Hydrogeologic Characterization of the Carrizozo Soil and Water Conservation District

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OPEN-FILE REPORT

Open-File Report 640—Hydrogeologic Characterization of the Carrizozo Soil and Water Conservation District

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EXECUTIVE SUMMARY

The Carrizozo Soil and Water Conservation District (CSWCD), located in New Mexico's northern Chihuahuan Desert, is an arid region with no perennial rivers. As a result, groundwater is the sole source of water for the region's agricultural, commercial, and domestic users. To better understand and protect these vital groundwater resources, the CSWCD funded this research to conduct an initial hydrogeologic inventory and analysis of existing groundwater information.

Data for this study were compiled from various sources, including drilling logs, pump tests, geologic maps, geochemical data from state and federal databases, geophysical records from deep wells, and other published research. Based on this information, we developed a hydrogeologic framework for the region. Additionally, a monitoring network of 11 wells was established to measure future groundwater levels and track changes over time.

The study area was divided into five subregions based on differences in regional geology: Sierra Blanca Basin, Jicarilla Intrusion Zone, Gallinas Mountains, Pecos Slope, and Chupadera Mesa. The Sierra Blanca Basin, found in the southwestern region of the study area, is a structural basin that heavily impacts groundwater flow. Water is forced to the surface by lower-permeability rocks at the basin's boundary. Older brines are brought to the surface, and they influence the groundwater chemistry at the basin's perimeter. Precipitation recharges the aquifers through the igneous rocks in the Sacramento Mountains and along arroyo channels following monsoon events.

The Jicarilla Intrusion Zone and Gallinas Mountains subregions are dominated by igneous intrusions that caused significant warping of the aquifer units. Along the base of these intrusions, deeper aquifers of the Yeso, Glorieta, and San Andres Formations, which are typically targeted by wells farther into the basin, are forced to the surface, allowing for more rapid recharge.

The Pecos Slope subregion, on the east side of the study area, is composed of more gently sloping aquifers that are less impacted by faulting and folding. Water in this subregion flows east, away from the Tularosa Basin and toward the Pecos River. The primary aquifer in this area is the Yeso Formation; the San Andres and Glorieta Formations are closer to the surface and less likely to be saturated.

The Chupadera Mesa subregion covers most of the western portion of the study area. This subregion has large, buried faults that uplift Chupadera Mesa to the west. There are very few well logs in the area, and little is known about the groundwater system here, but the lower Permian units are likely the primary aquifers in the area.

Looking east toward Carrizozo, New Mexico, above the Carrizozo lava field. *Photo by Fernando Najera*

INTRODUCTION

PROJECT BACKGROUND AND PURPOSE

The Carrizozo Soil and Water Conservation District (CSWCD) encompasses a diverse, geologically complex landscape in New Mexico's northern Tularosa Basin. The agency's mission is to promote responsible stewardship of natural resources by increasing conservation awareness and providing education, technical support, and financial assistance to residents within the district. One of the region's most significant and long-standing uncertainties has been the availability and sustainability of its groundwater resources.

To address this concern, CSWCD secured funding for the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) to conduct an initial hydrogeologic characterization of the area. The primary objective of this effort was to compile a comprehensive inventory of groundwater resources, including data from drilling logs and pump tests, geologic mapping, geochemical records from state and federal databases, and geophysical data from deep wells and previous studies. The resulting data compilation is a foundation for identifying key aquifers, evaluating groundwater availability, and guiding future research and resource management.

NMBGMR was asked to develop a preliminary summary of the region's hydrogeology using these data. This includes identifying potential aquifer units, interpreting geologic maps to infer subsurface structure, and evaluating how groundwater may flow through the various rock formations.

A key project component involved launching a groundwater-level monitoring network across the district. The network was proposed to include at least 10 sites, with continuous data loggers installed in at least five wells. This network monitors long-term groundwater trends and provides local users with information on the condition of their aquifers. The success of this initiative depends largely on community collaboration, particularly through access to private wells for monitoring purposes.

All data compiled for this project are summarized in this report and made available for public access via Google Earth (.kmz files)[1] and an interactive web map (https://weaver.newmexicowaterdata.org/groundwater).

DESCRIPTION OF THE STUDY AREA

The study area spans approximately 2,000 square miles and encompasses several distinct physiographic features. It lies within the northern portion of the Tularosa Basin, in the Chihuahuan Desert. This area receives annual precipitation ranging from around 10 inches in Carrizozo to 23 inches in the mountains surrounding the basin. The Tularosa Basin is a fault-bounded basin characterized by a down-dropped valley floor relative to the surrounding mountain ranges. The basin is flanked by north-south-trending normal faults: the Alamogordo fault to the east and the San Andres and Chupadera faults to the west. This structural configuration forms a classic *horst and graben* system, where elevated fault blocks (horsts) flank a subsided central block (graben). In this case, the Sacramento Mountains represent the eastern horst, the Tularosa Basin floor forms the graben, and the San Andres Mountains and Chupadera Mesa make up the western horst (Cather, 2009).

The northern Tularosa Basin also features significant igneous activity with prominent surface exposures. Sierra Blanca Peak—the highest mountain surrounding the basin and located just southeast of the study area—is composed of Oligocene volcanic rocks (Thompson, 1972) and Tertiary igneous intrusions (Mamer et al., 2014). One of the most striking volcanic features is the Carrizozo lava flow. This 5,000-year-old basalt flow stretches about 45 miles through the basin's center, making it one of the youngest basaltic flows in New Mexico (Dunbar, 1999).

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1   Google Earth files are available for download at https://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=640.

Northeast of Carrizozo, in the central part of the study area, multiple igneous intrusions have uplifted the surrounding sedimentary units, forming laccoliths. These intrusions are exposed at the surface as the Jicarilla Mountains, Gallinas Mountains, and Lone Mountain (Budding, 1964; Ryberg, 1968).

East of Corona, outside the Tularosa Basin, the geologic strata dip gently to the east in relatively flat-lying beds that have valleys incised by fluvial river systems.

The official boundary of the CSWCD is complex and has been simplified for the purposes of this study (Fig. 1). The district boundary intersects the Gallinas Mountains in the northwest and extends about 15 miles east of Corona in the northeast. From there, it runs south, approximately 15 miles east of the Jicarilla Mountains, continuing to the western edge of the Capitan Mountains. The boundary then follows the ridgeline of the Sacramento Mountains southward. The southern boundary encompasses the northern edge of the Three Rivers drainage, crosses the Godfrey Hills, and cuts through the middle of the Carrizozo lava flow. To the west, the district includes the western margin of the Tularosa Basin and parts of Chupadera Mesa.

Study Area Subregions

For this report, the study area is divided into five distinct subregions based on topographic and geologic features that influence hydrogeology: Sierra Blanca Basin, Jicarilla Intrusion Zone, Gallinas Mountains, Pecos Slope, and Chupadera Mesa (Fig. 1). These subdivisions provide a framework for describing the region's groundwater systems.

Sierra Blanca Basin

The southeastern region of the study area is dominated by a structural compression feature known as a *deformational basin*. Here, the rock units dip in a bowl shape, with Sierra Blanca Peak at the approximate center (southeast of the study area). This basin is unique because the Sierra Blanca volcanic field was intruded through its middle, leading to the basin being topographically higher in the middle. This causes older Cretaceous units like the Mancos Shale to be brought to the surface at the boundary of the basin structure, with younger units like the Cub Mountain and Sanders Canyon Formations remaining deeper in the middle of the basin (Fig. 2). A more detailed description of the hydrostratigraphic units can be found in the Results section of this report. The west side of the subregion is bisected by the north-south-trending Alamogordo normal fault, which has down-dropped the basin floor on the west side.

Jicarilla Intrusion Zone

The Jicarilla Mountains, found north of Carrizozo, are dominated by Tertiary intrusive igneous volcanics. These volcanic intrusions are known as *laccoliths*. These features form when a pocket of magma, or a *sill*, becomes trapped in the subsurface as the magma rises. As the sill continues to be filled with magma and expands, the rocks above it are slowly lifted and warped by the doming magma (Fig. 2). Over millions of years, the rock units above the intrusive laccoliths are eroded, exposing the solidified igneous rock below. Surrounding the laccoliths, the older sedimentary rocks that were lifted and warped are exposed at the surface. These igneous intrusions have caused significant faulting and warping in this area, bringing older rock to the surface at the base of the mountains before dipping under the younger Cretaceous rocks to the west.

Gallinas Mountains

The Gallinas Mountains, found in the northern part of the study area, are another Tertiary igneous intrusion. Like the Jicarilla Mountains, the Gallinas are an igneous intrusive laccolith that tilted and warped the older Permian sedimentary units. As a result, the Permian units crop out at high elevations on the flanks of the mountains before dipping to the south, and are found at greater depths in the basin.

Pecos Slope

The Pecos Slope covers much of the northeastern region of the study area. This subregion is dominated by relatively flat-lying Permian sedimentary units found east of the Jicarilla and Gallinas Mountains. These Permian units are composed primarily of marine sedimentary units, such as limestones, sandstones, shales, and evaporites, of the San Andres, Glorieta, and Yeso Formations. The geologic units tilt uniformly to the east.

Chupadera Mesa

Chupadera Mesa makes up the western portion of the study area. A north-south-trending normal fault runs through the area, down-dropping the Tularosa Basin to the east. On the surface, the area is primarily the Permian Glorieta and San Andres Formations, along with some Quaternary lava flows and sediments.
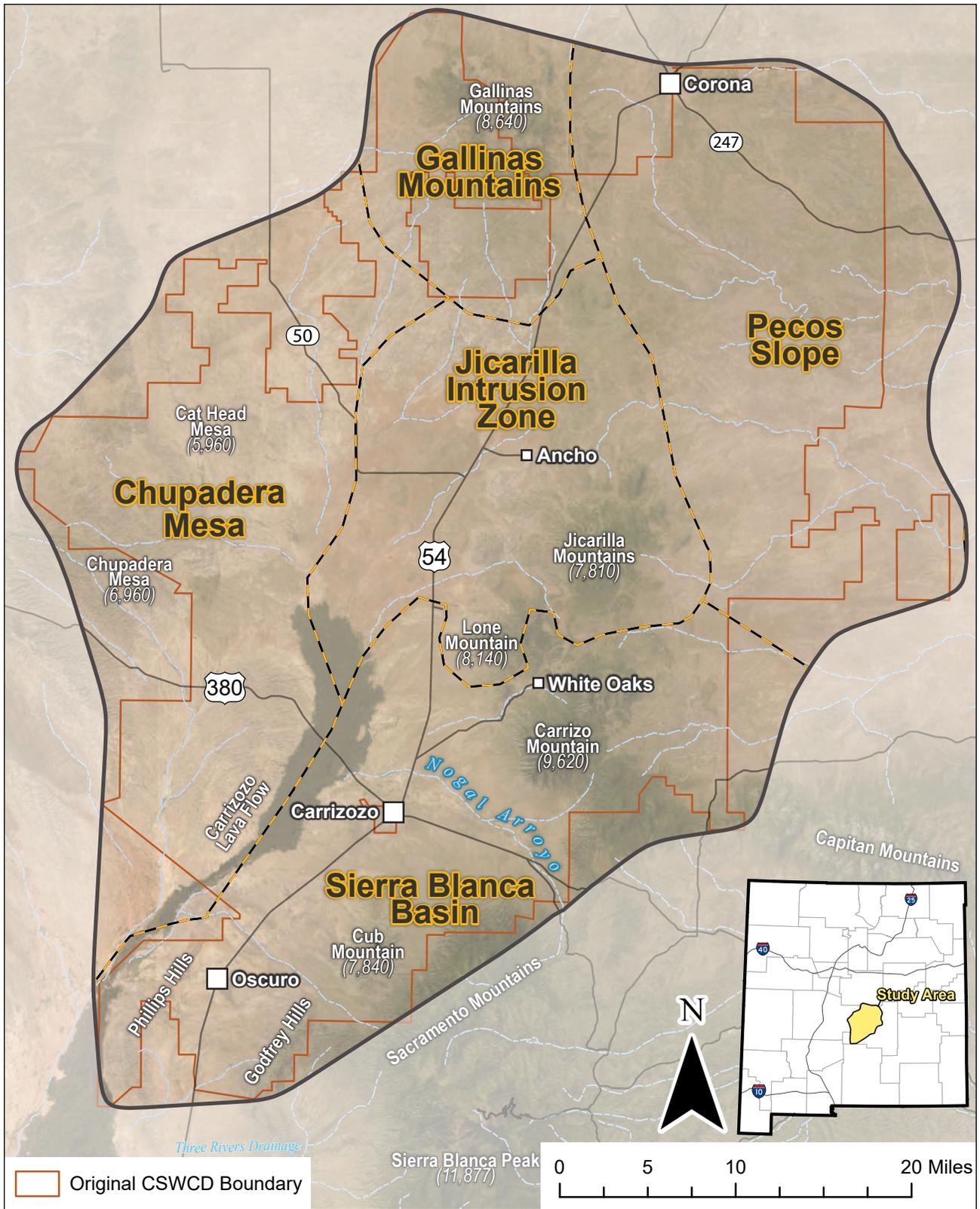
Figure 1. Topographic features in the study area. The dashed line marks the boundaries between the hydrogeologic subregions described in this report.
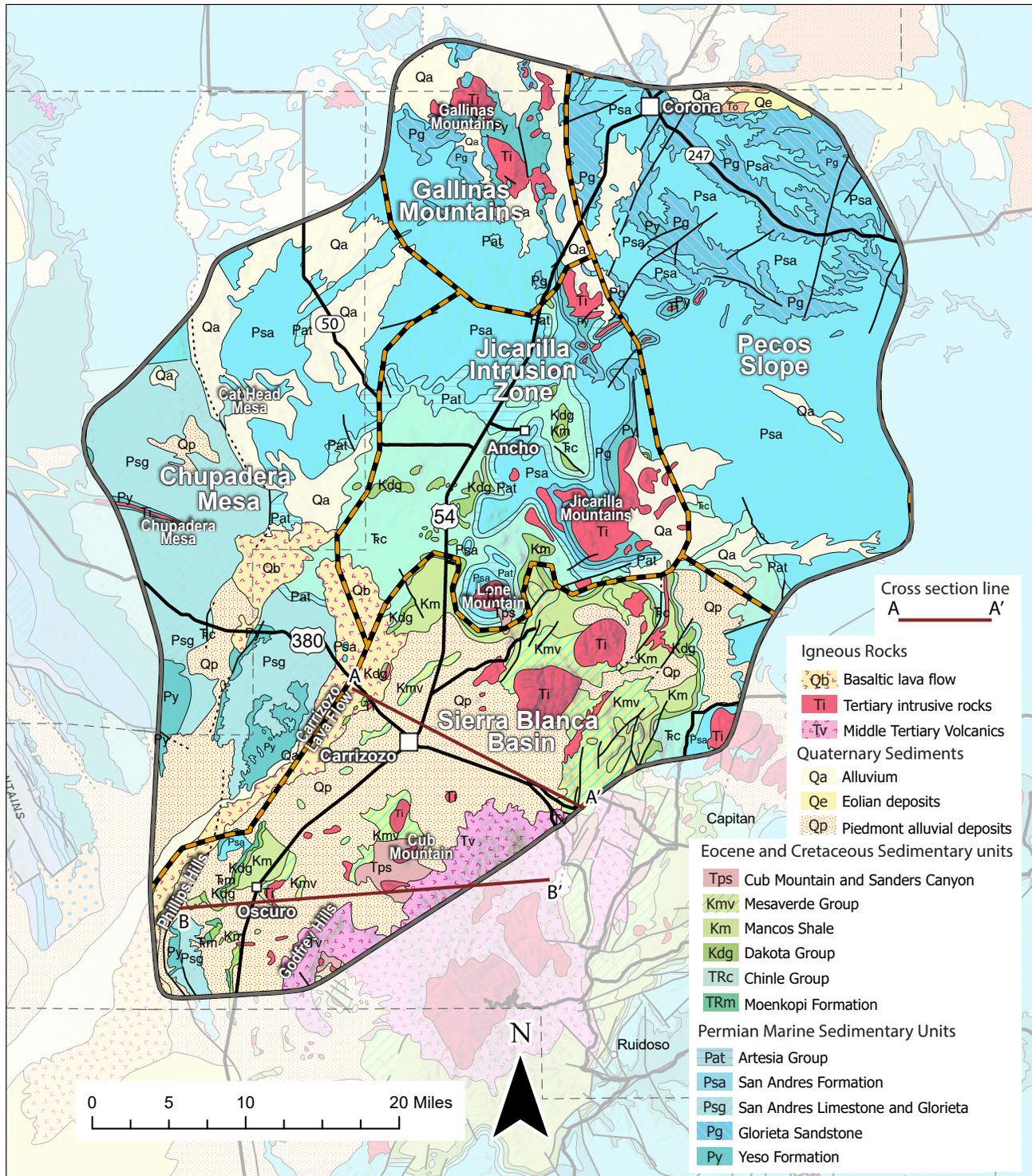
Figure 2. Geologic map of the study area. Cross-section lines labeled A–A´ and B–B´ are shown in Figure 21.

