Aquifer Storage and Recovery Report: Preliminary Assessment for the Lower Valley Water District

James Golab, Ph.D., P.G., Azzah AlKurdi

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by
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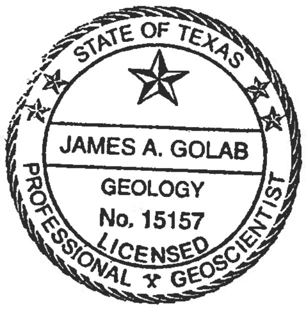

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Dr. Golab was responsible for working on all aspects of the study and preparing the report. The seal appearing on this document was authorized on April 11, 2025.

James Golab

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Cover photo courtesy of Erika Mancha "Near San Felipe Arroyo, El Paso County"

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1. Executive summary

Aquifer storage and recovery (ASR) utilizes injection wells for the local storage and subsequent recovery of water within an aquifer for beneficial use, and aquifer recharge (AR) is the intentional recharge of an aquifer through an injection well or other means of infiltration at the surface. Currently, there are five operational ASR and three operational AR projects in Texas, with five additional projects being piloted and four more projects authorized for testing. To meet future water needs, 11 regional water planning groups recommended 37 ASR and four AR projects in the 2022 State Water Plan. If implemented, ASR and AR would produce about 193,000 acre-feet per year of additional water supplies by 2070, constituting about 2.51 percent of all recommended water management strategies.

In 2019, the 86th Texas Legislature passed House Bill (HB) 721, which tasked the Texas Water Development Board (TWDB) with two legislative mandates: 1) to complete a statewide suitability survey of ASR and AR and 2) to conduct ASR or AR studies (Texas Water Code § 11.155). The TWDB was charged with implementing these mandates for the purpose of providing support for water planners, engineers, and government officials that may be investigating the development of ASR and AR projects within Texas. The statewide study created a methodology for surveying the suitability of areas for ASR or AR projects across Texas. The methodology was based on mapping the hydrogeological characteristics of the major and minor aquifers, sources of excess water, and water supply needs, as outlined in the house bill. The resulting survey was published in 2020 and serves as an effective tool for initial consideration of ASR and AR as potential water management strategies at statewide scale.

To fulfill the second mandate, the TWDB works with appropriate interested entities to conduct studies of ASR and AR projects identified in the state water plan or by others and reports the results of these studies to the regional water planning groups and interested persons. To determine studies viable for the TWDB to complete, a list of projects from the 2022 State Water Plan was compiled, and information from the plan was used to evaluate each project. Additional information was obtained by contacting each sponsor to verify and collect the most recent information on the status of their recommended ASR or AR project. Projects were scored on four primary criteria: sponsor interest, current planning status, data availability, and staff skills. This study is the third report created to fulfill this second legislative mandate.

This assessment provides a geological and data analysis of the ASR project for the Lower Valley Water District (LVWD) in the 2022 State Water Plan, discusses potential next steps toward developing this project, and provides an overview of the challenges this project may encounter. The LVWD is constructing a new wastewater treatment facility to treat municipal wastewater and is looking into injecting the excess advanced treated wastewater effluent into part of the Hueco Bolson aquifer. The LVWD currently receives its water supply from El Paso Water. The LVWD is interested in securing an alternative water source to maintain supply with affordable rates for the growing demands within its service area due to population growth. The TWDB ASR team selected this study because 1) the LVWD was interested in the team completing an ASR assessment, 2) the team had knowledge of the Hueco Bolson aquifer (the target aquifer for the ASR project), and 3) there was information available on the excess water and water needs from the statewide suitability survey.

To investigate the feasibility of ASR or AR for the LVWD, this study 1) collected publicly available data; 2) conducted stratigraphic analyses of the subsurface and surface geology using geophysical well logs, drillers logs, surface geologic maps, and previous studies that used seismic and airborne geophysical methods; and 3) analyzed water quality by using existing water quality tests and estimating salinity using geophysical well logs and the Alger-Harrison method. The LVWD service area entirely overlies the Hueco Bolson aquifer, a major Texas aquifer located east of the Franklin Mountains in far West Texas. The Hueco Bolson aquifer is an alluvial aquifer composed of tertiary and quaternary deposits consisting of unconsolidated and slightly consolidated basin-fill deposits of gravel and sand with interbedded lenses of silt and clay.

The surficial units of the aquifer are shallow and are used extensively for agricultural and industrial water production within the study area. These surface units are unconfined and not generally suitable for an ASR project but could be suitable for an AR project. The underlying Pliocene–Pleistocene basin-fill deposits of the aquifer are semiconfined sand and clay units. This study shows these units are relatively thick and contain areas that could be suitable for ASR. Additionally, the sand and gravel units in the surficial deposits would allow water to pass through from the surface to these deeper basin-fill deposits, making them highly suitable for AR. The aquifer is underlain by Mesozoic and Paleozoic bedrock units composed of marine carbonates and shales (carbonate bedrock). This study shows that these units are relatively deep, and both well log analysis and outcrop studies show that fluid flow is likely restricted to within faults and fractures, which potentially act as conduits to allow more saline water to enter the overlying aquifer units. These deep units do not contain many sandstone units or karst features, which prevents the storage of water for an ASR or AR project—their depth and characteristics are therefore likely to preclude an ASR or AR project.

The water quality analysis performed for this study inferred that the factors controlling salinity levels in the study area are well depth (salinity levels generally increase with depth); the Hueco Basin structure (faults and connection with the carbonate bedrock increases salinity level); and proximity to extensive municipal and irrigation pumping. The increased use of the Hueco Bolson aquifer over time has resulted in brackish water intrusion into the fresh zones of the aquifer. It is anticipated that more recent water quality measurements from these wells will give higher salinity ranges. Therefore, TWDB recommends that more comprehensive water quality testing be performed before making the final site selection for a proposed ASR or AR project.

The TWDB conducted a detailed assessment into the statewide suitability survey, which showed most of the LVWD service area was highly suitable in one or more of the three screening categories due to the presence of adequate hydrogeological properties, excess water availability, as well as municipal and agricultural water needs. The hydrogeological screenings for both ASR and AR show that the Hueco Bolson aquifer has good scores for several criteria, including specific yield and storativity, but the sandstone units underlying the surface units lack good confinement. This indicates that an AR project may be more feasible to implement in the study area. The TWDB evaluated the LVWD's water resources and water needs, including agricultural water needs, a parameter that was not included in the statewide survey. This analysis showed that the most abundant and available source of excess water is reclaimed water and that the highest water needs are for municipal and agricultural use in the study area. The final ASR and AR score for the study area fell in the most suitable category (> 0.7) except for a small segment to the southwestern side that did not receive a score due to absence of an aquifer.

This assessment shows that developing an ASR project in the LVWD's service area would be challenging because the surficial deposits in the study area are pumped extensively for agriculture and the units are unconfined. However, these surficial deposits would allow water to infiltrate the aquifer and would be suitable for an AR project—and the LVWD could benefit from supplementing current existing groundwater and reducing declines in the water table. The Hueco basin-fill deposits, which are pumped primarily by industrial and municipal users, are the most suitable and best target for an ASR project. Additionally, El Paso Water has previously encountered numerous issues implementing ASR in these deposits due to corrosion and screen plugging, which shows that the planning and maintenance costs of such a system would be very high. There is no indication that the carbonate bedrock within the study area contains sandstone units or extensive karst development, which prevents the storage and recharge of water. Therefore, an AR project located where the surficial deposits are thinner, less actively pumped, and composed of primarily sand and gravel would allow the recharged water to pass to the Hueco basin-fill deposits—reducing future water level declines and supplementing existing groundwater that could be used years later by industrial and municipal users within the area.

This assessment also highlights the gaps in the hydrologic data required to perform a full-scale aquifer characterization for the aquifer in the study area. Additional information is needed from test well drilling or geophysical surveys to help inform final site selection for an AR project. Covering a large portion of the study area may be possible using airborne geophysics. The sparsely populated study area makes airborne geophysical studies ideal, as there is less potential electromagnetic interference from electrical lines, industry, or houses. Seismic surveys may also be a viable alternative and provide a better understanding of the complex stratigraphy under the LVWD's service area and will likely provide the greatest detail at depth. Additionally, test holes to determine the lithology of specific locations are recommended. Test hole wells may also be necessary for groundwater testing, as the complex nature of the Hueco Bolson makes identifying groundwater quality patterns difficult.

Additionally, this assessment highlights there is currently no clear regulatory pathway to plan and permit an ASR system that uses advanced treated reclaimed wastewater in Texas. The TWDB recommends the LVWD work directly with the Texas Commission on Environmental Quality (TCEQ) in advance to discuss its potential ASR or AR project and permitting requirements and explore regulatory options.

In summary, due to the geologic issues and the corrosive nature of the native groundwater in the Hueco basin-fill deposits and the outstanding regulatory questions with using reclaimed water for ASR, this assessment recommends implementation of an AR project using surface infiltration basins for the LVWD. Infiltration basins located where the surficial units are hydrologically connected to the Hueco basin-fill deposits will allow surface recharge to infiltrate and supplement the amount of groundwater available in the area for both the LVWD and other users.

2. Background

Aquifer storage and recovery (ASR) utilizes injection wells for the local storage and subsequent recovery of water within an aquifer for beneficial use (Texas Water Code § 27.151). Aquifer recharge (AR) is the intentional recharge of an aquifer through an injection well or other means of infiltration at the surface, which may include projects that reduce declines in water level, supplement existing groundwater, or improve water quality (Texas Water Code § 27.201). Interest in both ASR and AR projects has been increasing across the United States due to decreasing water levels, increased reliance on vulnerable surface water supplies, and increased need for seasonal or emergency water storage (Pyne, 2005). Aquifer recharge from the surface is feasible in places where sediment near the surface is permeable and surface water can easily reach the water table. In less permeable sediment or for deeper aquifers, an injection well must be used (Pyne, 2005). Most ASR projects typically inject and recover water from the same location, as this provides significant engineering and cost advantages compared to having separate injection and recovery wells. Both ASR and AR can use a variety of treated sources of injected water (Pyne, 2005).

2.1 Aquifer storage and recovery in Texas

In Texas, ASR and AR have been used to store surface water, groundwater, and reclaimed water (Webb, 2015). Currently there are five operational ASR and three operational AR projects in Texas—with five additional projects being piloted and four more projects authorized for testing (Figure 2-1). The City of Kerrville plant became operational in 1998. This system has two ASR wells that store surface water from the Guadalupe River and has a recovery capacity of about 2.6 million gallons per day (Stein and Shockley, 2020). The ASR facility at San Antonio Water System's H2Oaks Center—located approximately 30 miles south of San Antonio—stores groundwater from the Edwards Aquifer and became operational in 2004. It has 29 ASR wells and a recovery capacity of about 60 million gallons per day (Morris and others, 2010). The Fred Hervey Water Reclamation Plant in El Paso stores reclaimed water and became operational in 1985. It has a spreading basin, a recharge well field with one active shallow vadose well, and a downgradient Hueco Bolson aquifer production well field (Reinert, 2017).

The TWDB ASR program is housed under the Innovative Water Technologies Department. It was created in 2009 with the TWDB funding the *An Assessment of Aquifer Storage and Recovery in Texas* study to determine why ASR was not being widely implemented in Texas (Malcolm Pirnie, 2011). As part of the study, 10 entities were surveyed and indicated that the concerns preventing them from implementing an ASR project were related to the recovery and quality of stored water, as well as implementation costs.

Four years later, the TWDB published Technical Note 15-04, "Aquifer Storage and Recovery in Texas: 2015," which summarized ASR activities in Texas (Webb, 2015). Also in 2015, the 84th Texas Legislature passed HB 655 amending the Texas Water Code to make the statute more conducive to implementing ASR projects. The 84th Texas Legislature also passed HB 1, Rider 25, which appropriated $1 million from the General Revenue Fund to the TWDB to fund groundwater conservation districts for demonstration projects or feasibility studies that will prove up aquifer storage and recovery or other innovative storage projects. As a result, the

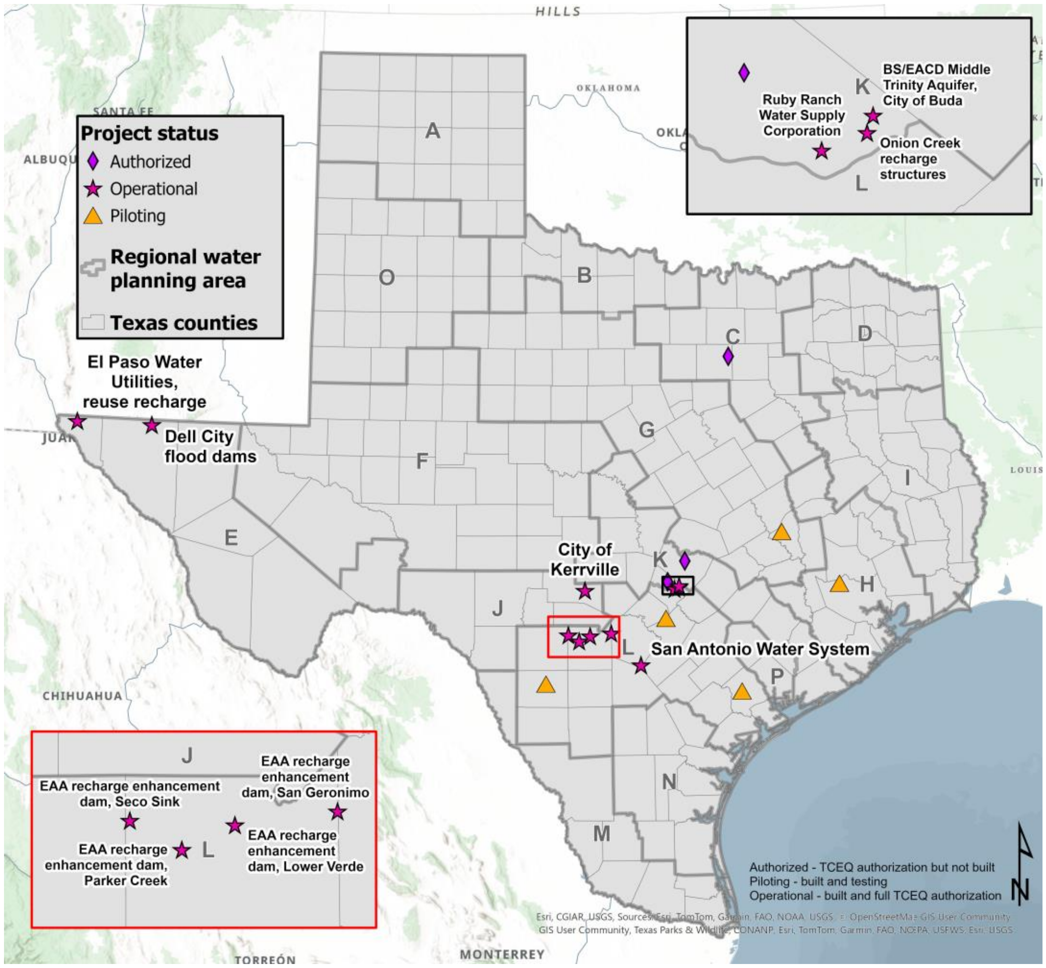


Figure 2-1. Operational, piloting, and authorized ASR and AR projects in Texas

TWDB provided funding to the Corpus Christi Aquifer Storage and Recovery Conservation District, the Edwards Aquifer Authority, and the Victoria County Groundwater Conservation District to acquire site-specific hydrogeological conditions for possible ASR projects by either drilling test wells or converting an existing groundwater production well to an ASR test well.

2.2 Legislative mandate

In 2019, the 86th Texas Legislature passed HB 721, which tasked the TWDB with two ASR-related legislative mandates (Texas Water Code § 11.155). The first mandate was to conduct a statewide survey to determine the relative suitability of using Texas aquifers for ASR and AR projects based on consideration of: 1) hydrogeological characteristics with a focus on storage potential, transmissivity, infiltration characteristics, storativity, recoverability, and water quality; 2) the frequency, volume, and distance to excess water available for potential storage; and 3) the current and future water supply needs identified in the state water plan. To implement the first mandate, the TWDB funded the *Statewide Survey of Aquifer Suitability for Aquifer Storage and Recovery Projects or Aquifer Recharge Projects* study that was completed in 2020 (Shaw and others, 2020). The TWDB submitted an overview of the statewide survey to the governor, lieutenant governor, and house speaker by December 15, 2020 (Shaw and others, 2020). The results of this statewide survey in the study area will be discussed later in the report.

The second mandate was for the TWDB to work with appropriate interested persons to conduct studies of ASR and AR projects identified in the state water plan or by others and report the results of these studies to the regional water planning groups and interested persons. To implement the second mandate, a newly formed ASR team with staff and funding appropriated from the Texas Legislature evaluated all ASR and AR recommended water management strategy projects in the 2017 and 2021 regional water plans.

2.3 Study selection process

To determine the first studies to initiate and fulfill the second mandate from HB 721, the TWDB researched ASR and AR projects recommended in the 2022 State Water Plan. The evaluation of each of the 33 projects included gathering information from the 2022 State Water Plan, calling project sponsors to obtain status of project and interest, and then classifying different components of projects. The information gathered for each project was scored according to the following criteria:

1. **Sponsor interest**: The level of interest a project sponsor expressed in having TWDB staff complete a study; a higher score was given to interested sponsors that identified a need for a study by the TWDB. Interest from the sponsor was the most important criterion since we would not be able to successfully complete a beneficial study that moved a project forward without sponsor support.
2. **Planning status**: The status of any work or studies related to the ASR project ranged from no studies to a complete facility. A higher score was given to projects with less work completed, because a TWDB study would provide more benefit.
3. **Data availability**: The relevant data available for the proposed ASR study. Existing data would allow the team to quickly start and complete the first ASR or AR study per the requirements of HB 721, so a higher score was given to proposed studies that had high-quality data readily available to complete them.
4. **Matching study type with staff skills and availability**: The type of study needed to advance the project had to match the skillset of TWDB staff and the timing of staff being available to complete the study.
5. **Online decade**: The decade listed in the regional water plan or state water plan for the water management strategy project. An earlier online decade was given a higher score.
6. **Source type**: This data was collected as additional information only and did not affect final scoring.

In addition to the listed criteria, each sponsor was contacted to verify and collect the most recent information on the status of their recommended ASR or AR project. The ASR team provided each project sponsor with background on the legislative mandate, the type of studies that could be completed by the team, and the rough timeline in which we were looking to complete the study. The first study selected to be completed was an aquifer characterization for the ASR component of the Guadalupe-Blanco River Authority Mid-Basin Water Supply Project (Croskrey and others, 2022). The second study was a longevity assessment of the public supply wells for the City of Bandera to evaluate the viability of existing wells and the need for an ASR project to meet the growing demand of the city and new subdivisions in Bandera County (AlKurdi and others, 2023).

Pursuant to the legislative mandate and our project scoring, this project was selected as the next study in a series of high-level ASR suitability assessments to be performed by the TWDB for the projects in the 2022 State Water Plan with no previous studies to assist stakeholders with the progress of these projects. This report is the first assessment that evaluates the suitability of ASR for the Lower Valley Water District (LVWD). The LVWD receives its water supply from El Paso Water, which currently meets the LVWD customers' water demands. However, with the population growth in the region, it is projected that water demands will significantly increase (WSP and Freese and Nichols, 2021). Additionally, El Paso Water is considering increasing its water rates by approximately 30 percent in 2024, which will increase costs and pose a challenge for LVWD and its mostly rural customers (Flores, 2023, personal communication). Given these two factors, LVWD is interested in securing a more affordable alternative water source to maintain supply for the growing demand within its service area. The LVWD has several recommended water management strategies listed in the 2022 State Water Plan, including the construction of a new wastewater treatment plant and an ASR project with a planned online decade of 2030. The District recently received federal funds for the construction of the new wastewater treatment plant for this strategy, which makes the project more feasible (Flores, 2023, personal communication).

The TWDB ASR team selected this study because 1) the LVWD was interested in an ASR evaluation, 2) the team had knowledge of the Hueco Bolson aquifer (the target aquifer for the ASR project), and (3) there was information available on the excess water and water needs from the Statewide ASR Suitability Survey (Shaw and others, 2020).

2.4 Lower Valley Water District – Wastewater treatment facility and ASR

The LVWD is constructing a new wastewater treatment facility to treat municipal wastewater and looking into injecting the excess treated wastewater effluent into the confined part of the Hueco Bolson aquifer through an ASR system (WSP and Freese and Nichols, 2021). The goal of this water management strategy is to balance supplies during high demand.

The proposed size of the new wastewater treatment facility is 3 million gallons per day. The LVWD explained that the plant will treat municipal wastewater to Type I reclaimed water standards. Type I reclaimed water is defined in Texas Water Code § 210.33 as water that is not potable but is suitable for human contact (TCEQ, 2023a). The new facility is permitted to discharge up to 900,000 gallons per day to the San Felipe Arroyo and drain to the Rio Grande (Flores, 2023, personal communication).

Within the Far West Regional Water Plan, the Hueco Bolson aquifer was determined to be the most suitable target to store the excess water due to its high storage volume potential as well as the minimal pumping activity from other wells that is not expected to affect the stored supply. The estimated excess treated wastewater to be available for injection is 5,589 acre-feet per year. The new ASR system will consist of two new 650-foot depth wells along with 5,280 feet of 12-inch diameter pipe network to convey water.

3. Study area

This section includes a description of the physical location of the study area as well as the geological structure of the ASR project target aquifer for storage.

3.1 Study location

This study focused on the LVWD service area located in the southern part of El Paso County in the Far West Regional Water Planning Group (Region E) (Figure 3-1). This arid region in Texas is characterized by a scarcity of water resources, which impacts the quality of life and economic health of the region. Most development and agriculture in the area takes place along the Rio Grande where access to shallow water and surface canals has historically been available. The LVWD provides water, wastewater, and solid waste services for the City of Socorro, the City of San Elizario, the Town of Clint, and other retail customers, such as El Paso County Sparks Addition, Sand Hills, and El Paso County Colonias with a service area of approximately 210 square miles. There is no groundwater conservation district managing groundwater withdrawals in El Paso County, however, the LVWD service area overlaps with part of the El Paso County Priority Groundwater Management Area, which is defined by TCEQ as an area under or expected to experience critical groundwater challenges within 50 years. The study area is also part of Groundwater Management Area 5.

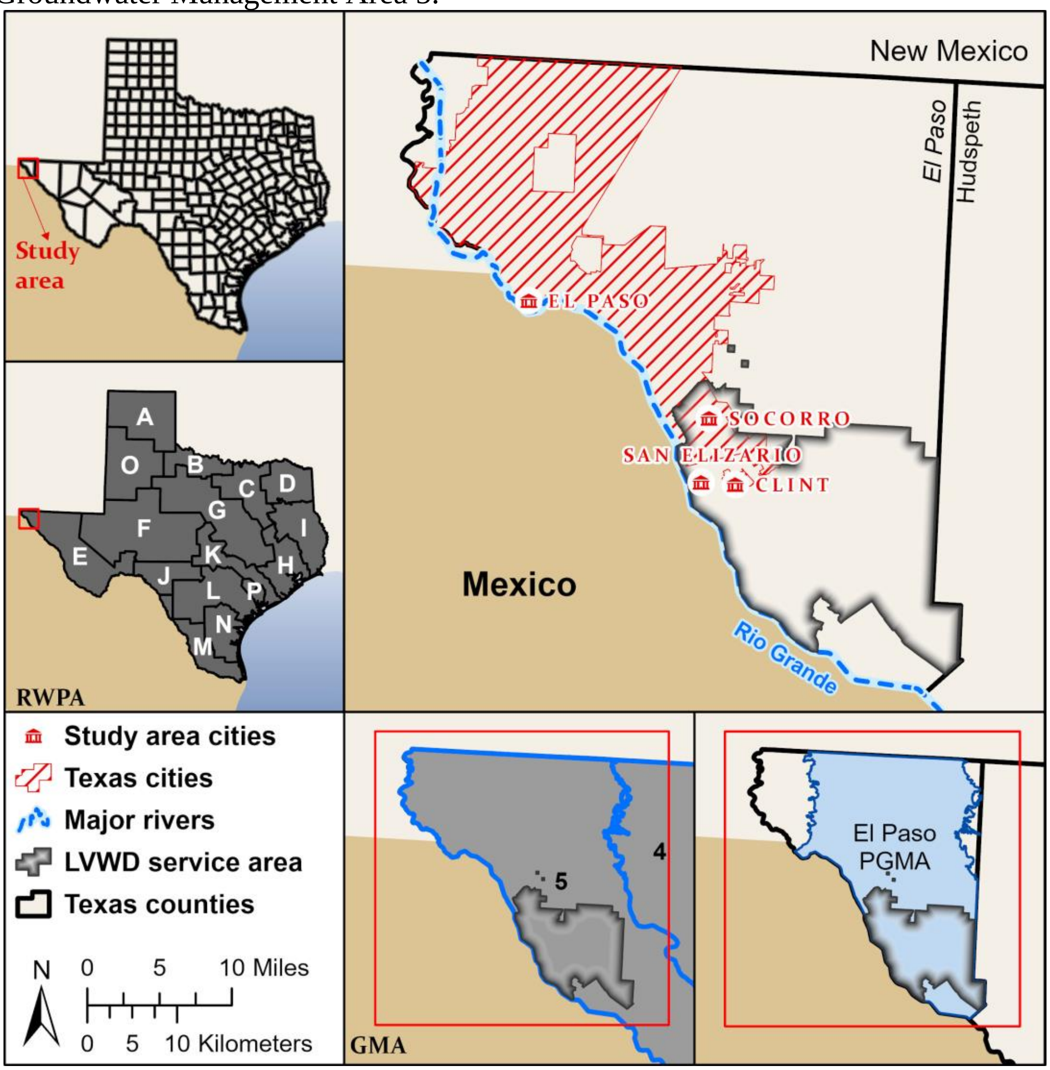


Figure 3-1. Lower Valley Water District service area administrative boundaries.

