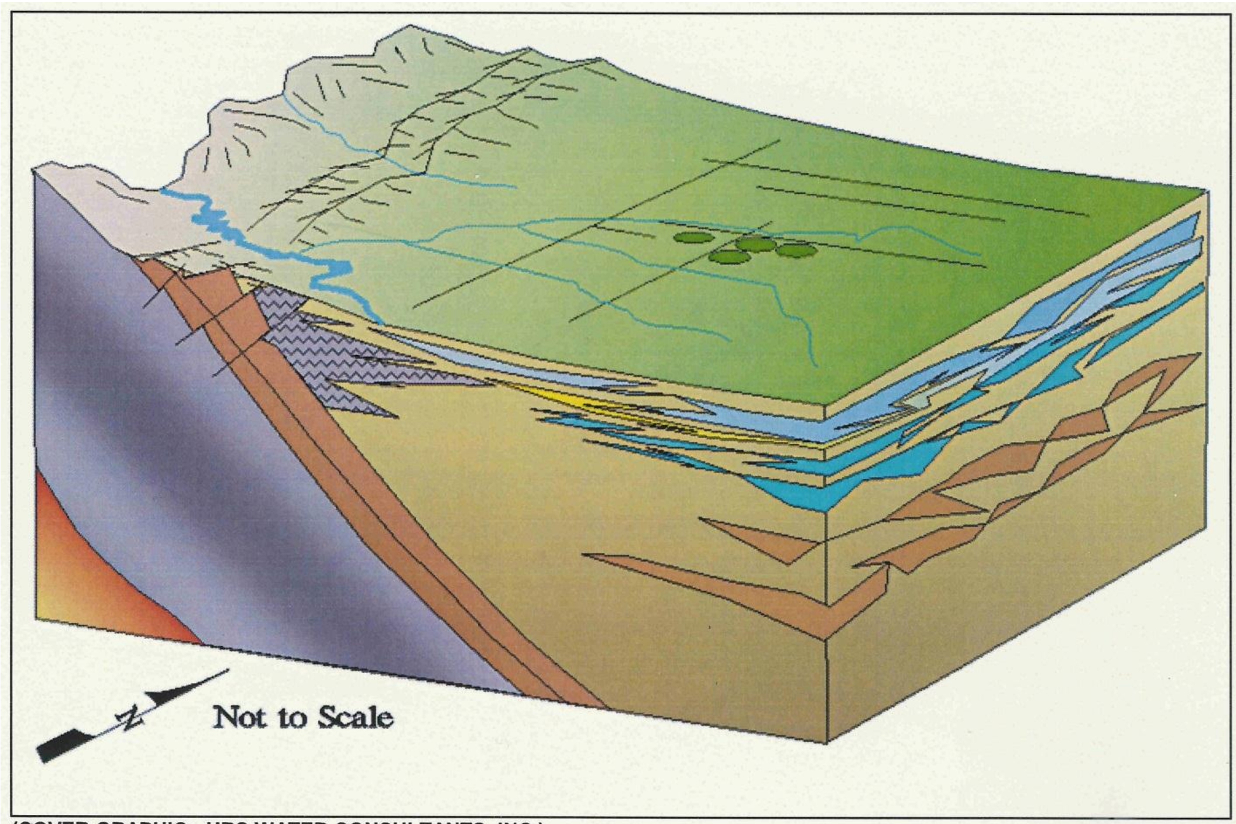
RIO GRANDE COUNTY HYDROGEOLOGIC STUDY



(COVER GRAPHIC: HRS WATER CONSULTANTS, INC.)

Report Prepared
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For
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EXECUTIVE SUMMARY

This report contains the results of a hydrogeologic investigation of central and western Rio Grande County, Colorado. The study was requested and funded by Rio Grande County, by means of a grant from the State Water Supply Reserve Account through the Rio Grande Basin Roundtable and Colorado Water Conservation Board. Applications to drill two oil exploration wells in the County were submitted to the Colorado Oil and Gas Conservation Commission in 2012. The proposed Dan A. Hughes Company DAHC-San Francisco Creek #1 well is located in the San Francisco Creek area, and the proposed First Liberty Energy, Inc. Basin #1 well is located in the Old Woman Creek area. The proposed oil wells prompted the County to initiate efforts to better understand the hydrogeology of the area in the vicinity of the proposed oil wells.

The project scope included the following:

(1) Summarize the geology as it pertains to oil and gas resources, including identification of which parts of the County may be underlain by potential oil or gas resources and that may experience future drilling;

(2) Summarize the history of oil and gas exploration in the County, including a brief description of the proposed oil wells;

(3) Describe the geology and hydrogeology of the Conejos Formation, which supplies ground water to wells near the proposed oil wells and is the most important bedrock aquifer in the mountainous part of the County;

(4) Perform a baseline sampling and chemical analysis of thirty-six existing water wells and springs in about a one-mile radius of the proposed wells to develop a water-quality baseline;

(5) Perform sampling and chemical analyses of six deep water wells to better understand water quality in the deeper parts of the Conejos aquifer;

(6) Evaluate the ground water hydrology and geology using the water well records of the Colorado Division of Water Resources and the geophysical logs and drill stem tests from previously drilled oil wells;

(7) Analyze and interpret the collected data; and

(8) Make recommendations to the County regarding how to protect ground water resources from potential impacts to ground water that might result from petroleum exploration and drilling.

Areas within the County where there is potential for future oil and gas exploration coincide with a geologic structure called the San Juan Sag. The sag is an elongate, trough-like structural depression in sedimentary rocks concealed beneath the thick pile of volcanic rocks and volcaniclastic rocks (sedimentary rocks consisting almost entirely of material eroded volcanoes) within the San Juan Volcanic Field. The San Juan Sag contains thick deposits of Mesozoic-age petroleum source rocks, including the Cretaceous Lewis Shale and Mancos Shale. The sag is a northeastward extension of the San Juan Basin, a well known prolific producer of petroleum.

The eastern margin of the San Juan Sag reportedly is controlled by a generally north-south-trending fault, the Cimarron Fault, whose trace is about at the longitude of Del Norte. The fault was located along the western margin of an ancient mountain range called the San Luis Uplift or

Highland. East of the fault the Mesozoic-age petroleum source rocks were eroded off the mountain uplift and there is little to no potential for oil and gas deposits in the eastern part of the County east of the fault. The petroleum source rocks are present in the subsurface west of the Cimarron Fault, and there is potential for oil and gas deposits and for exploration and production drilling in the part of the County that is west of the fault.

The primary water-bearing geologic deposits or aquifers that supply water to wells in the mountainous areas of Rio Grande County include shallow unconsolidated deposits such as the alluvium of the Rio Grande and streams tributary to the Rio Grande, and the widespread Conejos Formation. Due to the fact that most, if not all, of the water wells in the San Francisco Creek watershed and the Old Woman Creek watershed derive their water from the Conejos Formation aquifer, and because the Conejos previously has received very little attention in terms of its aquifer characteristics, this study concentrates on the Conejos Formation aquifer and its hydrologic relationship to the underlying petroleum reservoir rocks of interest for oil and gas exploration.

The water quality and the hydrologic properties of the Conejos Formation aquifer are discussed in this report in considerable detail, particularly in regard to the hydrogeology of the areas in the watersheds of San Francisco Creek and Old Woman Creek within approximately 1 ½ miles of the oil and gas test wells that recently have been permitted in those areas.

In summary, this study has found the Conejos Formation aquifer to be highly heterogeneous and anisotropic (that is, highly variable in its water-bearing characteristics and directions of ground water movement). This is mainly for two reasons:

- The deposits that make up the Conejos Formation vary widely in their water storage and transmitting capacity. In some areas the Conejos Formation consists of hard, but highly fractured, lava flows and related rocks; and in other areas it is composed of layered but variable sedimentary deposits of sandstone, siltstone, and other rocks originally derived from volcanic deposits (i.e. volcaniclastic rocks).
- Faulting, fracturing, and igneous intrusions associated with young volcanic activity have created potential pathways for ground water movement between shallow depth zones within the Conejos aquifer, such as the zone generally less than 1,500 feet deep from which most water wells draw their water, and deeper formations.

Results of several of the tasks done as part of this study, including water quality sampling of shallow and deeper water wells, analysis of geophysical logs, and analysis of water well records, all indicate to the study team that there is evidence of relatively deep circulation of ground water (to several thousand feet depth) and shallow (less than 1,000 feet depth) presence of oil and gas. Overall, this means there is evidence that there are no highly impermeable formations that would serve to hydrologically separate the underlying petroleum-bearing reservoir rocks and source rocks from the shallower fresh-water aquifers used by water wells in the mountainous areas of the County.

For this reason, the study team believes that the most prudent course of action is to make sure that the hydrogeology of the study area is well understood with greater accuracy than the present study allows, particularly in areas that will be of interest for petroleum development, and that certain reasonable protective measures are in place to make sure any risks of ground water contamination due to oil and gas drilling and production activities are minimized.

Accordingly, the study team makes several recommendations to the County based on the results of this hydrogeologic study and baseline water quality investigation. Our recommendations are contained in Section 11.0 of this report. Our recommendations, and the reasoning leading to each one, are repeated below in their entirety for the convenience of the Commissioners and residents of the County.

1. **Recommended oil and gas well drilling/completion/testing precautionary measures to protect against contamination of surface water and near-surface (i.e. alluvial) ground water within the immediate watershed.**

This study has found that there is substantial evidence of deep circulation of ground water, at least to several thousand feet depth in the Conejos Formation, and that there is significant permeability in the Conejos Formation that may serve to provide pathways for movement of water between deeper formations, the Conejos Formation, and near-surface (alluvial) ground water. For this reason, the study team recommends:

- An appropriate precautionary measure would be to require petroleum exploration or production wells to be cased and grouted (cemented) from the base of the Conejos Formation back up to ground surface, and that the grouted interval be tested for integrity by use of a CBL (cement bond log), pressure testing, or other means, before drilling and testing of the target formations for petroleum production.
- Drilling within 1,000 feet of an alluvial floodplain or an intermittent or ephemeral streambed should be avoided, unless precautionary measures are taken to prevent the escape of drilling fluids. For example, the conductor casing should be extended to adequate depths and cement grouted to protect shallow aquifers. The exact depth will depend on local aquifer conditions, which as yet have not been well characterized.

2. **Recommended longer-term water quality baseline studies to establish a fund of information against which to compare post-drilling water quality.**

This study has developed a strong initial sampling of water wells that provides a valuable fund of water quality data. However, this one-time sampling does not afford the opportunity to understand any seasonal variance in natural, background water quality. Also, several wells and springs within or near to the one-mile radius of the two proposed wells were not sampled during this study for various reasons (see section 6.8). Accordingly, the study team recommends that the County procure funding to sample the wells and springs identified in section 6.8 and for an annual sampling of a selected subset of the wells and springs sampled during this study. Particular wells chosen for further baseline water quality studies should be at least 30% to 50% of the wells sampled in this study, and should be selected on the basis of best information on the depth horizons from which the well draws water; a range of shallow to deep wells sampled; and wells that are in areas most likely to be of interest for future petroleum exploration drilling or that are located in the direction from a proposed oil well that ground water might be moving.

3. **Recommended longer-term hydrogeologic investigations designed to fill significant gaps in the knowledge base about ground water occurrence and movement of significance to Rio Grande County.**

This study provides a strong framework with which to begin to understand the hydrogeology of the aquifers in the mountainous areas of Rio Grande County. However, there remain significant data gaps. Accordingly, the study team recommends a longer-term hydrogeologic investigation. Potential components of a more comprehensive hydrogeologic study may include:

- Sampling and analysis of other deep water wells in the County, including those described in section 7.8.
- Field investigations to check the nature of mapped faults and identified lineaments (possible fault or fracture traces) that may enhance ground water movement. Field investigations should also attempt to better understand the distribution of various rock types within the Conejos Formation and their hydrologic properties.
- Development of an aquifer water level elevation contour map (or maps), to enable better identification of local (creek subdrainage) and regional (basin or sub-basin) ground water flow paths.
- Development of water balance estimates for individual creek subdrainages, to allow estimation of ground water recharge, discharge, changes in ground water storage, and other critical parameters.
- Perform properly instrumented pumping tests on selected existing wells, to help narrow the uncertainty in transmissivity, hydraulic conductivity, and storage characteristics of the Conejos Formation aquifer.
- Development of Piper trilinear diagrams of major anions and cations, to help understand the pathways of ground water movement and chemical changes in the subsurface.
- Consider a program of water sampling to include environmental isotope analyses, such as ^{18}O, ^{14}C, tritium, deuterium, and chlorofluorocarbon (CFC). These would allow estimation of ground water travel times since recharge, and thereby help understand the time of travel from the recharge (source) areas to water wells and to the San Luis Valley aquifers. Other methods of age dating ground water would support this effort.
- Ultimately, to best understand the ground water in the deeper part of the Conejos aquifer one or more deep hydrologic monitoring wells should be designed, drilled, completed, and monitored specifically for this purpose.

4. **Recommended measurements, water quality sampling, or other short-term activities to be undertaken by the County, by individual well owners, or by others, before, during, and after exploratory oil and gas drilling.**

COGCC Rule 609 Statewide Groundwater Baseline Sampling and Monitoring (draft as of this writing) includes a provision that the operator must sample at two sites located within two “groundwater sources or springs within a ½ mile radius of the proposed Oil and Gas Location”. Draft Rule 609 goes on to impose several criteria for selection of sampling locations. Based on this study, and the uniqueness of the geologic formations identified, the study team believes that only two sites within ½ mile are not adequate due to the strong evidence of ground water migration to several thousand feet depth, in a highly heterogeneous, fractured rock geologic environment. Accordingly, the study team recommends that the operator of a proposed petroleum well, the County, or individual well owners sample all available water wells and utilized springs that are within about one mile of a proposed petroleum exploration or production well for major ions, BTEX, and the other constituents as stated in Rule 609 (e) (2). The chemical analyses should also test for hydrocarbon gases, as was done during this project. If hydrocarbon gases are detected, then additional testing should be conducted to determine if the gas is biogenic or thermogenic in origin. If insufficient water wells are located within one mile of the well, then the radius of investigation should be expanded.

5. Other recommendations.

The majority of oil and gas exploratory drilling programs include geophysical logging only from the bottom of the surface casing (typically 1,000 feet deep or more) through the depth of interest to the operator. The study team recommends that the County require that the uppermost depth range of the oil and gas borehole be geophysically logged before it is cased and cemented. As a minimum, the study team recommends a suite of logs consisting of induction, gamma ray, caliper, SP, and a density or porosity log. This requirement would provide valuable data on the upper portion of the borehole at each drilling site that can aid in filling data gaps in the detailed stratigraphy, water quality, and porosity characteristics of the Conejos Formation for use in assessing local impacts to ground water resources.

We also recommend that a geologist selected by the County be allowed access to drilling locations to periodically observe the drilling of future petroleum wells in the County and that drill cuttings from the Conejos Formation be collected, properly labeled, and made available to the County-selected geologist for examination. These drill cuttings would improve the interpretation of geophysical logs recorded in the Conejos Formation.

The County should also work with State legislators to develop regulations that would require disclosure of mineral rights during real estate transactions. Potential buyers of real estate should be advised of "split estate" situations where the mineral rights are severed from surface rights. It should be relatively easy to determine if severed mineral rights are held by the Federal or State government, and whether those mineral rights are leased at the time of the real estate transaction. Unpatented mining claims on lands with Federal mineral rights also could be disclosed at that time to potential buyers of real estate. If the severed mineral rights are privately held, it may be difficult to ascertain exactly who owns the mineral rights, but at least the buyer would be aware that the property of interest is a split estate.

Another recommendation involves both education and improvement of the water-quality database. We recommend that the County encourage the school districts to include water-quality education, especially ground water, in their curriculum. As part of this effort, an on-going program to periodically test wells and springs for field parameters (e.g. temperature, pH, and conductivity) would provide educational opportunities for students and help to develop a long-term, basic water-quality baseline for the County. The County could also encourage graduate students at universities to do their thesis on the hydrogeology of the area. Grants or stipends would be ideal, but even in-kind support (e.g. housing) might entice students to conduct their research in the area.

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1.0 INTRODUCTION AND BACKGROUND

During 2012 two oil and gas exploration wells were proposed in Rio Grande County, one about 5 miles south of the Town of Del Norte and another about 5 miles northwest of Del Norte. Several petroleum exploration wells have been drilled in the western portion of Rio Grande County in the past. Several wells found evidence of oil or gas, and one reportedly produced 30 barrels of oil. The last well was drilled more than 20 years ago. The new proposed oil wells and the possible use of improved development techniques have caused community members and County officials to seek more information regarding potential negative environmental impacts. Of particular concern are potential impacts to the quality and quantity of ground water in aquifers at and near drill sites.

The land use near the proposed oil and gas exploration wells is predominately rural residential with homes on large subdivision lots or ± 40 acre tracts. The domestic water supply for these residences is from individual private wells. Further, it is believed that ground water availability for many agricultural and municipal wells located down-gradient is supplied in part from flow in the deeper ground water aquifers near these proposed oil and gas wells.

This new concern prompted the Rio Grande County Commissioners to seek funding for a study of the ground water aquifers and subsurface geologic formations in the western portion of the County, with a focus on the two proposed oil exploration well sites. Funding for the study was obtained from the State Water Supply Reserve Account through the Rio Grande Basin Roundtable and Colorado Water Conservation Board.

A specific objective of this study and report was to present information to improve the understanding of the existing ground water and related geologic formations near the proposed exploration sites. Further, it was proposed to utilize this information in developing and presenting oil and gas well drilling and casing recommendations that would provide reasonable protection of the usable ground water in the aquifers.

The study has included collection and interpretation of new data, as well as data from past studies and reports that focused on the area of interest. New data includes sampling and chemical analysis of water from most existing wells within about a one-mile radius of the two proposed drilling sites and similar sampling and chemical analysis of water from deeper wells, most of which are near the Town of South Fork. In addition, collection, new analysis and interpretation of existing data from driller's logs from water wells, and analysis of geologist's logs and geophysical logs from oil exploration wells have been performed. Past geologic and hydrogeological studies and reports have been collected, reviewed and interpreted to improve descriptions of subsurface geologic formations.

This report presents the findings of the study. A map showing the study area boundary and location of proposed oil wells is in Figure 1.1. The report includes several appendices that are available as separate digital PDF files. The appendices are:

Appendix A. ACZ Laboratory Analytical Results for COGA Baseline Samples
Appendix B. Sangre de Cristo Laboratory Analytical Results for Deep Well Samples

Appendix C. Reported Production Test Data for Wells in San Francisco Creek Area
Appendix D. Reported Production Test Data for Wells in Old Woman Creek Area
Appendix E. Evaluation of Water Salinities from Selected Wells, Rio Grande County, Colorado, by Digital Formation, Inc., Denver, Colorado
Appendix F. Preliminary Lineament Analysis

The study team included the following participants: Davis Engineering Service, Inc.: Allen Davey and Clinton Phillips; GeoLogical Solutions: Robert Kirkham; and HRS Water Consultants, Inc.: Eric Harmon, Eric Saenger, and Jimmy Schloss.

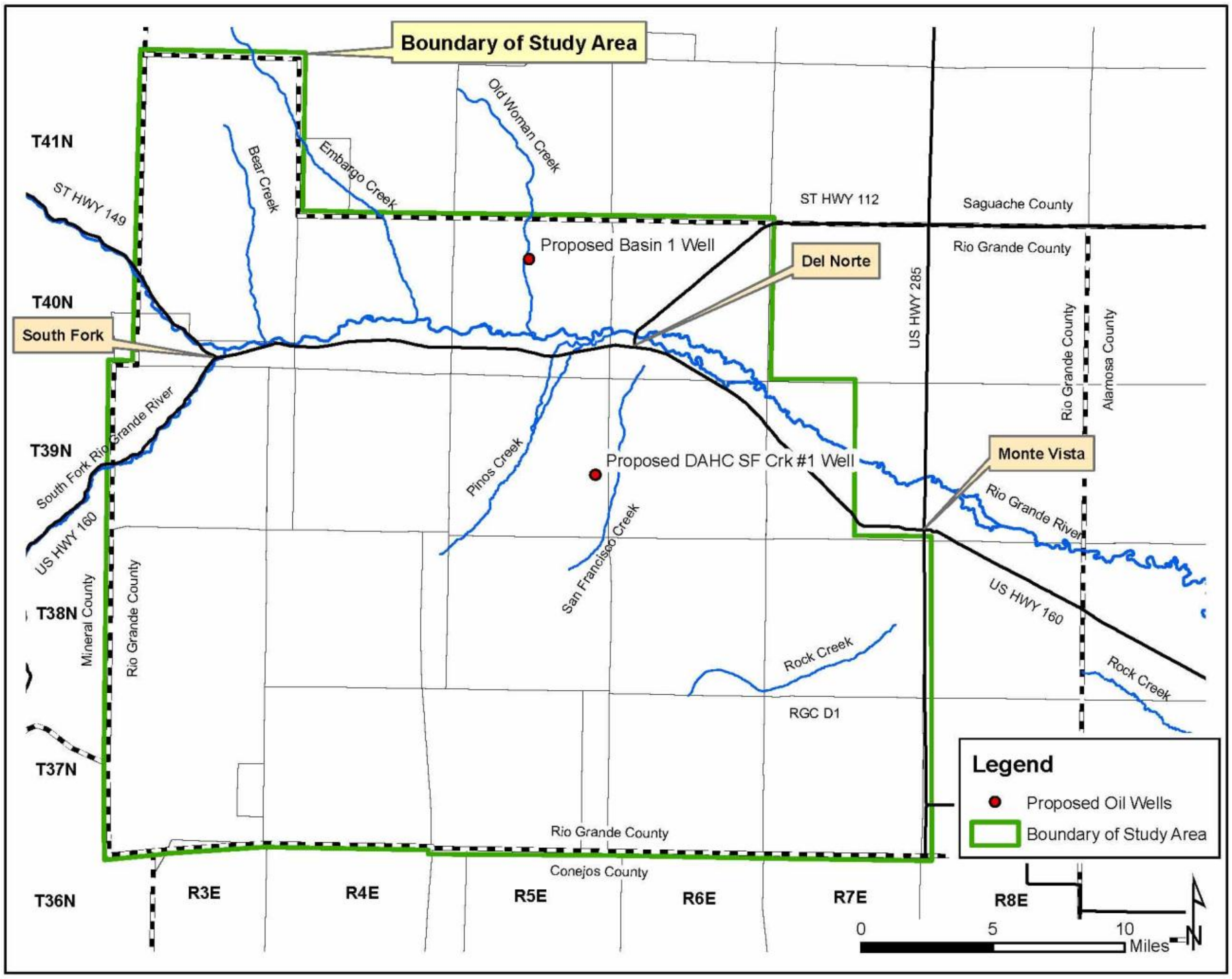

Figure 1.1. Map of study area boundary and location of proposed oil wells. The green line denotes the study area boundary, which approximately coincides with the mountainous part of Rio Grande County.

2.0 REVIEW OF PAST WORK

This section presents a summary of previous geologic and hydrogeologic studies that pertain to the study area, which is the mountainous area of Rio Grande County. This discussion is organized by major topic: first we summarize important published research on the geology of the San Juan foothills and mountains, and second we discuss significant research reports on the hydrogeology that describes ground water recharge and movement, and the nature of the geologic units of the study area in terms of their hydrologic characteristics. Discussion of the geology, oil and gas exploration, based in part on these previous studies, is included in Section 3 of this report.

Not all of the sources of basic information relevant to the geology and hydrology of the study area have been published, nor are all of the unpublished data sources particularly well known. This review summarizes the maps or papers that are considered particularly relevant to this study, and is not intended to be a complete summary of all published work. Where the authors have personal knowledge or experience in the study area that we believe is relevant, we have tried to incorporate that into our discussion and interpretations in later sections of this report. Also, much work has been done on the hydrogeology and ground water characteristics of the San Luis Valley, adjacent to the study area on its east side. Because the study area is considered a ground water recharge area to the aquifers in the San Luis Valley, we have reviewed several reports for that area also, even though strictly speaking they are not part of the study area.

2.1 Past Work on Geology of the Study Area

Likely the first published work on the geology of the San Juan Mountains, including the study area, was done as part of the 1877 *Geological And Geographical Atlas Of Colorado And Portions Of Adjacent Territory* by F.V. Hayden. This work describes many of the volcanic and sedimentary formations that we now recognize as key elements of the overall geography, stratigraphy, and geologic structure of the San Juan Mountains, and also contains more general descriptions of the foothills region and the San Luis Valley.

The more recent and near-surface geologic deposits, such as glacial moraines and streambed sediments in and adjacent to the study area were studied in depth and the results published in the 1932 publication: *Physiography and Quaternary Geology of the San Juan Mountains, Colorado by W.E. Atwood and K.F. Mather* (U. S. Geological Survey Professional Paper 166). This report provides detailed descriptions of the alluvial (stream-deposited) and glacial deposits that make up many of the water-bearing near-surface sediments along the Rio Grande and its perennial and intermittent tributary streams. This report also recognized that the topography of the study area that we observe today is chiefly controlled by the geologic structure of the underlying volcanic and sedimentary rocks.

There are U.S. Geological Survey geologists who have spent many years studying the geology of the San Juan Mountains, with particular emphasis on the volcanic rocks that comprise the aquifer and aquitard layers in much of the San Juans, including the San Francisco Creek and Old Woman Creek drainages and adjacent areas. A useful although somewhat general geologic map, published at a scale of 1:250,000 (1 inch equals approximately 4 miles) that covers the entirety of the study area as well as adjacent areas is:

> Steven, T.A., P.W. Lipman, W.J. Hail, Jr., F. Barker, and R.G. Luedke. 1974. *Geologic map of the Durango quadrangle, southwestern Colorado*. U.S. Geological Survey Miscellaneous Investigations Series Map I–764.

This map primarily depicts the bedrock formations in the study area. The primary bedrock aquifer in the study area from which water is pumped by residential and stock watering wells is the Conejos Formation, which is clearly mapped and identified on this map. The Conejos is broken down into two (sometimes more) distinct facies: the near-vent or lava flow facies, and the volcaniclastic facies. A "facies" in geologic terms is a body of rock that has certain general characteristics, due to a certain set of circumstances that led to its deposition. Further, and of importance to this study, the different facies of the Conejos have generally distinct characteristics that affect its ability to store and transmit ground water.

Other geologic maps that are more detailed (scale of 1:48,000; 1 inch equals approximately ¾ mile) that cover parts (although not all) of the study area and that have been reviewed for this study are:

> Lipman, Peter. Geologic Map of the Del Norte Area, Eastern San Juan Mountains, Colorado [map]. 1:48,000. Denver, CO. United States Department of the Interior, USGS, 1974; Generated using the National Geologic Map Database < http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html > 23 Oct. 2012

> Lipman, Peter. Geologic Map of the Platoro Quadrangle Caldera Area, Southeastern San Juan Mountains, Southwestern Colorado [map]. 1:48,000. Denver, CO. United States Department of the Interior, USGS, 1974; Generated using the National Geologic Map Database < http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html > 23 Oct. 2012

> Lipman, Peter and Thomas, Steven. Geologic Map of the South Fork Area, Eastern San Juan Mountains, Southwestern Colorado [map]. 1:48,000. Denver, CO. United States Department of the Interior, USGS, 1976; Generated using the National Geologic Map Database < http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html > 23 Oct. 2012

These maps were used primarily to provide more detail on the mapped formations within the study area, and to give a more accurate mapping of faults that may be important in terms of pathways for ground water movement.

Several more recent geologic studies of importance to understanding the subsurface stratigraphy and geologic structure of the region, with emphasis on the oil and gas potential of the eastern San Juan Mountains, including the study area, have been done since the mid-1980's by several authors, notably Robbie R. Gries and Brian S. Brister. The study team has reviewed and drawn upon these publications in summarizing our understanding of the geology of the area (Sections 3 and 4 of this report), including the origin and characteristics of the geology as related to the petroleum resources in the area. These publications include the following:

> Brister, B.S., 1991, Tertiary sedimentation and tectonics: San Juan Sag-San Luis Basin region, Colorado and New Mexico: Socorro, New Mexico Institute of Mining and Technology, Ph.D. thesis, 267 p.

Brister, B.S., and Chapin, C.E., 1994, Sedimentation and tectonics of the Laramide San Juan Sag, southwestern Colorado: The Mountain Geologist, v. 31, p. 2-18.

Brister, B.S., and Gries, R.R., 1994, Tertiary stratigraphy and tectonic development of the Alamosa Basin (northern San Luis Basin), Rio Grande Rift, south-central Colorado, *in* Keller, G.R., and Cather, S.M., eds., Basins of the Rio Grande Rift; Structure, stratigraphy, and tectonic setting: Geological Society of America, Special Paper 291, p. 39-58.

Gries, R.R., 1985, San Juan Sag: Cretaceous rocks in a volcanic-covered basin, south central Colorado: The Mountain Geologist, v. 22, no. 4, p. 167-179.

Gries, R.R., 1989, San Juan Sag; Oil and gas exploration in a newly discovered basin beneath the San Juan volcanic field, *in* Lorenz, J.C., and Lucas, S.G., eds., Energy frontiers in the Rockies: Albuquerque Geological Society, New Mexico, p. 69-78.

Gries, R.R., and Brister, B.S., 1989, New interpretations of seismic lines in the San Luis Valley, south-central Colorado, *in* Harmon, E.J., ed., Water in the valley: Colorado Ground-Water Association, 8th annual field trip, p. 241-254.

Gries, R.R., Clayton, J.L., and Leonard, C., 1997, Geology, thermal maturation, and source rock geochemistry in a volcanic covered basin: San Juan Sag, south-central Colorado: American Association of Petroleum Geologists Bulletin, v. 81, no. 7, p. 113-1160.

Some of the most important interpretations of the geology that were useful for this study are derived from these publications, in particular the structural and stratigraphic configuration of the older formations that underlie the Conejos Formation, such as the Blanco Basin Formation, Lewis Shale, Mancos Shale, Dakota Formation, their relationship to the Conejos Formation, and the presence and configuration of the geologic structure called the San Juan Sag. These relationships are shown in later figures and maps in this report, and are explained in Section 3. For example, one unusual aspect of the petroleum potential in the study area as compared to most petroleum producing areas is that some natural petroleum has been found in the Conejos Formation.

2.2 Past Work on the Hydrogeology of the Study Area

The occurrence and movement of ground water through the study area is complex, generally being characterized by ground water recharge and movement through near-surface soils and, where present, glacial and stream deposits. Ground water movement through bedrock formations in the study area, dominantly the Conejos Formation, takes place by two modes: water movement in the interstices between the rock grains (intergranular permeability) and water movement through fractures and joints in the rocks (fracture permeability). Although there have been many studies of ground water in the San Luis Valley east of the study area and some studies, as discussed previously, have been done relating to the geology and oil and gas potential of the eastern San Juan mountains, relatively few scientific investigations have sought to determine the aquifer characteristics and potential ground water pathways between the deeper strata targeted by oil and gas exploration, and the shallower strata (largely the Conejos Formation) that provide water to domestic wells in the study area and that may provide ground water recharge to the confined aquifer layers of the western SLV. This section is a brief summary of studies on ground water in or near the study area relevant to these questions.

Dr. David Huntley, in his Ph.D. thesis and in subsequent papers, presented estimates of the permeability of the Conejos Formation and also the joint-controlled fracture permeability of the ash-flow tuff formations that overlie the Conejos in some areas. Dr. Huntley's publications include:

> Huntley, D., 1979, Ground-water recharge to the aquifers of northern San Luis Valley, Colorado: Summary: Geological Society of America Bulletin, part 1, v. 90, p. 707-709.
>
> Huntley, D., 1976, Ground water recharge to the aquifers of northern San Luis Valley, Colorado: Golden, Colorado School of Mines, Ph.D. thesis, 240 p.

Although Dr. Huntley's work was more directly related to the Saguache Creek drainage and the Closed Basin of the San Luis Valley, his work is relevant and useful to this study.

Based on several field observations, Dr. Huntley concluded that the Conejos Formation and the younger ash-flow tuff units have significant hydraulic conductivity. For the Conejos, in volcanic material including at least two lava flows reported on the driller's log, on the basis of a pumping test of a Town of Saguache municipal well, Dr. Huntley reported a hydraulic conductivity (K) in the range of 1.06×10^{-3} to 1.3×10^{-3} cm/sec (3.0 to 3.7 ft/day). This value is indicative of an aquifer with moderate production rates from wells.

For the purposes of this report, the terms permeability and hydraulic conductivity are the same, although in a strict sense permeability is an intrinsic property of the rock, and hydraulic conductivity, in addition, includes factors for the specific gravity and the viscosity of the fluid moving through the rock.

Huntley reported an estimate of K for fractured, welded ash-flow tuff of the Fish Canyon Formation of approximately 5×10^{-2} cm/sec (140 ft/day) based on observed flow from a spring and a simple flownet analysis at Big Springs picnic ground, near Houghland Hill, in Saguache County. This is a high K value, and probably indicates an upper range for fractured, welded ash-flow tuffs in the eastern San Juan Mountains.

Huntley hypothesized that the underlying, fractured volcanic bedrock of the San Juan Mountains has relatively high bulk permeability (taking intergranular and fracture permeability together) and, partly due to the high K, has a regional-scale water table with a low water table gradient (Caine and Wilson, 2011). For ground water movement from the San Juan Mountains into the Closed Basin, Huntley estimated a range of relatively low hydraulic gradient values (0.0002–0.0008). Although this is an important hypothesis worthy of investigation, later studies have shown that an overall high K and low water table gradient is probably valid on a local basis, and is probably not applicable for the Conejos Formation as a whole over the study area.

In 1986-87, HRS Water Consultants, Inc. (HRS), on behalf of the Colorado Water Resources and Power Development Authority (CWRPDA), researched the feasibility of developing ground water from deep within the confined aquifer layers of the San Luis Valley – generally below 3,000 feet depth. That study resulted in several task reports, which were summarized in:

HRS Water Consultants, Inc., 1987, San Luis Valley Confined Aquifer Study Phase 1 Final Report: Colorado Water Resources and Power Development Authority.

Although the focus of the CWRPDA study was the SLV basin, part of that investigation involved estimation of the recharge to the deep confined layers from the eastern San Juan Mountains, including the study area. In that study, HRS concluded that on the order of 600,000 acre-feet per year (ac-ft/y) of water were recharged to the aquifers of the San Luis Valley from water that enters the SLV as streamflow or shallow, alluvial ground water, and subsequently is recharged to the SLV aquifers as ground water by percolation in the alluvial fans; and about 90,000 ac-ft/y are recharged as ground water to the SLV from the San Juans through bedrock formations, of which approximately 50,000 ac-ft/y flow through the Conejos Formation and the overlying ash-flow tuff formations (see table below).

Estimates of Ground Water Inflow from the San Juan Mountains
By HRS Water Consultants, Inc. (1987) on behalf of CWRPDA

Formation	Estimated Ground Water Inflow (ac-ft/yr)
Alluvium, unconfined, and upper confined (called HSU 1 and HSU 2) **NOTE: This estimate included rim inflow**	600,000
Conejos Fm. And Ash-Flow Tuff Formations (called HSU 3 and 4)	50,000
Sedimentary Formations below Conejos Fm. (called HSU 5)	40,000
Total of Bedrock Formation Inflow	90,000
TOTAL (including rim inflow)	**690,000**

In addition, during the CWRPDA 1987 study, the Waggoner-Baldridge # 1-19 San Francisco Creek oil well was being drilled (note: this well is called the San Francisco Creek Ranch #1 well in the Colorado Oil and Gas Commission records, and this name is used elsewhere in the report). CWRPDA used the opportunity to have additional geophysical and geologic logging done. The resulting information was useful in identifying the lithologic characteristics of the Conejos Formation at that location, and has been useful in the petrophysical analysis done as part of this study. At the time of the 1987 study, HRS tentatively concluded that potable water and relatively permeable Conejos volcaniclastic materials could be found down to approximately 1,700 feet depth.

Later studies helped refine estimates of aquifer characteristics of the Conejos Formation in the eastern San Juan Mountains. This work included a study of water well records in the eastern San Juan Mountains, including much of the study area, done by HRS for Davis Engineering, Inc. in 1999, and a further refinement of the same area, also done by HRS on behalf of the Colorado Water Conservation Board and the Colorado Division of Water Resources, as part of the Rio Grande Decision Support System (RGDSS):

HRS Water Consultants, Inc., 1999, Estimates of Ground Water Inflow, San Juan Mountains to the San Luis Valley, Colorado: Unpublished consultant's report, 14 p. plus figures.

HRS Water Consultants, Inc., 2004, Task 4 Final Report Ground Water Boundary Flow and Storage Change: CWCB and SEO, unpublished consultant's report, 54 p. plus figures.

Key conclusions from the 1999 study were that the average potentiometric (water table) gradient toward the San Luis Valley from the eastern San Juan Mountains was in the range of 0.007 feet per foot eastward (considerably higher than Huntley's estimates), but that there are many different slopes and directions of the ground water gradient, depending on the aquifer conditions in local subdrainages. That study also concluded that there are approximately 165,000 ac-ft/y of ground water that flow through the Conejos Formation and enter the SLV as ground water in total, between the CO-NM state line on the south, and Saguache Creek on the north. The 2004 RGDSS study revisited the inputs to the 1999 study, parsed the entire San Juan Mountain front into three parts, and overall found less ground water entering the SLV, based primarily on a lower estimate (0.5 to 1.0 ft/day) for the permeability of the Conejos Formation as shown in the following table.

RGDSS Darcy's Law Inflow Estimates: Western SLV Boundary		
Zone of Model Boundary	Model Layer	Darcy' s Law Inflow Estimates (3) (Ac-Ft/Yr)
CO-NM Line to Rio Grande River (includes Conejos, & other minor alluvial inflow	1	5,500
	2	28,000 – 57,000
	3	
	4	
	5	0
	Range: Best Estimate:	33,500 – 62,500 48,000
Rio Grande River to Saguache Creek includes Rio Grande, & other minor alluvial inflow)	1	3,500
	2	16,000 – 32,000
	3	
	4	
	5	0
	Range: Best Estimate	19,500 – 35,500 27,500
Saguache Creek to Poncha Pass (includes Saguache, & other minor alluvial inflow)	1	1,000
	2	16,000 – 28,000
	3	
	4	
	5	0
	Range Best Estimate	17,000 – 29,000 23,000
Total Western Boundary Ground Water Inflow	**Range** **Best Estimate**	**70,000 to 127,000** **98,500**

Notes:
1. HRS Water Consultants, Inc., 2002, RGDSS Task 22 Steady State Calibration.
2. HRS Water Consultants, Inc., 2002, RGDSS Task 23 Average Monthly Calibration.
3. This review. Compares to : 70,000 to 130,000 ac-ft/yr (HRS Water Consultants, Inc., 2000, RGDSS Task 4 Ground Water Budget.)

Some significant studies have concentrated on the San Luis Valley, and relate to the study area only peripherally. Notable studies include:

Mayo, A.L., Davey, A., and Christiansen, D., 2007, Groundwater flow patterns in the San Luis Valley, Colorado, USA revisited: an evaluation of solute and isotopic data: Hydrogeology Journal, v. 15, p. 383-408.

Brendle, D.L., 2002, Geophysical Logging to Determine Construction, Contributing Zones, and Appropriate Use of Water Levels Measured in Confined-Aquifer Network Wells, San Luis Valley, Colorado, 1998–2000: U.S. Geological Survey, Water Resources Investigations Report 02-4058, 58 p.

These studies contain relatively little information directly applicable to this study, although the studies do add to the overall understanding of the ground water flow characteristics from the San Juan Mountains to the San Luis Valley. The study by Mayo and other does contain relevant information on the general chemical composition of the streams entering the San Luis Valley from the San Juan Mountains (Mayo and others, p. 393):

> Streams entering the valley from both the San Juan Mountains and the Sangre de Cristo Range are of the $Ca^{2+} - HCO_3^-$ type with very low TDS contents, typically <100 mg/L (Table 2, Fig. 9). The mean SO_4^{2-} concentration is 14.6 mg/L and the median is only 5.0 mg/L. Low SO_4^{2-} springs are of the $Ca^{2+} - HCO_3^-$ type and typically have TDS in the range of 150–175 mg/L. Approximately 10% of San Juan Mountain and 33% of Sangre de Cristo Range streams have SO_4^{2-} concentration >20 mg/L.

Also, the isotopic composition of the ground water clearly shows the strong contribution of water from the San Juan Mountains that recharges the aquifers of the San Luis Valley.

The USGS (Brendle) 2002 study summarized well logging, including temperature, fluid conductivity, and downhole flowmeter logging, of a number of wells in the SLV. Although not directly applicable to the study area, these logs do demonstrate the strong dependence of ground water flow to the lithology and the degree of fracturing.

A recent in-depth study of ground water relevant to the San Juan Mountains (although it was not done within the study area) was the Ph.D. thesis of Dr. Marty Frisbee:

Frisbee, M.D., 2010, Streamflow generation processes and residence times in a large, mountainous watershed in the southern Rocky Mountains of Colorado, USA: Ph.D. Thesis, New Mexico Institute of Mining and Technology, 229 p.

The Frisbee study involved research in the Saguache Creek drainage that sought to help shed light on the physical processes that generate streamflow from ground water contributions, at larger watershed scales than small tributary streams. Correlative questions involve solute transport processes and aquifer residence times of ground water tributary to streams. Overall, while the processes that help drive ground water contribution amount and timing to mountain streams is useful, it may not be directly applicable to watersheds outside the author’s study area.

A recent study by Caine and Wilson uses a water budget approach to explore how ground water recharges, moves, and discharges in relatively small subdrainages in the San Juan Mountains.

Caine, J.S. and Wilson, A.B., 2011, The hydrogeology of the San Juan Mountains, *in* Blair, R. and Bracksieck, G., editors, The Eastern San Juan Mountains: their geology, ecology and human history: University Press of Colorado, p. 79-98.

The authors estimate the inflow and outflow of a small creek basin at reconnaissance level to explore various questions, including:

- How do steep slopes, as are common in the San Juan Mountains, allow for ground water recharge rather than simply causing precipitation to run off?
- How do the steep slopes translate into hydraulic (water table) gradients that drive ground water flow?
- Can extremely high water table gradients drive large volumes of meteoric (i.e. precipitation or snowmelt) water into the subsurface as recharge in this geologic environment?
- How does complex geology influence these processes and control ground water flow paths?

The authors do not attempt to fully answer all of these questions in a relatively brief reconnaissance level study, but they do present several conclusions that we believe are relevant to this study. Caine and Wilson state that the few hydraulic conductivity data available for volcanic bedrock in the San Juan Mountains indicate values in the general range of approximately 10^{-6} to 10^{-9} m/s, (0.28 ft/day to 0.00028 ft/day) inclusive of fracture and intergranular permeability. These numbers generally are consistent with the range of values reported in earlier studies, and that are found in the Old Woman Creek and San Francisco Creek areas within the overall study area.

The authors suggest that the available evidence of significant permeability, and the occurrence of ground water at various depths, indicate that the volcanic rocks that comprise the majority of the aquifer material in the San Juan Mountains is well connected, although through complex flow paths, from the surface to large depths. In addition, the authors suggest that there may be a high degree of heterogeneity in the volcanic and volcaniclastic rock aquifers at the scale of a creek subdrainage or even a smaller area, that could cause contaminant transport through complex ground water flow paths. The work done for this study in San Francisco Creek and Old Woman Creek on ground water chemistry and permeability leads us to agree with Caine and Wilson's general conclusion with respect to these creek drainages.

3.0. GEOLOGIC SETTING

3.1 Geologic Overview

The geology of Rio Grande County is very complex, and much of it is buried deep below ground level and not apparent in the landscape that we see today. To help understand the geologic setting and its relationships to hydrogeology and the potential oil resources, a geologic time chart, a stratigraphic column, a simplified regional geologic map, and a regional cross section are included in the report. This section draws upon the published works of many geologists. To avoid cluttering the text with abundant reference citations, which might impede the reading of the section by non-geologists, only the most relevant references are cited.

Figure 3.1 shows the geologic time periods, the approximate boundaries of the time periods, and, more importantly, the major geologic events that have occurred in the County and that are responsible for the area's complex geology. Figure 3.2 is a stratigraphic column that shows the geologic formations present in the project area. The regional geologic map (Figure 3.3) shows the distribution of the geologic formations in plan view. The region's complex geology is apparent in Figure 3.4, a cross section or vertical slice through the earth that starts near Pagosa Springs, crosses the Continental Divide near Wolf Creek Pass, then extends past the South Fork and Del Norte areas, across San Luis Valley, and ends at Blanca Peak.

The entire project area is underlain by a thick pile of volcanic lava flows, ash-flow tuffs, and associated sedimentary rocks that were eroded from or blown out of the volcanoes during the middle Tertiary, mostly from about 35 to 25 million years ago. These rocks have attracted the attention of many geologists for over a century. The general types of volcanic rocks and their distribution are fairly well known, as are the major geologic structures (faults and folds) that affect the volcanic rocks. Much effort has gone into studying the ash-flow tuffs, but less attention has focused on the andesitic lava flows and volcaniclastic rocks (volcanic-rich sedimentary rocks) in the Conejos Formation. Unfortunately, all of the sampled water wells, as well as most other bedrock wells in the project area produce their water from the less well understood volcanic and volcaniclastic rocks in the Conejos Formation.

This thick pile of volcanic rock conceals the underlying rocks, about which little was known until the past few decades. There are only a few places in the San Juan Mountains where erosion has carved "windows" though the volcanic pile and the older and underlying rocks can be seen in outcrop. Two of these windows are in the valley carved by the Conejos River where very ancient Precambrian igneous and metamorphic rocks are exposed beneath the volcanic rocks. Other windows through the San Juan volcanics lie north of Saguache. There, either the volcanic rocks rest on Precambrian rocks or on rocks that are older than the Cretaceous marine shales that are the source of much of the petroleum produced in Colorado. For these reasons, there was little interest in the rocks that underlie the volcanic rocks in the eastern San Juan Mountains.

