The Future of Desalination in Texas

2016 Biennial Report on Seawater and Brackish Groundwater Desalination

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Texas Water Development Board

The Future of Desalination in Texas

2016 Biennial Report to the Texas Legislature on Seawater and Brackish Groundwater Desalination

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Executive summary

Desalination, an important technology used to produce new water supplies around the world, is the process of removing dissolved solids and other minerals from saline water sources, which can include brackish groundwater and seawater. In 2015, the total number of desalination plants (brackish groundwater and seawater) worldwide was approximately 18,426, equivalent to a total installed capacity of 22.9 billion gallons per day (International Desalination Association, 2016a).

In the past decade, seawater desalination has become more prevalent nationally. In the United States, there are two large (>28,004 acre feet per year or 25 million gallons per day) operational seawater desalination facilities for municipal use: the Claude "Bud" Lewis Carlsbad Desalination Plant located in Carlsbad, California, and the Tampa Bay Seawater Desalination Plant in Tampa Bay, Florida.

Brackish groundwater is becoming an important water source that can help reduce the demand on fresh water supplies. Brackish groundwater contains dissolved salts with total dissolved solid concentration ranging from 1,000 to 10,000 milligrams per liter. In the United States, there are 325 municipal desalination plants—the majority of them located in Florida (45 percent), California (14 percent), and Texas (9 percent) (Mickley and others, 2011).

Texas has more than 2.7 billion acre-feet (879,797 billion gallons) of brackish groundwater in storage (LBG-Guyton Associates, 2003). Brackish groundwater is found in 26 of the 30 major and minor aquifers in Texas. As of 2012, Texas had 46 municipal desalination plants with a total design capacity of approximately 123 million gallons per day (138,000 acre-feet per year). Of these facilities, 12 use brackish surface water as the source water, accounting for a design capacity of 50 million gallons per day (56,000 acre-feet per year), and 34 use brackish groundwater, accounting for a design capacity of approximately 73 million gallons per day (82,000 acre-feet per year). These include plants with a capacity greater than 0.023 million gallons per day.

While the 2016 Biennial Report on Seawater and Groundwater Desalination is the seventh report in the series, marking the completion of 14 years toward advancing seawater desalination in Texas, it is the first report to discuss progress made in furthering brackish groundwater desalination and identifying and designating brackish groundwater production zones in the aquifers of the state.

Primary findings of the report are:

1. State funds to advance seawater and brackish groundwater desalination were exhausted in 2010. In 2015, the 84th Texas Legislature appropriated $2 million for contracts and administrative costs to help the Texas Water Development Board (TWDB) undertake studies of the House Bill 30 aquifers that required designation by December 1, 2016.
2. The relatively high cost of seawater desalination compared to the expense of developing other water supplies continues to be an impediment. Factors that affect the cost of seawater desalination include permitting, treatment, brine disposal, and transmission pipelines.
3. Although expensive, the drought resiliency of seawater desalination is still enticing. We expect Texas to have its first full production seawater desalination plant once M&G Resins USA, LLC finishes construction of its plant near Corpus Christi in 2017. The 2017 State Water Plan continues to identify seawater desalination as a viable strategy to meet future water needs. Several water providers are currently investigating seawater desalination as a future water supply option.
4. Legislation passed in 2015 streamlined and expedited the regulatory and permitting process associated with seawater desalination. Recent rules adopted by the Texas Commission on Environmental Quality (TCEQ) provide a quicker path for approving brackish groundwater desalination facilities.
5. The TWDB continues to make progress on mapping the brackish groundwater aquifers of the state.
6. The TWDB designated brackish groundwater production zones in the Carrizo-Wilcox, Gulf Coast, and Rustler aquifers.
7. Opportunities for continued state involvement include (1) facilitating meetings between water providers or municipalities and regulatory or planning agencies for the financial application and permitting process, (2) providing financing through existing programs to entities interested in pursuing seawater desalination, and (3) working with private and public partners to advance the implementation of seawater desalination in the state.
8. The TWDB's legislative appropriations request for the 2018–2019 biennium includes $2 million to continue progress on mapping brackish groundwater in the state.

Results of the Board's studies and activities in desalination

Since 2002, the TWDB has funded $3.2 million for seawater desalination studies, including three feasibility studies, two pilot-plant projects, and several guidance and research studies. The TWDB is monitoring the seawater industrial desalination plant M&G Resins USA, LLC is building which is expected to become operational in the first quarter of 2017. The City of Corpus Christi is also conducting two seawater desalination feasibility studies, one for municipal and the other for industrial use.

Between 2004 and 2009, the TWDB funded 17 projects and studies totaling $2.7 million related to brackish groundwater desalination, including the implementation of demonstration projects, preparation of guidance manuals, and conducting research studies. The TWDB is monitoring San Antonio Water System's 13,442-acre-feet-per-year (12-million-gallons-per-day) brackish groundwater desalination plant, which is expected to become operational in the last quarter of 2016. State funds to advance seawater and brackish groundwater desalination in Texas were exhausted in 2010.

In 2010, the TWDB funded three projects totaling $449,500 related to the Brackish Resources Aquifer Characterization System Program. Recently, with the passing of House Bill 30 (84th Texas Legislature, 2015) the TWDB funded seven aquifer projects totaling over $1.7 million. Contractors finished four aquifer projects (Carrizo-Wilcox, Gulf Coast, Blaine, and Rustler aquifers) in September 2016 and designated zones in three of the four aquifers in October 2016. Contractors are currently working on three aquifer projects (Trinity, Nacatoch, and Blossom aquifers) which we expect to be completed in August 2017. The TWDB is also currently working on two internal studies: (1) the Lipan Aquifer and (2) the Wilcox, Carrizo, Queen City, Sparta, and Yegua aquifers in Central Texas.

Research, regulatory, technical, and financial impediments to implementation

The relatively high cost and site specificity of seawater and brackish groundwater desalination compared to the cost of developing conventional fresh water supplies continue to be an impediment to advancing desalination in Texas. Factors that affect the cost of desalination include permitting, treatment, brine disposal, and transmission pipelines. In general, desalination projects depend on site-specific conditions as a result of which new studies each project requires. As water resources become scarcer due to drought and growth, desalination becomes a more enticing option.

The role of the State

The role of the State is to continue providing leadership and support to advance seawater and brackish groundwater desalination in Texas. Opportunities for continued state involvement include (1) facilitating meetings between water providers or municipalities and regulatory or planning agencies for the financial application and permitting process, (2) providing financing through existing TWDB programs to entities interested in pursuing seawater and brackish groundwater desalination, and (3) working with private and public partners to advance the implementation of desalination in the state.

Anticipated appropriation from general revenues

As part of the 2018–2019 legislative appropriations request, the TWDB requested baseline funding of $2 million to further desalination activities during the next biennium. The TWDB's current financial assistance programs are available to public entities that need assistance to fund the planning, design, and construction phases of seawater and brackish groundwater desalination plants. Since 1989, the TWDB has financed 34 desalination projects for a total of approximately $326 million.

Designation of brackish groundwater production zones

House Bill 30 (84th Texas Legislature, 2015), required the TWDB to designate brackish groundwater production zones in four aquifers, determine the volumes of water that a brackish groundwater production zone can produce over 30- and 50-year periods, and make recommendations on reasonable monitoring to observe the effects of brackish groundwater production within the zone.

On October 20, 2016, the Board designated one zone in the Carrizo-Wilcox Aquifer, four zones in the Gulf Coast Aquifer, three zones in the Rustler Aquifer, and no zones in the Blaine Aquifer. All the zones contain groundwater that is slightly to moderately saline (1,000 to 10,000 milligrams per liter of total dissolved solids).

The annual volume of brackish groundwater that could potentially be pumped from the designated zone is about 43,000 acre-feet per year in the Carrizo-Wilcox Aquifer, 45,700 acre-feet per year in Gulf Coast Aquifer, and 15,680 acre-feet per year in the Rustler Aquifer. For the Carrizo-Wilcox Aquifer, this amounts to 1.29 million acre-feet of brackish groundwater over 30 years and 2.15 million acre-feet over 50 years. For the Gulf Coast Aquifer, this amounts to 1.37 million acre-feet of brackish groundwater over 30 years and 2.28 million acre-feet over 50 years. For the Rustler Aquifer, this amounts to 0.47 million acre-feet of brackish groundwater over 30 years and 0.78 million acre-feet over 50 years.

In general, for the three aquifers that have designated zones, staff recommends monitoring aquifers above and below the zones to observe the effects of producing brackish groundwater from the zones. Staff also recommended monitoring the permeable sands associated with the shale units that serve as hydrogeological barriers above and below the aquifers.

Introduction

Desalination is an important water management strategy that has created new water supplies around the world. Desalination is the process of removing dissolved solids and other minerals from saline water sources, including brackish groundwater and seawater. Membranes are generally used to physically separate the dissolved solids from water. The most widely used commercial membrane technology is reverse osmosis, which uses high pressure to push water through the membranes.

The treatment process in a desalination plant typically consists of pretreatment, reverse osmosis, and post treatment. The raw (untreated) water enters the plant and goes through a series of filtration or membrane processes (such as strainers, cartridge filter, and microfiltration) to remove sand and suspended solids. Operators dose the water with antiscalant and acid to help prevent clogging the membranes. The operator then pumps the feed water to the reverse osmosis trains, which results in two streams: (1) the permeate (the desalted water) and (2) the concentrate (or brine where the salts are accumulated). In post treatment, operators add chemicals to the permeate or blend the permeate with raw water to add minerals and make it less corrosive. The concentrate from brackish desalination can be discharged to an appropriate water body, sanitary sewer, injection well, or evaporation pond. For seawater desalination, the brine is typically discharged back to the ocean using an outfall. A reverse osmosis system generally operates with 75 to 85 percent recovery for brackish desalination (for every 100 gallons desalinated, you achieve 75 to 85 gallons of fresh water) and 50 percent recovery for seawater desalination. The higher the recovery of the system and the higher the total dissolved solids of the raw water, the more the energy consumption and costs of the desalination plant increase.

In 2002, Governor Rick Perry announced his vision of meeting future water supply needs through seawater desalination and directed the TWDB to recommend a large-scale seawater desalination demonstration project. In 2003, the 78th Texas Legislature passed House Bill 1370 directing the TWDB to pursue seawater desalination and to report progress in a biennial report due December 1 of each even-numbered year.

TWDB efforts began with the identification of sites for a seawater desalination demonstration project. The first step was to issue a request for statements of interest to develop large-scale seawater desalination. In 2003, the TWDB selected three locations (cities of Corpus Christi, Brownsville, and Freeport) for feasibility studies. The 78th Texas Legislature subsequently appropriated $1.5 million to fund the studies. The cities completed these studies in 2004. In 2005, the 79th Texas Legislature appropriated $2.5 million for seawater desalination pilot studies. Between 2006 and 2008, the TWDB contracted for two pilot-plant studies: one at the

Brownsville Ship Channel by the Brownsville Public Utilities Board and the second on South Padre Island by the Laguna Madre Water District. In 2009 and 2010, the TWDB funded research studies on environmental permitting requirements to implement seawater desalination along the Texas Gulf Coast.

To build on the governor's desalination initiative, the TWDB established the Brackish Groundwater Desalination Initiative in 2004. The goal was to demonstrate the use of innovative and cost-effective desalination technologies and offer practical solutions to key challenges such as concentrate management and energy optimization. In 2005, the 79th Texas Legislature appropriated funds to support the first batch of demonstration projects. In 2007, the Texas Legislature appropriated funds to support five new studies and, in 2009, additional funds to support four demonstration projects. Funding for the demonstration projects ended in 2009.

Texas Water Code §16.060 requires the TWDB to undertake necessary steps to further the development of cost-effective water supplies from seawater or brackish groundwater desalination in the state and report the results of its studies and activities to the governor, lieutenant governor, and speaker of the house of representatives no later than December 1 of each even-numbered year. The report includes

1. the results of the Board's studies and activities related to seawater and brackish groundwater desalination during the preceding biennium;
2. an identification and evaluation of research, regulatory, technical, and financial impediments to implementing seawater or brackish groundwater desalination projects;
3. an evaluation of the role the State should play in furthering the development of large-scale seawater or brackish groundwater desalination projects in the state;
4. anticipated appropriation from general revenues necessary to continue investigating water desalination activities in the state during the next biennium; and
5. identification and designation of local or regional brackish groundwater production zones in areas of the state with moderate to high availability and productivity of brackish groundwater that can be used to reduce the use of fresh groundwater.

The 2016 biennial report is the first report to discuss both seawater and brackish groundwater desalination and the identification and designation of local or regional brackish groundwater production zones. With respect to seawater desalination, this is the seventh report in the series and marks the completion of 14 years of activities toward advancing seawater desalination and 12 years of activities furthering brackish groundwater desalination in Texas.

Seawater desalination

Various countries around the world use desalination to produce fresh water supplies, and it has gained momentum in the United States in the past decade. The installed global seawater desalination capacity was about 13.8 billion gallons per day, about 60 percent of the total installed desalination capacity (International Desalination Association, 2016a). Seawater has a total dissolved solid concentration of about 35,000 milligrams per liter or greater.

Current state of seawater desalination

In the United States, there are two large (larger than 28,004 acre feet per year or 25 million gallons per day) operational seawater desalination facilities for municipal use: (1) the Claude "Bud" Lewis Carlsbad Desalination Plant located in Carlsbad, California, and (2) the Tampa Bay Seawater Desalination Plant in Tampa Bay, Florida. Public-private partnerships were the financial mechanisms used to build both desalination plants. A third large seawater desalination plant is being rehabilitated in Santa Barbara, California, and is scheduled to become operational in January 2017.

Currently, California has a total of 10 small operating seawater desalination facilities along the Pacific Coast (Table 1). Of the six seawater desalination facilities that are active, three are used for municipal purposes. The Sand City Coastal Desalination Facility became operational in May 2011 (Sand City, 2016), and the Santa Catalina Island expansion and Carlsbad Desalination Plant became operational in December 2015. Future projects in California include nine active proposals for seawater desalination plants (Cooley, 2016). Additionally, there are two proposed plants in Baja California.

Table 1. Existing seawater desalination facilities in California.

Status	**Plant name**	**Size (million gallons per day)**	**Use**	**Operator**
Active	Monterey Bay Aquarium	0.008	Commercial	Monterey Bay Aquarium
Active	Diablo Canyon Power Plant	0.58	Industrial	Pacific Gas & Electric
Active	Gaviota Oil Heating Facility	0.41	Industrial	Chevron Corporation
Active	Sand City Coastal Desalination Facility	0.30	Municipal	City of Sand City
Active	Santa Catalina Island	0.325	Municipal	Southern California Edison*
Active	Carlsbad Desalination Plant	50.0	Municipal	Poseidon Water
Idle	Marina Desalination Plant	0.27	Municipal	Marina Coast Water District
Idle	Morro Bay Desalination Facility	0.60	Municipal	City of Morrow Bay
Idle	Charles Meyer Desalination Facility	2.80	Municipal	City of Santa Barbara
Unknown	San Nicholas Island	0.024	Municipal	San Nicholas Island

Source: (Cooley, 2016); Note: *City of Avalon is also an operator.

The 56,007-acre-foot-per-year (50-million-gallon-per-day) Carlsbad Desalination Plant, which became operational on December 14, 2015, can serve approximately 400,000 people in San Diego County (San Diego County Water Authority, 2016c). The plant is the biggest seawater desalination plant in the United States. In 2020, seawater desalination will account for approximately 8 to 10 percent of the San Diego region's water supply and about one-third of all locally generated water in San Diego County (San Diego County Water Authority, 2016b; 2016c). The planning phase of this project started in 1998 and took 12 years, with the permitting process that started in 2003 taking an additional seven years. San Diego County Water Authority has signed a 30-year water purchase agreement with Poseidon Water, with cost of water estimated at $2,125 to $2,368 per acre-foot in 2017 (San Diego County Water Authority, 2016a; Poseidon Water, 2016b).

The Carlsbad Desalination Plant is located adjacent to the Encina Power Station, which will be decommissioned in the near future. Nevertheless, the desalination plant is able to use and take advantage of existing infrastructure at the power plant. Seawater from the Pacific Ocean with a total dissolved solid concentration of approximately 33,500 milligrams per liter flows to the Agua Hedionda Lagoon (Poseidon Water, 2016b). Approximately 340,524 acre-feet per year (304 million gallons per day) of seawater is pumped from the lagoon to the power plant's cooling towers through an existing surface intake. About 224,029 acre-feet per year (200 million gallons per day) of cooling water is returned to a discharge pond and diluted with seawater and ultimately discharged back to the Pacific Ocean. The remaining 104 million gallons of cooling water is diverted to the desalination plant and treated. The treatment process includes multimedia filters and microfiltration, followed by reverse osmosis, and ends with mineralization and disinfection. Approximately 60,488 acre-feet per year (54 million gallons per day) of brine is also disposed to the discharge pond. The final product water is piped 10 miles to the San Diego County Water Authority Second Aqueduct.

The Charles E. Meyer Desalination Facility in the city of Santa Barbara was built in 1991 to provide an emergency water supply during a drought. It operated for three months and then was placed in standby mode, which it has been in since. In July 2015, the Santa Barbara City Council voted to reactivate the facility. When re-activated, the plant will produce about 3,360 acre-feet per year (3 million gallons per day) of water and can be expanded in the future to up to 9,969 acre-feet per year (8.9 million gallons per day) (City of Santa Barbara, 2016a). Seawater desalination will account for about 30 percent of the city's annual demands (City of Santa Barbara, 2016b).

The Tampa Bay Seawater Desalination plant in Tampa, Florida, first became fully operational in 2007 and has a design capacity of 28,004 acre-feet per year or 25 million gallons per day. It is co-located with and uses electricity generated from Tampa Electric's Big Bend Power Station. For source water, the seawater desalination plant uses approximately 49,286 acre-feet per year (44 million gallons per day) of warm water that has passed through the co-located power plant's cooling tower (Tampa Bay Water, undated). The treatment process includes pre-treatment, reverse osmosis, and post-treatment. The concentration of total dissolved solids in the raw water averages 26,000 milligrams per liter but can range from 10,000 to 30,000 milligrams per liter.

The desalinated water produced at the Tampa Bay Seawater Desalination Plant is piped to a regional water facility located 14 miles away and blended with treated surface water at a rate based on demand. Water from the desalination plant currently provides up to 10 percent of the region's needs (Tampa Bay Water, undated). Concentrate (21,283 acre-feet per year or 19 million gallons per day) resulting from the reverse osmosis process is returned to the Big Bend Power Station and blended with the cooling water stream. It is then discharged to a canal where it blends with seawater and eventually reaches Tampa Bay.

Past studies in Texas

Since 2002, the TWDB has funded $3.2 million in studies related to seawater desalination, including three feasibility studies, two pilot-plant projects, and several guidance and research studies (Table 2). By 2010, the $2.5 million appropriated by the 79th Texas Legislature for desalination demonstration activities had been spent. Since then, the TWDB has not funded additional seawater desalination studies with research funds.

Table 2. TWDB-funded reports on seawater desalination.

Report title	Study location	Study type
Lower Rio Grande Valley, Brownsville Seawater Desalination Demonstration Project (Brownsville Public Utilities Board, 2004)	City of Brownsville	Feasibility study
Large Scale Demonstration Desalination Feasibility Study (City of Corpus Christi, 2004)	City of Corpus Christi	Feasibility study
Freeport Seawater Desalination Project (Brazos River Authority, 2004)	City of Freeport	Feasibility study
Pilot Study Report, Texas Seawater Desalination Demonstration Project (Brownsville Public Utilities Board, 2008)	City of Brownsville	Pilot-plant study
Feasibility and Pilot Study, South Padre Island Seawater Desalination Project (Laguna Madre Water District, 2010)	South Padre Island	Pilot-plant study
Guidance Manual for Permitting Requirements in Texas for Desalination Facilities Using Reverse Osmosis Processes (R.W. Beck, Inc., 2004)	Not applicable	Guidance document
Lessons Learned from the Brownsville Seawater Pilot Study (Reiss Engineering Inc., 2009)	City of Brownsville	Guidance document
Texas Desal Project (Brownsville Public Utilities Board, 2011)	City of Brownsville	Guidance document

Brownsville feasibility and pilot-plant studies

From 2004 to 2011, the TWDB and the Brownsville Public Utilities Board conducted feasibility and pilot-plant studies and completed a scoping of permitting issues study and a conceptual layout and cost estimate for a full-scale seawater desalination production facility. Implementing a seawater desalination plant at the Brownsville Ship Channel could make effective use of those studies and deliver on the goal of this program. Seawater desalination would enhance the drought reliability of the region's water supply and offer a valuable reference for other potential projects with similar profiles located along the Gulf Coast.

The Brownsville Public Utilities Board has explored an increasingly smaller project to reduce the financial impact to its ratepayers and the state. In the 2010 and 2012 biennial seawater desalination reports, the TWDB reported that the plant capacity was reduced from an original 28,004 to 2,800 acre-feet per year (25 to 2.5 million gallons per day) with an estimated cost of $22.5 million. The amount of financial assistance (grant) requested from the 82nd Texas Legislature (2011) for this project was $9.5 million (TWDB, 2012). The project is currently on hold, pending procurement of funds by the Brownsville Public Utilities Board. On July 1, 2016, a regional water facility plan was completed for the Rio Grande Regional Water Authority evaluating seawater desalination (Blandford and Jenkins, 2016). The study evaluated a seawater desalination facility located at the Brownsville Navigation Channel or near the Gulf Coast. The approximate capital cost for a 22,403-acre-foot-per-year (20-million-gallon-per-day) facility at each location was $119 million and $229 million. The study concluded that seawater was a viable water supply for the Lower Rio Grande Valley.

South Padre Island feasibility and pilot-plant studies

Although South Padre Island was not one of the three original sites selected for a feasibility study as part of the Seawater Desalination Initiative (TWDB, 2002), the Laguna Madre Water District completed a feasibility and pilot-plant study and was part of the environmental scoping study for seawater desalination (Brownsville Public Utilities Board, 2011). The amount of financial assistance (grant) requested from the 82nd Texas Legislature (2011) for this project was $5 million (TWDB, 2012).

In May 2011, District voters approved two propositions: (1) Proposition I was for the issuance of bonds in the amount of $23,750,000 for system improvements and the levy of taxes in payment of the bonds and (2) Proposition II authorized the Laguna Madre Water District to issue bonds in the amount of $15,655,000 to finance construction of a seawater desalination facility and the levy of taxes in payment of the bonds.

In May 2014, the Laguna Madre Water District increased the total production capacity of its existing surface water treatment plant No. 2 by 2,240 acre-feet per year (2 million gallons per day) for a total production capacity of 7,841 acre-feet per year (7 million gallons per day). While this additional capacity strengthened the water supply system, it still relied on water from the Rio Grande, which is an unreliable source. The Laguna Madre Water District placed the seawater desalination project on hold while it explored potable reuse as an option (Laguna Madre Water District, 2014).

Pursuing the potable reuse option, Laguna Madre Water District conducted a feasibility study for an advanced water treatment plant in March 2015. The District evaluated siting a water reclamation facility adjacent to the existing Port Isabel Wastewater Treatment Plant to treat wastewater effluent from the plant to augment surface water in Reservoir 3. The study also examined other alternatives including a regional approach that involves receiving effluent from both Laguna Vista and Port Isabel wastewater treatment plants and treating the effluent at a single water reclamation facility. The feasibility study, which was completed in December 2015, concluded that the best location for a reclamation facility was near Water Treatment Plant 1 where wastewater effluent from Laguna Vista and Port Isabel Wastewater Treatment Plant would be treated and used to supplement water supplies in Reservoir 3. The next step for the District is to complete improvements to the Port Isabel Wastewater Treatment Plant in preparation for future indirect potable reuse implementation. On June 14, 2016, the TWDB approved $5.8 million for the district to complete the wastewater treatment plant improvements.

Corpus Christi feasibility study

In 2004, the TWDB and City of Corpus Christi completed a feasibility study that identified two sites, Barney Davis Power Plant and DuPont-OxyChem, as potential sites for a seawater desalination plant. Until recently, the City had not conducted additional work to advance the study into the next phase of pilot-scale testing.

In 2013, the City of Corpus Christi contracted with an engineering firm to conduct a 30-month initiative to design, build, and operate a demonstration municipal seawater desalination plant (City of Corpus Christi, 2014a). On April 22, 2014, the City approved funds to conduct the Variable Salinity Desalination Project. The City also received a $400,000 grant for the project from the U.S. Bureau of Reclamation through the Desalination and Water Purification Research program.

On August 12, 2014, the city council passed a resolution recommending that the 84th Texas Legislature (2015) appropriate funding for the Fiscal Year 2016 to implement seawater desalination projects (City of Corpus Christi, 2014c).

On November 18, 2014, the City Council also approved participation in an Industrial Seawater Desalination Facility Economic Feasibility Study and appropriated $50,000 (City of Corpus Christi, 2014b). The two projects are fully described in the Other Activities Section of this report.

Freeport feasibility study

The Brazos River Authority reports that no additional work has been conducted since the TWDB-funded feasibility study was completed in 2004 (Brazos River Authority, 2016). The study concluded that seawater desalination was feasible and recommended entities to seek financial assistance and conduct pilot-scale testing. The project consisted of the Brazos River Authority and Poseidon forming a private-public partnership and building a 10-million-gallon-per-day demonstration facility.

Seawater desalination in the 2017 State Water Plan

In the 2017 State Water Plan, four regional water planning groups (regions H, L, M, and N) included seawater desalination as a recommended water management strategy. This consists of 10 recommended water management strategies that may meet the water needs of a water user group (Appendix E, Table E-1). If implemented, these seawater desalination strategies will produce an estimated 116,000 acre-feet of new water supply per year by decade 2070. This constitutes about 1.4 percent of all recommended water management strategies in the state water plan. There are also two recommended water management projects in Region L that currently are not assigned to serve a specific water user group (in other words, the projects are recommended but are not planned to provide water to users during the 50-year planning period).

The Rio Grande Regional Water Planning Group (Region M) included seawater desalination as an alternative water management strategy, which is a strategy that can replace a recommended strategy in the regional water plan and consequently the state water plan if it turns out the recommended strategy cannot be achieved (Texas Administrative Code §357.10(1)). If implemented, the 28 strategies (Appendix E, Table E-2) would provide 81,000 acre-feet per year of water supplies by decade 2070.

To implement water management strategies, water user groups may need to execute a project to obtain the new water supplies. Regional water planning groups identified 11 recommended water management strategy projects for seawater desalination (Table 3). The difference between a water management strategy and project is that a strategy is a plan to meet a water need and the project is the infrastructure required to implement the strategy. Projects would develop, deliver, or treat additional water supply volumes at a specified capital cost. Projects can also conserve water for water user groups or wholesale water suppliers. One project may be associated with multiple water management strategies. For example, one project may support multiple water user groups that use that new supply.

The statewide weighted-average[1] seawater desalination unit cost of recommended projects is $1,431 per acre-foot. The projects are distributed along the Gulf Coast (Figure 1). For a few projects, sponsors have completed feasibility or pilot studies with the assistance of TWDB research funds.

Table 3. Seawater desalination projects in the 2017 State Water Plan.

ID	Region	Project sponsor	Project name	Feasibility study completed	Pilot study completed	Project level recommendation type
1	H	Brazos River Authority	Freeport seawater desalination	Yes	--	Recommended
2	L	San Antonio Water System	Seawater desalination	--	--	Recommended
3	L	Guadalupe Blanco River Authority	Integrated water-power project	Yes	--	Recommended
4	M	Brownsville Public Utilities Board	Brownsville seawater desalination demonstration	Yes	Yes	Recommended
5	M	Brownsville Public Utilities Board	Brownsville seawater desalination implementation	Yes	Yes	Recommended
6	N	Corpus Christi	Seawater desalination	Yes	--	Recommended
7	M	Laguna Madre Water District	Laguna Madre seawater desalination	Yes	Yes	Alternative
8	M	RGRWA	RGRWA ocean desal – Phase I	--	--	Alternative
9	M	RGRWA	RGRWA ocean desal - Phase II	--	--	Alternative
10	M	RGRWA	RGRWA ocean desal - Phase III	--	--	Alternative
11	M	RGRWA	RGRWA ocean desal - Phase IV	--	--	Alternative

Note: RGRWA = Rio Grande Regional Water Authority

[1] The weighted average is the average of values scaled by the relative volume of each strategy.

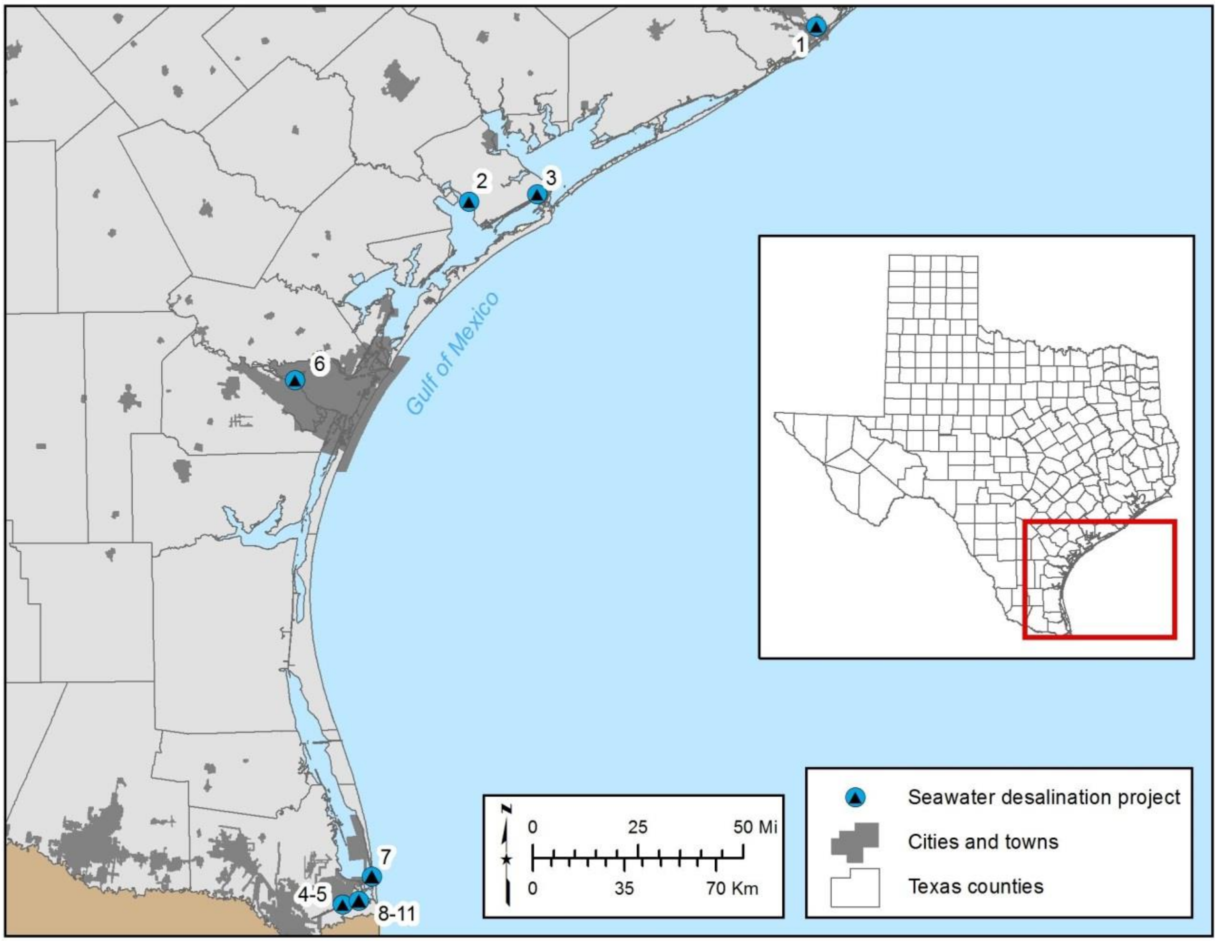


Figure 1. **Location of seawater desalination projects in the 2017 State Water Plan. Numbers refer to projects in Table 3.**

Region H Regional Water Planning Area

Seawater desalination is recommended as a water management strategy in the 2016 Region H Regional Water Plan to meet manufacturing demands in Brazoria County in decade 2040. Region H proposes a seawater desalination plant with an initial capacity of 11,200 acre-feet per year (10 million gallons per day) at the Dow Chemical Company complex in the City of Freeport. The facility would use an existing intake and discharge outfall and Dow's withdrawal and discharge permits, which would reduce construction costs and environmental impacts. Although Dow is not interested in sponsoring the project, other potential wholesale water providers that could be sponsors include the Brazos River Authority and the Gulf Coast Water Authority. The estimated capital cost to build the plant is about $133 million.

The Brazos River Authority and City of Freeport confirmed that no additional work has been completed on seawater desalination after their feasibility study was completed in 2004 (Brazos River Authority, Personal Communication, 2016).

South Central Texas (Region L) Regional Water Planning Area

The 2016 South Central Texas (Region L) Regional Water Plan includes two seawater desalination projects. San Antonio Water System proposes to build a seawater desalination plant adjacent to the San Antonio Bay near the City of Seadrift with a design capacity of 84,012 acre-feet per year (75 million gallons per day). A 126-mile-long pipeline would convey treated water to a location in southern Bexar County near the Twin Oaks Aquifer Storage and Recovery facility. The concentrate would be discharged 13 miles offshore to the Gulf of Mexico. The estimated total capital cost for the project is about $1.6 billion.

The San Antonio Water System's 2012 Water Management Plan lists seawater desalination as a conceptual solution for long-term projects for the 2040 to 2070 period. The plan states that each conceptual solution will be investigated and evaluated to prepare a solid foundation for future water supplies (San Antonio Water System, 2012). Staff from San Antonio Water System's water resources department confirmed that the seawater desalination project is in the initial conceptual stages and that the current focus is on other planned projects for the 2012 to 2020 period, including a brackish groundwater desalination plant (San Antonio Water System, Personal Communication, 2014).

The Guadalupe-Blanco River Authority Integrated Water-Power Project involves building a 100,000-acre-foot-per-year (89.3-million-gallon-per-day) seawater desalination plant near Port O'Connor in Calhoun County. Water would be conveyed via a 138-mile-long pipeline to Calhoun, Victoria, Gonzales, and Dewitt counties. The estimated total capital costs of the project are $1.6 billion.

Rio Grande (Region M) Regional Water Planning Area

The 2016 Rio Grande (Region M) Regional Water Plan includes seawater desalination as a recommended water management strategy. The proposed location of the seawater desalination plant is on the south shore of the Brownsville Ship Channel. The Brownsville Public Utilities Board is the sponsor for both phases of the project. The facility would come online in decade 2020 with initial capacity of 2,800 acre-feet per year (2.5 million gallons per day) and expanded to 28,000 acre-feet per year (25 million gallons per day) by decade 2060. The estimated capital costs of the desalination plant are about $56 million for Phase I and about $310 million for Phase II.

Coastal Bend (Region N) Regional Water Planning Area

The 2016 Coastal Bend (Region N) Regional Water Plan recommends a 22,420-acre-foot-per-year (20-million-gallon-per-day) seawater desalination that would come online in the 2030 decade. The treatment plant, estimated to cost $248 million, could be located between Nueces and Corpus Christi bays or at the Inner Ship Channel adjacent to the Broadway Wastewater Treatment Plant near the northeast corner of Corpus Christi Bay. The plant would serve Nueces and San Patricio counties. The City of Corpus Christ is currently participating in two feasibility studies related to seawater desalination that are described in the Other Seawater Desalination Activities section of this report.

Other seawater desalination activities

Several public entities are currently conducting feasibility studies in support of recommended water management strategies or implementing projects not included in the state water plan. These activities are described in detail below. Recent legislation passed by the Texas Legislature and their effects on regulations are also discussed.

Guadalupe-Blanco River Authority

The Guadalupe-Blanco River Authority, in partnership with the State of Texas General Land Office and the Texas Sustainable Energy Research Institute at The University of Texas at San Antonio, conducted a feasibility study to determine the best co-location for a seawater desalination plant and a power plant for their Integrated Water-Power Project. Other project partners included the City of Corpus Christi. The river authority obtained a $450,000 grant from the U.S. Bureau of Reclamation through the Title XVI Water Reclamation and Reuse Program to cover part of the costs for the feasibility study.

The feasibility study evaluated siting a 28,000- to 280,000-acre-foot-per-year (25- to 250-million-gallon-per-day) seawater desalination plant with a 500- to 3,000-megawatt co-located power plant (Guadalupe-Blanco River Authority, 2014). The study area extended from Freeport to Corpus Christi along the Gulf Coast. Representative site locations have been identified in San Patricio, Calhoun, Matagorda, and Brazos counties.

On December 1, 2015, the Guadalupe-Blanco River Authority received a $2 million loan from the TWDB through the State Water Implementation Fund for Texas to further study integration of a seawater desalination plant as a supplemental supply and continue project development. Project tasks include preliminary site selection and project sizing criteria, completing environmental surveys, and much more. A Phase I Report will be submitted to the TWDB in December 2016 and will consist of a series of technical memorandums on various subjects including site screening, desalination technologies, environmental compliance, and representative site evaluations. The anticipated study completion date is March 30, 2018.

City of Corpus Christi variable salinity desalination program

In 2013, the City of Corpus Christi contracted with an engineering firm to conduct a 30-month study to design, build, and operate a demonstration seawater desalination plant (City of Corpus Christi, 2014a). The study consists of four major components: literature review, desalination plant siting, pilot testing criteria, and pilot testing protocol. Water quality data was compiled from 17 locations. The team collected and analyzed water samples from 15 locations and compiled the remaining data from existing stations (Cocklin, 2016). The site for the 12-month-long pilot is located next to the existing Broadway Wastewater Treatment Plant located near the inner harbor. The team is currently finalizing the protocol and technical criteria for the pilot study and anticipates starting testing in the third quarter of 2017.

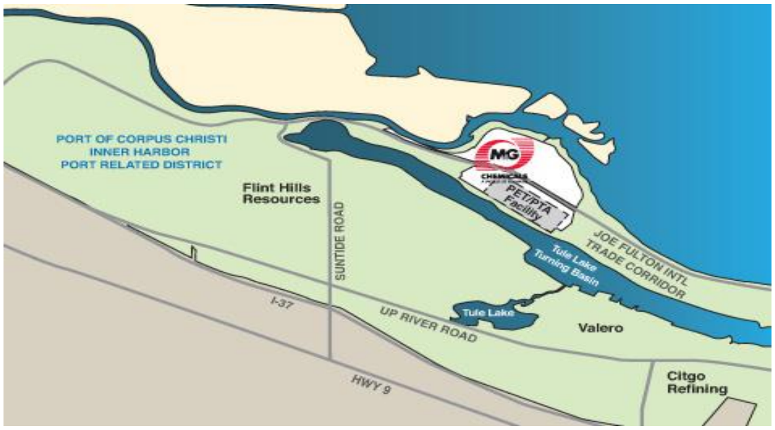
Industrial seawater desalination feasibility

A group of 15 stakeholders consisting of industries, water providers, and regional authorities has joined efforts to conduct a feasibility study on seawater desalination for industrial purposes. The Industrial Seawater Desalination Facility Economic Feasibility Study consists of two phases. The first phase of the study will evaluate locations, water sources, water delivery methods, and brine disposal for a seawater desalination plant. If the stakeholders decide to implement the project, the second phase will procure and implement the facility. The study participants include the City of Corpus Christi, Corpus Christi Regional Economic Development Corporation, San Patricio Municipal Water District, Port of Corpus Christi, DuPont, OxyChem, Sherwin Alumina Company, LyondellBassell Industries, Citgo, Flint Hills Resources, Valero, Topaz Power, AEP Texas, Cheniere Energy, and Voestalpine Texas.

Funding for the study is provided by Corpus Christi Regional Economic Development Corporation ($150,000) and Port Industries of Corpus Christi ($150,000) (City of Corpus Christi, 2014b). Phase I of the study is nearly complete and states that stakeholders prefer to build two seawater desalination plants each with a capacity of 11,201 acre-feet per year (10 million gallons per day) (Freese and Nichols, 2016). One plant could be located in Corpus Christi on the Inner Harbor Channel and the other in Ingleside on the La Quinta Channel. The desalinated water would be delivered using the Corpus Christi Regional System and funding pursued through the TWDB’s State Water Implementation Fund for Texas (Arroyo and Paulison, 2016). The port industries require 50 percent of the region’s municipal water demand. The industrial stakeholders are considering developing seawater desalination water supplies to ensure service continuity in the event of an extreme drought.

M&G Resins USA, LLC

M&G Resins USA, LLC, an Italian chemical company, is a producer of polyethylene terephthalate. Polyethylene terephthalate is used in making plastic packaging such as bottles and containers. In 2012, M&G Resins announced plans to build the world’s largest polyethylene terephthalate plant along with an integrated terephthalic acid plant in Corpus Christi. That same year it purchased about 412 acres of land in Corpus Christi from the Driscoll Foundation. The new polyethylene terephthalate plant is expected to have a production capacity of 1.1 million metric tons per year, and the terephthalic acid plant is expected to have a capacity of 1.3 million metric tons per year. The plants will be located at a site between Nueces Bay and the Viola Channel (Figure 2).



Source: Gruppo Mossi & Ghisolfi (M&G) Polymers

Figure 2. **Location of the polyethylene terephthalate and terephthalic acid plant in Port of Corpus Christi Inner Harbor.**

The two chemical plants require about 8,961 acre-feet per year (8 million gallons per day) of water for the manufacturing process (M&G Resins USA, 2014). To meet this requirement, the chemical company is building a seawater desalination plant onsite to supply 6,721 acre-feet per year (6 million gallons per day) of water and recover 2,240 acre-feet per year (2 million gallons per day) of water from their internal process. Approximately 80 percent of the water consumption in the manufacturing plant is for cooling purposes. The rest is used in the manufacturing process. The process can be a closed loop system because water is a byproduct of the polyethylene terephthalate and terephthalic acid process. The byproduct water can be treated and reused internally.

The seawater desalination plant will ensure that a reliable, drought-proof source of water is always available for use at the plants. Additionally, by locating a desalination plant onsite, the quality of water produced can be controlled to meet the requirements of the chemical plants. The desalination plant will be initially designed to suit M&G Resins' needs but can be expanded up to the maximum capacity of 24,643 acre-feet per year (22 million gallons per day) in the future. The planned seawater desalination plant is expected to require about 16,802 acre-feet per year (15 million gallons per day) of raw seawater from the Viola Channel. About 10,081 acre-feet per year (9 million gallons per day) of brine produced during the desalination process will be discharged back into the channel.

M&G Resins conducted studies to model the impact of salinity mixing from discharging brine into the channel. They conducted the studies to ensure that recirculation would not be an issue. The results of the simulation indicate that, in a worst-case scenario, the total dissolved solids concentration in the water of the channel would increase by about 1 percent.

The seawater desalination plant will consist of three cartridge filters units, five ultrafiltration trains, and four reverse osmosis trains. The design also includes a flotation system that will remove oil in emulsion and control turbidity. The outfall will be an above-surface diffuser. The distance between the intake and the outfall is approximately 800 to 900 feet. The seawater will be flocculated to minimize sedimentation effects from channel dredging and algae formation.

In February 2013, the company filed for a water permit with the Texas Commission on Environmental Quality to divert approximately 28,000 acre-feet of water per year (23 million gallons per day) from the Viola Channel. Archeological and geo-archeological investigations at the plant site were completed in March 2014 (Owens and Frederick, 2014). The water permit and wastewater discharge permit were granted in September 2014 (M&G Resins USA, 2014). The construction of the desalination plant is ongoing (Figure 3), and the plant will become operational in the first quarter of 2017 (M&G Resins USA, LLC, 2016).

(a) 

(b) 

Source: Gruppo Mossi & Ghisolfi (M&G) Polymers

Figure 3. Images showing the construction of the industrial seawater desalination plant as of (a) March 15, 2016 and (b) October 14, 2016.

Texas House Committee on Natural Resources

On November 4, 2015, the speaker of the Texas House of Representative assigned various interim committee charges to the House Committee on Natural Resources. On April 26, 2016, the committee conducted a hearing focused on water quality (Interim Charge 9) and desalination (Interim Charge 4) in Brownsville. More specifically, Interim Charge 4 consisted of evaluating the progress of seawater desalination near the Texas coast, building on the work of the Joint Interim Committee to Study Water Desalination (83rd Texas Legislative Session, 2015). The TWDB Chairman and staff provided testimony on the status of desalination in Texas.

House Bill 2031 and House Bill 4097

In 2015, the 84th Texas Legislature passed House Bill 2031 relating to the diversion, treatment, and use of marine seawater and the discharge of treated marine seawater and brine resulting from the desalination of marine seawater. The overall goal of the legislation was to streamline and expedite the regulatory and permitting process associated with seawater desalination. House Bill 2031 created Chapter 18 in Texas Water Code, which requires an entity to do the following:

- Obtain a permit to divert and use seawater if the point of diversion is located within three miles or less of the Gulf Coast or if the yearly average total dissolved solids concentration of the seawater is less than 20,000 milligrams per liter. The total dissolved solids concentration is required to be calculated based on monthly sampling for a year and provide the data to TCEQ (Texas Water Code §18.003(a) and (c)). If the point of diversion is more than three miles offshore, a permit is not required.
- Obtain a bed and bank permit to discharge and convey treated seawater via a lake, reservoir, flowing stream, or other impoundment. The desalinated water must be of the same quality of the receiving water body (Texas Water Code §18.004).

The bill also directed the Texas Parks and Wildlife Department and General Land Office to identify zones in the Gulf of Mexico where an entity can divert seawater for desalination and discharge waste from the desalination process. The study is required to be completed by September 1, 2018, and TCEQ is required to designate zones by September 1, 2020 (Texas Water Code §18.003(i)).

The legislature also passed House Bill 4097 relating to the use of seawater desalination for industrial purposes. The bill amended the Texas Water Code to allow an entity to divert and desalinate seawater for industrial purposes by obtaining the appropriate permits from Texas Commission on Environmental Quality (Texas Water Code §11.1405). The bill authorizes the disposal of water treatment residuals produced by desalination of seawater used for industrial purposes (Texas Water Code §26.0272). The bill also stipulates that a general permit may authorize the use of Class I injection well for the disposal of nonhazardous brine produced by desalination of seawater and must meet requirements of the federal underground injection control program administered by the Texas Commission on Environmental Quality (Texas Water Code §27.025).

House Bill 4097 also (1) directs the Public Utility Commission, in cooperation with the Electric Reliability Council of Texas and other transmission and distribution utilities, to study and determine if existing transmission and distribution planning processes can provide adequate infrastructure for seawater desalination projects and (2) directs the Public Utility Commission and the Electric Reliability Council of Texas to study the potential for seawater desalination projects to participate in existing demand response opportunities in the electric market. On November 16, 2016, TCEQ adopted proposed rulemaking for House Bill 2031 and House Bill 4097.

Brackish groundwater desalination

Brackish groundwater is becoming an important water source that can help reduce the demand on fresh water sources. Globally, the online desalination capacity of brackish groundwater is about 3.4 billion gallons per day (International Desalination Association, 2016b). Groundwater contains dissolved solids, often measured in units of milligrams per liter, and can be classified as fresh (0 to 1,000 milligrams per liter), slightly saline (>1,000 to 3,000 milligrams per liter), moderately saline (>3,000 to 10,000 milligrams per liter), very saline (>10,000 to 35,000 milligrams per liter), or brine (>35,000 milligrams per liter) (Winslow and Kister, 1956).

Current state of brackish groundwater desalination

In the United States, there are 325 municipal desalination plants primarily located in Florida (45 percent), California (14 percent), and Texas (9 percent). The majority (73 percent) of desalination plants in the nation employ reverse osmosis (Mickley and others, 2011). Improvements in desalination technologies have decreased costs and energy requirements and improved efficiency, making brackish groundwater desalination a more feasible method to produce new water supplies.

Brackish groundwater is an important water supply source in Texas. The state has more than 2.7 billion acre-feet of this resource (LBG-Guyton Associates, 2003). Brackish groundwater is found in 26 of the 30 major and minor aquifers in Texas. In the last two decades, the number of desalination plants operating and desalination capacity has increased in Texas (Figure 4).

