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Development of a 3D Hydrostratigraphic Model in the Northwestern Albuquerque Basin, New Mexico—Implications for the Santa Fe Group Aquifer, Stratigraphy, and Rift Structure

Daniel J. Koning, Luke Martin, Ethan Mamer, and Laila Sturgis
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DEVELOPMENT OF A 3D HYDROSTRATIGRAPHIC MODEL IN THE NORTHWESTERN ALBUQUERQUE BASIN, NEW MEXICO—IMPLICATIONS FOR THE SANTA FE GROUP AQUIFER, STRATIGRAPHY, AND RIFT STRUCTURE

DANIEL J. KONING[1], LUKE MARTIN[1], ETHAN MAMER[1], AND LAILA STURGIS[1]

[1] New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, NM 87109; dan.koning@nmt.edu

Abstract—This paper summarizes the mapping of hydrostratigraphic units in the subsurface of the northwestern Albuquerque Basin in order to better characterize the Santa Fe Group aquifer. The resulting 3D hydrostratigraphic model can be used to better understand groundwater resources as well as elucidate local geologic structures and rift tectonic history. To make this model, hydrostratigraphic unit (HSU) boundaries were projected downdip (into the subsurface) from mapped locations in well-exposed terrain on the study area's northern and western perimeters. Away from these exposures, the contacts were correlated among wells using a wireline and cuttings dataset from 37 wells. Iterative changes were made to these units based on how confidently their lithologies could be correlated and differences in their permeability data (hydraulic conductivity and lithologic proxies). The four final HSUs are called the Upper, Middle, and Lower Rio Rancho HSUs and the Zia HSU. Structural contours were drawn of the respective HSU boundaries which were converted to elevation and thickness rasters that collectively form a 3D hydrostratigraphic model of the basin.

Several observations and interpretations are made for the Upper and Middle Rio Rancho HSUs. One, the Middle Rio Rancho HSU is thicker and more extensive than the Upper Rio Rancho HSU. Both HSUs thicken toward the southeast, being thickest between the southeast corner of Rio Rancho and the intersection of Coors and Paseo del Norte Boulevards. These units thicken eastward across two major east-down faults near the west side of the study area: the San Ysidro and Zia faults. The latter fault forms the west boundary of the Montoyas graben. In this graben, HSUs are relatively thick, and in the Middle Rio Rancho HSU, the saturated zone extends northward 2.5 miles relative to adjoining areas. The Upper and Middle Rio Rancho HSUs thin across the Ziana horst block, which is bounded on the southwest by the northwest-trending Coronado–Alameda fault zone and on the east by the Tamaya fault. Their saturated zones are restricted to the southern part of the horst block and thicken notably east and south of the horst's bounding faults. Analyses of offset datums and thickness trends indicate that the Ziana horst mostly formed after 11 Ma. Post-6-Ma displacement on faults west of the Ziana horst may have controlled a paleodrainage that deposited coarse sediment in the Upper Rio Rancho HSU in and south of the Montoyas graben.

INTRODUCTION

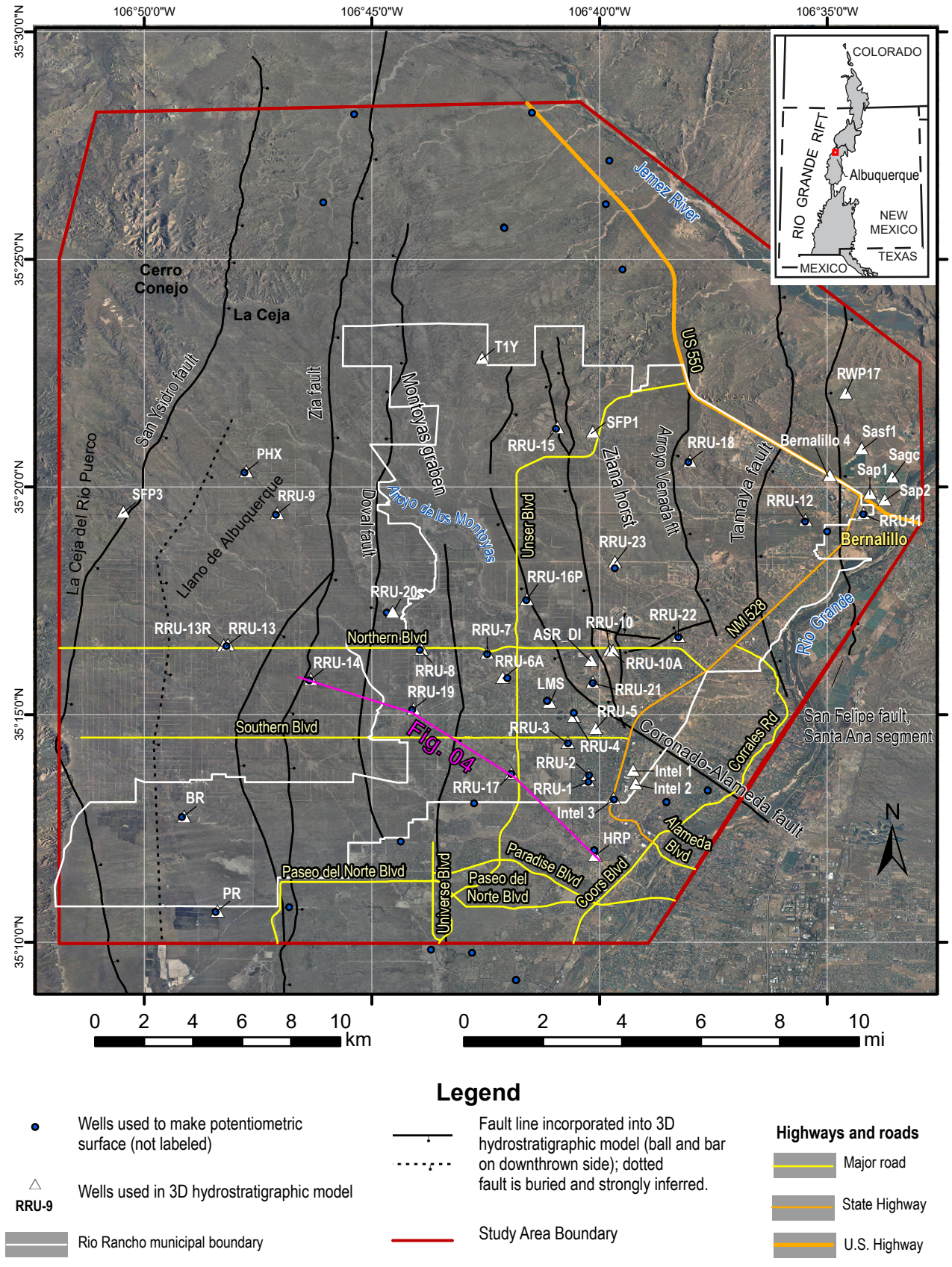
With a population of approximately 115,000, Rio Rancho is the third largest metropolitan area in New Mexico and has an annual growth rate of about 1.7–1.8% (World Population Review, 2025). However, since it lacks surface water rights (e.g., to the Rio Grande), the city relies solely on groundwater for domestic and municipal water usage. Managing its groundwater resources to accommodate its growing population is a challenge and priority for the city.

The Rio Rancho area is located in the northwestern part of the Albuquerque basin (Fig. 1). The area's topography corresponds to a gently eastward-sloping, mesa-like feature called Llano de Albuquerque. The west and north sides of the llano correspond to well-exposed, steep slopes and badlands called the La Ceja del Rio Puerco and La Ceja (Fig. 1).

The larger Rio Rancho area is underlain by the Santa Fe Group aquifer, consisting of sand interlayered with subordinate clay, silt, and gravel. These strata were deposited from ~25 to 1.5 Ma during Rio Grande rifting, concurrent with basin subsidence (Kelly, 1977; Chapin and Cather, 1994; Connell, 2004; Connell et al., 2013). These strata are amenable for detailed stratigraphic study because of good exposure at the north and west margins of the basin coupled with robust well data from 37 water and oil exploratory wells.

Because of the importance of groundwater to the city of Rio Rancho, in 2018, the city funded a three-year project with the New Mexico Bureau of Geology and Mineral Resources (NMBGMR) to provide the city with a groundwater-related database, additional data, and visuals to better understand their water supply and aquifer. To fulfill the latter two goals, the NMBGMR built a 3D hydrostratigraphic model of the Santa Fe Group aquifer in the northwestern Albuquerque Basin and assessed permeability differences within and among lithologic units exhibiting unique hydrologic properties units, hereafter referred to as hydrostratigraphic units (HSUs). Ancillary goals included construction of a preliminary potentiometric surface map and compilation of groundwater total dissolved solids (TDS) and radiocarbon age data.

This paper focuses on the preliminary potentiometric surface map and the hydrostratigraphic model, summarizing how these were made and presenting maps and other visuals to illustrate the Santa Fe Group aquifer in this area. We also discuss how the model and related input data inform us of local rift stratigraphy and structures. A companion paper in this guidebook focuses on groundwater resource implications from this project's synthesis of data relating to permeability, TDS,



Legend

- Wells used to make potentiometric surface (not labeled)
- △ RRU-9 — Wells used in 3D hydrostratigraphic model
- Rio Rancho municipal boundary
- Fault line incorporated into 3D hydrostratigraphic model (ball and bar on downthrown side); dotted fault is buried and strongly inferred.
- Study Area Boundary

Highways and roads

- Major road
- State Highway
- U.S. Highway

FIGURE 1. Map of study area with satellite imagery background. Select highways and roads are shown in addition to important wells and faults. The pink line is the correlation section of Figure 4. See Figure 5 for labeled wells used to make the potentiometric surface. Location of the study area relative to the Rio Grande rift and Albuquerque is illustrated by the inset map.

and groundwater radiocarbon ages (Koning et al., 2026a). More details of the overall study can be found in Koning et al. (2026b). The footprint of the model corresponds to the study area boundary in Figure 1, which also shows major faults and wells utilized in our study.

