Groundwater Resources Evaluation Report for Major and Minor Aquifers Beneath University Lands in Reagan, Crockett, Irion, Schleicher, Upton, and Pecos Counties, Texas

Prepared for **The University of Texas System**
University Lands
Midland, Texas

December 10, 2015

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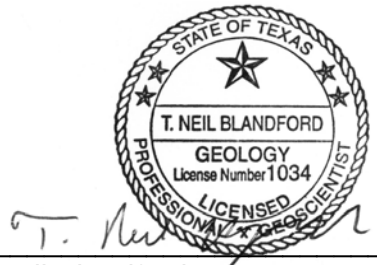
Mr. T. Neil Blandford was responsible for overall project management, hydrogeolgic analysis, report preparation including all graphics, and the 3D geologic model. The seal appearing on this document was authorized on December 10, 2015.



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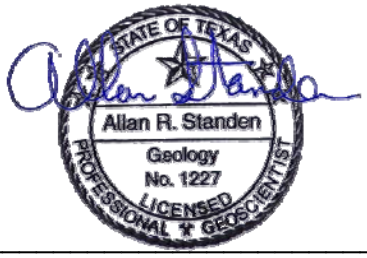
Mr. Allan R. Standen was responsible for the well log analysis and other geologic interpretations presented in this report, and assisted with development of cross sections, the 3D geologic model and report preparation. The seal appearing on this document was authorized on December 10, 2015.



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The important contributions of the following individuals to the project are gratefully acknowledged:

- Mr. Vince Clause of Allan R. Standen, LLC assisted Mr. Standen with well log interpretations and geologic analysis for Upton, Reagan and northern Crockett Counties.
- Farag Botros, PhD, P.E. of Daniel B. Stephens & Associates, Inc. developed the 3D geologic models under the direction of Neil Blandford.
- Mr. Gilbert J. Van Deventer, REM, P.G., provided input on the geologic structure and stratigraphy of the Upton, Reagan, and Crockett County areas and conducted a detailed review of the project completion report.
- Andrew Donnelly, P.G. of Daniel B. Stephens & Associates, Inc. assisted with the geology and hydrogeology sections of the report.

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Executive Summary

The Mission of University Lands is to manage and care for the Permanent University Fund (PUF) lands while maximizing the revenue generated for the benefit of Texas higher education. In July 2014, University Lands retained Daniel B. Stephens & Associates (DBS&A) to perform groundwater resource evaluations on selected areas of University Lands; this report presents the results of DBS&A's groundwater resource evaluation for University Lands in Pecos, Crockett, Upton, Reagan, Irion, and Schleicher Counties. The purpose of this study was to describe the geologic structure and stratigraphy of the major and minor aquifers on the University Lands to approximately 3,000 feet below ground surface.

The study area is located almost entirely within the Edwards Plateau region, which is underlain by the Edwards-Trinity (Plateau) Aquifer, a designated major aquifer by the Texas Water Development Board (TWDB). In addition, portions of the study area are underlain by the Dockum (Santa Rosa), Rustler, and Capitan Reef Complex Aquifers, designated as minor aquifers in Texas.

Data sources used for the geologic and hydrogeologic analyses include oil and gas well geophysical logs and water well data from the University Lands well library, geophysical logs, scout tickets and cable tool driller reports obtained from Bureau of Economic Geology (BEG), driller reports and water well data from the TWDB, and driller reports submitted to the Texas Department of Licensing and Regulation (TDLR). Well information was collected and screened for the University Lands tracts and immediately adjoining land. Ultimately, 969 data points were selected to interpret the geology and hydrogeology of the study area. The results of the geologic analysis are provided through cross sections, geologic unit thickness maps, and three-dimensional geologic models that can be viewed interactively.

This study identified 1,164 water wells completed in the Edwards-Trinity (Plateau) Aquifer on University Lands. In the western and central portion of the study area, the majority of wells are completed either in the Trinity Group or both the Edwards limestones and Trinity Group. In northeastern Crockett County and western Schleicher County, where the Trinity Group thins, wells are completed predominantly in the Edwards limestones.

Groundwater flow direction in the Trinity Group of the Edwards-Trinity (Plateau) Aquifer in Pecos County is to the east-northeast toward the Pecos River. Groundwater flow in central Crockett County is to the south, with a southwestern component of flow also toward the Pecos River. Groundwater flow in the five-county area (Upton, Reagan, Irion, northern Crockett, and western Schleicher Counties) is generally to the southeast. Based on available well hydrographs, changes in water levels through time are relatively small with no consistent trends. Reported well yield of the Edwards-Trinity (Plateau) Aquifer varies from several tens of gallons per minute (gpm) up to about 200 gpm, although higher well yields are reported in Pecos County.

Groundwater quality in the Edwards limestones portion of the Edwards-Trinity (Plateau) Aquifer in the eastern portion of the study area in northeastern Crockett, southern Irion, and western Schleicher Counties is generally fresh, with total dissolved solids (TDS) concentrations of 1,000 milligrams per liter (mg/L) or lower. Similar water quality is observed in Pecos County. In other regions, such as the Big Lake area in Reagan County, central Crockett County, and University Lands Blocks 49, 50, and 51 in northern Crockett and southeastern Reagan Counties, groundwater quality is generally slightly saline, with TDS concentrations of 1,000 to 3,000 mg/L. Groundwater in the Trinity Group portion of the Edwards-Trinity (Plateau) Aquifer is generally slightly saline, with TDS concentrations of 1,000 to 3,000 mg/L.

This study identified 410 water wells completed in the Dockum (Santa Rosa) Aquifer on University Lands. Regional groundwater flow within the Dockum Aquifer in Pecos, Upton, and northwestern Crockett Counties appears to be toward the Pecos River. West and northwest of Big Lake in Reagan County, a cone of depression in the Dockum Aquifer water level surface is evident in all or portions of University Lands Blocks 8, 9, 10, and 11. This is a region of significant water well development on University Lands, with wells completed in both the Dockum Aquifer and the Trinity portion of the Edwards-Trinity (Plateau) Aquifer. Reported well yield of the Dockum Aquifer is generally less than 150 gpm.

The groundwater quality for wells completed in the Dockum Aquifer and both the Dockum Aquifer and the Trinity Group portion of the Edwards-Trinity (Plateau) Aquifer is slightly saline, with TDS concentrations of about 2,000 to 3,000 mg/L. Groundwater in the Dockum Aquifer generally has higher TDS than groundwater in the overlying Trinity Group.

The Permian strata contain multiple potential brackish aquifer units, including the Yates, Queen, Grayburg, and San Andres Formations. In central and eastern Crockett County and western Schleicher County, the Dockum Group is absent and Permian formations are within 500 to 700 feet of the land surface, allowing for potential recharge from the overlying Edwards-Trinity (Plateau) Aquifer. A total of 23 Permian aquifer wells were identified on University Lands in the study area—21 in northeastern Crockett County and western Schleicher County, and 2 in central Crockett County. These wells are completed in the upper portion of the Artesia Group. All of these wells except for one have a reported yield less than 100 gpm, and many have yields less than 50 gpm. Reported water quality is slightly to moderately saline.

Conclusions based on the study results are as follows:

- Groundwater levels in Edwards-Trinity (Plateau) Aquifer appear to have declined at some locations on University Lands since the mid to late 2000s by several tens of feet, and at other locations water level decline has been small or non-existent. Where water level declines have occurred in the mid to late 2000s, they are generally of similar magnitude to historical declines. Two wells with historical water level data (one north of Big Lake in Reagan County and one in northeastern Crockett County) indicate a decline of approximately 10 feet greater than maximum historical levels, although more recent values indicate some water level recovery. Where they have occurred, recent water level declines are likely attributable to the combined effects of drought and increased oil and gas development activity. The water level dataset used in this report predates the potential effects of recent (2015) above-average precipitation that occurred across much of west Texas, and reduced groundwater pumping for oil and gas activity since October 2014 due to the industry-wide slow down.

- Based on a relatively limited dataset, water levels in the underlying Dockum (Santa Rosa) Aquifer appear to have declined beneath University Lands west and northwest of Big Lake, possibly by as much as approximately 100 feet. The declines are believed to be due to oil and gas development. The Dockum Aquifer water level dataset predates reduced groundwater pumping for oil and gas activity since October 2014 due to the industry-wide slow down.

- Many wells in the study area are completed across multiple aquifer units.

- The Dockum Aquifer is thin with limited production capacity or non-existent in the eastern portion of the study area in central and northeastern Crockett County, Schleicher County, and southern Irion County. Where the Dockum Group is missing, the first aquifer unit encountered below the Edwards-Trinity (Plateau) Aquifer is within the Permian Artesia Group.

- Dockum Aquifer well yield is variable in areas of significant Santa Rosa Formation thickness, but is generally less than 150 gpm. Total sand interval thickness in the Santa Rosa Formation can be used as an indicator of expected well yield. Based on this measure, Dockum Aquifer well yield would be expected to be low relative to other areas on University Lands in northern Crockett County, southeastern Reagan County, and University Lands Blocks 1, 4, 5, 6, 7, and 12 in south-central Reagan County.

1. Introduction

In July 2014, University Lands retained Daniel B. Stephens & Associates, Inc. (DBS&A) to perform hydrological studies of the groundwater resources on selected portions of University Lands in west Texas. The University Lands included in the groundwater studies are divided into two areas, referred to as the Northern Area and the Southern Area (Figure 1). This report presents the results of DBS&A's groundwater resource evaluation for University Lands in the Southern Area, which includes University Lands in Pecos, Crockett, Upton, Reagan, Irion, and Schleicher Counties. Allan R. Standen, LLC, under contract to DBS&A, performed most of the geologic analysis and interpretation presented in this report. The purpose of this study was to describe the geologic structure and stratigraphy of the major and minor aquifers underlying University Lands to a depth of approximately 3,000 feet below ground surface.

Data sources used for the geologic and hydrogeologic analyses include oil and gas well geophysical logs and water well data from the University Lands well library, geophysical logs, scout tickets and cable tool driller reports obtained from Bureau of Economic Geology (BEG), driller reports and water well data from the Texas Water Development Board (TWDB), and driller reports submitted to the Texas Department of Licensing and Regulation (TDLR).

Study results are provided in this report in the form of figures, geologic cross sections, and formation thickness maps. In addition, DBS&A constructed interactive three-dimensional (3D) geologic models using Leapfrog Hydro software. The 3D geologic models permit visualization of stratigraphic units and selected details of data points (wells) used to construct the model, as well as generation of cross sections at locations and orientations selected by the user.

Section 2 of this report provides an overview of the study area. Section 3 provides an overview of the regional geology and hydrogeology. Section 4 describes data sources and analyses, Section 5 presents the study results, and Section 6 provides conclusions.

2. Study Area

The study area includes all of University Lands in Pecos, Upton, Reagan, Crockett, Irion, and Schleicher Counties (Figure 2). University Lands that occur in Pecos County are referred to as the Pecos County area. University Lands that occur in Upton, Reagan, Irion, Schleicher, and northern Crockett Counties are referred to collectively as the five-county area, and University Lands in Crockett County Blocks 29 through 33 are referred to as the central Crockett County area.

The study area lies within the Edwards Plateau section of the Great Plains physiographic province, which extends from Pecos County eastward to the Hill Country west of the cities of Austin and San Antonio. The elevation of the Edwards Plateau ranges from about 1,000 feet above mean sea level (feet msl) in Uvalde County to over 3,000 feet msl in Ector County (Walker, 1979). This area is characterized by rolling plains to rugged canyons with steep walls and flat table tops formed by resistant carbonate rocks, with loose, thin soils (Anaya and Jones, 2009; Walker, 1979; Barker and Ardis, 1996). The Upper Pecos River cuts through the middle of the study area and is the primary surface water feature. The Pecos River is fed by numerous creeks, such as Live Oak Creek, Fourmile Draw, Johnson Draw, Buckhorn Draw, and Sixshooter Draw. These smaller creeks and drainages have cut through the more resistant limestone caprock to form the characteristic flat hilltops with steep-walled canyons prevalent throughout much of the Edwards Plateau. Few surface water bodies are present in the study area, and none are of significant size.

The study area climate is semiarid with hot, dry summers and mild winters. Maximum temperatures in the summer are typically in the mid to high 90s (in degrees Fahrenheit [°F]), and lows in the winter are typically in the 30s (Walker, 1979). Annual precipitation across the study area ranges from about 21 inches per year (in/yr) in western Schleicher County to about 14 in/yr in central Pecos County (Anaya and Jones, 2009). Precipitation amounts are generally the highest in the late spring (May and June) and fall (September and October) and lowest in the winter. Precipitation commonly occurs as scattered, intense thunderstorms (Anaya and Jones, 2009). The relatively high temperatures, low humidity, and prevailing winds result in high

evaporation rates; the average annual lake evaporation is between 75 and 80 in/yr (Anaya and Jones, 2009).

Prior to human development, the vegetation of the Edwards Plateau was dominated by grasslands, with wooded areas confined to the canyon areas containing a mix of hardwood species (Anaya and Jones, 2009). Oak forests and oak-juniper woodland still currently dominate the canyon areas, but the rest of the area has transformed into a vegetation mix of scrubby oak, juniper, and grass, along with mesquite and other shrubs due to fire suppression and historical livestock overgrazing (Anaya and Jones, 2009).

3. Overview of Geology and Hydrogeology

This section provides an overview of the regional geologic structure and stratigraphy (Section 3.1) and hydrogeology (Section 3.2) of the study area and adjoining regions based on existing reports.

3.1 Geology

The regional geology of the study area and adjoining regions is presented in Sections 3.1.1 and 3.2.2.

3.1.1 Structure

Figure 3 illustrates the major structural features underlying University Lands that may influence local rock types, depositional patterns, and geologic formation thickness and extent. This section briefly summarizes the creation of these major structural features. More detailed descriptions of the geologic history and development of structures in the Permian Basin are available on the BEG and Society for Sedimentary Geology (SEPM) websites (BEG, 2015; SEPM, 2015).

The Fort Stockton Uplift in eastern Pecos County (Figure 3) consists of Precambrian intrusive rock ranging in composition form granite to gabbro, and represents a dome that rises thousands of feet above the surrounding Precambrian basement rocks. This feature was created by late Paleozoic tectonic uplift. Subsequent erosion removed the older Paleozoic rocks from the Cambrian through the Mississippian. Late Pennsylvanian and Permian rocks cap the uplift (Flawn, 1956).

The geometry of the Permian Basin was initially created during the Hercynian Orogeny, a collision between North America and Gondwana Land (South America and Africa) plates during the late Mississippian. This collision gave rise to the Ouachita-Marathon Fold Belt south of the study area and started to deform the existing Tobosa Basin, ultimately initiating creation of the Delaware Basin, the Central Basin Platform, the Midland Basin, and the Val Verde Basin.

Continued deformation and subsidence of the Delaware and Midland Basins and uplift of the Central Basin Platform during the Pennsylvanian through the Middle Permian further defined these structural features (BEG, 2015; SEPM, 2015). The Sheffield Channel was created during early Guadalupian time and connected the Delaware Basin with the Midland Basin along the southern margin of the Midland Basin (SEPM, 2015).

3.1.2 Stratigraphy

A geologic column with corresponding hydrogeologic features is provided in Figure 4; the hydrogeology of the study area is discussed in Section 3.2. Surface geology was interpreted from digital Geologic Atlas of Texas (GAT) sheets for Fort Stockton (Anderson et al., 1982), Sonora (Barnes, 1981), San Angelo (Barnes, 1974b), and Pecos (Barnes, 1974a). Surface geology maps of the Pecos County, five-county, and central Crockett County areas are provided in Figures 5 through 7, respectively. Only sediments and rocks of Quaternary and Cretaceous age outcrop within the study area.

The following subsections provide brief descriptions of the geologic units from land surface through the Permian-age Guadalupian Series rocks. Older (deeper) formations are not considered in this study.

3.1.2.1 Quaternary Deposits

Thin layers of Quaternary sediments cover much of the land surface within the drainages and valleys throughout the study area (Figures 5 through 7). The Quaternary sediments consist of sand and silt, and may include small amounts of caliche and gravel.

3.1.2.2 Cretaceous Formations

This section provides an overview of the Cretaceous Period rocks, which comprise the primary aquifer in the study area, the Edwards-Trinity (Plateau) Aquifer.

3.1.2.2.1 Washita and Fredericksburg Groups. The uppermost geologic units throughout most of the Edwards Plateau area are the carbonates of the Washita and Fredericksburg Groups (Figure 4) historically referred to as “Edwards and associated limestones” (Barker and Ardis,

1996). These carbonate units, where permeable and saturated, form the upper portion of the Edwards-Trinity (Plateau) Aquifer. The Washita Group consists of the Del Rio Clay and Buda Limestone. The Fredericksburg Group consists of the Fort Terrett, Segovia, and Sue Peaks Formations (Anaya and Jones, 2009; Barnes, 1974a, 1974b, and 1981). These units typically consist of massive or nodular limestones (Rees and Buckner, 1980). The massive limestones of the Fredericksburg and Washita Groups are sometimes referred to together as the Edwards Group Limestones (Rees and Buckner, 1980). These resistant limestones often form ledges at hilltops and along canyon walls that are characteristic in the region, a pattern evident in Figures 5 through 7.

In this study, the Edwards and associated limestones (Barker and Ardis, 1996) or the Edwards Group Limestones (Rees and Buckner, 1980) are referred to as the Edwards limestones. The thickness of the Edwards limestones ranges from 0 feet in some drainages to over 600 feet on the tops of plateaus. The base of the Edwards limestones is equivalent to the top of the Trinity Group and is included in the 3D geologic models.

3.1.2.2.2 Trinity Group. The Trinity Group formations occur beneath the Fredericksburg Group and comprise the lower portion of the Edwards-Trinity (Plateau) Aquifer. The units that make up the Trinity Group are generally very fine- to coarse-grained sandstones, with some limestone and shale (Rees and Buckner, 1980). Trinity Group nomenclature is complicated, in that unit names not only vary across the Edwards Plateau, but have also changed through time. The Trinity Group formations generally include, from top to bottom, the Maxon Sand, the Glen Rose Formation, and the Basal Sand (Figure 4). Anaya and Jones (2009) note that these formations are often grouped together and may not be present in all areas.

The Maxon Sand occurs as sandstone, and if the Glen Rose and Basal Sand Formations are missing, may locally lie directly on underlying Permian or Triassic formations. The Glen Rose Formation is predominantly thin-bedded limestone and calcareous shale. The Basal Sand may contain some conglomerate and is generally fine- to medium-grained with calcareous cement. Based on a compilation of multiple prior studies, Bumgarner et al. (2012) list maximum thicknesses in the Pecos County region for the Maxon Sand, the Glen Rose Formation, and the

Basal Sand of 300 feet, 200 or more feet, and 100 feet, respectively. The top and base of the Trinity Group (undivided) are included in the 3D geologic models.

3.1.2.3 Triassic Formations

The Dockum Group is a 1,000- to 2,000-foot-thick sequence of sediments deposited in fluvial, deltaic, and lacustrine environments within a closed continental basin or basins, with sediments received from all directions (Ashworth et al., 1991; Bradley and Kalaswad, 2003). The Dockum Group represents the final filling in of several small, adjoining basins, including the Midland Basin (Figure 3) and the Palo Duro and Dalhart Basins farther to the north, all of which are separated by structural highs (Bradley and Kalaswad, 2003). The greatest thicknesses of Dockum Group sediments occur at the centers of the basins, and sediments pinch out along the basin margins. Beds in the Dockum Group are essentially horizontal, with a gentle dip toward the center of the basin (Bradley and Kalaswad, 2003). The top of the Dockum Group is a relatively smooth surface indicative of the final filling of the basin, while the base of the Dockum Group may be irregular, reflecting the structural features that affected deposition (Ewing et al., 2008).

The study area overlies the southern and southeastern margins of Dockum Group deposition. The Dockum Group occurs below the Trinity Group in Pecos County, in the northern portion of Block 29 in the central Crockett County area, and in approximately the western two-thirds of the five-county area. The estimated extent of the Dockum Group subcrop in the five-county area and the central Crockett County area are shown in Figures 6 and 7, respectively. The estimated Dockum Group extent illustrated on Figures 6 and 7 is similar to that of Walker (1979).

The Dockum Group is a minor aquifer in Texas and is the major focus of this study. The Dockum Group consists of complex terrigeneous, usually red in color, clastic, and lacustrine sediments ranging from shales and siltstones to sandstones and conglomerates that peripherally filled the Permian basins in West Texas (Ashworth et al., 1991; Ewing et al., 2008). Dockum Group rocks were subjected to several episodes of erosion during deposition.

Thicknesses of individual sandstone units within the Dockum Group range from several feet up to about 50 feet. These sandstone units are often lens-shaped, and therefore discontinuous

and difficult to correlate in the subsurface (Bradley and Kalaswad, 2003). Sandstone units are typically separated by sandy shale or shale units that range in thickness from about 50 to 100 feet (Ewing et al., 2008).

The Dockum Group stratigraphic nomenclature applied by the TWDB is as follows, from youngest to oldest: the Cooper Canyon Formation, the Trujillo Sandstone, the Tecovas Formation, and the Santa Rosa Formation (Ewing et al., 2008). The Cooper Canyon Formation and Trujillo Sandstone, which form the Upper Dockum Group, are not present in the study area. The Tecovas and Santa Rosa Formations, which form the Lower Dockum Group, are present beneath the study area (Figure 4). In the study area, the Tecovas Formation is a relatively thin shale to silty shale or siltstone. The Santa Rosa Formation consists of extensive red to reddish brown sandstone and conglomerate (Ashworth et al., 1991; Ewing et al., 2008). Although the Santa Rosa Formation includes multiple sand intervals, it also includes significant thicknesses of siltstone and shale interbedded with sandstone. The term "Santa Rosa" is often used by drillers and others for any sandstone unit in the Dockum Group that produces water.

The tops and bottoms of the Tecovas Formation and the Santa Rosa Formation are included in the 3D geologic models.

3.1.2.4 Permian Formations

This section provides an overview of the Permian Ochoan and Guadalupian Series rocks.

3.1.2.4.1 Ochoan Series. The Ochoan Series within the study area consists of (from youngest to oldest) the Dewey Lake, Rustler, and Salado Formations. The Rustler, Salado, and Tansill Formations (discussed in the following section) are collectively identified as "undifferentiated evaporites" on the cross sections and 3D geologic models.

The Dewey Lake Formation is often referred to as the Dewey Lake redbeds. The Dewey Lake Formation consists of interbedded red siltstone and shale (Armstrong and McMillion, 1961).

The Rustler Formation is recognized as a minor aquifer in Texas and can locally (in western Pecos County) provide significant quantities of brackish groundwater; it is reported in places to

be cavernous. The Rustler Formation outcrops in Culberson County, west of the study area, and is present in the subsurface beneath the study area. The Rustler Formation unconformably overlies the Salado Formation and has a thickness of 0 to 450 feet. The Rustler Formation consists largely of anhydrite and dolomite, but also has a basal zone of sand, conglomerate, and shale (Armstrong and McMillion, 1961; Brown, 1998).

The top of the Rustler Forty-Niner Member is shown in the 3D geologic models as the top surface of the undifferentiated evaporites. The Rustler Formation contains five to seven members, including, from youngest to oldest, the Forty-Niner Member, the Magenta Dolomite Member, the Tamarisk Member, the Culebra Dolomite Member, the Lower Gypsum and Mudstone Member, and the Siltstone Member. The top Forty-Niner Member of the Rustler Formation consists of two beds of massive anhydrite and gypsum readily identifiable on geophysical log gamma curves (Ewing et al., 2012). The formation is generally the thickest in the eastern half of its extent, in the middle of the Delaware Basin (Ewing et al., 2012). In central Pecos County, where the Rustler Formation is present beneath a portion of University Lands, the Rustler Formation is categorized into “Lower,” “Middle,” and “Upper” members and is less than 400 feet thick (Ewing et al., 2012).

The Salado Formation varies in thickness from less than 100 feet to over 2,200 feet. The northern portion of the Salado in Pecos County is predominantly halite with some anhydrite, and the southern half is more anhydrite with some dolomite (Armstrong and McMillion, 1961).

3.1.2.4.2 Artesia Group. The Artesia Group includes, from youngest to oldest, the Tansill, Yates, Seven Rivers, Queen, and Grayburg Formations. These formations are located along the western margins of the Central Basin Platform northward into the Northwest Shelf and eastward into the Midland Basin (Figure 3). These formations consist of stratigraphically cyclic mixed siliciclastic, carbonate, and evaporite sequences. Each formation is characterized by cyclic vertical facies that reflect sea-level changes. On the basis of lithology defined by type sections of each of these formations, the Artesia Group formations can be correlated across the Permian Basin (Nance, 2009). None of the Artesia Group formations outcrop in the study area.

The Artesia Group and the San Andres Formation rise from depth within the Midland Basin and form the base (forming an angular unconformity) of the Edwards-Trinity (Plateau) Aquifer along the eastern and southern edges of University Lands located in eastern and southern Crockett County and western Irion and Schleicher Counties. Because the red sandy lithologies of the Yates and Queen Formations could be confused with Dockum Group sandstone, a concentrated effort was made to map the top of the Yates Formation during this study. The following are brief lithological descriptions of the Artesia Group formations and in some cases their respective characteristic geophysical log signature. The remainder of this section is taken primarily from Nance (2009).

The Tansill Formation is recognized as a predominantly carbonate and evaporite sequence that is overlain by the Salado Formation and underlain by the sandstone beds of the Yates Formation. The Tansill carbonate is primarily dolostone, and the evaporites consist of anhydrite and halite. The Tansill sequence has very low gamma-ray log values relative to the underlying Yates sandstones (Nance, 2009). This unit is included with the undifferentiated Permian evaporites on the cross sections and in the 3D geologic models.

The Yates Formation has been correlated throughout the Midland and Palo Duro Basins. This formation consists of up to 300 feet of thick sandstone sequences with thin carbonate and evaporite interbeds. The sandstone units are typically well-sorted, fine- to very fine-grained sandstone and siltstone. Yates sandstone units are generally red, gray, and brown near land surface and may be mistakenly identified as Dockum Group sandstone where Yates sandstone and Dockum Group sandstone occur in relatively close proximity. The Yates sandstones have low gamma ray log signatures easily identified from the very low gamma signatures of the overlying Tansill Formation and the underlying Seven Rivers Formation evaporites (Nance, 2009). The top of the Yates Formation is included in the 3D geologic models.

The Seven Rivers, Queen, and Grayburg Formations are not included in the cross sections or the 3D geologic models, except that the base of the Grayburg Formation is equivalent to the top of the San Andres Formation. The Seven Rivers Formation consists of thick carbonate and anhydrite beds bounded by the overlying Yates Formation sandstones and the underlying Queen Formation sandstones. Thickness ranges from about 200 feet on the Eastern Shelf up

to 500 feet on the Central Basin Platform (Nance, 2009). The Queen Formation consists of thick sandstone beds with minor carbonate and evaporite beds. The formation thickness ranges from 1,000 feet in the center of the Midland Basin to 130 feet on the Eastern Shelf. The sandstones are very fine-grained with coarse-grained siltstones. The formation is mainly gray in color, but the bottom 50 feet is red when these rocks occur near land surface; the red Queen basal sandstones may be mistakenly identified as Dockum Group sandstone (Nance, 2009). The Grayburg Formation forms the base of the Artesia Group and consists of dolomite, anhydrite, and siltstone up to 300 feet thick. The dolomite grades to anhydrite eastward from the Central Basin Platform, and the Grayburg eventually transitions into a more siltstone-rich formation in the Midland Basin (Bebout, 1991).

3.1.2.4.3 San Andres Formation. The San Andres Formation (often called the San Andres Limestone) is the oldest formation of the Guadalupian Series, and directly underlies the Grayburg Formation of the Artesia Group. The San Andres Formation base usually consists of gray dolomite with limestone up to several hundred feet thick overlying the dolomite. The geophysical log signature for the top of the San Andres Formation is pronounced, and consists of a relatively low gamma signature characteristic of a limestone with minor fluctuations over a thickness of about 200 feet to more than 500 feet. The formation may include occasional thin shale with a large gamma kick. The top of the San Andres Formation is included in the 3D geologic models.

3.1.2.4.4 Capitan Reef Complex. The Capitan Reef Complex outcrops in the Glass Mountains in southern Pecos County and dips to the north where it occurs deep in the subsurface. The Capitan Reef Complex consists of limestones and dolomites deposited as a reef and reef talus zones around the margin of the Delaware Basin, creating a carbonate barrier between the Delaware and Midland Basins. The Capitan Reef Complex limestones and dolomites interfinger with the Artesia Group formations that occur to the east in the Midland Basin. Based on the Capitan Reef Complex stratigraphic model by Standen et al. (2009), the Capitan Reef Complex is as thick as 1,000 feet on the western edge of the University Lands in Pecos County; the Capitan Reef Complex does not occur beneath the central Crockett County area or the five-county area (Figure 3). The Capitan Reef Complex is recognized as a minor aquifer in Texas. The Capitan Reef Complex is included in the Pecos County 3D geologic models.

3.2 Hydrogeology

The study area is underlain by the Edwards-Trinity (Plateau) Aquifer, an unconfined (water table) aquifer designated as a major aquifer in Texas. Portions of the study area are also underlain by the Dockum, Rustler, and Capitan Reef Complex Aquifers, designated as minor aquifers in Texas. Other Permian geologic formations, not formally recognized as minor aquifer units in Texas, may provide usable quantities of brackish water where they occur relatively close to land surface in the eastern portion of the study area. These potential aquifer units are the permeable portions of the Yates, Queen, Grayburg, and San Andres Formations. Except for the Edwards-Trinity (Plateau) Aquifer, the aquifers within the study area are confined (water occurs under pressure greater than atmospheric), and aquifer outcrop does not occur. The following subsections provide an overview of the hydrogeology of the study area and adjoining regions based on existing reports.

3.2.1 Edwards-Trinity (Plateau) Aquifer

The Edwards-Trinity (Plateau) Aquifer is classified as a major aquifer by the state of Texas. It consists of Cretaceous-age limestones and dolomites of the Washita and Fredericksburg Groups and the underlying Trinity Group sandstone. The aquifer covers a large area that includes most of the Edwards Plateau region, from the Hill Country west of Austin and San Antonio to the Trans-Pecos region. While the majority of groundwater produced from this aquifer is used for irrigation, the aquifer is also used for livestock, domestic, and municipal purposes (LBG-Guyton, 2003).

In the eastern portion of the five-county area identified in Figure 6, Walker (1979) interprets the Santa Rosa Formation to be in hydrologic contact with the Trinity Group, and combines the Santa Rosa Formation with the overlying Edwards limestones and Trinity Group sediments to form one aquifer unit. In this same region, Walker (1979) maps the Chinle Formation as thin or non-existent. The Chinle Formation consists primarily of mudstone and shale, and is considered to be a confining (low-permeability) unit. The Chinle Formation described by Walker (1979) in the five-county area is apparently equivalent to the Tecovas Formation as used in this

report. As noted by Bradley and Kalaswad (2003), Dockum Group nomenclature is inconsistent in historical literature; in this report the nomenclature of Bradley and Kalaswad (2003) is used.

Large areas of the Edwards-Trinity (Plateau) Aquifer contain wells that produce only from the Edwards limestones because this upper portion of the aquifer provides sufficient yield of good quality water (where solution cavities or fractures occur), and the underlying Trinity Group portion of the aquifer has poorer quality groundwater. A low-permeability layer at the base of the Edwards limestones may restrict the movement of water between the Edwards and Trinity portions of the Edwards-Trinity (Plateau) Aquifer at many locations. These low-permeability beds of the Edwards limestones portion of the aquifer cause numerous small springs and seeps along incised stream valleys common in the region (Walker, 1979).

The Edwards limestones portion of the aquifer is typically unconfined and the Trinity Group is either under unconfined or confined conditions. Regional groundwater flow in the Edwards-Trinity (Plateau) Aquifer is controlled by geologic structure and regional dip. The base of the Cretaceous rocks slopes to the south and southwest, a trend reflected by the regional water table surface and the direction of groundwater flow (Walker, 1979). Locally, groundwater flow is toward numerous incised rivers and streams characteristic of the region, where the aquifer discharges and provides baseflow to these surface water bodies and to numerous springs. Groundwater flow is also affected by pumping wells (Walker, 1979; Hopkins, 1995). Throughout most of the Edwards Plateau area, water levels in the Edwards limestones portion of the Edwards-Trinity (Plateau) Aquifer respond mainly to variations in climate, and therefore have remained fairly constant through time (Anaya and Jones, 2009).

Recharge to the Edwards-Trinity (Plateau) Aquifer is from the infiltration of precipitation that falls on the land surface or from the infiltration of runoff within drainages. Because the Edwards limestones that compose the upper portion of the aquifer outcrop widely at land surface, much of the aquifer recharge does not occur as slow infiltration through the soil, but as larger, more rapid recharge events characteristic of a karst environment. Estimated recharge rates for the Edwards-Trinity (Plateau) Aquifer range from less than 0.5 in/yr to 2 in/yr (Long, 1959; Iglehart, 1967; Scanlon et al., 2002).

Well yields in the Edwards-Trinity (Plateau) Aquifer vary significantly. Well yields from 168 wells ranged from approximately 25 gallons per minute (gpm) to over 1,500 gpm, generally averaging between 100 and 400 gpm (Walker, 1979). Specific capacities in these wells generally averaged 1 to 10 gallons per minute per foot of drawdown in the well (gpm/ft). The mean hydraulic conductivity for the northern part of the Trinity Group is approximately 4.5 feet per day (ft/d) (Anaya and Jones, 2009). Across the entire aquifer, wells completed in the Trinity portion of the Edwards-Trinity (Plateau) have an average storage coefficient of 0.074 and hydraulic conductivities of about 2 to 5 ft/d (Walker, 1979). Ashworth (1983) reported that aquifer storativity ranges from 2×10^{-5} to 7.4×10^{-4}. Anaya and Jones (2009) report a range of storage coefficients of 8×10^{-6} to 6×10^{-3}.

Most groundwater obtained from the Edwards-Trinity (Plateau) Aquifer is considered "fresh," with total dissolved solids (TDS) concentrations less than 1,000 milligrams per liter (mg/L). This is true in part because many wells in the aquifer produce from only the Edwards limestones portion of the aquifer, and water quality in the Edwards limestones is better than that of the underlying Trinity Group. Water in the Edwards limestones is very hard, calcium-bicarbonate type water with TDS concentrations between 200 and 400 mg/L. In some wells the TDS concentration of groundwater produced from the Edwards portion of the aquifer can exceed 1,000 mg/L, apparently due to restricted groundwater circulation in certain areas (Walker, 1979).

Although the majority of the Edwards-Trinity (Plateau) Aquifer produces fresh groundwater, the water quality is generally poor in the northern and western parts of the aquifer (Hopkins, 1995). Much of the study area is located within the portion of the aquifer where TDS concentrations range up to approximately 3,000 mg/L (Hopkins, 1995; LBG-Guyton, 2003). Most wells in the study area produce water (in whole or in part) from the Trinity Group sediments. Trinity Group groundwater has higher TDS concentrations than Edwards limestones groundwater (LBG-Guyton, 2003). Trinity Group water is typically a calcium-bicarbonate-sulfate type, is very hard, and has variable TDS concentration (Walker, 1979).

3.2.2 Dockum Aquifer

The Dockum Aquifer is classified as a minor aquifer by the state of Texas, and is the term used for all of the water-bearing units in the Triassic Dockum Group (Bradley and Kalaswad, 2003). The Dockum Group is present from the Panhandle region of Texas to the Trans-Pecos region. The Dockum Group is typically divided into the Upper Dockum, consisting of the Cooper Canyon Formation and the Trujillo Sandstone, and the Lower Dockum, consisting of the Tecovas Formation and the Santa Rosa Sandstone. The Upper Dockum is absent in the study area, but the Lower Dockum (Tecovas Formation and Santa Rosa Formation) occurs throughout most of the study area, as illustrated in Figures 6 and 7. TWDB maps of the Dockum Aquifer do not show portions of the aquifer with an estimated downdip water quality of 5,000 mg/L TDS or greater (Bradley and Kalaswad, 2003). The TWDB maps do not include large portions of Pecos County where the Dockum Group does in fact exist.

Water in the Dockum Aquifer in the study area occurs under confined conditions. Dockum Aquifer water elevation maps published by the TWDB indicate an overall southerly to southeastern movement of groundwater in the aquifer prior to significant groundwater development (Ewing et al. 2008). Ewing et al. (2008) do not include the University Lands in Pecos County, and to our knowledge there are no published Dockum Aquifer water level maps for this area. Although there are no Dockum Aquifer well hydrographs within the study area, Dockum Aquifer hydrographs in other areas are variable, with some hydrographs indicating distinct water level declines over time and others showing stable water levels or only small declines (Bradley and Kalaswad, 2003). The regional direction of groundwater flow during recent periods has remained to the south or southeast, altered locally by pumping centers (Ewing et al., 2008).

Recharge to the Dockum Aquifer occurs from infiltration of precipitation or other sources of water in the outcrop areas, or from cross-formational flow from adjacent aquifers. The Dockum Group does not outcrop in the study area; the nearest outcrop area is more than 50 miles north-northwest in Mitchell and Howard Counties. Because the study area is far removed from the nearest outcrop area, Dockum Aquifer recharge occurring within or near the study area, as well as induced groundwater flow that occurs in response to groundwater pumping, is by cross-

formational flow from adjacent aquifer units that lie above or below the Dockum Group. Similarly, Dockum Aquifer discharge that does not occur to wells occurs as cross-formational groundwater flow to adjacent aquifers, most likely the overlying Edwards-Trinity (Plateau) Aquifer.

The primary groundwater-producing unit in the Dockum Aquifer is the basal Santa Rosa Formation, synonymous with the Santa Rosa Sandstone. Locally, any water-bearing sandstone in the Dockum Group is often referred to as the "Santa Rosa," a practice that has led to confusion in the literature regarding which geologic unit is actually the Santa Rosa Sandstone (Bradley and Kalaswad, 2003). Well yields in the Dockum Aquifer vary widely. Reported well yields range from as low as 0.5 gpm in Mitchell County to as high as 2,500 gpm in Winkler County (Bradley and Kalaswad, 2003). Bradley and Kalaswad (2003) report that specific capacities of Dockum Aquifer wells range from 0.14 to 25 gpm/ft, with an overall mean of about 4 gpm/ft. Ewing et al. (2008) report that analyses of multiple aquifer test results indicates hydraulic conductivities ranging from 1 to 100 ft/d, averaging between 20 and 30 ft/d. They also noted significant variability in hydraulic conductivity over short lateral distances in the Lower Dockum, and that hydraulic conductivity decreased with increasing depth. Reported storage coefficients range from about 4×10^{-5} to 2×10^{-3}, with mean estimates of approximately 1×10^{-4} or 2×10^{-4} (Bradley and Kalaswad, 2003; Ewing et al., 2008).

Regionally, Dockum Aquifer water quality ranges from fresh (TDS < 1,000 mg/L) in outcrop areas and a few other areas at the edges of the depositional basin, to highly saline brines with over 50,000 mg/L TDS in the middle of the basin (Ewing et al., 2008; LBG-Guyton, 2003). In the study area, Dockum Aquifer water is generally slightly saline, with TDS concentrations of 1,000 to 3,000 mg/L.

Regionally, uranium minerals have long been recognized to occur in the Dockum Group, and they are the source of some radiological constituents (radium-226 and -228) reported in some Dockum Aquifer water samples (Bradley and Kalaswad, 2003; McGowen et al., 1979). The concentrations of trace metals, including antimony, beryllium, cadmium, lead, mercury, selenium, and thallium, were reported to exceed drinking water regulatory limits in several counties (Bradley and Kalaswad, 2003).

3.2.3 Rustler Aquifer

The Rustler Aquifer is classified as a minor aquifer by the state of Texas. There are no known Rustler Aquifer wells on University Lands within the study area. Few studies have been performed on the hydrogeology of the Rustler Aquifer because of the small quantities of groundwater it produces and because sufficient quantities of better quality water can typically be produced from shallower aquifers (Ewing et al., 2012). Groundwater in the Rustler Aquifer primarily occurs in solution openings in dissolved limestone, dolomite, and gypsum, which results in highly variable well yields and poor water quality. The Rustler Aquifer extent as mapped by the TWDB includes University Lands Blocks 27, 28, and 165 in Pecos County southwest of Fort Stockton (Figure 2). The Rustler Formation occurs in the study area beyond the aquifer extent mapped by the TWDB, but the TWDB does not consider these additional regions to be part of the aquifer because the water has salinity greater than 5,000 mg/L TDS. Where groundwater is produced from the Rustler Aquifer, it is typically used for irrigation, livestock, domestic, and oil and gas water-flooding purposes.

The main production zones in the Rustler Aquifer are porous zones in the limestone and dolomite, which can be cavernous and highly productive. However, highly productive wells are sporadic and are often located close to low-productivity wells (White, 1971). Ewing et al. (2012) identify two independent flow systems within the Rustler Aquifer. One is a system of recharge in the Rustler outcrop area and discharge to the Pecos River and cross-formational flow to adjacent aquifers where the aquifer is shallow. A second flow system is indicated farther downdip closer to the study area, with water entering from the Tessey Limestone.

Within the study area, groundwater in the Rustler Aquifer occurs under confined conditions. Recharge to the Rustler Aquifer within the study area is from cross-formational flow (LBG-Guyton, 2003). Rustler Aquifer water also discharges to adjacent formations.

Regionally, relatively few wells are completed in the Rustler Aquifer. Ewing et al. (2012) report that only 95 wells completed in the Rustler Aquifer were identified in Texas, with 63 of these wells falling within the TWDB Rustler Aquifer boundary (primarily in Pecos and Reeves Counties). Consequently, little is known about the hydraulic properties of the Rustler Aquifer.

