San Jose Formation Hydrostratigraphy and Groundwater Conditions in the Vicinity of Lindrith, New Mexico

T. Neil Blandford, Christopher Wolf, William Casadevall, Farag Botros, and Kenneth Calhoun

2025, pp. 235-246. https://doi.org/10.56577/FFC-75.235

in:

Geology of the Eastern San Juan Basin - Fall Field Conference 2025, Hobbs, Kevin M.; Mathis, Allyson; Van Der Werff, Brittney;, New Mexico Geological Society 75 th Annual Fall Field Conference Guidebook, 227 p. https://doi.org/10.56577/FFC-75

This page is intentionally left blank to maintain order of facing pages.

New Mexico Geological Society Guidebook, 75th Fall Field Conference, 2025, p. 235–246, https://doi.org/10.56577/FFC-75.235

SAN JOSE FORMATION HYDROSTRATIGRAPHY AND GROUNDWATER CONDITIONS IN THE VICINITY OF LINDRITH, NEW MEXICO

T. NEIL BLANDFORD[1], CHRISTOPHER WOLF[1], WILLIAM CASADEVALL[1], FARAG BOTROS[1], AND KENNETH CALHOUN[1]

[1]Daniel B. Stephens & Associates, Inc., 6501 Americas Parkway NE, Suite 200, Albuquerque, NM 87110; nblandford@geo-logic.com

Abstract—This manuscript summarizes hydrogeologic analysis conducted for the saturated portions of the San Jose Formation in the vicinity of Lindrith, New Mexico. The majority of the analysis focused on the identification and evaluation of hydrostratigraphic units within a region of approximately 840 km^2 centered about Apache Ranch, located west of Lindrith. The targeted water supply for a potential irrigation project at the ranch is approximately 300 to 425 m below ground surface, which generally corresponds to the Cuba Mesa Member of the San Jose Formation. As part of the analysis, we constructed a detailed base of San Jose Formation (top of Nacimiento Formation) map, identified four hydrostratigraphic units within the San Jose Formation, and constructed an aquifer thickness map for hydrostratigraphic Unit 4, which consists primarily of the Cuba Mesa Member. We mapped the base of the San Jose Formation and identified hydrostratigraphic units based on analysis of more than 350 geophysical logs from oil and gas wells and 85 water well driller's logs. We also developed water-level surface maps for the Lindrith region and the entire extent of the San Jose Formation in New Mexico, and identified differences in hydraulic head between shallower and deeper portions of the San Jose Formation.

Our results indicated that the sand units of the Cuba Mesa Member appear favorable for the completion of wells with sufficient capacity for uses such as irrigation. Most wells in the region have low reported capacity because they are completed in shallower portions of the San Jose Formation that are characterized by higher proportions of shale or mudstone than those found in the Cuba Mesa Member. Due to the existence of extensive shale and mudstone in the shallower portions of the San Jose Formation, and to a lesser extent within the Cuba Mesa Member, the effects of groundwater pumping at depth will be limited at shallow wells.

INTRODUCTION

The San Juan Basin is located in northwestern New Mexico, and extends into Colorado, Utah, and Arizona (Fig. 1). The basin is well known for oil and gas production from its thick sequence of sedimentary rocks that range in age from the Paleozoic through the Cenozoic Eras. The largest water demands are for municipalities, irrigation, and the Navajo Nation along the San Juan River and its major tributaries and are supplied by surface water. Outside of the larger population centers, water demands for domestic, stock, and industrial (e.g., oil and gas) uses are supplied by groundwater. In the general vicinity of our study area, wells are typically completed within the shallowest geologic unit that will provide adequate water, which may be the San Jose Formation, the Nacimiento Formation, or the Ojo Alamo Sandstone, depending on location (Fig. 1).

Our investigation focused on the San Jose Formation, which is an interbedded sedimentary rock formation deposited as colluvium and alluvium within alluvial fans and fluvial systems. Sandy units provide water to wells and typically have limited vertical and horizontal extents; clayey units separate the sands. Most wells are completed in the shallow sands within 100 to 200 m of ground surface, and a few wells are completed in the deeper portions of the formation. The few deeper water wells and data from oil and gas exploration indicate that the San Jose Formation includes productive sand units at depths greater than 300 m below ground surface (bgs). We investigated these deeper sand units as a potential source of water by compiling geologic, hydrologic, and geophysical information available in the literature, well records from the New Mexico Office of the State Engineer (OSE), and records from the Oil Conservation Division (OCD) of the New Mexico Energy, Minerals

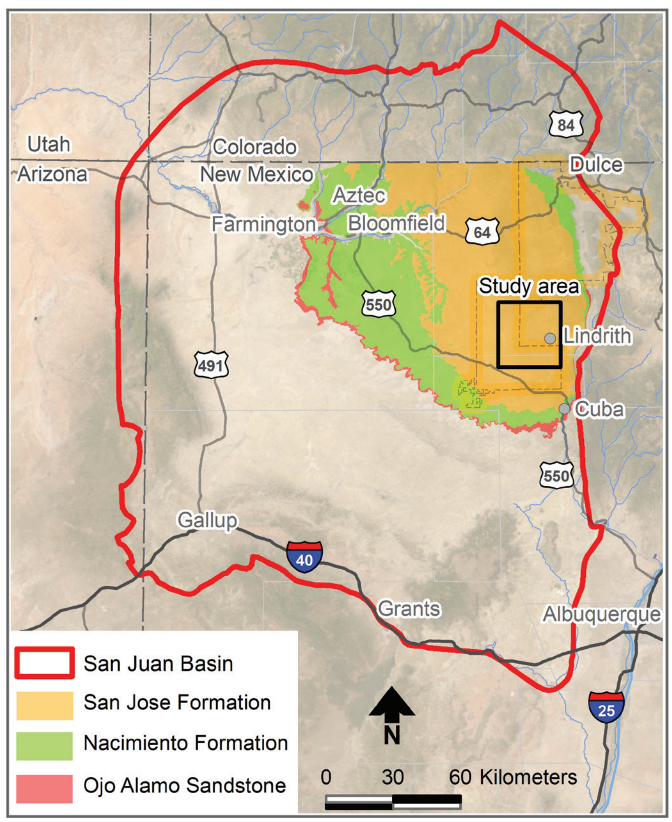


Figure 1. Extent of the San Juan Basin from Levings et al. (1990) and the San Jose, Nacimiento, and Ojo Alamo Sandstone Formations in New Mexico from Green and Jones (1997).

and Natural Resources Department. Our results indicate that the hydrogeology of the San Jose Formation is favorable for supporting wells completed in the deeper sand units. Due to the presence of extensive mudstone and shale within the San Jose Formation, pumping from the deeper sand units is expected to have limited effects at shallow wells completed above the deeper sands.

Our research provided an overview of portions of a hydrogeological study conducted in support of a water right application filed with the OSE by the owner of Apache Ranch, located west of Lindrith, New Mexico (Fig. 2). The application was for a new appropriation of groundwater for irrigation from wells completed at approximately 300 to 425 m bgs, which approximately corresponds to the Cuba Mesa Member of the Paleogene San Jose Formation. The application amount was for 600 acre-feet per year of water, which is a large quantity relative to other uses in the region. The study area (Fig. 2) refers to the nine township-range area that includes Townships 23 to 25 North and Ranges 2 to 4 West, although we also conducted an investigation outside this region to support development of a regional groundwater flow model not presented herein.

Apache Ranch is situated in the southern portion of the Tapicitos Plateau, a high plateau dissected by westward-flowing ephemeral and intermittent streams leaving numerous broad irregular sandstone-capped mesas (Baltz and West, 1967). The plateau extends west from the continental divide to the Largo Plains. Within the Apache Ranch area, elevations range from about 2,250 m (7,400 ft) to less than 2,070 m (6,800 ft) above mean sea level (msl) along Canada Larga, a large east-to-west ephemeral wash that bisects the ranch (Fig. 2).