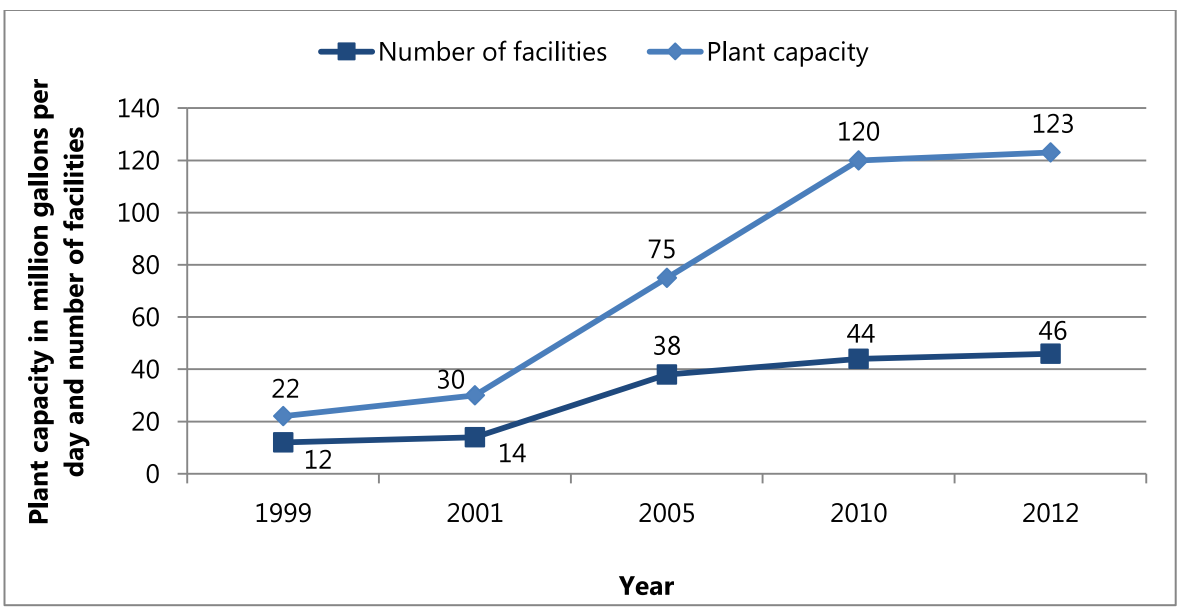


Figure 4. **The growth of municipal desalination facilities and installed design capacity in Texas over the last two decades.**

To track the growth of desalination, the TWDB maintains an online desalination plant database. In 2005, the TWDB funded a project to initially develop a desalination plant database that was completed by the Bureau of Economic Geology. In 2010, staff updated the information and made it available online (www2.twdb.texas.gov/apps/desal/DesalPlants.aspx). The TWDB desalination database provides a list of the 46 public water supply desalination plants with a capacity greater than 25.8 acre-feet per year (0.023 million gallons per day) in Texas. The TWDB is currently updating the desalination plant database and has sent out the survey to existing and new facilities.

As of 2012, there were 46 desalination plants for municipal use with capacity greater than 23,000 gallons per day (Table 4). In total, Texas has a desalination design capacity of approximately 138,000 acre-feet per year (123 million gallons per day) for municipal use (Figure 5). Of these facilities, 12 use brackish surface water as the source water, accounting for a design capacity of 56,000 acre-feet per year (50 million gallons per day), and 34 use brackish groundwater, accounting for a design capacity of approximately 82,000 acre-feet per year (73 million gallons per day). The predominant desalination technology used is reverse osmosis, which is used by 44 of the 46 desalination facilities. The largest inland desalination plant in the state is the Kay Bailey Hutchison Desalination Plant located in El Paso (27.5 million gallons per day).

Table 4. **Municipal brackish desalination facilities with a capacity greater than 0.023 million gallons per day in Texas.**

Facility name	City	Water source	Facility startup year	Facility design capacity[1] (MGD)
Big Bend Motor Inn	Terlingua	Groundwater	1989	0.057
City of Abilene (Hargesheimer Treatment Plant)	Tuscola	Surface water	2003	7.950
City of Bardwell	Bardwell	Groundwater	1980	0.252
City of Bayside	Bayside	Groundwater	1990	0.045
City of Beckville	Beckville	Groundwater	2004	0.216
City of Brady	Brady	Surface water	2005	3.000
City of Clarksville City	White Oak	Groundwater	2006	0.288
City of Evant	Evant	Groundwater	2010	0.100
City of Fort Stockton Osmosis/Desalination Facility	Fort Stockton	Groundwater	1996	6.500
City of Granbury	Granbury	Surface water	2007[2]	0.462
City of Hubbard	Hubbard	Groundwater	2002	0.648
City of Kenedy	Kenedy	Groundwater	1995	2.858
City of Laredo Santa Isabel Reverse Osmosis	Laredo	Groundwater	1996	0.100
City of Los Ybanez	Los Ybanez	Groundwater	1991	-[3]
City of Robinson	Waco	Surface water	1994	2.300
City of Seadrift	Seadrift	Groundwater	1998	0.610

Facility name	City	Water source	Facility startup year	Facility design capacity[1] (MGD)
City of Seymour	Seymour	Groundwater	1940	3.000
City of Sherman	Sherman	Surface water	1993	11.00
City of Tatum	Tatum	Groundwater	1999	0.324
Cypress Water Treatment Plant	Wichita Falls	Surface water	2008	10.00
Dell City	Dell City	Groundwater	1968	0.100
DS Waters of America, LP	Katy	Groundwater	1997	0.090
Esperanza Fresh Water Supply	Pecos	Groundwater	1990	0.023
Fort Hancock Reverse Osmosis (RO) Plant No. 1	Fort Hancock	Groundwater	2012	0.430
Holiday Beach Water Supply Corporation	Fulton	Groundwater	1960	0.150
Horizon Regional Municipal Utility District	Horizon City	Groundwater	2001	6.000
Kay Bailey Hutchison Desalination Plant	El Paso	Groundwater	2007	27.500
Lake Granbury Surface Water Advanced Treatment System	Granbury	Surface water	1989	12.500
Longhorn Ranch Motel	Alpine	Groundwater	1990	0.023
Midland Country Club	Midland	Groundwater	2004	0.023
North Alamo Water Supply Corporation (Doolittle)	San Juan	Groundwater	2008	3.500
North Alamo Water Supply Corporation (Lasara)	Edinburg	Groundwater	2005	1.200
North Alamo Water Supply Corporation (Owassa)	Raymondville	Groundwater	2008	2.000
North Cameron/Hidalgo Water Authority	Rio Hondo	Groundwater	2006	2.500
Oak Trail Shores	Granbury	Surface water	1985	1.584
Possum Kingdom Water Supply Corporation	Graford	Surface water	2003	1.000
River Oaks Ranch	Pflugerville	Groundwater	1985[4]	0.115
Southmost Regional Water Authority	Brownsville	Groundwater	2004	7.500
Sportsman's World Municipal Utility District	Strawn	Surface water	1984	0.083
Study Butte Terlingua Water System	Terlingua	Groundwater	2000	0.140
The Cliffs	Graford	Surface water	1991	0.381
Valley Municipal Utility District #2	Olmito	Groundwater	2000	1.000
Veolia Water Treatment Plant	Port Arthur	Surface water	1992	0.245
Victoria Road Reverse Osmosis Plant #5	Donna	Groundwater	2012	2.250
Water Runner, Inc.	Midland	Groundwater	2001	0.028
Windermere Water System	Austin	Groundwater	2003	2.880
			Total	**122.955**

Notes: MGD = Million gallons per day.
[1]Plant design capacity includes blending.
[2]Plant constructed in 1984 and implemented reverse osmosis in 2007.
[3]Design capacity data were not provided.
[4]Plant was rehabilitated in 2011.

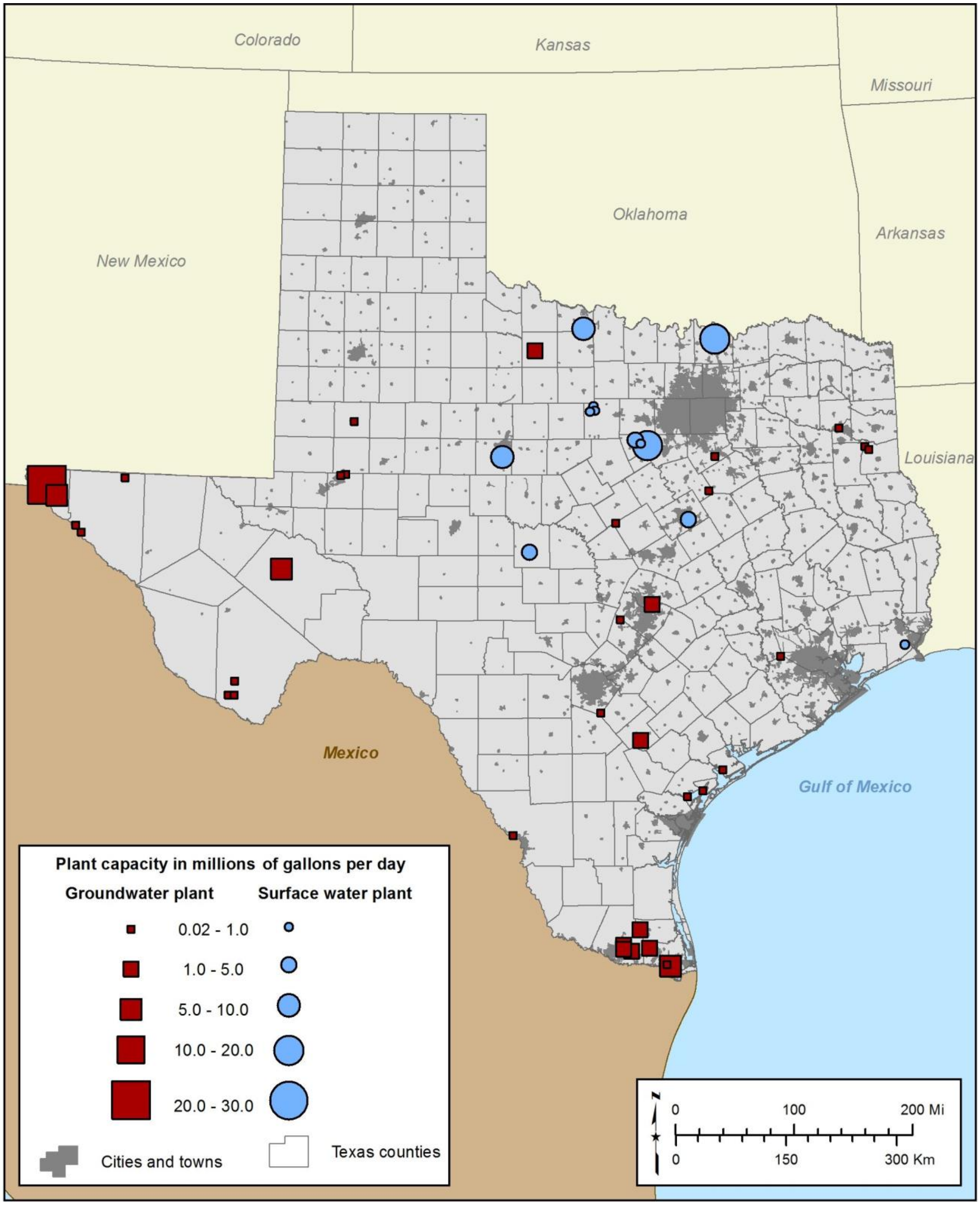


Figure 5. Distribution, size, and source water of existing municipal brackish desalination facilities in Texas with a design capacity of more than 0.023 million gallons per day.

Studies on brackish groundwater desalination

Between 2003 and 2011, the TWDB funded 17 projects and studies totaling $2.7 million related to brackish groundwater desalination including the implementation of demonstration projects, preparation of guidance manuals, and conducting research studies (Table 5). Since 2011, the TWDB has not funded projects due to lack of appropriations.

Table 5. TWDB-funded projects on brackish groundwater desalination.

Report title	Contractor	Short description	Study type	Year funded	Grant amount
Brackish Groundwater Manual for Texas Regional Water Planning Groups	LBG-Guyton Associates	The study identified potential brackish groundwater sources in Texas for future potable use.	Research	2003	$99,940
A Desalination Database for Texas	Bureau of Economic Geology	The study developed a desalination database for Texas.	Research	2004	$75,000
Self-Sealing Evaporation Ponds for Desalination Facilities in Texas	Bureau of Economic Geology	The study investigated regulatory requirements for developing a self-sealing evaporation pond.	Research	2005	$49,928
Guidance Manual for Brackish Groundwater Desalination in Texas	North Cameron Regional Water Supply Corporation	The project prepared a brackish groundwater desalination guidance manual using desalination plant in Cameron County as an example.	Demonstration	2006	$150,000
Demonstration of Efficiencies Gained by Utilizing Improved Reverse Osmosis Technologies	City of Kenedy/San Antonio River Authority	The project demonstrated the efficiencies gained by installing a new reverse osmosis system in an existing brackish groundwater desalination plant.	Demonstration	2006	$150,000
Assessment of the Whitehorse Aquifer as a Potential Source of Water Supply for the City of San Angelo	City of San Angelo/Upper Colorado River Authority	The project assessed the feasibility of the Whitehorse Aquifer in Irion County as a source of brackish water for the City of San Angelo.	Demonstration	2006	$300,000
Evaluation of Concentrate Management and Assessment of the Vibratory Shear Enhanced Process	San Antonio Water System	The project conducted a pilot test to assess the cost and technical feasibility of the Vibratory Shear Enhanced Process as a tool for reducing the volume of desalination concentrate.	Demonstration	2007	$205,000
Improving Recovery: A Concentrate Management Strategy for Inland Desalination	The University of Texas at Austin	The study investigated anti-scalant precipitation and electrodialysis to increase recovery in desalination of brackish groundwater.	Demonstration	2007	$238,500

Report title	Contractor	Short description	Study type	Year funded	Grant amount
Pilot Study to Demonstrate Volume Reduction of Reverse Osmosis Concentrate	El Paso Public Utilities Board	The study evaluated silica reduction in reverse osmosis concentrate through the addition of lime, and application of the vibratory shear enhanced process. A second phase of the project tested the use of seawater reverse osmosis membranes to increase water recovery.	Demonstration	2007	$228,557
An Integrated Wind-Water Desalination Demonstration Project for an Inland Municipality	City of Seminole	The City of Seminole conducted pilot testing using wind energy to desalinate brackish groundwater.	Demonstration	2008	$300,000
Assessment of Osmotic Mechanisms Pairing Desalination Concentrate and Wastewater Treatment	CH2M Hill	The study investigated the use of reverse osmosis concentrate as a draw solution in a forward osmosis process for recovering water from wastewater.	Research	2008	$90,000
Energy Optimization of Brackish Groundwater Reverse Osmosis Desalination	Affordable Desalination Collaboration	This study assessed and demonstrated energy optimization strategies for brackish groundwater desalination by reverse osmosis.	Research	2009	$496,783
Permitting Guidance Manual to Dispose Desalination Concentrate into a Class II Injection Well	CDM Smith, Inc.	The study developed an instruction manual and road map for permitting a Class II well for dual Class I-Class II purposes.	Demonstration	2010	$130,000
Upflow Calcite Contractor Design	Carollo Engineers, Inc.	The study developed design criteria for the post-treatment of permeate water using an upflow calcite contactor.	Demonstration	2010	$188,403
Demonstration of Fiberglass Well Casings in Brackish Groundwater Wells	North Alamo Water Supply Corporation	The project demonstrated the viability of using fiberglass well casing in water wells installed in brackish aquifers.	Demonstration	2010	$100,000
Demonstration of a High Recovery and Energy Efficient Reverse Osmosis System for Small-Scale Brackish Water Desalination	Texas Tech University	The study demonstrated the use of a reverse osmosis system with parallel elements for small-scale desalination with high recovery and energy efficiency.	Demonstration	2010	$101,597
Alternative to Pilot Plant Studies for Membrane Technologies	Carollo Engineers, Inc.	The project evaluated alternatives to the current regulatory requirements for pilot testing membranes.	Research	2011	$150,000

Brackish groundwater desalination in the 2017 State Water Plan

In the 2017 State Water Plan, eight regional water planning groups (regions E, F, H, J, L, M, N, and O) included groundwater desalination as a recommended water management strategy. In total, there are 78 recommended water management strategies that will help meet the water needs of a water user group (Appendix E, Table E-3).

If these recommended strategies are implemented, groundwater desalination will produce about 111,000 acre-feet per year of additional water supply by decade 2070. This constitutes about 1.3 percent of all recommended water management strategies in the state water plan. Additionally, there are five water management strategies in regions F, L, and P currently not assigned to serve a specific water user group.

Four planning groups (regions K, L, M, and N) included groundwater desalination as an alternative water management strategy, for a total of 36 strategies (Appendix E, Table E-4). If implemented, these strategies would produce 32,449 acre-feet per year of new water supplies by decade 2070. Additionally, there are eight alternative water management strategies in regions F, K, and L currently not assigned to serve a specific water user group.

The implementation of the recommended water management strategies may lead to the development of 27 desalination plants (27 projects have a new treatment plant component). More groundwater desalination may also occur in the future as a result of employing "groundwater wells and other" recommended water management strategies. The 2017 State Water Plan defines these strategies as "the development of single or multiple wells that may be part of new well fields or the expansion existing well fields."

Regional water planning groups propose to implement 39 groundwater desalination projects (Table 6). The difference between a water management strategy and project is that a strategy is a plan to meet a water need and the project is the infrastructure required to implement the strategy. Projects would develop, deliver, or treat additional water supply volumes at a specified capital cost. Projects can also conserve water for water user groups or wholesale water suppliers. One project may be associated with multiple water management strategies. For example, one project may support multiple water user groups that use that new supply.

The statewide weighted-average[2] groundwater desalination unit cost of recommended projects is about $713 per acre-foot. The desalination projects are concentrated in the western, central, and southern parts of Texas (Figure 6). The projects components may include pipelines, wells, new water treatment plants, and expansions of existing plants.

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[2] The weighted average is the average of values scaled by the relative volume of each strategy.

Table 6. Brackish groundwater desalination projects in the 2017 State Water Plan.

ID	Region	Project sponsor	Project name	Capital cost	Project level recommendation type
1	E	County-other (Hudspeth)	Hudspeth County-other (Dell city) - brackish groundwater desalination facility	$1,299,000	Recommended
2	E	El Paso	El Paso Water Utilities - expansion of the Kay Bailey Hutchison desalination plant	$37,200,000	Recommended
3	E	El Paso	El Paso Water Utilities - brackish groundwater at the Jonathan Rogers Wastewater Treatment Plant	$65,865,000	Recommended
4	E	Horizon Regional Municipal Utility District	Horizon Regional Municipal Utility District - additional wells and expansion of desalination plant	$56,443,000	Recommended
5	E	Lower Valley Water District	Lower Valley Water District - groundwater from proposed well field - Rio Grande Alluvium Aquifer	$37,490,000	Recommended
6	F	San Angelo	Desalination of other aquifer supplies in Tom Green County - San Angelo	$57,967,000	Recommended
7	F	Concho Rural Water Corporation	Desalination of other aquifer supplies in Tom Green County - Concho Rural Water Supply Corporation	$5,131,000	Recommended
8	H	Conroe	Conroe brackish groundwater desalination	$40,691,342	Recommended
9	H	County-other (Montgomery)	Infrastructure expansion - county-other, Montgomery County (San Jacinto River Authority group participants)	$8,629,118	Recommended
10	H	County-other (Montgomery)	Infrastructure expansion - county-other, Montgomery County - phase 1	$186,580,030	Recommended
11	H	County-other (Montgomery)	Infrastructure expansion - county-other, Montgomery County - phase 2	$390,977,830	Recommended
12	H	Brazosport Water Authority	Brackish groundwater development	$34,016,950	Recommended
13	J	County-other (Kerr)	City of Center Point / Upper Guadalupe River Authority - desalination plant	$14,539,000	Recommended
14	L	San Antonio Water System	Brackish Wilcox groundwater for San Antonio Water System	$53,162,000	Recommended
15	L	Canyon Regional Water Authority	Brackish Wilcox groundwater for Canyon Regional Water Authority	$62,787,000	Recommended

ID	Region	Project sponsor	Project name	Capital cost	Project level recommendation type
16	L	Schertz-Seguin Local Government Corporation	Brackish Wilcox groundwater for Schertz-Seguin Local Government Corporation	$54,133,000	Recommended
17	L	S S Water Supply Corporation	Brackish Wilcox groundwater for S S Water Supply Corporation	$16,864,000	Recommended
18	L	San Antonio Water System	Expanded brackish Wilcox project – San Antonio Water System	$723,175,000	Recommended
19	M	East Rio Hondo Water Supply Corporation; North Alamo Water Supply Corporation	North Cameron Regional water treatment plant wellfield expansion	$1,881,000	Recommended
20	M	Alamo	Alamo brackish groundwater desalination plant	$13,532,000	Recommended
21	M	El Jardin Water Supply Corporation	El Jardin new brackish groundwater desalination plant	$8,272,000	Recommended
22	M	Hebbronville	Hebbronville new brackish groundwater desalination plant	$8,275,000	Recommended
23	M	La Feria	La Feria water well with reverse osmosis unit	$6,260,000	Recommended
24	M	Lyford	Lyford brackish groundwater desalination	$6,950,000	Recommended
25	M	McAllen	McAllen brackish groundwater desalination plant	$31,218,000	Recommended
26	M	Mission	Mission brackish groundwater desalination plant	$31,914,000	Recommended
27	M	Union Water Supply Corporation	Union Water Supply Corporation brackish groundwater desalination plant	$8,282,000	Recommended
28	M	Laguna Madre Water District	Laguna Madre new brackish groundwater desalination plant	$22,564,000	Recommended
29	M	North Alamo Water Supply Corporation	North Alamo Water Supply Corporation delta area reverse osmosis water treatment plant expansion	$22,709,000	Recommended
30	M	Primera	Primera brackish groundwater desalination plant	$14,318,000	Recommended
31	M	Sharyland Water Supply Corporation	Sharyland well and reverse osmosis at water treatment plant 2	$13,253,000	Recommended
32	M	Sharyland Water Supply Corporation	Sharyland well and reverse osmosis at treatment plant 3	$13,253,000	Recommended
33	M	San Juan	San Juan water treatment plant No. 1 expansion	$9,561,000	Recommended

ID	Region	Project sponsor	Project name	Capital cost	Project level recommendation type
34	M	North Alamo Water Supply Corporation	North Alamo Water Supply Corporation La Sara reverse osmosis expansion	$13,260,000	Recommended
35	N	Alice	Brackish groundwater development - Alice	$33,277,000	Recommended
36	O	Seminole	Gaines County - Seminole groundwater desalination	$31,572,000	Recommended
37	O	Abernathy	Hale County - Abernathy groundwater desalination	$10,100,000	Recommended
38	O	Lubbock	Lubbock County - Lubbock brackish well field at the south water treatment plant	$34,531,740	Recommended
39	P	Lavaca Navidad River Authority	Lavaca-Navidad River Authority desalination	$31,393,000	Recommended
			Total	**$2,213,326,010**	

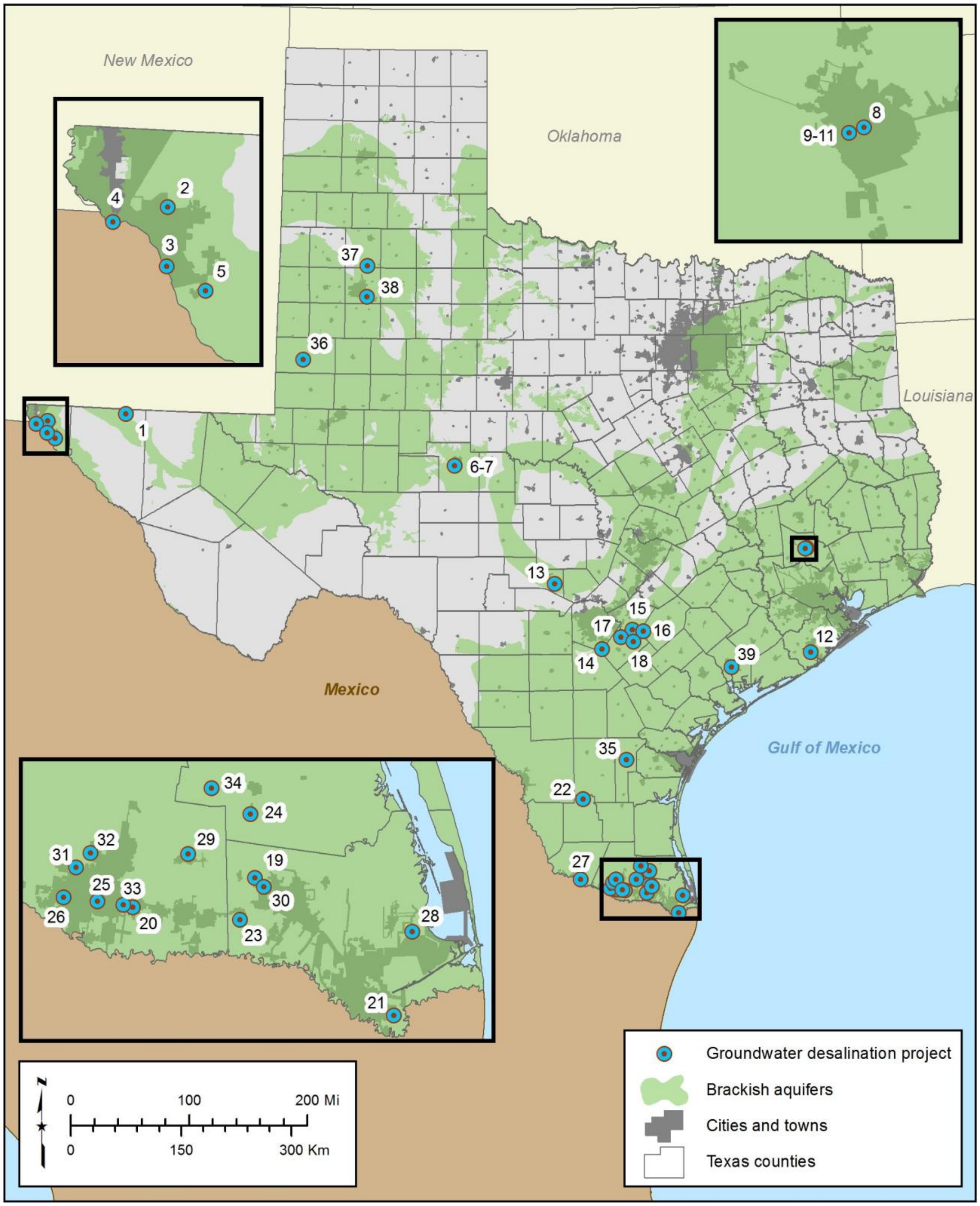


Figure 6. **Location of brackish groundwater desalination projects in the 2017 State Water Plan. Numbers refer to projects in Table 6.**

Far West Texas (Region E) Regional Water Planning Area

Brackish groundwater desalination is recommended as a water management strategy in the 2016 Far West Texas (Region E) Regional Water Plan to meet water demands starting in decade 2020. The desalination projects include the development of new wells, the construction of new desalination plants, and the expansion of existing facilities.

El Paso Water Utilities proposes to develop 10 new wells and build a new desalination plant near the Jonathan Rogers Water Treatment Plant. The brine would be disposed via a deep injection well. The capital costs of the project are $65.8 million. El Paso Water Utilities also plans to expand the Kay Bailey Hutchison Desalination Plant from 30,804 to 35,845 acre-feet per year (27.5 to 32 million gallons per day). The project is planned to be completed in phases, which would include seven new wells and one new deep injection well for a total capital cost of $37.2 million. The Utility also plans to import water from the Dell City area. The total capital costs are $110 million, which would include purchasing land, rehabilitating 15 wells and a pump station, and building a 12-mile pipeline and a 20,163-acre-foot-per-year (18-million-gallon-per-day) desalination plant. The TWDB provided a $150 million multi-year loan on July 21, 2016, and $50 million on December 2, 2015 from the State Water Implementation Fund for Texas to El Paso Water Utilities to purchase land and water rights above Bone Spring-Victorio Peak Aquifer.

The Lower Valley Water District proposes to develop an 11,201-acre-feet-per-year (10-million-gallon-per-day) plant along with a water storage tank, a disposal well, and seven new wells. The total capital costs are $37.4 million and include the land purchase. The District proposes a similar project with capital costs of $41.1 million that would develop groundwater from the Hueco Bolson Aquifer instead of the Rio Grande Alluvium Aquifer.

The Horizon Municipal Utility District plans to expand their existing desalination plant from 6,721 to 23,971 acre-feet per year (6.0 to 21.4 million gallons per day). This would include the development of nine new wells. The project capital costs are $56.4 million. Dell City also plans to expand its existing plant by replacing the electrodialysis reversal system with reverse osmosis system. The capital costs are $1.29 million.

Region F Regional Water Planning Area

The City of San Angelo and the Upper Colorado River Authority propose a future 7,841-acre-foot-per-year (7-million-gallon-per-day) desalination plant with six deep injection wells and a six-mile-long concentrate disposal pipeline. The project’s capital costs are $79.1 million. The City of San Angelo also proposes to build an 11,201-acre-foot-per-year (10-million-gallon-per-day) desalination plant with four deep injection wells at a total capital cost of $66.7 million.

The Concho Rural Water Corporation plans to build a 302-acre-foot-per-year (0.27-million-gallon-per-day) desalination plant and dispose of the concentrate in evaporation ponds. The capital costs are $5.13 million.

Region H Regional Water Planning Area

The City of Conroe proposes to build a desalination facility and treat groundwater from the Catahoula Aquifer. The capital costs for the project are $40.7 million.

Plateau (Region J) Regional Water Planning Area

The Upper Guadalupe River Authority and Eastern Kerr County propose to build a 1,344-acre-foot-per-year (1.2-million-gallon-per-day) facility using the Ellenburger Aquifer and dispose of the concentrate via evaporation ponds. The capital costs for the project are $14.5 million.

South Central Texas (Region L) Regional Water Planning Area

The S S Water Supply Corporation plans to pump brackish groundwater from the Wilcox Aquifer and treat it in a 2,240-acre-foot-per-year (2-million-gallon-per-day) desalination plant. The project would consist of three new groundwater wells, a two-mile-long pipeline, a storage water tank, and a deep injection well. The capital costs are approximately $16.9 million.

The Schertz-Seguin Local Government Corporation plans to develop six groundwater wells that would pump water to a 5,600-acre-foot-per-year (5-million-gallon-per-day) desalination facility. The concentrate would be disposed via deep well injection. The capital costs of the project are approximately $69.6 million. On July 21, 2016, the TWDB approved a $66.5 million loan from the State Water Implementation Fund for Texas for the Corporation to develop a wellfield above the Wilcox and Carrizo aquifers and build a water treatment facility and other project components.

The Canyon Regional Water Authority plans to develop up to 20 supply wells for a new brackish groundwater desalination plant. The project also includes separate water and concentrate pipelines and a deep well injection for concentrate disposal. The capital costs are approximately $186.7 million.

The San Antonio Water System plans to expand the capacity of the desalination plant currently under construction to 33,604 acre-feet per year (30 million gallons per day). The expansion will be completed in phases, which includes a 13,442-acre-foot-per-year (12-million-gallon-per-day) expansion in the second phase and a 6,721-acre-foot-per-year (6-million-gallon-per-day) expansion in the third phase. The second phase incudes the development of 12 wells and two deep injection wells at a capital cost of approximately $96.5 million. The third phase includes the development of six wells and one deep injection well for a total capital cost of $42.8 million.

The San Antonio Water System envisions another similar project that would include the development of two wellfields with 32 wells in one wellfield and 19 wells in the other. The groundwater would be conveyed by a 36-mile-long pipeline to two new desalination plants with design capacities of 34,948 to 49,958 acre-feet per year (31.2 and 44.6 million gallons per day). Concentrate disposal would occur via nine deep injection wells.

Rio Grande (Region M) Regional Water Planning Area

The Rio Grande Regional Water Planning Area has several desalination projects, which include the construction of new plants and expansion of existing facilities. The capacity of the North Cameron Regional Water Supply Corporation desalination plant would be increased from 1,288 to 2,576 acre-feet per year (1.15 to 2.30 million gallons per day) with the addition of a water supply well. The capital costs of the project are estimated to be $1.9 million. Similarly, the North Alamo Water Supply Corporation plans to increase the capacity of the La Sara Desalination Plant by 1,120 acre-feet per year (1 million gallons per day) with the addition of groundwater wells and reverse osmosis systems. The capital costs are estimated at $13.3 million. The City of San Juan is also recommending the expansion of its existing brackish groundwater desalination facilities.

The City of El Jardin plans to build a new 560-acre-foot-per-year (0.5-million-gallon-per-day) desalination plant for a total capital cost of about $8.3 million. The City of La Feria is also proposing to build a new desalination plant with capacity of 1,400 acre-feet per year (1.25 million gallons per day) and capital costs of approximately $6.3 million. Laguna Madre Water District is recommending the building of a 2,240-acre-foot-per-year (2-million-gallon-per-day) desalination facility for a total capital cost of $22.4 million. Similarly, North Alamo Water Supply Corporation is also planning to build a 2,240-acre-foot-per-year (2-million-gallon-per-day) desalination facility at a capital cost of $22.7 million. Other entities (Alamo, Hebbronville, Lyford, McAllen, Mission, Primera, Sharyland Water Supply Corporation, and Union Water Supply Corporation) are also recommending the construction of new brackish groundwater desalination facilities to provide new water supplies for the region.

Coastal Bend (Region N) Regional Water Planning Area

The City of Alice proposes to build a 4,481-acre-foot-per-year (4-million-gallon per-day) desalination facility and two new wells that would pump groundwater from the Jasper Formation. The concentrate would be piped and discharged to San Diego Creek that ultimately flows into San Fernando Creek. The capital costs for the project are about $33.3 million.

Llano Estacado (Region O) Regional Water Planning Area

The City of Abernathy plans to develop a 146-acre-foot-per-year (0.13-million-gallon-per-day) desalination facility with four production wells and one deep injection well. The City of Seminole proposes to develop a larger desalination plant with 11 production wells and six deep injection wells. The groundwater source for both projects would be the Santa Rosa Formation (Dockum

Aquifer). The estimated capital cost is $10.1 million for the Abernathy project and $31.6 million for the Seminole project.

The City of Lubbock plans to build a 1,680-acre-foot-per-year (1.5-million-gallon-per-day) desalination plant with four wells that would produce groundwater from the Santa Rosa Formation. The desalinated water would be blended with water from the South Water Treatment Plant. The concentrate would be disposed through two deep injection wells. The capital costs are approximately $34.5 million.

Lavaca (Region P) Regional Water Planning Area

The Lavaca-Navidad River Authority plans to develop a brackish groundwater desalination facility to provide water supplies for manufacturing at Formaosa Plastics. The Authority plans to build a 6,497 acre-foot-per-year (5.8-million-gallon-per-day) desalination plant with three groundwater supply wells. The concentrate would be discharged to Lavaca Bay. The project's capital costs are approximately $44.2 million.

Other brackish groundwater desalination activities

Several public entities are currently building desalination plants or conducting feasibility studies in support of recommended water management projects. These activities are described in more detail below. Recent modifications to regulations related to groundwater desalination are also discussed.

San Antonio Water System

San Antonio Water System is completing the building of Phase I of their desalination plant located south of San Antonio. The plant is anticipated to become operational in winter 2016. This is considered Phase I of their desalination project. The facility will have an initial design capacity of 13,442 acre-feet per year (12 million gallons per day) and will be expanded in two phases to add 13,442 acre-feet per year (12 million gallons per day) in the second phase and 6,721 acre-feet per year (6 million gallons per day) in the third phase. The first well field consists of (1) 12 supply wells with a total dissolved solids concentration ranging from 1,300 to 1,500 milligram per liter and (2) two deep injection wells. For the first phase, the capital costs are $118 million and the unit cost of the treated water is $1,177 per acre-foot. The total capital costs for all three phases including land acquisition are $411.4 million (San Antonio Water System, Personal Communication, 2016).

Brazosport Water Authority

On July 23, 2015, the TWDB approved a $28.3 million loan through the State Water Implementation Fund for Texas to the Brazosport Water Authority to design and build a brackish groundwater desalination plant. The proposed 6,721-acre-foot-per-year (6-million-gallon-per-day) desalination facility would pump groundwater using three wells located in the Gulf Coast Aquifer. The concentrate would be discharged to an impaired segment of the Brazos River. A cultural resources survey and wetland delineation of the project area has been completed. The Authority has begun the environmental permitting process with the Texas Historical Commission, Local Floodplain Administrator, U.S. Army Corps of Engineers, and Texas Parks and Wildlife Department. Most of these permitting agencies concluded there was no environmental impact to the surrounding area. To meet the Migratory Bird Treaty Act, Texas Parks and Wildlife provided conditions that the Brazosport Water Authority will need to comply with when they begin clearing the site. The next step is to install a demonstration and monitoring well to obtain water quality and aquifer-specific data.

Rio Grande Regional Water Authority

The Rio Grande Regional Water Authority in collaboration with the U.S. Bureau of Reclamation completed a basin study that encompassed an eight-county area. The study was completed in December 2013 and concluded that brackish groundwater desalination should be evaluated further as a viable water supply source for the area. The study recommended expanding existing groundwater desalination facilities and developing four new regional desalination plants. The U.S. Bureau of Reclamation provided funding in the amount of $214,655 through the WaterSMART Program. More recently, a regional water facility plan was completed for the Rio Grande Regional Water Authority on July 1, 2016 (Blandford and Jenkins, 2016). The purpose of the study was to thoroughly evaluate alternative water sources for the region. The study evaluated building (1) a desalination plant and wellfield of 58 wells in Cameron County for a total capital cost of $249.7 million and (2) a desalination plant and wellfield of 18 wells in Hidalgo County for a total capital cost of $86.9 million.

Alternatives to pilot-plant testing

In November 2015, the Texas Commission on Environmental Quality adopted rules to allow the use of computer models from membrane manufacturers for reverse osmosis systems used to treat secondary contaminants in groundwater as an alternative to conducting pilot testing. The TWDB funded a study in 2013 that helped evaluate computer model outputs to pilot- and demonstration-scale testing data to determine the accuracy and precision of the models. The Texas Commission on Environmental Quality determined that computer models could effectively demonstrate membrane performance of reverse osmosis system operated at normal conditions. The adopted rules provide a more expedited path for approving brackish groundwater desalination facilities.

Brackish Resources Aquifer Characterization System Program

In 2009, the 81st Texas Legislature provided funding to the TWDB to establish the Brackish Resources Aquifer Characterization System (BRACS). The goal of the program is to map and characterize the brackish portions of the aquifers in Texas in sufficient detail to provide useful information and data to regional water planning groups and other entities interested in using brackish groundwater as a water supply.

For each BRAC study, the TWDB collects as much geological, geophysical, and water-well data as is available in the public domain and uses the information to map and characterize both the vertical and horizontal extent of the aquifers in great detail. Groundwater is classified into five salinity classes: fresh, slightly saline, moderately saline, very saline, and brine (Winslow and Kister, 1956). The volume of groundwater in each salinity class is estimated based on the three-dimensional mapping of the salinity zones. The project deliverables, both the data and report, are available to the public on the TWDB website. All project data is compiled into a Microsoft Access database that is described in a detailed data dictionary (Meyer, 2014). Digital geophysical well logs are used for the studies and may be downloaded from the TWDB Water Data Interactive website (www2.twdb.texas.gov/apps/waterdatainteractive/groundwaterdataviewer).

Studies on brackish aquifers

Mapping of Texas' saline water resources dates back to 1956 (Winslow and Kister, 1956). In 1970, the TWDB funded a study "to make a reconnaissance and inventory of the principal saline aquifers in Texas that discussed the salinity, the productivity, and the geology of the aquifers" (Core Laboratories, 1972). In 2003, the TWDB funded a study to map the brackish aquifers and calculate the volume of brackish (slightly to moderately saline) groundwater available in these aquifers (LBG-Guyton Associates, 2003). The study was done to support the regional water planning process and help identify alternative sources to meet water demands. It estimated there was approximately 2.7 billion acre-feet of brackish groundwater in the aquifers in the state (LBG-Guyton Associates, 2003). While the study demonstrated that brackish groundwater is an important resource, it also highlighted the need for detailed aquifer studies.

In 2010, with the aid of legislative funding, the TWDB funded three research projects totaling $449,500 to support the BRACS program (Table 7). With the passing of House Bill 30 (84th Texas Legislature, 2015), the TWDB funded seven aquifer projects totaling over $1.7 million.

The TWDB completed four internal studies and presently has two ongoing studies. The four completed studies include the Pecos Valley Aquifer in West Texas (Meyer and others, 2012), the

Queen City and Sparta aquifers in Atascosa and McMullen counties (Wise, 2014), the Gulf Coast Aquifer in the Corpus Christi area (Meyer, 2012), and the Lower Rio Grande Valley (Meyer and others, 2014). Ongoing studies include the Lipan Aquifer and the Wilcox, Carrizo, Queen City, Sparta, and Yegua aquifers in Central Texas (Figure 7).

Table 7. TWDB-funded projects of the Brackish Resources Aquifer Characterization System Program.

Report title	Short description	Contractor	Study type	Year funded	Grant amount
Geophysical Well Log Data Collection Project	Geophysical well logs from brackish aquifers in the state were collected from multiple sources, digitized, and entered into a database.	Bureau of Economic Geology	Research	2010	$300,000
Brackish Groundwater Bibliography Project	The project developed a comprehensive bibliography of Texas brackish aquifers.	INTERA, Inc.	Research	2010	$99,500
An Assessment of Modeling Approaches to Brackish Aquifers in Texas	The study assessed groundwater modeling approaches for brackish aquifers.	INTERA, Inc.	Research	2010	$50,000
Identification of Potential Brackish Groundwater Production Areas - Carrizo Aquifer	The project mapped and characterized the aquifer and evaluated the aquifer for potential production areas.	Bureau of Economic Geology	Research	2016	$181,446
Identification of Potential Brackish Groundwater Production Areas - Gulf Coast Aquifer	The project mapped and characterized the aquifer and evaluated the aquifer for potential production areas.	INTERA, Inc.	Research	2016	$500,000
Brackish Groundwater in the Blaine Aquifer System, North Central Texas	The project mapped and characterized the aquifer and evaluated the aquifer for potential production areas.	Daniel B. Stephens & Associates, Inc.	Research	2016	$200,000
Identification of Potential Brackish Groundwater Production Areas - Rustler Aquifer	The project mapped and characterized the aquifer and evaluated the aquifer for potential production areas.	INTERA, Inc.	Research	2016	$200,000
Identification of Potential Brackish Groundwater Production Areas – Blossom Aquifer	The project will map and characterize the aquifer and evaluate the aquifer for potential production areas.	LBG-Guyton	Research	2016	$50,000
Identification of Potential Brackish Groundwater Production Areas - Nacatoch Aquifer	The project will map and characterize the aquifer and evaluate the aquifer for potential production areas.	LBG-Guyton	Research	2016	$150,000
Identification of Potential Brackish Groundwater Production Areas - Trinity Aquifer	The project will map and characterize the aquifer and evaluate the aquifer for potential production areas.	Southwest Research Institute	Research	2016	$400,000

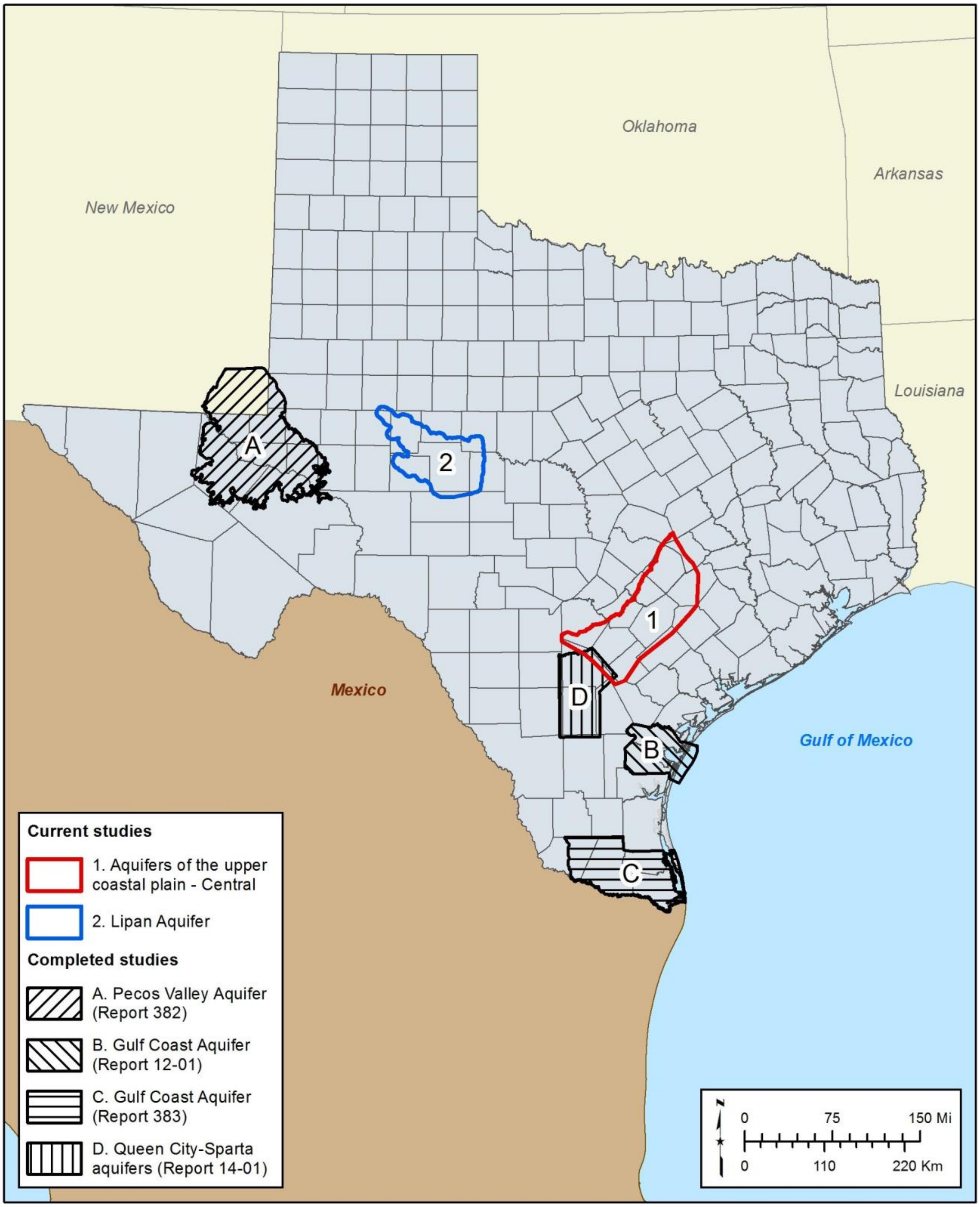


Figure 7. **Completed and ongoing studies of the Brackish Resources Aquifer Characterization System Program.**

House Bill 30

In 2015, the 84th Texas Legislature passed House Bill 30, directing the TWDB to conduct studies to identify and designate brackish groundwater production zones in the state. The legislation directed the TWDB to make designations in four aquifers—the Carrizo-Wilcox Aquifer located between the Colorado River and the Rio Grande, the Gulf Coast Aquifer and sediments bordering that aquifer, the Blaine Aquifer, and the Rustler Aquifer—and to report the designations to the legislature by December 1, 2016. The legislation further requires the TWDB to identify and designate brackish groundwater production zones in the remaining aquifers in the state before December 1, 2022.

House Bill 30 excluded certain areas from designation:

- The Edwards (Balcones Fault Zone) Aquifer located within the jurisdiction of the Edwards Aquifer Authority.
- Areas within the boundaries of the Barton Springs-Edwards Aquifer Conservation District, the Harris-Galveston Subsidence District, and the Fort Bend Subsidence District.
- Aquifers, subdivisions of aquifers, or geologic strata that have an average total dissolved solids concentration of more than 1,000 milligrams per liter and serve as a significant source of water supply for municipal, domestic, or agricultural purposes.
- Geologic formations that are designated or used for wastewater injection through the use of injection or disposal wells permitted under Texas Water Code Chapter 27.

House Bill 30 requires that brackish groundwater production zones are in areas with moderate to high availability and productivity and that are separated by hydrogeologic barriers sufficient to prevent significant impacts to water availability or water quality in geologic strata that have average total dissolved solids concentrations of 1,000 milligrams per liter or less.

For each zone, the TWDB was required to determine the amount of brackish groundwater that a zone is capable of producing over 30- and 50-year periods without causing a significant impact to water availability or water quality in surrounding aquifers. The TWDB was also required to make recommendations on reasonable monitoring to observe the effects of brackish groundwater production within the zone.

To assist the TWDB in making the designations, the legislature appropriated $2 million for contracts and administrative costs (House Bill 1, General Appropriations Act, 2015 Legislature, Regular Session, page IX-88, Sec. 18.30). The TWDB funded contract studies for three of the four aquifers specifically named in House Bill 30 and for three additional brackish aquifers (the Trinity, Blossom, and Nacatoch aquifers) selected by the TWDB (Figure 8) that will be completed in August 2017. The fourth aquifer named in House Bill 30 (the Carrizo-Wilcox Aquifer) was conducted as part of an ongoing TWDB-funded study.