METHODS

CARRIZOZO SOIL AND WATER CONSERVATION DISTRICT GROUNDWATER-LEVEL MONITORING NETWORK

With the support of this initial funding, NMBGMR established a groundwater-level monitoring network within the CSWCD. Groundwater-level monitoring is a critical component of effective groundwater management because it directly measures changes in groundwater storage. These data can be used to evaluate groundwater flow patterns and assess how aquifers respond to both climatic variability and human activity.

To implement the network, NMBGMR and CSWCD contacted well owners across the district to request access for monitoring. Preference was given to unequipped wells without pumps because these are more likely to represent static water levels unaffected by active pumping. Additionally, these open wells allow for easier manual measurement and the installation of continuous monitoring instruments without interfering with pumping equipment.

The current monitoring network includes 11 wells distributed throughout the study area (Fig. 3). Six of these wells are equipped with pressure transducers that record water levels every 12 hours. Two additional wells use acoustic measurement devices, which take water level readings every 8 hours. The remaining three wells, which are actively pumped, are measured manually. NMBGMR staff will revisit these network wells annually to download data and collect manual calibration measurements. Manual measurements are obtained using an electric water level sounder in open wells and a steel tape in pumped wells. Data from this monitoring network are available on the New Mexico Water Data website (weaver.newmexicowaterdata.org/groundwater).

Where possible, well records were obtained from the New Mexico Office of the State Engineer (NMOSE). These records typically describe the lithology encountered during drilling and indicate the depth at which water was found—key details for identifying the aquifer tapped by the well. In cases where well records were unavailable, nearby well logs were used to infer similar hydrogeologic conditions.

The monitored wells are completed in a variety of geologic units across the district:

- **Three wells** east of Corona are completed in the Permian **Yeso Formation**.
- **One well** in the **Gallinas Mountains** is completed in the Permian **San Andres Formation**.
- **Two wells** in the **Jicarilla region** are completed in the Triassic **Moenkopi Formation**.
- **Five wells** are located within the Sierra Blanca Basin structural zone:
    - Two are completed in **Quaternary basin-fill deposits**.
    - Two are screened in **Late Cretaceous to Eocene clastic rocks**.
    - One is completed in the Cretaceous **Dakota Sandstone**.

A summary of each site, including formation, location, and instrumentation, is provided in Table 1.

DATA COMPILATION

Geologic Maps

Several detailed geologic investigations and mapping efforts have focused on various parts of the study area. Most of the high-resolution geologic mapping has been concentrated in the southeastern portion of the region (Smith and Budding, 1959; Weber, 1964; Rawling and Koning, 2009; Kelley et al., 2014; Koning et al., 2014). In addition, multiple smaller-scale studies have been conducted throughout the district (Budding, 1964; Kelly and Thompson, 1964; Perhac, 1964; Grainger, 1974; Newcomer and Shomaker, 1991; Cather, 2009). A regional oil and gas investigation by Broadhead and Jones (2004)

Table 1. Inventory of wells that are part of the monitoring network, the geologic formation in which the well is completed, and the type of monitoring being performed. ft bgs = feet below ground surface.

Site Location				Site Information				Site Geology	
Point ID	Easting	Northing	Elevation (ft)	Date measured	Depth to water (ft bgs)	Monitoring type		Geologic unit	Period
CZ-0001	458700	3777051	6,062	3/26/2025	192.91	Pressure transducer		Yeso	Permian
CZ-0002	461434	3775588	6,018	3/26/2025	318.42	Manual measurement		Yeso	Permian
CZ-0003	469332	3771464	5,574	3/25/2025	286.94	Acoustic datalogger		Yeso	Permian
CZ-0004	427283	3754692	5,893	3/25/2025	120.1	Manual measurement		Moenkopi	Triassic
CZ-0006	422871	3750930	6,062	3/25/2025	101.78	Pressure transducer		Moenkopi	Triassic
TB-0103	414590	3726763	5,232	5/21/2025	61.16	Pressure transducer		Dakota	Cretaceous
TB-0182	409901	3709188	5,489	5/21/2025	118.84	Manual measurement		Clastic rocks	Cretaceous
TB-0209	423618	3730769	5,632	3/26/2025	78.12	Pressure transducer		Gallup	Cretaceous
TB-0212	420513	3739190	5,601	3/26/2025	33.06	Pressure transducer		Quaternary	Quaternary
WL-0007	433303	3783247	7,228	1/22/2025	640.4	Acoustic datalogger		San Andres	Permian
WL-0323	427556	3722064	5,771	11/14/2024	27.5	Pressure transducer		Quaternary	Quaternary

provides valuable insights into the area's broader structural geology. For a statewide overview, the 1:500,000-scale geologic map of New Mexico (NMBGMR, 2003) offers generalized geologic coverage of the entire region.

Well Logs (NMOSE and OCD)

A total of 408 well drillers' logs were obtained from the NMOSE Water Rights Reporting System (WRRS; Fig. 4). These point of diversion (POD) logs were used to help identify and characterize the geologic units in which the wells were completed. Many of the logs also provide additional details, such as depth to water at the time of drilling, the intended use of the well, and pump capacities.

In addition, a spreadsheet of oil and gas wells within the project area was compiled using data from the New Mexico Energy, Minerals and Natural Resources Department's Oil Conservation Division (OCD; Appendix A[2]). The dataset includes URLs linking to scanned well logs and individual OCD well detail pages. Nineteen oil and gas wells were identified in the study area; of these, 18 were plugged and one was canceled. Most of the associated logs include detailed lithologic descriptions that document the complete stratigraphic sequence penetrated by the well, often reaching basement rock. These logs offer

valuable insights into the area's geologic structure and rock unit boundaries.

Pump test data were also acquired from the NMOSE database for six wells within the study area (Fig. 4). These tests provide information on aquifer properties and were used to further characterize the hydrogeologic units in which the wells were completed. Of the six wells tested, three are completed in the San Andres Formation, one in basin-fill deposits, one in the Yeso Formation, and one in Cretaceous clastic rocks. The results from these tests are compiled in a spreadsheet provided in Appendix A.

Geochemical Data

Geochemical data were compiled using the NMBGMR Data Integration Engine (https://github.com/DataIntegrationGroup/DataIntegrationEngine). This tool aggregates water quality data from multiple sources, including NMBGMR, the New Mexico Environment Department's Drinking Water Bureau (DWB), and the U.S. Environmental Protection Agency's (EPA) Water Quality Portal (WQP), which incorporates data from federal agencies such as the U.S. Geological Survey's National Water Information System (NWIS). Data from these sources were accessed via application programming interfaces (APIs) and compiled into a standard schema and format through the integration engine.

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2   Appendix A is available for download at https://geoinfo.nmt.edu/publications/openfile/details.cfml?Volume=640.
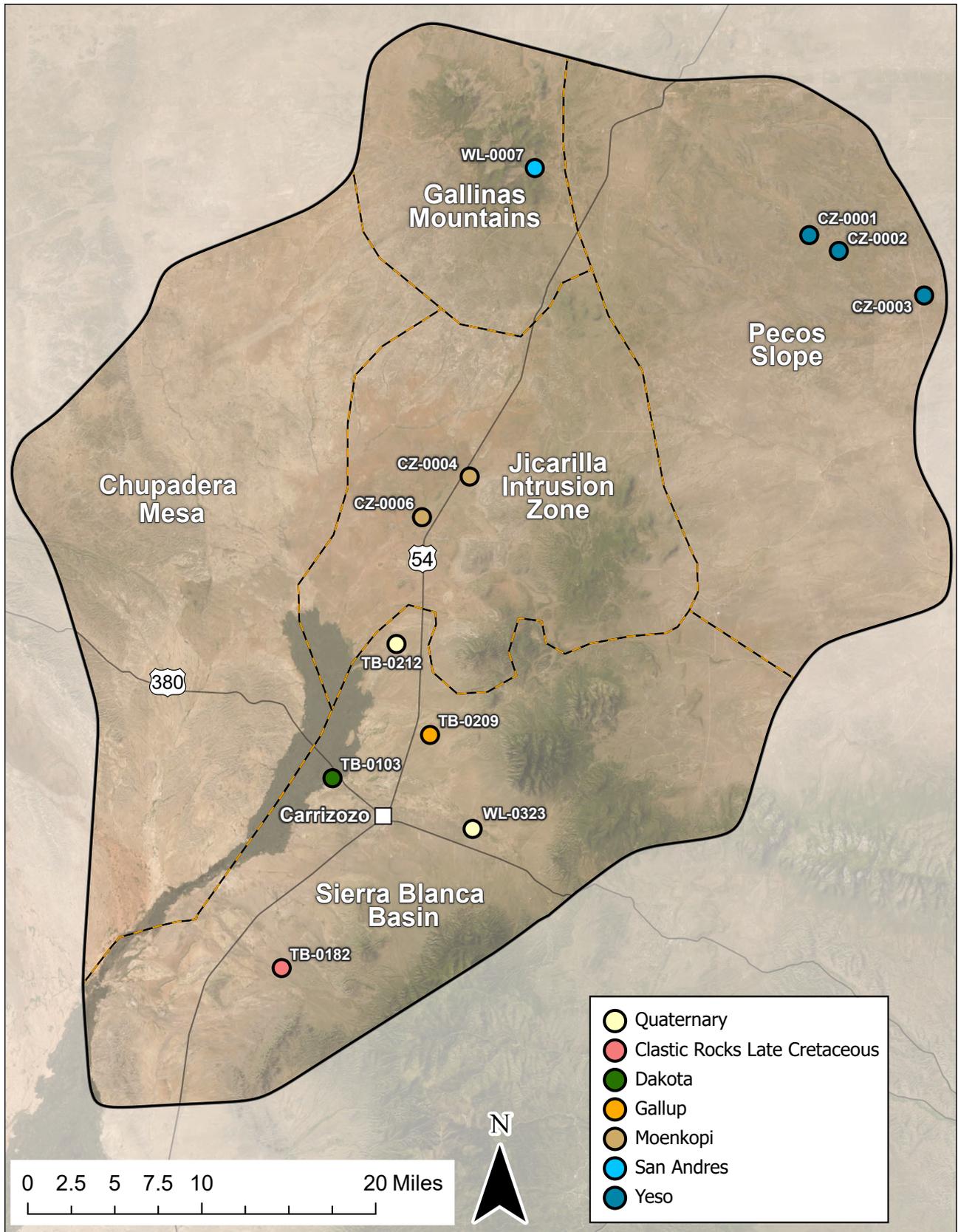
Figure 3. Locations of the selected wells in the monitoring network and the associated aquifer in which they are completed.
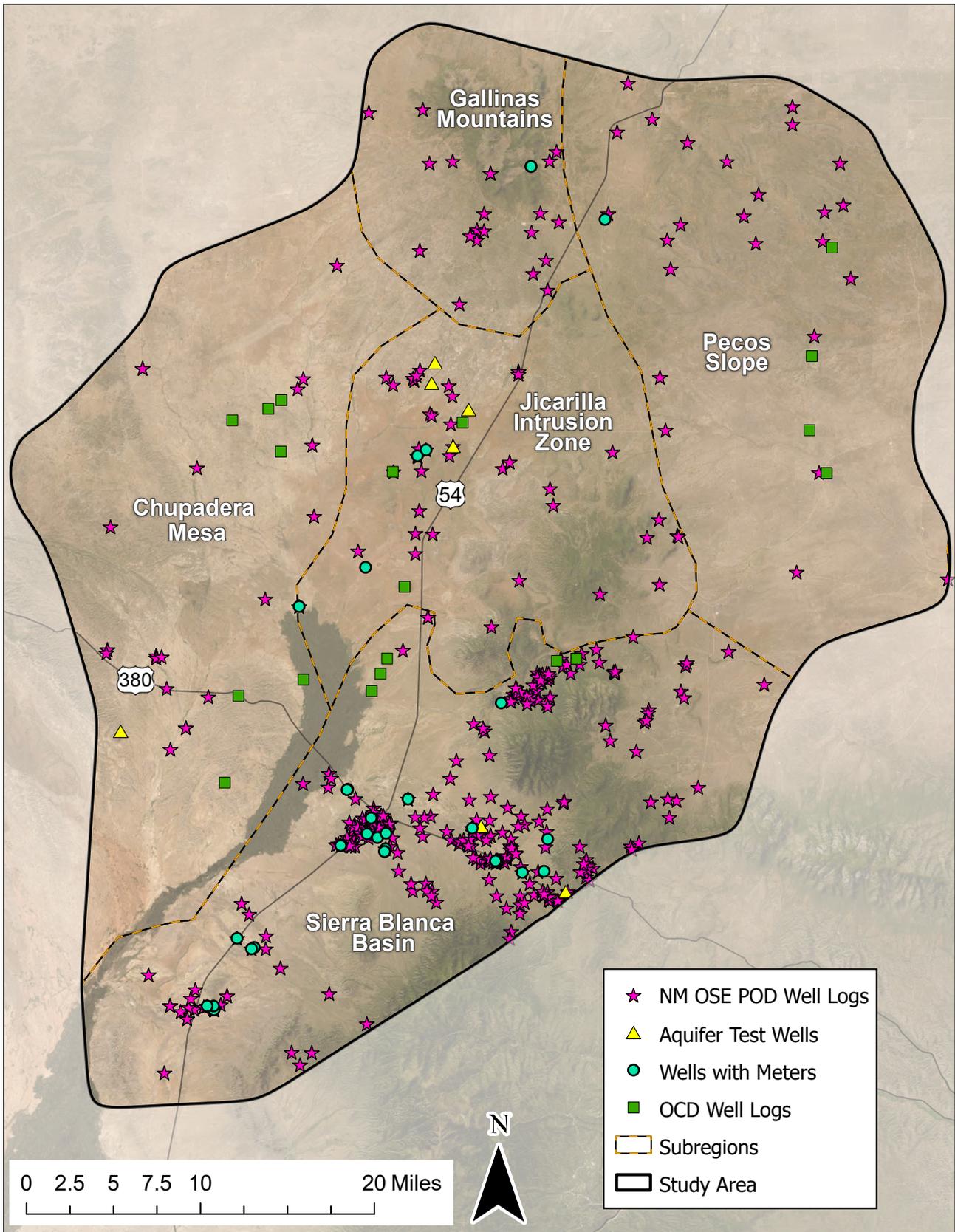
Figure 4. Locations of wells with New Mexico Office of the State Engineer points of diversion (NMOSE POD) logs, aquifer test data, or meters attached. Also shown are oil and gas wells with well records from the New Mexico Oil Conservation Division (OCD).