Previous Work

Relatively up-to-date treatments of the lithostratigraphy of Santa Fe Group strata in the study area are in Connell (2004; 2008a), Connell et al. (1999), and Koning et al. (2026c); these works also give an overview of usage of stratigraphic nomenclature. Intensive geologic and geophysical investigations in the northwestern Albuquerque Basin began during the early 1990s and continued through 2000–2010 (Koning et al., 2026b, appendix 1). An important component of these investigations was geologic mapping at the 1:24,000 scale (Cather et al., 1997; Koning et al., 1998; Personius et al., 2000; Koning and Personius, 2002; Personius, 2002; Thompson et al., 2009). Except for Thompson et al. (2009), these maps were synthesized and compiled by Williams and Cole (2007) and Connell (Fig. 2; 2008b). Lozinsky (1994) examined cuttings of deep wells and offered stratigraphic and paleodepositional interpretations of the Santa Fe Group. Additional stratigraphic insight of the Santa Fe Group was gained by studies of Allen et al. (1998) and Connell et al. (1998). Interpretations of the geologic structure of the Albuquerque Basin have used seismic data (May and Russell, 1994; Russell and Snelson, 1994), aeromagnetic data (Grauch, 1999; Grauch et al., 2001), and gravity data (Grauch et al., 1999; Grauch and Connell, 2013). Recent geologic mapping efforts have focused on the Rio Puerco Valley (centered ~6 miles west of the western boundary of the study area shown in Figure 1), which contains westernmost Santa Fe Group strata of the Albuquerque Basin, including the well-exposed badlands between Ceja del Rio Puerco and the Rio Puerco (Cikoski et al., 2012; Koning and Jochems, 2014; Koning and Rawling, 2017; Koning et al., 2026c).

Conceptual hydrostratigraphic models for the larger Albuquerque region were initiated by Hawley and Haase (1992), Hawley et al. (1995), Hawley (1996), and Thorn et al. (1993). To determine if there were geologic controls on well production and water quality in the Rio Rancho area, Riesterer et al.

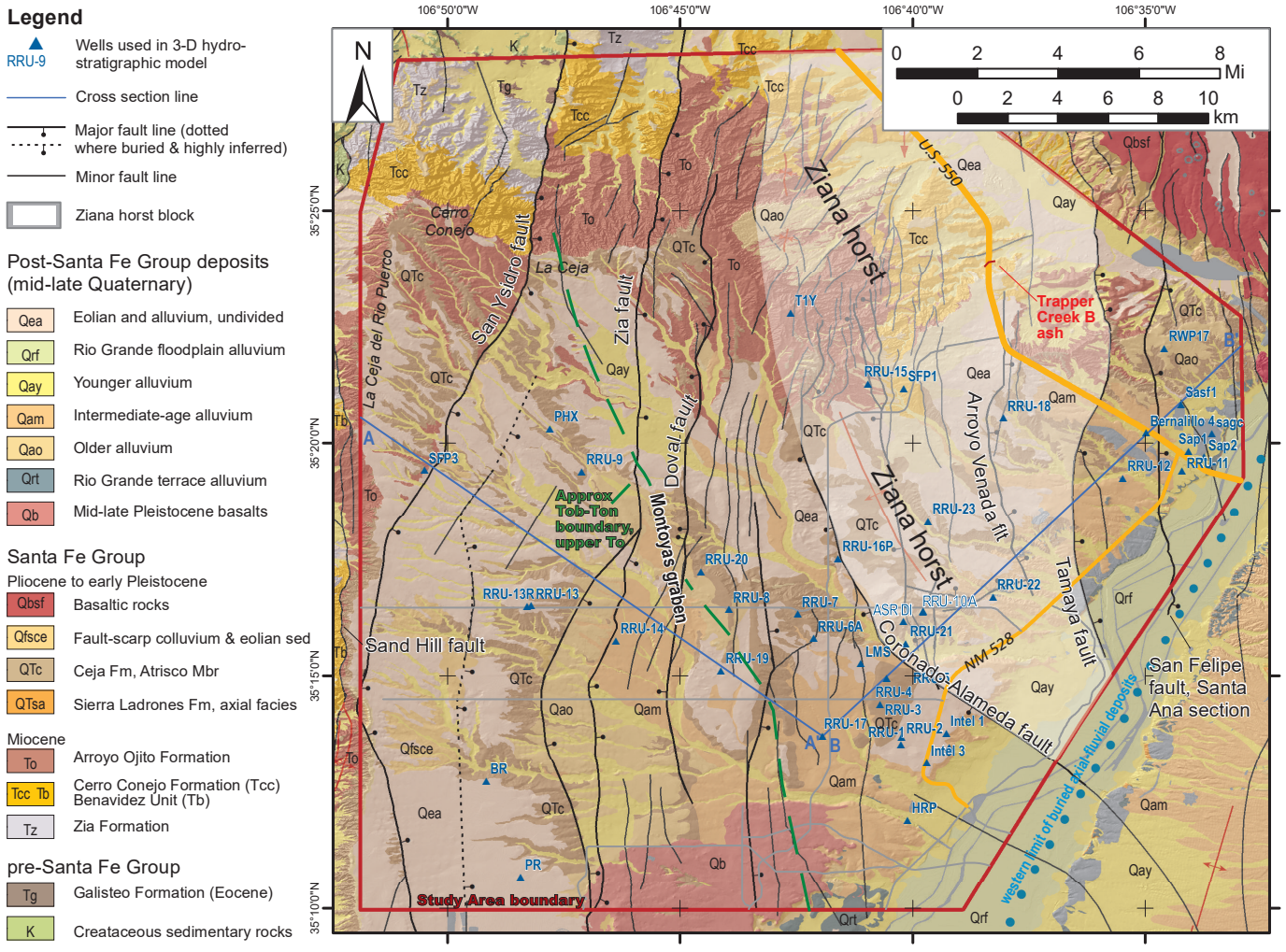


FIGURE 2. Geologic map of the study area, modified from Connell (2008a). Annotated blue lines are locations of cross sections A–A' and B–B' (Fig. 10). The Ziana horst block is shown by the white shading. The green, thick, dashed line marks the approximate central location in the upper Arroyo Ojito Formation of the ~3–4 mi-wide lateral gradation zone between the Loma Barbon and Navajo Draw Members, which is characterized by interfingering and mixing of sediment.

(2004) constructed structural contours of the upper, middle, and lower subdivisions of the Santa Fe Group (per Hawley and Kernodle, 2000) in the northwestern Albuquerque Basin. Subsurface mapping of lithostratigraphic units that approximated hydrostratigraphic units was conducted east and southeast of Rio Rancho (Koning et al., 2019).

Lithostratigraphy

A brief background of Santa Fe Group lithostratigraphy is useful to understand the hydrostratigraphic units comprising the 3D model (Fig. 3). The Santa Fe Group consists of all clastic sediment filling the Rio Grande rift and includes tongues of syn-rift volcanic rocks (Spiegel and Baldwin, 1963; Chapin and Cather, 1994). In the following, we summarize the lithostratigraphic units from oldest to youngest. For more detail on these units (including photographs) and their depositional environments, refer to Connell (2004, 2008a) and Koning et al. (2026c) and references therein.

The lowest formation in the Santa Fe Group is a 300–3,000 ft thick, sand-dominated succession called the Zia Formation (Fig. 3), whose age ranges from 20–17.5 Ma (Tedford and Barghoorn, 1999; Koning et al., 2026c). It consists primarily of fine- to medium-grained sandstone with minor clayey intervals. In its lower part, the Zia Formation contains a distinctive, light-colored, medium-grained sandstone called the Piedra Parada Member (Koning et al., 2026a, 2026b).

The Cerro Conejo Formation (~15–10 Ma) overlies the Zia Formation and is 600 to >1,037 ft thick (Connell et al., 1999; Connell, 2004; Koning et al., 2026b). For this study, we treat the Cerro Conejo Formation as a two-part unit. The lower–middle Cerro Conejo Formation consists of slightly reddish to orangish to tannish, tabular-bedded, mainly fine- to medium-grained sandstone and silty to muddy sandstone that locally make prominent ledges. The upper part of the Cerro Conejo Formation is composed of fluvially cross-stratified to massive, fine- to coarse-grained sandstone with a notable paucity of mudstone beds, correlative to unit Ncn of Koning et al. (2026c).

The Arroyo Ojito Formation (10–6.5 Ma; >1,300 ft thick) gradationally overlies the Cerro Conejo Formation and contains minor conglomeratic strata (Connell, 2004, 2008a). Arroyo Ojito strata are relatively consolidated, but only weakly cemented, and slightly tilted. The formation consists of sandstone, clayey–silty sandstone, mudstone, and conglomerate beds that are mostly tabular-bedded, although coarse channel fills may be lenticular. Three interfingering lithologic units (member-rank) are differentiated and listed here from west to east (Fig. 3). The westernmost Benavidez unit is mostly light-orange sand that contains >5% gravel beds typically composed of rounded chert (Koning et al., 2021, 2026c). The Navajo Draw Member exhibits a distinctive pale-yellow to pale-brown color and has a heterolithic gravel fraction dominated by volcanic rocks (to the north) and chert (to the south). The Loma Barbon Member is reddish yellow to strong brown and light-yellowish brown, and has a gravel assemblage dominated by granite, volcanic rocks, quartzite, and yellowish-brown or reddish-brown sandstones (Connell et al., 1999). The Loma Barbon Member overlies the Navajo Draw Member and interfingers westward with it. East of the Zia fault, the conglomeratic Picuda Peak Member overlies the Loma Barbon Member.

