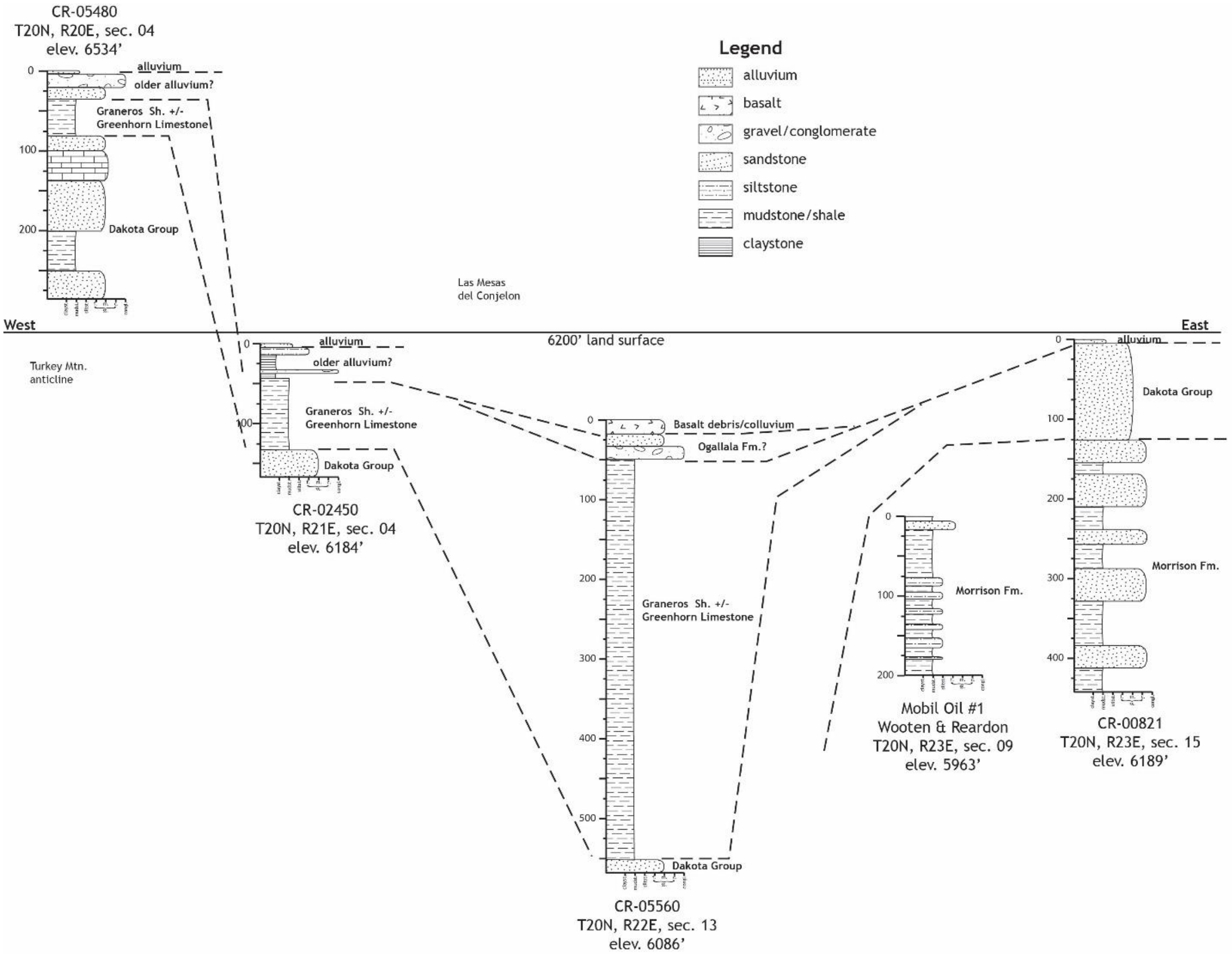

Figure 9. Cross-section 2, oriented west-east. CR-01171 is not shown in this cross section as the wellhead sits at over 7000', well above the cross-section's arbitrary datum line. Mobil Oil #1 is only the upper 200' of well log and cutting information. Preliminary mapping suggests CR-05560 is offset from Mobil Oil #1 and CR-00821 by a fault with significant structural relief.

We also are currently continuing micro-mapping of key drainages in the center part of the district to attempt to determine the scale of "recharge windows" in local arroyo bottoms. For this effort, we have been measuring the dimensions of mud-bottomed portions of arroyos and creek beds to compare to the overall dimensions of the entire arroyo. The mud-bottomed portions indicate where surface flow slows enough to pond, and thus may indicate where some recharge and/or shallow infiltration is entering the shallow subsurface. We will compare the total surface area of "recharge windows" to the total surface area of the creek bottom to determine the rough percentage of potential shallow infiltration area. Given the lack of significant tritium isotope concentrations in many of the samples from bedrock aquifers, shallow infiltration from surface flow is probably not a strong influence on recharge to bedrock aquifer units in the area.

Conclusions

Water chemistry, static water levels, well log data, and surface mapping demonstrate the complexity of the geology in the Mora-Wagon Mound District area. Zones of groundwater appear to occur at discrete depths over much of the Distric area: shallow (0 – 40'), intermediate (150-300') and deep (>350'), which appear to correlate reasonably well to alluvial (shallow), the Dakota Sandstone (intermediate) and the Morrison Formation (deep). Additional structural complexities, such as the Ocate anticline and the Turkey Mountains, as well as paleotopography developed on the Morrison Formation, bring deeper and older rock units to the surface. Radiocarbon dates do not have an obvious trend of younger waters to the west or to the east, although the youngest waters present were taken from the farthest west well. Very old radiocarbon ages, such as the oldest date obtained from south of the Turkey Mountains, may reflect interaction of those waters with carbonates in the Morrison Formation. Initial tritium data appear to indicate that there is some modern recharge reaching groundwater sources locally, but in many places there is not volumetrically significant young water making its way into the aquifer systems.