Well yields are highly variable, with wells capable of producing almost no groundwater and wells that can produce over 4,000 gpm (Ewing et al., 2012). Storage coefficient estimates for the Culebra Dolomite Member of the Rustler Formation range from 1.5×10^{-5} to 5.7×10^{-4} (Ewing et al., 2012).

Regionally, water quality in the Rustler Aquifer is poor, with most wells yielding saline to brine groundwater. Fresh groundwater is found only in a limited area near the Rustler Formation outcrop in Culberson County. An analysis of TWDB water quality records showed that over 90 percent of wells in the Rustler Aquifer produce groundwater with TDS concentrations that exceed 1,000 mg/L (Ewing et al., 2012). Brown (1998) indicated that Rustler Aquifer wells produced groundwater with TDS concentrations between 1,000 and 5,000 mg/L, with an average aquifer-wide TDS concentration of approximately 2,800 mg/L. No clear water quality patterns have been identified, but in general groundwater produced from the upper Rustler is of better quality than groundwater produced from the lower Rustler, which can be saline with TDS concentrations greater than 10,000 mg/L (LBG-Guyton, 2003). Rustler Aquifer groundwater is primarily a sodium and chloride water (White, 1971).

Trace metals concentrations are generally insignificant in groundwater produced from the Rustler Aquifer, with only iron and manganese concentrations above the drinking water standards in a few wells (Brown, 1998; Ewing et al., 2012). Naturally occurring radioactivity was also detected in many wells (Brown, 1998).

3.2.4 Capitan Reef Complex Aquifer

The Capitan Reef Complex Aquifer is classified as a minor aquifer by the state of Texas and is present in the porous limestones and dolomites of the Capitan Reef and related formations. This aquifer occurs beneath all or parts of University Lands Blocks 27, 28, and 165 in Pecos County southwest of Fort Stockton (Figure 2). In general, the Capitan Reef Complex Aquifer is composed of up to 2,000 feet of massive, cavernous limestone and dolomite. The aquifer forms a 7- to 10-mile-wide horseshoe shape essentially riming the Delaware Basin. The eastern side of the aquifer is present beneath University Lands in Winkler, Ward, and Pecos Counties, and ultimately terminates in the Glass Mountains to the south in Brewster County where the Capitan

Reef Complex outcrops (Figure 3). The Capitan Reef Complex Aquifer is not extensively developed in Texas, and is virtually undeveloped in the study area. Most groundwater produced from the aquifer is used for water-flooding in oil and gas reservoirs in Ward and Winkler Counties, and some agriculture in other counties outside of the study area (LBG-Guyton, 2003).

Regionally, well depths vary from shallow in the mountain areas where the formation outcrops to over 4,000 feet in Ward and Winkler Counties. In the downdip portion of the aquifer, groundwater is under significant hydraulic pressure. Due to the cavernous nature of the Capitan Reef Complex rocks, well yields can be high. Limited data and information exist on the aquifer hydraulic properties (White, 1971; LBG-Guyton, 2003). LBG-Guyton (2003) indicates that transmissivities of the Capitan Reef Complex Aquifer average approximately 40,000 gallons per day per foot (gpd/ft), but may be as high as 120,000 gpd/ft. Storage coefficients are estimated to be 1×10^{-3} to 1×10^{-4} (LBG-Guyton, 2003).

The quality of groundwater produced from the Capitan Reef Complex Aquifer is also highly variable. Fresh groundwater is generally present in and near the outcrop areas in the Glass Mountains in Brewster and Pecos Counties and the Guadalupe, Delaware, and Apache Mountains in Culberson County to the west (LBG-Guyton, 2003). Recharge from precipitation occurs on outcrops along the Guadalupe Mountains and by infiltration in the Glass Mountains (Richey and Wells, 1985). In the downdip areas, including Ward and Winkler Counties north of the study area, moderately saline to saline groundwater is produced, including some deep wells in Ward County producing groundwater with TDS concentrations in excess of 10,000 mg/L (Brown, 1997; LBG-Guyton, 2003). The eastern side of the Capitan Reef Complex, which includes the study area, produces groundwater that is notably warmer and has higher concentrations of all dissolved analytes relative to those observed for the western side of the aquifer, primarily in Culberson County (Brown, 1997). Naturally occurring radioactivity was detected in several deep wells in northern Pecos, Ward, and Winkler Counties, including gross alpha, gross beta, radium-226, and radium-228 (Brown, 1997). Groundwater produced from the deepest parts of the aquifer is corrosive and used only for secondary recovery operations in oil and gas production.

3.2.5 Potential Permian Aquifers

Multiple potential aquifer units are present within the Permian strata of the Guadalupian Series. These include permeable portions of the Yates, Queen, Grayburg, and San Andres Formations. This is particularly true to the east in central and eastern Crockett County and western Schleicher County, where the Dockum Group is absent and the Permian formations are relatively close to land surface, allowing for potential recharge from water that passes through the overlying Edwards-Trinity (Plateau) Aquifer. A total of 23 wells on University Lands in the eastern portion of the study area are completed in Permian strata.

4. Data Sources and Analysis

Data sources used for the geologic and hydrogeologic analyses include oil and gas well geophysical logs and water well data from the University Lands well library, geophysical logs, scout tickets and cable tool driller reports obtained from the BEG, driller reports and water well data from the TWDB (TWDB, 2015b), and driller reports submitted to the TDLR. Well information was collected and screened for the study area (Figure 2) and a 2-mile buffer surrounding each of the University Lands tracts. Ultimately, 969 data points were selected to interpret the geology and hydrogeology of the study area (Figure 8), although numerous additional data points were considered during the screening process as described below.

The goal of the geologic data analysis was to identify geologic formations that are known or potential aquifer units within approximately 3,000 feet of the land surface. Based on the project scope of work and additional discussions with University Lands, surfaces were evaluated for the following geologic formations and material types (Figure 4):

- Bottom of Edwards limestones (top of Trinity Group).
- Bottom of Trinity Group (top of Tecovas Formation, also top of Dockum Group).
- Bottom of Santa Rosa Formation (top of Dewey Lake Formation, also base of Dockum Group).
- Combined section of Permian evaporitic formations undifferentiated in this report. This section begins with the top of anhydrite of the Forty-Niner Member of the Rustler Formation, and ends at the top of the Yates Formation within the Artesia Group. The evaporite thickness includes the Rustler Formation, the Salado Formation, and the Tansill Formation of the Artesia Group where these units are present.
- The undifferentiated remaining formations of the Artesia Group, which are the Yates, Seven Rivers, Queen, and Grayburg Formations. The top of the San Andres Formation marks the base of the Artesia Group, and generally serves as the base surface in the geologic cross sections and the 3D geologic models.

- Where the Capitan Reef Complex is present in central Pecos County, its top surface serves as the base of the geologic interpretations.

In some instances additional formations were identified and entered into the database for some locations (e.g., Seven Rivers and Grayburg Formation tops in the Artesia Group). These additional picks are not represented in the 3D geologic models or the cross sections.

4.1 Data Screening and Consolidation

Each of the above-mentioned data sources contains a large number of well records and/or geophysical logs with potential limitations for data analysis. Data screening was conducted to identify well logs with reasonable location accuracy and appropriate information for the depths of investigation required for this study. The data screening approach is summarized in the following subsections.

4.1.1 Initial Data Screening

The BEG driller reports and scout tickets for each county needed an initial screening to determine if the well location was within the study area and contained pertinent geological information. Location accuracy was the most critical screening criterion.

Each of the University Lands geophysical logs was initially screened by viewing each scanned image (.pdf or .tif) to determine if the geophysical log starting depth was shallow enough to be useful for this study. It was assumed that the University Lands geophysical log database has accurate latitude and longitude coordinates. If the geophysical log run started before 500 feet, the geophysical log file was flagged for consideration during the second phase of screening. Many thousands of University Lands geophysical log files were considered in the initial screening process.

The University Lands water well dataset was not initially screened because it was assumed that for the recently completed wells all well location information was accurate (global positioning system [GPS] coordinates are provided) and nearly all wells have associated driller reports and

shallow geophysical logs. The intent was to use the University Lands water well driller reports and geophysical logs during the second phase of screening to supplement areas lacking well control and to provide increased water well data density in areas with high drilling activity. As of the writing of this report, there were 222 water well reports provided on the University Lands "Application to Pump a Water Well" form that are included in the University Lands water well database constructed as part of this project. These well completion data generally contain well construction diagrams, geophysical logs run prior to well completion, aquifer test (specific capacity) information, detailed location information, assorted other information related to the well and a copy of the TDLR report.

The BEG's hard copy cable tool driller reports for oil, gas, and water wells dataset and the scout ticket dataset are organized by county, operator and lease. Each driller report and scout ticket includes survey name, block, section, and distance from section lines. Information from the driller reports and scout ticket surveys was compared with a list of the study area survey information; wells within the study area were selected and API numbers with latitude and longitude information were obtained from the BEG. Over 10,000 BEG driller reports and scout tickets were considered during the initial screening process.

The TWDB and TDLR water well driller reports include latitude and longitude information. The initial screening of driller reports from the TWDB and TDLR was conducted to select deeper wells with good geologic descriptions. Wells shallower than 200 feet deep were excluded from consideration because they are unlikely to fully penetrate the Edwards-Trinity (Plateau) Aquifer. Exceptions to these general criteria were made where data density was low or a where a well was located in an incised valley where Trinity and Dockum Group information could potentially be obtained from the well log. Approximately 1,500 TWDB and TDLR driller reports were considered in the initial screening process.

If a well's latitude and longitude location did not correlate with other location attributes such as the State well grid and county, the well location coordinates were considered unreliable and the well was not used for this study.

4.1.2 Second Phase of Data Screening

The second phase of screening involved capturing the well information from the selected University Lands oil, gas and water well geophysical logs, BEG driller reports and scout tickets, TWDB driller reports, and TDLR driller reports. Pertinent data were entered into Excel spreadsheets that were converted into ESRI 10.2 ArcGIS shapefiles. The geographic information system (GIS) shapefiles of these datasets were reviewed simultaneously to determine well coverage and data source type distribution. Some portions of the study area had dense well control and wells needed to be removed from the dataset. Other areas had limited well control and wells were not removed.

The BEG maintains a geophysical log database that has API number location coordinates and geophysical log run top and bottom elevations. The BEG geophysical log library was used to help infill areas lacking well control.

Data sources were assigned priority as shown below. The highest-priority data generally provide the most useful data for subsequent analysis.

- Priority 1: University Lands oil, gas and water well geophysical logs and water well completion data
- Priority 2: BEG cable tool driller reports
- Priority 3: TDLR driller reports and BEG scout tickets
- Priority 4: TWDB driller reports (generally poor geological descriptions).

Each driller report (University Lands, BEG, TDLR, and TWDB) was reviewed a second time to determine the quality of geological descriptions and proximity to other well information. Driller reports with no rock color descriptions, numerous lithologies lumped into defined intervals, or descriptions for large intervals were removed from the dataset, as were driller reports in close proximity to one another with repetitive lithologic descriptions. Clusters of wells were thinned on a case-by-case basis, with University Lands geophysical logs and driller reports given priority over TDLR and TWDB driller reports.

Some geophysical logs also had quality issues, often related to poor gamma curve resolution, axis changes, or casing interferences in key geologic zones. Geophysical logs recorded with multiple tools, such as neutron, density, sonic, velocity, resistivity, or caliper, were preferred over geophysical logs with only gamma curves. Poor-quality gamma curves were generally removed from the dataset unless they were located in a region of sparse data.

4.1.3 Final Phase of Data Screening

After the surfaces were interpreted as summarized in Section 4.2, the final phase of data screening consisted of geologic surface refinement. ArcGIS 10.2 Kriging and Topo to Raster tools were used to generate initial geologic surfaces, from which regional trends and structural features could be identified. This regional-scale analysis was the first pass at geologic surface refinement. If a well location in the regional surface analysis exhibited an anomalous formation elevation, the well location and formation picks were either confirmed or deleted.

Aquifer elevation surfaces were also compared to published TWDB groundwater availability model (GAM) datasets where possible. GAM datasets are available for the Edwards Trinity (Plateau) (Anaya and Jones, 2009), Dockum (Ewing et al., 2008) and Rustler (Ewing et al., 2012) Aquifers. Overall, the aquifer elevation surfaces developed for University Lands are generally consistent with the corresponding surfaces in the GAMs.

4.2 Data Analysis and Assumptions

This section summarizes data analysis and assumptions for geophysical logs, driller reports, and scout tickets.

4.2.1 Geophysical Logs

The University Lands geophysical log library includes more than 40,000 oil and gas geophysical logs. Generally, the log tops begin at over 1,000 feet below ground surface (bgs), in which case the logs were rejected. Even for the logs that were selected for analysis, not all target geologic formations were identifiable due to variations in log quality. If confidence was low when

identifying a specific formation due to log quality, the value was left as null for that well location to avoid false readings.

The gamma log was the predominant log curve used for picking formation tops. Interpretations of sand or sandstone intervals using only a gamma curve without a neutron, velocity, or resistivity curve can be problematic because other lithologies such as limestone, dolomite, gypsum, and other evaporites also have a low gamma signature. For example, the base of the Edwards limestones sequence often transitions from a limestone to a shale and then to a formation with a low gamma signature. Because both limestone and sandstone have relatively low gamma signatures, the identification of this underlying lithology is interpretational if neutron, velocity, or resistivity curves are not available. If interpreted as sandstone, this interval would be the top of the Trinity Group, but if interpreted as limestone, the interval would be a continuation of the Edwards limestones sequence.

Some of the geophysical logs retained in the final dataset have poor-resolution gamma curves because there were no additional data points nearby. In most of these instances, formation top interpretations were more challenging, especially for the Dockum Group. These well locations usually received a low to very low confidence ranking.

The University Lands water well geophysical logs provide higher-resolution, more reliable formation picks, although some of these geophysical logs do not start until several hundred feet below land surface. The University Lands water well geophysical logs are supplemented by lithologic descriptions, useful for identification of the Dockum Group.

The interpretation of formation tops and bases on geophysical logs generally proceeded as follows:

- The top of the Trinity Group was assumed to be the first sand greater than 10 feet thick below the Edwards limestones sequence.
- The Tecovas Formation underlies the Trinity Group and serves as a regional marker for the top of the underlying Santa Rosa Formation and its associated Dockum (Santa Rosa) Aquifer. The top of the Tecovas Formation (and top of the Dockum Group) was

assumed to be a siltstone or shale sequence beginning at the base of the last Trinity Group sand.

- The base of the Tecovas Formation and top of the Santa Rosa Formation was identified as the first sand interval below the Tecovas Formation siltstones and shales. Although the Santa Rosa Formation includes multiple sand intervals, it also includes significant thicknesses of siltstone and shale interbedded with sandstone.

- The base of the Santa Rosa Formation was assumed to be the final (deepest) sand interval within the Dockum Group sequence; this is also the top of the Permian Dewey Lake Formation, which consists primarily of red siltstone and shale with no sandstone.

- The top of the Rustler Formation anhydrite (top of undifferentiated Permian evaporites) was assumed to be the first very low, sharp gamma signature.

- The top of the Yates Formation of the Artesia Group was assumed to be the first sandstone sequence that occurs below the undifferentiated Permian evaporites.

- The top of the San Andres Formation is the beginning of a thick dolomite/limestone sequence of 200 to more than 500 feet with a consistent low fluctuation gamma curve below the Queen Formation sandstones that form the base of the Artesia Group.

4.2.2 TDLR and TWDB Driller Reports and BEG Cable Tool Driller Reports

Some driller reports provide detailed lithologic descriptions while others are far less detailed. The driller descriptions usually had sufficient information to identify the top of the Trinity Group, the Dockum Group, and the Rustler Formation anhydrite. The general assumptions used while interpreting the driller report lithologic descriptions are as follows:

- The Trinity Group was assumed to be the top of the first gray to tan sand greater than 10 feet thick occurring below the Edwards limestones sequence.

- The top of Dockum Group (Tecovas Formation) pick was based on a color description of red or blue, and contained a lithology description of siltstone or shale followed by

additional redbeds. When redbed intervals could not be readily correlated with nearby wells, they were assumed to be false redbeds and were not selected as top of Dockum. The top of Dockum Group surface is an erosional (uneven) surface. Because there were areas of Dockum highs during deposition of the Trinity Group, "false" redbeds could be the result of erosional events where sediments from the Dockum highs were deposited within Trinity Group sediments.

- The lowest sand interval described in the Dockum Group redbed sequence was assumed to be the basal portion of the Santa Rosa Formation. The base of Santa Rosa Formation is the top of the Dewey Lake Formation.

- Within the limit of the lateral extent of the undifferentiated Permian evaporites (Figures 6 and 7), the first anhydrite encountered was assumed to be the top of the Rustler Formation, which is also the base of the Dewey Lake Formation.

4.2.3 Scout Tickets

Scout tickets do not include lithologic descriptions, but do list formation picks. Most often the picks are for formations at depths below the shallower aquifer units. However, some scout tickets provided Cretaceous (Edwards-Trinity), Triassic (Dockum Group), and Permian (Rustler Formation) top picks. Scout tickets were used to supplement geologic interpretations in areas with limited data.

4.3 Confidence Ranking for Formation Picks

Each well (data point) was assigned a formation pick confidence estimate to assist with interpretation reliability. The confidence ranking scale ranges from 1 to 4, with 1 representing the highest confidence and 4 representing the lowest confidence. The interpretation reliability attribute for a well location can be considered when using surfaces provided as part of this study. For example, if there is a cluster of wells with confidence values of 3 or 4, then the surface should be considered more "interpretive" and may benefit from refinement as additional well information becomes available. The following is a summary of the confidence value ranking system employed for this project:

- *Confidence Level 1:* Excellent geophysical log quality and log curve detail, usually includes gamma and neutron or resistivity curve and clear stratigraphic picks. Could serve as a type log if deeper picks are provided. Also includes good local well control and relatively close well spacing.

- *Confidence Level 2:* Good geophysical log quality and log curve detail, includes a good gamma curve and possibly a neutron or resistivity curve and relatively clear stratigraphic picks. Additional wells are in proximity.

- *Confidence Level 3:* Generally acceptable gamma curve but may have no neutron or resistivity curves or poor quality curves. Some or all of the stratigraphic picks are challenging. Only a few wells within a 1-mile radius.

- *Confidence Level 4:* Generally poor to very poor gamma curve with minimal resolution, usually with no additional geophysical log curves. Challenging stratigraphic picks. No wells or few wells within a 5-mile radius.

5. Results

This section provides the results of this study, focusing first on the geology (Section 5.1) and then the hydrogeology (Section 5.2).

5.1 Geology

The geologic interpretations are presented in cross sections, geologic unit thickness maps, and 3D interactive geologic models. The cross sections and geologic unit thickness maps for the Pecos County, five-county, and central Crockett County areas are provided in Appendices A, B, and C, respectively. The 3D geologic models for each of these subareas are provided in Appendix D.

5.1.1 Pecos County Area

The surface geology for the Pecos County area is provided in Figure 5, and eight geologic cross sections are provided in Appendix A. The surface geology is primarily outcrops of Buda Limestone and formations within the Washita and Fredericksburg Groups. Formation outcrops are covered in the valleys and drainages by Quaternary alluvium. There is limited outcrop of the Trinity Group in University Lands Block 27 (Figure 5).

Most faults illustrated on the cross sections have insufficient displacement to be illustrated in the 3D geologic model. Some faults appear to be concealed (age older than Triassic), while some appear to have affected the Cretaceous and Triassic units, as well as older units (see, for example, cross sections A2-A2' and D-D' in Appendix A). The University Lands in Pecos County lie predominantly within two distinct regions bounded by fault zones as delineated in Bumgarner et al. (2012).

Study results for each of the major geologic units are described in the following subsections.

5.1.1.1 Edwards Limestones and Trinity Group

The Edwards limestones in this area range in thickness from about 5 to over 600 feet, although throughout most of the area they are at least 100 to 200 feet thick The thickness of this unit is correlated with topography, with the thickest intervals beneath topographically high locations that have experienced less erosion, and the thinnest intervals within drainages. The Edwards limestones also generally thin to the north on University Lands in this area that are east of Fort Stockton (cross sections D-D', E-E', and F-F' and Figure A-10 in Appendix A).

The Trinity Group is present beneath the entire study area. Trinity Group elevation surface is a relatively smooth surface with higher elevations in the west and an overall eastward slope losing about 300 to 500 feet in elevation across the area. The Trinity Group thickness ranges from nearly zero to over 200 feet, although in most locations it is at least 40 feet thick (Figure A-11 in Appendix A). The Trinity Group is generally thickest in the southeast portion of the area in University Lands Blocks 17 and 18, and it is generally thinner in Block 26 overlying the Fort Stockton Uplift and in University Lands Blocks 27, 28, and 165, which overlie the Capitan Reef Complex (Figure 5 and Figure A-11 in Appendix A).

5.1.1.2 Dockum Group

The Dockum Group (Tecovas and Santa Rosa Formations) are present across most or all of the Pecos County area. The Dockum Group likely thins, and may even be absent, in portions of University Lands Block 26, where Permian strata deposited on the flanks of the Fort Stockton Uplift approach the ground surface.

The Tecovas Formation thickness ranges from about 10 to over 100 feet, with areas of greater thickness in the east (Figure A-12 in Appendix A). The Santa Rosa Formation thickness ranges from about 20 to more than 200 feet. The thickest Santa Rosa Formation (up to about 200 feet) occurs in University Lands Block 19. The Santa Rosa is less than 50 feet thick in the northern portion of University Lands Blocks 16 and 20 (Figure A-13 in Appendix A).

5.1.1.3 Rustler Anhydrite and Other Evaporites

The undifferentiated Permian evaporite sequence (including the Rustler Forty-Niner Member anhydrite) occurs throughout the Pecos County area, and has a thickness ranging from about

200 to 1,500 feet. The evaporite thickness is greatest in the blocks of University Lands southwest of Fort Stockton (Figure A-15 in Appendix A).

The anhydrite (evaporite) surface elevation is highest in Block 27 (near foothills of the Glass Mountains) and in Block 26 overlying the Fort Stockton Uplift (cross sections C-C' and D-D' in Appendix A). South of the Fort Stockton Uplift the anhydrite surface dips downward 200 to over 500 feet into the Sheffield Channel (Figure 3 and cross sections D-D' and E-E' in Appendix A). Moving east to northeast toward the Central Basin Platform, the anhydrite surface climbs 300 to 400 feet out of the Sheffield Channel onto the Central Basin Platform (cross section A2-A2' in Appendix A). Along the southern margin of the Central Basin Platform (University Lands Blocks 17, 18, and 19), the evaporites are nearly flat-lying (cross section B2-B2', E-E', and F-F' in Appendix A).

5.1.1.4 Artesia Group and San Andres Formation

The deeper geologic formations, especially the Artesia Group and San Andres Formation, are strongly influenced by local and regional structural features. Within the Pecos County area, the Artesia Group thickness ranges from about 300 up to nearly 1,400 feet (Figure A-16 in Appendix A).

Both the Artesia Group and the San Andres Formation drop in elevation from 500 to over 1,500 feet moving north to south into the Sheffield Channel structural feature (Figure 3; cross sections D-D' and E-E' in Appendix A). The top of the San Andres Formation is approximately 3,000 feet deep or more in the Sheffield Channel in University Lands Blocks 23 and 22 (cross section D-D' in Appendix A). Moving west to east, the Artesia Group and San Andres Formation dip upward onto the Central Basin platform, where they level out or slope upward at a modest rate (cross sections A1-A1', A2-A2', B1-B1', and B2-B2' in Appendix A).

No San Andres Formation top picks were positively identified on geophysical logs or driller reports for University Lands Blocks 27, 28, and 165 southwest of Fort Stockton. These blocks overlie or are immediately adjacent to the Capitan Reef Complex. In this area, the top of the Capitan Reef Complex as documented in Standen et al. (2009) was used in construction of the 3D geologic model. Also in this area, the top of the Artesia Group slopes upward to the south

(cross section C-C' in Appendix A), consistent with the regional trend of the underlying or adjacent Capitan Reef Complex.

5.1.2 Five-County Area

The five-county area is the most geologically complex area in this study. This area extends east from the Central Basin Platform to the eastern extent of the Midland Basin, with much of the structure and stratigraphy significantly influenced by the Ozona Arch and structural uplift within the southern portion of the Midland Basin (Figure 3). Permian and Triassic rocks dip to the west across the arch feature, and the Dockum Group and evaporite rocks thin from west to east and pinch out at the eastern margin extent of the Ozona Arch (Figures 3 and 6). East of the undifferentiated Permian evaporite pinch-out, rocks of the Permian Artesia Group underlie the Trinity Group (cross sections G2-G2' and H2-H2' in Appendix B).

A significant fault consistent with the transition for the Central Basin Platform to the Midland Basin (Figure 3) is evident in the cross sections through University Lands Blocks 13, 14, and 15 and is delineated on Figure 6. Cross sections H1-H1', I-I', and J-J' (Appendix B) illustrate the fault, which has up to about 700 feet of displacement. The fault affects the Permian section only, and apparently has not significantly affected the overlying Triassic and Cretaceous rocks. This fault is included in the 3D geologic model for the evaporite units and the San Andres Formation due to the significant offset of these geologic units.

Study results for each of the major geologic units are described in the following subsections.

5.1.2.1 Edwards-Trinity

In this area, the Edwards limestones vary in thickness from about 100 feet to over 600 feet. The Edwards limestones are generally absent in University Lands Blocks 14 and 15 and are relatively thin throughout much of the western portion of the five-county area. The Edwards limestones thicken to the east and south, with the thickest limestone occurring in Crockett County (Figure B-12 in Appendix B).

The Trinity Group is present across the entire five-county area, with outcrop in some of the deeper incised fluvial valleys (Figure 6). Trinity Group thickness ranges from 50 feet to over 200 feet. The Trinity Group generally thins to less than 100 feet in Schleicher, Irion, and northeastern Crockett Counties (cross sections G2-G2' and H2-H2' in Appendix B). The majority of the thicker intervals of the Trinity (150 to 200 feet) occur in southeastern Upton and southwestern Reagan Counties toward the center of Midland Basin (Figure 3; cross section G1-G1' and Figure B-13 in Appendix B).

5.1.2.2 Dockum Group

The Tecovas and Santa Rosa Formations (Dockum Group) have similar lateral extents and trends. The Dockum Group is absent in western Schleicher County, northeastern Crockett County, and central Irion County (Figure 6). The Dockum pinch-out overlies the westward dipping Permian Artesia Group formations along the eastern edge of the Midland Basin (Figure 3; cross sections G1-G1', G2-G2', H1-H1', and H2-H2' in Appendix B).

The Tecovas Formation thickness generally ranges from about 15 to 50 feet, although it can exceed 100 feet in places (Figure B-14 in Appendix B). Despite its limited thickness at some locations, west of the Dockum Group pinch out (Figure 6), the Tecovas Formation was consistently identified.

The Santa Rosa Formation ranges in thickness from about 100 feet to over 300 feet. The region of thickest Santa Rosa Formation occurs in University Lands Blocks 1 through 6 and 58 in southwestern Reagan and southeastern Upton Counties. The Santa Rosa Formation is generally less than 150 feet thick in Irion, northeastern Crockett, and southeastern Reagan Counties (Figure 6; Figure B-15 in Appendix B).

5.1.2.3 Rustler Anhydrite and Other Evaporites

The undifferentiated Permian evaporite sequence (including the Rustler Forty-Niner Member anhydrite) has a similar lateral extent as that of the Dockum Group (Figure 6). The anhydrite top surface has minor undulations locally and is deepest near the northwestern corner of the Ozona Arch and western edge of Midland Basin in eastern Upton County, and is shallowest over the Central Basin Platform and the eastern edge of the Midland Basin (Figure 3).

5.1.2.4 Artesia Group and San Andres Formation

The deeper geologic formations follow trends related to regional structural features (Figure 3; cross sections G2-G2' and H2-H2' in Appendix B). The Artesia Group and San Andres Formations occur at greatest depth in Upton and Reagan Counties near the center of the Midland Basin, and dip upward to the east approaching the basin margin where they are truncated by the overlying Cretaceous rocks, creating an angular unconformity. Consequently, the Artesia Group is thickest (2,000 feet or more) in southeastern Upton and southwestern Reagan Counties, and is considerably thinner (several hundred feet) in the eastern portion of the five-county area (Figure B-18 in Appendix B). The Artesia Group is also thinner where it overlies the Central Basin Platform in University Lands Block 14, where it is on the upthrown side of a major fault or fault zone (Figure 6; Figure B-4 in Appendix B).

The Permian Yates Formation sandstones (upper portion of the Artesia Group) are probably in close proximity to the Cretaceous Trinity Group sandstones in eastern Crockett and western Irion Counties. The Permian Queen Formation sandstones (lower portion of the Artesia Group) are probably in close proximity with the Cretaceous Trinity sandstones in Schleicher and western Irion Counties (cross sections G2-G2', H2-H2', and N-N' in Appendix B).

5.1.3 Central Crockett County Area

The surface geology of the central Crockett County area is provided in Figure 7, and four geologic cross sections are provided in Appendix C. The surface geology of this area consists primarily of outcrops of Buda Limestone and the Segovia Formation of the Fredericksburg Group. Bedrock is covered in the valleys and drainages by Quaternary alluvium and other deposits. The Trinity Group does not outcrop within the University Lands in central Crockett County, but does outcrop in the drainage immediately west of this area (Figure 7). Permian and Triassic rocks dip to the west, and the Dockum Group and evaporite rocks thin from west to east and pinch out across the northwestern corner of this area (Figure 7).

Study results for each of the major geologic units are described in the following subsections.

5.1.3.1 Edwards Limestones and Trinity Group

The Edwards limestones in this study area range in thickness from about 100 to 600 feet, with the greatest thickness beneath topographic highs as is characteristic of the region (Figure C-6 in Appendix C). The Trinity Group is present across this entire area, and ranges in thickness from about 35 to over 200 feet, but for the most part is about 150 feet thick or less (Figure C-7 in Appendix C). The Trinity Group top surface is relatively smooth with higher elevations in the northwest (Block 29), and slopes to the east losing about 250 feet in elevation.

5.1.3.2 Dockum Group

The Tecovas and Santa Rosa Formations thin and eventually pinch out in the northwestern portion of the study area (Figure 7). The Tecovas Formation thickness ranges from 0 to 25 feet (Figure C-8 in Appendix C). The underlying Permian Yates Formation is relatively close to land surface south and east of the Dockum Group pinch-out (cross sections O-O', P-P', and Q-Q' in Appendix C). The Yates Formation contains red beds that can easily be mistaken for Dockum Group redbeds.

The Santa Rosa Formation ranges from 0 to about 85 feet in thickness, with the maximum thickness in the northwestern portion of University Lands Block 29 (Figure C-9, Appendix C).

5.1.3.3 Rustler Anhydrite and Other Evaporites

The undifferentiated Permian evaporite sequence (including the Rustler Forty-Niner Member anhydrite) thins and eventually pinches out a few miles east and south of the Dockum Group pinch out in University Lands Block 29 and the northwest corner of University Lands Block 30 (Figure 7; cross sections O-O', P-P', and Q-Q' in Appendix C). The combined thickness of the evaporite rocks ranges from 0 to more than 200 feet (cross section O-O' and Figure C-11 in Appendix C).

5.1.3.4 Artesia Group and San Andres Formation

The Permian Artesia Group and San Andres Formation are influenced by southern and eastern edges of the Midland Basin. The Artesia Group and San Andres Formation dip upward from the Midland Basin, and are truncated by the overlying Cretaceous rocks, creating an angular unconformity (cross section P-P' in Appendix C). Sandstones of the Yates Formation (upper

Artesia Group) are probably in close proximity with the Cretaceous Trinity Group sandstones in eastern Crockett County.

5.2 Hydrogeology

This section presents available hydrogeologic data, analysis, and interpretations for the study area. Much of the analysis presented in this section is derived from information in the University Lands water well database described in Section 5.2.1. In addition, water quality is presented in accordance with the categories used by the TWDB based on TDS concentrations in mg/L, where fresh water is 0 to 1,000 mg/L, slightly saline water is 1,000 to 3,000 mg/L, moderately saline water is 3,000 to 10,000 mg/L, and very saline water is 10,000 to 35,000 mg/L.

5.2.1 University Lands Water Well Database

This section provides a brief overview of the University Lands water well database.

5.2.1.1 Database Construction

The University Lands water well database is a compilation of water well data from multiple sources, including University Lands water well applications, University Lands water well GIS shapefiles, the Railroad Commission of Texas, the TDLR-SDRD, and the TWDB (TWDB, 2015a). Combination of these data sources produced many duplicate records (records for the same well that appear in more than one dataset). The files were analyzed and compared with each other during a process of de-duplication. The well count for the entire database is 3,766 wells, of which 2,304 wells are located in the study area (143 wells in Pecos County, 2,020 wells in the five-county area, and 141 wells in central Crockett County).

5.2.1.2 Aquifer Designations

Water wells were assigned an aquifer, or multiple aquifers, by comparing the well attribute data to GIS-based aquifer surfaces extracted from the 3D geologic models described in Section 5.1. Attribute data include screen interval(s), well depth, and aquifer designation as assigned in the TWDB groundwater database. Within ArcGIS, each water well was assigned a value for the

depth of each aquifer at the well location. These depth values were then compared to the well's attribute data to identify in which aquifer the well is completed.

Because not all wells have these attributes, aquifer designations were assigned to each well based on hierarchal criteria. The screened intervals were used first to calculate whether the top of a well's screen and the bottom of a well's screen are in a particular aquifer. In many cases, this analysis resulted in wells being screened in multiple aquifers. There are 781 wells with screened interval data in the water well database within the southern study area. Of these wells, there are 8 in the Pecos County area, 767 in the five-county area, and 6 in the central Crockett County area.

There are 703 wells that have no screen interval data but have a well depth value. These wells were assigned an aquifer designation by calculating the deepest aquifer that the well depth intersects. Because the top of the screen is not known in this instance, only the deepest aquifer unit penetrated by the well was assigned based on the well depth. A portion of these wells may also be screened in the overlying aquifer. Because the Tecovas Formation is approximately 10 to 50 feet thick within the study area, an assumption was made that in order for a well to be considered completed in the Dockum Aquifer (Santa Rosa Formation), the well depth needed to extend more than 30 feet below the top of the Tecovas Formation.

Finally, there are 221 wells with no screen interval and no well depth value, but that have a TWDB aquifer code attribute. For these wells, the TWDB aquifer designation was used to assign the well to the corresponding aquifer designation used in the University Lands water well database. For example, "Antlers Sand" in the TWDB aquifer codes was assigned to "Trinity Group" in the University Lands water well database.

Of the 1,705 wells with a screen, depth, or aquifer attribute, 1,624 wells received an aquifer designation as provided in Table 1. Scenes can be selected in the 3D geologic models that illustrate water well depths and, where available, screen intervals.

5.2.2 Edwards-Trinity (Plateau) Aquifer

All of the water wells completed in the Edwards-Trinity (Plateau) Aquifer on University Lands within the study area, as available in the water well database, are illustrated in Figure 9. There are a total of 1,164 wells. Of the 1,164 wells, 448 are completed in the Edwards limestones portion of the aquifer, 410 are completed in the Trinity Group portion of the aquifer, and 306 are completed across both portions of the aquifer. In the western and central portion of the study area, the majority of wells are completed in the Trinity Group or both the Edwards limestones and the Trinity Group. In northeastern Crockett County and western Schleicher County, where the Trinity Group thins, wells are completed predominantly in the Edwards limestones (Figure 9).

Available water levels for wells with known screened intervals were plotted on working maps for comparison of the Edwards and Trinity aquifer units. In the Pecos County and central Crockett County areas, the observed water levels for wells completed in the Edwards limestones and the Trinity Group portions of the aquifer are similar, indicating that these two geologic units are well-connected hydraulically. In the five-county area, water levels in the Edwards limestones may be similar to, but are often higher than, water levels from nearby wells completed in the underlying Trinity Group. This condition is probably attributable to a lower-permeability zone near the base of the Edwards limestones, which does not appear to be ubiquitous within the five-county area.

A potentiometric surface (water level) map for the Trinity Group is provided in Figure 10. The contours are approximate because water levels corresponding to a range of dates were used to construct the map. As noted above, the water level contours for the Edwards limestones and Trinity Group aquifers would be the same or similar at many locations, but different at others. Therefore, Figure 10 is based on wells completed only in the Trinity Group; water levels from wells completed only in the Edwards limestones were not considered, and water levels from wells completed in both aquifer units were used only if they were consistent with nearby Trinity Group data points.

Groundwater flow in the Trinity Group aquifer in Pecos County is to the northeast or north, toward the Pecos River. Groundwater flow in central Crockett County is to the south, with a

southwestern component of flow also toward the Pecos River. Groundwater flow in the five-county area is generally to the southeast (Figure 10).

As noted in Section 3.2, changes in water levels through time are relatively small within the study area and do not indicate consistent upward or downward trends. This point is illustrated by the available Edwards-Trinity (Plateau) Aquifer well hydrographs obtained from the TWDB database presented in Figure 10. Groundwater levels in Edwards-Trinity (Plateau) Aquifer appear to have declined at some locations on University Lands since the mid to late 2000s by several tens of feet (e.g., well 44-45-702 in Reagan County); at other locations water level decline has been small or non-existent (e.g., well 54-13-707 in central Crockett County). Where recent water level declines have occurred, they are generally of similar magnitude to those observed during prior periods of time (Figure 10). Well 44-45-702 north of Big Lake in Reagan County and well 54-06-505 in northeastern Crockett County indicate a decline of approximately 10 feet greater than historical minimum water levels, although more recent values indicated some water level recovery. Recent water level declines, where they have occurred, are believed to be attributable to the combined effects of drought and increased oil and gas development activities. The water level dataset illustrated in Figure 10 predates the potential effects of recent (2015) increased precipitation relative to prior years that has occurred across much of west Texas, and reduced pumping for oil and gas activities since October 2014 due to the industry-wide slow down.

The reported yields from wells completed in the Edwards-Trinity (Plateau) Aquifer are presented in Figure 11. Reported yields are often approximate estimates provided by the driller, although pumping tests are required for water wells completed on University Lands. Reported well yields may be influenced by many factors other than aquifer properties, including well diameter, well screen placement, and pump capacity. Spatial trends in well yield are not evident in the five-county area. Wells in Pecos County Blocks 18, 19, and 20 exhibit the highest yield in the study area.

The total sand interval thickness for the Trinity Group is presented in Figure 12. The values provided in Figure 12 were determined by identification of sand intervals 10 feet or greater at the well locations indicated. For the most part, the total sand thickness within the Trinity Group

ranges from about 25 to 100 feet, although there are regions, such as University Lands Blocks 31, 44 through 47, and 50 in central and northern Crockett County, where the sand thickness is generally less than 25 feet.

The TDS concentrations of groundwater in the Edwards limestones portion of the Edwards-Trinity (Plateau) Aquifer are illustrated in Figure 13. In the eastern portion of the study area in northeastern Crockett, southern Irion, and western Schleicher Counties, where the underlying Trinity Group thins, the Dockum Group is absent, and wells are completed predominantly in the Edwards limestones, TDS concentrations are less than 1,000 mg/L. Similar water quality is observed in Pecos County. In other regions, such as the Big Lake area in Reagan County, central Crockett County, and University Lands Blocks 49, 50, and 51 in northern Crockett and southeastern Reagan Counties, the water quality is generally slightly saline, with TDS concentrations of 1,000 to 3,000 mg/L (Figure 13).

The TDS concentrations of groundwater in the Trinity Group portion of the Edwards-Trinity (Plateau) Aquifer are shown in Figure 14. As illustrated in the figure, there are some fresh water wells in the Trinity Group (TDS < 1,000 mg/L), but most Trinity Group wells appear to be slightly saline, with TDS concentrations of 1,000 to 3,000 mg/L.

5.2.3 Dockum Aquifer

The depth to the top of the Dockum Group from ground surface is presented in Figure 15. This depth is dependent on the ground surface elevation and the thickness of the overlying Cretaceous formations. The depth to the top of the Dockum Group varies from less than 100 feet within deeper-incised drainages to more than 700 feet beneath topographic highs.

The database contains 410 water wells completed in the Dockum Aquifer (Figure 16). Of the 410 wells, 148 are completed in the Dockum Aquifer only and 262 are completed in both the Dockum Group and the overlying Trinity Group. Because many of the Dockum Aquifer wells lack top of screen information and the aquifer designation was based on well depth only, a portion of the 148 Dockum Aquifer wells (i.e., those without screen information) may also be screened in the overlying Edwards-Trinity (Plateau) Aquifer.

Figure 17 provides an interpretive potentiometric surface map for the Dockum Aquifer. This figure is interpretive due to the limited number of data points, because static water levels reported over an extended period of time were used to construct the figure, and because well construction information is not available for some wells designated as Dockum Aquifer wells based on well depths only. Although the static water level data used to construct the contours in Figure 17 represent a span in years from 1947 to 2013, where recent static water levels are interspersed with older data, the values appear to be reasonably consistent.

Figure 17 indicates that groundwater flow within the Dockum Aquifer in Pecos, Upton, and northwestern Crockett Counties is toward the Pecos River, which is the likely point of regional groundwater discharge. West and northwest of the Big Lake area in Reagan County, a cone of depression in the Dockum Aquifer potentiometric surface is evident in all or portions of University Lands Blocks 8, 9, 10, 11, and 12 (Figure 17). Because well hydrographs are not available for the Dockum Aquifer, the amount of historical water level change in this region is unknown, but interpretation of the water level contours in Figure 17 suggests that drawdown on the order of 100 feet may have occurred. The water level dataset illustrated in Figure 17 predates the reduced pumping for oil and gas activities since October 2014 due to the industry-wide slow down.