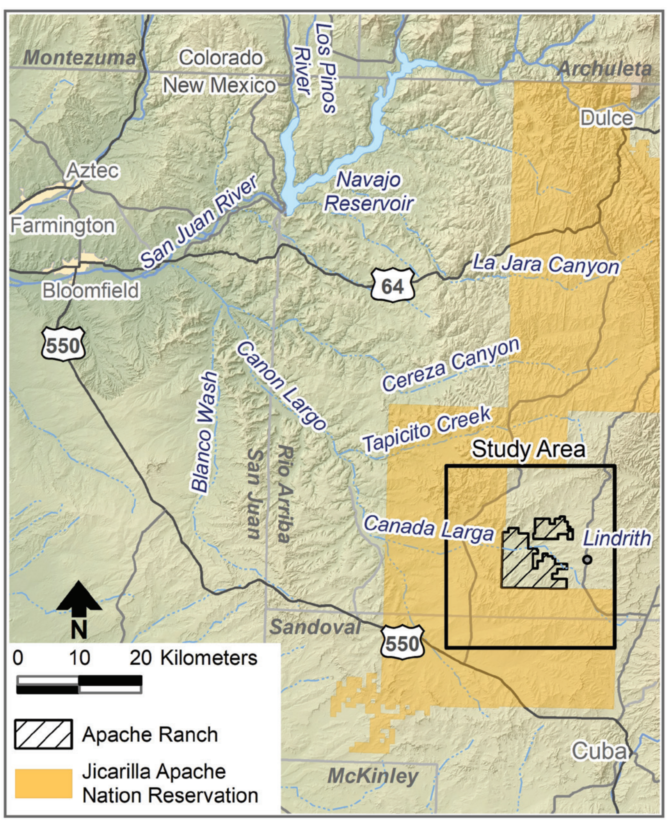


Figure 2. Location map of Apache Ranch and Lindrith, New Mexico with main geographic features.

GEOLOGIC SETTING

Numerous publications present the geology of the San Juan Basin in detail. The primary sources relied upon for this work include Baltz and West (1967), Baltz (1967), Stone et al. (1983), Levings et al. (1990), Smith and Lucas (1991), Smith (1992), Levings et al. (1996), and Hobbs and Pearthree (2021).

The San Juan Basin is a structural basin in the southeastern corner of the Colorado Plateau physiographic province. It developed during the Cretaceous–Paleogene Laramide orogeny. Regionally, the basin is an oval-shaped bowl, with the oldest geologic units observed along the basin edges where structural features (e.g., monoclines or faults) have caused them to crop out at ground surface. In the center of the basin, the oldest geologic units are encountered at depths greater than 3,000 m bgs (Stone et al., 1983). Although geologic structures such as faults and folds are common at the edges of the basin, they are rare within the basin interior. As the basin formed, sediments were deposited as the edges of the basin were uplifted relative to the basin center, resulting in units with moderate syndepositional dips. Some of the geologic contacts are considered angular unconformities (Baltz, 1967) or disconformities (Zellman et al., 2024), indicative of sporadic erosional, depositional, and deformational processes.

Apache Ranch is located southwest of the San Juan Basin axis, as depicted on the geologic maps in Baltz and West (1967) and Baltz (1967). Geologic units exposed in outcrop at Apache Ranch tend to dip into the subsurface toward the center of the basin and become progressively deeper below ground surface toward the basin axis.

Paleogene Period Formations

Our analysis focused on the Paleogene Period rocks that host the aquifer system of interest. Paleogene rocks include (oldest to youngest) the upper portion of the Ojo Alamo Sandstone, the Nacimiento Formation, and the San Jose Formation (Fig. 1).

The Nacimiento Formation reaches a total thickness of more than 450 m (Williamson and Lucas, 1992) and conformably overlies the Ojo Alamo Sandstone. The Ojo Alamo Sandstone and older geologic units were not part of this study. The Nacimiento Formation underlies the San Jose Formation. The Nacimiento Formation consists primarily of shale or mudstone and interbedded sandstones. Within the study area, a distinct shale unit approximately 30 to more than 60 m thick forms the uppermost portion of the Nacimiento Formation (and underlies the San Jose Formation) at most locations.

The San Jose Formation forms the land surface across much of the northeastern portion of the San Juan Basin (Fig. 1). It consists of interbedded sandstone, mudstone, and shale that unconformably overlie the Nacimiento Formation (Smith, 1992). The San Jose Formation consists of five members, four of which are recognized in our study area (Fig. 3). From oldest to youngest, these members are the Cuba Mesa, Regina, Llaves, and Tapicitos. These members and their lithologic facies have a complex intertonguing relationship reflecting their depositional environment in a braided stream and alluvial fan system (Baltz and West, 1967; Stone et al., 1983), with recent interpretations designating the depositional environment as a series of stacked or prograding alluvial fans (Zellman et al., 2024). Despite this complex relationship, the members are traceable across the basin in outcrop and in the subsurface using geophysical logs from oil and gas wells (e.g., Brimhall, 1973; Stone et al., 1983; Smith and Lucas, 1991). Physical characteristics of the sediments such as grain size, sorting, bedding, and the continuity of sandstone and mudstone layers influence the overall hydraulic conductivity and well yield of the San Jose Formation members.

The Cuba Mesa Member is a sandstone-dominated unit with minor mudstones (Smith and Lucas, 1991), believed to be associated with coarser sand units of proximal and medial fan deposits (Zellman et al., 2024). This member varies in thickness from about 100 m to more than 150 m, and thins toward the center of the basin. The Cuba Mesa Member occurs at the land surface to the south, west, and northwest of Apache Ranch (Fig. 3).

The Regina Member is a mudstone-dominated unit with a minor amount of sandstone with a conformable contact with the underlying Cuba Mesa Member. This unit is representative of medial and distal fan deposits (Zellman et al., 2024). A medial sandstone unit may be traced between wells. Sandstones in this member are typically lenticular and surrounded by mudstones (Smith and Lucas, 1991). Based on geophysical logs and outcrop measurements, Smith and Lucas (1991) stated that the Regina Member consists of two-thirds mudstone and one-third sandstone. This member occurs at land surface throughout the southern portion of Apache Ranch and much of the region south, east, and west of the ranch (Fig. 3).

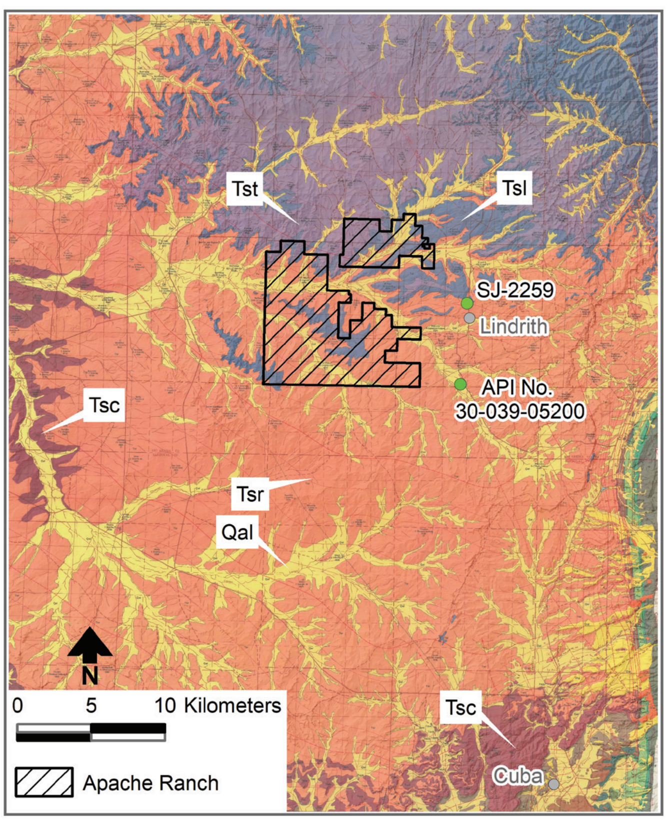


Figure 3. Surface geology in the vicinity of Lindrith from Baltz and West (1967). The Cuba Mesa (Tsc), Regina (Tsr), Llaves (Tsl) and Tapicitos (Tst) Members of the San Jose Formation are now referred to as Paleogene rather than Tertiary Period units. The identified wells are cross-referenced to Figures 4 and 7.

The Llaves and Tapicitos Members occur on the tops and slopes of mesas on Apache Ranch and form the land surface north and northeast of the ranch (Fig. 3). Due to similar depositional environments and lithologies, these two members can be difficult to distinguish from one another (Smith and Lucas, 1991). The Llaves Member typically consists of thick-bedded, coarse- to medium-grained sandstone units that often have conglomerate facies (Smith and Lucas, 1991). The Tapicitos Member consists of interbedded mudstone and sandstone units.

The basal sand unit of the San Jose Formation was the targeted water supply for a potential irrigation project at Apache Ranch. For the most part, the target aquifer is equivalent to the Cuba Mesa Member, but aquifer thickness maps may include sand layers in the lower Regina Member that intertongue with the Cuba Mesa Member.