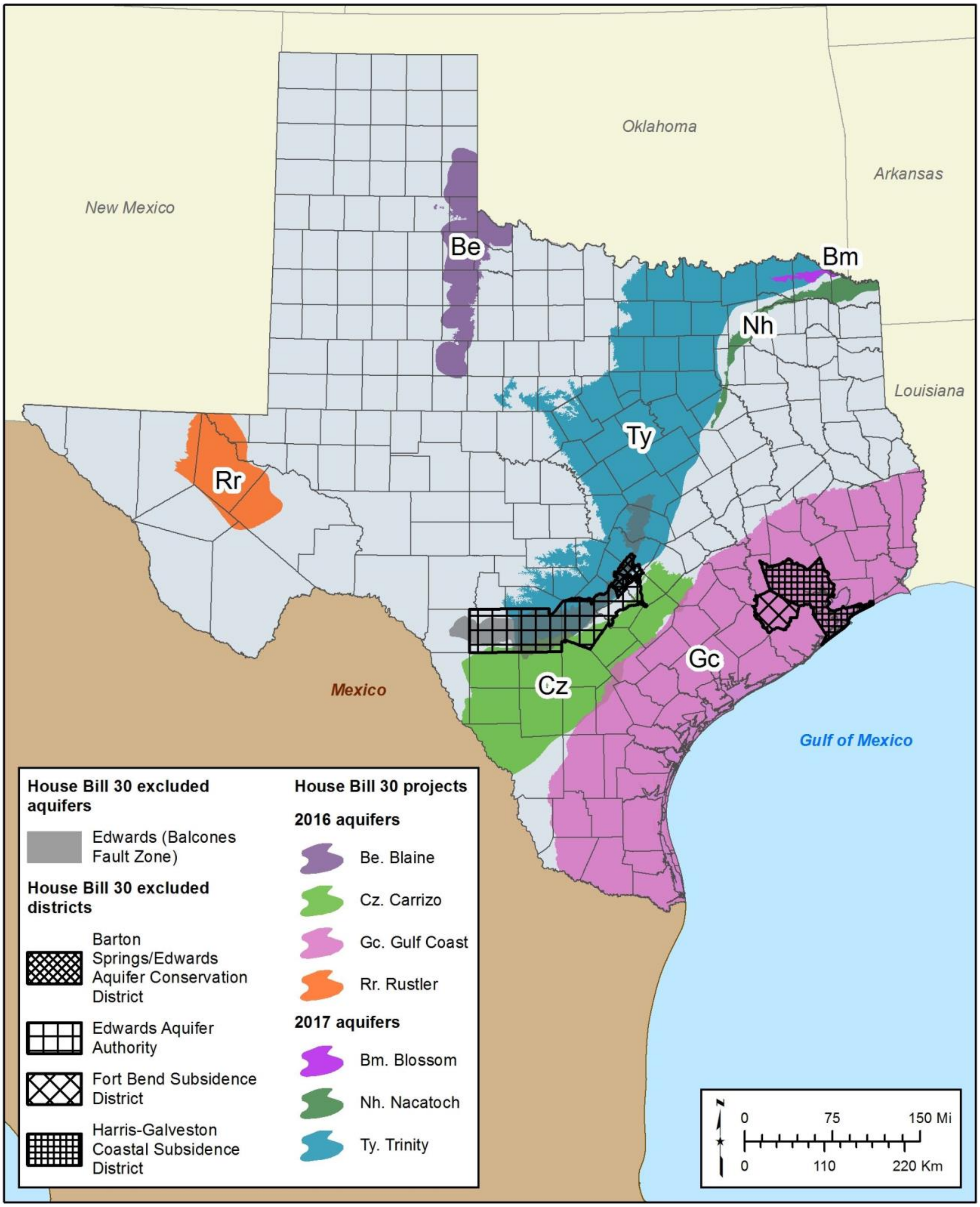


Figure 8. **House Bill 30 project area boundaries and excluded aquifer and districts.**

Implementation process

To achieve the goals of House Bill 30, the TWDB pursued the following process:

1. Contractors compiled and assessed available geologic and hydrologic information to identify proposed production areas.
2. Contractors assessed the hydrologic effects of pumping in the proposed production areas.
3. TWDB staff reviewed information from the contractors and information associated with exclusions (such as existing pumping, water quality, injection wells, impacts from pumping brackish groundwater in the proposed production zones) and developed possible zones for designation.
4. The Executive Administrator recommended proposed brackish groundwater production zones to our Board for possible approval.

Each step of the process provided ample opportunity for stakeholder review and comment. On October 26, 2015, staff held a stakeholder meeting in Austin to explain the TWDB's approach to implementing House Bill 30, solicit feedback on key terms in the bill (for example, significant impact), and receive comments on implementation of the legislation. Staff worked closely with contractors throughout the various stages of the project.

Between April and August 2016, staff held aquifer-specific stakeholder meetings to share results, solicit feedback, and request data. Details of the meetings are provided below.

- Carrizo-Wilcox Aquifer: Pleasanton, TX, November 19, 2015, and April 15, 2016
- Rustler Aquifer: Fort Stockton, TX, June 17, 2016
- Gulf Coast Aquifer: Austin, TX, June 22, 2016
- Blaine Aquifer: Quanah, TX, June 29, 2016, and Wellington, TX, August 18, 2016

Throughout the projects, the TWDB notified stakeholders of the meetings in advance via email. Information pertaining to all stakeholder meetings, including announcements, presentations, questions and answers, and comments, were posted on the TWDB website (www.twdb.texas.gov/innovativewater/bracs/HB30.asp) in a timely manner and stakeholders were notified by email about the availability of the information.

Early in the project, contractors submitted interim reports on the project methodology, which staff reviewed, provided written comments on, and held meetings with contractors to discuss issues and concerns. The TWDB received the draft reports for the four projects on August 1, 2016. Staff reviewed the data and information and provided written comments to the contractors on or around August 15, 2016. Staff also met with the contractors several times during this period to discuss the comments, request changes, and correct errors.

Contractors delivered the final reports and datasets to the TWDB in the first week of September 2016. We posted the final reports on the TWDB website soon thereafter. On September 9, 2016, we held a stakeholder meeting in Austin to present the results of the studies and solicit comments from stakeholders. We provided stakeholders advance notice of the meeting via email and also about the availability of the final reports on the TWDB website.

Following receipt of the final reports, staff conducted a thorough review of the results in the final report and datasets to ensure that the requirements of and exclusion criteria in House Bill 30 had been properly implemented. Staff evaluated the contractor-identified areas for (1) Class II injection well data using a 15-mile buffers around each well, (2) presence of domestic, municipal, and agricultural water wells using a 3-mile buffer around each well, (3) Class I, Class III, Class IV, and Class V injection wells, and (4) hydrogeologic barriers. We only placed buffers around Class II injection wells because none of the other injection wells were located in potential zones after we applied all of the other exclusions.

After detailed reviews, TWDB staff finalized the areas and provided them to the Executive Administrator with a recommendation for the Board to designate the areas as brackish groundwater production zones. The Board memo containing the Executive Administrator's recommendation was posted on the TWDB website about 10 days before the Board meeting and stakeholders were notified via email about its availability for review and comment. Staff received comments from four public entities and provided them to the Board before the meeting. On October 20, 2017, the Board approved the designation of brackish groundwater production zones in three of the four aquifers. Staff did not recommend a zone in the fourth aquifer.

The value of the scientific work we and our contractors conducted to inform the designation of brackish groundwater production zones extends well beyond the production zones. We analyzed the totality of the aquifer, which will be useful for anyone considering brackish desalination in other parts of the aquifer.

Key challenges

In the process of conducting the studies, TWDB staff and project contractors encountered several challenges relating to the evaluation of aquifer areas for zone designation and implementation of House Bill 30 criteria.

House Bill 30 excludes designation of brackish groundwater production zones in areas located in an aquifer or a geologic formation that serves as a significant source of water supply for municipal, domestic, or agricultural purposes. However, there is no single database in Texas that has a complete record of all installed water wells. Also, information on a vast majority of water wells is not available in the public domain or may not exist, and current datasets often are incomplete and do not contain information on current well owner, well type, or use.

House Bill 30 requires the TWDB to estimate the volume of brackish groundwater that a zone is capable of producing over 30- and 50-year periods. While a calibrated groundwater model for each zone containing multiple, simultaneous well fields and regional groundwater pumping would have been desirable, severe time constraints limited contractors to conducting simple, desktop analysis of groundwater production within a zone to estimate the impact to fresh water resources. Similarly, staff had to use a simple analysis to determine groundwater volume based on aquifer parameters and simulated drawdown.

As required by federal law, the vast majority of wastewater injection wells are installed in formations with native water greater than 10,000 milligrams per liter; however, a number of injection zones are located above, below, and lateral to geologic stratum containing brackish groundwater. Information we needed to determine the distance that injected fluids may have traveled both laterally and vertically from these wells was lacking, necessitating staff to adopt a conservative approach (using a 15-mile buffer around each injection well) when recommending brackish groundwater production zones. We will need to do additional work to further understand how injection activities in Texas may or may not effect large-scale brackish groundwater production. The TWDB may adjust the radius of the buffers based on future investigations.

As required by House Bill 30, stakeholders formed an integral part of the brackish groundwater production zone designation process. While it would have been desirable to include every potential stakeholder in the process, the size of the study areas (for example, the Gulf Coast Aquifer study area has 56 counties) and time constraints (less than one year to complete and report on the studies), precluded contacting each and every stakeholder in the study areas. Nevertheless, staff made reasonable efforts to engage stakeholders throughout the process.

Results of studies

Applying the criteria listed in House Bill 30, the TWDB designated brackish groundwater production zones in the three of the four aquifers, calculated the volumes of water that a brackish groundwater production zone can produce over 30- and 50-year periods, and recommended reasonable monitoring to observe the effects of brackish groundwater production within a zone. The characteristics of the zones in each aquifer are described in the sections that follow.

The brackish groundwater production zones designated by the Board are representative of the aquifers and do not include every possible area that might qualify for designation. For example, for practical reasons, small well fields (one or two wells) that would have a minor impact in an area were not recommended for designation. Lack of designation of such areas at this time does not preclude (1) designation of zones in these areas in the future or (2) development of the brackish resource in an area. At present, the designation of a brackish groundwater production zone has no regulatory or planning implications.

Carrizo-Wilcox Aquifer between the Colorado River and the Rio Grande

The Carrizo-Wilcox Aquifer is one of the nine major aquifers in Texas. It occurs in a belt paralleling the Gulf Coast and extends from Louisiana to the Rio Grande (Figure 9). The TWDB boundary for the Carrizo-Wilcox Aquifer includes outcrop and downdip extent of the Carrizo Formation and the Wilcox Group containing groundwater with a total dissolved solids concentration of less than 3,000 milligrams per liter (TWDB, 2007). The Carrizo–Wilcox Aquifer consists of interbedded sand, gravel, silt, clay, and lignite deposited during the Paleocene and Eocene periods in river, delta, tidal, and shelf environments (Figure 10). The primary use of groundwater from the Carrizo-Wilcox Aquifer is domestic, municipal, irrigation, livestock, and oil and gas production (George and others, 2011).

Designated brackish groundwater production zones

In the Carrizo-Wilcox Aquifer, the Board designated one brackish groundwater production zone (Figure 9). Zone CzWx1 is located in the lower Wilcox Aquifer (Figure 10) and contains groundwater that is slightly to moderately saline (1,000 to 10,000 milligrams per liter of total dissolved solids).

Depth to the top of the brackish groundwater production zone ranges from 1,400 feet to more than 3,000 feet below ground surface. The bottom depth of the zone ranges from 1,800 feet to more than 3,800 feet below ground surface. Approximately 140 feet of shale within the overlying middle Wilcox geological formation constitutes a hydrogeologic barrier between the zone and the overlying Carrizo Aquifer.

Volumes of brackish groundwater in the production zones

The volume of brackish groundwater that could be produced from the brackish groundwater production zone in the Carrizo-Wilcox Aquifer is estimated at 43,000 acre-feet per year. This equates to 1.29 million acre-feet of brackish groundwater over 30 years and 2.15 million acre-feet over 50 years.

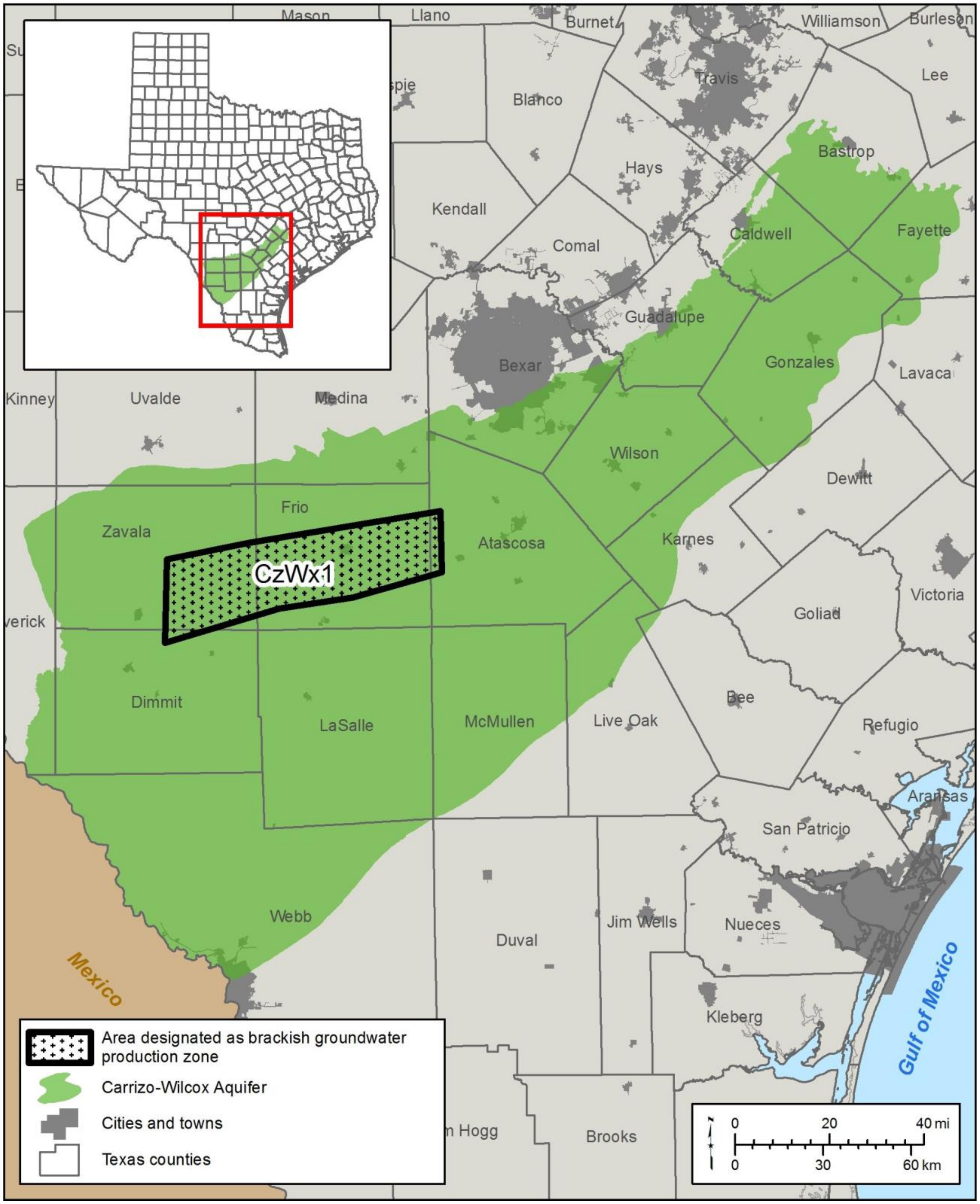
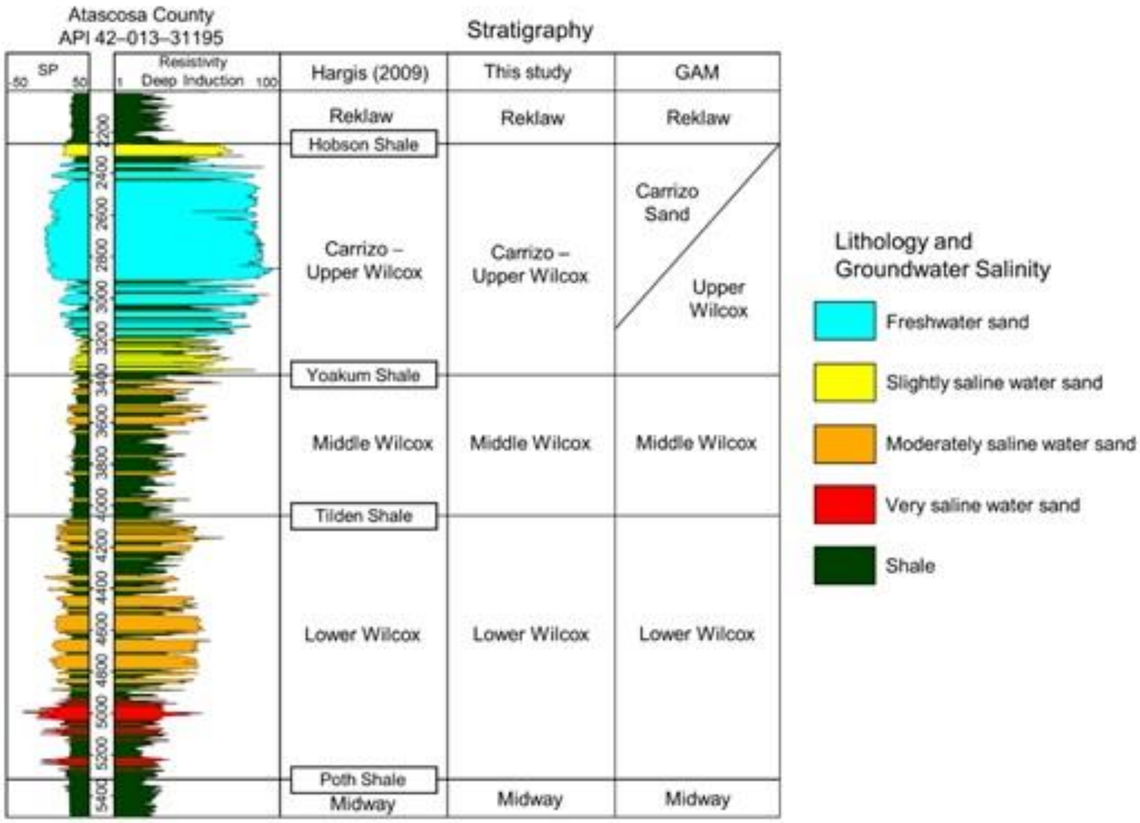


Figure 9. **Carrizo-Wilcox Aquifer located between the Colorado River and the Rio Grande showing one brackish groundwater production zone within the lower Wilcox Formation.**



Source: Hamlin and others, 2016

Figure 10. Stratigraphic subdivision of the Carrizo-Wilcox Aquifer in the project area.

Monitoring recommendations

Groundwater monitoring should focus on the overlying Carrizo Aquifer, which contains fresh water, and on both the lower Wilcox and Carrizo aquifers in the updip areas. Monitoring in the permeable sands in the middle Wilcox associated with confining layer is recommended to determine the potential source of Carrizo Aquifer impact due to development in (1) the Carrizo Aquifer or (2) the brackish lower Wilcox Aquifer. Monitoring is not required in the geological formations below the lower Wilcox because there are no known fresh or brackish aquifers in those geological formations in the region.

Gulf Coast Aquifer and sediments bordering that aquifer

The Gulf Coast Aquifer is one of the nine major aquifers in Texas. It parallels the coastline of the Gulf of Mexico and extends from the Louisiana-Texas border to the United States of America-Mexico border. The TWDB boundary of the Gulf Coast Aquifer includes outcrop and downdip areas containing groundwater with a total dissolved solids concentration of less than 3,000 milligrams per liter (TWDB, 2007). The Gulf Coast Aquifer System is made up of a number of aquifers, including the Chicot, Evangeline, and Jasper aquifers, separated by the Burkeville and Catahoula confining units (Figure 11). The Gulf Coast Aquifer System predominantly consists of discontinuous clay, silt, sand, and gravel beds. Domestic, municipal, irrigation, industrial, livestock, and oil and gas production are the primary uses of groundwater from the Gulf Coast Aquifer System.

Designated brackish groundwater production zones

In the Gulf Coast Aquifer, the Board designated four brackish groundwater production zones (Figure 12). The zones are in the Upper Lagarto (GCUL1), Middle Lagarto (GCML1), and Lower Lagarto (GCLL1 and GCLL2) geological formations (Figure 11) and contain groundwater that is slightly to moderately saline (1,000 to 10,000 milligrams per liter of total dissolved solids). Depth to the top of zone GCUL1 ranges from 1,308 feet to more than 2,100 feet below ground surface, while the bottom depth ranges from 1,927 feet to more than 2,700 feet below ground surface. Thickness of zone GCUL1 ranges from 573 to 718 feet. Approximately 60 to 120 feet of clay interbedded with sands is present across the transition between the Lower Goliad and the Upper Lagarto formations. This overlying geological formation may constitute a hydrogeologic barrier between zone GCUL1 and the overlying sands of the Lower Goliad Formation. There are no wells completed in the Lower Goliad Formation in this zone. In this zone, non-contiguous clays interbedded with sands range from 150 to 270 feet in thickness in the Lower Goliad Formation.

Depth to the top of the zone GCML1 ranges from 449 feet to more than 3,100 feet below ground surface, while the bottom depth ranges from 666 feet to more than 3,800 feet below ground surface. Thickness of zone GCML1 ranges from 178 to 756 feet. Approximately 25 to 80 feet of contiguous clay and 35 to 175 feet of non-contiguous clay interbedded with sands are present across the transition between the Upper Lagarto and the Middle Lagarto formations. These clays interbedded with sands may constitute a hydrogeologic barrier between zone GCML1 and the overlying sands of the Upper Lagarto Formation. We evaluated clays to approximately 100 feet above the top of the Middle Lagarto Formation because this was the maximum depth of water wells in the Upper Lagarto Formation within this zone.

Depth to the top of the zone GCLL1 ranges from 509 feet to more than 1,700 feet below ground surface, while the bottom depth ranges from 881 feet to more than 2,200 feet below ground surface. Thickness of zone GCLL1 ranges from 311 to 590 feet. Approximately 20 to 105 feet of contiguous clay and 45 to 160 feet of non-contiguous clay interbedded with sands are present across the transition between the Middle Lagarto and the Lower Lagarto formations. These clays interbedded with sands may constitute a hydrogeologic barrier between zone GCLL1 and the overlying sands of the Middle Lagarto Formation. Clays were evaluated to approximately 100 feet above the top of the Middle Lagarto Formation even though the maximum depth of water wells was 24 to 142 feet above the top of the Middle Lagarto Formation within this zone.

Depth to the top of the zone GCLL2 ranges from 883 feet to more than 1,900 feet below ground surface, while the bottom depth ranges from 1,289 feet to more than 2,600 feet below ground surface. Thickness of zone GCLL2 ranges from 406 to 628 feet. Approximately 25 to 40 feet of contiguous clay and 40 to 100 feet of non-contiguous clay interbedded with sands are present across the transition between the Middle Lagarto and the Lower Lagarto formations. These clays interbedded with sands may constitute a hydrogeologic barrier between zone GCLL2 and the overlying sands of the Middle Lagarto Formation. Clays were evaluated to approximately 180 feet above the bottom of the Middle Lagarto Formation because this was the maximum depth of water wells in the Middle Lagarto Formation within this zone.

Volume of brackish groundwater in the production zones

The volume of brackish groundwater that could potentially be pumped from the formations is 35,700 acre-feet per year from zone GCUL1, 2,079 acre-feet per year from zone GCML1, and 7,921 acre-feet per year from zones GCLL1 and GCLL2 (Table 8). The volumes of brackish groundwater that could be potentially produced from GCUL1 zone over 30- and 50-year periods is 1.07 million acre-feet and 1.785 million acre-feet, respectively. Zone GCML1 could potentially produce 0.062 million acre-feet of brackish groundwater over 30 years and 0.104 million acre-feet over 50 years. Zones GCLL1 and GCLL2 could potentially produce 0.238 million-acre feet over 30 years and 0.396 over 50 years.

Table 8. **Amount of brackish groundwater that could potentially be produced from zones in the Gulf Coast Aquifer.**

Aquifer	Zone name	Annual pumpage (acre-feet per year)	30-year cumulative (million acre-feet)	50-year cumulative (million acre-feet)
Upper Lagarto	GCUL1	35,700	1.07	1.785
Middle Lagarto	GCML1	2,079	0.062	0.104
Lower Lagarto	GCLL1	4,992	0.15	0.25
Lower Lagarto	GCLL2	2,929	0.088	0.146

Monitoring recommendations

Groundwater monitoring should focus on the lateral and updip portions of the brackish aquifer, on the underlying aquifer, and on the overlying aquifer containing fresh and brackish water in each zone. Monitoring in permeable sands associated with shale confining units is recommended to determine the potential source of adjacent aquifer impact due to development in (1) the adjacent aquifers or (2) the brackish zone aquifer (Table 9).

Table 9. Shale confining units with permeable sands recommended for monitoring.

Zone name	Brackish Lagarto Aquifer	Underlying aquifer	Overlying aquifer
GCUL1	Upper Lagarto	Middle Lagarto	Lower Goliad
GCML1	Middle Lagarto	Lower Lagarto	Upper Lagarto
GCLL1	Lower Lagarto	Oakville	Middle Lagarto
GCLL2	Lower Lagarto	Oakville	Middle Lagarto

<table>
<tr><th>Epoch and age (millions of years before present)</th><th>Geologic formation</th><th colspan="2">Hydrogeologic unit</th></tr>
<tr><td rowspan="2">Pleistocene (1.8–present)</td><td>Beaumont</td><td rowspan="3">Chicot Aquifer</td><td rowspan="10">Gulf Coast Aquifer</td></tr>
<tr><td>Lissie</td></tr>
<tr><td rowspan="2">Pliocene (5.6–1.8)</td><td>Willis</td></tr>
<tr><td>Upper Goliad</td><td rowspan="3">Evangeline Aquifer</td></tr>
<tr><td rowspan="5">Miocene (23.8–5.6)</td><td>Lower Goliad</td></tr>
<tr><td>Upper Lagarto</td></tr>
<tr><td>Middle Lagarto</td><td>Burkeville Confining Unit</td></tr>
<tr><td>Lower Lagarto</td><td rowspan="3">Jasper Aquifer</td></tr>
<tr><td>Oakville</td></tr>
<tr><td>Oligocene</td><td>(upper) Catahoula</td></tr>
</table>

Source: Modified from Young and others, 2010

Figure 11. Stratigraphy and hydrostratigraphy of the Gulf Coast Aquifer system in the project area.

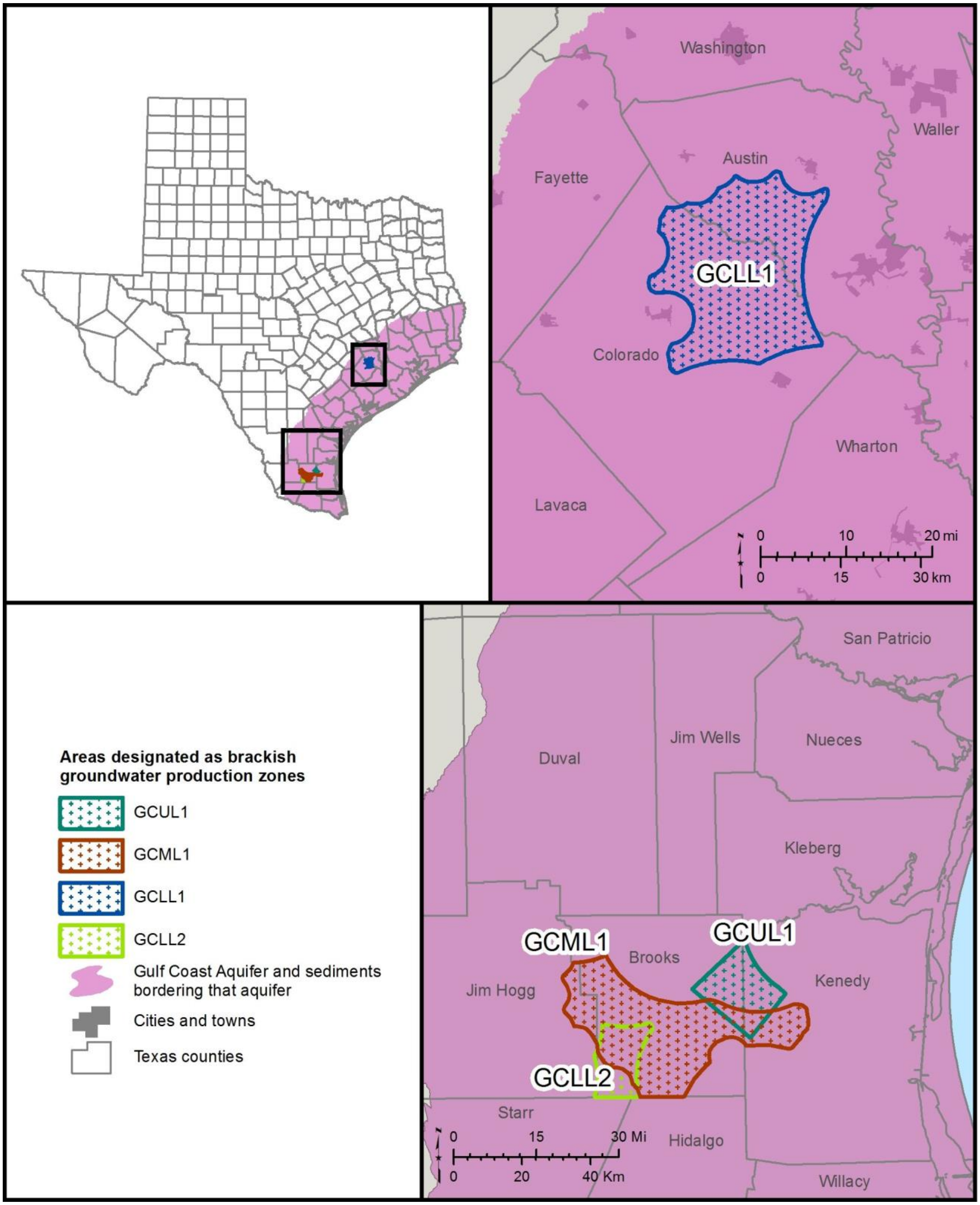


Figure 12. Gulf Coast Aquifer, sediments bordering that aquifer showing four brackish groundwater production zones.

Blaine Aquifer

The Blaine Aquifer is one of the 21 minor aquifers in Texas. It outcrops in a north-south orientation in the Rolling Plains region of north-central Texas and Oklahoma (Figure 13). The TWDB mapped extent of the Blaine Aquifer includes the outcrop and downdip extent of the Blaine Formation containing groundwater with a total dissolved solids concentration of less than 10,000 milligrams per liter (TWDB, 2007). The primary use of groundwater from the Blaine Aquifer System is domestic, municipal, irrigation, livestock, and oil and gas production.

Designated brackish groundwater production zones

TWDB staff did not recommend areas in the Blaine Aquifer for designation as brackish groundwater production zones (Figure 13) because the aquifer is a prominent water source for domestic and industrial uses.

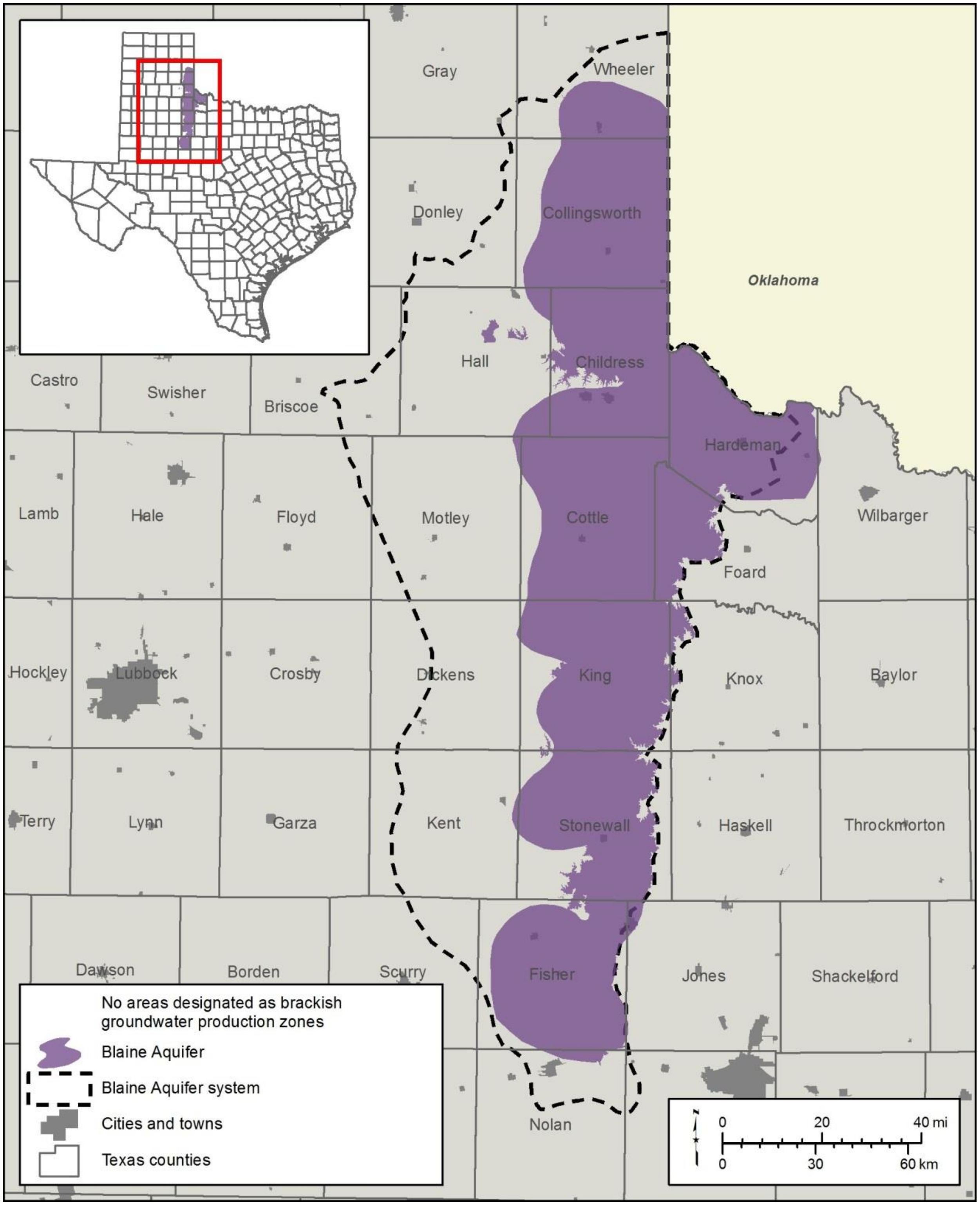


Figure 13. Blaine Aquifer showing no areas designated as brackish groundwater production zones.

Rustler Aquifer

The Rustler Aquifer is one of 21 minor aquifers in Texas. It is present in West Texas in the Rustler Formation and extends north into New Mexico . The TWDB boundary for the Rustler Aquifer includes the Rustler Formation outcrop and subcrop, cropped to exclude New Mexico in the north and groundwater where the total dissolved solids concentration is more than 5,000 milligrams per liter in the southeast (TWDB, 2007). The Rustler Formation consists of dolomite, limestone, and gypsum layers deposited in a shallow sea during the Permian Period (Figure 14). The primary uses of groundwater from the Rustler Aquifer are irrigation, livestock, and oil and gas production (George and others, 2011).

Designated brackish groundwater production zones

In the Rustler Aquifer, the Board designated three brackish groundwater production zones (Figure 15). Zones Rus1 and Rus3 are located in Magenta Dolomite, Culebra Dolomite, and the limestones of the Los Medaños members of the Rustler Aquifer, while zone Rus2 is located in the collapsed Rustler Aquifer (Figure 14). The zones contain groundwater that is slightly to moderately saline (1,000 to 10,000 milligrams per liter of total dissolved solids).

The top of Rus1 is 152 feet to more than 3,300 feet below ground surface with a mean depth of 1,459 feet. The thickness of this zone ranges from 81 feet to 214 feet, with a mean thickness of 145 feet. The top of brackish groundwater production zone Rus2 is 518 feet to more than 3,400 feet below ground surface with a mean depth of 1,631 feet. The thickness of this zone ranges from 100 feet to 836 feet, with a mean thickness of 323 feet. The top of brackish groundwater production zone Rus3 is 717 feet to more than 2,900 feet below ground surface with a mean depth of 1,054 feet. The thickness of this zone ranges from 103 feet to 241 feet, with a mean thickness of 157 feet. The base of zone Rus1 is 658 feet to more than 3,700 feet below ground surface with a mean depth of 1,904 feet. The base of zone Rus2 is 1,201 feet to more than 3,700 feet with a mean depth of 1,954 feet. The base of zone Rus3 is 1,152 feet to more than 3,300 feet below ground surface with a mean thickness 1,521 feet.

Hydrogeologic barriers in each zone include structural geological boundaries such as faults, the Dewey Lake Formation above the Rustler Aquifer, and the Salado Formation below the aquifer. Additionally, hydraulic distance barriers apply to zones Rus1 and Rus3 and distance from existing use. A hydraulic distance barrier is meant to prevent significant impact between an existing well and a hypothetical well in a brackish groundwater production zone.

Volume of brackish groundwater in the production zones

The estimated volume of brackish groundwater that could be pumped from the three brackish groundwater production zones is 15,680 acre-feet per year (Table 10). This equates to a total of

0.47 million acre-feet of brackish groundwater over 30 years and 0.78 million acre-feet over 50 years.

Table 10. **Amount of brackish groundwater that could potentially be produced from zones in the Rustler Aquifer.**

Aquifer	Zone name	Annual pumpage (acre-feet per year)	30-year cumulative (million acre-feet)	50-year cumulative (million acre-feet)
Rustler	Rus1	2,513	0.075	0.126
	Rus2	522	0.016	0.026
	Rus3	12,645	0.379	0.632

Monitoring recommendations

Parts of brackish groundwater production zone Rus1 in the Rustler Aquifer are overlain by one, none, or both the Pecos Valley and Edwards-Trinity (Plateau) aquifers. Minor aquifers in the area that may be adjacent to the Rustler Aquifer include the Capitan Reef Complex Aquifer to the southwest, the Igneous Aquifer to the south, and the Dockum Aquifer to the east. Groundwater monitoring should focus on those aquifers, where present, and on areas near existing use. Monitoring in permeable strata within adjacent confining units is recommended to determine the potential source of adjacent aquifer impacts due to development in (1) the adjacent aquifer or (2) the brackish Rustler Aquifer. Monitoring is not required below the Rustler Aquifer because there are no known fresh or brackish aquifers in the region.

All of brackish groundwater production zone Rus2 in the Rustler Aquifer is overlain by the Edwards-Trinity (Plateau) Aquifer. The only minor aquifer in the area that may be adjacent to the Rustler Aquifer is the Igneous Aquifer to the west. The Tessey Limestone is not a TWDB-designated major or minor aquifer in Texas but is used for water supply in the area and could be located hydrogeologically adjacent to the Rustler Aquifer east of brackish groundwater production zone Rus2. Groundwater monitoring should focus on those aquifers and the Tessey Limestone, where present, and on areas near existing use. Monitoring in permeable strata within adjacent confining units is recommended to determine the potential source of adjacent aquifer impact due to development in (1) the adjacent aquifer or (2) the brackish Rustler Aquifer. Monitoring is not required below the Rustler Aquifer because there are no known fresh or brackish aquifers in the region.

Parts of brackish groundwater production zone Rus3 for the Rustler Aquifer are overlain by either or both the Pecos Valley and the Edwards-Trinity (Plateau) aquifers. Minor aquifers in the area that may be adjacent to the Rustler Aquifer are the Dockum Aquifer which overlies most of the zone and the Igneous Aquifer which is present in the southwest corner. Groundwater monitoring should focus on those aquifers, where present, and on areas near existing use. Monitoring in permeable strata within adjacent confining units is recommended to determine the potential source of adjacent aquifer impact due to development in (1) the adjacent aquifer or (2) the brackish Rustler Aquifer. Monitoring is not required below the Rustler Aquifer because there are no known fresh or brackish aquifers in the region.

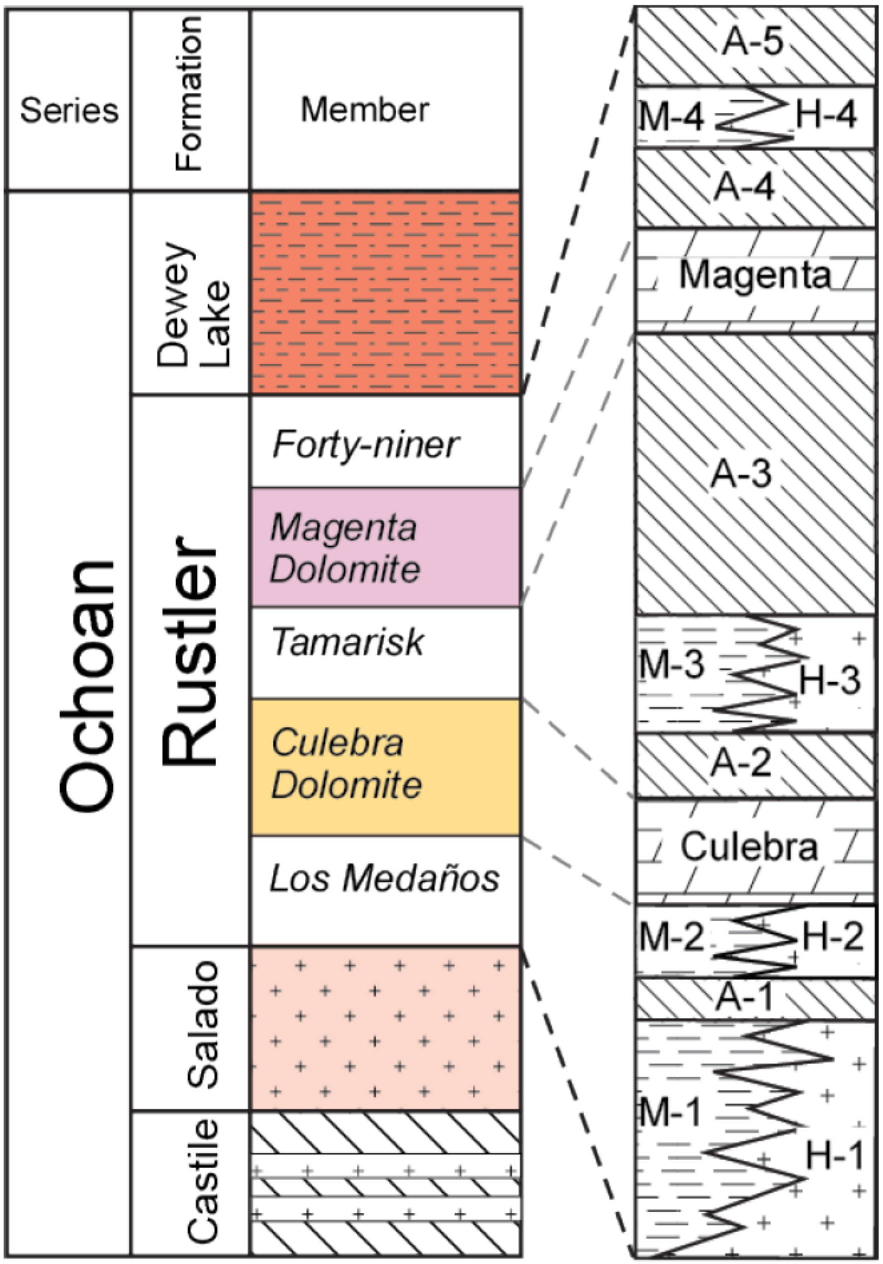


Figure 14. **Stratigraphy of the Rustler Aquifer (Lupton and others, 2016). For the informal submembers, "A"= anhydrite, "M"= mud and "H"= halite.**

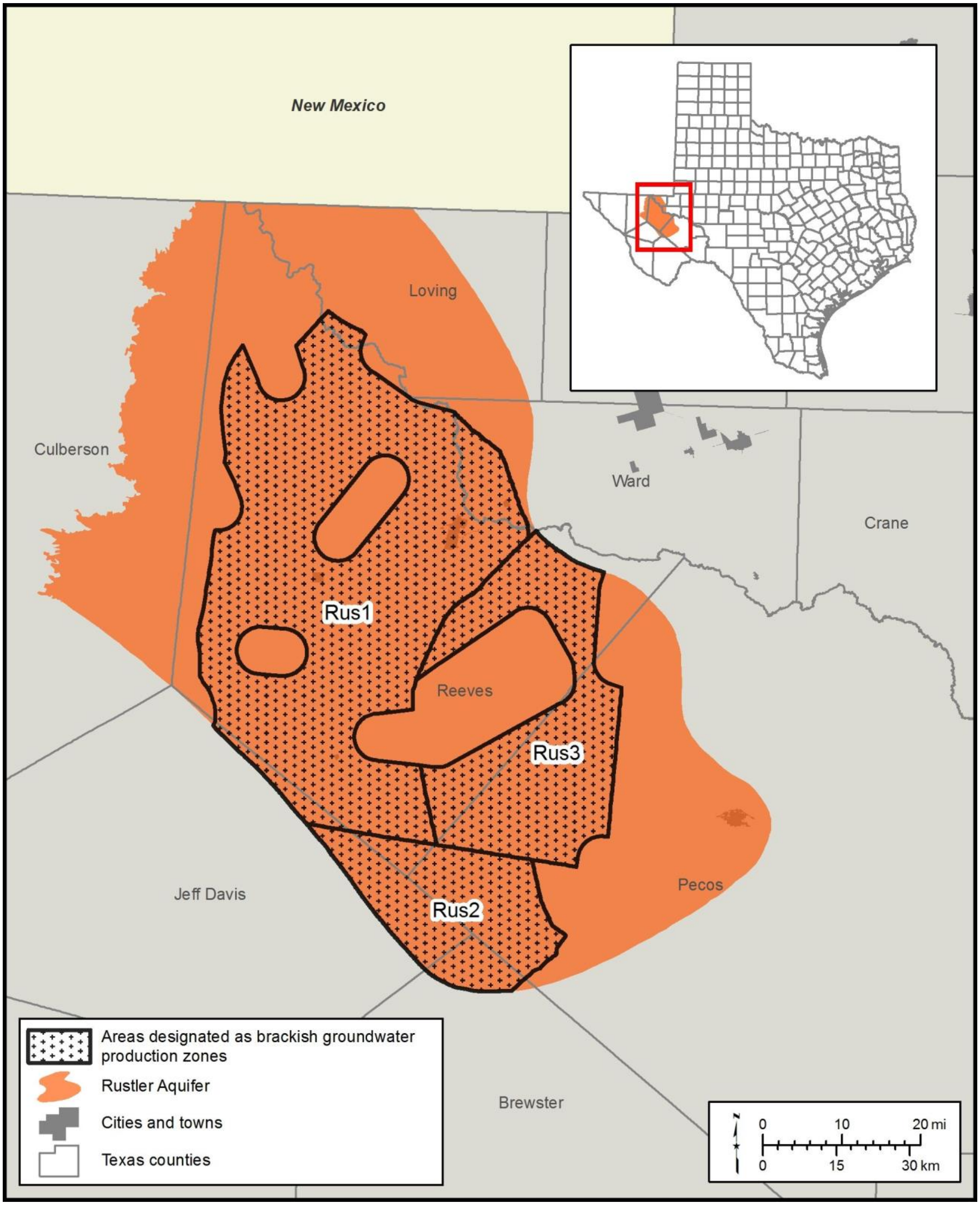


Figure 15. Rustler Aquifer showing three brackish groundwater production zones.

Identification and evaluation of research, regulatory, technical, and financial impediments to implementing seawater or brackish groundwater desalination projects

Desalination projects, both seawater and brackish groundwater, are driven by site-specific conditions. Source water quality, permitting requirements, construction costs, and operation costs are all dependent on local site conditions. Thus, impediments for desalination projects can be different for each project.

Research

A common obstacle to conducting research is the need for more funding. TWDB funds available to advance seawater and brackish groundwater desalination in Texas were exhausted in 2010. If funding should become available in the future, potential research topics specific to Texas have been identified in past TWDB studies and biennial reports (Brownsville Public Utilities Board, 2011; TWDB, 2010; Carollo Engineers, 2014; U.S. Environmental Protection Agency, 2014). These research topics remain relevant today and include:

- characterizing benthic fauna in areas that will be affected by concentrate discharges;
- determining the salinity tolerance of key aquatic species along the Texas Gulf Coast that may potentially be affected by desalination concentrate discharges;
- modeling currents and tides to determine impact on concentrate dispersion;
- improving thin-layer mixing models as part of far-field plume modeling;
- integrating desalinated seawater into existing drinking water distribution networks;
- revising regulatory bacteria and virus removal credits for reverse-osmosis membranes;
- studying subsurface intakes, including subsurface infiltration galleries, for entrainment data;
- quantifying construction impacts of subsurface intakes;
- quantifying differences in energy use and greenhouse gas emissions between open and subsurface intakes; and
- determining mitigation for impacts due to intake structures.

There is a need to develop a desalination research agenda and tangible pilot- and demonstration-scale projects that would help advance the implementation of desalination. There is also a need to update the permit decision model or roadmap developed by the TWDB in 2004 along with a corresponding guidance document to reflect the new streamlined and flexible permitting process recently adopted as a requirement of House Bill 2031 and 4097 (84th Texas Legislature, 2015).