But the conventional geologic thinking began to change in the 1970s when core from holes drilled for mineral exploration in the mountains north of Del Norte (Summer Coon Volcano) was found to contain fractures filled with biodegraded oil (Gries, 1985). Reports of oil seeping out of volcanic rocks, oil in mineral exploration core near Summitville, and analyses of soil along Embargo Creek prompted more interest in the oil potential of rocks beneath the San Juan Volcanic Field. The oil was thought to come from previously unknown petroleum source rocks that were beneath the volcanic rocks.

Oil exploration drilling and seismic investigations began in Rio Grande County in 1981 (Gries, 1985, 1989; Gries and others, 1997). Within a few short years these efforts demonstrated the existence of the San Juan Sag, a trough-like structural depression concealed beneath the San Juan Volcanic Field (Figure 3.5). The San Juan Sag contains thick deposits of Mesozoic-age petroleum source rocks, including the Cretaceous Lewis Shale and Mancos Shale. The sag is a northeastward extension of the San Juan Basin, a well known prolific producer of petroleum.

The eastern margin of the San Juan Sag is believed to be controlled by a generally north-south-trending fault, the Cimarron Fault, whose trace is about at the longitude of Del Norte. East of the fault the Mesozoic-age petroleum source rocks were eroded off the mountain uplift, but they were preserved in the San Juan Sag on the down-dropped west side of the fault. The northern and southern margins of the San Juan Sag extend far beyond the county line in those directions. The San Juan Sag exists beneath all of Rio Grande County, except for the area east of about a north-south line drawn approximately through Del Norte. Future oil and gas exploration potentially could occur in all areas underlain by the San Juan Sag.

3.2 Precambrian and Paleozoic History

Ancient Precambrian rock exists at depth almost everywhere beneath the County. These rocks are often referred to as basement rock. The only areas where Precambrian basement rocks may not be present are where much younger igneous intrusions associated with the middle Tertiary calderas and stratovolcanoes of the San Juan Volcanic Field intruded into and replaced the basement rock (Tweto, 1987). Because of this, Precambrian basement rock may not be present in the southwest part of the County in the vicinity of the Summitville Caldera and in a very small part of the northwest corner of the County along the margin of the La Garita Caldera (Lipman, 2006). The Precambrian also may be replaced by narrow, elongate igneous dikes related to the Summer Coon Volcano and Baughman Creek Volcanic Center north and northwest of Del Norte (Steven and others, 1974; Lipman, 1974, 2006).

The Precambrian basement rocks beneath the County are not well understood because they are buried beneath thousands of feet of younger sedimentary and volcanic rocks. The drill cuttings recovered from the six oil tests that extended to the Precambrian basement provide limited data with which to indentify the specific rock type penetrated by the well. Assuming the Precambrian rocks are similar to nearby outcrops in the Sangre de Cristo Mountains and in the Conejos River valley, they may chiefly consist of intrusive granitic rocks or metamorphic rocks about 1.5 to 1.7 billion years old. The Precambrian basement rocks play a role in the oil exploration drilling, because when drill holes reach the top of the Precambrian most companies will stop drilling.

During the early and middle parts of the Paleozoic Era Rio Grande County may have been episodically covered by shallow seas, as were areas further north in Saguache County near Bonanza. If the episodic early and middle Paleozoic seas covered the County, then sandstone, limestone, and shale would have been deposited. But when the Ancestral Rocky Mountains rose during the late Paleozoic, the entire County was uplifted to form mountains; any early and middle Paleozoic rocks that might have existed here would have been eroded off the uplift, exposing the underlying Precambrian basement rock. Figure 3.6 shows the paleogeography of the region about 300 million years ago. Rio Grande County was located in the heart of the ancestral mountain range called the Ancestral Uncompahgre-San Luis Uplift at that time.

Oil is produced from the early and middle Paleozoic rocks in other parts of Colorado. But there is no potential to produce oil from the early and middle Paleozoic rocks in the County because they were stripped off by erosion about 300 million years ago and do not exist in the subsurface beneath the County.

3.3 Triassic and Jurassic Periods

During the Triassic and Jurassic Periods the County continued to be elevated above sea level. Continental sediment probably was episodically deposited in the County during this time, but much of it was removed during several major periods of erosion (Berman and others, 1980). The only rocks of this time period found so far in drill holes in the County include the Jurassic-age Entrada Sandstone, Wanakah Formation, and Morrison Formation (Brister and Chapin, 1994) (see Figure 3.2).

3.4 Cretaceous Period and the Western Interior Seaway

During the early part of the Cretaceous Period (late Mesozoic Era) a major incursion of the sea spread across the interior of the North American continent. The seaway encroached from both the north and the south. By about 85 million years ago, both arms of the sea eventually joined to form a continuous seaway that spanned north-south across the interior of the continent (Figure 3.7). The seaway is often called the Western Interior Seaway, but it also has been known as the Cretaceous Seaway, the Niobraran Sea, and the North American Inland Sea.

As the sea transgressed (advanced) and regressed (retreated) across the continental interior, including Rio Grande County, thick sequences of marine and near-shore marine sediment were deposited. The sediments deposited by the Western Interior Seaway in the County were originally thousands of feet thick.

The Lewis Shale and Mancos Shale (Figure 3.2) are the thickest organic-rich shale formations in the project area; they are the primary petroleum source rocks in the County. In the western part of the County a section of non-marine sediment consisting of sandstone, mudstone, and perhaps coal lies between the Lewis and the Mancos. These non-marine rocks, called the Mesaverde Group, thin eastward and eventually pinch out in the subsurface beneath the County. In the eastern part of the County, the Lewis directly overlies the Mancos Shale and no Mesaverde rocks are present. The organic-rich shale was subsequently buried by more sediment and volcanic rocks, which slowly caused the temperature and pressure to increase. This increase encouraged the organics to “mature” into petroleum.

The sand deposited along the shore of the ocean as it spread across the region became the Dakota Formation, and the sand deposited along the shore as the ocean retreated became the Pictured Cliffs Sandstone. The Dakota Formation (also known as the Dakota Sandstone) is an important petroleum reservoir rock in other parts of Colorado, and it was the primary target of past drilling efforts in the project area. To the west and southwest, in the San Juan Basin, the Pictured Cliffs Sandstone also is a major reservoir rock for petroleum, but only small remnants of the Pictured

Cliffs are thought to remain in the County. Most of the Pictured Cliffs Sandstone was stripped off by erosion during a second period of mountain building called the Laramide Orogeny, which is described in the next section.

3.5 Late Cretaceous to early Tertiary Laramide Orogeny

Near the end of the Cretaceous Period tectonic forces once again caused major deformation affecting the Earth's crust in a large part of the western United States, including Rio Grande County. Major igneous intrusions and local volcanism accompanied the crustal deformation. This period of tectonism and igneous activity is called the Laramide Orogeny (Tweto, 1975; 1980). It began about 72 to 70 million years ago, and continued into the early Tertiary, lasting for about 20 million years.

The Laramide Orogeny was responsible for much of the geology that lies concealed beneath the San Juan Volcanic Field. One of the large Laramide uplifts, the Laramide San Luis Uplift, rose in part in the same location as the late Paleozoic Ancestral Uncompahgre-San Luis Uplift. Much of modern San Luis Valley was the site of former ancient mountain ranges that rose up during the late Paleozoic and Laramide episodes of mountain building. The western margin of the Laramide San Luis Uplift was located further east than the western edge of the late Paleozoic uplift; it runs north-south through Rio Grande County. A major fault along the western margin of the Laramide San Luis Uplift, the Cimarron Fault, was responsible for the uplift of the Laramide mountain range (Brister and Chapin, 1994).

According to published information, the Cimarron Fault trends generally north-south approximately through Del Norte (Brister and Chapin, 1994). The Cimarron Fault controls the presence and distribution of petroleum source rocks in the County. East of the fault, on the uplifted mountain block, the Cretaceous rocks were stripped off by erosion. Hence, petroleum source rocks do not exist east of the fault in eastern Rio Grande County. The San Juan Sag formed on the west side of the Cimarron Fault, and the petroleum source rocks are preserved in the sag on the west side of the fault.

The San Juan Sag is a trough-like structural depression. In map view the sag is elongated in a north-south direction, extending from west Del Norte to near Pagosa Springs (Figure 3.5). The up-arched Archuleta Anticlinorium near Pagosa Springs forms the southwest side of the sag (Figure 3.4), and the San Juan Basin, well known for its oil and gas production, lies west of the Archuleta Anticlinorium. The northern and southern flanks of the San Juan Sag are less well understood, but they apparently do extend beyond the County line in both directions.

Sediment eroded off the Laramide San Luis Uplift was deposited in the San Juan Sag. These sediments are rich in quartz and feldspar eroded from the Precambrian rocks exposed in the uplift. This Laramide "synorogenic" sediment is called the Blanco Basin Formation (Brister, 1991; Brister and Chapin, 1994).

3.6 Middle Tertiary Volcanism

During the middle of the Tertiary Period, starting at about 36 million years ago, a major phase of igneous activity initiated (Steven, 1975). By the time it ended around 25 million years ago, an extensive middle Tertiary volcanic field may have blanketed much of central Colorado and north-central New Mexico, including all of Rio Grande County (Figure 3.8). The project area is located in San Juan Volcanic Field, the most widespread and best preserved remnant of the very large middle Tertiary volcanic field.

The San Juan Volcanic Field was formed during two major phases of volcanic activity and one relatively minor one (Lipman and others, 1970; Steven, 1975; Lipman, 1974, 1976, 2006). Numerous andesitic stratovolcanoes were active during the first phase of activity, which started about 35 million years ago. The stratovolcanoes continued to erupt during the next phase of activity, but at a reduced level. By about 30 million years ago phase two had begun in earnest. Huge, abrupt, catastrophic explosions of silica-rich ash roared downslope from calderas (caldron-like features formed by explosion and later collapse of a volcano) during phase two. These ash clouds were extremely hot clouds of ash and gas that flowed rapidly across the landscape for many miles. Some ash flows extended eastward all the way across San Luis Valley (Figure 3.4).

After the rapid extrusion of the large volumes of molten material from a caldera, they often collapsed inward, forming deep, steep walled, collapsed calderas. The eruption from the La Garita Caldera is currently thought to be the largest well-documented volcanic eruption anywhere in the World. Starting about 26 million years ago, near the end of the middle Tertiary, the volcanism evolved into mostly basaltic volcanoes that produced relatively slow moving lava flows and minor amounts of ash during a minor third phase of volcanism. This phase of volcanism continued into the late Tertiary and the Quaternary, and is discussed in the following section.

The distribution of the volcanic rocks from the three phases of San Juan volcanism is shown in Figure 3.3, a simplified geologic map of the study area and adjacent areas. More detailed geologic maps showing the distribution of volcanic rocks in the County include Steven and others (1974), Lipman (1974, 1976, 2006), and Lipman and Steven (1976).

Rocks associated with the first phase of volcanic activity are lumped together into the Conejos Formation. They crop out at the ground surface in a north-south-oriented belt in the central part of the study area (Figure 3.3). The outcrop belt of Conejos Formation extends from near Del Norte in the east to South Fork in the west, and it narrows from north to south. Much of the developed land in the mountainous part of Rio Grande County lies within the outcrop belt of the Conejos Formation. The Conejos Formation also exists in the subsurface at relatively shallow depths beneath much of the rest of the study area.

The Conejos Formation is subdivided into two units in the study area. The rocks located near the old stratovolcanoes consist mostly of lava flows with minor amounts of ash and other types of material. These rocks are included in the vent facies of the Conejos Formation (Lipman, 1976). The lava flows typically are hard, dense rocks with no intergranular permeability, but fractures within them do provide permeability. In the outcrop shown in Figure 3.9 the fracture density is high in the central and right sides of the outcrop and much lower in the left side. A water well drilled in the highly fractured rocks, more often than not, would produce more ground water than a well drilled into the less fractured rocks.

The mudflows and streams coming off the Conejos stratovolcanoes were composed almost entirely of material eroded from the volcanoes. These sedimentary deposits are included in the volcaniclastic facies of the Conejos Formation. In places the volcaniclastic facies includes well indurated (i.e. hardened) beds of conglomerate that form good outcrops, but other parts of the formation are finer grained, less indurated, and tend to erode easily (Figure 3.10). The Conejos also includes the intrusive stocks (the feeder pipes for the volcano), dikes (narrow, vertical sheets of cooled magma), and sills (tabular igneous intrusions that follow the layering in rocks they intrude into).

Two of the stratovolcanoes formed north of the study area: the Summer Coon Volcano and the Baughman Creek volcanic center (Lipman, 1976). Dikes that radiate from the Summer Coon Volcano extend into the Old Woman Creek area. Some dikes form prominent landforms, such as Indian Head. Another stratovolcano was located in the southwest part of the County near Summitville.

Ash-flow tuffs from the second phase of volcanic activity crop out in much of the western part of the study area (Figure 3.3). They are broken by numerous northwest-southeast oriented faults, most of which are related to the Rio Grande Graben, a downdropped block of rock bounded by faults. An outcrop belt of ash-flow tuffs also borders the west side of San Luis Valley. Here the ash-flow tuffs are broken by relatively small displacement faults. The ash-flow tuffs formerly blanketed the area where the Conejos now crops out, but the ash-flow tuffs were removed from the area by erosion. The ash-flow tuffs were erupted from several different calderas, including the Summitville Caldera in the southwest part of the County. Intrusive igneous rocks crop out across widespread areas where the calderas once existed. These large intrusions perforated and replaced all older rocks, including the Precambrian and Cretaceous rocks.

3.7 Late Tertiary and Quaternary Tectonism, Volcanism, and Sedimentation

As the middle Tertiary volcanism waned, the region’s crust began to pull apart in response to east-west extension. Deep faults and fractures caused by the extension allowed molten rock from the mantle to move upward and erupt as low-silica basaltic volcanoes during the third phase of volcanism. Minor amounts of high-silica rhyolitic volcanism erupted locally.

All the basaltic flows from the third phase of volcanism in Rio Grande County are classified as Hinsdale Basalt. Today, only relatively small remnants of Hinsdale Basalt remain in the County. One of the largest remnants is on the drainage divide between Pinos Creek and Beaver Creek. Other prominent remnants are in the southeast corner of the study area, and on the top of Bennett Peak. No well preserved basaltic volcanoes remain in the County, but good examples can be seen at Los Mogotes in Conejos County (5 million years old) and at Mesita Volcano in Costilla County (1 million years old; Appelt, 1998).

The east-west extension tore apart the Earth's crust and created the Rio Grande Rift (Tweto, 1979a). The rift is a major north-south-trending tear in the Earth's crust that extends from Mexico and west Texas northward, through New Mexico and into Colorado (Figure 3.11).

As the rift gradually pulled apart, normal faults downdropped the crust within the rift, and sediment and volcanic rocks accumulated in the tectonically lowered basins within the rift. The sediment and volcanic rocks that fill the rift from San Luis Valley southward through New Mexico are called the Santa Fe Group. Rio Grande County is situated on the western flank of the San Luis Basin, one of the large structural basins formed within the Rio Grande Rift.

San Luis Basin is an east-tilted block bounded on the east by a major fault located at the base of the Sangre de Cristo Mountains, the Sangre de Cristo Fault (Brister and Gries, 1994). The east tilting of the Precambrian basement and overlying ash-flow tuffs and Santa Fe Group is obvious in the regional cross section shown in Figure 3.4. The volcanic rocks in the County also are east tilted; they dip east and extend into the subsurface beneath San Luis Valley. Many of the fractures and faults in the volcanic rocks in the study area may be a result of the regional extension and east tilting associated with the Rio Grande Rift.

Some of the faults in the study area were, or continue to be, active during rifting. They include the faults associated with the Rio Grande Graben near South Fork, and the faults that cut the ash-flow tuffs in the foothills west of Monte Vista.

During the Quaternary the climate repeatedly cooled during multiple, relatively long periods of glaciation, and then warmed during relatively short, warm, intervening interglacial periods between the ice ages. This part of the Quaternary is referred to as the Pleistocene. Glaciers slowly grew high in the mountains in the headwaters upstream of Rio Grande County. As the glaciers melted during the final phases of an ice age, tremendous volumes of glacial melt water flowed down the Rio Grande, carrying with it the gravel and sand found in the river terraces in the study area, as well as the thick deposits of gravel and sand found in the Rio Grande Fan that starts near the east edge of the study area and spreads out into eastern Rio Grande County and beyond.

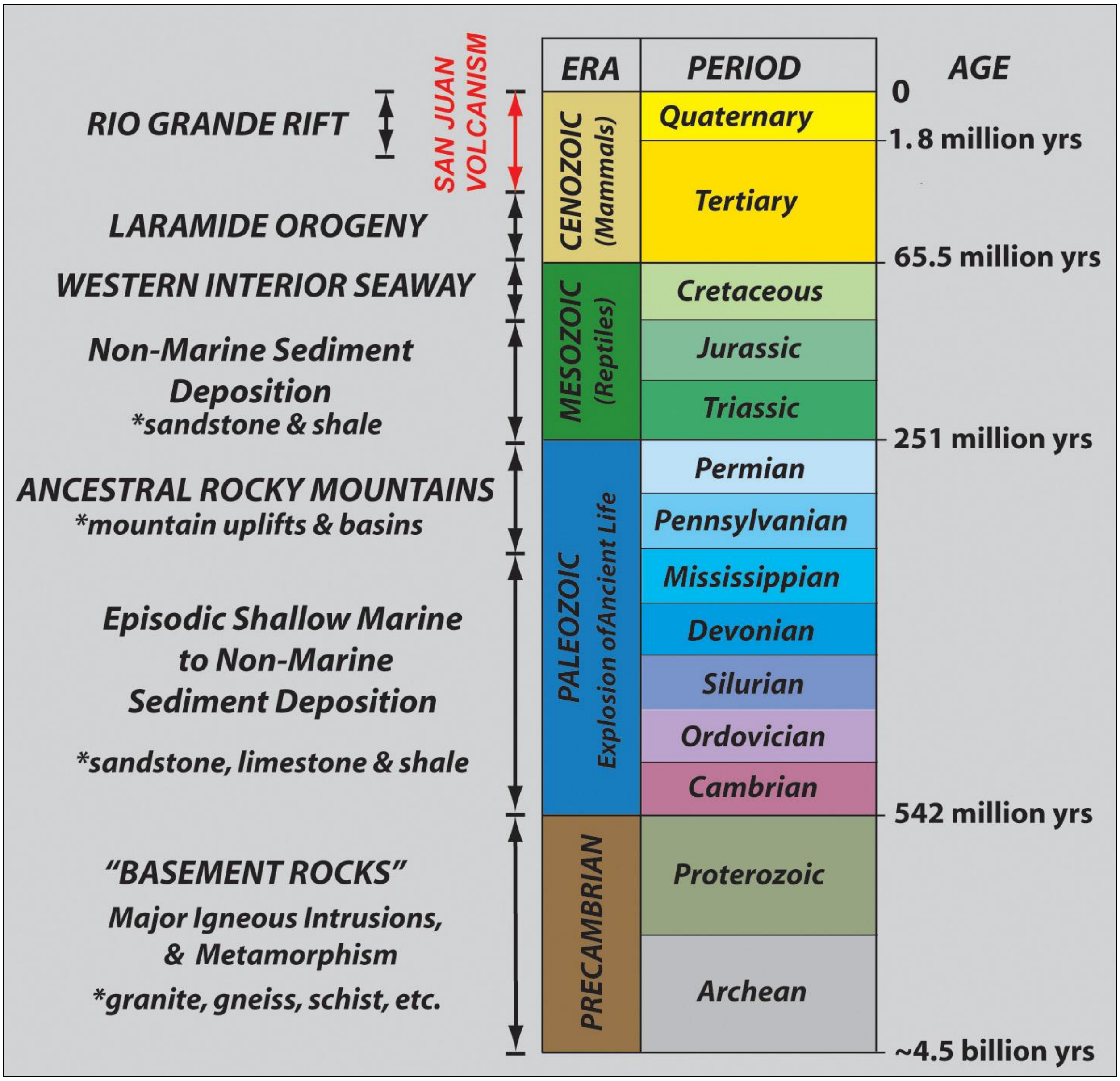

Figure 3.1. Geologic time chart. Also shows ages of the geologic eras and periods**,** and the major geologic events that have shaped the complex geology of Rio Grande County.

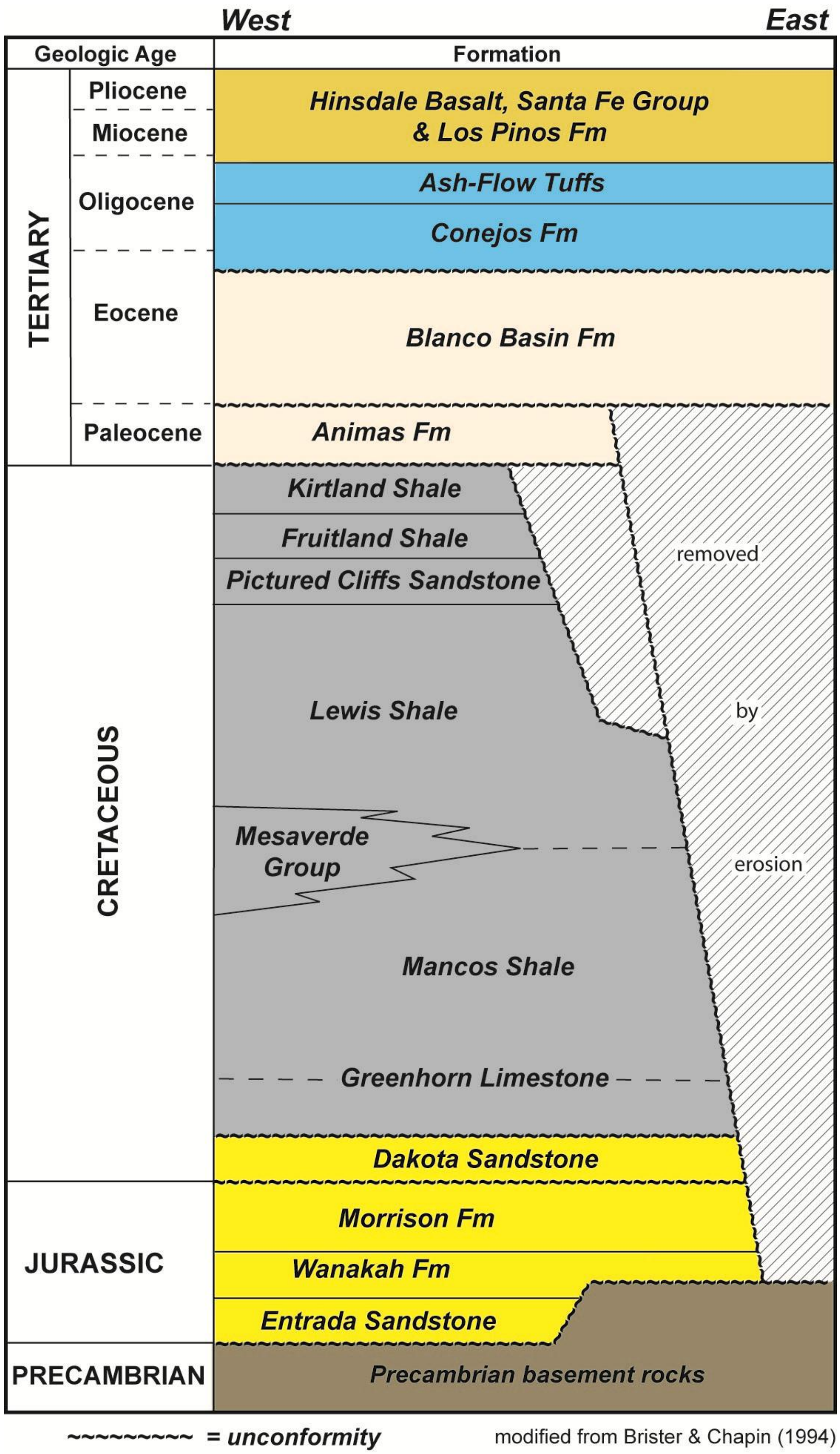

Figure 3.2. Stratigraphic column. Shows the geologic formations present in the project area.

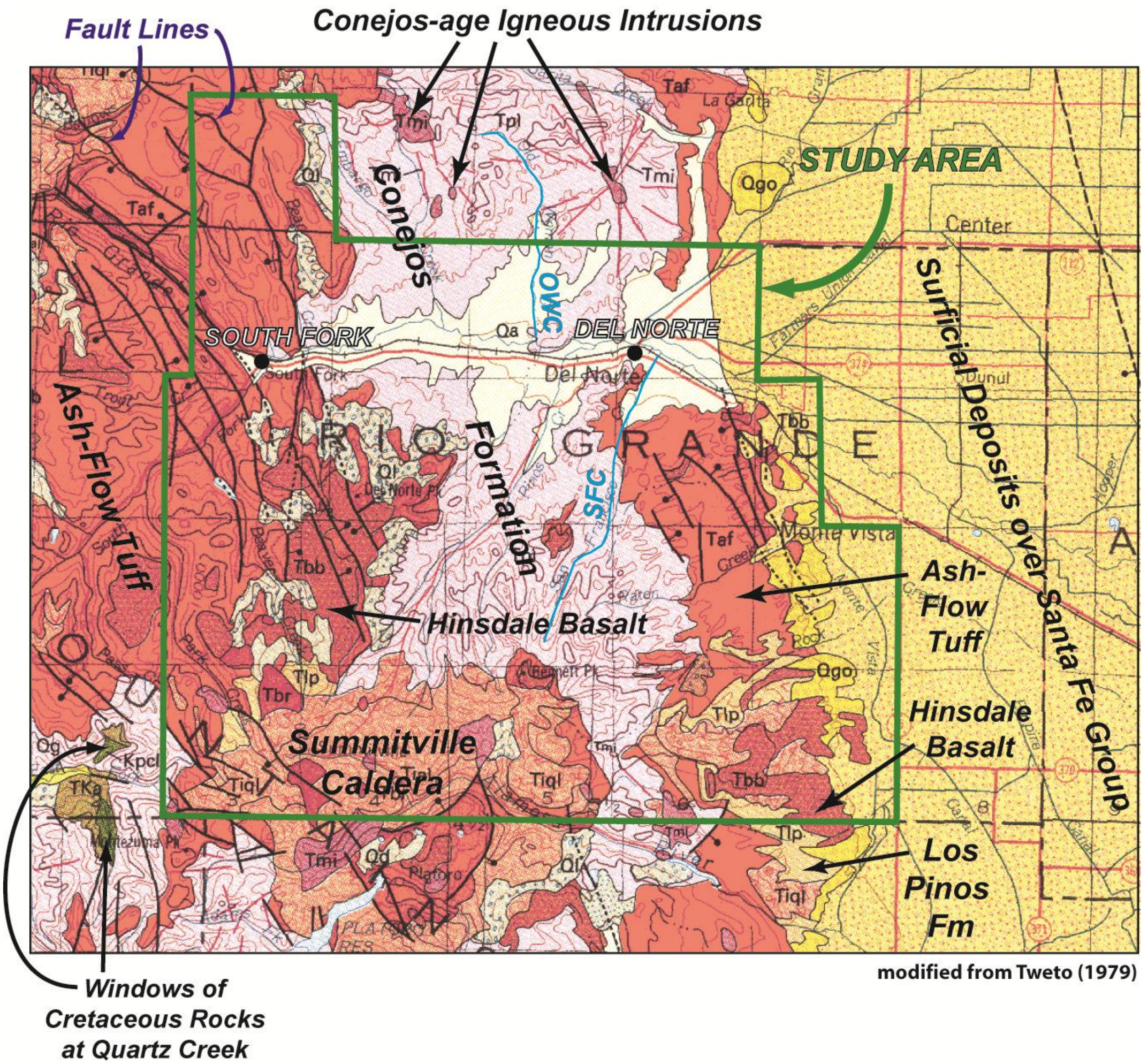

Figure 3.3. Simplified geologic map of the project area**.** Each geologic formation is shown in a different color, and the more important geologic formations are labeled with the large lettering. SFC = San Francisco Creek; OWC = Old Woman Creek. (modified from Tweto, 1979b)

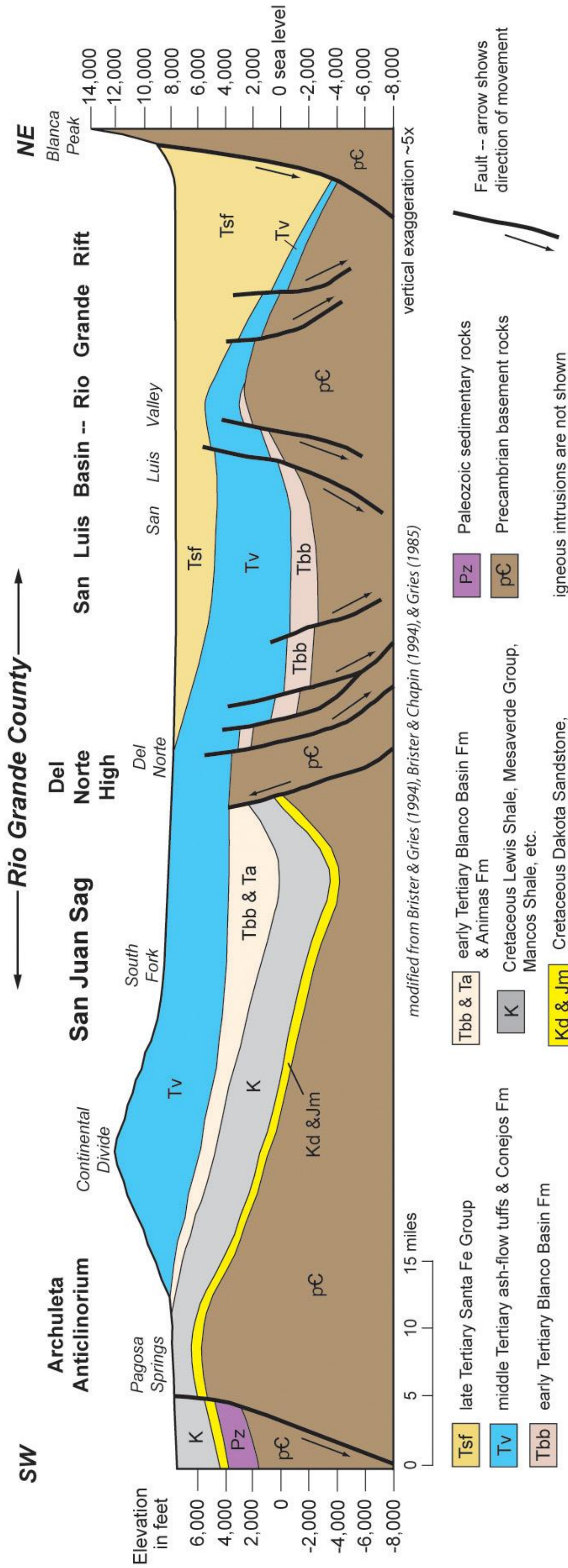

Figure 3.4. Simplified geologic cross section. Extends from near Pagosa Springs, past South Fork and Del Norte, and across the San Luis Basin to Blanca Peak. Rio Grande County spans the eastern part of the San Juan Sag, the Del Norte High, and the western part of San Luis Basin.

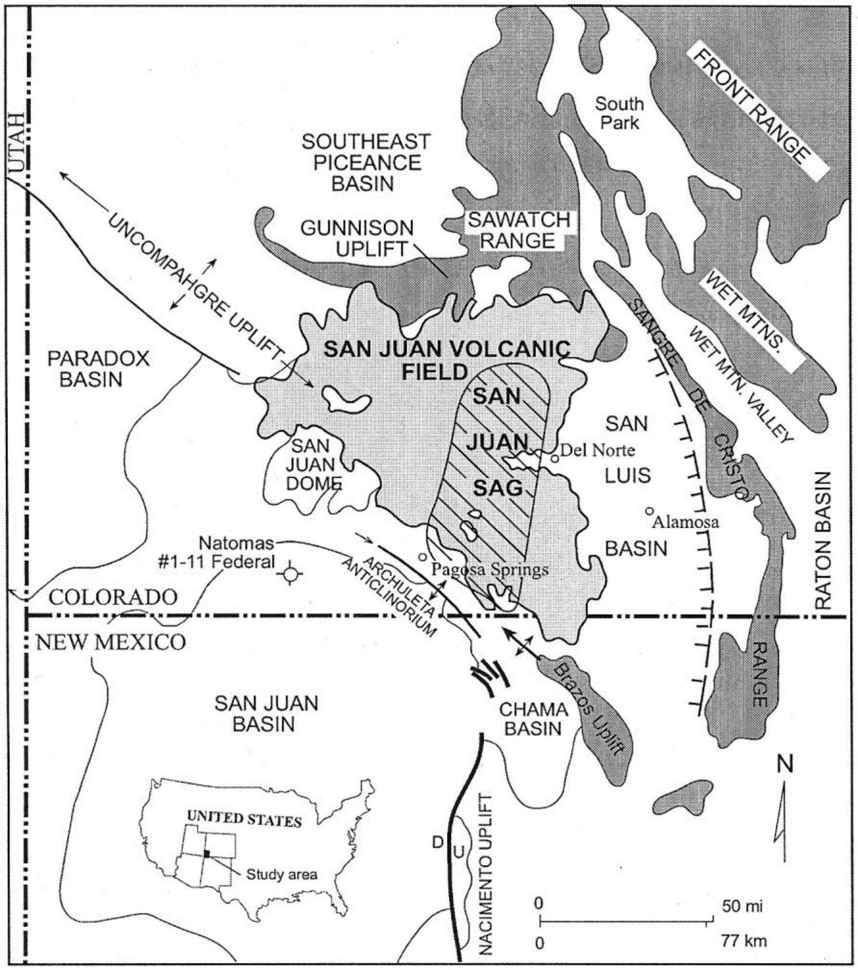

Figure 3.5. Regional map showing location of the San Juan Sag (from Gries and others, 1997).

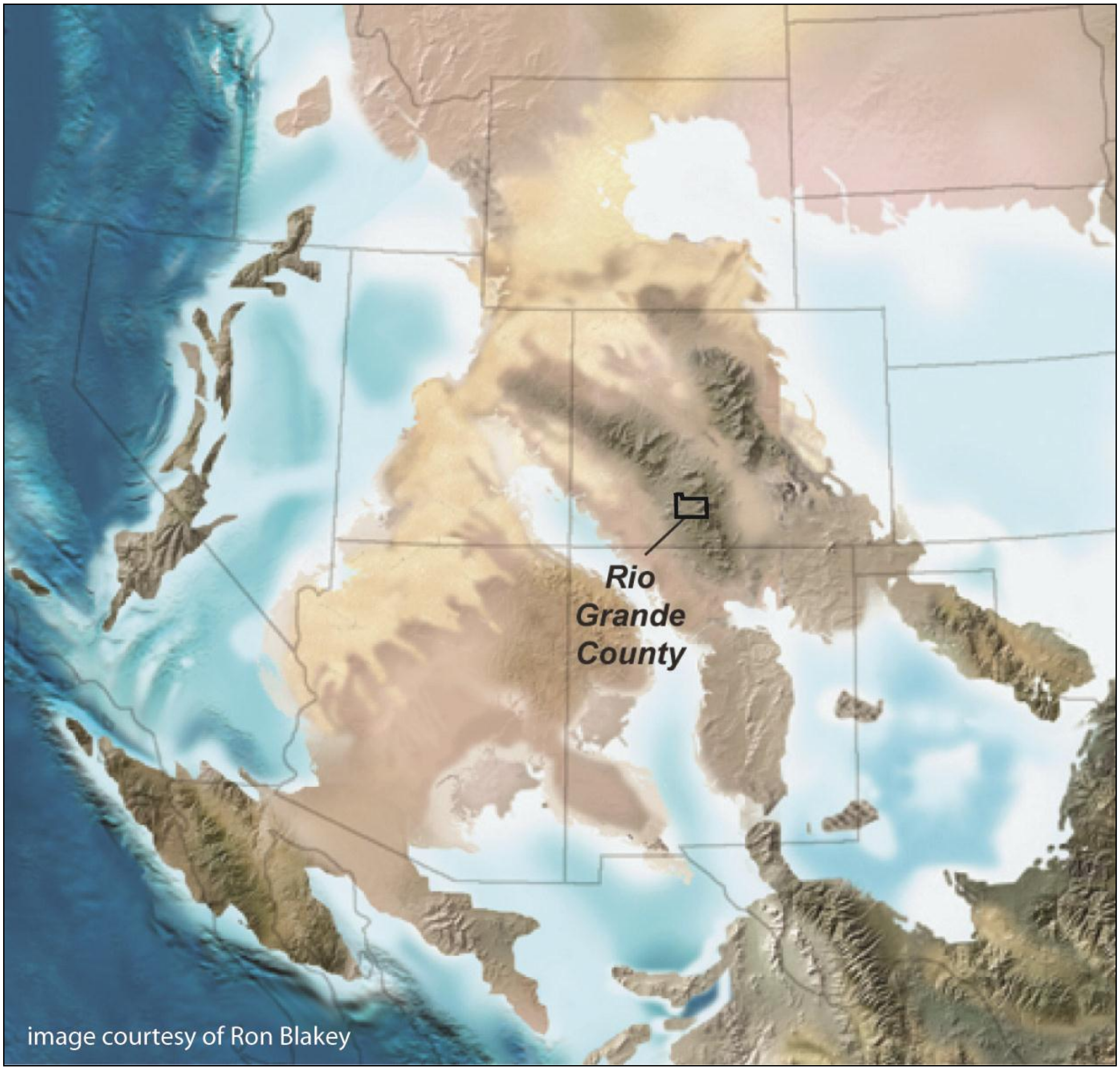

Figure 3.6. Paleogeographic map of the western United States ± 300 million years ago during the Pennsylvanian Period. Rio Grande County was located in the mountains of the Ancestral Uncompahgre-San Luis Uplift at this time.

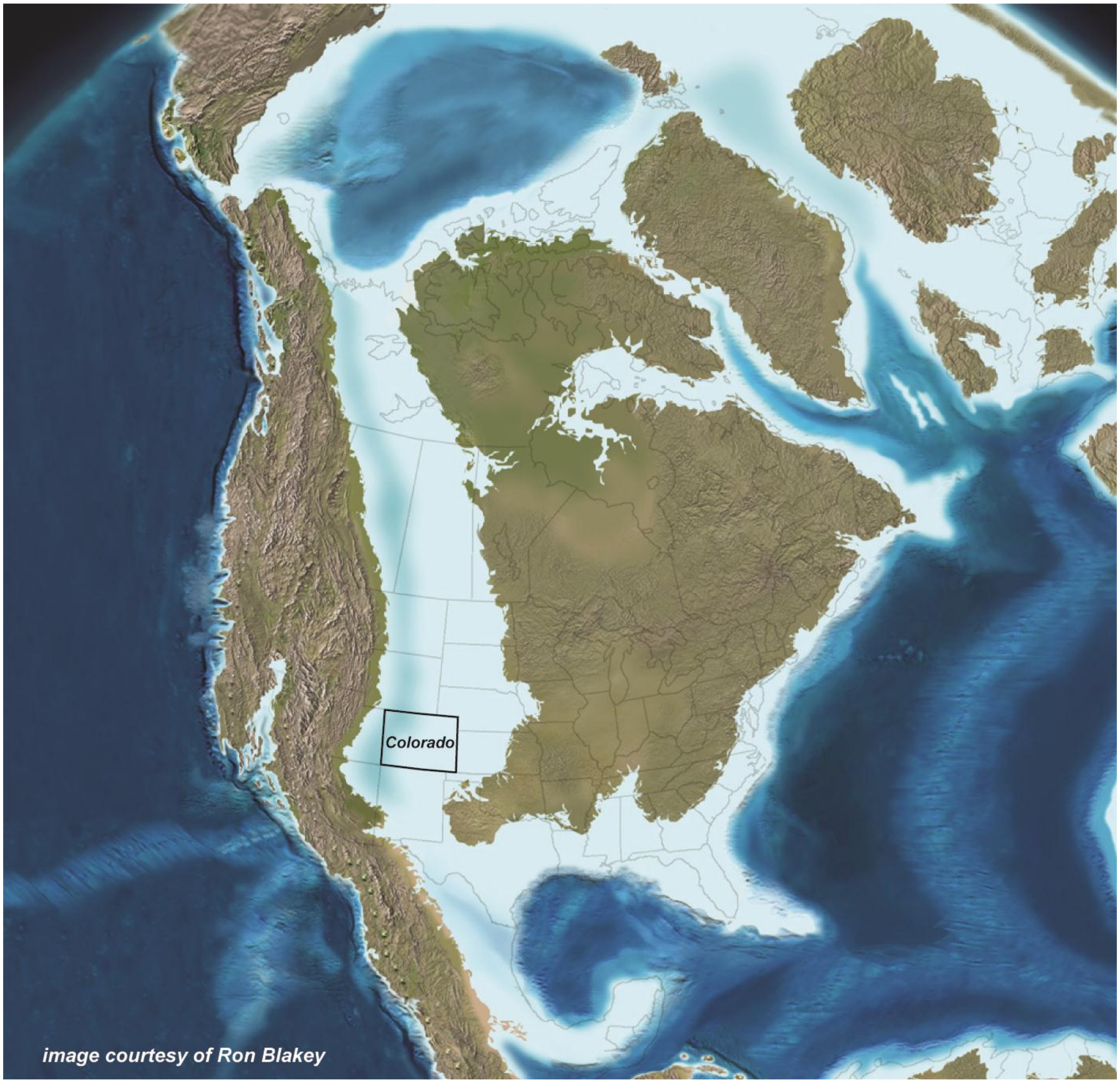

Figure 3.7. Paleogeographic map of the United States about ±85 million years ago when the Western Interior Seaway had spread across all of Colorado.

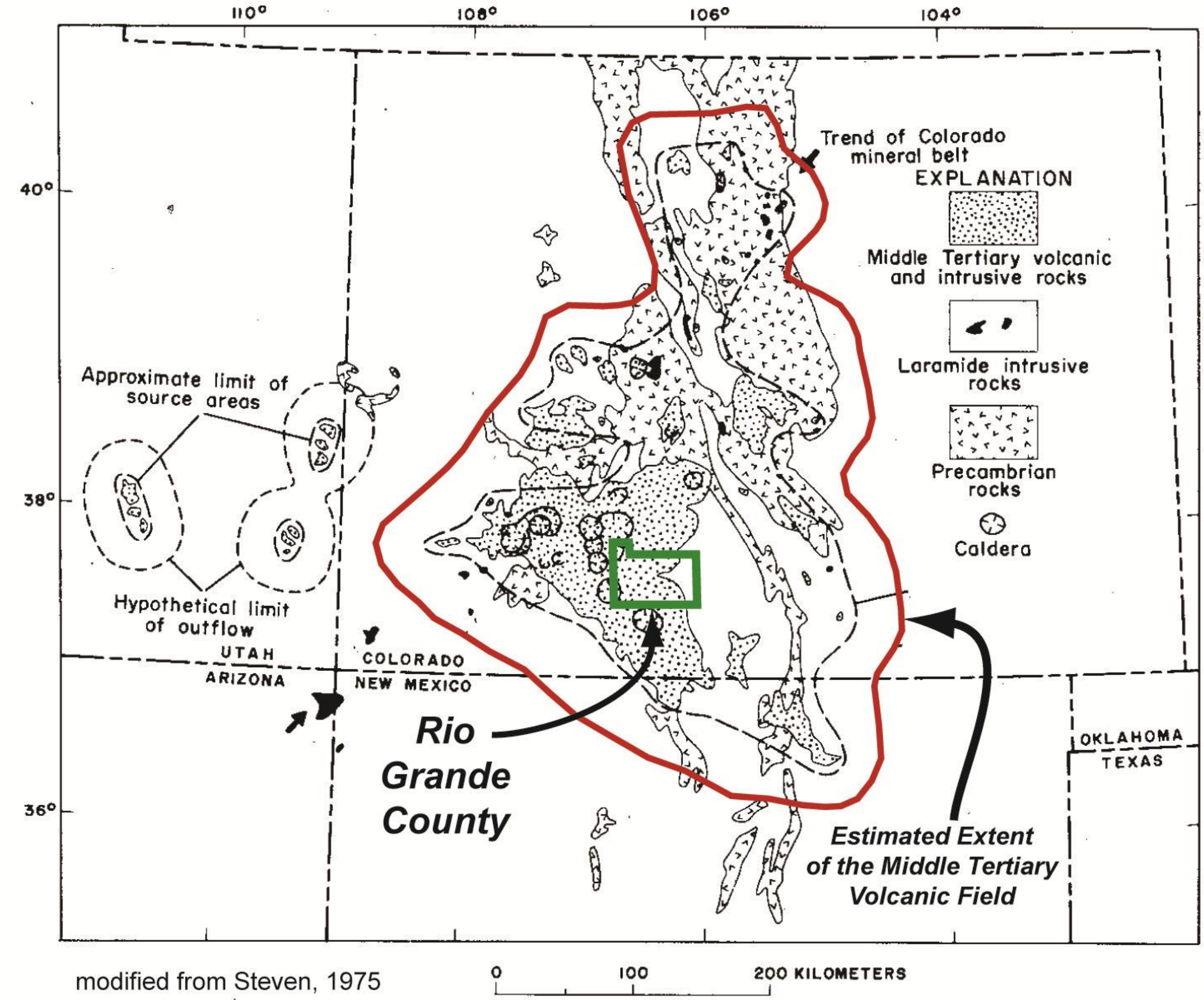

Figure 3.8. Extent of the middle Tertiary volcanic field**.** Rio Grande County is located in the San Juan Volcanic Field portion of the middle Tertiary volcanic field, which is thought to have formerly covered much of central Colorado and north-central New Mexico.

Figure 3.9. Photographs of the vent facies of the Conejos Formation near Bear Creek**.** In upper photo the layering associated with individual lava flows is apparent. Lower photo shows variation in fracture density in the lava flows. High fracture density in center and right side of outcrop; low fracture density in left side.