Most water wells in the study area are completed within one or more sand units of the upper to middle Regina Member, and only a handful of wells have been completed in the Cuba Mesa Member. The completion of existing water wells is a function of cost and the nature of the water need. Shallow wells are less expensive to complete, and high well yields are not required to supply the stock and single-household domestic uses prevalent in the region. The Llaves and Tapicitos Members occur above the regional water table in the study area and are not relevant to groundwater availability.

HYDROGEOLOGY

Detailed study and information regarding the hydrogeology of San Jose Formation is relatively limited. Baltz and West (1967) provided the first and most comprehensive study of the groundwater within Paleogene rocks in the Lindrith area. They provided detailed cross sections, tables of well information, and discussion of San Jose Formation groundwater, including the Cuba Mesa, Regina, Llaves and Tapicitos Members. Brimhall (1973) constructed two regional cross sections using electric logs from oil and gas wells, and divided the San Jose Formation into the same four members identified by Baltz (1962). Brimhall (1973) identified the Cuba Mesa and Llaves Members as sandstone facies that are the best aquifer units. Stone et al. (1983) provided an overview of all of the aquifers of the San Juan Basin, including the San Jose Formation. They noted that the Cuba Mesa and Llaves Members are predominantly sandstone, and the Regina and Tapicitos Members are primarily mudstone, but that the stratigraphy is complicated due to extensive intertonguing of adjacent members. Phillips and Tansey (1984) developed a quasi-three-dimensional groundwater flow model of the Ojo Alamo Sandstone and

Nacimiento Formation west of the study area, but also included a water-level surface map and other information for the western portion of the San Jose Formation. The U.S. Geological Survey (USGS) published Hydrologic Investigations Atlas 720 (Levings et al., 1990), which is a series of plates documenting aquifer units and groundwater conditions in the San Juan Basin for the San Jose Formation, Nacimiento Formation, and Animas Formation combined. Kernodle (1996) developed a regional groundwater flow model of the San Juan Basin that includes the San Jose Formation as a model layer; vertical variations of rock types within the San Jose Formation were not considered.

Using these studies as a starting point, we conducted additional analysis to identify the nature of hydrostratigraphic units in the San Jose Formation within and adjacent to Apache Ranch. This analysis was important for the determination of expected well yield and for the evaluation of groundwater pumping effects on adjacent wells, most of which are completed shallower than the targeted completion depth for the new wells.

Data Sources

Data sources used for analysis of the hydrostratigraphic units in the study area included the OCD oil and gas well database that includes geologic information and geophysical logs, and the New Mexico Water Rights Reporting System (NMWRRS) that includes water well data.

Oil and Gas Well Logs

There are numerous oil and gas wells within and surrounding the study area, and in many cases, geophysical logs and records that identify the tops of selected geologic formations were submitted to the OCD. Formation contacts commonly identified on the OCD logs are the top of the Nacimiento Formation, the top of the Ojo Alamo Sandstone, the top of the Kirtland Shale (base of the Ojo Alamo Sandstone), and various deeper formations.

Nearly 1,500 well records from the OCD database were identified for the study area. We queried information from the database including the well name, API number, location information, surface elevation, and well depth. We reviewed the OCD well card for all of the wells in the study area, and noted reported depths to the tops of the Nacimiento Formation, Ojo Alamo Sandstone, and Kirtland Formation where available. We then used a 10-m digital elevation model for the project area to identify the ground-surface elevation at each well location.

Water Well Logs

We obtained more than 220 water well records from the NMWRRS for the study area. After screening the initial downloaded files to exclude incorrectly located wells, shallow monitor wells, or well records not useful for other reasons, we used 85 wells with driller's logs in the hydrogeologic analysis. The logs vary in level of detail, but almost all indicate that the San Jose Formation consists of alternating layers of sandstone and shale, with water obtained from one or more sand units, as would be expected. Most of the wells have a reported yield of less than 20 gallons per minute (gpm), are small in diameter (i.e., 5 or 6 inches), and were drilled for single-household domestic or livestock purposes. Approximately 60% of the water wells are less than 122 m deep. We found 17 wells listed as 300 m or more in depth, but some of these deep wells included declarations of future use for plugged oil and gas wells that were never modified into water wells. Water wells completed at greater depths were typically intended to provide oil and gas industrial water supplies.

The Jicarilla Apache Nation surrounds Apache Ranch in all directions but east (Fig. 2). There are water wells on the Jicarilla Apache Nation, but information is not publicly available regarding the physical attributes of most of the wells. It is believed that wells on the Jicarilla Apache Nation are completed in a similar manner to those completed on adjacent, nontribal lands.

Base of San Jose Formation

We mapped the base of the San Jose Formation (top of Nacimiento Formation) using literature sources (Baltz, 1967; Baltz and West, 1967; Stone et al., 1983) and oil and gas well geophysical logs obtained from the OCD. Geologic cross sections from the literature and the geophysical logs show a distinct lithologic contrast between the basal sandstones of the San Jose Formation (Cuba Mesa Member) and the shale-dominated upper Nacimiento Formation.

We compared information from the oil and gas wells used in the cross sections of Baltz (1967), Baltz and West (1967), and Stone et al. (1983) to the geophysical logs from the same wells or nearby wells available in the OCD database. This comparison showed that the formation contact is distinguished by a distinct change from the sandstones in the lower San Jose Formation to the shale-dominated Nacimiento Formation. In the study area, the upper Nacimiento Formation consists of a well-defined shale layer typically 30 to 60 m thick, although there are sand lenses in the Nacimiento Formation at some locations within approximately 10 m of the base of the San Jose Formation. The top of the Nacimiento Formation was also identified on numerous OCD well cards, especially northeast of the study area.

We examined geophysical logs for more than 370 oil and gas wells within the study area to confirm existing cross sections and to determine the base of the San Jose Formation at additional locations not included on the published sections. Most of these logs were dual induction and electric logs, and included curves for spontaneous potential (SP), short and long normal resistivity, and conductivity. There are also natural gamma logs for many of the wells.

Figure 4 shows a typical induction-electric log from the ground surface through the San Jose Formation into the upper portion of the Nacimiento Formation at well API No. 30-039-05200 (see Fig. 3 for well location). The four hydrostratigraphic units identified in the San Jose Formation are

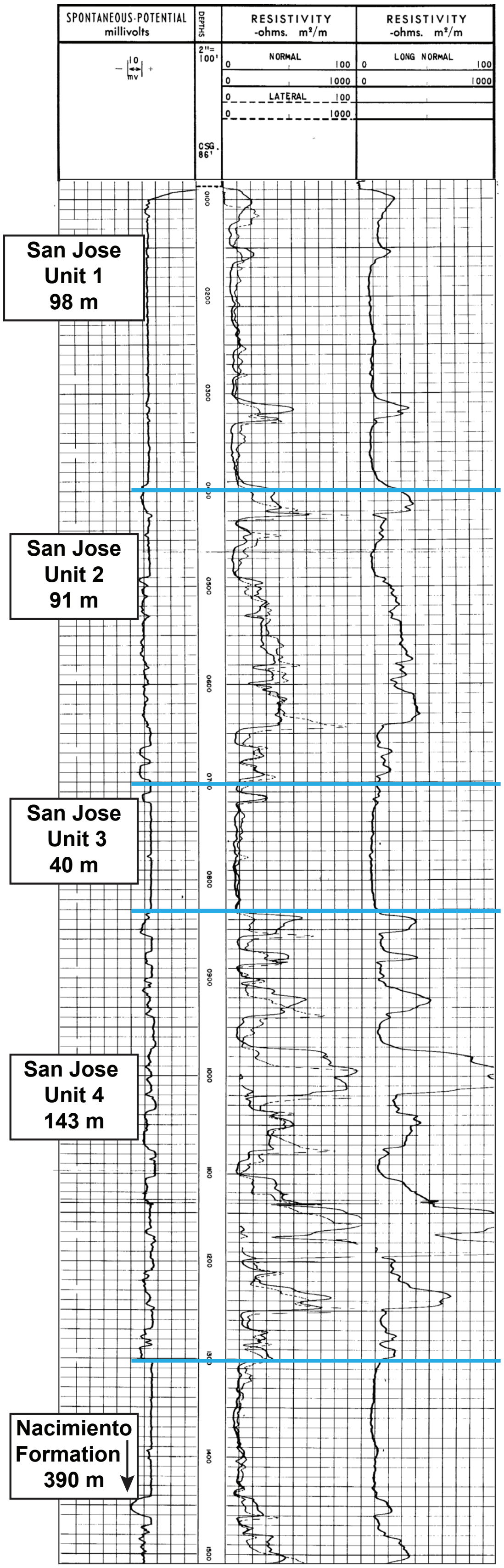


Figure 4. Upper portion of geophysical log for well API No. 30-039-05200 (San Juan Gas Corporation Federal # 33-B) showing hydrostratigraphic Units 1 through 4 in the Cuba Mesa and Regina Members of the San Jose Formation, and the San Jose Formation contact with the Nacimiento Formation.

discussed below. In general, the finer-grained units (e.g., shales and sandy shales) exhibit higher gamma, SP, and conductivity with lower resistivity. Coarse-grained units (e.g., sandstones, conglomerates, and shaley [or silty/clayey] sandstones) exhibit the opposite responses.