National and state water organizations, agencies, and universities continue investigating various aspects of desalination. Recent desalination studies funded by the WateReuse Foundation include an investigation of the following (WateReuse Foundation, 2016):

<u>Ongoing studies</u>

- Development of habitat restoration programs for the mitigation of impingement and entrainment effects from intakes for seawater desalination facilities (Project 13-06)
- Evaluation of natural gas to reduce carbon footprint and energy costs for desalination (Project 13-05)
- Database of permitting practices for seawater concentrate disposal (Project 13-07)
- Application of the bioluminescent saltwater assimilable organic carbon test as a tool for identifying and reducing reverse osmosis membrane fouling in desalination (Project 11-07)
- Desalination concentrate management policy analysis for the arid west (Project 11-09)
- Investigation of desalination membrane biofouling (Project 08-19)
- Development of public communication toolkit for desalination projects (Project 12-02)

<u>Completed studies in 2015</u>

- Case study of the City of Carlsbad and surrounding areas' experience with integrating desalinated seawater supply in municipal distribution systems (Project 15-06)
- Performance and cost review of existing desalination plants that use conventional and membrane pretreatment processes prior to reverse osmosis (Project 14-07)
- Emerging energy-reducing technologies for desalination applications (Project 11-04)
- Use of heated metal oxide particles as adsorbents for membrane fouling reduction in water reuse/desalination applications (Project 14-09)
- Methodology for assigning pathogen removal credits for sub-surface desalination intakes (Project 14-06)

In the past, the TWDB has partnered with the U.S. Bureau of Reclamation and their Oklahoma-Texas Area Office to conduct desalination research. We will continue to maintain this partnership. Reclamation has researched various topics related to innovative water technologies. The TWDB collaborated with Reclamation on six projects since 2013 through their General Planning Program (Table 11). Staff have also shared research needs and helped brainstorm topics for their Science and Technology Program. To date, Reclamation has awarded 24 projects in Texas through the Desalination and Water Purification Research Program, 5 projects through the Drought Response Program, 1 basin study through WaterSMART Program, 11 studies through Title XVI Research and Feasibility Study Grants, and 35 projects through Water and Energy Efficiency Grants.

Table 11. Projects completed in collaboration with the U.S. Bureau of Reclamation.

Project title	Date completed
State of Texas –tool for planning temporary water supply response in drought emergencies	January 2013
Variable source salinity desalination	January 2014
Estimating the cost of brackish groundwater desalination in Texas	July 2014
Treating brackish groundwater in Texas: a comparison of reverse osmosis and nanofiltration	May 2015
Developing a deterministic model for cleaning reverse osmosis membranes	June 2015
Refining interpretation techniques for determining brackish aquifer water quality	Ongoing

Regulatory

In general, the permitting process can be a barrier to public entities pursuing desalination. The Texas Commission on Environmental Quality and other agencies' permitting requirements will not be known until a few permitting cycles have been completed. A 2011 TWDB-funded study determined that a total of 26 federal and state permits may be required to implement a seawater desalination project along the Gulf Coast (Brownsville Public Utilities Board, 2011). The reports also included information about the timeframe and cost associated with each permit and the regulatory agency responsible for the permits.

A 2004 TWDB-funded study developed a permit-decision model that identifies major requirements through a decision tree analysis (R.W. Beck, Inc., 2004). The model can be applied to either a seawater or brackish water desalination facility that uses a reverse osmosis system. The model has three main categories: (1) raw water source, (2) facility, and (3) concentrate disposal. The study also provides an example of how to apply the permit decision model to a seawater desalination plant co-located with a power plant. As listed in the research category of this report, updating the permit decision model along with a corresponding guidance document is a research need.

There is also a research need to conduct case studies to become more familiar with the regulatory process. The industrial seawater desalination plant currently being built by M&G Resins USA, LLC in Corpus Christi can provide an opportunity to gather data. However, a seawater desalination facility built to produce drinking water will likely have different permitting requirements and that process will be fine tuned as more is learned on the subject.

Technical

The Brownsville and the South Padre Island pilot-plant studies conducted between 2008 and 2010 tested treatment technologies that are now six to eight years old. Recent advances in desalination technology make the results of these pilot tests dated. Consequently, additional piloting of technologies may be needed to pursue seawater desalination. Since brackish groundwater desalination is currently implemented in Texas, conducting pilot- and demonstration-scale testing may be a better approach to further advance application. Targeting entities that have conducted feasibility studies and providing these entities funding for pilot-scale testing and demonstration-scale testing may help advance the implementation of desalination.

Financial

Despite the improvements to reverse osmosis membranes and the increased cost competitiveness of desalination, creating a new water supply from seawater and brackish groundwater is still relatively more expensive than developing supplies from existing fresh sources, if available. Desalinating seawater and brackish groundwater is more costly for a number of reasons, but predominantly because of salinity concentration (about 1,000 to 35,000 milligrams per liter). Higher-salinity water requires more pressure in the treatment process, which increases the energy costs. Other factors that affect cost include the intake and outfall structures, the water supply wells, the pre-treatment process, the brine disposal method, and the length of distribution pipelines. Additionally, the permitting process can increase the cost by requiring entities to obtain many permits and conduct environmental studies.

In 2013, a TWDB-funded study developed the Unified Costing Model for the 16 regional water planning groups to use when preparing their cost estimates for projects (TWDB, 2013). The purpose of the costing model was to bring uniformity to the cost estimates developed by the regional water planning groups. The costing tool allows the user to enter desalination plants. The tool was first used in the fourth regional water planning cycle from 2011 and 2016. Overall, the costing model standardizes cost estimates used in water planning across the state.

The greatest challenge to implementing a large-scale seawater and brackish groundwater desalination facility in Texas is the relatively high cost compared to less expensive conventional supplies. Additionally, the public entities that would implement the first projects may face greater risks and adopt a more conservative approach. Therefore, public entities need financial assistance to implement desalination projects. For the recommended 2.5-million-gallon-per-day seawater desalination plant in Brownsville, the TWDB requested a $9.5 million financial grant from the 83rd Texas Legislature (TWDB, 2012).

Evaluation of the role the State should play in furthering the development of large-scale seawater or brackish groundwater desalination projects in the state

The purpose of the Seawater and Brackish Groundwater Desalination Initiative was to accelerate the development of cost-effective desalination water supplies and innovative technologies in Texas. Since their inception in 2002 and 2004, the ultimate goal has been to install desalination plants—in particular a full-scale seawater desalination facility—to demonstrate the potential of desalination as a new water source.

The role of the State is to continue providing leadership and supporting the advancement of desalination in Texas. The State has taken the first steps by identifying and addressing past and current challenges to seawater and brackish groundwater desalination. Fulfilling this role during the upcoming biennium would require consideration of the following:

- Facilitating an efficient permitting process
  The permitting process can be challenging for entities pursuing seawater desalination for the first time. The State can assist in the permitting process by participating in and facilitating meetings between water providers or municipalities and regulatory agencies. The Texas Commission on Environmental Quality is the state agency that has regulatory authority over public drinking water quality and treatment requirements. It also oversees the issuance of permits for water diversions and waste discharges.

- Informing the public of funding opportunities
  Political subdivisions such as cities, counties, utility districts, and authorities are eligible for TWDB loan and grant programs. The low-interest loans provide funding for water supply projects, including desalination projects. The state should continue keeping the public informed of these and other funding opportunities.

- Seeking partnering opportunities with the private sector
  Public-private partnership is one method of implementing a large-scale desalination project. Recent legislative changes in Texas have made it easier for the private sector to develop public infrastructure, including water production facilities. The TWDB can provide support to entities pursuing these partnerships in the development of seawater and brackish groundwater desalination facilities. Existing TWDB funding programs can accommodate public-private partnerships as long as the project meets eligibility

requirements. However, the TWDB can only provide funding to a political subdivision in the partnership. The TWDB can work with the new Center for Alternative Finance and Procurement at the Texas Facilities Commission to help public entities learn more about this financing mechanism.

Anticipated appropriation from general revenues necessary to continue investigating water desalination activities in the state during the next biennium

As part of the legislative appropriations request for the 2018–2019 biennium, the TWDB requested baseline funding of $2 million to continue mapping brackish groundwater in the state. The TWDB's financial programs are also available to public entities to fund the planning, design, and construction phases of seawater and brackish groundwater desalination plants.

Since 1989, the TWDB has financed 34 desalination projects (Table 12) for a total of about $326 million. Desalination projects are eligible for financing from various agency programs, including the Drinking Water State Revolving Fund, the Texas Water Development Fund, and the State Participation Program. Desalination projects in the state water plan are also eligible to benefit from the State Water Implementation Fund for Texas (SWIFT). To date, the TWDB has funded two projects (Guadalupe-Blanco River Authority and Brazosport Water Authority) through the SWIFT program.

The TWDB will continue to monitor desalination activities with current resources and seek partnering opportunities with public and private entities to advance seawater and brackish groundwater desalination in Texas.

Table 12. Desalination projects funded through the TWDB's financial programs (as of October 2016).

No.	Entity	Funding program	Funding amount	Funding date	Project name
1	Wellman	DWSRF	$1,122,654	05/05/2016	Nitrate and fluoride removal
2	Seymour	DWSRF	$4,140,476	04/11/2016	Water system improvements
3	Loop Water Supply Corporation	DWSRF	$170,000	12/14/2015	Water treatment plant improvements
4	Brazosport Water Authority	SWIFT	$28,300,000	07/23/2015	Brackish groundwater reverse osmosis water treatment plant and water wells
5	Guadalupe-Blanco River Authority	SWIFT	$2,000,000	07/23/2015	Integrated Water and Power Plant project
6	Granbury	DWSRF	$16,430,000	03/26/2015	City of Granbury water treatment plant
7	Baylor Water Supply Corporation	DWSRF	$500,000	02/25/2015	Urgent need - Bufkin well field development
8	San Antonio Water System	DWSRF	$75,920,000	11/06/2014	Water Resources Integration pipeline
9	Raymondville	DWSRF	$3,800,000	09/19/2013	Well and reverse osmosis system

No.	Entity	Funding program	Funding amount	Funding date	Project name
10	Dell City	DWSRF	$244,450	05/16/2013	Reverse osmosis treatment plant
11	Andrews	SAAP	$388,000	01/19/2012	Water treatment system
12	Montgomery County Municipal Utility District #8	WDF	$5,450,000	09/22/2011	Walden conjunctive use water treatment plant design
13	Roscoe	DWSRF	$1,765,000	05/04/2011	Reverse osmosis water treatment plant
14	Fort Hancock Water Improvement Control District	EDAP	$3,012,990	04/22/2010	Water well and RO treatment facility
15	Fort Griffin Special Utility District	DWSRF	$2,355,000	10/15/2009	Throckmorton County water lines
16	Millersview-Doole Water Supply Corporation	DWSRF	$10,857,148	10/15/2009	Surface water treatment plant and distribution lines
17	San Antonio Water System	WIF	$109,550,000	07/16/2009	Brackish groundwater desalination
18	Stephens Regional Special Utility District	DWSRF; WDF	$11,800,000	05/21/2009	Water treatment plant and transmission lines
19	Greater Texoma Utility Authority	WIF	$835,000	12/15/2008	Northwest Grayson County Water Improvement Control District #1 Surface water treatment plant
20	Possum Kingdom Water Supply Corporation	DWSRF	$1,625,000	07/18/2006	Water treatment plant expansion
21	East Rio Hondo Water Supply Corporation	RWAF	$4,150,000	11/15/2005	North reverse osmosis plant transmission line
22	Clarksville City	WDF	$1,530,000	02/15/2005	George Richey Road water wells
23	Ballinger	DWSRF	$3,865,000	06/16/2004	Lake Ballinger water line
24	El Paso	WAF;SAAP	$1,240,000	03/20/2002	Eastside desalination plan
25	Horizon Regional Municipal Utility District	WDF	$7,780,000	11/14/2001	Reverse osmosis treatment plant
26	Burleson Co Municipal Utility District #1	DWSRF	$1,560,000	09/19/2001	Reverse osmosis treatment facility
27	Holiday Beach Water Supply Corporation	WDF	$470,000	11/15/2000	Reverse osmosis water plant
28	Harlingen	CWSRF	$1,845,000	04/19/2000	Wastewater treatment plant #2 sludge process
29	Brady	DWSRF	$9,405,000	03/09/2000	New surface water treatment plant and storage tank
30	Palmer	DWSRF	$1,405,000	07/14/1999	Reverse osmosis plant
31	Possum Kingdom Water Supply Corporation	DWSRF	$4,700,000	12/17/1998	Regional water system
32	Lorena	WDF	$3,335,000	10/16/1997	Robinson transmission line
33	Haciendas del Norte Water Improvement District	WDF	$1,725,000	08/20/1997	East Montana transmission and RO unit
34	Harlingen	WAF	$2,000,000	04/20/1989	Wastewater treatment plant #2 expansion

Note:

CWSRF = Clean Water State Revolving Fund
DWSRF = Drinking Water State Revolving Fund
EDAP = Economically Distressed Areas Program
RWAF = Rural Water Assistance Fund
SAAP = Special Appropriation Act Program
SWIFT = State Water Implementation Fund for Texas
WIF = Water Infrastructure Fund
WAF = Water Assistance Fund
WDF = Water Development Fun

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Appendix A: Carrizo-Wilcox Aquifer project

Appendix A: Carrizo-Wilcox Aquifer project (Colorado River to the Rio Grande)

Project summary

The objective of this project was to map the fresh and saline groundwater resources of the Carrizo-Wilcox Aquifer between the Colorado River and the Rio Grande, meet the requirements of House Bill 30 brackish groundwater production zone designation, and support the TWDB's groundwater availability modeling and brackish resources aquifer mapping projects.

The project produced an interpretation of:

1. the top and bottom of the Carrizo–upper Wilcox, middle Wilcox, and lower Wilcox geological formations;
2. the top and bottom of sand and clay layers within these geological formations;
3. water quality from existing water quality analyses and geophysical well logs to define the four salinity zone classes of fresh (0 to 1,000 milligrams per liter of total dissolved solids), slightly saline (>1,000 to 3,000 milligrams per liter of total dissolved solids), moderately saline (>3,000 to 10,000 milligrams per liter of total dissolved solids), and very saline (10,000 to 35,000 milligrams per liter of total dissolved solids);
4. the top and bottom salinity zone surfaces in three dimensions;
5. groundwater volume in the four salinity zone classes;
6. potential hydrogeologic barriers;
7. potential production areas;
8. simple groundwater modeling of potential production areas with a limited range of pumping over a 30- and 50-year time frame;
9. drawdown estimates indicating potential impact to the same and adjacent aquifers; and
10. exclusion criteria listed in House Bill 30.

We conducted stakeholder meetings to share project information, receive comments, and solicit data.

We (1) reviewed the contract report and data and (2) evaluated House Bill 30 exclusion criteria in each potential production area. The TWDB designated one brackish groundwater production zone within the project area. Zone CzWx1 is located in the lower Wilcox Aquifer and contains groundwater that is slightly to moderately saline (1,000 to 10,000 milligrams per liter of total dissolved solids).

The volume of brackish groundwater that could be produced from brackish groundwater production zone CzWx1 is estimated at 43,000 acre-feet per year. This equates to 1.29 million acre-feet of brackish groundwater over 30 years and 2.15 million acre-feet over 50 years.

The top of brackish groundwater production zone CzWx1 is 1,400 feet to more than 3,000 feet below ground surface and the bottom is 1,800 feet to more than 3,800 feet below ground surface. Thickness of the brackish groundwater production zones is 330 to 790 feet. Approximately 140 feet of shale within the overlying middle Wilcox geological formation constitutes a hydrogeologic barrier between the brackish groundwater production zone and the overlying Carrizo Aquifer.

Groundwater monitoring should focus on the overlying Carrizo Aquifer that contains fresh water and on both the lower Wilcox and Carrizo aquifers in the updip areas. Monitoring in middle Wilcox sands is recommended to determine the potential source of Carrizo Aquifer impact due to development in (1) the Carrizo Aquifer or (2) the brackish lower Wilcox. Monitoring is not required below the lower Wilcox because there are no known fresh or brackish aquifers in that geological formation in the region.

The brackish groundwater production zone does not contain known water wells (domestic, municipal, or agricultural that are using fresh or brackish groundwater) or known injection wells (Class I, II, III, IV, or V injection wells; Texas Water Code, Chapter 27, Injection Wells) that meet the exclusion criteria in House Bill 30.

Project history and previous investigations

The project was initially contracted to support the TWDB Groundwater Availability Modeling program for the Carrizo-Wilcox, Queen City, and Sparta aquifers in Groundwater Management Area 13. After passage of House Bill 30 by the 84th Texas Legislature, we amended the contract to include a study of the Carrizo-Wilcox Aquifer (between the Colorado River and the Rio Grande). The contract amendment required the results of the Carrizo-Wilcox Aquifer project to be provided to the TWDB by August 31, 2016 (to meet the House Bill 30 deadline of December 1, 2016), and for the Queen City and Sparta aquifers by May 2017. The contracted project included a regional reconnaissance effort designed to meet the requirements of House Bill 30 and provide information on the extent and volume of brackish groundwater within the Carrizo-Wilcox Aquifer and the location of potential production areas. We are evaluating portions of Bastrop and Fayette counties, not included in the Groundwater Management Area 13 project, as part of an ongoing brackish aquifer mapping study.

The Carrizo-Wilcox project is built upon decades of existing groundwater studies conducted by local, state, and federal agencies. Significant studies include the TWDB groundwater availability modeling projects (Deeds and others, 2003; Dutton and others, 2003; Kelley and others, 2004), Bureau of Economic Geology projects (Hamlin, 1988; Hamlin and de la Rocha, 2015), and the TWDB brackish resources aquifer characterization study (in progress). Thousands of well records have been compiled and stored in the TWDB Groundwater Database (TWDB, 2016a) and the TWDB BRACS Database (TWDB, 2016b) that we used for these projects.

Project approach

We conducted a general stakeholder meeting in October 2015 to kick-off the implementation of House Bill 30 and solicit comments. After we approved the contract, the contractor (1) collected well data, (2) evaluated the geology and groundwater of the Carrizo-Wilcox Aquifer, (3) prepared database and GIS files, and (4) identified potential production areas. We then conducted a stakeholder meeting to solicit comments on the potential production areas and worked with the contractor to develop a list of potential production areas on which groundwater modeling could be conducted. The contractor (1) performed the groundwater modeling, (2) prepared a draft report, and (3) submitted the draft report and data to us. We reviewed the draft report and data and provided technical comments to the contractor for consideration in the final report and datasets. We also conducted a meeting in September 2016 to discuss the results of this project and the other three House Bill 30 projects and solicit stakeholder comments on the final reports. We reviewed the report, evaluated the data, and considered stakeholder comments and made a recommendation to the Board through the Executive Administrator for the designation of one brackish groundwater production zone.

Contract information

TWDB contract number: 1548301855

Cost:

- Contract: $380,000
- Amendment: $181,446
- Total: $561,446

Contractor:

- The University of Texas at Austin, Bureau of Economic Geology (Principal)
- INTERA, Inc.

Project duration: approximately 25 months

- Project approved by Board: April 29, 2015
- Contract signed: August 24, 2015
- Contract amendment signed: February 23, 2016

- Draft Carrizo-Wilcox report delivered: August 31, 2016
- Final report including Queen City and Sparta aquifers due: May 31, 2017

Public entities

Counties

The Carrizo-Wilcox Aquifer in the project area is present in all or part of Atascosa, Bastrop, Bee, Bexar, Caldwell, DeWitt, Dimmit, Duval, Fayette, Frio, Gonzales, Guadalupe, Karnes, LaSalle, Lavaca, Live Oak, Maverick, McMullen, Medina, Uvalde, Webb, Wilson, and Zavala counties (Figure A-1).

Cities and towns

The Carrizo-Wilcox Aquifer in the project area underlies all or part of the cities and towns of Asherton, Bastrop, Big Wells, Carrizo Springs, Charlotte, China Grove, Christine, Cotulla, Crystal City, Devine, Dilley, Eagle Pass, Elmendorf, Encinal, Falls City, Flatonia, Floresville, Gonzales, Jourdanton, La Grange, La Vernia, Laredo, Lockhart, Luling, Lytle, Moulton, Natalia, New Berlin, Nixon, Pearsall, Pleasanton, Poteet, Poth, San Antonio, Seguin, Smiley, Smithville, Somerset, St. Hedwig, Stockdale, Three Rivers, and Waelder (Figure A-1).

Groundwater management areas

The Carrizo-Wilcox Aquifer in the project area is present in all or part of groundwater management areas 12, 13, 15, and 16 (Figure A-2).

http://www.twdb.texas.gov/groundwater/management_areas/index.asp

Regional water planning areas

The Carrizo-Wilcox Aquifer in the project area is present in all or part of regional water planning areas K, L, M, N, and P (Figure A-2).

https://www.twdb.texas.gov/waterplanning/rwp/

Groundwater conservation districts

The Carrizo-Wilcox Aquifer in the project area is present in all or parts of Bee Groundwater Conservation District, Edwards Aquifer Authority, Evergreen Underground Water Conservation District, Duval County Groundwater Conservation District, Gonzales County Underground Water Conservation District, Guadalupe County Groundwater Conservation District, Fayette County Groundwater Conservation District, Live Oak Underground Water Conservation District, Lost Pines Groundwater Conservation District, McMullen Groundwater Conservation District, Medina County Groundwater Conservation District, Pecan Valley Groundwater Conservation District, Plum Creek Conservation District, Uvalde Underground Water Conservation District, and Wintergarden Groundwater Conservation District (Figure A-3).

Methodology

The contractor interpreted geophysical well logs and used information in published reports (for example, Hamlin, 1988) to map the top and bottom of each geological formation in the Carrizo–Wilcox Aquifer and the top and bottom of sand and shale layers within these geological formations. The contractor also used this data to develop three-dimensional surfaces for each geological formation and the sand data to develop net sand and sand percent maps for each formation.

The contractor used existing chemical analysis of water samples from water wells to develop a relationship between the concentration of total dissolved solids in aquifer water and resistivity obtained from geophysical well logs. The contractor used this relationship to create a reconnaissance level "quick look" method for log interpretation that allowed the use of geophysical well logs to interpret salinity of sands within the geological formations. The contractor used the Winslow and Kister (1956) salinity classification to subdivide groundwater in the Carrizo–Wilcox Aquifer into four salinity classes (fresh [0 to 999 milligrams per liter total dissolved solids]; slightly saline [1,000 to 2,999 milligrams per liter total dissolved solids]; moderately saline [3,000 to 9,999 milligrams per liter total dissolved solids]; very saline [10,000 to 35,000 milligrams per liter total dissolved solids]). The contractor prepared 29 figures showing Carrizo-Wilcox Aquifer net sand maps, salinity zones, and stratigraphic and structural cross-sections.

We reviewed the contractors report and data (Hamlin and others, 2016) and evaluated House Bill 30 exclusion criteria in each potential production area. The TWDB designated brackish groundwater production zone CzWx1 in the same region as PPA3 (Figure 4).

Based on the contractor's study, we recommended groundwater modeling for four potential production areas (PPAs) containing brackish groundwater (Figure A-5). Areas PPA1, PPA2, and PPA3 are located in the lower Wilcox Formation, and PPA4 is located in the Carrizo-upper Wilcox Formation. The contractor (1) developed a simple groundwater model for each PPA with a hypothetical updip and downdip well field, (2) modeled three different pumping rates (5,000, 15,000, and 30,000 acre-feet per year) using two different sets of model input data (Hamlin and others, 2016), and (3) used the modeling results to evaluate potential impact in the overlying aquifers and updip areas within the aquifer containing the brackish groundwater.

Hydrogeology

The Carrizo-Wilcox Aquifer is one of the nine major aquifers in Texas. It occurs in a belt paralleling the Gulf Coast and extends from Louisiana to the Rio Grande. The TWDB boundary for the Carrizo-Wilcox Aquifer includes outcrop and downdip extent of the Carrizo Formation and the Wilcox Group containing groundwater with a total dissolved solids concentration of less than 3,000 milligrams per liter (TWDB, 2007). The geological formations that make up the Carrizo-Wilcox Aquifer extend farther downdip than the TWDB boundary and include increasingly more saline water. The Carrizo Aquifer south of the San Marcos Arch is thicker, the sands are more connected, and the aquifer contains more fresh water than it does north of the San Marcos Arch where the Wilcox Aquifer is more significant.

The primary use of groundwater from the Carrizo-Wilcox Aquifer is domestic, municipal, irrigation, livestock, and oil and gas production (George and others, 2011). Use of lower Wilcox brackish groundwater by the San Antonio Water System began in fall 2016 with the completion of Phase 1 of a 30-million-gallon-per-day desalination plant that is scheduled to be fully built out by 2026.

The top of brackish groundwater production zone CzWx1 is 1,400 feet to more than 3,000 feet below ground surface and the bottom is 1,800 feet to more than 3,800 feet below ground surface. Brackish groundwater production zone CzWx1 is between 330 and 790 feet in thickness. Approximately 140 feet of shale within the overlying middle Wilcox geological formation constitutes a hydrogeologic barrier between the brackish groundwater production zone and the overlying Carrizo Aquifer.

Lithology and stratigraphy

The Carrizo-Wilcox Aquifer consists of interbedded sand, gravel, silt, clay, and lignite deposited during the Paleocene and Eocene periods in river, delta, tidal, and shelf environments. In the project area, these rocks can be as much as 4,000 feet thick. The aquifer can be present in several geological formations which include (from younger to older) the Carrizo-upper Wilcox, the middle Wilcox, and the lower Wilcox (Figure A-6).

The Carrizo-Wilcox Aquifer is overlain by and separated from the Queen City Aquifer (a TWDB-designated minor aquifer) by the Reklaw Formation, which contains layers of sand and marine shale. Shale in the Midway Group underlies the Wilcox Group and forms a regional aquitard. In places, the Poth Sands interbedded with layers of shale immediately underlies the Wilcox Group.

Water quantity

We calculated the volume of brackish groundwater that the brackish groundwater production zone is capable of producing over a 30- and 50-year period using the contractor's simple desktop groundwater modeling of a hypothetical well field. Using a pumping rate of 15,000 acre-feet, the contractor modeled groundwater levels which showed a decline of approximately 250 feet at the well field in the lower Wilcox Aquifer after 50 years of pumping with lesser declines farther away from the well field (Hamlin and others, 2016). The contractor estimated that after 50 years of production, water level decline in the overlying Carrizo Aquifer would be 10 feet at the well field with smaller declines farther away from the well field. We estimated that the volume of brackish groundwater that could be produced from the zone is 43,000 acre-feet per year. Production of this volume of groundwater annually equates to 1.29 million acre-feet over a 30-year time period and 2.15 million acre-feet over a 50-year time period. We based the volumetric estimates on water level declines of 250 feet and a confined storativity value of 0.0003 (Deeds and others, 2003). Our volume calculations assume all drawdown is limited to the extent of the boundaries of the zone.

We estimated the volume of drainable brackish groundwater in the lower Wilcox within the brackish groundwater production zone is 17.3 million acre-feet. This assumes that only a fraction of the groundwater will drain to wells within the zone if the entire lower Wilcox Aquifer within the zone is completely pumped. The estimate is based on draining the total thickness of the lower Wilcox sands using a (1) specific yield value equal to 0.1, (2) confined storage head drawdown of approximately 1,830 feet, and (3) confined storativity value equal to 0.0003 (Deeds and others, 2003).

The volume of drainable groundwater using the total volume of sand layers within the Carrizo-Wilcox Aquifer in Groundwater Management Area 13 is 779.7 million acre-feet (Table A-1). The volume of drainable groundwater using the total volume of aquifer layers within the Carrizo-Wilcox Aquifer in Groundwater Management Area 13 is 2,044.6 million acre-feet (Table A-2).

Table A-1. Volume of drainable groundwater within the Carrizo-Wilcox Aquifer in Groundwater Management Area 13 using (1) total volume of sand layers, (2) specific yield, and (3) the groundwater availability model layers (Hamlin and others, 2016, Table 5-3).

Aquifer unit	Volume of water (million acre-feet)				
	Fresh*	Slightly saline*	Moderately saline*	Very saline*	Total
Carrizo	228.1	61.9	23.7	6.7	320.4
Upper Wilcox	27.4	45.0	45.0	10.9	128.3
Middle Wilcox	11.7	24.9	44.8	50.2	131.6
Lower Wilcox	3.2	30.1	57.9	108.2	199.4
Total	270.4	161.9	171.4	176.0	779.7

Notes:

Fresh = 0 to 999 milligrams per liter total dissolved solids

Slightly saline = 1,000 to 2,999 milligrams per liter total dissolved solids

Moderately saline = 3,000 to 9,999 milligrams per liter total dissolved solids

Very saline = 10,000 to 35,000 milligrams per liter total dissolved solids

Table A-2. **Volume of drainable groundwater within the Carrizo-Wilcox Aquifer in Groundwater Management Area 13 using (1) total volume of the aquifer layers, (2) specific yield, and (3) the groundwater availability model layers (Hamlin and others, 2016, Table 5-3).**

	Volume of water (million acre-feet)				
Aquifer unit	**Fresh***	**Slightly saline***	**Moderately saline***	**Very saline***	**Total**
Carrizo	340.6	107.1	43.6	11.6	502.9
Upper Wilcox	69.9	120.3	128.0	34.0	352.2
Middle Wilcox	37.0	70.3	147.9	224.5	479.7
Lower Wilcox	16.4	77.4	144.7	471.3	709.8
Total	463.9	375.1	464.2	741.4	2,044.6

Notes:

Fresh = 0 to 999 milligrams per liter total dissolved solids
Slightly saline = 1,000 to 2,999 milligrams per liter total dissolved solids
Moderately saline = 3,000 to 9,999 milligrams per liter total dissolved solids
Very saline = 10,000 to 35,000 milligrams per liter total dissolved solids

Wade and Bradley (2013) estimated the volume of drainable Carrizo-Wilcox Aquifer groundwater (total storage of 1,952 million acre-feet) using the Total Estimated Recoverable Storage Method for Groundwater Management Area 13.

LBG-Guyton Associates (2003) calculated the groundwater volume in their study of brackish groundwater in Texas. The volume of slightly and moderately saline groundwater within the Carrizo-Wilcox Aquifer in regional water planning areas L, M, N, and P (roughly equivalent to Groundwater Management Area 13 for the Carrizo-Wilcox Aquifer) is 231.2 million acre-feet. This volume is substantially lower than that reported by the contractor of the present study (333.3 million acre-feet) by summing the same salinity zones and can be attributed to different values for specific yield, confined storativity, areal extent of saline zones, and estimated thickness of productive sands.

The contractor also included two other calculations of groundwater volume using porosity instead of specific yield. These values are not presented because it is not feasible or recommended to completely remove all of the groundwater.

Water quality

The Carrizo-Wilcox Aquifer within the project area contains groundwater with total dissolved solids concentrations ranging from 50 to more than 13,000 milligrams per liter (Figure A-7).

Water wells completed in the Carrizo Aquifer are present from outcrop areas to the downdip extent of the TWDB designated aquifer.

In Medina County, fresh water in the Carrizo Aquifer extends from the outcrop areas to more than 60 miles downdip. In contrast, in Bastrop County, fresh water only extends downdip about

28 miles from the outcrop in the northern part of the project area. Most likely, this is a function of the thicker interconnected Carrizo–upper Wilcox sands in the southern part of the project area and normal faults in other parts of the project area.

Water wells in the Wilcox Aquifer are generally completed in the outcrop areas, although some brackish wells may be present as far downdip as 30 miles from the outcrops.

Fresh water in the Wilcox Aquifer is generally limited to outcrop areas and areas immediately downdip of them. In the northern part of the project area, thick interconnected sands within the Simsboro Formation of the Wilcox Group contain fresh water that becomes increasingly more saline downdip from the outcrop. Groundwater quality in the Wilcox Group is generally more saline in the project area and increases in salinity to very saline or brine in the deeper, downdip extent of the project area.

Hydrogeologic barriers

Hydrogeologic barriers in the project area include normal faults that are roughly parallel to the orientation of the outcrop. These faults were formed by two major processes: (1) extension associated with underlying salt movement and (2) growth faults associated with extensive sediment loading above unconsolidated marine sediments. Normal faults offset sand strata either entirely or partially. We did not consider faulting as a hydrogeologic barrier in the designation of brackish groundwater production zone CzWx1.

Shale layers act as low-permeability hydrogeologic barriers and may be regional or sub-regional in extent. The middle Wilcox Formation (and equivalent Calvert Bluff Formation) is regional, separating the lower Wilcox from the overlying Carrizo–upper Wilcox strata over much of the project area. For example, approximately 140 feet of shale (composed of individual, thinner layers interbedded with layers of sand) in the middle Wilcox Formation constitutes a hydrogeologic barrier between the brackish groundwater production zone (CzWx1) in the lower Wilcox and the overlying Carrizo aquifers.

The contractor identified layers of sand and shale on geophysical well logs and used this information for groundwater volume calculations and analysis of groundwater flow barriers.

Groundwater monitoring

House Bill 30 requires the TWDB to recommend reasonable monitoring to observe the effects of brackish groundwater production within a zone. The need for groundwater monitoring should be evaluated on a case-by-case basis considering the purpose of the monitoring, well field location, source aquifer, spatial relationships of salinity zones, and the expected volume of groundwater withdrawal. For example, monitoring may not be required if only one or two wells are planned for development. Monitoring may include observing water levels in (1) overlying and underlying aquifers, (2) confining layers, and (3) locations lateral, updip, and downdip in the same aquifer consistent with the purpose of the monitoring. Monitoring could also focus on water quality (for example, salinity changes) and quantity (for example, water level changes). Monitoring may include the use of existing well control or installation of new monitor wells.

Groundwater monitoring should focus on (1) the overlying Carrizo Aquifer that contains fresh water, (2) sand within the middle Wilcox confining layer, and (3) the lower Wilcox and Carrizo aquifers in the updip areas. Monitoring middle Wilcox sands may help determine the potential source of Carrizo Aquifer impact due to development in the Carrizo Aquifer or the brackish lower Wilcox. Monitoring is not required below the lower Wilcox because there are no known fresh or brackish aquifers in those geological formations in the region.

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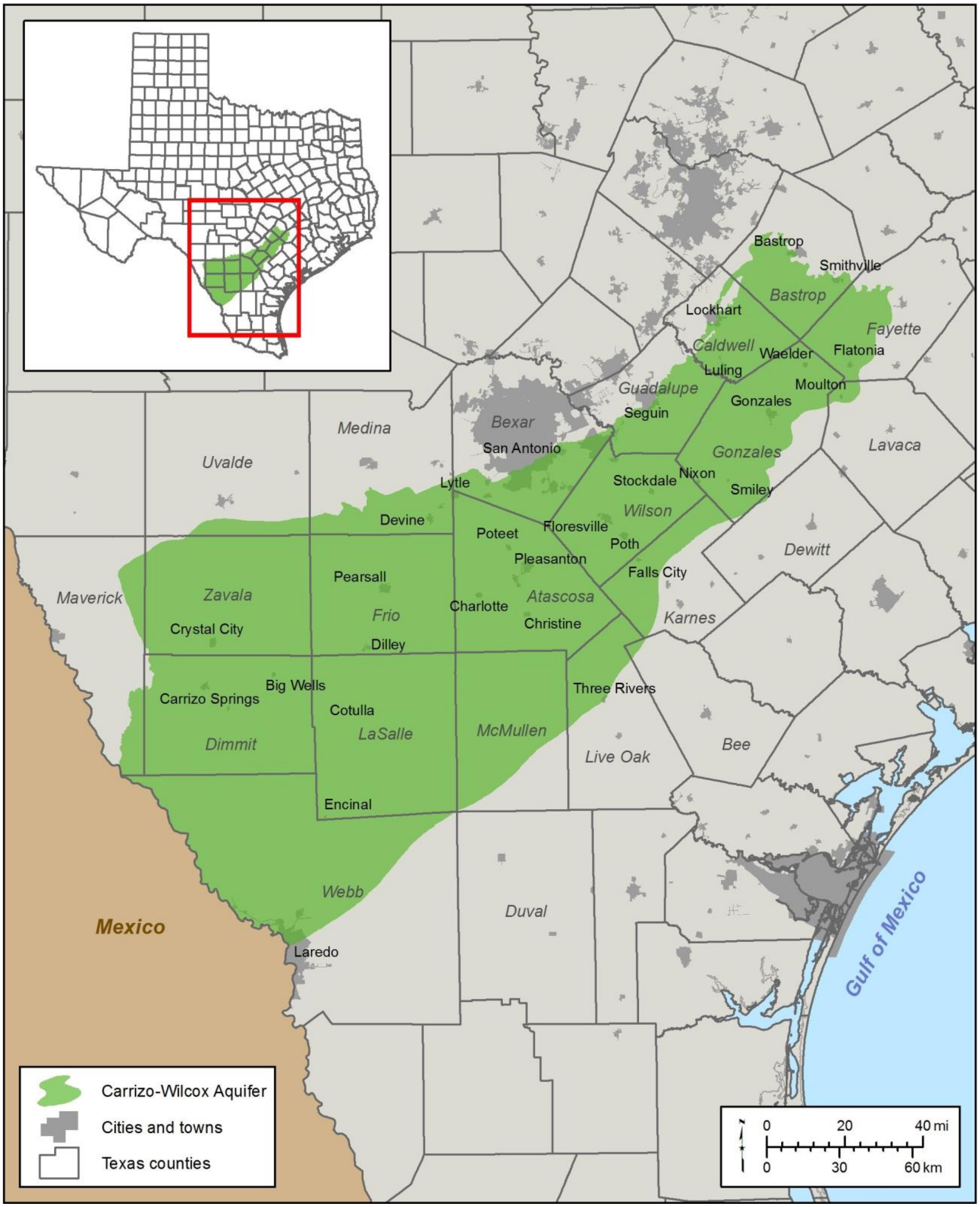

Figure A-1. **The extent of the Carrizo-Wilcox Aquifer project area. The northeastern extent of the Carrizo-Wilcox Aquifer is not shown.**

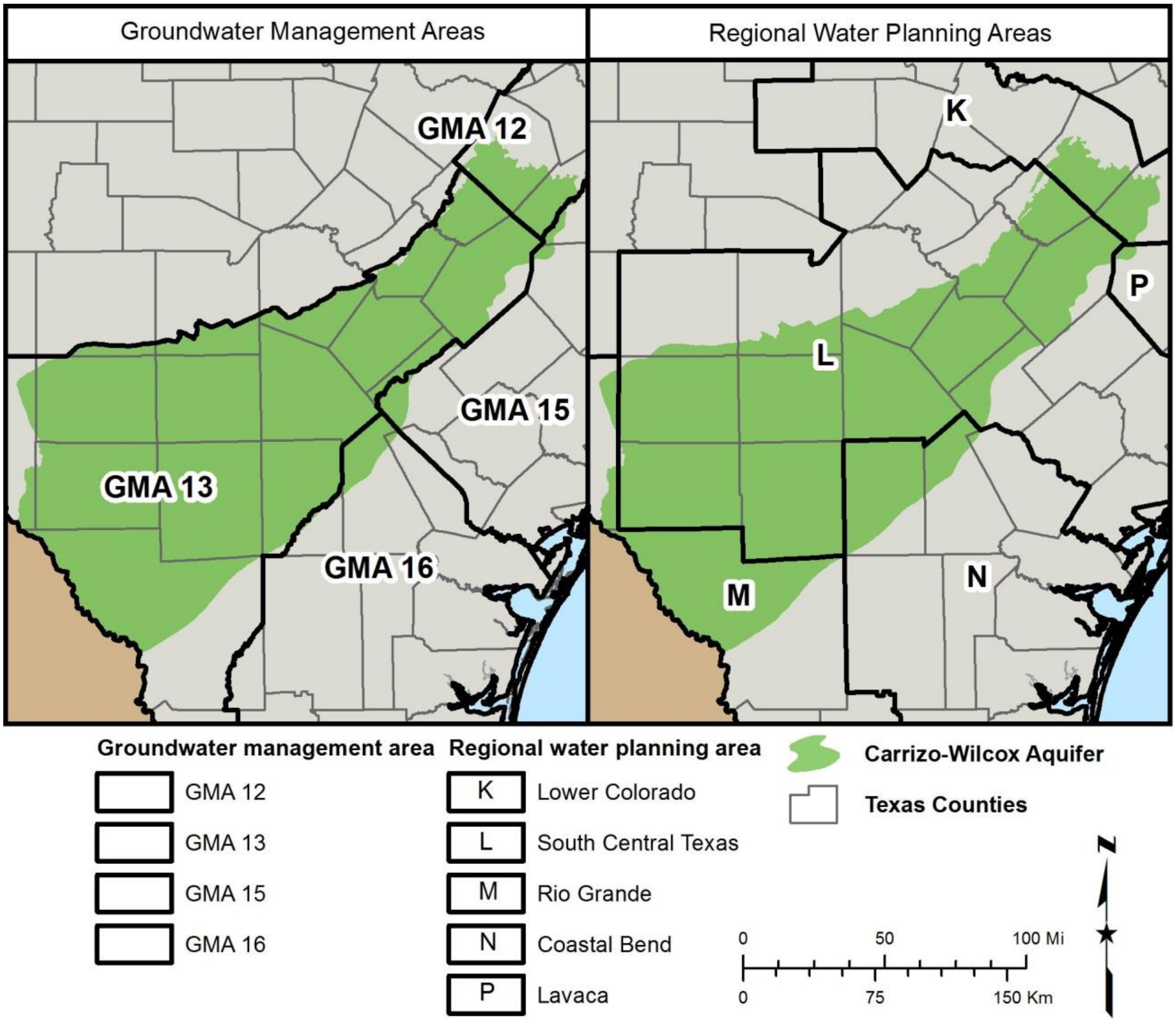

Figure A-2. **Regional water planning areas and groundwater management areas in the Carrizo-Wilcox Aquifer project area.**

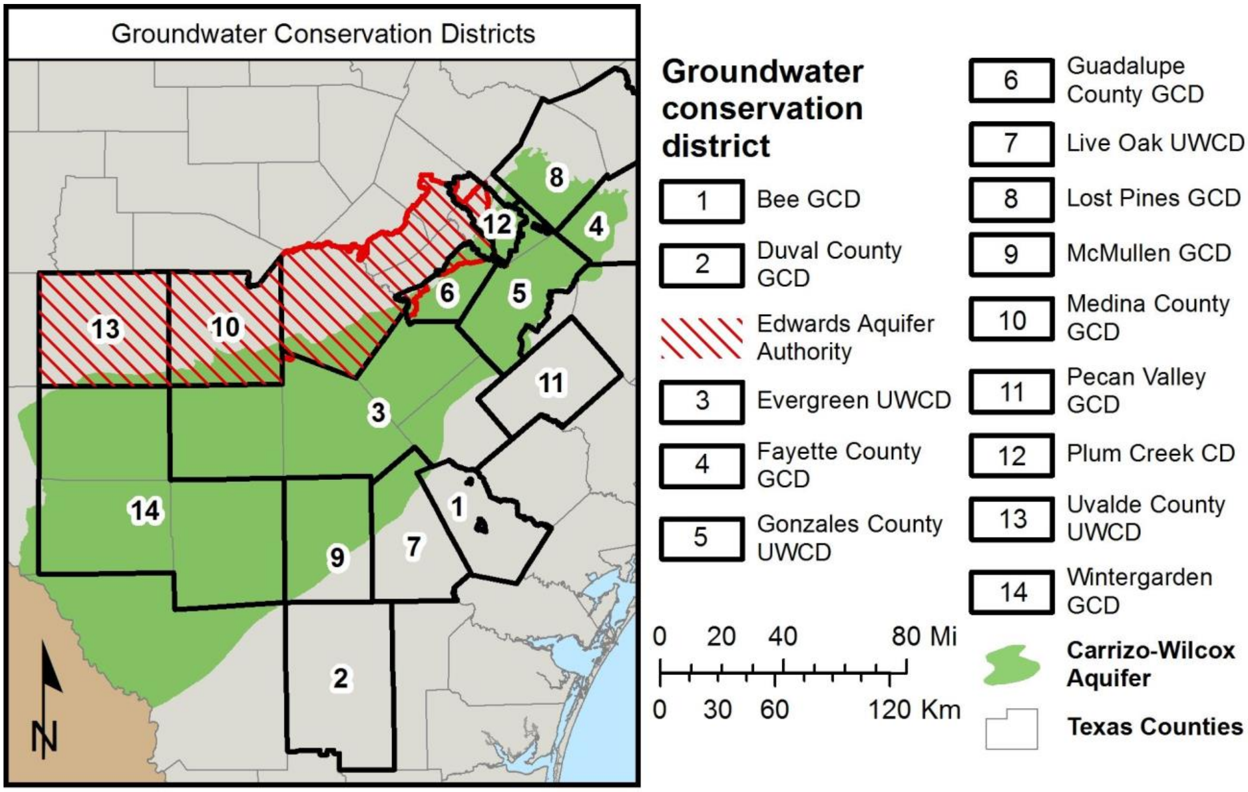

Figure A-3. **Groundwater conservation districts within the Carrizo-Wilcox project area. Acronyms used: CD = Conservation District; GCD = Groundwater Conservation District; UWCD = Underground Water Conservation District.**

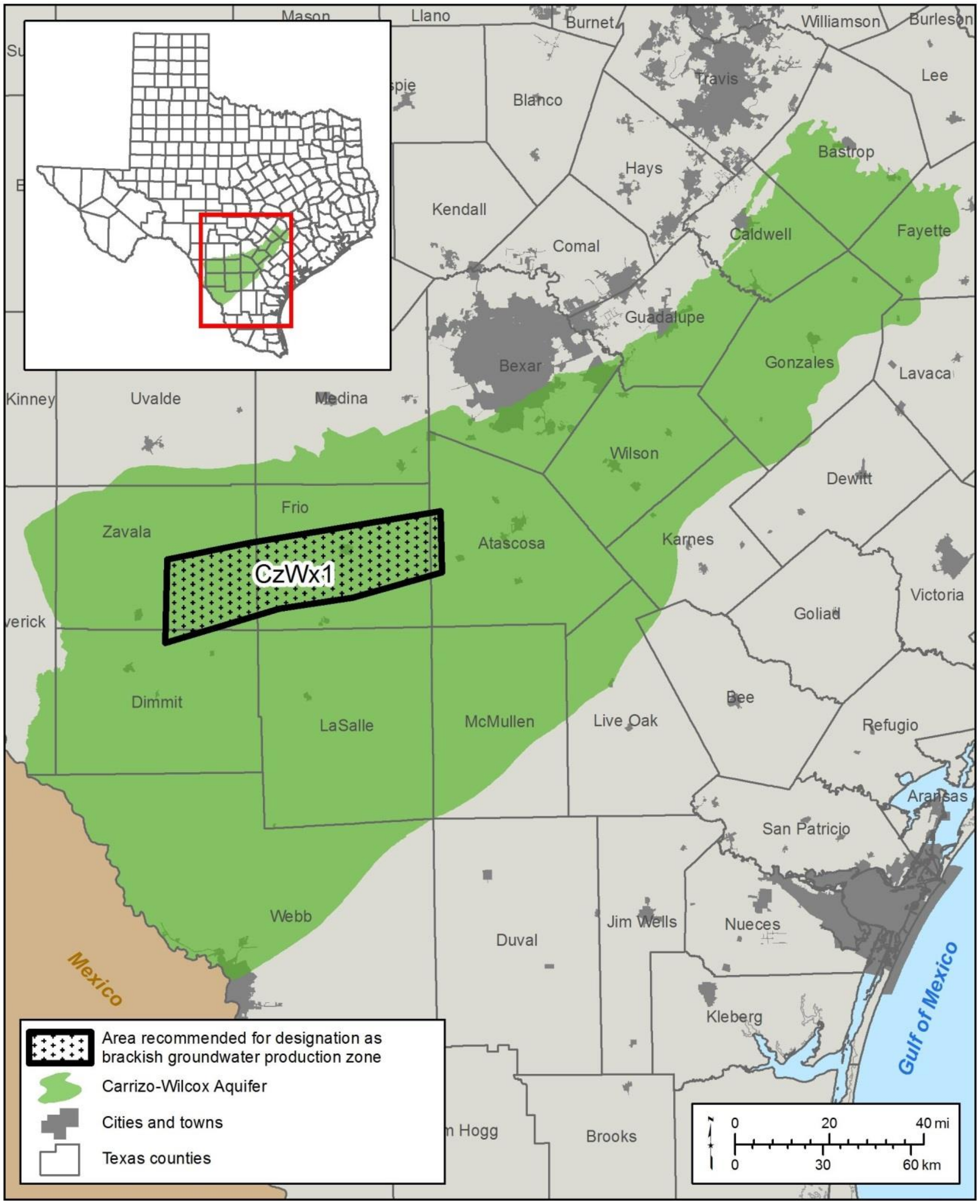

Figure A-4. **Carrizo-Wilcox Aquifer located between the Colorado River and the Rio Grande. The TWDB designated one brackish groundwater production zone (CzWx1) within the lower Wilcox Formation. The zone contains slightly saline (1,000 to 2,999 milligrams per liter of total dissolved solids) to moderately saline (3,000 to 9,999 milligrams per liter of total dissolved solids) groundwater.**

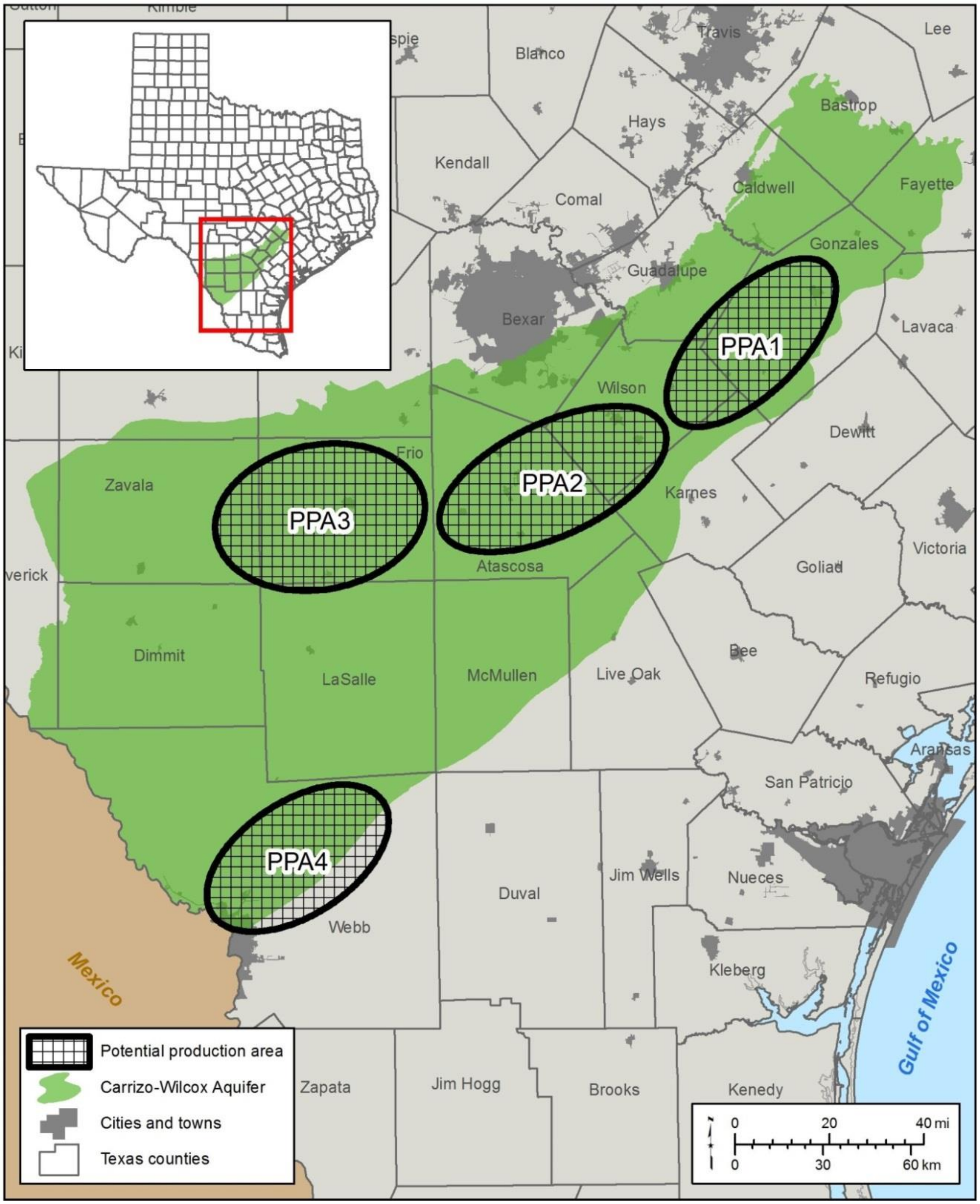

Figure A-5. Potential production areas in the Carrizo-Wilcox Aquifer project area.