Figure 3.10. Photographs of the volcaniclastic facies of the Conejos Formation at the sampled spring RGC31. Conglomerate beds in upper photo; sandy mudstone bed in lower photo.

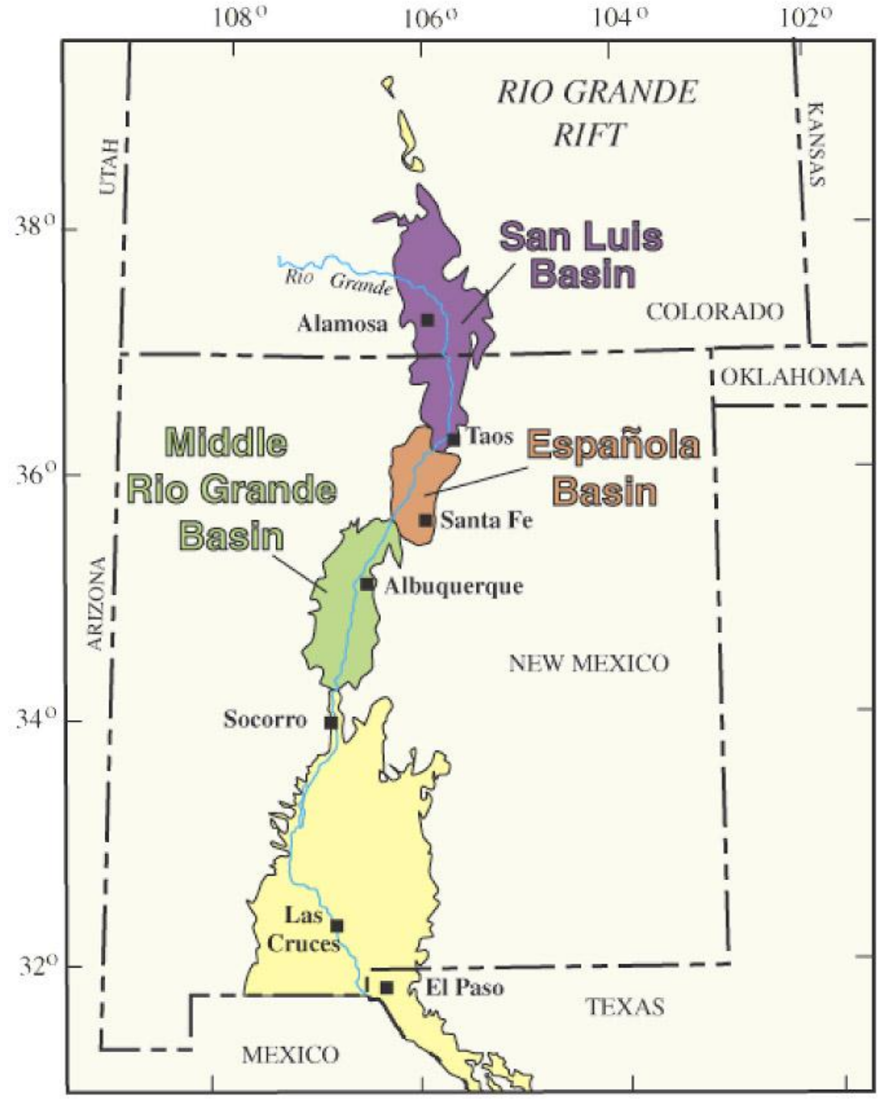

Figure 3.11. Map showing extent of Rio Grande Rift**.** (courtesy of U.S. Geological Survey)

4.0 OIL AND GAS ACTIVITIES

4.1 Exploration and Production History

Gries (1985, 1989) described the evolving geologic observations and theories that prompted the initial exploration for petroleum in the rocks beneath the San Juan Volcanic Field. The following paragraphs on the history of oil exploration in the study area are summarized from these two publications.

Kelly (1955) was the first geologist to hypothesize the existence of Cretaceous rocks beneath the San Juan Volcanic Field. He named the structural feature in which the Cretaceous rocks were preserved the San Juan Sag. Larson and Cross (1956) presented a cross section that also depicted Cretaceous rocks beneath the volcanic field.

Plouff and Pakiser (1972), however, interpreted geophysical data (aeromagnetic and gravity data) to suggest the presence of a widespread, near-surface igneous intrusion beneath the volcanic rocks. The intrusion was hypothesized as the source of the numerous San Juan volcanoes. This interpretation discouraged exploration for petroleum in Rio Grande County, because any potential oil-bearing rocks that might once have existed beneath the volcanic field would have been replaced by the large igneous intrusion.

The discovery of oil in volcanic rocks in the area changed geologists' perspectives about the potential for oil beneath the volcanic rocks. In 1975 oil was reported by William Bowles in core drilled for mineral exploration in the igneous stock of the Summer Coon Volcano about six miles north of Del Norte. An oil seep in volcanic rocks along Hope Creek north of Big Meadows was found by Bob and Bill Ellithorpe. William E. Baker, Sr., and W. E. Baker, Jr., reported mineral exploration core at Summitville that contained vesicles (holes) in the volcanic rocks that were filled with oil. They also found an oil seep in the Cretaceous rocks that are exposed in small "windows" at Quartz Creek (Figure 3.3), where erosion has removed the volcanic rocks and revealed the underlying Cretaceous rocks. These discoveries sparked interest in the petroleum potential of rocks underlying the San Juan Volcanic Field and prompted the drilling of oil exploration wells.

Amarex, Inc. drilled the first oil exploration hole on San Francisco Creek in 1982. It was located in section 36, T39N, R5E (see Figure 4.1 and Table 4.1 for location), and drilled to a depth of 4,787 feet, all in the Conejos Formation (Table 4.2). According to Gries (1985), the Amarex C-1 stratigraphic test hole penetrated only thick beds of volcaniclastic sedimentary rocks and thin andesitic lava flows and tuff in the Conejos Formation. The lower 787 feet of the hole was cored, and live oil was found in saturated fractures in volcanic rocks at depths of 4,408 feet, 4,722 feet, 4,736 feet, and 4,740 feet below ground level (Gries, 1985). Although this test well did not extend through the volcanic rocks, the presence of oil in fractured volcanic rocks encouraged further exploration.

In 1984 Milestone Petroleum drilled the AMF #1 well on the north side of the Rio Grande about five miles west of Del Norte (Figure 4.1). This well penetrated through the volcanics and encountered underlying Tertiary sediments of the Blanco Basin and Animas Formations, and also Cretaceous sedimentary formations, including the Lewis Shale, Mancos Shale, and Dakota Formation. Several igneous sills within the Tertiary and Cretaceous sedimentary rocks also were present in the well. Traces of oil or gas were reported in the Tertiary sedimentary rocks under the volcanic cover, in the Cretaceous shales, and in the igneous sills. But the primary target, the Dakota Formation, contained only water.

In 1984, shortly after the Milestone well was drilled, Kirby Petroleum drilled the LGM #1 well to a depth of 6,770 feet in the Old Woman Creek area. Strong indications of gas were found in an igneous sill in the Mancos Shale, but efforts to complete the well were unsuccessful. In 1985 they drilled a second well nearby, the Jynnifer #1, and successfully completed it in the igneous sill in the Mancos Shale.

Gries (1985) reported that the Jynnifer #1 well produced 30 barrels of oil per day. No production records for this well were located in the Colorado Oil and Gas Conservation Commission (COGCC) online database. Note that the COGCC records now indicate the operator for these two wells is Faith Energy Exploration Company. Two additional oil tests were drilled in the Old Woman Creek area in 1985; the Needham-Medford #1 and Mosley 1-10, but neither produced oil or gas. Figure 4.2 is a cross section by Gries (1985) that illustrates the subsurface geology in the Old Woman Creek area based on the oil wells that have been drilled.

Oil exploration returned to the San Francisco Creek area in 1986 with the drilling of the San Francisco Creek Ranch #1 well by Waggoner-Baldridge Energy Company. However, this well turned out to be located on the east side of the Cimarron Fault, a major fault the offsets Precambrian and Cretaceous rocks but not the overlying volcanic rocks. The San Francisco Creek Ranch #1 well found the Tertiary Blanco Basin Formation beneath the volcanic rocks, but the Blanco Basin Formation rests directly on the Precambrian basement rock. The Cretaceous rocks had been removed from this area by erosion. In 1990 Waggoner-Baldridge drilled two more oil tests, the Horseshoe Mountain 1-10 and Horseshoe Mountain 1-14 wells in the San Francisco Creek area. Cretaceous rocks were present in both wells, but neither was completed as an oil well.

Other oil tests that have been drilled in the study area include the Federal 32-17 well by Meridian Oil, Inc. in 1988 and Amoco Production Company's Beaver Mountain #1 well in 1990. Both of these wells were located in the mountains southeast of South Fork, and both penetrated Cretaceous rocks. Neither was completed as an oil well. Heartland Oil and Gas, Inc. drilled a well at the eastern end of Greenie Mountain in the southeast part of the County in 1989. No Cretaceous rocks were found in this well. No oil wells have been drilled in Rio Grande County since 1990.

Table 4.1 describes the operator, well name, American Petroleum Institute's well identification number, location, status, and completion date for petroleum exploration holes drilled in and near Rio Grande County. The table also has data on a geothermal test well drilled in Alamosa. The primary source of information in Table 4.1 is the COGCC online database. The operator's name shown in the table is the one currently listed by the COGCC; it may not be the same operator's name as when the well was drilled. Table 4.1 also shows oil wells that were permitted by the

COGCC, but never drilled. Additional information on the wells in Table 4.1 comes from Gries (1985) and Brister and Chapin (1994), and information about the Alamosa geothermal #1 well is from Phetteplace and Kunze (1983) and Zeisloft and Sibbett (1985).

The ten oil wells and stratigraphic test drilled in the study area, along with another seven wells drilled nearby, provide valuable geologic information. Their locations are shown in Figure 4.1. Table 4.2 contains stratigraphic information, mostly the depths to the tops of geologic formations, that is from these deep drill holes. The COGCC's unpublished well information summaries has limited data on the depths to the tops of some formations for some of the wells, and it also contains other operator-provided information, including well completion reports.

Most of the geologic information contained in Table 4.2, however, is from the Ph.D. thesis of Brister (1991) and from publications by Brister and Chapin (1994), Brister and Gries (1994), Gries (1985, 1989), Gries and Brister (1989), Gries and others (1997), and Powell (1958). Geologic information from the Alamosa Geothermal #1 test is contained in Phetteplace and Kunze (1983) and Zeisloft and Sibbett (1985).

4.2 Proposed Oil Wells

The COGCC has approved permit applications for two new oil wells, one in the Old Woman Creek area and one in the San Francisco Creek area. Locations of the wells are shown on Figure 4.1 and listed in Table 4.1. The Dan A. Hughes Company DAHC-San Francisco Creek #1 well is located on Lot 46 of the San Francisco Creek Ranches subdivision. It will be drilled between the Waggoner-Baldridge San Francisco Creek Ranch #1 well and their Horseshoe Mountain 1-14 well. A permit from the Bureau of Land Management will be needed before this well can be drilled, because the mineral rights at that location are owned by the Federal government. An Environmental Assessment is being prepared by the Bureau of Land Management as part of this process. Rio Grande County will also need to issue a permit before the well can be drilled.

The proposed depth of the DAHC-San Francisco Creek #1 well is 6,600 feet. The COGCC is requiring surface casing to be set to a depth of 1,100 feet and that the annulus (space between the well casing and the edge of the borehole) be cemented. The operator should conduct a formation integrity test to check the effectiveness of the cement after the hole is drilled another 50 feet below the bottom of the surface casing.

First Liberty Energy, Inc. has received a permit from the COGCC to drill the Basin #1 well in the Old Woman Creek area. This hole will be drilled between the Jynnifer #1 well and the Mosley 1-10 well. Although the proposed well is not within a subdivision, there are many ~35 to 40 acre tracts of private land in proximity to the well, and there is a small acreage subdivision located slightly less than one mile west-northwest of the well. A permit is not needed from the Bureau of Land Management, because the mineral rights are privately owned, but a permit from the County will be needed.

Proposed depth of the Basin #1 well is 9,000 feet. The COGCC has stipulated that the surface casing extend to a depth of 1,200 feet and that the annulus between the casing and the borehole be cemented. A formation integrity test is required after the hole is drilled 50 feet below the bottom of the surface casing.

4.3 Availability of Seismic Data

Two seismic brokers were contacted regarding availability of seismic data: Exploration Geophysics, Inc. and M&M Geo-Digital Services, Inc., both located in Denver. Figure 4.3 shows the 2D seismic lines that are available for licensing. 3D seismic also may be available for an estimated 50 square mile area centered on the Rio Grande and extending from Del Norte west to Embargo Creek.

To understand the subsurface geology better than what is available in the published literature, acquiring one or more of these seismic lines likely will be necessary. The cost of acquiring the 2D seismic lines typically averages about $1,000 to $2,500 per mile, depending on parameters. In addition to licensing the seismic data, a geophysicist will be needed to reprocess and interpret the seismic data, and that cost probably would exceed the cost of acquiring the seismic data.

Table 4.1. General information on petroleum wells and a geothermal test well**.** Wells are listed by county and by American Petroleum Institute well number. Sources of information: Colorado Oil and Gas Conservation Commission online database; Gries, 1985; Brister and Chapin, 1994; Phetteplace and Kunze, 1983; Zeisloft and Sibbett, 1985; and field work conducted for this project.

Operator	Well Name	API Number[1]	County	Latitude	Longitude	Legal Description	Status[2]	Date Completed[3]	Stratigraphic Information
Amerada Petroleum Corp.	Colorado- State F #1	05-003-5000	Alamosa	37.619929	-105.885423	SE SE 16-39N-10E	DA	10/21/1959	Y
Energy Services	Alamosa #1 Geothermal	none	Alamosa	37.447860	-105.869340	C SW 15-37N-10E	TA	12/6/1981	Y
Champlin Petroleum Co.	Federal 34A-13 #1	05-02106003	Conejos	37.268602	-106.499709	SW SE 13-35N-4.5N	DA	11/17/1985	Y
Milestone Petroleum Inc.	AMF 1	05-105-6001	Rio Grande	37.696865	-106.448901	NW SE 20-40N-5E	DA	11/3/1984	Y
Faith Energy Exploration Co.	LGM 1	05-105-6002	Rio Grande	37.723770	-106.423840	SE SE 9-40N-5E	DA[3]	11/28/1984	y
Faith Energy Exploration Co.	Jynnifer 1	05-105-6003	Rio Grande	37.726194	-106.427083	NE SE 9-40N-5E	PA	5/15/1985	Y
Coda Energy Inc.	Mosley 1-10	05-105-6004	Rio Grande	37.726175	-106.420590	NW SW 10-40N-5E	DA	10/21/1985	Y
Waggoner-Baldridge Energy Co.	San Francisco Creek Ranch 1	05-105-6005	Rio Grande	37.608277	-106.366217	NW SW 19-39N-6E	DA	11/29/1986	Y
Meridian Oil Inc.	South Fork Federal 23-17	05-105-6006	Rio Grande	37.626126	-106.561623	NE SW 17-39N-4E	DA	9/30/1988	Y
Wolverine Exploration Co.	Agua Ramon 43-5 #1	05-105-6007	Rio Grande	37.740254	-106.552334	NE SE 5-40N-4E	AL	nd[4]	N
Amoco Production Co.	Beaver Mountain 1	05-105-6008	Rio Grande	37.630705	-106.613765	NE NW 13-39N-3E	DA	9/21/1990	Y
Heartland Oil & Gas Inc.	La Escondido Uno #1	05-105-6009	Rio Grande	37.477007	-106.198861	C SW 3-37N-7E	DA	12/4/1989	Y
Waggoner-Baldridge Energy Co.	Horseshoe Mountain 1-10	05-105-6010	Rio Grande	37.637136	-106.406789	NE SE 10-39N-5E	DA	2/10/1990	Y
Coda Energy Inc.	Mosley 1-9	05-105-6011	Rio Grande	37.726175	-106.430060	NW SE 9-40N-5E	AL	nd	N
Waggoner-Baldridge Energy Co.	Federal Horseshoe Mtn 1-23	05-105-6012	Rio Grande	37.607507	-106.389088	NE SE 29-39N-5E	AL	nd	N
Waggoner-Baldridge Energy Co.	Horseshoe Mountain 1-14	05-105-6013	Rio Grande	37.622247	-106.388918	NE SE 14-39N-5E	DA	10/2/1990	Y
Dan A Hughes Co.	DAHC-San Francisco Creek #1	05-105-6018	Rio Grande	37.607789	-106.377440	NW SE 24-39N-5E	PP	nd	N
Amarex, Inc.	C-1 stratigraphic test	none	Rio Grande	37.585690	-106.368940	36-39N-R5E	PA?	1982	Y
First Liberty Energy Inc.	Basin #1	05-105-6019	Rio Grande	37.726122	-106.425207	NE SE 9-40N-5E	P	nd	N
Tennessee Gas Transmission Co.	Colorado State B #1	05-109-5001	Saguache	37.793565	-106.173413	SW SE 14-41N-7E	DA	12/30/1959	Y
Orrin Tucker	Tucker-Thomas #1	05-109-5002	Saguache	37.805695	-106.039149	NE NE 13-41N-8E	DA	12/31/1952	Y
Needham & Medford Exploration	Needham-Medford #1	05-109-6001	Saguache	37.757234	-106.429611	SW NW 33-1N-5E	DA	3/19/1985	Y
Champlin Petroleum Co.	Federal 24A #1	05-109-6002	Saguache	38.086119	-106.375022	SE SW 1-44N-5E	DA	12/24/1985	Y
Wolverine Exploration Co.	Hellgate 21A-8 #1	05-109-6003	Saguache	37.909272	-106.339749	NE NW 8-42N-6E	DA	8/26/1989	Y

1) American Petroleum Institute unique well identifier applied to each petroleum exploration or production well drilled in the United States
2) PA=plugged and abandoned; DA=dry and abandoned; AL=abandoned location (not drilled); TA=temporarily abandoned; PP=BLM permit pending; P=permitted by COGCC
3) COGCC summary records describe this well as an abandoned location; elsewhere in their database they report completion information for it
4) nd=not drilled

Table 4.2. Geologic information from petroleum wells and a geothermal well in and near Rio Grande County. Wells are listed based on location from west to east. Souces of information: Brister and Chapin, 1994; Phetteplace and Kunze, 1983; Zeisloft and Sibbett, 1985; and Gries, 1985.

Well Operater & Well Name	KB elev.[1] (feet)	Fm. at GL[2]	Top[3] Taf	Top Tc	Base Tc (feet)	Elev. base Tc (feet)	Thickness of Tc	Top of Kl / Km (feet)	Elev. Top Kl/ Km (feet)	Top Kd (feet)	Elev. Top Kd (feet)	Top pC (feet)	Elev. Top of pC (feet)	Total Depth (feet)	Fm at TD[4]
Amoco Production Beaver Mtn #1	9,700	Taf		~1200	6,002	3,698	~4,800	6,210	3,490	9,509	191	10,838	-1,138	10,950	pC
Meridian Oil South Fork Fed. 23-17	10,086	Tc			5,865	4,221	>5,865	9,500	586	13,330	-3,244			13,586	Jm
Champlin Petroleum Federal 34A-13 #1	9,463	Tc			2,815	6,648	>2,815	2,970	6,493	4,400	5,063	6,200	3,263	6,751	pC
Milestone Petroleum AMF #1	7,999	Tc			3,450	4,549	>3,450	6,240	1,759	9,200	-1,201			9,447	Jm
Faith Energy Explor. Jynnifer #1	8,193	Tc			4,580	3,613	>4,580	5,900	2,293	8,150	43	?		9,264	pC
Needham-Medford Explor. Needham-Medford #1	8,197	Tc			3,950	4,247	3,950	5,155	3,042	7,720	477	8,460	-263	8,821	pC
Coda Energy Mosley #1-10	8,178	Tc			4,450	3,728	4,450	5,970	2,208	8,000	178	8,540	-362	9,011	pC
Waggoner-Baldridge Horseshoe Mtn #1-10	8,334	Tc			5,770	2,564	>5,770	5,810	2,524	6,615	1,719	7,275	1,059	7,361	pC
Waggoner-Baldridge Horseshoe Mtn #1-14	8,433				5,720	2,713		5,850	2,583	6,095	2,338	6,690	1,743	6,765	pC
Waggoner-Baldridge San Fran. Ck. Ranch #1	8,562	Tc			4,990	3,572		np[5]		np		5,790	2,772	5,873	pC
Amarex, Inc. C-1 stratigraphic test	8,835	Tc			<4,048		>4,787							4,787	Tc
Champlin Petroleum Federal 24A #1	8,950	Taf		580	2,230	6,720	1,650	2,630	6,320	2,730	6,220	3,130	5,820	3,266	pC
Wolverine Explor. Hellgate21A-8 #1	9,978	Tc			7,490	2,488		np		np		11,690	-1,712	11,996	pC
Heartland Oil & Gas La Escondido Uno #1	7,941	Tlp	~600	2,550	6,949	992	4,399	np		np		7,110	831	8,120	pC
Tennessee Gas Trans. Colo. State B#1	7,675	Tsf	2,072	3,580	7,810	-135	4,230	np		np		9,920	-2,245	10,350	pC
Orrin Tucker Tucker-Thomas #1	7,605	Tsf	3,650	5,550	7,920	-315	2,370	?		?		?		8,023	Tbb
Amerada Petrol. Colo.-State F #1	7,569	Tsf	1,742	2,990	4,310	3,259	1,320	np		np		4,690	2,879	6,072	pC
Energy Services Alamosa #1 Geothermal	7,535	Tsf	1,980	3,750	6,370	1,165	2,620	np		np		6,780	755	7,125	pC

1) elevation of kelly bushing, or ground level if kelly bushing elevation is not known
2) formation symbols used in report: Tsf=Tertiary Santa Fe Group; Tlp=Los Pinos Fm; Taf=Tertiary ash-flow tuffs; Tc=Tertiary Conejos Fm; Tbb=Tertiary Blanco Basin Fm; Kl=Cretaceous Lewis Shale; Km=Cretaceous Mancos Shale; Kd=Cretaceous Dakota Fm; Jurassic Morrison Fm; pC=Precambrian basement rocks
3) formation top is depth in feet from the kelly bushing
4) formation at total depth or bottom of well
5) formation not present in well

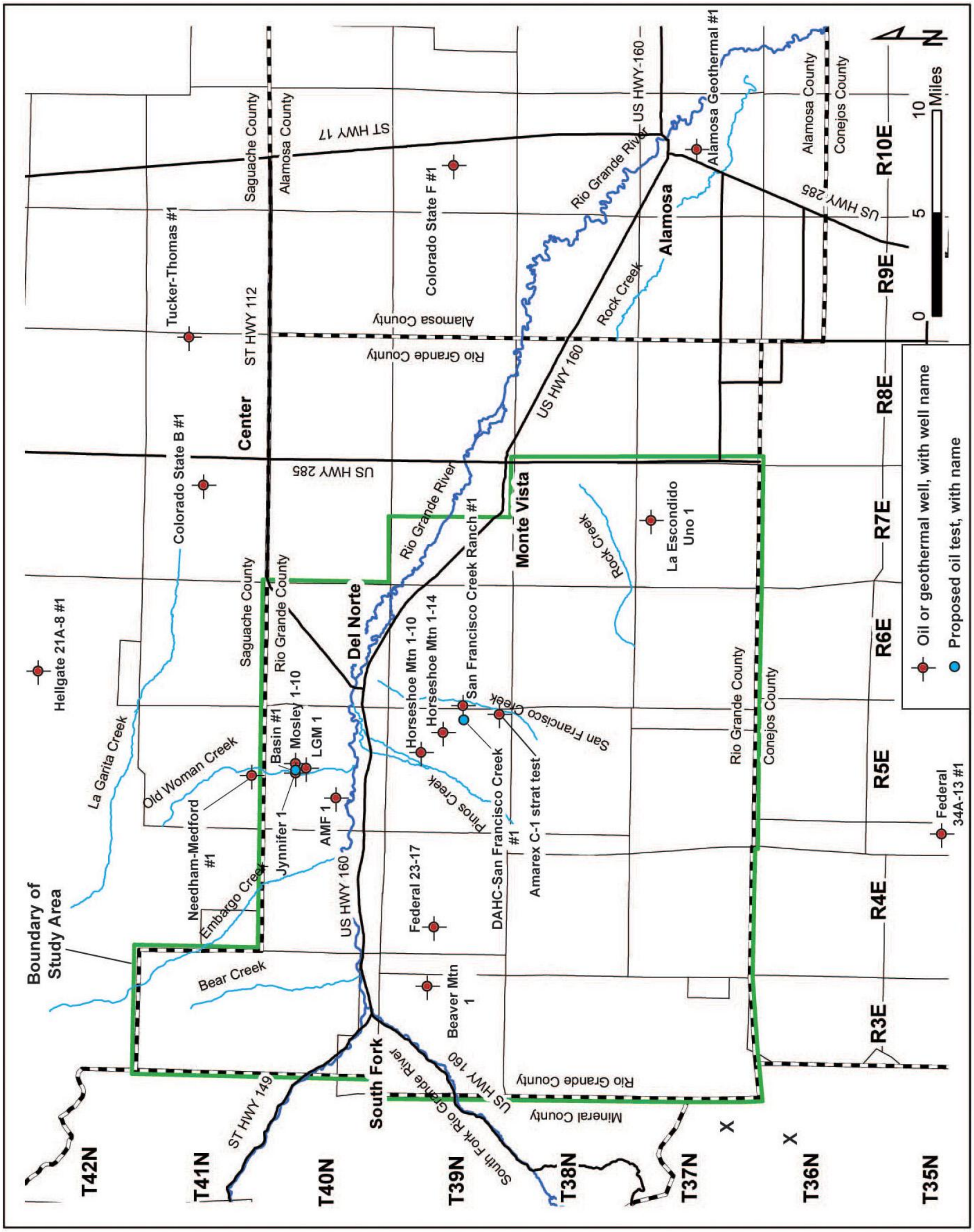

Figure 4.1. Location map for oil and geothermal wells in or near Rio Grande County.

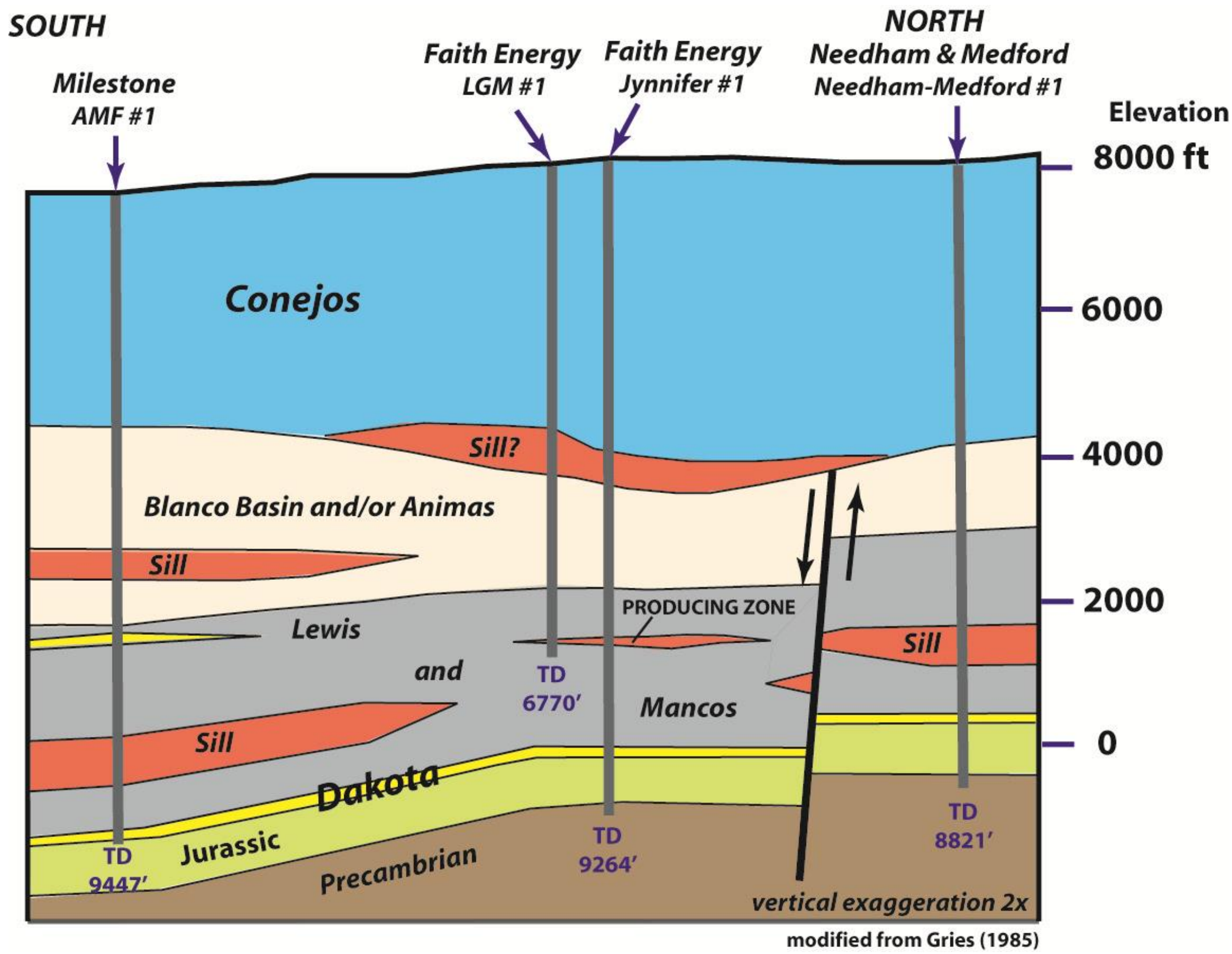

Figure 4.2. Cross section illustrating the subsurface geology in Old Woman Creek area**.**

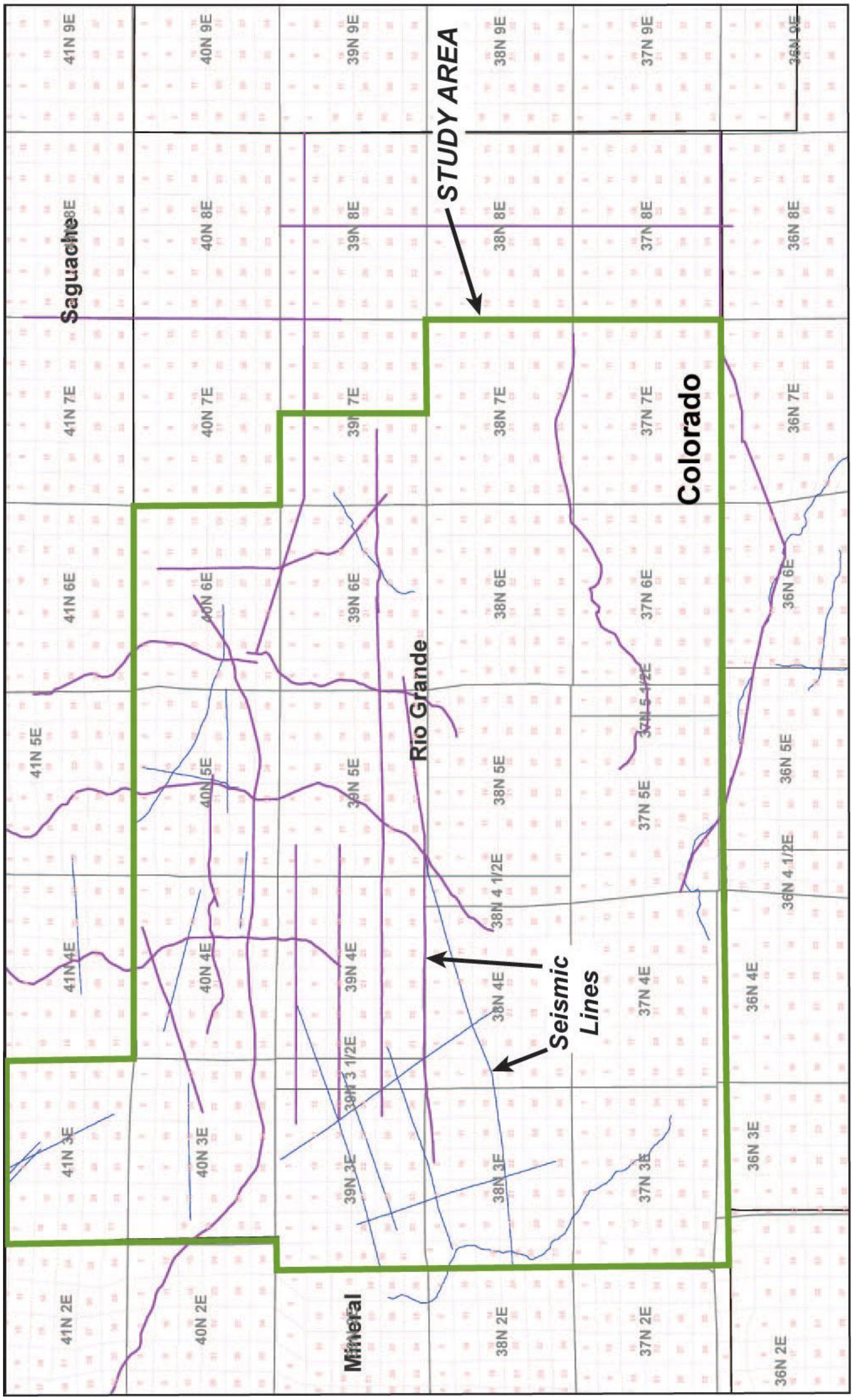

Figure 4.3. Locations of 2D seismic lines available for licensing**.** (modified from Exploration Geophysics, Inc., 2012, personal communication)

5.0 WATER SAMPLING PROGRAM

5.1 Overview

Nearly three thousand constructed water wells exist in the study area, according to the Colorado Division of Water Resources (CDWR) records. Figure 5.1 shows the distribution of water wells in the study area. Most wells are located in the valleys of the Rio Grande and its tributaries, or on the floor of San Luis Valley east of the foothills. Other concentrations of water wells exist in the subdivisions between South Fork and Del Norte.

The water sampling program involved three aspects. The primary focus was establishment of baseline water quality for wells and springs in about a one-mile radius of the proposed Hughes oil well in the San Francisco Creek area (SFC area) and the First Liberty oil well in the Old Woman Creek area (OWC area). The second aspect of the water sampling program involved deep water wells to assess the quality of water produced by the deepest water wells in the study area. The third aspect of the water sampling program involved owner-supplied water-quality analyses for two deep wells at Beaver Mountain Estates. The locations of the SFC area and OWC area, as well as the sampled deep wells and the Beaver Mountain Estates wells are shown on the regional map in Figure 5.2.

Water-quality analyses for forty-two wells and springs are described in this report. A replicate sample was also collected from one of the wells and submitted for lab analysis, resulting in a total of forty-three analyzed samples. Table 5.1 contains information on the type of sample (well or spring), owner's name and address, location, and elevation. The CDWR permit number or water court case number, date of well completion, well depth, casing, production rate, and static level are presented in Table 5.2. The date and time of sampling, water temperature, field pH, and conductivity of each sample is listed in Table 5.3. Also included in Table 5.3 are the sampling procedure, specific information about the sampling point, and the color and presence of sediment. Odors and bubbles were not noted at any of the wells or springs, and the water from only a few wells had color or sediment.

Thirty-seven water samples from thirty-six wells and springs near the proposed oil tests were analyzed following the baseline recommendations of the Colorado Oil and Gas Association (2011; herein called the COGA baseline). A replicate sample was collected from one of the wells in the SFC area. Parameters included in the COGA baseline analysis are:

> Boron, calcium, iron, magnesium, manganese, potassium, selenium, sodium, and strontium; alkalinity, bromide, chloride, nitrate/nitrite, phosphorus, and total dissolved solids concentration (TDS); and organic hydrocarbons including benzene, toluene, ethylbenzene, and xylene (BTEX), and methane gas.

Wells selected for COGA baseline analysis were chosen based on proximity to the two proposed oil test wells (within about one-mile radius of the oil tests), presence of a pump with power to it so water could be pumped from the well, and consent by the well owner.

Samples submitted for COGA baseline analysis were analyzed by ACZ Laboratories, Inc., a certified commercial laboratory located in Steamboat Springs, Colorado. In addition to methane, as recommended by the COGA, ACZ also tested for the organic gases butane, ethane, ethylene, and propane. Samples analyzed for dissolved metals were filtered in the lab (0.45 µm filter size). Table 5.4 shows the analytical results for the inorganic parameters listed by sample number; Table 5.5 contains the analytical results for the inorganic parameters grouped by area, either OWC or SFC; and Table 5.6 provides the results for the organic parameters. Refer to Appendix A for the original laboratory reports for each sample analyzed for the COGA baseline and for the lab's QA/QC data.

Water samples from four deep water wells were submitted for drinking water analysis by Sangre de Cristo Laboratory, Inc., a certified commercial laboratory located in Alamosa, Colorado. The four wells were selected for drinking water analysis based upon their depth (only the deepest wells were considered), perforated interval (wells with perforated casing only near the bottom of the well were preferred), and consent by the well owner. Several of the deep wells of interest that were not sampled were at homes occupied only seasonally. Water systems at some of these seasonal homes had been winterized, and sampling was not feasible. In other cases well owners were out-of-state and not available to provide access to their well for sampling.

Parameters included in Sangre de Cristo lab's standard drinking water analysis include:

> Arsenic, aluminum, chromium, cadmium, chloride, copper, fluoride, iron, manganese, nitrate, nitrite, phosphate, sodium, sulfate, zinc, alkalinity, and TDS.

These parameters are thought by local health experts to be the most important factors for drinking water in the San Luis Valley community (Evelyn Vigil, 2012, Sangre de Cristo Lab, personal communication). The drinking water analyses were not filtered. The rationale for analyzing the drinking water samples for total constituents (both dissolved and solid) is that when humans drink water, both the dissolved and solid constituents are ingested. Because the samples were not filtered, the metal concentrations in the drinking water analyses should be considered total values. The analytical results for the drinking water tests are listed in Table 5.7.

Water samples from two public water-supply wells at Beaver Mountain Estates were collected in 2005 by the property owner's association and submitted for analysis to comply with regulations. The president of the property owner's association for Beaver Mountains Estates, Robert Tonetti, provided copies of these water-quality analyses. The public water-supply wells were analyzed for a large suite of parameters, including many human-made compounds, but only the following parameters are shown in Table 5.8:

> Aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, fluoride, iron, lead, magnesium, manganese, mercury, nickel, selenium, thorium, uranium, zinc, alkalinity, hardness, TDS, and the organic compounds benzene, toluene, ethylbenzene, and xylene (BTEX).

In addition to the water-quality analyses, field parameters, and field observations previously mentioned, well locations were determined using a hand-held GPS receiver, and current well owner's names and contact information were collected.

5.2 Sampling Protocols

The general guidelines for sampling water wells recommended by the U.S. Geological Survey (2006) were used during this investigation. However, the sampled water wells were domestic wells in use by the owners, not monitoring wells. Because of this, several modifications to the protocols were needed.

For example, the well caps were not removed and water levels in the wells were not monitored while purging the well. We did not want to chance interruption of the water supply to the owner in case the water level monitoring equipment became entangled with the pump, stand pipe, or wiring. Some wells produced very limited amounts of water (as little as 1 quart/minute), and the consent to sample these low-yielding wells was often predicated on our not pumping the well or water storage tank dry. Some wells are powered by solar electric systems, which limited the amount of time a well could be pumped before the batteries were drained of power. In these situations less than the desirable amount of water was purged from the well prior to sampling.

If a reported well yield was relatively high, and the well could be purged for a relatively long period of time, the temperature, pH, and conductivity of the pumped water was monitored. When the field parameters stabilized, a water sample was collected.

Refer to Table 5.3 for a description of the amount of time water was run prior to sampling, the estimated rate of well pumping, and also the specific location where the sample was collected. This table also contains sampling information for the springs. If these wells and springs are tested again in the future, it is recommended that the same sampling location and well purging criteria be used.

Samples were collected from as near to the well as feasible. In some cases a hydrant was located at or next to the well, but at other locations the sample was collected from a faucet on an outside wall of the home. In our most distal sampling situations the sample was collected after a holding tank because that was the first available access point to well water. Water sample bottles typically were filled directly from the hydrant or faucet. For sample bottles containing a preservative, a disposable syringe was used to top off the bottle to avoid overfilling and dilution of the preservation. In a few locations a short (~10 feet long) hose had to be used because sampling location was inside a structure, and the owner did not want water spilled onto the floor of the structure, or the faucet was positioned such that sample bottles could not be filled directly from the faucet.

One replicate sample was submitted for lab analysis. Sample RGC27 is a replicate of sample RGC26.

5.3 Laboratory Methods

Laboratory methods used by ACZ and Sangre de Cristo labs are listed in Table 5.9.

5.4 Maximum Contaminant Levels

The Colorado Department of Public Health and Environment (2010) has established maximum contaminant levels (MCLs) in drinking water for several parameters. The parameters with MCLs that were included in either the COGA baseline analyses, the drinking water analyses, or the public water-supply analyses are listed in Table 5.10. There are primary MCLs that public water-supplies must meet and that private wells are recommended to also meet. Secondary MCLs have been established for several parameters, mostly based on taste and staining; these MCLs are desirable but not required for public water-supplies to attain.

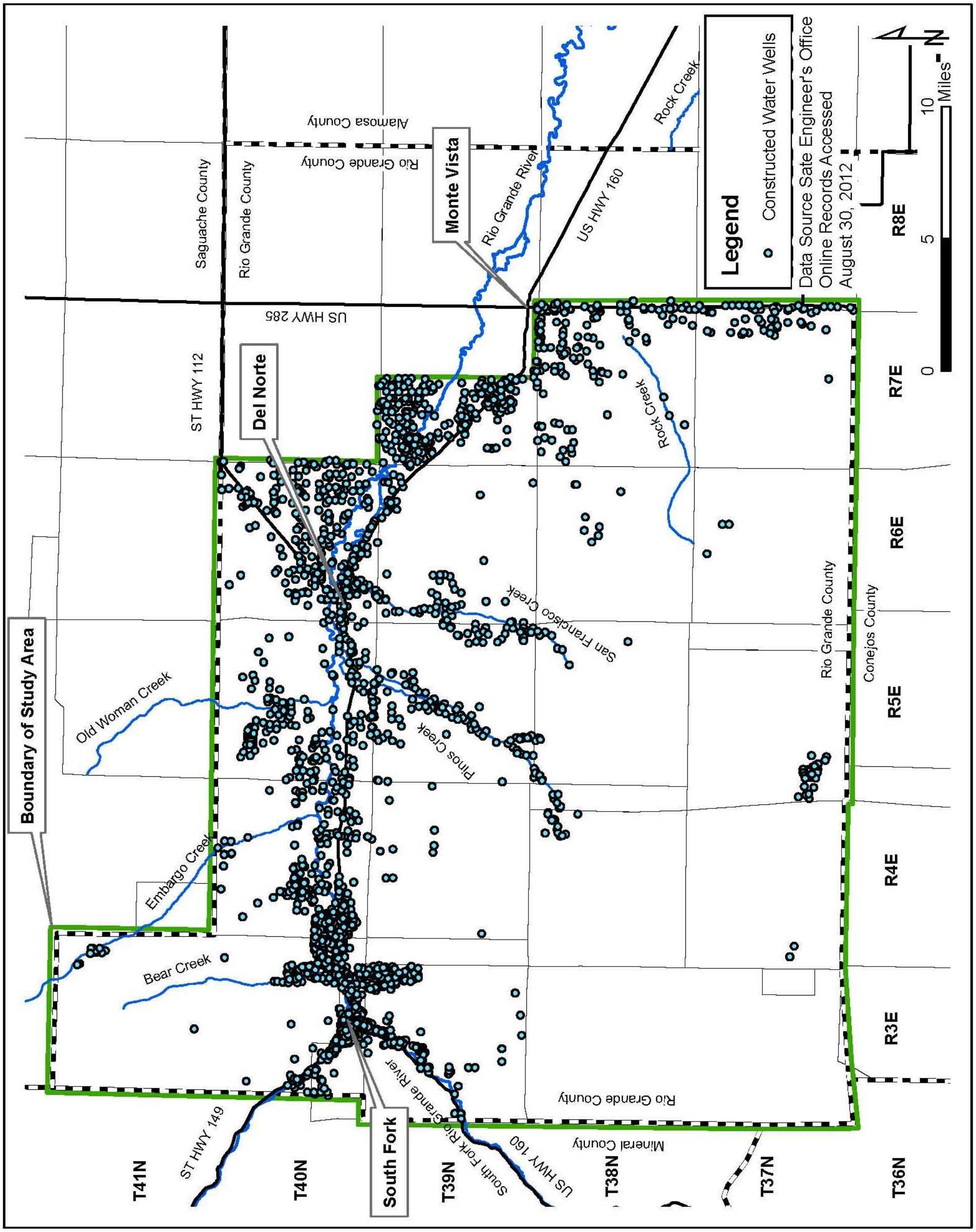

Figure 5.1. Distribution of constructed water wells in the study area. Data from CDWR online records.