Figure 5 provides the contoured elevation of the base of the San Jose Formation within the study area based on 373 geophysical logs. The top of Nacimiento/base of San Jose Formation surface in Figure 5 joins well with the regional, less-detailed surface provided in Stone et al. (1983). The average thickness of the Nacimiento Formation within the study area is approximately 425 m.

Hydrostratigraphic Units

Based on review and analysis of the geophysical logs and water well logs, we identified four hydrostratigraphic units within the San Jose Formation in the study area (Fig. 4). Unit 1 extends from ground surface to a depth of about 100 to 150 m or more depending on the ground-surface elevation. This unit consists of interbedded sandstone and shale, but generally has a higher percentage of shale than underlying Unit 2. This unit likely corresponds to the upper portion of the Regina Member.

Unit 2 is composed primarily of sandstone layers. On geophysical logs, the sandstones have relatively high electrical resistivity. The sandstone intervals are greater than 30 m thick with few fine-grained layers. This unit has a total thickness of approximately 100 m, and likely corresponds to the medial portion of the Regina Member in the Lindrith region.

Unit 3 contains a predominance of low-permeability mudstone units, with some sandstone lenses of limited thickness. This unit ranges in thickness from about 35 to 100 m, but on average is about 60 m thick. This unit is generally equivalent to the lower, shale-dominated portion of the Regina Member.

Unit 4 is the basal portion of the San Jose Formation bounded below by distinctive shale beds of the Nacimiento Formation. This unit is characterized by the increased occurrence of sandstone units with individual sand layers more than 18 m thick. Unit 4 is generally equivalent to the Cuba Mesa Member of the San Jose Formation, but may locally include sandstone lenses at the base of the Regina Member. Figure 6 is an isopach of Unit 4 based on the analysis of more than 300 OCD well logs. This unit ranges from about 60 to 180 m in thickness, and averages about 135 m in thickness within the study area. Although Unit 4 has higher overall sand content relative to shallower units of the of the San Jose Formation, thick sand lenses are not found at all locations, and the thickness presented in Figure 6 includes shale and mudstone layers interbedded with the sands (Fig. 4). The orange data points in Figure 6 identify well locations where mudstone units in Unit 4 are more pervasive relative to other wells.

Units 1, 2, and 4 are aquifer units, and Unit 3 is a confining unit. Unit 4 has the highest potential well yield, followed by Unit 2 and then Unit 1. Most water wells in the Lindrith area are completed in Units 1 and 2, and only a handful of wells are completed in Units 3 or 4. Even though Units 1, 2, and 4 are designated as aquifers, the vertical movement of water within and between these units is limited by the predominance of laterally extensive interbedded shale and mudstone layers that exist in all units, but are more prevalent in Units 1 and 2.

The driller's log for well SJ-2259, the supply well for the Lindrith Community Water Corporation, provides a good example of how Units 1 through 4 may appear on a water well driller's log. This well is completed with 18 m of screen placed in Unit 4, from 321 to 339 m bgs. Figure 3 provides the well location. Figure 7 provides the well log geologic description with the identification of hydrostratigraphic Units 1 through 4.

Groundwater in each of the hydrostratigraphic units can occur under both confined and unconfined conditions. Unconfined conditions exist in the outcrop area of each unit or in subcrop where the overlying unit is not saturated. The shallowest unit (Unit 1) is primarily unconfined, although groundwater in the deeper sandstones of this unit may be confined to semiconfined.

Groundwater Flow, Recharge, and Discharge

To better understand the groundwater flow system in the study area and to estimate the saturated thickness of the hydrostratigraphic units where they are unconfined, we developed a water-level surface map by hand contouring static water levels reported for water wells upon their completion (Fig. 8). This approach is believed to be reasonable because existing information indicates that water levels in the San Jose Formation have not changed substantially through time, which is consistent with the fact that there are no large groundwater uses in the Lindrith area. Although we consider the map approximate because it is based on water levels reported for wells completed in hydrostratigraphic Units 1 and 2 at different times and depths, it does illustrate that the direction of horizontal groundwater flow is generally from east to west, and that the highest San Jose Formation water levels are found east and northeast of Lindrith in the region of highest land-surface elevation.

The direction of vertical groundwater flow based on existing data is downward, consistent with the observation that the Lindrith region and areas of higher land-surface elevation east of Lindrith are zones of groundwater recharge. For example, the upper San Jose Formation aquifer (hydrostratigraphic Units 1 and 2) water-level surface in the vicinity of deep San Jose Formation wells SJ-2259 (Fig. 3) and SJ-0212 (about 2 km southwest of Lindrith) is between 2,120 and 2,135 m msl. However, the static water-level elevations at the two deep wells (hydrostratigraphic Unit 4) are 2,055 and 2,045 m msl, respectively; more than 70 m lower than the contoured shallow hydrostratigraphic Unit 1 and 2 water levels (the deep well water levels were not used to construct Fig. 8).

Significant differences in hydraulic head also occur between the San Jose Formation aquifer and the underlying Nacimiento Formation. The red contours on the eastern side of Figure 8

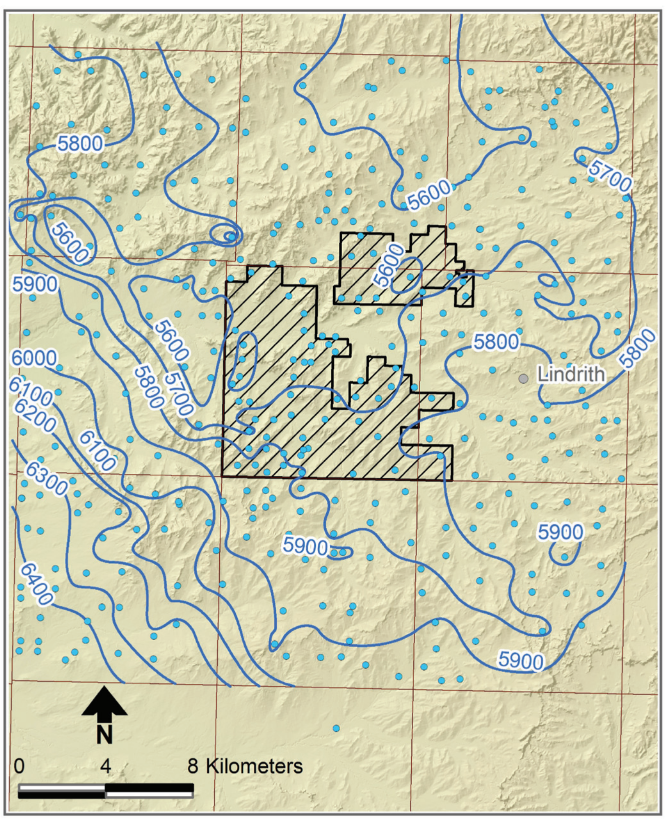


Figure 5. Elevation of the contact at the base of the San Jose Formation and the top of Nacimiento Formation within the study area in feet above mean sea level. Contour elevations range from 1,951 to 1,707 m (6,400 to 5,600 ft) msl.