The Plio–Pleistocene Ceja Formation caps the Santa Fe Group sequence and is a few to several hundred feet thick. It coarsens upward to a gravelly sand and overlies an unconformity near the northern and western margins of the study area. The Ceja Formation includes three members relevant to groundwater. In the west, the Atrisco Member is overlain by the Rio Puerco Member. The Rio Puerco Member is composed of sandy gravel and gravelly sand, whereas gravel is relatively sparse in the sandstones and mudstone-dominated strata of the

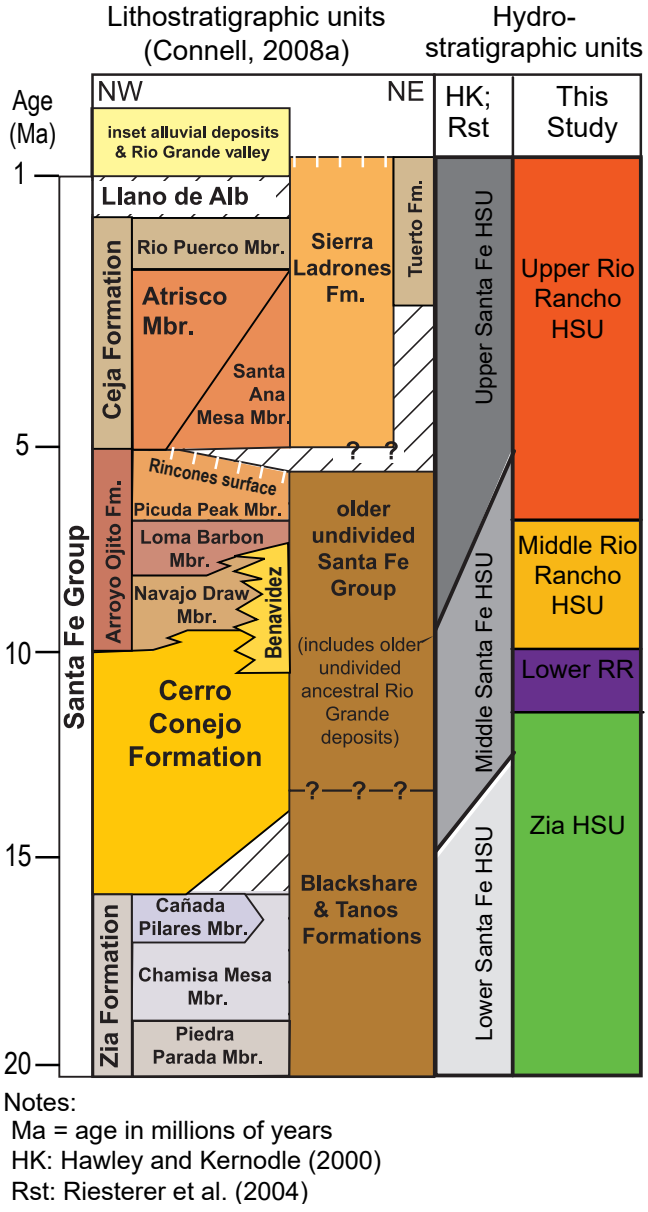


FIGURE 3. Lithostratigraphic nomenclature of and its correlation to the hydrostratigraphic units used in previous studies and this study. Figure modified from Connell (2008a) based on Koning and Jochems (2014), Koning and Rawling (2017), and Koning et al. (2021, 2026b).

Atrisco Member. Near the eastern study area boundary, reddish sand, silt-clay, and granite-rich gravel is assigned to the Santa Ana Mesa Member.

METHODS

Establishing Hydrostratigraphic Units

Our hydrostratigraphic model includes four hydrostratigraphic units. A hydrostratigraphic unit is a zone (corresponding to a layer in the study area) in an aquifer that has unique physical properties pertaining to groundwater; these properties include permeability, porosity, yield, or hydraulic conductivity. A hydrostratigraphic unit can include both saturated and unsaturated zones (Fetter, 1988; Weight and Sonderegger, 2001). Our initial scheme for the delineation of hydrostratigraphic units (HSUs) was based on categorizing lithostratigraphic units using field observations conducted during extensive geologic mapping by the lead author in the badlands near La Ceja and Ceja de la Puerco, located north and west of Rio Rancho (Figs. 1 and 2; Koning et al., 1998; Koning and Personius, 2002; Koning and Jochems, 2014; Koning and Rawling, 2017). To determine if these units were HSUs suitable for inclusion into a potential hydrostratigraphic model we (1) tested if they could be recognized and correlated in wells, and (2) tested if they had unique hydrogeologic properties. The initial stratigraphic scheme was subsequently iteratively changed based on subsurface correlations and assessment of lithologic and hydrogeologic uniqueness. Data from 37 wells (Appendix 1) and Kingdom software (IHS Markit, 2021) were used to evaluate subsurface strata and vertical trends in porosity and clay content. Cuttings descriptions were obtained from consultant reports (Koning et al., 2026a, 2026b, appendix 1) except for wells whose cuttings were archived in the NMBGMR Cuttings Library. These cuttings were described by the lead author, and these descriptions provided lithologic data (i.e., sand and gravel composition, color, and texture) that aided in subsurface correlations. (Koning et al., 2026b, appendix 3). In addition to this descriptive data, digital files of wireline (downhole geophysical) data were used to make stratigraphic picks.

About a dozen cross sections were made in the Kingdom software that allowed determination of the units that could be reliably correlated in the subsurface. These cross sections were made using well logs that include descriptive and wireline data. Particularly useful wireline logs include induction logs (a variant of resistivity logs), gamma-ray logs, neutron logs, and density logs (Fig. 4). The wireline curves are influenced by the proportion of clay. Since clay directly impacts the degree of permeability, using these logs to correlate subsurface strata directly or indirectly (depending on the log) relates to defining potential hydrostratigraphic units. Whether HSUs indeed had unique permeability properties was subsequently tested by compilation of hydraulic conductivities derived from pumping test data.

Mapping a Groundwater Potentiometric Surface

We constructed a new map of the potentiometric surface in the northwestern Albuquerque Basin in order to constrain the top of the saturated zone within the HSUs and construct isopach maps of the saturated portions. We updated the potentiometric surface maps of Kernodle (1998) by incorporating post-2000 (calendar year) groundwater levels (Appendix 3). However, paucity of recent water-level data near the northern and western margins of the study area necessitated using older (1956–1984) water levels in that area. Water-level data for dates when a well seemed to be experiencing pronounced drawdown, presumably due to active or nearby pumping, were excluded. Other constraints used to construct the potentiometric surface are given in Koning et al. (2026b).

The resulting map of the potentiometric surface elevation has a grid element size of 418 ft x 418 ft and is presented in Figure 5. Note that the input data for this map were not as rigorously screened as the U.S. Geological Survey's potentiometric maps produced for Albuquerque (e.g., Galanter and Curry, 2019), as exemplified in our inclusion of water levels spanning decades. Therefore, this map should be considered as an approximation of the potentiometric surface, likely locally having up to 10–100 ft of inferred vertical error, especially toward the northwest corner of the study area (i.e., where elevation contour lines are dashed in Fig. 5).

Mapping Hydrostratigraphic Units Tops

The final hydrostratigraphic model consists of a set of raster surfaces, each of which corresponds to the top of one of the four HSUs (recall that a given HSU can include saturated and unsaturated strata). The top of the Upper Rio Rancho HSU corresponds to surface topography. For the other three HSUs, raster surfaces were made using the Topo-to-Raster ArcGIS tool, whose inputs were elevations of the HSU tops in the 37 studied wells combined with their structural contours.

Except for the Upper Rio Rancho HSU, the lithostratigraphic-top equivalent of any given HSU was identified in outcrops north and east of Rio Rancho. Then, using geologic mapping compiled by Connell (2008b), structural contours were drawn southward from the La Ceja and eastward from Ceja del Rio Puerco outcrops. These structural contour maps are available in an ArcGIS database (Koning et al., 2026b, appendix 6). Attitudes from geologic maps, stratigraphic picks in wells (Appendix 1), and mapped locations of major faults were essential for drawing structural contours away from outcrops. Major faults, defined as those with vertical offsets of more than about 300 ft, were explicitly incorporated by drawing structural contours of their associated fault planes, beginning with their mapped ground trace and extending downdip according to dip values shown on the geologic map of Connell (2008b). Where no dip data existed, we assumed a dip value consistent with those measured on nearby faults. Vertical displacements for a given fault were used to offset the HSU structural contours and were determined by apparent offsets of strata in the Kingdom software cross sections as well as vertical displacements

calculated from offset contacts on the geologic map of Connell (2008b).

The potentiometric surface map allowed us to constrain the top of the saturated zone in a given HSU. Details of the procedure are given in Appendix 2 and in Koning et al. (2026b). Working from the Zia HSU upward to the Upper Rio Rancho HSU, we first defined the saturated extent of the base of a given HSU. Then, within that saturated extent, we merged two rasters to obtain the top of the saturated zone: (1) a raster showing the HSU top where it is fully saturated throughout its whole thickness, and (2) a raster containing the elevation of the potentiometric surface where the HSU is only partially saturated.

RESULTS

Nomenclature of Hydrostratigraphic Units

The final iteration yielded four hydrostratigraphic units that can be correlated in the subsurface and that are listed in ascending stratigraphic order and with lithostratigraphic counterparts in parentheses in Figure 3: Zia HSU (lower–middle Cerro Conejo Formation containing notable clay-rich beds, and the entire underlying Zia Formation); Lower Rio Rancho HSU (upper, sand-dominated Cerro Conejo Formation); Middle Rio Rancho HSU (Navajo Draw and Loma Barbon Members of Arroyo Ojito Formation, and the Benavidez unit

