Explanatory Report for Desired Future Conditions *(Final)*
Groundwater Management Area 4

Prepared for:

Groundwater Management Area 4

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Table of Contents

List of Tables

List of Figures

Appendices

Appendix A – Resolution Adopting Desired Future Conditions and Posted Agendas
Appendix B – Total Estimated Recoverable Storage Report (TWDB Task 13-028)
Appendix C – Region E Socioeconomic Report
Appendix D – Igneous Aquifer Groundwater Uses and Demands
Appendix E – West Texas Bolsons Groundwater Uses and Demands

1.0 Groundwater Management Area 4

1.1 Background and Setting

Groundwater Management Area 4 is one of sixteen groundwater management areas in Texas, and covers Far West Texas, except for a portion of Hudspeth County and most of El Paso County (Figure 1). Groundwater Management Area 4 covers all or portions of the following counties: Brewster, Culberson, Hudspeth, Jeff Davis, and Presidio (Figure 2).

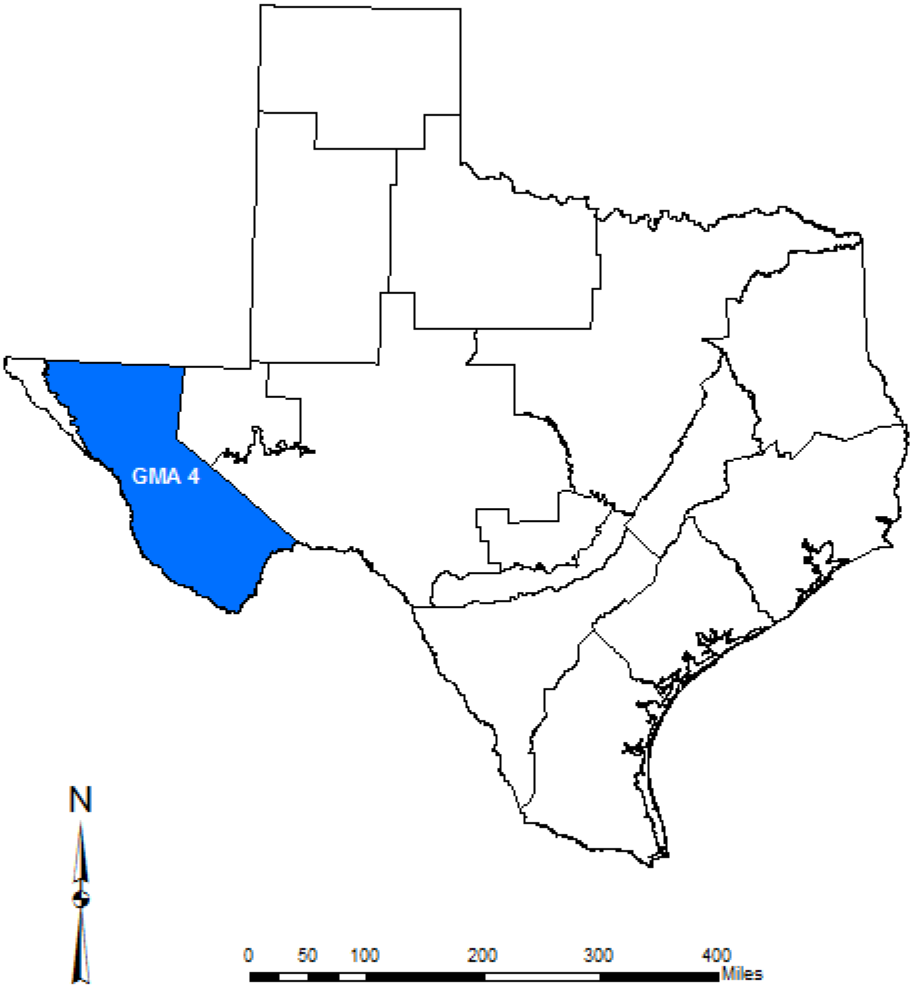


Figure 1. Groundwater Management Area 4

Figure 2. Counties in Groundwater Management Area 4

There are five groundwater conservation districts in Groundwater Management Area 4: Brewster County Groundwater Conservation District, Culberson County Groundwater Conservation District, Hudspeth County Underground Water Conservation District No. 1, Jeff Davis Underground Water Conservation District, and Presidio Underground Water Conservation District (Figure 3).

Figure 3. Groundwater Conservation Districts in GMA 4

As designated by the Texas Water Development Board, the following named aquifers occur in Groundwater Management Area 4:

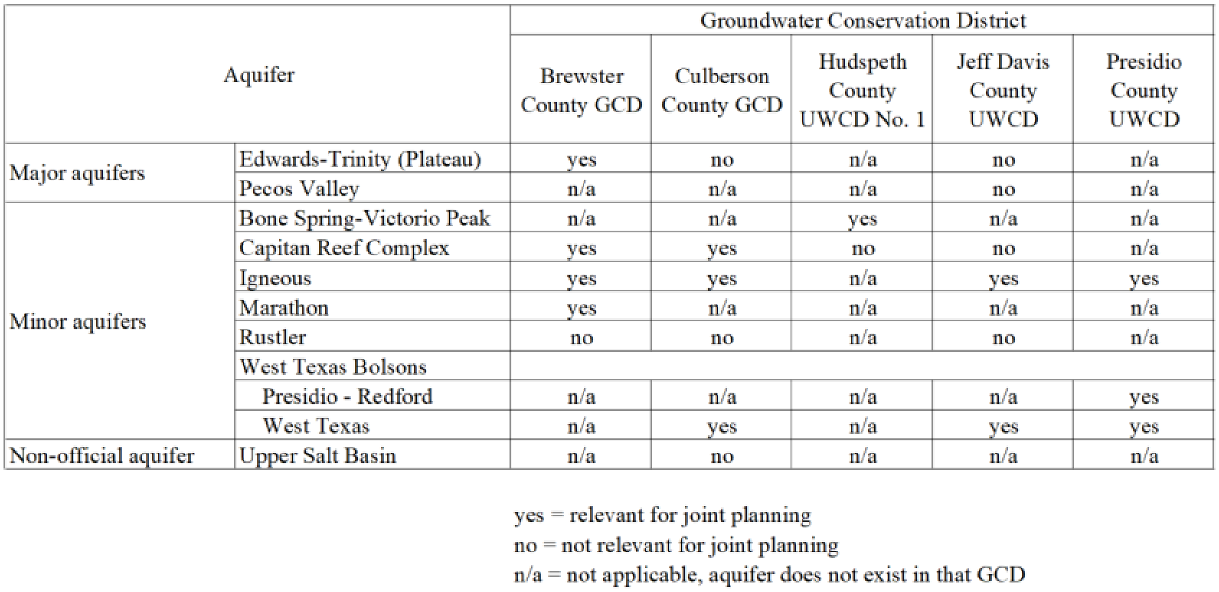
- Major Aquifers
  - Edwards-Trinity (Plateau)
  - Pecos Valley
- Minor Aquifers
  - Bone Spring-Victorio Peak
  - Capitan Reef Complex
  - Igneous
  - Marathon
  - Rustler
  - West Texas Bolsons
    - Salt Basin
    - Presidio-Redford Bolson