Future work includes continued monitoring of static water level measurements to continue tracking rates of changes between minimum and maximum use seasons and on an annual basis. Continued geologic mapping and petroleum well log analyses will assist in developing a better picture of the complexities of the subsurface. In addition to the data collection efforts described above, we are also working with Rio Mora National Wildlife Refuge and Moore Hydrology to install thermocouple nests in two drainages to examine shallow infiltration via temperature measurements. We are also partnering with the University of North Caroline-Charlotte's stable isotope laboratory to process samples for oxygen and hydrogen stable isotopes.

References

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Appendices

Appendix I: Static Water Level Measurements

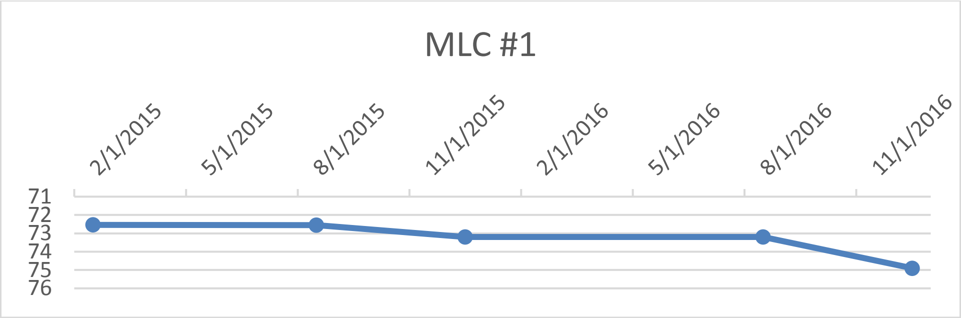
Individual well static water level measurements, corrected to land surface. *indicates measurement that is significantly different than previous or following measurements. For some wells, this is probably related to maintenance performed on the well that caused it to draw more water after the maintenance (e.g. LG #1). For wells where a measurement could not be obtained, “nm” indicates “not measured”.

ID	Date Measured	Depth to Water Below Land Surface (feet)
MLC #2	2/12/2015	72.54
	8/17/2015	72.55
	12/8/2015	73.2
	8/15/2016	73.2
	12/13/2016	74.9
MLC #1	1/19/2015	133.7*
	8/18/2015	106.3
	12/8/2015	109.31
	8/15/2016	110.52
	12/13/2016	115.26
SR #1	1/19/2015	nm
	8/18/2015	136.4
	12/8/2015	118.64
	8/15/2016	111.6
	12/12/2016	112.89
SR #3	1/19/2015	233.3
	8/18/2015	233.06
	12/8/2015	233.12
	8/15/2016	233.42
	12/12/2016	233.02
SR #5	1/19/2015	116.38
	8/18/2015	116.28
	12/8/2015	116.37
	8/15/2016	116.92
	12/12/2016	116.58

FUR #1	2/24/2016	104.03
	8/23/2016	104.78
	3/22/2017	100.8
FUR #4	1/20/2015	73.69
	8/19/2015	71.89
	2/24/2016	75.31
	8/23/2016	74.34
	3/22/2017	67.36
FUR #9	1/20/2015	2.91
	8/19/2015	83.85
	3/22/2017	nm
FUR #10	2/24/2016	70.86
	8/16/2016	69.07
	3/22/2017	70.61
TWR #1	1/20/2015	87.06
	8/17/2015	86.19
	12/10/2015	85.41
	8/26/2016	85.72
	12/15/2016	86.54
TWR #2	1/20/2015	46.24
	5/21/2015	45.48
	8/17/2015	42.74
	12/10/2015	43.1
	8/26/2016	42.95
	12/15/2016	44.73
RMNWR #1	2/8/2015	129.51
	8/19/2015	129.31
	12/9/2015	129.01
	8/16/2016	130.96
	12/14/2016	130.82
RMNWR #2	2/8/2015	28.4
	8/19/2015	27.81
	12/9/2015	29
	8/16/2016	29.09
	12/14/2016	30.57

RMNWR #3	2/8/2015	3.75
	8/19/2015	2.62
	12/9/2015	3.45
	8/16/2016	3.75
	12/14/2016	3.78
WMR #1	2/9/2015	38.1
	8/20/2015	44.6
	12/8/2015	32.86*
	8/16/2016	28.91*
WMR #2	2/9/2015	23.9
	8/20/2015	24.59
	12/8/2015	24.71
	8/16/2016	24.87
	12/12/2016	25.02
WMR #3	2/9/2015	46.82
	8/20/2015	46.62
	12/8/2015	46.26
	8/16/2016	46.47
	12/12/2016	46.6
DG #1	2/9/2015	174.83
	8/19/2015	174.86
	12/10/2015	175.0
	8/17/2016	175.21
	1/26/2017	174.15
S&S #1	2/10/2015	43.82
	8/18/2015	44.31
	12/9/2015	45.88
	8/15/2016	48.22
	12/12/2016	44.13
S&S #2	2/10/2015	24.52
	8/18/2015	25.87
	12/9/2015	24.2
	8/15/2016	60.05*
	12/12/2016	25.12
EC #1	2/12/2015	393.84