3.2 Geologic setting

Southern El Paso County is located over the Hueco Bolson, which is a part of a series of north trending connected basins within the Rio Grande rift system (Collins and Raney, 1995; Fisher and Mullican, 1989; Budhathoki and others, 2018). The Hueco Bolson trends north to south, is approximately 200 miles long and over 25 miles wide, and grades into the Tularosa Basin northward in New Mexico. The northern portion of the Hueco Bolson contains north-south trending faults throughout the depositional system (Figure 3-2). Both the sediments below and within the Hueco Bolson record a complex tectonic and depositional history (Collins and Raney, 1991, 2000; Hadi, 1991).

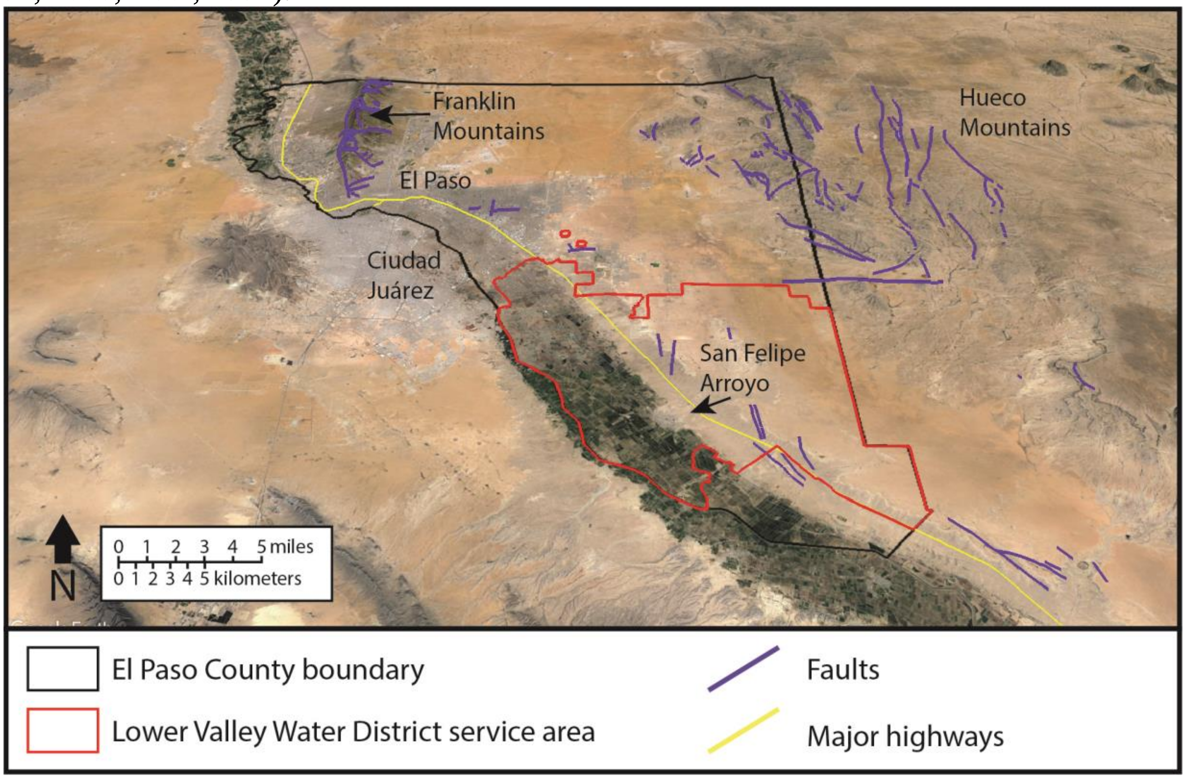


Figure 3-2. Google Earth imagery of El Paso County showing locations of major topographic features. Image has an eye altitude of 38 miles and three-times vertical exaggeration.

3.2.1 *Structural History*

The Hueco Bolson overlies a large northwest-to-southeast trending structural zone referred to as the Texas Lineament (Figure 3-3) (Collins and Raney, 1991). Deformation of this area began during the Precambrian, and the faults created during this time have remained an area of structural weakness throughout the depositional record of the area (Collins and Raney, 1991; Hadi, 1991).

During the Late Pennsylvanian, compressional tectonics from the development of the Ancestral Rocky Mountains created the Pedragosa and Orogrande basins where the modern Hueco Bolson is located, which are filled with primarily shallow marine carbonates (Hadi, 1991).

Extensional faulting from the Late Triassic to Early Jurassic led to the development of the Chihuahua basin, a deep north-south trending marine basin that contains Mesozoic evaporites, carbonates, and sandstones (Hadi, 1991; Haenggi, 2002). The normal faults that bound the Chihuahua basin were overlain by carbonates and can only be seen in the subsurface. The Clint Fault, which is located within the study area, is interpreted to be one of these basin bounding faults (Collins and Raney, 1991).

The later compressional tectonics from the Late Cretaceous to Eocene associated with the Laramide uplift reactivated many of the faults within the Chihuahua basin and created the Chihuahua tectonic belt (Hadi, 1991). The thick evaporite deposits located at the base of the Chihuahua basin allowed the carbonate rocks above it to be moved, creating a series of northwest-trending thrust faults and folds. During the late part of the Laramide uplift, during the Late Oligocene to Early Miocene, volcanic activity created several intrusions across the area (Collins and Raney, 1991).

During the Eocene, the regional tectonics shifted to an extensional regime, which created the Rio Grande rift, an asymmetric graben, which is the origin of the Hueco Bolson and Tularosa basin (Collins and Raney, 1991; Hadi, 1991; Sheng and others, 2001; Avila, 2016). Normal faults are common within the Hueco Basin, and those that have offset quaternary deposits may be seen on the surface (Figure 3-4). The Hueco Bolson has been informally divided into two sub-basins: the northwest and southeast Hueco basins. The LVWD service area is located on the southern edge of the northwest sub-basin. Faults in this area are generally oriented north-south (Collins and Raney, 1991).

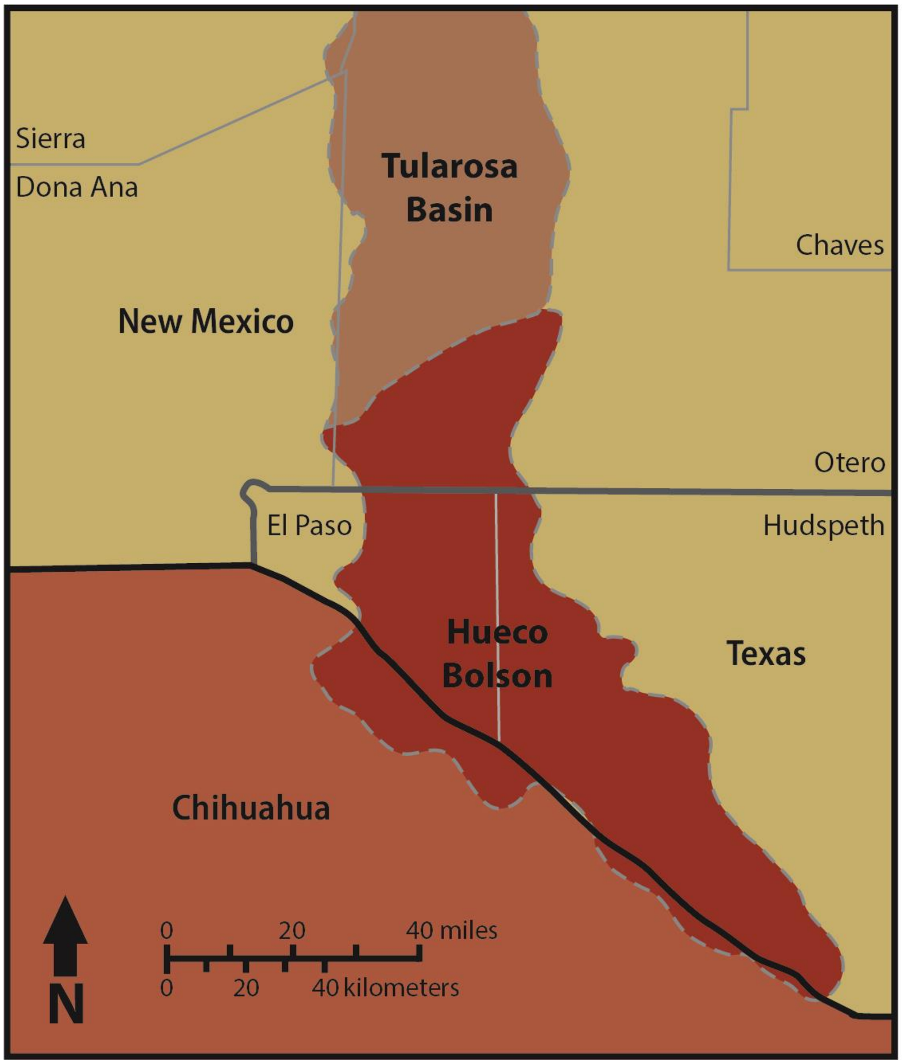


Figure 3-3. **Location of the Hueco Bolson and Tularosa basin in Texas, New Mexico, and Mexico. Modified from Sheng and others (2001).**

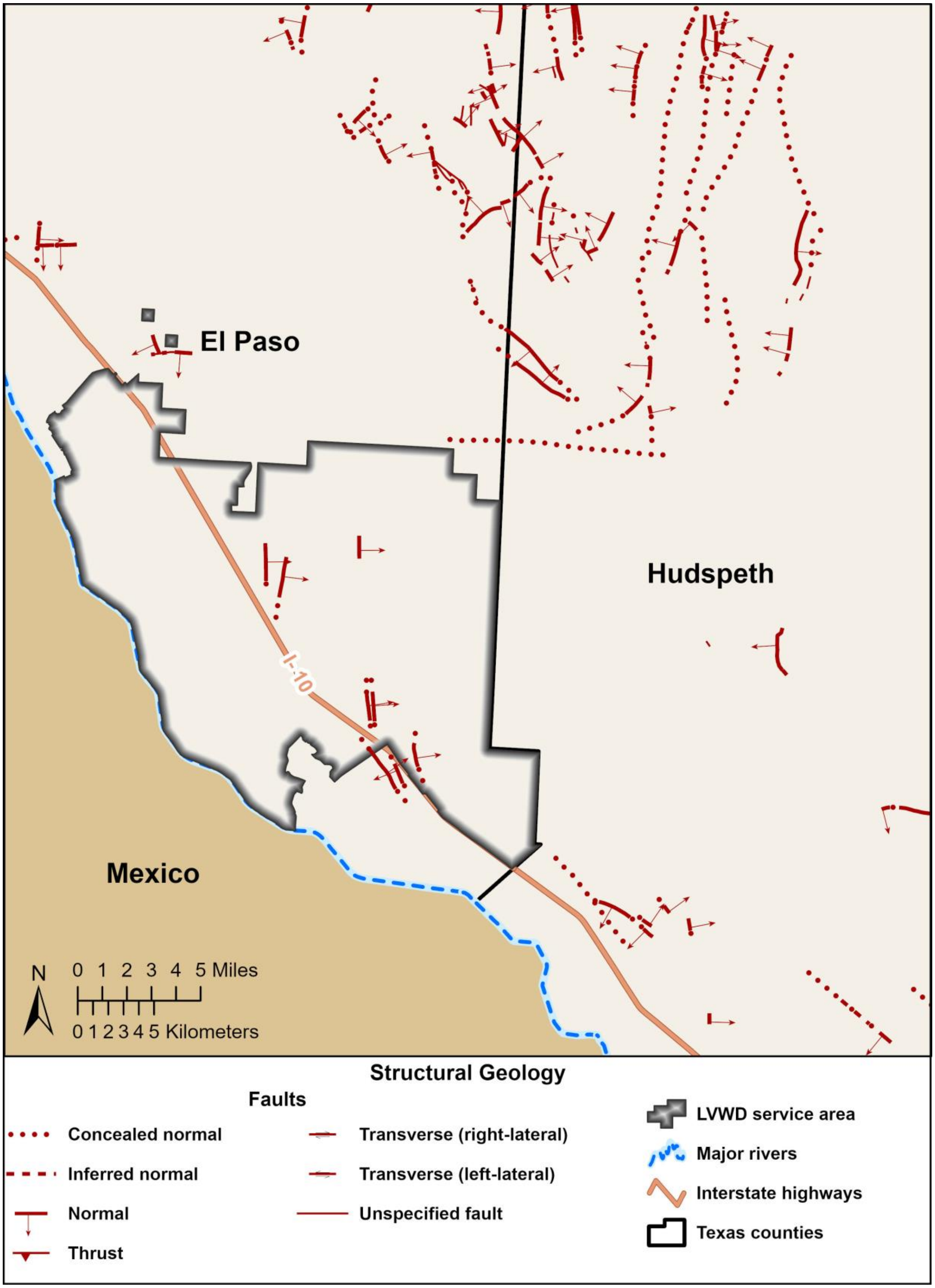


Figure 3-4. Surface structural geology map of the Lower Valley Water District study area.

3.2.2 *Depositional history*

Precambrian rock outcrops are found in the Franklin Mountains in the northern part of El Paso County as well as to the east of the study area in Hudspeth County (Collins and Raney, 2000). These rocks display a history of metamorphism and deformation prior to the deposition of the marine Paleozoic units that form the bedrock under most of the Hueco and Mesilla bolsons (Collins and Raney, 2000). Outcrops of the Precambrian basement in the foothills of the Hueco Mountains are primarily granite and were deposited between 1,260 and 1,130 million years ago (Hadi, 1991; Collins and Raney, 2000).

The Paleozoic and Mesozoic bedrock present under most of the Hueco Bolson is primarily marine carbonates and shales (Hadi, 1991) (Figure 3-5). Outcrops of these units can be seen in the Hueco Mountains on the eastern margin of the Hueco Bolson, northeast of the study area (Collins and Raney, 2000). Several large-scale sequences consisting of uplift, erosion, and depositional environments created a series of unconformities (Hadi, 1991). The uppermost Paleozoic unit in the Hueco Bolson is the Permian Hueco Limestone, which underlies the Hueco basin-fill units in the northern portion of the study area (Figure 3-6). The Hueco Limestone consists of marine limestone, dolomitic limestone, and shale (Collins and Raney, 2000). The unit is divided into three informal members based on shale marker beds at the base of the members (Collins and Raney, 2000). The Hueco Limestone is approximately 2,200 feet thick at the base of the Franklin Mountains and approximately 1,500 feet thick in the Hueco Mountains (Hadi, 1991). However, within the central basin and this study area, the total thickness of the unit is indeterminate—with only one well penetrating 2,980 feet but not reaching the base of the unit (Hadi, 1991).

Compressional tectonics during the Laramide Uplift caused the entire Chihuahua basin to be uplifted and eroded. There is a large erosional unconformity between the Permian Hueco Group and the overlying Cretaceous units (Hadi, 1991). The Cretaceous Campgrande Formation underlies the southern section of the study area and is characterized by a thick evaporite base overlain by interbedded limestone, sandstone, conglomerates, and shale units (Hadi, 1991; Collins and Raney, 2000). Not much information is available about the Cretaceous units underlying the study area, but compressional tectonics have thickened the units, creating several repeating sections (Hadi, 1991). A well within the study area measured over 6,910 feet of repeated section but did not fully penetrate the Cretaceous units (Hadi, 1991). Due to data limitations, the Paleozoic and Mesozoic bedrock present in the region was mapped as a single unit referred to as the Carbonate bedrock.

Following deposition of the Mesozoic units, the transition to extensional tectonics led to igneous intrusions (Collins and Raney, 2000; Figure 3-5). These intrusive rocks are primarily composed of andesite or fine-grained syenite and monzonite that can be seen in outcrops in the Franklin and Hueco mountains (Hadi, 1991; Collins and Raney, 2000). These intrusions may be present in the Paleozoic and Mesozoic rocks below the study area but have not been mapped due to lack of adequate subsurface data.

Above the major unconformity, the Hueco Bolson is filled with Miocene–Pleistocene aged deposits, which are the primary focus of this study. These deposits consist of unconsolidated to poorly consolidated siliciclastic sediments deposited in fluvial, alluvial, and lacustrine environments (Hadi, 1991; Budhathoki and others, 2018). The Miocene–Pleistocene Fort Hancock Formation consists of interbedded sand, silt, and mud with some evaporite deposits. This unit is highly heterogenous and contains many individual sand bodies that pinch out over short distances (Hadi, 1991). The Fort Hancock Formation is interpreted to have been deposited in a primarily lacustrine and alluvial environment (Budhathoki and others, 2018; Collins and Raney, 2000). Some studies have also identified small-scale fluvial deposits within the formation (Budhathoki and others, 2018).

The overlying Pliocene–Pleistocene Camp Rice Formation primarily consists of sand and gravel deposits with minor amounts of silt and clay (Collins and Raney, 2000). The Camp Rice Formation is interpreted as primarily a braided river system with some alluvial deposits (Budhathoki and others, 2018). The Camp Rice Formation lies unconformably above and downcuts into the Fort Hancock Formation (Budhathoki and others, 2018). Due to data limitations within the study area, the Fort Hancock and Camp Rice formations were mapped as a single unit referred to as the Hueco basin-fill deposits.

The surficial units within the study area consist of a series of several Pleistocene gravel beds, eolian deposits, and the Rio Grande Alluvium (Budhathoki and others, 2018). The gravel beds have informally named the Miser, Madden, Gills, Ramey, and Balluco gravels. These gravel deposits are overlain by modern eolian deposits and the Rio Grande Alluvium (Had, 1991). The Rio Grande Alluvium can be difficult to distinguish from the Camp Rice and Fort Hancock formations due to the much of the alluvium being reworked older Pleistocene sediment, however, the presence of the Pleistocene gravel beds within the study area makes it relatively easy to distinguish in logs.

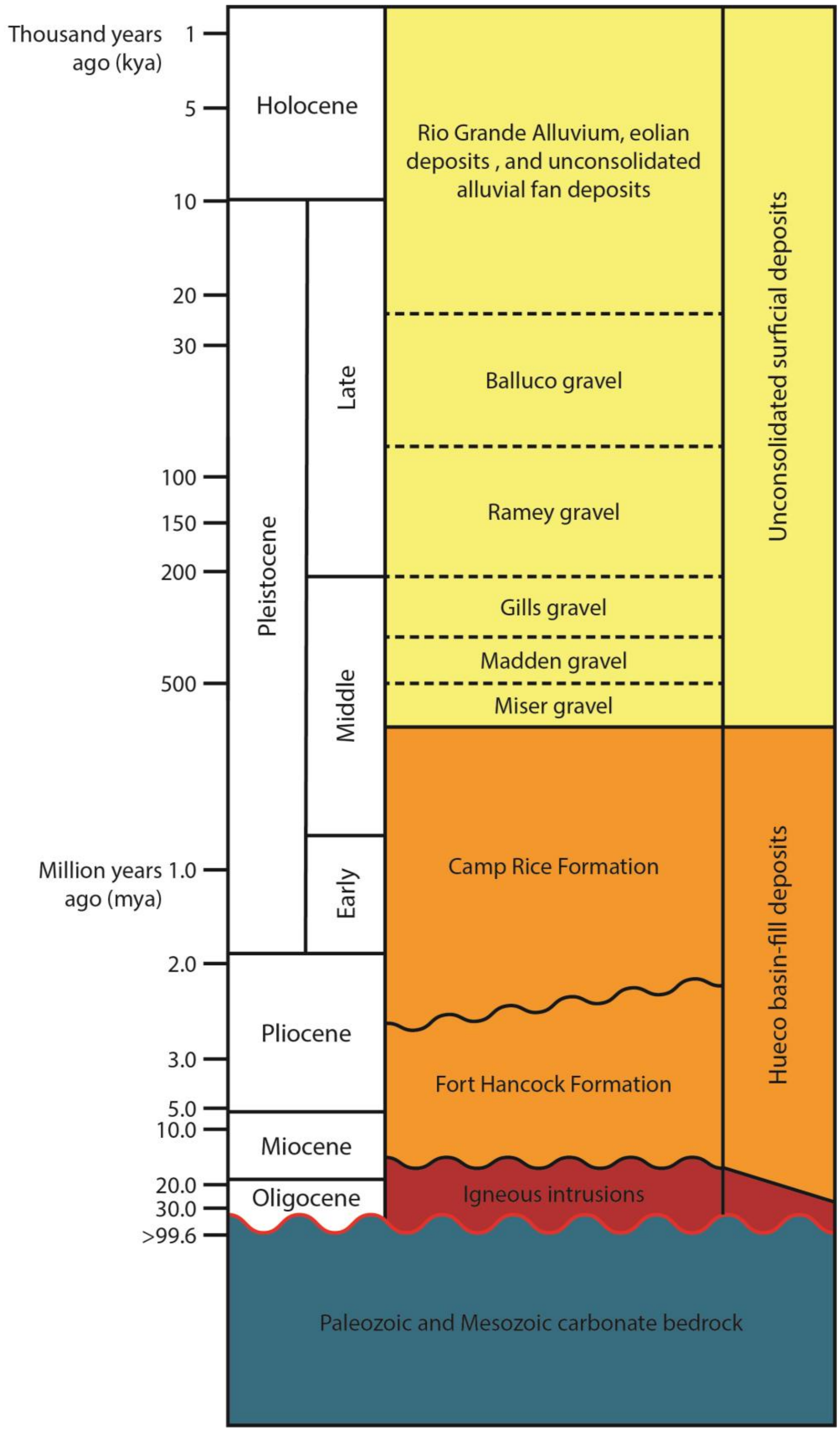


Figure 3-5. **Stratigraphic column of the Hueco Bolson within the study area. Geologic ages are in Thousand years ago (kya) and Million years ago (mya). Modified from Budhathoki and others (2018).**

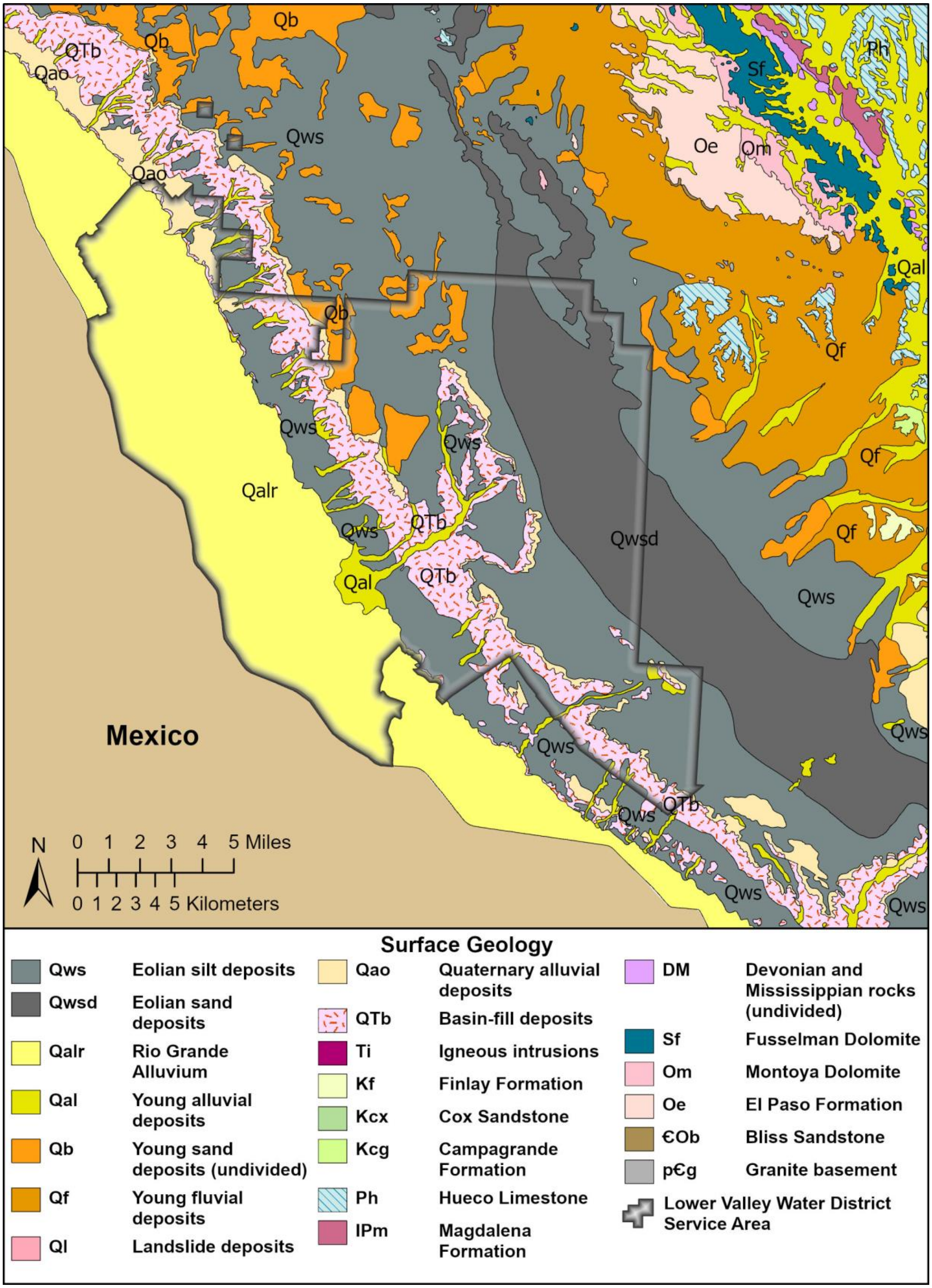


Figure 3-6. Surface geologic map for the study area with features from the digital Geologic Atlas of Texas (TWDB. 2007).