The Presidio-Redford Bolson in Presidio County and the Salt Basin were recognized by GMA 4 as subdivisions of the West Texas Bolsons Aquifer for purposes of joint planning. The Upper Salt Basin had been classified as a relevant aquifer by GMA 4. The Upper Salt Basin is in Culberson County just north of the boundary of the West Texas Bolsons Aquifer. However, in 2016, this aquifer was classified as not relevant for purposes of joint planning.

As part of his technical assistance efforts with Groundwater Management Area 4, Robert Bradley, of the Texas Water Development Board, prepared a summary table that showed what aquifers were present in each district, and, if present, if they were considered relevant for purposes of joint planning in 2010 and in 2016. A modified version of the summary table is presented as Table 1.

Please note that the aquifers that are considered not relevant for purposes of joint planning in all of Groundwater Management Area 4 are the Pecos Valley, Rustler Aquifer, and the Upper Salt Basin. All other aquifers are relevant in at least one groundwater conservation district.

Table 1. Summary of Relevant and Non-Relevant Aquifers in Each GCD



Aquifer		Groundwater Conservation District				
		Brewster County GCD	Culberson County GCD	Hudspeth County UWCD No. 1	Jeff Davis County UWCD	Presidio County UWCD
Major aquifers	Edwards-Trinity (Plateau)	yes	no	n/a	no	n/a
	Pecos Valley	n/a	n/a	n/a	no	n/a
Minor aquifers	Bone Spring-Victorio Peak	n/a	n/a	yes	n/a	n/a
	Capitan Reef Complex	yes	yes	no	no	n/a
	Igneous	yes	yes	n/a	yes	yes
	Marathon	yes	n/a	n/a	n/a	n/a
	Rustler	no	no	n/a	no	n/a
	West Texas Bolsons					
	Presidio - Redford	n/a	n/a	n/a	n/a	yes
	West Texas	n/a	yes	n/a	yes	yes
Non-official aquifer	Upper Salt Basin	n/a	no	n/a	n/a	n/a

yes = relevant for joint planning
no = not relevant for joint planning
n/a = not applicable, aquifer does not exist in that GCD

1.2 Overview of Joint Planning Process and Report

During the second round of joint planning, discussion, and consideration of the various statutory factors by GMA 4 occurred over several meetings between June 19, 2014 and March 31, 2016. Because these discussions were common to all aquifers and some of the discussion involved classifying relevant and non-relevant aquifers for purposes of joint planning, Section 3 of this report summarizes the discussion at each meeting. This information is then useful to place in context the items as they are discussed in sections that discuss individual aquifers or groups of aquifers in Sections 4 to 10 of this report.

The groundwater conservation districts in Groundwater Management Area 4 have decided that there is no compelling reason to modify the desired future conditions for this third round of joint planning. The groundwater conservation districts in Groundwater Management Area 4 have also decided to begin to consider in detail the need to modify and update desired future conditions for the next round of joint planning (i.e. 2026). There is a stated commitment to begin the review process in late 2021 and early 2022 to carefully consider any changes and develop them in a transparent manner.

Section 4 of this report cover aquifers that are not relevant for purposes of joint planning. For each of the "non-relevant" aquifers (Pecos Valley, Rustler and Upper Salt Basin), the discussion covers the items required by TWDB as supporting documentation to classify these aquifers as not relevant for purposes of joint planning. This includes:

- Maps of the aquifer extent.
- Summary of aquifer characteristics, demands, and historic uses, including total recoverable storage.
- An explanation of why the aquifer is not relevant for purposes of joint planning.

The relevant aquifers for which desired future conditions have been adopted is organized as follows:

- Section 5: Bone Spring-Victorio Peak Aquifer
- Section 6: Capitan Reef Complex Aquifer
- Section 7: Edwards-Trinity (Plateau) Aquifer
- Section 8: Igneous and the Salt Basin portion of the West Texas Bolsons aquifers
- Section 9: Marathon Aquifer
- Section 10: Presidio-Redford Bolson subdivision of the West Texas Bolsons Aquifer

The Igneous and Salt Basin portion of the West Texas Bolsons Aquifer are combined because the aquifers are in communication with each other, and a single groundwater availability model was used in the development of the desired future conditions.

Sections 5 to 10 are further subdivided to cover the required elements of the explanatory report based on guidance from the TWDB:

- Policy Justification
- Technical Justification
- Factor Consideration
    - Aquifer Uses and Conditions
    - Water Supply Needs and Water Management Strategies
    - Hydrologic Conditions
        - Total Estimated Recoverable Storage
        - Average Annual Recharge, Inflows, and Discharge
    - Other Environmental Impacts
    - Subsidence
    - Socioeconomic Impacts
    - Impact on Private Property Rights
    - Feasibility of Achieving the Desired Future Conditions
    - Other Information
- Discussion of Other Desired Future Conditions Considered

The required discussion of public comments is presented in Section 11.

2.0 Desired Future Conditions History

2.1 2016 Desired Future Conditions

Desired future conditions were proposed at the GMA 4 meeting of March 31, 2016. The districts received comments during a 90-day period following voting to propose the desired future conditions. On September 20, 2017, the groundwater conservation districts in GMA 4 adopted the desired future conditions without change from the proposed desired future conditions as follows:

Brewster County GCD: **for the period from 2010-2060**
3-ft drawdown for the Edwards-Trinity (Plateau) Aquifer
10-ft drawdown for the Igneous Aquifer
0-ft drawdown for the Marathon Aquifer
0-ft drawdown for the Capitan Reef Complex
The Rustler was classified as non-relevant for joint planning purposes.