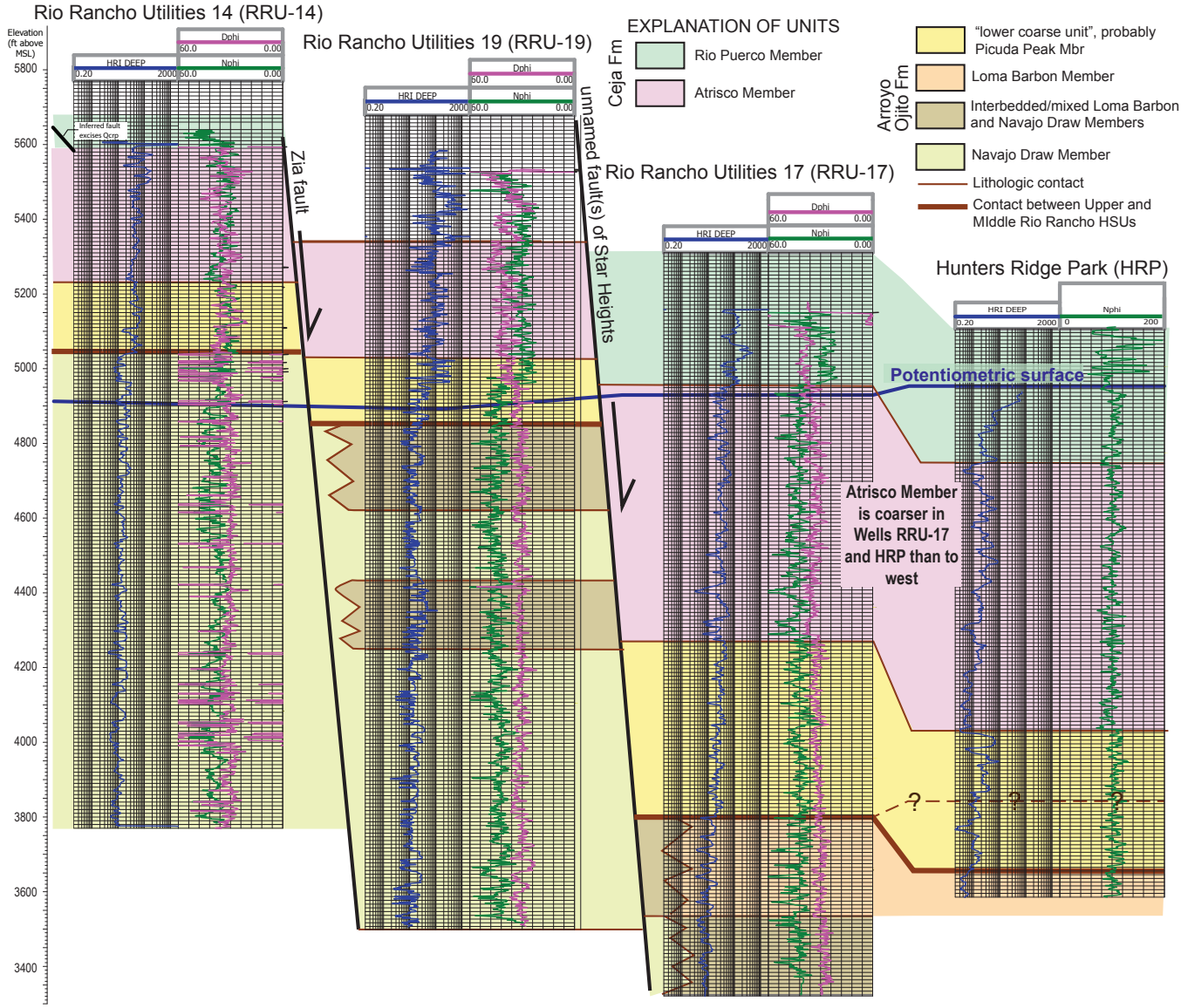


FIGURE 4. Subsurface stratigraphic correlation among Rio Rancho Utility Wells RRU-14, RRU-19, RRU-17, and the Hunters Ridge Park Piezometer. The wells are aligned northwest–southeast and the correlation line is shown in pink in Figure 1. The "lower coarse unit" correlates in part to the Picuda Peak Member of the Arroyo Ojito Formation (sensu Connell, 2008b). The lower coarse unit thickens east of the unnamed fault projecting north of Universe Boulevard, in large part due to syndepositional east-down faulting. The Navajo Draw Member observed in well RRU-14 interfingers eastward into the Loma Barbon Member, with a mixed/interbedded unit mapped in between (brown shade). Abbreviations in the well headings: HRI_deep = deep induction curve (ohm-meters), Dphi = density porosity curve; Nphi = neutron porosity curve. Descriptions and wireline data are in Koning et al. (2026b). Note how the deep induction curve shifts to the right upsection in these wells, consistent with a general upward coarsening trend in the Santa Fe Group.

of Koning et al., 2021, 2026c); and the Upper Rio Rancho HSU (Picuda Peak Member of Arroyo Ojito Formation and Ceja Formation). The lower–middle Zia Formation, corresponding to the sand-dominated Piedra Parada Member, appears to extend across the northern study area (based on its identification in the oil exploratory wells of Santa Fe Pacific 1, Santa Fe Pacific 3, and Tamara) and could potentially be a fifth HSU. We lumped this sandy, lowermost Santa Fe Group unit within the Zia HSU because of its great depth and general lack of penetration by existing water wells. Thus, the extent and thickness of this lowermost sandy unit (Piedra Parada Member) is poorly understood and it lacks pumping test data.

Maps of Hydrostratigraphic Unit Surfaces and Thicknesses

Sixteen map plates in Koning et al. (2026b) illustrate the geometry and elevations of the bounding surfaces of the mapped hydrostratigraphic units, in addition to illustrating their thickness variations. In this paper, we present only a subset of these maps. Figure 6 shows the structural contours defining the tops of the Middle and Lower Rio Rancho HSUs. The rest of the figures pertain to the Upper and Middle Rio Rancho HSUs and show thicknesses of their combined saturated and unsaturated strata (Fig. 7), elevations of the top of the saturated zone (Fig. 8), and the thickness of the saturated zone (Fig. 9). We synthesized the subsurface geometry of the hydrostratigraphic units using a 3D block diagram (Fig. 10). The southern and eastern faces of the 3D block diagram (Fig. 10) correspond to the cross-sectional lines shown in Figure 2 (blue lines labeled A–A' and B–B'). Note that the Upper and Lower Rio Rancho HSUs are thinner than the Middle Rio Rancho HSU. Also, the Upper and Middle Rio Rancho HSUs increase in thickness to the southeast and east of the Tamaya and San Felipe faults. Both appear to thin over the Ziana horst (Fig. 10).

Geologic Structures

The aforementioned maps and 3D block diagram illustrate several aspects of the geologic structure of the northwest Albuquerque Basin. Hydrostratigraphic unit surfaces generally dip to the south or southeast except for the east dips in the southwest corner of the study area (Fig. 6; Connell, 2008b) and perhaps east of the San Felipe fault (where near and south of U.S. Route 550, the dip direction is not certain due to lack of deep well data). The surfaces are offset by several major faults. The geometry of these surfaces and their association with faults define important structural features that are discussed below from west to east.

Western faults

The San Ysidro and Zia faults are major structures on the west side of the Albuquerque Basin. About 100–1,000 ft of east-down vertical displacement of the HSU surfaces is modeled to occur across each of these structures (Fig. 6). The saturated part of the Middle Rio Rancho HSU is generally only present on the east side of the San Ysidro fault and thickens notably east of the Zia fault. Between the Zia and Coronado–Alameda faults and south of Southern Boulevard, the Middle Rio Rancho HSU is >2,800 ft (Figs. 8 and 9).

Montoyas graben

Between the Zia fault and the Ziana horst is a structurally depressed area, referred to as the Montoyas graben (after the nearby Arroyo de los Montoyas); this graben is bisected by the west-down Doval fault (Figs. 2 and 6–9). East of the Doval fault, map data (Connell, 2008b) indicate that strata strike south–southeast and dip west–southwest, so the eastern part of the graben is modeled as a ~003° southwest-dipping homocline. Approximately a hundred to a few hundred feet of west-down offset is inferred to occur along the Doval fault, so the deepest part of the graben is modeled as a narrow (~2 mi), north-trending arm bracketed between the Doval and Zia faults (Figs. 2 and 6). It is in this arm that the saturated Middle Rio Rancho HSU is estimated to be ~2,000 ft thick for ~6 miles north of Northern Boulevard (Fig. 9).

The Montoyas graben merges with the deeper part of the central Albuquerque Basin close to the south end of the Doval fault, near the western end of Paseo del Norte (Figs. 6–10). Saturated strata of the Upper Rio Rancho HSU are present only south of Northern Boulevard. A north-striking fault is inferred from an aeromagnetic lineament (Connell, 2008b) and the top-of-bedrock surface in Grauch and Connell (2013). It approximately coincides with the unnamed faults of Star Heights (Personius and Jochems, 2016). The underlying saturated portion of the Middle Rio Rancho HSU is estimated to be about 3,000–4,000 ft thick on the immediate west side of this unnamed fault (Fig. 9). The amount of throw across this fault is modeled at between 200 and 600 ft, but there is considerable uncertainty south of the Rio Rancho city boundary in how much the Upper and Middle Rio Rancho HSUs thicken across the fault due to lack of deep well coverage (i.e., well HRP is the only deep well in the area and it does not penetrate the Middle Rio Rancho HSU).

Southeast Rio Rancho

Well data indicate relatively steep southward dips of the Upper and Middle Rio Rancho HSU near the eastern end of Southern and Northern Boulevards (Fig. 6). The related structure was called the Loma Colorado transition zone in Hawley and Whitworth (1996). This structure defines the southern end of the Ziana horst (see below) and results in the Upper and Middle Rio Rancho HSUs thickening to the south (Figs. 7 and 9).

Based on this structure and the top-of-bedrock surface of Grauch and Connell (2013), we infer that the collective HSUs are thickest in the southeast corner of the study area, in the vicinity of the intersection of Coors Boulevard and Paseo del Norte (Fig. 7). Here, the saturated part of the Upper Rio Rancho HSU is interpreted to be 1,500–1,800 ft thick, and the underlying saturated strata of the Middle Rio Rancho HSU is inferred

to be more than 3,000 ft thick. In the area between the unnamed fault near Universe Boulevard and the Coronado–Alameda fault, the saturated Upper Rio Rancho HSU thins northward and pinches out about midway between Southern and Northern Boulevards (Fig. 9). Thus, the thickest saturated part of the Upper Rio Rancho HSU, with the highest aquifer transmissivity, is interpreted to be located in the southeast corner of the study area (Fig. 9).