3.2.3 *Hydrogeology*

The geologic units that the LVWD service area overlies contain a portion of the Hueco-Mesilla Bolsons Aquifer (Figure 3-7) (George and others, 2011). This aquifer is a major Texas aquifer and can be split into the Hueco Bolson, which the LVWD service area overlies, and Mesilla Bolson aquifers. The Hueco Bolson aquifer is located east of the Franklin Mountains and extends under the Rio Grande into Mexico (George and others, 2011). The average length of the aquifer is 200 miles in both the United States and Mexico, with an average width of 25 miles, and a maximum thickness of 9,000 feet (Sheng and Devere, 2005, and George and others, 2011).

The Hueco Bolson aquifer is usually characterized as an unconfined aquifer within the unconsolidated units above the Paleozoic–Mesozoic bedrock, which combines the Hueco basin-fill and unconsolidated surficial deposits used in this study. In terms of hydrogeologic parameters, aquifer tests in production wells located in the El Paso Water service area gave an average horizontal hydraulic conductivity of 32.8 feet per day, which is within the range for a well in conductive semi-pervious media (Bear, 1972). The maximum and minimum hydraulic conductivity values from these tests were 164 feet per day and 3.3 feet per day, respectively. As for vertical hydraulic conductivities, results from laboratory measurements ranged from 0.02 to 0.07 feet per day (Heywood and Yager, 2002).

Extensive pumping of the Hueco Bolson aquifer, especially during drought conditions when surface water supplies diminish, resulted in a decline in water levels and deterioration in groundwater quality. Large cones of depression have been observed in the vicinity of municipal wells, which lead to a change in the regional groundwater flow towards their centers (Hibbs and others, 2006). Drawdown levels reached several hundred feet over the past decades. In 1990, the Hueco Bolson aquifer was expected to remain for a maximum of 60 years (WSP and Freese and Nichols, 2021). The Hueco Bolson aquifer receives limited natural recharge by mountain front, seepage from the Rio Grande, and unlined canals, as well as artificial recharge from irrigation returns and deep-well injection (Sheng and Devere, 2005). Parts of the Hueco basin-fill deposits are semi-confined, however, there is no one defined confining bed for the entire aquifer, as all clay beds are discontinuous (Sheng and Devere, 2005). There is no connection between the Hueco Bolson aquifer and any other major or minor aquifer (George and others, 2011).

The western portion of the LVWD service area overlies sand and clay deposits from the modern Rio Grande, which is primarily used for private water wells for irrigation. These private wells are generally shallow with well depths that are a few tens of feet deep at maximum (Hibbs and others, 2006). Groundwater produced from these surficial deposits is extensively used for irrigation within the study area. Due to the unconfined nature of these deposits and the large cones of depression due to extensive usage, these units were mapped together and not considered extensively for ASR or AR development.

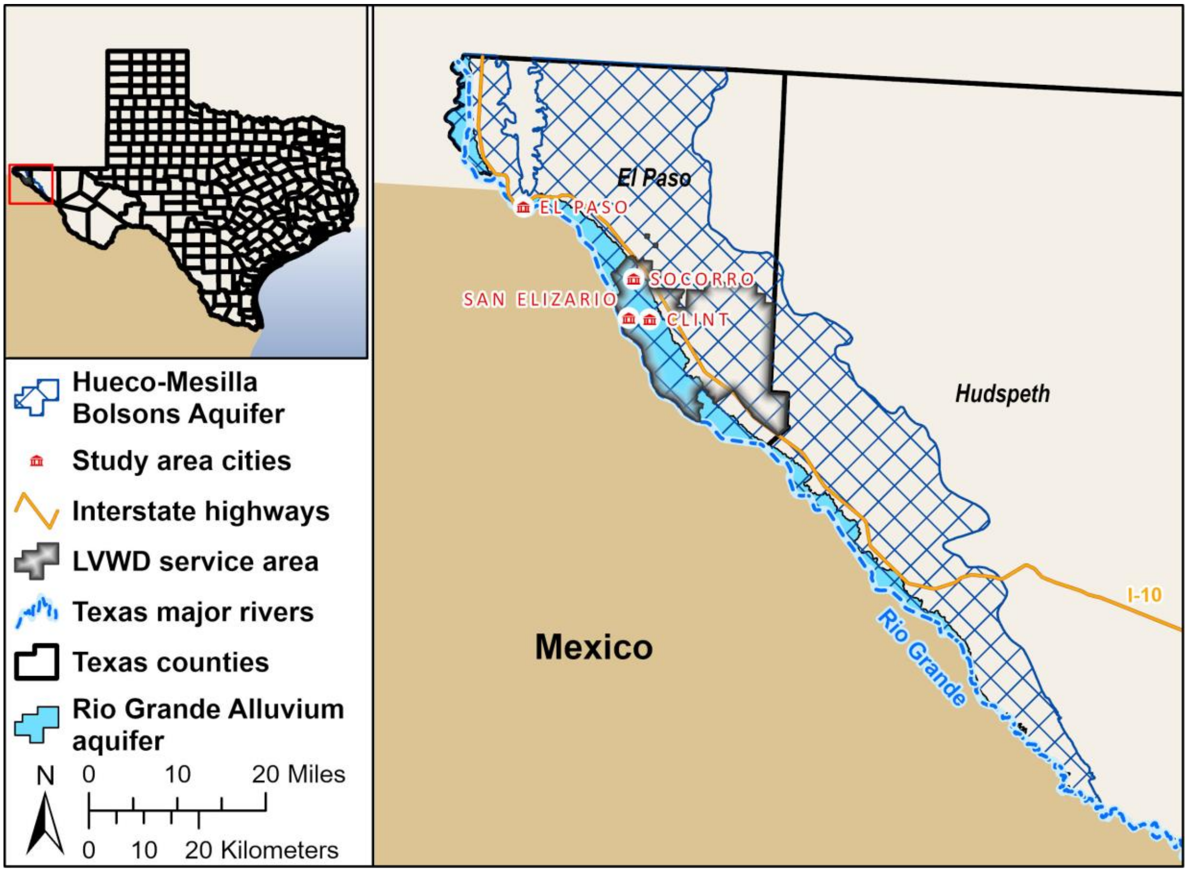


Figure 3-7. Extent of the Hueco-Mesilla Bolsons Aquifer in Texas.

4. Stratigraphy and water quality

Geophysical well logs and drillers logs were primarily used to define the top and bottom of stratigraphic units for this study (Figure 4-1). Seismic interpretations from previous studies were used in place of log analysis where data was not available. Water quality data was collected from publicly available datasets. Geophysical logs were also used to calculate total dissolved solids (TDS) concentration using the Alger-Harrison method.

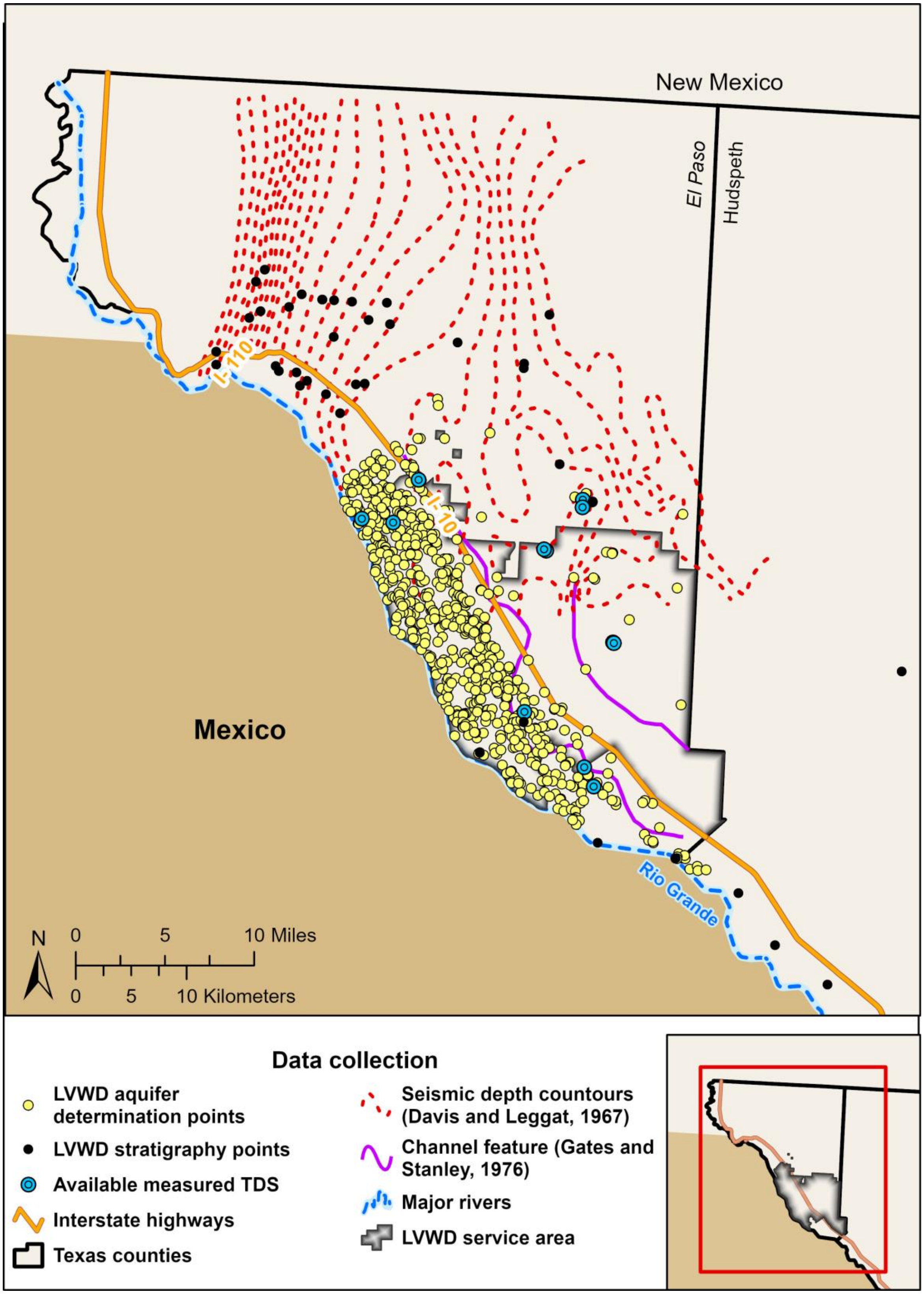


Figure 4-1. Map showing location of all data points used for stratigraphic and water quality analysis.

4.1 Stratigraphy

For this study we divided the geology into three distinct stratigraphic units based on available data and previous research. These units are, from youngest to oldest: surficial deposits, Pliocene–Pleistocene basin-fill deposits, and Paleozoic–Mesozoic carbonate bedrock. Two primary contacts were mapped:

1. The bottom of the surficial deposits with the top of the Pliocene–Pleistocene basin-fill deposits.
2. The bottom of the Pliocene–Pleistocene basin-fill deposits with the top of the Paleozoic–Mesozoic carbonate bedrock.

In addition to the elevation picks from geophysical well logs, outcrop elevation points were used to create contact elevation maps. The outcrop elevation points for the basin-fill deposits from the digital Geologic Atlas of Texas were assigned values from the ground surface 30-meter digital elevation model. We used these points to bring the interpolated elevation values from the subsurface to the outcrop. The resulting correlated elevation maps were then used to map the depth and thickness of the basin fill.

Few wells were available that penetrated the basin-fill deposits, so seismic interpretations from Davis and Leggat (1967) were used to complete the surface. The resulting correlated elevation maps were then used to map the depth and thickness of the Carrizo-Wilcox Aquifer in the study.

4.1.1 *Top of the Pliocene–Pleistocene basin-fill deposits*

The basin-fill deposits unit in this study includes both the Camp Rice and Fort Hancock formations. These two units were combined for this study because of their similar lithologic characteristics and a lack of consistent well control over the entire study area. A study by Gates and Stanley (1976) identified a channel feature synonymous with the Camp Rice Formation. Similarly, the unconsolidated surficial deposits were mapped as a single unit, which included the Rio Grande alluvium, eolian deposits, and Pleistocene gravel beds. The contact between these two units can easily be picked out in well logs by identifying the base of the Pleistocene gravel beds, which have a distinct high-resistivity signature and negative spontaneous potential kick associated with them. Typically, all five named gravel beds can be individually identified in logs.

This study used 39 geophysical well logs to identify the elevation of the top of the basin-fill deposits (Figure 4-2). Only six of the geophysical well logs were located within the study area, whereas three were located south of the study area near the Rio Grande and 30 were located north of the study area within the El Paso metropolitan area. The surface elevation of this contact ranges from 3,217 to 4,179 feet above mean level within the study area. In general, the highest elevation of the surface is to the east, where the deposits outcrop and dip gradually to the west. The depth map for the top of the Pliocene–Pleistocene basin-fill deposits was created by subtracting the unit's elevation surface values from the elevation of the earth's surface using the digital elevation model (Figure 4-3). The depth of the contact ranges from 0 to 567 feet below the ground surface. In general, the depth map parallels the elevation map where the shallowest depths are in the east at the outcrop, and the unit becomes deeper westward. However, the depth map is somewhat complicated by surface features such as the San Filipe Arroyo and the Clint Fault.

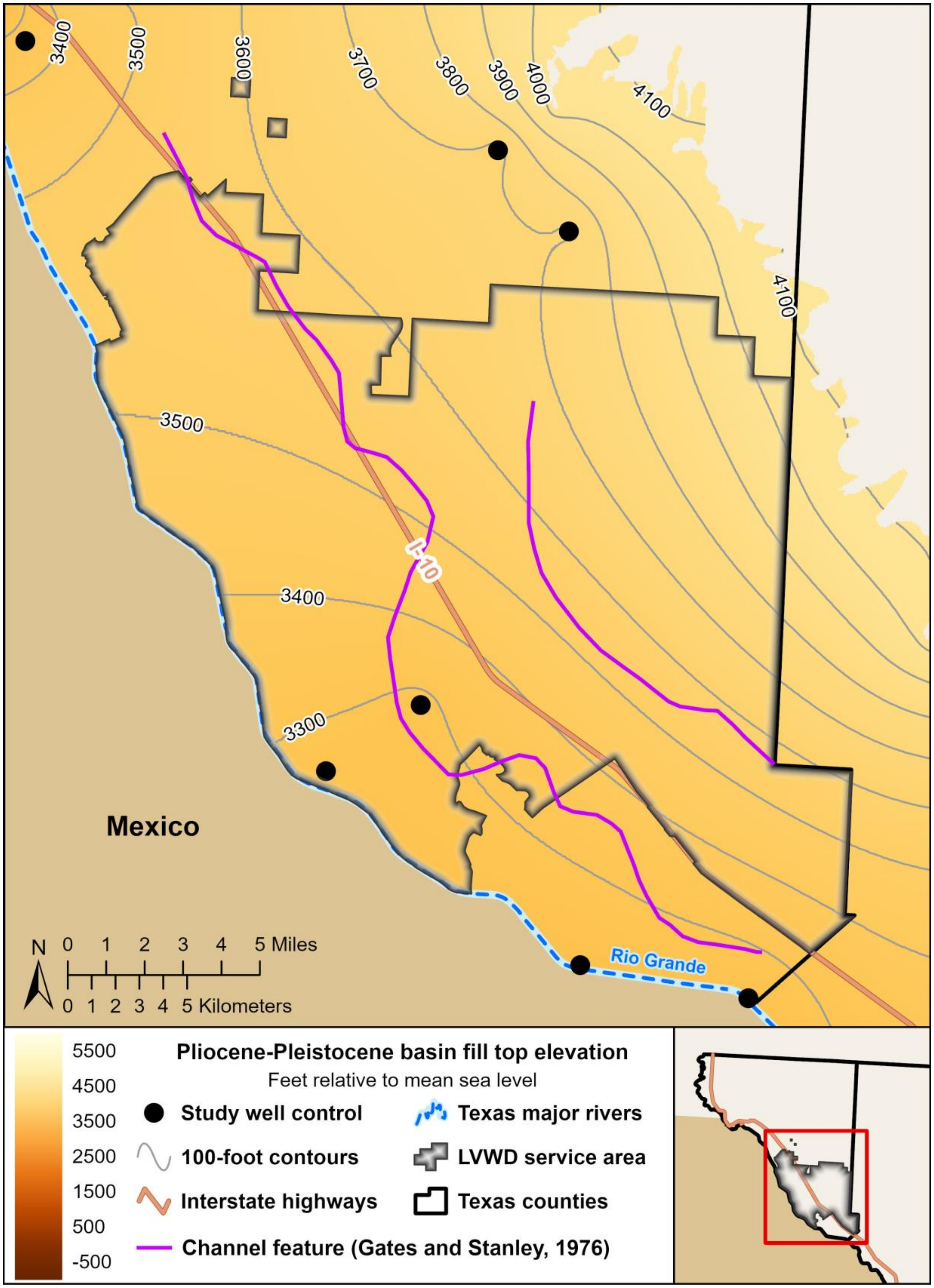


Figure 4-2. Pliocene–Pleistocene basin-fill deposits top elevation surface (feet relative to mean sea level).

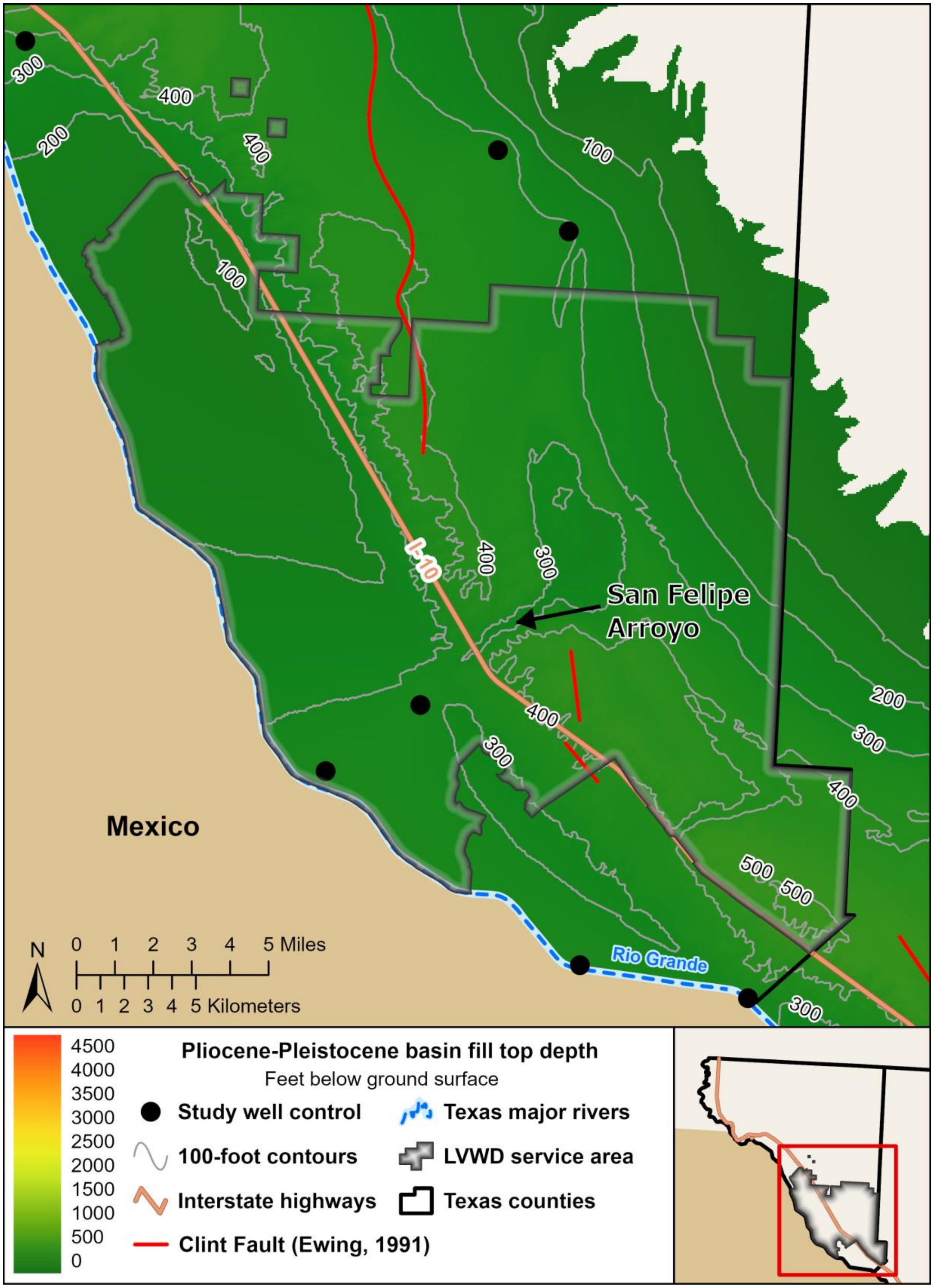


Figure 4-3. Pliocene–Pleistocene basin-fill deposits top depth in feet.

4.1.2 *Top of the Paleozoic–Mesozoic carbonate bedrock*

The bedrock units that underlie the basin-fill deposits contain the Permian Hueco Group and several Mesozoic units. Very little well control is available within the study area that penetrates the basin-fill deposits and little lithologic information is available on these units outside of the Hueco Mountains. Due to the lack of available well data, a previous seismic study examined the contact between the basin-fill deposits and the underlying bedrock was also used (Davis and Leggat, 1967). The transition from the basin-fill deposits to the underlying carbonate bedrock can be difficult to determine on logs because at depth, the salinity of the groundwater suppresses the resistivity signature. However, the interbedded, marly nature of the carbonates can be identified by examining subtle variations in the resistivity and spontaneous potential logs. Additionally, the caliper log, when present, can be used to identify when the rock transitions from indurated carbonate to the unconsolidated sands in the basin-fill deposits. Additionally, the carbonate bedrock within the study area appears to not be very porous and contains only isolated permeable beds. Likely fluid flow within these units is isolated to the faults and fractures that run through the area.

This study used six well logs to identify the top of the Paleozoic–Mesozoic carbonate bedrock. Only four logs were located within the mapped area, with one located to the south near the Rio Grande, and one oil and gas test well east of the study area in Hudspeth County. Due to the lack of well control, seismic depth contours from Davis and Leggat (1967) were used to fill in areas where there was no data. Because these contours were in depth from the surface in feet, the depth map was the first to be created for this surface (Figure 4-4). Depths in the mapping area ranged from 179 to 4,032 feet below the surface. Generally, the deepest area of contact is in the center of the mapping area, creating a deep depression. This is likely caused by the presence of the Clint Fault, which has displaced the bedrock. The overall inconsistency seen in the depth map is also likely due to smaller faults that are present throughout the area. The elevation map for the top of the Paleozoic–Mesozoic carbonate bedrock was created by subtracting the unit's depth surface values from the elevation of the earth's surface using the digital elevation model (Figure 4-5). The elevation map displays the same general patterns seen in the depth map.