Culberson County GCD: for the period from 2010-2060
50-ft drawdown for the Capitan Reef Complex
78-ft drawdown for the Salt Basin portion of the West Texas Bolsons
66-ft drawdown for the Igneous Aquifer
The Edwards Trinity (Plateau) and Upper Salt Basin were classified as non-relevant for joint planning purposes.

Hudspeth County UWCD No. 1:
0-ft drawdown for the period from 2010 until 2060 for the Bone Springs-Victorio Peak Aquifer, averaged across the portion of the aquifer within the boundaries of the District.
The Capitan Reef has been deemed not relevant for joint planning purpose.

Jeff Davis County UWCD: for the period from 2010-2060
20-ft drawdown for the Igneous Aquifer
72-ft drawdown for the Salt Basin portion of the West Texas Bolsons
The Edwards-Trinity (Plateau), Pecos Valley Aquifer, Capitan Reef Complex, and the Rustler were classified as non-relevant for joint planning purposes.

Presidio County UWCD: for the period from 2010-2060
14-ft drawdown for the Igneous Aquifer
72-ft drawdown for the Salt Basin of the West Texas Bolsons
72-ft drawdown for the Presidio-Redford Bolson

2.2 2021 Desired Future Conditions

After considering the nine statutory factors and after reviewing groundwater monitoring data for the last several years, the groundwater conservation districts in Groundwater Management Area 4 decided that there was no need to modify the desired future conditions adopted in 2016. For completeness, they are repeated below:

Brewster County GCD: for the period from 2010-2060
3-ft drawdown for the Edwards-Trinity (Plateau) Aquifer
10-ft drawdown for the Igneous Aquifer
0-ft drawdown for the Marathon Aquifer
0-ft drawdown for the Capitan Reef Complex
The Rustler was classified as non-relevant for joint planning purposes.

Culberson County GCD: for the period from 2010-2060
50-ft drawdown for the Capitan Reef Complex
78-ft drawdown for the Salt Basin portion of the West Texas Bolsons
66-ft drawdown for the Igneous Aquifer
The Edwards Trinity (Plateau) and Upper Salt Basin were classified as non-relevant for joint planning purposes.

Hudspeth County UWCD No. 1:
0-ft drawdown for the period from 2010 until 2060 for the Bone Springs-Victorio Peak Aquifer, averaged across the portion of the aquifer within the boundaries of the District.
The Capitan Reef has been deemed not relevant for joint planning purpose.

Jeff Davis County UWCD: for the period from 2010-2060
20-ft drawdown for the Igneous Aquifer
72-ft drawdown for the Salt Basin portion of the West Texas Bolsons
The Edwards-Trinity (Plateau), Pecos Valley Aquifer, Capitan Reef Complex, and the Rustler were classified as non-relevant for joint planning purposes.

Presidio County UWCD: for the period from 2010-2060
14-ft drawdown for the Igneous Aquifer
72-ft drawdown for the Salt Basin of the West Texas Bolsons
72-ft drawdown for the Presidio-Redford Bolson

The groundwater conservation districts in Groundwater Management Area 4 voted to propose these desired future conditions on February 3, 2021.

After a 90-day public comment period, the groundwater conservation districts in Groundwater Management Area 4 voted to adopt the desired future conditions on June 17, 2021. A copy of the resolution is presented in Appendix A. The posted agendas for the Groundwater Management Area 4 meeting of June 21, 2021 are also included in Appendix A.

3.0 Summary of GMA 4 Meeting Discussions Related to Statutory Factors

Discussion and consideration of the various statutory factors by GMA 4 occurred over several meetings between June 19, 2014 and March 31, 2016. Because these discussions were common to all aquifers and some of the discussion involved classifying relevant and non-relevant aquifers for purposes of joint planning, this section of the report summarizes the discussion at each meeting. This information is then useful to place in context the items as they are discussed in sections that discuss individual aquifers or groups of aquifers in Sections 4 to 10 of this report. The summaries were developed from the approved meeting minutes.

3.1 GMA 4 Meeting of June 19, 2014

This was an organizational meeting in which the groundwater conservation districts prioritized the factor discussion for the next meeting. At the next meeting, the groundwater conservation districts planned to discuss environmental impacts, socioeconomic impacts, and private property impacts.

3.2 GMA 4 Meeting of November 20, 2014

At this meeting, aquifer uses and conditions, and water supply needs were discussed with Robert Bradley of the TWDB. In addition, the groundwater conservation districts agreed to focus attention on classifying aquifers as relevant and non-relevant.

3.3 GMA 4 Meeting of January 29, 2015

At this meeting, the following factors were discussed:

- Aquifer uses or conditions within the management area, including conditions that differ substantially from one geographic area to another;
    - For each aquifer, subdivision of an aquifer, or geologic strata
    - For each geographic area overlying an aquifer

- The water supply needs and water management strategies included in the state water plan;

- Hydrological conditions, including for each aquifer in the management area the total estimated recoverable storage as provided by the executive administrator, and the average annual recharge, inflows, and discharge;

- Other environmental impacts, including impacts on spring flow and other interactions between groundwater and surface water

The groundwater conservation districts also discussed:

- Relevant and Non- Relevant Aquifers presented during the last planning process
- Possible changes that will be made during this planning cycle
- DFC rate and drawdown
- Model Runs completed in 2010 and their applicability to the current round of joint planning

For the next meeting, each groundwater conservation district would return to the next meeting with board approved Relevant and Non-Relevant Aquifers for group planning purposes.

3.4 GMA 4 Meeting of April 30, 2015

At this meeting, each groundwater conservation district reported on individual Board action on classifying relevant and non-relevant aquifers as follows:

- Jeff Davis County- Approved by Board March 12, 2015; No Change
- Hudspeth County- Approved by Resolution; No Change
- Brewster County- Approved by Minutes; All Aquifers Relevant
- Culberson County- Approved by Resolution; Capitan, Igneous, and West Texas Bolsons deemed Relevant
- Presidio County- Stated that all are Relevant; however, no approval by Minutes or Resolution

There was also discussion of the following statutory factors:

- Subsidence: Not applicable for GMA 4
- Socioeconomic impacts: Because the MAG provides sufficient water to meet all needs in Region E, there are no impacts associated with not meeting the Regional Water Plan.
- Private property rights: The districts recognize Water Code Section 36.002, and can curb production and encourage conservation. This discussion on this factor will also occur at the next meeting
- Feasibility of achieving the DFC: Robert Bradley of the TWDB will provide more detail in future meetings since this discussion was linked to simulations with the GAMs

3.5 GMA 4 Meeting of September 17, 2015

At this meeting, each groundwater conservation district reported on individual Board action on classifying relevant and non-relevant aquifers as follows:

- Jeff Davis County- Approved by Board March 12, 2015; No Change
- Hudspeth County- Approved by Resolution; No Change
- Brewster County- Approved by Minutes; All Aquifers Relevant
- Culberson County- Approved by Resolution; Capitan, Igneous, and West Texas Bolsons deemed Relevant
- Presidio County- Stated that all are Relevant; however, no approval by Minutes or Resolution

The discussion of the impacts and interests and rights in private property and balancing the highest possible use and conservation continued and will be a reoccurring item on future agendas "until all are satisfied".