RESULTS

HYDROSTRATIGRAPHIC UNITS

The study area encompasses a diverse range of sedimentary and igneous rock formations that significantly influence groundwater occurrence and flow. The sedimentary rocks include carbonates (limestone and dolomite), evaporites (gypsum and anhydrite), and clastic deposits (conglomerate, sandstone, siltstone, and claystone), along with their unconsolidated or weakly cemented counterparts—gravel, sand, silt, and clay. Carbonate and evaporite units are restricted to older Paleozoic marine sequences, often exhibiting varied porosity and permeability. The igneous rocks in the region consist of both extrusive (lava flows) and intrusive bodies, including dikes, sills, laccoliths, and stocks (Mamer et al., 2014).

The following sections describe these rock units in stratigraphic order, from oldest to youngest, with a focus on hydrogeologically relevant characteristics, such as lithology, porosity, permeability, and potential for aquifer development. For reference, Figure 5 provides a schematic stratigraphic column showing the general succession of rock units from the Permian through the Oligocene.

Yeso Formation (Permian)

The Yeso Formation, approximately 1,300 feet thick, is primarily composed of red and yellow siltstone, gray limestone, and thinly bedded gypsum. Near its base, where it transitions into the Abo Formation, there is a brown sand and gravel layer that has been identified as a targeted aquifer south of Corona. The upper section of the Yeso contains interbedded gypsum, limestone, and red siltstone. Fractured limestone within the Yeso is a significant aquifer that represents the primary groundwater source east of Corona. Although the Yeso Formation is generally deeply buried across the study area, it is exposed at the surface where doming occurs around laccolithic intrusions in the Jicarilla and Gallinas Mountains. Hydraulic conductivity tests conducted near the study area report values of approximately 0.02 ft/day in the unfractured siltstones and gypsum beds, increasing to 0.6 and 1.5 ft/day in more highly fractured zones (Wasiolek, 1991).

San Andres Formation (Permian)

The San Andres Formation comprises approximately 1,000 feet of interbedded limestone, sandstone, dolomite, gypsum, and anhydrite beds. Near its base, where it transitions into the Yeso Formation, the Glorieta Sandstone (a subunit of the San Andres Formation) forms a thin yet productive aquifer where it is saturated. Groundwater flow within the San Andres is primarily through fractures that have been enlarged by dissolution processes. This formation is a major aquifer in the region, particularly west of Ancho and south of the Gallinas Mountains. Hydraulic properties derived from pumping tests in the area and surrounding regions show significant variability, with hydraulic conductivity values ranging from 0.02 to 10 ft/day (Romero and Silver, 2009).

Clastic Rocks from the Permian, Triassic, and Cretaceous Periods

These formations consist of several discontinuous units that are generally aquitards and do not provide substantial water. The lower section includes the Grayburg Formation and the Artesia Group, primarily composed of fine-grained sandstones, siltstone, gypsum, shale, and dolomite. Regional modeling studies have described this unit as having a very low horizontal hydraulic conductivity of about 0.0001 ft/day, reflecting its function as an aquitard (Romero and Silver, 2009). Above this, the Moenkopi Formation is characterized by reddish-brown, fine- to coarse-grained sandstone and mudstone. It is well-cemented, likely impeding groundwater flow. The Dakota Sandstone is relatively thin and consists of fine- to very coarse-grained sandstone; it is also well-cemented. Hydraulic tests of wells completed in the Dakota Sandstone east of the study area indicate

hydraulic conductivity values ranging from 0.2 to 5.3 ft/day (Darr et al., 2014). Higher in the Dakota, siltstone and shale-mudstone beds increase as the formation grades into the overlying Mancos Shale. Due to their well-cemented nature, groundwater flow in these units is limited, occurring mainly through fractures and joints or along bedding planes.

Mancos Shale (Late Cretaceous)

The Mancos Shale is a marine unit dominated by thick gray to yellow shale layers, which form an aquitard. It is exposed at the surface west of Carrizozo, cropping out along the base of the Sierra Blanca Basin.
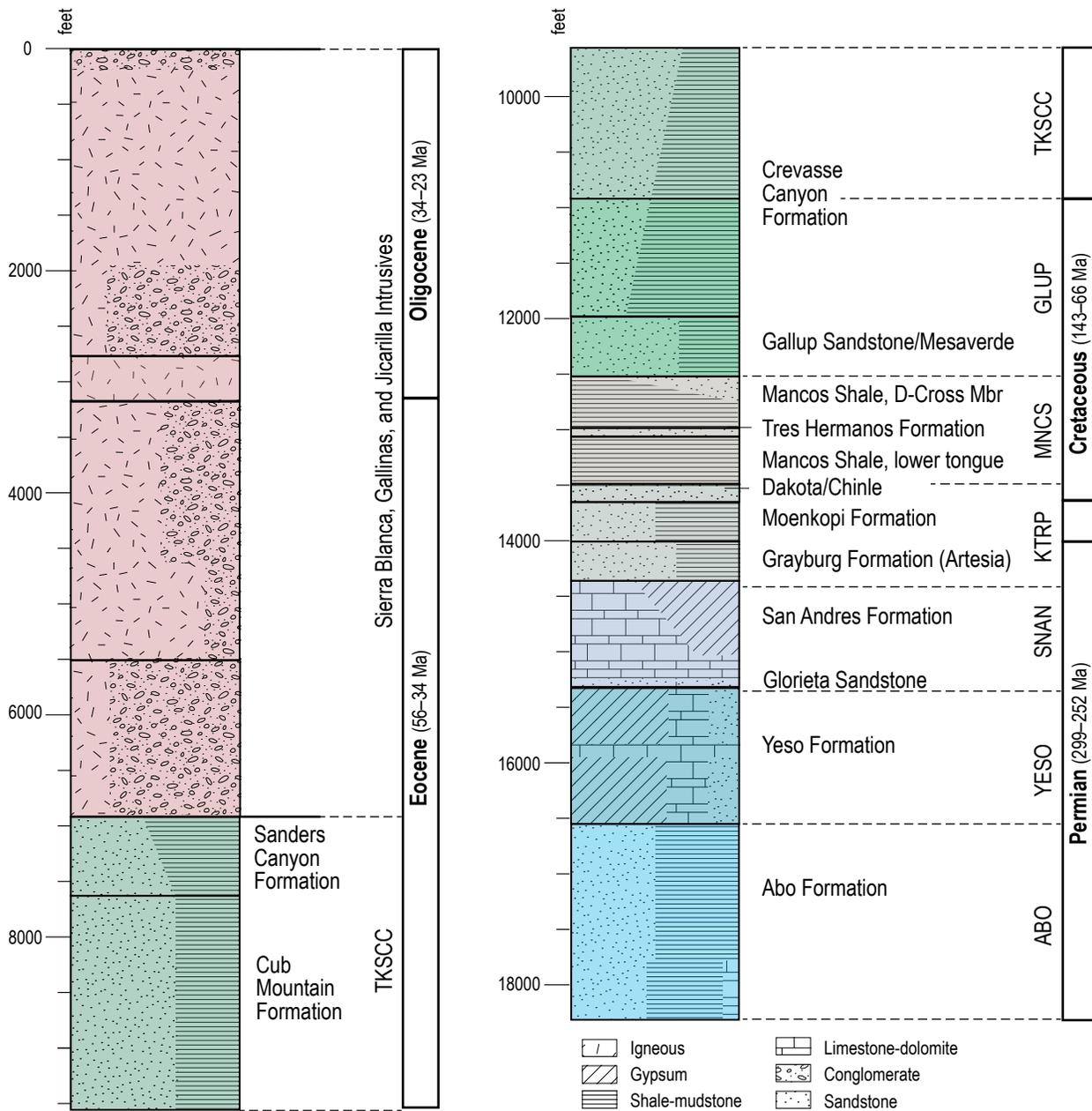

Figure 5. Schematic stratigraphic section illustrating all the rock units in the study area (modified from Mamer et al., 2014). Approximate formation thickness is shown in feet on the left.

Gallup Sandstone and Lower Crevasse Canyon Formation (Late Cretaceous)

The Gallup Sandstone consists of laterally extensive tongues of white and yellow sandstone, interbedded with gray shale layers. Due to this shale layering, it likely functions as a poor aquifer. The lower Crevasse Canyon Formation is primarily composed of yellow, very fine- to medium-grained river channel deposits, along with clayey and silty floodplain sediments. Interbedded coal and carbonaceous mudstone beds occur within swamp or floodplain mudstones. This formation is estimated to have a relatively low hydraulic conductivity, approximately 0.01 ft/day (Mamer et al., 2014).

Clastic Rocks, Late Cretaceous and Eocene (upper Crevasse Canyon, Cub Mountain, and Sanders Canyon Formations)

These units consist of weakly cemented floodplain and channel-fill deposits, primarily sandstone and siltstone. Due to their poor consolidation, they generally exhibit higher hydraulic conductivity, modeled between approximately 0.1 and 2 ft/day (Mamer et al., 2014). These sediments form productive aquifers, especially east of Carrizozo.

Igneous Rocks

The study area contains numerous igneous formations, with the Sierra Blanca volcano being the largest. The Jicarilla and Gallinas Mountains also host significant intrusive peaks. Assessing the hydraulic properties of these igneous units is challenging; groundwater flow, if present, likely occurs through fractures and faults within these rocks. Igneous intrusions can act both as conduits for groundwater flow and as barriers, depending on their fracture connectivity and structure; as a result, estimating their hydraulic parameters is difficult (Mamer et al., 2014). Pump test data from these units show extreme variability, ranging from 0.02 to 3.2 ft/day (Miller et al., 2007; Romero and Silver, 2009).

Quaternary Alluvium

The Quaternary alluvium is composed of weakly to well-consolidated sediments dominated by sands and gravels. These deposits accumulate in the basin's flatter areas and, when saturated, serve as excellent aquifers because water moves rapidly through their coarse materials compared to the deeper sedimentary units. Modeled hydraulic conductivity for these alluvial deposits ranges from 5 to 20 ft/day (Romero and Silver, 2009). The alluvium is generally thinner in this region than in areas farther south near Alamogordo, ranging from 50 to 300 ft thick.

PRECIPITATION AND GROUNDWATER RECHARGE

Groundwater recharge refers to the process by which water from sources such as rainfall, snowmelt, or streamflow infiltrates the ground and replenishes aquifers. In the CSWCD, where no perennial rivers exist, groundwater is the sole water source, making it critical to understand how recharge occurs and the factors that influence it.

The primary source of precipitation in the Tularosa Basin and surrounding mountains is the North American Monsoon. This seasonal weather pattern brings moist air northward from the eastern Pacific, Gulf of California, and Gulf of Mexico, resulting in intense afternoon thunderstorms, especially during July, August, and September. These summer storms account for over half of the region's annual precipitation. In contrast, the months from November through April are typically much drier. During this period, frontal systems bring snowfall to the higher elevations that border the basin (National Weather Service Climate Prediction Center, 2003). Precipitation patterns strongly correlate with elevation: as moist air is forced upward by mountainous terrain, it cools and condenses, leading to greater rainfall and snowfall at higher elevations (Mamer et al., 2014; Fig. 6).

Recharge typically occurs in two ways: diffuse recharge and focused recharge. Diffuse recharge happens primarily at higher elevations, where sustained precipitation or snowmelt can infiltrate the ground before being lost to evaporation or runoff. Snowmelt is especially effective because its gradual, prolonged release allows deeper infiltration. Focused recharge, on the other hand, tends to occur at lower elevations along arroyo channels. During intense monsoon storms, rainfall often exceeds the soil's infiltration capacity, generating runoff that concentrates in arroyos. This runoff can then infiltrate further into the basin, where conditions allow.

Previous studies have attempted to quantify recharge in the Sierra Blanca Basin. Waltemeyer (2001) used a basin-climatic characteristic model

to estimate arroyo discharge into the basin based on catchment area and average precipitation tied to elevation (Fig. 6). Mamer et al. (2014) employed a Darcy flow approach using estimated hydraulic properties of the aquifers, interpolated aquifer thickness, and the hydraulic gradient of the regional water table to estimate groundwater movement and recharge.

WATER CHEMISTRY ANALYSIS

Major Ion Chemistry and Water Type

Plotting major cation (calcium [Ca], magnesium [Mg], sodium [Na], potassium [K]) and anion (bicarbonate [HCO_3], carbonate [CO_3], sulfate [SO_4], chloride [Cl]) concentrations on a Piper diagram reveals distinct water types across the study area's subregions (Fig. 7). Different aquifers and groundwater flow pathways influence water chemistry, imparting unique geochemical signatures to each subregion.

Water samples from the Pecos Slope cluster tightly in the upper portion of the Piper diagram, characterized by calcium sulfate-rich chemistry indicative of chemical weathering from carbonate rocks. In contrast, waters from the Sierra Blanca Basin are richer in calcium chloride and display a
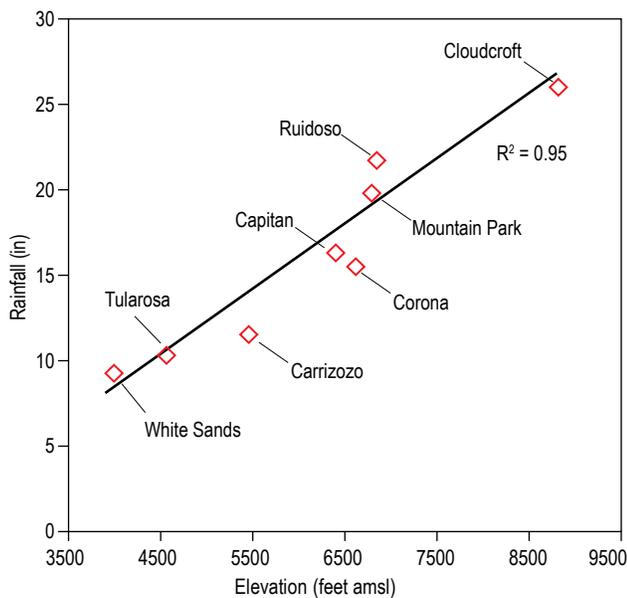

Figure 6. Average annual precipitation versus elevation for eight weather stations in and around the Tularosa Basin. Total annual precipitation increases linearly with elevation. This relationship between elevation and rainfall can be used to interpolate rainfall at other locations based on elevation. amsl = above mean sea level.

broader range, including mixing with sodium and potassium and elevated chloride concentrations.

