Mora-Wagon Mound SWCD

Hydrogeology Project

Annual Progress Report

2015-2016

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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. During the 2015-2016 fiscal year, ZGC measured static water level in 34 wells in August and December of 2015, revised mapping already performed in the area between Watrous and Colmor, began mapping around Ocate and Fort Union, obtained six trace metal chemistry samples, 6 pre-fracking baseline chemistry samples, three radiocarbon dating samples, and five tritium dating 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 assistance in making contact with multiple land owners.

Static Water Level Measurements

In August and December of 2015, depth to water was measured in 34 wells spread across the county to document maximum (August) and minimum (December) use water levels. The project began with 25 wells and nine wells were added to the network over the course of 2015 and in the early spring of 2016. 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 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 corresponds to the Dakota Sandstone and that the deeper zone corresponds to the Morrison Formation or Permian rocks.

From January to December of 2015, 14 of the original 25 wells showed increases in water level and nine showed decreases. Two wells could not be measured in December 2015 and one of these wells were measured in May of 2016. These wells are not considered here for the annual change from winter to winter. The nine wells that showed decreasing water levels over the course of the year are located in pastures that see moderate to heavy grazing use through the course of the year. Decreasing water levels in these areas may not reflect permanent draw-down of the water table, but recent heavy use during the time water level measurements were made.

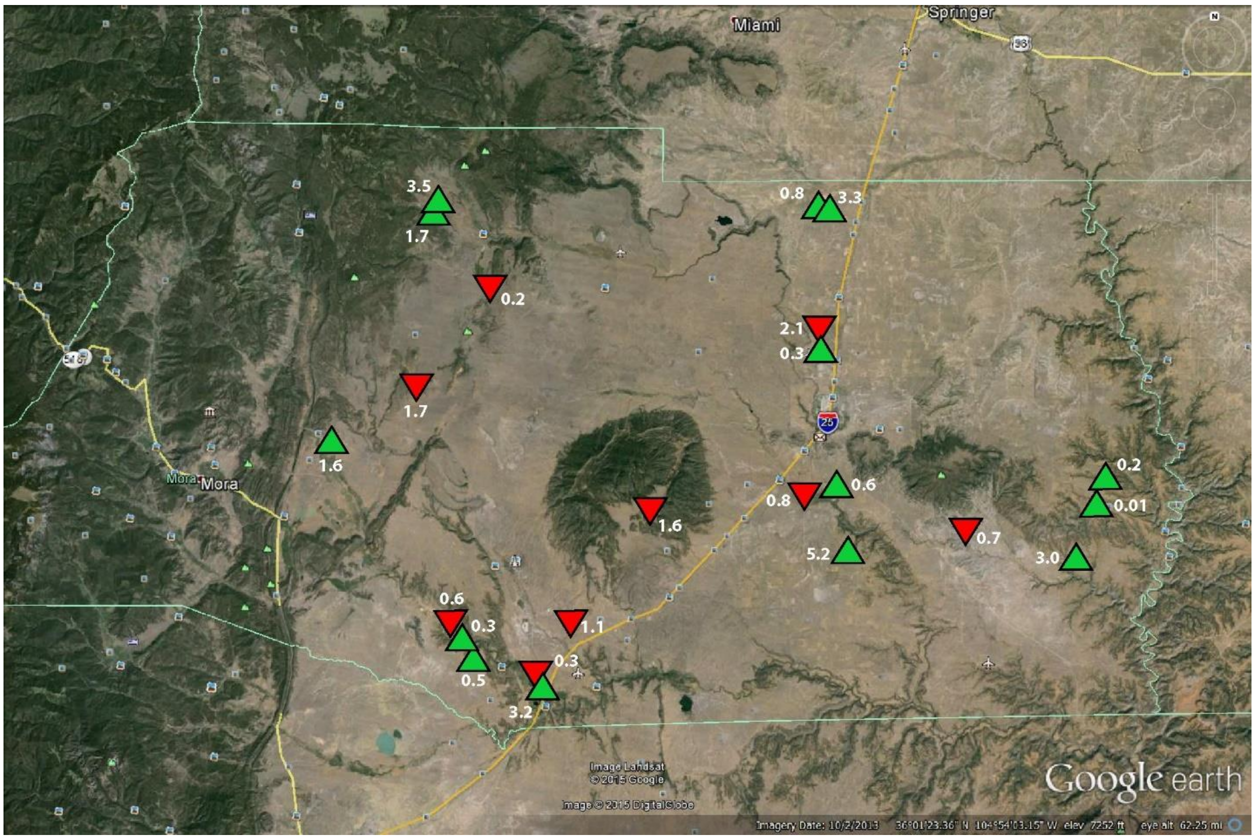

Figure 1. Rate of change in feet of static water levels in wells in the MWMSWCD network.