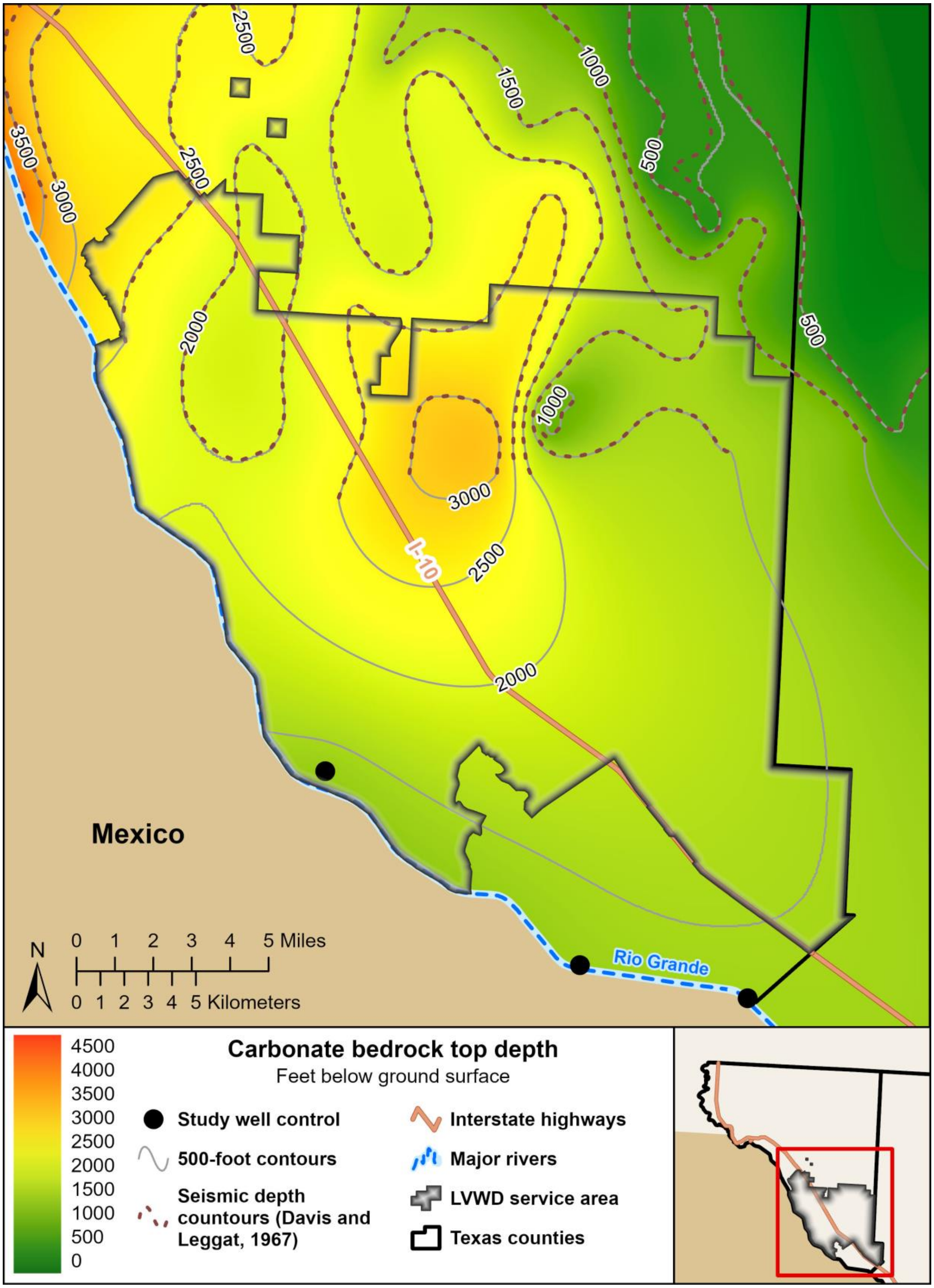


Figure 4-4. **Paleozoic–Mesozoic carbonate bedrock top depth in feet.**

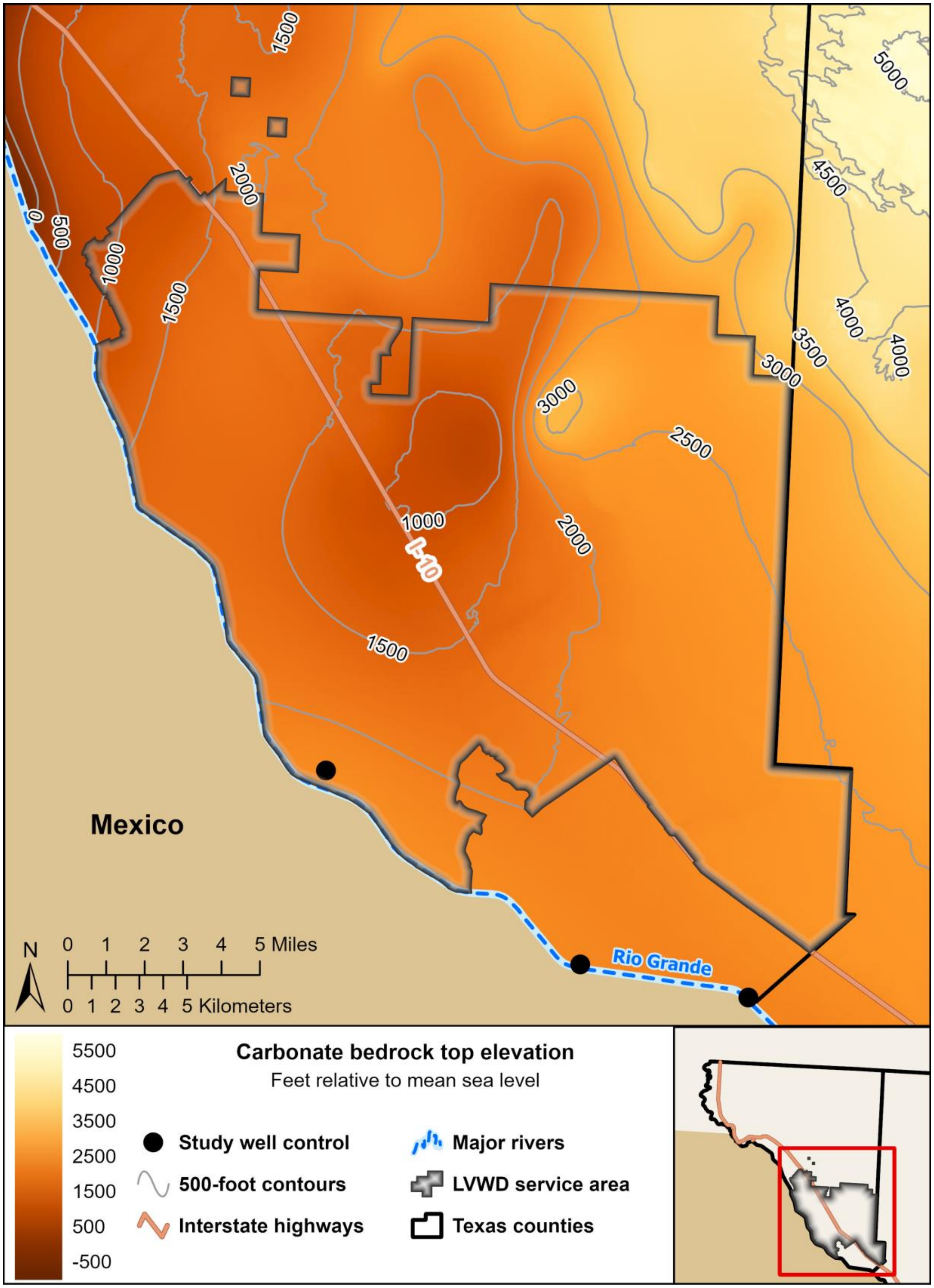


Figure 4-5. Paleozoic–Mesozoic carbonate bedrock top elevation surface (feet relative to mean sea level).

4.1.3 *Thickness of the surficial deposits*

This study grouped the Rio Grande Alluvium, gravel beds and eolian deposits into a single unit above the basin-fill deposits. Although there are distinct lithologic differences between the alluvial deposits in the western portion of the study area and the eolian deposits in the east, both are unconfined and relatively thin. These interpolated surfaces were more detailed than the surfaces incorporated in the groundwater availability model (Heywood and Richard, 2002). A thickness map of these surficial deposits was developed using raster math by subtracting the raster values of the top elevation of the basin-fill deposits from the values of the 30-meter digital elevation model. The surficial deposits are up to 567 feet; however, the maximum thickness of the unit is the thick deposits of eolian deposits east of the Clint Fault and to the south of the LVWD service area (Figure 4-6). Most of the Rio Grande alluvium is less than 200 feet thick. The Rio Grande alluvium is heavily pumped for agriculture and affected by multiple cones of depression. As shown by the El Paso Water ASR and AR project, any water from an infiltration basin will likely move rapidly toward the underlying basin-fill deposits.

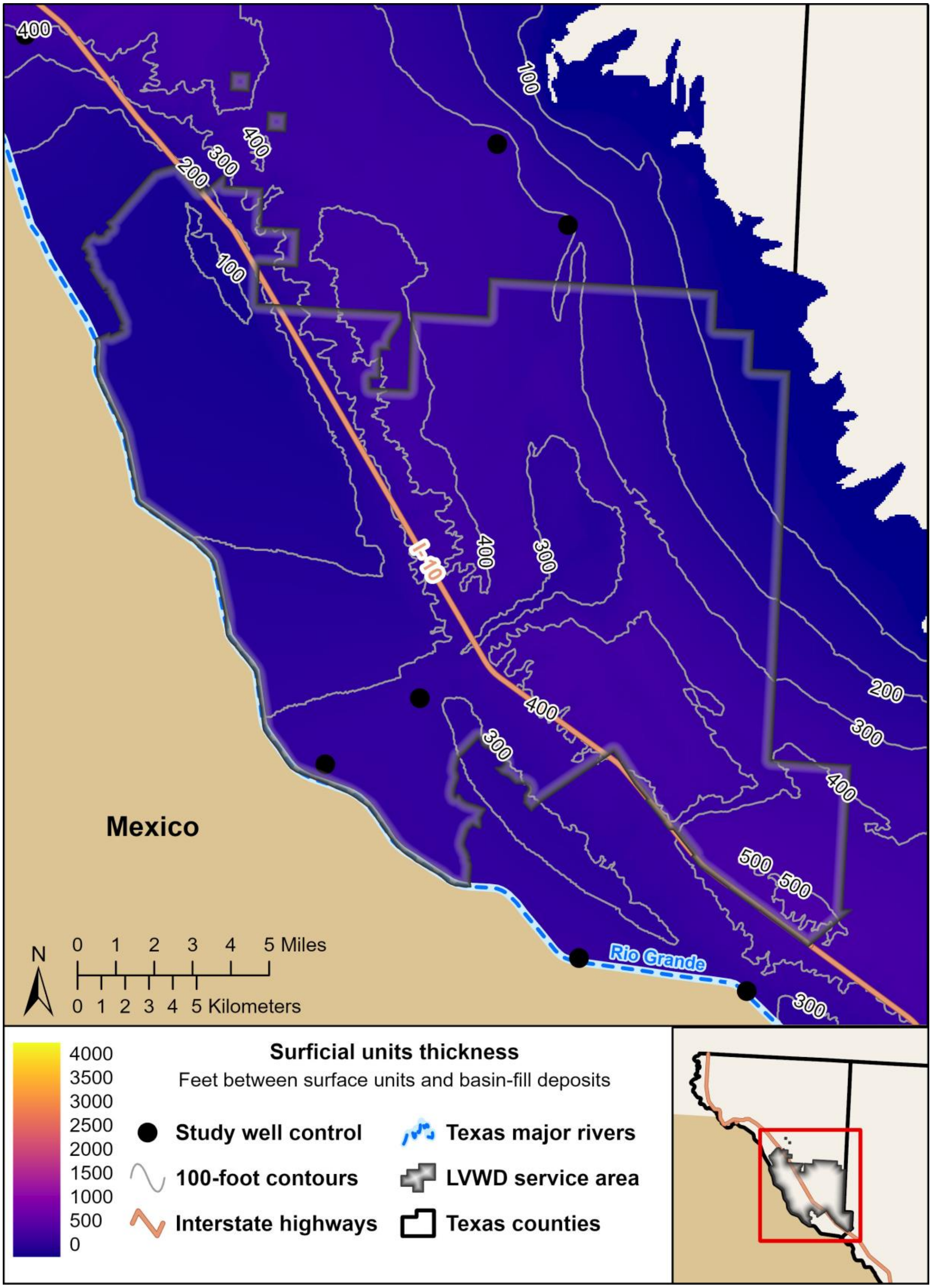


Figure 4-6. Thickness map of the surficial deposits in feet.

4.1.4 *Thickness of the Pliocene–Pleistocene basin-fill deposits*

The surficial deposits in the study area are being pumped extensively for agriculture and therefore present a difficult setting for developing an ASR or AR project. While there is little data on the carbonate bedrock within the study area, outcrop studies indicate that the units likely only have extensive porosity along faults due to the Permian Hueco group being composed of limestone and shale (Hadi, 1991). Although the Cretaceous units in the area may contain sands, no indication of sandstone units was seen in the few well logs that penetrated the bedrock units. This makes the carbonate bedrock units poor targets for ASR, and their depth precludes an AR project (Hadi, 1991). Additional examination of the Pliocene–Pleistocene basin-fill deposits was needed to fully identify the portion of the aquifer that would be suitable for an ASR or AR project. A thickness map of the basin-fill deposits was developed using raster math and subtracting the raster values of the elevation of the carbonate bedrock from the top of the basin-fill deposits (Figure 4-7). The thickness of the basin-fill deposits within the mapped area ranges from 249 to 3,865 feet. The thickest portion of the unit is in the center of the study area. Generally, the thickness map is similar to the depth of the carbonate bedrock map due to extensive subsurface faulting.

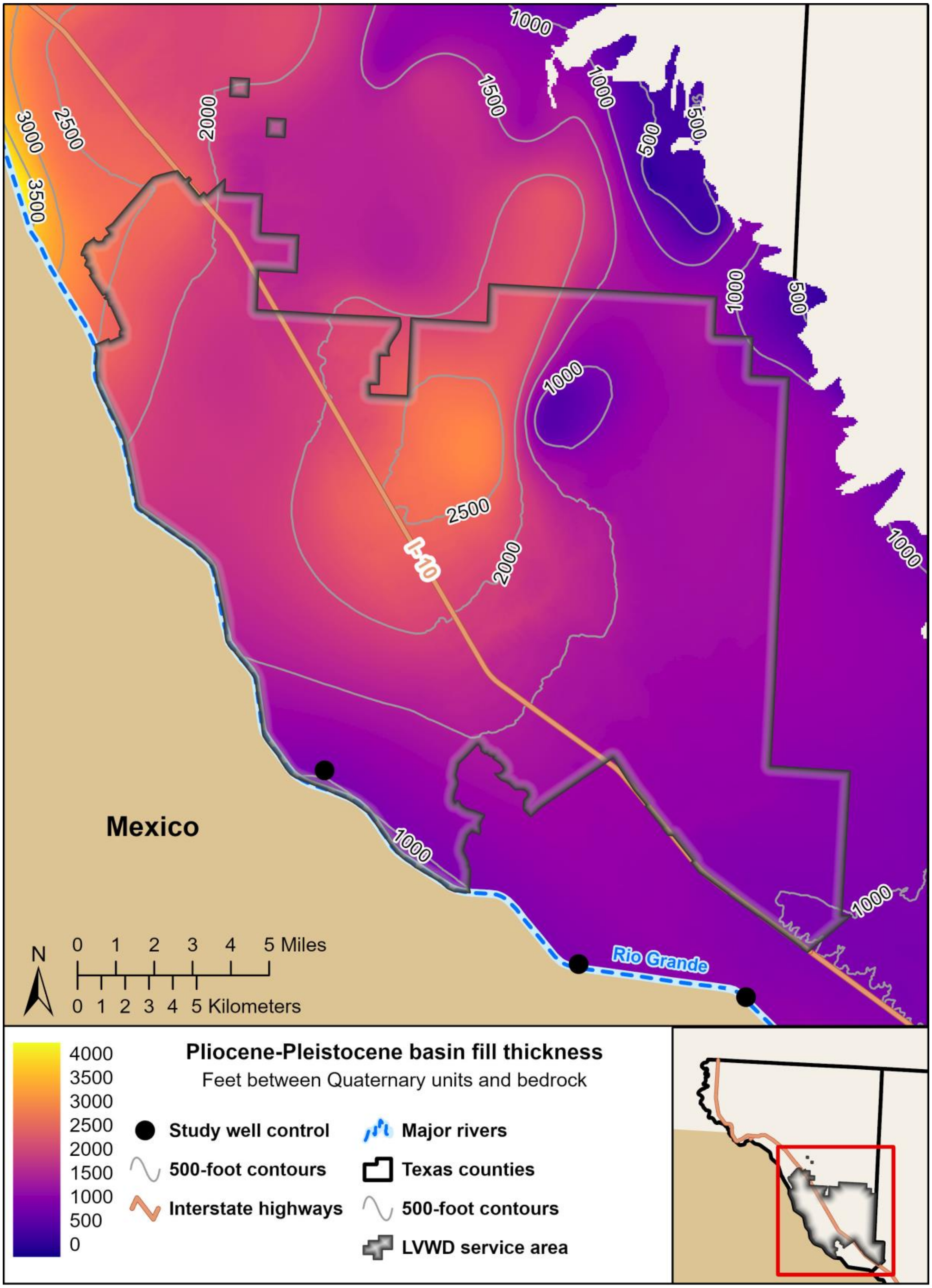


Figure 4-7. **Thickness map of the Pliocene–Pleistocene basin-fill deposits in feet.**

4.2 Water Quality

One of the hydrogeological characteristics important for ASR and AR is the water quality of the native groundwater. One of the most important water quality aspects is the salinity or TDS of the water, defined as the total concentration of all dissolved molecules and ions reported in units of milligrams per liter. The salinity of the native groundwater must be considered when assessing possible chemical interactions with the source water, designing the project, planning operations, and applying for permits.

In general, the Hueco Bolson aquifer water quality is characterized by a thin freshwater zone underlain by slightly saline groundwater (Sheng and Devere, 2005). Freshwater occurs in the upper portion of the aquifer and extends to less than 100 feet below the surface in some parts of the aquifer. Saline zones primarily are in the southern, deeper parts of the aquifer (Heywood and Yager, 2002). For this salinity level analysis, we considered measured water quality samples from wells and calculated TDS concentrations from geophysical well logs. These data were tabulated and are available in the TWDB BRACS Database (section 11, Appendix C).

4.2.1 *Measured water quality*

Water quality data were gathered from the TWDB Groundwater Database (TWDB, 2023a) for wells that were determined to be completed only below the surficial deposits. This determination was done by comparing the screen and casing depths of wells to the formation top and bottom depths. Out of the 22 wells assigned in the study area, 11 wells had available water measurements for the basin-fill deposits (Figure 4-8). More details about TDS data verification and quality control method are in Appendix A – Aquifer determination, stratigraphy, and water quality methods. Water quality data for one well only (BRACS Well-ID 34059) were obtained from the United States Geological Survey (USGS) produced water database (Blondes and others, 2016). This well is located far to the east, outside the study area; however, it is completed in a deeper and mostly carbonate bedrock, thus the high salinity levels.

Most available measurements were from the 1970s. Only two wells had more recent measured TDS samples. State Well Number (SWN) 4922623—located in the furthest north portion of the LVWD service area—had a water sample from 2004 and is an irrigation well drilled in 1980 with a depth of 400 feet. SWN 4931919 is a public supply well located in the south in the City of Fabens outside of the LVWD service area and had a water sample from 2018 that was drilled in 1990 with a total depth of 500 feet. Both wells had multiple samples taken over time as shown on the graphs in Figure 4-8. The irrigation well TDS levels significantly increased in about 25 years from fresh to slightly saline, whereas the public supply well TDS levels remained within the fresh range for 38 years.

Geophysical logs in the vicinity of each well were examined to determine if the increased TDS levels in the irrigation well are due to the structure/geology of the basin-fill deposits at that location. There is no definitive contrast between the geophysical logs except for a thicker clay bed near the public supply well location, which prevents communication with the carbonate bedrock (characterized by higher salinity) below it. In terms of production, both wells have comparable rates between 600 and 800 gallons per minute, however, the irrigation well is located closer to the Rio Grande in a thick section of the Rio Grande alluvium. This implies a possible mixing of groundwaters and drawing from both the surface water influenced alluvium as well as the basin-fill deposits. The irrigation well is also close to the Clint Fault and may be drawing saline water up from the carbonate bedrock. Further, the agricultural well is the sole supply source for the entity and may be continuously pumped, whereas the public supply well is one of several wells owned by the City of Fabens. So, the City could be alternating or partially using each of their wells. Continuous pumping may lead to more substantial draw up of the lower saline water.

No pattern of salinity levels and location is identified. The most saline wells are two industrial wells located in the east central part of the study area (State Well Numbers 4932504 and 4932505). These wells extend down to a depth of 1,300 feet and are in a faulted part of the carbonate bedrock. The Clint Fault most likely creates communication with the basin-fill deposits above it, resulting in higher TDS values as seen in the well located far east out of the study area (API number 42222930192). The shallowest well in the basin-fill deposits—which is in the northwest close to the Rio Grande (SWN 4922847) in the heavy agricultural activity area—is moderately saline.

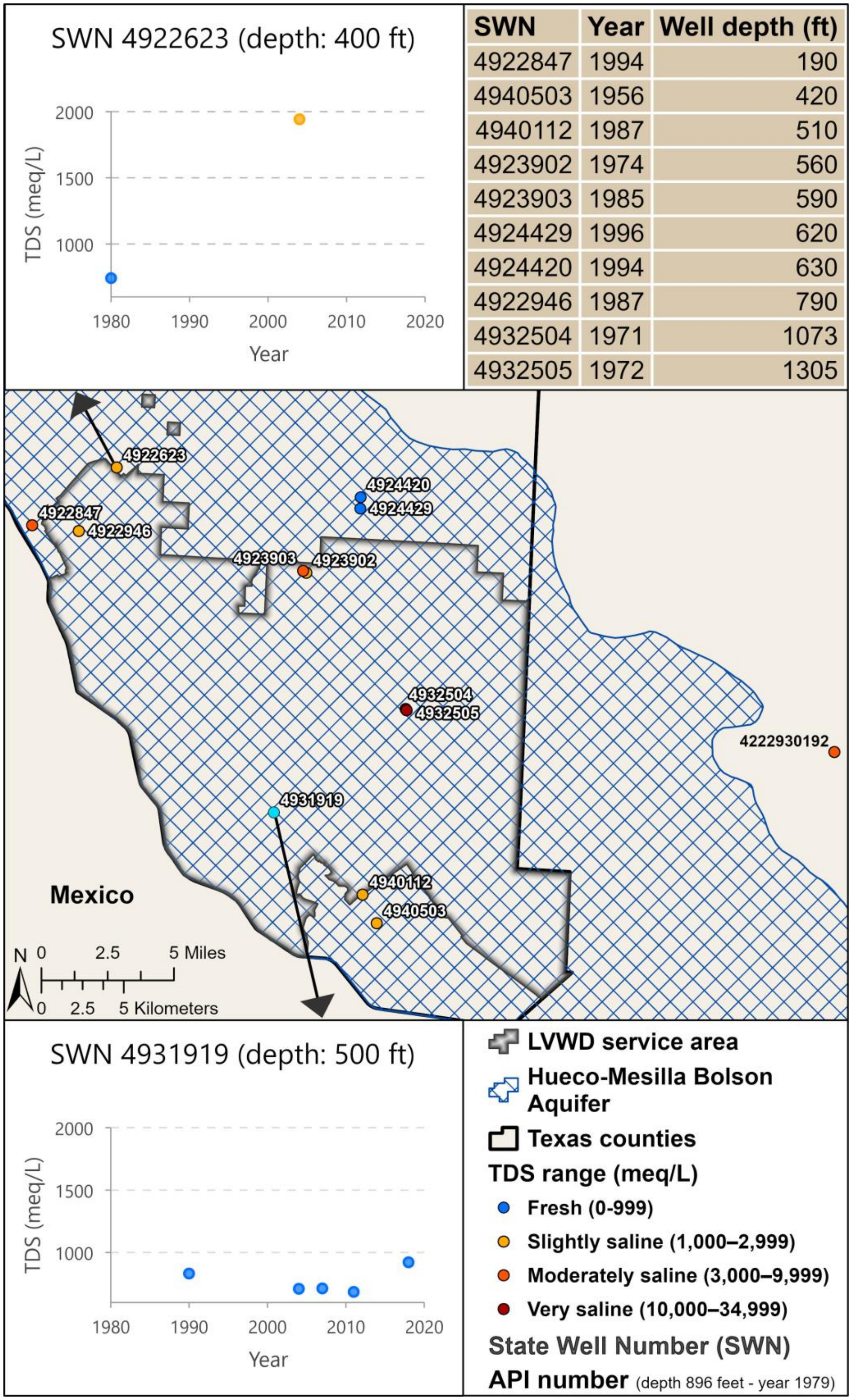


Figure 4-8. **Hueco Basin wells with available water quality data and equivalent salinity ranges (TDS concentration). SWN = State Well Number.**

4.2.2 ***Calculated total dissolved solids***

Due to the scarcity and sparse distribution of available measured water quality samples within the LVWD service area, salinity levels were estimated from geophysical well logs to increase spatial coverage. These data are also available in the BRACS Database (section 11, Appendix C). We compared the results of several methodologies with the measured water quality data and confirmed that the Alger-Harrison (Alger and Harrison, 1989) method produced results that were representative of the measured TDS levels in the study area. Commonly, the Alger-Harrison method has been used in carbonate depositional systems but produced similar results to measured water quality samples in the basin-fill deposits (Robinson and others, 2019 and Robinson and others, 2022). This result is potentially due to the significant presence of carbonate cement in the basin-fill deposits caused by the erosion and reworking of the underlying carbonate bedrock. A detailed description of the Alger-Harrison method and its application in this study is in Appendix A – Aquifer determination, stratigraphy, and water quality methods. This method provided seven additional points of TDS levels within and in the vicinity of the LVWD service area.