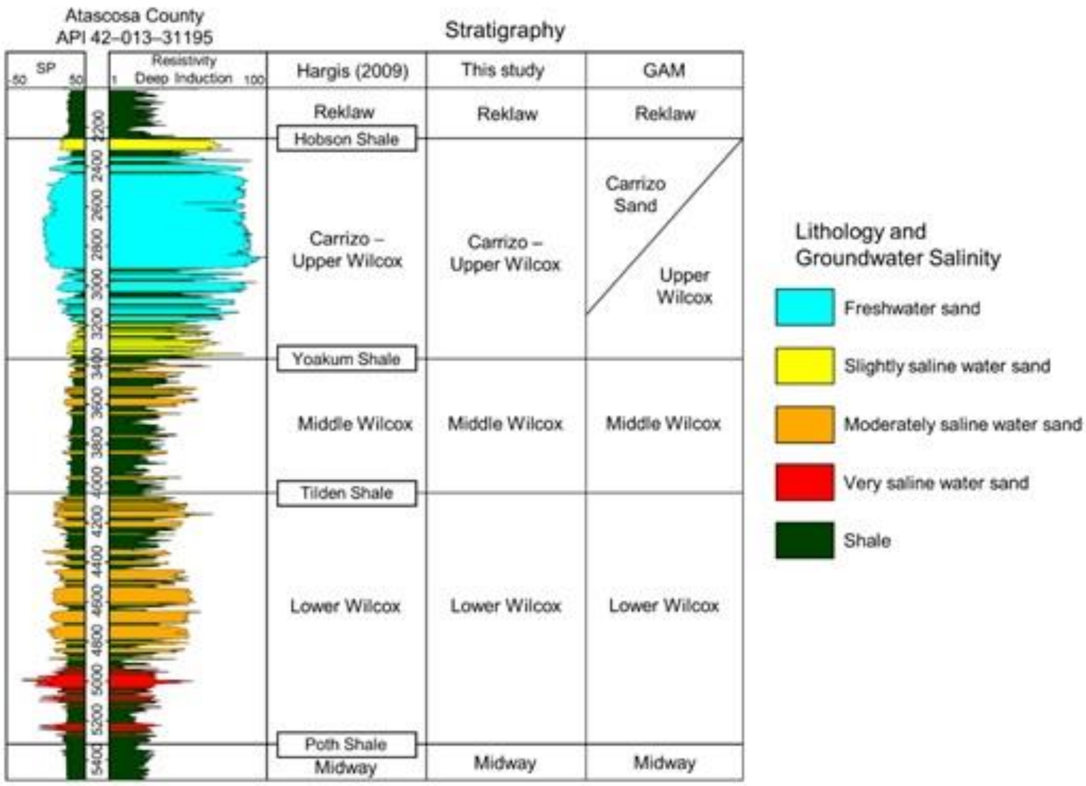

Figure A-6. **Stratigraphic subdivision of the Carrizo-Wilcox Aquifer in the project area. The aquifer includes the Carrizo-upper Wilcox, middle Wilcox, and lower Wilcox geological formations. The resistivity and spontaneous potential tools on the geophysical well log have been divided into sand and shale layers. The sand layers were interpreted and are colored based on salinity (total dissolved solids) using the U.S. Geological Survey salinity classification (Winslow and Kister, 1956). Figure from Hamlin and others (2016, Figure 4-2).**

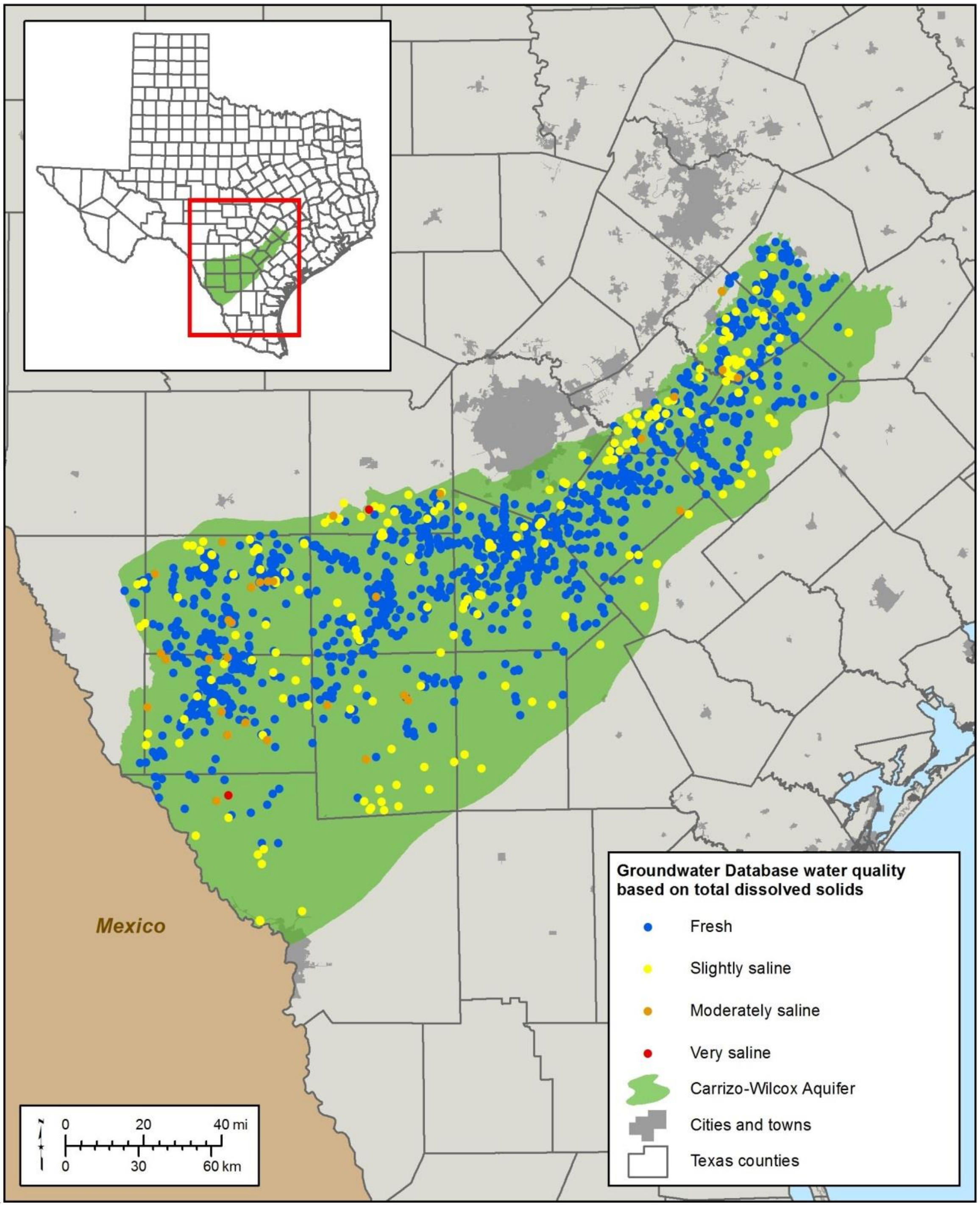

Figure A-7. Carrizo-Wilcox Aquifer total dissolved solids concentration based on the most recent samples in the TWDB Groundwater Database. Salinity classes are defined as fresh (0 to 999 milligrams per liter total dissolved solids), slightly saline (1,000 to 2,999 milligrams per liter total dissolved solids), moderately saline (3,000 to 9,999 milligrams per liter total dissolved solids), and very saline (10,000 to 35,000 milligrams per liter total dissolved solids).

Appendix B: Gulf Coast Aquifer project

Appendix B: Gulf Coast Aquifer System project

Project summary

The goal of this project was to map the fresh and saline groundwater resources of the Gulf Coast Aquifer System, meet the requirements of House Bill 30 brackish groundwater production zone designation, and support the TWDB's brackish aquifer mapping effort.

The project produced an interpretation of:

1. the top and bottom of the Beaumont, Lissie, Willis, Upper Goliad, Lower Goliad, Upper Lagarto, Middle Lagarto, Lower Lagarto, Oakville, and Catahoula geological formations;
2. the top and bottom of sand and clay layers within the geological formations;
3. water quality from existing water quality analyses and geophysical well logs to define the four salinity classes of fresh (0 to 1,000 milligrams per liter of total dissolved solids), slightly saline (>1,000 to 3,000 milligrams per liter of total dissolved solids), moderately saline (>3,000 to 10,000 milligrams per liter of total dissolved solids), and very saline (>10,000 to 35,000 milligrams per liter of total dissolved solids);
4. the top and bottom salinity zone surfaces in three dimensions;
5. groundwater volume in the four salinity classes;
6. potential hydrogeologic barriers;
7. potential production areas;
8. simple groundwater modeling of potential production areas with a limited range of pumping over a 30- and 50-year time frame;
9. drawdown estimates indicating potential impact to the same and adjacent aquifers; and
10. exclusion criteria listed in House Bill 30.

The TWDB designated four brackish groundwater production zones within the project area (zones GCUL1, GCML1, GCLL1, and GCLL2). The zones are located in the Upper Lagarto (GCUL1), Middle Lagarto (GCML1), and Lower Lagarto (GCLL1 and GCLL2) geological formations and contain groundwater that is slightly to moderately saline (1,000 to 9,999 milligrams per liter of total dissolved solids). The overlying geological formations contain clay and clay with interbedded sands that can act as a hydrogeologic barrier between the designated zones and the overlying aquifers. Site-specific variability in the configuration of sands and clays is evident.

The volume of brackish groundwater that could be produced over 50 years from brackish groundwater production zone GCUL1 is approximately 1.785 million acre-feet, GCML1 is approximately 0.104 million acre-feet, GCLL1 is approximately 0.250 million acre-feet, and GCLL2 is approximately 0.146 million acre-feet.

The top of the brackish groundwater production zone GCUL1 is 1,308 feet to more than 2,100 feet below ground surface, and the bottom is 1,927 feet to more than 2,700 feet below ground surface. Thickness of the brackish groundwater production zone GCUL1 ranges from 573 feet to 718 feet. Hydrogeologic barriers associated with this zone include approximately 60 to 120 feet of clay interbedded with sands that are present across the transition between the Lower Goliad and the Upper Lagarto formations. There are no wells completed in the Lower Goliad Formation in this zone. Non-contiguous clays interbedded with sands within this zone range from 150 to 270 feet in the Lower Goliad Formation.

The top of the brackish groundwater production zone GCML1 is 449 feet to more than 3,100 feet below ground surface, and the bottom is 666 feet to more than 3,800 feet below ground surface. Thickness of the brackish groundwater production zone GCML1 ranges from 178 feet to 756 feet. Hydrogeologic barriers associated with this zone include approximately 25 to 80 feet of contiguous clay and 35 to 175 feet of non-contiguous clay interbedded with sands that are present across the transition between the Upper Lagarto and the Middle Lagarto formations. We evaluated clays to approximately 100 feet above the top of the Middle Lagarto Formation because this was the maximum depth of water wells in the Upper Lagarto Formation within this zone.

The top of the brackish groundwater production zone GCLL1 is 509 feet to more than 1,700 feet below ground surface, while the bottom is 881 feet to more than 2,200 feet below ground surface. Thickness of the brackish groundwater production zone GCLL1 ranges from 311 feet to 590 feet. Hydrogeologic barriers associated with this zone include approximately 20 to 105 feet of contiguous clay and 45 to 160 feet of non-contiguous clay interbedded with sands that are present across the transition between the Middle Lagarto and the Lower Lagarto formations. We evaluated clays to approximately 100 feet above the top of the Middle Lagarto Formation even though the maximum depth of water wells was 24 to 142 feet above the top of the Middle Lagarto Formation within this zone.

The top of the brackish groundwater production zone GCLL2 is 883 feet to more than 1,900 feet below ground surface, while the bottom is 1,289 feet to more than 2,600 feet below ground surface. Thickness of the brackish groundwater production zone GCLL2 ranges from 406 to 628 feet. Hydrogeologic barriers associated with this zone include approximately 25 to 40 feet of contiguous clay and 40 to 100 feet of non-contiguous clay interbedded with sands and are present across the transition between the Middle Lagarto and the Lower Lagarto formations. We evaluated clays to approximately 180 feet above the bottom of the Middle Lagarto

Formation because this was the maximum depth of water wells in the Middle Lagarto Formation within this zone.

In the Gulf Coast Aquifer System, groundwater monitoring should focus on the lateral and updip portions of the brackish aquifer, on the underlying aquifer, and on the overlying aquifer containing fresh and brackish water. Monitoring in permeable sand units associated with clay confining units is recommended to determine the potential source of adjacent aquifer impact due to development in (1) the adjacent aquifers or (2) the brackish zone aquifer.

The designated zones do not contain known water wells (domestic, municipal, or agricultural that are using fresh or brackish groundwater) or injection wells (Class I, II, III, IV, or V injection wells; Texas Water Code, Chapter 27, Injection Wells) that meet the exclusion criteria in House Bill 30.

Project history and previous investigations

In 2015, the 84th Texas Legislature passed House Bill 30 directing the TWDB to conduct studies to identify and designate brackish groundwater production zones in four aquifers by December 1, 2016. One of these was the Gulf Coast Aquifer and sediments bordering that aquifer (Catahoula Formation) that extends from the Texas-Louisiana border to the southern county lines of Brooks, Jim Hogg, and Kenedy counties and from the outcrop areas of these aquifers to the Gulf of Mexico. The study we contracted was a regional scoping effort conducted to meet the requirements of House Bill 30 to provide information on the extent and volume of brackish groundwater within the Gulf Coast Aquifer System and the identification of potential production areas that could be considered for designation as brackish groundwater production zones by the TWDB. We did not recommended areas in the Lower Rio Grande Valley (Cameron, Hidalgo, Starr, and Willacy counties) as brackish groundwater production zones because results from a recent TWDB study (Meyer and others, 2014) indicated that the region contains areas of mixed fresh and slightly saline groundwater. The region also has a substantial number of brackish groundwater wells and Class II injection wells.

The Gulf Coast Aquifer project builds upon decades of existing groundwater studies conducted by private industries, and local, state, and federal agencies. Significant studies include the TWDB groundwater availability modeling projects (for example, Chowdhury and Mace, 2003; Chowdhury and others, 2004; and Hutchison and others, 2011), INTERA related projects (for example, Young and Kelley, 2006; Knox and others, 2007; Young and others, 2009; Young and others, 2010; Young and others, 2012; Young and Lupton, 2014; and Young and others, 2014), and the TWDB brackish aquifer reports (Kalaswad and Arroyo, 2006; Meyer, 2012; Meyer and others, 2014; and Meyer, 2014). Thousands of well records used in these projects have been compiled into the TWDB Groundwater Database (TWDB, 2016a) and the TWDB BRACS Database (TWDB, 2016b).

Project approach

We conducted a general stakeholder meeting in October 2015 to kick off the implementation of House Bill 30 and solicit comments. Once we approved the contract, the contractor (1) collected well data, (2) evaluated the geology and groundwater of the Gulf Coast Aquifer System, (3) prepared database and GIS files, and (4) identified potential production areas. We conducted a stakeholder meeting to solicit comments on the potential production areas and worked with the contractor to develop a list of potential production areas that would undergo groundwater modeling. The contractor (1) performed the groundwater modeling, (2) prepared a draft report, and (3) submitted the draft report and data to us. We reviewed the draft report and data and provided technical comments to the contractor for consideration in the final draft report and datasets. We conducted a stakeholder meeting in September 2016 to address all four aquifer projects and to solicit comments on the final reports. We evaluated the report, data, and stakeholder comments and made a recommendation to the Board for the designation of four brackish groundwater production zones.

Contract information

TWDB contract number: 1600011947

Cost: $500,000

Contractor:

- INTERA, Inc. (Principal)
- Jack Sharp, Ph.D., P.G., The University of Texas at Austin
- Justin Sutherland, Ph.D., P.E., Carollo Engineers
- Thomas Ewing, Ph.D., P.G., Frontera Exploration Consultants
- The University of Texas at Austin, Bureau of Economic Geology
- DrillingInfo
- Subsurface Library

Project duration: approximately 8 months

- Project approved by Board: January 6, 2016
- Contract signed: March 22, 2016
- Final report delivered: August 31, 2016

Public entities

Counties

The Gulf Coast Aquifer System is present in all or part of Angelina, Aransas, Atascosa, Austin, Bee, Brazoria, Brazos, Brooks, Calhoun, Cameron, Chambers, Colorado, Dewitt, Duval, Fayette, Fort Bend, Galveston, Goliad, Gonzales, Grimes, Hardin, Harris, Hidalgo, Jackson, Jasper, Jefferson, Jim Hogg, Jim Wells, Karnes, Kenedy, Kleberg, Lavaca, Liberty, Live Oak, Matagorda, McMullen, Montgomery, Newton, Nueces, Orange, Polk, Refugio, Sabine, San Jacinto, San Patricio, Starr, Trinity, Tyler, Victoria, Walker, Waller, Washington, Webb, Wharton, Willacy, and Zapata counties (Figure B-1).

Cities and towns

The Gulf Coast Aquifer System underlies all or part of the cities and towns of Alamo, Alice, Alton, Alvin, Angleton, Bay City, Baytown, Beaumont, Beeville, Bellaire, Brenham, Brownsville, Clute, Conroe, Corpus Christi, Deer Park, Donna, Dickinson, Edinburg, EL Campo, Freeport, Friendswood, Galena Park, Galveston, Groves, Harlingen, Hidalgo, Houston, Humble, Huntsville, Jacinto City, Katy, Kingsville, La Marque, La Porte, Lake Jackson, League City, Lumberton, McAllen, Mercedes, Mission, Missouri City, Nederland, Orange, Pasadena, Pearland, Pharr, Port Arthur, Port Lavaca, Port Neches, Raymondville, Richmond, Rio Grande City, Robstown, Rosenberg, San Benito, Santa Fe, San Juan, Seabrook, South Houston, Stafford, Sugar Land, Texas City, Tomball, Victoria, Vidor, Webster, Weslaco, and West University Place (using data from the Texas Department of Transportation [2015] with population greater than 10,000).

Groundwater management areas

The Gulf Coast Aquifer System is present in all or part of groundwater management areas 11, 12, 13, 14, 15, and 16 (Figure B-2):
http://www.twdb.texas.gov/groundwater/management_areas/index.asp

Regional water planning areas

The Gulf Coast Aquifer System is present in all or part of regional water planning areas G, H, I, K, L, M, N, and P (Figure B-2): https://www.twdb.texas.gov/waterplanning/rwp/

Groundwater conservation districts

The Gulf Coast Aquifer System is present in all or part of Aransas County Groundwater Conservation District, Bee Groundwater Conservation District, Bluebonnet Groundwater Conservation District, Brazoria County Groundwater Conservation District, Brazos Valley Groundwater Conservation District, Brush Country Groundwater Conservation District, Calhoun County Groundwater Conservation District, Coastal Bend Groundwater Conservation District, Coastal Plains Groundwater Conservation District, Colorado County Groundwater Conservation District, Corpus Christi Aquifer Storage and Recovery Conservation District, Duval County

Groundwater Conservation District, Evergreen Underground Water Conservation District, Fayette County Groundwater Conservation District, Goliad County Groundwater Conservation District, Gonzales County Underground Water Conservation District, Kenedy County Groundwater Conservation District, Live Oak Underground Water Conservation District, Lone Star Groundwater Conservation District, Lower Trinity Groundwater Conservation District, McMullen Groundwater Conservation District, Pecan Valley Groundwater Conservation District, Pineywoods Groundwater Conservation District, Red Sands Groundwater Conservation District, Refugio Groundwater Conservation District, San Patricio Groundwater Conservation District, Southeast Texas Groundwater Conservation District, Starr County Groundwater Conservation District, Texana Groundwater Conservation District, and Victoria Groundwater Conservation District. The Gulf Coast Aquifer System also includes the Harris-Galveston Coastal Subsidence District and the Fort Bend Subsidence District, although brackish groundwater production zone designation is precluded in these districts due to House Bill 30 (Figure B-3).

Methodology

The contractor used geophysical well logs and data in published reports (for example, Young and others, 2012) to map the top and bottom of each geological formation in the Gulf Coast Aquifer System (Figure B-4) and the top and bottom of sand and clay layers within these geological formations. The contractor used this data to develop three-dimensional surfaces for each geological formation and sand data to develop net sand and sand percent maps for each formation. The contractor used only sand layers and clay layers as the lithologic profiles from the geophysical well logs and driller logs (Young and others, 2016).

To develop a relationship between the concentration of total dissolved solids in aquifer water and resistivity obtained from geophysical well logs, the contractor used existing chemical analysis of water quality samples from water wells. The contractor used this relationship to create a reconnaissance level method for log interpretation that allowed the use of geophysical well logs to interpret salinity of sands within the geological formations. Based on the classification of groundwater quality by Winslow and Kister (1956), the contractor classified groundwater in the Gulf Coast Aquifer System into four salinity classes (fresh [0 to 999 milligrams per liter total dissolved solids]; slightly saline [1,000 to 2,999 milligrams per liter total dissolved solids]; moderately saline [3,000 to 9,999 milligrams per liter total dissolved solids]; and very saline [10,000 to 35,000 milligrams per liter total dissolved solids]). The contractor developed numerous figures showing Gulf Coast Aquifer System net sand maps, salinity zones, and stratigraphic and structural cross-sections.

We (1) reviewed the contractor's report and data and (2) evaluated House Bill 30 exclusion criteria in each potential production area. TWDB-designated brackish groundwater production zones GCUL1 in the same region as PPA UL-6, GCML1 in the same region as PPA ML-6, GCLL1 in the same region as PPA LL-2, and GCLL2 in the same region as PPA LL-3 (Figure B-5).

The contractor identified 20 potential production areas (PPAs) containing brackish groundwater for groundwater modeling. PPAs CAT-1, CAT-2, and CAT-3 are located within the Catahoula Formation; PPAs OK-1, OK-2, and OK-3 within the Oakville Formation; PPAs LL-1, LL-2, and LL-3 within the Lower Lagarto Formation; potential production areas ML-4, and ML-6 within the Middle Lagarto Formation; PPAs UL-4, UL-5, and UL-6 within the Upper Lagarto; PPAs LG-4, LG-5, and LG-6 within the Lower Goliad Formation; and PPAs UG-4, UG-5, and UG-6 within the Upper Goliad Formation (Figures B-6, B-7, B-8, B-9, B-10, B-11, and B-12). The contractor developed a simple groundwater model for each PPA with a hypothetical updip and downdip well field. The contractor modeled three different pumping rates (3,000, 10,000, and 20,000 acre-feet) using two different sets of model input data (Young and others, 2016). The contractor used the results of the modeling to evaluate potential impact in the (1) overlying aquifers and (2) updip areas within the aquifer containing the brackish groundwater zone.

The top of the brackish groundwater production zone GCUL1 is 1,308 feet to more than 2,100 feet below ground surface, while the bottom is 1,927 feet to more than 2,700 feet below ground surface. Thickness of the brackish groundwater production zone GCUL1 ranges from 573 feet to 718 feet.

The top of the brackish groundwater production zone GCML1 is 449 feet to more than 3,100 feet below ground surface, while the bottom is 666 feet to more than 3,800 feet below ground surface. Thickness of the brackish groundwater production zone GCML1 ranges from 178 feet to 756 feet.

The top of the brackish groundwater production zone GCLL1 is 509 feet to more than 1,700 feet below ground surface, while the bottom is 881 feet to more than 2,200 feet below ground surface. Thickness of the brackish groundwater production zone GCLL1 ranges from 311 feet to 590 feet.

The top of the brackish groundwater production zone GCLL2 is 883 feet to more than 1,900 feet below ground surface, while the bottom is 1,289 feet to more than 2,600 feet below ground surface. Thickness of the brackish groundwater production zone GCLL2 ranges from 406 to 628 feet.

We estimated the volume of brackish groundwater that could be produced over 50 years from brackish groundwater production zones as follows: GCUL1 is approximately 1.785 million acre-feet, GCML1 is approximately 0.104 million acre-feet, GCLL1 is approximately 0.250 million acre-feet and GCLL2 is approximately 0.146 million acre-feet (Table B-1).

Table B-1. Volumes of brackish groundwater in the production zones.

Aquifer	Zone name	Annual pumping (acre-feet per year)	Brackish groundwater volumes (million acre-feet per year)	
			30-year cumulative volume	50-year cumulative volume
Upper Lagarto	GCUL1	35,700	1.071	1.785
Middle Lagarto	GCML1	2,079	0.062	0.104
Lower Lagarto	GCLL1	4,992	0.150	0.250
Lower Lagarto	GCLL2	2,929	0.088	0.146

Hydrogeology

The Gulf Coast Aquifer is one of the nine major aquifers in Texas. It parallels the coastline of the Gulf of Mexico and extends from the Louisiana-Texas border to the United States of America-Mexico border. The TWDB boundary of the Gulf Coast Aquifer includes outcrop and downdip areas containing groundwater with a total dissolved solids concentration of less than 3,000 milligrams per liter (TWDB, 2007). The geological formations that make up the Gulf Coast Aquifer System extend farther downdip than the TWDB boundary and include increasingly saline water.

Domestic, municipal, irrigation, industrial, livestock, and oil and gas production are the primary uses of groundwater from the Gulf Coast Aquifer System. As of February 2016, there were 12 brackish groundwater desalination plants using water from the Gulf Coast Aquifer System. The largest concentration of groundwater desalination plants is in the Lower Rio Grande Valley with seven existing plants and more planned for the future.

Lithology and stratigraphy

The Gulf Coast Aquifer System consists of a number of aquifers, including the Chicot, Evangeline, and Jasper aquifers, separated by the Burkeville confining unit (Figure B-4). The Gulf Coast Aquifer System predominantly consists of discontinuous clay, silt, sand, and gravel beds. The Chicot Aquifer includes, from shallowest to deepest, the Beaumont and Lissie formations of Pleistocene age and the Willis Formation of Pliocene age. The Evangeline Aquifer includes the Upper Goliad Formation of early Pliocene and late Miocene age, the Lower Goliad Formation of late Miocene age, and the Upper Lagarto Formation of late and middle Miocene age. The Jasper Aquifer includes the Lower Lagarto and Oakville formations of early Miocene age and the Catahoula Formation of Oligocene age. The maximum total sand thickness for freshwater in the Gulf Coast Aquifer System ranges from 700 feet in the south to 1,300 feet in the north (George and others, 2011). The maximum total thickness for slightly saline groundwater in the Gulf Coast Aquifer ranges from 500 to 2,000 feet. The maximum total thickness for moderately saline groundwater in the Gulf Coast Aquifer ranges from 500 to 2,500 feet. The maximum total thickness for very saline groundwater in the Gulf Coast Aquifer ranges from 500 to 4,000 feet (Young and others, 2016).

The Yegua-Jackson Aquifer (a TWDB-designated minor aquifer) underlies the Catahoula Formation. Quaternary and recent sediments overlying the Gulf Coast Aquifer System include beach-ridge and barrier-flat sand, fluviatile terrace, windblown, fill and spoil, and alluvium (no TWDB-designated aquifers overlie the Gulf Coast Aquifer System). Pumping tests and monitoring wells are necessary to better define where pumping from the Gulf Coast Aquifer may impact these adjacent aquifers. Young and others (2010) provide additional details on the methodology for building the hydrogeologic framework.

Water quantity

We calculated the volume of brackish groundwater that each of the brackish groundwater production zones are capable of producing over a 30- and 50-year period based on simple desktop groundwater modeling of a hypothetical well field. The contractor modeled a pumping rate of 10,000 acre-feet of groundwater over 50 years in 15 well fields across five cross-sections in the Gulf Coast Aquifer System (Young and others, 2016).

Brackish groundwater production zone GCLL1 is located 12 to 38 miles southwest of Well Field 2c. The contractor indicated approximately 228 feet of water level decline after 50 years of production in the Lower Lagarto Formation at the well field, with smaller declines farther away. The contractor estimated that after 50 years of production, water level decline in the overlying Middle Lagarto formation is 76 feet at the well field with smaller declines farther away from the well field. The contractor estimated that after 50 years of production, water level decline in the underlying Oakville Formation is 192 feet at the well field with smaller declines farther away from the well field. We estimated the volume of brackish groundwater that could be produced from this zone is 4,992 acre-feet per year over a 50-year time period (Table B-1). Production of this volume of groundwater annually equates to 0.150 million acre-feet per year over a 30-year time period and 0.250 million acre-feet over a 50-year time period (Table B-1). We based the volumetric estimates on water level declines of 228 feet and a mean confined storativity value of 0.00011 (Young and others, 2016). Our volume calculations assume all drawdown is limited to the extent of the boundaries of the zone.

Brackish groundwater production zone GCLL2 is located 82 to 97 miles south of Well Field 4a. The contractor indicated approximately 157 feet of water level decline after 50 years of production in the Lower Lagarto Formation at the well field, with smaller declines farther away. The contractor estimated that after 50 years of production, water level decline in the overlying Middle Lagarto formation is 91 feet at the well field with smaller declines farther away from the well field. The contractor estimated that after 50 years of production, water level decline in the underlying Oakville Formation is 149 feet at the well field with smaller declines farther away from the well field. We estimated the volume of brackish groundwater that could be produced from this zone is 2,929 acre-feet per year over a 50-year time frame (Table B-1). Production of this volume of groundwater annually equates to 0.088 million acre-feet per year over a 30-year time period and 0.146 million acre-feet over a 50-year time period (Table B-1). We based the volumetric estimates on water level declines of 157 feet and a mean confined storativity value of 0.00028 (Young and others, 2016). Our volume calculations assume all drawdown is limited to the extent of the boundaries of the zone.

Brackish groundwater production zone GCML1 is located 29 to 60 miles south of Well Field 5b. The contractor indicated approximately 34 feet of water level decline after 50 years of production in the Middle Lagarto Formation at the well field, with smaller declines farther away. The contractor estimated that after 50 years of production, water level decline in the overlying Upper Lagarto Formation is 21 feet at the well field with smaller declines farther away from the well field. The contractor estimated that after 50 years of production, water level decline in the underlying Lower Lagarto Formation is 27 feet at the well field with smaller declines farther away from the well field. We estimated the volume of brackish groundwater that could be produced from this zone is 2,079 acre-feet per year over a 50-year time period (Table B-1). Production of this volume of groundwater annually equates to 0.062 million acre-feet per year over a 30-year time period and 0.104 million acre-feet over a 50-year time period (Table B-1). We based the volumetric estimates on water-level declines of 34 feet and a mean confined storativity value of 0.00018 (Young and others, 2016). Our volume calculations assume all drawdown is limited to the extent of the boundaries of the zone.

Brackish groundwater production zone GCUL1 is located 60 to 78 miles south of Well Field 4b. The contractor indicated approximately 123 feet of water level decline after 50 years of production in the Upper Lagarto Formation at the well field, with smaller declines farther away. The contractor estimated that after 50 years of production, water level decline in the overlying Lower Goliad Formation is 73 feet at the well field with smaller declines farther away from the well field. The contractor estimated that after 50 years of production, water level decline in the underlying Middle Lagarto Formation is 49 feet at the well field with smaller declines farther away from the well field. We estimated the volume of brackish groundwater that could be produced in this zone is 35,700 acre-feet per year over a 50-year time period (Table B-1). Production of this volume of groundwater annually equates to 1.071 million acre-feet per year over a 30-year time period and 1.785 million acre-feet over a 50-year time period (Table B-1). We based the volumetric estimates on water level declines of 123 feet and a mean confined storativity value of 0.00316 (Young and others, 2016). Our volume calculations assume all drawdown is limited to the extent of the boundaries of the zone.

The contractor estimated the volume of drainable groundwater using the volume of sand layers within the Gulf Coast Aquifer System in groundwater management areas 11, 12, 13, 14, 15, and 16 (Table B-2). The estimate is based on draining the total thickness of the Gulf Coast Aquifer System using (1) total volume of the sand layers, (2) specific yield, and (3) the model layers (Young and others, 2016, Table 12-3). The contractor estimated the volume of drainable groundwater using the total thickness of the Gulf Coast Aquifer System in groundwater management areas 11, 12, 13, 14, 15, and 16 (Table B-3). The estimate is based on draining the total thickness of the Gulf Coast Aquifer System using (1) total volume of the aquifer layers, (2) specific yield, and (3) the model layers (Young and others, 2016, Table 12-3).

Table B-2. Volume of drainable groundwater within the Gulf Coast Aquifer System in groundwater management areas 11, 12, 13, 14, 15, and 16 using (1) total volume of the sand layers, (2) specific yield, and (3) the GAM model layers (Young and others, 2016, Table 12-3).

Formation	Volume of water (million acre-feet)					
	Fresh*	Slightly saline*	Moderately saline*	Very saline*	Brine*	Total
Beaumont	21.4	36.2	9.5	5.2	0.3	72.6
Lissie	76.0	44.9	18.1	11.4	0.7	151.1
Willis	97.8	69.3	21.7	26.7	3.1	218.6
Upper Goliad	13.3	13.0	7.5	19.9	6.4	60.1
Lower Goliad	11.6	9.2	7.0	17.3	6.0	51.1
Upper Lagarto	12.7	11.3	9.1	17.6	6.0	56.7
Middle Lagarto	3.8	7.2	7.3	19.0	8.4	45.7
Lower Lagarto	26.4	83.9	51.8	121.7	47.6	331.4
Oakville	44.3	75.1	79.7	254.8	76.2	530.1
Catahoula	20.9	104.7	157.1	118.5	8.0	409.2
Total	**328.2**	**454.8**	**368.8**	**612.1**	**162.7**	**1,926.6**

Notes:

Fresh = 0 to 999 milligrams per liter total dissolved solids

Slightly saline = 1,000 to 2,999 milligrams per liter total dissolved solids

Moderately saline = 3,000 to 9,999 milligrams per liter total dissolved solids

Very saline = 10,000 to 34,999 milligrams per liter total dissolved solids

Brine = >35,000 milligrams per liter total dissolved solids

Table B-3. Volume of drainable groundwater within the Gulf Coast Aquifer System in groundwater management areas 11, 12, 13, 14, 15, and 16 using (1) total volume of the aquifer layers, (2) specific yield, and (3) the GAM model layers (Young and others, 2016, Table 12-3).

	Volume of water (million acre-feet)					
Formation	**Fresh***	**Slightly saline***	**Moderately saline***	**Very saline***	**Brine***	**Total**
Beaumont	33.4	56.1	16.0	9.2	0.5	115.2
Lissie	110.8	74.7	31.4	23.2	1.2	241.3
Willis	153.8	121.6	43.4	52.0	5.9	376.7
Upper Goliad	25.1	26.3	16.4	42.8	13.8	124.4
Lower Goliad	26.8	20.9	18.0	44.0	14.4	124.1
Upper Lagarto	27.4	28.1	25.4	45.5	12.8	139.2
Middle Lagarto	8.0	19.3	21.9	49.2	17.3	115.7
Lower Lagarto	55.5	201.0	151.3	319.9	108.0	835.7
Oakville	84.3	166.3	206.6	596.9	172.6	1,226.7
Catahoula	52.5	287.0	497.4	410.1	26.2	1,273.2
Total	**577.6**	**1,001.3**	**1,027.8**	**1,592.8**	**372.7**	**4,572.2**

Notes:

Fresh = 0 to 999 milligrams per liter total dissolved solids
Slightly saline = 1,000 to 2,999 milligrams per liter total dissolved solids
Moderately saline = 3,000 to 9,999 milligrams per liter total dissolved solids
Very saline = 10,000 to 34,999 milligrams per liter total dissolved solids
Brine = >35,000 milligrams per liter total dissolved solids

Meyer and others (2014) estimated groundwater volumes for areas in the Gulf Coast Aquifer System in the Lower Rio Grande Valley (Cameron, Hidalgo, Starr, and Willacy counties). There is approximately 40 million acre-feet of slightly saline groundwater, 112 million acre-feet of moderately saline groundwater, and 123 million acre-feet of very saline groundwater in the Gulf Coast Aquifer System in the Lower Rio Grande Valley. Not all of the brackish groundwater can be produced economically or even be produced (Meyer and others, 2014).

Wade and others (2014a) estimated the volumes of drainable Gulf Coast Aquifer groundwater (total storage equals 1,447,000 acre-feet) by county using the Total Estimated Recoverable Storage method for Groundwater Management Area 11. Wade and Shi (2014) estimated the volume by county of drainable Gulf Coast Aquifer groundwater (total storage equals 450,000 acre-feet) using the Total Estimated Recoverable Storage method for Groundwater Management Area 12. Wade and Bradley (2013) estimated the volume by county of drainable Gulf Coast Aquifer groundwater (total storage equals 2,460,000 acre-feet) using the Total Estimated Recoverable Storage method for Groundwater Management Area 13. Wade and others (2014b) estimated the volume by county of drainable Gulf Coast Aquifer groundwater (total storage equals 2,776,000,000 acre-feet) using the Total Estimated Recoverable Storage method for Groundwater Management Area 14. Wade and Anaya (2014) estimated the volume by county of drainable Gulf Coast Aquifer groundwater (total storage equals 368,800,000 acre-feet) using the Total Estimated Recoverable Storage method for Groundwater Management Area 15. Jigmond and Wade (2013) estimated the volume by county of drainable Gulf Coast Aquifer groundwater (total storage equals 1,014,350,000 acre-feet) using the Total Estimated Recoverable Storage method for Groundwater Management Area 16.

LBG-Guyton Associates (2003) calculated the groundwater volume in their study of brackish groundwater in Texas. The estimated volume of slightly saline and moderately saline groundwater within the Gulf Coast Aquifer System in regional water planning areas G, H, I, K, L, M, N, and P is 522.5 million acre-feet. This volume is substantially smaller than that reported by the contractor (823.6 million acre-feet; Table B-2). The differences can likely be attributed to different values for specific yield, storativity, areal extent of saline zones, and estimated thickness of productive sands used by the contractor.

Young and others (2016) also included two other calculations of groundwater volume using porosity instead of specific yield. These values are not presented because it is not feasible or recommended to completely remove all of the groundwater.

Water quality

Water quality in the Gulf Coast Aquifer System varies with depth and location (Figure B-13). In general, water quality is better at shallow depths and degrades with increasing depth. Furthermore, water quality is predominantly good in the central and northeastern parts of the Gulf Coast Aquifer System and declines to the south, especially around the vicinity of Corpus Christi. In the Chicot Aquifer, water quality is generally fresh in the northern and central portions of the aquifer but gets poorer in the southern and coastal portions of the aquifer. Similarly, the Evangeline Aquifer, Jasper Aquifer, and the Catahoula formations generally have fresher water quality in the northern and central parts of the aquifer than in other areas. Also, radionuclides generally are present in higher concentrations in the southern portions of the Chicot, Evangeline, and Jasper aquifers than in other areas of the aquifer. The maximum total thickness of slightly saline groundwater in the Gulf Coast Aquifer ranges from 500 to 2,000 feet. The maximum total thickness of moderately saline groundwater in the Gulf Coast Aquifer ranges from 500 to 2,500 feet. The maximum total thickness for very saline groundwater in the Gulf Coast Aquifer ranges from 500 to 4,000 feet (Young and others, 2016).

Hydrogeologic barriers

Hydrogeologic barriers can impede the flow of groundwater. In the Gulf Coast Aquifer System, hydrogeologic barriers include normal faults that are oriented roughly parallel to the outcrops. These faults were formed from two major processes: 1) extension associated with underlying salt movement, and 2) growth faults associated with extensive sediment loading above unconsolidated marine sediments. Normal faults offset sand strata either entirely or partially. Research on, interpretation of, and modeling for the Gulf Coast Aquifer System indicate that none of the major faults that are present in the Gulf Coast Aquifer System will significantly impact groundwater flow (Young and others, 2016). Consequently, faulting was not considered as a hydrogeologic barrier in the designation of brackish ground water production zones GCLL1, GCLL2, GCML1, and GCUL1.

Clay layers act as low-permeability hydrogeologic barriers and may be regional or sub-regional in extent. The Middle Lagarto Formation (and equivalent Burkeville Confining Unit) is regional across the Gulf Coast Aquifer System. Though previous studies have indicated this is a regional aquitard, the results from Young and others (2016) indicate that this formation contains more sand than previously thought.

Hydrogeologic barriers associated with brackish groundwater production zone GCUL1 include approximately 60 to 120 feet of clay interbedded with sands that are present across the transition between the Lower Goliad and the Upper Lagarto formations. The 60 to 120 feet of clay interbedded with sands may constitute a hydrogeologic barrier between this zone and the overlying sands of the Lower Goliad Formation. There are no wells completed in the Lower Goliad Formation in this zone. Non-contiguous clays interbedded with sands range from 150 to 270 feet in the Lower Goliad Formation within this zone.

Hydrogeologic barriers associated with brackish groundwater production zone GCML1 include approximately 25 to 80 feet of contiguous clay and 35 to 175 feet of non-contiguous clay interbedded with sands and are present across the transition between the Upper Lagarto and the Middle Lagarto formations. These clays interbedded with sands may constitute a hydrogeologic barrier between this zone and the overlying sands of the Upper Lagarto Formation. We evaluated clays to approximately 100 feet above the top of the Middle Lagarto Formation because this was the maximum depth of water wells in the Upper Lagarto Formation within this zone.

Hydrogeologic barriers associated with brackish groundwater production zone GCLL1 include approximately 20 to 105 feet of contiguous clay and 45 to 160 feet of non-contiguous clay interbedded with sands and are present across the transition between the Middle Lagarto and the Lower Lagarto formations. These clays interbedded with sands may constitute a hydrogeologic barrier between this zone and the overlying sands of the Middle Lagarto Formation. We evaluated clays to approximately 100 feet above the top of the Middle Lagarto Formation even though the maximum depth of water wells was 24 to 142 feet above the top of the Middle Lagarto Formation within this zone.

Hydrogeologic barriers associated with brackish groundwater production zone GCLL2 include approximately 25 to 40 feet of contiguous clay and 40 to 100 feet of non-contiguous clay interbedded with sands and are present across the transition between the Middle Lagarto and the Lower Lagarto formations. These clays interbedded with sands may constitute a hydrogeologic barrier between this zone and the overlying sands of the Middle Lagarto Formation. We evaluated clays to approximately 180 feet above the bottom of the Middle Lagarto Formation because this was the maximum depth of water wells in the Middle Lagarto Formation within this zone.

Groundwater monitoring

House Bill 30 requires the TWDB to recommend reasonable monitoring to observe the effects of brackish groundwater production within each zone. The need for groundwater monitoring should be evaluated on a case-by-case basis and consider the purpose of the monitoring, well field location, source aquifer, salinity zone spatial relationships, and expected volume of groundwater withdrawal. For example, monitoring may not be required if only one or two wells are planned for development. Monitoring may include the overlying and underlying aquifers and locations lateral, updip, and downdip in the same aquifer consistent with the purpose of the monitoring. Monitoring could focus on quality (for example, salinity changes) and quantity (for example, water level changes). Monitoring may include using existing well control or new monitor wells.

Groundwater monitoring should focus on the lateral and updip portions of the brackish aquifer, on the underlying aquifer, and on the overlying aquifer containing fresh and brackish water (Table B-4). Monitoring in permeable sands associated with clay confining units is recommended to determine the potential source of adjacent aquifer impact due to development in (1) the adjacent aquifers or (2) the brackish zone aquifer.

Table B-4. Overlying and underlying aquifers for each brackish groundwater production zone in the Gulf Coast Aquifer System.

Zone name	Brackish Lagarto Aquifer	Underlying aquifer	Overlying aquifer
GCUL1	Upper Lagarto	Middle Lagarto	Lower Goliad
GCML1	Middle Lagarto	Lower Lagarto	Upper Lagarto
GCLL1	Lower Lagarto	Oakville	Middle Lagarto
GCLL2	Lower Lagarto	Oakville	Middle Lagarto

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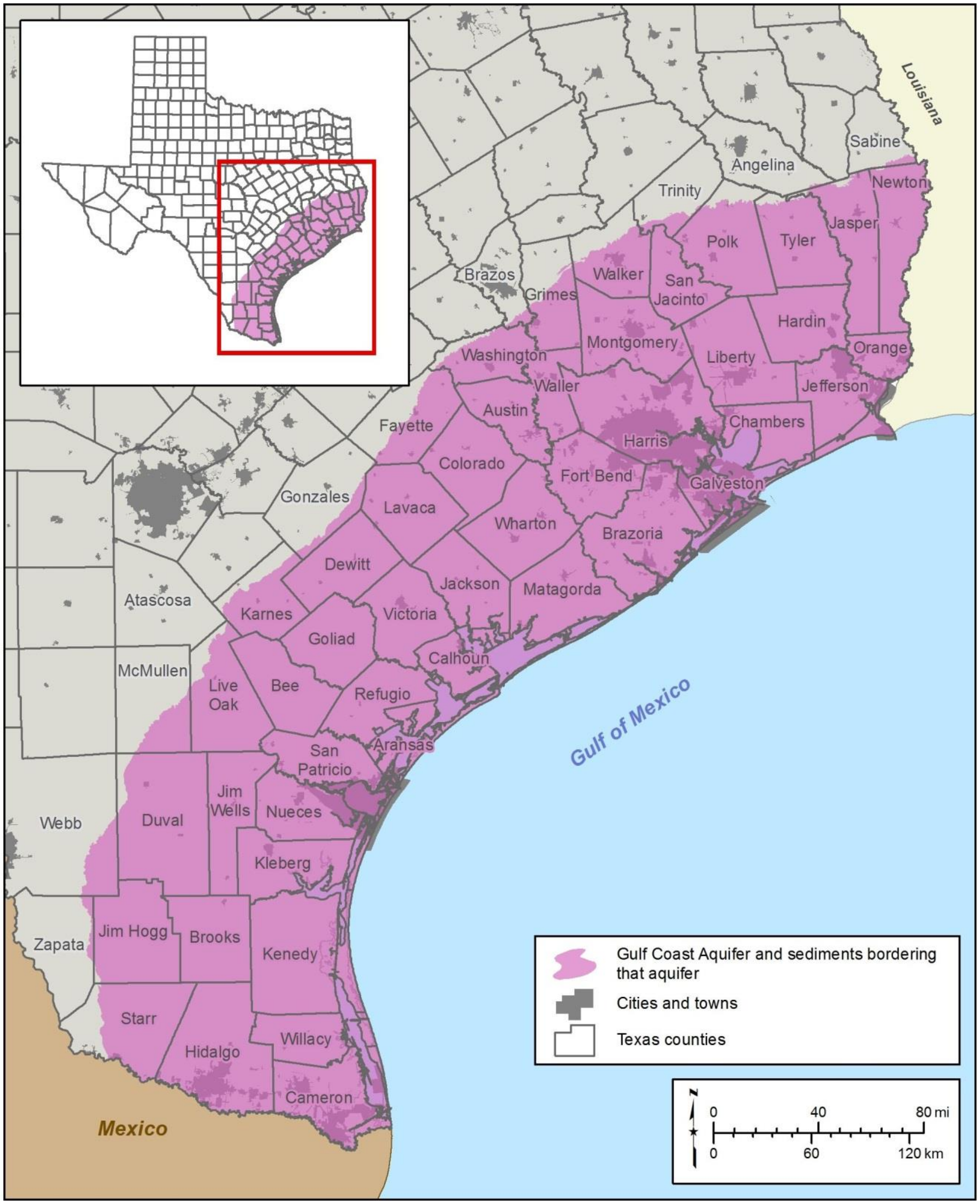

Figure B-1. Counties, cities, and towns present in the Gulf Coast Aquifer System project area.