The major water chemistry of the region was compared to the EPA National Primary and Secondary Drinking Water Standards (**https://www.epa.gov/ground-water-and-drinking-water/national-primary-drinking-water-regulations**). Primary standards are set for contaminants of known health concern. In contrast, secondary standards typically refer to naturally occurring contaminants that aren't necessarily harmful, but that can affect the water's odor, color, and taste. These drinking water standards are only enforceable in public water systems, but they provide a reference point for the relative water quality in private wells.

Total Dissolved Solids

Total dissolved solids (TDS) measurements indicate the sum of the cations and anions mentioned in the previous section, providing a measurement of water quality. In the study area, older brines are brought to the surface and mix with the shallow aquifer system via the faulting that bounds the Tularosa Basin. These brines, rich in sulfate, are considerably older than water in the shallow aquifer system and have higher TDS values. TDS concentration data spanned the period from 1906 to 2024 and included 135 observations from 129 wells. All TDS measurements exceeded the EPA secondary standard of 500 milligrams per liter (mg/L), with the lowest recorded value being 598 mg/L (Fig. 8). Twenty wells showed TDS concentrations below 1,000 mg/L, primarily located south of Carrizozo and east of Cub Mountain. Among the three wells with TDS levels exceeding 5,000 mg/L, two are situated just west of Phillips Hills and one is near Carrizozo. For wells with multiple observations, the most recent sample is plotted. In this region, the elevated TDS levels are likely driven by the high sulfate content of the water, as the chloride concentrations are fairly low. Elevated sulfate concentrations are not an immediate health concern but can cause intestinal distress.

Arsenic

Arsenic concentration data were collected from 28 wells between 1993 and 2024. Arsenic data were available from a limited number of wells in the Sierra Blanca Basin. Among the 64 observations across the study area, none exceeded the EPA primary standard of 0.01 mg/L; however, six samples collected in

2010 from the southern portion of the study area were exactly at this limit (Fig. 9). For wells with multiple observations, the most recent sample is plotted. Arsenic is a carcinogen, and long-term consumption of water containing arsenic above the standard can lead to serious health problems.

Chloride

Chloride concentration data included 185 observations collected from 174 wells between 1903 and 2012. Chloride concentrations were below or well below the EPA secondary limit of 250 mg/L in the Gallinas and Corona areas and the draws south of Carrizozo. However, many wells—especially in the Sierra Blanca Basin—exceeded this suggested limit by two to three times. Elevated chloride levels were also observed west-northwest of Carrizozo (Fig. 10). For wells with multiple observations, the most recent sample is plotted. While these elevated concentrations may cause a salty taste in the water, they do not pose health risks.

Fluoride

Fluoride concentration data collected from 1906 to 2024 included 139 observations from 105 wells. Two wells, located within a few yards of each other in Red Cloud Canyon northwest of Gallinas, showed fluoride concentrations above the 2 mg/L secondary limit (2.13 mg/L and 2.14 mg/L; Fig. 11). However, these concentrations have been variable over time and have occasionally tested below the limit. No wells were near the primary limit of 4 mg/L. Elevated fluoride levels are common in volcanic rocks due to the dissolution of hydrogen fluoride gases into the surrounding rocks. For wells with multiple observations, the most recent sample is plotted.

Nitrate

Nitrate concentration data collected between 1906 and 2009 consisted of 65 observations from 56 wells. Most wells exhibited nitrate concentrations below the primary limit of 10 mg/L; however, 14 wells showed elevated levels (Fig. 12). Several wells had concentrations roughly double the limit, while one well measured five times the limit (53 mg/L) and another reached 26 times the limit (261 mg/L). Only four wells had nitrate measurements and well completion depth data, but no clear relationship was observed between depth and nitrate concentration. For wells with multiple observations, the most recent sample is plotted. Elevated nitrate levels are typically due to human-derived sources such as fertilizer, manure, and septic tanks. Nitrate concentrations above the primary limit can pose serious health risks, particularly for infants.

Uranium

Uranium data available in the study area were collected between 1982 and 2024 and included 36 observations from 23 wells. No wells sampled for uranium exceeded the EPA primary standard of 0.03 mg/L; however, two wells north of Carrizozo showed elevated concentrations of 0.02 mg/L (Fig. 13). These wells are completed in the Mancos Shale and Moenkopi Formation. For wells with multiple observations, the most recent sample is plotted. Although these levels are below regulatory limits, it is important to note that any amount of uranium in drinking water carries some health risk.

Sulfate

Sulfate concentration data collected between 1903 and 2012 included 187 observations from 179 wells. Of the 179 wells sampled for sulfate in the study area, only five had concentrations below the EPA secondary standard of 250 mg/L (Fig. 14). Two of these wells are located at Ancho, one just southeast of Carrizozo, and two at Oscuro. Most sulfate measurements exceeded the limit by about two times, and four wells showed concentrations as much as ten times higher. The highest sulfate levels were observed in the hills west of the lava flow in Socorro County and at the southern tip of the study area, with the maximum concentration recorded southwest of Corona (3,200 mg/L). For wells with multiple observations, the most recent sample is plotted. Elevated sulfate levels can cause a salty taste in water, and very high levels may lead to gastrointestinal discomfort, although some individuals may acclimate over time. High sulfate concentrations typically indicate prolonged water residence time in carbonate aquifers rich in gypsum, such as the Yeso and San Andres Formations. The observed increase in sulfate concentrations downslope from the Sacramento Mountains suggests that recharge occurs in areas with less carbonate content and that sulfate levels rise as groundwater flows into the basin.

Silica

Silica concentration data were collected between 1984 and 2014 from 83 wells (Fig. 15). Although the EPA has not established a secondary standard

for silica, it is a valuable indicator for tracing groundwater flow paths. Water that interacts with volcanic rocks tends to weather and dissolve silica, imparting a distinctive chemical signature. The highest silica concentrations in the study area are found in the Sierra Blanca Basin, consistent with the predominantly volcanic composition of the mountains to the southeast. In contrast, silica levels in the Chupadera Mesa subregion to the west are considerably lower, suggesting a different groundwater source for that part of the basin. The northern Pecos Slope subregion exhibits slightly elevated silica concentrations, indicating some groundwater recharge through the igneous formations of the Gallinas Mountains. For wells with multiple observations, the most recent sample is plotted.

Groundwater Contamination

Several active groundwater contamination sites exist within the study area, most related to leaking petroleum storage tanks in Carrizozo. Additionally, the Cimarron Mining Corp. Superfund site, located in Carrizozo, was formerly a mill that utilized cyanide for the extraction of precious metals, resulting in soil and groundwater contamination.

WATER USE

Estimating water use at a local scale is challenging because New Mexico's water use data are generally estimated only by county or watershed (Valdez et al., 2024), and the study area often overlaps parts of these larger units. The most comprehensive quantitative groundwater use data come from metered wells reported to the New Mexico Office of the State Engineer (NMOSE) via the Water Rights Reporting System (WRRS). However, only 34 wells with meters exist within the study area, representing fewer than 5% of the known wells, which makes quantitative estimates based on these data an underestimate.

Qualitative water use data were based on point of diversion (POD) data collected from the NMOSE WRRS (Fig. 16). There were 669 PODs in the study area, with well completion depths and categorized well uses dating back to 1873. Because permits for failed exploratory wells are sometimes not completed, the NMOSE POD database was filtered for wells with completion dates to determine if a well

was indeed drilled at a location. The data were also aggregated to the primary uses shown in Figure 16.

The vast majority of wells are for livestock use only (226) and single-home domestic use only (209). Similar types of use were grouped to visualize the many uses and avoid an overwhelming number of categories (Fig. 17). Categories were organized according to New Mexico Statutes Annotated (NMSA) § 72-12-1:

- **Livestock:** 72-12-1 livestock watering, non-72-12-1 livestock watering
- **Domestic:** 72-12-1 domestic one household, 72-12-1 domestic and livestock watering, 72-12-1 multiple domestic households, non-72-12-1 domestic and livestock watering, non-72-12-1 domestic one household
- **Commercial:** Commercial, 72-12-1 sanitary in conjunction with a commercial use

The following uses were not grouped with other uses:

- Irrigation
- Municipal (city- or county-supplied water)
- Monitoring well
- Exploration
- Mining, milling, or oil