The discussion on the feasibility of achieving the desired future conditions was focused on a discussion with Robert Bradley of the TWDB regarding model runs.

Other information relevant to desired future conditions was reported as follows:

- Presidio County GCD- Did not have available at this time
- Jeff Davis UWCD- Submitted by adopted minutes
- Hudspeth County UWCD- Did not have available at this time
- Culberson County GCD- Submitted by resolution
- Brewster County GCD- Did not have available at this time

Finally, there was a discussion with public participation on modeled available groundwater (MAG). Specifically, there was a concern regarding reliance on the MAG in situations where there is limited information and that it would limit private property rights. There was general agreement by the groundwater conservation districts on this point. Robert Bradley of TWDB stated that the total estimated recoverable storage is an important number, but "does not take into consideration what would have to be done to actually get the water".

3.6 GMA 4 Meeting of January 14, 2016

At this meeting, Jeff Davis County UWCD shared proposed statements regarding private property and socioeconomic factor consideration. There were also discussions of achieving desired future conditions and the timeline to vote for proposed desired future conditions.

3.7 GMA 4 Meeting of February 18, 2016

At this meeting, Robert Bradley of TWDB provided an overview of the process. Items still pending were discussed. There was discussion of how to accurately state base line year for planning and the how to express uncertainty. In addition, the 90-day public comment period and public hearing process was discussed.

It was agreed that there would be a vote on proposed desired future conditions at the next meeting.

3.8 GMA 4 Meeting of March 31, 2016

At this meeting, the floor was opened for any public comments regarding the proposed desired future conditions, and there were none. After some discussion of the procedures for public hearings and the petition process, there was unanimous approval of the proposed desired future conditions.

4.0 Aquifers that are Not Relevant for Purposes of Joint Planning

4.1 Pecos Valley Aquifer

As described in George and others (2011, pg. 57):

> The Pecos Valley Aquifer is a major aquifer in West Texas. Water-bearing sediments include alluvial and windblown deposits in the Pecos River Valley. These sediments fill several structural basins, the largest of which are the Pecos Trough in the west and Monument Draw Trough in the east. Thickness of the alluvial fill reaches 1,500 feet, and freshwater saturated thickness averages about 250 feet. The water quality is highly variable, the water being typically hard, and generally better in the Monument Draw Trough than in the Pecos Trough. Total dissolved solids in groundwater from Monument Draw Trough are usually less than 1,000 milligrams per liter. The aquifer is characterized by high levels of chloride and sulfate in excess of secondary drinking water standards, resulting from previous oil field activities. In addition, naturally occurring arsenic and radionuclides occur in excess of primary drinking water standards. More than 80 percent of groundwater pumped from the aquifer is used for irrigation, and the rest is withdrawn for municipal supplies, industrial use, and power generation. Localized water level declines in south-central Reeves and northwest Pecos counties have moderated since the late 1970s as irrigation pumping has decreased; however, water levels continue to decline in central Ward County because of increased municipal and industrial pumping. The Region F Regional Water Planning Group recommended several water management strategies in their 2006 Regional Water Plan that would use the Pecos Valley Aquifer, including drilling new wells, developing two well fields in Winkler and Loving counties, and reallocating supplies.

The Pecos Valley Aquifer occurs in the northeastern part of Jeff Davis County (Figure 4), and overlies the subcrop portion of the Edwards-Trinity (Plateau) Aquifer. Thorkildsen and Backhouse (2010b) estimated the total subcrop area of the Edwards-Trinity (Plateau) Aquifer in Jeff Davis County is about 4,700 acres, and the area of the Pecos Valley Aquifer in Jeff Davis County is also about 4,700 acres.

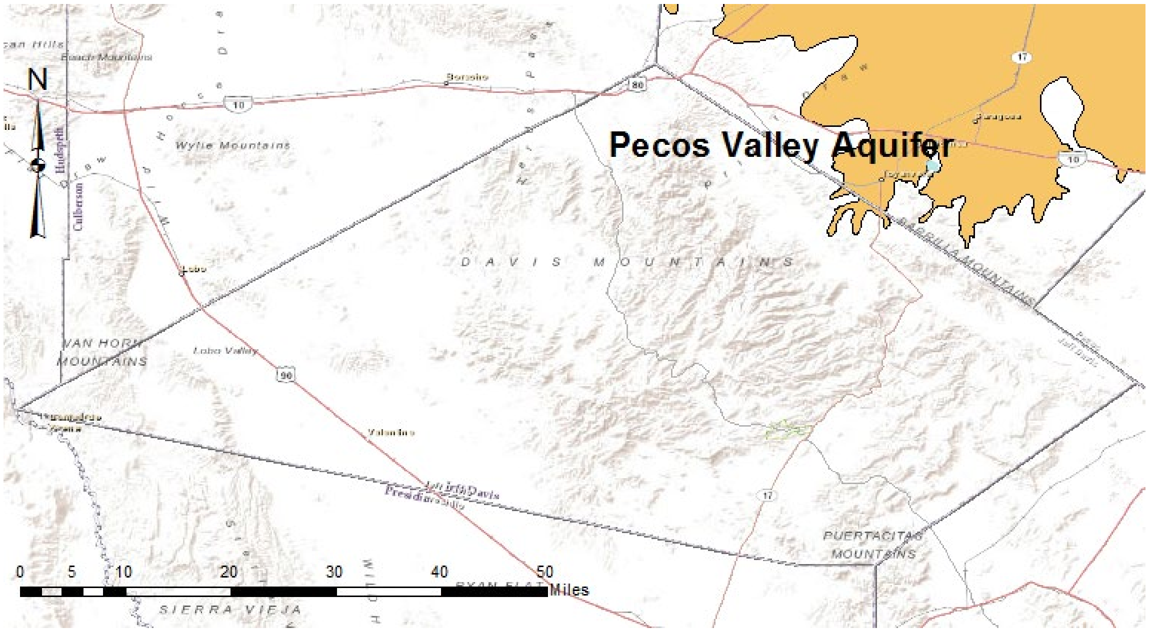


Figure 4. Location of the Pecos Valley Aquifer in Jeff Davis County

Historic pumping estimates from the TWDB historic database from the Pecos Valley Aquifer in Jeff Davis County from 2000 to 2005 is ranged from 27 to 50 acre-feet per year. Estimates after 2006 are not available.