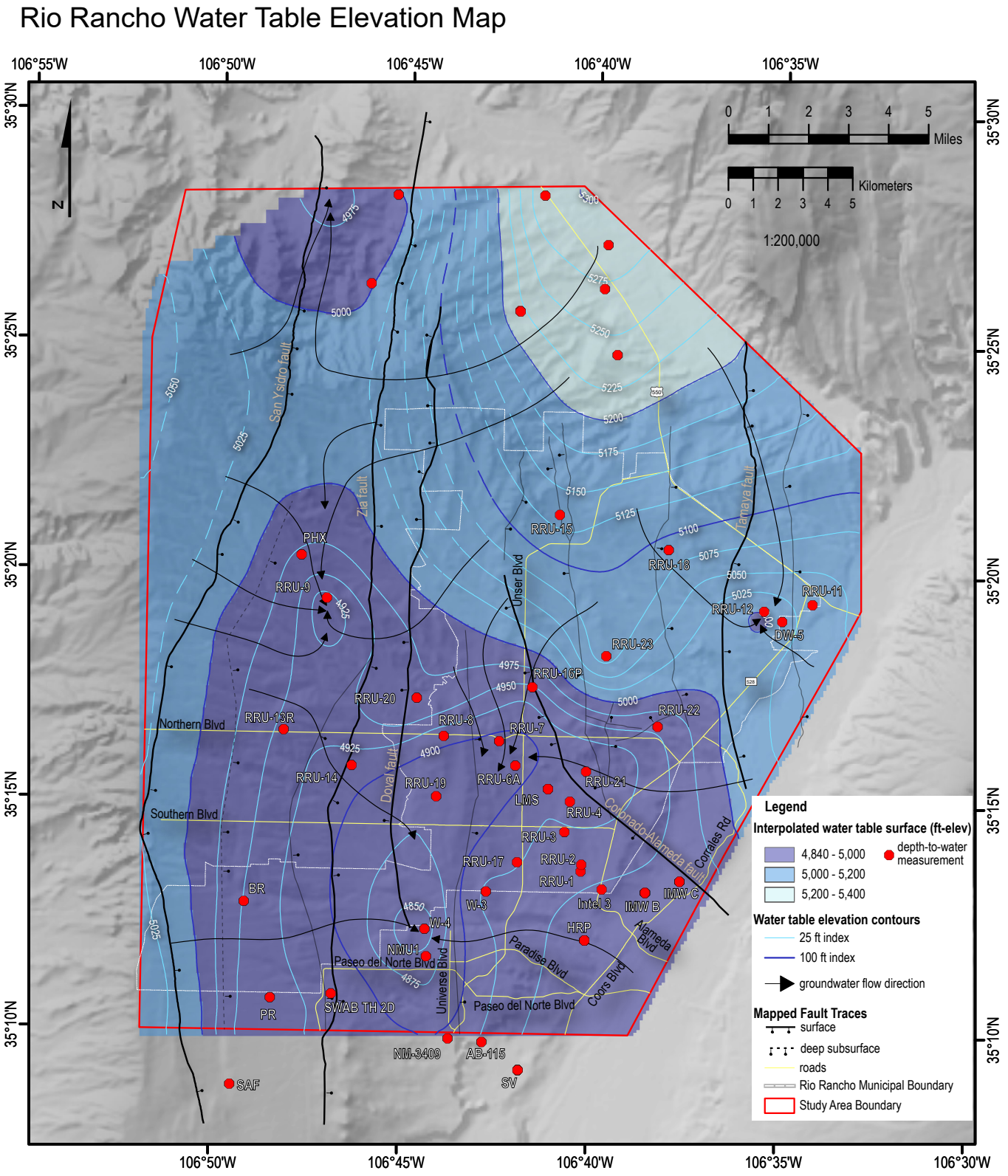
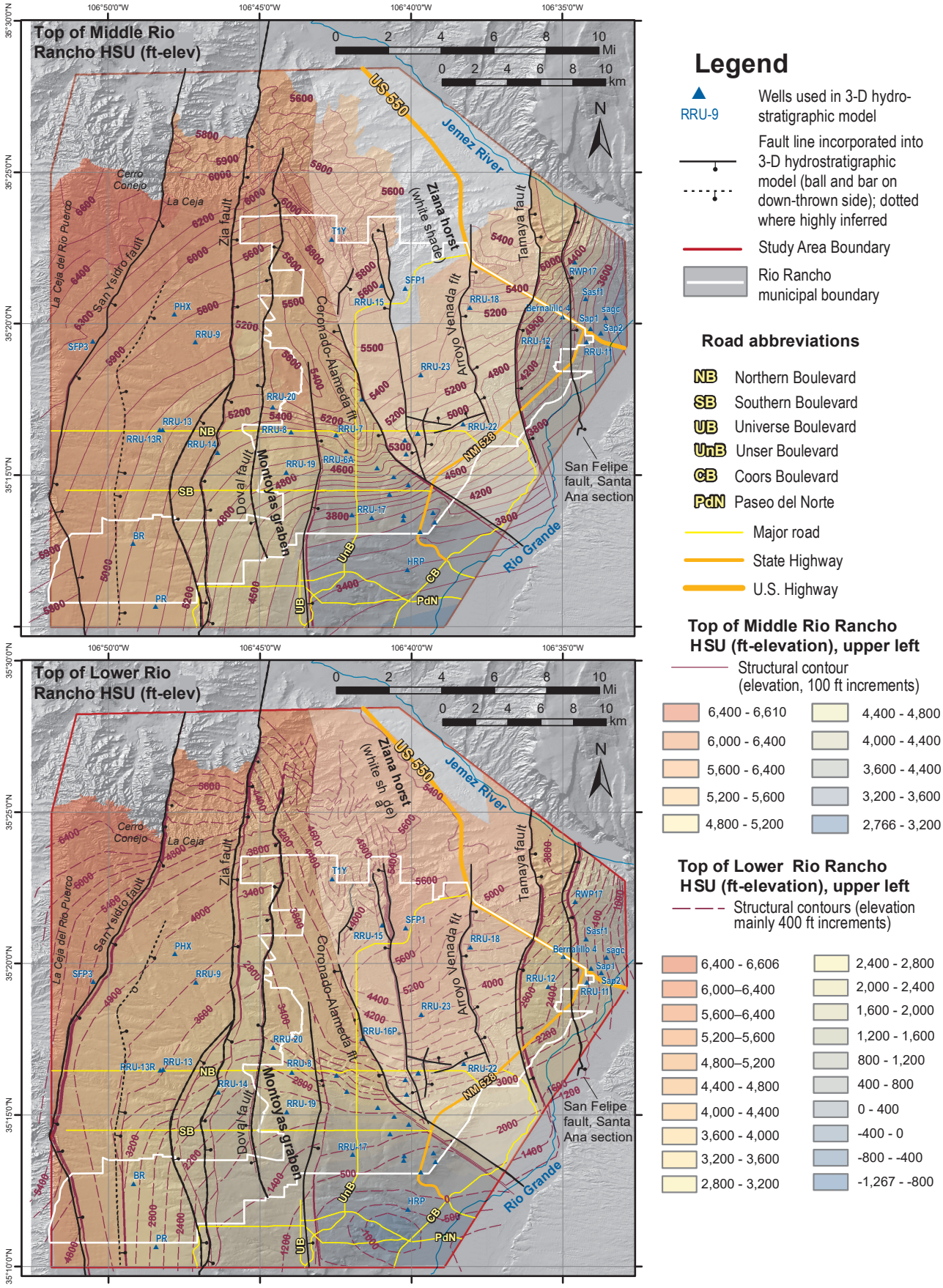


FIGURE 5. Contours showing the elevation (in feet above mean sea level) of the potentiometric surface. Dashed contour lines indicate relatively high uncertainty. Wells used to make the potentiometric surface map are shown as red circles.



Legend

RRU-9 — Wells used in 3-D hydrostratigraphic model

Fault line incorporated into 3-D hydrostratigraphic model (ball and bar on down-thrown side); dotted where highly inferred

Study Area Boundary

Rio Rancho municipal boundary

Road abbreviations

NB Northern Boulevard
SB Southern Boulevard
UB Universe Boulevard
UnB Unser Boulevard
CB Coors Boulevard
PdN Paseo del Norte

Major road
State Highway
U.S. Highway

Top of Middle Rio Rancho HSU (ft-elevation), upper left

Structural contour (elevation, 100 ft increments)

6,400 - 6,610	4,400 - 4,800
6,000 - 6,400	4,000 - 4,400
5,600 - 6,400	3,600 - 4,400
5,200 - 5,600	3,200 - 3,600
4,800 - 5,200	2,766 - 3,200

Top of Lower Rio Rancho HSU (ft-elevation), upper left

Structural contours (elevation mainly 400 ft increments)

6,400 - 6,606	2,400 - 2,800
6,000–6,400	2,000 - 2,400
5,600–6,400	1,600 - 2,000
5,200–5,600	1,200 - 1,600
4,800–5,200	800 - 1,200
4,400 - 4,800	400 - 800
4,000 - 4,400	0 - 400
3,600 - 4,000	-400 - 0
3,200 - 3,600	-800 - -400
2,800 - 3,200	-1,267 - -800

FIGURE 6. Structural contours of elevation (ft) indicating the top of the Middle Rio Rancho HSU (top) and the Lower Rio Rancho HSU (bottom). The HSUs include both saturated and unsaturated strata.

Ziana horst

The Ziana horst (referred to as the Ziana anticline in Black and Hiss, 1974) extends south–southeasterly across the east–central part of the study area (Figs. 2 and 6–10). It is bounded mainly by the aforementioned, west–southwest-down Coronado–Alameda fault and a series of east-down faults that include the Tamaya and San Felipe faults. North of Rio Rancho, the Coronado–Alameda fault appears to lose displacement and terminate northward, and the western margin of the Ziana horst is mainly a southwest-dipping homocline merging westward with the eastern Montoyas graben. Many internal, relatively small-displacement faults are present within the delineated horst block, which form a particularly complex network near wells RRU-10A and RRU-21 between the eastern ends of Northern and Southern Boulevards (Figs. 2 and 6–9).