Water Chemistry

Approximately one 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 (Figure 2). One sample, RMNWR #2 was repeated for a second year to observe changes in water chemistry through time. 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) (Figure 3).

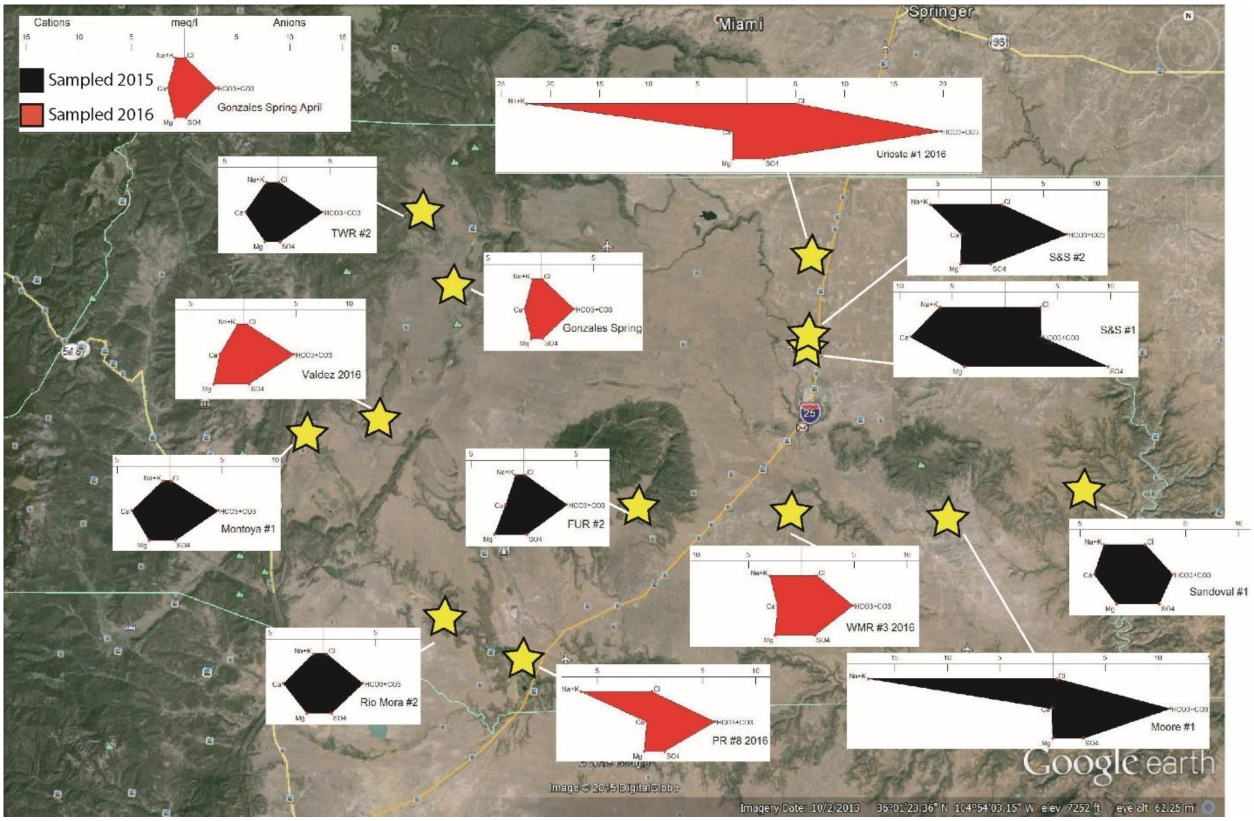

Figure 2. Well locations with water chemistry samples taken. The shape of each polygon is related to the relative proportions of different cations and anions in the water. Samples showing a high abundance of Na+K may indicate water interacting with arkosic sandstones in the Morrison Formation.

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 (Figure 2, 3). 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 commonly cemented with calcite, which can dissolve to provide carbonate, calcium and some magnesium. 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. 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.