The number of new livestock wells in the study area spiked in the 1940s and 1950s before quickly falling off in the 1960s (Figs. 18 and 19). The annual number of new livestock wells was fairly consistent for the second half of the 20th century and into the 21st century. Domestic well permitting jumped in the 1980s and peaked in the 2000s. The decade with the most new PODs was the 2000s, when 92 domestic wells, 25 livestock wells, 6 irrigation wells, and 3 commercial wells were drilled. Notably, while new irrigation wells were drilled throughout the period of record, there was a relatively significant increase in the 1970s before tapering off to zero in the first part of the 2020s (Figs. 18 and 19). The average depth of wells drilled throughout the area has also increased since the 1980s. While this could indicate declining water levels, it could also be the result of wells being drilled in new areas with deeper available aquifers or improvements in drilling techniques that allow deeper wells to be installed (Fig. 20).
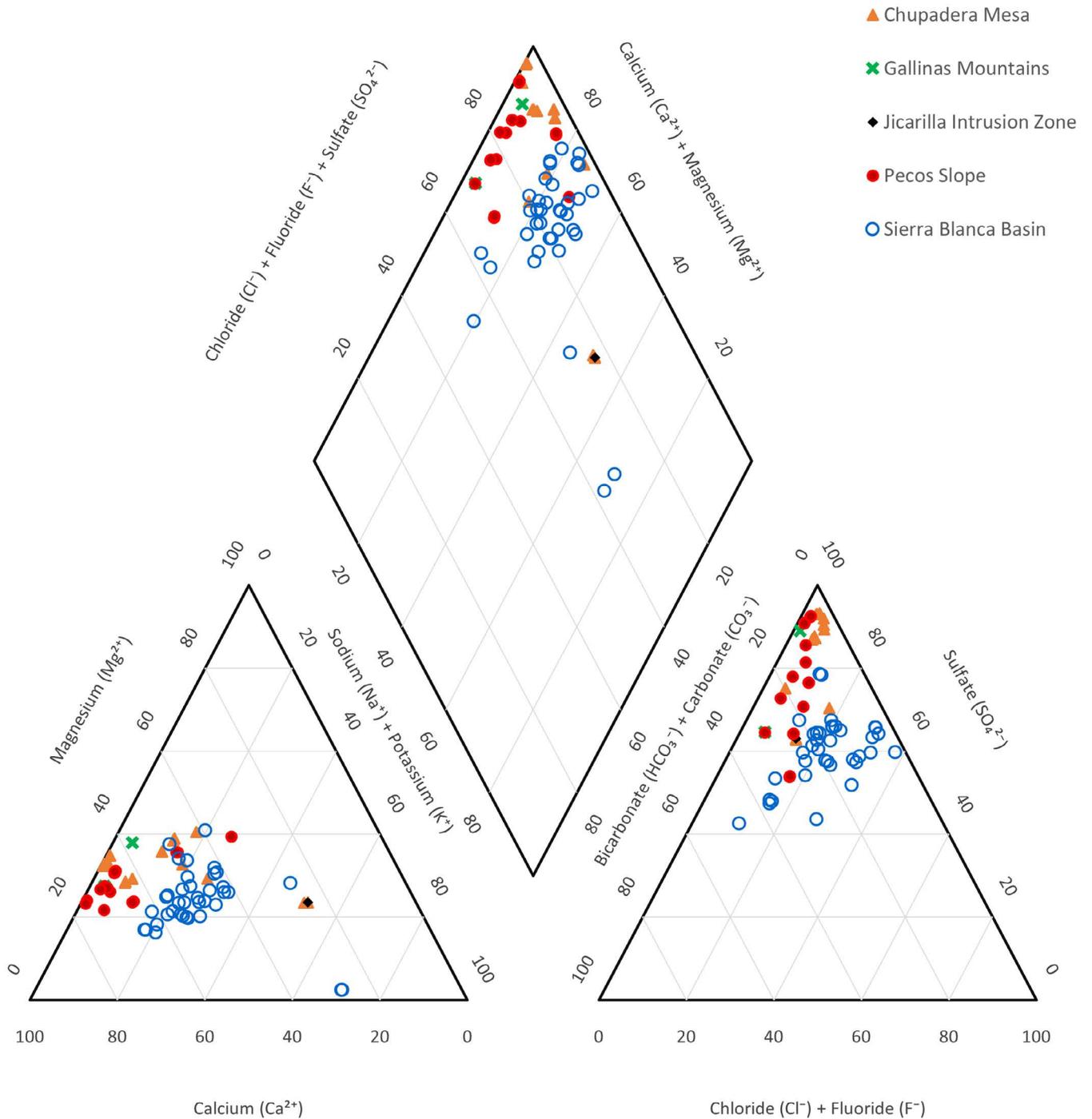
Figure 7. Piper diagram showing the percentage of ion content in well samples broken out by the different subregions.
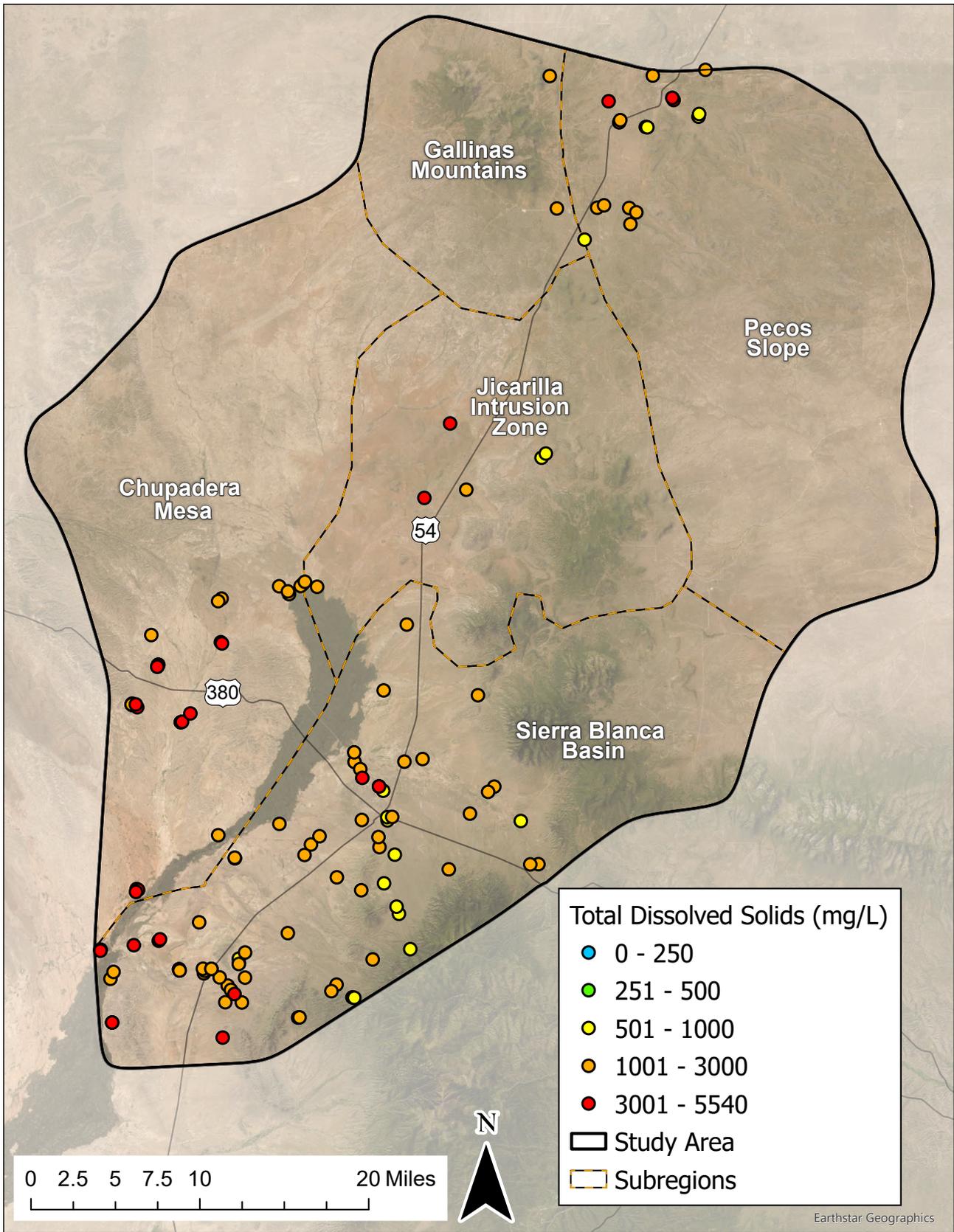
Figure 8. Total dissolved solids (TDS) concentrations in mg/L from wells in the study area. The yellow, orange, and red points exceed the EPA secondary drinking water standard of 500 mg/L.