Comparison of static water levels in selected wells screened in the Dockum Aquifer with nearby wells screened in the Trinity Group indicates significant differences in water levels. For example, in Reagan County Block 9, the reported static water level in Dockum Aquifer well 303711 is approximately 50 feet higher than the water level in Trinity Group well 320697, located approximately 1 mile away. In Reagan County Block 48 southeast of Big Lake, the water level in Dockum Aquifer well 302727 is about 100 feet higher than the water levels in Trinity Group wells 320706 and 320709, both of which are located approximately ½ mile from well 302727.

The reported yields from wells completed in the Dockum Aquifer are presented in Figure 18. Reported well yields can be influenced by many factors other than aquifer properties, including well diameter, well screen placement, and pump capacity. Most of the Dockum Aquifer wells illustrated in Figure 18 produce 150 gpm or less, and spatial trends in well yield are not evident.

The total sand interval thickness for the Dockum Group is presented in Figure 19. The values provided in Figure 19 are the sum of sand intervals 10 feet or greater at the selected well locations. The total sand thickness within the Dockum Group in Reagan, Crockett, and Irion Counties is generally approximately 10 to 25 feet, although total sand thickness of 25 to 100 feet is common at well locations along Highway 67 and at wells north of Highway 67 in Reagan County. Total Dockum Group sand thickness of 25 to over 100 feet is prevalent in Pecos County (Figure 19).

Comparison of the total sand thickness in Figure 19 with the total thickness of Santa Rosa Formation in the five-county area (Figure B-15 in Appendix B) illustrates that the predominant formation matrix is fine-grained, low-permeability material such as siltstone and mudstone. The fine-grained, low-permeability sediments within the Santa Rosa and overlying Tecovas Formations impede the vertical movement of groundwater between the Dockum Aquifer and the overlying Edwards-Trinity (Plateau) Aquifer.

The TDS concentrations of groundwater for wells completed in the Dockum Aquifer and both the Dockum Aquifer and the Trinity Group portion of the Edwards-Trinity (Plateau) Aquifer are illustrated in Figure 20. With the exception of one well with a TDS concentration greater than 10,000 mg/L in the north-central portion of Reagan County Block 9, Dockum Aquifer water is slightly saline, with TDS concentrations of about 2,000 to 3,000 mg/L. Wells completed in both the Dockum Group and the overlying Trinity Group exhibit fresh to moderately saline water quality, although the majority of wells are slightly saline (Figure 20).

5.2.4 Permian Aquifers

Multiple potential brackish aquifer units are present in the Permian strata of the Guadalupian Series. These include permeable portions of the Yates, Queen, Grayburg, and San Andres Formations. This is particularly true to the east in central and eastern Crockett County and western Schleicher County, where the Dockum Group is absent and Permian formations are relatively close to land surface, allowing for potential recharge from water that passes through the overlying Edwards-Trinity (Plateau) Aquifer.

A total of 23 Permian aquifer wells were identified on University Lands in the study area—21 in northeastern Crockett County and western Schleicher County and 2 in central Crockett County (Figure 16). These wells are completed in the upper portion of the Artesia Group. All of these wells except for one have a reported yield less than 100 gpm, and many have yields less than 50 gpm (Figure 18). Reported water quality is slightly to moderately saline (Figure 20).

5.2.5 Groundwater Volume Estimates

Approximate estimates of the volume of groundwater beneath the University Lands in the study area were made for the Trinity Group, the Dockum Aquifer (Santa Rosa Formation), and the productive portions of the Artesia Group formations. These estimates were made based on the thickness and extent of each of these geologic units as rendered in the 3D geologic models.

The estimated volume of Trinity Group sediments was multiplied by an effective porosity of 5 percent (0.05) to obtain an estimate of the water volume. In addition, it was assumed that the full thickness of the Trinity Group was saturated at all locations beneath University Lands, which is not the case at all locations. The Santa Rosa Formation volume was multiplied by an effective porosity of 2 percent (0.02) to obtain an estimate of water volume. The Artesia Group volume was multiplied by a factor of 0.4 as a gross estimate of the ratio of sediments that might produce water to a well. The subsequent volume estimate was then multiplied by an effective porosity of 0.005 to obtain the water volume estimate.

The results of this analysis are provided in Table 2. As indicated in the table, the estimated volume of groundwater beneath University Lands in the study area is approximately 5.6 million acre-feet for the Trinity Group, 2.3 million acre-feet for the Dockum Aquifer, and 0.4 million acre-feet for the potential Artesia Group aquifers. One acre-foot is equivalent to 325,851 gallons, or about 7,758 barrels. *These volume estimates are approximate and are not indicative of recoverable groundwater in any area.* Recoverable groundwater depends on numerous factors, including aquifer depth, aquifer hydraulic properties, depth to the potentiometric surface under pumping conditions, and groundwater quality relative to its intended use.

6. Conclusions

The primary conclusions based on the results of this study are as follows:

- Groundwater levels in Edwards-Trinity (Plateau) Aquifer appear to have declined at some locations on University Lands since the mid to late 2000s by several tens of feet, and at other locations water level decline has been small or non-existent. Where water level declines have occurred in the mid to late 2000s, they are generally of similar magnitude to historical declines. Two wells with historical water levels (one north of Big Lake in Reagan County and one in northeastern Crockett County) indicate a decline of approximately 10 feet greater than maximum historical levels, although more recent values indicate some water level recovery. Where they have occurred, recent water level declines are likely attributable to the combined effects of drought and increased oil and gas development activity. The water level dataset used in this report predates the potential effects of recent (2015) above-average precipitation that occurred across much of west Texas, and reduced groundwater pumping for oil and gas activity since October 2014 due to the industry-wide slow down.

- Based on a relatively limited dataset, water levels in the underlying Dockum (Santa Rosa) Aquifer appear to have declined beneath University Lands west and northwest of Big Lake, possibly by as much as approximately 100 feet. The declines are believed to be due to oil and gas development. The Dockum Aquifer water level dataset predates reduced groundwater pumping for oil and gas activity since October 2014 due to the industry-wide slow down.

- Many wells in the study area are completed across multiple aquifer units.

- The Dockum Aquifer is thin with limited production capacity or non-existent in the eastern portion of the study area in central and northeastern Crockett County, Schleicher County, and southern Irion County (Figure 21). Where the Dockum Group is missing, the first aquifer unit encountered below the Edwards-Trinity (Plateau) Aquifer is within the Permian Artesia Group.

- Dockum Aquifer well yield is variable in areas of significant Santa Rosa Formation thickness but is generally less than 150 gpm. Total sand interval thickness in the Santa Rosa Formation can be used as an indicator of expected well yield. Based on this measure, Dockum Aquifer well yield would be expected to be low relative to other areas on University Lands in northern Crockett County, southeastern Reagan County, and University Lands Blocks 1, 4, 5, 6, 7, and 12 in south-central Reagan County, as illustrated in Figure 21.

- A limited number of wells (23) are completed in the upper portion of the Permian Artesia Group in the eastern portion of the study area where the Dockum Aquifer is absent. The yields of these wells are generally less than 100 gpm.

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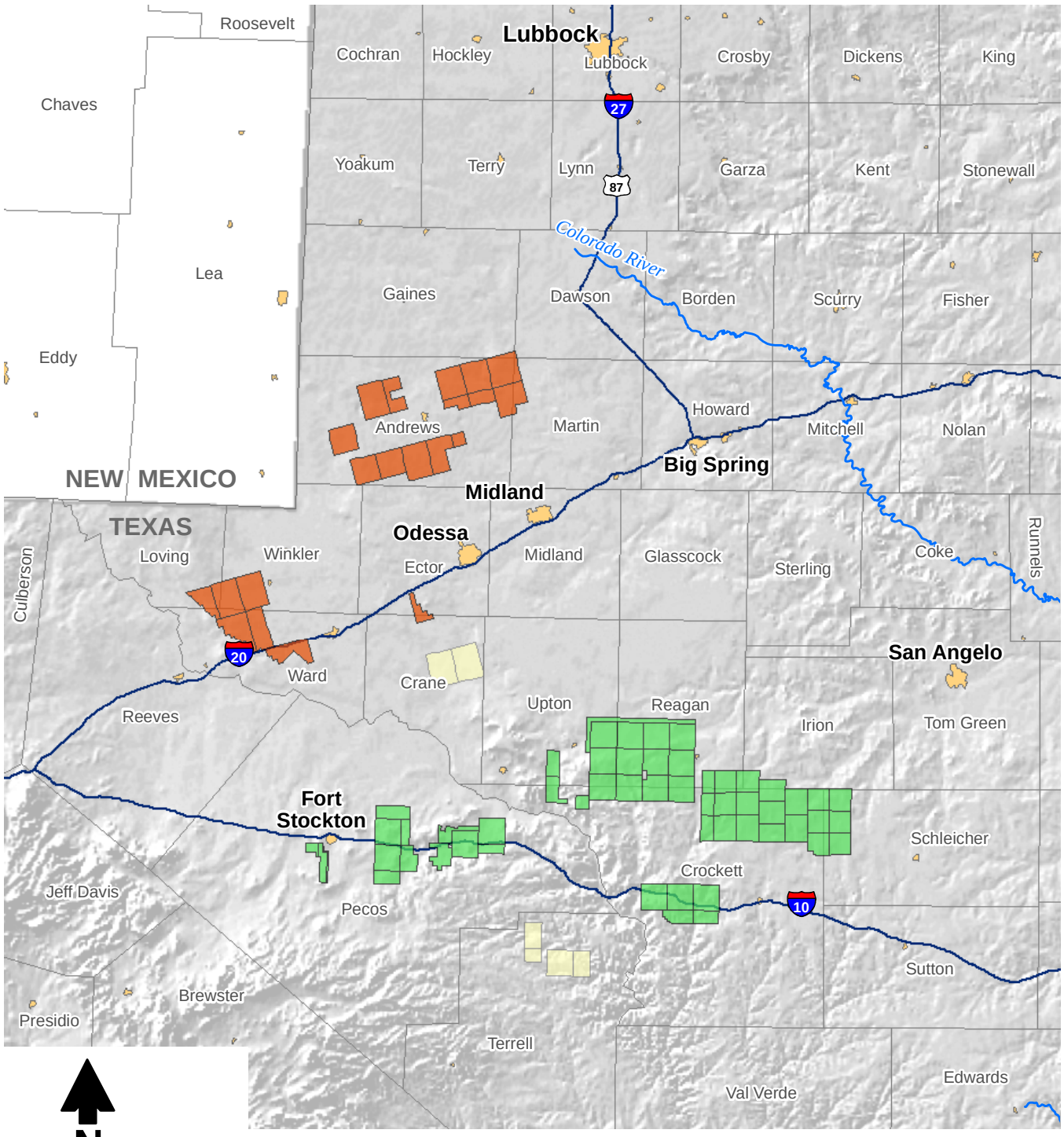
Figures



Explanation

- University Lands (Northern study area)
- University Lands (Southern study area)
- Other University Lands
- Urban area
- County

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG01_GW_RESOURCE_EVAL_RPT_STUDY_AREAS.MXD

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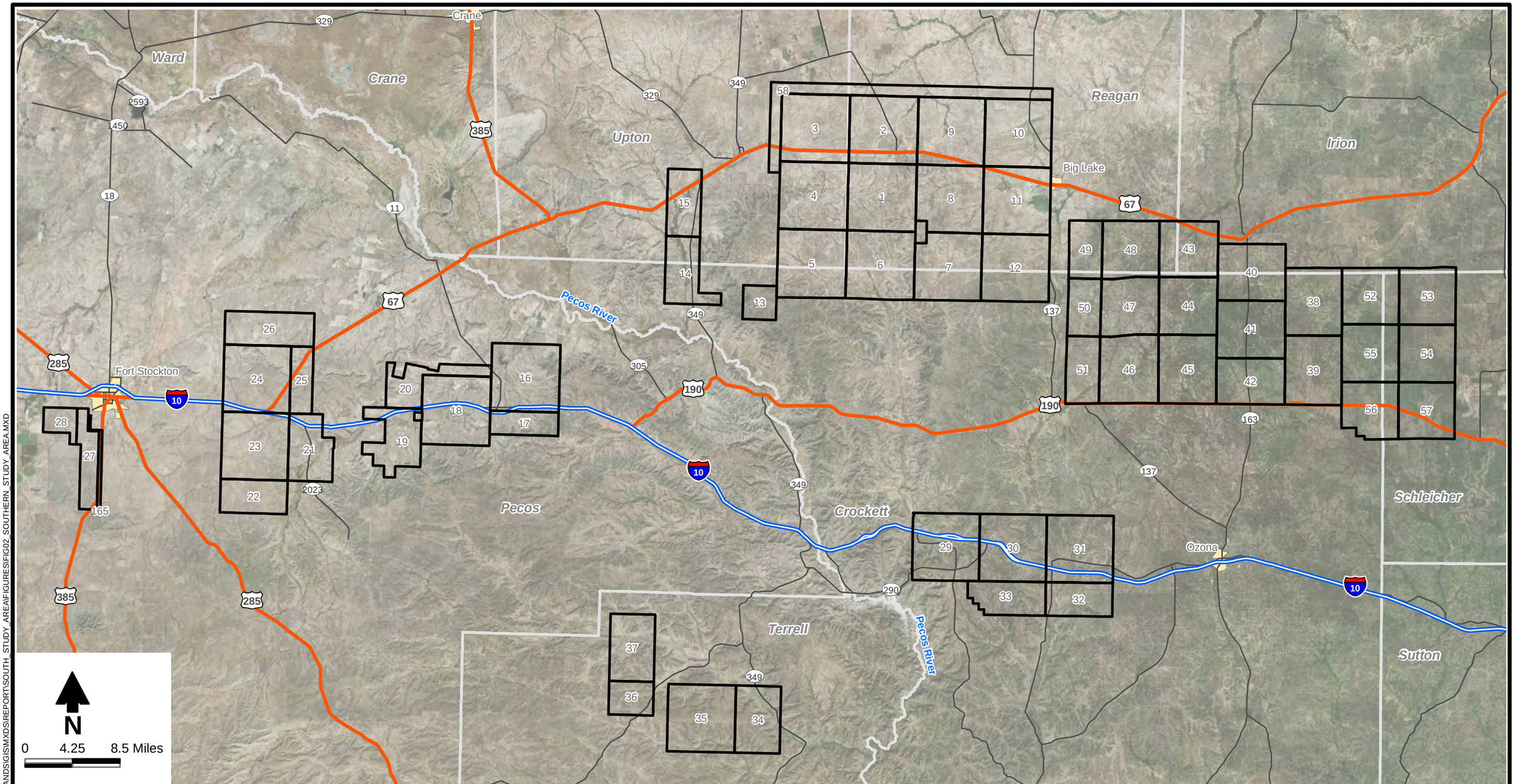
Groundwater Resource Evaluation Report Study Areas

Figure 1



Note: South study area does not include University Lands in Terrell County

Explanation

- University Lands and block number
- Urban area
- County

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Southern Study Area

Figure 2

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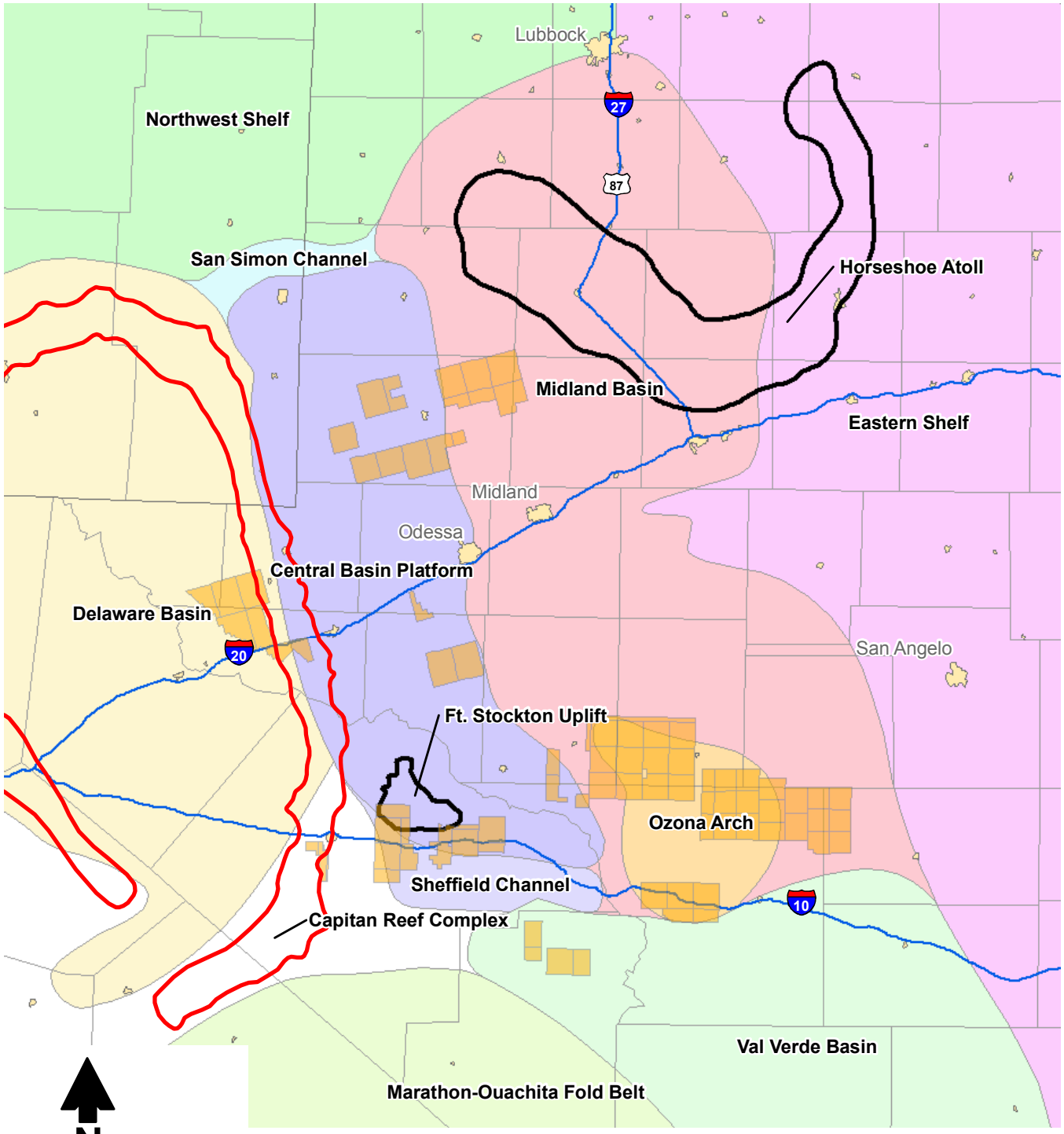

Sources: Dutton et al. (2005) and Ewing (1991)

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West Texas Regional Geologic Structure

Figure 3

Period	Group/Series	Formation	Aquifer
Quaternary		Alluvium	Above the water table (not saturated)
Cretaceous	Terilingua Group	Boquillas Flags	
	Washita Group	Buda Limestone Del Rio Clay	
	Fredericksburg Group	Fort Terrett Segovia Sue Peaks	Edwards-Trinity (Plateau) – major aquifer
	Trinity Group	Maxon Sand Glen Rose Basal Sand	
Triassic	Dockum Group	Cooper Canyon Trujillo Sandstone	Upper Dockum – not present
		Tecovas Santa Rosa	Lower Dockum – minor aquifer (Santa Rosa)
Permian	Ochoan Series	Dewey Lake	Confining unit
		Rustler	Rustler – minor aquifer
		Salado	Confining unit
	Guadalupian Series	Capitan Reef Complex / Artesia Group: Tansill, Yates, Seven Rivers / Queen, Grayburg	Capitan Reef – minor aquifer Other potential aquifers in Yates, Queen, Grayburg, and San Andres
		Capitan Reef Complex: San Andres	
	Leonardian Series	Clearfork Wichita	Not considered in study
	Wolfcampian Series	Wolfcamp	
Pennsylvanian	Pennsylvanian	Cisco Canyon Strawn Bend (Atoka)	
Mississippian	Mississippian	Barnett	
Devonian	Devonian	Woodford	
Silurian	Silurian	Fusselman	
Ordovician	Ordovician	Montoya Simpson Ellenburger	

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Geologic Column and Corresponding Aquifer Units

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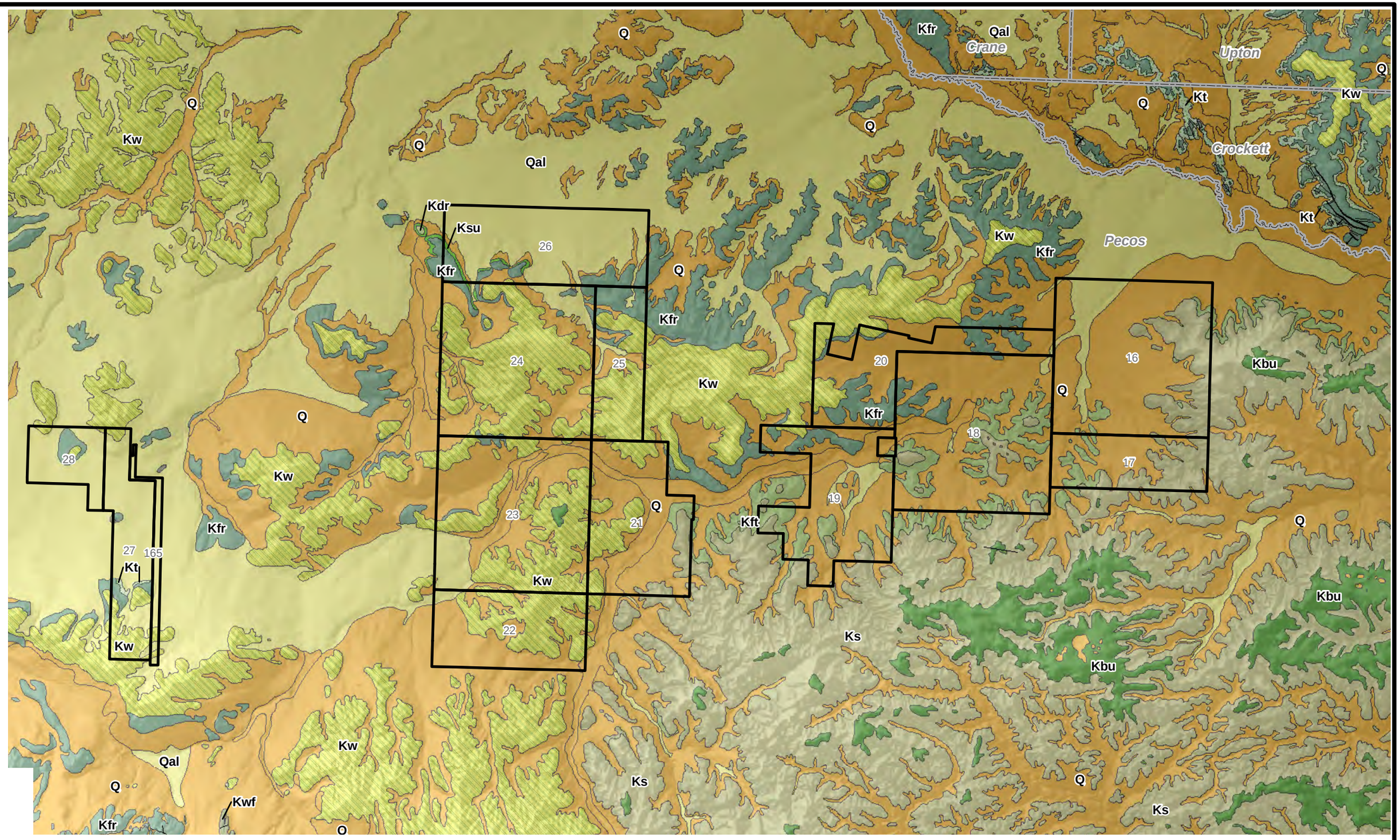
Figure 4



N

0 2 4 Miles

Explanation

- University Lands and block number
- County

Geology

Fault Type

- Normal
- Unspecified

- Qal - Quaternary alluvium
- Q - Quaternary deposits (undivided)
- Kbu - Buda Limestone
- Kdr - Del Rio Clay
- Kwf - Washita and Fredricksburg Groups (undivided)
- Kw - Washita Group
- Kfr - Fredericksburg Group
- Kft - Fort Terrett Formation (Fredericksburg Group)
- Ks - Segovia Formation (Fredericksburg Group)
- Ksu - Sue Peaks Formation
- Kt - Trinity Group (undivided)

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Pecos County Area Surface Geology

Figure 5

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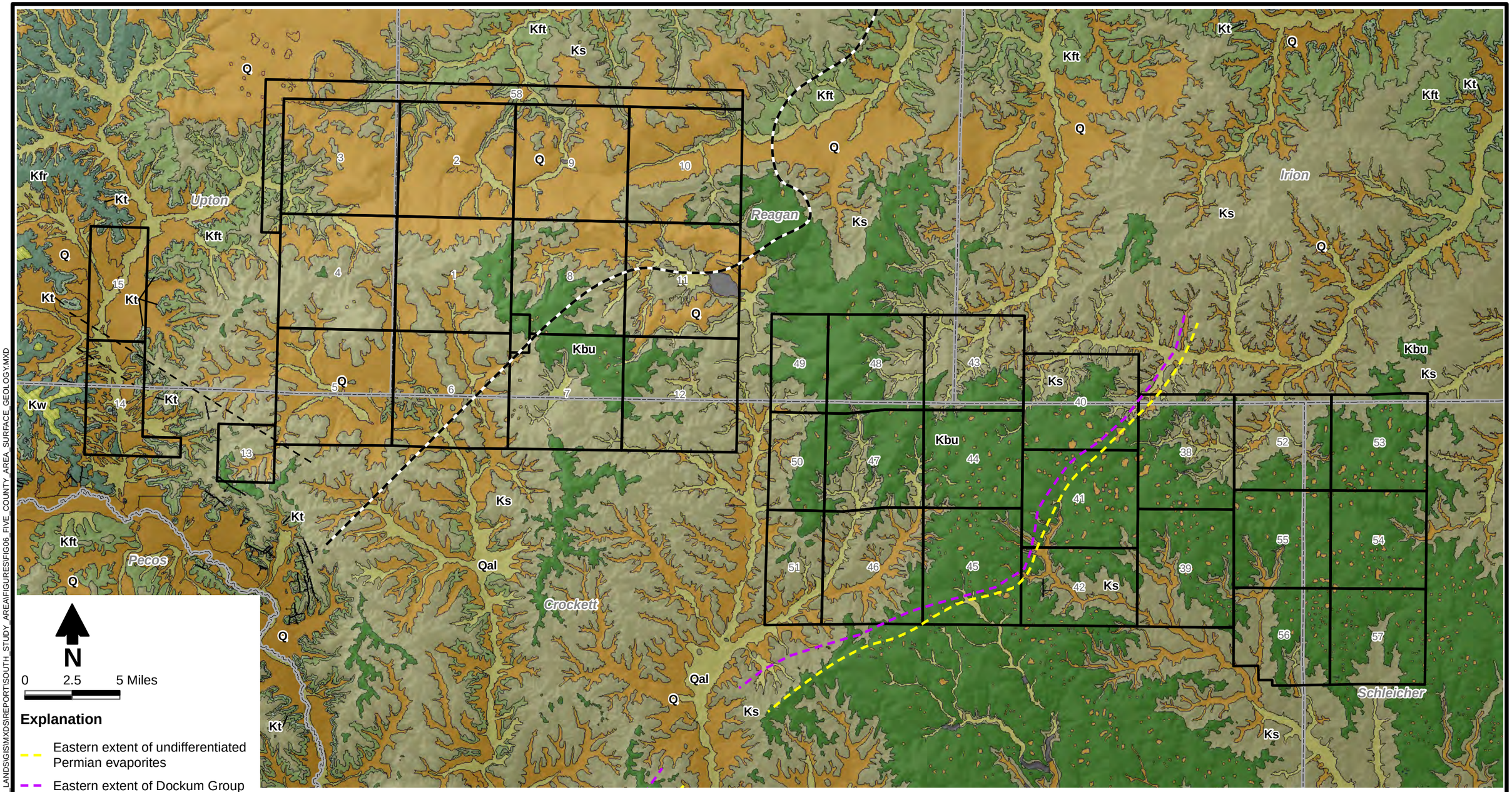

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Five-County Area Surface Geology

Figure 6

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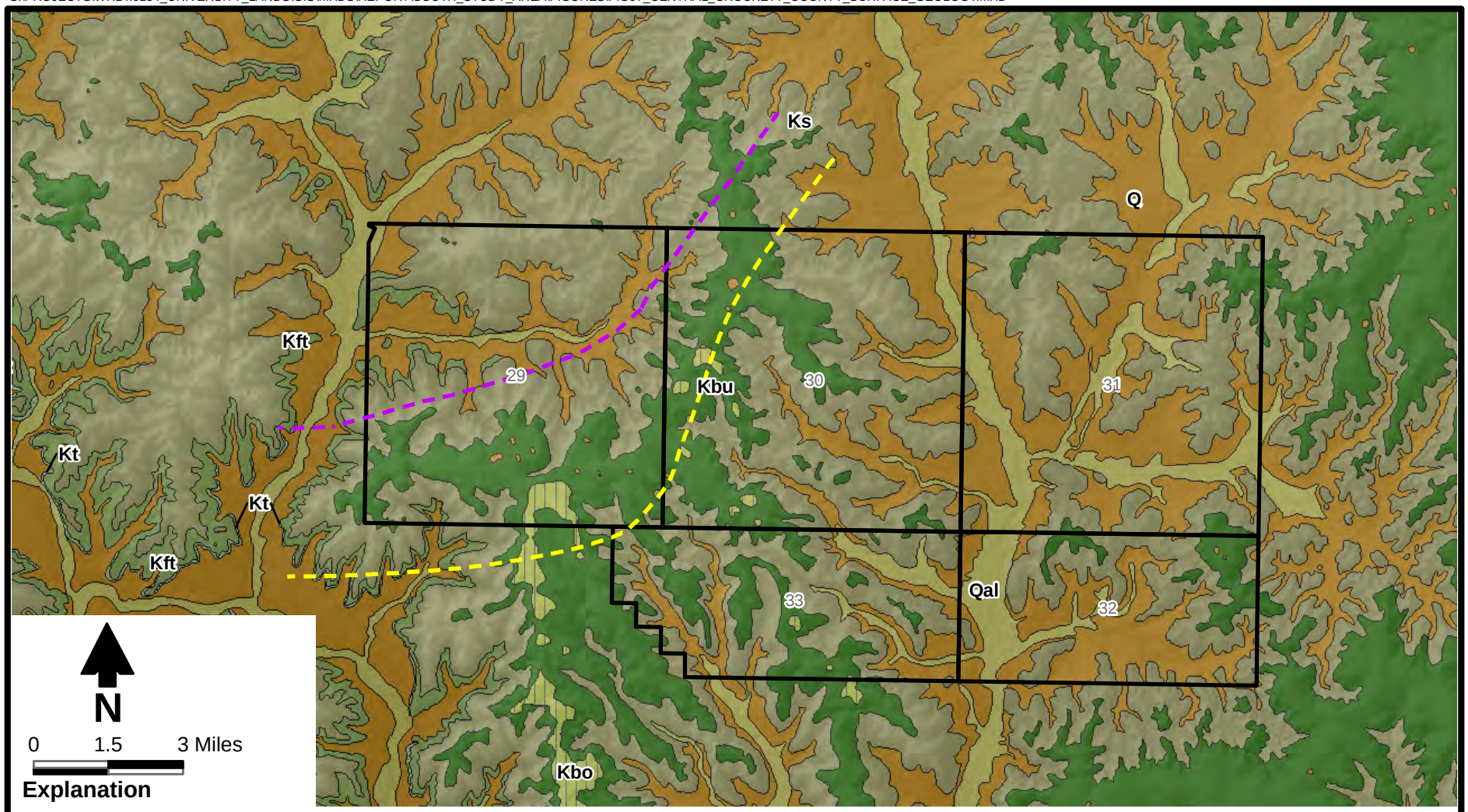

Explanation

- Eastern extent of undifferentiated Permian evaporites
- Eastern extent of Dockum Group
- University Lands and block number
- County

Geology

- Qal - Quaternary alluvium
- Q - Quaternary deposits (undivided)
- Kbo - Boquillas Flags (Terlingua Group)
- Kbu - Buda Limestone
- Ks - Segovia Formation (Fredericksburg Group)
- Kft - Fort Terrett Formation (Fredericksburg Group)
- Kt - Trinity Group (undivided)

Figure 7

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Central Crockett County Surface Geology

Ward
Crane
Upton
Reagan
Irion
Pecos
Crockett
Terrell
Schleicher
Sutton
Crane
Big Lake
Fort Stockton
Ozona
Pecos River
Pecos River
329
385
67
11
18
1450
2593
285
10
349
305
190
137
163
165
2023
290
N
0 4.25 8.5 Miles

Explanation

- Water well driller report
- Scout ticket
- Oil and gas well driller report
- Oil and gas geophysical log
- University Lands and block number
- Urban area
- County

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Data Sources for Geologic Analysis

Figure 8

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG09_WELLS_COMPLETED_IN_THE_EDWARDS_TRINITY_PLATEAU_AQUIFER.MXD

Ward
Crane
Upton
Reagan
Irion
Crockett
Schleicher
Sutton
Terrell
Pecos
Big Lake
Ozona
Fort Stockton
Pecos River

N
0 4.25 8.5 Miles

Explanation

- University Lands and block number
- Urban area
- County
- Well completed in Edwards limestones
- Well completed in Trinity Group
- Well completed within Edwards limestones and Trinity Group
- Well with no aquifer designation
- Well completed according to University Lands Groundwater Management Plan (2013)

Note: Aquifer designations based on stratigraphic interpretation provided in this report.

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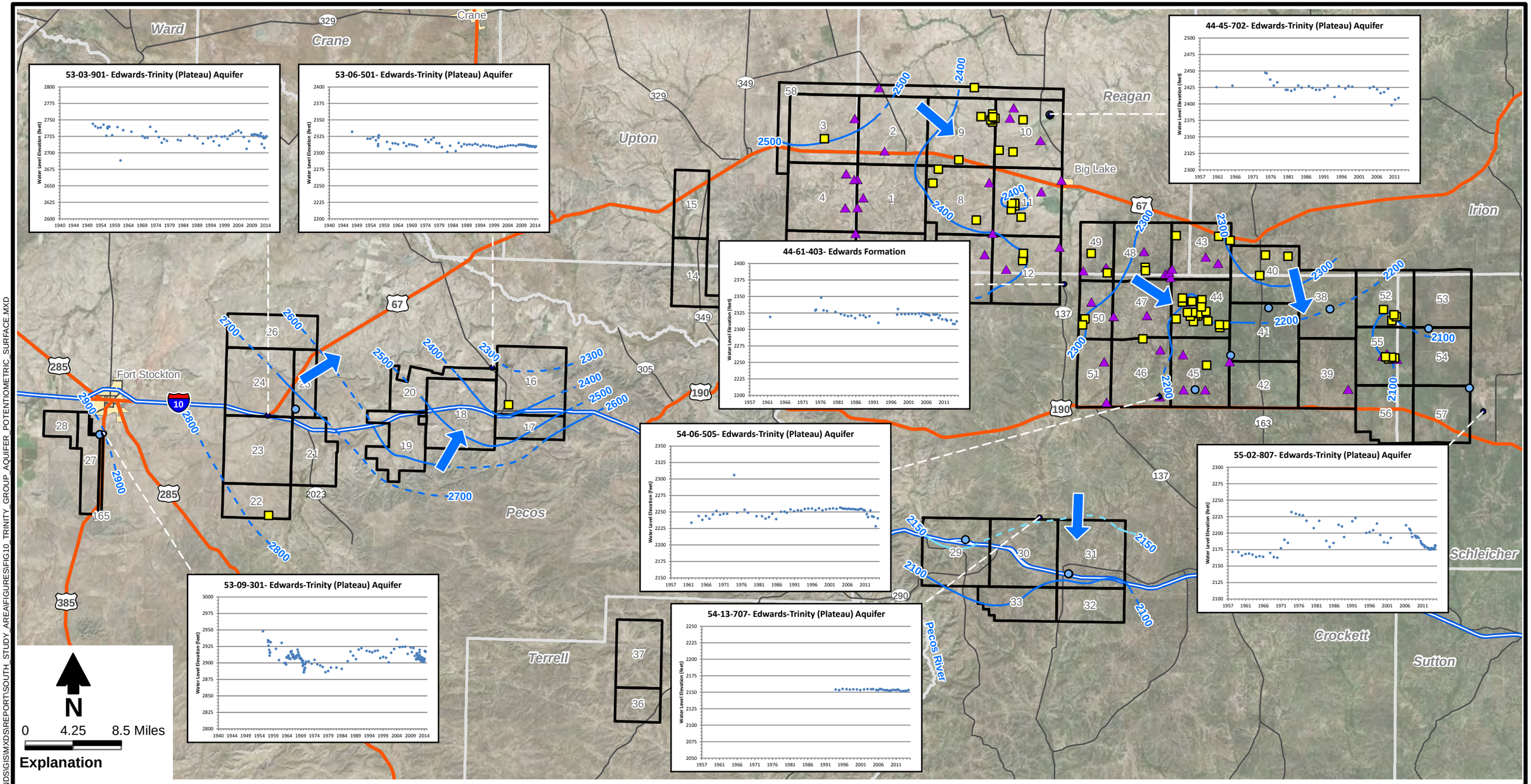
Wells Completed in the Edwards-Trinity (Plateau) Aquifer

Figure 9

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG10_TRINITY_GROUP_AQUIFER_POTENTIOMETRIC_SURFACE.MXD



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Trinity Group Potentiometric Surface

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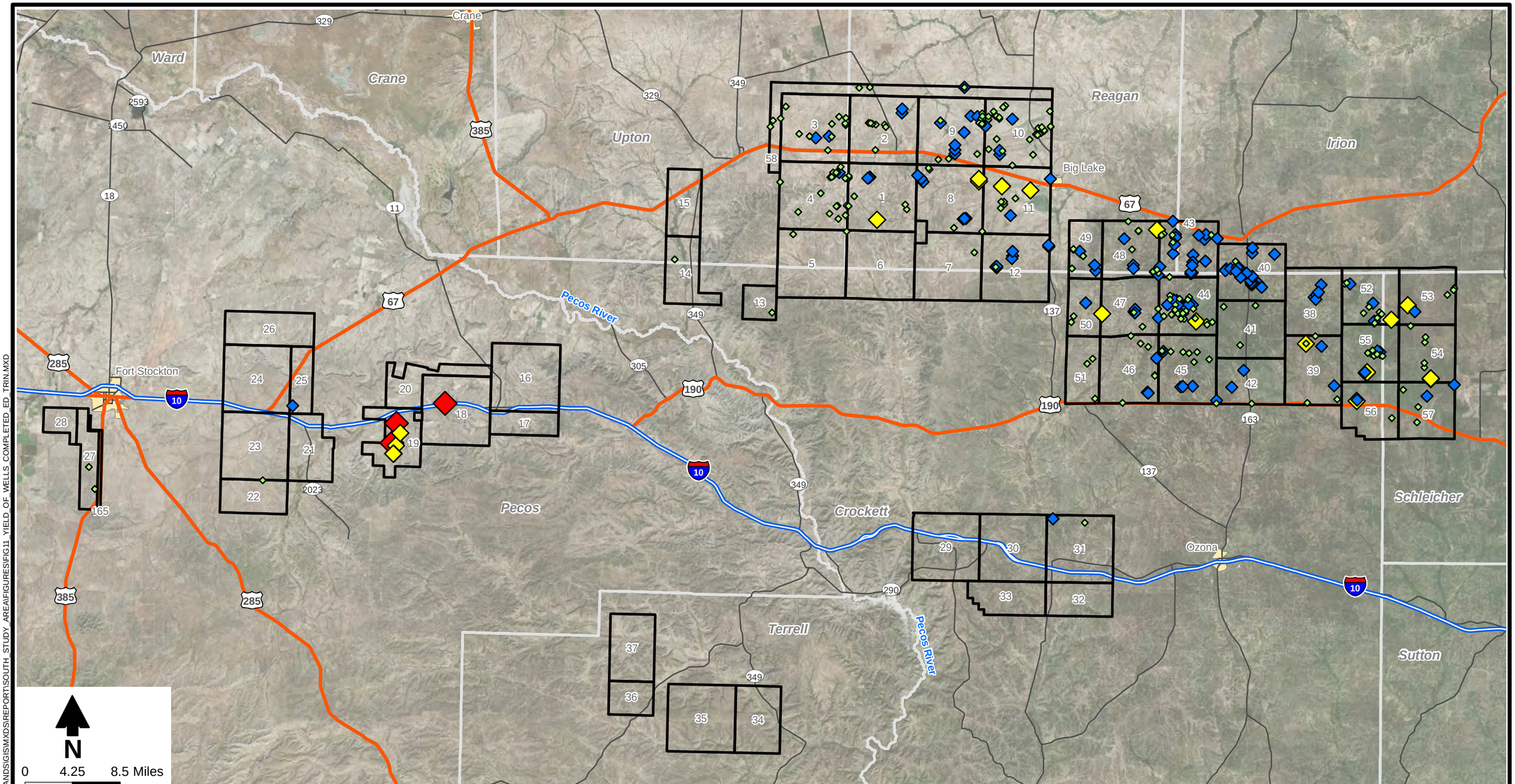
Figure 10