	8/17/2015	392.93
	12/10/2015	392.2
	8/16/2016	392.9
	12/14/2016	393.19
EV #1	2/18/2015	261.37
	8/28/2015	263.19
	12/10/2015	263.11
	8/16/2016	263.24
	12/15/2016	263.68
U #1	5/20/2015	51.2
	8/18/2015	49.4
	12/11/2015	50.44
	8/17/2016	53.43
	12/12/2016	50.42
U #2	5/20/2015	27.23
	8/18/2015	27.03
	12/11/2015	23.96
	8/17/2016	30.56
	12/12/2016	28.37
F #1	2/25/2016	23.97
	8/16/2016	24.08
	12/14/2016	24.12
F #2	2/25/2016	64.84
	8/16/2016	66.02
	12/14/2016	66.13
F #3	2/25/2016	38.65
	8/16/2016	38.52
	12/14/2016	38.49
LG #1	4/22/2016	54.98*
	8/17/2016	162.35
	1/26/2017	162.36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5/1/2015
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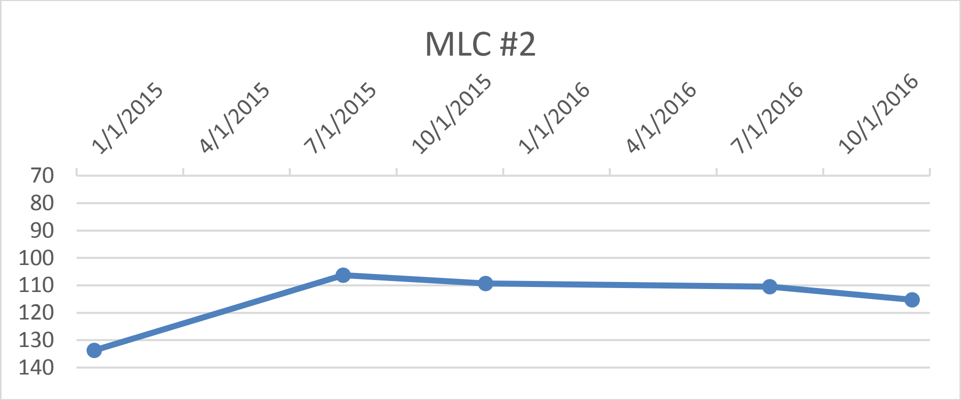
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4/1/2015
7/1/2015
10/1/2015
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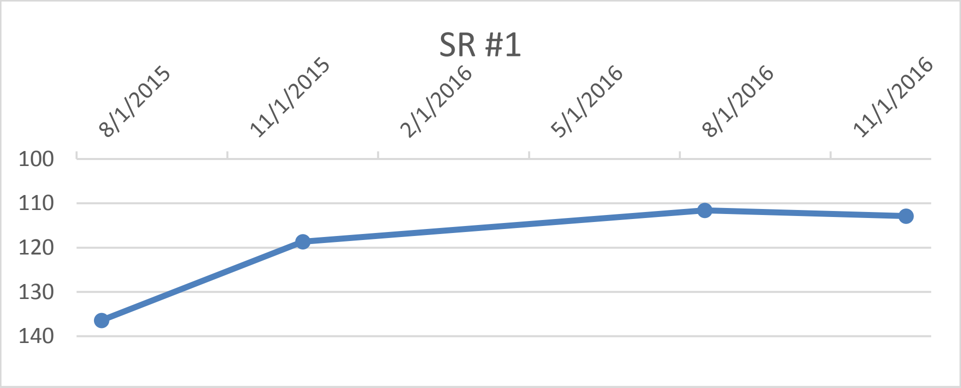
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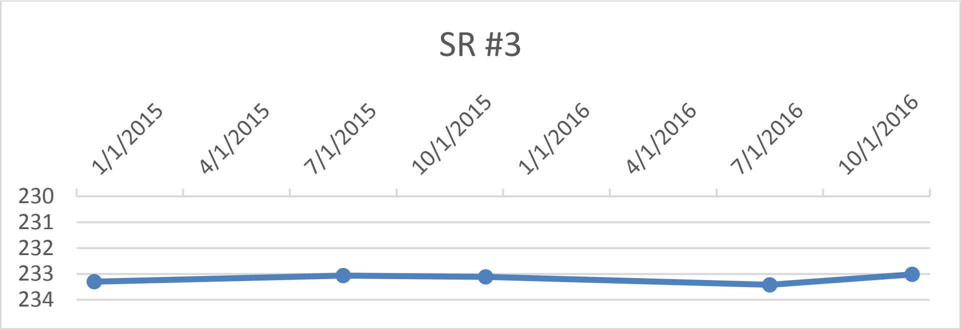
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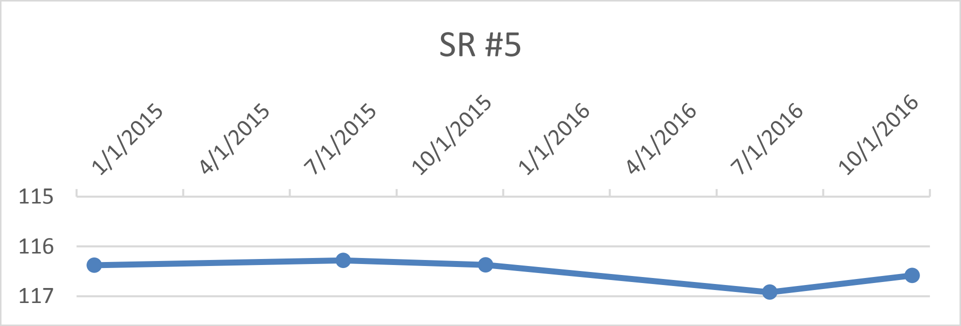
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7/1/2016
10/1/2016
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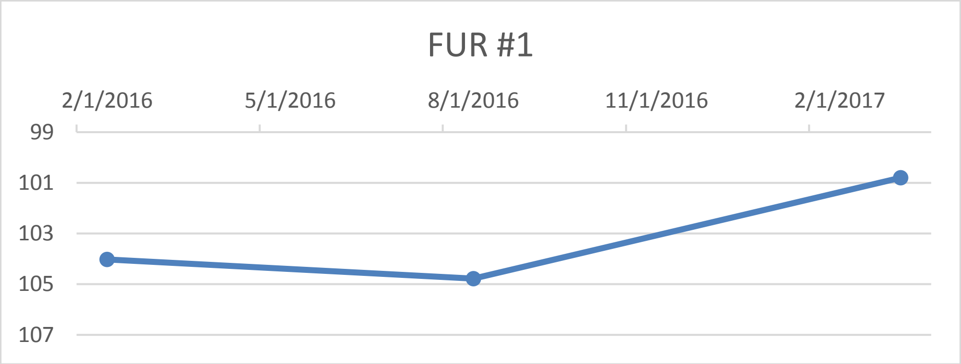
116
117