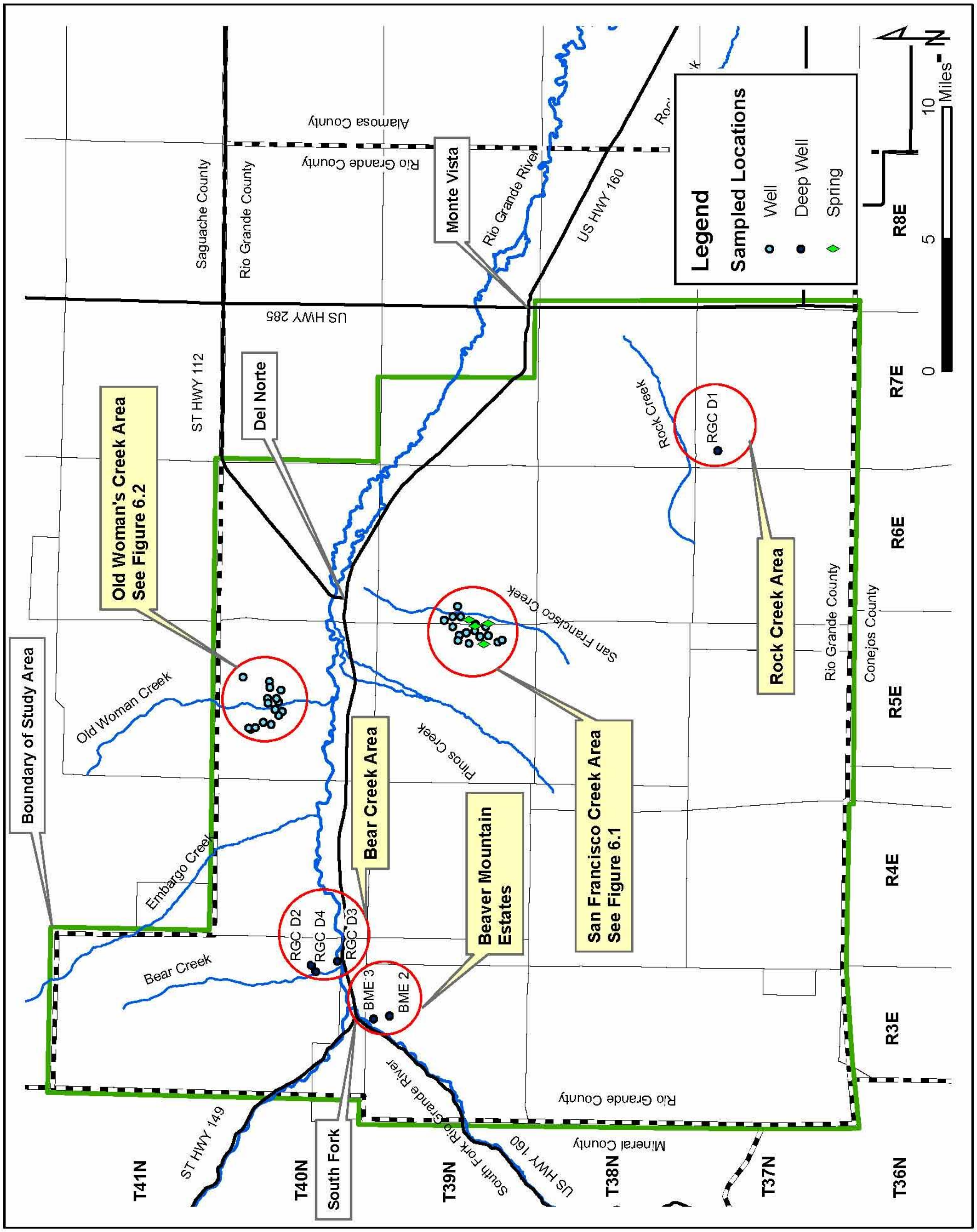

Figure 5.2. Regional location map for wells sampled during this study. Data from CDWR online records

Table 5.1. General water sample information.

Sample ID[1]	Sample Type[2]	Area[3]	Owner's Name	Address (in Rio Grande Co.)	Legal Description[4]	UTM m E	UTM m N	Grd Elev[5] (feet)
RGC1	W	OWC	Mikeljack	690 CR 66	P NW NE 15-40-5	375714	4175666	8108
RGC2	W	OWC	Whiddon	561 CR 66A	SE NE 16-40-5	374500	4175111	8082
RGC3	W	OWC	Mayeux	384 Twin Mountain Dr	NW SE 16-40-5	373893	4174901	8081
RGC4	W	OWC	Lucero	608 Twin Mountain Dr	SW NE 16-40-5	374007	4175318	8096
RGC5	W	OWC	Batzer	545 Twin Mountain Dr	SE NW 16-40-5	373653	4175095	8096
RGC6	W	OWC	Arnold	900 CR 66A	NW NW 15-40-5	374677	4175773	8125
RGC7	W	OWC	Hanna	1025 CR 66A	NE NE 16-40-5	374426	4175766	8130
RGC8	W	OWC	Boyd	800 CR 66	P NE 10-40-5	375995	4177275	8252
RGC9	W	OWC	Hargis	1068 CR 70	SW SW 9-40-5	373224	4176051	8167
RGC10	W	OWC	Hudson	16175 CR 15	SE NW 15-40-5	375206	4174976	8077
RGC11	W	OWC	Simmel	890 CR 70	NW NW 16-40-5	373108	4175555	8113
RGC12	W	OWC	Blickhahn	92 Pinon Rd	NW SE SE NE 8-40-5	372821	4176792	8196
RGC13	W	OWC	Bousquet	652 CR 66A	SW NW 15-40-5	374662	4175238	8088
RGC14	W	SFC	Kuehn	142 Wild Horse Ln	L50 SFCR F2	378684	4163669	8457
RGC15	W	SFC	Gazzola	5567 CR 13	L44 SFCR F2	379202	4163088	8543
RGC16	W	SFC	Peckham	814 Cedar Springs Rd	L37 SFCR F2	378113	4161742	8744
RGC17	W	SFC	Justus	444 Wagon Wheel Rd	L45 SFCR F2	378801	4163136	8592
RGC18	W	SFC	Callard	1247 Wagon Wheel Rd	L55 SFCR F2	378537	4164108	8412
RGC19	W	SFC	Wolter & Constance	1232 Wagon Wheel Rd	L56 SFCR F2	378222	4164169	8399
RGC20	W	SFC	Haden	142 Antelope Trail	L42 SFCR F2	378503	4162312	8665
RGC21	W	OWC	Phares	755 CR 66	NE NW 15-40-5	375357	4175640	8109
RGC22	W	SFC	Williams	596 Antelope Trail	L36 SFCR F2	378260	4161479	8855
RGC23	W	SFC	Peterson	95 Cedar Springs Rd	L43 SFCR F2	379076	4162469	8612
RGC24	W	SFC	I & J Prewitt	366 Frisco Pass Rd	L89 SFCR F3	380300	4164206	8486
RGC25	W	SFC	I & J Prewitt	none	NW 19-39-6	379677	4163991	8444
RGC26	W	SFC	Larsen	4617 CR 13	L60 SFCR F2	379674	4164478	8415
RGC27	W	SFC	Larsen	4617 CR 13	L60 SFCR F2	379674	4164478	8415
RGC28	W	SFC	Larsen	567 Old Schoolhouse Rd	L57 SFCR F2	379076	4164475	8399
RGC29	W	SFC	Larsen	141 Old Schoolhouse Rd	L62 SFCR F2	379438	4165008	8335
RGC30	W	SFC	Sweet	284 Antelope Trail	L40 SFCR F2	378451	4162842	8685
RGC31	S	SFC	Taggart&Fleming/USFS	none	NE NW 25-39-5	377986	4162634	8608
RGC32	S	SFC	Gazzola	5567 CR 13	L44 SFCR F2	379093	4163152	8524
RGC33	W	OWC	Clark	93 Pinion Rd	SW NE SE NE 8-40-5	372884	4176928	8208
RGC34	W	SFC	Woods	948 Wagon Wheel Rd	L48 SFCR F2	378039	4163501	8515
RGC35	S	SFC	L & C Prewitt	5700 CR 13	NW NW 30-39-6	379255	4162387	8640
RGC36	S	SFC	L & C Prewitt	95 Wagon Wheel Rd	L52 & 53 SFCR F2	379479	4163552	8495
RGC37	W	OWC	Dowd	1419 CR 70	NE NE SE 8-40-5	372918	4176527	8177
RGC D1	W	DW	Sutphin	3000 BLM Rd 5700A	S/2 SE 6-37-7	389786	4148341	8542
RGC D2	W	DW	Street	3792 Bear Creek Circle	L39 SFR BC F2	358420	4173127	8596
RGC D3	W	DW	Fietek	3313 CR 15	L112 SFR BC F4	358673	4171529	8158
RGC D4	W	DW	Person	160 Marmot Ln	L28 SFR BC F1	358027	4172828	8530
BME2	W	BME	Beaver Mtn Estates	utility easement	L43 BME P2	355326	4168331	8642
BME3	W	BME	Beaver Mtn Estates	utility easement	L47 BME P3 F2	355141	4169296	8490

1) samples RGC 1 to 37: wells and springs in ~1 mile radius of proposed oil test wells; RGC27 is replicate of RGC26
samples RGC D1 to D4: sampled deep wells in study area
samples BME2 & BME3: public water-supply wells for Beaver Mountain Estates
2) W = water well; S = spring
3) OWC = Old Woman Creek area; SFC=San Francisco Creek area; DW=deep well; BME=Beaver Mountain Estates deep well
4) L = lot; F = filing; P = phase; SFCR = San Francisco Creek Ranch subdivision; BME = Beaver Mountain Estates
SFR BC = South Fork Ranches subdivision, Bear Creek filing
P NW NE 15-40-5 = part of the northwest 1/4 of the northeast of section 15, T40N, R5E
5) ground elevation estimated from topographic map based on location of UTM coordinates

Table 5.2. Water well completion information, production rate, and static water levels. Data from CDWR online records.

Sample ID	Permit # or Court Case #[1]	Date of Well Completion	well depth (feet)	Elevation of Well Bottom (feet)[2]	Top Perf. Interval (feet)[3]	Bottom Perf. Interval (feet)[4]	Production Rate (gpm)	Static Level[5] (feet)
RGC1	224981	11/1/2000	510	7598	470	510	20	>0
RGC2	208072	2/18/2000	300	7782	260	300	4	-26
RGC3	224994	10/13/2000	300	7781	260	300	4	-34
RGC4	208065-A	6/19/2000	405	7691	385	405	2	-280
RGC5	227812	8/10/2001	440	7656	380	440	1	-41
RGC6	196293-A	4/27/2007	306	7909	246	306	100	>0
RGC7	227792	9/16/2001	440	7690	380	440	15	>0
RGC8	279784	6/3/1993	285	7967	265	285	2	-268
RGC9	219104	10/18/1999	500	7667	180	500	1	-178
RGC10	209784	6/3/1998	300	7777	200	300	5	-44
RGC11	195682	8/28/1997	300	7813	280	300	5	-28
RGC12	216042	3/17/2000	200	7996	160	200	3	-16
RGC13	258610	9/28/2004	540	7548	480	540	8	>0
RGC14	204499	8/29/1997	100	8357	80	100	30	-21
RGC15	203404	8/10/1997	70	8473	55	70	15	-20
RGC16	208063	2/26/1998	220	8524	200	220	15	-86
RGC17	205065	2/24/2000	355	8237	335	355	5	-180
RGC18	199576	3/26/1997	121	8291	61	121	22	-23
RGC19	204494	10/10/1997	203	8196	143	203	4.5	-40
RGC20	209791	5/6/1998	320	8345	300	320	4	-100
RGC21	228777	11/6/2000	450	7659	410	450	60	>0
RGC22	205069	9/15/1997	450	8405	430	450	10	-202
RGC23	205397	3/10/1998	140	8472	120	140	5	-51
RGC24	204075	8/26/1997	215	8271	195	215	16	-113
RGC25	None	not a permitted well - no well construction, static water level, or yield information						
RGC26	199573	3/26/1997	202	8213	102	202	6	-39
RGC27	199573	3/26/1997	202	8213	102	202	6	-39
RGC28	199574	7/28/1998	200	8199	140	200	20	-50
RGC29	199561	3/27/1997	140	8195	80	140	11	-30
RGC30	205390	9/3/1999	280	8405	260	280	5.5	-155
RGC31	*	this is a spring - no decree - no well construction information						
RGC32	*	this is a spring - no decree - no well construction information						
RGC33	216041	5/1/1999	200	8008	160	200	5	-3
RGC34	205067	2/23/1998	230	8285	191	211	12	-57
RGC35	*	this is a spring - no decree - no well construction information						
RGC36	96CW35	this is a spring - no well construction information						
RGC37	65001-F	10/16/2006	380	7797	320	380	15	-60
RGC D1	287015	1/4/2012	900	7642	850	900	1-2	-450
RGC D2	55328-FR	12/2/2002	890	7706	850	890	80+	-35
RGC D3	65339-F	3/21/2006	1400	6758	100	1400	1quart/min	-110
RGC D4	55440-F	5/9/2001	1170	7360	200	1170	3	-212
BME2	57640-F	7/4/2002	1260	7382	300	1260	20	-180
BME3	61314-F	10/18/2004	1200	7290	180	1200	20	-50

1) permit number of well, or water court case number of decreed spring; * = spring without court decree
none=well is not registered with State Engineer
2) determined by subtracting well depth from ground elevation listed in Table 5.1
3) top of the highest perforated casing or top of open hole
4) bottom of the lowest perforated casing or bottom of open hole
5) static level of >0 feet indicates a flowing well

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Table 5.3. Field parameters for sampled wells and springs.

Sample #	Sample Date	Sample Time	Temp. °C	Field pH	Conductivity (uS)	Sampling Procedure	Sample Location
RGC1	9/14/12	9:30	15.8	9.48	527	Weak flowing well; flowing at ~1-2 gpm upon arrival; pumped an additional ~2 gpm for 30 min. prior to sampling	Outside faucet on NE side of house, after water passes through PT[1]
RGC2	9/14/12	10:50	11.8	8.81	635	Very low producing well; per owner's request, pumped only ~2 gpm for 10 min. before sampling	Faucet in small structure with PT; sample collected before PT
RGC3	9/14/12	11:40	13.4	8.21	618	Owner pumped water for ~2 hrs prior to arrival; an additional ~5 gpm pumped for 5 min. prior to sampling	Hydrant[2] between well and shop bldg; before PT
RGC4	9/14/12	12:10	14.3	9.47	511	Very low producing well; per owner's request, pumped only ~2 gpm for 1 minute before sampling	Hydrant ~50 ft N of well; before PT
RGC5	9/14/12	13:00	15.3	9.91	462	Low producing well; pumped ~5 gpm for 15 min. before sampling	Hydrant located in tack shed ~200 ft W of well; uncertain if before PT
RGC6	9/14/12	14:50	15.2	9.72	588	Strong flowing well; owners had watered lawn for 2 hrs before arrival; flowed an additional ~5 gpm for 10 min. before sampling; ~25-30 gpm flowed from well when valve at well was opened	Valve at well; no PT
RGC7	9/14/12	15:45	14.4	9.71	582	Weak flowing well; owner used ~ 2 gpm to water trees for ~2 hrs before arrival; ran ~ 2 gpm more for 1 minute before sampling	Hydrant next to well; before PT
RGC8	9/14/12	17:05	13.8	8.08	786	Solar power for well; battery charge was low; allowed to pump only ~2 gpm for 1 minute before sampling	Faucet at PT, located in old railroad car
RGC9	9/14/12	18:25	15.2	9.60	606	Water is pumped directly from well to holding tank; Ran ~2 gpm for 10 minutes before sampling to clear pipes from tank to faucet	Faucet at PT in small structure (First place where sample can be obtained
RGC10	9/17/12	15:50	15.0	9.92	462	Low producing well; per owner's request, pumped only ~2 gpm for 15 min.	Outside faucet on NW side of house; uncertain if before PT
RGC11	9/17/12	17:50	13.2	9.61	422	Owners using water ~ 1hr prior to arrival; pumped an additional ~5 gpm for 5 min.	Hydrant at well; before PT
RGC12	9/17/12	18:40	12.6	9.69	432	Low producing well; pumped ~ 2 gpm for 5 minutes before sampling	Well and PT in below-ground vault; faucet at sediment filter in vault; before PT
RGC13	9/18/12	10:40	13.7	9.72	577	Weak flowing well; flowing ~1 gpm on arrival; Pumped ~5 gpm for 10 min. before sampling	Hydrant at well; before PT
RGC14	9/18/12	15:05	10.0	7.25	583	Per owner's request pumped ~2 gpm for 20 min. before sampling	Outside faucet at well; before PT
RGC15	9/18/12	17:15	9.9	7.39	294	Pumped ~5 gpm for 20 min. before sampling	Hydrant ~10 ft from well; before PT
RGC16	9/24/12	10:10	10.8	7.52	323	Pumped ~5 gpm for 30 min. before sampling	Hydrant ~15 ft from well; before PT
RGC17	9/24/12	12:05	11.6	7.66	331	Pumped ~2 gpm for 30 min. before sampling	Outside faucet on S side of house; after PT
RGC18	9/24/12	13:15	9.9	7.12	392	Pumped ~5 gpm for 30 min. before sampling	Hydrant next to well; before PT
RGC19	9/24/12	16:15	13.2	7.20	728	Pumped ~2 gpm for 30 min., then flow rapidly decreased, so sample was promptly collected; reduced flow perhaps due to low charge in batteries of solar system	Inside faucet on pipe that enters through floor of mechanical room; before PT

(continued on next page)

Table 5.3. Continued.

Sample #	Sample Date	Sample Time	Temp. °C	Field pH	Conductivity (uS)	Sampling Procedure	Sample Location & color, if not clear
RGC20	9/24/12	17:20	12.5	7.72	440	Pumped ~5 gpm for 20 min. before sampling	Hydrant on S side of house; uncertain if before PT
RGC21	9/24/12	18:40	16.7	9.70	563	Well continuously flows at ~ 3 gpm; no additional pumping before sample collection	End of black plastic pipe; pipe comes well house and ends at old canal
RGC22	9/26/12	8:05	12.2	7.99	316	Pumped ~2 gpm for 30 min. before sampling	Well house locked; sampled at outside faucet on W side of house; after PT
RGC23	9/26/12	9:20	10.6	7.72	318	Pumped ~2 gpm for 30 min. before sampling	Outside faucet on N side of house; probably after PT
RGC24	9/26/12	11:40	12.1	7.58	293	Pumped ~2 gpm for 45 min. before sampling	Outside faucet on N side of house; probably after PT
RGC25	9/26/12	12:20	9.0	6.99	199	Pumped ~5 gpm for 25 min. before sampling	Hydrant next to underground vault w/ PT; well on opposite side of vault; uncertain if sample after or before PT
RGC26	9/26/12	13:15	10.8	7.70	357	Pumped ~5 gpm for 30 min. before sampling	Hydrant next to well; before PT
RGC27	9/26/12	13:50	11.6	7.62	354	Pumped ~5 gpm for 30 min. before sampling	Hydrant next to well; before PT
RGC28	10/1/12	10:55	10.6	7.06	371	Pumped ~1.5 gpm for 45 min. before sampling; solar power	Threaded pipe end on well head
RGC29	10/1/12	12:45	10.6	7.45	381	Renter was pumping water upon arrival; pumped additional ~5 gpm for 25 min. before sampling	Hydrant next to well; before PT
RGC30	10/1/12	14:00	11.3	7.61	301	Pumped ~5 gpm for 30 min. before sampling	Hydrant between well and house; before PT; water initially was pale yellow brown but rapidly cleared
RGC31	10/1/12	14:50	10.5	7.59	328	Removed old boards over spring box; spring flows ~1-2 gpm	In spring box
RGC32	10/1/12	16:05	11.8	7.15	305	Dug small hole at spring to collect water; let settle for 5 days; used syringe to remove water from hole and fill bottles	Excavated hole at spring
RGC33	10/3/12	9:25	12.8	9.68	441	Low producing well; well in use upon arrival; at owner request, pumped only ~2 gpm for 5 min. before sampling	hydrant ~15 ft from well; after PT
RGC34	10/3/12	11:15	12.9	6.52	1098	Pumped ~3 gpm for 20 minutes before sampling	Outside hydrant on W wall of house; before PT, filter, and RO unit; initally was red-brown, but rapidly cleared
RGC35	10/3/12	14:10	9.4	7.37	181	Used syringe to extract water from shallow stream discharging from covered spring box and to fill the sample bottles	Shallow stream discharging from covered spring box
RGC36	10/3/12	15:05	10.6	6.99	229	Removed a plank from over the spring box; used syringe to extract water from spring box and then fill sample bottles	In spring box
RGC37	10/22/12	18:35	16.2	9.65	556	Pumped ~10 gpm for 35 min. before sampling	Outside faucet on NE side of house, next to garage; after PT
RGC D1	10/16/12	13:50	17.0	8.17	182	Pumped 1 hr 45 min.; started at ~6 gpm and ended at 2.8 gpm; new well with new pump; powered by generator	Valve at end of 40 ft long PVC pipe that comes from well head; no PT

(continued on next page)

Table 5.3. Continued.

Sample #	Sample Date	Sample Time	Temp. °C	Field pH	Conductivity (uS)	Sampling Procedure	Sample Location & color, if not clear
RGC D2	10/18/12	11:50	19.8	9.07	362	Pumped 1 hr 30 min. at ~10 gpm before sampling; discharge constant during entire purge	Hydrant on top of well casing; before PT
RGC D3	10/24/12	10:10	19.1	8.59	354	Very low producing well; at owner's request only ~ 2 gpm was pumped from holding tank for 5 minutes before sampling; amount pumped was sufficient to purge small PT and pipe between holding tank and sampling location	Well water is pumped directly into a holding tank, and from there is piped into a concrete vault with steel lid before continuing to house; vault contains small PT and electronic controls; sample collected from faucet at PT within the vault
RGC D4	10/24/12	12:25	17.2	8.92	342	Pumped 1 hr 20 min. before sampling; started at ~12 gpm and ended at ~9 gpm	Hydrant next to well
BME2[3]	10/18/12	15:10	14.0	8.84	307	Unknown[4]	Field parameters measured on sample collected at valve in chlorination vault before sand filter and chlorination unit; sample contained sediment
BME3[5]	10/18/12	14:20	25.9	9.38	646	Unknown[4]	Valve at well head; water was slightly milky

1) PT = pressure tank
2) Hydrant = frost-free outside hydrant
3) date and time when field parameters were measured; analyzed sample was collected by Beaver Mtn Estates representative on 9/13/05
4) analyzed sample was collected by Beaver Mtn Estates representative prior to current project
5) date and time when field parameters were measured; analyzed sample collected by Beaver Mtn Estates representative on 5/24/05

Table 5.4. Analytical results for the COGA baseline inorganic parameters**,** listed by sample number. Analyses by ACZ Lab.

Sample Number		Dissolved Metals Analysis									Wet Chemistry											
											Alkalinity as $CaCO_3$											
		B	Ca	Fe	Mg	Mn	K	Se	Na	Sr	HCO_3	CO_3	OH	Total Alk	Br	Cl	NO_2/NO_3 as N	P	SO_4	Cond.	pH[3]	TDS
	units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µS		mg/L
	MDL[1]	0.01	0.20	0.02	0.20	0.005	0.30	0.0001	0.30	0.01	2	2	2	2	0.05	0.5	0.02	0.01	0.5	1		10
	PQL[2]	0.05	1.00	0.05	1.00	0.03	2.00	0.003	2.00	0.05	20	20	20	20	0.25	2.5	0.10	0.05	2.5	10		20
RGC1		0.17	1.4	0.02 B[4]	U[5]	U	0.7 B	0.0002 B	99.8	0.01 B	91	80	U	171	0.177 B	14.25	U	0.02 B	54.77	475	9.2	300
RGC2		0.42	17.3	U	2.3	U	1.5 B	0.0008	97.0	0.09	54	U	U	55	0.363	27.83	0.90	0.01 B	170.70	576	8.4	360
RGC3		0.04 B	46.4	U	6.5	U	0.7 B	0.0041	71.0	0.25	180	9 B	U	189	0.231 B	16.86	0.50	0.05 B	74.90	549	8.4	370
RGC4		0.52	1.4	U	U	0.005 B	0.4 B	0.0017	96.8	0.01 B	75	24	U	99	0.279	22.24	1.45	0.03 B	76.03	461	9.1	270
RGC5		0.89	0.9 B	0.18	U	U	U	U	90.7	0.03 B	60	63	U	123	0.167 B	11.84	0.03 B	0.01 B	39.64	416	9.7	250
RGC6		0.22	0.6 B	U	U	U	0.4 B	U	111	U	122	109	U	232	0.112 B	10.89	U	0.02 B	11.27	532	9.6	330
RGC7		0.24	0.09 B	U	U	U	0.5 B	0.0001 B	121	U	125	106	U	230	0.115 B	10.94	U	0.02 B	11.96	531	9.6	340
RGC8		0.06	66.5	U	7.8	0.007 B[4]	5.6	0.0064	73.3	0.40	128	U	U	130	0.219 B	16.72	3.25	0.03 B	211.45	693	8.3	500
RGC9		1.58	1.0 B	U	U	U	0.4 B	U	121	0.01 B	122	85	U	207	0.206 B	15.35	U	0.01 B	28.41	545	9.5	350
RGC10		1.39	2.0	U	U	U	0.5 B	U	87.1	0.01 B	47	63	U	111	0.230 B	19.88	0.09 B	0.01 B	39.65	424	9.7	250
RGC11		0.20	0.8 B	U	U	U	U	0.0003 B[4]	77.2	U	79	45	U	124	0.186 B	12.75	0.03 B	0.02 B	38.30	382	9.5	230
RGC12		0.13	1.2	U	U	U	0.4 B	U	85.4	U	82	60	U	142	0.126 B	7.71	U	0.01 B	37.47	389	9.5	250
RGC13		0.24	0.7 B	U	U	U	0.4 B	U	114	U	134	91	U	225	0.116	10.89	U	0.02 B	12.74	538	9.5	330
RGC14		0.02 B	57.4	U	13.4	0.082	7.0	0.0101	17.1	0.35	123	U	U	123	0.164 B	8.35	0.85	1.63	127.78	506	7.5	370
RGC15		0.01 B	28.0	U	6.0	U	2.9	0.0003 B	6.9	0.22	125	U	U	125	U	1.67 B	0.40	0.12	6.20	259	8.1	180
RGC16		0.02 B	19.4	U	5.7	U	2.2	0.0023	12.7	0.19	103	U	U	103	0.114 B	5.51	0.87	0.14	31.04	285	8.0	230
RGC17		0.02 B	21.3	U	5.9	0.026 B	3.3	0.0016	11.5	0.14	109	U	U	109	0.154 B	6.53	0.84	0.05 B	30.90	299	8.1	230
RGC18		0.02 B	28.2	0.39	7.2	0.037	3.7	0.0003	14.0	0.25	128	U	U	128	0.124 B	6.60	0.05 B	0.19	49.49	358	7.8	270
RGC19		0.04 B	39.7	U	20.8	0.072	5.4	U	39.9	0.22	289	U	U	289	0.117 B	7.79	U	0.08	58.69	648	8.0	450
RGC20		0.02 B	28.4	0.15	10.6	0.170	4.7	0.0020	21.7	0.15	180	U	U	180	0.098 B	5.51	U	0.07	22.27	392	8.1	290
RGC21		0.22	0.5 B	U	U	U	0.5 B	0.0037	92.4	U	118	110	U	228	0.111 B	10.89	U	0.01 B	9.93	521	9.6	360
RGC22		0.03 B	20.7	U	6.4	U	2.9	0.0016	14.2	0.18	112	U	U	112	0.101 B	4.35	0.54	0.09	27.39	283	8.3	230
RGC23		0.03 B	22.2	U	6.2	U	3.7	0.0004	16.4	0.15	119	U	U	119	0.090 B	4.03	0.21	0.08	19.80	278	8.2	220
RGC24		0.03 B	20.4	U	4.3	0.029 B	4.5	0.0002 B	16.7	0.11	121	U	U	121	0.090 B	3.90	U	0.10	22.75	262	8.1	200
RGC25		U	13.6	U	3.5	U	3.7	0.0002 B	3.6	0.10	80	U	U	80	U	2.26 B	0.21	0.22	6.85	179	7.7	180
RGC26		0.03 B	21.9	U	7.4	0.030	6.4	0.0003	15.7	0.19	109	U	U	109	0.142 B	9.16	0.17	0.09	35.08	315	8.2	230
RGC27		0.02 B	21.9	U	7.3	0.016 B	6.3	0.0003	15.4	0.18	110	U	U	110	0.141 B	9.15	0.10 B	0.09	35.04	312	8.1	240
RGC28		0.03 B	41.2	U	10.5	0.053	5.3	U	17.4	0.25	180	U	U	180	0.070 B	2.77	U	0.04 B	31.45	413	7.9	240
RGC29		0.02 B	45.2	U	9.8	U	6.1	0.0004	13.4	0.35	141	U	U	141	0.081 B	5.96	0.71	0.17	17.63	346	8.1	230
RGC30		0.01 B	32.6	U	7.7	U	3.9	0.0022	13.4	0.25	104	U	U	104	0.130 B	6.20	2.10	0.12	18.78	279	8.2	200
RGC31		0.02 B[4]	34.0	U	9.2	U	3.8	0.0013	16.6	0.29	114	U	U	114	0.114 B	5.75	1.10	0.17	25.82	300	8.2	220
RGC32		0.01 B	38.8	0.09	8.0	0.031	4.3	U	10.1	0.30	133	U	U	133	0.076 B	3.36	U	0.17	8.66	288	8.1	190
RGC33		0.10	1.10	U	U	U	0.4 B	U	91.2	U	92	52	U	144	0.148 B	9.09	U	0.01 B	37.43	410	9.4	260
RGC34		0.03 B	111	0.38	50.6	0.087	14.1	0.0028	61.5	0.53	495	U	U	495	0.148 B	14.02	1.00	0.21	74.98	1030	7.7	670
RGC35		U	21.5	U	4.8	U	3.6	U	5.1	0.16	78	U	U	78	U	0.83 B	0.22	0.16	3.12	167	8.2	130
RGC36		U	28.9	U	6.3	U	5.5	U	5.3	0.22	99	U	U	99	U	1.27 B	0.4	0.18	3.8	210	8.1	150
RGC37		0.17	0.8	U	U	U	U	U	108	U	130	63	U	193	0.147 B	9.61	0.02 B	0.01 B	49.70	539	9.4	340

1 = Method Detection Limit; 2 = Practical Quantitation Limit; 3 = exceeded holding time, see Table 5.3 for field pH; 4 = estimated because analyte concentration is between MDL and PQL; 5 = not detected

Table 5.5. Analytical results for the COGA baseline inorganic parameters, grouped by area (OWC or SFC). Analyses by ACZ Lab.

Sample Number	Area		Dissolved Metals Analysis									Wet Chemistry											
												Alkalinity as $CaCO_3$											
			B	Ca	Fe	Mg	Mn	K	Se	Na	Sr	HCO_3	CO_3	OH	Total Alk	Br	Cl	NO_2/NO_3 as N	P	SO_4	Cond.	pH[3]	TDS
		units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µS		mg/L
		MDL[1]	0.01	0.20	0.02	0.20	0.005	0.30	0.0001	0.30	0.01	2	2	2	2	0.05	0.5	0.02	0.01	0.5	1		10
		PQL[2]	0.05	1.00	0.05	1.00	0.03	2.00	0.003	2.00	0.05	20	20	20	20	0.25	2.5	0.10	0.05	2.5	10		20
RGC1	OWC		0.17	1.4	0.02 B[4]	U[5]	U	0.7 B	0.0002 B	99.8	0.01 B	91	80	U	171	0.177 B	14.25	U	0.02 B	54.77	475	9.2	300
RGC2	OWC		0.42	17.3	U	2.3	U	1.5 B	0.0008	97.0	0.09	54	U	U	55	0.363	27.83	0.90	0.01 B	170.70	576	8.4	360
RGC3	OWC		0.04 B	46.4	U	6.5	U	0.7 B	0.0041	71.0	0.25	180	9 B	U	189	0.231 B	16.86	0.50	0.05 B	74.90	549	8.4	370
RGC4	OWC		0.52	1.4	U	U	0.005 B	0.4 B	0.0017	96.8	0.01 B	75	24	U	99	0.279	22.24	1.45	0.03 B	76.03	461	9.1	270
RGC5	OWC		0.89	0.9 B	0.18	U	U	U	U	90.7	0.03 B	60	63	U	123	0.167 B	11.84	0.03 B	0.01 B	39.64	416	9.7	250
RGC6	OWC		0.22	0.6 B	U	U	U	0.4 B	U	111	U	122	109	U	232	0.112 B	10.89	U	0.02 B	11.27	532	9.6	330
RGC7	OWC		0.24	0.09 B	U	U	U	0.5 B	0.0001 B	121	U	125	106	U	230	0.115 B	10.94	U	0.02 B	11.96	531	9.6	340
RGC8	OWC		0.06	66.5	U	7.8	0.007 B[4]	5.6	0.0064	73.3	0.40	128	U	U	130	0.219 B	16.72	3.25	0.03 B	211.45	693	8.3	500
RGC9	OWC		1.58	1.0 B	U	U	U	0.4 B	U	121	0.01 B	122	85	U	207	0.206 B	15.35	U	0.01 B	28.41	545	9.5	350
RGC10	OWC		1.39	2.0	U	U	U	0.5 B	U	87.1	0.01 B	47	63	U	111	0.230 B	19.88	0.09 B	0.01 B	39.65	424	9.7	250
RGC11	OWC		0.20	0.8 B	U	U	U	U	0.0003 B[4]	77.2	U	79	45	U	124	0.186 B	12.75	0.03 B	0.02 B	38.30	382	9.5	230
RGC12	OWC		0.13	1.2	U	U	U	0.4 B	U	85.4	U	82	60	U	142	0.126 B	7.71	U	0.01 B	37.47	389	9.5	250
RGC13	OWC		0.24	0.7 B	U	U	U	0.4 B	U	114	U	134	91	U	225	0.116	10.89	U	0.02 B	12.74	538	9.5	330
RGC21	OWC		0.22	0.5 B	U	U	U	0.5 B	0.0037	92.4	U	118	110	U	228	0.111 B	10.89	U	0.01 B	9.93	521	9.6	360
RGC33	OWC		0.10	1.10	U	U	U	0.4 B	U	91.2	U	92	52	U	144	0.148 B	9.09	U	0.01 B	37.43	410	9.4	260
RGC37	OWC		0.17	0.8	U	U	U	U	U	108	U	130	63	U	193	0.147 B	9.61	0.02 B	0.01 B	49.70	539	9.4	340
RGC14	SFC		0.02 B	57.4	U	13.4	0.082	7.0	0.0101	17.1	0.35	123	U	U	123	0.164 B	8.35	0.85	1.63	127.78	506	7.5	370
RGC15	SFC		0.01 B	28.0	U	6.0	U	2.9	0.0003 B	6.9	0.22	125	U	U	125	U	1.67 B	0.40	0.12	6.20	259	8.1	180
RGC16	SFC		0.02 B	19.4	U	5.7	U	2.2	0.0023	12.7	0.19	103	U	U	103	0.114 B	5.51	0.87	0.14	31.04	285	8.0	230
RGC17	SFC		0.02 B	21.3	U	5.9	0.026 B	3.3	0.0016	11.5	0.14	109	U	U	109	0.154 B	6.53	0.84	0.05 B	30.90	299	8.1	230
RGC18	SFC		0.02 B	28.2	0.39	7.2	0.037	3.7	0.0003	14.0	0.25	128	U	U	128	0.124 B	6.60	0.05 B	0.19	49.49	358	7.8	270
RGC19	SFC		0.04 B	39.7	U	20.8	0.072	5.4	U	39.9	0.22	289	U	U	289	0.117 B	7.79	U	0.08	58.69	648	8.0	450
RGC20	SFC		0.02 B	28.4	0.15	10.6	0.170	4.7	0.0020	21.7	0.15	180	U	U	180	0.098 B	5.51	U	0.07	22.27	392	8.1	290
RGC22	SFC		0.03 B	20.7	U	6.4	U	2.9	0.0016	14.2	0.18	112	U	U	112	0.101 B	4.35	0.54	0.09	27.39	283	8.3	230
RGC23	SFC		0.03 B	22.2	U	6.2	U	3.7	0.0004	16.4	0.15	119	U	U	119	0.090 B	4.03	0.21	0.08	19.80	278	8.2	220
RGC24	SFC		0.03 B	20.4	U	4.3	0.029 B	4.5	0.0002 B	16.7	0.11	121	U	U	121	0.090 B	3.90	U	0.10	22.75	262	8.1	200
RGC25	SFC		U	13.6	U	3.5	U	3.7	0.0002 B	3.6	0.10	80	U	U	80	U	2.26 B	0.21	0.22	6.85	179	7.7	180
RGC26	SFC		0.03 B	21.9	U	7.4	0.030	6.4	0.0003	15.7	0.19	109	U	U	109	0.142 B	9.16	0.17	0.09	35.08	315	8.2	230
RGC27	SFC		0.02 B	21.9	U	7.3	0.016 B	6.3	0.0003	15.4	0.18	110	U	U	110	0.141 B	9.15	0.10 B	0.09	35.04	312	8.1	240
RGC28	SFC		0.03 B	41.2	U	10.5	0.053	5.3	U	17.4	0.25	180	U	U	180	0.070 B	2.77	U	0.04 B	31.45	413	7.9	240
RGC29	SFC		0.02 B	45.2	U	9.8	U	6.1	0.0004	13.4	0.35	141	U	U	141	0.081 B	5.96	0.71	0.17	17.63	346	8.1	230
RGC30	SFC		0.01 B	32.6	U	7.7	U	3.9	0.0022	13.4	0.25	104	U	U	104	0.130 B	6.20	2.10	0.12	18.78	279	8.2	200
RGC31	SFC		0.02 B[4]	34.0	U	9.2	U	3.8	0.0013	16.6	0.29	114	U	U	114	0.114 B	5.75	1.10	0.17	25.82	300	8.2	220
RGC32	SFC		0.01 B	38.8	0.09	8.0	0.031	4.3	U	10.1	0.30	133	U	U	133	0.076 B	3.36	U	0.17	8.66	288	8.1	190
RGC34	SFC		0.03 B	111	0.38	50.6	0.087	14.1	0.0028	61.5	0.53	495	U	U	495	0.148 B	14.02	1.00	0.21	74.98	1030	7.7	670
RGC35	SFC		U	21.5	U	4.8	U	3.6	U	5.1	0.16	78	U	U	78	U	0.83 B	0.22	0.16	3.12	167	8.2	130
RGC36	SFC		U	28.9	U	6.3	U	5.5	U	5.3	0.22	99	U	U	99	U	1.27 B	0.4	0.18	3.8	210	8.1	150

1 = Method Detection Limit; 2 = Practical Quantitation Limit; 3 = exceeded holding time, see Table 5.3 for field pH; 4 = estimated because analyte concentration is between MDL and PQL; 5 = not detected

Table 5.6. Analytical results for the COGA baseline organic parameters**,** listed by sample number. Analyses by ACZ Lab.

Sample Number		BTEX					Hydrocarbon Gases				
		Benzene	Ethylbenzene	m p Xylene	o Xylene	Toulene	Butane	Ethane	Ethylene	Methane	Propane
	units	µg/L	µg/L	µg/L	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	MDL[1]	1	1	2	1	1	0.03	0.02	0.03	0.009	0.03
	PQL[2]	1	1	2	1	1	0.03	0.02	0.03	0.009	0.03
RGC1		U	U	U	U	U	U	U	U	U	U
RGC2		U	U	U	U	U	U	U	U	U	U
RGC3		U	U	U	U	U	U	U	U	U	U
RGC4		U	U	U	U	U	U	U	U	U	U
RGC5		U	U	U	U	U	U	U	U	U	U
RGC6		U	U	U	U	U	U	U	U	U	U
RGC7		U	U	U	U	U	U	U	U	U	U
RGC8		U	U	U	U	U	U	U	U	U	U
RGC9		U	U	U	U	U	U	U	U	U	U
RGC10		U	U	U	U	U	U	U	U	U	U
RGC11		U	U	U	U	U	U	U	U	U	U
RGC12		U	U	U	U	U	U	U	U	U	U
RGC13		U	U	U	U	U	U	U	U	U	U
RGC14		U	U	U	U	U	U	U	U	U	U
RGC15		U	U	U	U	U	U	U	U	U	U
RGC16		U	U	U	U	U	U	U	U	U	U
RGC17		U	U	U	U	U	U	U	U	U	U
RGC18		U	U	U	U	U	U	U	U	U	U
RGC19		U	U	U	U	U	U	U	U	U	U
RGC20		U	U	U	U	U	U	U	U	U	U
RGC21		U	U	U	U	U	U	U	U	U	U
RGC22		U	U	U	U	U	U	U	U	U	U
RGC23		U	U	U	U	U	U	U	U	U	U
RGC24		U	U	U	U	U	U	U	U	U	U
RGC25		U	U	U	U	U	U	U	U	U	U
RGC26		U	U	U	U	U	U	U	U	U	U
RGC27		U	U	U	U	U	U	U	U	U	U
RGC28		U	U	U	U	U	U	U	U	U	U
RGC29		U	U	U	U	U	U	U	U	U	U
RGC30		U	U	U	U	U	U	U	U	U	U
RGC31		U	U	U	U	U	U	U	U	U	U
RGC32		U	U	U	U	U	U	U	U	0.012	U
RGC33		U	U	U	U	U	U	U	U	U	U
RGC34		U	U	U	U	U	U	U	U	U	U
RGC35		U	U	U	U	U	U	U	U	U	U
RGC36		U	U	U	U	U	U	U	U	U	U
RGC37		U	U	U	U	U	U	U	U	U	U
	1 = Method Detection Limit; 2 = Practical Quantitation Limit										

Table 5.7. Drinking water analyses for deep wells**.** Analyses by Sangre de Cristo Lab.

Sample #		As	Al	Cr	Cd	Cl	Cu	F	Fe	Pb	Mn	Zn	Na	NO_3	NO_2	PO_4	Alkalinity Hardness	SO_4	Lab pH	TDS
	Units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	MDL[1]	0.001	0.01	0.0008	0.0002	0.1	0.001	0.019	0.024	0.0006	0.021	0.005	0.5	0.19	0.09	0.10	0.1	1.0	0-14	1.0
	MCL[2]	0.01	.02*	0.100	0.005	250*	1.30	4.0	0.3*	0.015	0.3*	5.0	20.0	10	1.0	0	**	250*	6.0-7.8	500
RGC-D1		<0.001	0.364	0.005	ND	1.80	ND	0.22	0.144	0.0006	0.330	0.908	5.2	0.4	ND	ND	78	2.1	7.1	117
RGC-D2		<0.001	0.025	ND	<0.0002	4.20	0.002	0.66	0.146	<0.0006	0.413	ND	56.2	ND	ND	ND	98	51.6	8.1	230
RGC-D3		<0.001	0.136	ND	ND	4.00	0.024	2.61	0.621	0.002	0.204	0.012	67.3	ND	ND	ND	92	33	7.6	218
RGC-D4		<0.001	0.130	ND	ND	10.60	0.027	2.37	0.602	0.001	0.202	0.13	69	ND	ND	ND	89	42	7.6	225

1 = Method Detection Limit. 2 = Maximum Contaminant Level per Colorado Department of Public Health. * = Secondary MCL based on aesthetics. ** = Does not have a MCL.

Table 5.8. Water-quality analyses for public water-supply wells at Beaver Mountain Estates (provided by Robert Tonetti, president of property owner's association, 2012).

Sample Number	Inorganic Parameters													
		Al	Sb	As	Ba	Be	Cd	Ca	Cr	Cu	Fl	Fe	Pb	Mg
	units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	MDL[1]	0.025	0.002	0.002	0.01	0.001	0.0005	0.40	0.006	0.010	0.40	0.2	0.002	0.05
BME2		U[2]	U	U	U	U	U	8.1	U	U	1.0	U	U	1.4
BME3			U	U	U	U	U		U		9.3			

Sample Number	Inorganic Parameters-continued												
		Mn	Hg	Ni	Se	Ag	Na	Th	U	Zn	Total Alkalinity as $CaCO_3$	Total Harness as $CaCO_3$	TDS
	units	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	MDL	0.005	0.0001	0.01	0.002	0.0002	0.5	0.001	0.001	0.005	5.0	1.2	
BME2		U	U	U	U	U	54	U	U	0.0076	116	26	200
BME3			U	U	U		160	U			276	2.2	430

Sample Number	Organic Parameters				
		Benzene	Ethybenzene	Toluene	Xylene (total)
	units	µg/L	µg/L	µg/L	µg/L
	MDL	0.50	0.50	0.50	0.50
BME2		U	U	U	U
BME3		U	U	0.71	U

1 = Method Detection Limit

2 = not detected

Table 5.9. Laboratory analytical methods**.**

Methods Used for COGA Baseline Analyses by ACZ Laboratories, Inc.

Inorganic Parameters	
Boron, dissolved:	M200.7 ICP
Calcium, dissolved:	M200.7 ICP
Iron, dissolved :	M200.7 ICP
Magnesium, dissolved:	M200.7 ICP
Manganese, dissolved:	M200.7 ICP
Potassium, dissolved:	M200.7 ICP
Selenium, dissolved:	M200.8 ICP-MS
Sodium, dissolved:	M200.7 ICP
Strontium, dissolved:	M200.7 ICP
Alkalinity as $CaCO^3$:	SM2320B - Titration
Bromide:	M300.0 - Ion Chromatography
Chloride:	M300.0 - Ion Chromatography
Nitrate/Nitrite as N:	M353.2 – H_2SO_4 preserved
pH:	SM4500H+ B
Phosphorous, total:	M365.1 – Auto Ascorbic Acid
TDS:	SM254C
Sulfate:	M300.0 – Ion Chromatography

Organic Parameters	
BTEX:	Analysis Method: M8021B GC/PID; Extract Method: 5030C
Hydrocarbon Gas:	Analysis Method: RSKSOP-175 (GC/FID)

Lab Methods Used for Drinking Water Analyses by Sangre de Cristo Laboratory, Inc.