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Yield of Wells Completed in the Edwards-Trinity (Plateau) Aquifer

Figure 11

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG11_YIELD_OF_WELLS_COMPLETED_ED_TRIN.MXD

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG12_TOTAL_SAND_INTERVAL_THICKNESS_TRINITY.MXD

Ward
Crane
Upton
Reagan
Irion
Crockett
Pecos
Terrell
Schleicher
Sutton
Fort Stockton
Big Lake
Ozona
Pecos River

N

0 4.25 8.5 Miles

Explanation

- Eastern extent of undifferentiated Permian evaporites
- Eastern extent of Dockum Group
- University Lands and block number
- Urban area
- County

Total sand interval thickness (feet)

- 10 - 25
- 26 - 50
- 51 - 100
- > 100

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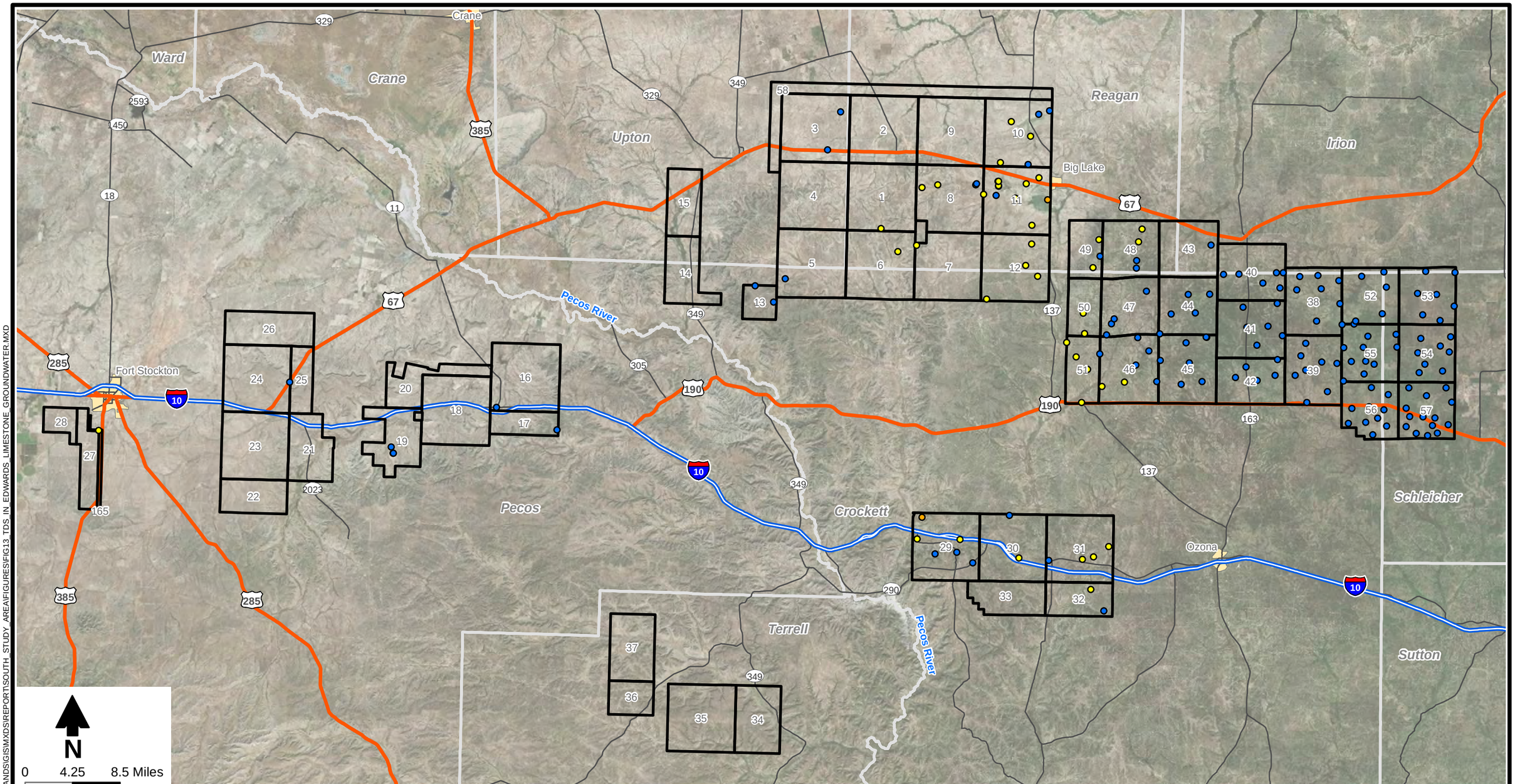
Total Sand Interval Thickness for the Trinity Group

Figure 12



N

0 4.25 8.5 Miles

Explanation

- University Lands and block number
- Urban area
- County

TDS in groundwater (mg/L)

- 0 - 1,000
- 1,001 - 3,000
- 3,001 - 10,000
- > 10,000

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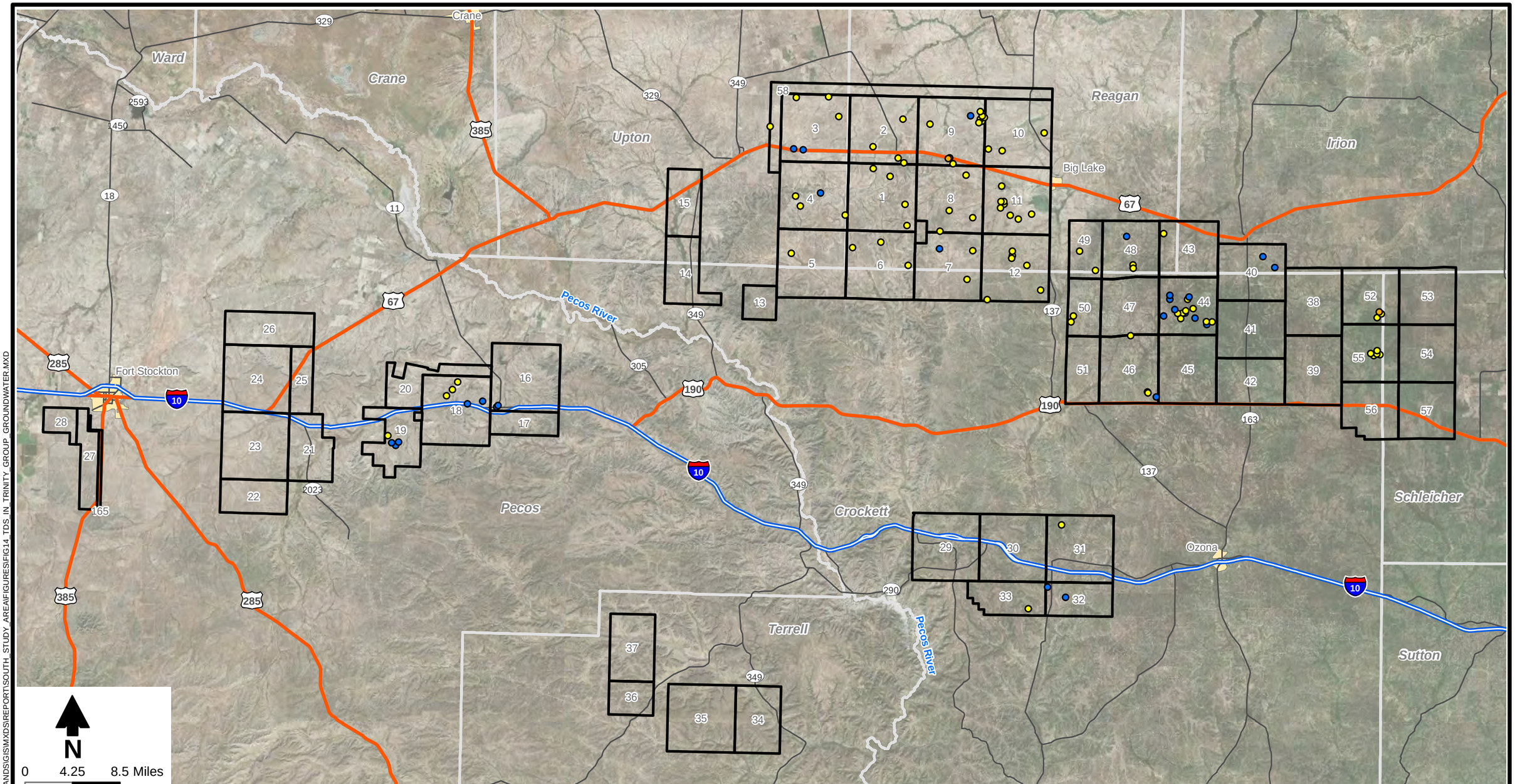
TDS in Edwards Limestones Groundwater

Figure 13

S:\PROJECTS\WR14.0154 UNIVERSITY LANDS\GIS\MXDS\REPORT\SOUTH STUDY AREA\FIGURES\FIG13 TDS IN EDWARDS LIMESTONE GROUNDWATER.MXD



S:\PROJECTS\WR14.0154 UNIVERSITY LANDS\GIS\MXDS\REPORT\SOUTH STUDY AREA\FIGURES\FIG14 TDS IN TRINITY GROUP GROUNDWATER.MXD

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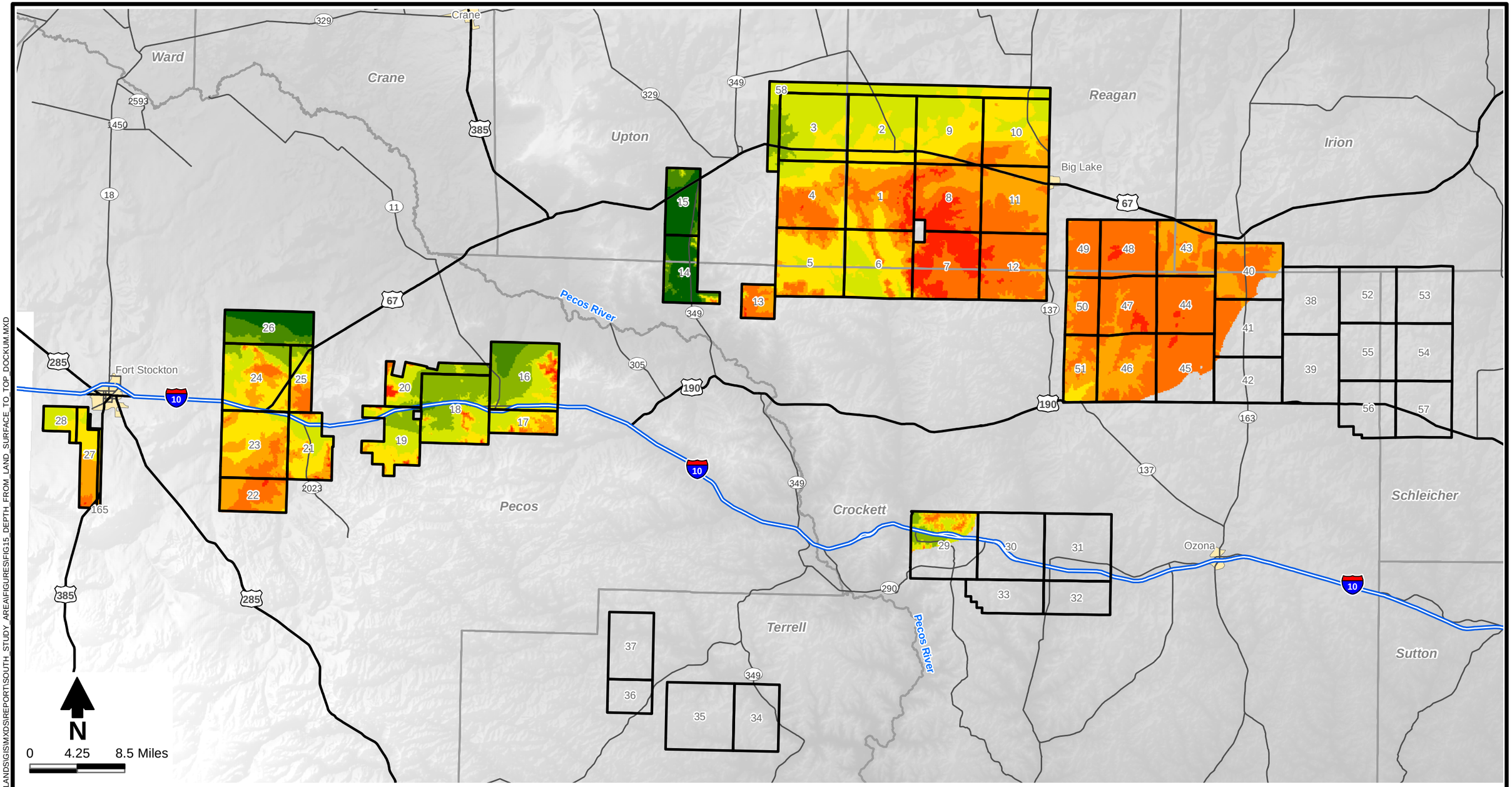
TDS in Trinity Group Groundwater

Figure 14



S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG15_DEPTH_FROM_LAND_SURFACE_TO_TOP_DOCKUM.MXD

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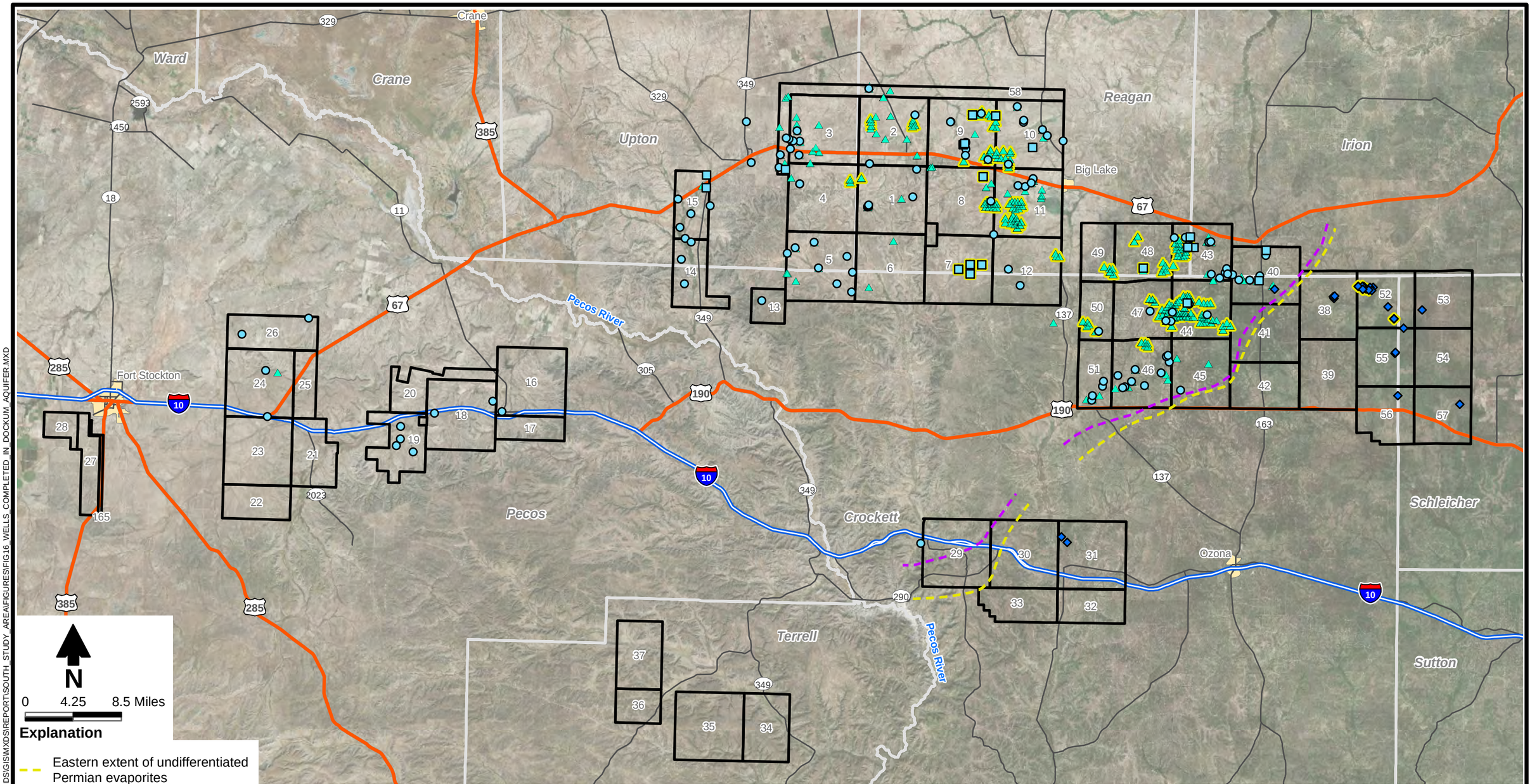
Depth from Land Surface to Top of Dockum Group

Figure 15

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG16_WELLS_COMPLETED_IN_DOCKUM_AQUIFER.MXD



Explanation

- Eastern extent of undifferentiated Permian evaporites
- Eastern extent of Dockum Group
- University Lands and block number
- Urban area
- County
- Well completed in Dockum Group based on screen interval
- Well completed in Dockum Group based on well depth
- Well completed in Dockum and Trinity Group based on screen interval
- Well completed in Artesia Group based on screen interval
- Well completed according to University Lands Groundwater Management Plan (2013)

Note: 1. Aquifer designations based on stratigraphic interpretation provided in this report.
2. Dockum Group well determined from well depth may also be completed in Trinity Group.

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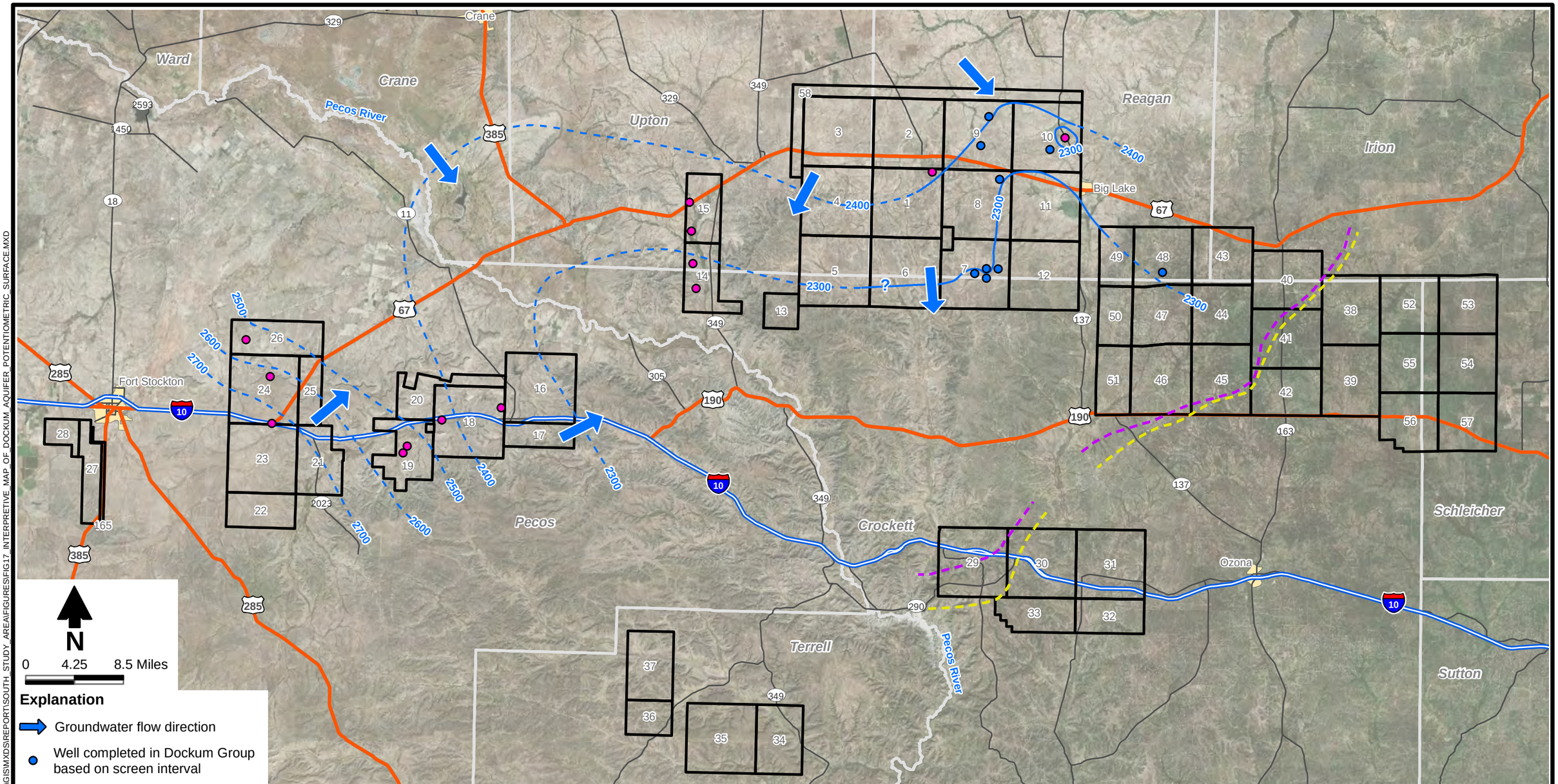
Wells Completed in the Dockum Aquifer and Artesia Group

Figure 16



Note: 1. Aquifer designations based on stratigraphic interpretation provided in this report.
2. Dockum Group well determined from well depth may also be completed in Trinity Group.

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG17_INTERPRETIVE_MAP_OF_DOCKUM_AQUIFER_POTENTIOMETRIC_SURFACE.MXD

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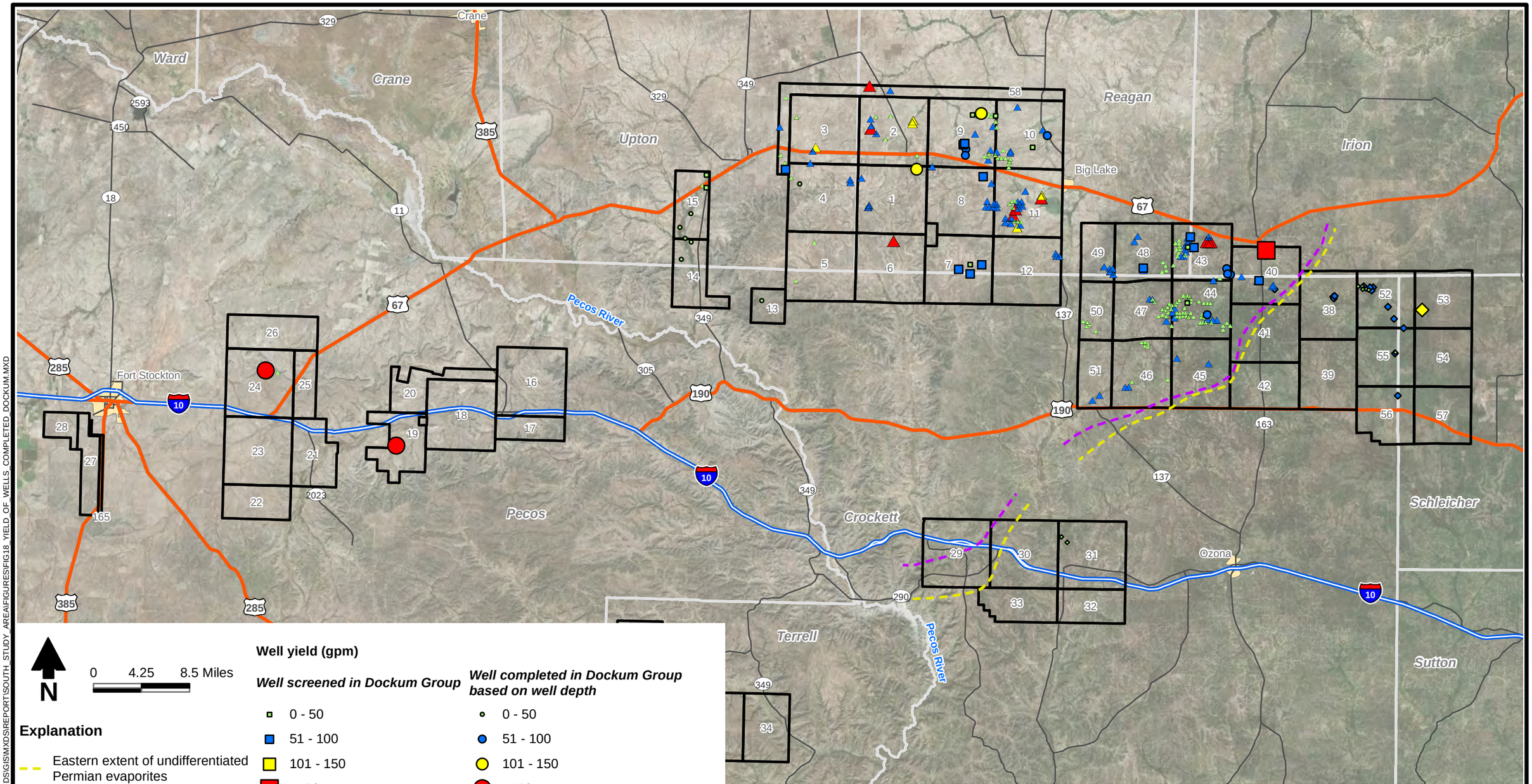
Interpretive Map of Dockum Aquifer Potentiometric Surface

Figure 17



Note: 1. Aquifer designations based on stratigraphic interpretation provided in this report.
2. Dockum Group well determined from well depth may also be completed in Trinity Group.

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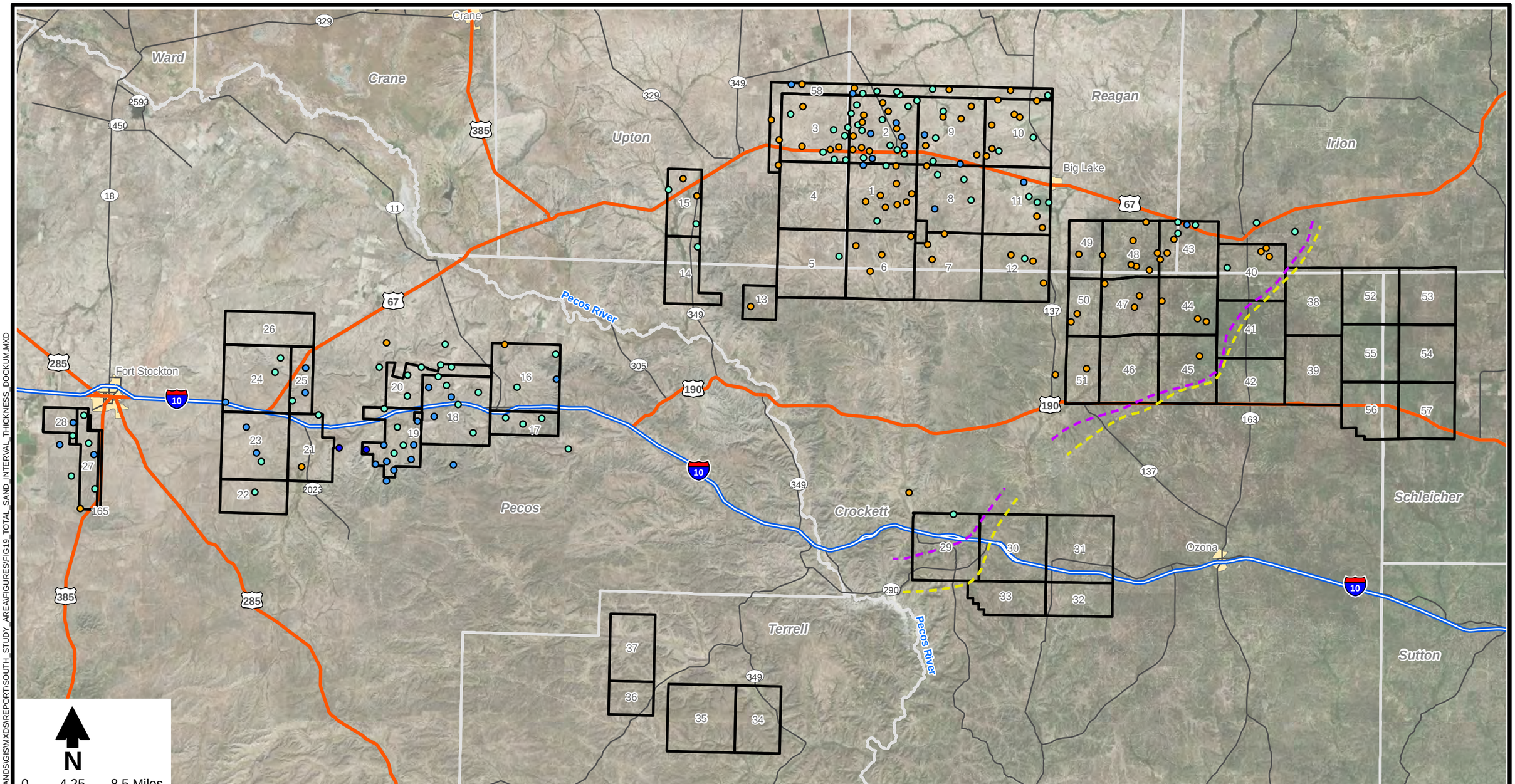
Yield of Wells Completed in the Dockum Aquifer and Artesia Group

Figure 18



Explanation

- Eastern extent of undifferentiated Permian evaporites
- Eastern extent of Dockum Group
- University Lands and block number
- Urban area
- County

Total sand interval thickness (feet)

- 10 - 25
- 26 - 50
- 51 - 100
- >100

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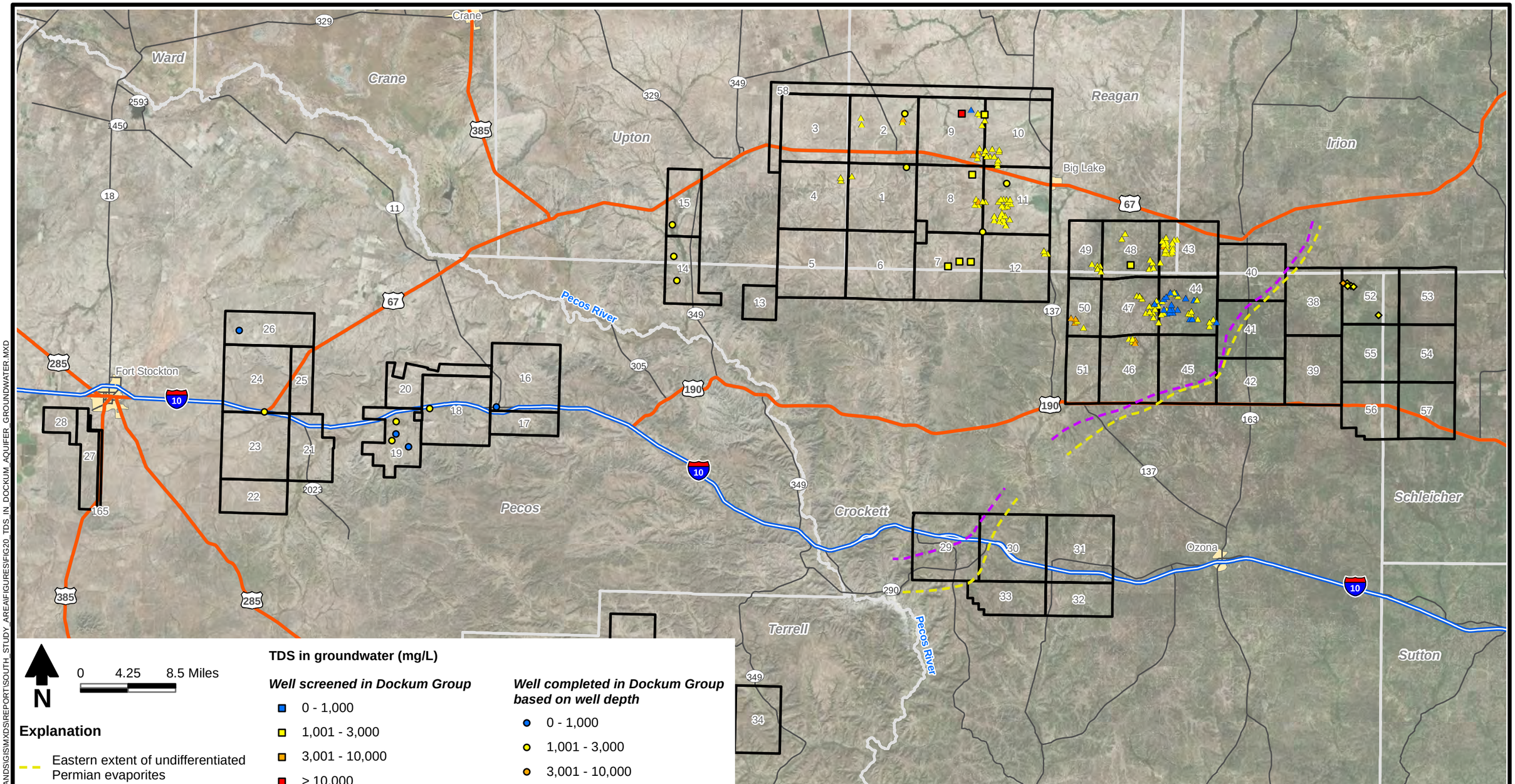
Total Sand Interval Thickness for the Dockum Aquifer

Figure 19

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG19_TOTAL_SAND_INTERVAL_THICKNESS_DOCKUM.MXD

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\FIGURES\FIG20_TDS_IN_DOCKUM_AQUIFER_GROUNDWATER.MXD



0 4.25 8.5 Miles

N

Explanation

- Eastern extent of undifferentiated Permian evaporites
- Eastern extent of Dockum Group
- University Lands and block number
- Urban area
- County

TDS in groundwater (mg/L)

Well screened in Dockum Group

- 0 - 1,000
- 1,001 - 3,000
- 3,001 - 10,000
- > 10,000

Well screened in Dockum Group and Trinity Group

- 0 - 1,000
- 1,001 - 3,000
- 3,001 - 10,000
- > 10,000

Well completed in Dockum Group based on well depth

- 0 - 1,000
- 1,001 - 3,000
- 3,001 - 10,000
- > 10,000

Well screened in Artesia Group

- 0 - 1,000
- 1,001 - 3,000
- 3,001 - 10,000
- > 10,000

Note: 1. Aquifer designations based on stratigraphic interpretation provided in this report.
2. Dockum Group well determined from well depth may also be completed in Trinity Group.

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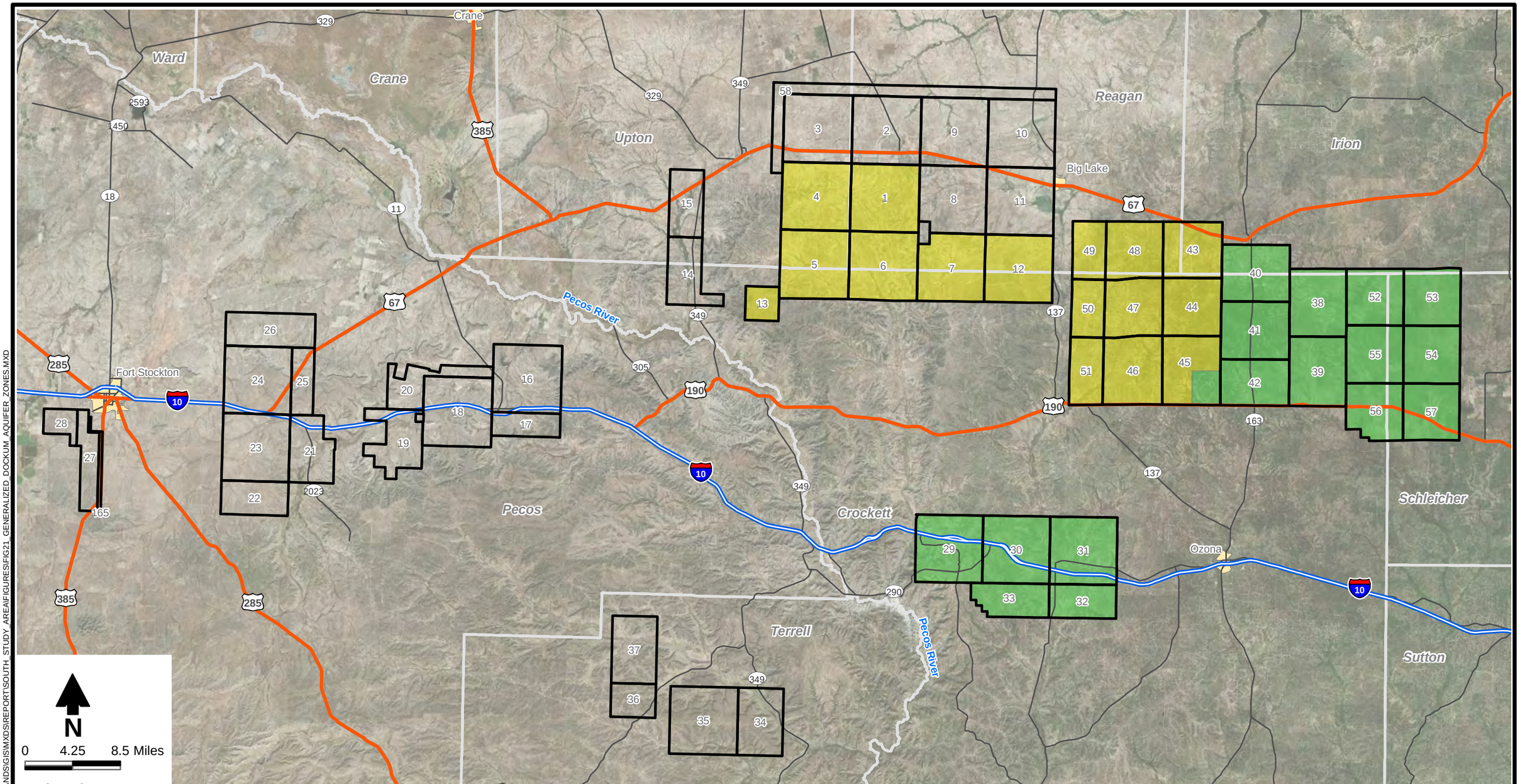
TDS of Dockum Aquifer and Artesia Group Groundwater

Figure 20



S:\PROJECTS\WR14.0154 UNIVERSITY LANDS\GIS\MXDS\REPORT\SOUTH STUDY AREA\FIGURES\FIG21 GENERALIZED DOCKUM AQUIFER ZONES.MXD

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Generalized Dockum Aquifer Zones

Figure 21

Tables

Table 1. Summary of Water Well Aquifer Designations

Aquifer/Formation Designation	Number of Wells
Edwards limestones	448
Trinity Group	410
Edwards limestones and Trinity Group combined	306
Dockum Group (Santa Rosa)	148
Dockum Group (Santa Rosa) and Trinity Group combined	262
Edwards, Trinity, and Dockum (Santa Rosa) combined	31
Permian/Artesia Group	23
Unknown due to lack of well attribute data	676
Total	2,304

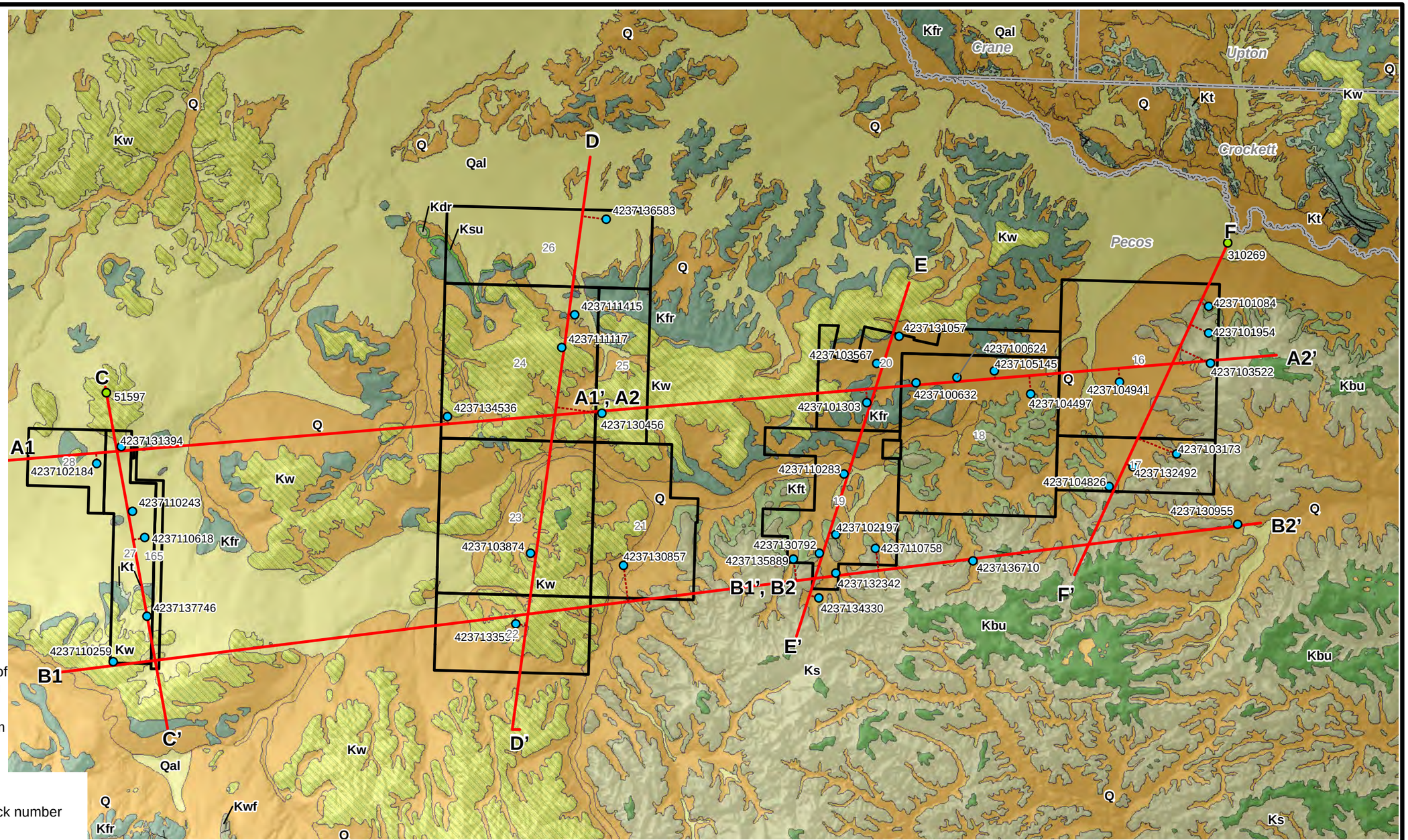
Table 2. Estimated Volume of Groundwater Beneath University Lands

Area	Groundwater Volume (acre-feet)			
	Trinity Group (Lower Portion of Edwards-Trinity Aquifer) [a]	Dockum Aquifer (Santa Rosa Formation) [b]	Artesia Group (potential aquifer unit) [c]	Total
Pecos County Area	1,130,000	422,000	73,600	1,625,600
Five-County Area	4,080,000	1,820,000	293,320	6,193,320
Central Crockett County	370,000	9,000	28,880	407,880
Total	5,580,000	2,251,000	395,800	8,226,800

[a] Assumed effective porosity of 0.05; unit assumed to be saturated at all locations.
[b] Assumed effective porosity of 0.02.
[c] Assumed that 40% of Artesia Group sediments might produce water to a well, and effective porosity of 0.001.