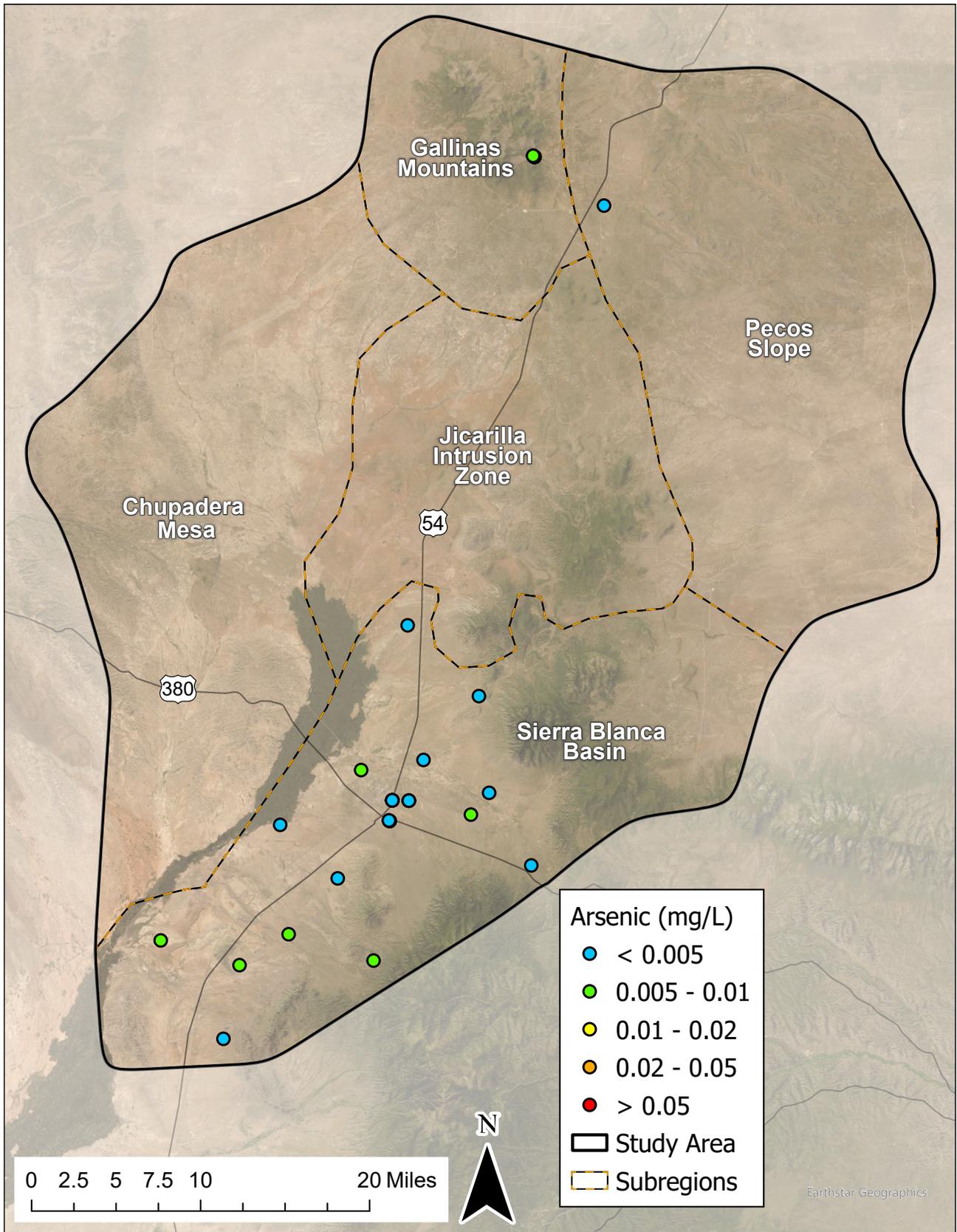
Figure 9. Arsenic concentrations in mg/L from wells in the study area. No samples exceeded the EPA primary drinking water standard of 0.01 mg/L.
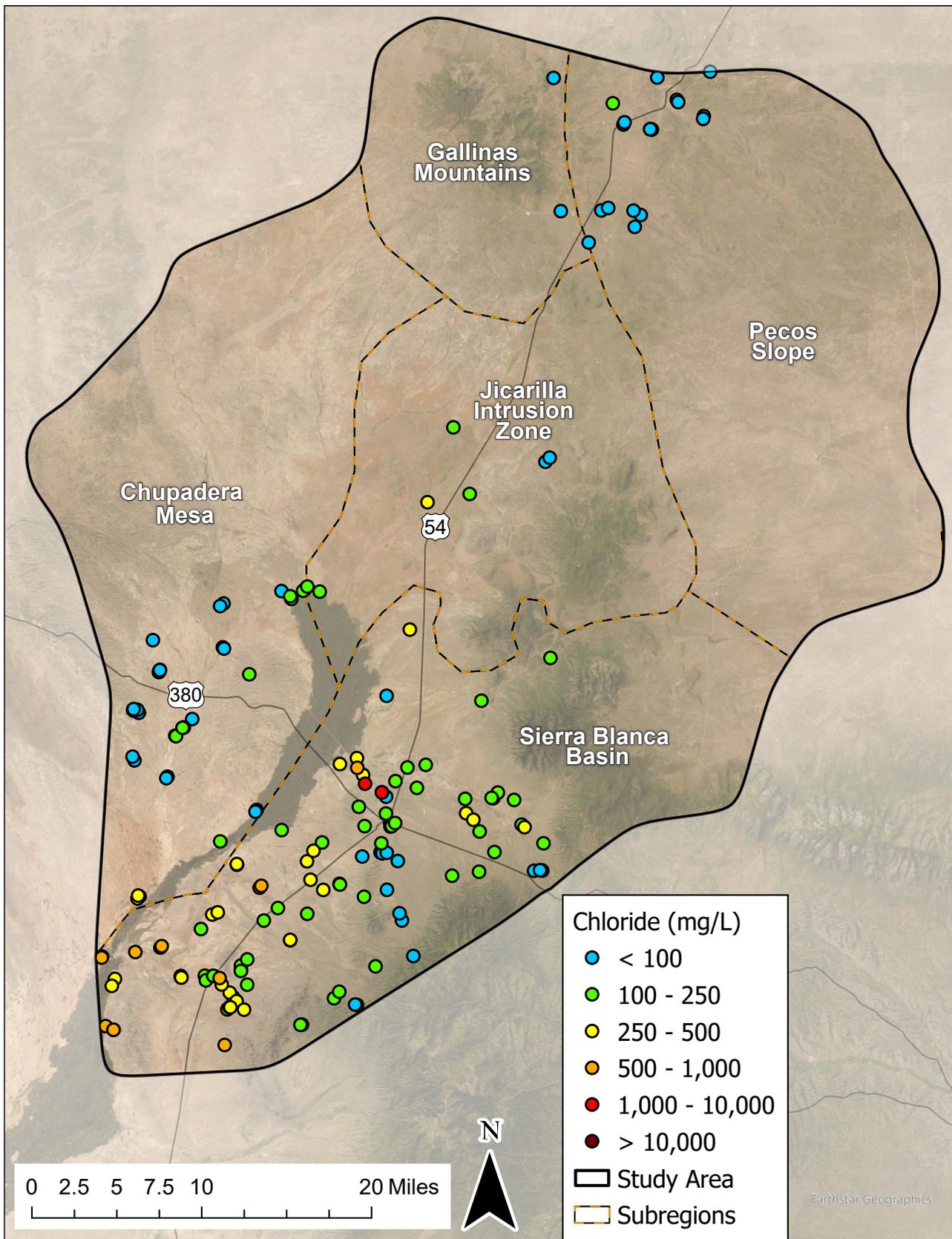
Figure 10. Chloride concentrations in mg/L from wells in the study area. The yellow, orange, and red points exceed the EPA secondary drinking water standard of 250 mg/L.
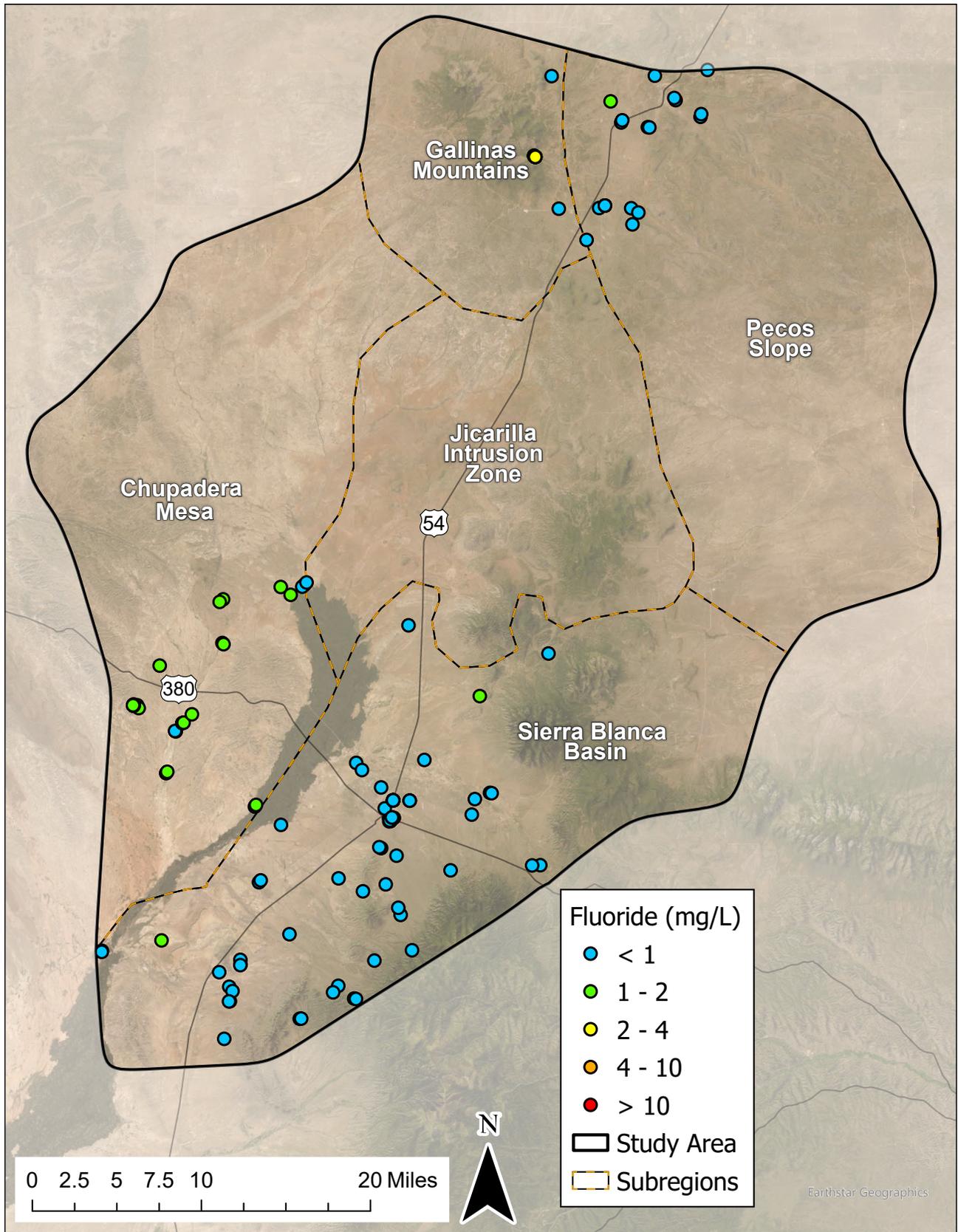
Figure 11. Fluoride concentrations in mg/L from wells in the study area. The yellow points exceed the EPA secondary drinking water standard of 2 mg/L.
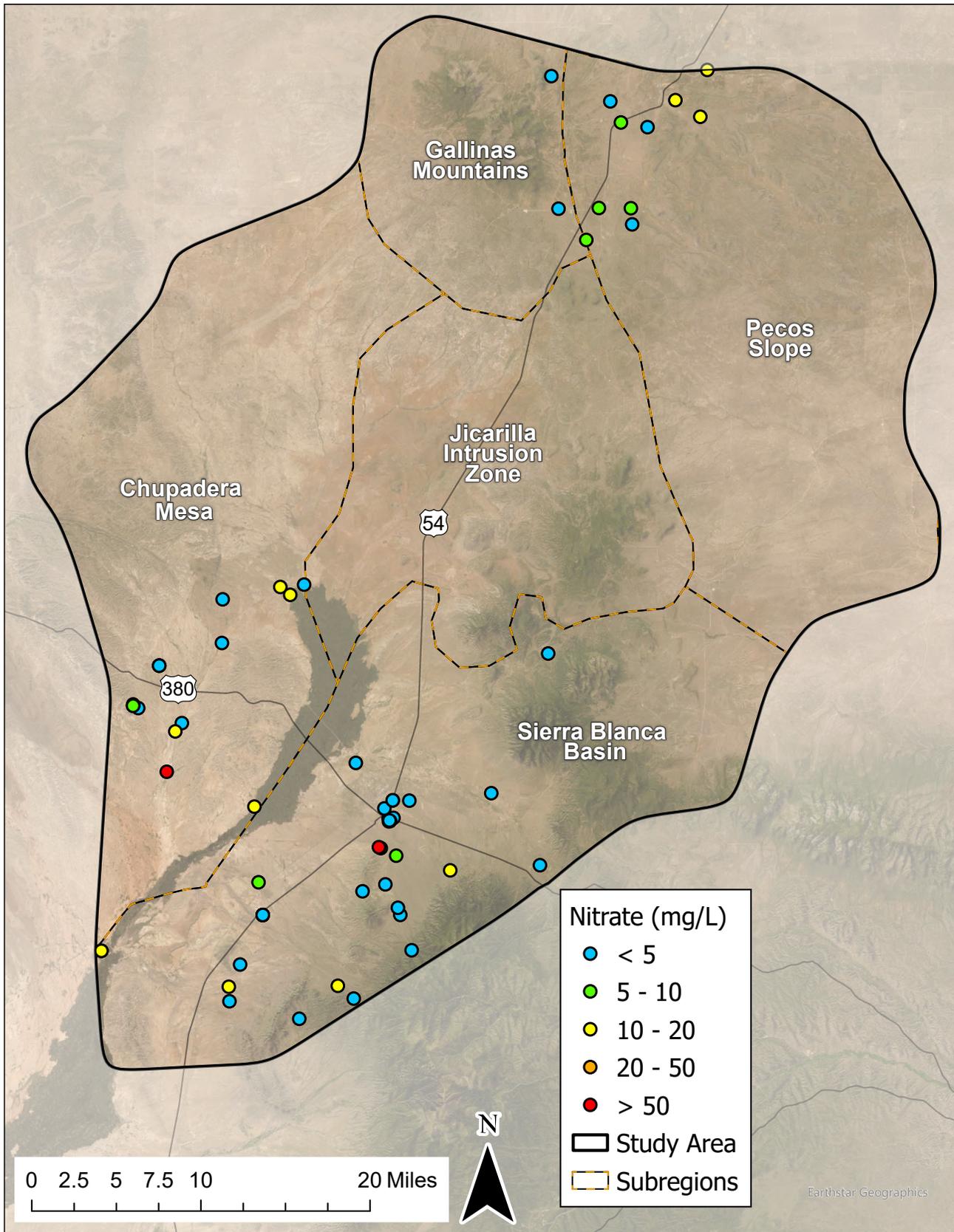
Figure 12. Nitrate concentrations in mg/L from wells in the study area. The yellow, orange, and red points exceed the EPA primary drinking water standard of 10 mg/L.
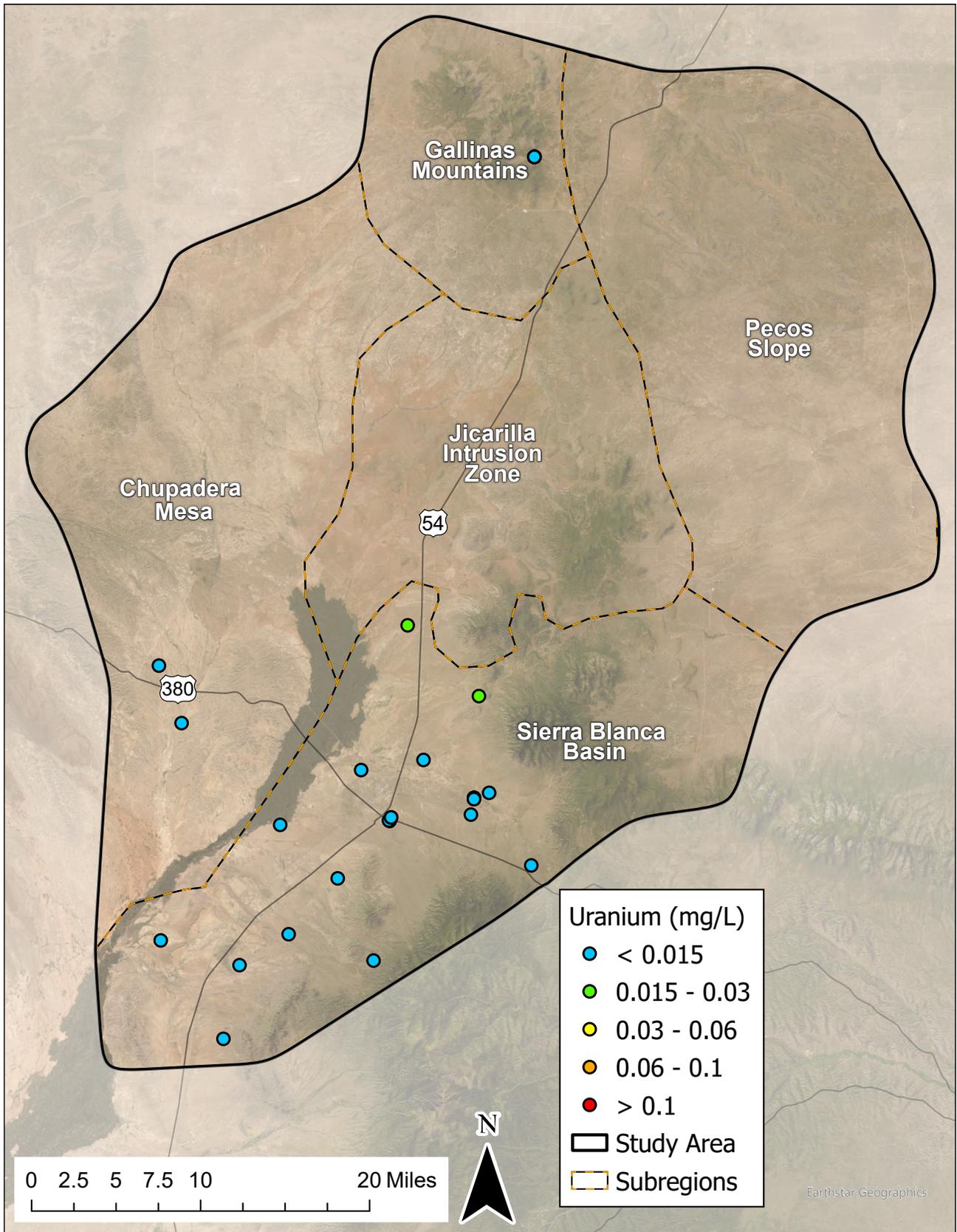
Figure 13. Uranium concentrations in mg/L from wells in the study area. No wells exceeded the EPA primary drinking water standard of 0.03 mg/L.
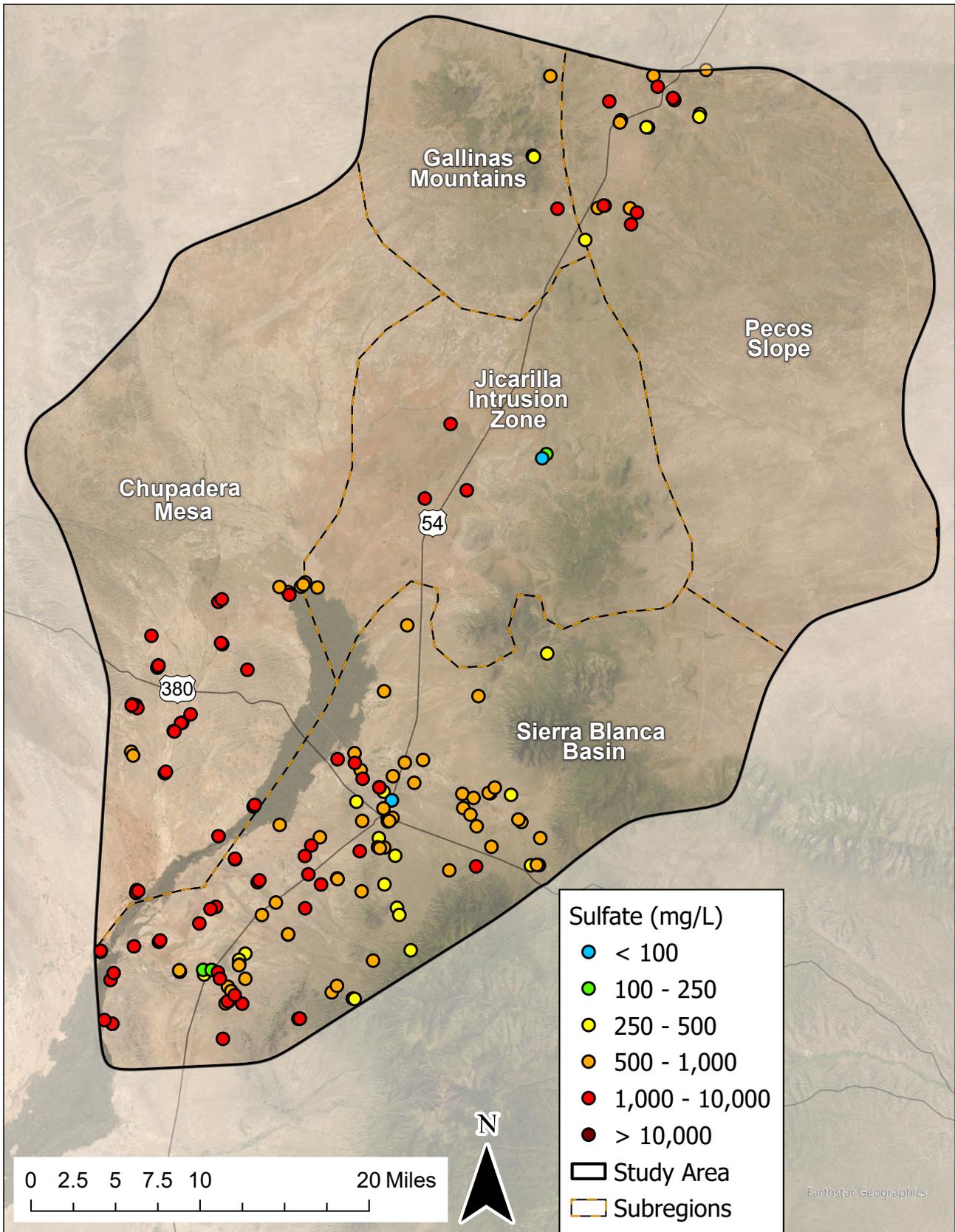
Figure 14. Sulfate concentrations in mg/L from wells in the study area. The yellow, orange, and red points exceed the EPA secondary drinking water standard of 250 mg/L.
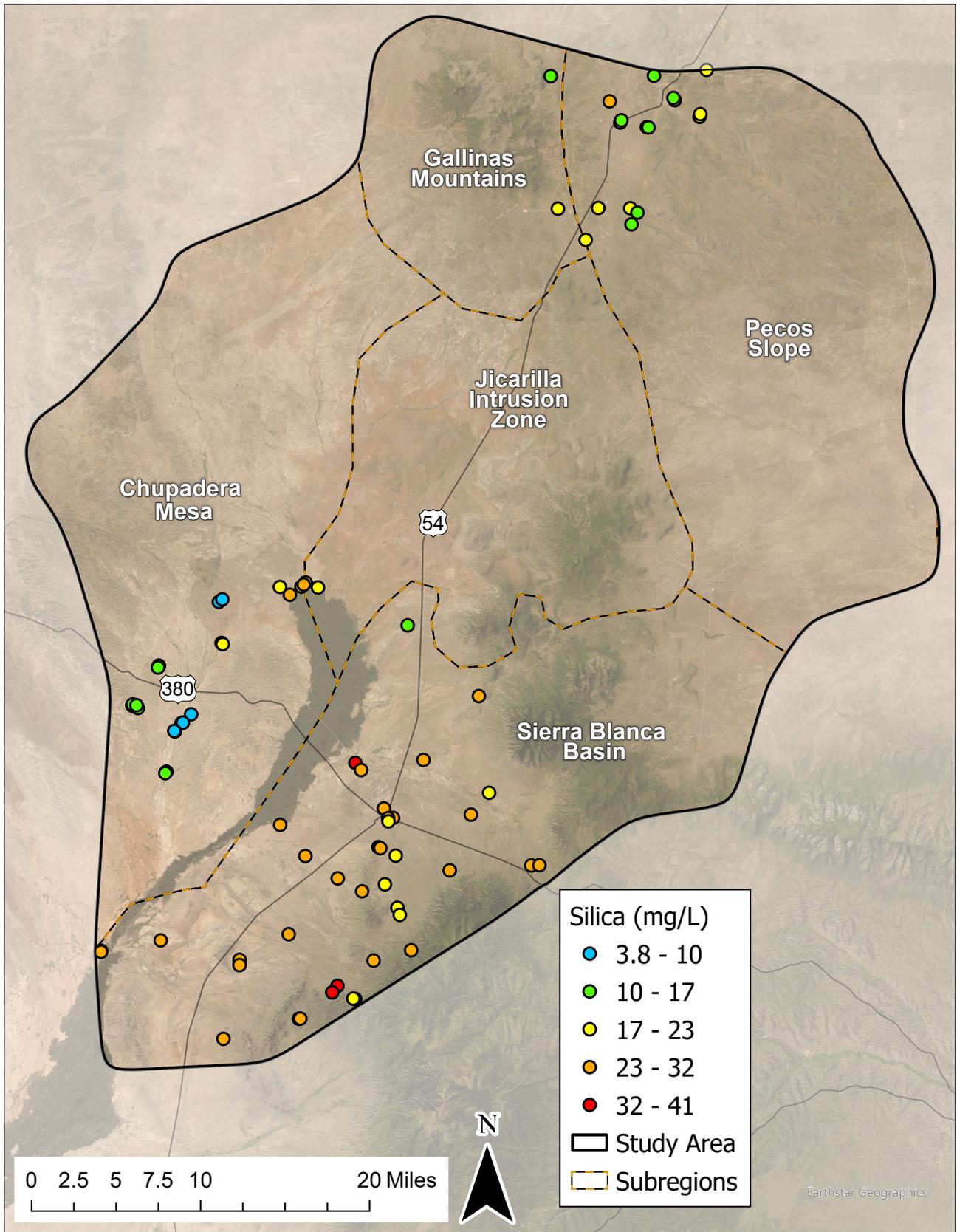
Figure 15. Silica concentrations in mg/L from wells in the study area. Water that passes through igneous rocks typically has higher silica content.