Alkalinity Hardness:	2340A
Arsenic:	200.9
Aluminum:	200.9
Chromium:	200.9
Cadmium:	200.9
Chloride:	300.0
Copper:	200.9
Fluoride:	300.0
Iron:	300.0
Lead:	200.9
Manganese:	200.9
Nitrate:	300.0
Nitrite:	300.0
pH:	150.1
Phosphate:	300.0
Sodium:	200.9
Sulfate:	300.0
TDS:	160.1
Zinc:	200.9

Table 5.10. Primary and secondary maximum contaminant levels and action levels for parameters included in Tables 5.4, 5.5, 5.6, 5.7, and 5.9. (from Colorado Department of Public Health and Environment, 2010; U.S. Environmental Protection Agency, 2009; Evelyn Vigil, Sangre de Cristo Laboratory, 2012, personal communication)

Primary MCLs

Antimony:	0.006 mg/L
Arsenic:	0.01 mg/L
Barium:	2.0 mg/L
Beryllium:	0.004 mg/L
Cadmium:	0.005 mg/L
Chromium:	0.1 mg/L
Copper:	1.3 mg/L
Fluoride:	4.0 mg/L
Lead:	0.015 mg/L (action level)
Mercury:	0.002 mg/L
Nitrate:	10 mg/L
Nitrite:	1.0 mg/L
Phosphate:	0 mg/L
Selenium:	0.05 mg/L
Benzene:	5 ug/L
Ethylbenzene:	700 ug/L
Toluene:	1,000 ug/L
Xylene:	10,000 ug/L

Secondary MCLs

Aluminum:	0.2 mg/L
Chloride:	250 mg/L
Copper:	1.0 mg/L
Iron:	0.3 mg/L
Manganese:	0.3 mg/L
Silver:	0.1 mg/L
Sulfate:	250 mg/l
Zinc:	5.0 mg/L
TDS:	500 mg/L

6.0 WATER WELLS AND SPRINGS NEAR THE PROPOSED OIL WELLS

6.1 Location of Wells

Legal descriptions and UTM coordinates for water wells and springs sampled in the San Francisco Creek (SFC) area near the proposed Hughes DAHC-San Francisco Creek #1 oil well and in the Old Woman Creek (OWC) area near the proposed First Liberty Basin #1 oil well are listed in Table 3.1. The UTM coordinates for all sampled water wells were obtained using a hand-held GPS receiver. Locations of the sampled wells in the SFC area are shown on Figure 6.1; well locations in the OWC area are in Figure 6.2. Locations of the proposed oil wells and also previously drilled oil wells in the areas also are shown on these figures. Sixteen wells and four springs were sampled in the SFC area. Sixteen water wells were sampled in the OWC area. A replicate sample (RGC27) was collected at a well (RGC26) in the SFC area for QA/QC purposes.

6.2 Reported Depth of Wells

The reported depths of the sampled water wells in the SFC and OWC areas are listed in Table 5.2 (from CDWR online records). The depths of the sampled wells in the SFC area also are shown on Figure 6.3, and depths of the sampled wells in the OWC area are shown on Figure 6.4. The sampled wells in the SFC area range from 70 to 320 feet deep. The sampled wells in the OWC area are 200 to 540 feet deep.

Note that four different wells were drilled under CDWR permit number 196293/196293-A in the OWC area. The first well drilled under this permit was 884 feet deep, but it was abandoned, as were the subsequent two wells. The fourth drilled well is the well that was sampled for this study (RGC6).

6.3 Reported Static Water Levels

The reported static water levels in sampled water wells in the SFC and OWC areas are listed in Table 5.2 (from CDWR online records). Figures 6.5 and 6.6, respectively, show the reported static water levels in the sampled wells in the SFC area and OWC area.

Static water levels in the SFC area range from 20 to 202 feet below ground level. The springs in the SFC area are assigned static water levels of 0 feet. Five wells in the OWC area are flowing wells; other wells have static water levels that vary from 3 to 280 feet below ground level.

6.4. Reported Pumping Rates

The reported pumping rates of sampled water wells in the SFC and OWC areas are listed in Table 5.3 (from CDWR online records). Production rates or yields for sampled water wells in the SFC area are also shown in Figure 6.7. The wells in the SFC area produced 4 to 22 per minute (gpm). Figure 6.8 shows the production rates for sampled wells in the OWC area. They range from 1 to 100 gpm, with most rates being between 1 and 10 gpm. Wells with the highest production rates in the OWC area are flowing wells.

6.5 Other Water Characteristics

None of the sampled wells and springs had noticeable odor or taste, and none was reported by the well owners. Samples RGC30 and RGC34, both from wells in the SFC area, initially were a pale yellow brown or red brown color, but both rapidly cleared upon pumping of the well (Table 5.3). All other water samples were clear. Small amounts of organic material were noted in all four spring samples.

Water temperatures of the sampled wells and springs in the SFC area are listed in Table 5.3 and shown in Figure 6.9. The temperatures ranged from 9.0 to 13.2 ^{o}C. Lowest temperatures were measured in the springs and wells nearest to San Francisco Creek. Warmer temperatures were recorded in the wells on the northwest and southern sides of the area. Shallow wells tended to have lower temperatures than the deeper wells.

Water temperatures of the sampled wells in the OWC area are listed in Table 5.3 and shown in Figure 6.10. Temperatures in the OWC area were generally higher than those in the SFC area; they varied from 11.8 to 16.7 ^{o}C. Highest temperatures usually were associated with the flowing wells and with the deeper wells.

6.6 Water Analyses

The measured field parameters and laboratory water-quality analyses are contained in Tables 5.3, 5.4, 5.5, and 5.6. Almost all of the sampled wells and springs were alkali, with field pH ranging up to 9.9. One sample in the SFC area has a slightly acidic pH of 6.5, and one spring and one well in the SFC area have near neutral pH values of 6.99. Well water in the OWC area is more alkaline than the wells and springs in the SFC area. Field pH in the OWC area is as high as 9.9 (RGC5); most samples have a pH of 8.8 to 9.7; and the lowest pH is 8.1 (RGC8). In the SFC area the pH varies from 6.5 to 8.0. Most tested water in the SFC area has a pH of 7.0 to 7.7.

Sodium concentrations in the OWC area ranged from 71 to 121 mg/L and are higher than in the SFC area, where sodium concentrations vary from 3.6 to 61.5 mg/L. In the OWC area calcium concentrations are generally low; some are below the Practical Quantitative Limit, but others are as high as 66.5 mg/L. In contrast, the calcium concentrations in the SFC area tend to be higher, ranging from 13.6 to 111 mg/L, with most waters containing 20 to 40 mg/L. Magnesium concentrations are typically below detection limits in the OWC area. In the SFC area they generally are higher, varying from 3.5 to 50.6 mg/L, with most waters having low concentrations of only 5 to 10 mg/L. Potassium values generally were below the Practical Quantitative Limit in the OWC area, and in the SCF area they range only from 2.2 to 14.1 mg/L.

Bicarbonate concentrations are typically higher in the SFC area (78 to 495 mg/L) than in the OWC area (54 to 180 mg/L). All carbonate concentrations are below the detection limit in the SFC area; in the OWC area they vary from below detection limits to as much as 110 mg/L. Hydroxide concentrations are below detection limits in all samples in both areas. Chloride concentrations are slightly higher in the OWC area (8 to 28 mg/L) than in the SFC area (range from below Practical Quantitative Limit to 14 mg/L). Sulfate concentrations generally are slightly higher in the OWC area (10 to 211 mg/L) than in the SFC area (3 to 127 mg/L), but they vary considerably.

Total dissolved solids concentrations (TDS) in all samples were usually between 150 and 400 mg/L. The lowest TDS was 130 mg/L in a spring near San Francisco Creek (RGC35), and the highest TDS was 670 mg/L in a 230 feet deep well (RGC34), also in the SFC area. In general TDS was slightly higher in samples from the OWC area than the SFC area. Figure 6.11 shows the TDS values in the SFC area and also computer-generated contour lines of those values. The lowest TDS concentrations are closest to San Francisco Creek, and the highest TDS values are farthest from the creek.

The northern end of 200 mg/L contour line in Figure 6.11 could be redrawn so that it parallels the creek, not bend eastward and cross the creek. And another 200 mg/L contour line could be added on the east side of the creek, running through the 200 mg/L data point and approximately parallel to the 200 mg/L contour on the west side of the creek. This would result in an interpretation that indicates the lowest TDS values follow the creek and the TDS increases going away from the creek on both the west and east sides of the creek.

TDS concentrations in the Old Woman Creek area are shown in Figure 6.12. TDS concentrations are higher in the northeast part of the area and lower on the west and southeast parts.

Concentrations of benzene, ethylbenzene, xylene, and toluene (BTEX) are below detection limits in all samples. Concentrations of butane, ethane, ethylene, and propane gases also are below detection limits in all samples. Methane gas was detected in only one sample (RGC32); the concentration (0.012 mg/L) was slightly above the Practical Quantitative Limit. This sample is from a spring in the SFC area that supports a well developed wetland. In order to collect this sample, a shallow hole was excavated into the organic-rich sediment at the spring. The methane in sample RGC32 may be biogenic gas generated from decomposition of organic material in the wetland.

6.7 Geologic Sources of Sampled Well and Spring Water

The geologic formations in which the sampled wells in the OWC and SFC areas are completed, and also the geologic formations from which springs issue, were assessed using geologic mapping by Steven and others (1974) and Lipman (1976), geologic logs prepared by well drillers and submitted to the CDWR, and preliminary reconnaissance level field investigations.

All sampled water wells in the OWC area probably produce water from the vent facies of the Conejos Formation, which consists chiefly of andesitic lava flows. The sampled water wells in the SFC area probably produce water from the volcaniclastic facies of the Conejos Formation, which is composed mostly of sedimentary rocks eroded from the volcanoes. A few of the wells in the SFC area (e.g. RGC24, RGC26, RGC29) may have started in ash-flow tuff, but the wells probably drilled through the base of the tuff and into the top of the Conejos Formation within 10 to 50 feet of the ground surface.

Three of the sampled springs in the SFC area discharge from surficial deposits that overlie the volcaniclastic facies of the Conejos Formation. The surficial deposits consist of unconsolidated sand, gravel, and clay, and are thought to be relatively thin (5 to 30 feet thick). One spring (RGC31) appears to discharge directly from volcaniclastic bedrock in the Conejos Formation.

6.8 Other Wells and Springs Near the Proposed Oil Test Wells

Several wells and springs in the SFC and OWC areas exist within about one mile of the proposed oil wells. These wells and springs were not sampled for the various reasons described below, but they should be considered for sampling in future investigations.

In the SFC area, a well on lot 47 (permit # 201686) was not sampled because the property was recently foreclosed and the electric meter was removed from the power pole. The well on lots 38 and 39 (permit # 209786) has a pump, but it is not connected to a source of electricity; a generator is needed to power this pump. The well on lot 41 (permit # 208220) did not have a pump installed. A well on lots 57 and 59 (permit # 199575) has a pump, but it is not connected to a source of power; a generator is needed to power this pump. Springs on or near lots 57 and 59 were sampled by the operator of the proposed oil well, but we were unable to locate their initial points of discharge; we decided not to sample flowing surface water in Spring Branch.

Several permitted wells lie a short distance beyond the one-mile radius of the proposed oil well in the SFC area. Wells on the north and northeast side of a one-mile radius from the proposed oil well include permit #s 30387, 201002, 203805, 224960, and 274750. A spring reportedly also exists near well # 201002. Wells on the south side of the one-mile radius include permit #s 199594 and 203406. These wells and springs in the SFC area should be considered for sampling in future studies.

A number of wells in the OWC area that are either within or just outside the one-mile radius were not sampled. Wells within the one-mile radius that were not sampled include the following:

-permit # 54484; no pump
-permit # 54960; no pump
-permit # 170799; no pump
-permit # 198571; solar electric system, but apparently no power reaches the pump
-permit # 225757; no pump
-permit # 260596; no electricity, electric meter is removed
-permit # 271165; no pump

Other unsampled wells in the OWC area that are located outside of, but near to, the one-mile radius include permit #s 54517, 195679, 195681, 195684, 195686, 2098012, 243207, 258649, and 278811. Several wells in the Rio Grande Ranchos subdivision also are located near to, but west of, the one-mile radius from the proposed oil well. If future studies are undertaken in the OWC area it may be desirable to sample these wells.

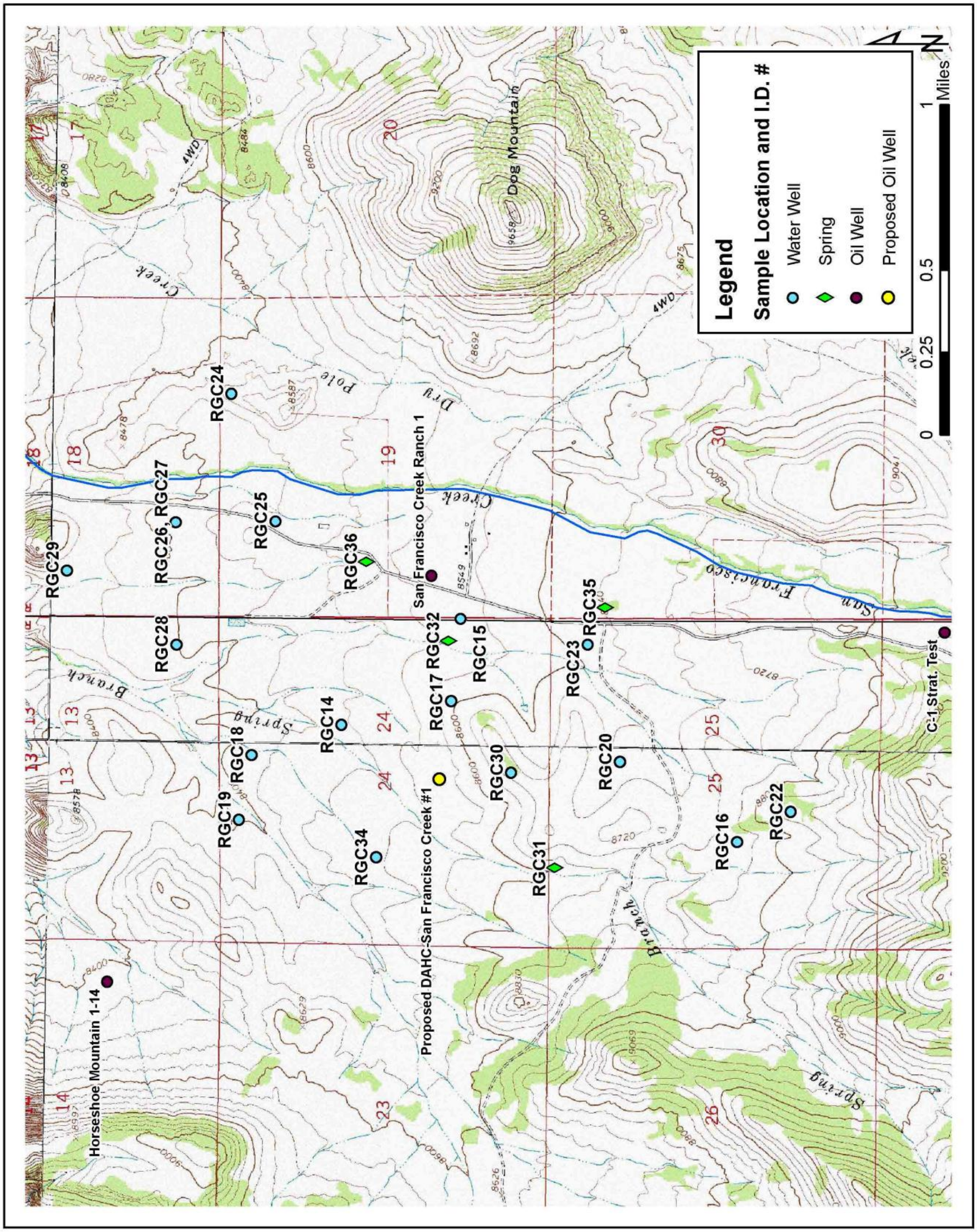

Figure 6.1. Location map for sampled wells and springs and drilled and proposed oil wells in the San Francisco Creek area**.**

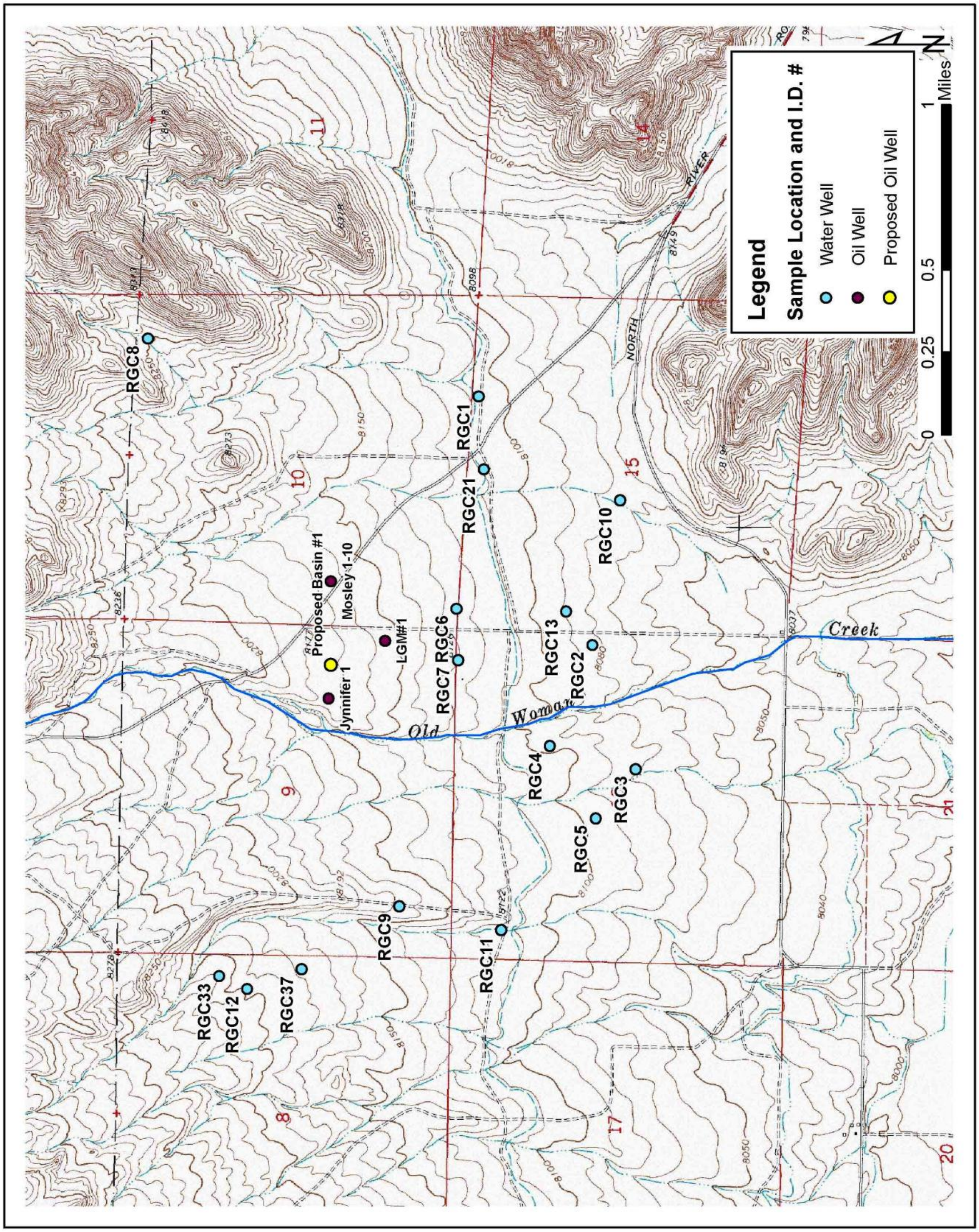

Figure 6.2. Location map for sampled water wells and drilled and proposed oil wells in the Old Woman Creek area**.**

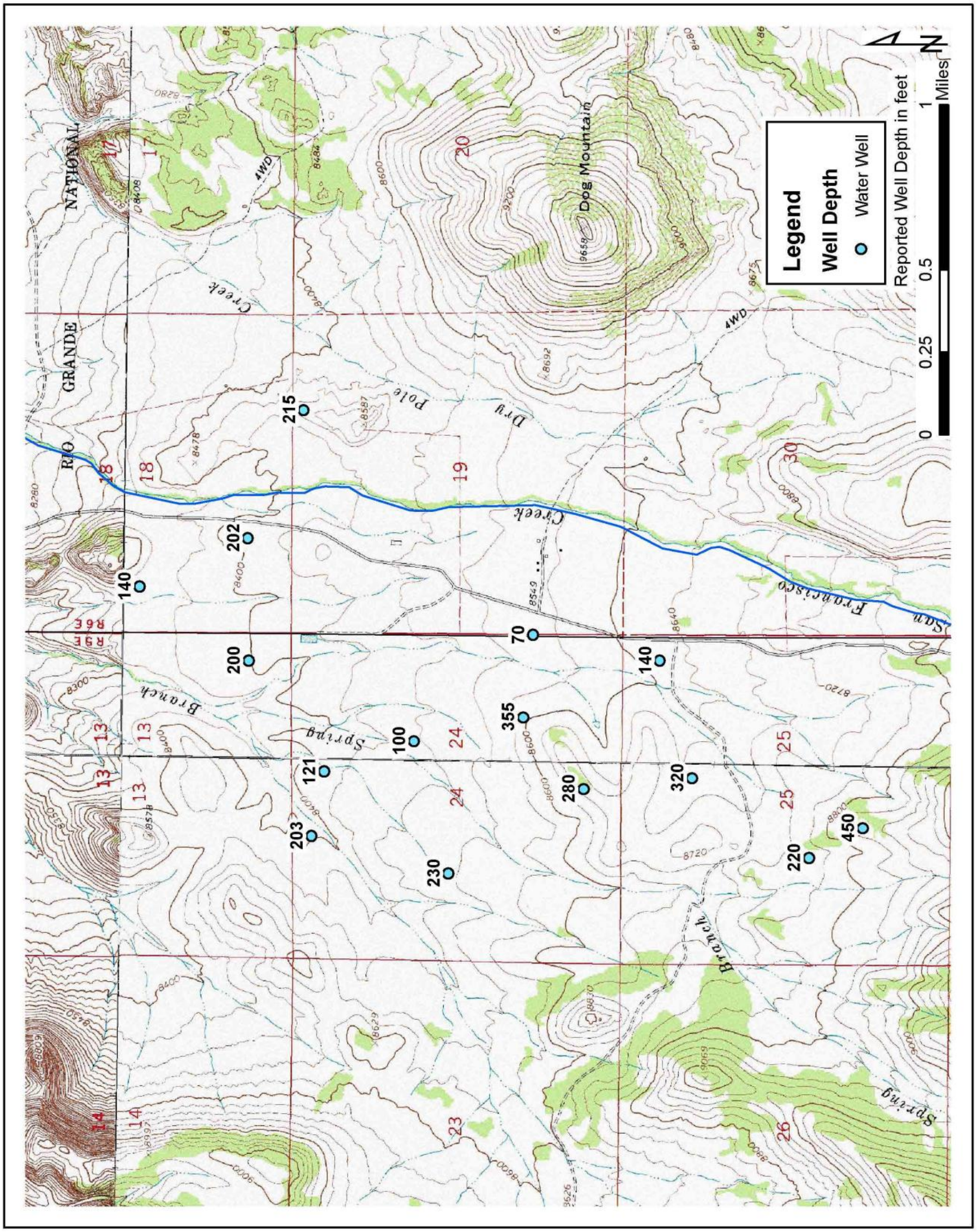

Figure 6.3. Reported depths of sampled water wells in the San Francisco Creek area**.**

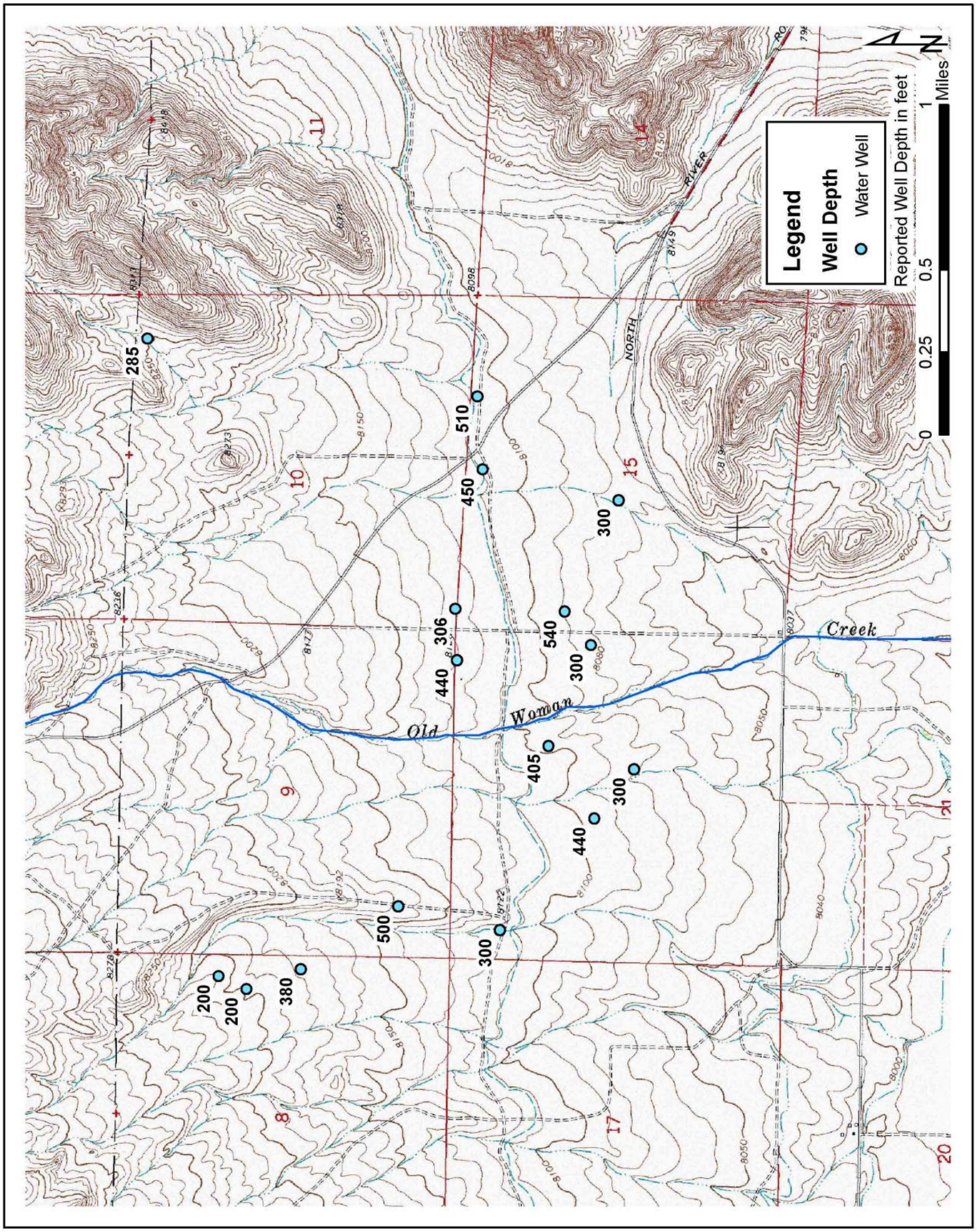

Figure 6.4. Reported depths of sampled water wells in the Old Woman Creek area**.**

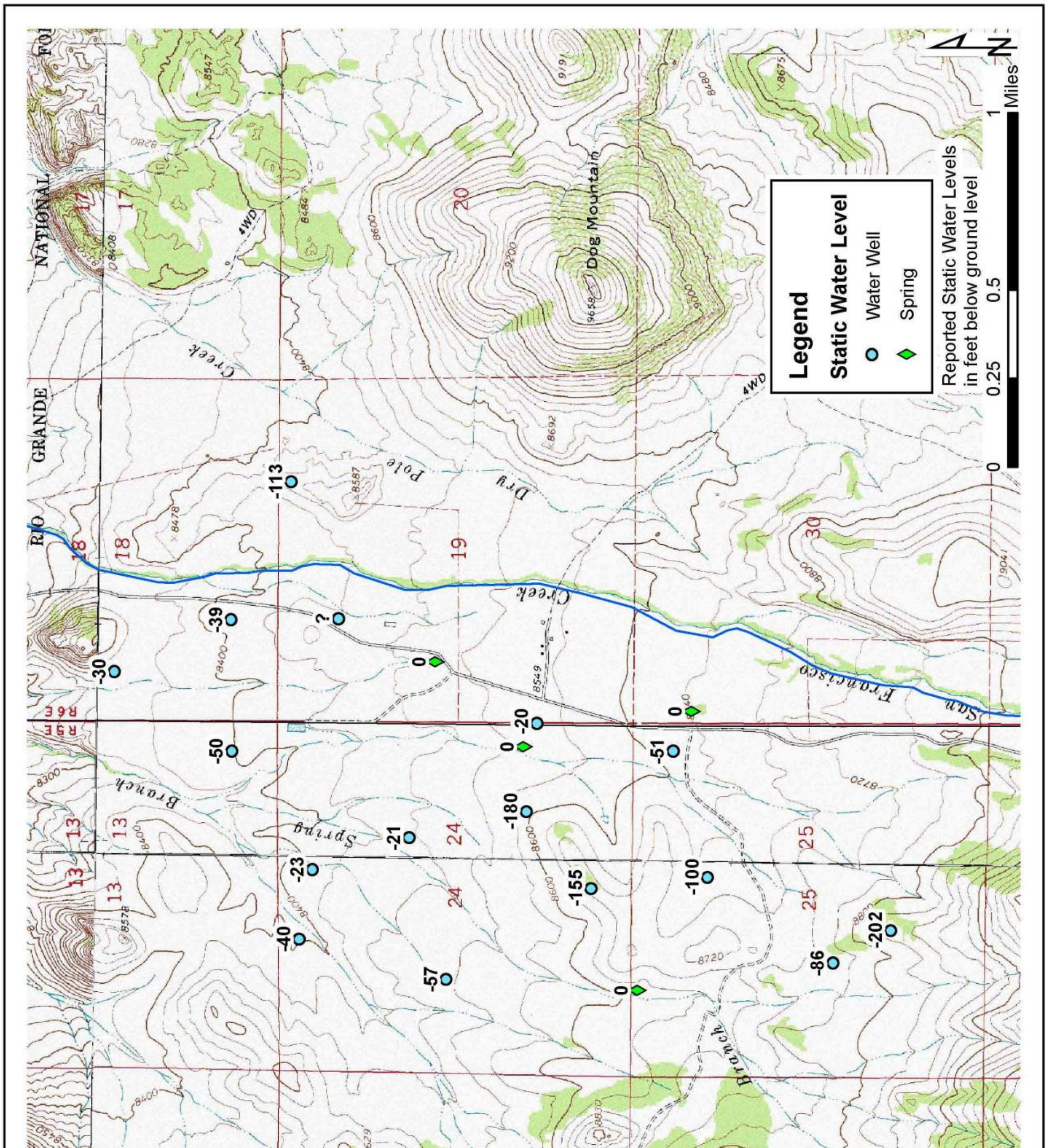

Figure 6.5. Reported static water levels in sampled wells in the San Francisco Creek area**.** Static levels for springs are "0"; and the well with the "?" indicates no data is available for it.

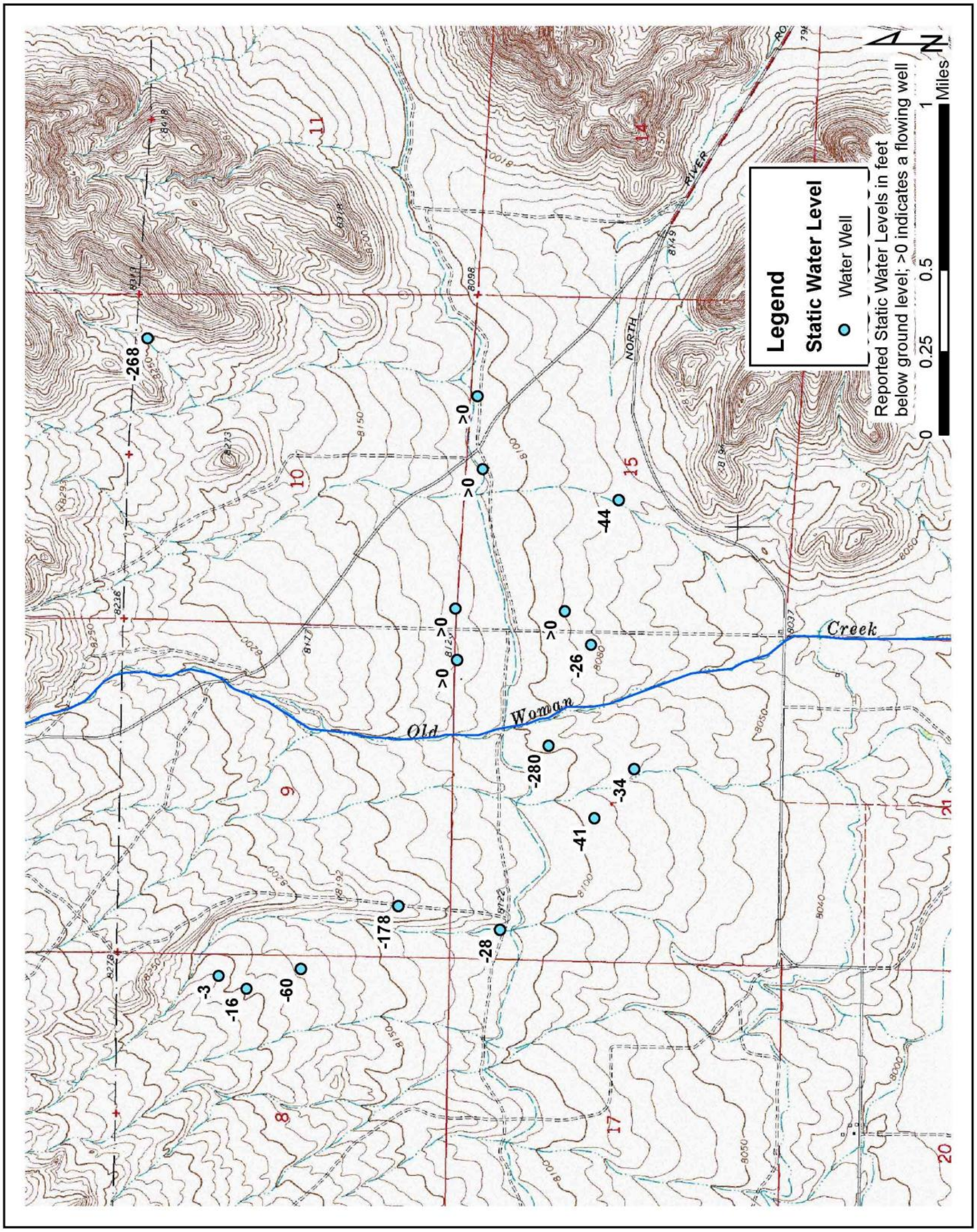

Figure 6.6. Reported static water levels in sampled wells in the Old Woman Creek area**.** Values shown as “>0” indicate a flowing well.

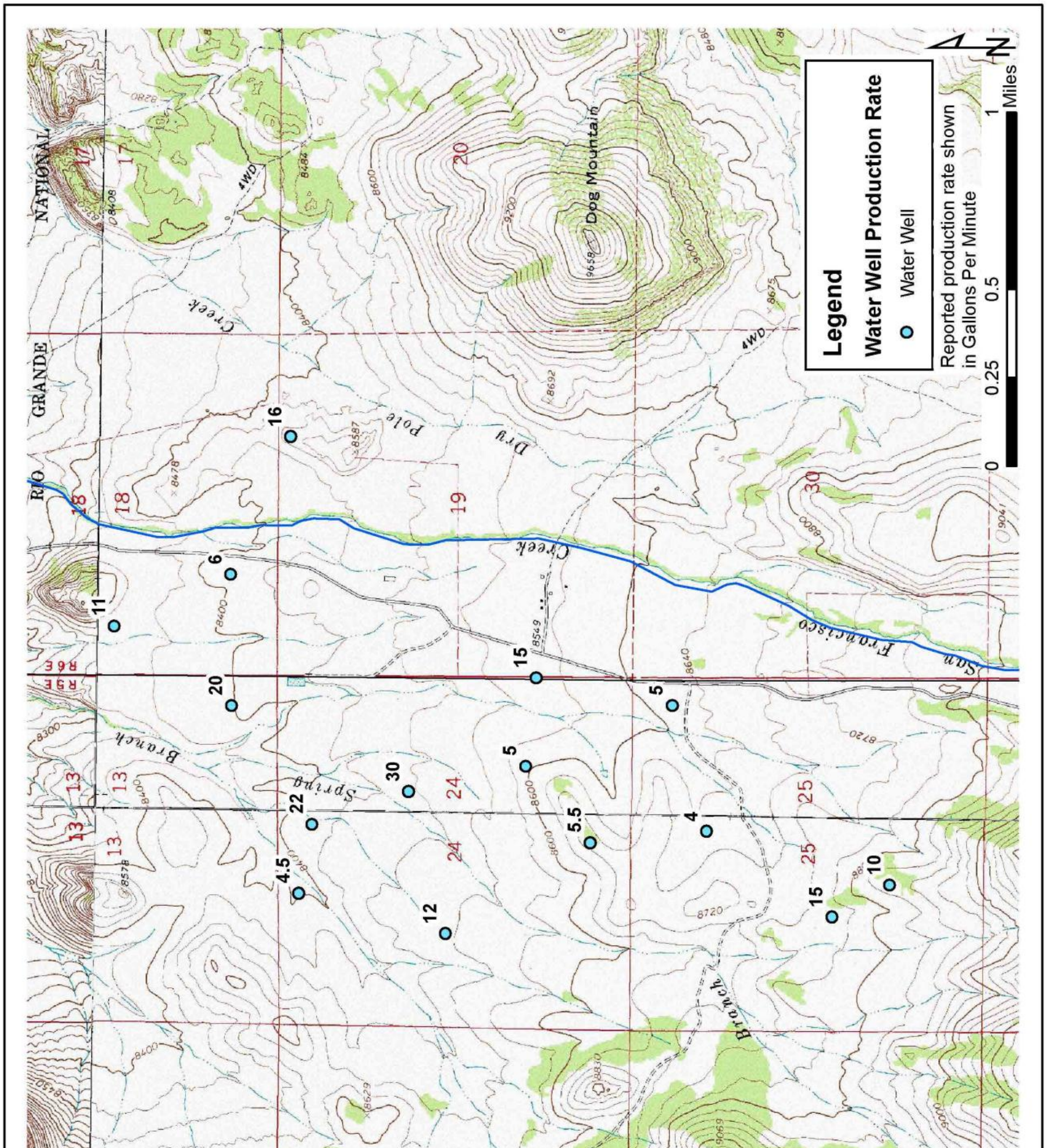

Figure 6.7. Reported production rates for sampled wells in the San Francisco Creek area**.**

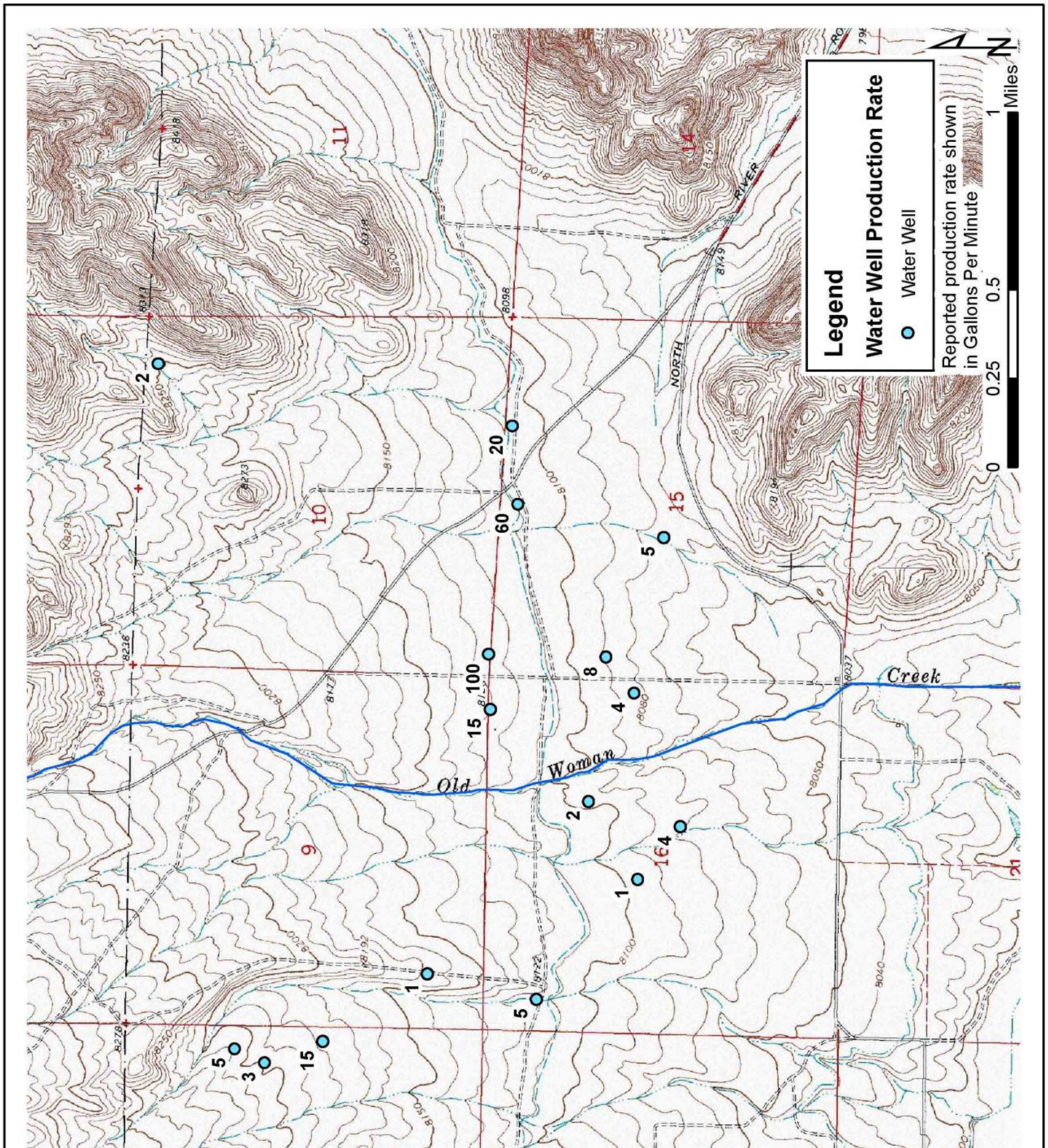

Figure 6.8. Reported production rates for sampled wells in the Old Woman Creek area**.**

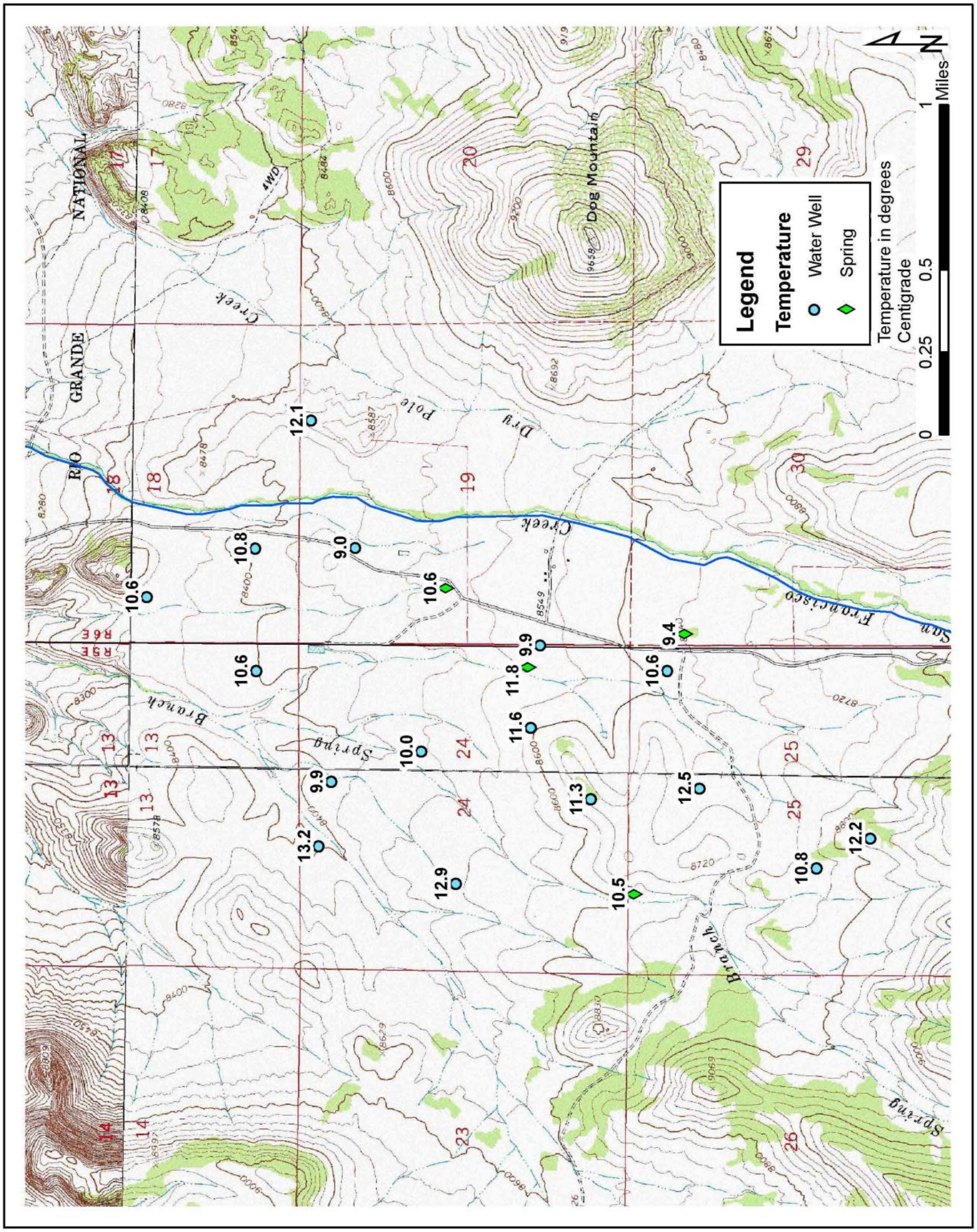

Figure 6.9. Water temperatures (in degrees Celsius) of sampled wells and springs in the San Francisco Creek area**.**