Appendix A

Geologic Cross Sections and Unit Thickness Maps for Pecos County Area



Explanation

- Well (Texas Department of Licensing and Regulation [TDLR] tracking number)
- Well (American Petroleum Institute [API] well ID)
- Cross section line
- Projection line
- University Lands and block number
- County

Geology

Fault Type

- Normal
- Unspecified

- Qal - Quaternary alluvium
- Q - Quaternary deposits (undivided)
- Kbu - Buda Limestone
- Kdr - Del Rio Clay
- Kwf - Washita and Fredricksburg Groups (undivided)
- Kw - Washita Group
- Kfr - Fredericksburg Group
- Kft - Fort Terrett Formation (Fredericksburg Group)
- Ks - Segovia Formation (Fredericksburg Group)
- Ksu - Sue Peaks Formation
- Kt - Trinity Group (undivided)

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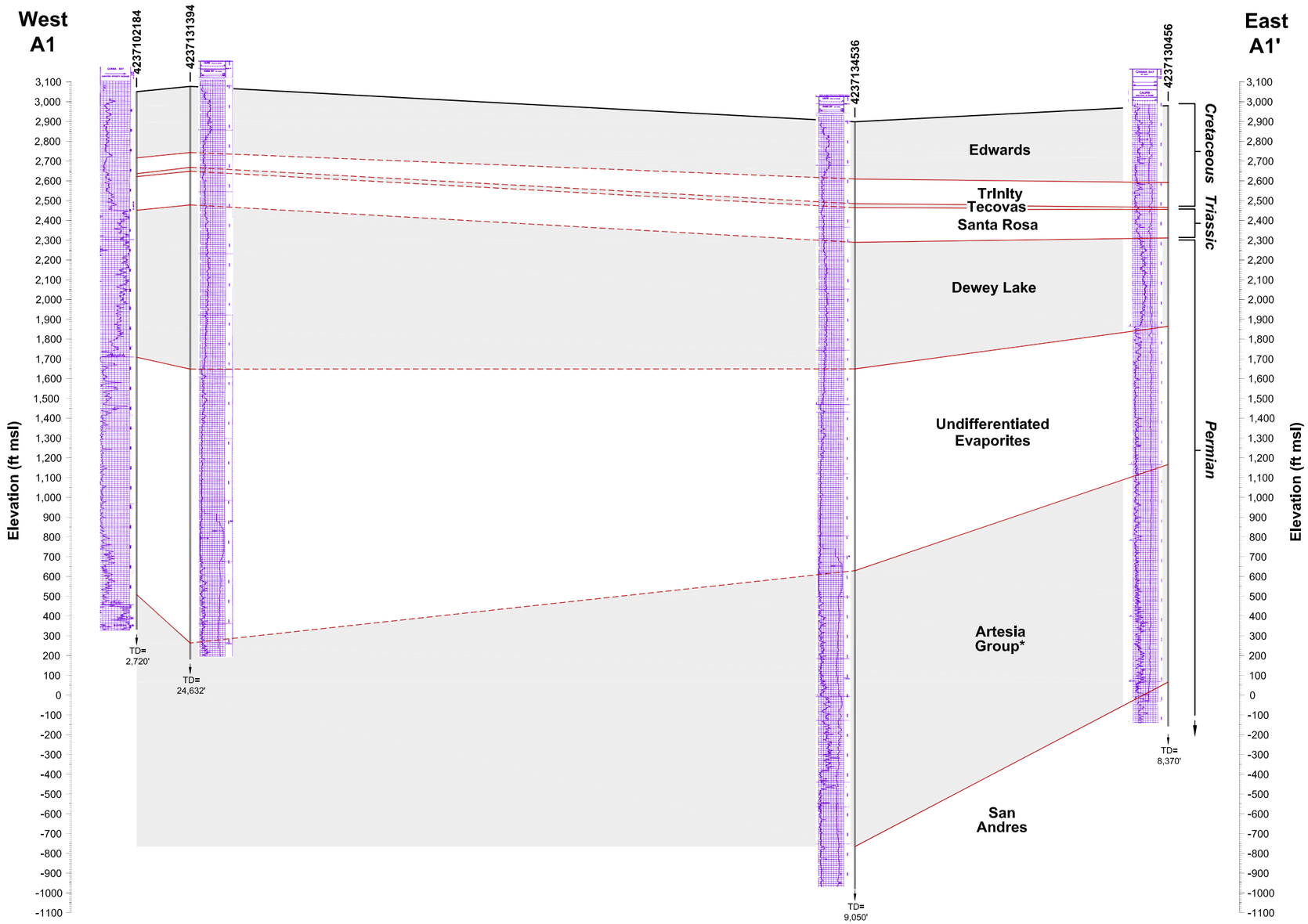
Pecos County Area Surface Geology (A1-A1’ Through F-F’)

Figure A-1

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGA-1_PECOS_COUNTY_SURFACE_GEOLOGY.MXD



0 12,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4237102184).

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West to East Geologic Cross Section A1-A1'

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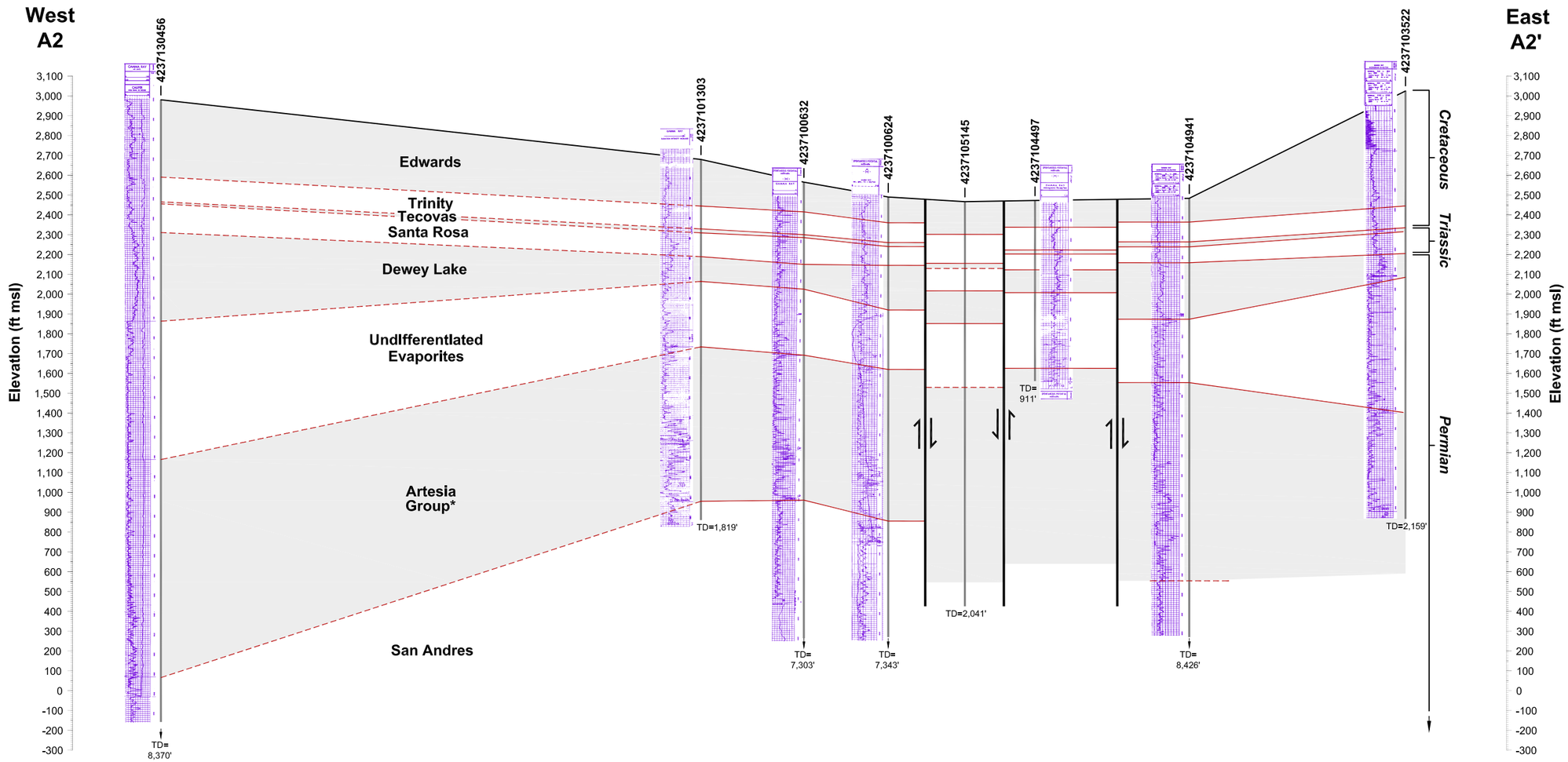
Figure A-2

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_A1-A1'_through_F-F'.dwg



0 12,000 ft

20X vertical exaggeration

Explanation

Interpreted normal fault with direction of movement indicated.

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4237130456).

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_A1-A1'_through_F-F'.dwg

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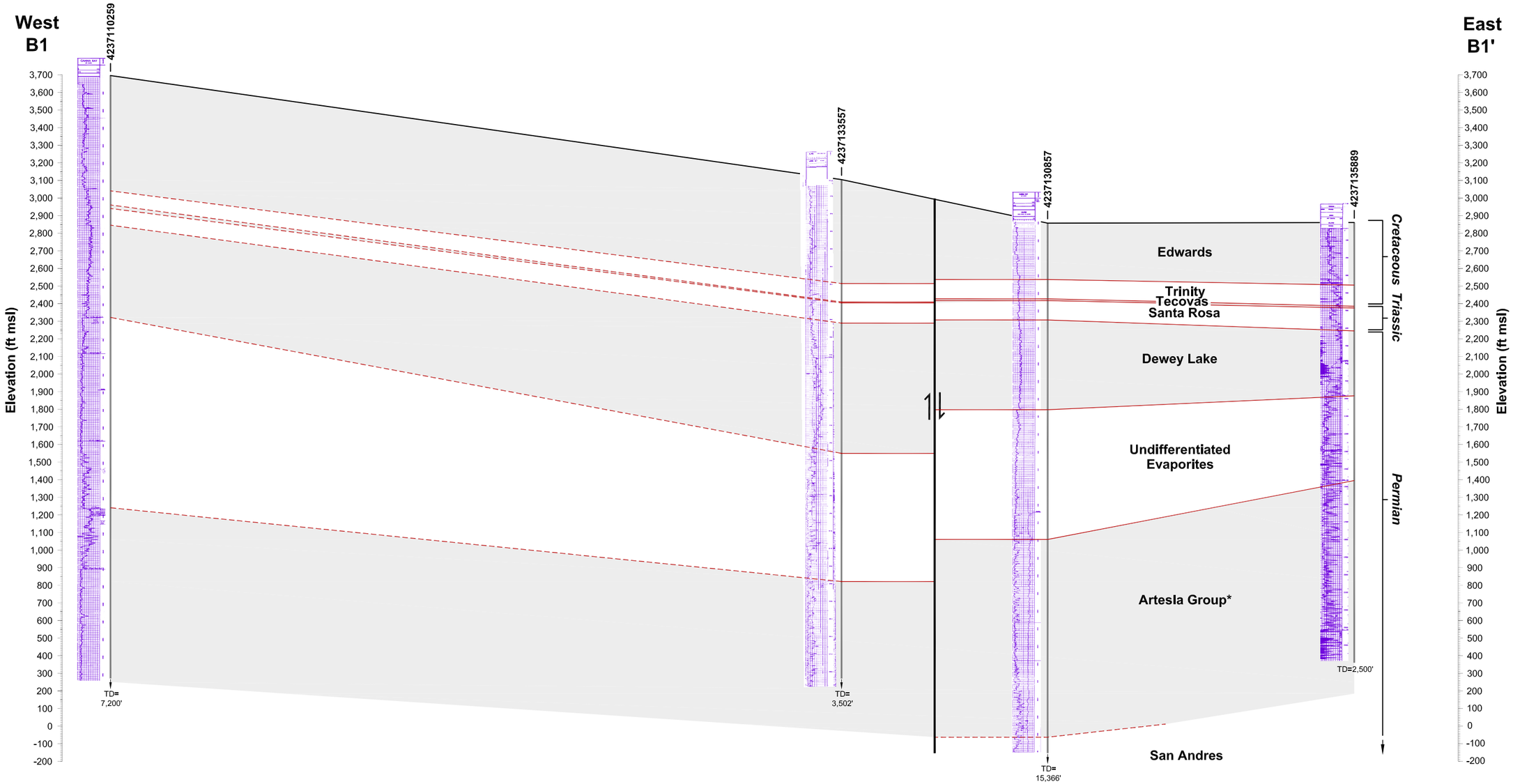
West to East Geologic Cross Section A2-A2'

Figure A-3



Explanation

Interpreted normal fault with direction of movement indicated.

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4237110259).

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_A1-A1'_through_F-F'.dwg

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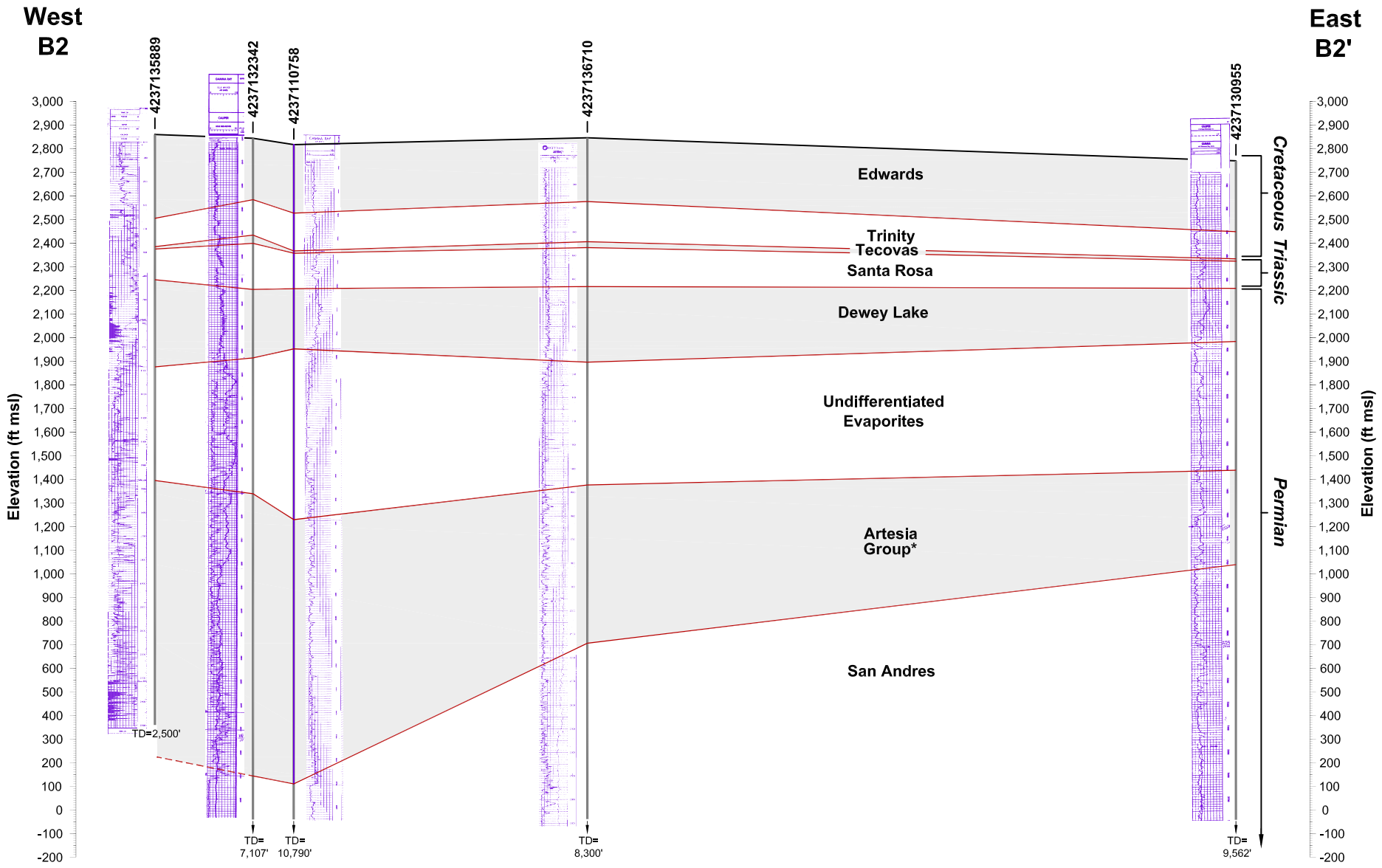
West to East Geologic Cross Section B1-B1'

Figure A-4

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_A1-A1'_through_F-F'.dwg



0 12,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4237135889).

Figure A-5

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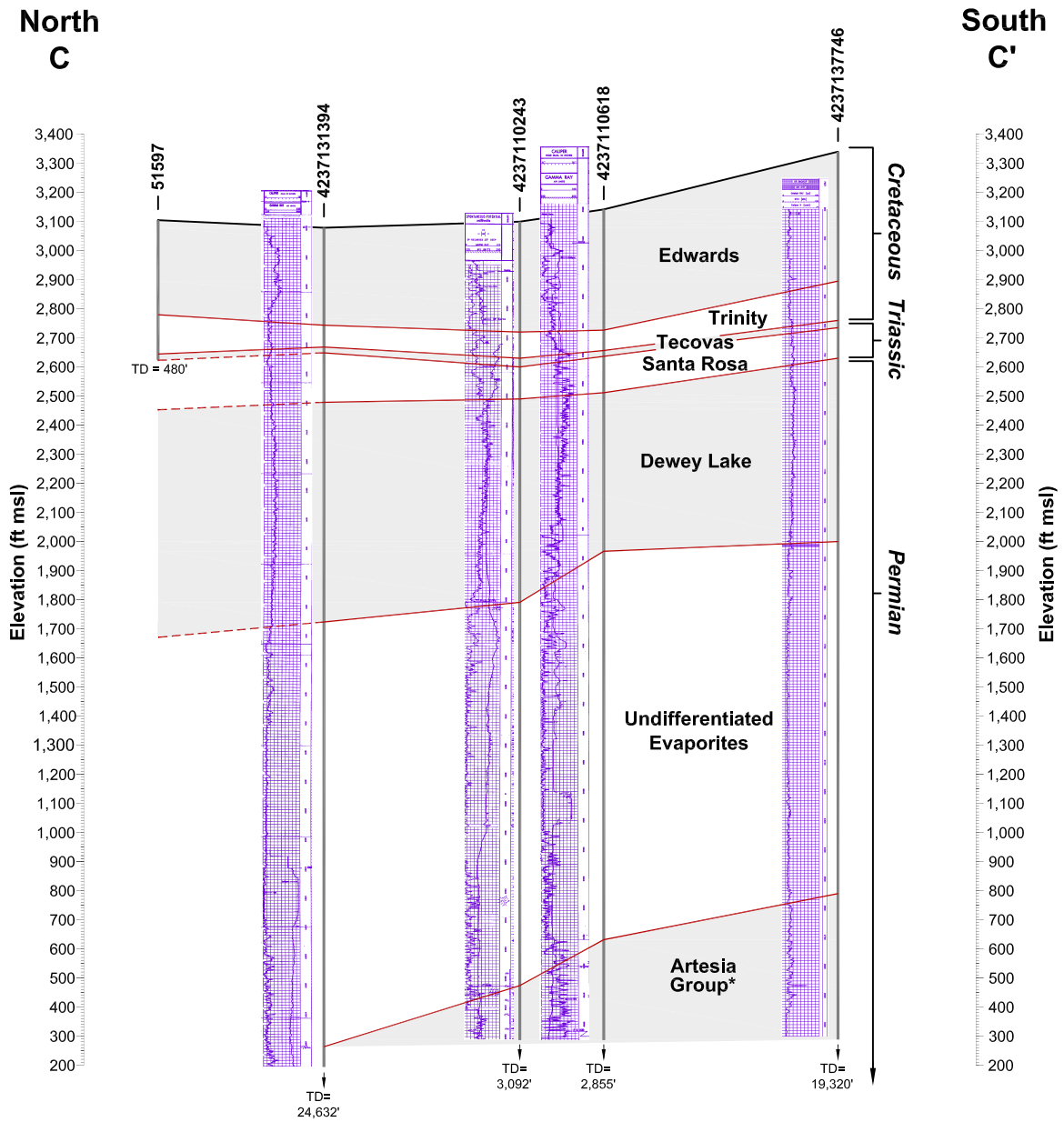
North to South Geologic Cross Section B2-B2'

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_A1-A1'_through_F-F'.dwg



Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. Well identifiers are API (e.g. 4237131394) or TDLR (e.g. 51597).

0 12,000 ft

20X vertical exaggeration

Figure A-6

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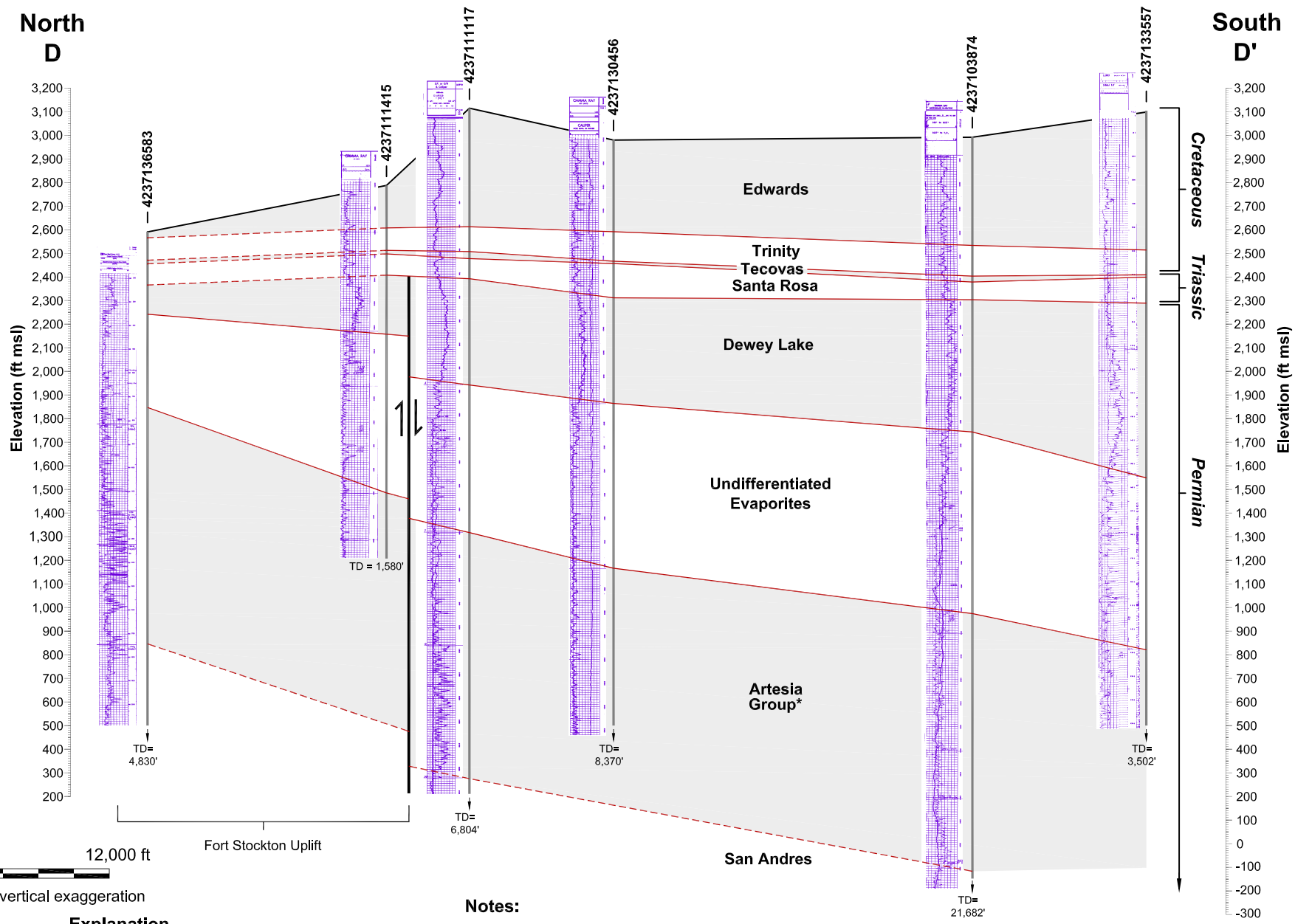
North to South Geologic Cross Section C-C'

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_A1-A1'_through_F-F'.dwg



Explanation

Interpreted normal fault with direction of movement indicated.

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4237136583).

Figure A-7

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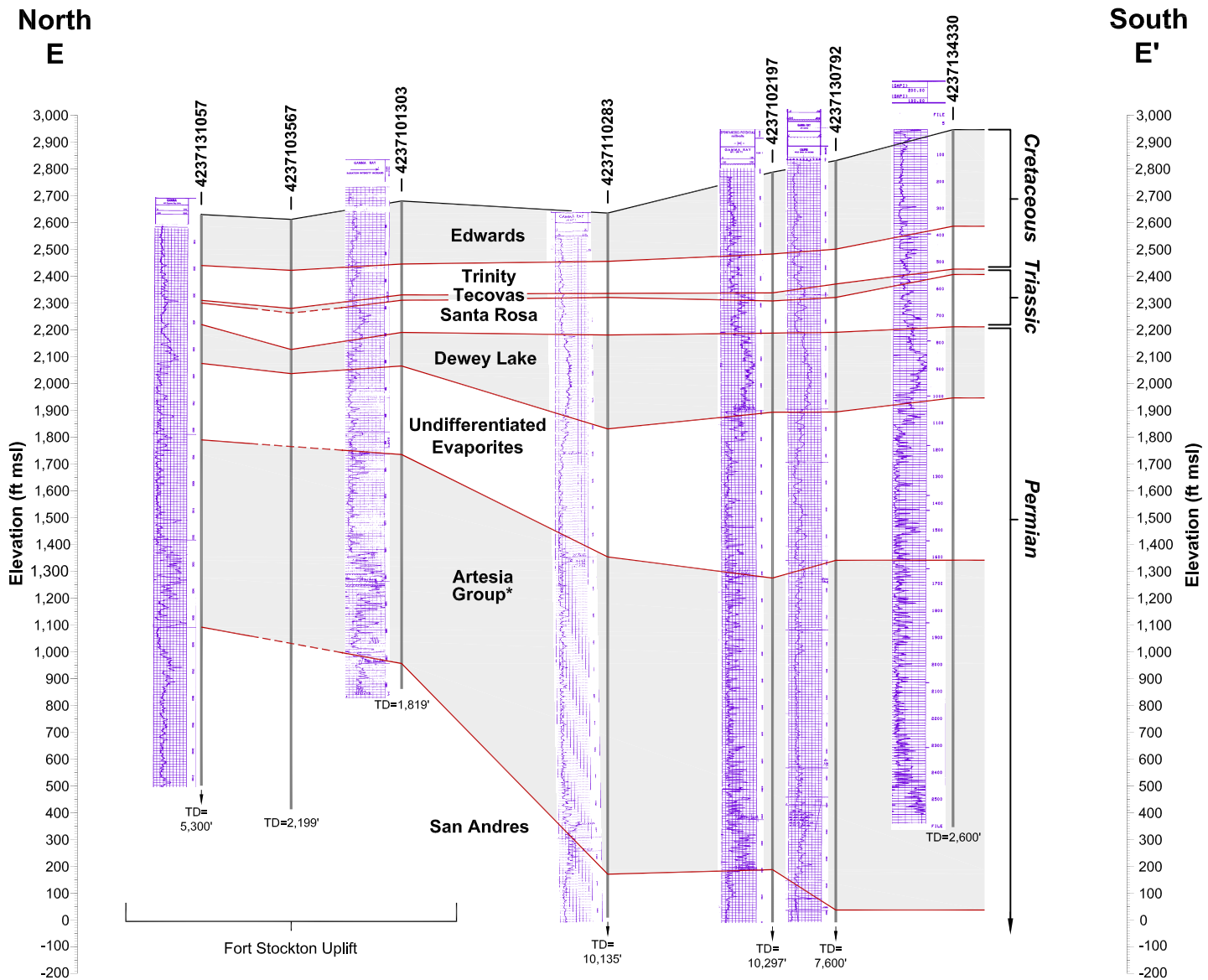
North to South Geologic Cross Section D-D'

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_A1-A1'_through_F-F'.dwg



0 12,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4237131057).

Figure A-8

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North to South Geologic Cross Section E-E'

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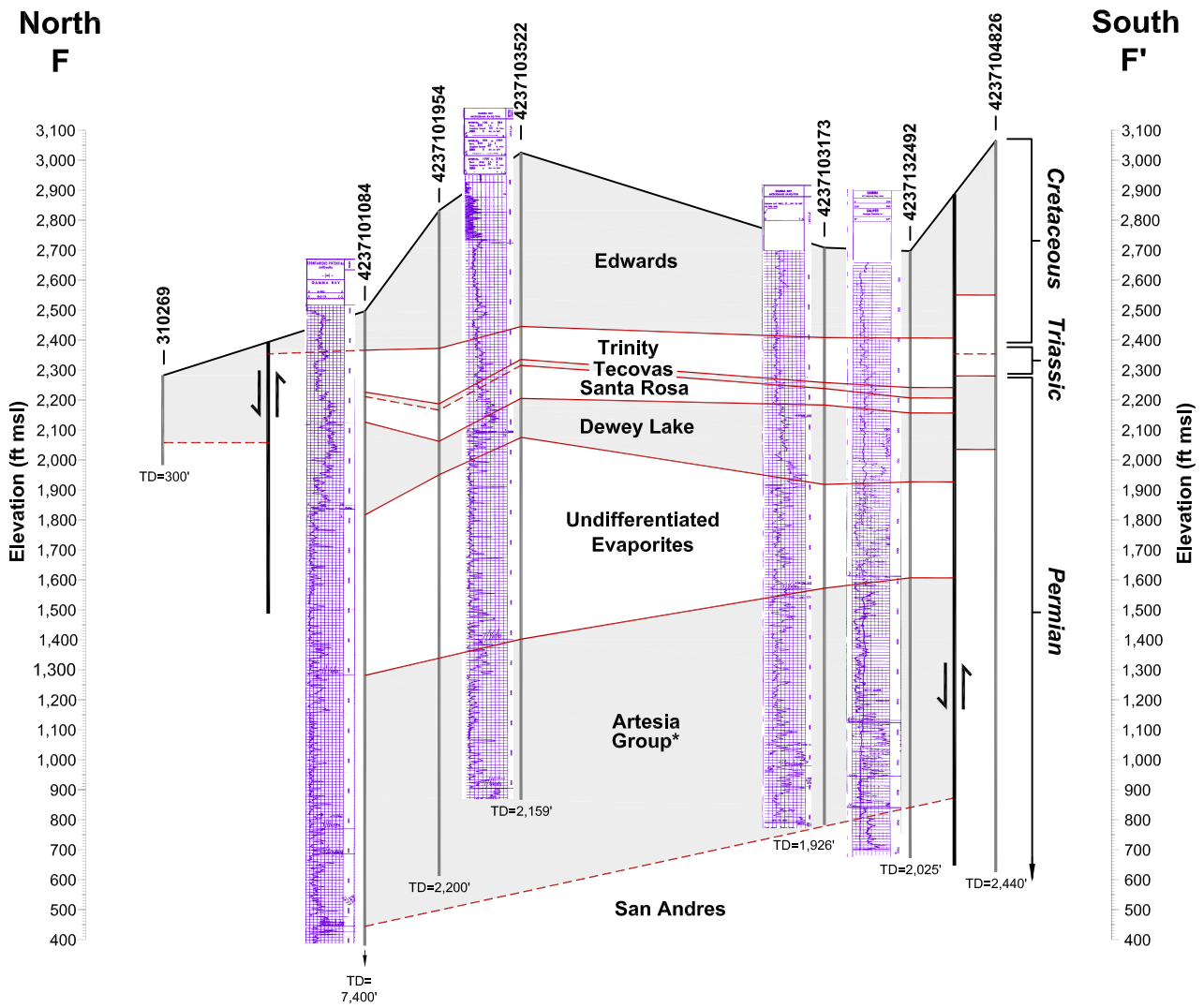
S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_A1-A1'_through_F-F'.dwg



0 12,000 ft

20X vertical exaggeration

Explanation

Interpreted normal fault with direction of movement indicated.

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. Well identifiers are API (e.g. 4237101084) or TDLR (e.g. 310269).

Figure A-9

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North to South Geologic Cross Section F-F'

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGA-10_PECOS_COUNTY_THICKNESS_EDWARDS.MXD

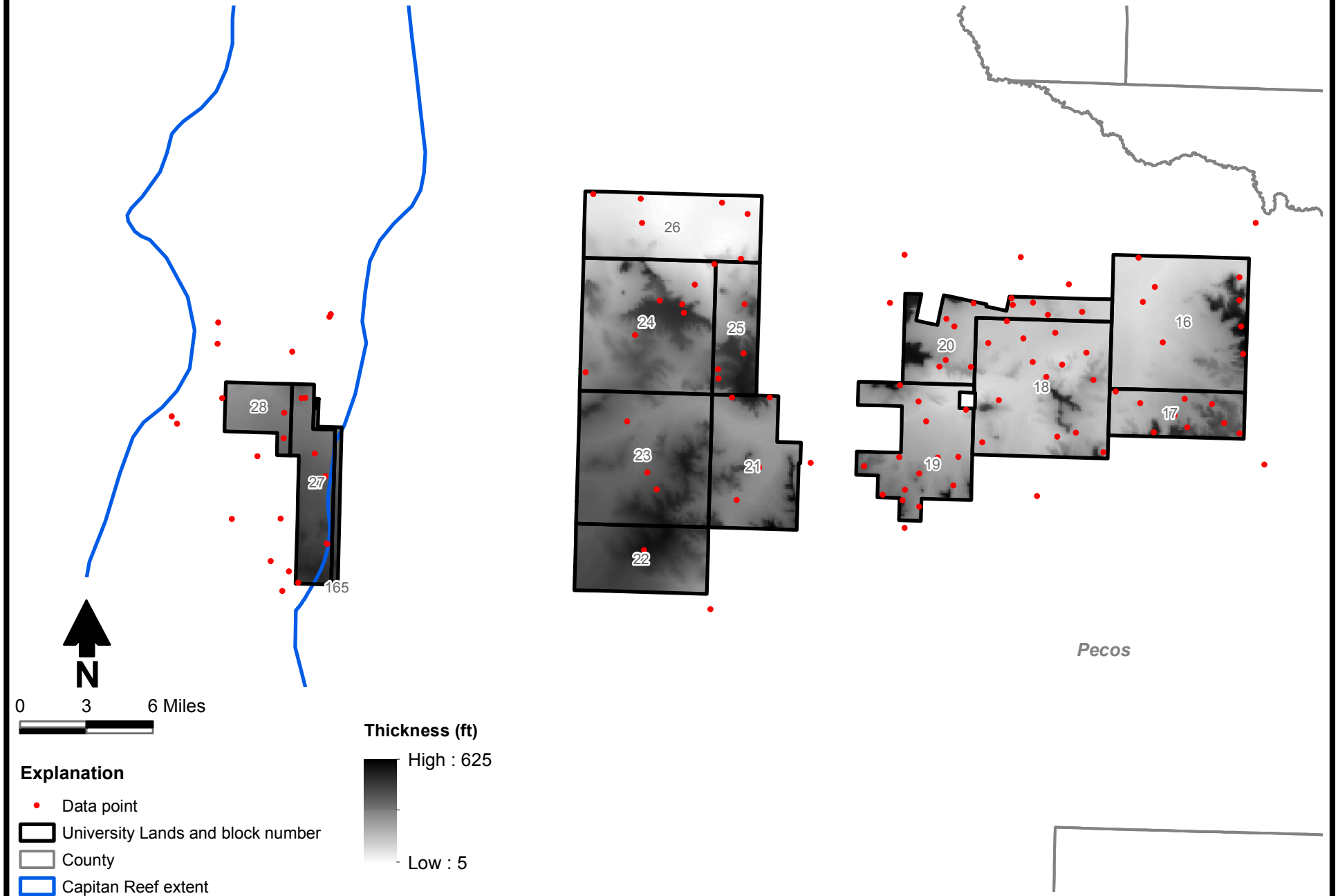

Figure A-10

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Thickness of Edwards Limestones

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGA-11_PECOS_COUNTY_THICKNESS_TRINITY.MXD

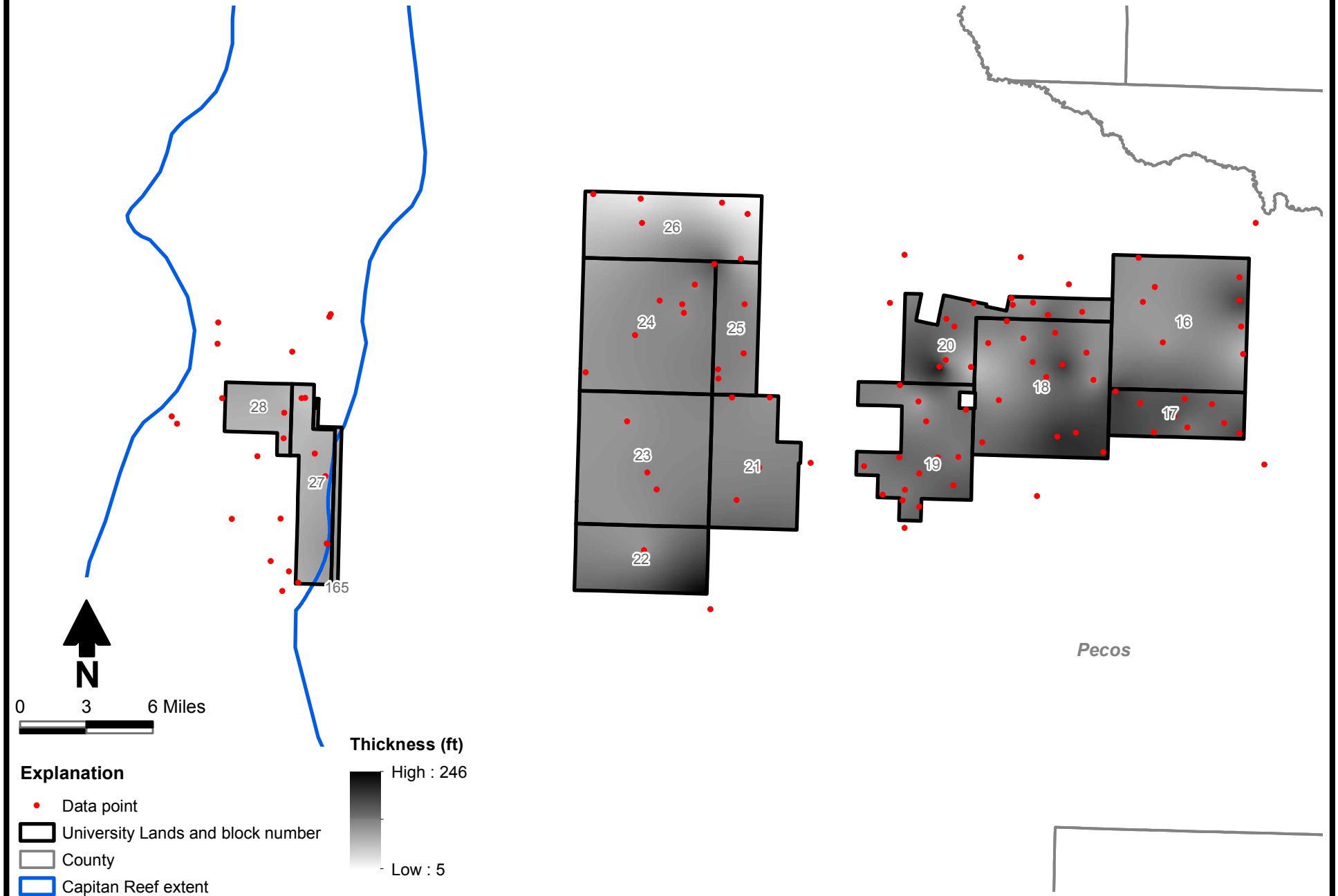

Figure A-11

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Thickness of Trinity Group

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S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGA-12_PECOS_COUNTY_THICKNESS_TECOVAS.MXD