Total storage in Jeff Davis County was estimated to be 740,000 acre-feet by Boghici and others (2014). Total estimated recoverable storage for Jeff Davis County is between 185,000 and 555,000 acre-feet, which represents between 25 and 75 percent of the total storage. Boghici and others (2014) is presented in Appendix B.

Due to its lack of use and limited areal extent, the Pecos Valley Aquifer is not relevant for purposes of joint planning in Jeff Davis County.

4.2 Rustler Aquifer

As described in George and others (2011, pg. 145):

> *The Rustler Aquifer* is a minor aquifer located in Brewster, Culberson, Jeff Davis, Loving, Pecos, Reeves, and Ward counties. The aquifer consists of the carbonates and evaporites of the Rustler Formation, which is the youngest unit of the Late Permian Ochoan Series. The Rustler Formation is 250 to 670 feet thick and extends downdip into the subsurface toward the center of the Delaware Basin to the east. It becomes thinner along the eastern margin of the Delaware Basin and across the Central Basin Platform and Val Verde Basin. There it conformably overlies the Salado Formation. Groundwater occurs in partly dissolved dolomite, limestone, and gypsum. Most of the water production comes from fractures and solution openings in the upper part of the formation. Although some parts of

> the aquifer produce freshwater containing less than 1,000 milligrams per liter of total dissolved solids, the water is generally slightly to moderately saline and contains total dissolved solids ranging between 1,000 and 4,600 milligrams per liter. The water is used primarily for irrigation, livestock, and waterflooding operations in oil-producing areas. Fluctuations in water levels over time most likely reflect long-term variations in water use patterns. The regional water planning groups in their 2006 Regional Water Plans did not propose any water management strategies for the Rustler Aquifer.

The Rustler Aquifer occurs in the eastern part of Culberson County, the northeastern part of Jeff Davis County, and the northern tip of Brewster County (Figure 5).

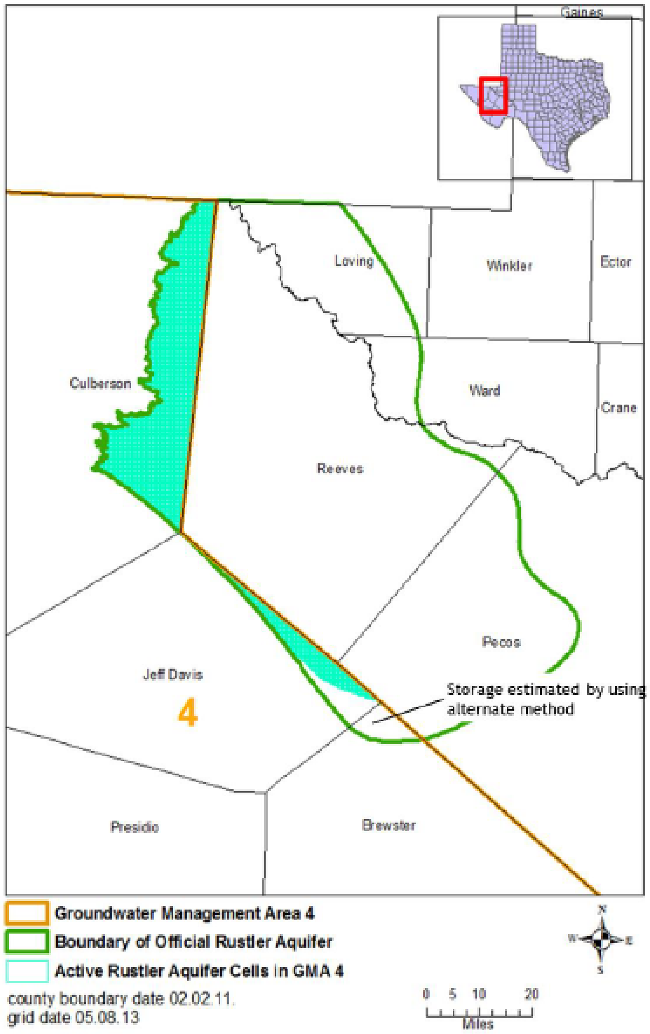


Figure 5. Extent of the Rustler Aquifer in GMA 4
From Boghici and others (2014)

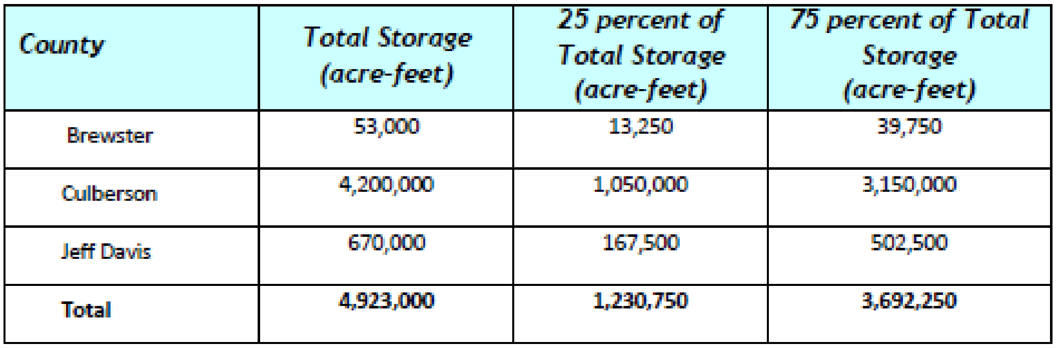
Based on the work of Ewing and others (2012, pg. 4-116) The Rustler outcrops in Culberson County and dips to the east. In Jeff Davis County, depth to the top of the Rustler Aquifer is generally between 1,000 and 2,000 feet and is generally more than 2,000 feet in Brewster County.

Please note that the Rustler Aquifer in Culberson County is generally outside the boundaries of the Culberson County GCD.

The TWDB historic pumping database for Jeff Davis County from 1993 to 2012 shows no historic groundwater use from this aquifer in Brewster and Jeff Davis counties. Historic pumping in Culberson County from 1993 to 2012 has ranged from 25 to 47 acre-feet per year.