Trace metal analyses did not show any significant concentrations of 26 different metals, ranging from aluminum and arsenic to uranium (EPA method 200.8). We also collected samples from four wells and two springs for a complete pre-fracking baseline chemistry. These samples are used to demonstrate the concentration of various chemicals prior to potential development of hydrocarbon reserves in the Wagon Mound area. Analyses included testing for the presence of volatile organics, gasoline, diesel, methane and pesticides. All six samples showed no measurable amounts of any of these materials.

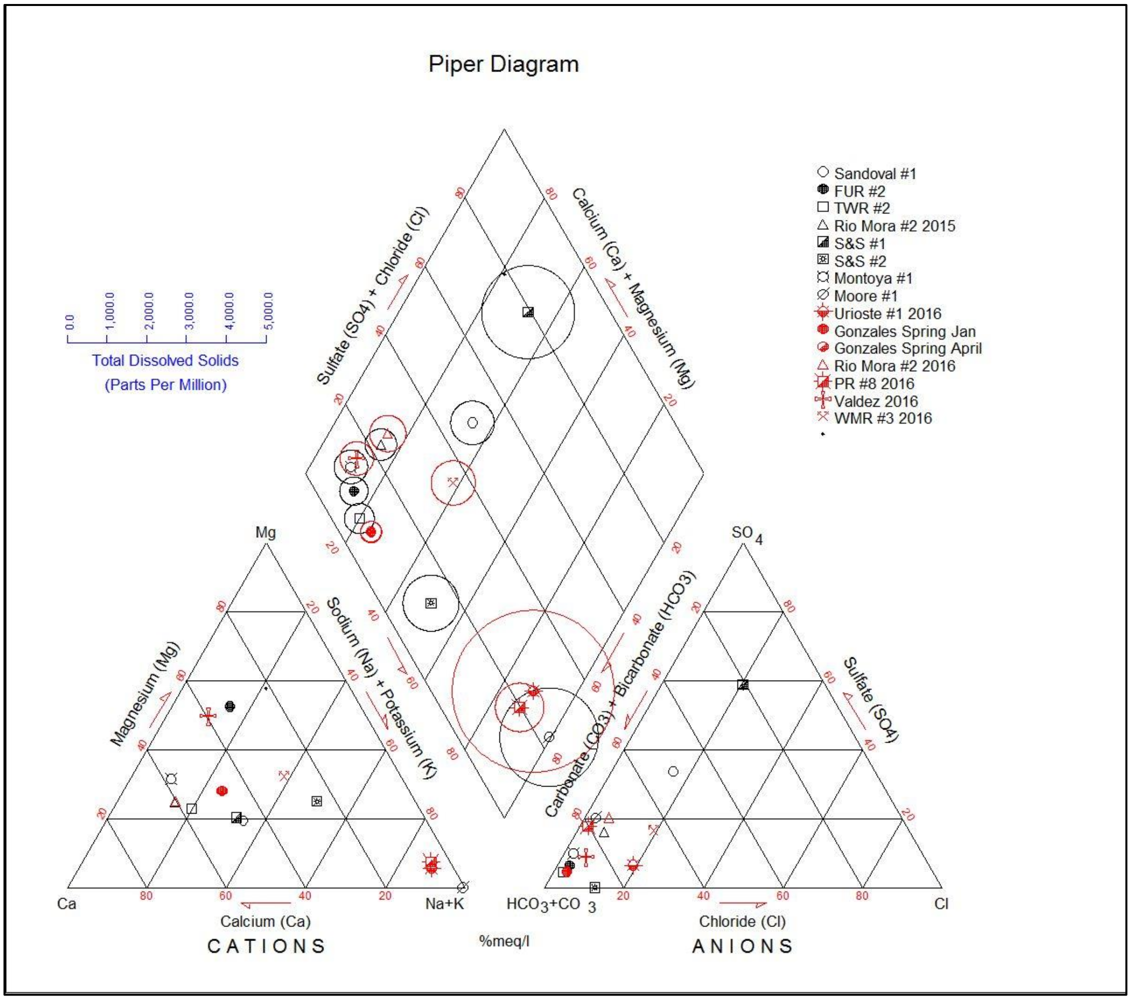

Figure 3. Piper diagram for water chemistry samples collected in the 2014-2015 and 2015-2016 fiscal years from the Mora-Wagon Mound area. Circles indicate total dissolved solids for each well – larger circles indicate higher TDS.