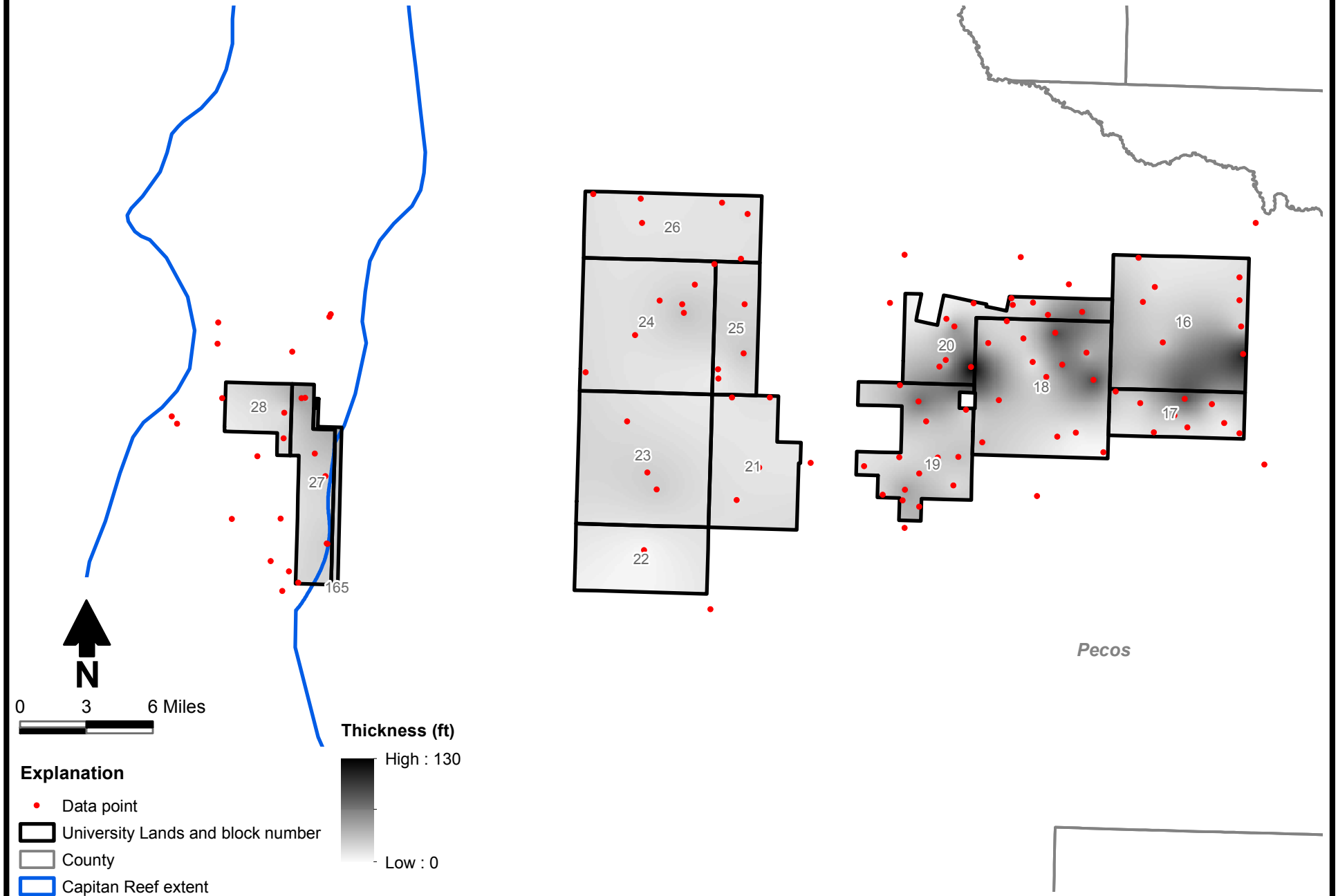

Figure A-12

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Thickness of Tecovas Formation

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S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGA-13_PECOS_COUNTY_THICKNESS_SANTAROSA.MXD

Figure A-13

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Thickness of Santa Rosa Formation

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S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGA-14_PECOS_COUNTY_THICKNESS_DEWEYLAKE.MXD

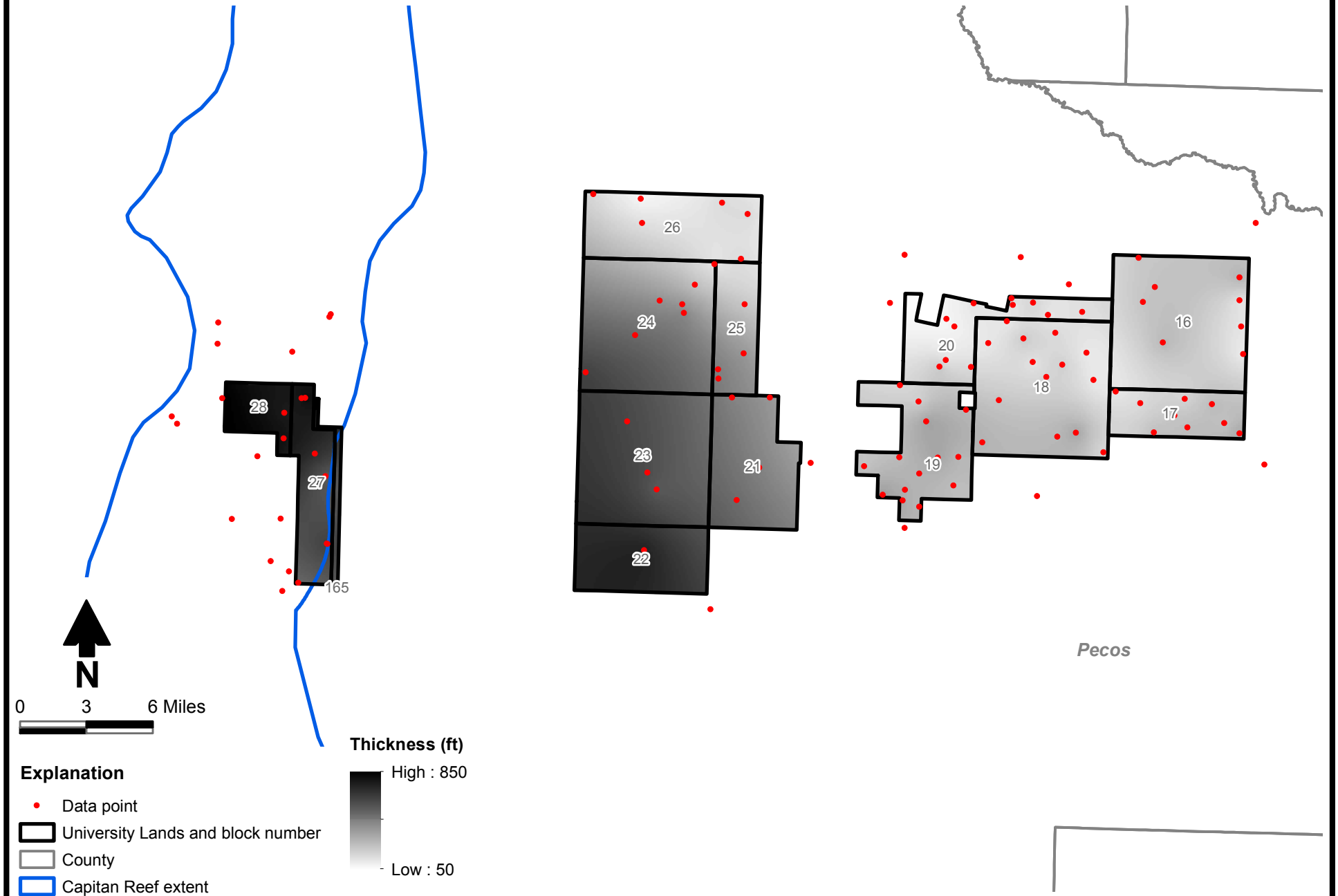

Figure A-14

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Thickness of Dewey Lake Formation

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGA-15_PECOS_COUNTY_THICKNESS_EVAPORITES.MXD

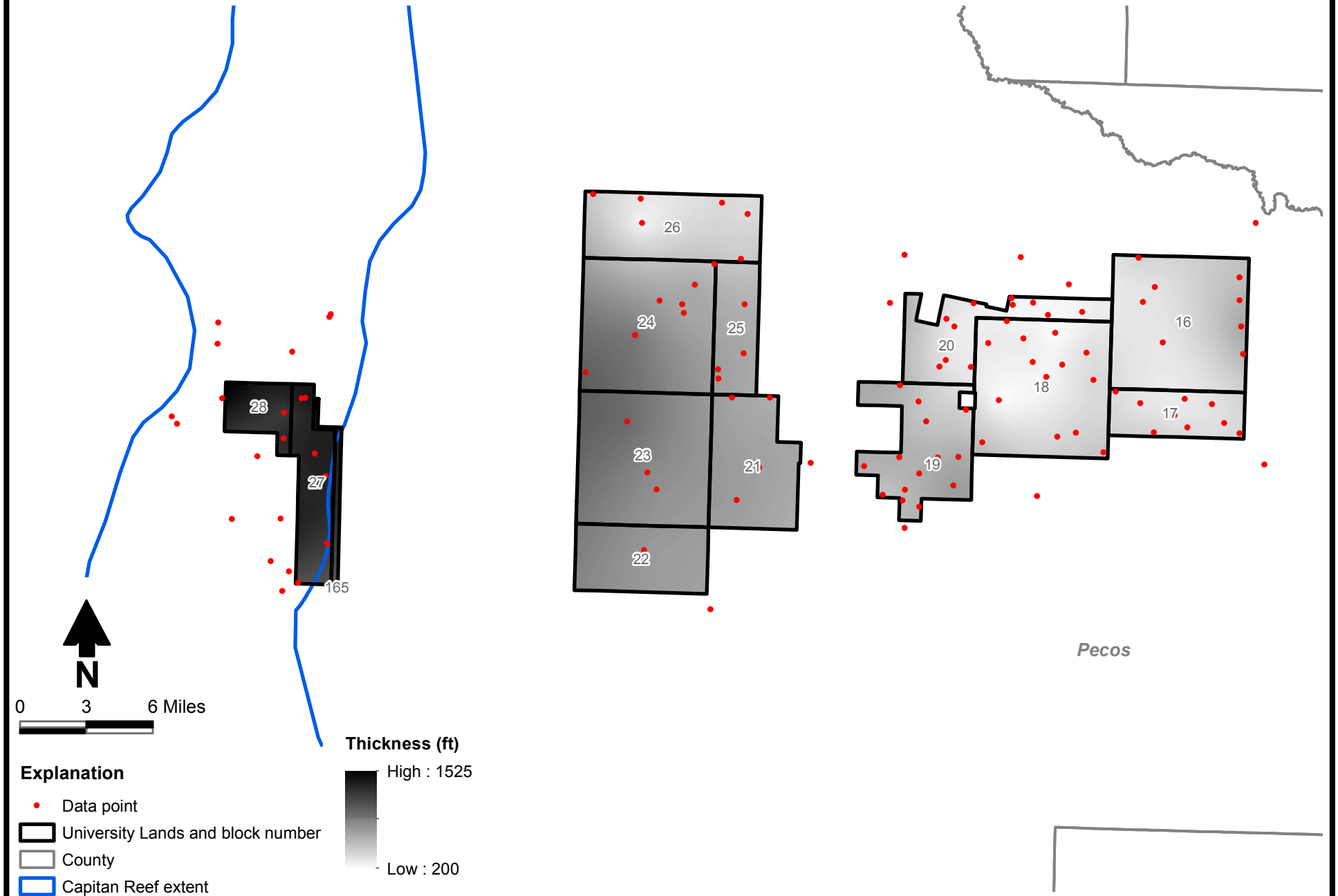

Figure A-15

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Thickness of Undifferentiated Permian Evaporites

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGA-16_PECOS_COUNTY_THICKNESS_ARTESIAGROUP.MXD

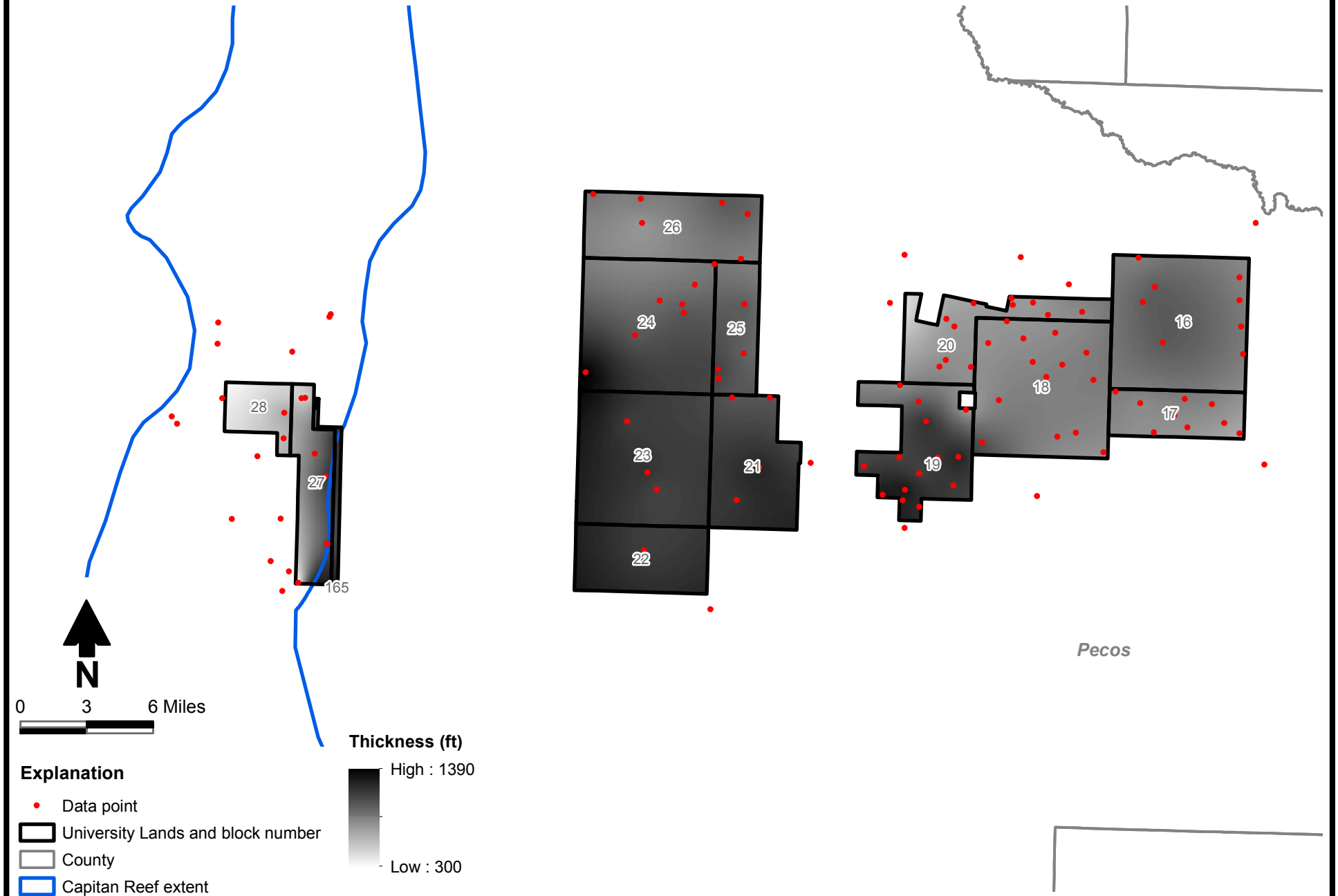

Figure A-16

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Thickness of Artesia Group

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGA-17_PECOS_COUNTY_THICKNESS_CAPITANREEF.MXD

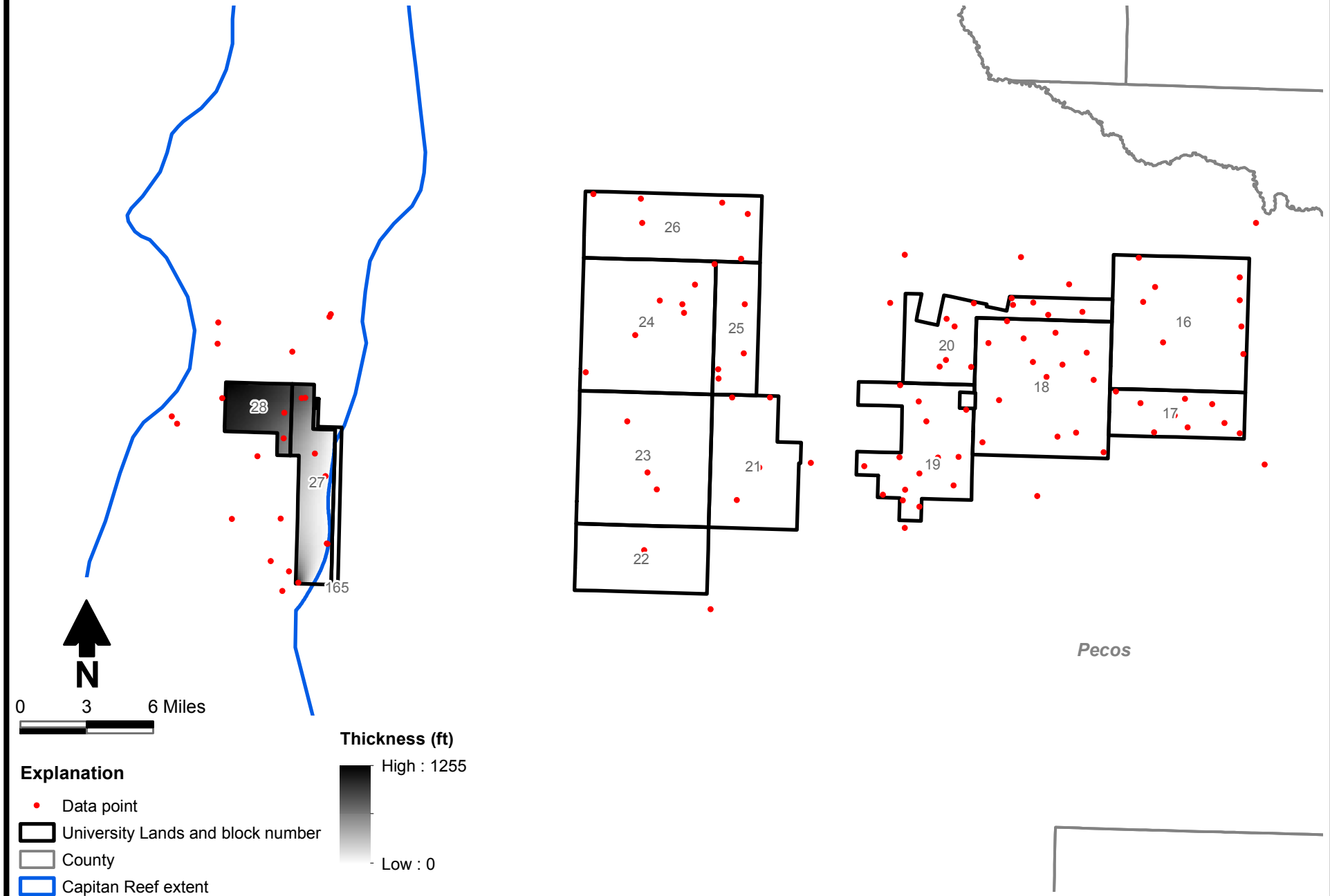

Figure A-17

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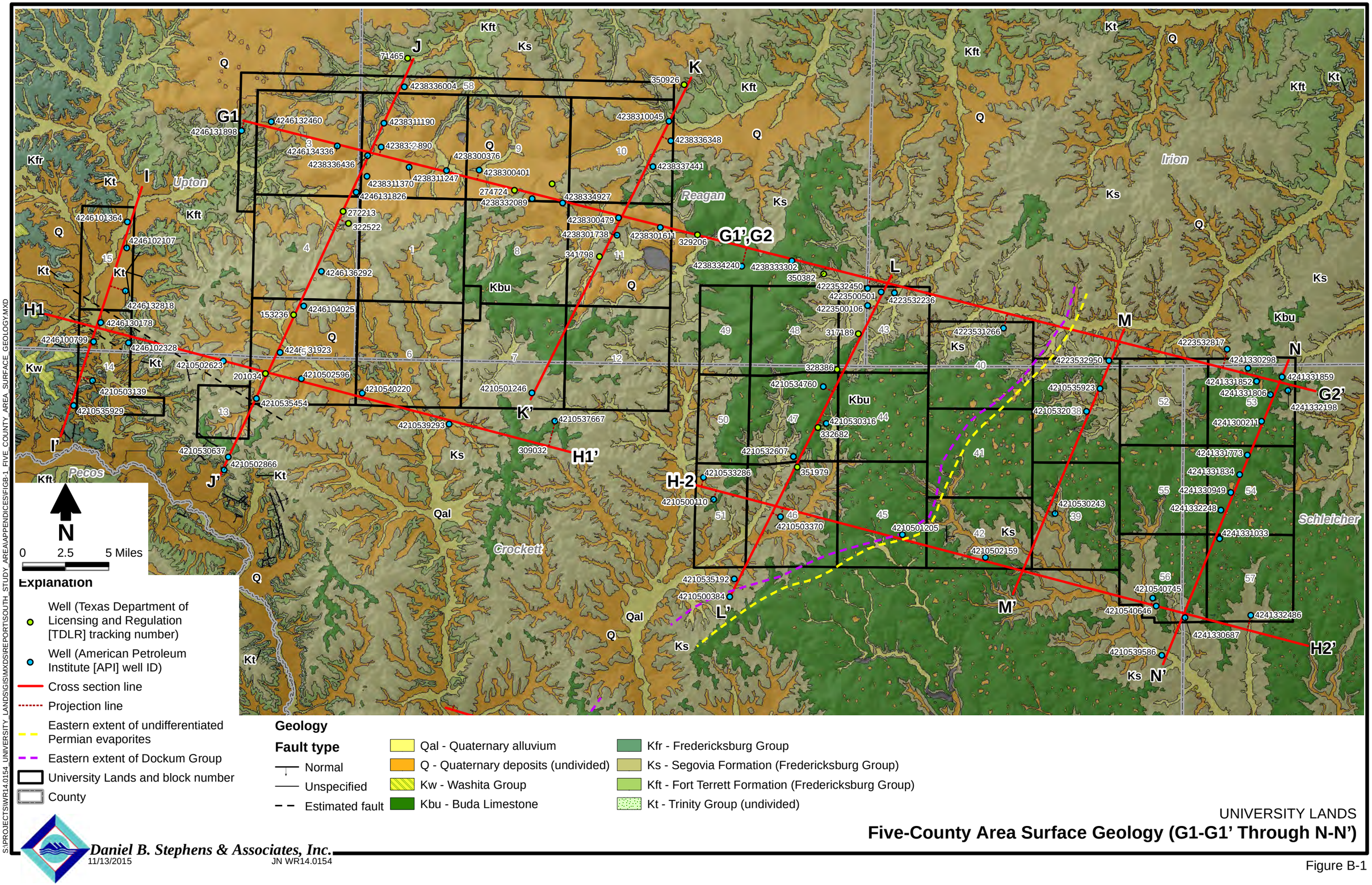
Thickness of Capitan Reef Complex

Appendix B

Geologic Cross Sections and Unit Thickness Maps for Five-County Area



S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORTS\SOUTH_STUDY_AREA\APPENDICES\FIGB-1_FIVE_COUNTY_AREA_SURFACE_GEOLOGY.MXD

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Five-County Area Surface Geology (G1-G1' Through N-N')

Figure B-1

West
G1

East
G1'

Elevation (ft msl)

Triassic Cretaceous

Permian

4246131898 | 4246132460 | 4246134336 | 4238336436 | 4238311247 | 4238300376 | 4238300401 | 274724 | 4238332089 | 4238334927 | 4238300479 | 4238301611 | 329206 | 4238334240

Edwards

Trinity
Tecovas

Santa Rosa

Dewey Lake

Undifferentiated
Evaporites

Artesia
Group*

San
Andres

TD=500'

TD=615'

TD=
12,500'

TD=
11,815'

TD=
12,086'

TD=
10,392'

TD=
6,838'

TD=
8,961'

TD=
8,408'

TD=
8,050'

TD=
12,260'

TD=
9,624'

TD=
9,624'

TD=2,650'

0 12,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. Well identifiers are API (e.g. 4246131898) or TDLR (e.g. 274724).

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West to East Geologic Cross Section G1-G1'

Figure B-2

West
G2

East
G2'

4238334240 | 4238333302 | 350382 | 4223532450 | 4223532236 | 4223531266 | 4223532950 | 4223532817 | 4241330298 | 4241331852 | 4241332198

Cretaceous

Triassic

Permian

Edwards

Trinity

Tecovas

Santa Rosa

Dewey Lake

Undifferentiated Evaporites

Artesia Group*

San Andres

TD=700'

TD=2,650'

TD=2,689'

TD=6,520'

TD=6,450'

TD=8,840'

TD=7,800'

TD=7,153'

TD=7,175'

TD=7,217'

TD=7,052'

No Dewey Lake Formation

No undifferentiated evaporites

No Dockum Group

Elevation (ft msl)

3,000 2,900 2,800 2,700 2,600 2,500 2,400 2,300 2,200 2,100 2,000 1,900 1,800 1,700 1,600 1,500 1,400 1,300 1,200 1,100 1,000 900 800 700 600 500 400 300 200 100 0 -100 -200 -300 -400 -500 -600 -700 -800 -900 -1,000 -1,100 -1,200

0 13,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. Well identifiers are API (e.g. 4238334240) or TDLR (e.g. 350382).

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West to East Geologic Cross Section G2-G2'

Figure B-3

West
H1

East
H1'

Elevation (ft msl)

4246130178
4246102328
4210502623
201034
4210502596
4210540220
4210539293
4210537667

Edwards
Trinity
Tecovas
Santa Rosa
Dewey Lake
Undifferentiated Evaporites
Artesia Group*
San Andres

Cretaceous
Triassic
Permian

TD=540'
TD=2,099'
TD= 8,655'
Trinity outcrop
TD= 11,675'
TD= 11,377'
TD= 9,450'
TD= 9,604'
TD=2,904'

0 12,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. Well identifiers are API (e.g. 4246130178) or TDLR (e.g. 201034).

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West to East Geologic Cross Section H1-H1'

Figure B-4

West
H2

East
H2'

Elevation (ft msl)

Cretaceous

Triassic

Permian

4210533286
4210500110
4210503370
4210501205
4210502159
4210540745
4210540646
4241330687
4241332486

Edwards
Trinity
Tecovas
Santa Rosa
Dewey Lake
Undifferentiated Evaporites
Artesia Group*
San Andres

TD=2,652'
TD=2,481'
TD=2,721'
TD=8,252'
TD=8,718'
TD=8,685'
TD=8,778'
TD=9,631'
TD=8,350'

No Dewey Lake Formation
No undifferentiated evaporites
No Dockum Group

0 13,000 ft
20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4210533286).

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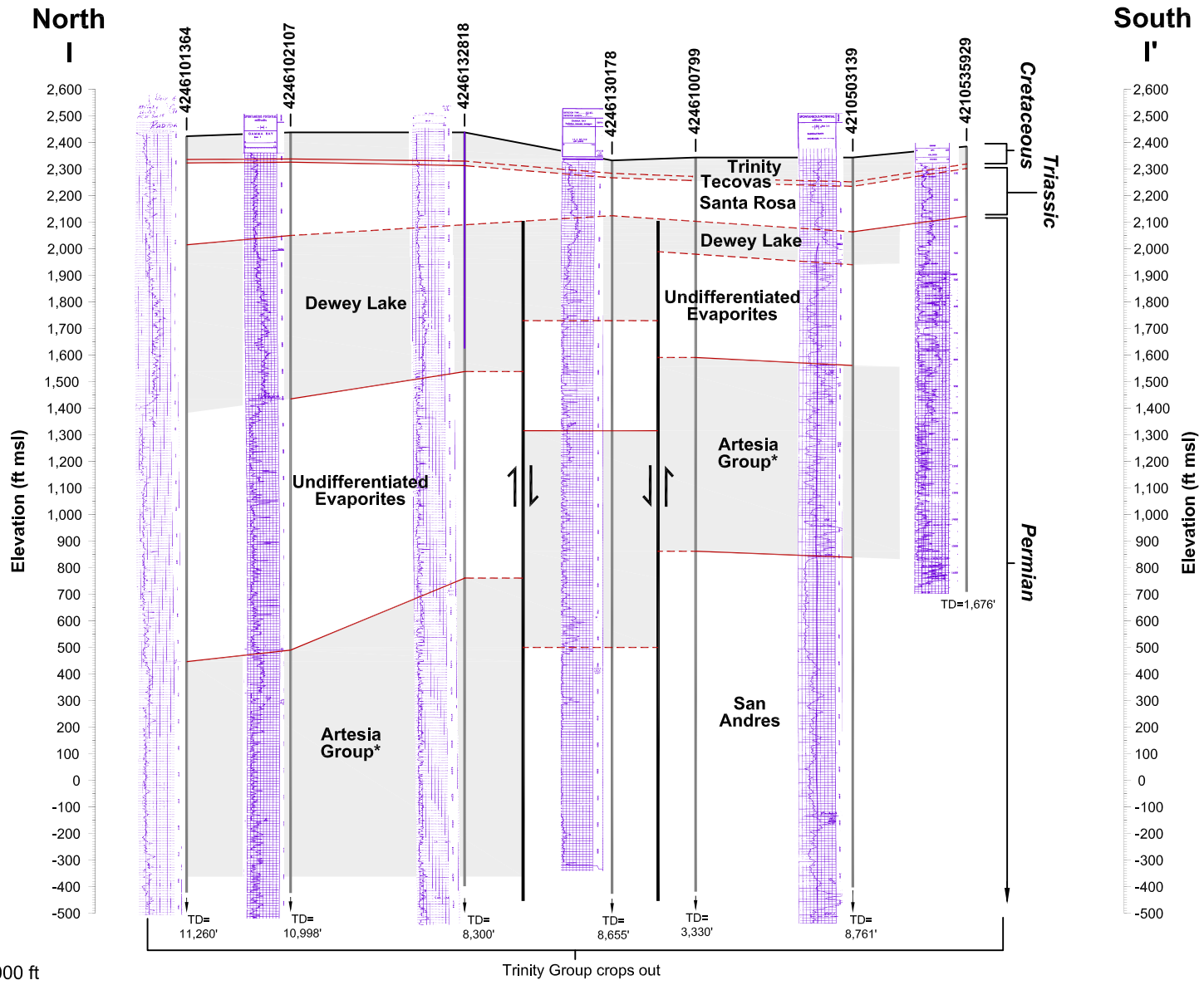
UNIVERSITY LANDS

West to East Geologic Cross Section H2-H2'

Figure B-5

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_G1-G1'_through_N-N'.dwg



Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4246101364).

Figure B-6

UNIVERSITY LANDS

North to South Geologic Cross Section I-I'

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11/13/2015

JN WR14.0154

North
J

South
J'

71465 | 4238336004 | 4238311190 | 4238335890 | 4238311370 | 4246131826 | 272213 | 322522 | 4246136292 | 4246104025 | 153236 | 4246131923 | 201034 | 4210535454 | 4210530637 | 4210502866

Edwards

Trinity

Tecovas

Santa Rosa

Dewey Lake

Undifferentiated Evaporites

Artesia Group*

San Andres

TD = 320'

TD = 555'

Log depth = 680'

TD = 540'

TD = 540'

TD= 8,520'

TD= 7,445'

TD= 8,922'

TD= 7,160'

TD= 7,795'

TD= 10,202'

11,500'

TD= 11,582'

TD= 11,560'

TD= 8,202'

TD= 8,085'

Cretaceous

Triassic

Permian

Elevation (ft msl)

3,000 2,900 2,800 2,700 2,600 2,500 2,400 2,300 2,200 2,100 2,000 1,900 1,800 1,700 1,600 1,500 1,400 1,300 1,200 1,100 1,000 900 800 700 600 500 400 300 200 100 0 -100 -200 -300 -400 -500 -600 -700 -800 -900 -1,000 -1,100 -1,200 -1,300 -1,400 -1,500

0 12,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. Well identifiers are API (e.g. 4238336004) or TDLR (e.g. 714656).

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_G1-G1'_through_N-N'.dwg

Daniel B. Stephens & Associates, Inc.

11/13/2015

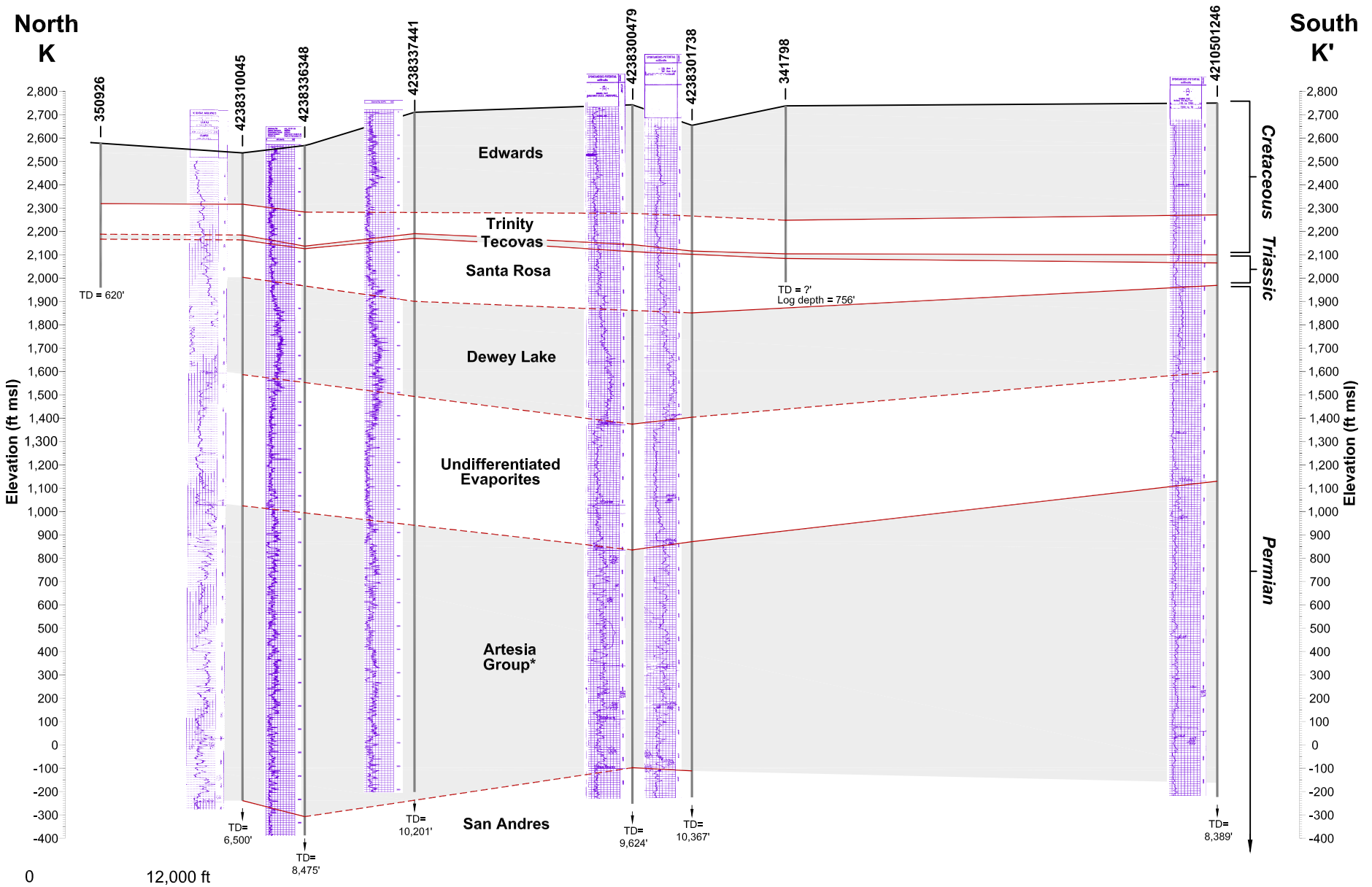
JN WR14.0154

UNIVERSITY LANDS

North to South Geologic Cross Section J-J'

Figure B-7

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_G1-G1'_through_N-N'.dwg



Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. Well identifiers are API (e.g. 4238310045) or TDLR (e.g. 350926).

Figure B-8

Daniel B. Stephens & Associates, Inc.

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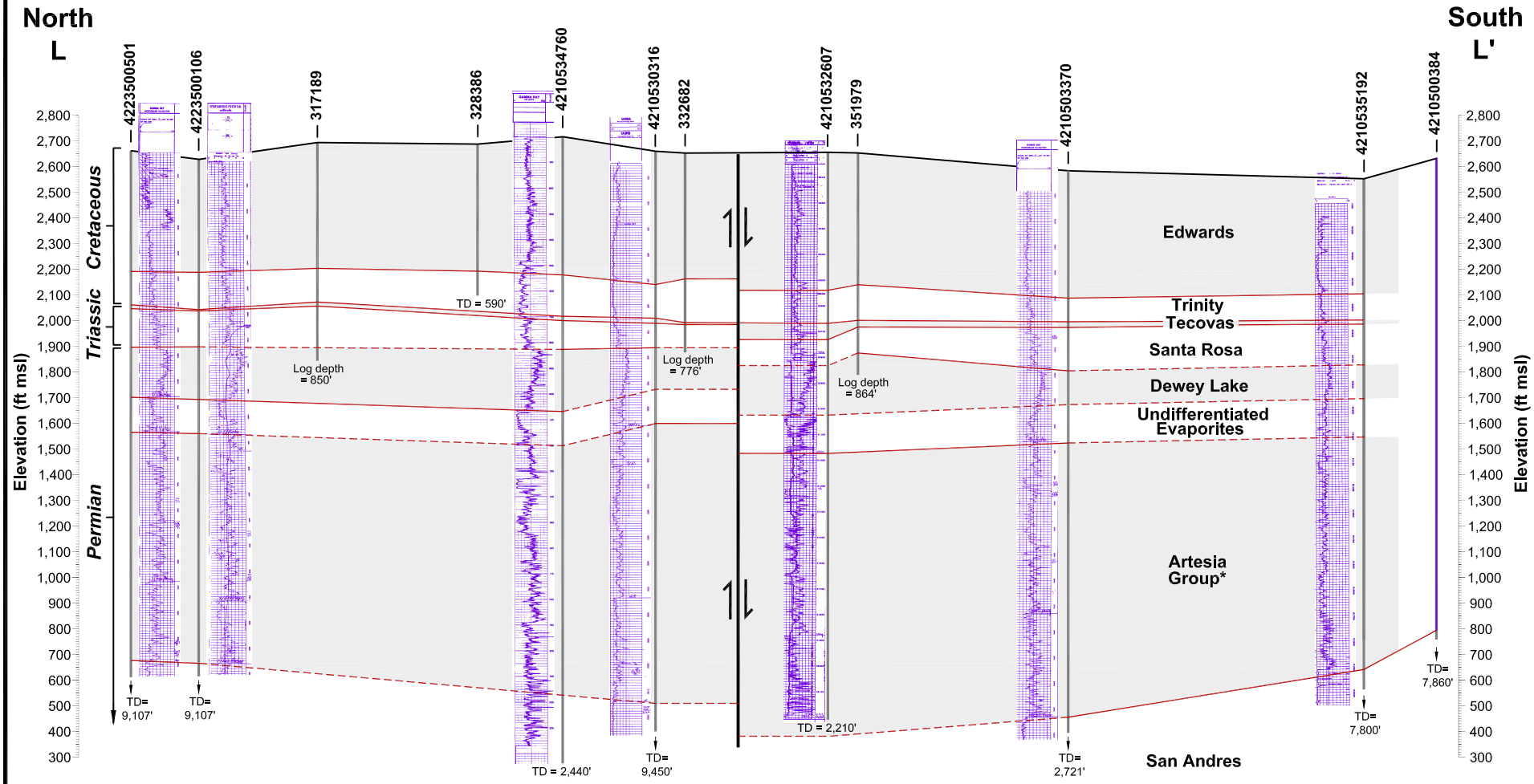
JN WR14.0154

UNIVERSITY LANDS

North to South Geologic Cross Section K-K'

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_G1-G1'_through_N-N'.dwg



0 12,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. Well identifiers are API (e.g. 4223500501) or TDLR (e.g. 317189).