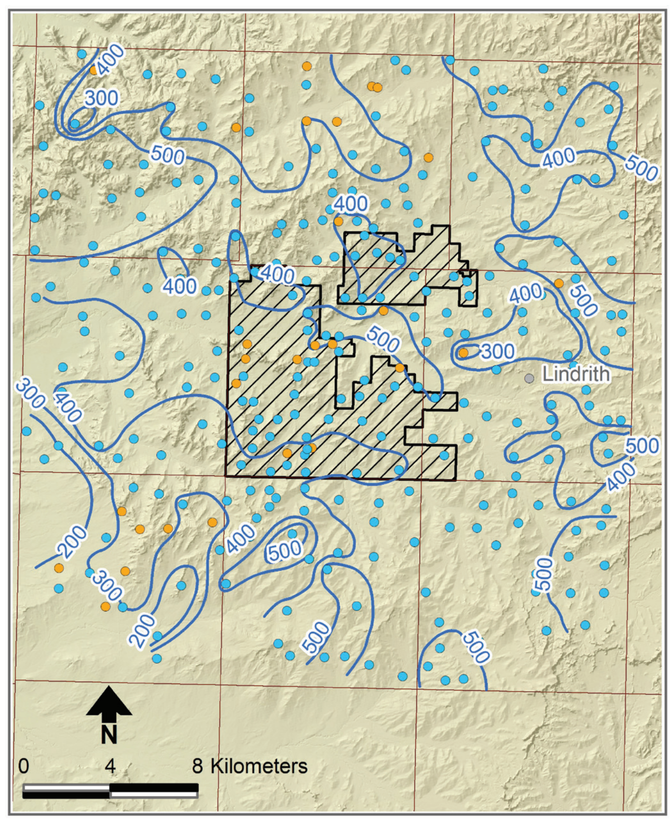


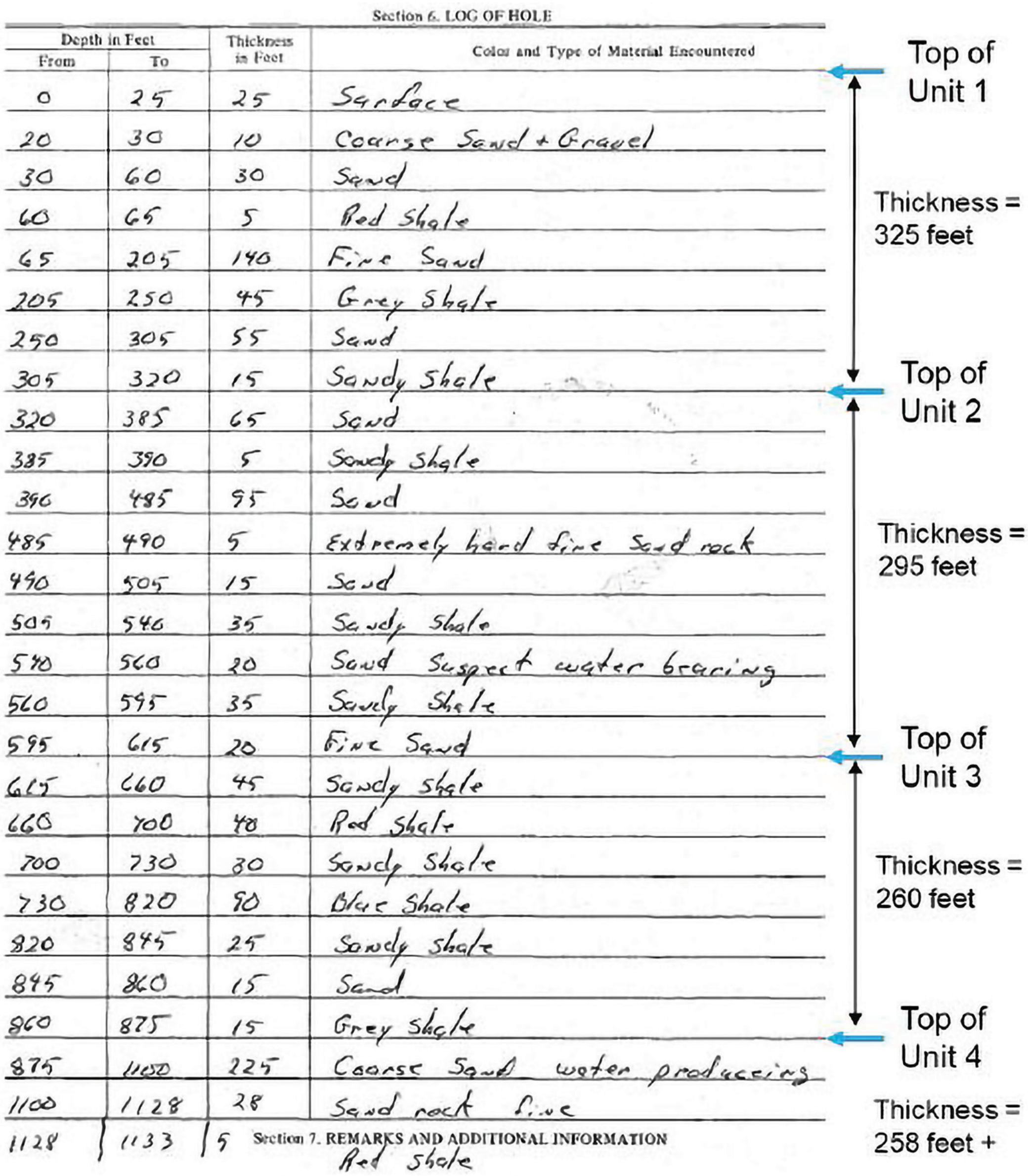
Figure 6. Thickness of hydrostratigraphic Unit 4 of the San Jose Formation. This unit is targeted for water supply and is generally coincident with the Cuba Mesa Member. Thickness contours range from 61 m (200 ft) to 152 m (500 ft). Mapped thickness includes interbedded shale and mudstone units. Locations where shale and mudstone units are more pervasive relative to other wells marked in orange.

are based on the water-level elevations reported for four wells completed in the Nacimiento Formation (wells RG-75251, RG-79954, RG-87711, and RG-91699); these contoured water levels are approximately 120 m lower than the San Jose Formation water-level surface about 2 km to the west.

The findings of downward groundwater flow in the Lindrith region both within the San Jose Formation and between the San Jose Formation and the underlying Nacimiento Formation are consistent with the prior studies of Baltz and West (1967) and Kernodle (1996), who identified the Lindrith region as one of groundwater recharge.

We expanded the study area water-level map in Figure 8 to cover the extent of the San Jose Formation in New Mexico as part of a groundwater model development effort. We developed the map based on the reported static water levels in wells obtained from the NMWRRS and the USGS, and also used streambed elevations in perennial reaches of Canyon Largo, the land-surface elevations at springs, and Navajo Lake and San Juan River elevations in the north (Fig. 9). Figure 9 identifies areas where the San Jose Formation is believed to be dry based on geologic mapping (e.g., the cross section in Hobbs and Pearthree, 2021) and the identification of areas where well completions transition from the San Jose Formation to sand lenses in the underlying Nacimiento Formation.

Figure 9 indicates that groundwater flow in the San Jose Formation is generally from east to west, although there appears to be a trough feature south of the study area approximately parallel to U.S. Route 550. This feature indicates that groundwater recharges in the higher-elevation regions south of the study area in the vicinity of the San Juan River-Rio Puerco watershed divide and the Cuba Mesa Member outcrop (Fig. 3). The shape of the water-level contours may also indicate that the transmissivity of the Cuba Mesa Member may be higher in the trough region relative to other locations, although this



Section 6. LOG OF HOLE

Depth in Feet From	Depth in Feet To	Thickness in Feet	Color and Type of Material Encountered
0	25	25	Surface
20	30	10	Coarse Sand + Gravel
30	60	30	Sand
60	65	5	Red Shale
65	205	140	Fine Sand
205	250	45	Grey Shale
250	305	55	Sand
305	320	15	Sandy Shale
320	385	65	Sand
385	390	5	Sandy Shale
390	485	95	Sand
485	490	5	Extremely hard fine Sand rock
490	505	15	Sand
505	540	35	Sandy Shale
540	560	20	Sand Suspect water bearing
560	595	35	Sandy Shale
595	615	20	Fine Sand
615	660	45	Sandy Shale
660	700	40	Red Shale
700	730	30	Sandy Shale
730	820	90	Blue Shale
820	845	25	Sandy Shale
845	860	15	Sand
860	875	15	Grey Shale
875	1100	225	Coarse Sand water producing
1100	1128	28	Sand rock fine
1128	1133	5	Red Shale

Section 7. REMARKS AND ADDITIONAL INFORMATION

Figure 7. Water well SJ-2259 driller's log with San Jose Formation hydrostratigraphic units identified. Note the 69 m (225 ft) of coarse sand. It does not appear that this boring reached the bottom of hydrostratigraphic Unit 4.

hypothesis would need to be confirmed through additional mapping and aquifer testing.