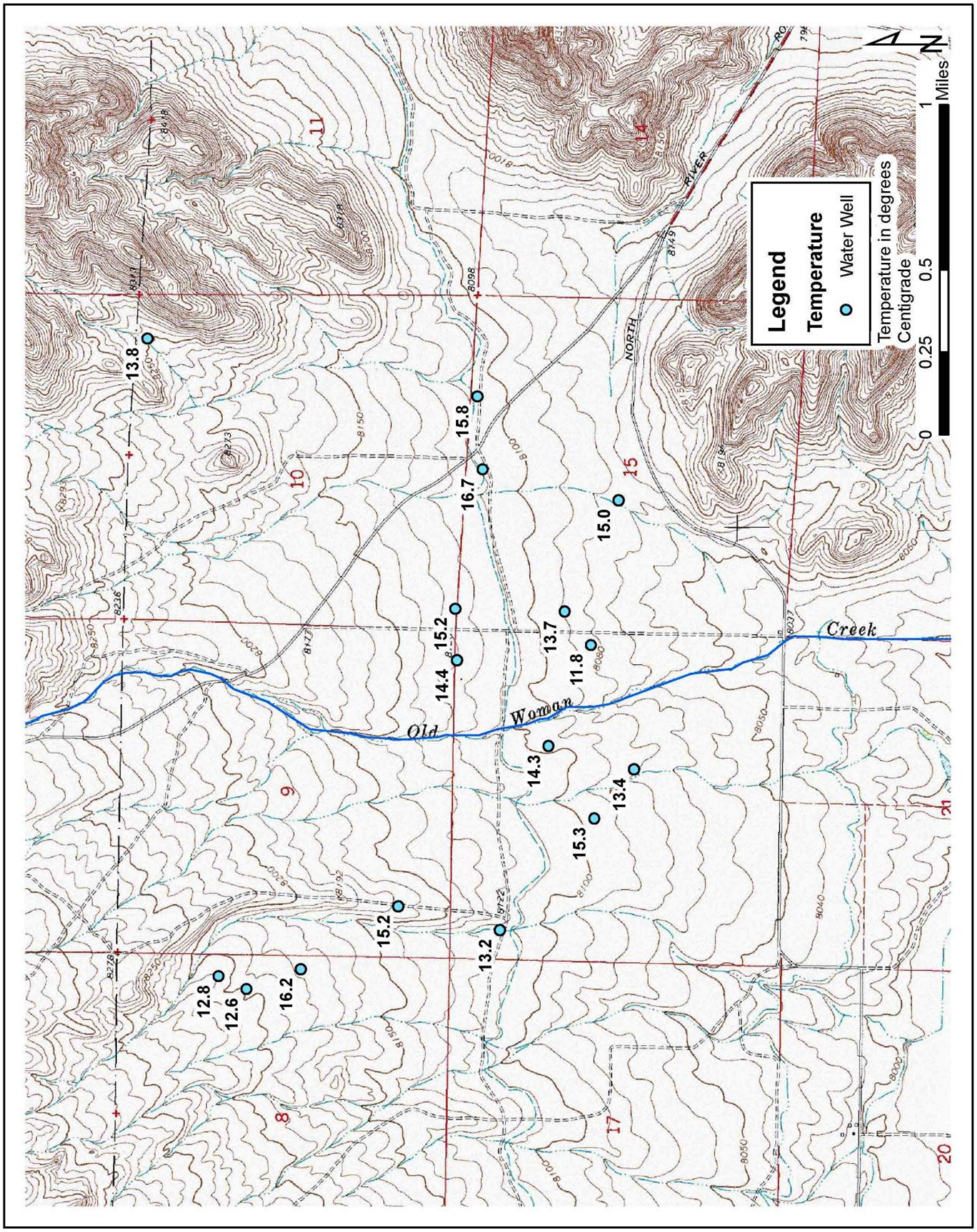

Figure 6.10. Water temperatures (in degrees Celsius) of sampled water wells in the Old Woman Creek area**.**

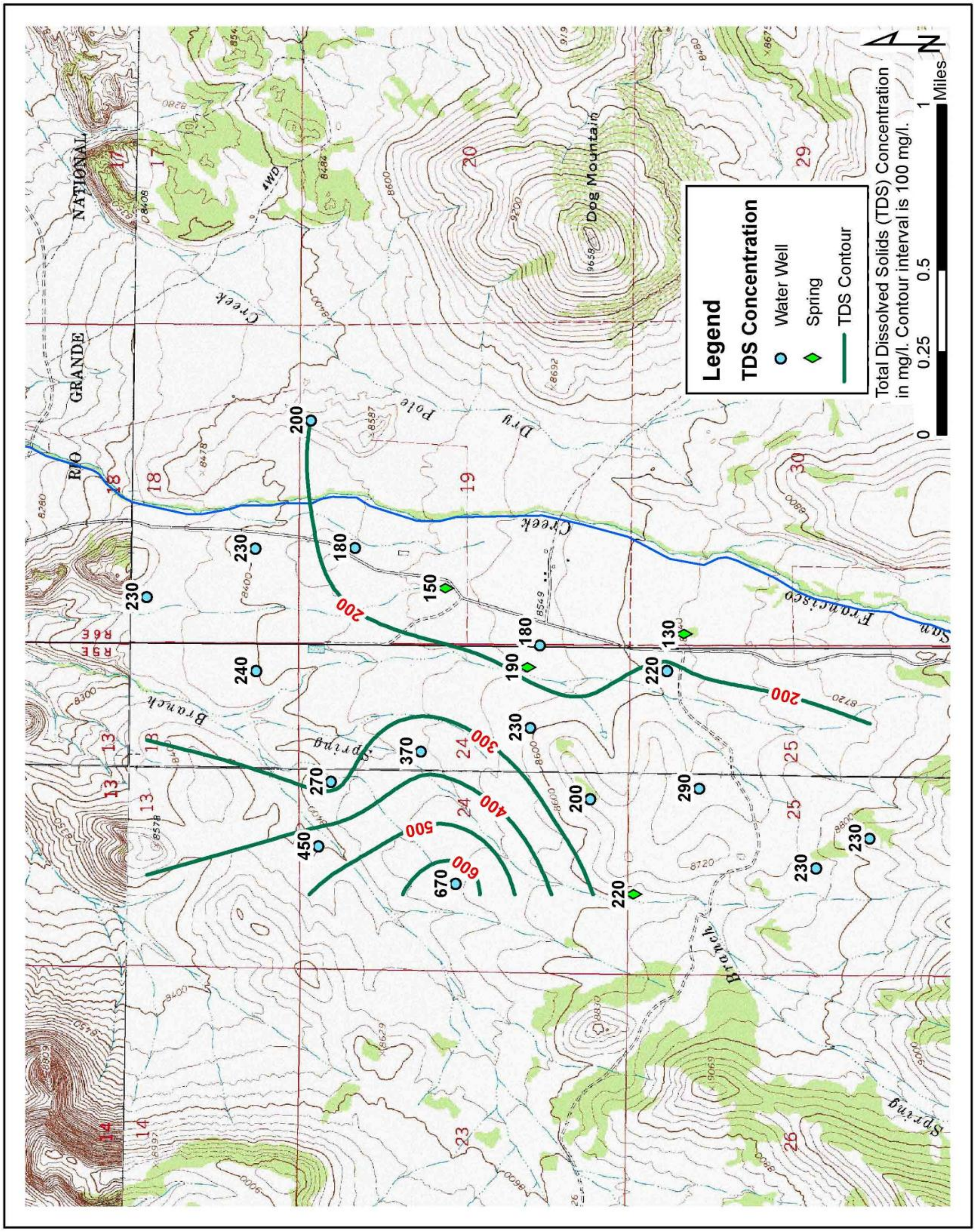

Figure 6.11. TDS (in mg/L) of well water and springs in the San Francisco Creek area**.** Contour interval 100 mg/L.

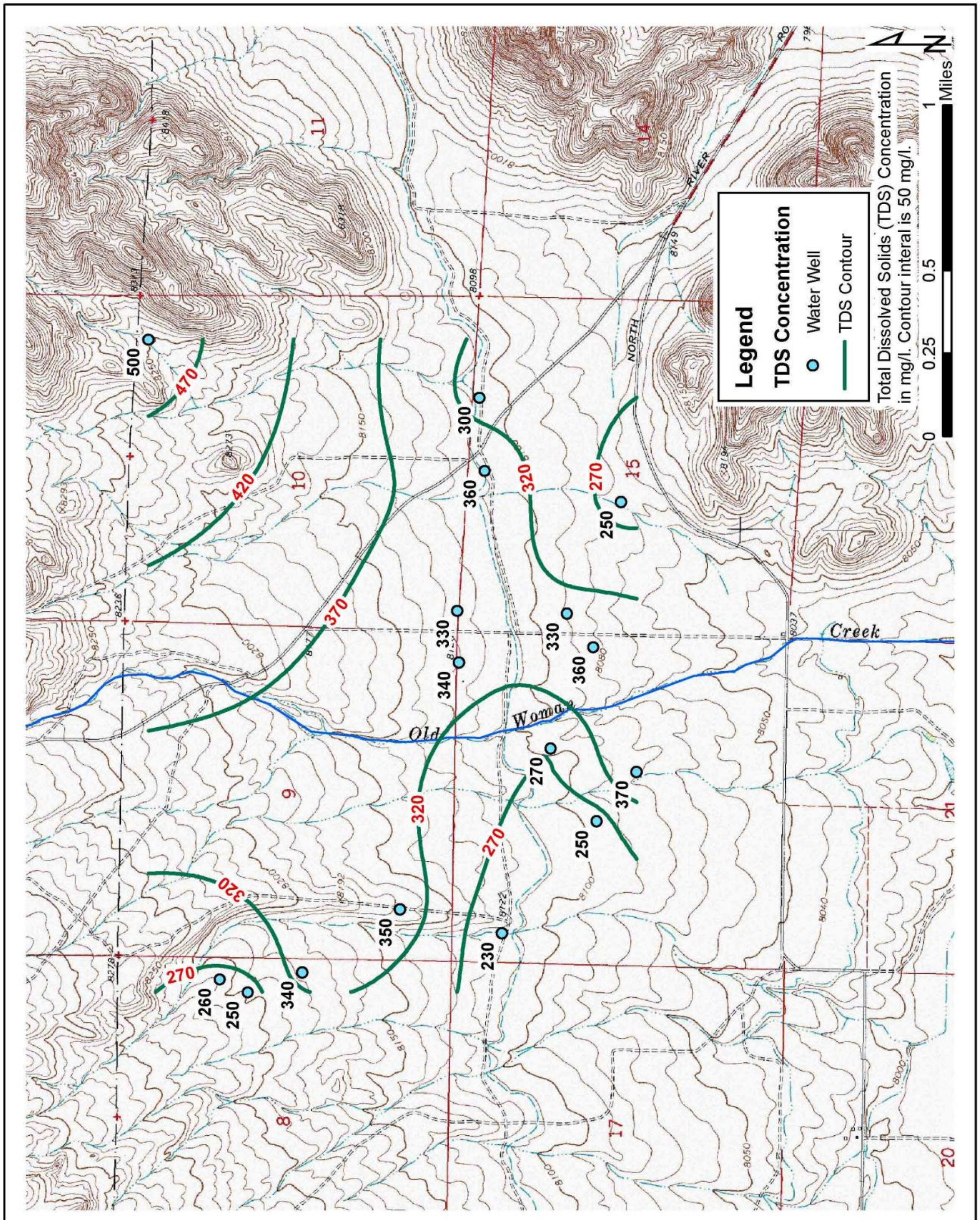

Figure 6.12. TDS (in mg/L) of well water in the Old Woman Creek area**.** Contour interval 50 mg/L.

7.0 DEEP WATER WELLS

7.1 Location and Depth of Deep Wells

According to the online records from the well permit database of the Colorado Division of Water Resources, State Engineer's Office (CDWR) there are twenty-six water wells in the study area that are at least 800 feet deep. Locations of these deep wells are shown in Figure 7.1. The wells are color-coded by depth range. Fourteen wells are between 800 and 1,000 feet deep, seven wells are 1,000 and 1,200 feet deep, and five wells are 1,200 and 1,400 feet deep.

Four of the deep wells were selected for sampling and testing by Sangre de Cristo Lab using their drinking water analysis (see Table 5.7 for test results). These are the Sutphin well (permit # 287015; sample RGC D1); Street well (permit # 55328-FR; sample RGC D2); Fietek well (permit # 65339-F; sample RGC D3); and Person well (permit # 55440-F; sample RGC D4).

Water-quality analyses for two other deep wells were provided by Robert Tonetti, president of the property owners' association for the Beaver Mountain Estates subdivision. Both wells are part of the public water-supply system for the subdivision. The water samples were collected in 2005 and analyzed for the comprehensive set of parameters required by the Colorado Department of Public Health and Environment for public water-supply wells. The wells are named the BME2 well (permit # 57640-F) and BME3 well (permit # 61314-F). See Table 5.8 for test results.

7.2 Sutphin Well

The Sutphin well (RGC D1) is located in the foothills near the northeast end of Greenie Mountain (Figures 5.2 and 7.1). This well is in the southeast corner of the study area, near where the volcanic rocks disappear into the subsurface beneath the floor of San Luis Valley. The well was drilled to a depth of 900 feet.

According to the well owners, the well was dry to a depth of 820 feet, where a small flow of water was encountered. A stronger flow of water was at 880 feet deep. Perforated casing was set from 850 to 900 feet. Static water level was estimated at 450 feet when the well was pump tested by the pump installer on May 9, 2012. The pumping rate was reported at 5 gpm, but the length of the test and the pumping water level were not reported. The well construction and test report indicates the well produced 1 to 2 gpm during a 2 hour test performed in January, 2012, shortly after the well was completed. Based on published geologic mapping by Steven and others (1974) and nearby geologic mapping by Lipman (1974), as well as reconnaissance evaluation of cuttings from the hole, the well probably is completed in the vent facies of the Conejos Formation.

The well owner connected a generator to the wiring from the pump to facilitate sample collection. The well was purged for 1 hour and 45 minutes prior to collection of a sample for analysis (Table 5.3). The pumping rate started at about 6 gpm and slowed to 2.8 gpm when pumping ended. Water temperature in the Sutphin well initially was 10.7 ^{o}C and gradually warmed to 17.0 ^{o}C by the time the sample for lab analysis was collected. pH initially was 8.36 but rapidly stabilized at 8.17. When first measured, conductivity was 196 microsiemens (µS), and at the end of the well purging it was 182 µS.

Total dissolved solids concentration (TDS) was 117 mg/L, the lowest TDS of all analyzed samples, and all dissolved parameters met the primary drinking water standards (Table 5.8). The well water slightly exceeds the secondary drinking water standards for aluminum (0.364 mg/L) and for manganese (0.330 mg/L), but other tested parameters were well below drinking water standards. Even sodium was low (5.2 mg/L), which is among the very lowest sodium concentrations of all the samples.

7.3 Street Well

The Street well (RGC D2) is located in the Bear Creek filing of the South Fork Ranches development northeast of South Fork (Figures 5.2 and 7.1). It was drilled to a depth of 890 feet, and perforated casing was installed from 850 to 890 feet. According to the well owner, the hole was dry to a depth of 880 feet. Drilling continued to 890 feet when suddenly the drill rig began to shake, and the drill pipe tried to rise up out of the hole. A large flow of ground water under high pressure was encountered at 890 feet deep, and the rig was unable to drill any deeper.

Based on geologic mapping by Lipman and Steven (1976), the well driller's geologic log, and visual observations of the geology while in the field, the Street well probably is completed in the vent facies of the Conejos Formation. The well is about one-half mile east of the easternmost fault associated with the Rio Grande Graben. The fault probably dips west at a high angle away from the well, and it is unlikely that the mapped fault trace was encountered in the well, but fractures or unmapped faults associated with the graben perhaps were. Based on very brief field reconnaissance, the well may be located at the intersection of two prominent fracture zones.

The reported static level was at 35 feet, and the reported production rate was 80+ gpm in 2003. Prior to sampling, the well was pumped for one hour and thirty minutes at about 10 gpm (Table 5.3). No reduction in flow was noted while the well was purged. Water temperature in the Street well started at 17.6 ^{o}C and stabilized at 19.8 ^{o}C after about thirty minutes of pumping. Conductivity was 362 µS, and pH was 9.07 when the well was sampled.   The conductivity stabilized about twenty minutes after pumping started, and pH was essentially constant as the well was purged.

TDS was 230 mg/L, similar to many of the much shallower wells that were sampled during the study (Table 5.8). Sodium, at a concentration of 56 mg/L, was moderately high, but it was lower than the sodium values in most sampled wells in the OWC area, and similar to the upper range of sodium concentrations in wells in the SFC area. The manganese concentration was 0.413 mg/L, which is slightly higher than the secondary drinking water standard, and the aluminum concentration (0.025 mg/L) also was slightly higher than the secondary drinking water standard. All other analyzed parameters were either not detected or were well below drinking water standards. Sulfate concentration (52 mg/L) was somewhat high, but well within the range of sulfate values in the water wells in the SFC and OWC areas.

7.4 Fietek Well

The Fietek well (RGC D3) also is in the Bear Creek filing of the South Fork Ranches development northeast of South Fork (Figures 5.2 and 7.1). This well is 1,400 feet deep, and is the deepest well sampled during the study. The well is located near the base of a hillslope, only about 200 feet from the Rio Grande and about 20 to 30 feet above it.

The geologic setting of the Fietek well is similar to the Street well. Geologic mapping, the geologic log by the driller, and field observations indicate that much of the drilled hole and probably also the main water-producing zone are within the vent facies of the Conejos Formation. The Fietek well also is located about one-half mile east of mapped faults associated with the Rio Grande Graben, and the well probably does not intersect the mapped faults. The well is located at an elevation of about 8,158 feet, approximately 440 feet lower in elevation than the 8,596 feet elevation of the Street well.

The exact depth at which the Fietek well produces water is uncertain. The well owner was not on-site when drilling occurred, and the driller did not report where ground water was encountered in the well. Perforated casing was installed from 100 feet to the bottom of the well at 1,400 feet, therefore, it is possible that some of the water produced from this well is from relatively shallow depths. The static level was reported at 110 feet when the well was drilled in 2006 and at 42 feet when the pump was installed in 2007. Three other deep dry holes (depths of 970, 950, and 1,150 feet) were drilled nearby on this property prior to the successful completion of the sampled well. This suggests the water produced from the sampled well probably comes from deep in the well.

According to the well construction and test report, the Fietek well produced only one quart of water per minute when tested for an 18 hour period. The pump installation and test report suggests a production rate of 2 gpm, but states that the well pumps dry in about 7 hours. The well pumps uphill to a storage tank located near the home, and the well system is designed to limit pumping to a maximum of 2 gpm, and to shut down if the pump runs dry.

The analyzed sample from this well was collected from a faucet after the water passed through the storage tank. At the owner's request, and to avoid draining the storage tank, only about 2 gpm were pumped from the storage tank for 5 minutes before the sample was collected (Table 5.3). Temperature (19.1 ^{o}C), conductivity (354 µS), and pH (8.57) in the Fietek well were stable during the very short purging time, which is to be expected, since the water came from the storage tank.

TDS of the water from the Fietek well is only 218 mg/L, similar to much shallower wells that were sampled during the project (Table 5.8). Sodium concentration was 67 mg/L, which is lower than the sodium values in wells in the OWC area and higher than the sodium concentrations in the SFC area wells, but still well below drinking water standards. Iron, with a concentration of 0.62 mg/L, was the only constituent that exceeded the secondary drinking water standard.   All other tested parameters in the Fietek well were below drinking water standards.

7.5 Person Well

The Person well (RGC D4) also is located in the Bear Creek filing of the South Fork Ranches development northeast of South Fork (Figures 5.2 and 7.1). It is at an elevation similar to the Street well, and also is believed to be drilled and completed in the vent facies of the Conejos Formation. This well also is east of the faults associated with the Rio Grande Graben, but is somewhat closer (~one-quarter mile) to the mapped trace of the fault that follows Bear Creek valley. It is unlikely that the well penetrated the mapped fault, since the fault probably dips west at a high angle.

The depth of the Person well is 1,170 feet. The driller reported water at 930 feet deep, and the well owner recalled that the well was dry to at least 700 feet deep. Perforated casing, however, was installed from 200 to 1,170 feet in the well. The static level was reported at 212 feet in the well construction and test report, and the production rate was reported at 3 gpm during a one hour test in 2001. A static level of 200 feet was reported on the pump installation and test report, and the production rate apparently was 10 gpm initially, but "settled at about 6 gpm". The length of that test was not reported.

Prior to sample collection, the well was purged for one hour and 20 minutes (Table 5.3). Initially the production rate was about 12 gpm, and it slowed to about 9 gpm at the end of the purge. Water temperature in the Person well was 21.4 ^{o}C at the beginning of the purge, but rapidly cooled to 17.2 ^{o}C. Conductivity was stable throughout the test at 342 µS, as was pH, which was 8.92 at the end of the purge; it fluctuated only about 0.1 pH unit from beginning to end of the well purge.

Water chemistry of the Person well was very similar to the Fietek well (Table 5.8). TDS was 225 mg/L; iron concentration was 0.60 mg/L, slightly above the secondary drinking water standard; and the sodium concentration was 69 mg/L. Other analyzed parameters were either below the detection limit or below the drinking water standard.

7.6 Beaver Mountain Estates Well BME2

Well BME2 is one of the public water-supply wells that provide water to the homes in Beaver Mountain Estates. It is located in the foothills south of South Fork, near the western edge of the study area (Figures 5.2 and 7.1). The well is situated within the interior of the Rio Grande Graben, about 400 feet east of a mapped fault with down-to-west movement. The fault forms the eastern side of the keystone graben in the central part of the Rio Grande Graben (Lipman and Steven, 1976).

Based on geologic mapping by Lipman and Steven (1976), the driller's geologic log, and field observations, well BME2 started in the Masonic Park Tuff, but should have encountered the vent facies of the Conejos Formation at a relatively shallow depth. Geologic maps suggest that only about 100 feet of Masonic Park Tuff should be present overlying the vent facies of the Conejos Formation at the well. The driller's geologic log describes a change from brown volcanic rock to gray volcanic rock at a depth of 76 feet. This may mark the contact between the Masonic Park Tuff and Conejos. Well BME2 probably is completed in the vent facies of the Conejos Formation.

Well BME2 is 1,260 feet deep. In the well construction and test report filed with the CDWR, water was encountered at 330 and 1,130 feet deep. Perforated casing was set from 250 to 1,260 feet below ground level. The static water level was at 180 feet, and the production rate was 20 gpm during a 1 hour test in 2002. The well reportedly produced 30 gpm during a 3 hour test when the pump was installed.

Field parameters were measured at BME2 on October 18, 2012 (Table 5.3). Dale Weaver, water operator for the Beaver Mountain Estates public water-supply system, and Robert Tonetti, president of their property owner's association, facilitated this work. Prior to testing, the well was pumped for 15 minutes, and about 600 gallons were delivered into the community's storage tanks, according to the well's flow meter. The tested sample was collected in the chlorination vault from a valve located upstream of the sand filter and chlorination unit. Temperature was 14.0 ^{o}C, conductivity was 307 µS, and pH was 8.84.

The chemical analysis reported in Table 5.8 was performed on a water sample collected on September 13, 2005 by representatives of the subdivision. The sampling protocol and exact sampling location are not known. TDS of the sample was 200 mg/L, very similar to other sampled wells, including ones that are much shallower. Sodium concentration was 54 mg/L, which is lower than the concentration in sampled wells at OWC area, and higher than all but one of the sampled wells in the SFC area. Most other inorganic parameters were below the detection limits, as were the four organic BTEX parameters.

7.7 Beaver Mountain Estates Well BME3

Well BME3 is a well that was intended for use in the Beaver Mountain Estates public water-supply system, but never put into service because the fluoride concentrations exceeded drinking water standards. The well is located in the foothills south of South Fork, near the western edge of the study area (Figures 5.2 and 7.1). Well BME3 is located about one-half mile north of and is in a similar geologic setting to well BME2. BME3 also is situated within the interior of the Rio Grande Graben. BME3 is located about 1,000 feet east of the trace of a mapped fault with down-to-west movement (Lipman and Steven 1976). The fault forms the eastern side of the keystone graben in the central part of the Rio Grande Graben.

Well BME3 was drilled to a depth of 1,200 feet in 2004. When visited in September, 2004, the well was 850 feet deep, and the driller stated that small flows of water were encountered at 300 and 790 feet; their combined flows were estimated at about 2 or 3 gpm. A new drill rig and drilling company took over drilling operations when the well was at 850 feet deep and extended the well to 1,200 feet. The well construction and test report submitted to the CDWR by the new driller reported that water was encountered at 1,100 feet and that the static level was at 50 feet. The casing record in the well construction and test report states that perforated casing was installed in several intervals in the well: 180 to 200 feet, 380 to 400 feet, 580 to 600 feet, 900 to 1,080 feet, and 1,080 to 1,200 feet below ground level. The reported production rate was 20 gpm, based on two pump tests. One pump test lasted one hour, and a second test on a different day pumped for two hours. This well apparently produces ground water from several depths, but the majority of the water probably is from the deeper part of the well.

Field parameters for well BME3 were measured on October 18, 2012 (Table 5.3). Dale Weaver, operator of the water system, turned on the pump to facilitate water testing. The well was pumped for one hour at a rate of 32 gpm, based on the flow meter installed on the well. The water was cloudy throughout the test. Mr. Weaver explained that during a 26-hour test the flow diminished to 23 gpm.

Water temperature initially was 11.1 ^{o}C during the one-hour purge conducted prior to measuring field parameters. The temperature abruptly rose after 10 minutes of pumping, and by the end of the one-hour test it was 25.9 ^{o}C. Mr. Weaver reported that the temperature was about 28 ^{o}C at the end of a previously conducted 26-hour test. Conductivity dropped from 709 to 646 µS during the one-hour test, and pH changed from 9.59 to 9.38 after one hour of pumping. The rates of change for temperature, conductivity, and pH slowed during the test but still had not yet stabilized.

The chemical analysis for well BME3 that is reported in Table 5.8 was for a sample collected by representatives of Beaver Mountain Estates on May 24, 2005. TDS was 430 mg/L, which is higher than most other wells sampled during the project. Sodium concentration was 160 mg/L, second highest of all analyzed wells. Fluoride concentration was 9.3 mg/L, over two times higher than the primary drinking water standard. The well water also contained 0.71 µg/L of toluene. Although BME3 was the only well or spring sampled during our study that contained any of the organic BTEX parameters, it was at a very low concentration, far below the maximum contaminant level of 1,000 µg/L. Mr. Weaver and Mr. Tonetti suspected the slight toluene contamination might have resulted from the drilling of the well. Most all other tested parameters were below detection limits.

7.8 Other Deep Wells Potentially Suitable for Study

Several other deep wells in the study area should be considered for evaluation and sampling in future studies. For example, oil was present in drill cuttings from the 1,100 feet deep Falk well in Pinos Creek (permit # 218616) (Clinton Self, well driller, 2012, personal communication). A photograph of oil-saturated cuttings from the Falk well is in Figure 7.2. Note the oil-stained sample bag in which the cuttings were stored. Water in this well could be tested using the COGA baseline analysis to assess the affect of naturally occurring petroleum in the Conejos aquifer on well water chemistry. This well does not have a pump installed in it (Irene Falk, 2012, personal communication). Mr. Self also mentioned that oil was observed in drill cuttings from a well his company drilled in Alpine Village. Further study of this well also is warranted. The natural occurrence of petroleum in drill cuttings from water wells, along with the oil seeps in volcanic rocks at Hope Creek and oil in core drilled for mineral exploration at Summer Coon Volcano and at Summitville indicates natural petroleum has migrated upwards from source rocks and reservoirs and may be encountered in water wells completed in the Conejos aquifer.

According to the CDWR records, other deep wells that may offer potential to better understand water quality at depth include the following:

-permit #227819: 1,130 feet deep; water reported at 1,098 feet; perforated casing at 1,070 to 1,130 feet; 50 gpm; static level 256 feet; no pump
-permit #54967-F: 1,255 feet deep; water reported at 1,210 feet; perforated casing at 205 to 1,255 feet; 100 gpm; flowing well
-permit #65586-F: 1,100 feet deep; water reported at 700 feet; perforated casing at 300 to 1,100 feet; 1 gpm; static level 450 feet
-permit #204513: 844 feet deep; perforated casing at 544 to 844 feet; static level 105 feet
-permit #236822: 800 feet deep; perforated casing at 740 to 800 feet
-permit #213762: 806 feet deep; dry to 540 feet; water reported at 540 feet deep (1 gpm), 700 feet (7 gpm), and 800 feet (11 gpm); perforated casing at 646 to 806 feet; static level 484 feet
-permit #57654-F: 800 feet deep; perforated casing at 200 to 800 feet; 4 gpm; static level 190 feet
-permit #239585: 995 feet deep; water reported at 120 feet; perforated casing at 120 to 995 feet; 1 quart per minute; static level 120 feet
-permit #63831-F: 810 feet deep; water reported at 225 feet; perforated casing at 210 to 810 feet; ½ gpm; static level 45 feet

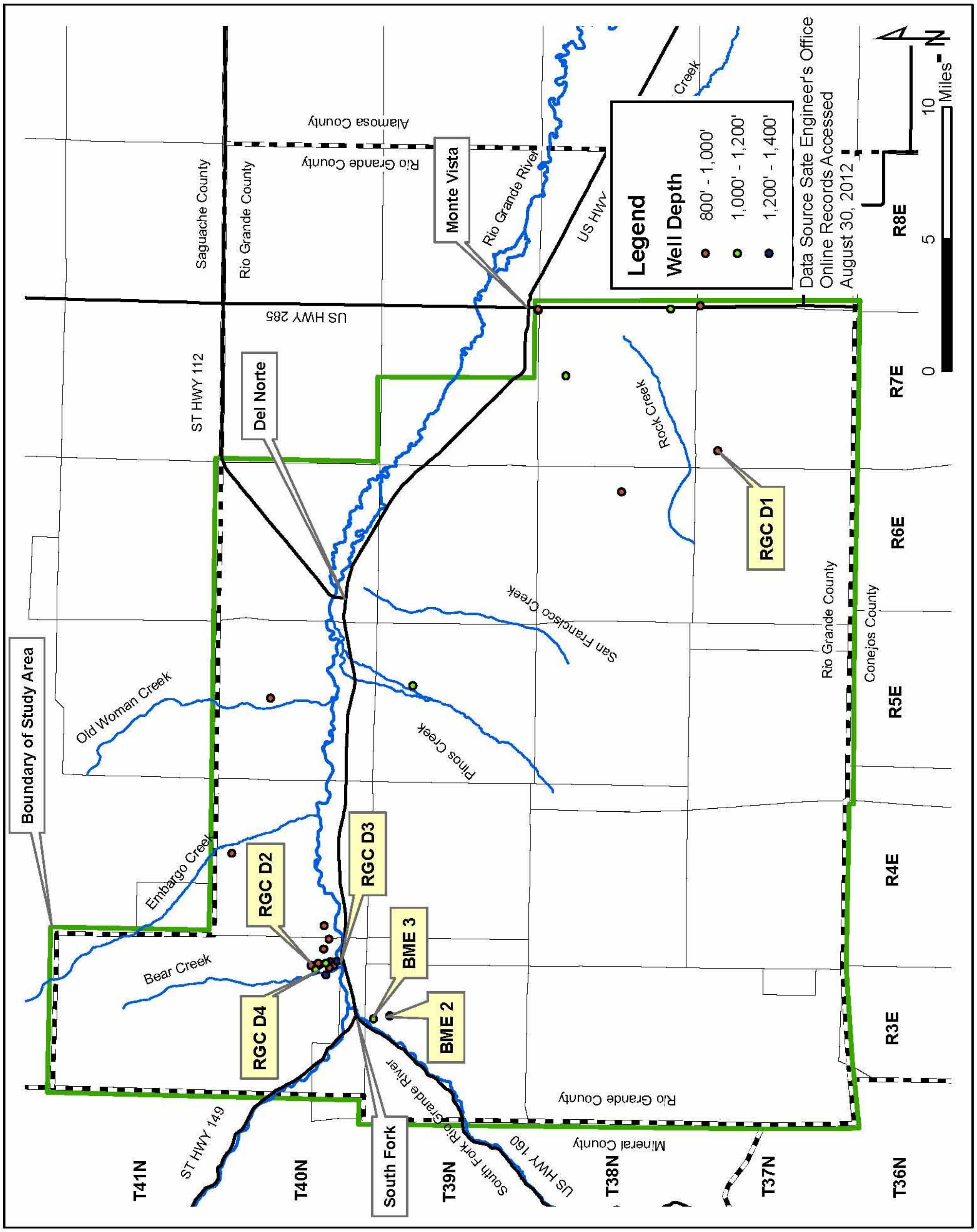

Figure 7.1. Location of deep wells in the study area, color-coded by depth**.** Wells with water-quality analyses are labeled.

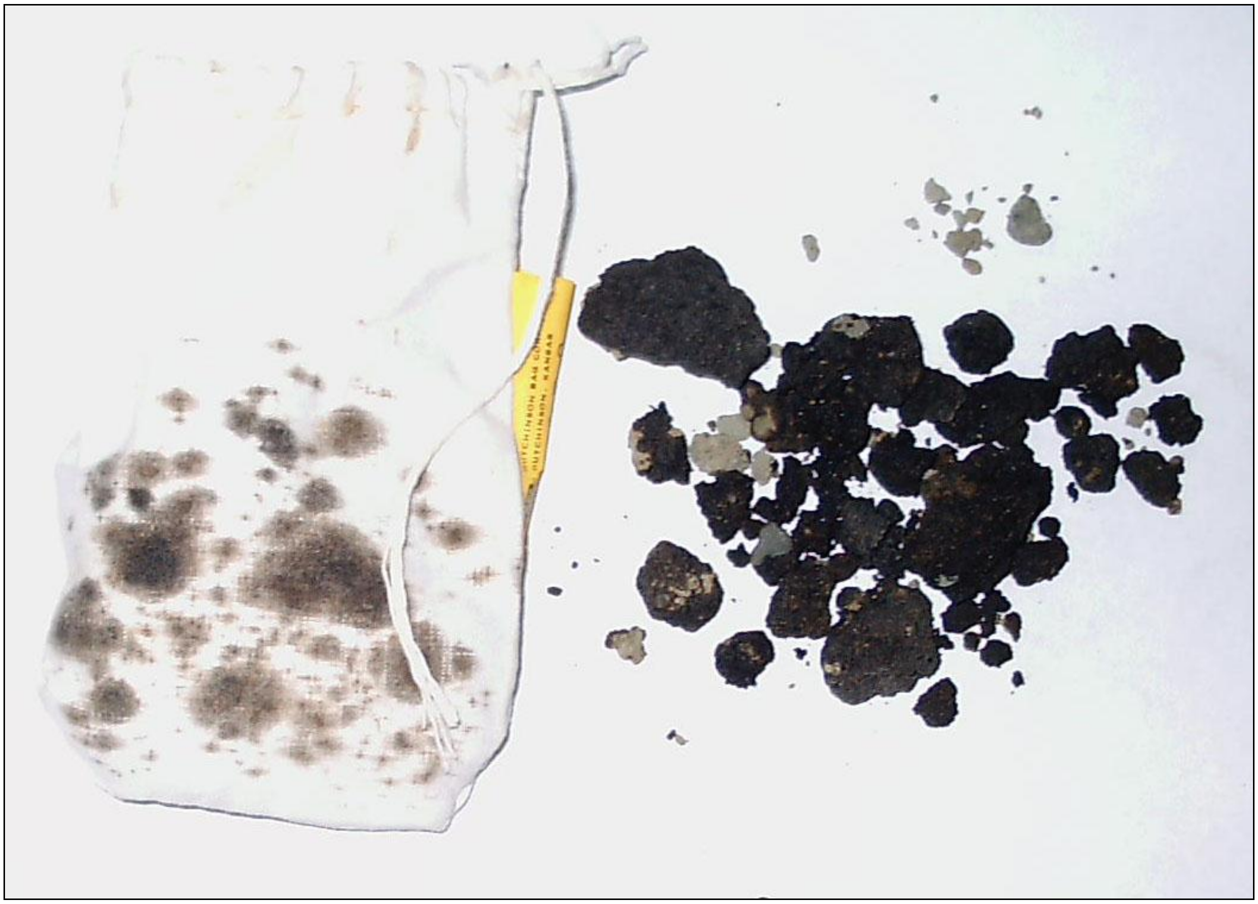

Figure 7.2. Photograph of oil-saturated cuttings from Falk water well. Note oil staining of cloth sample bag.

8.0 DATA INTERPRETATIONS

8.1 Geologic Interpretations from Oil and Geothermal Wells

Geologic information from the oil and geothermal wells drilled in the area are used to construct what geologists call structure contour maps and isopach maps. Structure contour maps are similar to topographic contour maps. On "topo" maps the lines on them represent equal elevations of the ground surface. On a structure contour map the lines represent equal elevations of the top or bottom of a given formation or rock layer. An isopach map shows the thickness of a formation or rock unit, and the contour lines on it represent equal thickness of the formation.

Relatively few oil wells have been drilled in the area, and this investigation has not had access to any seismic reflection data or interpretations, which can help to interpret subsurface geology. As a result, isopach and structure contour maps derived from the limited well data should be considered very approximate. New subsurface information will almost certainly result in modifications to the structure contour and thickness maps in this report. However, having some data is better than no data, so the maps do provide useful information and improve the understanding of the hydrogeology and also some aspects related to the drilling of future oil wells.

Figure 8.1 is a structure contour map on the base of the Conejos Formation. Another way to think of this map is as a topographic map of the landscape as it existed before the San Juan Volcanic Field blanketed it with volcanic rocks. In general, the base of the Conejos decreases in elevation from west to east across the study area. This same regional east dip of the volcanic rocks also is apparent in the regional cross section (Figure 3.4). Near Monte Vista the base of the Conejos is estimated to be a few hundred feet above sea level. At South Fork it is an estimated 4,700 feet above sea level. In the northern and southern parts of the area the contour lines are oriented generally north-south, but between Del Norte and South Fork the contour lines swing westward. This creates an anomalous area where the base of the Conejos is lower than or depressed relative to adjoining areas to the north and south.

The modern configuration of the base of the Conejos results from a combination of three main factors: (1) the paleo-topography that existed prior to when the Conejos was deposited; (2) eastward tilting of the region as the Rio Grande Rift developed; and (3) displacement of the base of the Conejos by faults that were active after or during deposition of the Conejos. If there was a topographic low in the paleo-topography, it would have been a paleovalley, and it probably had an east flowing river or stream in it. If so, there potentially could be river gravel or conglomerate preserved on the floor of the paleovalley. Those deposits, although deep in the subsurface, might contain ground water.

This topographic depression also could be a result of fault movement after or during the eruption of Conejos volcanoes. Since only extensional forces are thought to have affected the Earth's crust since middle Tertiary time, the depression, if a result of fault movements, might be a graben. If the Conejos rocks are faulted in or next to the topographic depression they might be more fractured and have higher permeability and transmissivity. The theory that faulting might be responsible for the topographic depression may be less probable than the paleovalley theory. The Rio Grande Graben, which is exposed at the Earth's surface and has been active since middle Tertiary time, is oriented north-south, whereas the depression trends east-west. In either case, the topographic depression in the base of the Conejos may have important hydrogeologic properties.

In areas where the Conejos Formation crops out or is overlain only by surficial deposits, Figure 8.1 can be used to estimate the thickness of the Conejos Formation or the depth to the base of the formation at a given location. For example, at Del Norte the base of the Conejos is at an estimated elevation of 2,200 feet, and the elevation of the ground surface is at about 7,880 feet. The thickness of the Conejos Formation at Del Norte is the difference between those elevations; approximately 5,680 feet. A well drilled at Del Norte would need to be that deep in order to reach the base of the Conejos. At South Fork the base of the Conejos is at an estimated elevation of about 4,700 feet, and the ground elevation is about 8,200 feet, resulting in a thickness of about 3,500 feet.

Figure 8.2 is a structure contour map showing the approximate elevation of the top of the Dakota Formation, which was the primary target of most oil wells drilled in the area. The deepest part of the San Juan Sag is between Del Norte and South Fork, and south of highway 160. In contrast to the map on the base of the Conejos, which has a regional slope to the east, the map for the Dakota looks more like a "bull's eye" or a bowl, with the center of the bowl thousands of feet lower than the rim. This configuration reflects the influence of the San Juan Sag on the Cretaceous rocks, which were folded into an elongated bowl-like configuration by the sag. Since the middle Tertiary volcanic rocks post-date the formation of the San Juan Sag, which formed during the Laramide Orogeny (see section 3.0), they were not folded by the sag, but they were tilted eastward by rift-related deformation during the late Tertiary and Quaternary.

Another major difference between the structure map for the Conejos and the one for the Dakota is the lack of contour lines east of Del Norte. As described in section 3.0, the Cimarron Fault bounds the east side of the San Juan Sag, and the Dakota Formation was removed by erosion east of the fault. Since the Dakota does not exist east of the fault, the top of the formation can not be contoured.

The top of the Dakota Formation is 3,244 feet *below* sea level at the Meridian Federal 23-17 well. On the flanks of the sag, in the south-central and northwest parts of the County, the top of the Dakota Formation is 3,000 to 4,000 feet *above* sea level. Thus, the structural relief of the sag is a minimum of 6,000 to 7,000 feet, making it a major Laramide structural feature.

The contour lines in Figure 8.2 are drawn assuming the Meridian Federal 23-17 well was at or near the deepest part of the sag, which may or may not be true. If this well was not drilled in the deepest part of the sag, then the configuration of the contour lines could be somewhat different, but the general bowl shape still would exist.

Since the Dakota is and perhaps will continue to be the primary target of oil wells, the approximate depth of future oil wells can be estimated from Figure 8.2. For example, if an oil well was proposed near South Fork, it would need to be drilled to an estimated depth of about 7,200 feet to reach just the top of the Dakota (ground elevation at South Fork [8,200 feet] minus the elevation of the top of the Dakota [about 1,000 feet]). Note that in the northwest and southwest parts of the County the Dakota apparently does not exist because it was replaced by middle Tertiary intrusions associated with the volcanic calderas.

Figure 8.3 is a structure contour map drawn on the top of the Precambrian basement rocks. The contour lines drawn on this map also reflect the influence of the San Juan Sag, and the Precambrian map has the same 'bull's eye" or bowl shape as the Dakota map. The Precambrian map should be considered more approximate than the Dakota map because fewer wells were drilled to the Precambrian basement and there are fewer data points available to prepare the map.

The top of the Precambrian surface may be as much as 4,000 feet *below* sea level in the deepest part of the San Juan Sag. This depth is an estimate, because the Meridian Federal 23-17 well was not deep enough to reach the Precambrian basement. The top of the Precambrian is estimated to be about 1,000 to 2,000 feet *above* sea level on the flanks of the sag. Precambrian basement rocks are present east of the Cimarron Fault but are not mapped due to there being few wells that extend to the Precambrian in that area, making any effort to contour the surface speculative.

The approximate maximum depth of a future oil test hole at any given location can be estimated using Figure 8.3 because petroleum companies probably will terminate drilling when the basement rocks are reached. For example, at South Fork the ground elevation is at about 8,200 feet above sea level and the top of the basement rocks are estimated to be about 300 feet below sea level. A hole drilled at South Fork would need to be about 8,500 feet deep to reach the top of the Precambrian basement rocks.

Figure 8.4 is an isopach map showing the approximate thickness of the combined Lewis Shale and Mancos Shale. In the western part of the study area the Mesaverde Group lies between the Lewis and the Mancos, but the Mesaverde Group thins and eventually pinches completely out within the middle of the study area. From there eastward to the Cimarron Fault, the Lewis rests directly on the Mancos. As with the Dakota Formation, the Lewis and Mancos are not present east of the Cimarron Fault where they were removed by erosion.

The thickness of the Lewis and Mancos may be important in the future, if petroleum companies decide to produce shale oil or shale gas from these rocks. As much as 3,800 feet of organic-rich shale is preserved in the vicinity of the Meridian Federal 23-17 well. The shale sequence may exceed 3,000 feet in thickness in an elongate area in the central part of the sag. If in the future wells are drilled to produce shale oil or shale gas, it is possible that they may be most interested in areas where the shale is thickest.

On the flanks of the sag pre-middle Tertiary erosion has removed part or all of the shale sequence; only 300 feet of Lewis and Mancos was present in the Waggoner-Baldridge Horseshoe Mountain 1-14 well between San Francisco Creek and Pinos Creek. Due to the sparse drill hole control on the flanks of the sag, the area where the shale is thinned by erosion is shown only as having a thickness of less than 2,000 feet and no contour lines are drawn.

8.2 Interpretation of Water Quality

Detailed analysis of the water chemistry is beyond the scope of this project. Only general observations on the water chemistry are offered in this report. The water types can be determined for the samples collected from wells and springs in proximity to the two proposed wells that were tested for parameters included in the COGA baseline analysis. They are described in section 8.2.1. Samples submitted for drinking water analysis and the analyses provided by Beaver Mountain Estates do not include all the parameters needed to determine the water type.