UNIVERSITY LANDS

North to South Geologic Cross Section L-L'

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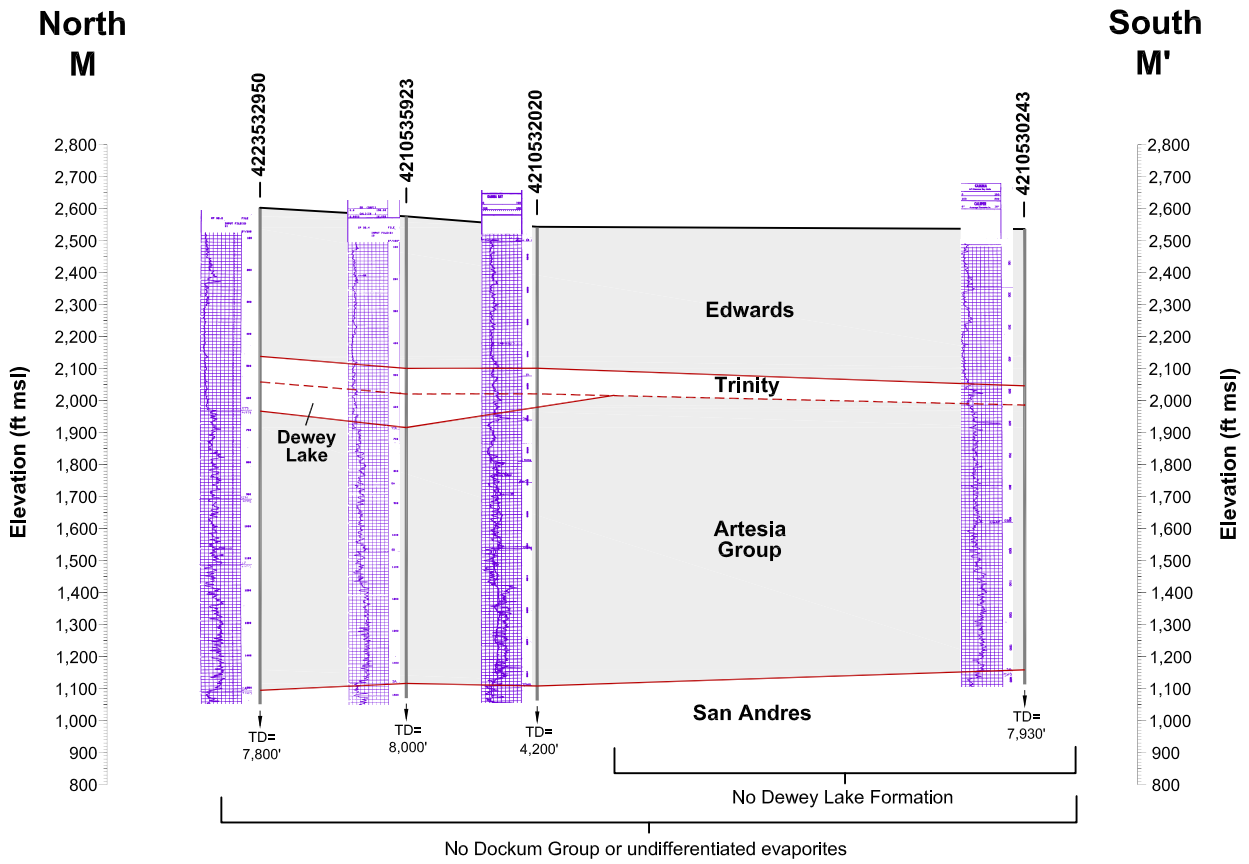
11/13/2015 JN WR14.0154

Figure B-9

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_G1-G1'_through_N-N'.dwg



0 12,000 ft

20X vertical exaggeration

Notes:

1. Contacts dashed where inferred.
2. API well identifier (e.g. 4223532950).

Figure B-10

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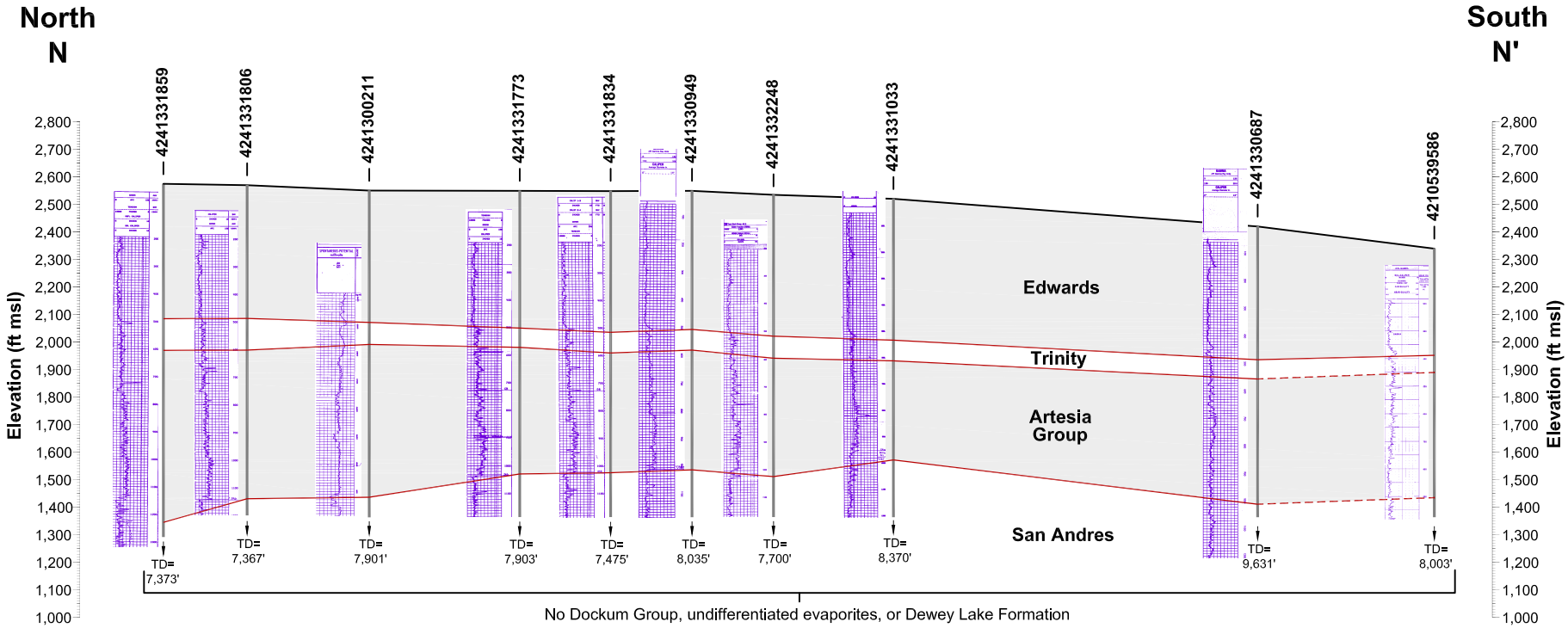
12/7/2015 JN WR14.0154

UNIVERSITY LANDS

North to South Geologic Cross Section M-M'

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_G1-G1'_through_N-N'.dwg



0 12,000 ft

20X vertical exaggeration

Notes:

1. Contacts dashed where inferred.
2. API well identifier (e.g. 4241331859).

Figure B-11

UNIVERSITY LANDS

North to South Geologic Cross Section N-N'

Daniel B. Stephens & Associates, Inc.

12/7/2015 JN WR14.0154

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGB-12_FIVE_COUNTY_AREA_THICKNESS_EDWARDS.MXD

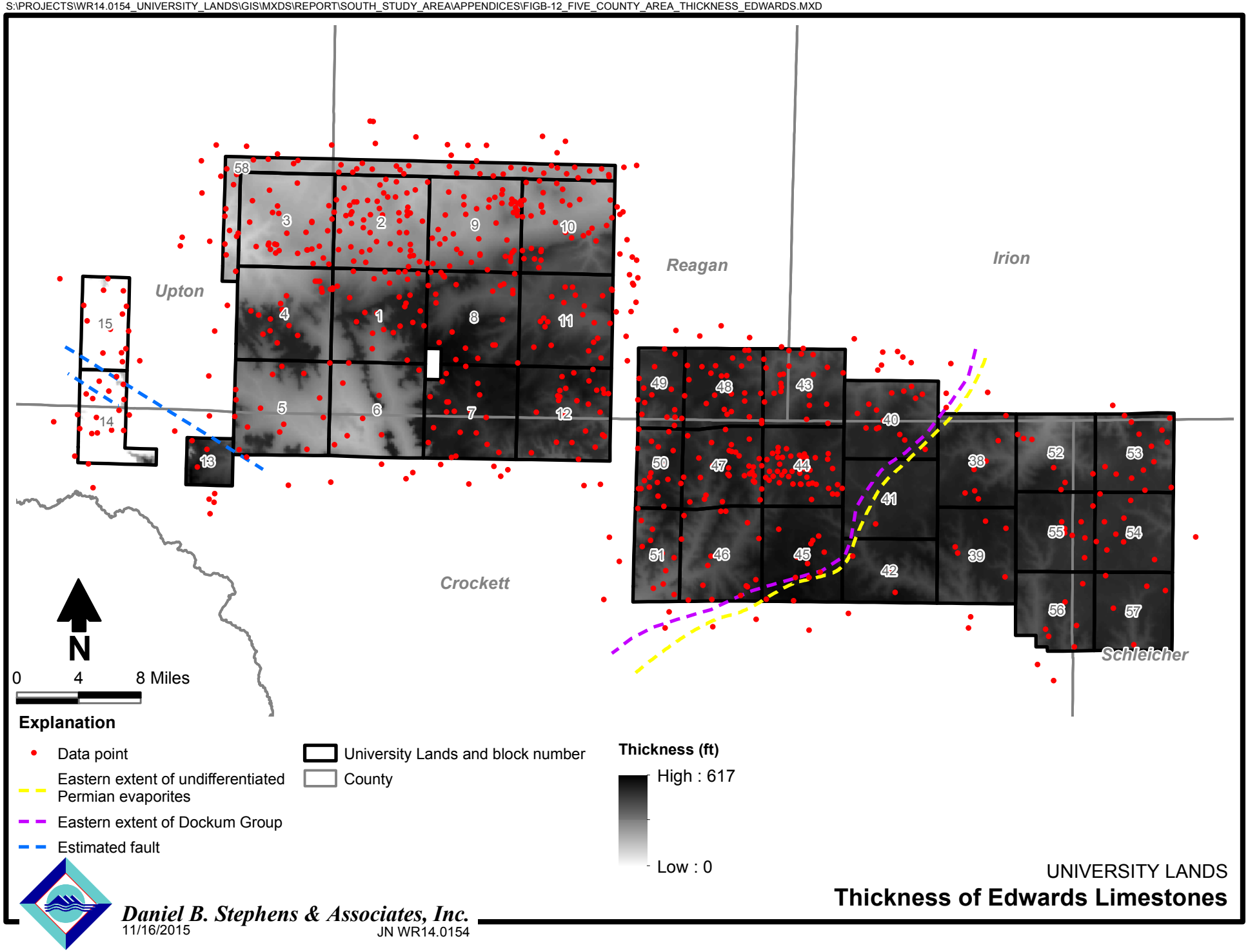


Figure B-12

UNIVERSITY LANDS

Thickness of Edwards Limestones

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JN WR14.0154

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGB-13_FIVE_COUNTY_AREA_THICKNESS_TRINITY.MXD

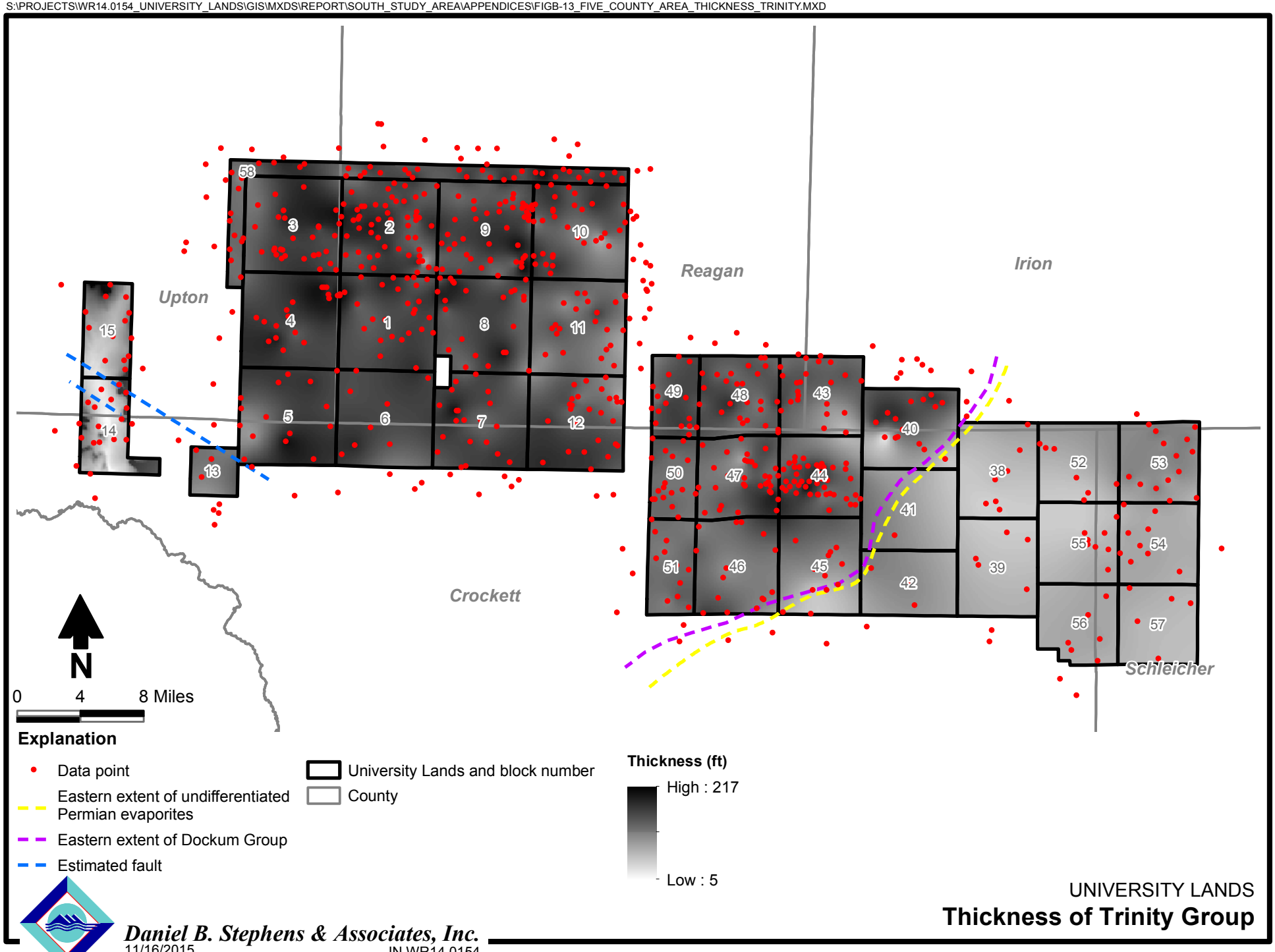

Figure B-13

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JN WR14.0154

UNIVERSITY LANDS
Thickness of Trinity Group

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGB-14_FIVE_COUNTY_AREA_THICKNESS_TECOVAS.MXD

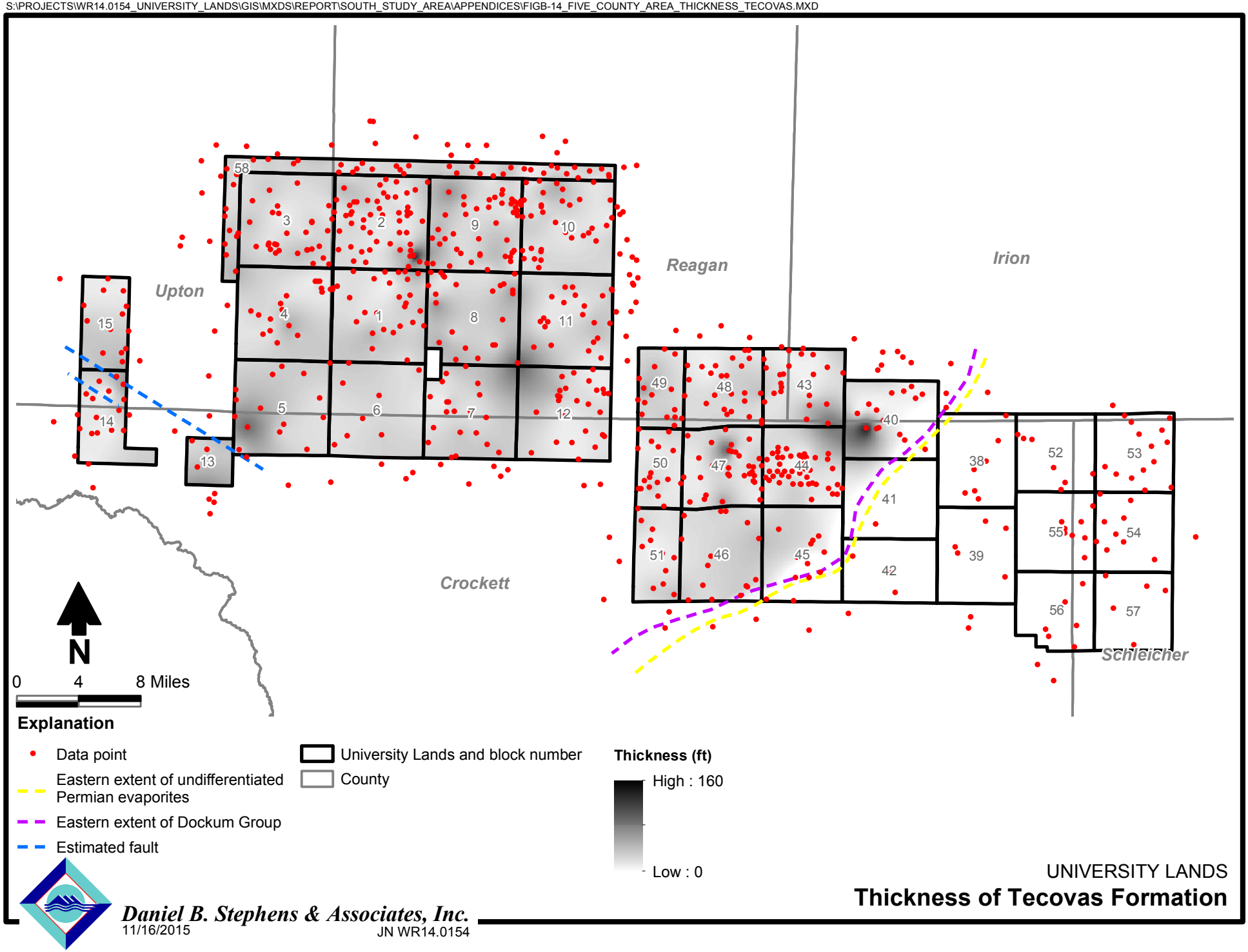

Figure B-14

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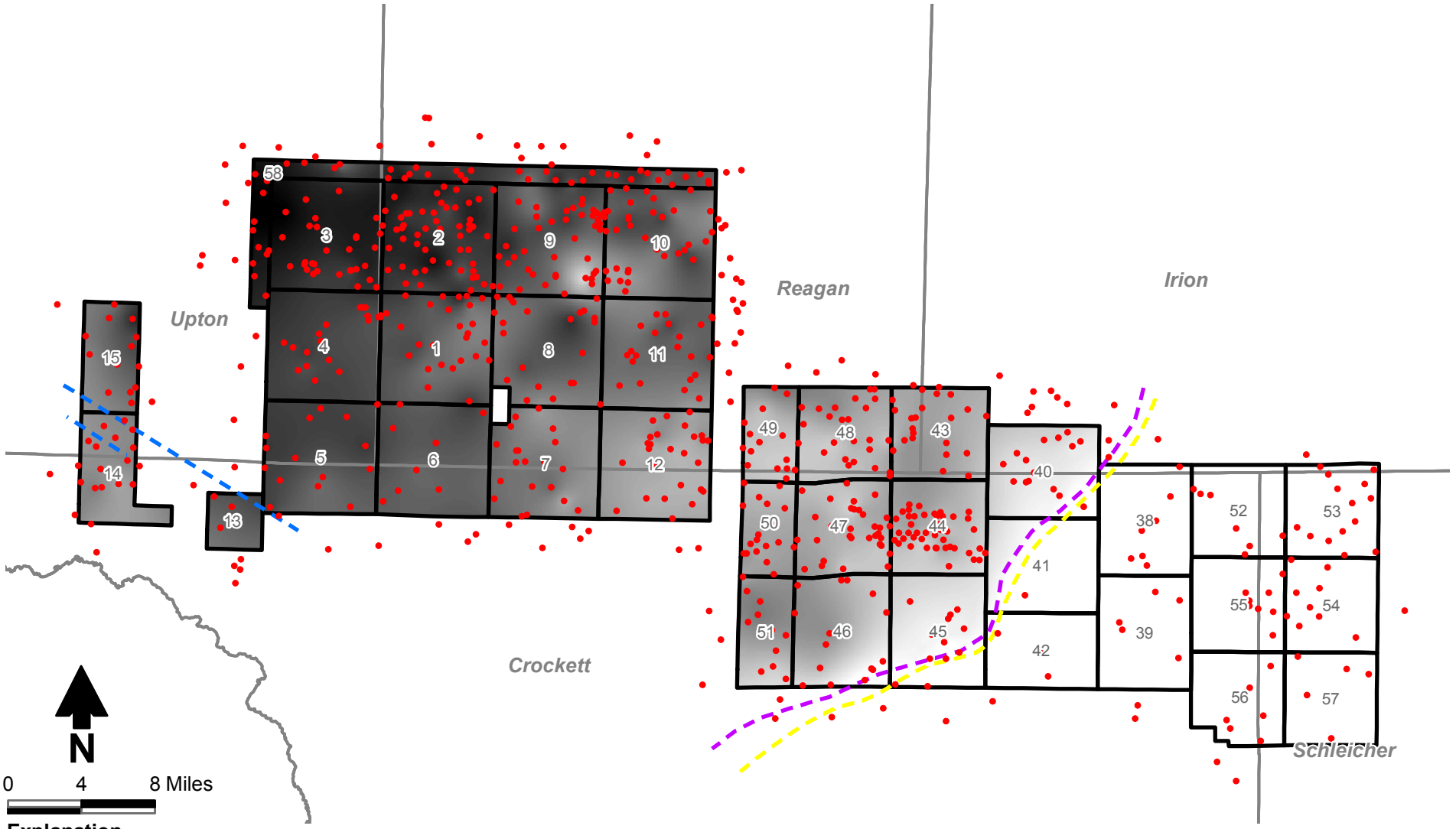
11/16/2015
JN WR14.0154

UNIVERSITY LANDS
Thickness of Tecovas Formation

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGB-15_FIVE_COUNTY_AREA_THICKNESS_SANTAROSA.MXD



Explanation

- Data point
- Eastern extent of undifferentiated Permian evaporites
- Eastern extent of Dockum Group
- Estimated fault
- University Lands and block number
- County

Thickness (ft)

High : 367

Low : 0

Figure B-15

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UNIVERSITY LANDS

Thickness of Santa Rosa Formation

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGB-16_FIVE_COUNTY_AREA_THICKNESS_DEWEYLAKE.MXD

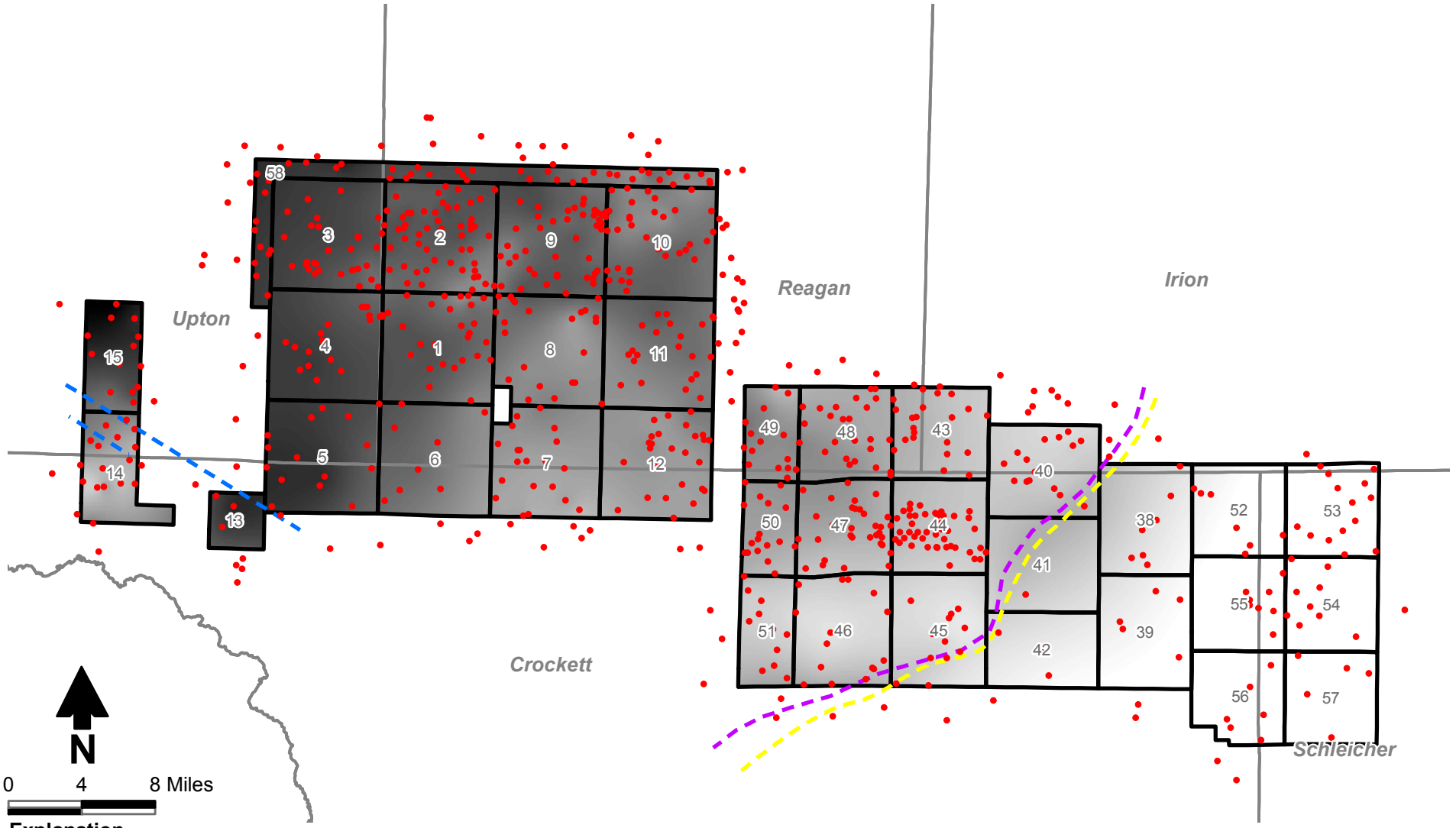

Figure B-16

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JN WR14.0154

UNIVERSITY LANDS
Thickness of Dewey Lake Formation

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGB-17_FIVE_COUNTY_AREA_THICKNESS_EVAPORITES.MXD

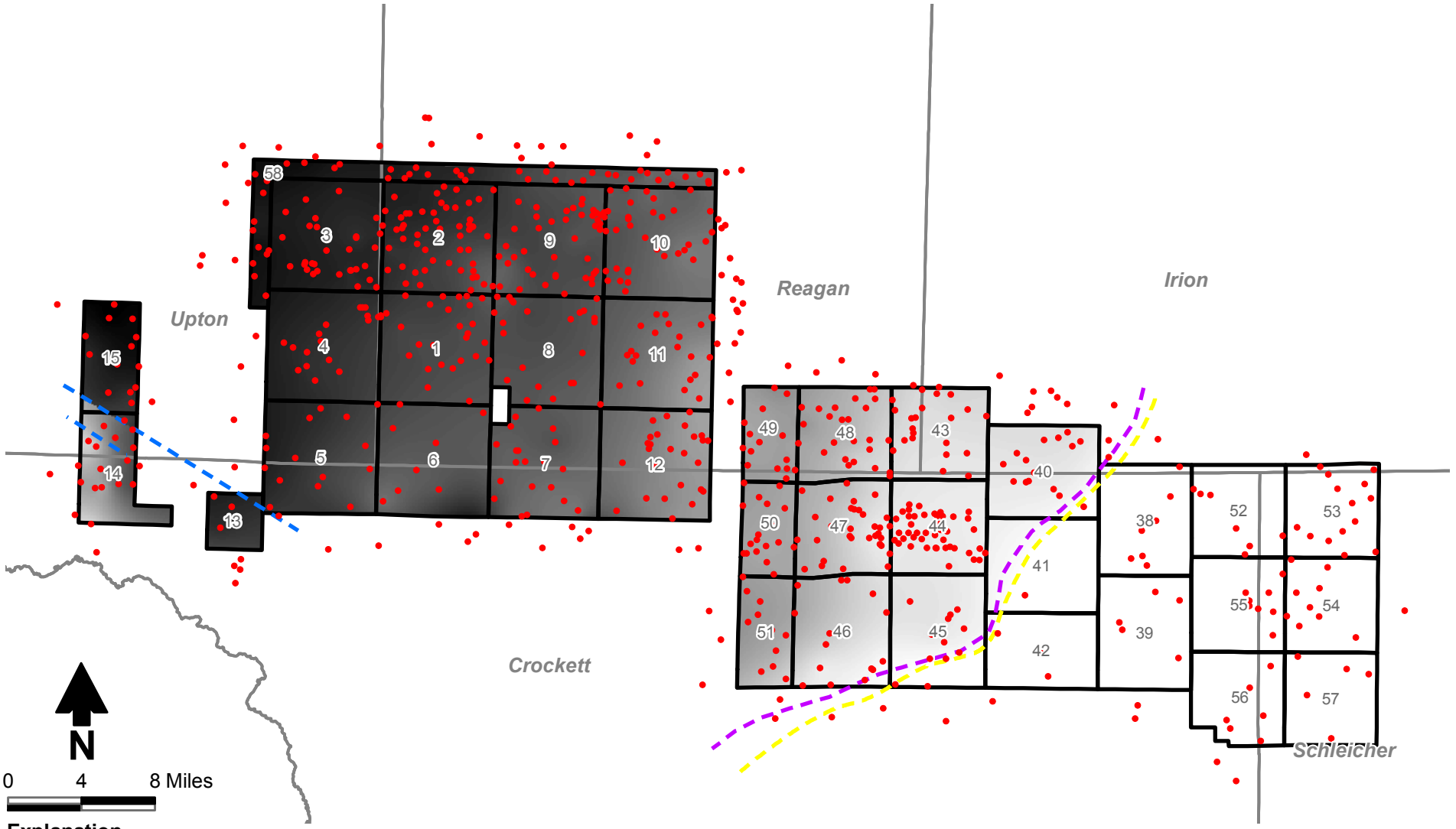

Figure B-17

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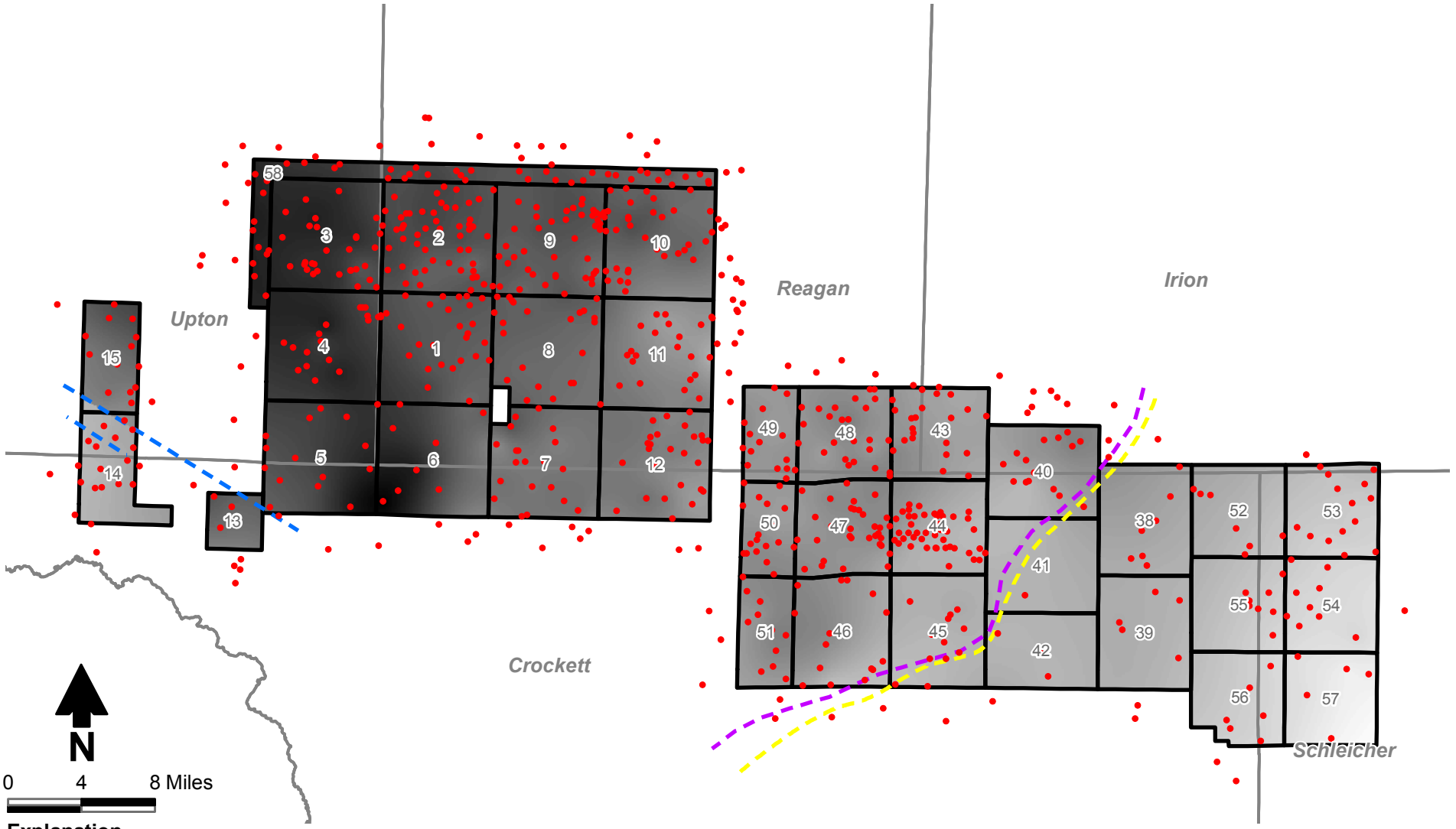
UNIVERSITY LANDS
Thickness of Evaporites

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGB-18_FIVE_COUNTY_AREA_THICKNESS_ARTESIAGROUP.MXD



Explanation

- Data point
- Eastern extent of undifferentiated Permian evaporites
- Eastern extent of Dockum Group
- Estimated fault
- University Lands and block number
- County

Thickness (ft)

High : 2200

Low : 120

Figure B-18

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UNIVERSITY LANDS

Thickness of Artesia Group

Appendix C

Geologic Cross Sections and Unit Thickness Maps for Central Crockett County Area

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGC-1_CENTRAL_CROCKETT_COUNTY_SURFACE_GEOLOGY.MXD

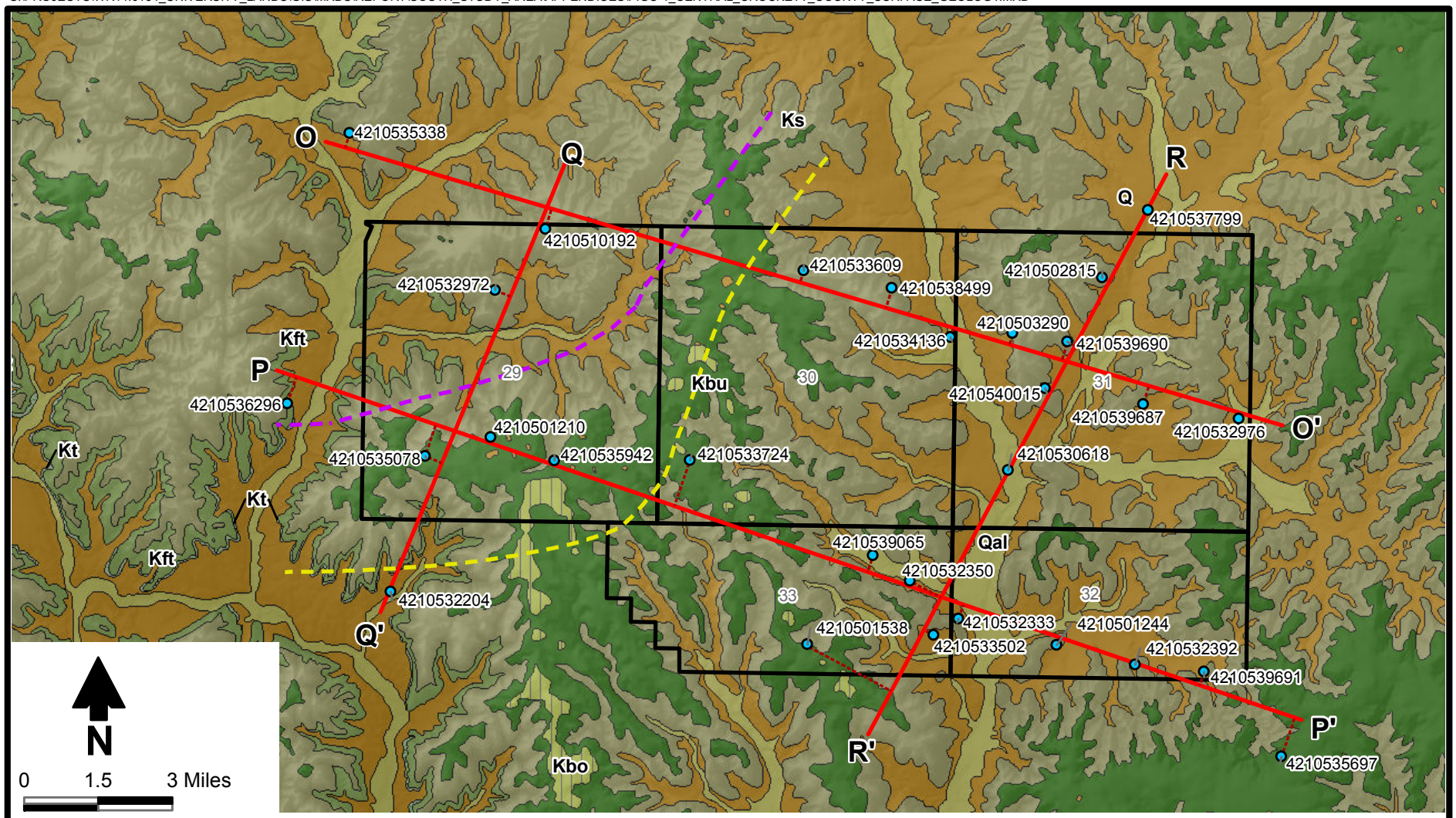

Figure C-1

UNIVERSITY LANDS

Central Crockett County Surface Geology (O-O' to R-R')

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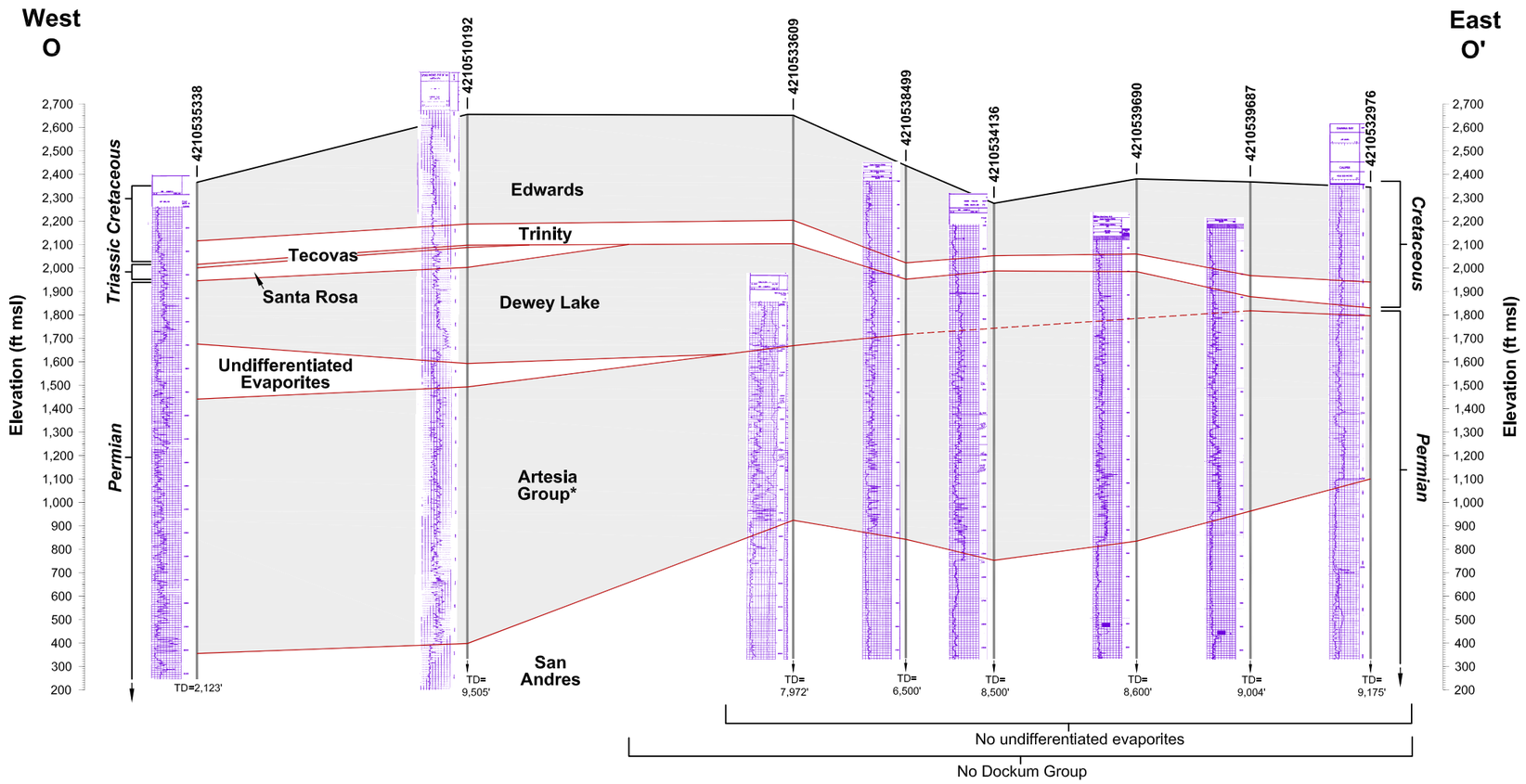
11/16/2015

JN WR14.0154



Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4210535338).