Groundwater discharges from the San Jose and Nacimiento Formations at springs and seeps along Canon Largo and the lower portion of its tributaries west and northwest of Apache Ranch (Fig. 2). In these groundwater discharge areas, San Jose Formation hydrostratigraphic Unit 4 (Cuba Mesa Member) is at or near land surface (Figs. 3 and 9) and small springs and seeps are found (Baltz and West, 1967). Some San Jose Formation groundwater from members above the Cuba Mesa discharges north and northeast of the study area at springs or seeps in east-to-west-oriented drainages and their tributaries, such as Tapicito Creek, Cereza Canyon, and La Jara Canyon (Fig. 2). Groundwater in the San Jose Formation not extracted by wells either discharges at springs and seeps, is used by small patches of vegetation near springs and seeps, or infiltrates downward into the Nacimiento Formation. In the north, some San Jose Formation water may discharge to Navajo Reservoir.

Changes in Water Levels Through Time

We downloaded available information on water-level

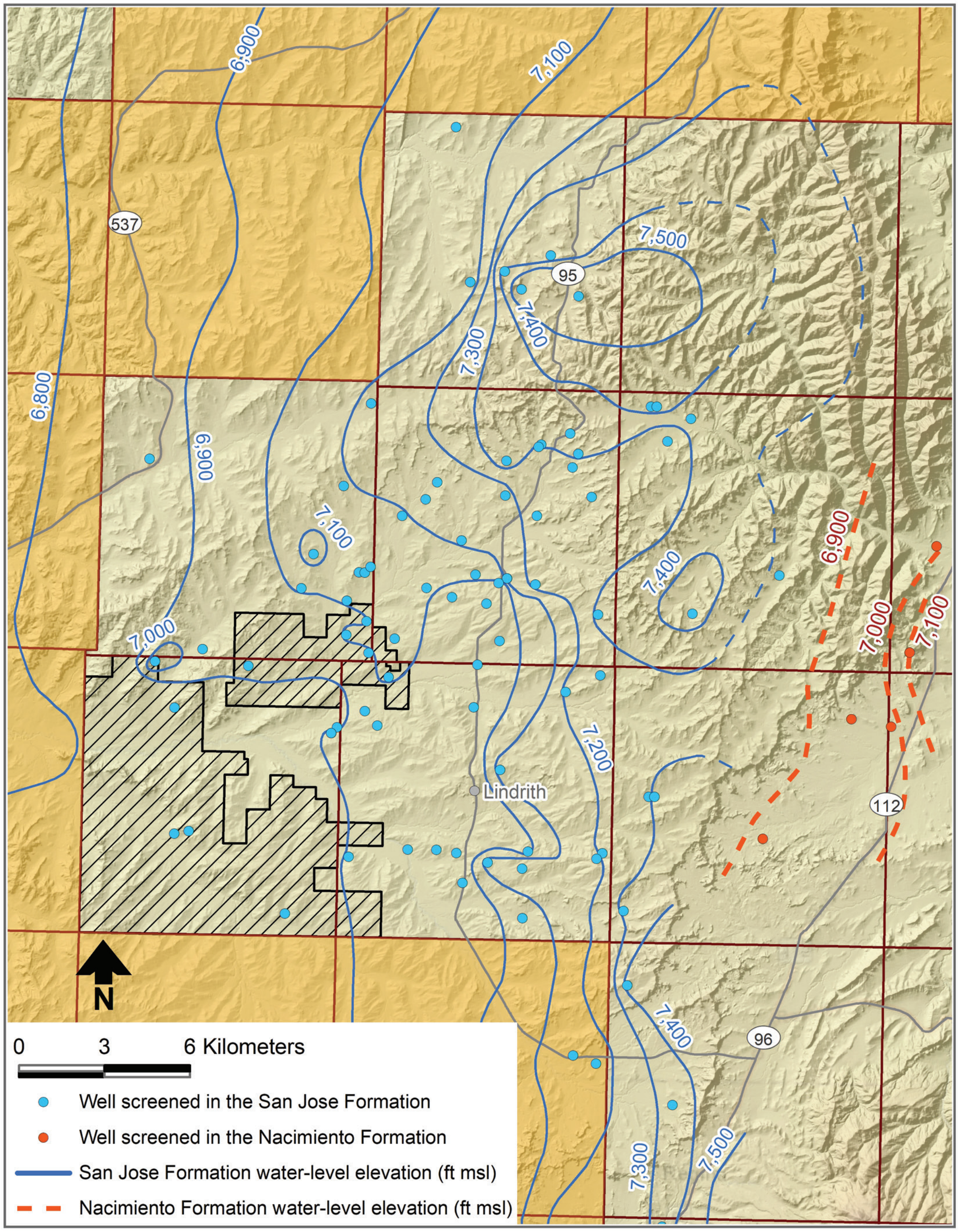


Figure 8. Water-level surface map of the San Jose Formation near Lindrith; contours range from about 2,287 to 2,073 m (7,500 to 6,800 ft) msl. Water levels used for contouring taken primarily from wells completed in hydrostratigraphic Units 1 and 2 of the San Jose Formation. Water-level surface in the Nacimiento Formation outcrop shown in red on east side of the figure.

measurements through time for San Jose Formation wells from the USGS online portal (USGS, 2024), and evaluated hydrographs for wells that had three or more data points. Figure 10 shows the hydrograph well locations.

Review of the hydrograph water levels indicated that groundwater levels in the San Jose Formation are generally stable or rising. To present the information, we plotted the change in water level through time at each well relative to the first recorded water level at the well (Fig. 11). This figure indicates that observed water levels at the five USGS monitor wells have generally remained steady or have risen through time, in one case (e.g., well 363051107071901) by more than 15 m.

The observation that groundwater levels are generally stable or even increasing seems plausible, as most water wells in the region are for small stock and domestic uses, and larger potential water uses such as that for oil and gas activity are not as prevalent in the region as they once were. In addition, larger water demand centers, such as Bloomfield, Aztec, and Farmington, use surface water as their primary source of supply.