FUR #1
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5/1/2016
8/1/2016
11/1/2016
2/1/2017
99
101
103
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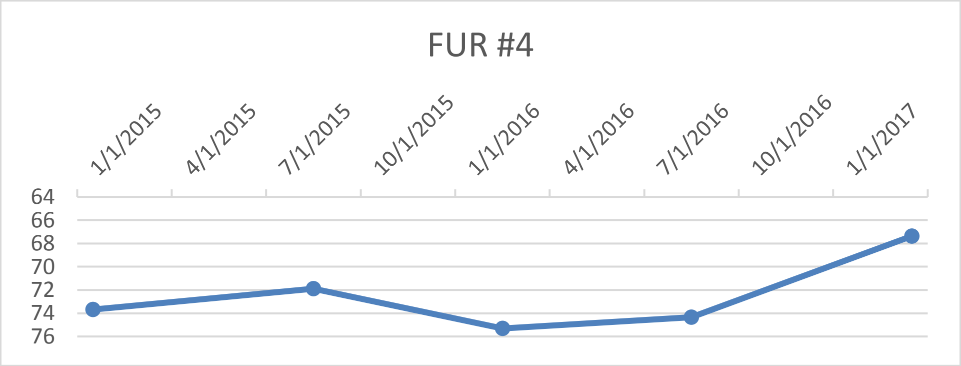
107


FUR #4
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10/1/2016
1/1/2017
64
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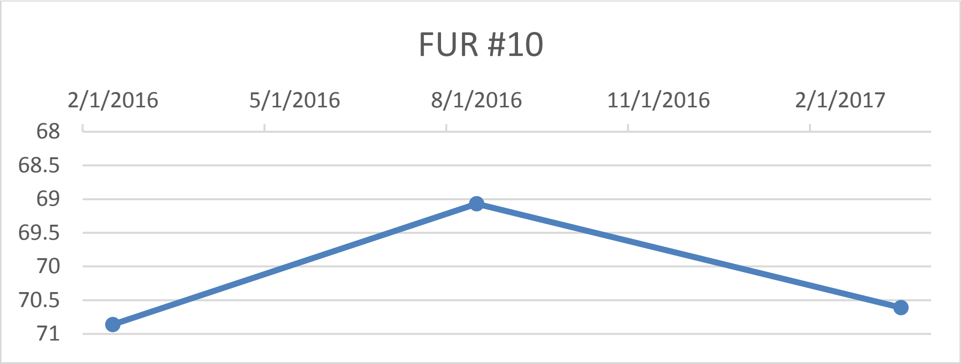
FUR #10
2/1/2016
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2/1/2017
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68.5
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69.5
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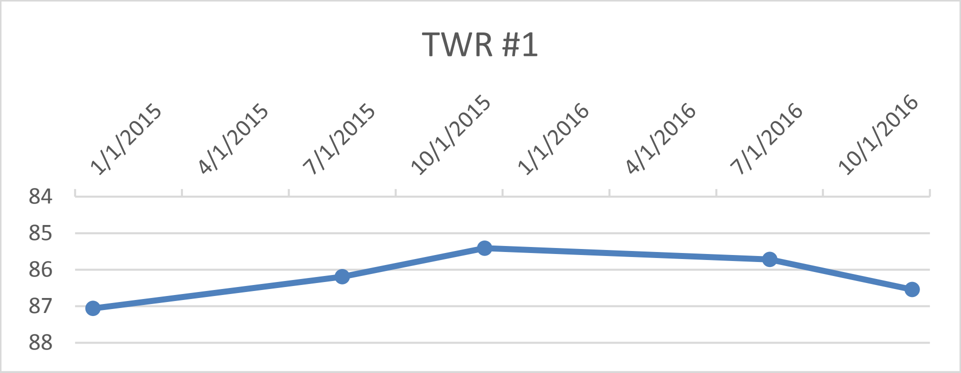
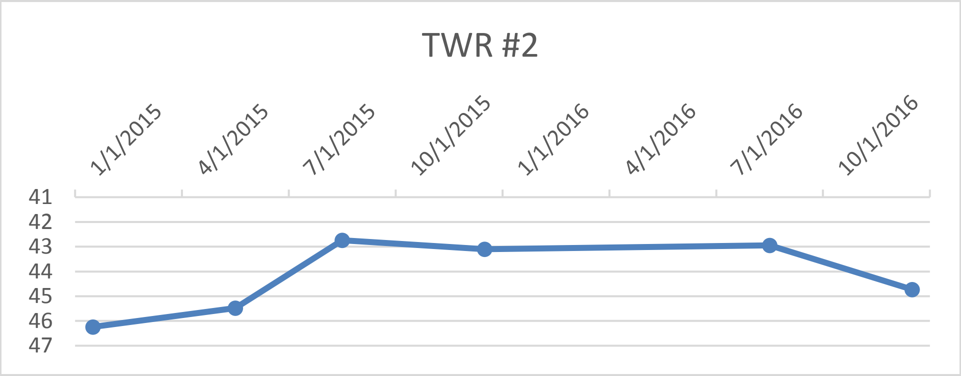
70.5
71