0 12,000 ft

20X vertical exaggeration

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_O-O'_through_R-R'.dwg

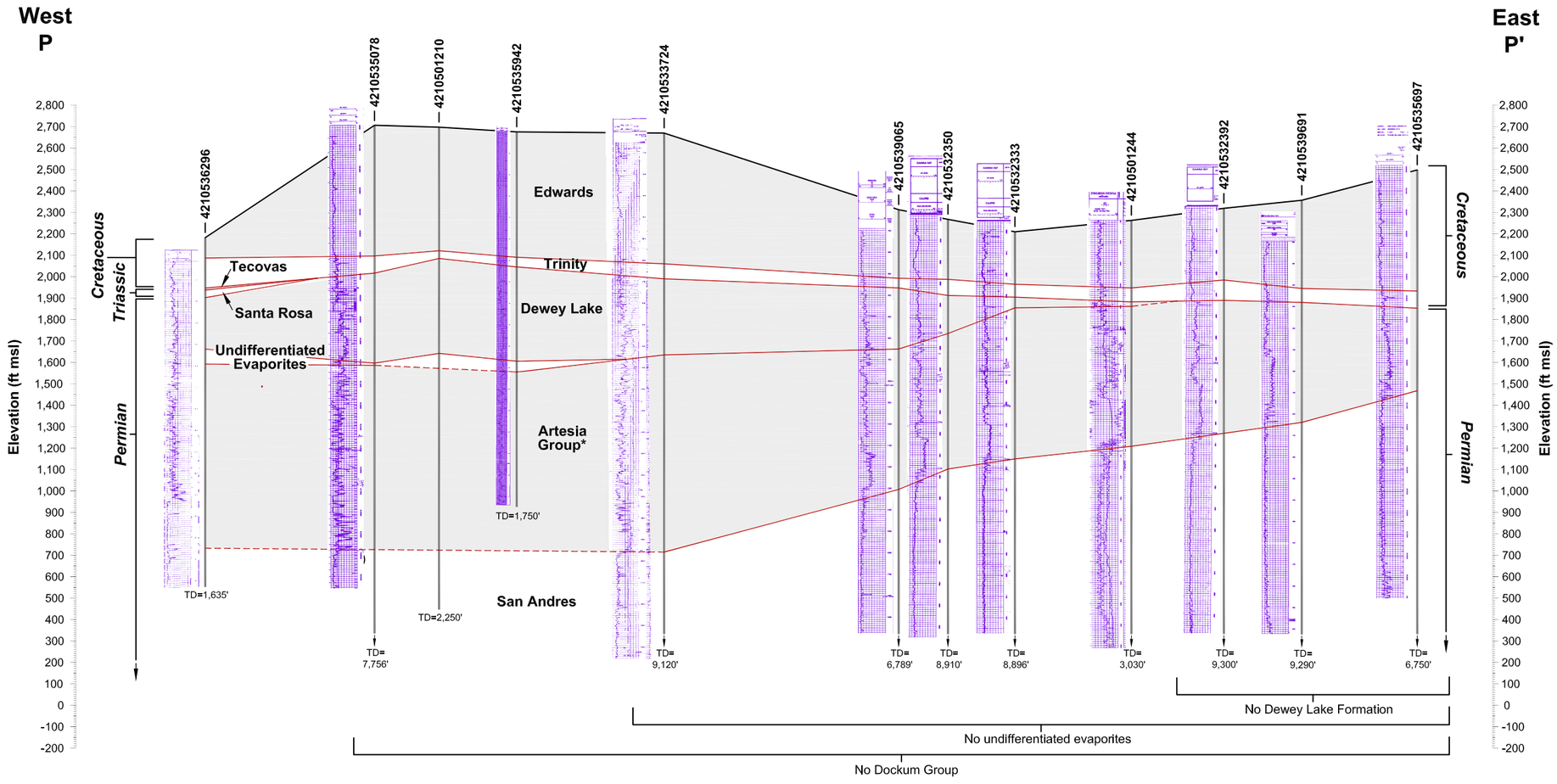
Daniel B. Stephens & Associates, Inc.

11/16/2015 JN WR14.0154

UNIVERSITY LANDS

West to East Geologic Cross Section O-O'

Figure C-2



0 12,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4210536296).

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_O-O'_through_R-R'.dwg

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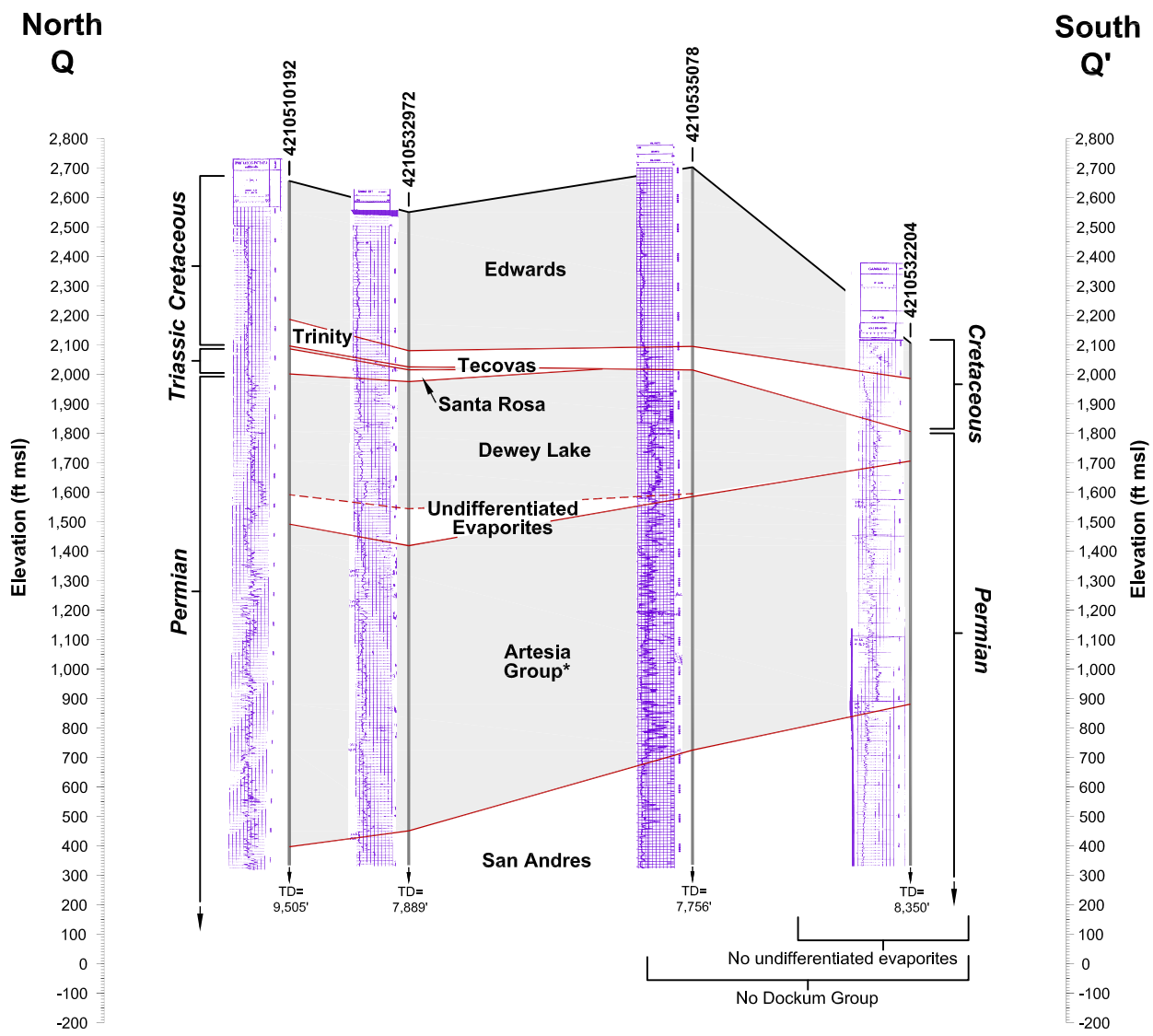
11/16/2015 JN WR14.0154

UNIVERSITY LANDS

West to East Geologic Cross Section P-P'

Figure C-3

S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_O-O'_through_R-R'.dwg



0 12,000 ft

20X vertical exaggeration

Notes:

1. *Tansill Formation included with undifferentiated evaporites.
2. Contacts dashed where inferred.
3. API well identifier (e.g. 4210510192).

Figure C-4

UNIVERSITY LANDS

North to South Geologic Cross Section Q-Q'

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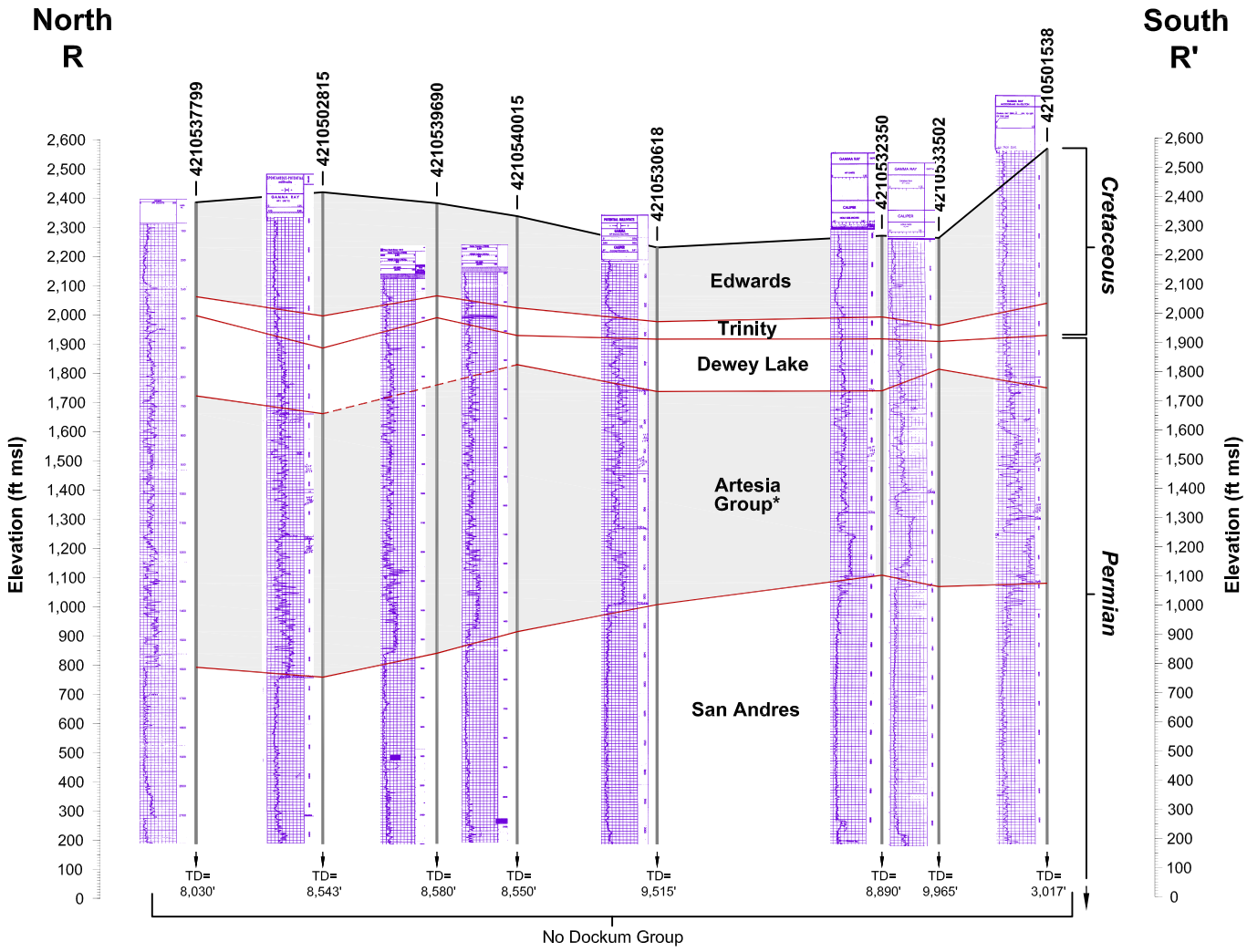
S:\Projects\WR14.0154_University_Lands\VR_Drawings\Cross_Sections_O-O'_through_R-R'.dwg



0 12,000 ft

20X vertical exaggeration

Notes:

1. Contacts dashed where inferred.
2. API well identifier (e.g. 4210537799).

Figure C-5

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UNIVERSITY LANDS

North to South Geologic Cross Section R-R'

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGC-6_CENTRAL_CROCKETT_COUNTY_THICKNESS_EDWARDS.MXD

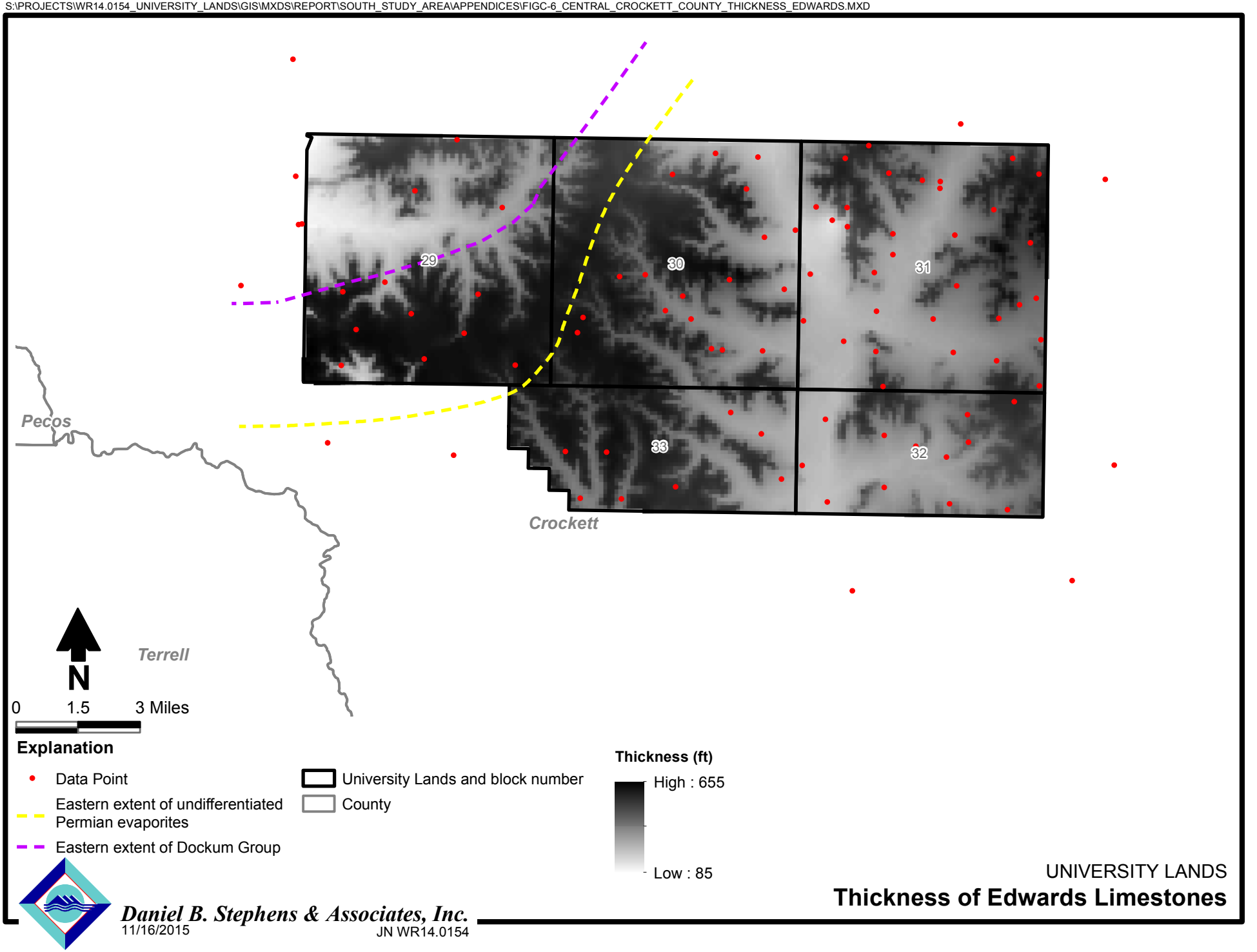

Figure C-6

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JN WR14.0154

UNIVERSITY LANDS
Thickness of Edwards Limestones

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGC-7_CENTRAL_CROCKETT_COUNTY_THICKNESS_TRINITY.MXD

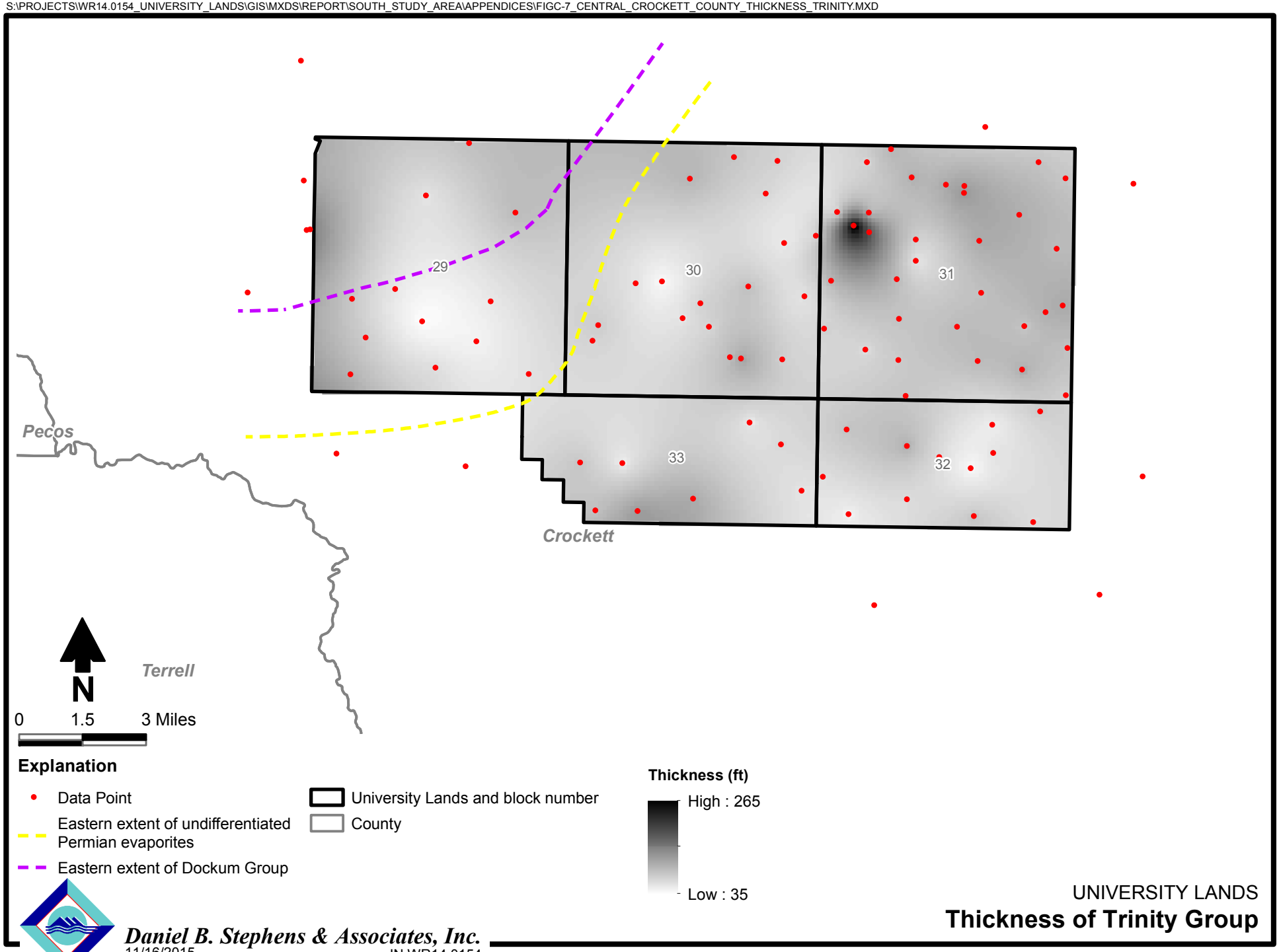

Figure C-7

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JN WR14.0154

UNIVERSITY LANDS
Thickness of Trinity Group

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGC-8_CENTRAL_CROCKETT_COUNTY_THICKNESS_TECOVAS.MXD

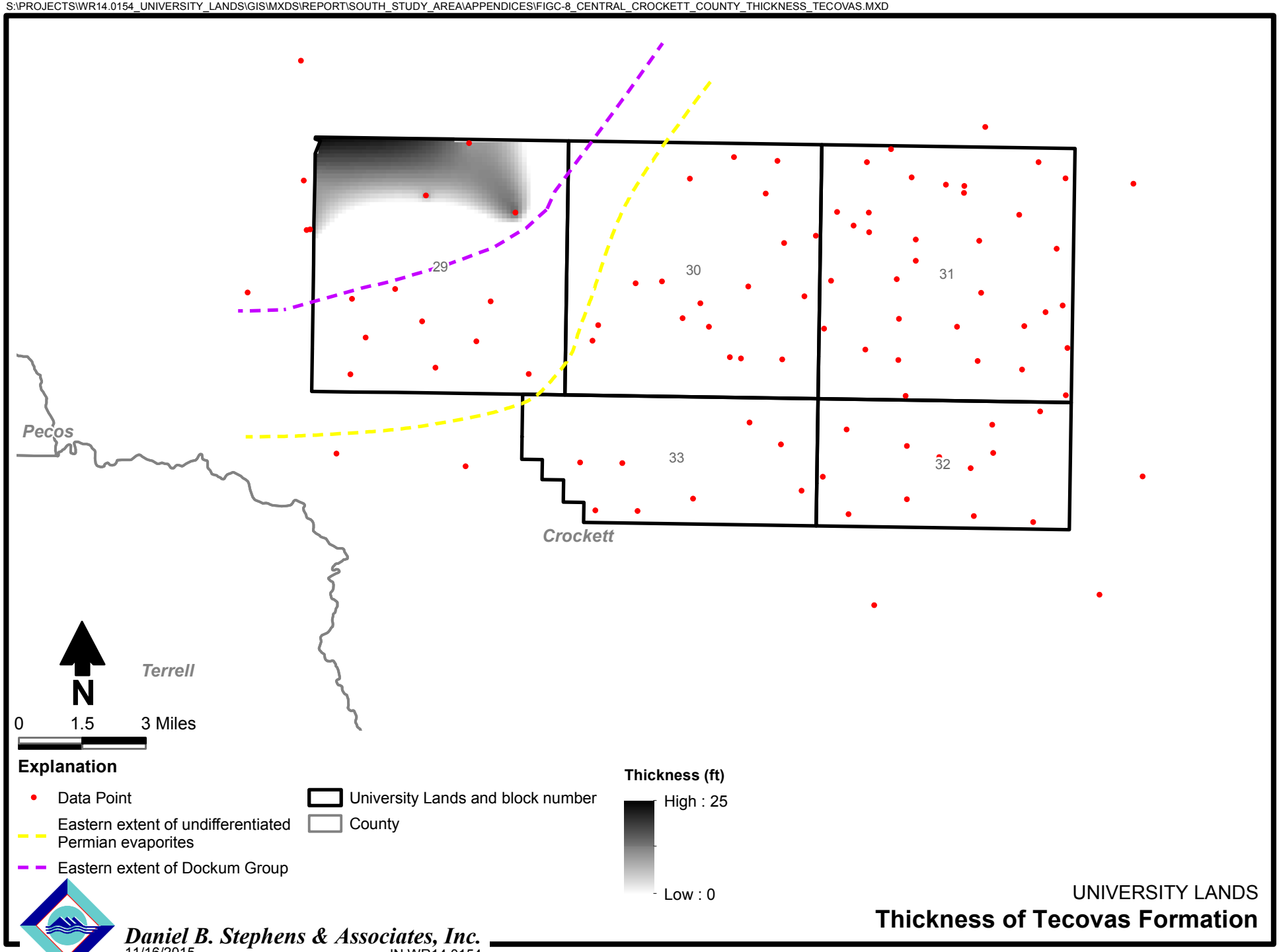

Figure C-8

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11/16/2015
JN WR14.0154

UNIVERSITY LANDS
Thickness of Tecovas Formation

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGC-9_CENTRAL_CROCKETT_COUNTY_THICKNESS_SANTAROSA.MXD

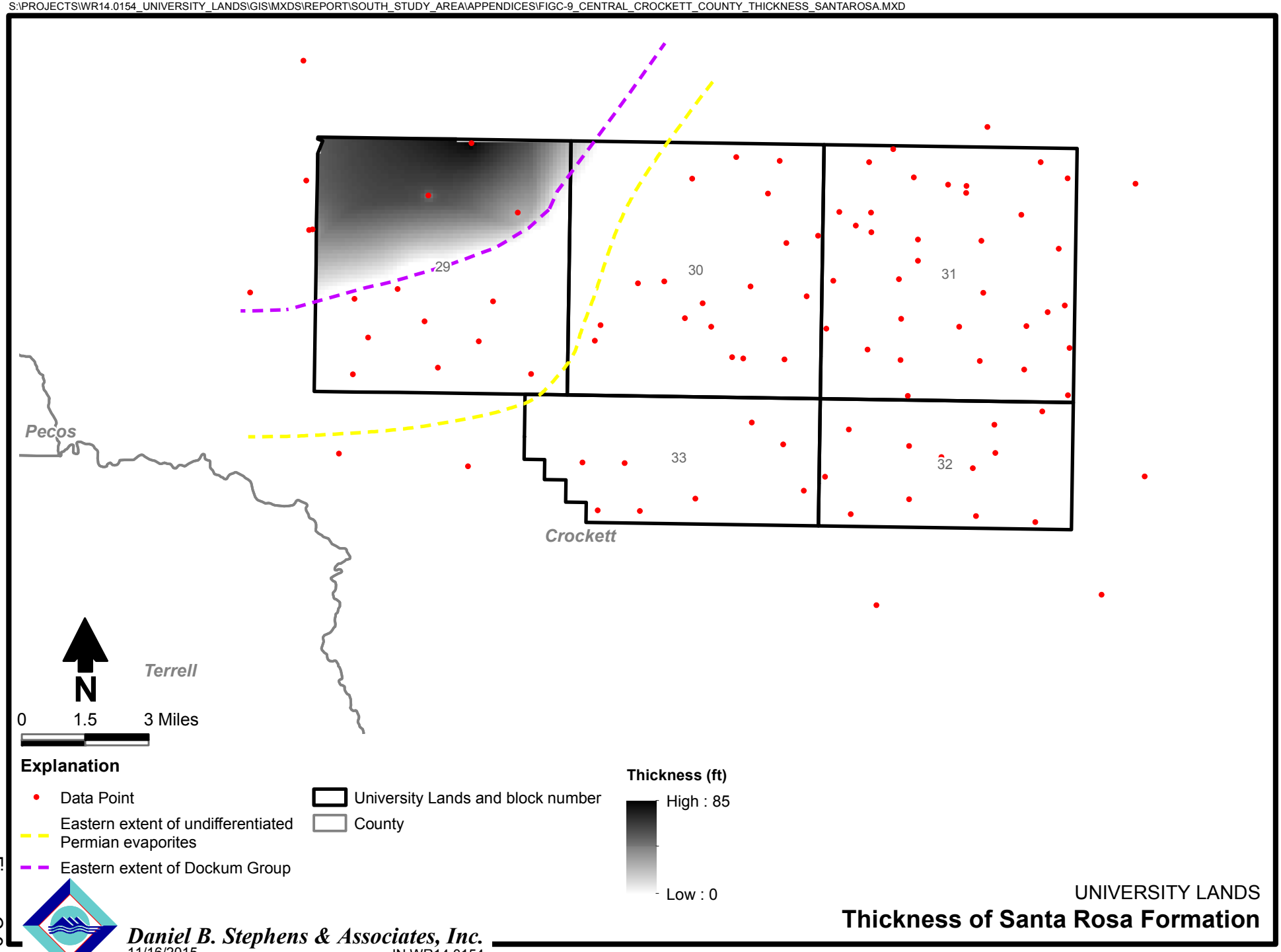

Figure C-9

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11/16/2015
JN WR14.0154

UNIVERSITY LANDS

Thickness of Santa Rosa Formation

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGC-10_CENTRAL_CROCKETT_COUNTY_THICKNESS_DEWEYLAKE.MXD

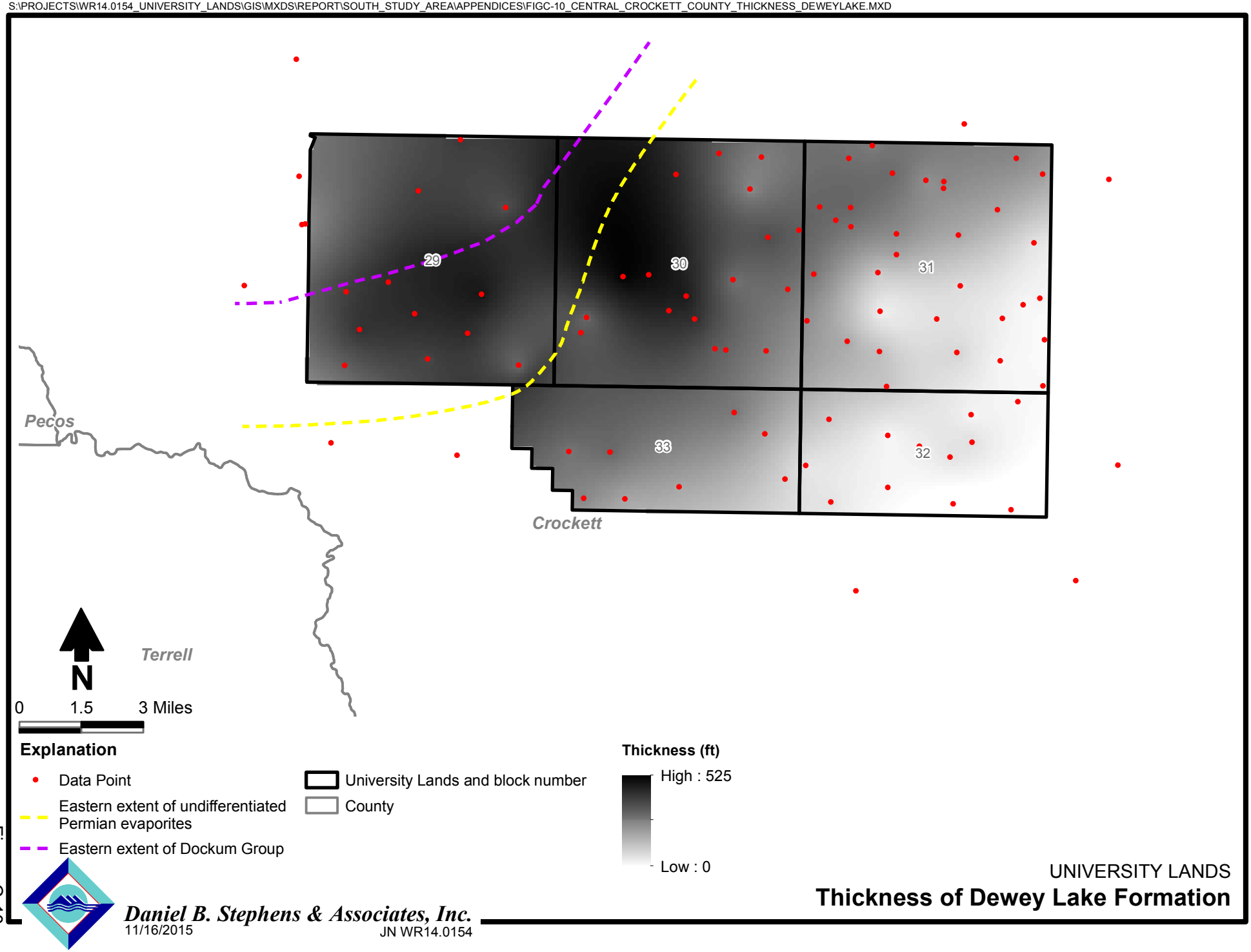

Figure C-10

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11/16/2015
JN WR14.0154

UNIVERSITY LANDS

Thickness of Dewey Lake Formation

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGC-11_CENTRAL_CROCKETT_COUNTY_THICKNESS_EVAPORITES.MXD

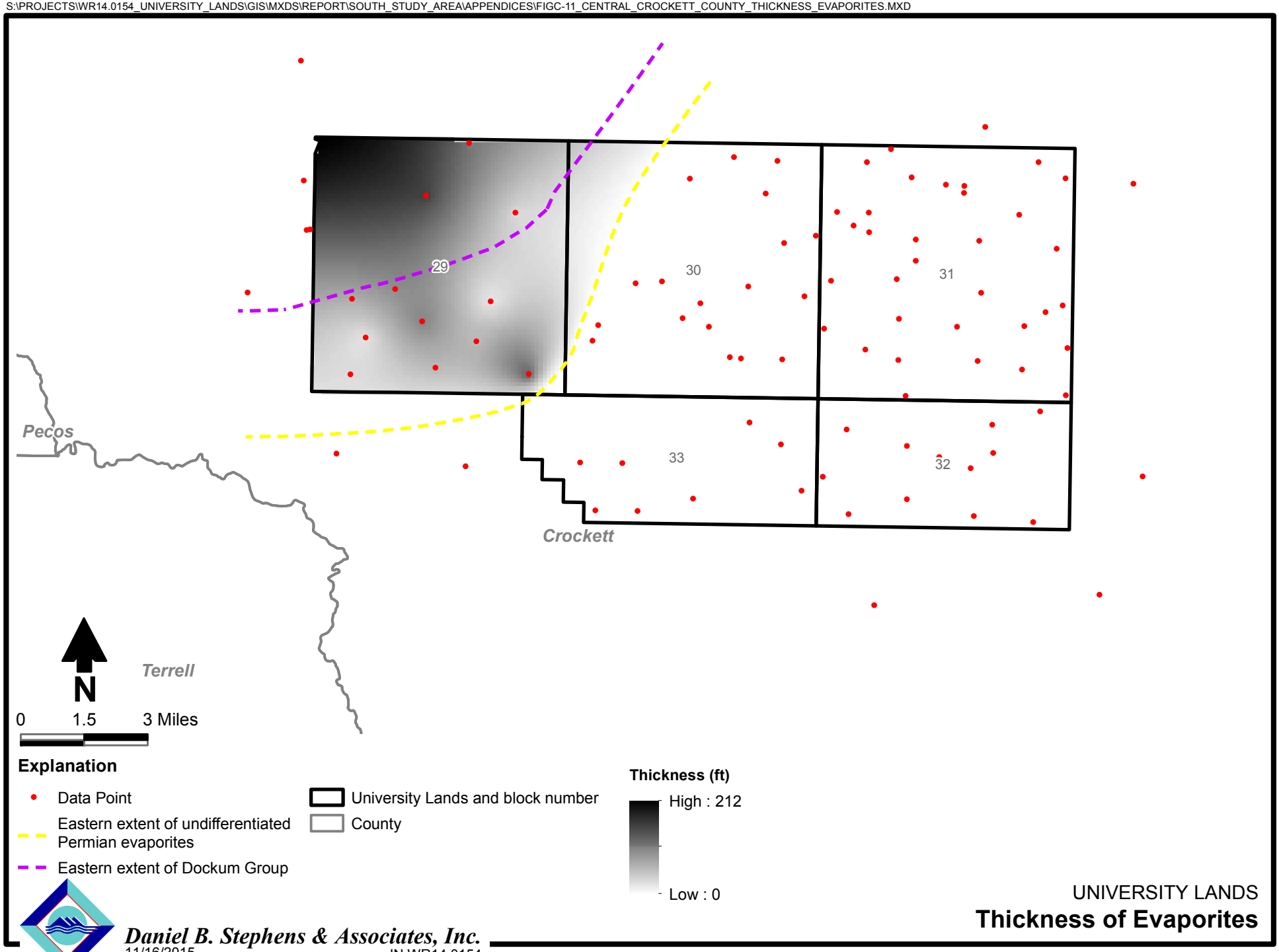

Figure C-11

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11/16/2015
JN WR14.0154

UNIVERSITY LANDS
Thickness of Evaporites

S:\PROJECTS\WR14.0154_UNIVERSITY_LANDS\GIS\MXDS\REPORT\SOUTH_STUDY_AREA\APPENDICES\FIGC-12_CENTRAL_CROCKETT_COUNTY_THICKNESS_ARTESIAGROUP.MXD

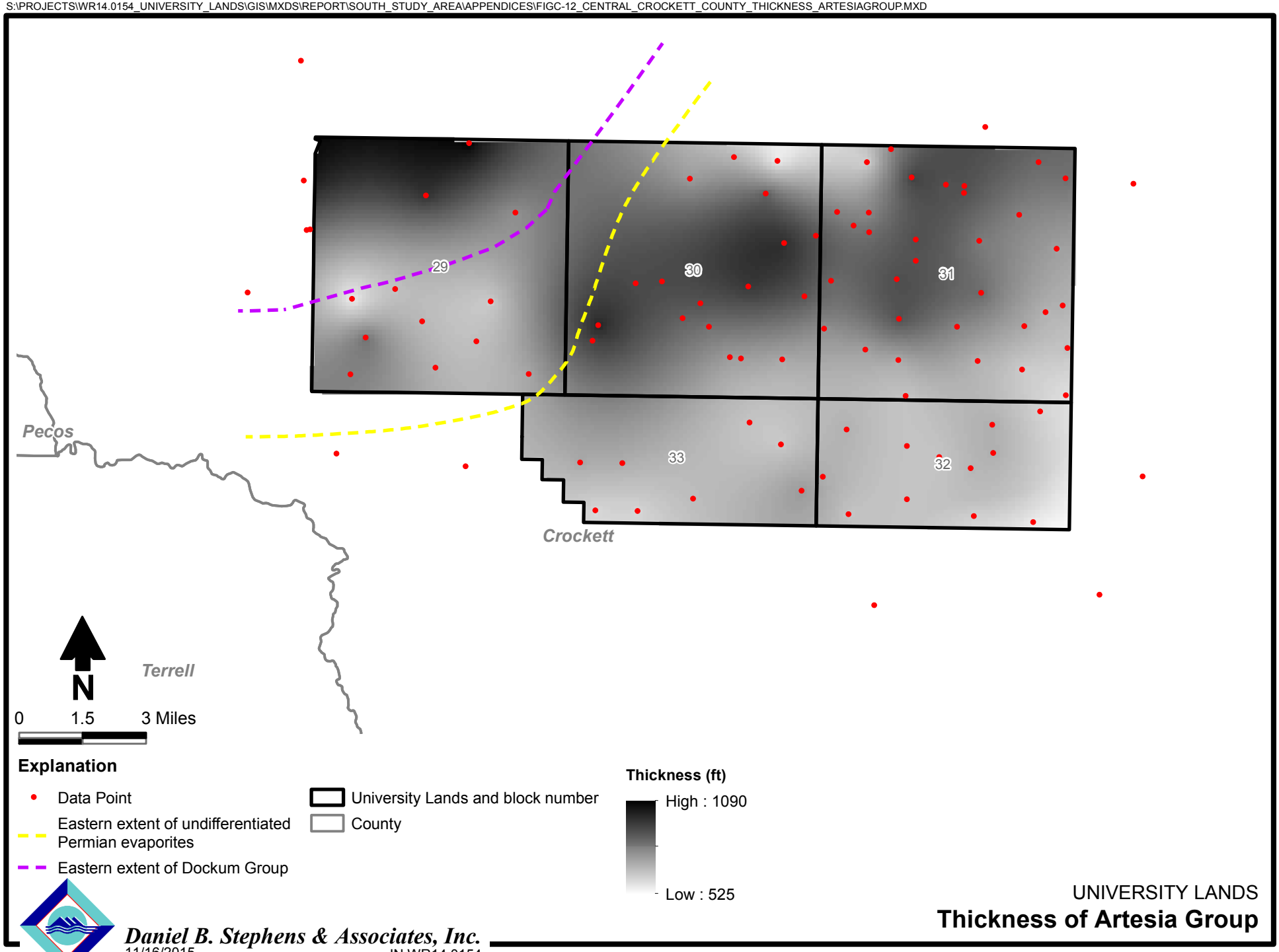

Figure C-12

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JN WR14.0154

UNIVERSITY LANDS
Thickness of Artesia Group

Appendix D

Three-Dimensional Geologic Models

This appendix has been provided separately to University Lands.