To reconcile geometries during the structural contouring of HSU tops, we reinterpreted the mapping of the two innermost faults of the Ziana horst (see Personius et al., 2000; Connell, 2008b). The western of the two faults (unnamed) continues northward from previously mapped faults near well RRU-10. Our contouring effort east of well RRU-16P necessitated this fault being west-down, and we connected it to previously mapped west-down faults near wells RRU-15 and SFP-1 (Figs. 2, 6 and 8). The eastern of the two inner faults is a large east-down fault immediately west of well RRU-18 (Fig. 2), which we called the Arroyo Venada fault, the majority of which was mapped earlier by Personius et al. (2000).

On the Ziana horst, the tops of the HSUs generally strike east–northeast and dip south–southeast (e.g., Figs. 6 and 8). Furthermore, the Upper and Middle Rio Rancho HSUs pinch out to the north–northwest on this horst (Fig. 7). This results in a north–northwest pinch out of the saturated parts of these two HSUs as well (Figs. 8 and 9). The saturated Upper Rio Rancho HSU is generally restricted to the southeast of State Road 528 (Figs. 8 and 9). The saturated Middle Rio Rancho HSU extends only about 3 miles north of wells RRU-10 and RRU-10A on the footwall (west side) of the Arroyo Venada fault (Figs. 8 and 9). However, it continues 7–8 miles northward on the west side of the aforementioned, unnamed fault extending from wells RRU-10 to RRU-15, where it is 600–1,000 ft thick and thickens to 800–1,200 ft west of the Coronado–Alameda fault (Figs. 8 and 9). Between the Arroyo Venada and Tamaya faults, the saturated part of Middle Rio Rancho HSU is only a few hundred feet thick near U.S. 550 but increases southward to be >1,000 ft thick near NM 528 (Fig. 9).

Bernalillo area, east of the Tamaya fault

Because cumulative fault displacement commonly scales with fault length (Figs. 1 and 2; Cowie and Schulz, 1992; Schulz, 2002), the observation that the Tamaya and San Felipe faults (Santa Ana section) are 9–12 miles long implies hundreds of feet of vertical offset. A thickened hanging wall section is consistent with our interpretation that studied wells east of the San Felipe fault don't fully penetrate the Upper Rio Rancho HSU except for well RWP17 (Appendix 1). Due to this lack of penetration, HSU tops and saturated thicknesses for the HSUs east of the San Felipe fault, in the Bernalillo area, are approximate with a large amount of uncertainty.

DISCUSSION

Saturated Thickness Variations

Upper Rio Rancho Hydrostratigraphic Unit

The Upper Rio Rancho HSU is interpreted to be a preferred target aquifer because of its slightly higher permeabilities, the fact it is the shallowest of the four HSUs, and its higher recharge potential because it appears to have hydraulic connection with the Rio Grande (Koning et al., 2026a, 2026b). This hydraulic connection would occur along the Rio Grande near the southeast corner of our study area (Fig. 9, upper panel), and the associated groundwater flow would travel from the east to the west (black flow lines in Fig. 5). However, the Upper Rio Rancho HSU in most of the study area is unsaturated, with its saturated area located in the southeastern corner of the study area and along the eastern boundary. The saturated portion of the Upper Rio Rancho HSU is thickest near the intersection of Coors Boulevard and Paseo del Norte (partly due to the increase in the elevation of the potentiometric surface in that direction) and thins to the north. Near the western extent of Paseo del Norte, extending north to Southern Boulevard, the saturated part of the Upper Rio Rancho HSU is less than 500 ft thick and bounded on the west by the east-down Zia fault. In this area, the saturated Upper Rio Rancho HSU thins to the west and north due to the east–southeast stratal dips there (Fig. 6) and the geometry of the potentiometric surface. The northern edge of the saturated part of the Upper Rio Rancho HSU lies between Southern and Northern Boulevards, and it thins notably northeast across the Coronado–Alameda fault. East of the Tamaya fault in the northeastern study area, the saturated zone of the Upper Rio Rancho HSU is inferred to be several hundred feet thick, thickening east of the Santa Ana section of the San Felipe fault.

Middle Rio Rancho Hydrostratigraphic Unit

The saturated part of the Middle Rio Rancho HSU covers a much larger area and is generally much thicker than the Upper Rio Rancho HSU. It also extends notably farther northwest compared to the Upper Rio Rancho HSU, reaching to the San Ysidro fault (Figs. 8 and 9). West of the Zia fault and north of Southern Boulevard, its saturated thickness is generally 1,000–1,500 ft, increasing southward to 2,000 to 2,500 ft within 2 miles west of the west end of Paseo del Norte (west of Zia fault). A 1,200–3,000-ft-thick prong of saturated Middle Rio Rancho HSU extends northward into the Montoyas graben, inferred as being thickest between the Zia and Doval faults and thinning eastward from the Doval fault (Figs. 8 and 9). The saturated part of the Middle Rio Rancho HSU covers much more of the Ziana horst than the saturated Upper Rio Rancho HSU, pinching out ~0.6 mile northward of well RRU-23 between the

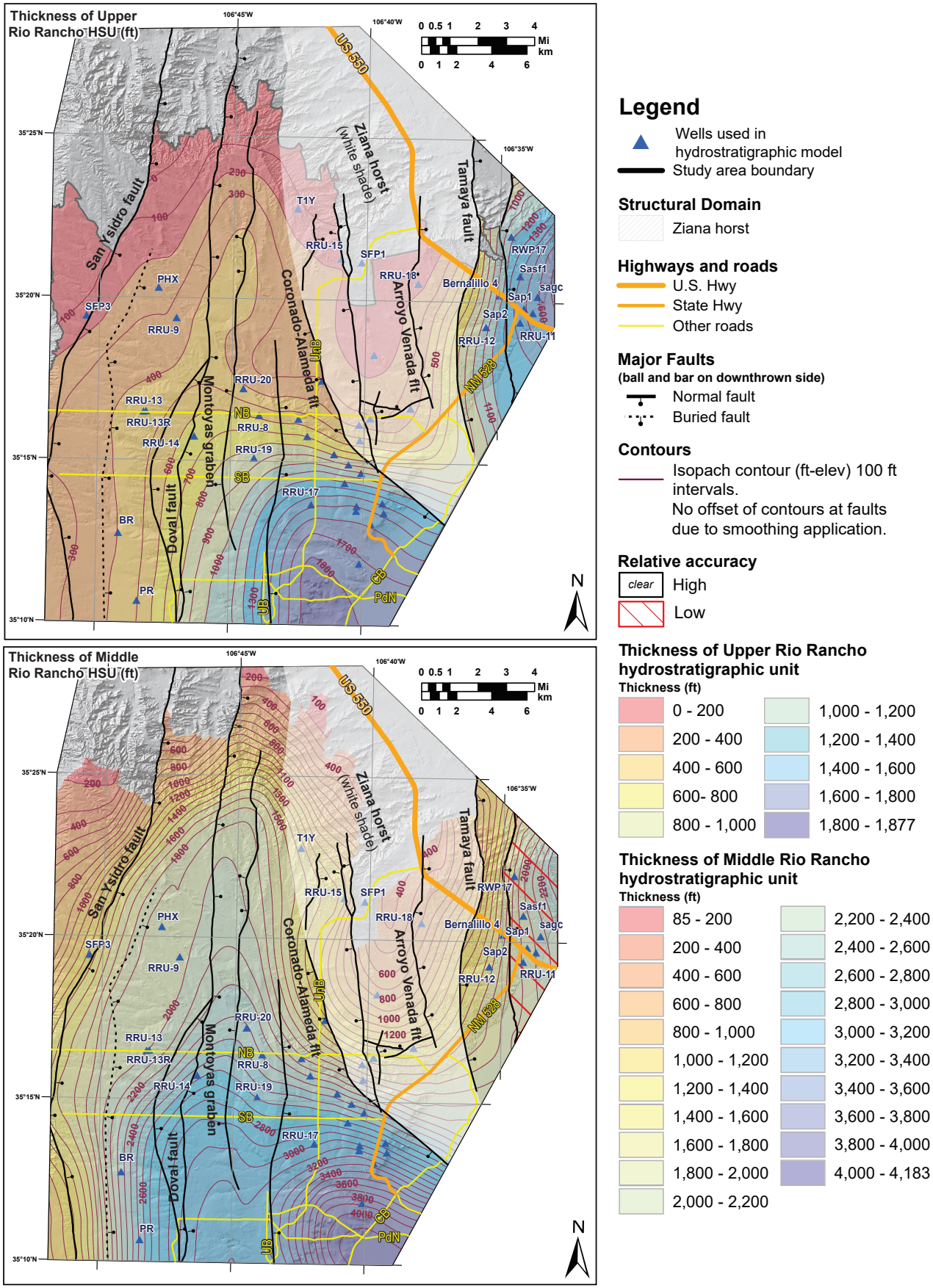
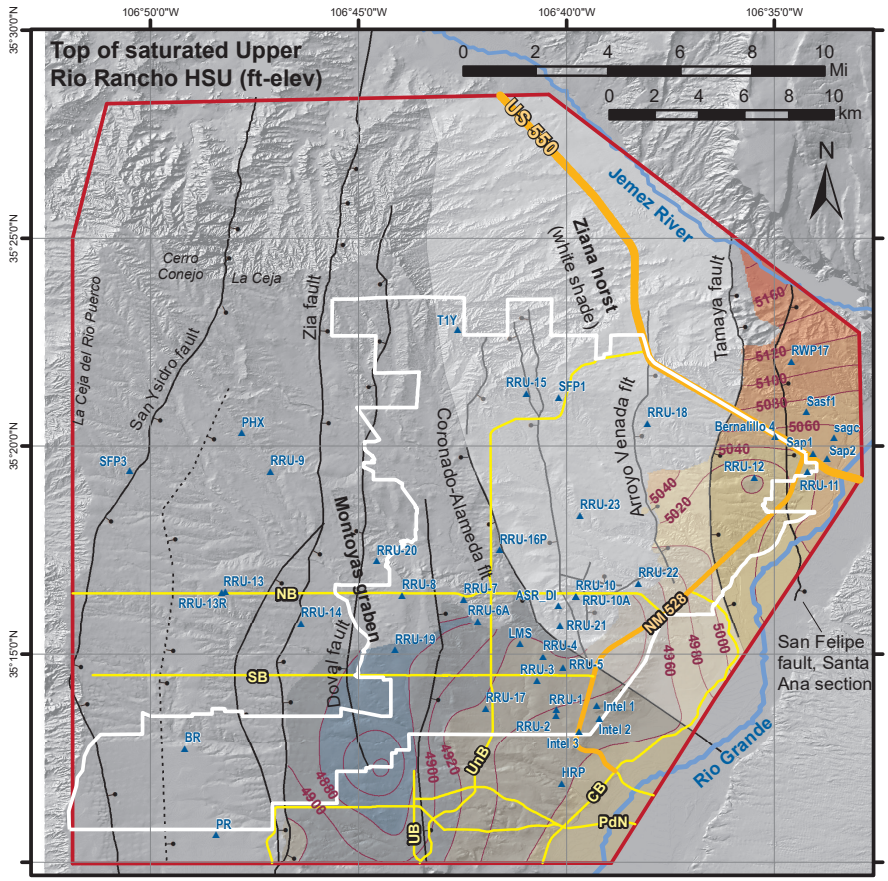
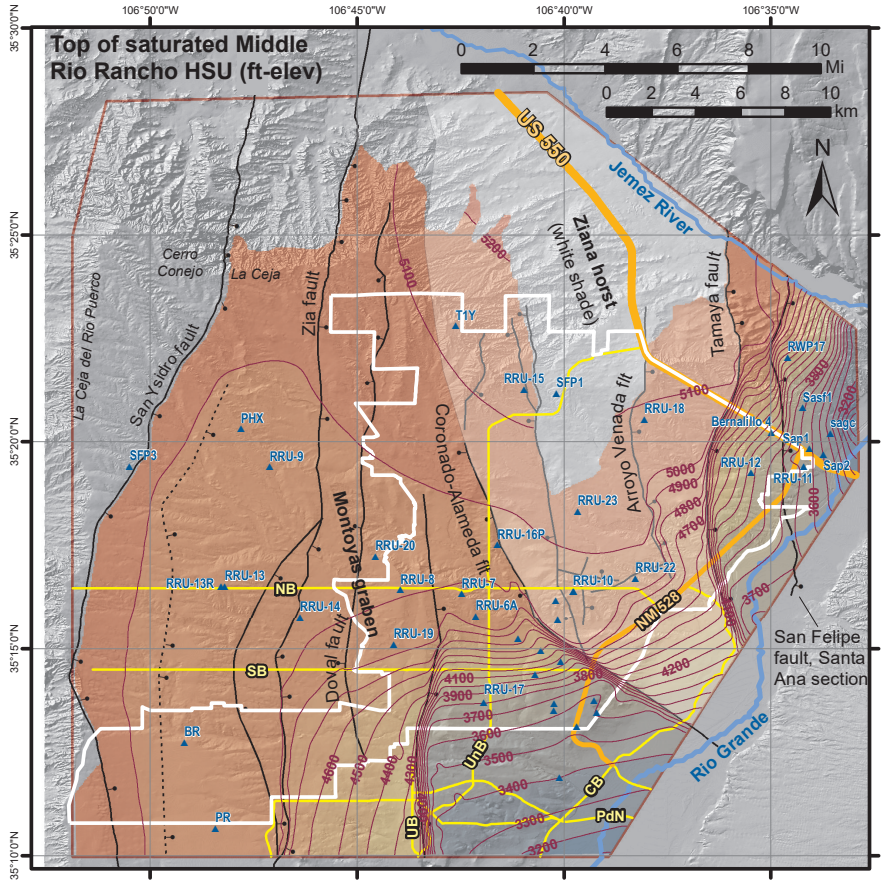