TWR #1
1/1/2015
4/1/2015
7/1/2015
10/1/2015
1/1/2016
4/1/2016
7/1/2016
10/1/2016
84
85
86
87
88


TWR #2
1/1/2015
4/1/2015
7/1/2015
10/1/2015
1/1/2016
4/1/2016
7/1/2016
10/1/2016
41
42
43
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45
46
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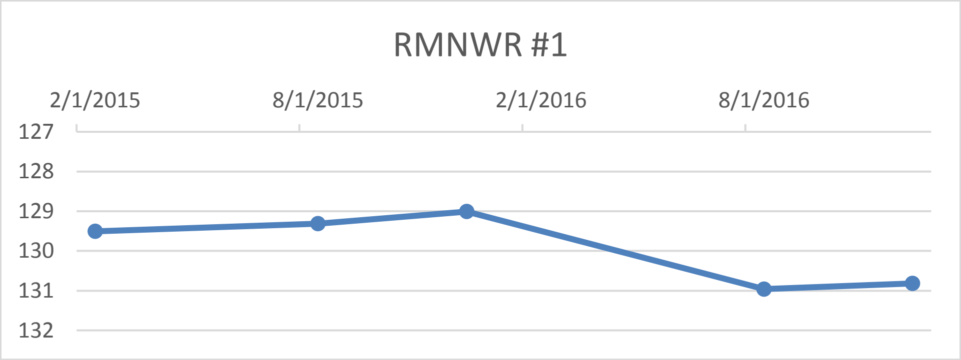
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2/1/2015
8/1/2015
2/1/2016
8/1/2016
127
128
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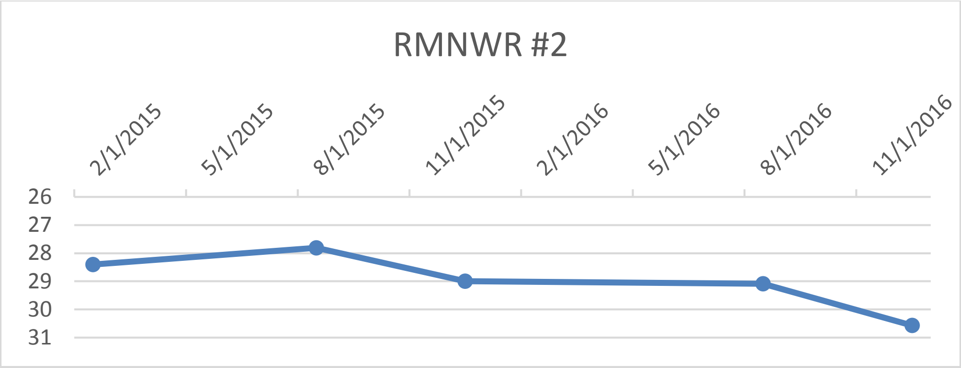
131
132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2/1/2015
5/1/2015
8/1/2015
11/1/2015
2/1/2016
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8/1/2016
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26
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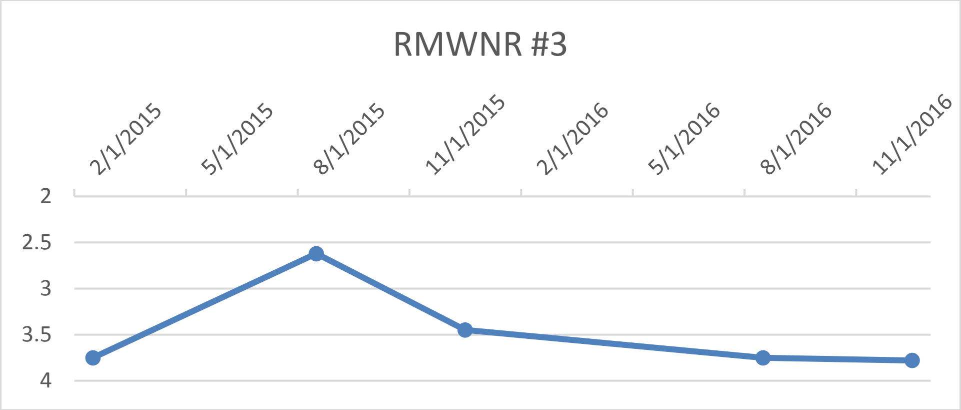
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2/1/2015
5/1/2015
8/1/2015
11/1/2015
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5/1/2016
8/1/2016
11/1/2016
2
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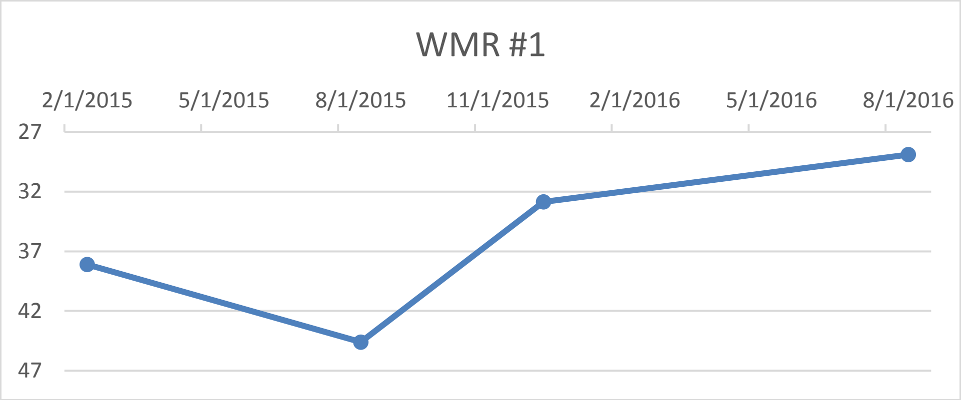
3
3.5
4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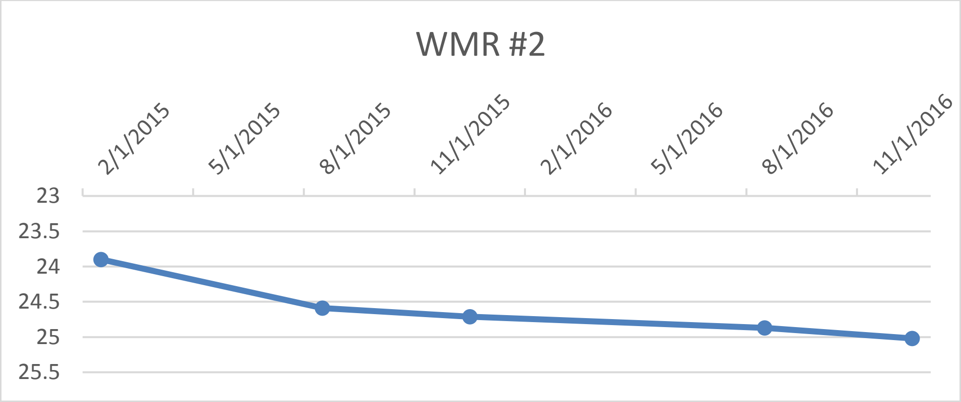
2/1/2015
5/1/2015
8/1/2015
11/1/2015
2/1/2016
5/1/2016
8/1/2016
27
32
37
42
47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2/1/2015
5/1/2015
8/1/2015
11/1/2015
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8/1/2016
11/1/2016
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24.5
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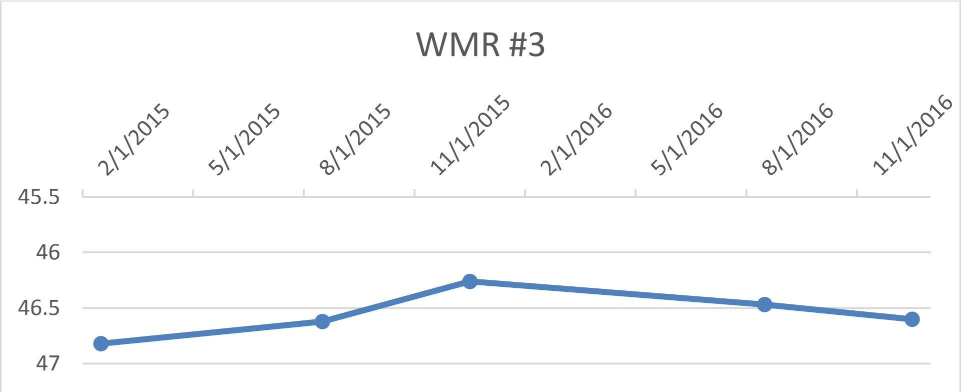
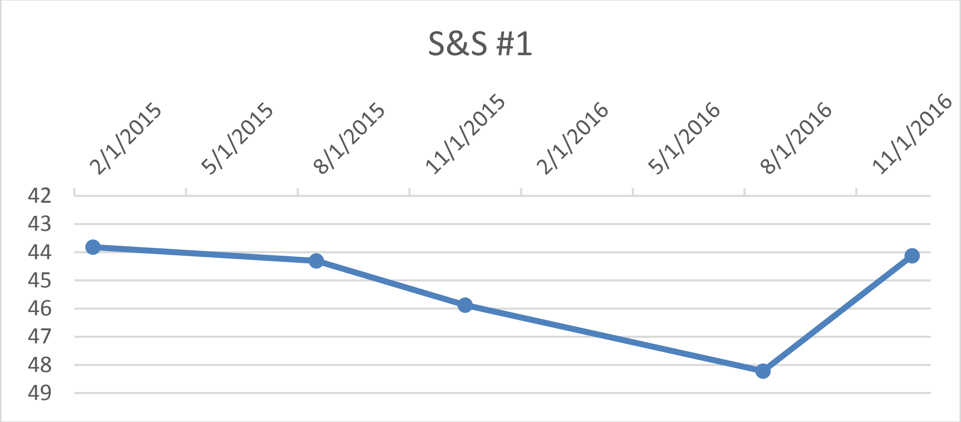
25.5