Carbon-14 and Tritium Dates

We collected one liter of water from two springs and one well (Figure 4). 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, Permian strata and shallow alluvial aquifers are unlikely to contribute significant amounts of "dead" carbon due to a lack of significant quantities of carbonate rocks. Locally, the Morrison Formation includes thin limestone beds that may influence the apparent age of groundwater from wells completed through the Morrison Formation. The samples collected yielded the following average residence times: ~310 years before present (YBP) at the S&S spring north of Wagon Mound, ~920 YBP at springs at Rancho Montoya near Ocate and ~26,070 YBP for a well east of Wagon Mound. The significantly older 14-carbon result from the well east of Wagon Mound may indicate a complete lack of recharge to the aquifer(s) the well is completed through or may indicate that the well is drawing part or all of its water from a fractured limestone in the Morrison Formation, which would yield an artificially older result.

Five 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 and 15 TU indicate waters that are modern (5-10 years old). Tritium results from the Mora-Wagon Mound area are listed below:

Sample ID	Tritium (in TU)	Age Interpretation	^{14}C Date
Wagon Mound Spring	2.12	Modern	820 YBP
WMR #3	0.08	Pre-1952/no recharge	2,440 YBP
PR #7	0.03	Pre-1952/no recharge	21,630 YBP
S&S #1	2.17	Modern	10 YBP
Montoya	-0.03	Pre-1952/no recharge	7,880 YBP

The very young ages at the S&S #1 well and at Wagon Mound Spring 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 aquifer units (Dakota Group, Morrison Formation) are more internally partitioned than might otherwise be expected. In addition, paleotopography and possible faulting in the subsurface bring older rocks (and possibly older waters) closer to the surface.