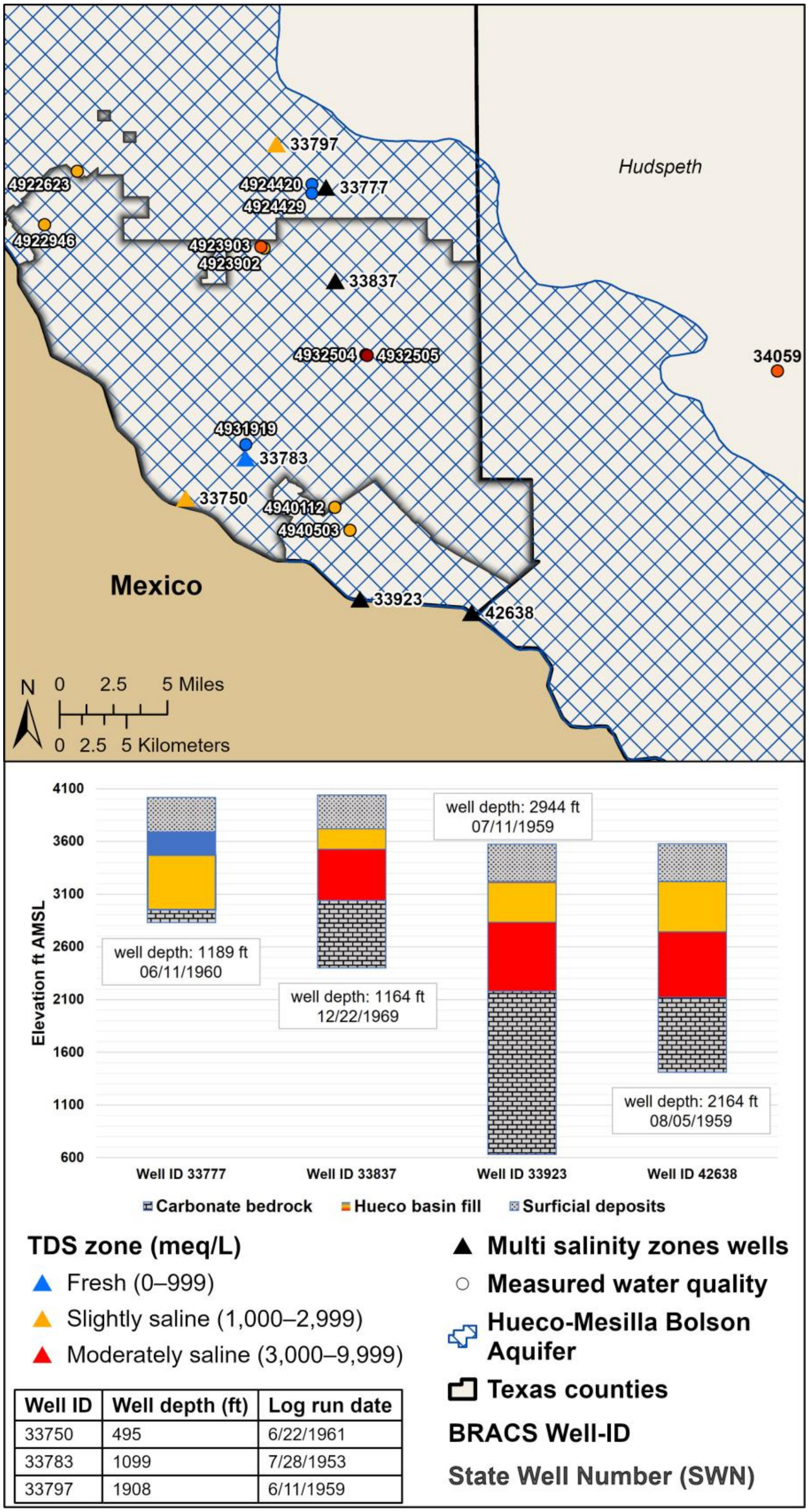
Detailed salinity zone mapping was impractical for this study because of insufficient data. However, by using resistivity readings from well logs, we were able to identify different salinity zones per depth in four out of the seven wells as shown on the graph in Figure 4-9. All these wells extend deeper than the bottom of the basin-fill deposits with geophysical logs as old as the 1950s.

Three out of the four wells have moderately saline zones that extend to a depth range from 999 feet below ground level in north of the LVWD service area (Well-ID 33837) to 1,339 feet in the south of the area (Well-ID 33923). Only one well, (Well-ID 33777) has a fresh zone extending down to a depth of 790 feet. This well is located northeast outside of the study area within a one-mile distance from two fresh groundwater measurements (SWN 9424420 and 4924429), creating a well pair for verifying TDS calculation results.

The salinity level match in this well pair confirms that the Alger-Harrison method is appropriate for estimating salinity levels in the study area. Another well pair with matching salinity levels is located in the south of the study area—Well ID 33783 and SWN 4931919. The calculated salinity level is from a log run in 1950 for 1,099 feet well depth. In addition, two single-zone slightly saline levels were estimated in the north (Well-ID 33797) and southwest of the study area (Well-ID 33750).

From the water quality analysis, it can be inferred that the factors controlling salinity levels in the study area are well depth (salinity levels generally increase with depth), the Hueco Basin structure (faults and connection with the Permian Hueco Group increases salinity level), and proximity to extensive municipal and irrigation pumping.

As mentioned previously, the increased use of the Hueco Bolson aquifer over time resulted in brackish water intrusion into the fresh zones of the aquifer. It is anticipated that more recent water quality measurements from these wells would give higher salinity ranges. Therefore, it is recommended that more comprehensive water quality testing be performed before making the final site selection for the proposed LVWD AR project.



Well ID	Well depth (ft)	Log run date
33750	495	6/22/1961
33783	1099	7/28/1953
33797	1908	6/11/1959

Figure 4-9. **Calculated water quality from well log resistivity readings. Well-ID is the BRACS Database unique identification number.**

5. Suitability analysis

The Statewide Survey of Aquifer Suitability for Aquifer Storage and Recovery Projects or Aquifer Recharge Projects (referred to as the Statewide ASR Suitability Survey in this report) mapped Texas with 50,000-by-50,000-foot grid cells and screened each grid cell for three primary criteria to determine suitability for ASR or AR as identified in Texas Water Code § 11.155 (Shaw and others, 2020):

1. Hydrogeological characteristics (including storage potential, transmissivity, infiltration, storativity, recoverability, and water quality)
2. Frequency, volume, and distance to excess water that may be available for storage
3. Current and projected future water supply needs identified in the state water plan

Each of these three criteria was screened independently and screening scores were normalized to a score of 0–1. In grid cells where two or more aquifers were present, the aquifer with the highest scoring hydrogeological characteristics was used for the screening. Due to the complex nature of many ASR and AR projects, values for excess water and water needs screening scores were considered for a distance up to two grid cells from any given aquifer score, and a weight was applied to give stronger consideration to closer grid cells.

Because all three criteria are considered critical for the successful completion of an ASR or AR project, only grid cells that contained scores for all three screenings were given a final ASR or AR rating. This final suitability rating placed regions into one of three general categories of relative suitability: less, moderately, or most suitable. Additional details on the methodology used for rating ASR or AR suitability across the state are found in Shaw and others (2020).

5.1 Hydrogeology

The hydrologic screening evaluates aquifers in Texas for ASR and AR suitability based on aquifer characteristics such as storage potential, transmissivity, infiltration characteristics, storativity, recoverability, and water quality. These characteristics fall into one or more of three main suitability categories: recharge, storage, and recoverability.

The hydrogeological screening for ASR and AR considers both recharge and storage suitability parameters, however, recoverability parameters are considered only for ASR screening. The goal of AR projects is commonly to enhance recharge and improve groundwater conditions rather than to recover stored water later, therefore recoverability does not impact the overall success of an AR project.

The hydrogeological screening in the Statewide ASR Suitability Survey used values for all 31 major and minor aquifers of Texas. Previous studies and modeling have considered all units above the carbonate bedrock in the Hueco-Mesilla Bolsons as part of the aquifer. Therefore, this screening does not differentiate between the basin-fill and the surficial deposits.

5.1.1 ***ASR hydrogeologic screening***

For the hydrogeological screening, the LVWD service area received a medium (0.5-0.7) to high (> 0.7) suitability score for ASR projects (Figure 5-1). The Hueco-Mesilla Bolsons Aquifer (HMBL) has a normalized hydrogeological screening score between 0.68 and 0.74. The five cells that are partially within the study area all have the same scores for the hydrogeologic screening parameters, except for two: groundwater quality and available draw up (Table 5-1).

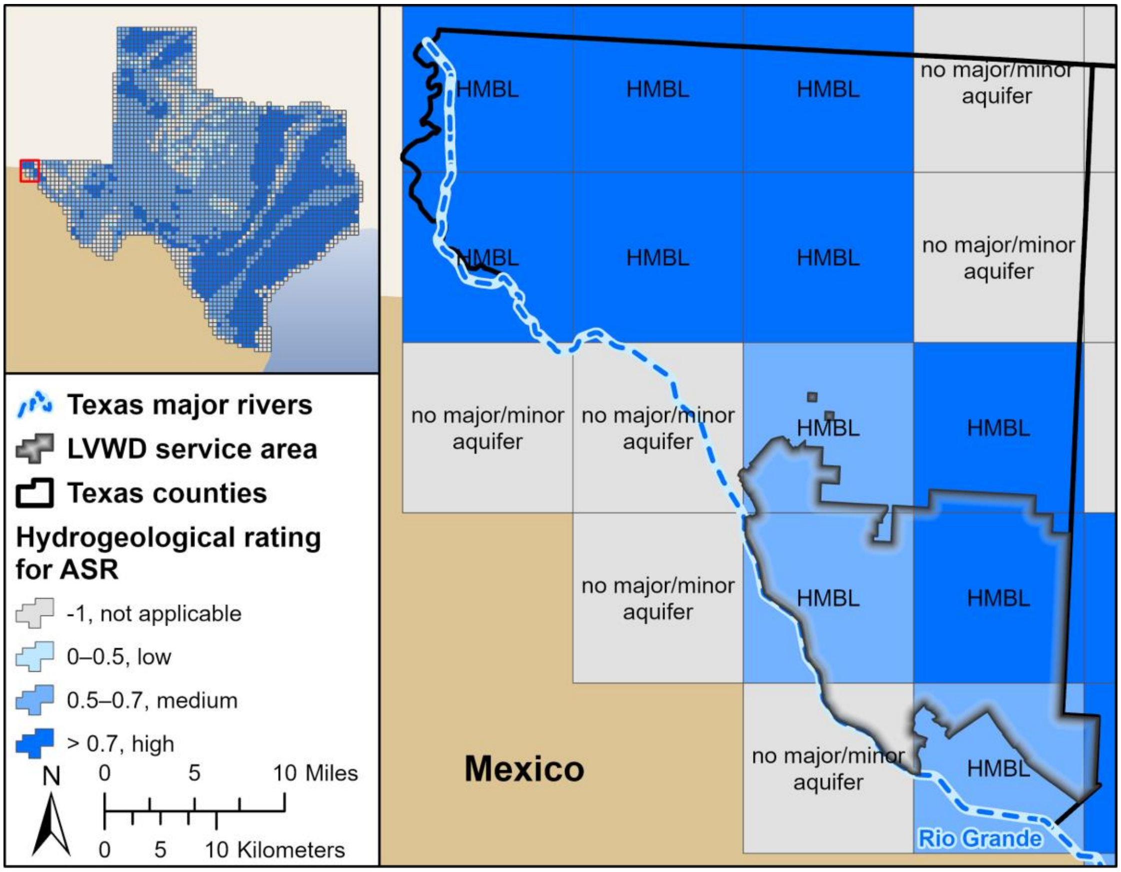


Figure 5-1. Hydrogeological parameter screening results for ASR from the statewide survey for the LVWD service area. Grid cells are labeled with Hueco-Mesilla Bolsons Aquifer (HMBL) the highest scoring aquifer in that location (Shaw and others, 2020).

Table 5-1. ASR hydrogeological screening parameter values for the Hueco-Mesilla Bolsons Aquifer from the Statewide ASR Suitability Survey within the study area. Units are given for each value.

Parameter	Value	Normalized score
Storage zone depth	1406–1503 feet	0.75
Horizontal hydraulic conductivity	3.0–9.4 feet/day	0.5
Draw-up available	88–418.5 feet	0.2–1.0
Dominant lithology	Sand	1.0
Aquifer thickness	1406.3–1503.9 feet	1.0
Aquifer storativity	-	-
Sediment age	9 million years	1.0
Confinement	unconfined	0.1
Groundwater quality	1119.8–4876.7 mg/L	0.8–0.5
Drift velocity	4.8–15.4 feet/year	1.0
Drawdown available	772.9–812.3 feet	1.0

The water quality parameter is impacted by the shallow fresh/saline groundwater interface, as mentioned in Section 3.1. Extensive groundwater pumpage that accrued in the second half of the 20th century in the highly populated areas overlaying the aquifer resulted in brackish water being drawn toward the surface and degradation in water quality (Heywood and Yager, 2002). For ASR projects, high salinity native groundwater levels can be managed by developing a large buffer zone (Shaw and others, 2020). There are also other ASR projects in the 2022 State Water Plan that consider injecting water into brackish/saline parts of target aquifers (e.g., the saline Edwards ASR project).

It is likely that groundwater quality in the study area has been affected by irrigation return flows since most of the agricultural lands within the study area are close to the Rio Grande (as discussed in Section 5.3). However, the Statewide ASR Suitability Survey considered only TDS or salinity level for the evaluation of the water quality parameter in the hydrogeology screening. Groundwater contamination due to irrigation return was not evaluated due to lack of data at the spatial scale of the survey. Therefore, the cells with low hydrogeology scores in the west of the study area are not attributed to water quality contamination. The effect of irrigation return flows is of concern for unconfined aquifers and AR projects, and the LVWD ASR project targets a semi-confined segment of the Hueco Bolson aquifer. Further site-specific water quality analysis would be needed to understand what effects these potential contamination sources could have on an ASR or AR project.

Section 4.2 discussed that the deepest wells with available water quality data are in the eastern part of the study area and are very saline. However, this eastern part of the study area falls in a cell with a high hydrogeological suitability score, which means that the water quality analysis of the statewide suitability survey, along with other hydrogeology parameters, are in the favorable range for successful ASR (i.e., low groundwater salinity). While the Statewide ASR Suitability Survey provides valuable regional information, this discrepancy highlights the benefit of completing an area focused analysis like this study.

The Statewide ASR Suitability Survey lumps the basin-fill deposits and the unconfined Rio Grande Alluvium due to the similarity in the geology/structure that makes it difficult to differentiate them. As discussed in Section 4, our stratigraphic surfaces are based on separating these units, and the rest of our investigation is on wells completed in only the basin-fill deposits or deeper. In addition, the large grid cell size used in the Statewide ASR Suitability Survey contains a vast number of wells, and most of them are Rio Grande Alluvium wells—the properties of which are averaged across the cell size and do not capture the anomalies like the high salinity of the two industrial wells highlighted.

The Statewide ASR Suitability Survey defines draw-up available levels as the distance between the static water level and the ground surface. Drainage of agricultural lands also affects draw-up levels, except where the irrigation canal extensions are concrete lined. Hibbs and others (2006) concluded that leakage from unlined agricultural channels accounts for the majority of the recharge in the Hueco Bolson aquifer. Additionally, groundwater levels are typically elevated near streams in aquifer/surface water connected systems (i.e., unconfined cells with lower hydrogeology scores). This does not present a concern for the LVWD ASR since the project is planned to be implemented in the semi-confined part of the aquifer.

5.1.2 *AR hydrogeologic screening*

All the cells within the LVWD service area scored high on the AR hydrogeologic screening with normalized scores between 0.81 and 0.88 (Figure 5-2). Table 5-2 lists the hydrogeologic screening parameters for AR suitability. All cells received the same normalized score for most of the parameters. The vertical hydraulic conductivity and depth to water table are the only two parameters with different scores among the cells. There is no definitive explanation for the change in vertical conductivity because, as mentioned previously, the subsurface geology in the area is very complex. As for the variation in water table depth, it can be attributed to the difference in elevation between the cells with the lower ground surface in the west (by the Rio Grande) and the almost 300-foot-higher ground surface in the plateau area to the east.

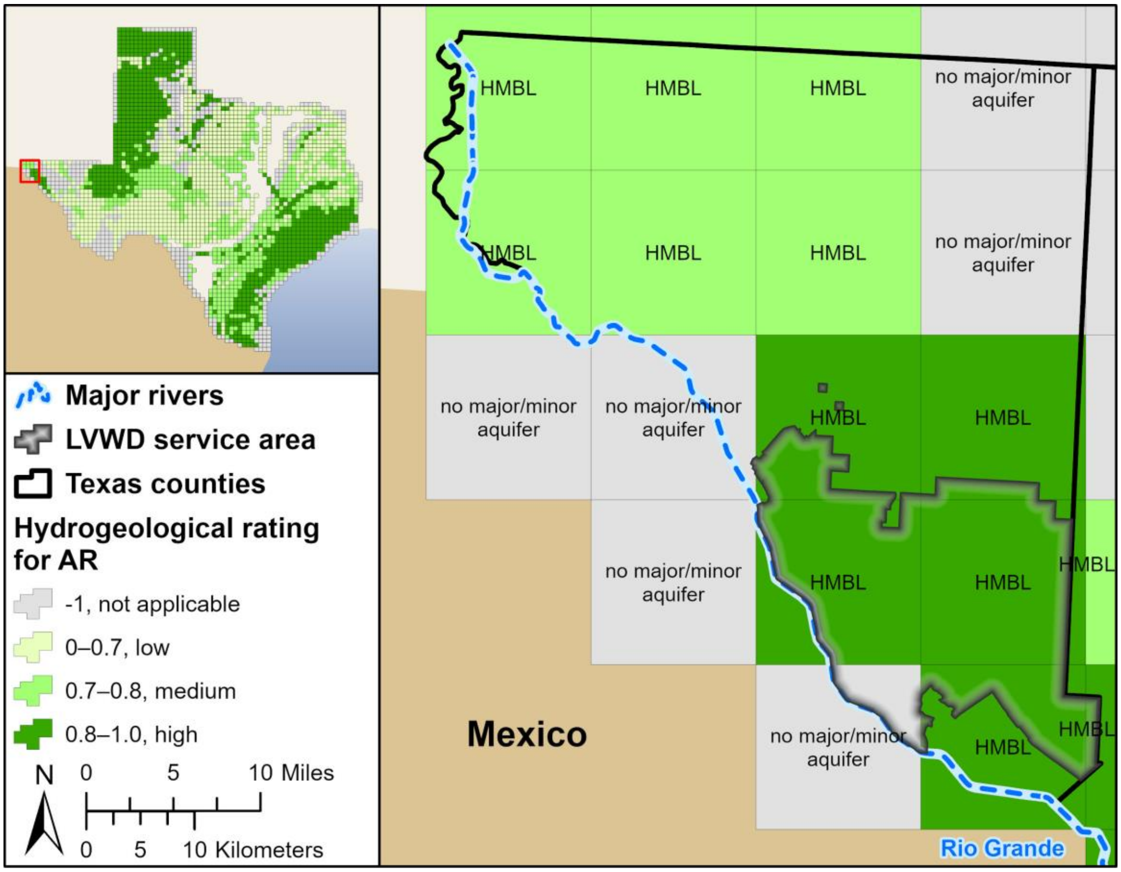


Figure 5-2. Hydrogeological parameter screening results for AR from the statewide survey for the LVWD service area. Grid cells are labeled with Hueco-Mesilla Bolsons Aquifer (HMBL) the highest scoring aquifer in that location (Shaw and others, 2020).

Table 5-2. AR hydrogeological screening parameter values for the Hueco-Mesilla Bolsons Aquifer from the Statewide ASR Suitability Survey within the study area. Units are given for each value.

Parameter	Value	Normalized score
Horizontal hydraulic conductivity	3.0–9.4 feet/day	0.5
Vertical hydraulic conductivity	4.1–7.7 feet/day	0.1–0.77
Topographic slope	0.9–1.7 degrees	1.0
Sediment age	9 million years	1.0
Aquifer dominant lithology	Sand	1.0
Specific yield	0.18 (/)	1.0
Depth to water table	87.9–418.5 feet	0.5–1.0

5.2 Excess water sources screening

Existing available supply, as defined by the 2022 State Water Plan, is “water supplies that are physically and legally available to be produced and delivered with current permits, current contracts, and existing infrastructure immediately in the event of an onset of drought of record conditions.”

The considered water supply sources for planning purposes are surface water, groundwater, and reclaimed water. Reclaimed water is treated wastewater effluent discharge and is typically available near metropolitan areas with large municipal wastewater effluent return flows.

The LVWD's sole source of potable municipal water supply is El Paso Water. The LVWD represents approximately 4 percent of El Paso Water' total demands (Section 5.3). The LVWD purchases a blended supply that is mostly groundwater from the Hueco-Mesilla Bolsons Aquifer in addition to surface water from the Rio Grande. The LVWD has Rio Grande water rights that it transfers to El Paso Water in exchange for treated drinking water ready for distribution. Table 5-3 lists the existing available supply for El Paso Water.

Table 5-3. El Paso Water's existing water supply per source.

WUG name	Source region	Source description	Existing supply (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
El Paso Water	E	Direct reuse*	6,000	6,000	6,000	6,000	6,000	6,000
	E	Hueco-Mesilla Bolsons Aquifer | El Paso County	115,000	115,000	115,000	115,000	115,000	115,000
	E	Rio Grande run-of-river	10,000	10,000	10,000	10,000	10,000	10,000
El Paso Water Total			131,000	131,000	131,000	131,000	131,000	131,000

*Direct reuse in El Paso County is used for irrigation only.

The agricultural activity within the LVWD service area depends on Hueco Bolson aquifer private wells. Existing supply available for the irrigation water user group in El Paso County is listed in Table 5-4 (WSP and Freese and Nichols, 2021). Irrigation needs in the LVWD are discussed in Section 5.3.

Table 5-4. Irrigation existing available supply by source in El Paso County (acre-feet per year).

Source	2020	2030	2040	2050	2060	2070
Hueco-Mesilla Bolsons Aquifer | El Paso County	7,392	7,392	7,392	7,392	7,392	7,392
Other aquifer | El Paso County	30,000	30,000	30,000	30,000	30,000	30,000
Rio Grande indirect reuse	34,169	34,169	34,169	34,169	34,169	34,169
Rio Grande run-of-river	31,605	31,605	31,605	31,605	31,605	31,605
Existing supply total	103,166	103,166	103,166	103,166	103,166	103,166

The Statewide ASR Suitability Survey rated the "excess water" category in most of the LVWD service area as highly suitable for ASR (>0.67) with a small portion that received a medium score (0.34-0.67). As expected from the lack of surface water in that region, the Statewide ASR Suitability survey identified no potential excess surface water in the LVWD service area.

However, potential excess Hueco-Mesilla Bolsons Aquifer groundwater that could be available for ASR was identified in all the cells in the study area. Since the Hueco-Mesilla Bolsons Aquifer is the target for the LVWD ASR project, this excess groundwater can be more beneficial for other potential projects. The LVWD has a recommended water management strategy in the Far West 2021 Regional Water Plan that considers constructing a wellfield in the Hueco Bolson aquifer. Due to the salinity of groundwater in this area, a desalination plant is proposed as part of the strategy as well.

The Statewide ASR Suitability Survey also identified excess reclaimed water in two cells within the study area that have existing water treatment plants: Horizon Regional Municipal Utility District in the northern part of the study area and City Plant and El Paso Water Control and Improvement District 4 in the south, as shown in Figure 5-3. In addition, two other plants exist in the vicinity of the service area: Roberto R Bustamante Wastewater Treatment Plant to the northeast and Tornillo Wastewater Treatment Plant to the south of the LVWD service area.

Table 5-5 lists the TCEQ (2023b) specifications for each of these water treatment plants, and Table 5-6 lists the projected available volumes based on analysis from the Statewide ASR Suitability Survey (Shaw and others, 2020). These numbers represent gross volumes before subtracting the planned reclaimed water use according to the 2022 State Water Plan. For example, treated wastewater from the Roberto R. Bustamante Wastewater Treatment Plant is considered as source for one of the El Paso Water direct potable reuse projects (WSP and Freese and Nichols, 2021). Future work on the LVWD ASR project should consider estimating the net available reclaimed water if it is determined to be a potential source.