Total estimated recoverable storage in the Rustler Aquifer in GMA 4 was reported by Boghici and others (2014) and is presented below in Table 2. Boghici and others (2014) is presented in Appendix B.

Table 2. Total Estimated Recoverable Storage in GMA 4: Rustler Aquifer



County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster	53,000	13,250	39,750
Culberson	4,200,000	1,050,000	3,150,000
Jeff Davis	670,000	167,500	502,500
Total	**4,923,000**	**1,230,750**	**3,692,250**

Due to its lack of use, the depth, and limited areal extent, the Rustler Aquifer is not relevant for purposes of joint planning in GMA 4.

4.3 Upper Salt Basin

The Upper Salt Basin is a non-official aquifer that was classified as relevant for purposes of joint planning in 2010 by GMA 4. During this round of joint planning, the aquifer is now considered not relevant for purposes of joint planning. Pursuant to guidance from the Texas Water Development Board, a non-official aquifer that was relevant in 2010 that is now considered not relevant requires documentation for that classification.

The location of the Upper Salt Basin is shown in Figure 6. TWDB does not recognize the Upper Salt Basin as an official aquifer, therefore there are no specific historic pumping estimates. However, TWDB does track “unknown” aquifers. In Culberson County, pumping from 2008 to 2012 was estimated to be between 21 and 247 acre-feet per year in “unknown” aquifers.

As described in Boghici and others (2014, pg. 11), the Upper Salt Basin is assumed to be under water-table conditions in Culberson County. Furthermore, aquifer-wide saturated thickness was estimated to be 440 feet.

Total estimated recoverable storage was estimated to be between 925,000 and 2,775,000 acre-feet in Culberson County (Boghici, 2014, pg. 24). Boghici and others (2014) is presented in Appendix B.

Due to its limited areal extent, limited use, and isolation from other relevant aquifers, the Upper Salt Basin is not relevant for purposes of joint planning in GMA 4.

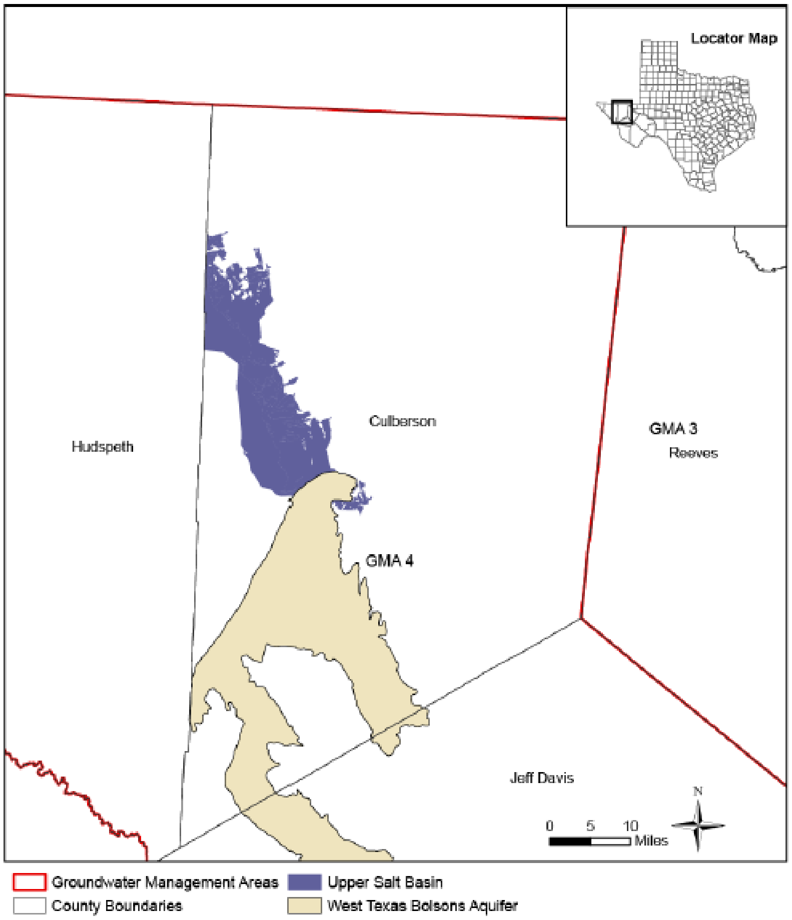


Figure 6. Location of Upper Salt Basin
From Boghici and others (2014)

5.0 Bone Spring-Victorio Peak Aquifer

5.1 Aquifer Description and Location

As described in George and others (2011, pg. 83):

> The Bone Spring–Victorio Peak Aquifer is a minor aquifer located in northern Hudspeth County. The principal water-bearing units in the aquifer are the Bone Spring and Victorio Peak limestones, both Permian in age. The formations produce groundwater from solution cavities developed along joints and fracture planes. Groundwater flows regionally toward the east-northeast through the aquifer, although a significant amount of groundwater also flows into the Dell Valley area from the Sacramento Mountains in New Mexico along a set of northwest-southeast-trending fractures. Water is generally slightly saline, with total dissolved solids of 1,000 to 3,000 milligrams per liter. In the Dell Valley area, total dissolved solids increase to 3,000 to 10,000 milligrams per liter. Water quality in this area appears to be controlled by two mechanisms: (1) groundwater flowing through the aquifer system and dissolving minerals along its flow path and (2) irrigation water percolating down through the soil zone. Significant amounts of groundwater have been pumped and are being pumped from the aquifer in the Dell Valley area. Since the late 1940s, pumping has been the principal means of discharge for the aquifer. Pumping to the south and west of the Dell Valley area is limited to scattered wells used for livestock or domestic purposes. Water levels have declined in the Dell Valley area from 5 to 60 feet, with an average of about 30 feet over a period of about 55 years. These declines are most likely due to pumping for irrigation. Water levels over the last 30 years, however, have been relatively constant, except for the last few years, during which water levels have declined because of drought. The Far West Texas Regional Water Planning Group, in its 2006 Regional Water Plan, recommended a water management strategy to redevelop and expand a well field in the Bone Spring–Victorio Peak Aquifer, desalinate the water, and transport it to El Paso County.