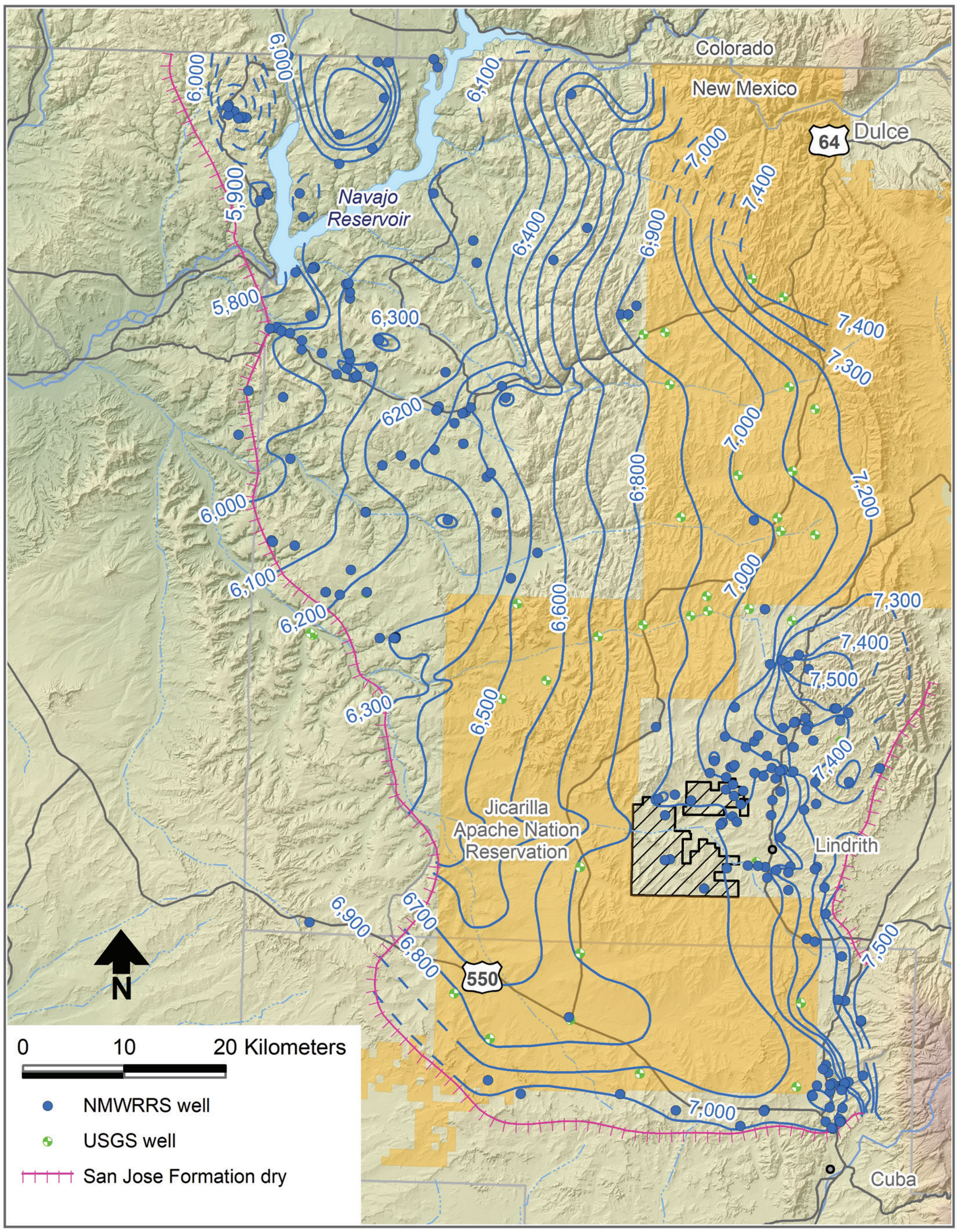


Figure 9. Regional map of San Jose Formation water-level surface in New Mexico in feet above mean sea level. Along the western and southern portions of the San Jose Formation, the regional water table occurs in the Cuba Mesa Member and overlying units (if they exist) are not saturated. In the central and eastern portions of the San Jose Formation, saturated conditions occur in one or more of the younger San Jose Formation members in addition to the Cuba Mesa. In these regions, the figure represents water levels from sandstone units in the upper portion of the San Jose Formation that may be under unconfined, semiconfined, or confined conditions.

TABLE 1. Aquifer hydraulic properties.

Source	Transmissivity (m^2/d)	Horizontal Hydraulic Conductivity (m/d)	Vertical Hydraulic Conductivity (m/d)	Specific Storage (m^{-1})	Specific Yield	Comments
San Jose Formation						
SJ-2259 Proof of Completion of Well - Lindrith Community Water Corporation	9.4	0.5	—	—	—	Well screened 18 m (60 ft) within the Cuba Mesa Member of the San Jose Formation. Assumed well efficiency of 70%.
Kelley et al. (2014)	—	—	—	1.6 x 10^{-6}	0.05	Combined San Jose and Nacimiento Formations.
Intera (2011)	—	0.15	6 x 10^{-4}	3.3 x 10^{-5}	0.1	
Kernodle (1996)	—	0.06	6 x 10^{-4}	—	—	
Stone et al. (1983)	4–11	0.12–0.36	—	—	—	Transmissivity range from two tests; thickness of tested wells reported as 30.5 m (100 ft) on p. 25.
Nacimiento Formation						
Intera (2011)	—	0.003	3 x 10^{-5}	3.3 x 10^{-5}	0.1	
Kernodle (1996)	—	0.003	3 x 10^{-5}	—	—	

m^2/d = Meters squared per day
m/d = Meters per day

Aquifer Hydraulic Properties

Table 1 provides a compilation of aquifer hydraulic properties for the San Jose Formation and the underlying Nacimiento Formation. The sources of information presented in the table include groundwater modeling studies, groundwater studies that summarized aquifer properties obtained through field testing, and the proof of completion for well SJ-2259.

The Unit 4 transmissivity and hydraulic conductivity determined from well SJ-2259 testing is the only new information in Table 1. Well SJ-2259 is owned by the Lindrith Community Water Corporation, a community-owned utility cooperative serving approximately 130 people. This well is screened within a portion of Unit 4 logged by the driller as "coarse sand, water producing" (Fig. 7). We determined the aquifer transmissivity using the specific capacity analytical method, where the transmissivity is backcalculated based on the measured specific capacity of the well; we assumed a well efficiency of 70%. We obtained the hydraulic conductivity by dividing the estimated transmissivity by the screen length of 18 m. The resulting hydraulic conductivity of 0.5 m per day is not particularly high, but if a well could be screened across 50 to 100 m of this type of material, it may produce the quantity of water required for higher-volume uses such as irrigated agriculture.

CONCLUSIONS

We identified four hydrostratigraphic units in the study area through the analysis of oil and gas well geophysical logs and water well completion information. Units 1 through 3 are within the Regina Member of the San Jose Formation, and Unit 4 is equivalent to the Cuba Mesa Member. The sand layers of the Cuba Mesa Member appear favorable at most locations for the completion of wells with sufficient capacity for uses such as irrigation. Most wells in the region have low reported yield because they are completed in shallower portions of the

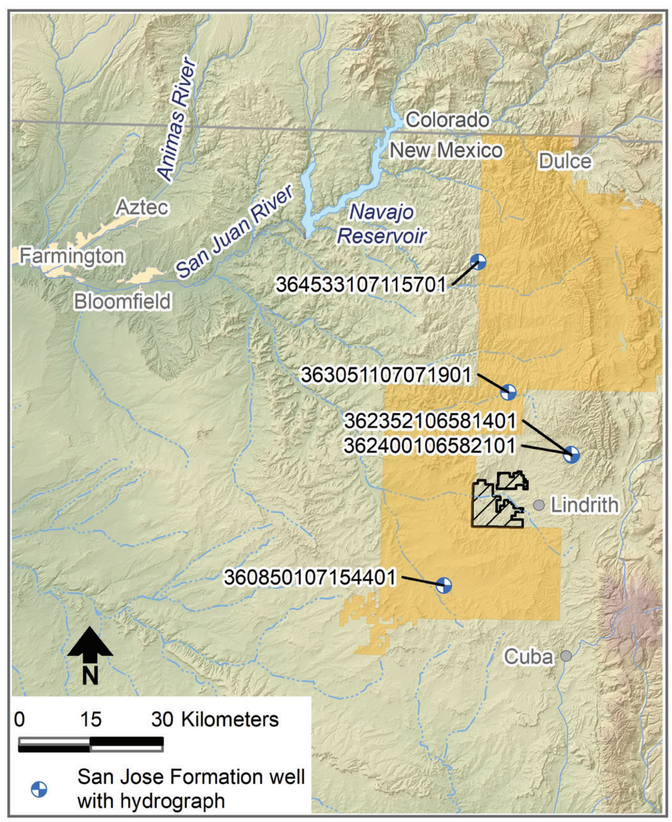


Figure 10. Locations of San Jose Formation wells with three or more water-level measurements from USGS (2024). Well 360850107154401 southwest of Lindrith is completed in hydrostratigraphic Unit 4 (Cuba Mesa Member), and the other four wells are completed in one of the overlying members.