WMR #3
2/1/2015
5/1/2015
8/1/2015
11/1/2015
2/1/2016
5/1/2016
8/1/2016
11/1/2016
45.5
46
46.5
47


S&S #1
2/1/2015
5/1/2015
8/1/2015
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5/1/2016
8/1/2016
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44
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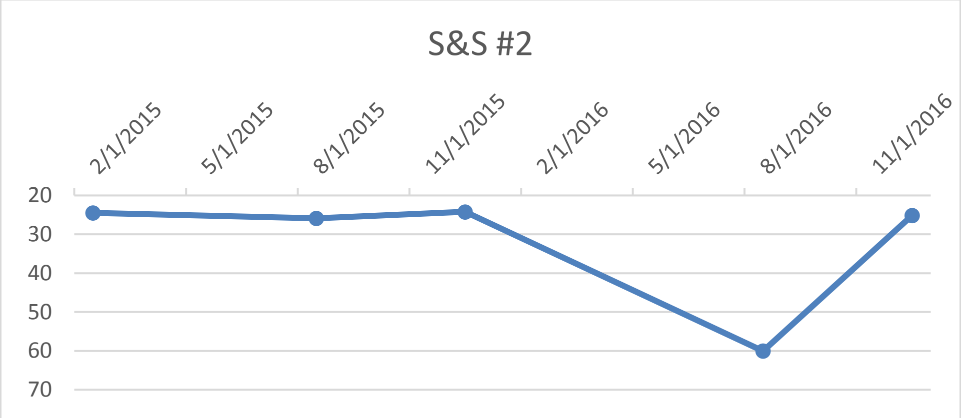
47
48
49