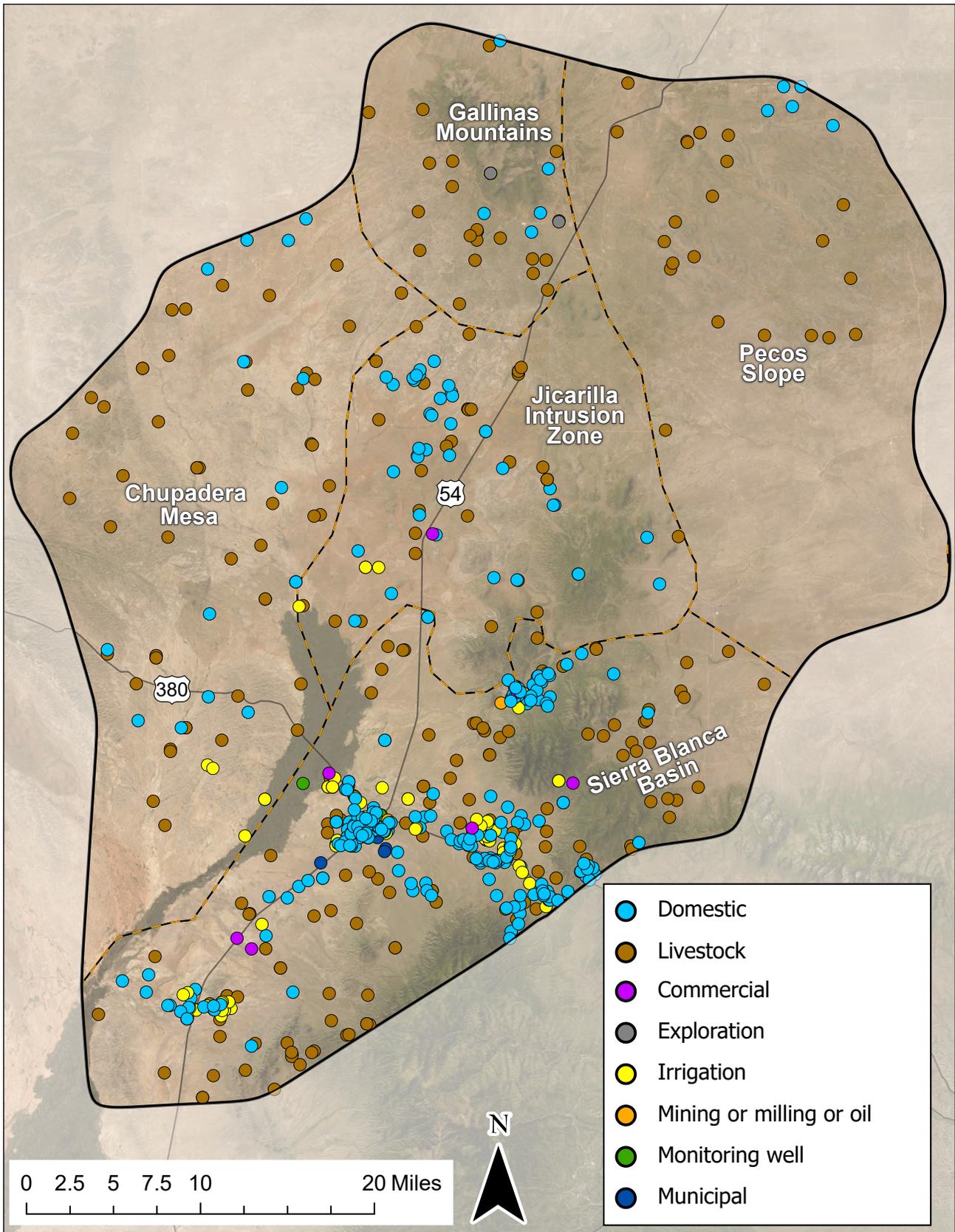
Figure 16. All PODs in the study area with available well use and completion date data. There were 669 PODs in the study area with well completion depths that are categorized as one of the uses listed in the figure.
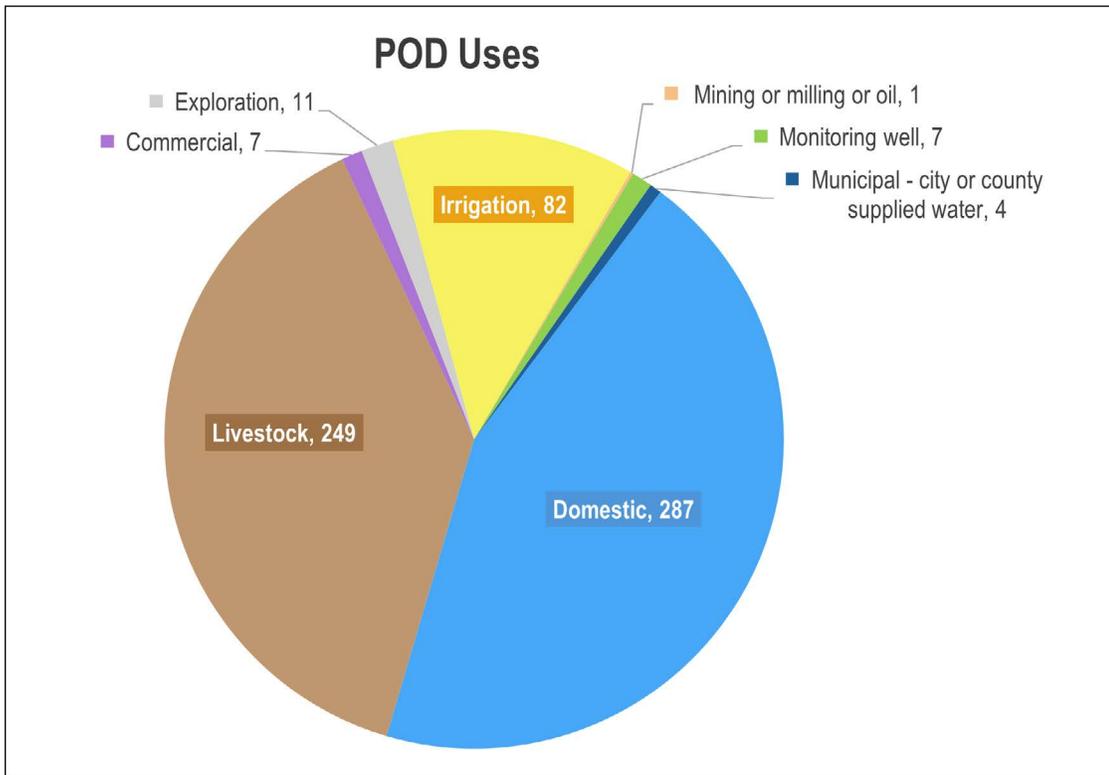
Figure 17. Documented use for each POD from 1873 through 2024. Most wells are permitted for domestic (287) and livestock use (249).
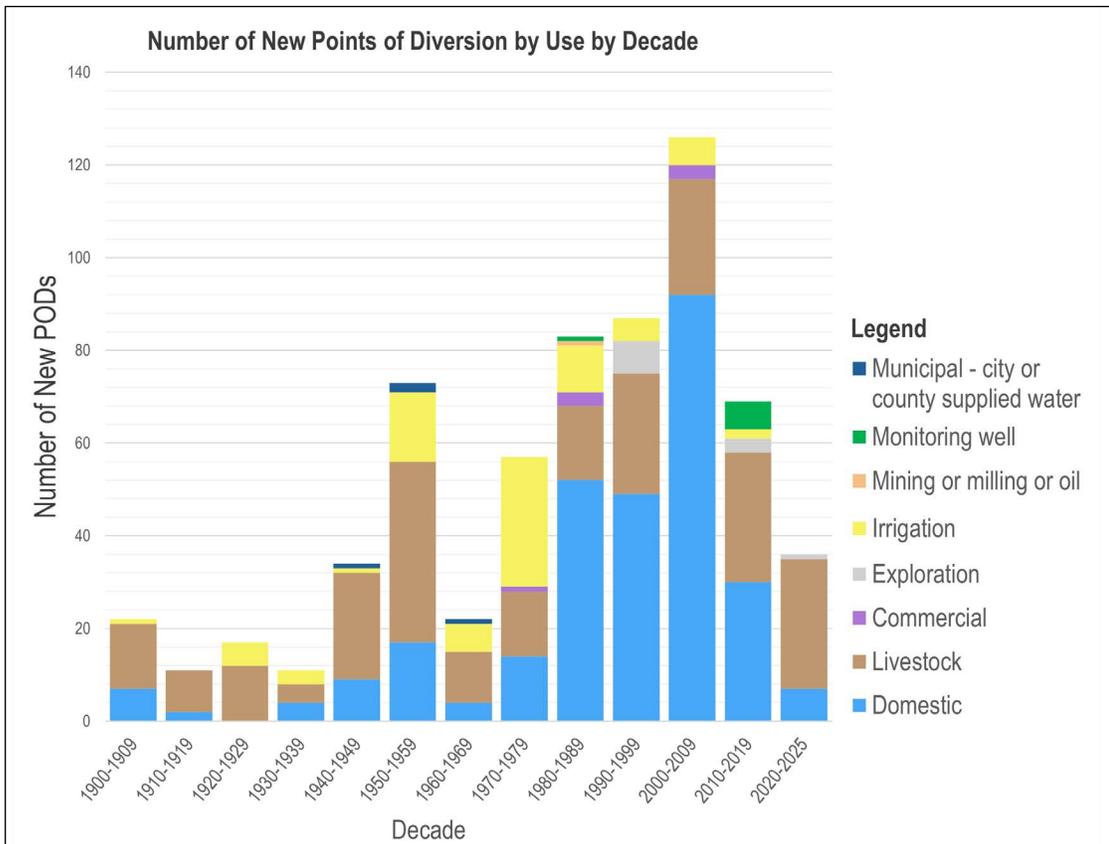
Figure 18. Number of new PODs by use in each decade since 1900. Livestock wells were a frequent source of new PODs, while new domestic wells did not take off until the 1980s, peaking in the 2000s before falling off in the 2010s and early 2020s.
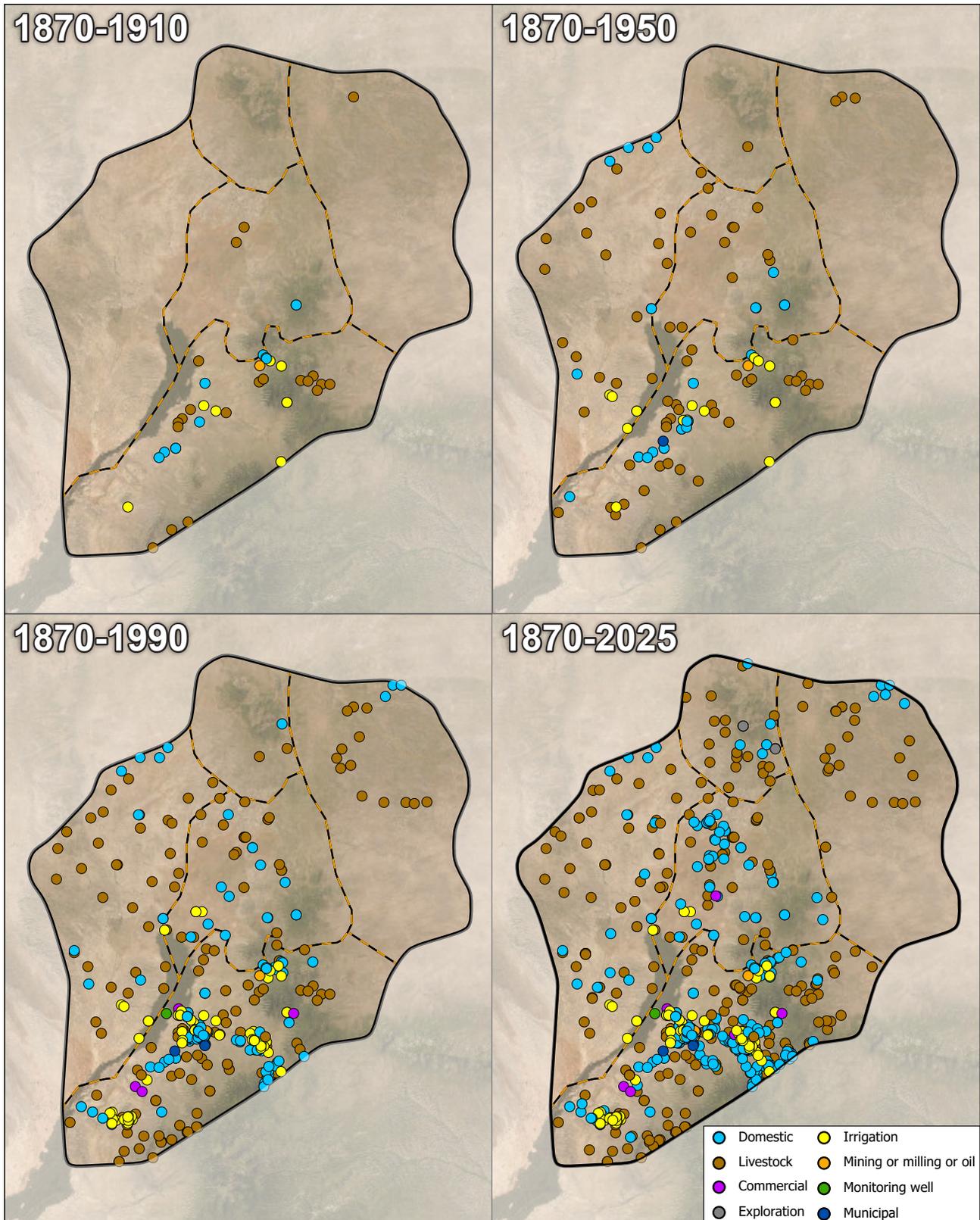
Figure 19. Cumulative PODs through time in approximately 40-year time steps from the 1870s to 2025.
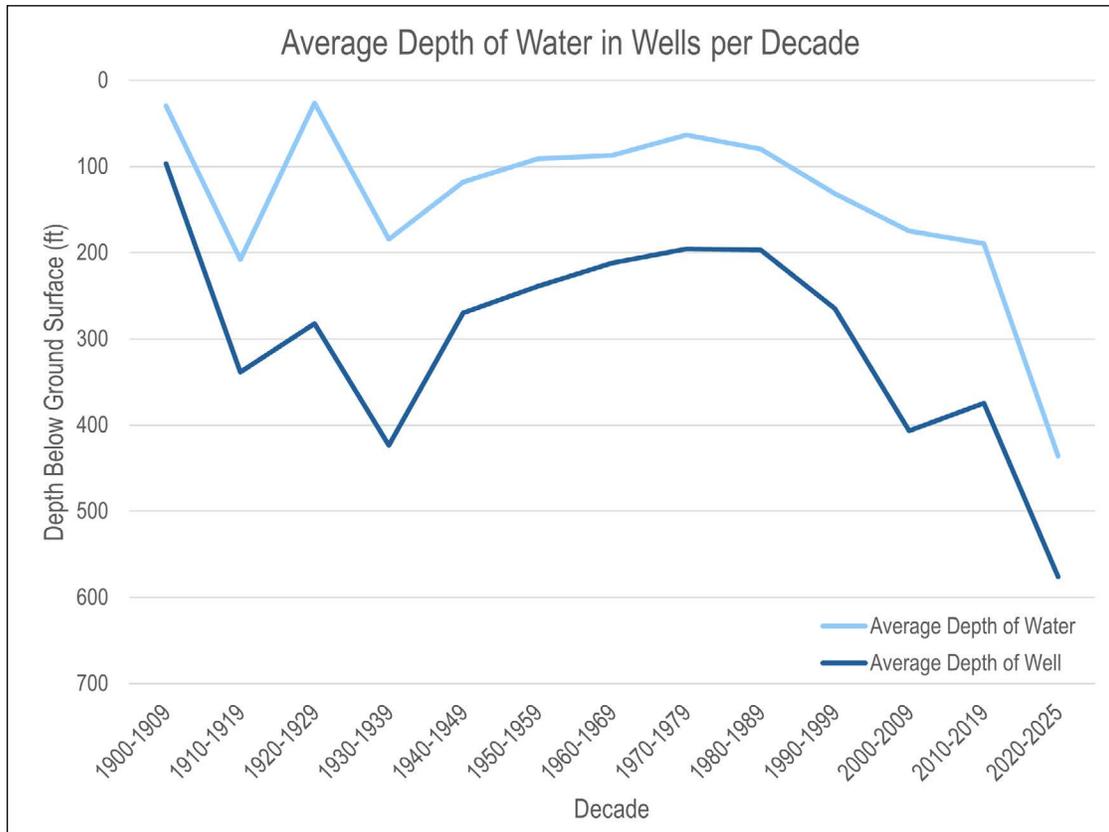
Figure 20. Average depths of wells at the time of their completion from NMOSE POD records. Average depths have generally increased since the 1980s; this could be the result of wells being drilled where aquifers happen to be deeper or declining water levels in historically utilized aquifers. Unfortunately, there are not enough long-term water level records to conclude whether general water levels have been dropping over this time frame.