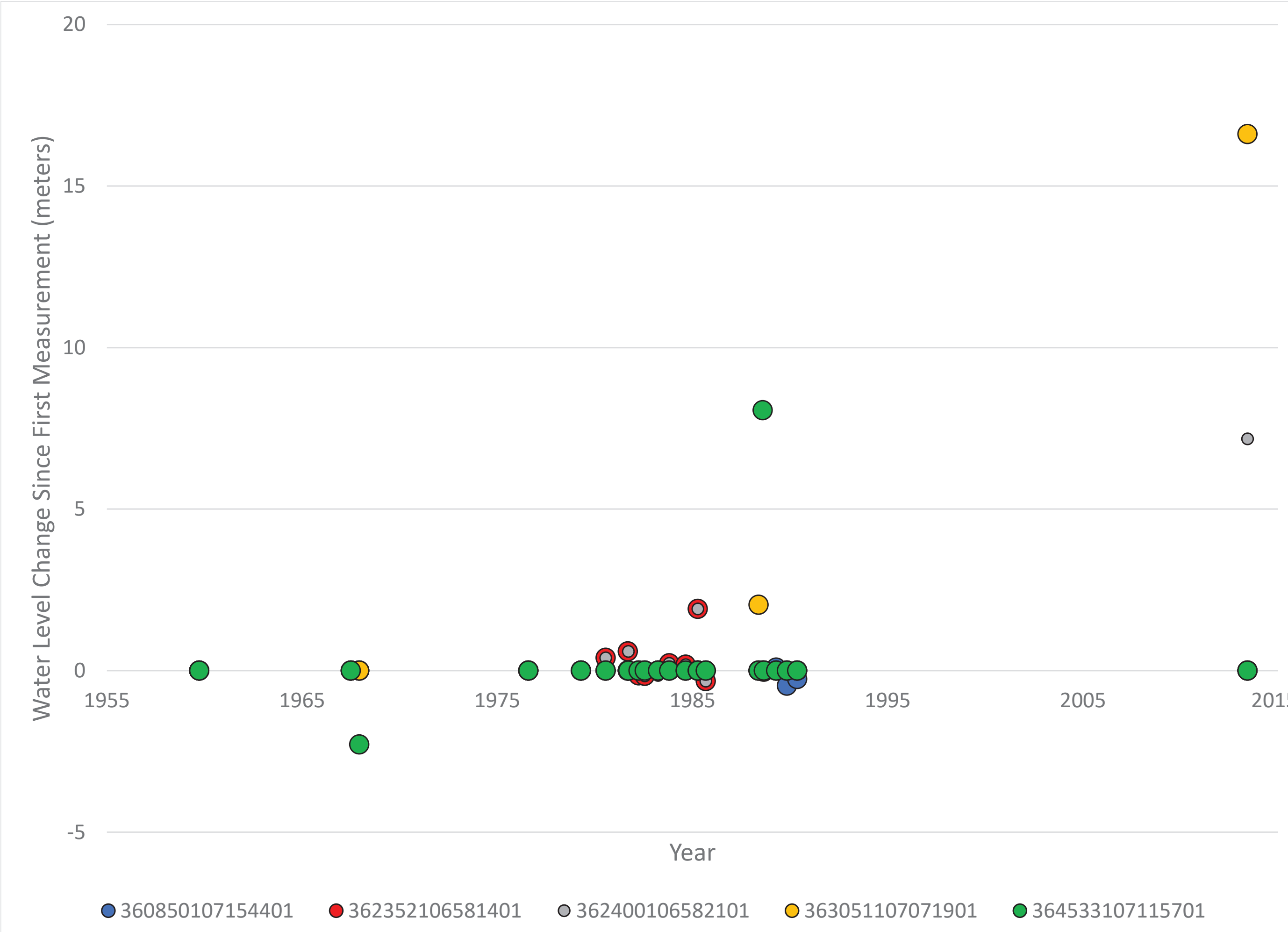


Figure 11. Net water-level change from the first measurement for each of the five USGS monitor wells shown in Figure 10. Positive values are water-level rises and negative values are water-level declines.

San Jose Formation, and the deep (greater than about 300 m) portions of the formation have generally not been targeted or investigated for groundwater development. Due to the predominance of shale and mudstone layers in shallower portions of the San Jose Formation, and to a lesser extent within the Cuba Mesa Member itself, the effects of groundwater pumping at depth will be limited at wells completed above the Cuba Mesa Member. Additional field testing will help to confirm these conclusions.

Groundwater recharges the San Jose and Nacimiento Formations in the Lindrith region, and vertical hydraulic gradients are downward. Horizontal groundwater flow in the San Jose Formation is generally east to west on a regional scale, with groundwater flow to the northwest near Canon Largo. In the far southern portion of the San Jose Formation, groundwater flow is from south to north. Qualitative observation of springs within the San Jose Formation outcrop and groundwater discharge zones along Canon Largo indicates that most natural groundwater discharge from the San Jose Formation occurs from the Cuba Mesa Member at or near Canon Largo.

ACKNOWLEDGMENTS

We thank Dr. Fred Phillips, Dr. John Shomaker, and Dr. Kevin Hobbs for their helpful reviews and insights. Their comments, suggestions, and questions significantly improved the initial version of this manuscript.

REFERENCES

Baltz, E.H., 1962, Stratigraphy and Geologic Structure of Uppermost Cretaceous and Tertiary Rocks of the East-Central Part of the San Juan Basin, New Mexico [Ph.D. dissertation]: Albuquerque, University of New Mexico, 294 p. https://doi.org/10.3133/ofr625

Baltz, E.H., 1967, Stratigraphy and regional tectonic implications of part of Upper Cretaceous and Tertiary rocks, east-central San Juan Basin, New Mexico: U.S. Geological Survey Professional Paper 552, 101 p., prepared in cooperation with the Jicarilla Apache Tribe. https://doi.org/10.3133/pp552

Baltz, E.H. and West, S.W., 1967, Ground-water resources of the southern part of Jicarilla Apache Indian Reservation and adjacent areas, New Mexico: U.S. Geological Survey Water-Supply Paper 1576H, prepared in cooperation with the Jicarilla Apache Tribe. https://doi.org/10.3133/pp552

Brimhall, R.M., 1973, Ground water hydrology of Tertiary rocks of the San Juan Basin, New Mexico, *in* Fassett, J.E. ed., Cretaceous and Tertiary rocks of the southern Colorado Plateau: Four Corners Geological Society Memoir, p. 197–207.

Green, G.N. and Jones, G.E., 1997, The digital geologic map of New Mexico in ARC/INFO format: U.S. Geological Survey Open-File Report 97-0052. https://doi.org/10.3133/ofr9752

Hobbs, K.M. and Pearthree, K.S., 2021, Geologic map of the Chaco Canyon 30 x 60-minute quadrangle, New Mexico: New Mexico Bureau of Geology and Mineral Resources Open-File Geologic Map 292, scale 1:100,000. https://doi.org/10.58799/OF-GM-292

Intera Incorporated, 2011, Assessment of potential groundwater level changes from dewatering at the proposed Roca Honda Mine, McKinley County, New Mexico: Prepared for Roca Honda Resources, LLC, Santa Fe, New Mexico, November 4, 2011.

Kelley, S., Engler, T., Cather, M., Pokorny, C., Yang, C.-H., Mamer, E., Hoffman, G., Wilch, J., Johnson, P., and Zeigler, K., 2014, Hydrologic assessment of oil and gas resource development of the Mancos Shale in the San Juan Basin, New Mexico: New Mexico Bureau of Geology and Mineral Resources Open-File Report 566, 64 p. https://doi.org/10.58799/OFR-566

Kernodle, J.M., 1996, Hydrogeology and steady-state simulation of ground-water flow in the San Juan Basin, New Mexico, Colorado, Arizona, and Utah: U.S. Geological Survey Water-Resources Investigations Report 95-4187, 117 p.

Levings, G.W., Craigg, S.D., Dam, W.L., Kernodle, J.M., and Thorn, C.R., 1990, Hydrogeology of the San Jose, Nacimiento, and Animas Formations in the San Juan structural basin, New Mexico, Colorado, Arizona, and Utah: U.S. Geological Survey Hydrologic Investigations Atlas HA-720-A, 2 sheets.

Levings, G.W., J.M. Kernodle, and C.R. Thorn. 1996, Summary of the San Juan structural basin regional aquifer-system analysis, New Mexico, Colorado, Arizona, and Utah: U.S. Geological Survey Water-Resources Investigations Report 95-4188, 55 p.

Phillips, F.M. and Tansey, M.K., 1984, An integrated isotopic/physical approach to a numerical model of groundwater flow in the San Juan Basin: Technical completion report submitted to New Mexico Water Resources Research Institute, 146 p.

Smith, L.N. and Lucas, S.G., 1991, Stratigraphy, sedimentology, and paleontology of the lower Eocene San Jose Formation in the central portion of the San Juan Basin, northwestern New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 126, 44 p. https://doi.org/10.58799/B-126

Smith, L.N., 1992, Stratigraphy, sediment dispersal and paleogeography of the Lower Eocene San Jose Formation, San Juan Basin, New Mexico and Colorado: New Mexico Geological Society, Guidebook 43, p. 297–309. https://doi.org/10.56577/FFC-43.297

Stone, W.J., Lyford, F.P., Frenzel, P.F., Mizell, N.H., and Padgett, E.T., 1983, Hydrogeology and water resources of the San Juan Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 6, 70 p. https://doi.org/10.58799/HR-6

U.S. Geological Survey, 2024, Water Data for the Nation: https://waterdata.usgs.gov/nwis (accessed 16 February 2024).

Williamson, T.E. and Lucas, S.G., 1992, Stratigraphy and mammalian biostratigraphy of the Paleocene Nacimiento Formation, Southern San Juan Basin, New Mexico, New Mexico Geological Society, Guidebook 43, p. 265–296. https://doi.org/10.56577/FFC-43.265

Zellman, K.L., Plink-Björklund, P., and Spangler, L., 2024, Progradational-to-retrogradational styles of Palaeogene fluvial fan successions in the San Juan Basin, New Mexico: Basin Research, v. 36, e12823. https://doi.org/10.1111/bre.12823