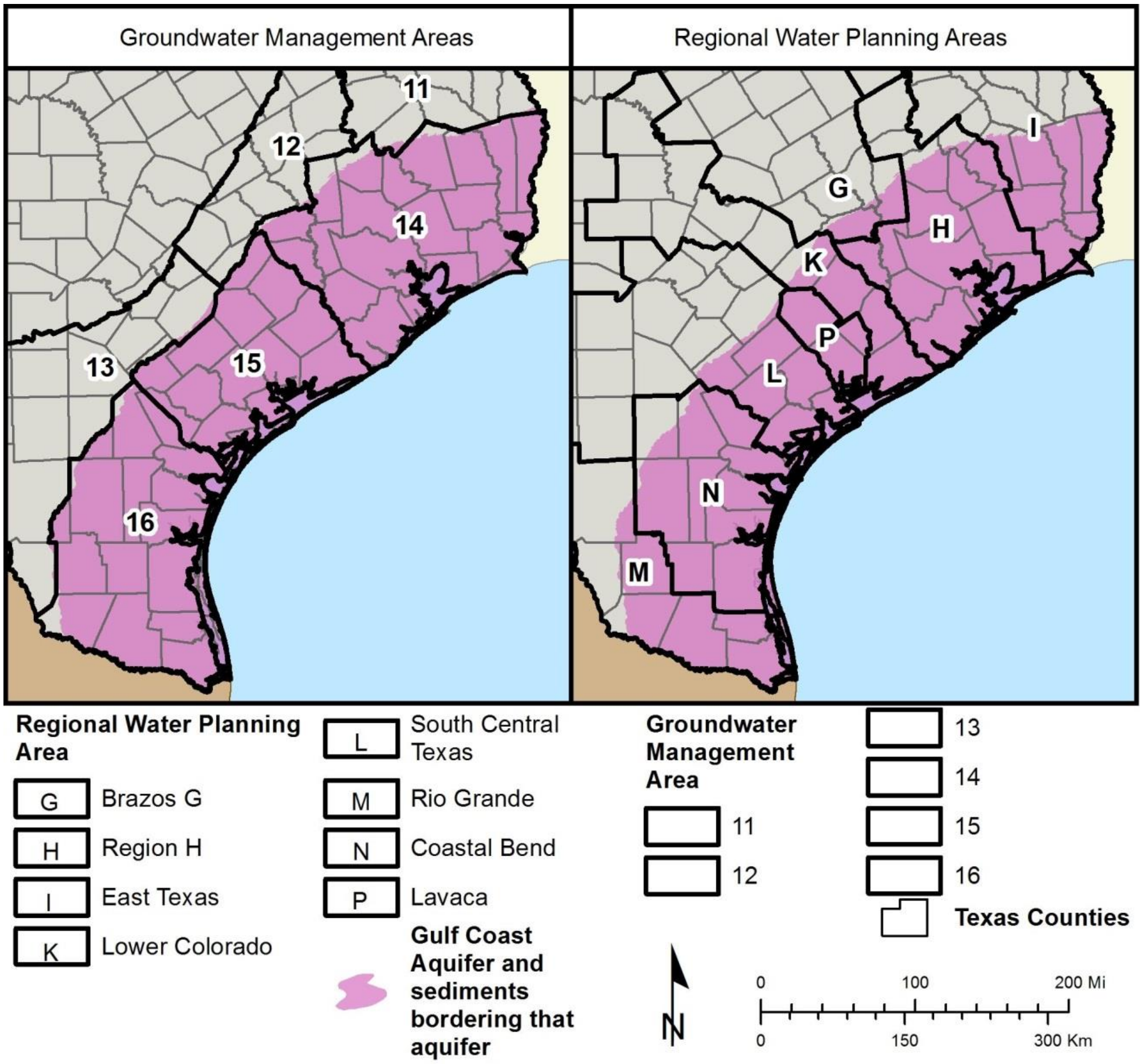

Figure B-2. **Regional water planning areas and groundwater management areas in the Gulf Coast Aquifer System project area.**

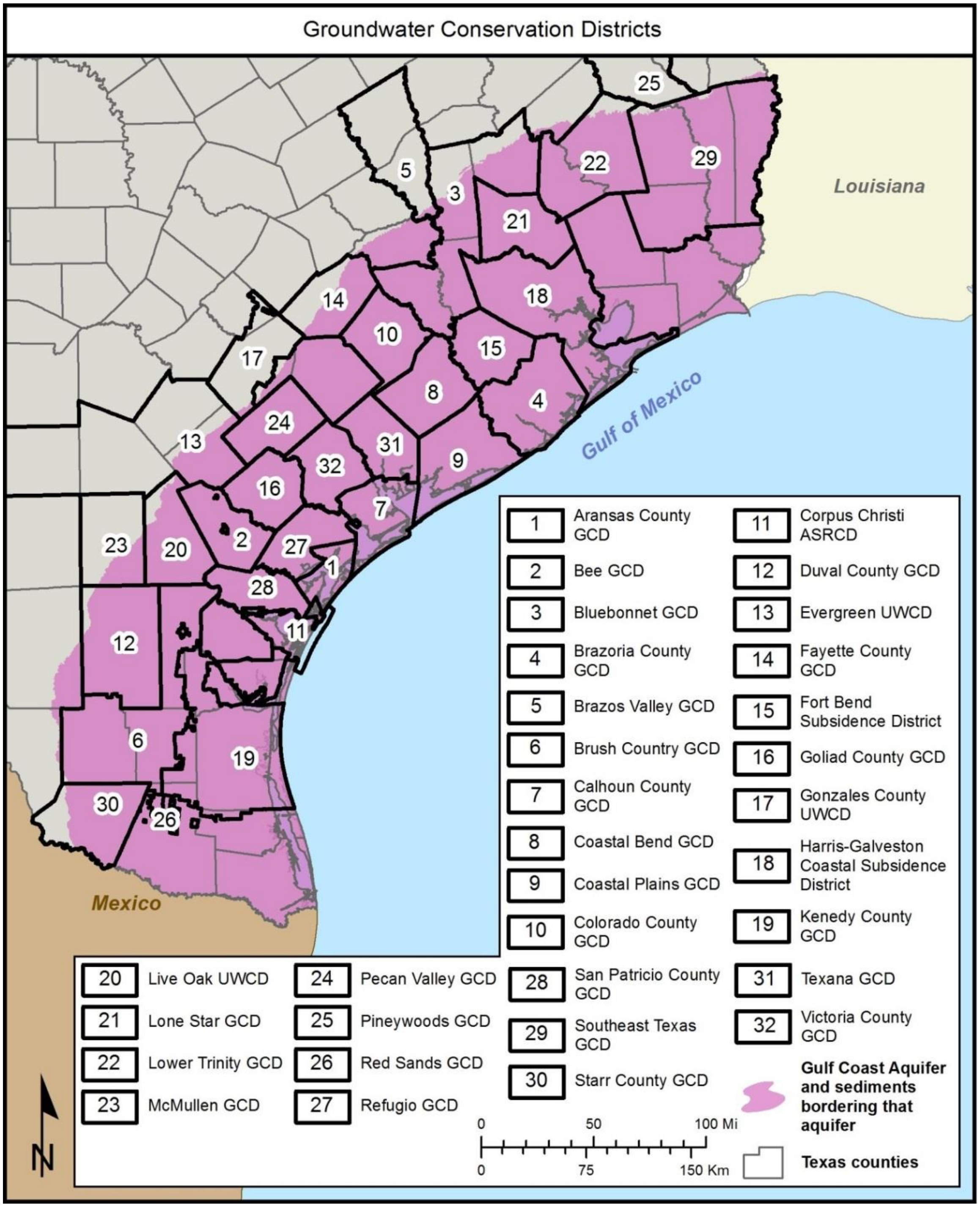

Figure B-3. **Groundwater conservation district boundaries within the Gulf Coast Aquifer System project area. Acronyms used: ASRCD = Aquifer Storage and Recovery Conservation District; GCD = Groundwater Conservation District; UWCD = Underground Water Conservation District.**

Epoch and age (millions of years before present)	Geologic formation	Hydrogeologic unit	
Pleistocene (1.8–present)	Beaumont	Chicot Aquifer	Gulf Coast Aquifer
	Lissie		
Pliocene (5.6–1.8)	Willis		
Miocene (23.8–5.6)	Upper Goliad	Evangeline Aquifer	
	Lower Goliad		
	Upper Lagarto		
	Middle Lagarto	Burkeville Confining Unit	
	Lower Lagarto	Jasper Aquifer	
	Oakville		
Oligocene	(upper) Catahoula		

Figure B-4. **Stratigraphy and hydrostratigraphy of the Gulf Coast Aquifer system in the project area (modified from Young and others, 2010). The Gulf Coast Aquifer comprises the Chicot, Evangeline, and Jasper aquifers. Formation assignment to epoch and age are not resolved.**

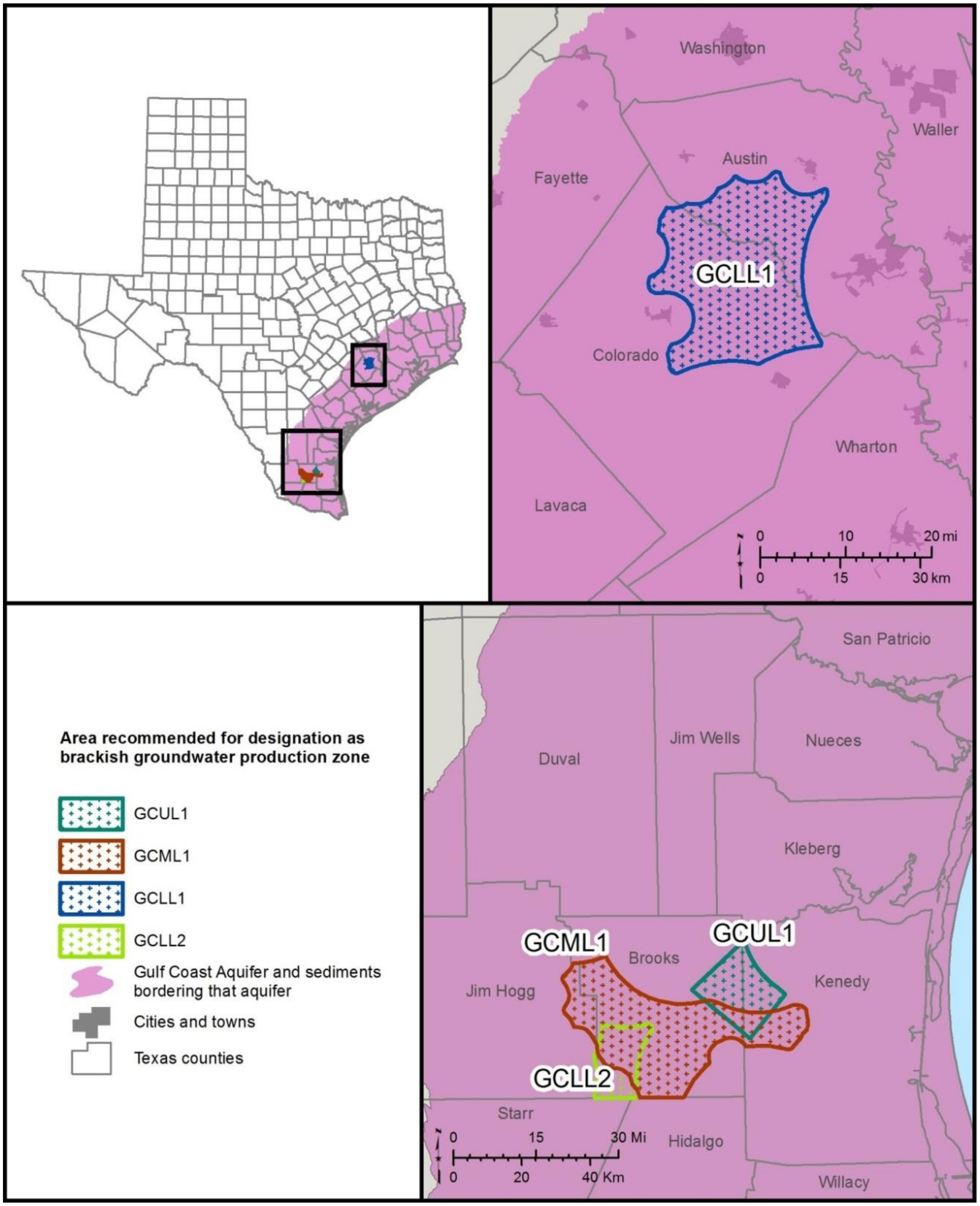

Figure B-5. **Gulf Coast Aquifer, sediments bordering that aquifer, and four brackish groundwater production zones (GCUL1, GCML1, GCLL1, and GCLL2). The areas contain groundwater that is slightly to moderately saline (1,000 to 9,999 milligrams per liter of total dissolved solids).**

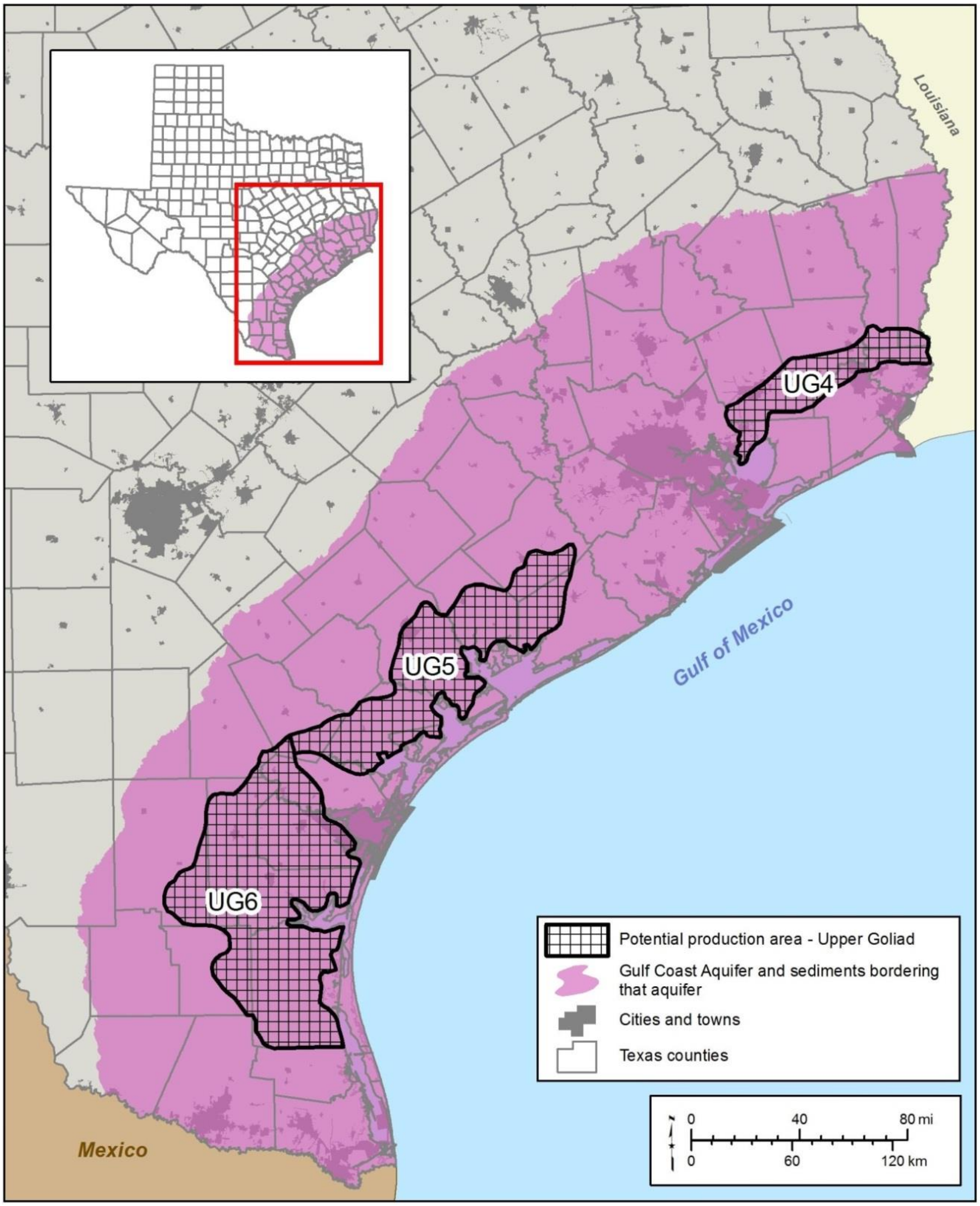

Figure B-6. Potential production areas in the Upper Goliad Formation in the Gulf Coast Aquifer System.

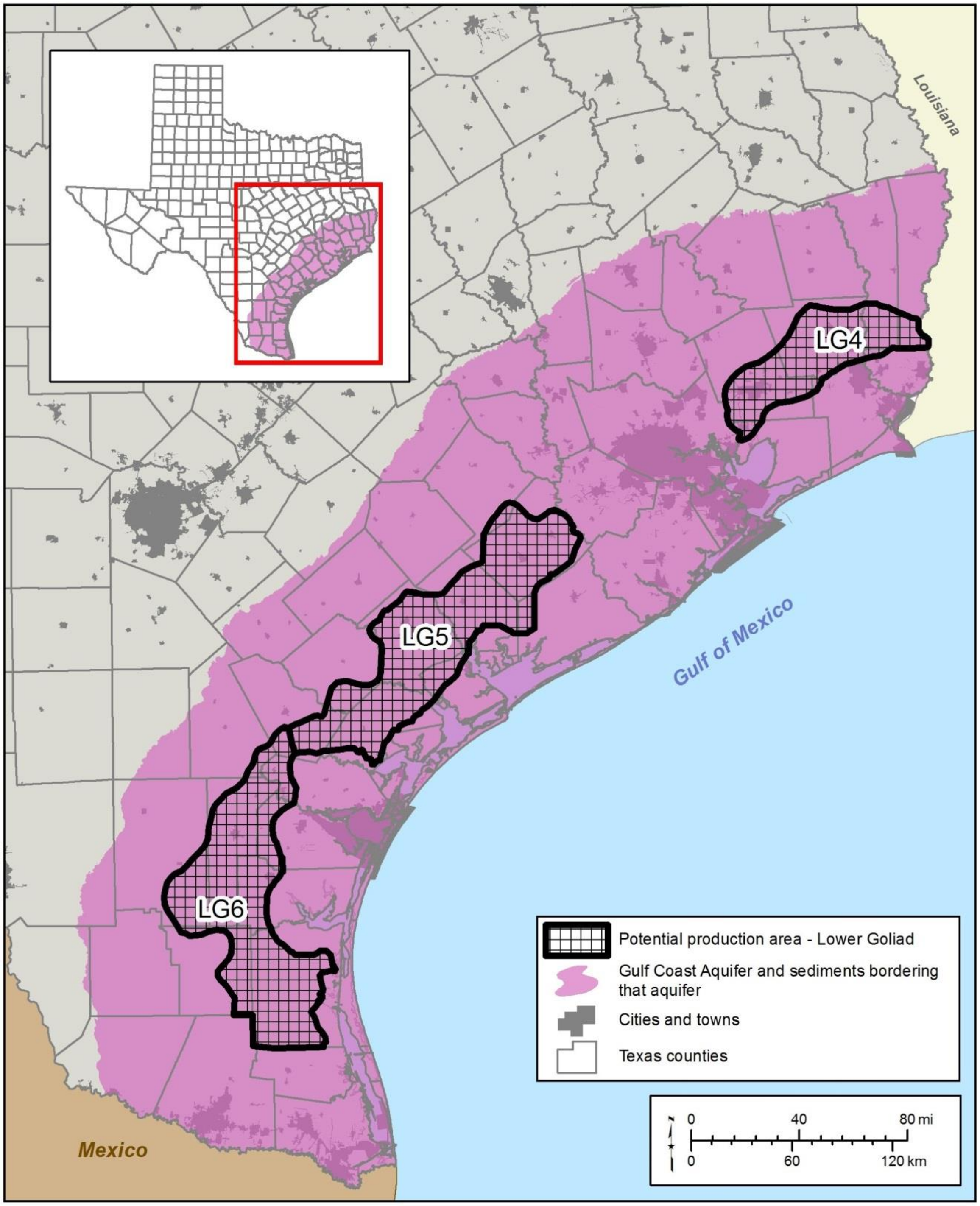

Figure B-7. **Potential production areas in the Lower Goliad Formation in the Gulf Coast Aquifer System.**

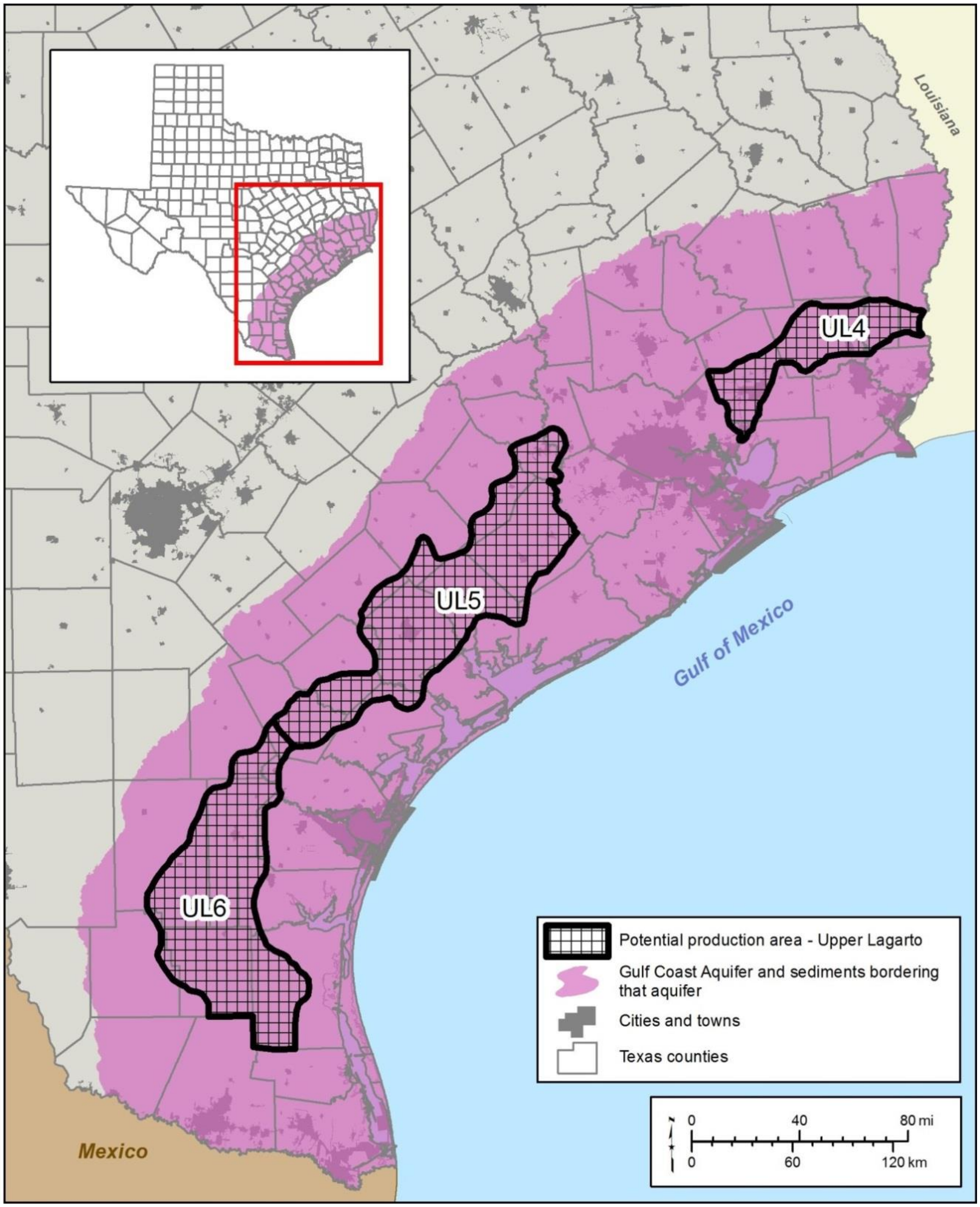

Figure B-8. Potential production areas in the Upper Lagarto Formation in the Gulf Coast Aquifer System.

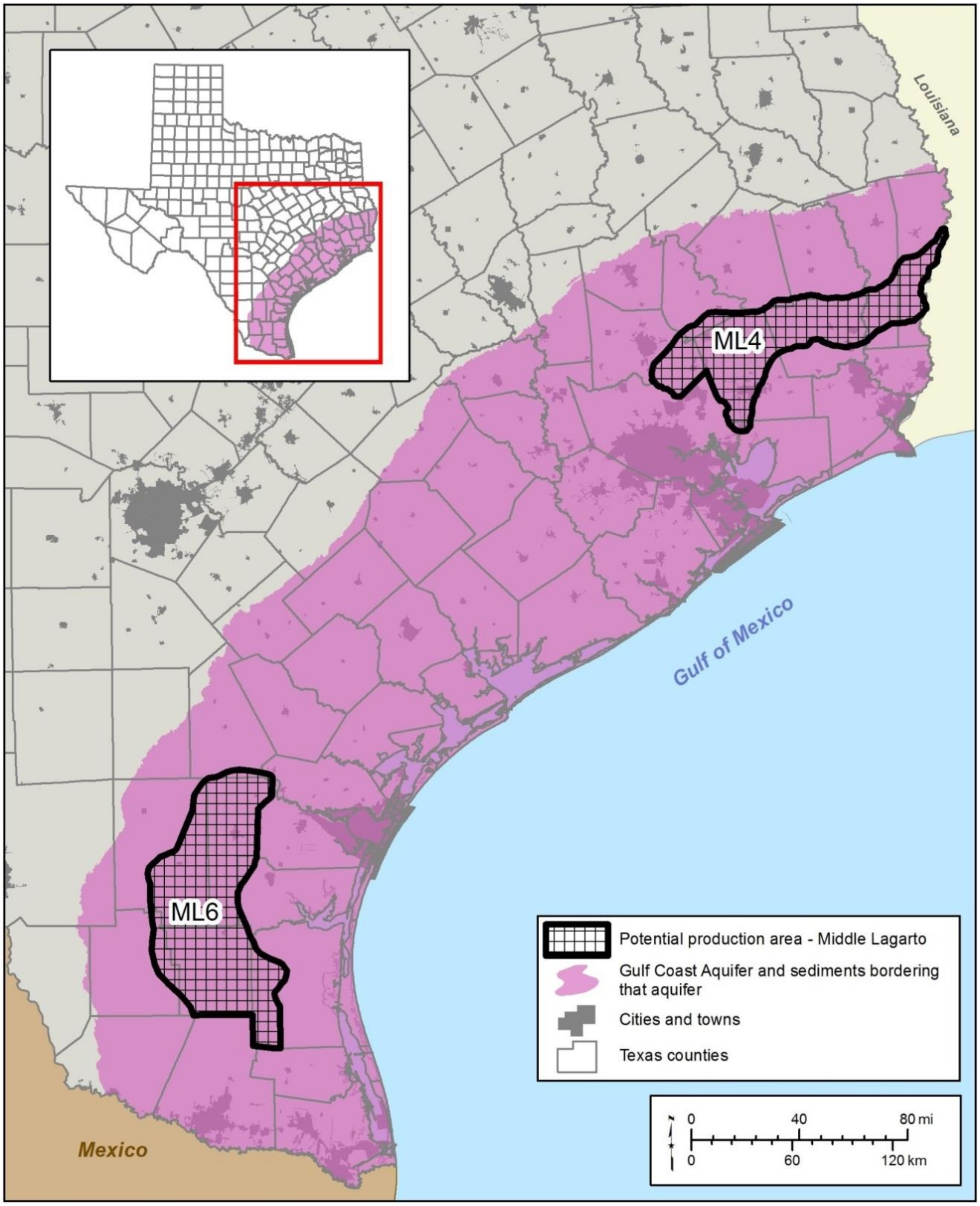

Figure B-9. Potential production areas in the Middle Lagarto Formation in the Gulf Coast Aquifer System.

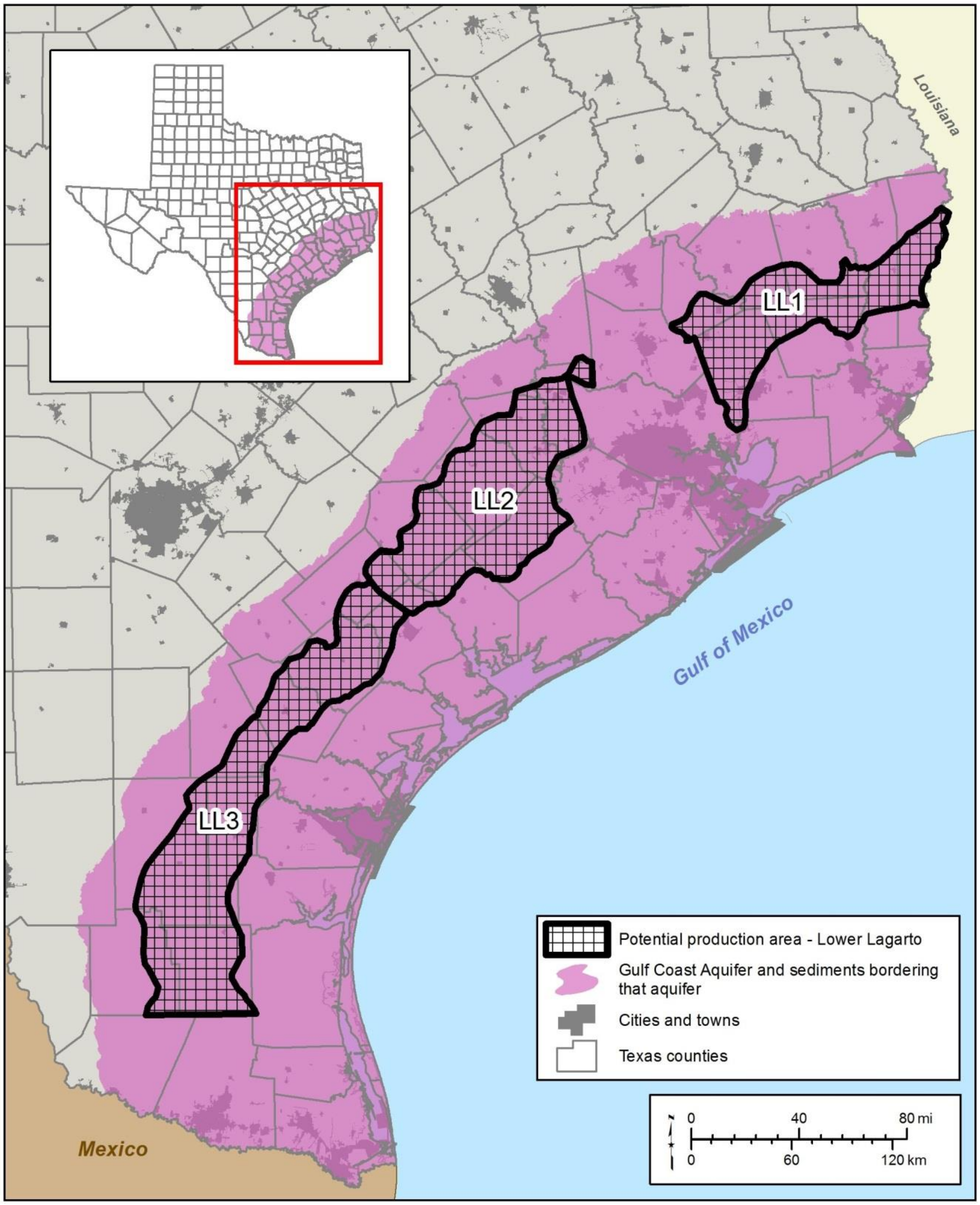

Figure B-10. **Potential production areas in the Lower Lagarto Formation in the Gulf Coast Aquifer System.**

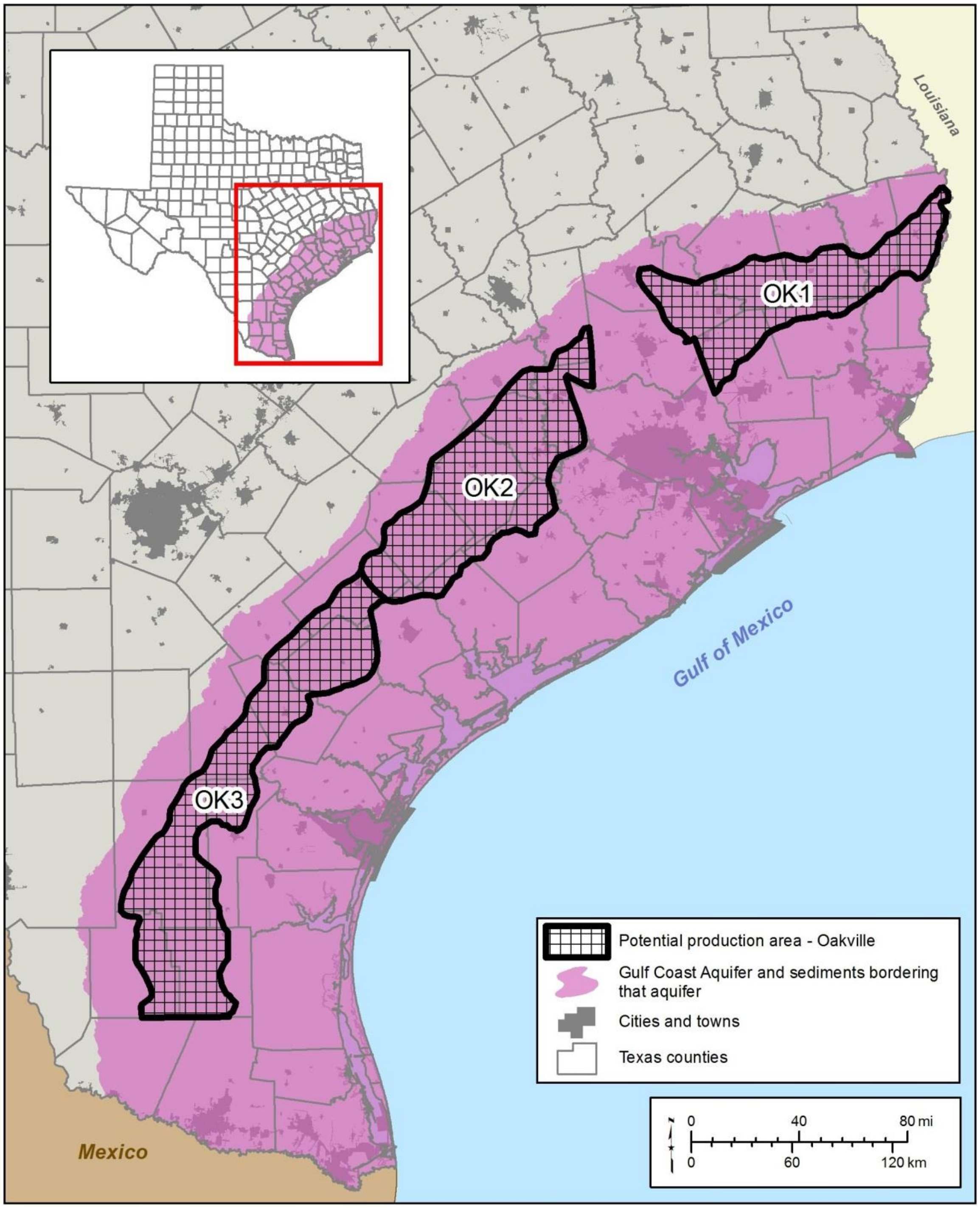

Figure B-11. Potential production areas in the Oakville Formation in the Gulf Coast Aquifer System.

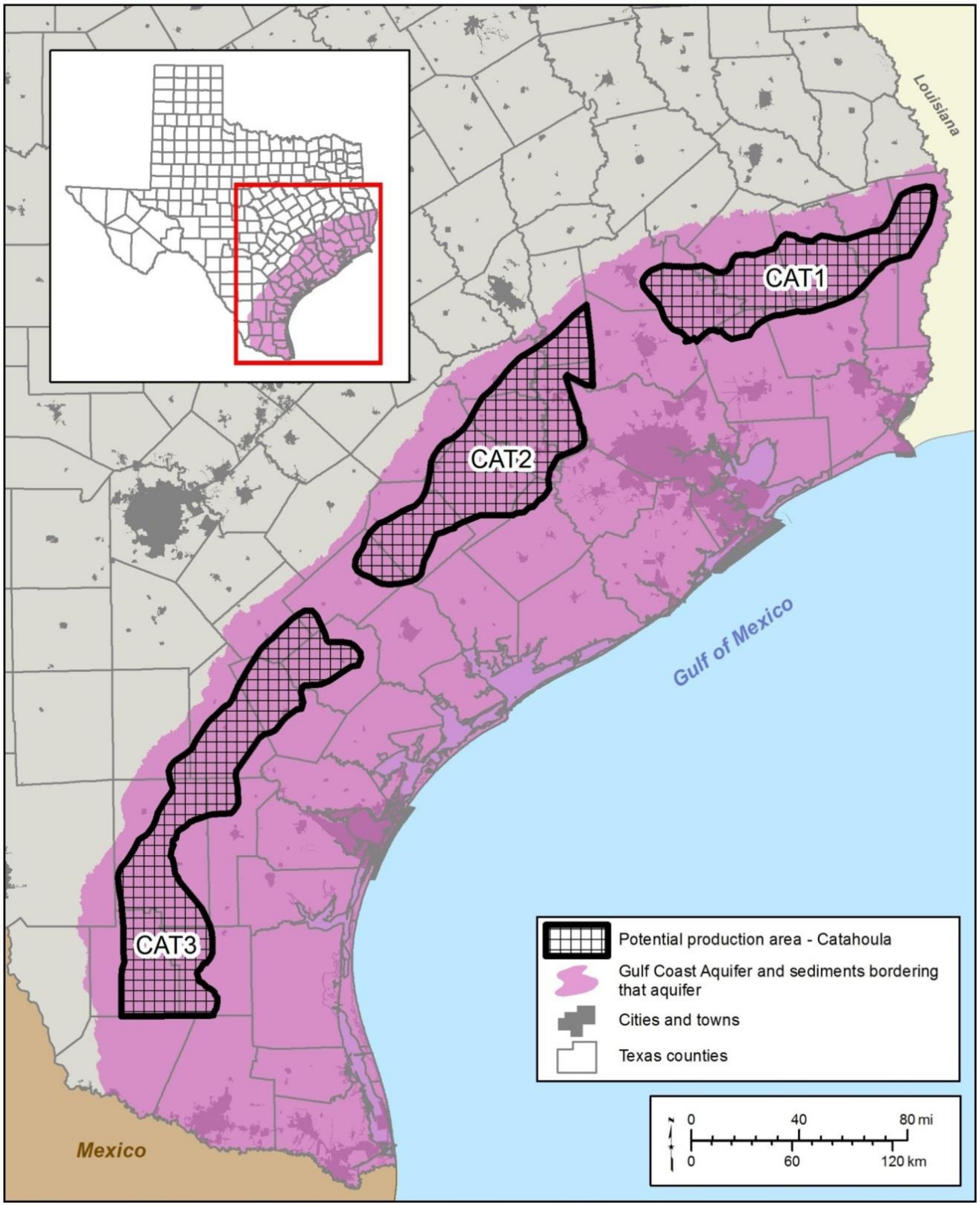

Figure B-12. **Potential production areas in the Catahoula Formation in the Gulf Coast Aquifer System.**

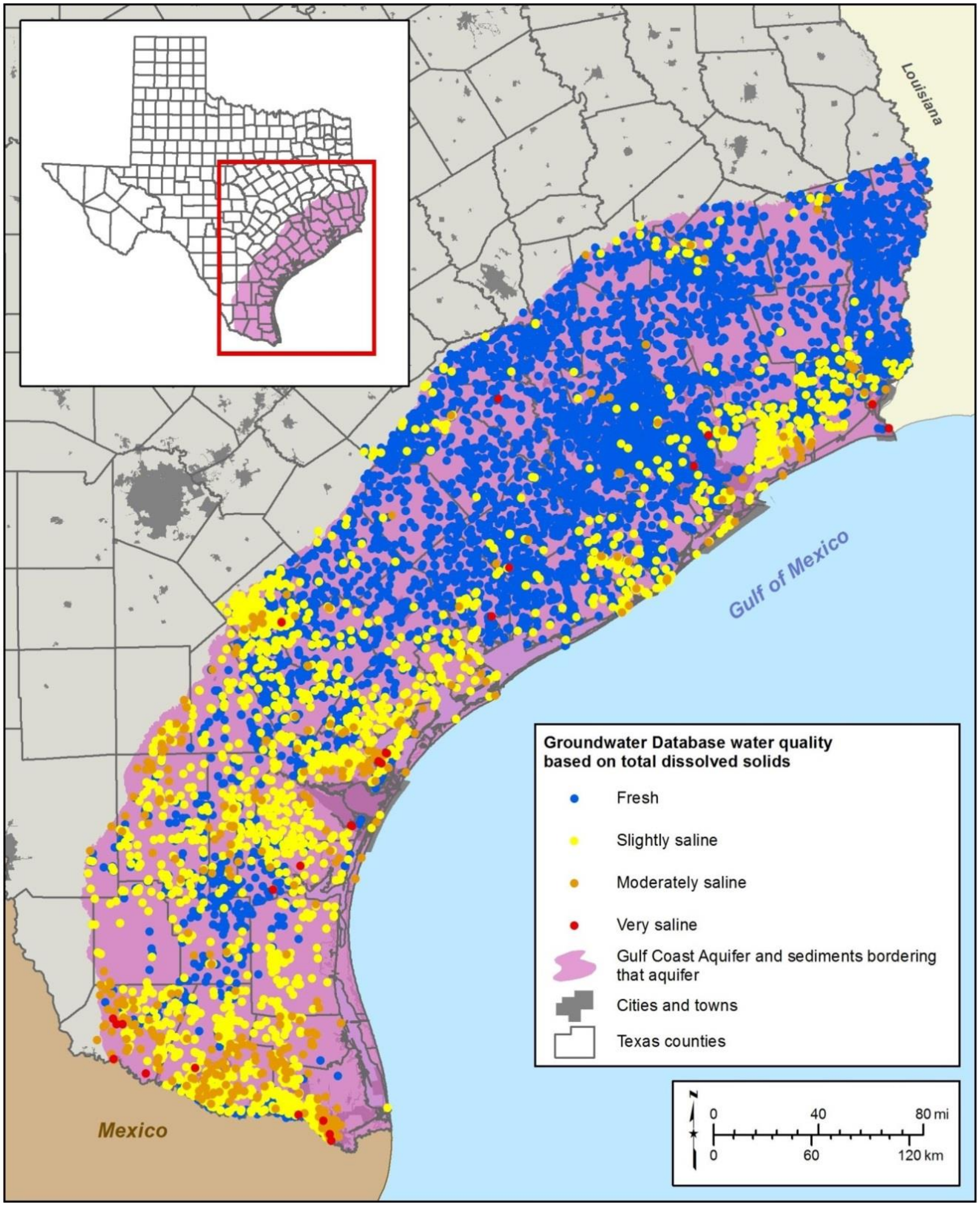

Figure B-13. Groundwater quality in the Gulf Coast Aquifer System showing total dissolved solids concentration based on the most recent samples in the TWDB Groundwater Database. Salinity classes are defined as: fresh (0 to 999 milligrams per liter total dissolved solids), slightly saline (1,000 to 2,999 milligrams per liter total dissolved solids), moderately saline (3,000 to 9,999 milligrams per liter total dissolved solids), and very saline (10,000 to 35,000 milligrams per liter total dissolved solids).

Appendix C: Blaine Aquifer project

Appendix C: Blaine Aquifer Project

Project summary

The goal of this project was to map the fresh and saline groundwater resources of the Blaine Aquifer and meet the requirements of House Bill 30 for designating brackish groundwater production zones.

The project produced an interpretation of:

1. the top and bottom of the Blaine Aquifer System;
2. production interval analysis including mapping of sinkholes and formation cavities;
3. the top and bottom of groundwater salinity zone surfaces in three dimensions;
4. groundwater levels;
5. water quality data;
6. potential production areas;
7. geophysical log analysis to define the brine interface;
8. simple groundwater modeling of potential production areas with a limited range of pumping over a 30-and 50-year time frame;
9. drawdown estimates indicating potential impact to the same and adjacent aquifers; and
10. exclusion criteria listed in House Bill 30. The TWDB conducted stakeholder meetings to share project information, receive comments, and solicit data.

The TWDB did not designate brackish groundwater production zones within the project area. Therefore, we did not estimate the volume of brackish groundwater nor did we develop groundwater monitoring requirements.

Project history and previous investigations

In 2015, the 84th Texas Legislature passed House Bill 30 directing the Texas Water Development Board (TWDB) to conduct studies to identify and designate brackish groundwater production zones in four aquifers and to report the designations to the legislature by December 1, 2016. The Blaine Aquifer was one of the four aquifers.

To help undertake studies of the aquifers required to be designated by December 1, 2016, the legislature appropriated $2 million to the TWDB for contracts and administrative costs (House Bill 1, General Appropriations Act, 2015 Legislature, Regular Session, page IX-88, Sec. 18.30). On October 13, 2015, the Board authorized the Executive Administrator to publish a Request for Qualifications to fund contract studies for three of the four aquifers specifically named in House Bill 30 (Gulf Coast, Blaine, and Rustler aquifers) and for three additional aquifers selected by the TWDB (Trinity, Blossom, and Nacatoch aquifers). The fourth aquifer required to be studied and reported on by House Bill 30 before December 1, 2016 (the Carrizo-Wilcox Aquifer) was conducted as part of an ongoing TWDB-funded project. Contractors delivered final reports for the four House Bill 30 projects at the end of August or early September 2016. The contracted project for the Blaine Aquifer included a regional reconnaissance effort designed to meet the requirements of House Bill 30 and provided information on the extent and volume of brackish groundwater within the aquifer and the location of potential production areas.

This project is built upon decades of studies conducted by local, state, and federal agencies. Significant studies include the TWDB groundwater availability modeling project that included the Blaine as a lower model layer below the Seymour Aquifer (Ewing and others, 2004), a Bureau of Economic Geology project (Richter and Kreitler, 1986), U.S. Geological Survey projects (Runkle and others, 1997; Runkle and McLean, 1995), and the TWDB groundwater resource studies (Duffin and Beynon, 1992; Hopkins and Muller, 2011; Maderak, 1972 and 1973; and Smith, 1970). Hundreds of well records used in these projects have been compiled and stored in the TWDB Groundwater Database (TWDB, 2016a) and the TWDB BRACS Database (TWDB, 2016b).

Project approach

We conducted a general stakeholder meeting in October 2015 to kick off the implementation of House Bill 30 and solicit comments. Once we approved the contract, the contractor (1) collected well data, (2) evaluated the geology and groundwater of the Blaine Aquifer, (3) prepared database and GIS files, and (4) identified potential production areas. We conducted two stakeholder meetings to solicit comments on the potential production areas and worked with the contractor to develop a list of potential production areas that would undergo groundwater modeling. The contractor (1) performed the groundwater modeling, (2) prepared a draft report, and (3) submitted the draft report and data to us. We reviewed the draft report and data and provided technical comments to the contractor for consideration in the final draft report and datasets. We conducted a stakeholder meeting in September 2016 to discuss all four aquifer projects and to solicit comments on the final reports. We evaluated the report, data, and stakeholder comments and made a recommendation to the Board to not designate any brackish groundwater production zones in the aquifer.

Contract information

TWDB contract number: 1600011948

Cost: $200,000

Contractor:

- Daniel B. Stephens and Associates, Inc. (Principal)
- John Shomaker and Associates, Inc.
- ARS, LLC.
- Michelle A. Sutherland, LLC.

Project duration: approximately 8 months

- Board approved: January 6, 2016
- Contract signed: April 11, 2016
- Final report delivered: August 31, 2016

Public entities

Counties

The Blaine Aquifer System in the project area is present in all or part of Foard, Gray, Hall, Hardeman, Jones, Kent, King, Knox, Motley, Nolan, Scurry, Stonewall, Wheeler, and Wilbarger counties (Figure C-1).

Cities and towns

The Blaine Aquifer System in the project area underlies all or part of the cities and towns of Afton, Aspermont, Childress, Dickens, Dodson, Estelline, Girard, Hamlin, Jayton, Lakeview, Matador, Memphis, Paducah, Quail, Quanah, Quitaque, Roaring Springs, Roby, Rotan, Samnorwood, Shamrock, Sweetwater, Spur, Turkey, and Wellington, (Figure C-1).