Purchasing reclaimed water from any of these wastewater treatment plants could be another option for the LVWD to consider to secure more supply in general and for the ASR project. In addition, with the federal funding received for the LVWD wastewater treatment plant, the District might also consider purchasing untreated wastewater to reduce the cost and treat it in the new plant. From the above, it can be concluded that excess treated wastewater is the most feasible source for the LVWD ASR project.

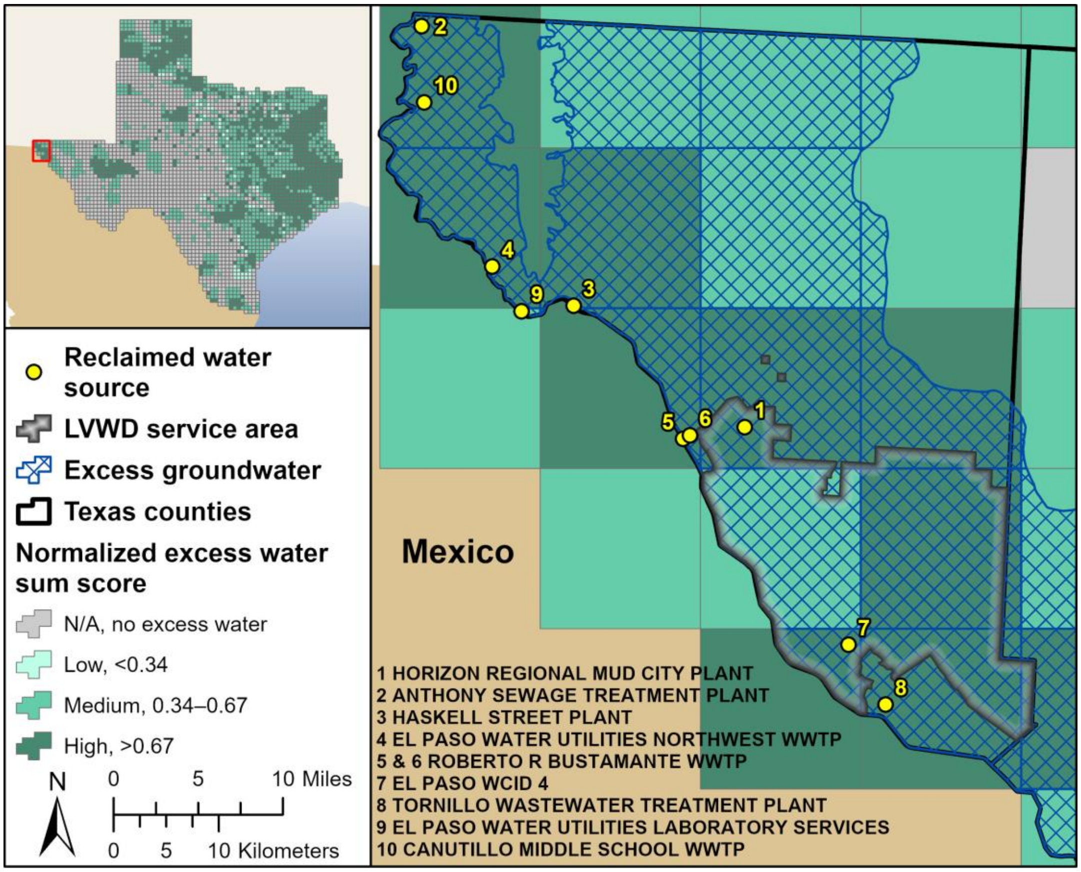


Figure 5-3. Excess water ratings, excess available groundwater, and reclaimed water sources from the statewide ASR and AR survey for the study area (Shaw and others, 2020). HMBL = Hueco-Mesilla Bolsons Aquifer. MUD = Municipal Utility District, WCID = Water Control and Improvement District, and WWTP = Wastewater Treatment Plant.

Table 5-5. Sewage treatment plants TCEQ information.

Name	Primary business	Customer names	Customer role	TPDES/EPA ID*	ID status	Map number
Horizon Regional Municipal Utility District City Plant	Domestic	Horizon Regional Municipal Utility District	Owner Operator	TX0086045	Active	1
Roberto R Bustamante Wastewater Treatment Plant	Domestic	El Paso Water Public Service Board	Owner Operator	TX0101605	Active	5 & 6
El Paso Water Conservation Improvement District 4	Domestic	El Paso County Water Conservation Improvement District 4	Owner Operator	TX0065013	Active	7
Tornillo Wastewater Treatment Plant	Domestic	El Paso County Tornillo Water Improvement District	Owner Operator	TX0126772	Active	8

*TPDES/EPA ID = Texas Pollutant Discharge Elimination System/ Environmental Protection Agency ID number.

Table 5-6. Projected discharge volumes from the Statewide ASR Suitability Survey (acre-feet per year).

Plant	Average discharge 2020	Average discharge 2040	Average discharge 2070
Horizon Regional Municipal Utility District City Plant	1,124	1,430	1,843
Roberto R Bustamante Wastewater Treatment Plant	49,129	62,473	80,541
El Paso Water Conservation Improvement District 4	606	771	994
Tornillo Wastewater Treatment Plant	169	215	278
Total excess reclaimed water	**51,028**	**64,889**	**83,656**

5.3 Water supply needs

The LVWD is a major water provider as defined by the Far West Texas Water Planning Region, which defines such a provider as "an entity that currently provides significant water supplies (>5,000 acre-feet per year) to other users and which will continue to develop new supplies to meet future needs of those whom they supply during the period covered by this Plan," (WSP and Freese and Nichols, 2021). The LVWD provides water to more than 5 percent of El Paso County population. The 2021 Far West Texas Regional Water Plan projects that the population served by the LWVD water user group will increase by over 90 percent between the decades 2020 and 2070 (Table 5-7).

Table 5-7. LVWD customers population and percentage of El Paso County total population.

	2020	2030	2040	2050	2060	2070
LVWD (Socorro, Clint, San Elizario)	53,059	63,682	73,546	83,325	92,582	101,287
El Paso County total population	925,565	1,055,903	1,176,945	1,296,927	1,410,527	1,517,340
Percentage of El Paso County	5.7	6	6.2	6.4	6.6	6.7

As mentioned in Section 5.2, LVWD receives its supply from El Paso Water as a sole supplier, with 4 percent of the total El Paso Water demands in 2020 (Table 5-8). As with the increase in population, the demands are projected to increase from 5,714 to 10,045 acre-feet per year between 2020 and 2070. More than 50 percent of the LVWD demands in 2020 come from the City of San Elizario, expected to increase to 61 percent by 2070. The City of Socorro is the second largest with 47 percent of the LVWD demands in 2020, which will decrease to 38 percent by 2070. The Town of Clint is the smallest customer with 1 percent of the LVWD demand, which will remain constant between 2022 and 2070.

Table 5-8. El Paso Water and Lower Valley Water District water demands.

Major water provider	Receiving entity	Water demands (acre-feet/year)					
		2020	2030	2040	2050	2060	2070
El Paso Water	Lower Valley Water District	5,714	6,563	7,398	8,290	9,189	10,045
	Total demand	**137,479**	**150,245**	**161,497**	**173,735**	**186,304**	**198,364**
	Percentage of total demands	4	4	5	5	5	5
Lower Valley Water District	San Elizario	2,971	3,610	4,217	4,891	5,513	6,127
	Percentage of total demands	52	55	57	59	60	61
	Socorro	2,686	2,888	3,107	3,316	3,584	3,818
	Percentage of total demands	47	44	42	40	39	38
	Clint	57	66	74	83	92	100
	Percentage of total demands	1	1.01	1	1	1	1
	Total Demand	**5,714**	**6,563**	**7,398**	**8,290**	**9,189**	**10,045**

The water needs for the LVWD, as defined by the regional water plan, is the deficit of the projected demands that is not met by the available supply (Table 5-9). Since the projected El Paso Water supply remains at 4,356 acre-feet per year through the next 50 years, and the demands will increase, the total needs for the LVWD in 2070 are projected to be more than four times the needs in 2020 (WSP and Freese and Nichols, 2021). In addition, it is anticipated that the El Paso Water rates will increase by approximately 30 percent in 2024, which will pose a challenge to the LVWD in meeting the needs of its mostly rural customers (Flores, 2023, personal communication).

Table 5-9. Lower Valley Water District water supply needs (acre-feet per year).

Major Water Provider		2020	2030	2040	2050	2060	2070
Lower Valley Water District	Total supply	4,356	4,356	4,356	4,356	4,356	4,356
	Total demand	5,714	6,563	7,398	8,290	9,189	10,045
	Need	1,358	2,207	3,042	3,934	4,833	5,689

Unmet needs are calculated by deducting the projected demands from the total existing supply and the recommended water management strategies projected volumes. These strategies are expected, once implemented, to secure enough supply to meet the District's needs, therefore, there are no unmet needs listed for the LWVD in the regional water plan.

Table 5-10 list the results of the LVWD's water supply needs screening of the Statewide ASR Suitability Survey (Shaw and others, 2020).

Table 5-10. Municipal water supply needs results for the Lower Valley Water District from Shaw and others, 2020.

Field name	**Value**	**Definition**
Water needs score	0.83	Category final score based on the values below
Water needs max	5,689	Maximum water supply needs between 2020 and 2070 in acre-feet per year
Water needs max score	0.50	Ranking of 0 to 1 as follows: Needs ≥ 35,000 acre-feet per year – 1 Needs ≥ 15,000 and < 35,000 acre-feet per year – 0.75 Needs ≥ 2,500 and < 15,000 acre-feet per year – 0.5 Needs ≥ 500 and < 2,500 acre-feet per year – 0.25 Needs < 500 acre-feet per year – 0
First needs decade	2020	The first decade with reported need
First needs decade score	1	Ranking of 0 to 1 as follows: 2020-2030 – 1 2040 – 0.75 2050 – 0.5 2060-2070 – 0.25
Per volume	0.57	Needs as percent volume of demand (maximum 2020-2070 period)
Per Volume S	1	Ranking of 0 to 1 as follows: <10% – 0.25 ≥10 and ≤ 25% – 0.5 >25 and ≤ 40% – 0.75 >40% – 1
Unmet needs	0	Yes – 1, No – 0
Length of need	1	< 20 years – 0, ≥ 20 years – 1
Sole supply	1	Yes – 1, No – 0
Existing supply	1	Groundwater – 1 Surface water – 0.25 Both – 0.5
Recommended ASR water management strategy	1	Yes – 1, No – 0

Figure 5-4 shows that the entire LVWD service area falls on “water supply needs” high suitability grid cells, and this is primarily due to the municipal needs in the area, which extend north and northwest to urban areas including the City of El Paso. The region to the east of the study area has no identified municipal water user group, thus the grid cells did not receive a “water supply needs” score.

This analysis does not reflect the irrigation water user group needs since it was not considered by Shaw and others (2020) for the lack of spatially referenced information. The LVWD service area is mostly rural with major dependency on agriculture that significantly increases irrigation needs. The Far West Regional Water Plan provides irrigation water user group demands and needs information at the El Paso County level (Table 5-11).

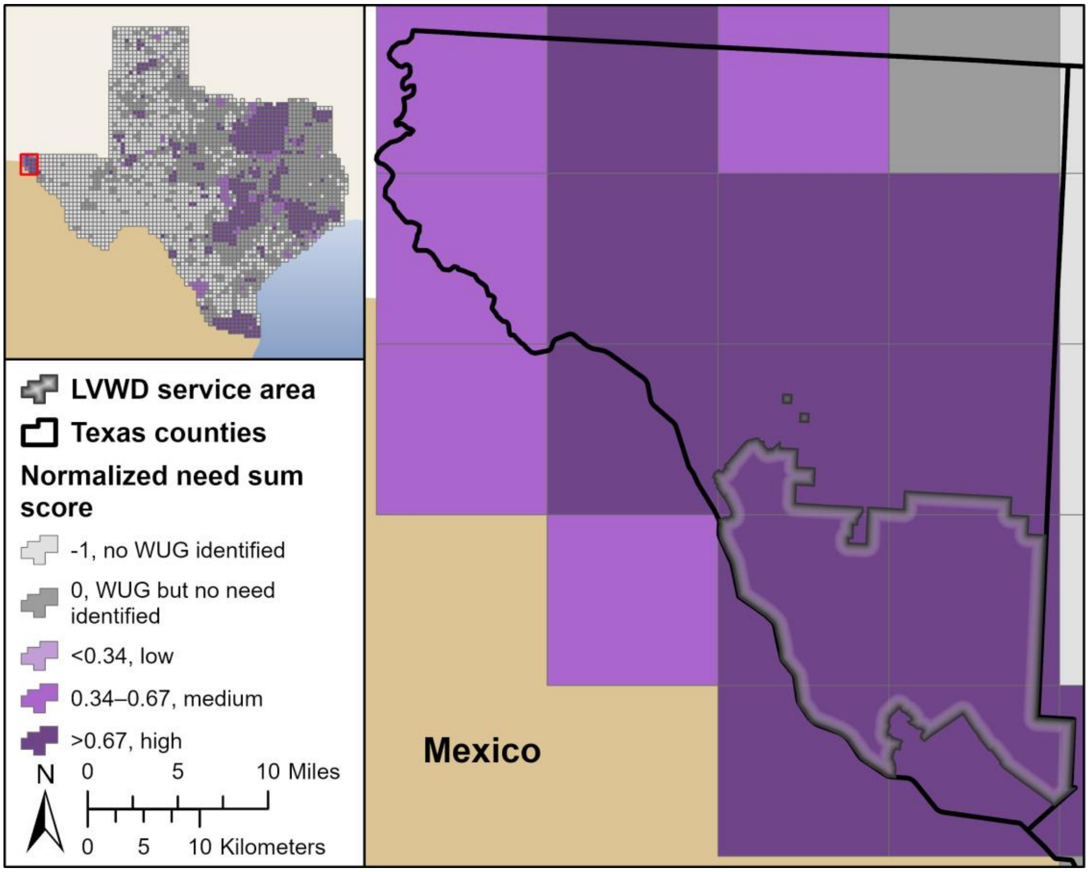


Figure 5-4. **Water supply needs category results from Shaw and others, 2020. WUG = water user group.**

Table 5-11. **Irrigation Water User Group information for El Paso County (acre-feet per year)**

Irrigation water user group	2020	2030	2040	2050	2060	2070
Demands	149,570	149,570	149,570	149,570	149,570	149,570
Need	46,404	46,404	46,404	46,404	46,404	46,404
Unmet needs	12,941	9,691	9,691	9,691	9,691	9,691

To estimate the irrigation needs in LVWD service area, at a sub-county level, we compared the agricultural lands within the LVWD service area to the total agricultural lands in El Paso County. This was achievable using the 2022 Cropland Data Layer provided by United States Department of Agriculture (USDA) CropScape (USDA, 2022). This dataset is developed using moderate resolution satellite images calibrated with extensive agricultural field data (Boryan and others, 2011). The agricultural Cropland Data Layer, within the LVWD service, includes the following categories of crops: alfalfa, corn, cotton, double crop winter wheat/cotton, fallow/idle cropland, grasslands, grapes, other hay/ non-alfalfa, pecan, sorghum, triticale, and winter wheat (Figure 5-5).

We excluded the grass crop category from our analysis for two reasons. The USDA agricultural layer does not differentiate between rainfed and irrigated crops, and our analysis focuses on irrigation-dependent fields. In addition, grass covered an extensive portion of El Paso County that resulted in unreasonable estimates of agricultural lands within the study area.

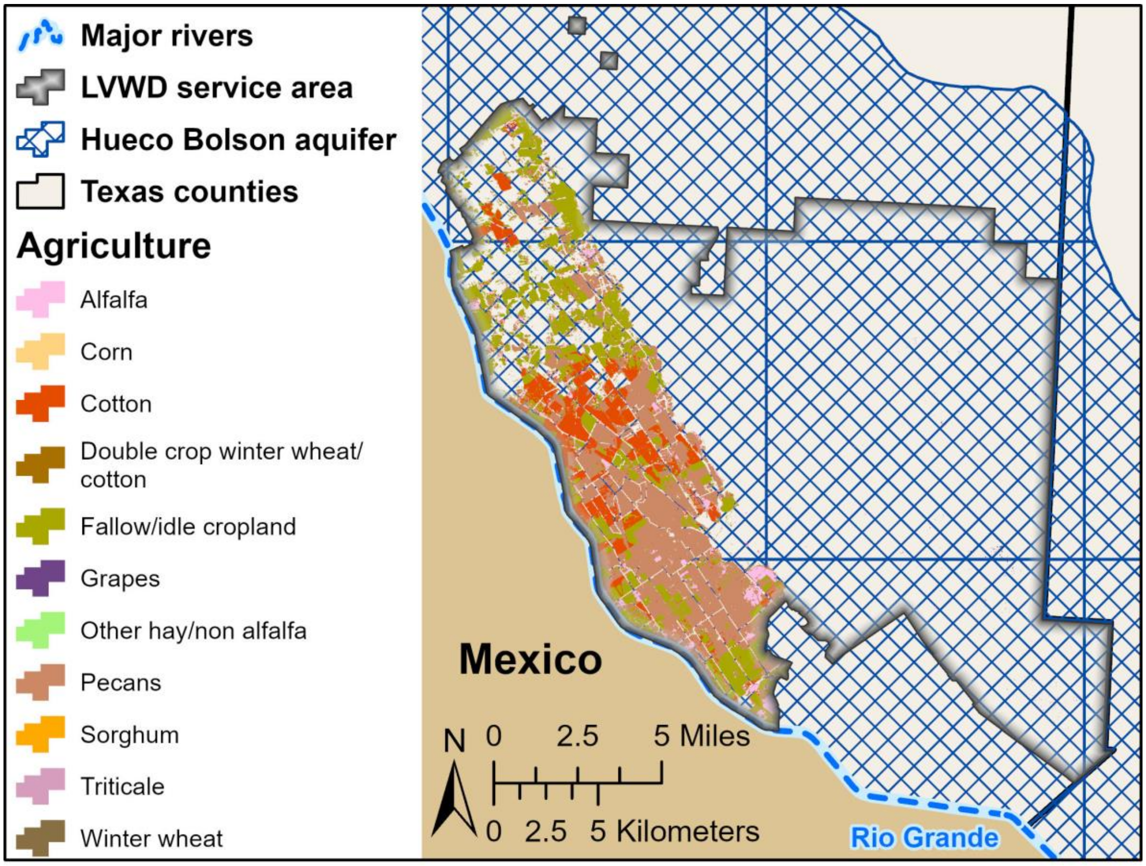


Figure 5-5. Agricultural lands and crop types grown in LVWD service area.

The percentage of the total acreage covered by the considered crops in the LVWD service area (33,989 acers) compared to the total acreage in El Paso County (49,820 acers) is 68 percent. These acreage values fall within the range of 40,000-50,000 acres of irrigated land in El Paso County Water Improvement District #1 (EPCWID #1) in any given year, according to the 2021 Far West Texas Regional Water Plan. Table 5-12 lists the irrigation needs in the LVWD service area based on the Cropland Data Layer percentage of agricultural lands of the total agricultural lands in El Paso County.

Table 5-12. Irrigation needs in the Lower Valley Water District service area (acre-feet per year)

Irrigation Water User Group	2020	2030	2040	2050	2060	2070
Needs	31,555	31,555	31,555	31,555	31,555	31,555
Unmet Needs	8,800	6,590	6,590	6,590	6,590	6,590

Further, the Normalized Difference Vegetation Index calculated from Landsat 8 images taken during the irrigation seasons of 2018 and 2019 to estimate irrigation amounts during these seasons identified a total area of 44,667 and 39,467 acers of irrigated fields in 2018 and 2019, respectively, within the EPCWID #1 area (Blair, 2020 and 2021). The 2018 estimate falls within the reported EPCWID #1 acreage range; however, the 2019 estimate is slightly below the range.

The results of the studies show that 165,207 and 136,967 acre-feet of irrigation water were applied in 2018 and 2019, respectively. The average of these values (151,087 acre-feet) is close to the projected irrigation demands average in the coming five decades (149,570 acre-feet) reported by the 2021 Far West Texas Regional Water Plan.

The final suitability rating integrates the previous screening categories and assigns a final suitability score to only the cells with scores from all of them. ASR and AR suitability screening overlaps in the excess available water and water supply needs categories and separates in the hydrogeology screening parameters; thus, the final suitability score for ASR is different than AR for the same location and aquifer.

5.4 Final scores

Final scores were calculated by combining the three screenings described above. In grid cells where more than one aquifer was present, the highest-scoring aquifer was assigned to the final ASR and AR grid (Shaw and others, 2020). The grid cells that met all three criteria were given a normalized score describing their suitability for an ASR or AR project. These final scores incorporate averages across the entire grid cell and surrounding cells, so additional site-specific tests need to be completed to verify the optimal placement for any project.

5.4.1 *ASR final score*

Most of the LVWD service area scored as highly suitable in one or more of the three screening categories due to the presence of adequate hydrogeological properties, excess water availability, as well as municipal and agricultural water needs. Thus, the final ASR score also fell in the most suitable category (> 0.7) for the majority of the study area—with the exception of a small segment to the southwestern side of the LVWD service area that did not receive a final ASR score due to absence of an aquifer (Figure 5-6). However, due to the low hydrogeology score in the cells to the west of the study area, as mentioned in section 5.1, it would be more suitable to consider the east or northeast side for the ASR well location.

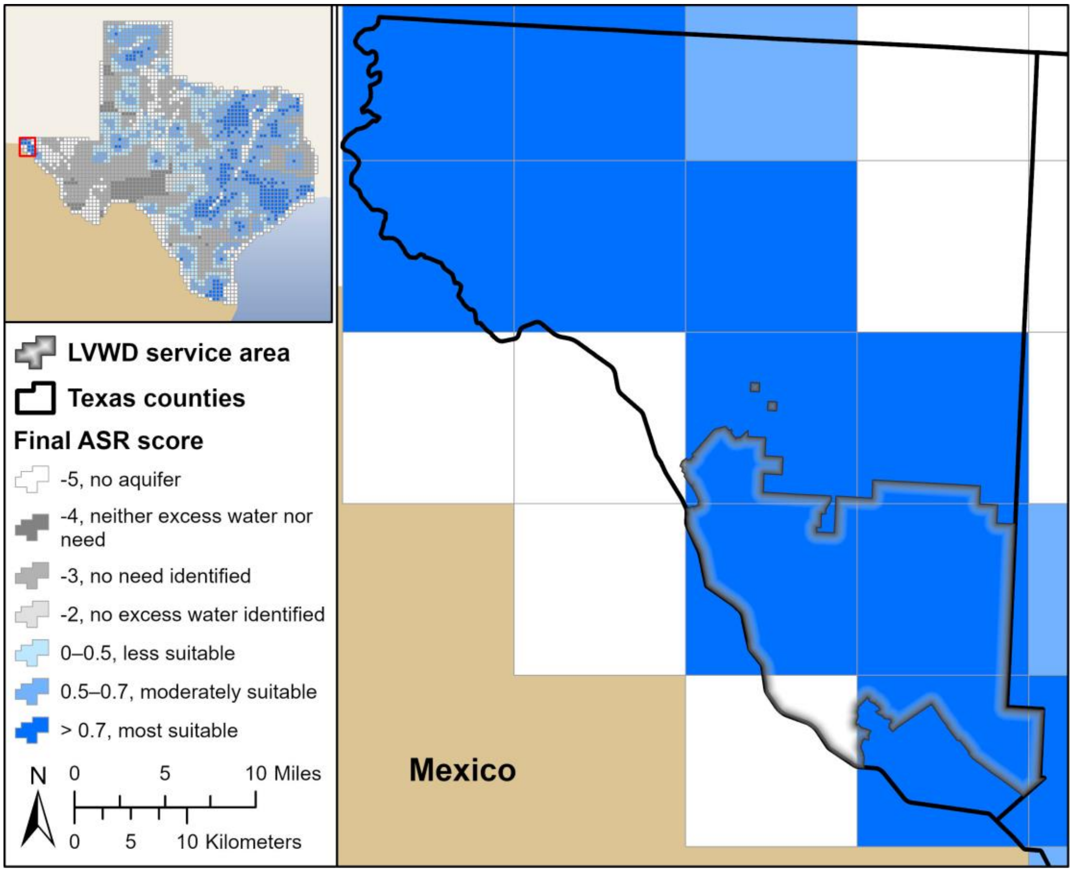


Figure 5-6. Final suitability ratings for aquifer storage and recovery from the Statewide ASR Suitability Survey for the study area (Shaw and others, 2020).

5.4.2 *AR final score*

Similar to ASR, AR final results show that all the cells in the LVWD service area are highly suitable except where there is no aquifer in the southwest corner of the study area (Figure 5-7). The rest of the cells received scores for all three screening categories, which were mostly favorable for AR. The hydrogeological parameter for AR did not show less suitable parts within the study area compared to ASR hydrogeology results. This is also confirmed by the existing operating Fred Hervey Water Reclamation Plant. The most suitable AR location recommendation, in this case, will rely on other factors like TCEQ infiltration basin permitting requirements detailed in Section 6.4.