S&S #2
2/1/2015
5/1/2015
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8/1/2016
11/1/2016
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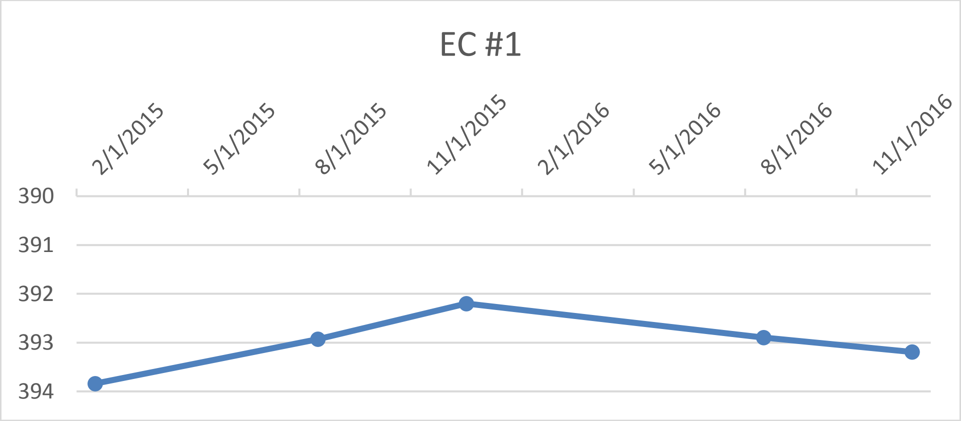
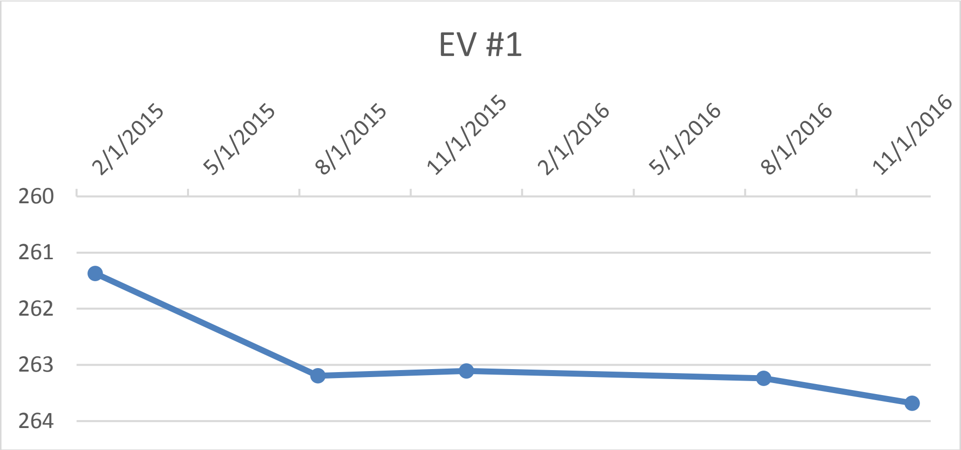
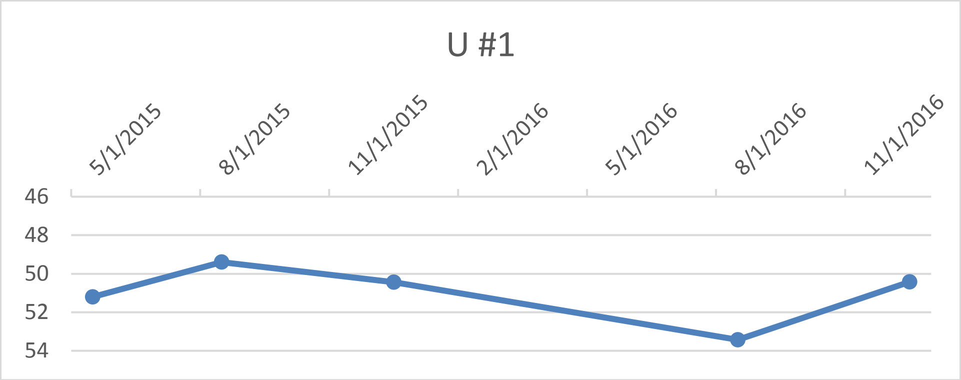

EC #1
2/1/2015
5/1/2015
8/1/2015
11/1/2015
2/1/2016
5/1/2016
8/1/2016
11/1/2016
390
391
392
393
394


EV #1
2/1/2015
5/1/2015
8/1/2015
11/1/2015
2/1/2016
5/1/2016
8/1/2016
11/1/2016
260
261
262
263
264


U #1
5/1/2015
8/1/2015
11/1/2015
2/1/2016
5/1/2016
8/1/2016
11/1/2016
46
48
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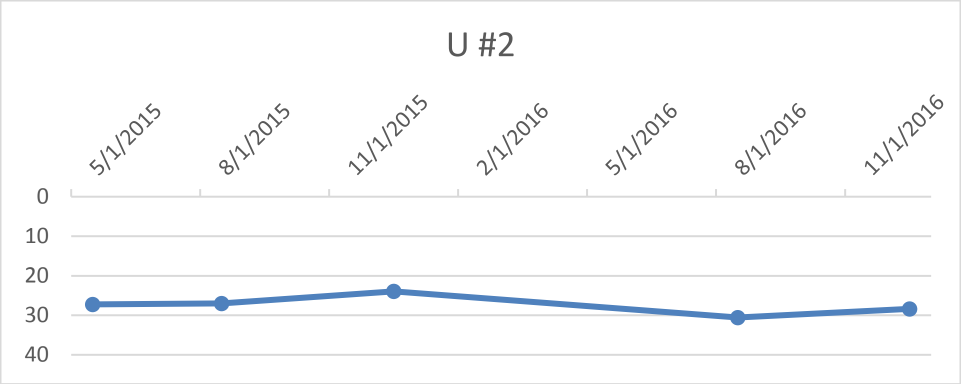
52
54