Groundwater management areas

The Blaine Aquifer System in the project area is present in all or part of groundwater management areas 1, 2, 6, and 7 (Figure C-2). http://www.twdb.texas.gov/groundwater/management_areas/index.asp

Regional water planning areas

The Blaine Aquifer System in the project area is present in all or part of regional water planning areas A, B, F, G, and O (Figure C-2). https://www.twdb.texas.gov/waterplanning/rwp/

Groundwater conservation districts

The Blaine Aquifer System in the project area is present in all or parts of Clear Fork Groundwater Conservation District, Gateway Water Conservation District, Mesquite Groundwater Conservation District, Panhandle Groundwater Conservation District, Rolling Plains Groundwater Conservation District, and Wes-Tex Groundwater Conservation District (Figure C-2).

Methodology

The contractor used (1) geophysical well logs, driller reports, and published reports to map the top and bottom of the Blaine Aquifer System, (2) static water-level data to develop a water level surface, (3) geophysical well logs to interpreted the brine interface surface within the Blaine Aquifer, and (4) these data to develop three-dimensional surfaces used for subsequent volume calculations and other tasks.

The contractor mapped areas of known karst (for example, sinkholes) and voids (for example, solution-enlarged fractures) using air photos and driller well reports. These features represent potential areas of relatively high aquifer productivity because most producible groundwater in the aquifer is related to karstic features.

The contractor identified eight potential production areas in areas outside apparent exclusion zones (containing: wells referenced in House Bill 30; buffers around populated places where water wells are likely to occur; buffers around irrigated acreage where water wells are likely to occur; one wildlife management area) where moderate to high availability of groundwater is present (Figure C-3). We conducted two stakeholder meetings and received feedback and additional well data that we used to further refine potential production areas. The contractor eliminated five of the eight potential production areas due to the presence of exclusions identified by stakeholders.

We reviewed the contractor's report and data (Finch and others, 2016) and evaluated House Bill 30 exclusion criteria in each potential production area. Ultimately, the TWDB did not designate brackish groundwater production zones in the Blaine Aquifer. Because there are no designated zones, we did not prepare brackish groundwater volume estimates or recommended groundwater monitoring.

Hydrogeology

The Blaine Aquifer is one of the 21 minor aquifers in Texas. It outcrops in a north-south-trending belt in the Rolling Plains region of north-central Texas and Oklahoma. The extent of the TWDB-designated Blaine Aquifer includes the outcrop and downdip extent of the Blaine Formation containing groundwater with a total dissolved solids concentration of less than 10,000 milligrams per liter (TWDB, 2007). The area includes the Whitehorse Group strata that are located stratigraphically above the Blaine Formation (Figure C-4). The Whitehorse Group is a known aquifer unit, although it is not officially designated as a major or minor aquifer by the TWDB. The Whitehorse Group and the Blaine Aquifer are hydraulically connected and constitute a single groundwater flow system in north-central Texas and southwestern Oklahoma. For this reason, the contractor evaluated the Whitehorse Group and the Blaine Formation as a single system: the Blaine Aquifer System.

The Blaine Aquifer System is shallow, relatively thin, dependent on groundwater recharge within the outcrop area, contains slightly to moderately saline water, and composed primarily of gypsum and anhydrite with interbedded dolomite, shale, and very few sand strata. Groundwater occurs in solution-enlarged karstic features with highly variable well yields and water quality. Fresh water occurs in limited portions of the aquifer system in topographically high regions in recharge zones. The majority of wells contain slightly to moderately saline groundwater. The Blaine Aquifer System is bounded below by the Flowerpot Shale or a brine interface. The brine interface separates brackish groundwater from brine.

The primary uses of groundwater from the Blaine Aquifer System are domestic, municipal, irrigation, livestock, and oil and gas production. Due to high salinity, the majority of groundwater is not used for human consumption.

Lithology/stratigraphy

The Blaine Formation is composed primarily of gypsum and anhydrite with interbedded dolomite, shale, and very few sand strata. The net thickness of shale in the Blaine Formation increases to the south. The Whitehorse Group contains gypsum, dolomite, shale, and red sand. Karst features such as fractures and voids, which developed from dissolution of gypsum and anhydrite, allow for localized increase in transmissivity leading to high well yield. The density of voids and fractures can change abruptly throughout the Blaine Aquifer System and water well production is difficult to predict. In the northern portion of the system, the base of the aquifer is the Flowerpot Shale. In the southern portion of the Blaine Aquifer System, the base of the aquifer is the brine interface surface. The transition from fresh and brackish groundwater to brine is very abrupt throughout the Blaine Aquifer System.

Water quantity

The TWDB did not designate brackish groundwater production zones in the Blaine Aquifer. Therefore, we did not calculate the volume of brackish groundwater that can be produced over 30- and 50-year timeframes.

The contractor estimated that the Blaine Aquifer System contains about 19.3 million acre-feet of brackish groundwater in place (Table C-1). They calculated this volume by multiplying the total volume of the saturated aquifer with a specific yield value of 0.01 (Finch and others, 2016).

Because the base of the aquifer is either the Flowerpot Shale or the brine interface, the amount of very saline water is quite low. This quantity should be considered with caution as only a small portion of the volume could be extracted from the Blaine Aquifer System without detrimental effects. These effects could include depleted aquifer saturated thickness or significant degradation of groundwater quality.

Table C-1. **Volume of drainable groundwater within the Blaine Aquifer System using (1) total volume of the aquifer layers, (2) specific yield, and (3) the stratigraphic and water table surfaces developed by Finch and others, 2016 (Table 12-1).**

Aquifer	Volume of water (million acre-feet)			
	Fresh*	Slightly and moderately saline*	Very saline*	Total
Blaine System	1.2	17.9	0.2	19.3

Notes:

Fresh = 0 to 999 milligrams per liter total dissolved solids
Slightly and moderately saline = 1,000 to 9,999 milligrams per liter total dissolved solids
Very saline = 10,000 to 35,000 milligrams per liter total dissolved solids

LBG-Guyton Associates (2003) calculated groundwater volumes of different salinities in the major and minor aquifers of Texas. The volume of slightly and moderately saline groundwater within the Blaine Aquifer in regional water planning areas A, B, F, and G is 19.6 million acre-feet. The volume of slightly and moderately saline groundwater within the Whitehorse Group in regional water planning areas A, B, G, and O is 14.9 million acre-feet. The two volumes total about 34.5 million acre-feet. This volume is almost twice the 17.9 million acre-feet estimated by the contractor for the Blaine Aquifer project. The difference in the volumes can be attributed to different aquifer parameter values (for example, specific yield) used by LBG-Guyton Associates (2003), the estimated thickness of the Blaine Aquifer and Whitehorse Group, and the areal extent of the aquifer.

Jones and others (2013), Kohlrenken (2015), and Kohlrenken and others (2013) estimated the volume of drainable Blaine Aquifer groundwater (total storage equals 171.7 million acre-feet) using the Total Estimated Recoverable Storage (TERS) method for groundwater management areas 1, 6, and 7, which is similar to the technique used by Finch and others (2016). The Total Estimated Recoverable Storage volume is approximately 10 times the volume calculated by the contractor. This difference in volumes can be attributed to different input datasets: the contractor used a finer stratigraphic analysis such as the brine interface as the bottom of the aquifer, resulting in a thinner saturated thickness of the useable groundwater in the Blaine Aquifer. Kohlrenken (2015) used a coarser resolution (1 mile x 1 mile grid) in their numerical model due to the larger areal extent of the study.

Water quality

The Blaine Aquifer within the project area contains groundwater with total dissolved solids concentrations ranging from 206 to 12,800 milligrams per liter total dissolved solids (Figure C-5). More than 99 percent of the wells sampled in the TWDB Groundwater Database have sulfate concentrations that exceed the Texas Commission on Environmental Quality secondary standard of 300 milligrams per liter. This is due to dissolution of gypsum strata in the Blaine Formation. In the Blaine Aquifer System, above the brine interface, available water quality data from water wells do not show a correlation of salinity with depth. The brine interface is a boundary at which salinity abruptly increases to more than 100,000 milligrams per liter of total dissolved solids. Brine springs discharge to surface water, for example on the Stonewall-King county line, while other springs have water that is slightly to moderately saline. Some fresh water springs are also present in the project area.

Hydrogeologic barriers

There are no hydrogeologic barriers at the top of the Blaine Aquifer System because it is covered with alluvium or overlain by the Seymour Aquifer. The Flowerpot Shale underlies much of the Blaine Aquifer System and serves as a hydrogeologic barrier under the aquifer. Water wells installed in areas where the brine interface exists in the Blaine Aquifer should be developed with care because there is no hydrogeologic barrier between the brackish groundwater and the brine.

Groundwater monitoring

We did not develop groundwater monitoring recommendations for brackish groundwater production zones because no zones were designated in the aquifer.

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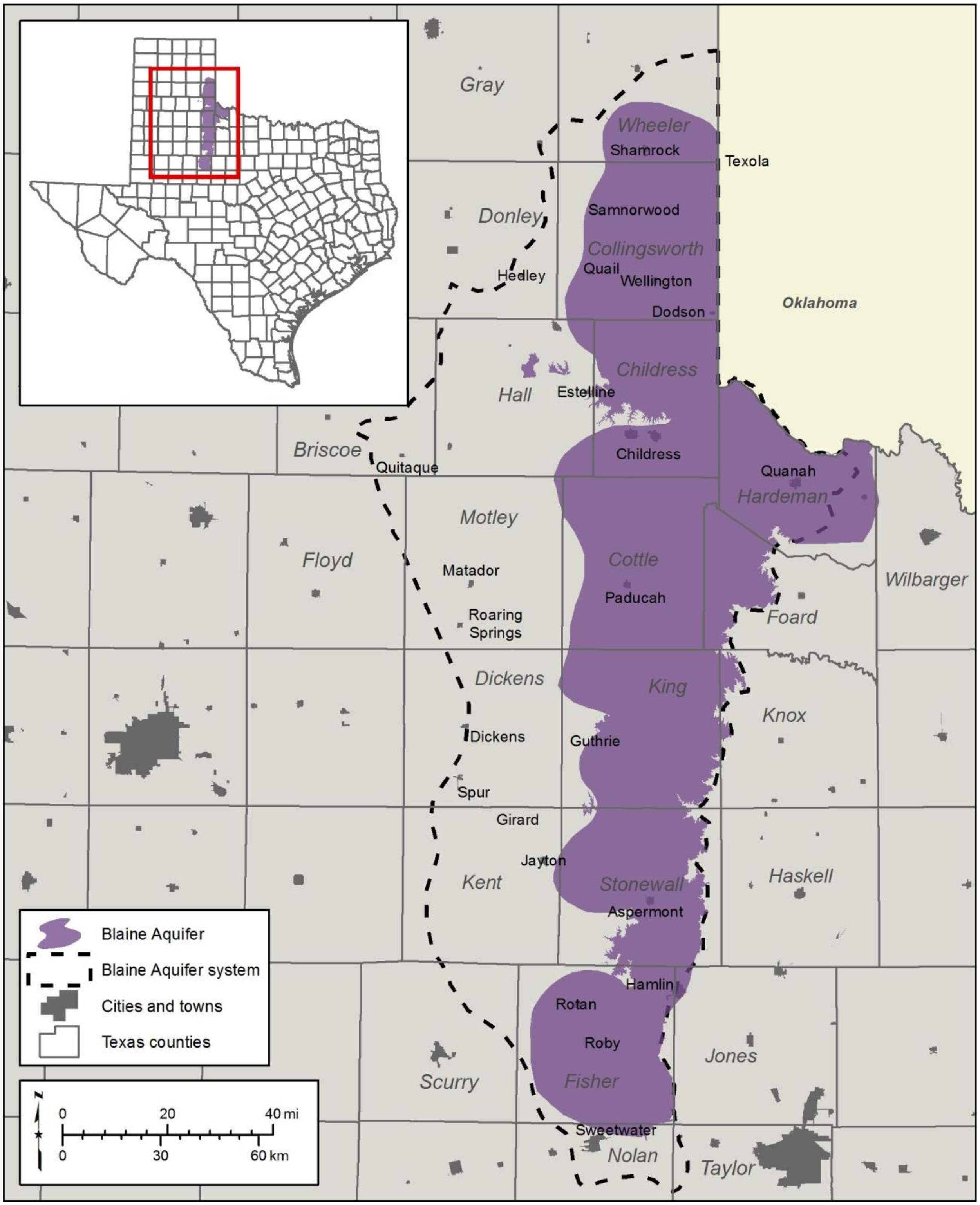

Figure C-1. **Towns, cities, and counties present in the Blaine Aquifer project area.**

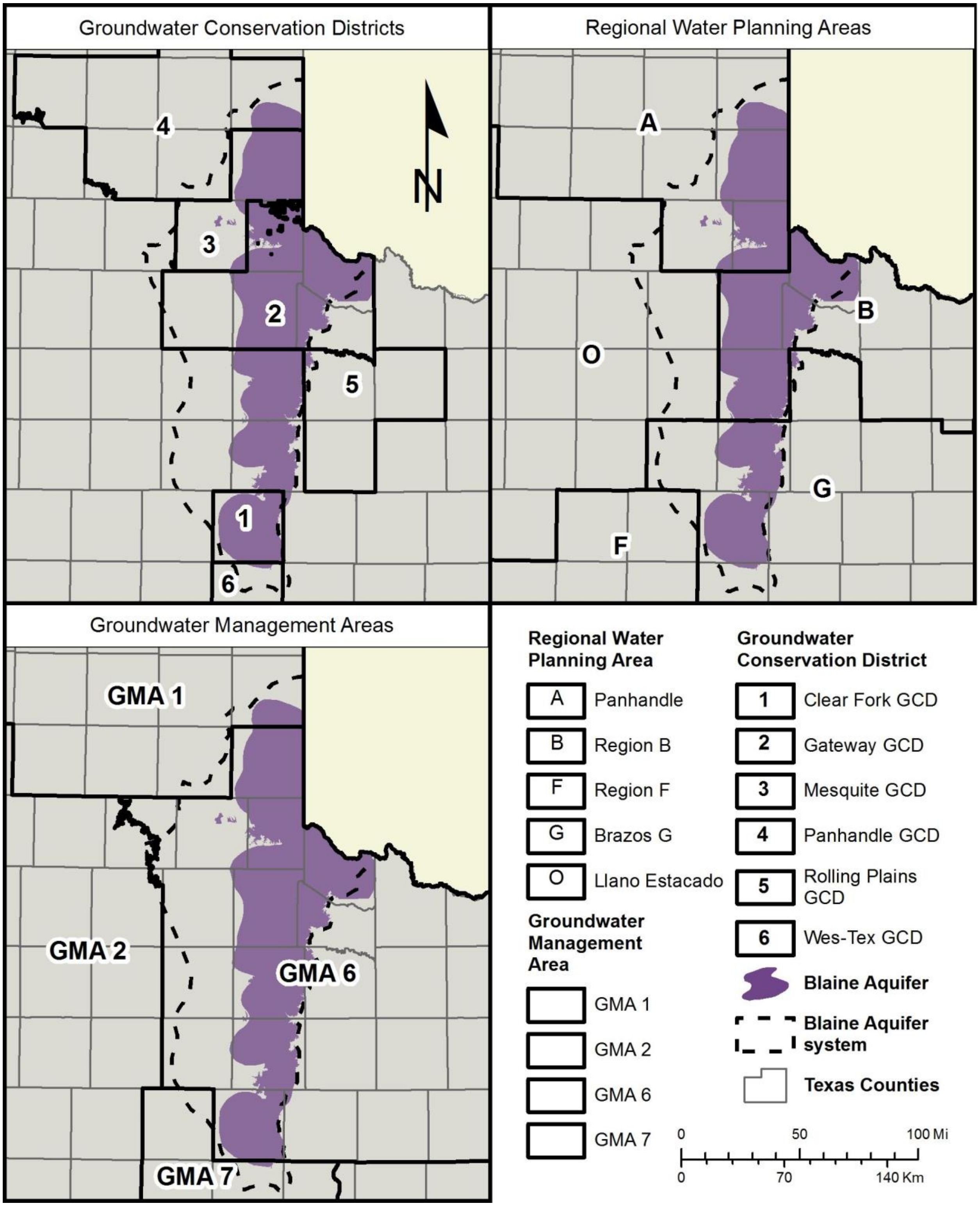

Figure C-2. **Groundwater conservation districts, regional water planning areas, and groundwater management areas in the Blaine Aquifer project area. Acronyms used: GCD = Groundwater Conservation District; GMA = Groundwater Management Area.**

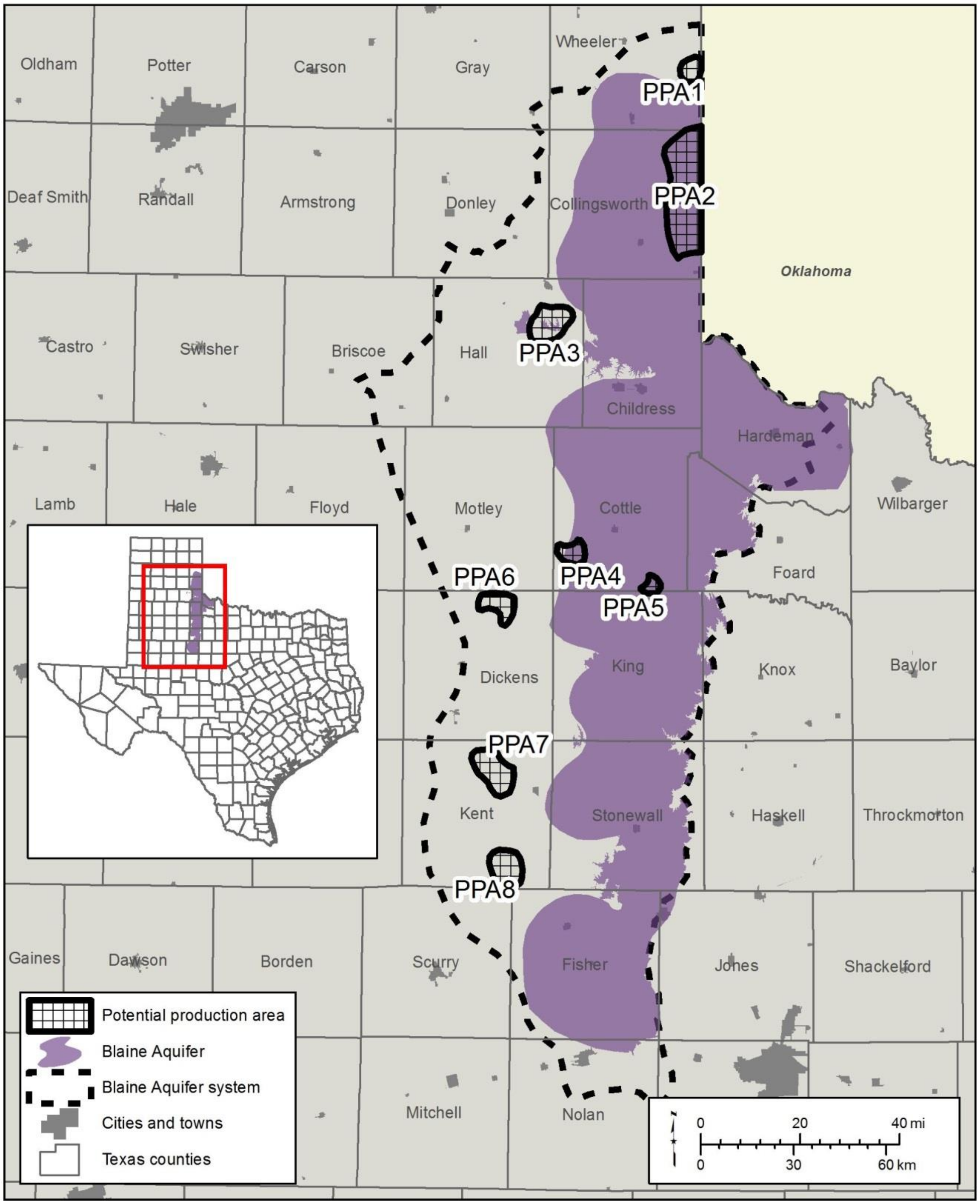

Figure C-3. The eight potential production areas (PPA1 to PPA8) identified by the contractor in the Blaine Aquifer System project area.

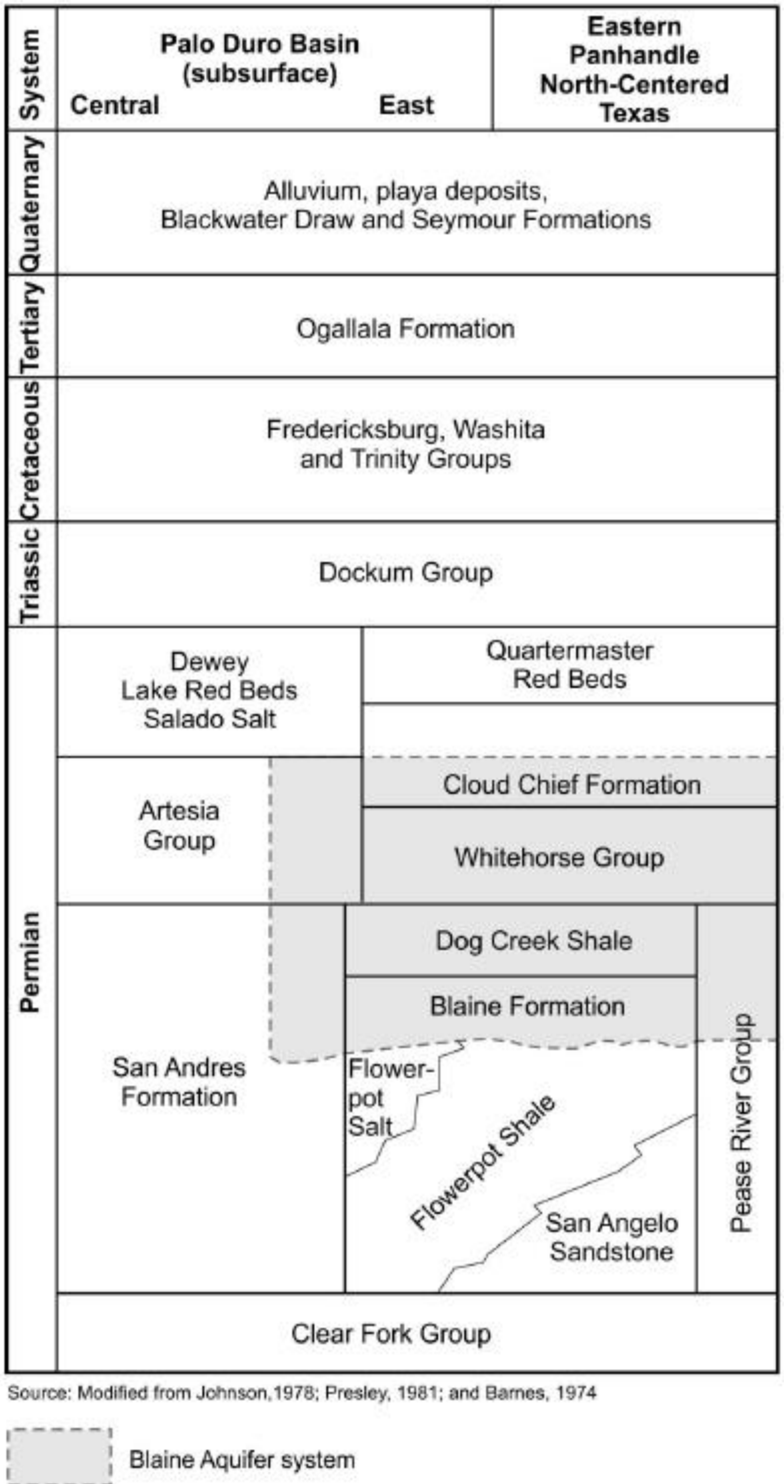

Figure C-4. **Stratigraphy of the Blaine Aquifer System. Figure from Finch and others (2016, Figure 5-3).**

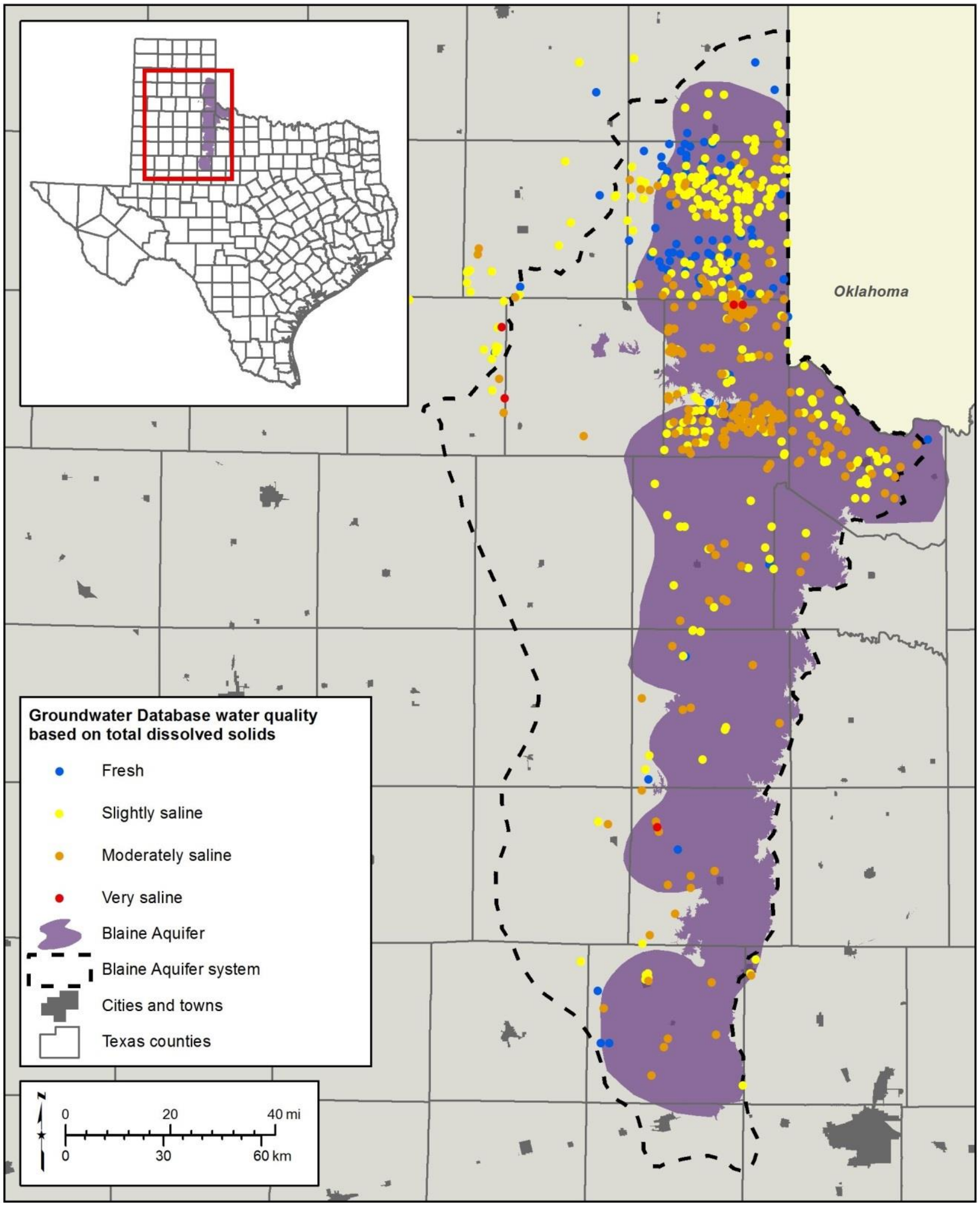

Figure C-5. **Salinity (total dissolved solids) of water samples from the Blaine Aquifer and Whitehorse Group based on the most recent samples in the TWDB Groundwater Database. Fresh (0 to 999 milligrams per liter total dissolved solids), slightly saline (1,000 to 2,999 milligrams per liter total dissolved solids), moderately saline (3,000 to 9,999 milligrams per liter total dissolved solids), and very saline (10,000 to 35,000 milligrams per liter total dissolved solids).**

Appendix D: Rustler Aquifer project

Appendix D: Rustler Aquifer Project

Project summary

The objective of this project was to map the fresh and saline groundwater resources of the Rustler Aquifer and meet the requirements of House Bill 30 for designating brackish groundwater production zones.

The project produced an interpretation of:

1. stratigraphic picks for the top of the Rustler Formation, Magenta Dolomite, Tamarisk Member, Culebra Dolomite, Los Medaños Member, Los Medaños limestones submember, lower Los Medaños submember, and Salado Formation;
2. the top and bottom of lithological units within the geological formations;
3. water quality from existing water quality analyses and geophysical well logs to define the four salinity classes of fresh (0 to 1,000 milligrams per liter of total dissolved solids), slightly saline (>1,000 to 3,000 milligrams per liter of total dissolved solids), moderately saline (>3,000 to 10,000 milligrams per liter of total dissolved solids), very saline (>10,000 to 35,000 milligrams per liter of total dissolved solids);
4. the sensitivity of log variables for the project area;
5. key well logs for the project area to develop simplified water quality calculations;
6. groundwater volume for the four salinity classes;
7. potential hydrogeologic barriers;
8. potential production areas;
9. simple groundwater modeling of potential production areas with a limited range of pumping over a 30-and 50-year time frame;
10. drawdown maps for scenario 3 of the groundwater model; and
11. exclusion criteria listed in House Bill 30.

We conducted stakeholder meetings to share project information, receive comments, and solicit data.

The TWDB designated three brackish groundwater production zones within the project area (Figure D-1, zones Rus1, Rus2, and Rus3). Zones Rus1 and Rus3 would produce water from the Magenta Dolomite, Culebra Dolomite, and the Los Medaños limestones of the Rustler Formation, and Rus2 would produce water from the collapsed Rustler Aquifer (Figure D-2). These zones contain groundwater that is slightly to moderately saline (1,000 to 9,999 milligrams per liter of total dissolved solids).

We estimate that the volume of brackish groundwater that could be produced over 50 years from brackish groundwater production zone Rus1 is 126,000 acre-feet, Rus2 is 26,000 acre-feet, and Rus3 is 632,000 acre-feet. This amounts to 0.47 million acre-feet of brackish groundwater over 30 years and 0.78 million acre-feet over 50 years.

The top of brackish groundwater production zone Rus1 is 152 feet to more than 3,300 feet below ground surface with a mean depth of 1,459 feet. The thickness of this zone ranges from 81 feet to 214 feet with a mean thickness of 145 feet. The top of brackish groundwater production zone Rus2 is 518 feet to more than 3,400 feet below ground surface with a mean depth of 1,631 feet. The thickness of this zone ranges from 100 feet to 836 feet with a mean thickness of 323 feet. The top of brackish groundwater production zone Rus3 is 717 feet to more than 2,900 feet below ground surface with a mean depth of 1,054 feet. The thickness of this zone ranges from 103 feet to 241 feet with a mean thickness of 157 feet. The base of zone Rus1 is 658 feet to more than 3,700 feet below ground surface with a mean depth of 1,904 feet. The base of zone Rus2 is 1,201 feet to more than 3,700 feet with a mean depth of 1,954 feet. The base of zone Rus3 is 1,152 feet to more than 3,300 feet below ground surface with a mean thickness 1,521 feet.

Hydrogeologic barriers in each brackish groundwater production zone in the study area include structural geological boundaries such as faults, the Dewey Lake Formation that is present above the Rustler Aquifer, and the Salado Formation that is present below the aquifer. Additionally, distance barriers from existing use apply to zones Rus1 and Rus3.

Groundwater monitoring should focus on the overlying and laterally adjacent aquifers that contain fresh water or existing use. Monitoring in hydrogeologic barriers is recommended to determine the potential source of impacts to fresh water or existing use due to development in (1) surrounding aquifers or (2) the Rustler Aquifer. Monitoring is not required below the Rustler Aquifer because there are no known fresh or brackish aquifers in the Salado Formation in the region.

The brackish groundwater production zones do not contain known water wells (domestic, municipal, or agricultural that are using fresh or brackish groundwater) or known injection wells (Class I, II, III, IV, or V injection wells; Texas Water Code, Chapter 27, Injection Wells) that meet the exclusion criteria in House Bill 30.

Project history and previous investigations

In 2015, the 84th Texas Legislature passed House Bill 30 directing the TWDB to conduct studies to identify and designate brackish groundwater production zones in four aquifers and to report the designations to the legislature by December 1, 2016. The Rustler Aquifer was one of the four aquifers.

To help undertake studies of the aquifers required to be designated by December 1, 2016, the legislature appropriated $2 million to the TWDB for contracts and administrative costs (House Bill 1, General Appropriations Act, 2015 Legislature, Regular Session, page IX-88, Sec. 18.30). On October 13, 2015, the Board authorized the Executive Administrator to publish a Request for Qualifications to fund contract studies for three of the four aquifers specifically named in House Bill 30 (Blaine, Gulf Coast, and Rustler aquifers) and for three additional aquifers selected by the TWDB (Trinity, Blossom, and Nacatoch aquifers). We completed the Carrizo-Wilcox Aquifer project, the fourth aquifer required to be studied and reported on by House Bill 30, before December 1, 2016, as part of an ongoing TWDB-funded project. The contractors completed and delivered final reports for the four House Bill 30 projects at the end of August or early September 2016. The contracted project for the Rustler Aquifer included a regional reconnaissance designed to meet the requirements of House Bill 30 and provided information on the extent and volume of brackish groundwater within the aquifer.

The Rustler Aquifer project is built upon decades of existing groundwater studies conducted by local, state, and federal agencies. Significant studies include the TWDB groundwater availability modeling project (Ewing and others, 2012), lithology (Vine, 1963), structure (Hiss, 1976), hydrogeology related to the Waste Isolation Pilot Plant investigations in New Mexico (Powers and Holt, 2010), reports by the TWDB (Boghici and others, 2014; Boghici and Van Broekhoven, 2001), brackish aquifer studies by the TWDB (Meyer and others, 2012), and a report on the geology of La Escalera Ranch (Finch, 2015). The Rustler Aquifer project used thousands of well records compiled and stored in the TWDB Groundwater Database (TWDB, 2016b) and the TWDB BRACS Database (TWDB, 2016c).

Project approach

We conducted a general stakeholder meeting in October 2015 to kick off the implementation of House Bill 30 and solicit comments. Once we approved the contract, the contractor (1) collected well data, (2) evaluated the geology and groundwater of the Rustler Aquifer, (3) prepared database and GIS files, and (4) identified potential production areas. We conducted a stakeholder meeting to solicit comments on the potential production areas and worked with the contractor to develop a list of potential production areas that would undergo groundwater modeling. The contractor (1) performed the groundwater modeling, (2) prepared a draft report, and (3) submitted the draft report and data to us. We reviewed the draft report and data and provided technical comments to the contractor for consideration in the final draft report and datasets. We conducted a stakeholder meeting in September 2016 to address all four aquifer projects and to solicit comments on the final reports. We evaluated the report, data, and stakeholder comments and made a recommendation to the Board for the designation of three brackish groundwater production zones.

Contract information

TWDB contract number: 1600011949

Cost: $200,000

Contractor:

- INTERA, Inc. (Principal)
- Jack Sharp, Ph.D., P.G., The University of Texas at Austin
- Dennis Powers, Ph.D., P.G., Dennis Powers Consulting
- Carlos Torres-Verdin, Ph.D., P.G., The University of Texas at Austin
- Justin Sutherland, Ph.D., P.E., Carollo Engineers

Project duration: approximately 8 months

- Project approved by Board: January 6, 2016
- Contract executed: March 20, 2016
- Final report delivered: August 31, 2016

Public entities

Counties

The Rustler Aquifer project area is present in all or part of Brewster, Culberson, Jeff Davis, Loving, Pecos, Reeves, and Ward counties (Figure D-3).

Cities and towns

The cities of Balmorhea, Barstow, Fort Stockton, Pecos, and Toyah are located in the Rustler Aquifer project area (Figure D-3).

Groundwater management areas

The Rustler Aquifer project area is present in all or parts of groundwater management areas 3, 4, and 7 (Figure D-4).

www.twdb.texas.gov/groundwater/management_areas/index.asp

Regional water planning areas

The Rustler Aquifer project area is present in parts of regional water planning areas E and F (Figure D-4).

www.twdb.texas.gov/waterplanning/rwp/

Groundwater conservation districts

The Rustler Aquifer project is present in all or parts of Brewster County Groundwater Conservation District, Jeff Davis Underground Water Conservation District, Middle Pecos Groundwater Conservation, and Reeves County Groundwater Conservation District (Figure D-4).

Methodology

The contractor used geophysical well logs and data in published reports to map the top and bottom of geologic members and lithologic units in the Rustler Aquifer. They used the picks to identify regional structural features in the project area and to develop three-dimensional surfaces for the Rustler Formation and the water-bearing units in the formation. In addition to searching for well logs for stratigraphic picks, the contractor identified useful resistivity/induction and porosity logs to perform a sensitivity analysis. In total, 26 key wells met the contractor's criteria.

The contractor vetted existing chemical analysis of water samples from water wells possibly drawing from the Rustler Aquifer using publicly available information such as well total depth, screening intervals, aquifer codes, and water chemistry. They identified 84 wells accounting for 133 water quality samples. Because there are so few publicly available water quality samples for the Rustler Aquifer, they excluded water quality measurements with ionic balance variations of more than 15 percent from consideration instead of the more standard 5 percent. They then excluded samples in excess of 10,000 milligrams per liter total dissolved solids since it was suspected that these samples were contaminated with brine from outside the Rustler Aquifer. The contractor's procedure resulted in 103 water quality measurements from 64 wells for the project.

The contractor conducted a sensitivity analysis to determine the magnitude of influence that variables such as borehole geometry, mud filtrate salinity, and volume of shale had on the response of geophysical tools. They used petrophysical software to evaluate header consistency, correct depth shifting, calculate downhole temperature, calculate mud-filtrate resistivity, calculate porosity, calculate formation water resistivity, and calculate the sodium chloride total dissolved solids equivalent for the 26 key well logs. Then they calculated the total dissolved solids concentrations from the sodium chloride equivalent total dissolved solids using a linear regression between sampled water quality total dissolved solids and sodium chloride equivalent total dissolved solids. Finally, they calculated water quality from an additional 19 wells using a similar but abbreviated method that leveraged information gained from the 26 key well logs. This method used the calculated porosity, deep resistivity, a porosity exponent of 2.0, and the formation water resistivity. More details on the methodologies used to calculate water quality from geophysical logs is available in Section 13 of the report by Lupton and others (2016).

The contractor modeled theoretical pumping in the five potential production areas (PPA) with a range of hydraulic variables over a 30- and 50-year time frame (Figure D-5). They placed areas PPA1, PPA2, PPA3, and PPA5 in the "2 – Normal" stratigraphic zone that represented areas where they could distinguish all three water-bearing units of the Rustler Aquifer (the Magenta Dolomite, Culebra Dolomite, and Los Medaños limestones) on geophysical well logs. Area PPA4 was in the "1 – Collapsed" stratigraphic zone that represented areas where the three water-bearing units of the Rustler Formation could not be discerned from geophysical well logs probably due to dissolution and collapse. To model the productivity of the potential production areas, the contractor used the TWDB's Rustler Aquifer groundwater availability model (version 1.0) to simulate hypothetical well fields, one well field at a time. The contractor placed multiple well fields in some potential production areas. After each model run, they calculated the drawdown or water level decline relative to a baseline run without the potential well field to determine the impacts of pumping on the exclusion zone boundaries and existing wells. They performed additional sensitivity model runs to test the influences of Rustler Aquifer parameters such as hydraulic conductivity, vertical anisotropy, and storativity on the productivity of the theoretical well fields. More details on the methodology used to build the hydrogeologic framework are available in Lupton and others (2016).

We reviewed the contractor's report and data (Lupton and others, 2016) and evaluated publicly available data for House Bill 30 exclusion criteria in each PPA. We then provided recommendations to the Board through the Executive Administrator for designation of brackish groundwater production zones Rus1 (in the same region as PPA1), Rus2 (in the same region as PPA4), and Rus3 (in the same region as PPA3).

Hydrogeology

The Rustler Aquifer is one of 21 minor aquifers in Texas. It is present in West Texas in the Rustler Formation and extends north into New Mexico. The TWDB boundary for the Rustler Aquifer includes the Rustler Formation outcrop and subcrop and excludes portions in New Mexico in the north and aquifer areas in the southeast with total dissolved solids concentration of more than 5,000 milligrams per liter (TWDB, 2007).

The primary uses of groundwater from the Rustler Aquifer are irrigation, livestock, and oil and gas production (George and others, 2011). The only strategy in the 2017 State Water Plan that uses groundwater from the Rustler Aquifer is located in Culberson County. It is allocated to the mining water user group and assumes that four new 380-foot-deep wells will be installed to provide an additional 590 acre-feet per year (TWDB, 2016a). There is no known large scale desalination currently taking place using brackish groundwater from the Rustler Aquifer.

Lithology/stratigraphy

The Rustler Formation consists of dolomite, limestone, and gypsum layers deposited in a shallow sea during the Permian Period. The average thickness of the formation is 450 feet. Fractures and voids in the rocks, some of which developed from dissolution and collapse, allow for the storage and movement of groundwater. The density of voids and fractures can change abruptly in the water-bearing members of the Rustler Aquifer (Magenta Dolomite, Culebra Dolomite, limestones in the Los Medaños, and strata within the collapsed Rustler Formation), and water well production is difficult to predict (Figure D-2).

Water quantity

We calculated volumes of brackish water that the zones are capable of producing in 12 different scenarios over a 30- and 50-year period based on the modeling of hypothetical well fields in TWDB's Rustler groundwater availability model (in superposition mode) by the contractor (Ewing and others, 2012). The contractor provided drawdown maps for the modeled 50-year pumping in scenario 3. We used scenario 3 maximum drawdown along the brackish groundwater production zone boundary for the change in head to calculate the annual produced volumes. We identified 22.5 feet of drawdown for Rus1, 22.9 feet for Rus2, and 17.2 feet for Rus3. For Rus1 and Rus3, we used the total thickness of the water-bearing units (Magenta Dolomite, Culebra Dolomite, and in the Los Medaños Limestone) to calculate volumes.

As mapped by the contractor, the thickness of the water-bearing units accounts for approximately 33 percent of the entire Rustler Formation thickness. Since the contractor could not identify the water-bearing units on well logs from zone Rus2, we used 33 percent of the Rustler Formation thickness in this area to calculate volume. We used the specific storage and cell area from the model grid shapefile provided with the contracted report to calculate the confined aquifer volume. We estimate that over a period of 50 years, 2,513 acre-feet per year of brackish groundwater could be produced from zone Rus1 (Table D-1). Production of this volume of groundwater annually equates to 0.075 million acre-feet over a 30-year time period and 0.126 million acre-feet over a 50-year time period. For zone Rus2, we estimate that 522 acre-feet of brackish groundwater could be produced annually over 50 years. Production of this volume of groundwater equates to 0.016 million acre-feet over a 30-year period and 0.026 million acre-feet over a 50-year period. For Rus3, we estimate that 12,645 acre-feet of brackish groundwater could be produced annually for 50 years. Production of this volume of groundwater equates to 0.379 million acre-feet over 30 years and 0.632 million acre-feet over 50 years. The estimated volumes assume that all drawdown is limited to the extent of the boundaries of the zone. We used this assumption to simplify parameters for straightforward comparison.

Table D-1 **Volume of brackish groundwater that could be potentially produced from the three brackish groundwater production zones designated for the Rustler Aquifer over 30- and 50-year periods based on values provided in Lupton and others (2016).**

Aquifer	Zone	Annual pumpage (acre-feet/year)	30-year cumulative (million acre-feet)	50-year cumulative (million acre-feet)
Rustler	Rus1	2,513	0.075	0.126
	Rus2	522	0.016	0.026
	Rus3	12,645	0.379	0.632

We estimate the volume of drainable brackish groundwater within the Rustler Aquifer brackish groundwater production zones to be 9.39 million acre-feet (Table D-2). We assumed a fraction of the groundwater will drain to wells within the zones if the entire Rustler Aquifer within the zone is completely pumped. The estimate is based on a (1) specific yield value equal to 0.03 (Boghici and others, 2014), (2) confined storage head drawdown based on the 2008 values from the TWDB Rustler Aquifer groundwater availability model (Ewing and others, 2012), (3) confined storativity values (Lupton and others, 2016), and (4) draining the total thickness of the Rustler Formation or water-bearing units, depending on the stratigraphic zone.

Table D-2 **Volume of drainable groundwater within the three Rustler Aquifer brackish groundwater production zones using (1) the net thickness of water-bearing units for Rus1 and Rus3, (2) the entire Rustler Formation thickness for Rus2, (3) specific yield in the outcrop, (4) storativity and specific yield in the confined portions of the aquifer, and (5) area based on ¼-mile grid cells (Lupton and others, 2016).**

Aquifer	Zone	Total drainable volume (million acre-feet)	Area (million acres)
Rustler	Rus1	4.63	0.99
	Rus2	2.44	0.25
	Rus3	2.32	0.37

We estimated the total volume of drainable groundwater within the entire extent of the TWDB-defined Rustler Aquifer by salinity class (Table D-3). To perform the volume calculation, we used (1) the thickness of water-bearing units, (2) entire Rustler Formation thickness for "collapsed" areas, (3) specific yield in the outcrop, (4) confined storativity and specific yield in the confined portions of the aquifer, and (5) area based on ¼-mile grid cells (Lupton and others, 2016, Table 12-2).

Table D-3 **Volume of drainable groundwater within the Rustler Aquifer using (1) the thickness of water-bearing units, (2) entire Rustler Formation thickness for "collapsed" areas, (3) specific yield in the outcrop, (4) confined storativity and specific yield in the confined portions of the aquifer, and (5) area based on ¼-mile grid cells (Lupton and others, 2016, Table 12-2).**

	Volume of water (million acre-feet)				
Aquifer unit	**Fresh***	**Slightly saline***	**Moderately saline***	**Very saline***	**Total**
Collapse	0.09	5.53	0.21	0.00	5.83
Magenta	0.00	0.41	0.84	0.08	1.33
Culebra	0.00	2.39	3.49	0.14	6.02
Los Medaños	0.00	1.84	3.37	0.15	5.36
Rustler Aquifer	0.09	10.17	7.91	0.37	18.54

Notes:

Fresh = 0 to 999 milligrams per liter total dissolved solids
Slightly saline = 1,000 to 2,999 milligrams per liter total dissolved solids
Moderately saline = 3,000 to 9,999 milligrams per liter total dissolved solids
Very saline = 10,000 to 35,000 milligrams per liter total dissolved solids

Boghici and others (2014) estimated the volume of drainable Rustler Aquifer groundwater (total storage equals 4.92 million acre-feet) using the Total Estimated Recoverable Storage (TERS) method for Groundwater Management Area 4, which is similar to the technique used by Lupton and others (2016) shown in Table D-3. Lupton and others' (2016) estimate for Groundwater Management Area 4 is 3.40 million acre-feet. Both of these volume estimates used the cell grid from the TWDB's Rustler Aquifer groundwater availability model and a specific storage value of 0.03. Differences between the methodologies of the two included (1) values used for the top and bottom of the aquifer, (2) how to calculate the volume for the part of the Rustler Aquifer that does not have a model, and (3) the version of the Rustler Aquifer model used. For the Rustler Formation tops and bottoms, Boghici and others (2014) used the elevations and thicknesses from the Rustler Aquifer groundwater availability model (version 1.01). Lupton and others (2016) used elevations and thicknesses generated by splitting the Rustler Formation into water-bearing units based on members of the Rustler Formation. This resulted in a reduction in the total thickness used in volume calculations and most likely accounts for the difference in the estimated volumes. To address the lack of a model in parts of Brewster and Jeff David counties, both studies used GIS to calculate the area, treated the area as unconfined, and used a specific yield value of 0.03. However, Boghici and others (2014) applied a standard thickness of 50 feet and Lupton and others (2016) used a range of thickness values from the rasters they generated by making stratigraphic picks for the members of the Rustler Formation. Finally, Lupton and others (2016) used version 1.0 of the Rustler Aquifer groundwater model (Ewing and others,

2012) and Boghici and others (2014) used version 1.01. However, the differences in these two models would not have resulted in a significant difference in aquifer wide volume estimates.

The 1997 State Water Plan estimated that there could be 4,000 acre-feet of annual water use without impacting net storage (TWDB, 1997). In the 2017 State Water Plan, an annual groundwater existing supply of 2,521 acre-feet per year and annual groundwater availability of 15,222 acre-feet are anticipated from the Rustler Aquifer (TWDB, 2016a). For this project, the estimated annual volume from brackish groundwater production zones Rus1, Rus2, and Rus3 would be more than 15,000 acre-feet per year. The 2017 State Water Plan considered the entire aquifer, and it is extremely unlikely to impossible that the well efficiency needed to meet that volume for just the brackish groundwater production zones could be achieved.

LBG-Guyton Associates (2003) estimated the volume of slightly and moderately saline groundwater within the TWDB defined Rustler Aquifer to be 36.86 million acre-feet of water in place and 0.013 million acre-feet of water in the confined portions of the aquifer. This volume is substantially larger than the volume estimated by the contractor for slightly and moderately saline groundwater in the Rustler Aquifer (18.08 million acre-feet total drainable water). This variance is likely due to different values used for confined storativity, areal extent of saline zones, and the estimated thickness of water-bearing units. Since Lupton and others (2016) estimated volumes based on only water-bearing units for the majority of the project area, it is expected that their volume would be markedly less than volumes that considered the entire Rustler Formation.