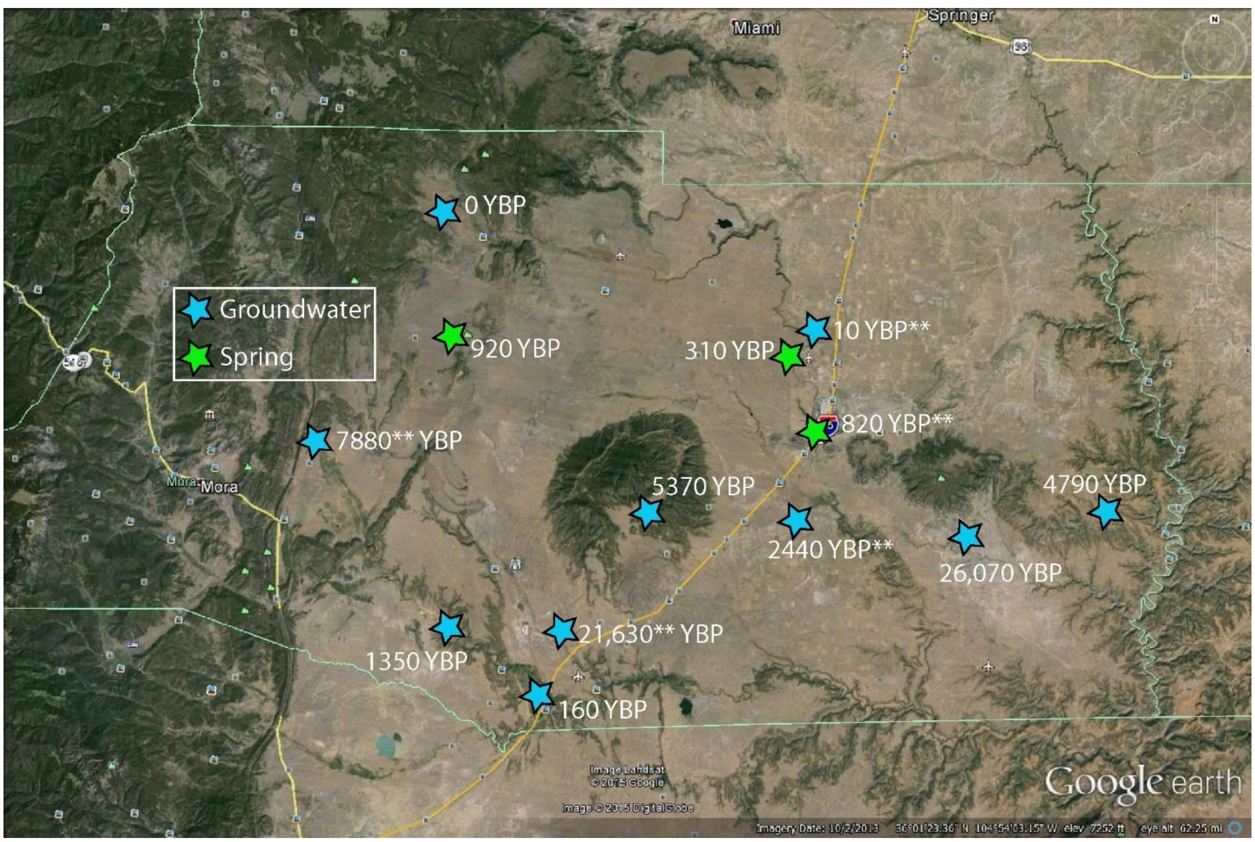

Figure 4. ^{14}C age determinations for all wells sampled from 2014 through 2016. **indicates sample analyzed for tritium.

Geologic Mapping

We have mapped an approximately four-mile-wide strip from Watrous north to Colmor in order to incorporate areas with known groundwater issues, such as declining flows and water quality problems. Bedrock outcrops include (in age order) the Cretaceous Dakota Sandstone, Graneros Shale, Greenhorn Limestone, Carlisle Shale and Quaternary volcanic deposits as well as recent eolian sand and alluvial deposits. Descriptions of these units are provided in the 2014-2015 annual progress report (Zeigler et al., 2015). A partially completed digital version of the northern Watrous quadrangle shows distribution of bedrock outcrops and younger deposits (Figure 5). Mapping efforts have also been completed on Twin Willows Ranch near Ocate and are partly complete for the eastern half of Fort Union Ranch.

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, including a syncline observed in Wolf Creek northeast of Watrous. We also observed significant variation in the cementation of the Dakota Group sandstones. Locally the sandstone is so completely cemented with silica that it is an orthoquartzite.