TDS is reported for all samples included in this study. Figure 8.5 plots TDS versus well depth. As might be expected, the TDS of the springs is low relative to most sampled wells. The spring with the highest TDS discharges from bedrock, and the other springs issue from surficial deposits of unknown thickness that overlie the Conejos volcaniclastic facies. The highest TDS (670 mg/L) was in a relatively shallow well (230 feet) in the western part of the SFC area. A nearby relatively shallow well (203 feet) had the third highest TDS (450 mg/L). This indicates the TDS in the western part of the SFC area is higher at greater distance west of San Francisco Creek. Figure 6.11 illustrates this trend, which is suggestive of mixing of deeper lower-quality ground water with shallow better-quality water in proximity to San Francisco Creek. The well with second highest TDS (500 mg/L) was from a relatively shallow well (285 feet) in the OWC area. This well (RGC8) is located in the northeast part of the OWC area, about one mile from the next closest sampled water well.

Surprisingly, the lowest TDS value of all sampled wells (117 mg/L) was found in one of the deeper wells (900 feet). And it is located at the eastern edge of the foothills near where the volcanic rocks dip below the floor of San Luis Valley. Initially, it was suspected that the water chemistry of this well water might reflect the quality of ground water after it had travelled considerable distance in the Conejos, but apparently the ground water in this well is recharged from a more proximal source, perhaps Rock Creek.

All but one of the deepest sampled wells had relatively low TDS values when compared to the shallower wells (Figure 8.5). The TDS of these deep wells is similar to the TDS of the springs. The deep well with the highest TDS had a TDS concentration that was below the recommended TDS for drinking water (500 mg/L), and it was lower than the TDS of three of the sampled shallow wells. A trend line drawn on the TDS versus depth plot suggests that TDS decreases with depth, which is an unlikely scenario. A more probable explanation of the low TDS values in the deep wells is that the quality of water in the Conejos aquifer is variable and heterogeneous.

8.2.1 Interpretation of COGA Baseline Analyses

Most of the sampled waters in the OWC area are sodium bicarbonate or sodium sulfate types of water. In the SFC area most of the sampled waters are calcium-sodium bicarbonate or calcium bicarbonate types of water. A few wells in the OWC area are sodium sulfate or calcium-sodium sulfate-bicarbonate waters.

Nearly all of the sampled wells and springs were alkali, with field pH ranging up to 9.9. All tested well water in the OWC was slightly more alkali than the wells and springs in SFC, where one sample from a well (RGC34) was slightly acidic. This well also had the highest TDS of all samples, and its iron and sulfate concentrations were relatively high. This may reflect the presence of pyrite (an iron sulfide mineral) in the Conejos, as lithologic logs for some oil wells have reported pyrite in drill cuttings from the Conejos.

Well water in the OWC area contained higher concentrations of sodium and slightly higher concentrations of chloride, carbonate, and sulfate than the wells and springs in the SFC area. The samples from wells and springs in the SFC area were generally higher in calcium, magnesium, potassium, and bicarbonate than the wells in the OWC area.

The differences in water chemistry between the sampled waters in the OWC and SFC areas may be related to the rocks in which the wells in OWC and SFC areas are completed, or perhaps to the slope aspect, the presence of a perennial stream in SFC, and/or the proximity of the areas to higher elevation mountains that receive greater precipitation. All sampled water wells in the OWC area probably produce water from lava flows in the Conejos vent facies, whereas the sampled water wells in the SFC area produce water from the Conejos volcaniclastic facies, which is composed mostly of sedimentary rocks eroded from the volcanoes

San Francisco Creek is a perennial stream, whereas Old Woman Creek seldom has surface flow. San Francisco Creek flows northward and has a north-facing aspect. Old Woman Creek has a south-facing aspect. The headwaters of San Francisco Creek attain elevations as much as 13,203 feet at Bennett Peak, it was glaciated during past Pleistocene ice ages, and it contains alpine environments. In contrast, the highest elevations in the headwaters of Old Woman Creek reach elevations of only about 11,000 feet, the headwaters were never glaciated, and it lacks any alpine environments.

None of the sampled wells in the OWC and SFC areas contained detectable BTEX, and only one sample from a spring in SFC had any detectable hydrocarbon gases. Methane was detected at concentrations slightly above the Practical Quantitative Limit in sample RGC32. This spring supports a wetland, and the methane is suspected to be biogenic gas generated from decomposition of organic material in the wetland, not from thermogenic gas from petroleum.

8.2.2. Interpretation of Deep Well Analyses

As noted above, one of the surprising results of this study is that water quality in the deeper wells is generally better than in the shallower wells. Potable water was found in all six of the deep wells for which there is data, including the 1,400-feet-deep RGC D3 well. Most parameters for which there are drinking water standards (Table 5.10) were either not detected in the deep wells, or the concentrations were below the drinking water standards.

Only one of the deep wells contained a constituent that exceeded primary drinking water standards. Well BME 3 contained 9.3 mg/L of fluoride, over two times higher than the primary drinking water standard. This 1,200-feet-deep well also was the only well included in the study that has warm water (28 ^{o}C/ 83 ^{o}F at the end of the 26-hour test by the water system operator). Rather than install a treatment system, a replacement well was drilled. Although only 400 feet deep, the replacement well had a sufficient flow of water for the public water-supply system, and preliminary tests indicate the fluoride concentration is well below the drinking water standard (Robert Tonetti, 2012, personal communication).

Some of the sampled deep wells did slightly exceed some secondary drinking water standards. The Sutphin and Street wells slightly exceeded the secondary drinking water standards for aluminum and manganese. Iron concentrations in the Fietek and Person wells slightly exceeded the secondary drinking water standard for that parameter.

8.3 Interpretation of Water Well Records

All of the available driller's reports or pump installer's reports were reviewed for water wells located within 1.5 miles of the proposed oil and gas test wells in the SFC and OWC areas. Due to the somewhat subjective nature of driller's descriptions of the rock types drilled, and the typical short test duration and lack of measurement controls on testing, much of the data from this source must be used judiciously. Taken as a whole, however, this source of data can be used, with judgment, to help characterize the general nature of the ground water system in a given area. We have used this source of data to form a broad concept of the aquifer characteristics of the SFC and OWC areas.

8.3.1 Geologic Rock Types

Apart from the near-surface unconsolidated materials (soils and alluvium) encountered in some wells, virtually the entire set of available water well logs describe lithologies that are characteristic of the Conejos Formation. Some wells definitively describe volcanic rocks such as andesite (a common rock type in the vent facies of the Conejos Formation); while others describe sandstone and claystone – typically components of the volcaniclastic facies of the Conejos Formation. There was relatively little correlation in strata from well to well, although some rock types did appear to correspond for at least short distances. This is evidence of the heterogeneity of the Conejos Formation in the study area. Overall, the water well records for both the SFC and OWC areas within 1.5 miles of the proposed oil and gas test wells reflect a highly heterogeneous mixture of volcanic and volcaniclastic rocks, varying from quite permeable (e.g. fractured andesite) to relatively impermeable (e.g. claystone).

8.3.2 Estimation of Transmissivity from Specific Capacity

We have used the database of water well records to estimate the range of transmissivity that is found in water wells in the SFC and OWC areas. Transmissivity (T) is a term used to describe the ease or difficulty with which water can flow through the entire saturated thickness of an aquifer. T is the product of the hydraulic conductivity (K) of a material multiplied by the saturated thickness (m) of the aquifer. Transmissivity (T) can be estimated from specific capacity (Sc). Specific capacity is defined as the pumping rate in gallons per minute from a pumping test divided by the feet of drawdown at that pumping rate. This technique for estimation of transmissivity is used when well-controlled pumping tests are not available for detailed analysis. The T from Sc analysis is general, and should be viewed as an indicator of a general range of T until better test data becomes available.

Driller's or pump installer's completion reports for wells located within the 1.5 miles of the proposed oil wells were obtained from the State Engineer's well database. The well records selected for specific capacity analysis reported, at a minimum, total depth, pumping rate, static water level, pumping water level, and borehole diameter. All of the wells were drilled using the air rotary method and thus the reported testing method was by air lift. Due to this method the pumping water level was at the base of the air lift pipe (probably the drill pipe). A few wells had short duration (less than 3 hours) pumping tests reported by the pump installer.

Appendix C and Appendix D list the wells used and the calculated estimates of T and average hydraulic conductivity (K) values for the Conejos Formation aquifer for the area within the 1.5 miles of the proposed oil wells, respectively. The calculation of the estimated transmissivity involved the following steps, using a standard and well-accepted methodology (Driscoll, 1986):

1. Calculate an initial estimate of T = Sc x 2000 (for a bedrock aquifer).
2. Input this initial estimated T value into the following formula: (0.3 x T x t)/ (r^2 x Sy) where t is the length of the test period in days, r is the radius of the borehole in feet and Sy is the estimated specific yield of the aquifer material. If the duration of the pumping test was not specified, a value of 2 hours (0.08333 days) was estimated, as this duration is commonly seen in older driller's records in Colorado. The specific yield for this alluvial aquifer was estimated to be 0.20 based on the materials reported on the driller's logs.
3. Calculate the base 10 log (Log10) of the value calculated in Step 2 and multiply by 264, a unit-conversion coefficient.
4. Recalculate the estimated value of T and round the result to the nearest 100 by multiplying the Sc times the value calculated in Step 3.

The average T and K values for the volcanic aquifer within 1.5 miles of each of the two proposed oil wells are shown in detail in Appendices C and D.

8.3.2.1 Transmissivity in San Francisco Creek Area

An analysis was made of the nine wells in the SFC area that had both an air lift test and a pump test to see if there was any significant difference between the two methods. For this set of wells, the average specific capacity for the air tests was 0.18 gallons/foot drawdown and for the pump test it was 0.37 gallons/foot drawdown. Also for this set of wells, the average T from the air tests was 136 gallons per day per foot (gpd/ft) and from the pump tests was 339 gpd/ft. In calculating the hydraulic conductivity K it was assumed that the saturated thickness of the aquifer was the interval from the reported static water level to total depth of the well. The average K value for the air tests was 0.18 ft/day and for the pump tests was 0.47 ft/day. The averages for all of the reported tests were: Sc = 0.2 gallons/foot drawdown, T = 180.7 gpd/ft, and K = 0.3 ft/day.

A plot of well total depth verses depth to static water level (Figure 8.6) shows that on average the deeper the well the deeper the static water level, which indicates that this area is within the recharge area of the Conejos Formation. A plot of the depth to the midpoint of the saturated interval versus K shows that K is relatively constant with depth.

8.3.2.2 Transmissivity in Old Woman Creek Area

An analysis was made of the eleven wells in the OWC area that had both an air lift test and a pump test to see if there was any significant difference between the two methods. For this set of wells, the average specific capacity for the air tests was 0.08 gallons/foot drawdown and for the pump test it was 0.21 gallons/foot drawdown. Also for this set of wells, the average T from the air tests was 50.5 gpd/ft and from the pump tests was 165 gpd/ft. In calculating the hydraulic conductivity K it was assumed that the saturated thickness of the aquifer was the interval from the reported static water level to total depth of the well. The average K value for the air tests was 0.03 ft/day and for the pump tests was 0.11 ft/day. The averages for all of the reported tests were: Sc = 0.08 gallons/foot drawdown, T = 54.1 gpd/ft, and K = 0.07 ft/day.

A plot of well total depth versus depth to static water level (Figure 8.7) shows that with the exception of two wells there is no discernible pattern of depth of well versus the static water level. A plot of the depth to the midpoint of the saturated interval versus K shows that K is relatively constant with depth.

8.3.3 Summary of Interpretation of Water Well Records

Driller's reports and pump installer's reports constitutes a noisy data set. However, analysis of these data do give a general concept of the hydrogeologic characteristics in the San Francisco Creek and Old Woman Creek areas in terms of changes in water levels with depth, pumping rate, and hydraulic conductivity. This section summarizes the results of the analysis of water well records.

Figures 8.6 and 8.7 show the trends of piezometric head (reported static water level) graphed against reported total well depth (TD), for all water wells within 1.5 miles of the proposed oil wells in the SFC and OWC watersheds. As is not surprising, both the SFC and OWC areas show increasing water levels with depth, indicating that ground water generally is moving generally downward, so that both areas are recharge areas - an unsurprising result, as we know the upper reaches of the subdrainages in the study area do provide recharge to the Conejos aquifer. However, the trends in the SFC area are more consistent than the water level trends in the OWC area. In both areas the data are highly scattered, and consistency is only a relative term. In the upper ~450 to 500', there may be a relatively steady trend of downward movement of ground water from surface to a deeper aquifer horizon that has not been reached in this set of wells.

In the Old Woman Creek area, if we take out the two anomalous data points at about 300' and 500' TD, there is very little trend of increasing water level depth with well depth. This may be indicative of a very weak downward water table gradient, and may also be indicative of more lateral movement than downward movement, coupled with anisotropy in the formation. Overall, we hypothesize that this data set indicates a strongly anisotropic aquifer, with the possibility of relatively permeable fractures.

Trends of reported pumping rate plotted against TD shows different trends in SFC and OWC, as shown in Figures 8.8 and 8.9. These graphs show weak trends at best, and may not indicate any trend at all of production rate as a function of well depth. In the SFC area, we do see a weak indication of a slight decrease in pumping rate (Q) with increase in well depth (TD). In the OWC area, we see little if any trend. Bear in mind that these two graphs do not discriminate by screened interval in the wells represented, so these basic plots of Q versus well TD may mean there is a general, even if weak, trend of decreasing K with depth, with the exception of the anomalous data points that may indicate fracture permeability. If most wells are slotted or screened in the majority of their drilled and cased depth, the drillers, in general, have reported little if any additional production below the first 100 to 200 feet.

Based on the iterative method to estimate K based on Sc as described above, the results of the water well records are somewhat more definitive (Figures 8.10 and 8.11). Note that these graphs separate whether the well was pumped or was airlifted. Estimated K is plotted against the estimated median depth of the aquifer producing zone, which in this case is estimated, approximately, as the median depth between reported static water level and TD.

Figures 8.10 and 8.11 show different results for the SFC area as compared to the OWC area. In the SFC area, there is a slight, although perhaps not significant, trend of increasing K as a function of depth. This visual trend may not be significant, given the very large scatter in the data. This is in contrast to the OWC area, where there is a somewhat clearer trend of decrease in K with increasing depth. In addition, there is approximately a factor of 10 lower K, as a median value, in the OWC area as compared to the SFC area.

Overall, it appears there is a less permeable and less "active" ground water system in the OWC area than exists in the SFC area within 1.5 miles of the proposed oil test wells, to a depth of approximately 500 feet. We hypothesize that this may be related more strongly to the aspect (i.e. dominant compass direction) of these drainages, with significantly more snowpack and greater recharge in SFC than in OWC, than it is to any geologic differences in the Conejos Formation. The aspect (direction) is illustrated by the fact that San Francisco Creek, open to the north with a higher average snowpack, usually has a base flow near its lower end on the order of 1 cubic feet per second (cfs) and Old Woman Creek rarely flows in its upper reaches except in occasional thunderstorm events.

In summary, the dominant features of both the OWC area and the SFC area within 1.5 miles of the proposed oil wells are:

- A general trend of increasing water level with depth; these are both recharge areas, and water is moving downward from the surface to over 500 feet deep, and possibly over 1,000 feet deep.
- The Conejos Formation rocks that compose the aquifer in both areas are highly heterogeneous, and exhibit characteristics that vary widely in terms of hydraulic conductivity. This probably reflects the highly heterogeneous nature of the formation.
- The general range of hydraulic conductivity values from this analysis is in general agreement with the ranges of K for the Conejos Formation estimated by Huntley (1979) and Caine and Wilson (2011).

8.4 Interpretation of Geophysical Logs and Drill Stem Tests from Oil Wells

Approximately two dozen oil and gas exploration holes have been drilled in or near the study area. All of these were geophysically logged, using varying logging tools and techniques depending on when the well was drilled, and the objectives of the operator. Typically geophysical logging of oil and gas (and also deep, confined water wells) is done to ascertain formation contacts, porosity, presence of hydrocarbons, water saturation, and other physical characteristics.

8.4.1 Petrophysics Analysis

For this study, a specialist in petrophysical log analysis was retained as a subconsultant to perform an analysis of formation water resistivities over a range of depths, for as many oil and gas exploration wells as could be performed, and that were found to be suitable. The firm of Digital Formation of Denver, Colorado has performed an analysis of eight wells. The eight wells analyzed were:

AMF 1
Beaver Mountain #1
Horseshoe Mountain 1-14
Jynnifer 1
Mosley 1-10
Needham-Medford #1
San Francisco Creek Ranch #1
South Fork Federal no. 23-17

This set of eight wells were selected because they had a good log suite available for analysis; they were in areas of interest in the study area, and a few had logs all the way up to ground surface. The purpose of the petrophysical log analysis was to provide estimates of the formation water resistivity (which can be used to estimate ground water salinity) from shallower (Conejos Formation) to deeper (early Tertiary and Cretaceous formations targeted as petroleum reservoir rocks).

Digital Formation's report on the log analysis is included in this report as Appendix E. The results of the petrophysical analysis of the logs can be summarized as follows:

- No abrupt changes from potable to nonpotable ground water were seen in any of the eight wells analyzed. This was somewhat surprising to the study team, and indicates that there may be pathways for ground water circulation that extend to great depth. It also indicates that no widespread, low permeability layer exists that would serve to hydrologically separate the overlying Conejos aquifer from the underlying formations.
- The analyzed logs indicate a wide variation in ground water salinity, which varies from well to well.
- Generally, the analysis shows greater salinity concentrations with increasing depth. This is expected, and serves to indicate a trend of decreasing ground water movement with increasing depth. However, this general trend did not hold for every well, and relatively fresh water was found at great depth (over 6,000 feet) in one well; and nonpotable saline water was found in the 1,000 foot depth range in the Conejos Formation in another well.
- The majority of the geophysical logs indicate marginal or nonpotable water, in terms of salinity, even in depth intervals where the water well sampling program of this study indicate fresh, potable water of low salinity. This probably illustrates a limitation on the accuracy of this method of analysis.

8.4.1.1 Limitations of the Petrophysical Analysis

The methods used to perform the petrophysical analysis are standard and well-accepted methods in use on a regular basis in the oil and gas industry, and also in hydrogeology to some degree. However, it must be understood that the analysis methods should be seen as general, and not as absolute measures of salinity. In general, it is more important to view these analyses for their trends, rather than for their absolute values, for several reasons:

- The methods of analysis are based on results of empirical tests done in areas where the rock lithologies may be quite different from the study area.
- The methods are dependent on the quality of the geophysical logs. In this study area, with relatively fresh formation water and most commonly a freshwater drilling mud, there is little SP log development, which depends on contrast in fluid characteristics between the water fraction of the drilling mud, and the formation water.
- One of the methods (Rw from SSP method) is dependent on an accurate measurement of Rmf, which is the resistivity of the drilling mud filtrate. This parameter may not be accurate in some instances, which can lead to erroneous estimates of salinity.

8.4.2 Drill Stem Tests

During the drilling of oil and gas wells a drill stem test (DST) may be performed to evaluate the productivity of a gas or oil bearing zone that has been encountered, or is suspected, during the drilling. A drill stem test is performed by lowering a drill stem tool into the borehole. The tool is attached to the drill pipe and consists of the following parts: one or more packers (inflatable rubber bladders used to form a seal between the drill pipe and the borehole wall to isolate the hydrocarbon-bearing zone from the rest of the borehole), one or more pressure and possibly temperature recording units that include a clock, one or more units to allow formation fluids to enter the tool and move into the drill string, a sampler to contain the last sample of formation fluid(s) to enter the tool, and any auxiliary tools as deemed necessary by the drilling and/or testing company.

Once the tool is placed at the appropriate depth by lowering the drill pipe into the borehole, the tool can be opened and closed to provide for several flow periods to allow formation fluids, under the natural pressure of the formation, to enter the tool and thus into the drill pipe. The pressure readings over the time of the test are recorded during the open and closed periods, which are then analyzed when brought to the surface. The time versus pressure plot is etched on a black coated metal chart by a stylus. The charts are read on a special reader and the pressure and time recorded by the operator.

The open and closed periods and the changes in pressure measured during those periods allow computation of the permeability of the formation in the depth interval being tested. Any formation fluids that enter the DST tool and the drill string are also brought to the surface when the tool is removed from the borehole, where they can be collected and chemically analyzed.

The typical data from a DST as reported to the COGCC consists of the interval tested (top and bottom depth), formation tested, amount and type of fluids recovered in the drill pipe, amount and type of fluids recovered in the sampler, sampler pressure, temperature at stated depth, resistivity of recovered fluids and temperature and possibly chloride content of fluids. A description of the testing is generally included with a description of what was taking place at the surface during the testing. If a complete test analysis is sent to the COGCC, the calculated permeability, if performed, will also be reported.

Ten oil wells and one stratigraphic test hole have been drilled within Rio Grande County (Figure 4.1). Data for the oil wells is available from COGCC, and also from Brister and Chapin (1994) and Brister and Gries (1994). Data for the Amarex stratigraphic test is available in Gries (1985, 1989). Another oil well was drilled just north of the north county line in the OWC area. Six of the oil wells within the study area have data on one or more DSTs. DSTs were performed in the Conejos, Blanco Basin, Lewis/Mancos, and Dakota formations. As DSTs are not generally performed unless a hydrocarbon show was seen in the drill cuttings or drilling mud, the relatively large range of depths and formation over which the DSTs were performed indicates that there are hydrocarbons that have migrated upward from the source rocks into various shallower formations including the Conejos Formation. With the exception of the Beaver Mountain # 1 well, the available DSTs were performed at or below 3,900 feet below ground level. In the Beaver Mountain No. 1, DSTs were performed as shallow as 1,562 feet below ground level. The decision to do DSTs at the Beaver Mountain No. 1 well most likely was based, in part, on the core data analysis showing some oil saturation as shallow as 2,002 feet below ground level.

For the DSTs that recovered formation water, the calculated chloride content ranged from very fresh drinking water quality of less than 109 mg/L (Needham-Medford #1 from the Dakota Formation at 7,855 to 7,902 feet below ground level) to non-potable at 3,900 mg/l (Beaver Mountain #1 from Conejos Formation at 1,562 to 1,677 feet below ground level).

Only one permeability value was calculated and reported to the COGCC. This was for a DST in the Dakota Formation at the Horseshoe Mountain 1-10 well. The calculated hydraulic conductivity was 0.045 feet/day. This is a low value, but not extraordinarily low, and still is within the range that we see for some of the lower-permeability Conejos Formation clay-rich volcaniclastic or unfractured volcanic rocks.

At the Beaver Mountain #1 well the Conejos Formation was cored in the interval from 1,590 to 10,170 feet. From the core analysis the calculated hydraulic conductivity in the interval from 1,736 to 6,198 feet ranged from 10^{-5} to 5×10^{-2} (0.05) ft/day. The upper end of these values is in the range of the K values calculated from the water well analysis of specific capacity for the Conejos Formation.

8.5 General Directions of Ground Water Movement in the Study Area

Ground water movement in the SFC area is generally northward, down-valley and towards the Rio Grande. This is common and expected in short travel-path aquifers. Ground water movement in the OWC area is uncertain and may reflect strong aquifer heterogeneity even at a local scale in the range of the water well depths. Longer, regional travel paths of ground water in the Conejos aquifer are expected to trend generally north towards the Rio Grande and east towards San Luis Valley, but data developed for this study are not sufficient to assess this aspect.

8.6 Heterogeneity and Variability of Conejos Formation Aquifer

As discussed in section 8.2 and shown on Figure 8.5, the TDS of five of the deepest sampled wells were low relative to the shallow sampled wells, and similar to the TDS of the springs. Usually TDS increases with depth. Water-quality information from other deep wells in the area might be helpful to better understand this apparent anomalous trend of better quality water at depth.

In the OWC area, there are flowing wells in close proximity to wells of similar depth that do not flow and in some cases have very deep reported static water levels (Figure 6.6). For example, well RGC4 is about 1/3 mile from flowing wells, yet the static water in this well is 280 feet *below* ground level. The flowing wells tend to be slightly deeper than the wells that do not flow; however, the flowing well with the highest production rate (RGC6) is about 100 feet less deep than the nearby well that does not flow. Admittedly, the static water levels are reported values that were measured in different years, but these data do support the variability of static water levels in the OWC area and presence of flowing wells in close proximity to wells that do not flow and may have static levels far below ground level.

The varying elevations of static water levels in the OWC area are depicted on Figure 8.12. In contrast, the elevations of static water levels in the SFC area's wells (Figure 8.13) show a gradual decrease in elevation northward. When contoured, this information indicates water movement northward, down the valley of San Francisco Creek and towards the Rio Grande River. The different behaviors in static water levels in the SFC and OWC areas may relate to the facies in the Conejos aquifer that the wells are completed in. Wells in the SFC area are completed in the Conejos volcaniclastic facies, in which intergranular porosity and permeability may exist. Whereas the wells in the OWC area are completed in the Conejos vent facies, in which fractures control permeability.

Several case histories of water well drilling on properties within the study area provide specific examples of the heterogeneous and variable nature of the Conejos Formation. These case histories are based upon records in the CDWR files and conversations with well owners and well drillers.

A good example of the heterogeneous and variable nature of ground water in the Conejos Formation aquifer involves the history of well drilling on the ~40 acre parcel in the OWC area on which the above described flowing well (RGC6; permit #196293-A) is located. The following summary describes the well drilling history on this parcel.

The first well drilled on this property was 882 feet deep. The reported static level was 17.5 feet, and the production rate was 40 gpm. According to the well construction and test report a flow of 1 gpm was hit at a depth of 380 feet, but the 40 gpm flow was from 864 feet deep. The well had to be abandoned, reportedly because a pipe joint became loose while trying to pull the pump, and the pump and part of the stand pipe fell into the well.

The second well drilled on the property was only 308 feet deep and produced only 1 quart per minute. It was abandoned, and a third well was drilled to a depth of 510 feet. This well also produced only 1 quart per minute; it was abandoned and a fourth well was drilled.

The fourth well (RGC6) was drilled to a depth of only 306 feet, but it was a flowing well that produced 100 gpm according to the well construction and test report. The water was produced from fractured rock at a depth of 286 to 306 feet. When tested in the field the well flowed at about 25 to 30 gpm from a valve that may have restricted the flow.

In summary, the shallowest well (306 feet deep) drilled on this relatively small parcel in the OWC area was the only one of the four wells on the parcel that had sufficient hydrostatic pressure to flow above ground level. Two of the wells, one 308 feet deep and a second 510 feet deep produced almost no water. The deepest well on the property (882 feet) produced a good amount of water from a depth of 864 feet, but only one gpm from a depth of 380 feet and no water production at the same depth that the flowing well produces water from.

Examples of the variability and heterogeneous nature of the Conejos aquifer also exist in the Bear Creek filing of South Fork Ranches northeast of South Fork. The Street well (RGC D2; permit #55328-F-R) was drilled to a depth of 890 feet, and perforated casing was installed from 850 to 890 feet. According to the well owner, the hole was dry to a depth of 880 feet. The reported static level was at 35 feet, and the reported production rate was 80+ gpm. This well is the second well drilled on this small parcel of land, and it was drilled only about 20 feet from the first well. The first well (permit #55328-F) was drilled to a similar depth of 900 feet, but it produced only 2 gpm and had a much deeper static level of 300 feet. This well was abandoned because the casing was damaged while trying to pull the pump.

Four wells have been drilled on the Fietek property in the Bear Creek filing of the South Fork Ranches. The wells were originally drilled under permit #62988-F, but this permit was cancelled and the existing well that was sampled (RGC3) was permitted as #65339-F. All four wells are in close proximity (an area with ~200 foot radius), and they all are located within about 200 to 450 feet of the Rio Grande. Since the wells were located very near to the river, the landowner logically assumed that obtaining a good well would be relatively easy. But the first well was 970 feet deep and described as a dry hole that produced only 0.046 gpm. The second dry hole was 950 feet deep; no water production was reported for the second well. The third dry hole was 1,150 feet deep with no water production. The fourth well (RGC3) was 1,400 feet deep, produced only 1 quart per minute, but had a static level of 110 feet. The drilling of four wells in close proximity that have little to no water yield is not unique, but it demonstrates the minimum depth (1,400 feet) to which wells in the Conejos Formation may have to be drilled to find water, even small quantities of water. Another interesting aspect of the Fietek well is the apparent absence of hydrologic connection between water in the Rio Grande and in the alluvial aquifer and the water within the Conejos aquifer at this location.

The deep public water-supply wells at Beaver Mountain Estates also illustrate the heterogeneous nature of the Conejos aquifer. Well BME2 (permit #57640-F) is 1,260 feet deep. It produces

~20 to 30 gpm of good quality, cool water from depths of 330 and 1,130 feet. In contrast, well BME3, located about one-half mile north of BME2 and in a similar geologic setting within the Rio Grande Graben, contains warm water with poorer quality (fluoride exceeds primary drinking water standard). Elevation of the bottom of well BME3 is about 90 feet lower than the bottom of BME2, but the static water levels are reported to be within about 20 feet. Apparently ground water with much different quality and temperature can exist within the Conejos aquifer at about the same elevation in the same or nearby area. The new well drilled for the water-supply system is located between BME2 and BME3, but is only 400 feet deep and reportedly produces about a similar amount of water as the deeper wells, demonstrating the variability of water production at depth in a small area.

8.7 Qualitative Assessment of Vulnerability of Water Wells in Oil Exploration Areas

Overall, the strongly heterogeneous nature of the Conejos aquifer tapped by the majority of water wells in the study area, coupled with the lack of any abrupt depth demarcation between shallower, potable waters and deeper, saline waters strongly suggests to the study team that water wells down gradient of oil drilling operations may be vulnerable to contamination unless appropriate environmental controls are in place.

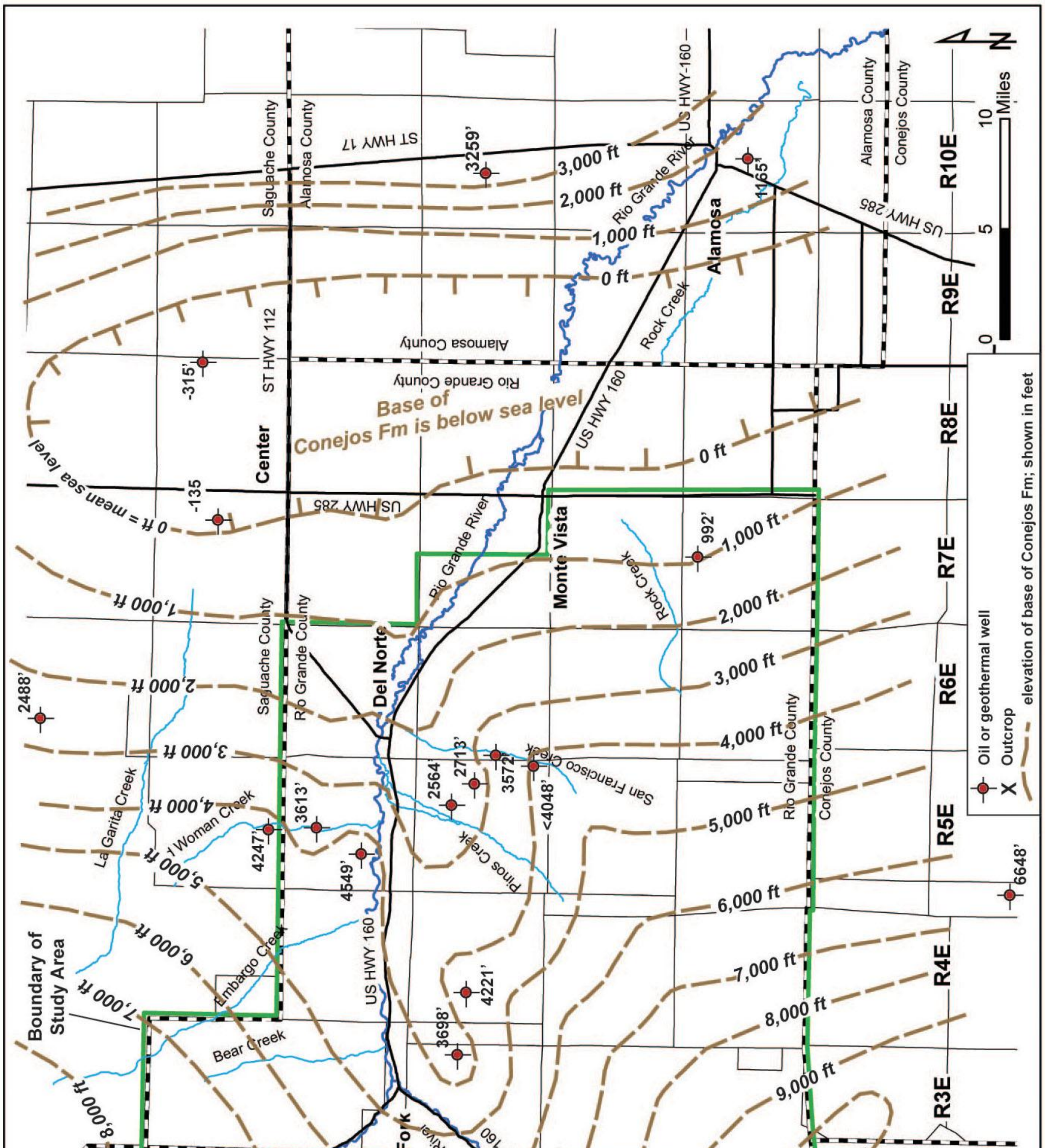

Figure 8.1. Map showing approximate elevation of the base of the Conejos Formation**.**

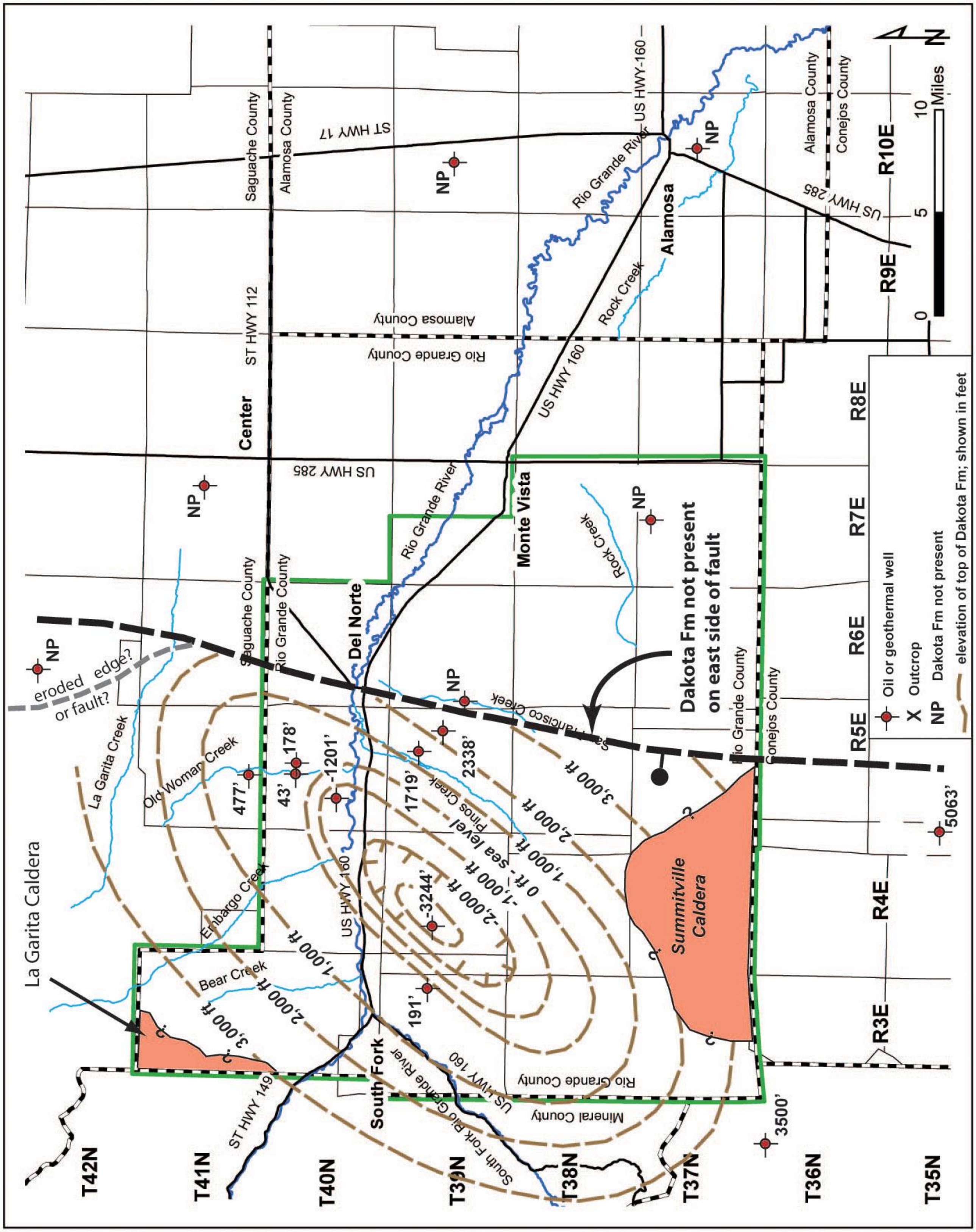

Figure 8.2. Map showing approximate elevation of the top of the Dakota Formation**.**

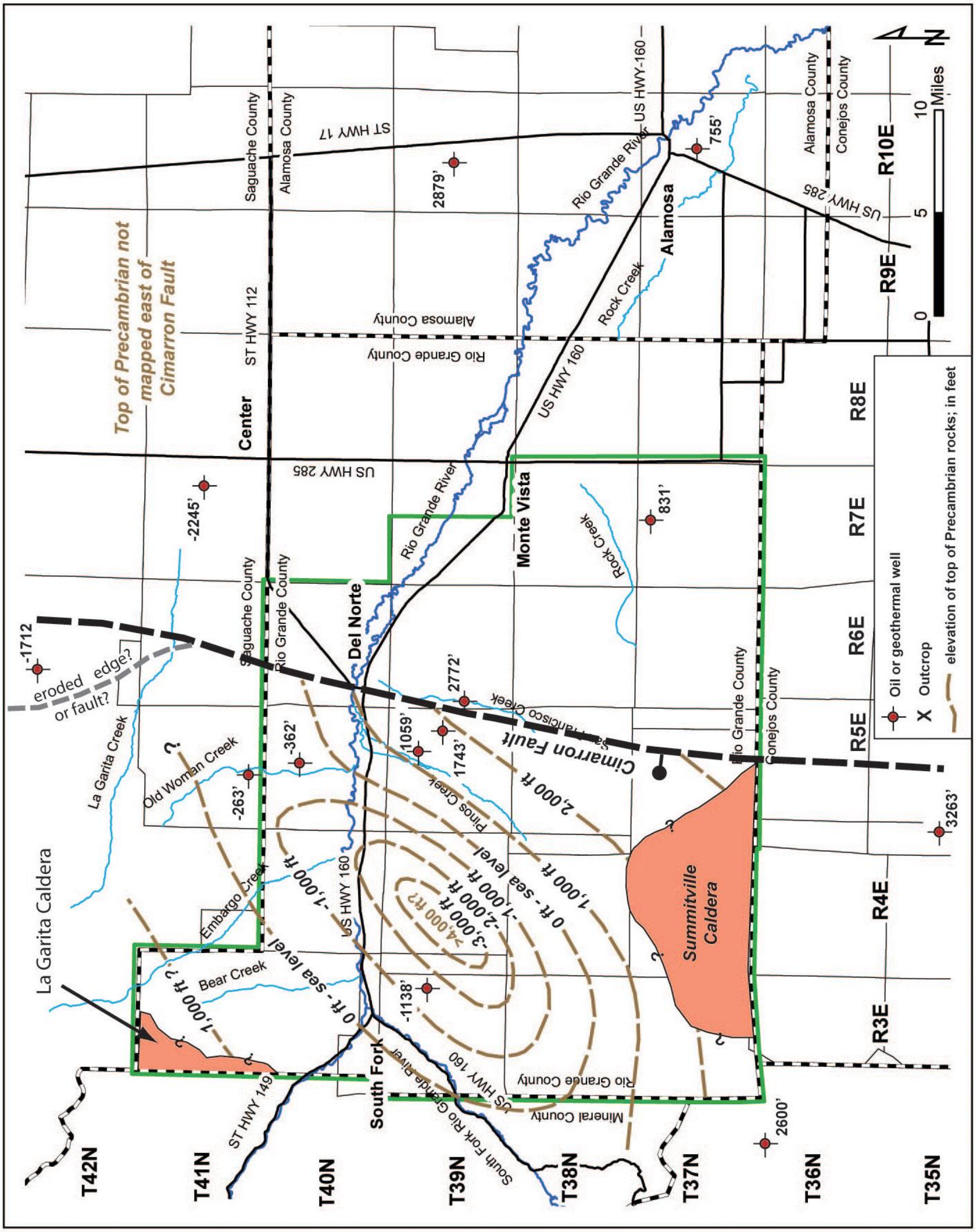

Figure 8.3. Map showing approximate elevation of the top of the Precambrian basement**.**

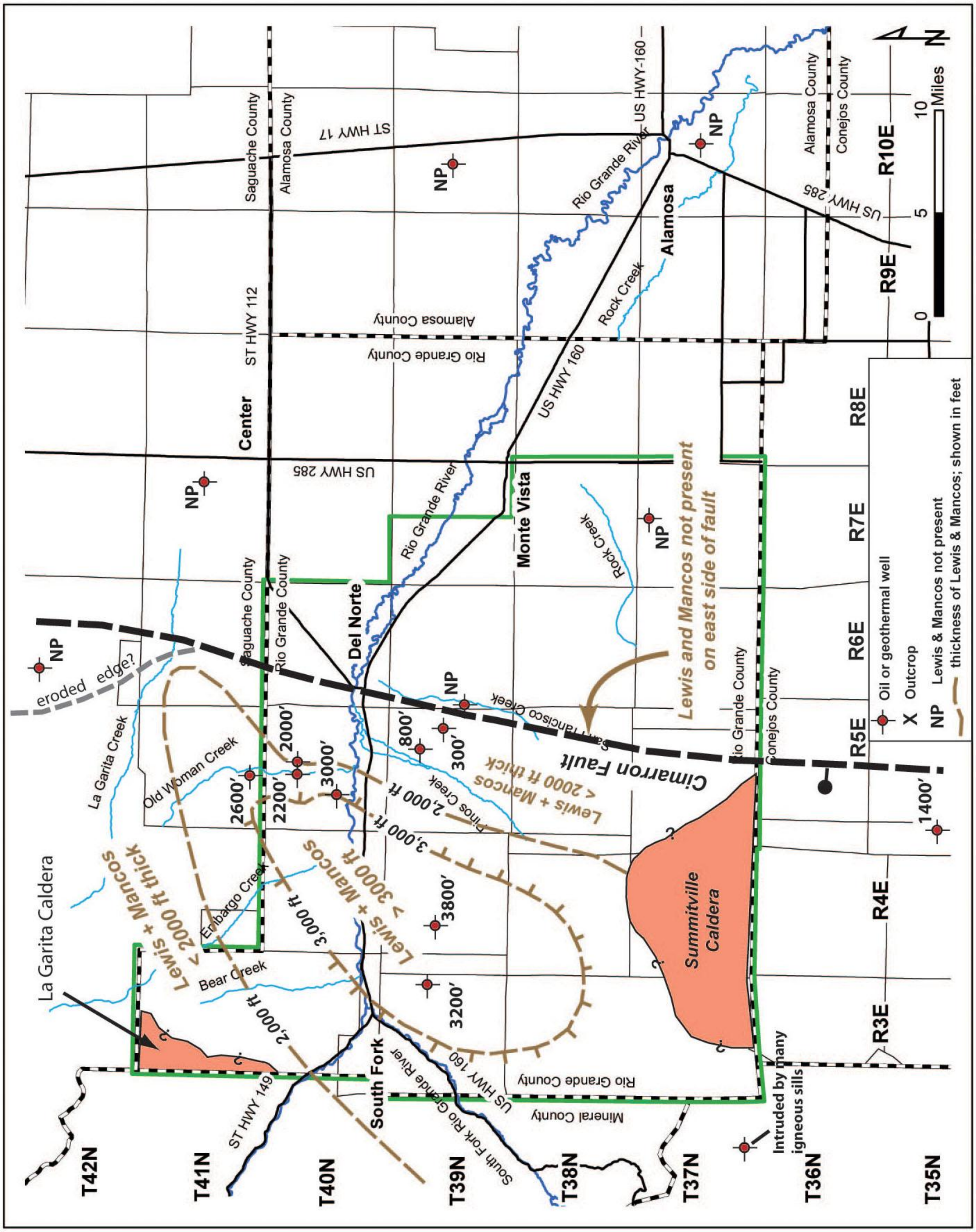

Figure 8.4. Map showing approximate thickness of the Lewis Shale and Mancos Shale**.**

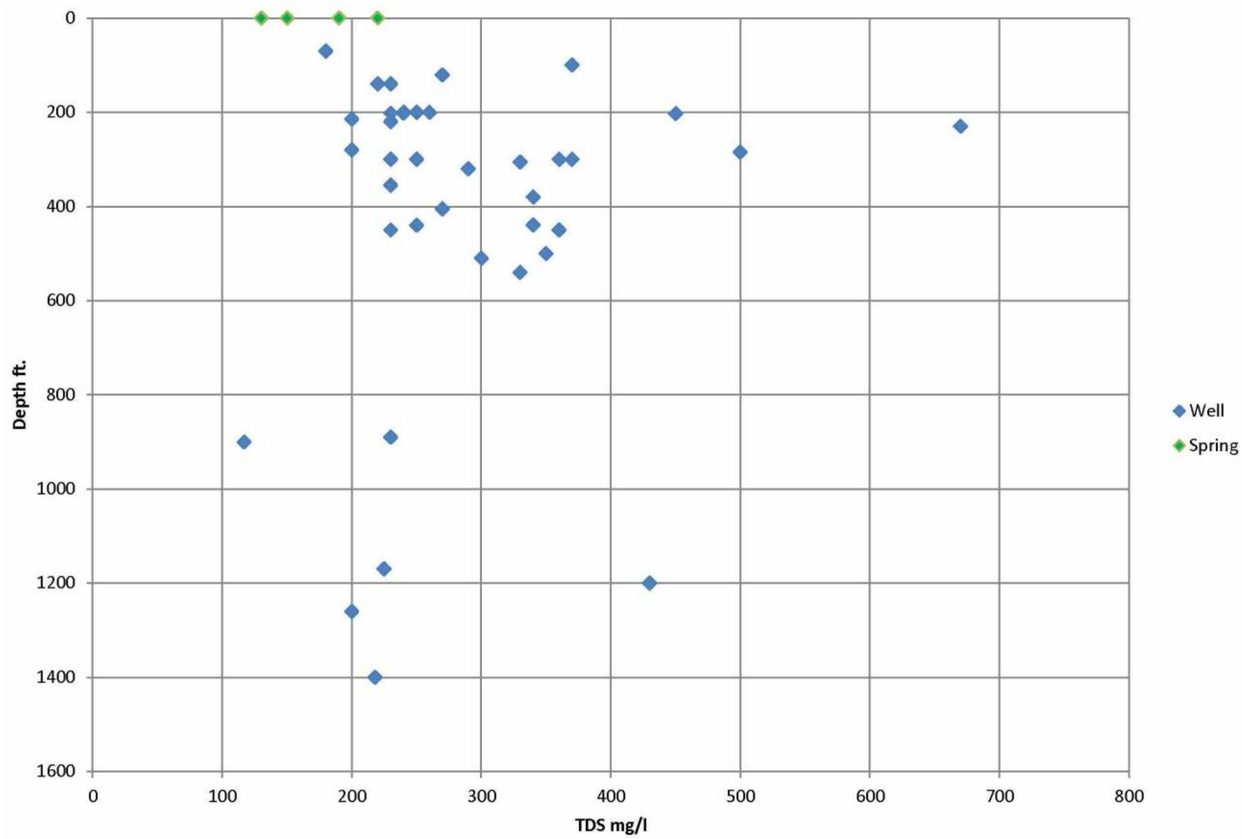

Figure 8.5. Graph of TDS versus depth for all water samples**.**

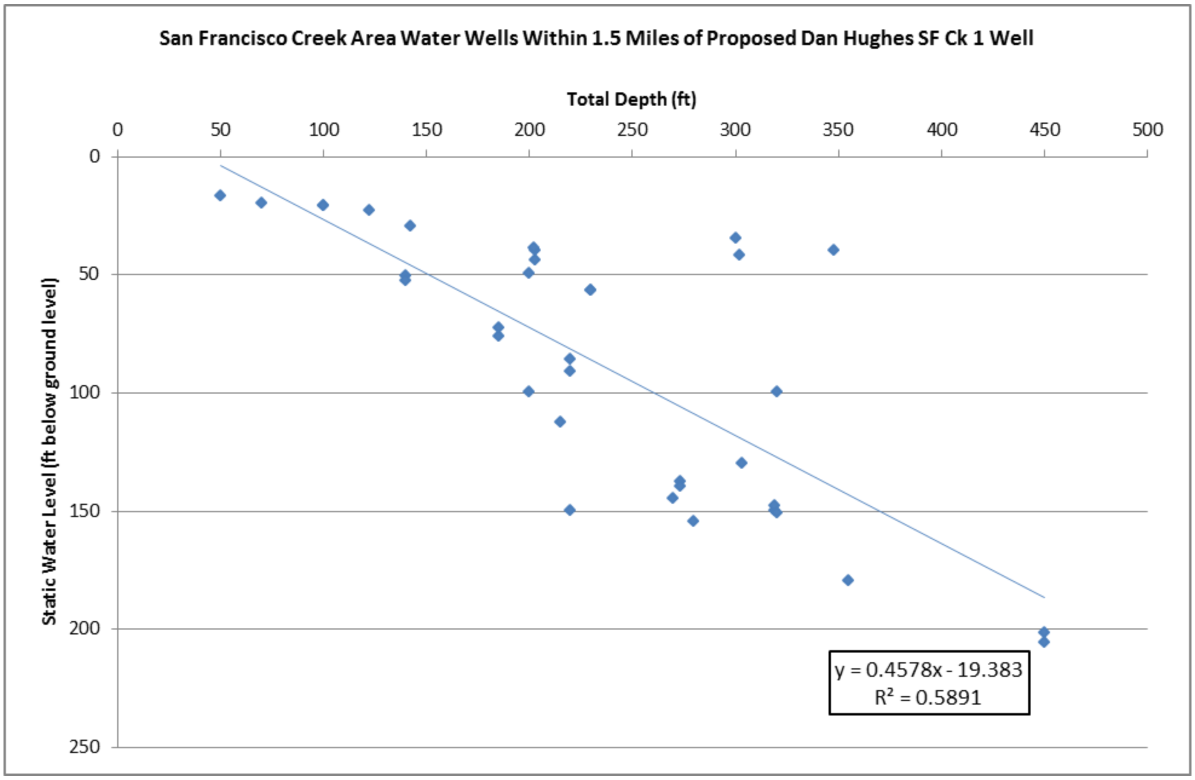

Figure 8.6. Graph of static water level versus depth for water wells in the SFC area within 1.5 miles of the proposed Hughes DAHC-San Francisco Creek #1 oil well.