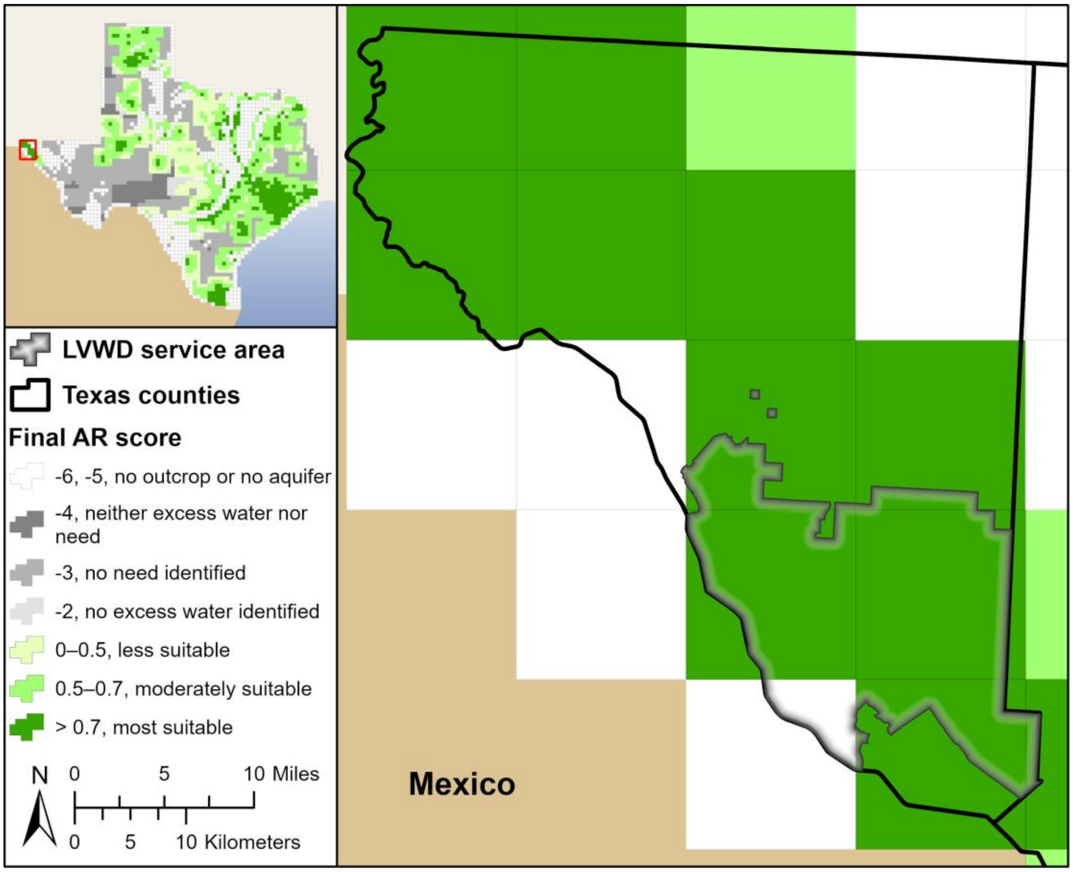


Figure 5-7. Final suitability ratings for aquifer recharge from the Statewide ASR Suitability Survey for the study area (Shaw and others, 2020).

6. Discussion

The LVWD is interested in diversifying its water supply to continue providing water to customers and reduce dependency on buying water from El Paso Water. As part of this effort, the LVWD is interested in an ASR or AR project. The challenges and benefits generally associated with ASR and AR projects are well documented (Pyne, 2005; National Research Council, 2008; Dillon and others, 2009; Maliva and Missimer, 2008, 2010; Bloetscher, 2015). This study looked at the publicly available data for the LVWD's study area to investigate the best options to pursue and to identify the additional field data that would need to be collected.

6.1 ASR and AR in El Paso County

West Texas has a dry climate and water concerns have been present in the area for many years. Interest in ASR and AR projects in El Paso County can be seen as early as the 1940s. A study by Sundstrom and Hood (1952) outlines the findings of a feasibility study on ASR in the Hueco and Mesilla basins conducted by the U.S. Geological Survey for the City of El Paso. This report outlined the major concerns in the area at the time—including that the groundwater production from the Hueco Bolson exceeded the recharge of El Paso's well field by 5 million gallons per day and that the chloride content of the groundwater was increasing. Sundstrom and Hood (1952) also showed that stream flow was available from the Rio Grande during the winter, when irrigation demand was limited and that supplies from both ground and surface water were available during winter months for use in a potential recharge project. Pumping and recharge tests performed as part of this study concluded that water could be injected into the Hueco basin-fill deposits during times of low demand, and over 90 percent of the injected water could be recovered (Sundstrom and Hood, 1952).

The City of El Paso again worked with the U.S. Geological Survey in 1980 to produce a study investigating the use of advanced treated reclaimed water for ASR (Garza and others, 1980). This study looked at the residence time, recovery, and long-term effects of injection in the Hueco basin-fill deposits by developing simulations based on a previous groundwater pumping model (Meye, 1976; Garza and others, 1980). Garza and others (1980) ran short-term (one-year) simulations to determine the hydraulic gradients associated with injection and recovery so that well placement could be planned to maximize recovery and allow the water to remain in the aquifer for a predetermined period. These short-term simulations showed that the water would move between 550 and 760 feet per year.

Garza and others (1980) also ran long-term (up to 20 years) simulations to assess the effects water injection would have on water level declines in the Hueco Bolson over time. These simulations show that the potentiometric head would rise approximately 10 feet at the injection wells after the first 10 years of operation. However, water level declines could range from a few feet near the injection sites to more than 20 feet approximately 2 miles to the northwest of the injection wells. After 20 years, the potentiometric head at the injection wells would remain constant and water level decline in the southwest may reach 35 feet (Garza and others, 1980).

Garza and others (1980) also investigated the effects reclaimed water quality would have on the injection well and the aquifer. This study showed that some clogging of the wells through mineral precipitation could be expected but managed through well rehabilitation. The study also revealed that there was a low risk of chemical interactions by mineral precipitation or dissolution of the aquifer materials because reclaimed water usually contains low amounts of calcite and iron. However, this study cautioned that further testing on redox potential of the aquifer would have to be completed and that the high total dissolved solids of reclaimed water could pose an issue of decreasing transmissivity in clay-rich areas.

El Paso Water completed an ASR pilot project from 1981 to 1983 with injection and recovery tests being conducted by the U.S. Geological Survey (White, 1983; White and Sladek, 1990). A single well was drilled for this pilot study and the source water for injection was piped from El Paso’s production wells (White and Sladek, 1990). Both 3- and 24-day pump tests were completed in 1981, and further testing was conducted in 1982 and 1983 to understand the injection efficiency and recovery potential (White and Sladek, 1990). These tests concluded that the Hueco basin-fill deposits could be successfully used for storage and recovery of water. The water table near the injection site is 350 feet below the ground surface, which allows a buildup of hydraulic head over 250 feet without issue (Sheng, 2005). However, the injection efficiency is much less than the recovery efficiency in these deposits, and excessive injection pressure may cause sloughing of the aquifer surrounding the borehole and reduce injection efficiency due to it being unconsolidated. This pilot project coincided with the construction of the Fred Hervey Water Reclamation Plant (White, 1983).

El Paso Water began construction of its ASR system in 1982, which included the Fred Hervey Water Reclamation Plant and 10 injection wells (White and Sladek, 1990). An additional injection well was completed in 1988. These injection wells were completed with galvanized steel casings and well screens (Reinert, 2017). Injection of reclaimed water began in 1985 at a rate of 1 million gallons per day (White and Sladek, 1990). Injected water moves from the injection wells to production wells up to 3 miles away from the injection wells (Sheng, 2005; Reinert, 2017). Injection well placement was based on the results of the pilot study and determined to allow for five years of residence time before reaching the production wells (White and Sladek, 1990; Sheng, 2005).

The treatment process train at the Fred Hervey Water Reclamation Plant includes screening, degritting, primary settling, two-stage biological treatment, lime coagulation, sand filtration, ozone disinfection, granular activated carbon filtration, storage, and chlorination (White and Sladek, 1990). Results of monitoring injection during the first five years of the ASR project's operation showed that water levels had begun to reach equilibrium (White and Sladek, 1990). Since 1985, more than 80,000 acre-feet of reclaimed water have been injected into the Hueco basin-fill deposits through this project (Reinert, 2017).

El Paso's injection wells were scheduled for rehabilitation every six months to prevent degradation (Sheng, 2005). However, as the injections wells operated over time, they began to experience problems with corrosion and decreased efficiency (Sheng, 2005). The corrosion of the casing material was caused by electric potential from existing cathodically protected gas pipelines and the chemical composition of the injected water (Sheng. 2005; Reinert, 2017). This issue highlights the importance of using the correct materials and understanding the chemical compatibility of the water and well materials. Some wells were converted to PVC casing and screens were converted to stainless steel (Sheng, 2005; Reinert, 2017). Due to ongoing issues with corrosion and well screen plugging over time, most of the ASR wells were taken out of service, and only two remain operational today (Reinert, 2017).

El Paso Water worked with the American Water Works Research Foundation in 2003 to compare alternative recharge methods, including spreading basins and dry wells (Reinert, 2017). Infiltration basins were found to be a viable and cost-effective alternative to ASR wells for the Hueco basin, which was able to maintain a high recharge rate (Sheng, 2005; Reinert, 2017). Since 2005, El Paso has moved toward using infiltration basins for recharge almost exclusively and does not plan to continue using injection wells in the long term (Reinert, 2017). Recently, El Paso has begun work on a surface infiltration system referred to as an "enhanced arroyo" that will be used to allow recharge of additional reclaimed water from the Fred Hervey Reclamation Plant. This project is being permitted through the TCEQ as an "Alternative reclaimed water system" under 30 TAC § 210.41. The city also has plans for recharge basins for surface water from the Rio Grande (Reinert, 2017, 2024).

Since the development of El Paso Water' ASR project in 1985, there have been several changes to how injection wells are permitted in the state of Texas. Currently, all Class V injection wells—which would be used to inject water into an active aquifer—are permitted by the TCEQ's Underground Injection Control Program, which is focused on protecting Texas' aquifers in accordance with the Safe Drinking Water Act. While both treated surface water and groundwater have been approved for injection through a Class V well, no entity in Texas has attempted to implement the injection of reclaimed water into an aquifer as part of an ASR project (TCEQ, personal communication, 2023, 2025). The City of El Paso's ASR predated the development of these new regulations; however, a new ASR system injecting reclaimed water would be challenging to implement. There have also been several recent studies investigating the use of reclaimed water in ASR and AR projects (EPA, 2023).

6.2 Well construction considerations from salinity and geochemistry analysis

While successful ASR projects have been implemented in a variety of groundwater salinity conditions, refined salinity mapping for the groundwater in the potential project area facilitates better decision making on well field location, well construction design, water treatment, piloting design, and project costs for ASR facilities. Understanding the hydrogeological characteristics of an aquifer is critical to designing a well for optimal performance. The characteristics of both raw and treated water may affect the operations and efficiency of a well; therefore, geochemical data on both the native groundwater and the treated injected water should be considered for this project and when designing any ASR project in general (Pyne, 2005).

The LVWD is planning on using advanced treated wastewater for this project. As seen in the El Paso Water ASR project, this source water typically has a high chloride and sodium content, and the lime coagulation used in the Fred Hervey Plant meant that the injected water had a relatively high pH (Sheng., 2005). These factors may lead to the mobilization of such minerals as iron and manganese and could eventually cause well clogging.

As mentioned previously, the available measured water quality in the LVWD service area is limited, which hinders performing detailed and refined salinity mapping. In addition, the sparse spatial distribution of the measured water quality showed no definitive pattern of changes in salinity levels across the study area. However, high salinity levels were found in agricultural areas near the Rio Grande and where there is potential communication between the Hueco Bolson and Rio Grande Alluvium or the Hueco Group (carbonate). The LVWD should consider more detailed TDS testing in its service area to better inform implementation of the considered ASR project.

One of the primary considerations affecting well construction is whether the native groundwater is corrosive or incrusting (scaling). Measured water quality values can be used to calculate the water's Langelier Saturation Index (LSI), which is an estimation of the saturation of calcium carbonate within the sample (Mehmert, 2007). The LSI is calculated using a sample's pH, alkalinity, calcium concentration, total dissolved solids, and water temperature (Mehmert, 2007). If the LSI is negative, the water will be corrosive to the casing and screen. If the LSI is positive, then the water will tend to deposit calcium carbonate on the casing and screen (i.e., incrusting). Additional factors may also contribute to the corrosiveness of the water and are listed below (Mehmert, 2007).

The primary geochemical characteristics of water that indicate corrosive water conditions include

- pH that creates a negative LSI (commonly less than 6.5),

- hydrogen sulfide concentration greater than 1 mg/L,
- TDS greater than 1,000 mg/L,
- free carbon dioxide concentration greater than 50 mg/L, and
- chloride concentration greater than 200 mg/L.

The primary geochemical characteristics of water that indicate incrusting water conditions include

- pH that creates a positive LSI (commonly greater than 7.5),
- carbonate hardness greater than 300 mg/L,
- total iron concentration greater than 0.5 mg/L, and
- total manganese concentration greater than 0.2 mg/L.

We calculated the LSI using the available measured water quality data (Section 4.2.1) to determine the potential impact of the Hueco Bolson water on well casing and screen. This information is tabulated and available in the BRACS Database (Section 11, Appendix C). Predictably, the few available data points did not offer enough information to infer a general pattern of corrosion or incrusting. However, it did show a wide range or variability within the study area, which is an intriguing factor that warrants further geochemical testing of the Hueco Bolson aquifer, such as major cations and anions, as well as TDS, to inform new water development in the area including ASR and AR.

Figure 6-1 shows that the corrosiveness of the water in the irrigation well in the northeast side of the study area (SWN 4922623) increased over time with the increase in salinity levels. Whereas the LSI in the City of Fabens well (SWN 4931919) fluctuated between positive and negative despite that the TDS levels remained within the fresh range for the same water quality samples. As mentioned in Section 4.2.1, these are the only wells with multiple water quality measurements over time that enabled examining the change of LSI with time.

Other examples of increased corrosion with increased salinity levels are SWN 4923902, 4923903, and 4922847. Counter intuitively, the most saline wells in the study area (SWN 4932504 and 4932505) have the highest incrusting ranges (0.5-0.99). These wells are the deepest wells in the study area, thus, the TDS levels in these wells is high and results in high hardness (alkalinity), which makes the LSI more susceptible to incrusting water conditions. Corrosion also increases with high acidity levels, as seen in SWN 4924420 and 4924429. Despite the low salinity levels (less than 999 milliequivalents per liter) in these wells, the pH levels were the lowest (7.4 and 7.6) in the study area. Corrosive groundwater can cause well casings and screens to deteriorate, and accumulation of mineral deposits can negatively impact well performance. Therefore, material selection is critical for this potential ASR or AR system (Spencer and others, 2013).

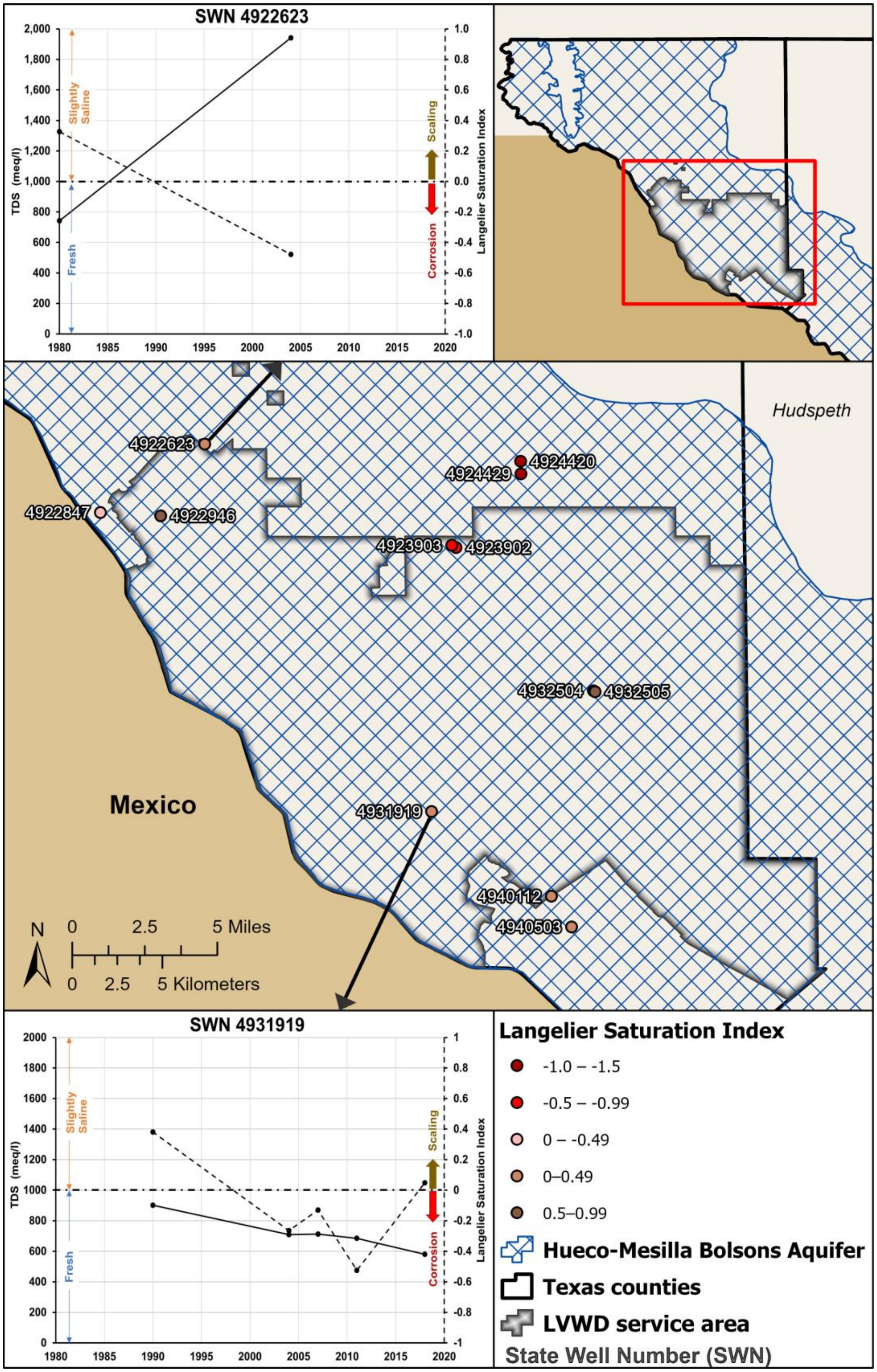


Figure 6-1. Langelier Saturation Index ranges in the study area based on available water quality samples.

There are several materials commonly used for well casing and screens that are approved by the TCEQ (Spencer and others, 2013). These materials include plastic, low carbon steel, stainless steel, high-steel low-alloy steel (HSLA), fiberglass, and various alloys used for specialized conditions (Mehmert, 2007; Spencer and others, 2013). Plastic casing is highly resistant to corrosion and is commonly used in shallow vadose wells (Spencer and others, 2013). Plastic casing, however, has relatively low strength and is therefore not suitable for deeper wells or the stresses associated with ASR injection and storage (Pyne, 2005; Spencer and others, 2013). Carbon steel is low cost and the most used casing material in Texas; however, it is highly susceptible to corrosion and can only be used in wells with groundwater that has a positive LSI (Mehmert, 2007; Spencer and others, 2013).

HSLA does not have a specific composition but can be formulated to be moderately corrosion resistant (Spencer and others, 2013). HSLA can be high cost and is not a common material; therefore, it is generally only used in specialized projects. Stainless steel is commonly used in water wells where corrosion resistance is needed, and there are several types readily available (Spencer and others 2013). Fiberglass casing is relatively new, very corrosion resistant, and generally costs less than stainless steel. However, fiberglass casing is not nearly as strong as carbon or stainless steel, requires special handling and permitting, and is not commonly available (Spencer and others, 2013). Other alloys such as Hastelloy C can be formatted to be both strong and resistant to corrosion in high salinity to brine conditions (Mehmert, 2007). These alloys are often very high cost and are generally only considered if the project requires resistance to such conditions (Mehmert, 2007).

For native groundwater with scaling potential, removal of mineral deposits is often achieved with acid treatment. Therefore, in locations where frequent use of acids is anticipated, corrosion-resistant materials should be used for the well casing and screen.

6.3 Limitations and future data collection

One of the primary challenges with implementation of an ASR or AR project in southern El Paso County is the lack of available geological information, particularly at depth. Many studies focused on the Hueco Bolson have focused on the northern portion of the county, near the City of El Paso (e.g., Knowles and Kennedy, 1958; Davis and Leggat, 1967; Budhathoki and others, 2018). However, there have been some studies investigating southern sections of the Hueco Bolson primarily using outcrop or surface geophysics (i.e., Gates and Stanley, 1976). Due to the Hueco Bolson's heterogenous geology, it is difficult to predict the subsurface geology throughout the study area because of the sparse data coverage. This report is designed to be a first look at the overall geologic and hydrologic environment of the study area.

Additional data collection will be needed for the design of an ASR or AR system. Covering a large portion of the study area may be possible using airborne geophysics. The sparsely populated study area makes airborne geophysical studies ideal, as there is less potential electromagnetic interference from electrical lines, industry, or houses. Seismic surveys may also be a viable alternative and provide a better understanding of the complex stratigraphy under the LVWD's service area. Seismic data also will likely provide the greatest detail at depth. Additionally, test holes to determine the lithology of specific locations are recommended. Test wells may also be necessary for groundwater testing as the complex nature of the Hueco Bolson makes identifying groundwater quality patterns difficult.

6.4 Regulation and permitting

All ASR injection and recovery wells in Texas must be authorized by the Underground Injection Control Program at TCEQ. The only operating reclaimed water system in Texas is the ASR-AR hybrid system in El Paso, which predates TCEQ authority to permit injection wells in the state of Texas. At this time, however, there is no established regulatory path for authorizing an ASR system using reclaimed water, as the injectate and would need to be accomplished on a case-by-case basis (TCEQ, personal communication, 2025). Such a project would require the interested water producer to coordinate with several TCEQ programs to demonstrate that the reclaimed water would be treated to a level that would not degrade the aquifer (TCEQ, personal communication, 2025). The process envisioned would likely be similar to the case-by-case system TCEQ uses for direct potable reuse systems, but as of this report's publication date has not been pursued by any Texas entity for reclaimed water injection. Ongoing studies on reclaimed water injection into aquifers may lead to changes in the regulations as technology and science develop (EPA, 2023).

The LVWD may also consider the use of AR for this project, which would begin the permitting process as an "Alternative reclaimed water system" under 30 Texas Administrative Code (TAC) § 210.41. TCEQ has authority to permit disposal of municipal treated wastewater adjacent to waters in the state through a Texas Land Application Permit (TCEQ, 2024a). TLAPs authorize disposal of treated effluent via irrigation, evaporation, subsurface land application, or subsurface area drip dispersal systems. Regulatory requirements for subsurface area drip dispersal systems are in 30 TAC Chapter 222 and other types of land application authorizations are regulated under 30 TAC Chapter 309.

30 TAC Chapter 309 Subchapter B also includes requirements for the location of the facility, fields, holding structures, and buffer zones. The design of the treatment facility is regulated under 30 TAC Chapter 217 for the design of the facility and holding ponds. TCEQ resources, including Texas Land Application Permit application forms, can be found on the TCEQ's website. The Small Business and Local Government Assistance team, under the TCEQ's office of Compliance and Enforcement, offers compliance tools, guidance, and services to aid smaller entities with understanding TCEQ rules and requirements (TCEQ, 2024b).

Eligibility requirements for this program include the following:

- Small business: 100 or fewer employees in all locations
- Small local governments:
    - 50,000 or fewer city population
    - 100,000 or fewer county population
- School districts of 100,000 or fewer students

The LVWD serves approximately 54,000 people in El Paso County, 6.4 percent of the country's population, which increases the possibility of being eligible for the Small Business and Local Government Assistance program (North American Development Bank, 2021). The Small

Business and Local Government Assistance team has local staff representatives in each of the TCEQ regional offices. LVWD is in TCEQ Region 6 with headquarters in El Paso County (TCEQ, 2024c). The LVWD should contact Region 6 for additional information on the program and available assistance.

The TCEQ's general guideline is to submit a Texas Land Application Permit application package at least 330 days before the first day disposal capacity is anticipated. If the application passes through the administrative and technical reviews as well as a public comment period (if applicable), the TCEQ issues the permit with provisions that the applicant must comply with. This includes provisions on effluent limits, monitoring requirements, and design limitations for the infiltration basins.

7. Conclusions

Both ASR and AR are flexible and commonly cost-effective water supply and storage strategies that are gaining interest across Texas (Pirnie, 2011; Morris and others 2010). ASR and AR projects can be used to provide drought resilience and maximize the efficiency of the existing water infrastructure. In general, ASR systems are half the capital cost of other water storage options—such as surface reservoirs or storage tanks—and AR projects may have similar or lesser costs (Morris and others, 2010; Reinert, 2017). Additionally, ASR and AR systems have several practical advantages over other water storage strategies, such as reduced loss to evaporation and minimal environmental impact.