FIGURE 7. Isopach (foot-thickness) map of the Upper Rio Rancho HSU (top) and Middle Rio Rancho HSU (bottom). The HSUs include both saturated and unsaturated strata.





Legend

RRU-9 — Wells used in 3-D hydrostratigraphic model

Fault line incorporated into 3-D hydrostratigraphic model (ball and bar on down-thrown side); dotted where highly inferred

Study Area Boundary

Rio Rancho municipal boundary

Road abbreviations

- NB Northern Boulevard
- SB Southern Boulevard
- UB Universe Boulevard
- UnB Unser Boulevard
- CB Coors Boulevard
- PdN Paseo del Norte

Major road

State Highway

U.S. Highway

Top of saturated Upper Rio Rancho HSU (ft-elevation)

Elevation contour (40 ft increments)
No offset by faults shown due to smoothing

5,160 – 5,197	4,960 – 5,000
5,120 – 5,160	4,920 – 4,960
5,080 – 5,120	4,880 – 4,920
5,040 – 5,080	4,838 – 4,880
5,000 – 5,040	

Top of saturated Middle Rio Rancho HSU (ft-elevation)

Elevation contour (200 ft increments)
No offset by faults shown due to smoothing

5,200 – 5,229	4,000 – 4,200
5,000 – 5,200	3,800 – 4,000
4,800 – 5,000	3,600 – 3,800
4,600 – 4,800	3,400 – 3,600
4,400 – 4,600	3,200 – 3,400
4,200 – 4,400	2,815 – 3,200

FIGURE 8. Elevation (ft) of the upper surface of the saturated zone for the Upper Rio Rancho HSU (top) and the Middle Rio Rancho HSU (bottom).

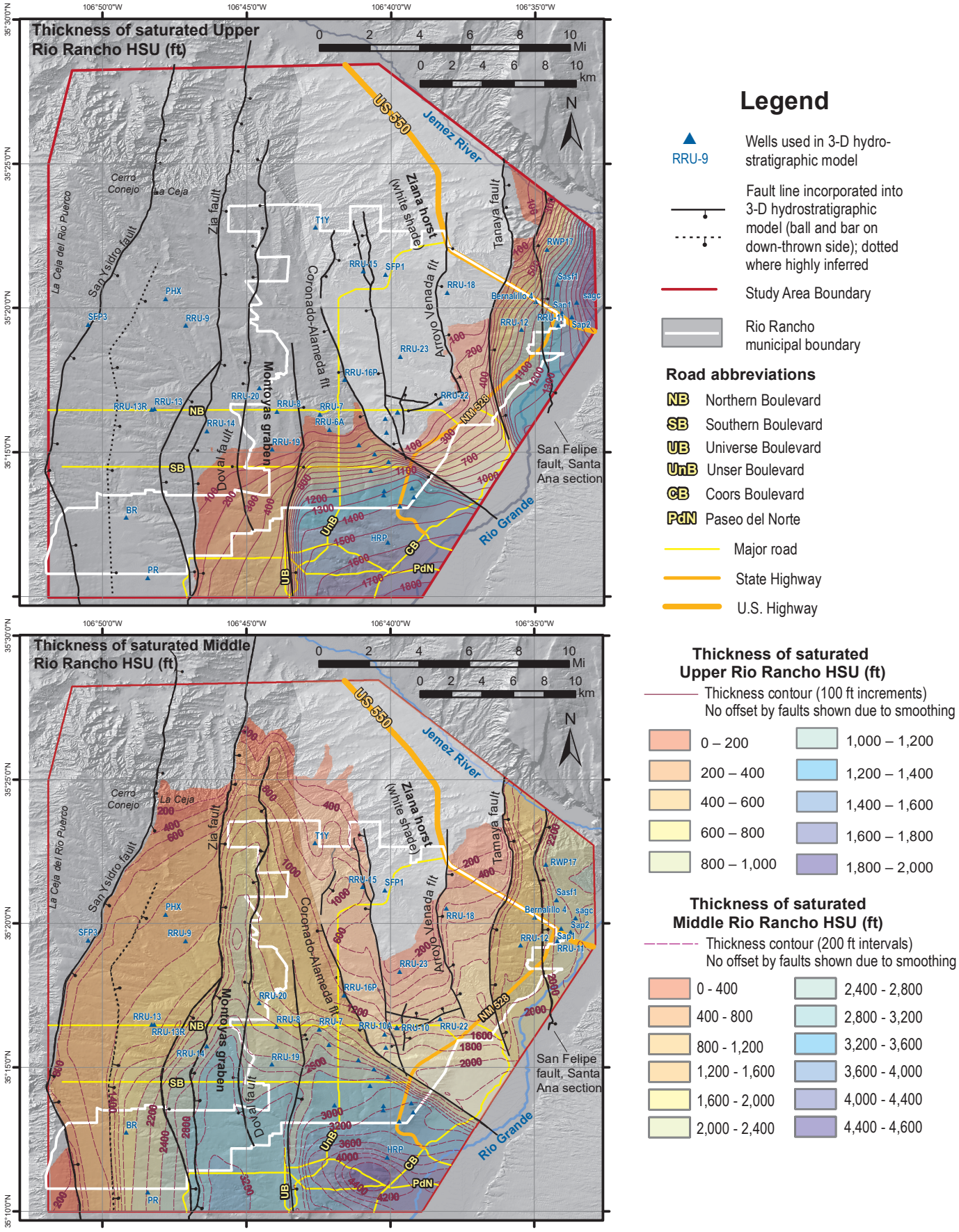


FIGURE 9. Isopach (foot-thickness) map of the saturated zone of the Upper Rio Rancho (top) and Middle Rio Rancho HSU (bottom).

unnamed fault passing close to well RRU-15 and the Arroyo Venada fault (Figs. 8 and 9). The saturated Middle Rio Rancho unit is generally >1,500 ft thick east of the Tamaya fault and is inferred to be >2,000 ft east of the Santa Ana section of the Felipe fault. In the southeast corner of the study area, the saturated Middle Rio Rancho HSU is interpreted to be 2,800–4,400 ft (Fig. 9), but this thickness is poorly constrained because no wells penetrate the entire unit there.

Compilation of hydraulic conductivity and specific capacity data from pumping tests indicate that, in general, the Middle Rio Rancho HSU is likely to be less permeable compared to the Upper Rio Rancho HSU (Koning et al., 2026a, 2026b). However, the greater thicknesses of the Middle Rio Rancho HSU results in relatively high transmissivities (transmissivity = hydraulic conductivity times thickness of saturated sediment). Therefore, one can consider the Middle Rio Rancho HSU an important groundwater resource in the northwestern Albuquerque Basin.