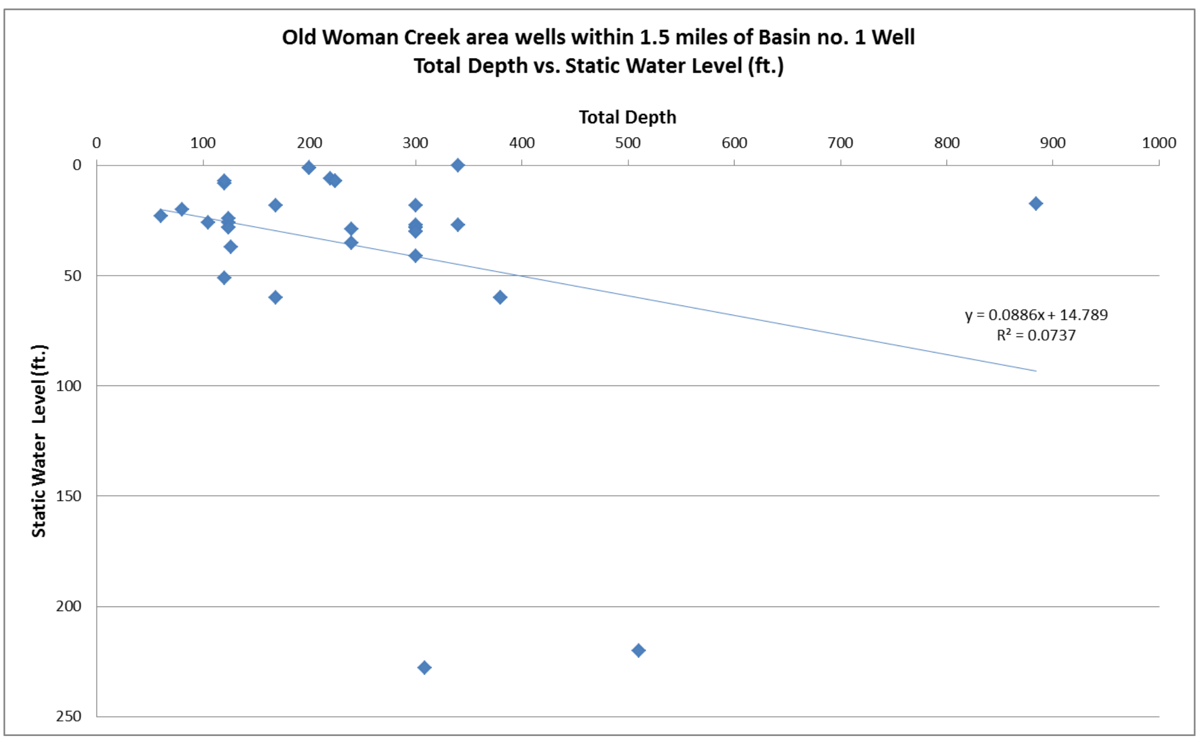

Figure 8.7. Graph of static water level versus depth for water wells in the OWC area within 1.5 miles of the proposed First Liberty Basin #1 oil well.

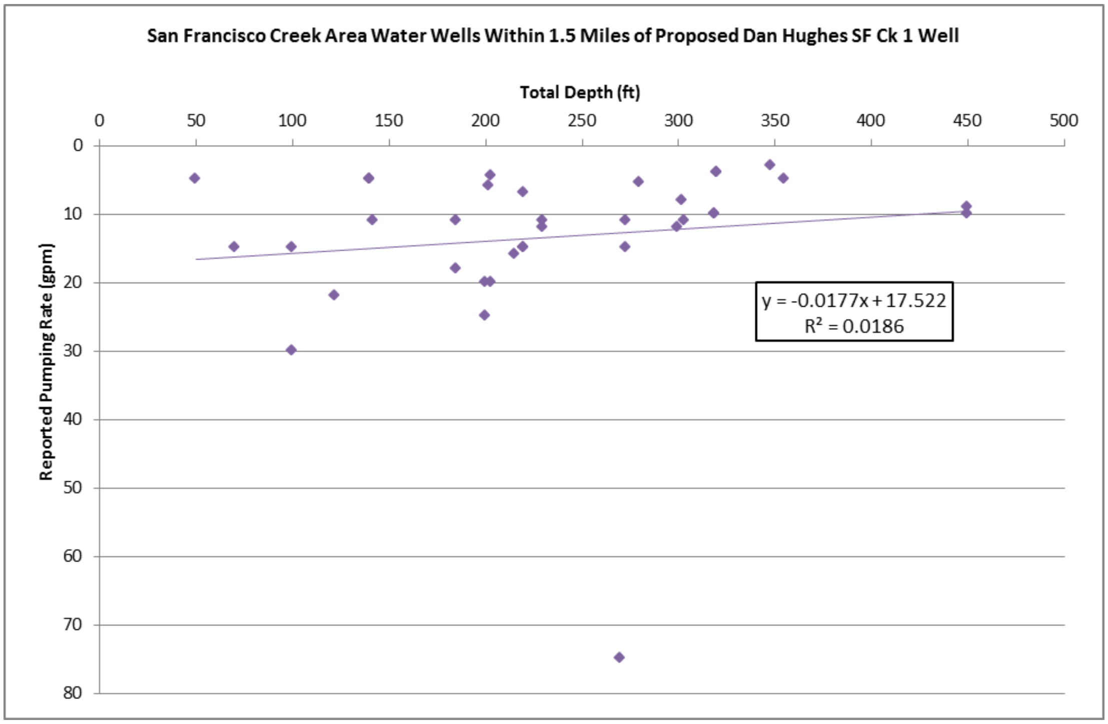

Figure 8.8. Graph of reported pumping rate versus total depth for water wells in SFC area within 1.5 miles of the proposed Hughes DAHC-San Francisco Creek #1 oil well.

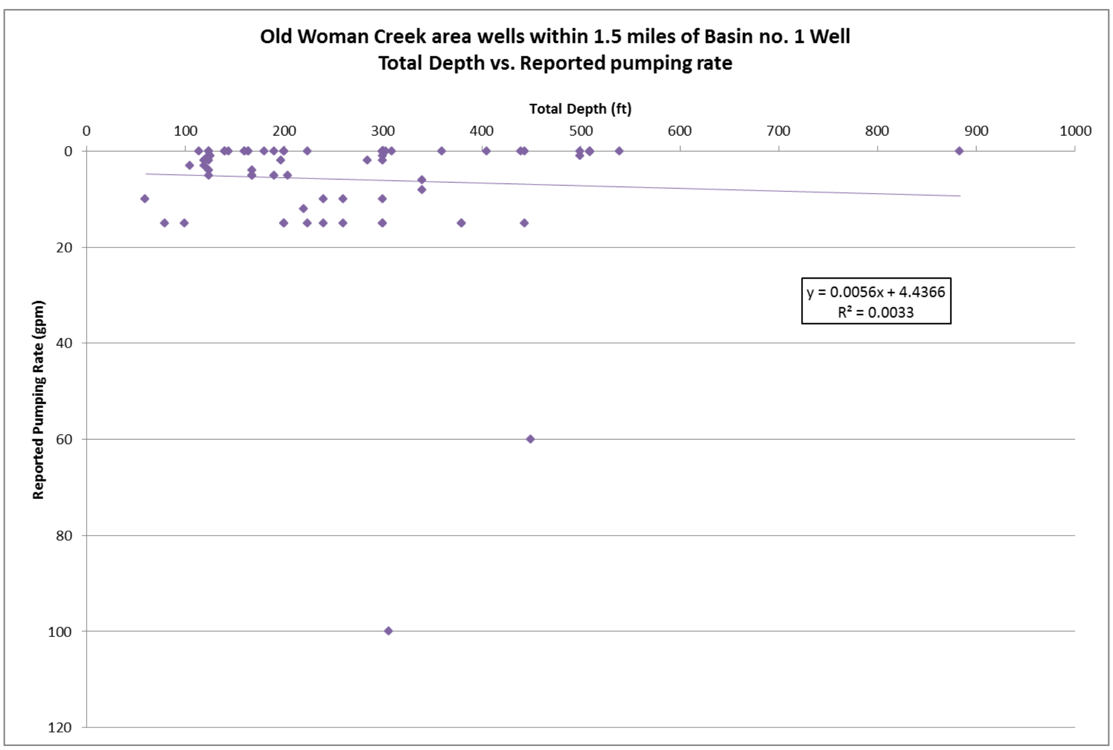

Figure 8.9. Graph of reported pumping rate versus total depth for water wells in OWC area within 1.5 miles of the proposed First Liberty Basin #1 oil well.

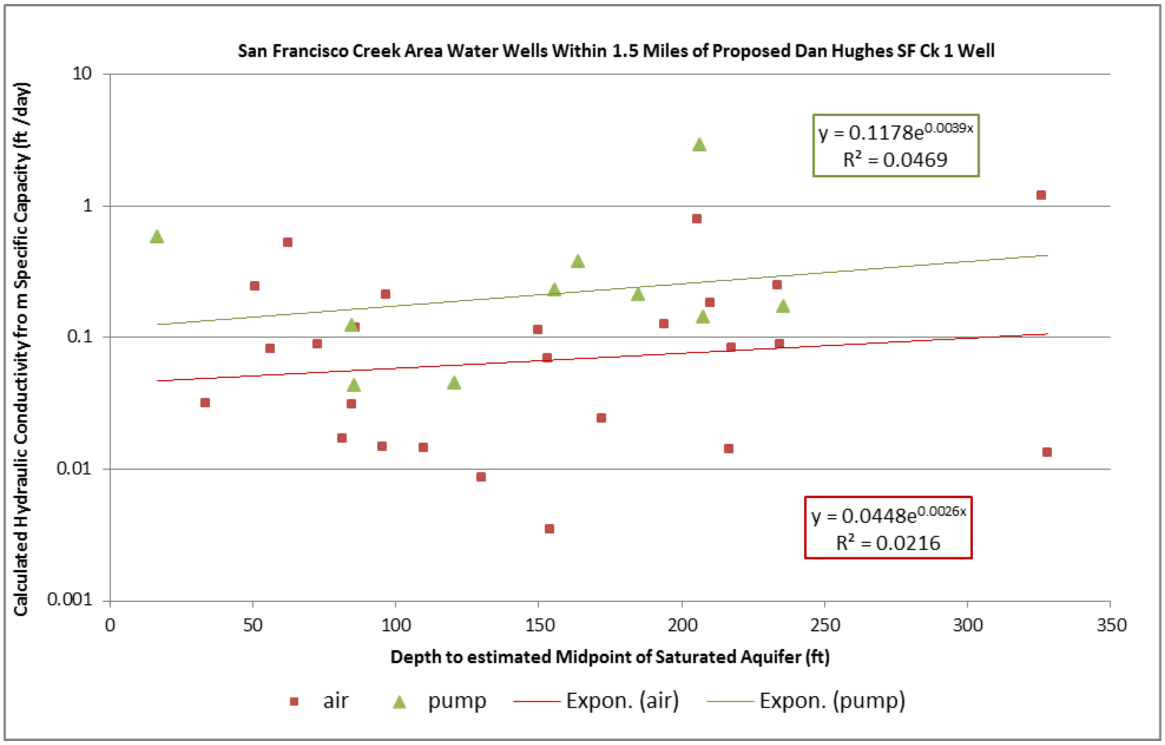

Figure 8.10. Graph of calculated hydraulic conductivity versus depth to estimated midpoint of saturated aquifer for water wells in the SFC area within 1.5 miles of the proposed oil well.

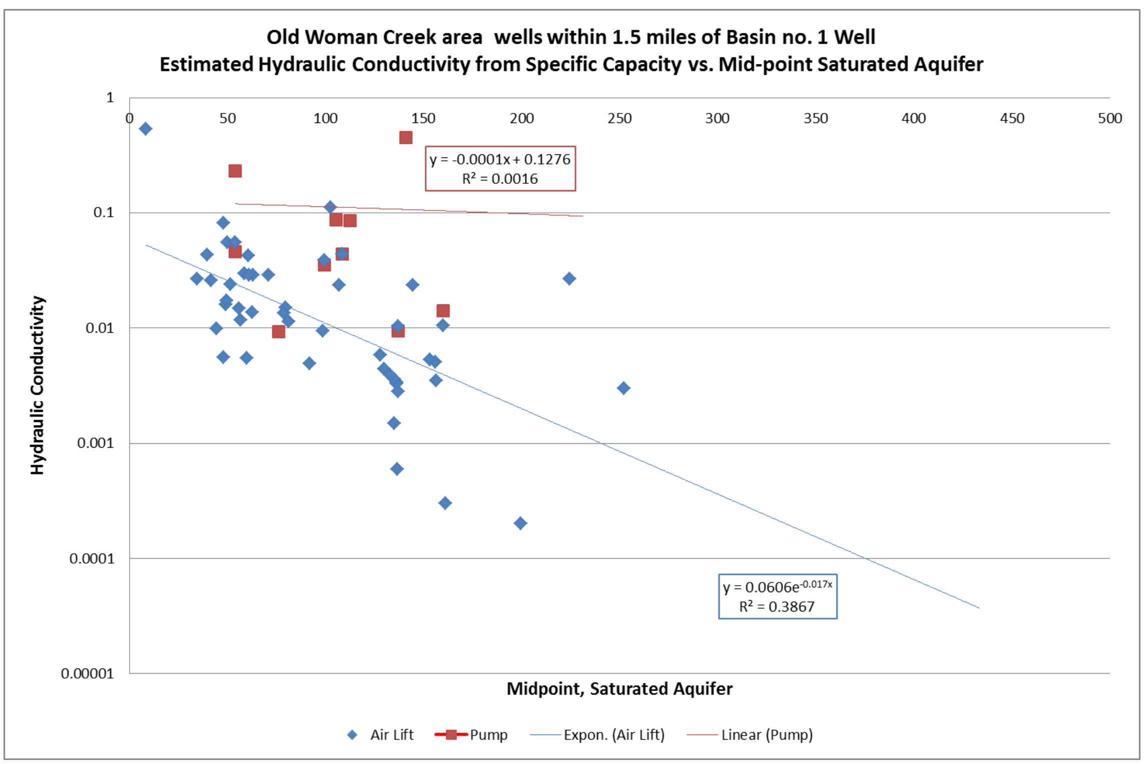

Figure 8.11. Graph of calculated hydraulic conductivity versus depth to estimated midpoint of saturated aquifer for water wells in the OWC area within 1.5 miles of the proposed oil well.

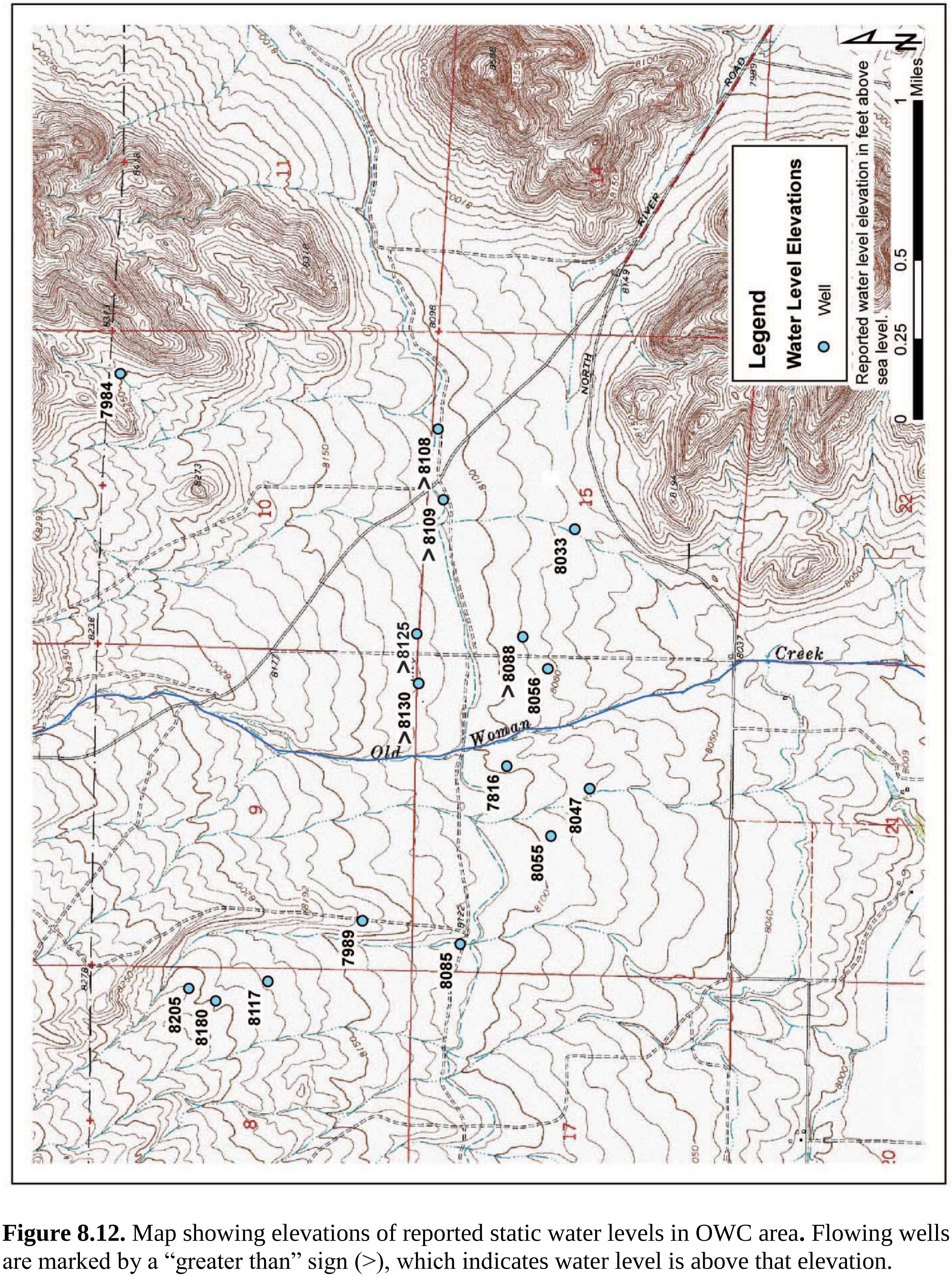

Figure 8.12. Map showing elevations of reported static water levels in OWC area**.** Flowing wells are marked by a "greater than" sign (>), which indicates water level is above that elevation.

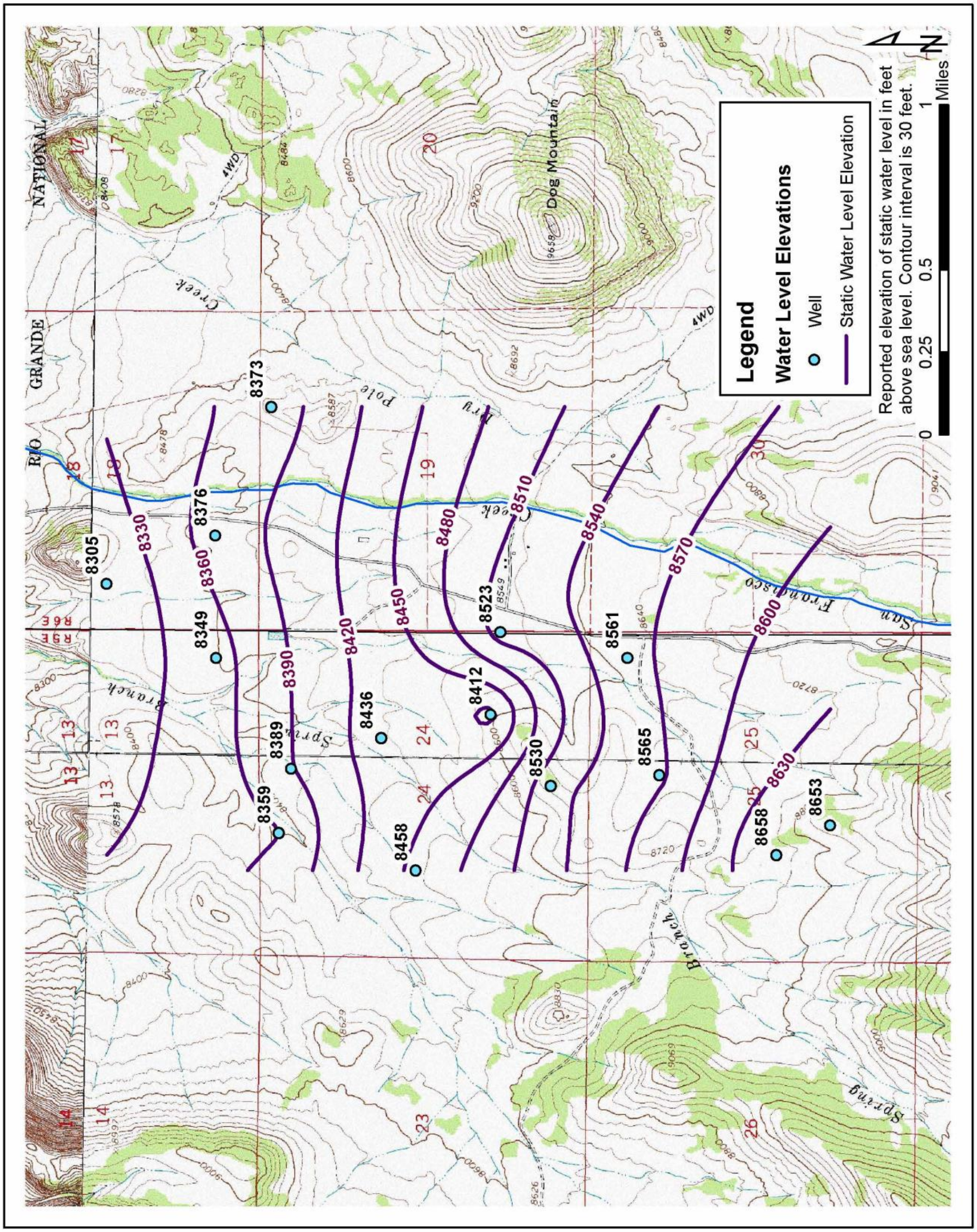

Figure 8.13. Map showing elevations of reported static water levels and springs in SFC area**.** Contour lines show equal elevations of the reported static water levels.

9.0 DEFINITIONS OF POTABLE, FRESH, AND USABLE WATER

There is a general consensus in regulations and common practice that in the process of drilling for oil and gas, good quality ground water should be protected. In most cases, subsurface formations containing such ground water should be separated from the bore hole in a manner that would prevent hydrocarbons from entering the formations. This separation is often accomplished by placing solid casing through the section of the well where good quality water exists or may exist and installing cement in the annular space between the outside of the case and the bore hole to seal the annulus and prevent uphole migration of petroleum and associated extremely poor quality water. A question that may invoke disagreement is the definition of good quality water. Common terms that are used to describe such water are "potable", "fresh" and "usable".

Definition of "potable" is commonly described in State health department and Federal regulations. The acceptable concentrations of common chemical constituents contained in "potable" water according to the Colorado Department of Public Health and Environment are described in section 5.4 – Maximum Contaminant Levels. "Potable" water is acceptable for human consumption without further treatment and is usually considered the highest quality of water in an aquifer. Lesser quality water such as "Fresh" and "Usable" is less clearly defined and commonly classified by the concentration of total dissolved solids (TDS). The desirable concentration of TDS in "potable" water is less than 500 mg/L.

"Fresh" does not have a clear definition, but references commonly describe it as water with less than 500 parts per million (ppm) of dissolved salts (salinity). This is similar to the "potable" water MCL of a TDS of 500 mg/L. There are references that include a definition to 3000 ppm salinity.

The broadest water quality category is "Usable" water. Definitions of "Usable" water are included in Bureau of Land Management (BLM) regulation 43 CFR 3160 which addresses "Onshore Oil and Gas Operations". The referenced regulation indicates "The (drilling) operator shall isolate freshwater-bearing and other usable water containing 5,000 ppm or less of dissolved solids and other mineral-bearing formations and protect them from contamination". Proposed BLM regulations (Federal Register Volume 77, Number 92; Friday, May 11, 2012) for Oil and Gas; Well Stimulation, Including Hydraulic Fracturing, on Federal and Indian Lands indicate that "Usable Water means generally those waters containing up to 10,000 ppm of total dissolved solids".

The U.S. Environmental Protection Agency defines an "underground source of drinking water" or aquifer in 40 CFR § 144.3 as follows:

Underground source of drinking water (USDW) means an aquifer or its portion:

(a)(1) which supplies any public water system; or

(2) which contains a sufficient quantity of ground water to supply a public water system; and

(i) currently supplies drinking water for human consumption; or

(ii) contains fewer than 10,000 mg/L total dissolved solids; and

(b) which is not an exempted aquifer.

The U.S. Environmental Protection Agency also defines an "exempted aquifer" as follows:

An aquifer or a portion thereof which meets the criteria for an "underground source of drinking water" in §146.3 may be determined under 40 CFR 144.8 to be an "exempted aquifer" if it meets the following criteria:

(a) it does not currently serve as a source of drinking water; and

(b) it cannot now and will not in the future serve as a source of drinking water because:

(1) it is a mineral, hydrocarbon or geothermal energy producing, or can be demonstrated by a permit applicant as part of a permit application for a Class II or III operation to contain minerals or hydrocarbons that considering their quantity and location are expected to be commercially producible.

(2) it is situated at a depth or location which makes recovery of water for drinking water purposes economically or technologically impractical;

(3) it is so contaminated that it would be economically or technologically impractical to render that water fit for human consumption; or

(4) it is located over a Class III well mining area subject to subsidence or catastrophic collapse; or

(c) the total dissolved solids content of the ground water is more than 3,000 mg/L and less than 10,000 mg/L and it is not reasonably expected to supply a public water system.

10.0 CONCLUSIONS

- Nearly 3,000 constructed water wells exist in the study area. They produce water from unconfined alluvial aquifers and confined bedrock aquifers. Many private residences and businesses and at least one public water supply system rely upon ground water pumped from these aquifers.

- The Conejos Formation aquifer is the primary bedrock aquifer in the mountainous part of Rio Grande County. Existing water wells are as much as 1,400 feet deep.

- Based on information from previously drilled oil exploration wells, the Conejos Formation is as much as 5,865 feet thick.

- Sampled water wells in the OWC area and all sampled deep wells produce water from the vent facies of the Conejos Formation, which consists mostly of fractured lava flows in proximity to the ancient volcanoes. Sampled water wells in the SFC area are completed in the volcaniclastic facies of the Conejos Formation. This facies is composed chiefly of sedimentary conglomerate, sandstone, and mudstone that contain clasts and grains eroded from the volcanic rocks and deposited on the flanks of the ancient volcanoes and between them.

- The Conejos Formation aquifer is very heterogeneous, especially the vent facies. For example, flowing water wells with high production rates exist near other water wells completed at similar or greater depths, but that produce very little water and have deep static water levels. The temperature and water chemistry of ground water in the Conejos aquifer also can vary significantly in nearby wells drilled to similar depths.

- Geophysical data for previously drilled oil exploration wells, chemistry of ground water in the Conejos aquifer, and other factors provide evidence of deep circulation of ground water in the aquifer.

- None of the sampled water wells within about one mile of the proposed oil wells contained detectable concentrations of BTEX (benzene, ethylbenzene, xylene, and toluene) or the hydrocarbon gases of methane, butane, ethane, ethylene, and propane. One sampled spring in the SFC area contained very low concentrations of methane; the source of this methane may be biologic decomposition of organic material in the wetland associated with the spring.

- Surprisingly, the deep sampled water wells had lower TDS (total dissolved solids concentration) than most shallow sampled wells. The lowest TDS measured during the study was from a 900 feet deep well that produces water from depths of 820 and 880 feet deep.

- Naturally occurring oil seeps in the volcanic rocks in the eastern San Juan Mountains, oil observed in fractures in Conejos volcanic rock obtained from core holes drilled for mineral exploration at Summitville in the southwest part of the study area and near the Summer Coon Volcano about six miles north of Del Norte indicate natural petroleum has migrated upwards from source rocks and potential oil reservoirs.   This is evidence that no highly impermeable, continuous formations exist in the area that would serve to hydrologically separate the underlying petroleum-bearing source and reservoir rocks from the shallower fresh-water aquifers used by water wells in the area. This observation is corroborated by petrophysical analysis of logs from eight petroleum test holes, none of which showed evidence of impermeable strata that would serve to separate the zone of usable water in the Conejos Formation aquifer from deeper formations.

- The oil seeps and oil in drill core and cuttings prompted interest in the potential for oil and gas beneath the San Juan Volcanic Field in Rio Grande County and adjoining counties. Ten oil exploration wells and stratigraphic test holes were drilled in the County between 1982 and 1990. Information from these wells, other wells drilled nearby, and from geophysical seismic investigations confirmed the existence of the San Juan Sag, an elongate, trough-like structural depression that extends from about Del Norte to Pagosa Springs. The sag is a northeast extension of the San Juan Basin, a known prolific producer of oil and gas.

- The San Juan Sag contains thick deposits of Cretaceous-age, organic-rich, marine shale that are the source rocks for petroleum. The margins of the sag are not apparent at the ground surface because the structure and the petroleum-bearing rocks preserved in it are buried by thousands of feet of volcanic rock in the San Juan Volcanic Field. The eastern edge of the sag apparently coincides with the Cimarron Fault, which formed along the western margin of a buried, ancient, mountain range called the Laramide-age San Luis Uplift.

- According to published information, the Cimarron Fault and the western margin of the San Luis Uplift trend generally north-south about through Del Norte. East of the fault, on the uplifted mountain block, the Cretaceous rocks were stripped off by erosion. Therefore, petroleum source rocks do not exist and the potential for oil and gas is low to nil in about the eastern one-third of Rio Grande County. The San Juan Sag and the Cretaceous rocks preserved in it underlie about the western two-thirds of the County, and future petroleum exploration and perhaps production may occur in that part of the County.

- The presence of natural oil seeps, oil in core and cuttings, and natural gas from drillstem tests from the Conejos Formation indicates water wells also have potential to be constructed in rock that contains natural oil and gas, which may affect the water quality in those wells.

- Available data suggest the depths of cement-grouted surface casing required by the COGCC in the proposed two oil wells (1,100 feet depth in the Hughes well in the SFC area and 1,200 feet depth in the First Liberty well in the OWC area) may not be adequate to safeguard the Conejos aquifer from potential contamination resulting from oil exploration drilling and production.

- The Conejos aquifer is an "underground source of drinking water" or aquifer as defined by the U.S. Environmental Protection Agency. The deeper part of the Conejos aquifer potentially could be classified as an "exempted aquifer" because it may be economically impractical to recover water from great depths or the ground water within it may have a TDS greater than 3,000 mg/L. However, the Conejos aquifer provides water to at least one public water system, and in the future, depending on the hydrogeologic conditions, wells for public and private water systems may need to recover water from the deeper parts of the Conejos aquifer. Also, deep water wells currently are technologically feasible, not impractical, and the economics of a deep well for public supply water system or private well depend upon the financial condition of the well owner or development. And in the future the economics of recovery of ground water from wells may change as water supplies become tighter and more precious. The highest measured TDS in the wells sampled in this study is 670 mg/L in a 230 feet deep well, and the deepest well is 1,400 feet deep and had a TDS of only 218 mg/L. Both concentrations are much lower than the 3,000 mg/L concentration noted in the EPA definitions. No water quality analyses are available for very deep ground water in the Conejos.

11.0 RECOMMENDATIONS

The study team offers the following recommendations for discussion and consideration by the Commissioners and the residents of Rio Grande County. Our recommendations follow the format shown in the original proposal to the Rio Grande Roundtable and Colorado Water Conservation Board and are listed in the same order as in the proposal. Some of these recommendations address the adequacy of the provisions of COGCC Rule 609 "Statewide Groundwater Baseline Sampling and Monitoring" (as it currently exists in draft form) with respect to the hydrogeology of the potable ground water resources in Rio Grande County, as discussed in this study.

1. **Recommended oil and gas well drilling/completion/testing precautionary measures to protect against contamination of surface water and near-surface (i.e. alluvial) ground water within the immediate watershed.**

This study has found that there is substantial evidence of deep circulation of ground water, at least to several thousand feet depth in the Conejos Formation, and that there is significant permeability in the Conejos Formation that may serve to provide pathways for movement of water between deeper formations, the Conejos Formation, and near-surface (alluvial) ground water. For this reason, the study team recommends:

- An appropriate precautionary measure would be to require petroleum exploration or production wells to be cased and grouted (cemented) from the base of the Conejos Formation back up to ground surface, and that the grouted interval be tested for integrity by use of a CBL (cement bond log), pressure testing, or other means, before drilling and testing of the target formations for petroleum production.
- Drilling within 1,000 feet of an alluvial floodplain or an intermittent or ephemeral streambed should be avoided, unless precautionary measures are taken to prevent the escape of drilling fluids. For example, the conductor casing should be extended to adequate depths and cement grouted to protect shallow aquifers. The exact depth will depend on local aquifer conditions, which as yet have not been well characterized.

2. Recommended longer-term water quality baseline studies to establish a fund of information against which to compare post-drilling water quality.

This study has developed a strong initial sampling of water wells that provides a valuable fund of water quality data. However, this one-time sampling does not afford the opportunity to understand any seasonal variance in natural, background water quality. Also, several wells and springs within or near to the one-mile radius of the two proposed wells were not sampled during this study for various reasons (see section 6.8). Accordingly, the study team recommends that the County procure funding to sample the wells and springs identified in section 6.8 and for an annual sampling of a selected subset of the wells and springs sampled during this study. Particular wells chosen for further baseline water quality studies should include at least 30% to 50% of the wells sampled in this study, and should be selected on the basis of best information on the depth horizons from which the well draws water; a range of shallow to deep wells sampled; and wells that are in areas most likely to be of interest for future petroleum exploration drilling or that are located in the direction from a proposed oil well that ground water might be moving.

3. Recommended longer-term hydrogeologic investigations designed to fill significant gaps in the knowledge base about ground water occurrence and movement of significance to Rio Grande County.

This study provides a strong framework with which to begin to understand the hydrogeology of the aquifers in the mountainous areas of Rio Grande County. However, there remain significant data gaps. Accordingly, the study team recommends a longer-term hydrogeologic investigation. Potential components of a more comprehensive hydrogeologic study may include:

- Sampling and analysis of other deep water wells in the County, including those described in section 7.8.
- Field investigations to check the nature of mapped faults and identified lineaments (possible fault or fracture traces) that may enhance ground water movement. Field

investigations should also attempt to better understand the distribution of various rock types within the Conejos Formation and their hydrologic properties.

- Development of an aquifer water level elevation contour map (or maps), to enable better identification of local (creek subdrainage) and regional (basin or sub-basin) ground water flow paths.
- Development of water balance estimates for individual creek subdrainages, to allow estimation of ground water recharge, discharge, changes in ground water storage, and other critical parameters.
- Perform properly instrumented pumping tests on selected existing wells, to help narrow the uncertainty in transmissivity, hydraulic conductivity, and storage characteristics of the Conejos Formation aquifer.
- Development of Piper trilinear diagrams of major anions and cations, to help understand the pathways of ground water movement and chemical changes in the subsurface.
- Consider a program of water sampling to include environmental isotope analyses, such as ^{18}O, ^{14}C, tritium, deuterium, and chlorofluorocarbon (CFC). These would allow estimation of ground water travel times since recharge, and thereby help understand the time of travel from the recharge (source) areas to water wells and to the San Luis Valley aquifers. Other methods of age dating ground water would support this effort.
- Ultimately, to best understand the ground water in the deeper part of the Conejos aquifer one or more deep hydrologic monitoring wells should be designed, drilled, completed, and monitored specifically for this purpose.

4. Recommended measurements, water quality sampling, or other short-term activities to be undertaken by the County, by individual well owners, or by others, before, during, and after exploratory oil and gas drilling.

COGCC Rule 609 Statewide Groundwater Baseline Sampling and Monitoring (draft as of this writing) includes a provision that the operator must sample at two sites located within two "groundwater sources or springs within a ½ mile radius of the proposed Oil and Gas Location". Draft Rule 609 goes on to impose several criteria for selection of sampling locations. Based on this study, and the uniqueness of the geologic formations identified, the study team believes that only two sites within ½ mile are not adequate due to the strong evidence of ground water migration to several thousand feet depth, in a highly heterogeneous, fractured rock geologic environment. Accordingly, the study team recommends that the operator of a proposed petroleum well, the County, or individual well owners sample all available water wells and utilized springs that are within about one mile of a proposed petroleum exploration or production well for major ions, BTEX, and the other constituents as stated in Rule 609 (e) (2). The chemical analyses should also test for hydrocarbon gases, as was done during this project. If hydrocarbon gases are detected, then additional testing should be conducted to determine if the gas is biogenic or thermogenic in origin. If insufficient water wells are located within one mile of the well, then the radius of investigation should be expanded.

5. Other recommendations.

The majority of oil and gas exploratory drilling programs include geophysical logging only from the bottom of the surface casing (typically 1,000 feet deep or more) through the depth of interest to the operator. The study team recommends that the County require that the uppermost depth range of the oil and gas borehole be geophysically logged before it is cased and cemented. As a minimum, the study team recommends a suite of logs consisting of induction, gamma ray, caliper, SP, and a density or porosity log. This requirement would provide valuable data on the upper portion of the borehole at each drilling site that can aid in filling data gaps in the detailed stratigraphy, water quality, and porosity characteristics of the Conejos Formation for use in assessing local impacts to ground water resources.

We also recommend that a geologist selected by the County be allowed access to drilling locations to periodically observe the drilling of future petroleum wells in the County and that drill cuttings from the Conejos Formation be collected, properly labeled, and made available to the County-selected geologist for examination. These drill cuttings would improve the interpretation of geophysical logs recorded in the Conejos Formation.

The County should also work with State legislators to develop regulations that would require disclosure of mineral rights during real estate transactions. Potential buyers of real estate should be advised of "split estate" situations where the mineral rights are severed from surface rights. It should be relatively easy to determine if severed mineral rights are held by the Federal or State government, and whether those mineral rights are leased at the time of the real estate transaction. Unpatented mining claims on lands with Federal mineral rights also could be disclosed at that time to provide potential buyers of real estate. If the severed mineral rights are privately held, it may be difficult to ascertain exactly who owns the mineral rights, but at least the buyer would be aware that the property of interest is a split estate.

Another recommendation involves both education and improvement of the water-quality database. We recommend that the County encourage the school districts to include water-quality education, especially ground water, in their curriculum. As part of this effort, an on-going program to periodically test wells and springs for field parameters (e.g. temperature, pH, and conductivity) would provide educational opportunities for students and help to develop a long-term, basic, water-quality baseline for the County. A potential program that might assist in the development of a program of this type is the River Watch of Colorado, which is partnered with the Colorado Watershed Assembly and Colorado Division of Parks and Wildlife (http://www.coloradoriverwatch.org). The County could also encourage graduate students at universities to do their thesis on the hydrogeology of the area. Grants or stipends would be ideal, but even in-kind support (e.g. housing) might entice students to conduct their research in the area.

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13.0 ABBREVIATIONS USED IN THE REPORT

COGCC	Colorado Oil and Gas Conservation Commission
CDWR	Colorado Division of Water Resources
COGA	Colorado Oil and Gas Association
SFC	San Francisco Creek
OWC	Old Woman Creek
RGDSS	Rio Grande Decision Support System
UTM	Universal Transverse Mercator coordinate system
TD	Total depth of well
DST	Drill stem test
MCL	Maximum contaminant level
TDS	Total dissolved solids concentration
BTEX	Organic hydrocarbon compounds benzene, toulene, ethylbenzene, and xylene
mg/L	Concentration in milligrams per liter
^{o}C	Temperature in degrees Celsius
gpm	Gallons per minute
cm/sc	Centimeters per second
ft/day	Feet per day
Q	Pumping rate
ac-ft/yr	Acre-feet per year
K	Hydraulic conductivity (in this report the terms permeability and hydraulic conductivity are the same, although in a strict sense permeability is an intrinsic property of the rock, and hydraulic conductivity, in addition, includes factors for the specific gravity and the viscosity of the fluid moving through the rock)
T	Transmissivity (ease or difficulty with which water can flow through the entire saturated thickness of an aquifer)
m	Saturated thickness
Sc	Specific capacity (pumping rate in gallons per minute from a pumping test divided by the feet of drawdown at that pumping rate)

CERTIFICATE OF ENGINEER

RIO GRANDE COUNTY HYDROGEOLOGIC STUDY

The team that prepared this study included the following participants: Davis Engineering Service, Inc.: John Allen Davey, P.E. and Clinton Phillips; GeoLogical Solutions: Robert Kirkham; and HRS Water Consultants, Inc.: Eric Harmon, Eric Saenger, and Jimmy Schloss.

With the exception of Sections 1.0 and 9.0, which were drafted by Mr. Davey, this study was conducted and the report was prepared by technical members of GeoLogical Solutions and HRS Water Consultants, Inc. Mr. Davey assisted with the review and assembly of the report and coordinated the efforts of team members to meet the objectives of the study. Mr. Phillips provided drafting and geographic information system mapping.

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