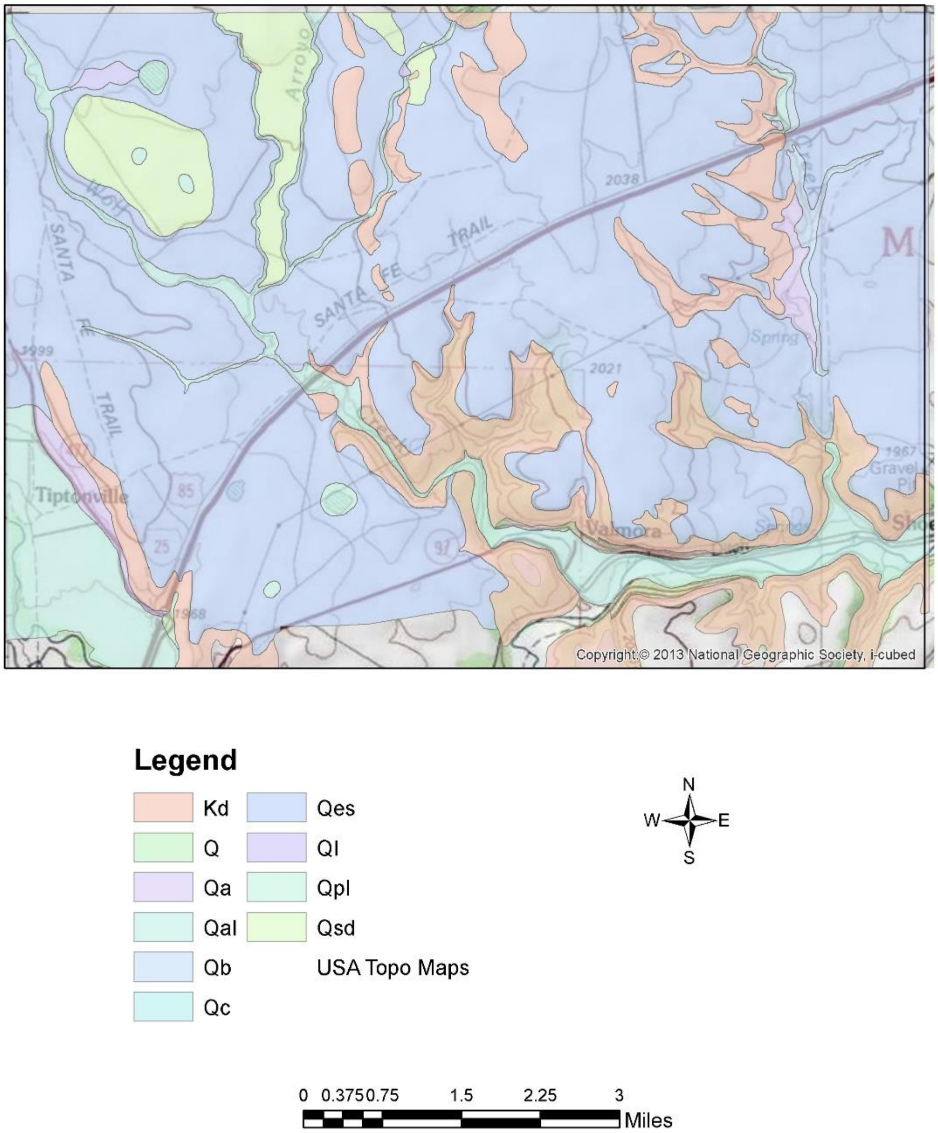

Figure 5. Partially digitized map of the northern Watrous quadrangle showing exposures of bedrock units.

Conclusions

Water chemistry, static water levels and surface mapping demonstrate the complexity of the geology in the Mora-Wagon Mound District area. Zones of groundwater appear to occur at discrete elevations: 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.

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Appendices

Appendix I: Static Water Level Measurements

Individual well static water level measurements, corrected to land surface. *indicates measurement that may not be correct. For wells where a measurement could not be obtained, "nm" indicates "not measured".

ID	Date Measured	Depth to Water Below Land Surface (feet)
MLC #1	2/12/2015	72.54
	8/17/2015	72.55
	12/8/2015	73.2
MLC #2	1/19/2015	133.7*
	8/18/2015	106.3
	12/8/2015	109.31
SR #1	1/19/2015	nm
	8/18/2015	136.4
	12/8/2015	118.64
SR #3	1/19/2015	233.3
	8/18/2015	233.06
	12/8/2015	233.12
SR #5	1/19/2015	116.38
	8/18/2015	116.28
	12/8/2015	116.37
FUR #1	2/24/2016	104.03
FUR #2	2/24/2016	103.97
FUR #4	1/20/2015	73.69
	8/19/2015	71.89
	2/24/2016	75.31
FUR #8	1/20/2015	108.13
	8/19/2015	nm
FUR #9	1/20/2015	2.91
	8/19/2015	83.85

FUR #10	2/24/2016	70.86
TWR #1	1/20/2015	87.06
	8/17/2015	86.19
	12/10/2015	85.41
TWR #2	1/20/2015	46.24
	5/21/2015	45.48
	8/17/2015	42.74
	12/10/2015	43.1
RMNWR #1	2/8/2015	129.51
	8/19/2015	129.31
	12/9/2015	129.01
RMNWR #2	2/8/2015	28.4
	8/19/2015	27.81
	12/9/2015	29
RMNWR #3	2/8/2015	3.75
	8/19/2015	2.62
	12/9/2015	3.45
PR #2	2/8/2015	9.04
	8/1/2015	5.51
	12/12/2015	5.85
PR #4	8/3/2015	1.85
	12/12/2015	2.5
PR #5	2/8/2015	3.65
	8/1/2015	2.78
	12/9/2015	3.9
PR #6	8/3/2015	2.87
	12/12/2015	3.57
PR #7	2/8/2015	91.9
	8/1/2015	92.68
	12/9/2015	93.04
PR #9	8/3/2015	13.33

	12/9/2015	16.3
WMR #1	2/9/2015	38.1
	8/20/2015	44.6
	12/8/2015	32.86
WMR #2	2/9/2015	23.9
	8/20/2015	24.59
	12/8/2015	24.71
WMR #3	2/9/2015	46.82
	8/20/2015	46.62
	12/8/2015	46.26
DG #1	2/9/2015	174.83
	8/19/2015	174.86
	12/10/2015	175
DG #2	2/9/2015	nm
S&S #1	2/10/2015	43.82
	8/18/2015	44.31
	12/9/2015	45.88
S&S #2	2/10/2015	24.52
	8/18/2015	25.87
	12/9/2015	24.2
Cruz	2/12/2015	393.84
	8/17/2015	392.93
	12/10/2015	392.2
Valdez	2/18/2015	261.37
	8/28/2015	263.19
	12/10/2015	263.11
Urioste #1	5/20/2015	51.2
	8/18/2015	49.4
	12/11/2015	50.44
Urioste #2	5/20/2015	27.23
	8/18/2015	27.03

	12/11/2015	23.96
Farrell #1	2/25/2016	23.97
Farrell #2	2/25/2016	64.84
Farrell #3	2/25/2016	38.65