New Lithostratigraphic Insights

The stratigraphic correlations and cuttings and wireline log data used to construct the hydrostratigraphic model yielded new insights on the lithostratigraphy of the Santa Fe Group. We briefly summarize these findings below:

- There is commonly upward coarsening within strata comprising the upper Middle and the Upper Rio Rancho HSUs. This upward coarsening is apparent on wireline data as well as inspection of drill cuttings (Koning et al., 2026b, appendices 3 and 4). In most places, this upward coarsening is gradual and occurs over tens to hundreds of feet. However, some wells in the northwestern part of the study area have a relatively sharp contacts at the base of the Upper Rio Rancho HSU (Fig. 4) (i.e., wells RRU-7, RRU-8, and RRU-9; Koning et al., 2026b, appendix 4). These sharp contacts may possibly be manifestations of an unconformity in the section. This unconformity may correlate to the Rincones paleosurface, the unconformity separating Pliocene and Miocene strata (Connell, 2008a).
- In a southward direction, there is a ~3–4-mi-wide gradational zone between the Loma Barbon and Navajo Draw Members of the Arroyo Ojito Formation (Fig. 4), whose approximate map location is shown in Figure 2. This gradation is probably due to southward convergence of the two associated paleodrainage systems (see Connell et al., 1999; Connell, 2004) and the back-and-forth (east–west) shifting of this common boundary.
- The Lower Rio Rancho HSU is extensive in an east-west direction and does not appear to thin across the Ziana horst block (Fig. 10); rather, eastward thickening may occur in that direction (Fig. 10; Koning et al., 2026b, plate 7), consistent with northeast-thickening of the Cerro Conejo Formation in the cross sections in Riesterer et al. (2008).
- The fine-grained sediments of the Atrisco Member of the Ceja Formation observed in wells RRU-13R and RRU-14 coarsen eastward of about the longitude of well RRU-19 (Fig. 4). Furthermore, the lower coarse unit shown in Figure 4 (probably correlative to the Picuda Peak Member of the Arroyo Ojito Formation) thickens eastward of that well (Fig. 4). The lower coarse unit is mostly composed of granitic and volcanic detritus (with a paucity of mafic detritus). Based on this composition and consideration of bedrock source areas, we interpret that the unit trends north–northwest and represents deposition by a southward-flowing drainage approximating the Jemez River. The position of this paleodrainage may be controlled by subsidence along the Coronado–Alameda fault and the inferred fault along Universe Boulevard; to the north, tectonic subsidence of the Zia fault may also have controlled the position of this paleodrainage. The coarse-grained nature of this unnamed unit and the coarser texture of the Atrisco Member above it is important because this coarse package extends southward to where the saturated part of the Upper Rio Rancho HSU has a notable thickness (for example, well HRP in the southeast study area). Thus, the coarse sediment delivered by this paleodrainage may partly explain why the Upper Rio Rancho HSU is more likely to have higher permeability (for permeability data and discussion, see Koning et al., 2026a).

Tectonic Uplift of Ziana Horst

Two observations indicate that the Ziana horst was notably tectonically active after ~11 Ma. First, the upper Cerro Conejo Formation (coinciding with the Lower Rio Rancho HSU) either thickens eastward or maintains about the same thickness across the Ziana horst, but the overlying Arroyo Ojito Formation (Middle and Upper Rio Rancho HSUs) thins significantly across this structure (Figs. 7 and 10). Second, 11.3–11.2-Ma Trapper Creek B ashes are seen at ground level (Fig. 2) in the footwall of the Arroyo Venada fault, one of the major eastern-bounding faults of the horst. These same volcanic ashes lie at 2,070–2,080 ft depth in the hanging wall (in well RRU-18), as discussed in Koning et al. (2026b, appendix 8). Using this ash as a structural datum, our structural contouring of the top of the Cerro Conejo Formation indicates ~600 ft of east-down vertical displacement on the Arroyo Venada fault and several hundred feet of structural relief from a south-down structural ramp on the eastern (hanging wall) side of the fault (Fig. 6). That structural relief must have occurred after the deposition of the 11.3-11.2-Ma Trapper Creek B ashes, but this seems to have happened after 10 Ma because the upper Cerro Conejo Formation (Lower Rio Rancho HSU) does not appear to thin across the uplift.

CONCLUSIONS

Our study differentiated four hydrostratigraphic units (HSUs) in the northwestern Albuquerque basin and modeled them in the subsurface. We constructed a 3D geologic model showing the elevations of the bounding surfaces of these HSUs, and this model explicitly includes the major faults that offset them. This model will be useful for potential future studies

such as calculating groundwater volumes and for creating groundwater-flow models of the area. Structural contouring indicates a graben (Montoyas graben) between the Zia fault and Ziana horst.

The model shows the distribution of the extent and thicknesses of saturated and unsaturated portions of the HSUs. Thick saturated portions of the Upper Rio Rancho HSU (~500 to 2,000 ft thick) are only found east of the Tamaya fault and in the southeastern part of the study area, south of Southern Boulevard and southwest of the Coronado–Alameda fault. The saturated thickness of the Middle Rio Rancho HSU is about twice that of the Lower Rio Rancho HSU, and is more than 1,000 ft thick across most of the study area, including a northward prong extending upward between the Ziana horst and the Zia fault. Several wells indicate a coarsening upward trend in this HSU (Fig. 4). In addition, the data used to construct the 3D hydrostratigraphic model are used to interpret that the Ziana horst mainly formed after 11 Ma.

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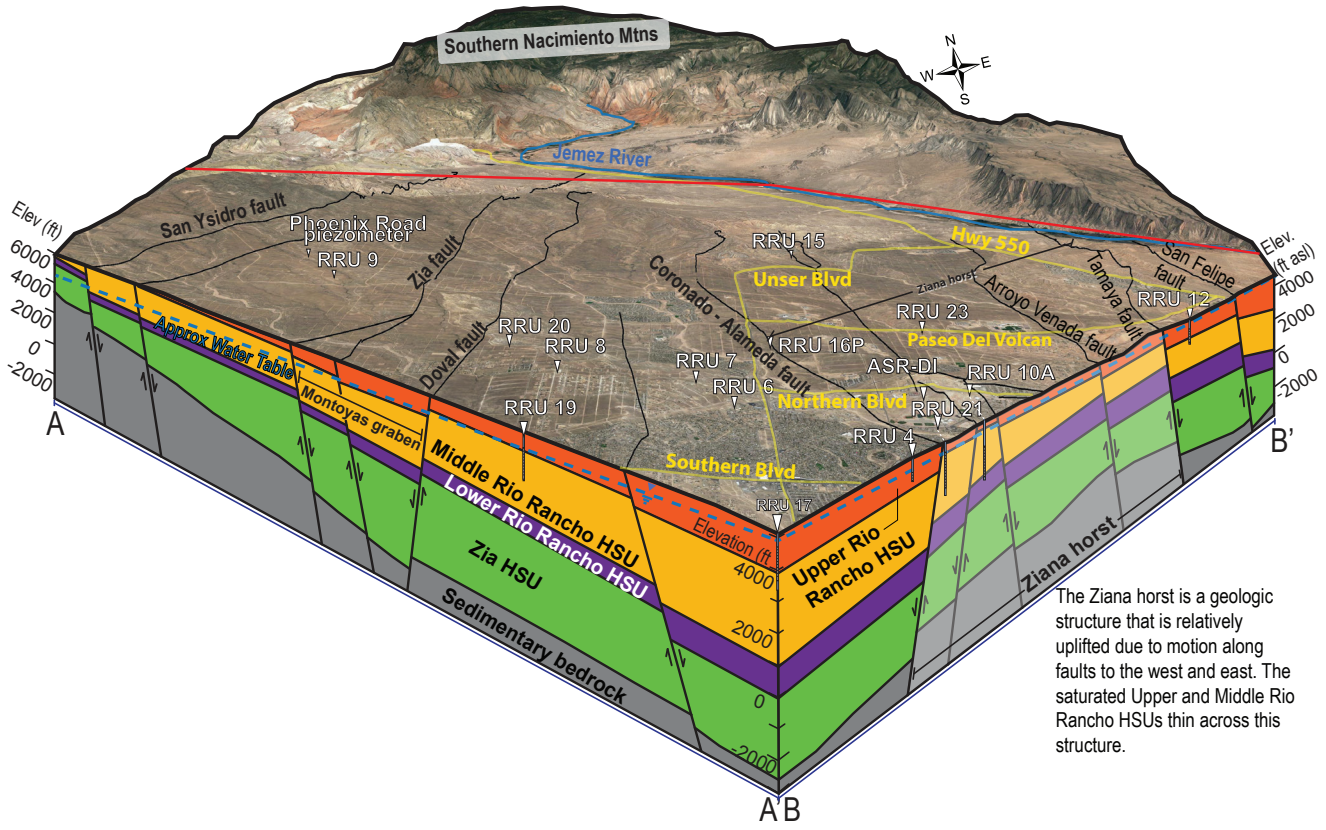


FIGURE 10. Three-dimensional block diagram of the hydrogeologic subsurface model under the northwestern Albuquerque Basin. View is to the NNE. The faces of the block diagram correspond to the cross-sectional lines shown in Figure 2. The four colored layers are the HSUs designated in this study. Faults are depicted by thick black lines on the surface and subsurface; the relative sense of vertical motion along a fault is shown by arrows. Surface locations of wells correspond to the white triangles. The subsurface extent and screen depth of a well projected to a cross-sectional line (face of the diagram) is shown by a vertical line, and the screen depth is indicated by the closely spaced horizontal lines.

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A dog’s loyalty and cheerful energy helps keep a field geologist walking all day. These two dogs stand on an outcrop of Cerro Conejo Formation sandstone in the badlands underlying the Ceja del Rio Puerco, located 14 miles west of Rio Rancho. These strata would correlate to the upper Zia hydrostratigraphic unit discussed in the next paper. Photograph by Daniel Koning.