The aquifer is entirely in Hudspeth County (Figure 7):

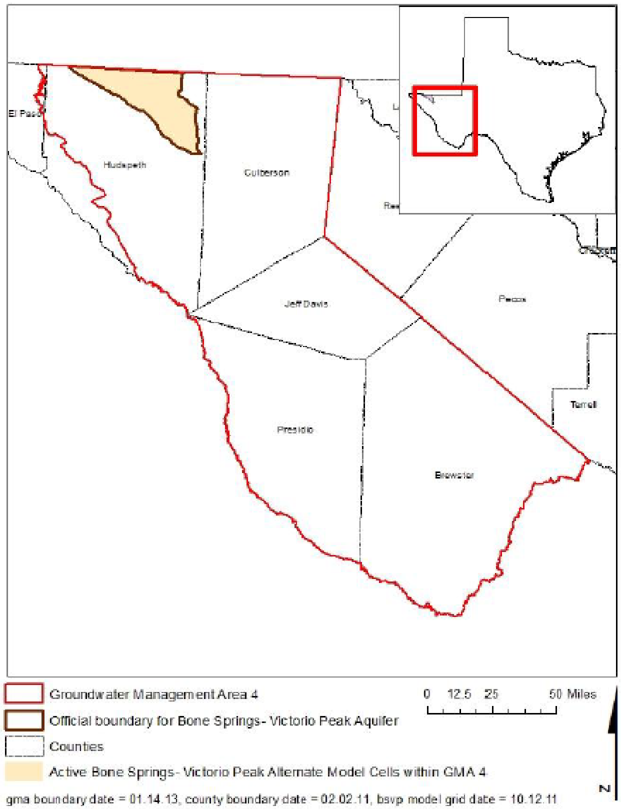


Figure 7. Location of Bone Spring-Victorio Peak Aquifer
From Boghici and others (2014)

5.2 Policy Justifications

As developed more fully in this report, the proposed desired future condition was adopted after considering:

- Aquifer uses and conditions within Groundwater Management Area 4
- Water supply needs and water management strategies included in the 2012 State Water Plan
- Hydrologic conditions within Groundwater Management Area 4 including total estimated recoverable storage, average annual recharge, inflows, and discharge
- Other environmental impacts, including spring flow and other interactions between groundwater and surface water
- The impact on subsidence
- Socioeconomic impacts reasonably expected to occur
- The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater as recognized under Texas Water Code Section 36.002
- The feasibility of achieving the desired future condition
- Other information

In addition, the proposed desired future condition provides a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater in Groundwater Management Area 4.

There is no set formula or equation for calculating groundwater availability. This is because an estimate of groundwater availability requires the blending of policy and science. Given that the tools for scientific analysis (groundwater models) contain limitations and uncertainty, policy provides the guidance and defines the bounds that science can use to calculate groundwater availability.

As developed more fully below, many of these factors could only be considered on a qualitative level since the available tools to evaluate these impacts have limitations and uncertainty.

5.3 Technical Justification

The process of using the groundwater model in developing desired future conditions revolves around the concept of incorporating many of the elements of the nine factors (e.g. current uses and water management strategies in the regional plan). For the Bone Spring-Victorio Peak Aquifer, five scenarios were evaluated in 2010 at the request of Hudspeth County UWCD No. 1 (Hutchison, 2010), and the results discussed prior to adopting a desired future condition.

Some critics of the process asserted that the districts were "reverse-engineering" the desired future conditions by specifying pumping (e.g., the modeled available groundwater) and then adopting the resulting drawdown as the desired future condition. However, it must be remembered that among the input parameters for a predictive groundwater model run is pumping, and among the outputs of a predictive groundwater model run is drawdown. Thus, an iterative approach of running several predictive scenarios with models and then evaluating the results is a necessary (and time-consuming) step in the process of developing desired future conditions.

One part of the reverse-engineering critique of the process has been that "science" should be used in the development of desired future conditions. The critique plays on the unfortunate name of the groundwater models in Texas (Groundwater Availability Models) which could suggest that the models yield an availability number. This is simply a mischaracterization of how the models work (i.e. what is a model input and what is a model output).

The critique also relies on a fairly narrow definition of the term *science* and fails to recognize that the adoption of a desired future condition is primarily a policy decision. The call to use science in the development of desired future conditions seems to equate the term *science* with the terms *facts* and *truth*. Although the Latin origin of the word means knowledge, the term *science* also refers to the application of the scientific method. The scientific method is discussed in many textbooks and can be viewed as a means to quantify cause-and-effect relationships and to make useful predictions.

In the case of groundwater management, the scientific method can be used to understand the relationship between groundwater pumping and drawdown, or groundwater pumping and spring flow. A groundwater model is a tool that can be used to run “experiments” to better understand the cause-and-effect relationships within a groundwater system as they relate to groundwater management.

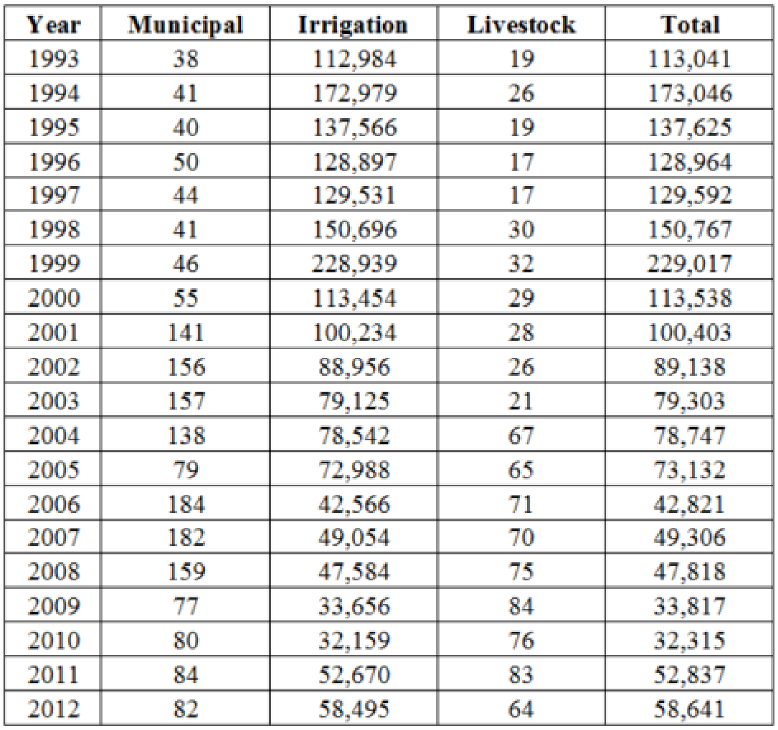
Much of the consideration of the nine statutory factors involves understanding the effects or the impacts of a desired future condition (e.g. groundwater-surface water interaction and property rights). The use of the models in this manner in evaluating the impacts of alternative futures is an effective means of developing information for the groundwater conservation districts as they develop desired future conditions.