CONCLUSIONS

REGIONAL HYDROGEOLOGIC FRAMEWORK

To understand the factors controlling groundwater flow in a region, it is essential to examine all available data. By integrating compiled water chemistry, precipitation and recharge patterns, water levels, and geologic mapping, we can better interpret the hydrogeologic framework and groundwater flow dynamics.

The study area is divided into five hydrogeologic subregions: **Sierra Blanca Basin, Jicarilla Intrusion Zone, Pecos Slope, Gallinas Mountains**, and **Chupadera Mesa** (Fig. 2).

Sierra Blanca Basin

Although the Sierra Blanca mountain range is topographically prominent, it consists primarily of volcanic and intrusive igneous rocks that fill a structural basin. This structural basin causes the surrounding sedimentary rocks to dip inward toward Sierra Blanca Peak. This eastward dip is visible in the Carrizozo and Godfrey Hills area on the geologic cross section (Fig. 21).

The area is bisected by the north-south-trending Alamogordo normal fault, which has down-dropped the basin floor on the west side. The primary aquifers are Late Cretaceous and Eocene clastic rocks and Quaternary basin-fill deposits.

At the margins of the Sierra Blanca structural basin, older and less-permeable shale units are tilted to the surface. Several springs occur along this boundary, where groundwater is forced upward.

Water levels in the Sierra Blanca Basin typically range from 20 to 200 feet below ground surface (bgs). Groundwater generally flows east to west, moving downgradient from the Sacramento Mountains (Fig. 22). Most recharge is believed to originate in the high mountains, primarily through infiltration of snowmelt. This recharge mechanism is supported by water chemistry data, which indicate that elevated silica concentrations suggest groundwater interacts with volcanic and igneous rocks in the mountainous recharge zone before reaching the basin (Fig. 15).

Chloride concentrations peak at the base of the mountains, from Carrizozo southward along the mountain front. This pattern suggests mixing with deeper brines that are entering the aquifers from below, likely driven upward by the presence of lower-permeability units cropping out along the basin's perimeter and faulting at the mountain front.

Additional recharge occurs along the bases of arroyos draining the mountains during intense monsoon storms, with Nogal Arroyo representing the largest recharge feature. The Sacramento Mountains receive significantly more precipitation than other nearby peaks due to their greater elevation, resulting in more sustained aquifer recharge. Recharge estimates by Mamer et al. (2014) and Waltemeyer (2001) suggest that approximately 5,000 to 8,800 acre-feet of water per year enters the basin from the Sacramento Mountains.

Jicarilla Intrusion Zone

North of Carrizozo, the landscape is dominated by intrusive igneous laccoliths—volcanic intrusions that uplift and tilt the surrounding sedimentary units into dome-shaped features. This tilting causes the strata to slope radially outward from the igneous intrusions of the Jicarilla Mountains. Well log data from NMOSE indicate that the primary saturated aquifer targeted by wells in this region is fracture flow within the San Andres Formation, Cretaceous units such as the Dakota Sandstone, and the Triassic Moenkopi Formation.

Water levels here are highly variable due to the warping of water-bearing geologic units caused by the intrusions, with depths to groundwater ranging from approximately 150 to 1,000 feet bgs, depending on the presence and saturation of different aquifer units. Groundwater generally flows east to west,

away from the mountains and toward the basin center. Although wells are scarce on the east side of the Jicarilla Mountains, groundwater likely flows eastward into the Pecos Basin as well.

Recharge is presumed to occur at the base of the laccoliths, where fractured sections of the San Andres Formation and Cretaceous formations are exposed at the surface. Given that the Jicarilla Mountains peak at around 7,800 feet and receive an estimated 20 inches of annual precipitation (Fig. 6), recharge to the surrounding aquifers is likely limited.

Pecos Slope

Moving northeast from the Jicarilla intrusions, the geologic units become less disturbed, forming relatively uniform, flat-lying beds that dip slightly eastward. Beneath Corona lies an ancient north-south-trending Precambrian mountain range known as the Pedernal Uplift. When Permian strata were deposited atop this uplift, the topographic high caused sediment deposits to be thinner directly above the Precambrian rocks, with thickness increasing to the east and west.

The primary aquifer in this area is fracture flow within the Yeso Formation, with groundwater generally flowing from west to east. Where present and saturated, the San Andres Formation and Glorieta Sandstone are also productive aquifers, though wells in this region are sparse. Elevated sulfate concentrations support the interpretation that the primary aquifers are carbonate rock units (Fig. 14). Water levels range from 200 to 400 feet bgs and slope eastward. Recharge mechanisms are unclear but may include water entering the aquifers from the eastern Gallinas Mountains.

Gallinas Mountains

The Gallinas Mountains, located in the northern part of the study area, represent another igneous intrusion. Like the Jicarilla region, the emplacement of these intrusive rocks has uplifted older units, such as the Yeso Formation, forcing them to the surface. This uplift causes the strata to slope southward, away from the Gallinas Mountains. Well logs from NMOSE indicate that the primary aquifer targeted for water in this area is the Glorieta Sandstone, which lies at the base of the San Andres Formation. In some wells, where the Glorieta is unsaturated, deeper drilling has accessed a fractured limestone section within the Yeso Formation.
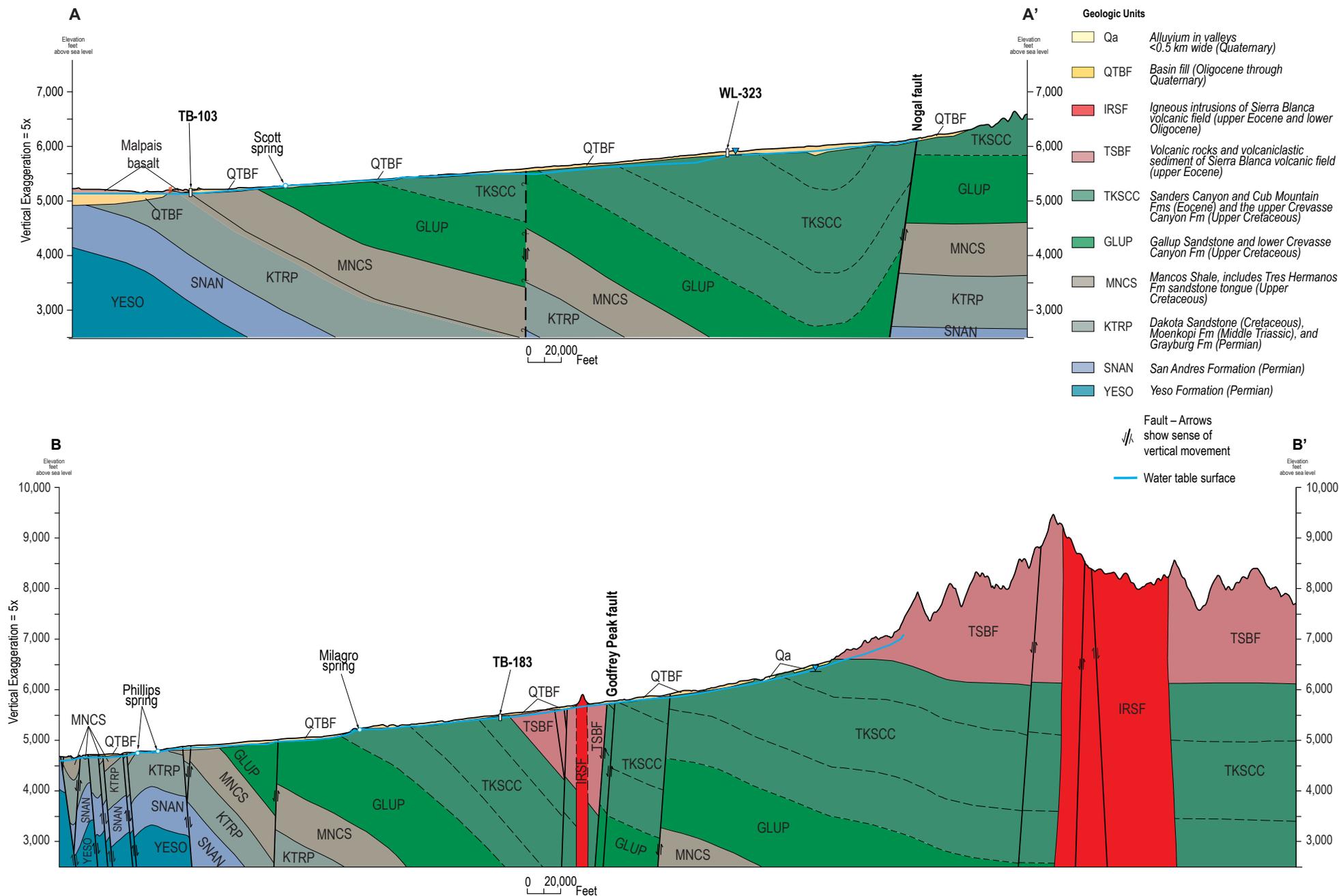
Groundwater levels also slope southward, indicating that recharge occurs where the aquifers are exposed in the mountains, with water flowing away from the Gallinas Mountains. Water depths are deep, typically ranging from 400 to 900 feet bgs. Although the Gallinas Mountains rise nearly 1,000 feet higher than the Jicarilla Mountains, their spatial extent is relatively small, suggesting that recharge rates in this area are likely low.

Chupadera Mesa

Located in the western half of the study area, Chupadera Mesa has very limited well data. A north-south-trending normal fault, referred to as the Claunch sag, down-drops the eastern basin. Due to the sparse well logs, determining the primary aquifer is difficult; however, the Yeso and San Andres Formations are likely the primary water-bearing units. High sulfate concentrations further suggest that these carbonate formations serve as the principal aquifers.

DATA GAPS AND RECOMMENDATIONS FOR FUTURE WORK

While the southeastern portion of the study area benefits from detailed geologic mapping and comprehensive water chemistry data, other regions remain understudied. Enhanced geologic mapping of the Gallinas and Jicarilla Mountains would improve understanding of aquifer geometries. Cross sections of these areas would further clarify the distribution of geologic units that make up the aquifers. Additional water chemistry sampling in the Gallinas, Jicarilla, and Chupadera Mesa regions would help identify primary aquifers and recharge pathways. Landowner participation remains a significant challenge because limited well access constrains sampling and monitoring opportunities.
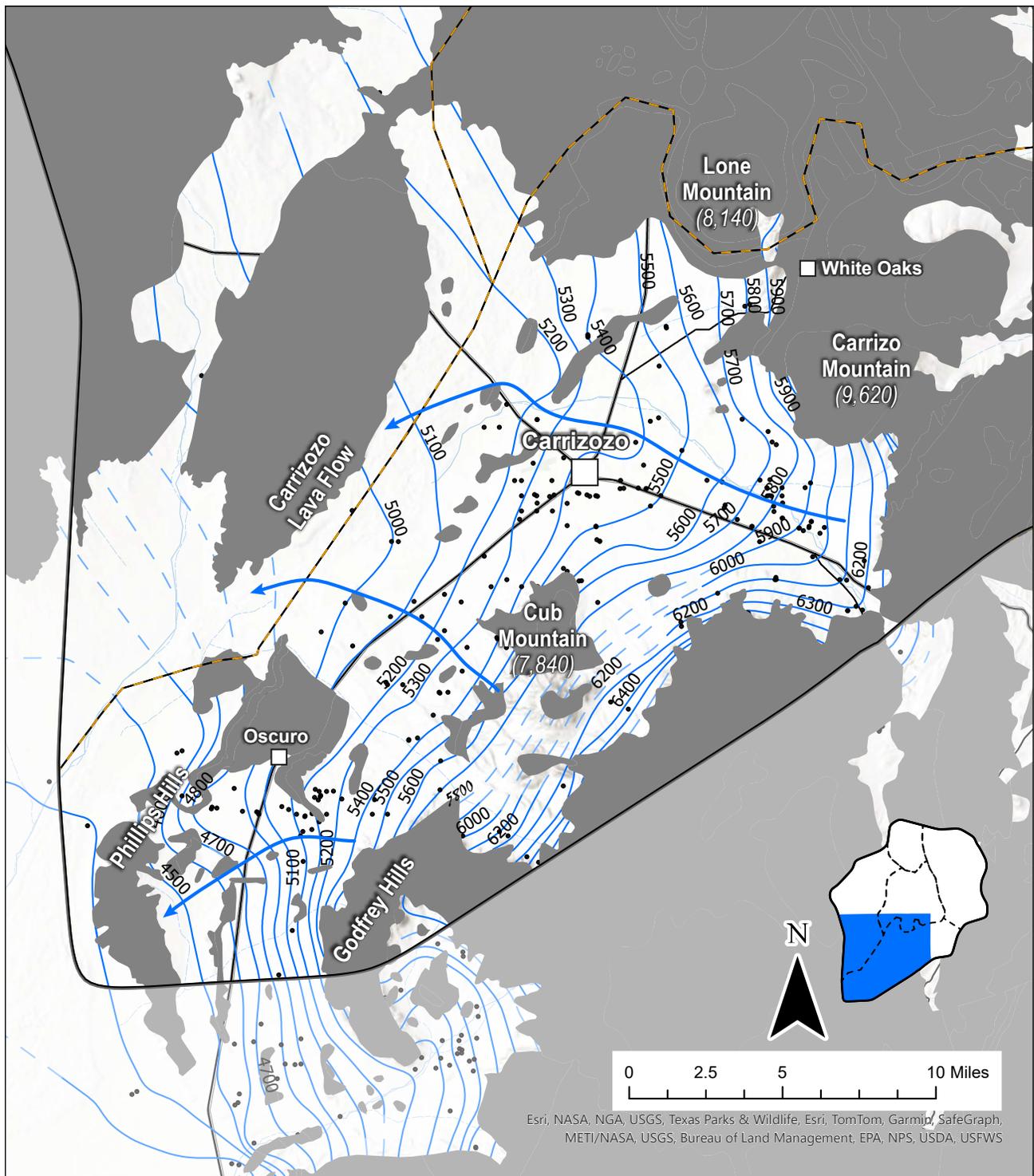
Figure 21. Geologic cross sections showing the structure of the Sierra Blanca Basin. Locations of these cross sections are marked in Figure 2 (modified from Mamer et al., 2014).

Figure 22. Water table elevation map (in feet) in the Sierra Blanca Basin. Elevations were drawn using water level measurements collected by NMBGMR between 2011 and 2013. The small black dots represent well locations. The large blue arrows indicate the direction of groundwater flow. Water table contours were restricted to areas where bedrock is not exposed at the surface.

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