Water quality

Rustler Aquifer water wells with water quality analyses are sparse and unevenly distributed. The majority of measurements are from the outcrop in Culberson County, southeast Reeves County, and northwest Pecos County. Total dissolved solids concentrations for the Rustler Aquifer within the project area range from 507 to more than 10,000 milligrams per liter (Figure D-6). The majority of measured total dissolved solids concentrations in the Rustler Aquifer range between 3,000 and 5,000 milligrams per liter. The contractor suspected wells with total dissolved solids greater than 10,000 milligrams per liter had been affected by water from deeper brine aquifers. The contractor excluded these samples for use in the project, including at least one sample that contained total dissolved solids at a concentration of 89,716 milligrams per liter.

Slightly saline groundwater (>1,000 to 3,000 milligrams per liter of total dissolved solids) accounts for approximately half (55 percent) of the groundwater in the Rustler Aquifer and is mainly present in the western and southern areas of the aquifer. Moderately saline groundwater (>3,000 to 10,000 milligrams per liter of total dissolved solids) accounts for the other half (43 percent) of the groundwater in the aquifer and is mainly present in the northern and eastern parts of the aquifer. Very saline groundwater (>10,000 to 35,000 milligrams per liter of total dissolved solids) constitutes approximately 2 percent of the groundwater in the Rustler Aquifer and mostly occurs in Loving County. Fresh groundwater in the Rustler Aquifer is rare (less than 1 percent) and the known water samples occur as a cluster in and near the outcrop of the Rustler Formation in Culberson County. Most of the fresh water samples in the project area are from wells installed in other aquifers such as the Pecos Valley Alluvium, Edwards-Trinity Plateau, Dockum, and Capitan Reef Complex. The contractor did not find groundwater of brine quality in quantities large enough to map on a regional scale in the Rustler Aquifer. There are few water quality measurements in the TWDB Groundwater Database for groundwater in the Rustler Formation that is outside of the TWDB-designated Rustler Aquifer boundary. These samples tend to be moderately to very saline.

Hydrogeologic barriers

Hydrogeologic barriers impede the flow of groundwater. Silts and clays in the Dewey Lake Formation overlie much of the Rustler Aquifer and serve as a hydrogeologic barrier at the top of the aquifer. Where the Dewey Lake Formation is absent or fractured, water could possibly travel between the Rustler Aquifer and overlying aquifers. The evaporites in the Salado Formation underlie much of the Rustler Aquifer and serve as a hydrogeologic barrier below the aquifer. Where the Salado Formation is absent, the Rustler Aquifer may exchange water with underlying aquifers. Major geologic structures in the area may also impede the flow of groundwater. We and the contractor used faults interpreted as structural hydrogeologic barriers in the Rustler Aquifer groundwater availability model in this project (Ewing and others, 2012). More pumping data on either side of these barriers is needed to determine the extent to which they restrict water movement.

Groundwater monitoring

House Bill 30 requires the TWDB to recommend reasonable monitoring to observe the effects of brackish groundwater production within the zone. The need for groundwater monitoring should be evaluated on a case-by-case basis considering the purpose of the monitoring, well field location, source aquifer, spatial relationships of salinity zone, and expected volume of groundwater withdrawal. For example, monitoring may not be required if only one or two wells are planned for development. Monitoring may include observing water levels in (1) overlying and underlying aquifers, (2) confining layers, and (3) locations lateral, updip, and downdip in the same geologic stratum. Monitoring could focus on water quality (for example, salinity changes) and quantity (for example, water-level changes). Monitoring may also include using existing well control or installing new monitor wells. Groundwater monitoring should focus on aquifers, where present, and on areas near existing use. Monitoring in adjacent confining units is recommended to determine the potential source of adjacent aquifer impact due to development in (1) adjacent aquifers or (2) the Rustler Aquifer. Monitoring is not required below the Rustler Aquifer because there are no known fresh or brackish aquifers in the region.

Groundwater monitoring in brackish groundwater production zone Rus1 in the Rustler Aquifer should focus on (1) areas overlain by one, none, or both the Pecos Valley and Edwards-Trinity (Plateau) aquifers, (2) aquifers in the area that may be adjacent to the Rustler Aquifer, including the Capitan Reef Complex Aquifer to the southwest, the Igneous Aquifer to the south, and the Dockum Aquifer to the east, and (3) areas near or in anticipated hydrogeologic barriers such as the distance between the zone and existing use, faults, and the overlying Dewey Lake Formation.

Groundwater monitoring in brackish groundwater production zone Rus2 in the Rustler Aquifer should focus on (1) parts overlain by the Edwards-Trinity (Plateau) Aquifer, (2) aquifers in the area that may be adjacent to the Rustler Aquifer such as the Igneous Aquifer to the west, (3) the Tessey Limestone, which is not a major or minor aquifer designated by the TWDB but is used for water supply in the area and could be located hydrogeologically adjacent to the Rustler Aquifer east of brackish groundwater production zone Rus2, and (4) areas near or in anticipated hydrogeologic barriers such as the distance between the zone and existing use, faults, and the overlying Dewey Lake Formation.

Groundwater monitoring in brackish groundwater production zone Rus3 for the Rustler Aquifer should focus on (1) parts overlain by either or both the Pecos Valley and the Edwards-Trinity (Plateau) aquifers, (2) aquifers in the area that may be adjacent to the Rustler Aquifer such as the Dockum Aquifer, which overlies most of the zone, and the Igneous Aquifer, which is present in the southwest corner, and (3) areas near or in anticipated hydrogeologic barriers such as the distance between the zone and existing use, faults, and the overlying Dewey Lake Formation.

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Map of west Texas. Rustler Aquifer in these counties: Culberson, Reeves, Loving, Ward, Jeff Davis, Pecos, and Brewster. Areas desingated as brackish groundwater production zones: Rus1 - Loving, Ward, Jeff Davis, and Reeves counties, Rus2 - Reeves, Jeff Davis, Brewster, and Pecos counties, Rus3 - Reeves and Pecos counties.

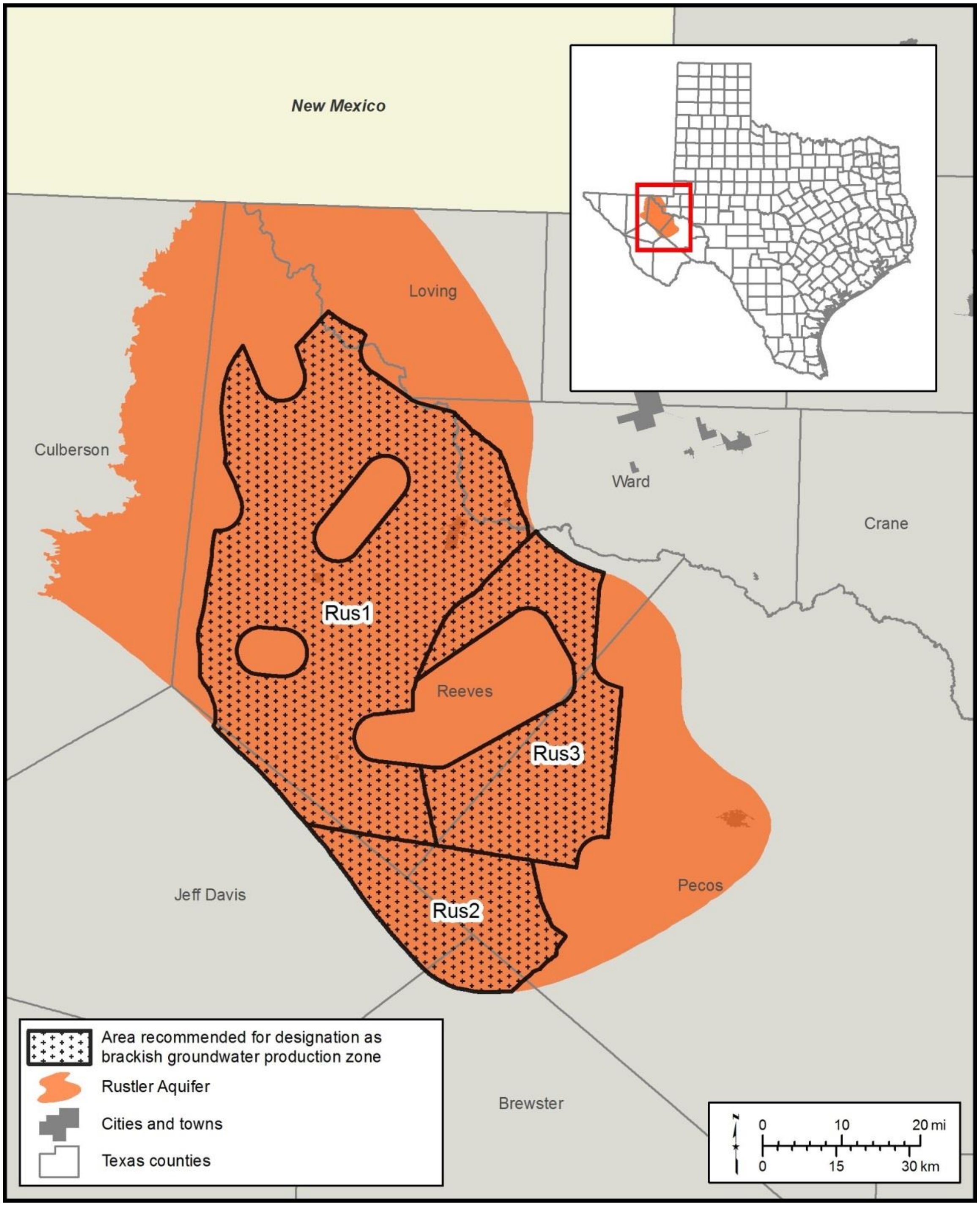

Figure D-1. **The TWDB designated three brackish groundwater production zones within the Rustler Aquifer (Rus1, Rus2, and Rus3). The zones contain slightly to moderately saline groundwater (1,000 to 9,999 milligrams per liter of total dissolved solids).**

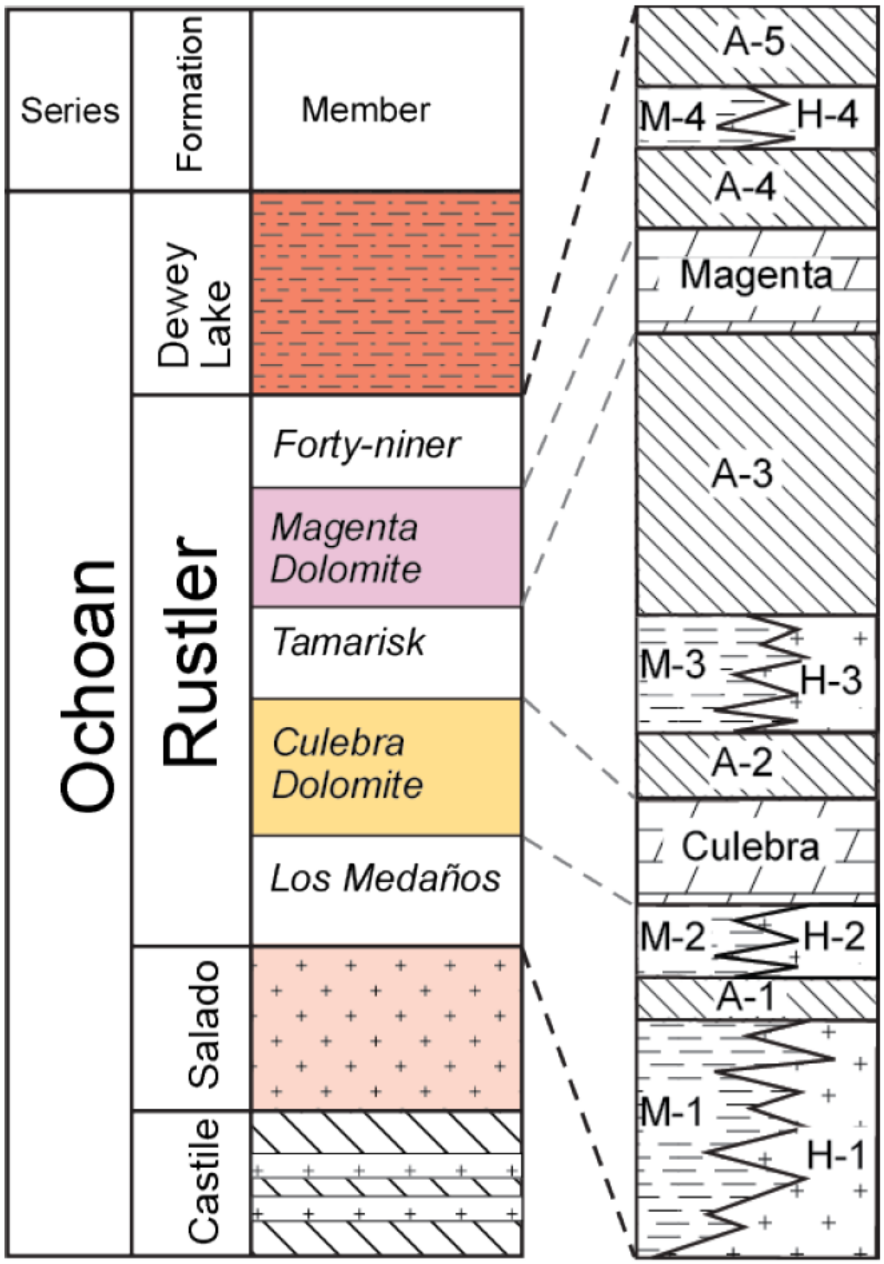

Figure D-2. **Stratigraphy of the Rustler Aquifer (Lupton and others, 2016). The Rustler Aquifer occurs in the Rustler Formation, which forms part of the Upper Permian Ochoan series in the Delaware Basin of West Texas and New Mexico. The Rustler Formation is subdivided into its members and informal submembers. For the informal submembers, "A" = anhydrite, "M" = mud, and "H" = halite. The Delaware Mountain Group occurs below the Castile Formation in the majority of the project area. Lateral equivalent units, mainly the Capitan/Goat Seep Reefs and members of the Artesia Group, occur beneath the Castile Formation in the southeastern portions of the project area.**

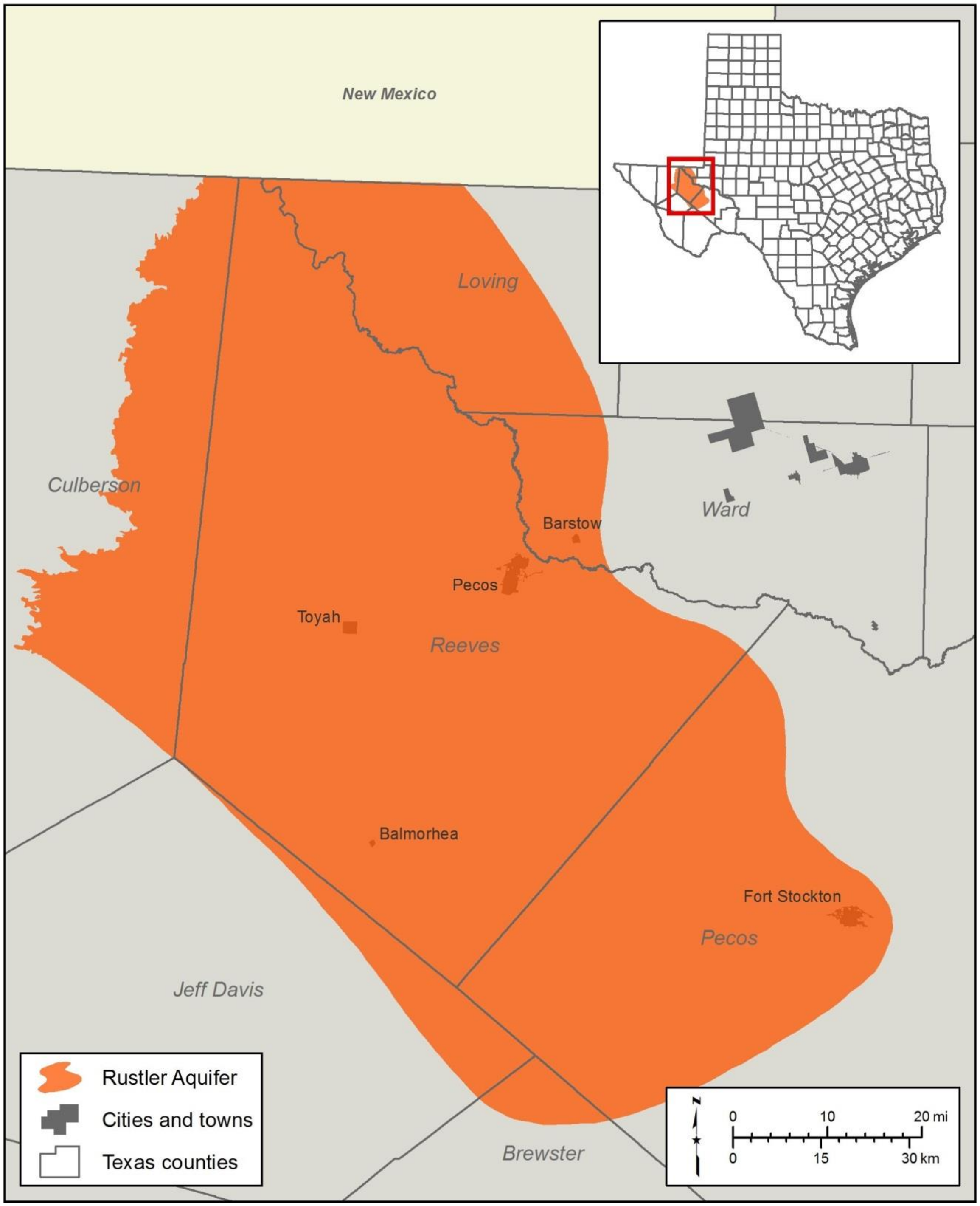

Figure D-3. **Towns, cities, and counties present in the TWDB defined Rustler Aquifer. The aquifer defined the project area.**

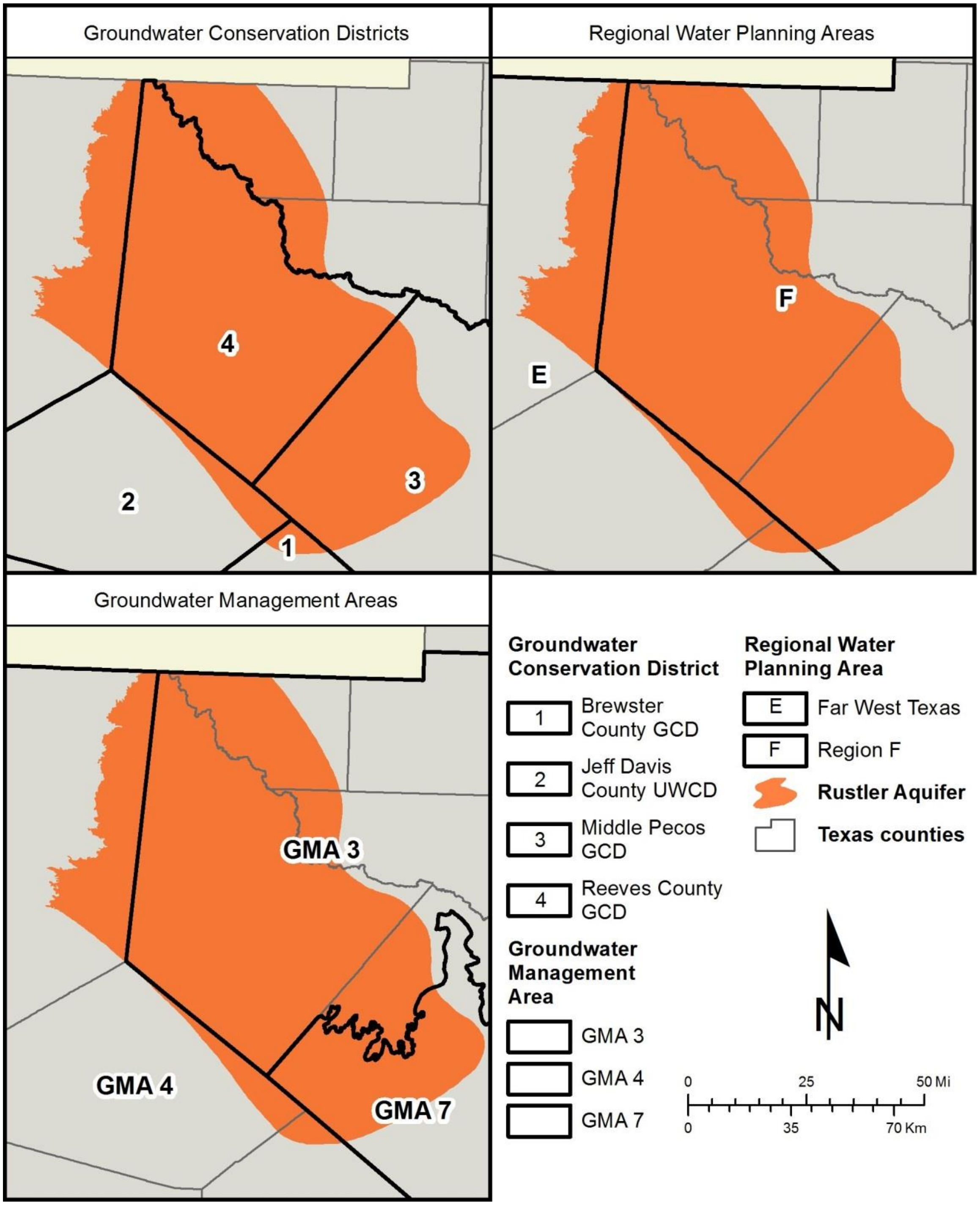

Figure D-4. **Groundwater conservation districts, regional water planning areas, and groundwater management areas in the Rustler Aquifer project area. Acronyms used: GCD = Groundwater Conservation District; GMA = Groundwater Management Area; UWCD = Underground Water Conservation District.**

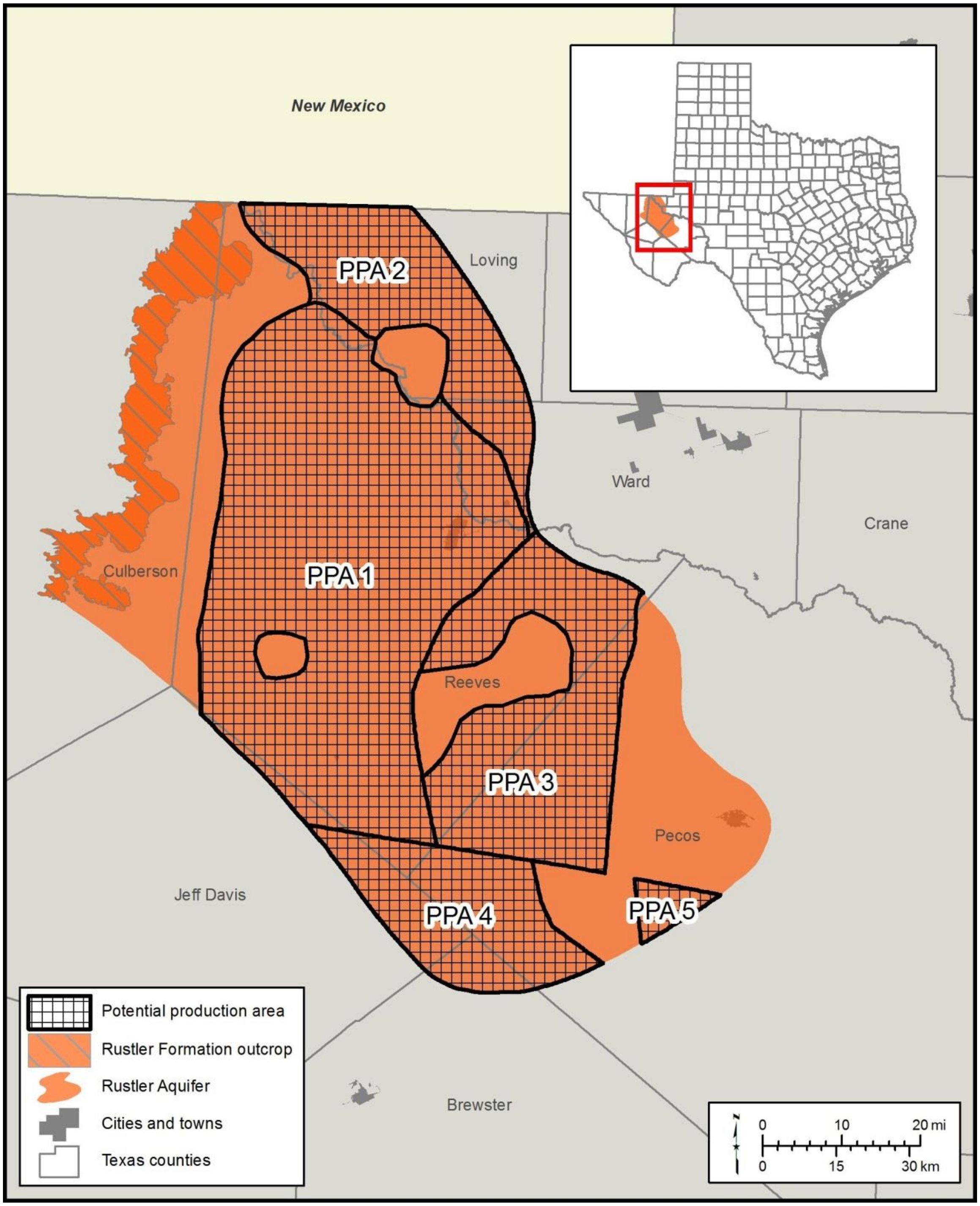

Figure D-5. **Rustler Aquifer potential production areas modeled by the contractor (Lupton and others, 2016).**

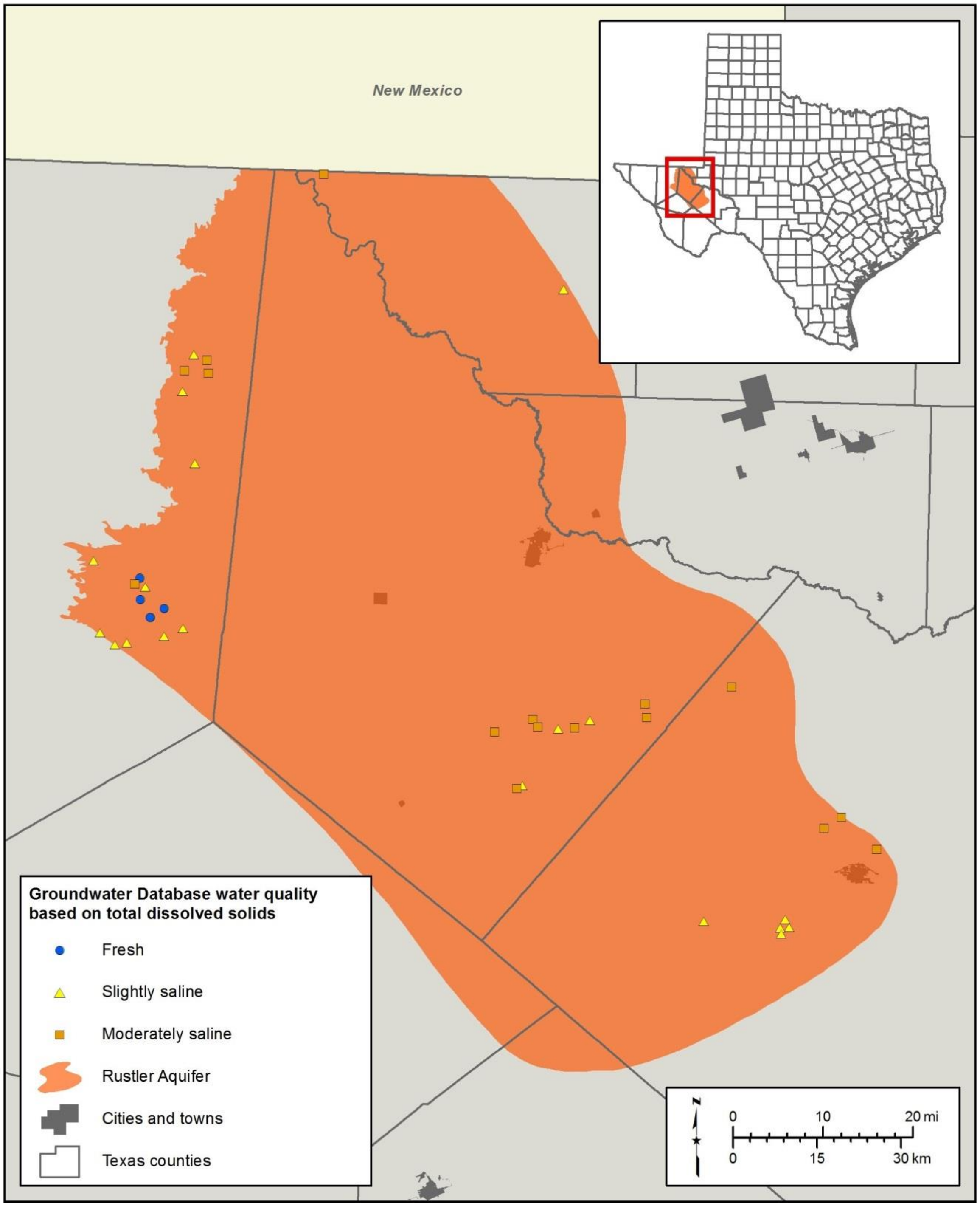

Figure D-6. Salinity (total dissolved solids) of water samples from the Rustler Aquifer based on the most recent samples in the TWDB Groundwater Database. Fresh (0 to 999 milligrams per liter total dissolved solids), slightly saline (1,000 to 2,999 milligrams per liter total dissolved solids), and moderately saline (3,000 to 9,999 milligrams per liter total dissolved solids).

Appendix E: Tables

Table E-1. Recommended water management strategies for seawater desalination in the 2017 State Water Plan.

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
H	Freeport seawater desalination	Manufacturing, Brazoria County	0	0	11,200	11,200	11,200	11,200
L	Integrated water-power project	Guadalupe Blanco River Authority*	-	-	-	-	-	-
L	Seawater desalination	San Antonio Water System*	-	-	-	-	-	-
L	Seawater desalination	San Antonio	0	0	12,319	23,337	37,364	48,278
L	Seawater desalination	San Antonio Water System	0	0	5,700	5,700	5,700	5,700
M	Brownsville seawater desalination	Brownsville	2,603	2,603	2,603	2,603	26,022	26,022
M	Brownsville seawater desalination	El Jardin Water Supply Corporation	108	108	108	108	1,081	1,081
M	Brownsville seawater desalination	Manufacturing, Cameron County	56	56	56	56	565	565
M	Brownsville seawater desalination	Steam electric power, Cameron County	33	33	33	33	332	332
N	Seawater desalination	Manufacturing, Nueces County	0	9,000	9,000	9,000	9,000	9,000
N	Seawater desalination	Manufacturing, San Patricio County	0	9,000	9,000	9,000	9,000	9,000
N	Seawater desalination	Steam electric power, Nueces County	0	4,420	4,420	4,420	4,420	4,420
		Total	**2,800**	**25,220**	**54,439**	**65,457**	**104,684**	**115,598**

Notes: *Unassigned water volumes to specific water user group.

Table E-2. Alternative water management strategies for seawater desalination in the 2017 State Water Plan.

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
M	Laguna Madre seawater desalination	Laguna Vista	390	390	390	390	390	390
M	Laguna Madre seawater desalination	Port Isabel	213	213	213	213	213	213
M	Laguna Madre seawater desalination	South Padre Island	517	517	517	517	517	517
M	RGRWA regional facility project – seawater desalination	Agua Supply Utility District	0	69	43	467	1,282	2,176
M	RGRWA Regional Facility Project – seawater Desalination	Alamo	183	147	137	475	1,017	1,508
M	RGRWA regional facility project – seawater desalination	Brownsville	0	0	31	1,224	4,222	7,864
M	RGRWA regional facility project – seawater desalination	Donna	0	15	40	201	502	822
M	RGRWA regional facility project – seawater desalination	East Rio Hondo Water Supply Corporation	0	5	40	209	557	925
M	RGRWA regional facility project – seawater desalination	Edinburg	762	623	571	1,957	4,222	6,202
M	RGRWA regional facility project – seawater desalination	Harlingen	0	0	68	564	1,686	2,981
M	RGRWA regional facility project – seawater desalination	Hidalgo	86	78	75	258	571	840
M	RGRWA regional facility project – seawater desalination	Hidalgo County Municipal Utility District #1	64	44	34	105	223	326
M	RGRWA regional facility project – seawater desalination	La Feria	0	5	12	64	167	274
M	RGRWA regional facility project – seawater desalination	Laguna Vista	183	123	102	338	711	1,028
M	RGRWA regional facility project – seawater desalination	McAllen	934	1,256	1,335	4,889	10,966	16,500
M	RGRWA regional facility project – seawater desalination	Mercedes	54	69	71	258	585	874

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
M	RGRWA regional facility project – seawater desalination	Military Highway Water Supply Corporation	236	201	189	669	1,463	2,193
M	RGRWA regional facility project – seawater desalination	Mission	1,428	1,094	975	3,278	6,995	10,177
M	RGRWA regional facility project – seawater desalination	North Alamo Water Supply Corporation	0	172	192	1,410	3,442	5,808
M	RGRWA regional facility project – seawater desalination	Olmito Water Supply Corporation	0	0	0	16	70	137
M	RGRWA regional facility project – seawater desalination	Pharr	4	201	258	1,015	2,397	3,684
M	RGRWA regional facility project – seawater desalination	Port Isabel	97	64	53	177	362	531
M	RGRWA regional facility project – seawater desalination	Rancho Viejo	0	0	0	0	28	86
M	RGRWA regional facility project – seawater desalination	San Benito	0	0	0	0	167	428
M	RGRWA regional facility project – seawater desalination	San Juan	376	280	242	846	1,825	2,690
M	RGRWA regional facility project – seawater desalination	Sharyland Water Supply Corporation	226	422	478	1,804	4,375	6,117
M	RGRWA regional facility project – seawater desalination	South Padre Island	236	162	137	443	934	1,371
M	RGRWA regional facility project – seawater desalination	Weslaco	601	442	385	1,281	2,731	3,958
		Total	**6,590**	**6,592**	**6,588**	**23,068**	**52,620**	**80,620**

Notes: RGRWA = Rio Grande Regional Water Authority

Table E-3 Groundwater desalination recommended water management strategies in the 2017 State Water Plan.

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
E	Additional groundwater wells - Rustler Aquifer	Mining, Culberson County	590	590	590	590	590	590
E	Additional groundwater well - West Texas Bolsons Aquifer	Mining, Culberson County	590	590	590	590	590	590
E	Dell City - brackish groundwater desalination facility	County-other, Hudspeth County	111	111	111	111	111	111
E	Brackish groundwater at the Jonathan Rogers Wastewater Treatment Plant	El Paso	0	0	11,000	11,000	11,000	11,000
E	Expansion of the Kay Bailey Hutchison Desalination Plant	El Paso	1,260	2,520	2,520	2,520	2,520	2,520
E	Hudspeth County Conservation and Reclamation District #1 - additional groundwater wells	Irrigation, Hudspeth County	230	230	230	230	230	230
E	Additional wells and expansion of desalination plant	Horizon City	0	1,457	3,195	4,923	6,562	8,107
E	Additional wells and expansion of desalination plant	Horizon Regional Municipal Utility District	8,652	8,652	8,652	8,652	8,652	8,652
	Additional wells and expansion of desalination plant	Horizon Regional Municipal Utility District	8,652	8,652	8,652	8,652	8,652	8,652
E	Mining - additional groundwater well	Mining, Hudspeth County	30	30	30	30	30	30
E	Groundwater from proposed well field – Rio Grande Alluvium Aquifer	Lower Valley Water District	6,800	6,800	6,800	6,800	6,800	6,800
F	Desalination of other aquifer supplies in Tom Green County	Concho Rural Water Supply Corporation	150	150	150	150	150	150
F	Desalination of other aquifer supplies	County-other, Tom Green County	0	0	0	96	105	115
F	Desalination of other aquifer supplies	Manufacturing, Tom Green County	0	0	0	312	366	425
F	Desalination of other aquifer supplies	San Angelo	0	0	0	2,928	2,600	2,973
F	Desalination of other aquifer supplies	San Angelo*	-	-	-	-	-	-

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
H	Brackish groundwater supplies	County-other, Montgomery County	0	0	0	0	3,622	10,000
H	Brackish groundwater supplies	Dobbin-Plantersville Water Supply Corporation	153	327	570	890	1,337	1,930
H	Conroe brackish groundwater desalination	Conroe	5,600	5,600	5,600	5,600	5,600	5,600
H	New / expanded contract with Brazosport Water Authority - brackish groundwater	County-other, Brazoria County	1,147	1,063	1,003	937	865	800
H	Panorama and Shenandoah Joint Group	Shenandoah	0	0	472	472	472	472
H	San Jacinto River Authority Catahoula Aquifer supplies	County-other, Montgomery County	3,920	3,920	3,920	3,920	3,920	3,920
H	San Jacinto River Authority Catahoula Aquifer supplies	Steam-electric power, Montgomery County	3,920	3,920	3,920	3,920	3,920	3,920
J	Livestock - additional groundwater wells	Livestock, Kinney County	22	22	22	22	22	22
L	Brackish Wilcox Aquifer groundwater	Canyon Regional Water Authority*	-	-	-	-	-	-
L	Brackish Wilcox Aquifer groundwater	County Line Water Supply Corporation	0	0	0	251	440	641
L	Brackish Wilcox Aquifer groundwater	Green Valley Special Utility District	0	0	0	0	0	619
L	Brackish Wilcox Aquifer groundwater	Alamo Heights	796	848	820	807	805	805
L	Brackish Wilcox Aquifer groundwater	Atascosa Rural Water Supply Corporation	1,167	1,446	1,708	1,970	2,218	2,448
L	Brackish Wilcox Aquifer groundwater	County-other, Bexar County	0	0	0	1,898	2,113	1,823
L	Brackish Wilcox Aquifer groundwater	Kirby	137	207	181	172	169	169
L	Brackish Wilcox Aquifer groundwater	Leon Valley	97	147	196	254	317	377
L	Brackish Wilcox Aquifer groundwater	San Antonio	3,425	2,974	2,717	521	0	0
L	Brackish Wilcox Aquifer groundwater	S S Water Supply Corporation	0	0	0	0	0	234
L	Brackish Wilcox Aquifer groundwater	Schertz-Seguin Local Government Corporation*	-	-	-	-	-	-

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
L	Expanded brackish Wilcox Aquifer groundwater	San Antonio Water System*	-	-	-	-	-	-
M	Alamo brackish groundwater desalination plant	Alamo	1,000	1,000	1,000	1,000	1,000	1,000
M	El Jardin new brackish groundwater desalination plant	El Jardin Water Supply Corporation	560	560	560	560	560	560
M	Hebbronville new brackish groundwater desalination plant	Hebbronville	560	560	560	560	560	560
M	La Feria water well with reverse osmosis unit	La Feria	1,120	1,120	1,120	1,120	1,120	1,120
M	Laguna Madre new brackish groundwater desalination plant	Laguna Vista	780	780	780	780	780	780
M	Laguna Madre new brackish groundwater desalination plant	Manufacturing, Cameron County	1	1	1	1	1	1
M	Laguna Madre new brackish groundwater desalination plant	Port Isabel	425	425	425	425	425	425
M	Laguna Madre new brackish groundwater desalination plant	South Padre Island	1,034	1,034	1,034	1,034	1,034	1,034
M	Lyford brackish groundwater well and desalination	Lyford	1,120	1,120	1,120	1,120	1,120	1,120
M	McAllen brackish groundwater desalination plant	McAllen	2,688	2,688	2,688	2,688	2,688	2,688
M	Mission brackish groundwater desalination plant	Mission	2,688	2,688	2,688	2,688	2,688	2,688
M	North Alamo Water Supply Corporation delta area reverse osmosis water treatment plant expansion	County-other, Hidalgo County	0	0	0	0	2	2
M	North Alamo Water Supply Corporation delta area reverse osmosis water treatment plant expansion	Edinburg	0	0	0	0	4	4
M	North Alamo Water Supply Corporation delta area reverse osmosis water treatment plant expansion	Military Highway Water Supply Corporation	0	0	0	0	1	1

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
M	North Alamo Water Supply Corporation delta area reverse osmosis water treatment plant	North Alamo Water Supply Corporation	0	0	0	0	1,410	1,410
M	North Alamo Water Supply Corporation delta area reverse osmosis water treatment plant expansion	Primera	0	0	0	0	4	4
M	North Alamo Water Supply Corporation delta area reverse osmosis water treatment plant expansion	San Juan	0	0	0	0	800	800
M	North Alamo Water Supply Corporation delta area reverse osmosis water treatment plant expansion	San Perlita	0	0	0	0	19	19
M	North Alamo Water Supply Corporation La Sara reverse osmosis plant expansion	County-other, Hidalgo County	0	0	0	0	0	37
M	North Alamo Water Supply Corporation La Sara reverse osmosis plant expansion	Edinburg	0	0	0	0	0	2
M	North Alamo Water Supply Corporation La Sara reverse osmosis plant expansion	Manufacturing, Hidalgo County	0	0	0	0	0	1
M	North Alamo Water Supply Corporation La Sara reverse osmosis plant expansion	Manufacturing, Willacy County	0	0	0	0	0	1
M	North Alamo Water Supply Corporation La Sara reverse osmosis plant expansion	Military Highway Water Supply Corporation	0	0	0	0	0	1
M	North Alamo Water Supply Corporation La Sara reverse osmosis plant expansion	North Alamo Water Supply Corporation	0	0	0	0	0	997
M	North Alamo Water Supply Corporation La Sara reverse osmosis plant expansion	Primera	0	0	0	0	0	2
M	North Alamo Water Supply Corporation La Sara reverse osmosis plant expansion	San Juan	0	0	0	0	0	70

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
M	North Alamo Water Supply Corporation La Sara reverse osmosis plant expansion	San Perlita	0	0	0	0	0	9
M	North Cameron regional water treatment plant wellfield expansion	County-other, Hidalgo County	1	1	1	1	1	1
M	North Cameron regional water treatment plant wellfield expansion	Edinburg	1	1	1	1	1	1
M	North Cameron regional water treatment plant wellfield expansion	Manufacturing, Hidalgo County	160	160	160	160	160	160
M	North Cameron regional water treatment plant wellfield expansion	Manufacturing, Willacy County	85	85	85	85	85	85
M	North Cameron regional water treatment plant wellfield expansion	Primera	1	1	1	1	1	1
M	North Cameron regional water treatment plant wellfield expansion	San Juan	52	52	52	52	52	52
M	North Cameron regional water treatment plant wellfield expansion	San Perlita	7	7	7	7	7	7
M	Primera reverse osmosis plant with well	Primera	1,120	1,120	1,120	1,120	1,120	1,120
M	San Juan water treatment plant upgrade and expansion to include brackish groundwater desalination	San Juan	1,792	1,792	1,792	1,792	1,792	1,792
M	Sharyland Water Supply Corporation well and reverse osmosis unit at water treatment plant #2	Alton	189	189	189	189	189	189
M	Sharyland Water Supply Corporation well and reverse osmosis unit at water treatment plant #2	Palmhurst	90	90	90	90	90	90
M	Sharyland Water Supply Corporation well and reverse osmosis unit at water treatment plant #2	Sharyland Water Supply Corporation	621	621	621	621	621	621
M	Sharyland Water Supply Corporation well and reverse osmosis unit at water treatment plant #3	Alton	171	171	171	171	171	171

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
M	Sharyland Water Supply Corporation well and reverse osmosis unit at water treatment plant #3	Palmhurst	72	72	72	72	72	72
M	Sharyland Water Supply Corporation well and reverse osmosis unit at water treatment plant #3	Sharyland Water Supply Corporation	657	657	657	657	657	657
M	Union Water Supply Corporation brackish groundwater desalination plant	Union Water Supply Corporation	560	560	560	560	560	560
N	Brackish groundwater development - Alice	Alice	3,363	3,363	3,363	3,363	3,363	3,363
O	Gaines County - Seminole groundwater desalination	Seminole	500	500	500	500	500	500
O	Hale County - Abernathy groundwater desalination	Abernathy	150	150	150	150	150	150
O	Lubbock County - Lubbock brackish well field at the south water treatment plant	Lubbock	1,120	1,120	1,120	1,120	1,120	1,120
P	Lavaca Navidad River Authority desalination - brackish groundwater	Lavaca Navidad River Authority*	-	-	-	-	-	-
		Total	**70,137**	**72,944**	**86,337**	**91,906**	**99,706**	**110,773**

Notes: *Unassigned water volumes to specific water user group

Table E-4. Groundwater desalination alternative water management strategies in the 2017 State Water Plan.

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
F	Midland - development of groundwater in Midland County (previously used for mining)	Midland*	-	-	-	-	-	-
F	Odessa - develop Capitan Reef Complex Aquifer supplies in Ward County	Odessa*	-	-	-	-	-	-
F	Odessa - develop Edwards-Trinity and Capitan Reef Complex Aquifer supplies in Pecos County - I & II	Odessa*	-	-	-	-	-	-
K	City of Austin – brackish groundwater desalination	Austin	0	5,000	5,000	5,000	5,000	5,000
K	Brackish groundwater desalination	Lower Colorado River Authority*	-	-	-	-	-	-
L	Brackish Wilcox	SS Water Supply Corporation	0	0	0	0	0	1,120
L	Brackish Wilcox groundwater	San Antonio Water System*	-	-	-	-	-	-
L	Brackish Wilcox groundwater	Canyon Regional Water Authority*	-	-	-	-	-	-
L	Expanded brackish project	San Antonio Water System*	-	-	-	-	-	-
L	Brackish Wilcox	Schertz-Seguin Local Government Corporation*	-	-	-	-	-	-
M	New brackish groundwater desalination plant	Agua Supply Utility District	0	0	0	1,212	1,212	1,212
M	Agua Supply Utility District new brackish groundwater desalination plant	County-other, Hidalgo County	0	0	0	14	14	14
M	Agua Supply Utility District new brackish groundwater desalination plant	La Joya	0	0	0	40	40	40
M	Agua Supply Utility District new brackish groundwater desalination plant	Mission	0	0	0	7	7	7
M	Agua Supply Utility District new brackish groundwater desalination plant	Palmview	0	0	0	160	160	160
M	Agua Supply Utility District new brackish groundwater desalination plant	Penitas	0	0	0	130	130	130
M	Agua Supply Utility District new brackish groundwater desalination plant	Sullivan City	0	0	0	117	117	117

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
M	New brackish groundwater desalination plant	Combes	0	0	0	125	125	125
M	New brackish groundwater desalination plant	Donna	700	700	700	1,000	1,000	1,000
M	New brackish groundwater desalination plant	Eagle Pass	0	0	0	560	560	560
M	New brackish groundwater desalination plant	Elsa	560	560	560	560	560	560
M	Harlingen new brackish groundwater desalination plant	Combes	0	0	21	21	21	21
M	Harlingen new brackish groundwater desalination plant	County-other, Cameron County	0	0	10	10	10	10
M	Harlingen new brackish groundwater desalination plant	East Rio Hondo Water Supply Corporation	0	0	14	14	14	14
M	New brackish groundwater desalination plant	Harlingen	0	0	888	888	888	888
M	Harlingen new brackish groundwater desalination plant	Manufacturing, Cameron County	0	0	12	12	12	12
M	Harlingen new brackish groundwater desalination plant	Military Highway Water Supply Corporation	0	0	9	9	9	9
M	Harlingen new brackish groundwater desalination plant	Palm valley	0	0	19	19	19	19
M	Harlingen new brackish groundwater desalination plant	Primera	0	0	26	26	26	26
M	New brackish groundwater desalination plant	La Villa	560	560	560	560	560	560
M	New brackish groundwater desalination plant	Laredo	0	0	0	5,000	5,000	5,000
M	New brackish groundwater desalination plant	Mercedes	0	0	435	435	435	435
M	New brackish groundwater desalination plant	Olmito Water Supply Corporation	560	560	560	560	560	560
M	Rio Grande City new brackish groundwater desalination plant	County-other, Starr County	0	43	43	43	43	43
M	New brackish groundwater desalination plant	Rio Grande City	0	469	469	469	469	469
M	Rio Grande City new brackish groundwater desalination plant	Rio Water Supply Corporation	0	48	48	48	48	48

Region	Water management strategy	Water user group	Water supplies by decade (acre-feet per year)					
			2020	2030	2040	2050	2060	2070
M	New brackish groundwater desalination plant	Santa Rosa	0	560	560	560	560	560
M	Valley Municipal Utility District 2 new brackish groundwater desalination plant	Brownsville	0	0	0	0	10	10
M	Valley Municipal Utility District 2 new brackish groundwater desalination plant	County-other, Cameron County	0	0	0	0	3	3
M	Valley Municipal Utility District 2 new brackish groundwater desalination plant	Rancho Viejo	0	0	0	0	87	87
M	New brackish groundwater desalination plant	Weslaco	0	1,630	1,630	1,630	1,630	1,630
N	Brackish groundwater desalination - regional	Manufacturing, Nueces County	0	0	4,000	4,000	4,000	4,000
N	Brackish groundwater desalination - regional	Manufacturing, San Patricio County	0	0	4,000	4,000	4,000	4,000
N	Brackish groundwater desalination - regional	Steam-electric power, Nueces County	0	0	4,000	4,000	4,000	4,000
		Total	**2,380**	**10,130**	**23,564**	**31,229**	**31,329**	**32,449**

Notes: *Unassigned water volumes to specific water user group