The LVWD needed to understand the suitability of the Hueco Bolson aquifer for the ASR component of its water management strategy project in the 2022 State Water Plan. The district received federal funding to construct a wastewater treatment facility to treat wastewater to near drinking water standards (Flores, 2023, personal communication). The treatment plant will help the district by providing wastewater services without relying on El Paso Water for treatment. Currently, the treatment plant will discharge advanced treated wastewater to the San Felipe Arroyo, where it will flow towards the Rio Grande. However, when excess advanced treated wastewater is available, the LVWD wants to store it in the Hueco Bolson aquifer through either an ASR or AR system (WSP and Freese and Nichols, 2021).

The deeper portions of the Hueco Bolson aquifer around the study area are poorly studied and the lack of geophysical logs and water quality measurements prevented a full aquifer characterization and detailed salinity zone mapping. The available geophysical logs in the study area were used to map the top of the Hueco basin-fill deposits; however, very few wells are drilled deep enough to reach the bottom of the unit, so previously published seismic data and geophysical surveys were used to map the bottom surface. This study provides high-level analysis of geologic characteristics and groundwater quality to inform future planning of water supply and storage strategies for the LVWD. A successful ASR or AR project within the study will require more site-specific data collection, such as geophysics (ground or airborne) and test well drilling and testing to provide the best chance of success for a project.

The Paleozoic and Mesozoic bedrock present under most of the Hueco Bolson is primarily marine carbonates and shales. This study shows that these units are relatively deep, approximately 1,000 to more than 3,000 feet below the ground surface, and that fluid flow is likely restricted to faults and fractures within the unit. Wells near the Clint Fault and to the east indicate that the water in these units is moderately to very saline. Additional information on these units is difficult to locate as little work has been done. Further investigation, such as test wells or seismic surveys, would be needed to consider the feasibility of an ASR project, and the depth of the units precludes an AR project.

The Miocene–Pleistocene Hueco basin-fill deposits consist of unconsolidated to poorly consolidated siliciclastic sediments deposited in fluvial, alluvial, and lacustrine environments. These beds are up to 567 feet below ground surface and are generally deepest near the Rio Grande. These beds are complex and contain sand beds that can be challenging to correlate with limited data. These units also have complex hydrogeology that is affected by the presence of surface features, active pumping, and faults. However, these units are semi-confined and not currently used extensively in the LVWD service area for water production. Although test wells may be needed, these units provide the best opportunity for development of an ASR or AR project. According to previous studies, the Camp Rice Formation, which cuts through the study area, may contain more sand—and therefore may be more suitable for ASR or AR—but further testing would be needed to verify this hypothesis. Additionally, work done by El Paso Water shows that recharge wells in these units tend to corrode and have problems with screen plugging, which makes AR utilizing infiltration basins more viable.

The surficial units within the study area (the Rio Grande alluvium, gravel beds, and eolian deposits) are shallow and are used extensively for water production for both agricultural and industrial use. Although an AR project utilizing infiltration basins could be considered in these shallow units, the extensive pumping has created extensive cones of depression, and the highly permeable gravels within much of the area allow water to easily flow into the underlying Hueco basin-fill deposits. These factors would make planning and operation of either an ASR or AR project using the surficial units as the storage zone challenging to manage.

The salinity analysis of the few available water quality measurements showed that salinity tends to increase in the area near the Rio Grande, which is primarily used for agriculture. The general degradation in water quality of the Hueco basin-fill deposits in this portion of the study area could be explained by the potential connection with the Rio Grande Alluvium in addition to intensive irrigation pumping. Fresh water zones are seen in the shallower parts of the Hueco basin-fill deposits, particularly where they are confined by thick clay beds. However, there is no definitive spatial pattern for these zones that can be determined due to data sparsity. Most wells only had a single measurement per well, therefore, water quality trends over time could not be determined across the entire study area.

As for changes in water quality with depth, higher salinity levels are reported in deep wells, especially in the eastern portion of the study area, and this might be due to communication with the underlying carbonate bedrock through faults and fractures. Additional water quality tests during site selection may be necessary to determine what steps would be needed to verify water compatibility with the native groundwater where the project is located (Sheng, 2005).

Total dissolved solids analysis from geophysical logs that extended below the bottom of the Hueco basin-fill deposits into the carbonate bedrock showed multiple levels of salinity up to moderately saline. Generally, literature reports that there has been an increase in brackish water intrusion into the fresher zones of the Hueco Bolson aquifer due to extensive municipal and irrigation pumping. A more up-to-date investigation of the aquifer, ideally through a test well, should give a more precise description of the fresh zones' locations, extents, and depths. This is an essential requirement for assessing the suitability of an AR project and should be considered in the next phase of the project's timeline.

Information and scores from the statewide suitability survey were further investigated using the analysis conducted from this report. The hydrogeological characteristics of the Hueco Bolson aquifer within the LVWD study area show that the area is moderately suitable for ASR and highly suitable for AR. However, while investigating a site for such a project, potential contamination from irrigation return flows, which was not included in the suitability survey, should be considered. Additionally, according to the Statewide ASR Suitability Survey, there is little to no available surface water and little available groundwater for injection.

However, there are several sources of reclaimed water throughout the study area that could be used to recharge the aquifer. The LVWD is planning on using advanced treated wastewater from its own facility, but additional water could be purchased from several additional sources. The Statewide ASR Suitability Survey shows that the LVWD has supply needs to meeet, especially for municipal use. The population within the LWVD is projected to increase more than 90 percent by 2070. Additionally, although irrigation supply needs are not considered in the statewide survey, this study estimated LVWD irrigation needs as 6,590 acre-feet per year by 2070. An AR project within the LVWD using reclaimed water would benefit both the residents and agricultural industry in the area; however, obtaining regulatory authorization may prove to be a challenge.

Overall, this assessment shows that the LVWD could benefit from an AR project. The most abundant available source of excess water within the region is reclaimed water, and the LVWD is currently planning to build a wastewater treatment plant that would produce this type of water. The hydrogeological characteristics and suitability analysis results indicate that an AR project using infiltration basins to supplement the existing groundwater and reduce declines in the water table to be the most viable option for the district. The TCEQ considers AR projects using reclaimed water as alternative reclaimed water systems, whereas infiltration basins that are part of this kind of project would be permitted as a subsurface area drip dispersal system. However, due to the complexity and scarce data throughout the LVWD service area, additional testing, such as geophysics or test wells, will be needed to verify future site selection and feasibility for such an AR project.

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9. Appendix A – Aquifer determination, stratigraphy, and water quality methods

We utilized geophysical well logs to define the top and bottom of hydrostratigraphic units and to calculate total dissolved solids (TDS) concentration of the native groundwater. Geophysical well logs are produced from tools that are lowered into a well bore with a wireline and retrieved back to the ground surface at a specific rate to measure various rock, fluid, borehole, casing, and cement properties.

9.1 Stratigraphy and lithology

Stratigraphic and lithologic analysis of geophysical wells was done using IHS Kingdom® software, which allowed geophysical wells to be examined at multiple scales across the study area. All geologic data used is shown in Figure 9-1.

The general stratigraphic mapping process used is outlined below:

1. Search the BRACS Database for geophysical well logs.
2. Depth-calibrate all geophysical logs in the study area.
3. Set up a project in IHS Kingdom®.
4. Import relevant BRACS Database data and depth calibrated logs into the Kingdom® project.
5. Review previous studies on the stratigraphy of the Hueco Bolson.
6. Export the stratigraphic depths data back to the BRACS Database.
7. Create stratigraphic elevation point shapefiles for the Hueco basin-fill deposits and the carbonate bedrock
8. Build additional data as needed for surface interpolation such as outcrop extents, digital elevation model for the ground surface, and outcrop elevation points.
9. Digitize interpreted depth contours from seismic study.
10. Interpolate the data inputs (points and contours) to build raster surfaces.
11. Review the raster surfaces and run through the mapping process again until quality control is complete.

Information from driller's reports was obtained from scanned PDFs in the Submitted Driller's Report Database (TWDB, 2019c). Due to differences between the records of companies and drillers, a process developed by the TWDB was used to simplify these descriptions into a consistent terminology that matched the four-tier system used in the geophysical well log interpretation. Further information on this method is in Section 6.4 of TWDB Report 385 (Meyer and others, 2020).

Lithology was described using a nomenclature system. Lithologic interpretations of the siliciclastic unites are based on the relative amounts of gravel, sand, and clay present within the section. These lithologic divisions are defined as gravel (more than 50 percent gravel), sand (100 percent sand), sand with clay (65 percent sand and 34 percent clay), clay with sand (35 percent sand and 64 percent clay), and clay (100 percent clay). Lithologic interpretations for the carbonate sections of the unit were based on the relative amount of limestone and mud. These divisions were limestone (100 percent limestone or dolostone), marl (50 percent limestone and 50 percent mud), carbonate mud (100 percent mud) and evaporite (100 percent evaporite).

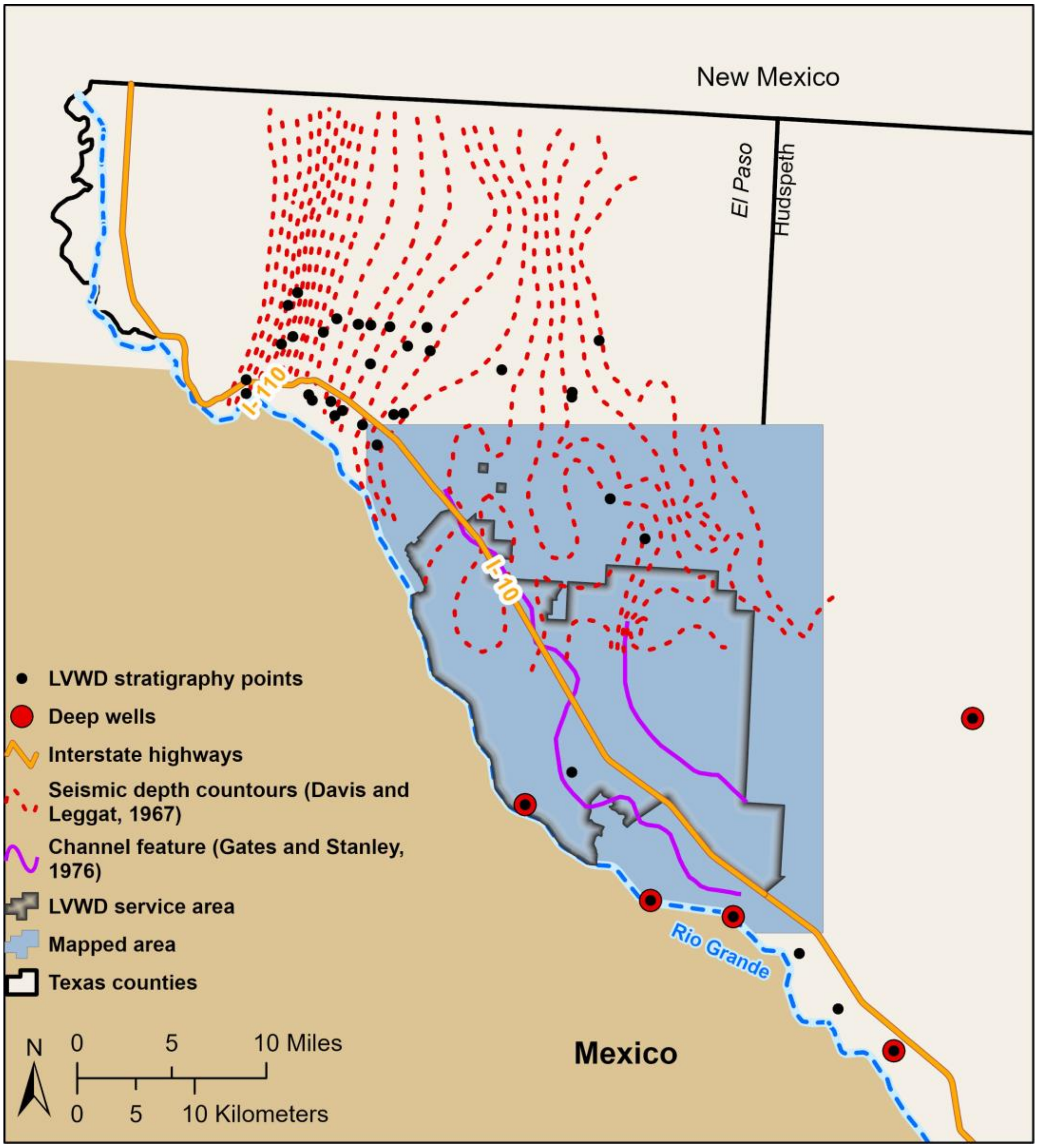

Figure 9-1. Data set used in stratigraphic and lithologic analysis.

9.2 Aquifer determination

To determine which wells in the mapped area were completed within the Hueco basin-fill deposits or the carbonate bedrock, an aquifer determination table for each formation was created in the BRACS Database. These tables were used to assign the correct aquifer to every well in the study area. This aquifer assignment creates a framework for the analysis of lithology and water quality data. This process uses the top and bottom depths for the Hueco basin-fill deposits and the tops of barbonate bedrock from the stratigraphy rasters created in Section 4.1.

The aquifer determination tables contain all well control (from BRACS and Groundwater databases) in the study area and were populated with well construction information such as screen intervals or total depth. The tables were also populated with the top and bottom depths of the Hueco basin-fill or the tops of carbonate bedrock from the stratigraphic analysis (see Section 4.1). Using queries within the database, each well's screen interval is compared with the top and bottom depths of the formation to assign the correct formation to the well. If well screen information was missing, the total depth of the well was used to determine whether it was completed within the formations of interest. If a well was partially completed within a formation or not within the formation at all, an identifier was assigned to indicate those situations. Wells that were identified as partially completed in the formation of interest were manually reviewed and reassigned as needed based on professional judgement.

9.3 Water quality

Water quality includes a broad range of biological, chemical, and physical properties of water. However, for this analysis water quality refers to the Total Dissolved Solids (TDS) defined as the total concentration of all dissolved molecules and ions reported in units of milligrams per liter. The TDS concentration of water is also referred to as the salinity of the water. Five salinity classes defined by TDS concentrations are used throughout this report following usage in the United States Geological Survey USGS paper by Winslow and Kister (1956):

- fresh water (0 to 999 milligrams per liter TDS)
- slightly saline water (1,000 to 2,999 milligrams per liter TDS)
- moderately saline water (3,000 to 9,999 milligrams per liter TDS)
- very saline water (10,000 to 34,999 milligrams per liter TDS)
- brine (>35,000 milligrams per liter TDS)

Two data sources for salinity class well control were used: measured water quality and TDS calculated from geophysical well logs. This section describes the applied methods as well as data quality control.

9.3.1 *Measured water quality verification (quality control)*

Measured water quality data were collected from the TWDB Groundwater Database. To verify the accuracy of reported major constituent values, the charge balance was calculated between the major anions and cations (in milliequivalents per liter) using the following formulas:

Total cation milliequivalents per liter = ((Ca^{2+} * 0.0499) + (Mg^{2+} * 0.08229) + (Na^{+} * 0.0435) + (K^{+} * 0.02557) + (Sr^{2+} * 0.0228))

Total anion milliequivalents per liter = ((CO_3^{2-} * 0.03333) + (HCO_3^{-} * 0.01639) + (SO_4 * 0.02082) + (Cl^{-} * 0.02821) + (F^{-} * 0.05264) + (NO_3^{-} * 0.01613))

Where:
Ca^{2+} = Calcium, Mg^{2+} = Magnesium, K^{+} = Potassium, Na^{+} = Sodium, Sr^{2+} = Strontium, SiO_2 = Silicate, HCO_3^{-} = Bicarbonate, CO_3^{2-} = Carbonate, Cl^{-} = Chlorine, SO_4^{2-} = Sulfate, F^{-} = Fluoride, NO_3^{-} = Nitrate

The total cation milliequivalents per liter was compared to the total anion milliequivalents per liter, which should be equal in an ionically balanced sample. Any samples with an absolute percent difference in charge balance greater than five percent were considered unbalanced. Only samples with a balanced ionic charge were included in this analysis. These data were tabulated and available in the BRACS Database (section 11, Appendix C).

9.3.2 *Alger-Harison method for calculating TDS concentration*

We used the modified Alger-Harrison method (Alger and Harrison, 1989) in several studies to calculate groundwater salinity estimates in carbonates (Robinson and others, 2019 and Robinson and others, 2022). The method relies on Archie's equation (Archie, 1942) and that the ratio of shallow resistivity and deep resistivity is similar to the ratio of the resistivity of the mud filtrate and the native groundwater (Alger and Harrison, 1989). Resistivity is the ability of the formation and groundwater surrounding the borehole to conduct electricity. Dry rocks represent good electrical insulators where electricity only passes through if it contains conducting groundwater (depending on salinity levels). In a clean, clay-free sand saturated with 100 percent water, Alger and Harrison (1989) shows that:

$$R_o = R_w \cdot \frac{a}{\phi^m} \qquad \text{Equation 9-1}$$

and

$$R_{xo} = R_{mf} \cdot \frac{a}{\phi^m} \qquad \text{Equation 9-2}$$

Rearranging the equations yields:

$$\frac{R_o}{R_w} = \frac{a}{\phi^m} \qquad \text{Equation 9-3}$$

and

$$\frac{R_{xo}}{R_{mf}} = \frac{a}{\phi^m} \qquad \text{Equation 9-4}$$

Then

$$\frac{R_o}{R_w} = \frac{R_{xo}}{R_{mf}} \qquad \text{Equation 9-5}$$

$$R_w = \frac{R_o . R_{mf}}{R_{xo}} \qquad \text{Equation 9-6}$$

Where:
Rw = resistivity of formation water (ohm-meter)
Rmf = resistivity of mud filtrate (ohm-meter)
Rxo = resistivity of the flushed zone near the wellbore (ohm-meter)
Ro = resistivity of the formation matrix and fluid (ohm-meter)
a = Winsauer factor (unitless)
ϕ = porosity (unitless as a decimal)
m = cementation exponent (unitless)

Although we were able to find available Hueco basin-fill deposit porosity estimates from literature, 0.18 (TWDB and New Mexico WRRI, 1997), the Alger-Harrison equation does not require porosity values or the cementation exponent from Archie's equation. The Alger-Harrison method is simple to apply, however, it requires that the mud parameters are reported on the log header and that resistivity tools were used to record resistivity in the mud-filtrate in the shallow flushed zone and the native groundwater in the deep zone.

The few available geophysical well logs in the study area had incomplete headers, hence we calculated the resistivity of mud filtrate using Robinson and other (2022) linear regression equation (Equation 9-7) for mud filtrate resistivity and mud resistivity normalized to a temperature of 75 degrees Fahrenheit. This equation was developed from 259 wells in the Trinity Aquifer with available geophysical log resistivity values. The linear regression coefficient of determination (R^2) for this equation is 0.9495. These data were tabulated and available in the BRACS database (section 11, Appendix C). We determined that the use of this equation was appropriate for the carbonate bedrock portion of the study area due to its similar geologic limestone and dolomitic characteristics.

$$R_{mf75} = 0.9157 * R_{m75} - 0.1446 \quad \text{Equation 9-7}$$

Where:
Rm75 = resistivity of the mud calculated at 75 degrees Fahrenheit (ohm-meter)
Rmf75 = resistivity of the mud filtrate calculated at 75 degrees Fahrenheit (ohm-meter)

All the used logs had shallow resistivity tool and, given that some of these logs were very old (pre-1960), they had a limestone deep resistivity tool. This is the deepest-sensing laterolog curve in the old dual-laterolog device and it is no longer used. Its advantage is that it is the least affected by bed boundary effects. This was achieved by implementing a laterolog focusing device that mitigated bed boundary effects. The designation “limestone” came from the fact that limestone formations typically exhibit very large resistivities and could also be affected by bed boundaries in thin beds (De Witte, 1954).

9.3.3 *Langelier saturation index calculation*

The Langelier Saturation Index (LSI) (1936) is a calculation of the potential for water to corrode or scale pipes (Equation 9-8). The calculation uses a sample’s pH, alkalinity, calcium concentration, total dissolved solids, and water temperature (Mehmert, 2007; Anwar, 2020). Negative LSI values indicate corrosive conditions, and positive values indicate scaling conditions.

$$LSI = pH - pHs \quad \text{Equation 9-8}$$

Where:
pH = measured pH of the sample
pHs: pH of the water when saturated with calcium

The pH of the water when saturated with calcium (pHs) can be calculated using Equation 9-9.

$$pH_s = (9.3 + A + B) - (C + D) \quad \text{Equation 9-9}$$

Where:
$A = (\text{Log}_{10}\ [\text{TDS}] - 1) / 10$
$B = -13.12 \times \text{Log}_{10}\ (^{o}\text{C} + 273) + 34.55$
$C = \text{Log}_{10}\ [Ca^{2+} \text{ as } CaCO_3] - 0.4$
$D = \text{Log}_{10}\ [\text{alkalinity as } CaCO_3]$

10. Appendix B – Geographic information system datasets

All geographic information system datasets and files prepared for this study are available for download from the TWDB website. These files were created using ArcGIS Pro® 9.2.5 and the Spatial Analyst® extension software by Environmental Systems Research Institute, Inc. (ESRI).

Point files are in the ArcGIS® feature class format. Point files of well control used for general purposes are originally projected as a geographic projection North America with the North American Datum 1983 as the horizontal datum. Point files are re-projected to a TWDB groundwater availability model projection and the North American Datum 1983 as the horizontal datum.

All surface files are in the ArcGIS® raster dataset integer grid file format with a groundwater availability model projection and the North American Datum 1983 as the horizontal datum.

Polygon and polyline files are in the ArcGIS® feature class format with a groundwater availability model projection and the North American Datum 1983 as the horizontal datum.

All well records are managed in the Microsoft® Access® BRACS Database. Well records are queried from the database and imported into ArcGIS® for spatial analysis. When new attributes are obtained for a well using ArcGIS® the information is imported into Microsoft® Access® and the well record is updated. Every well record in each supporting database used for this study contains latitude and longitude coordinates in the format of decimal degrees with a North American Datum of 1983. These well records are imported into ArcGIS® and georeferenced in a geographic coordinate system in North America with the North American Datum 1983 as the horizontal datum.

11. Appendix C – BRACS Database

All point-based well and geophysical well log information for this study is managed in the BRACS Database using Microsoft® Access® for Microsoft 365. When spatial analysis is required, copies of information are exported into ArcGIS®. Information developed in ArcGIS® is then imported back to the BRACS Database and the tables are updated accordingly. Although this approach may be cumbersome, it takes advantage of the strengths of each software. The study also relied on other software for specific tasks, including Microsoft® Excel® and IHS-Markit Kingdom®.

For the study, we assembled information from external agencies and updated these databases frequently. Each of these supporting databases are maintained in Microsoft® Access® and GIS files were developed for spatial analysis and well selection. Many of the database objects were built from scratch or were redesigned to meet project objectives. Data from external agencies or projects were available in many different data designs, so establishing a common design structure proved beneficial in leveraging information compiled by other groups.

The BRACS and supporting databases are fully relational. Data fields common to multiple datasets have been standardized in data type and name with lookup tables shared between all databases. Database object names use a self-documenting style that follows the Hungarian naming convention (Novalis, 1999). The volume of project information required us to develop comprehensive data entry and analysis procedures (coded as tools) that were embedded on forms used to display information. Visual Basic for Applications® is the programming language used in Microsoft® Access®, and most code was written at the Microsoft® ActiveX® Data Objects level with full code annotation. The code for geophysical well log resistivity analysis was specifically designed with a custom BRACS class object to support a rapid analysis of information with the benefit of only appending data when the user approves the results.

We develop custom tables for each study and incorporate them into the BRACS Database and add a study appendix describing these tables to the BRACS Data Dictionary after each study is completed. The custom tables developed for this study contain the final data used, are produced in the methodology section, and are listed in Table 11-1. These tables are available in the BRACS Database (TWDB, 2023b). Documentation and definition of the BRACS Database generic tables used for most of the studies is available in the BRACS Data Dictionary (Laughlin and others, 2023). Both are available for download from the TWDB website (www.twdb.texas.gov/groundwater/bracs/database.asp). Documentation of this study's tables should be available in the next edition of the BRACS Data Dictionary.

Table 11-1. Tables in the BRACS Database containing data used in and produced by this study.

Table name	**Table description**
gBRACS_ST_LVWD	This table contains all the wells in the study area with corresponding spatial data and geological formation depths and elevation values.
tblAquiferDetermination_LVWD	This table contains information on which aquifer(s) may be used or penetrated by a well in the study area.
tblBRACS_LVWD_MasterWaterQuality	This table contains a copy of every water quality record in the study area organized with one record per well per date sampled with constituents in separate fields.
gLVWD_HB_Calculated_TDS	This table contained the TDS values calculated using the Alger-Harison method along with the respective salinity level.
tbl_LVWD_Saturation_Index_Calculation	This table contains the Langelier Saturation Index calculation for the available water quality samples.