U #2
5/1/2015
8/1/2015
11/1/2015
2/1/2016
5/1/2016
8/1/2016
11/1/2016
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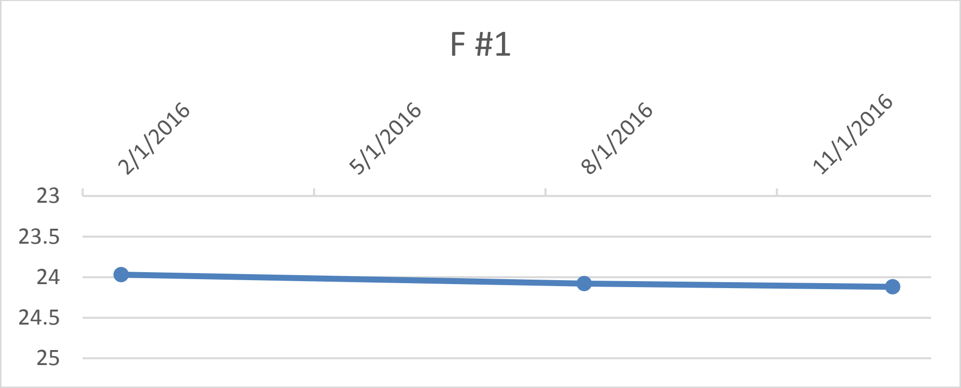
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2/1/2016
5/1/2016
8/1/2016
11/1/2016
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23.5
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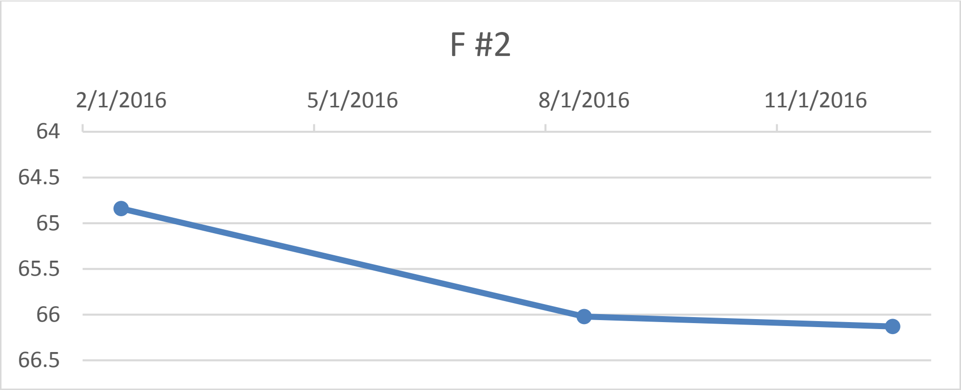
25


F #2
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11/1/2016
64
64.5
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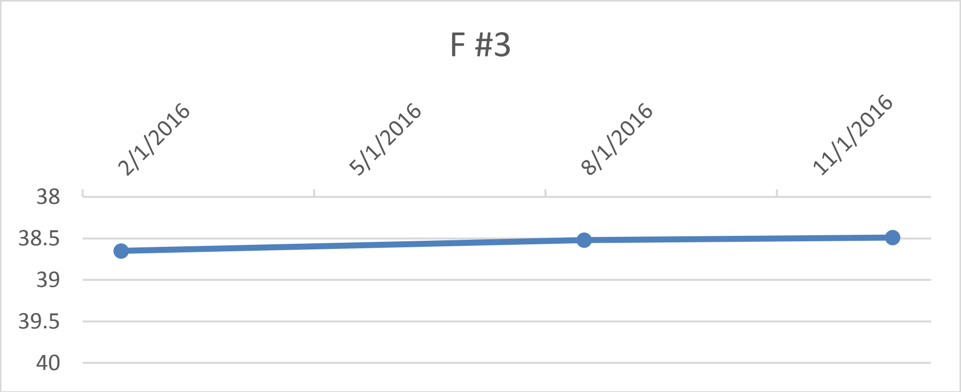
65.5
66
66.5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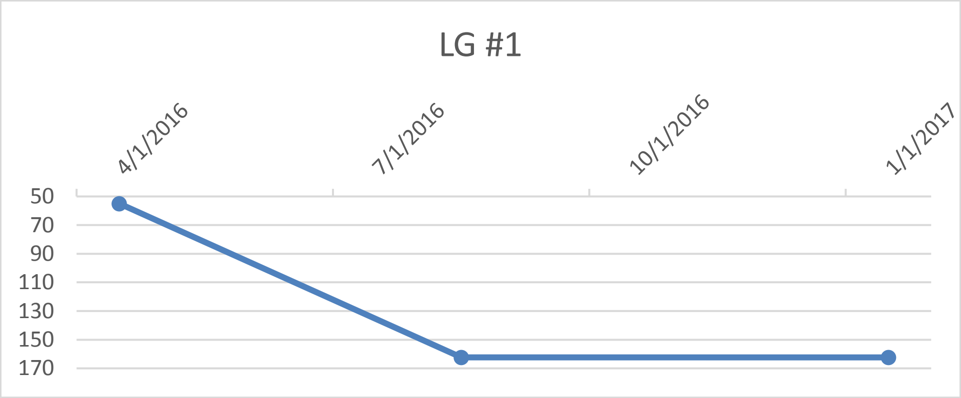
40


LG #1
4/1/2016
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10/1/2016
1/1/2017
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150
170