5.4 Factor Consideration

5.4.1 Groundwater Demands and Uses

Table 3 summarizes the TWDB estimates of groundwater demands and uses for the Bone Spring-Victorio Peak Aquifer in Hudspeth County.

Table 3. Groundwater Demands and Uses, 1993 to 2012, Bone Spring-Victorio Peak Aquifer
All Values in AF/yr



Year	Municipal	Irrigation	Livestock	Total
1993	38	112,984	19	113,041
1994	41	172,979	26	173,046
1995	40	137,566	19	137,625
1996	50	128,897	17	128,964
1997	44	129,531	17	129,592
1998	41	150,696	30	150,767
1999	46	228,939	32	229,017
2000	55	113,454	29	113,538
2001	141	100,234	28	100,403
2002	156	88,956	26	89,138
2003	157	79,125	21	79,303
2004	138	78,542	67	78,747
2005	79	72,988	65	73,132
2006	184	42,566	71	42,821
2007	182	49,054	70	49,306
2008	159	47,584	75	47,818
2009	77	33,656	84	33,817
2010	80	32,159	76	32,315
2011	84	52,670	83	52,837
2012	82	58,495	64	58,641

5.4.2 Water Supply Needs and Water Management Strategies

Ashworth and others (2016, pp. 5-9 and 5-11) identified two water management strategies associated with the Bone Spring-Victorio Peak Aquifer. Strategy E-23 calls for the pumping of 10,000 AF/yr of groundwater starting in 2060 and 20,000 AF/yr in 2070 for supply to the City of El Paso with a capital cost of about $303 million. The pumping does not represent an increase in pumping, but a change of use from irrigation to municipal.

Strategy E-50 calls for a brackish groundwater desalination facility with a supply of 111 AF/yr, and a capital cost of about $1.3 million. Please note that two other water management strategies (E-55 and E-56) are incorrectly attributed to the Bone Spring-Victorio Peak Aquifer.

5.4.3 Hydrologic Conditions, Including Total Estimated Recoverable Storage

The hydrologic conditions considered under this factor include:

- Total estimated recoverable storage
- Average annual recharge
- Average annual inflows
- Average annual discharge

The total estimated recoverable storage was reported by the Texas Water Development Board (Boghici and others, 2014). Total estimated storage was reported as 3.7 million acre-feet. Total estimated recoverable storage was reported as a range (25 to 75 percent of the total storage) between 925,000 acre-feet to 2.775 million acre-feet. Boghici and others (2014) is presented in Appendix B.

Jones (2012b, pg. 6) reported the following:

- Average annual recharge from precipitation: 256 AF/yr
- Estimated annual volume of flow into the district within each aquifer in the district: 110,805 AF/yr
- Estimated annual volume of flow out of the district within each aquifer in the district: 39,825 AF/yr

5.4.4 Other Environmental Impacts

The impacts under this factor include spring flow and other interactions between groundwater and surface water.

Jones (2012b, pg. 6) estimated that the estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers is zero.

5.4.5 Subsidence

Subsidence is not an issue in the Bone Spring-Victorio Peak Aquifer.

5.4.6 Socioeconomic Impacts

The Texas Water Development Board prepared reports on the socioeconomic impacts of not meeting water needs for each of the Regional Planning Groups during development of the 2021 Regional Water Plans. Because the development of this desired future condition used the State Water Plan demands and water management strategies as an important foundation, it is reasonable to conclude that the socioeconomic impacts associated with this proposed desired future condition can be evaluated in the context of not meeting the listed water management strategies. Groundwater Management Area 4 is covered by Regional Planning Group E. The socioeconomic impact reports for Regions E is presented in Appendix C.

5.4.7 Impact on Private Property Rights

The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater is recognized under Texas Water Code Section 36.002.

The desired future conditions adopted by GMA 4 are consistent with protecting property rights of landowners who are currently pumping groundwater and landowners who have chosen to conserve groundwater by not pumping. As required by Chapter 36 of the Water Code, GMA 4 considered these impacts and balanced them with the increasing demand of water in the GMA 4 area, and concluded that, on balance and with appropriate monitoring and project specific review during the permitting process, all the Region E strategies can be included in the desired future condition.

At the April 30, 2015 meeting of GMA 4, the districts recognized that to protect all property rights, the districts have the authority to curb production and encourage conservation.

5.4.8 Feasibility of Achieving the Desired Future Conditions

Groundwater monitoring in terms of pumping and groundwater levels provide the means evaluate consistency with the desired future condition. Groundwater levels are routinely monitored by the districts and by TWDB in GMA 4. Evaluating the monitoring data is a routine task for the districts, and the comparison of these data with the desired future conditions is covered in each district's management plan. These comparisons are useful to guide the update of the DFCs that are required every five years.

5.4.9 Other Information

No other information was used in the development of the desired future conditions.

5.5 Discussion of Other Desired Future Conditions Considered

During development of the desired future conditions in 2010, GMA 4 considered five specific alternatives evaluated in Hutchison (2010), which were a subset of 772 simulations from Hutchison (2008). The five specific alternatives considered the alternative drawdowns after 50 years from 0 to 20 feet. The 772 simulations covered a wide range of pumping increases, decreases and variable climatic conditions. No additional evaluations were made as part of the second or third round of joint planning.

6.0 Capitan Reef Complex

6.1 Aquifer Description and Location

As described by George and others (2011, pg. 91):

> *The Capitan Reef Complex Aquifer* is a minor aquifer located in Culberson, Hudspeth, Jeff Davis, Brewster, Pecos, Reeves, Ward, and Winkler counties. It is exposed in mountain ranges of Far West Texas; elsewhere it occurs in the subsurface. The aquifer is composed of as much as 2,360 feet of massive, cavernous dolomite and limestone. Water-bearing formations include the Capitan Limestone, Goat Seep Dolomite, and most of the Carlsbad facies of the Artesia Group, including the Grayburg, Queen, Seven Rivers, Yates, and Tansill formations. Water is contained in solution cavities and fractures that are unevenly distributed within these formations. Water from the Capitan Reef Complex Aquifer is thought to contribute to the base flow of San Solomon Springs in Reeves County. Overall, the aquifer contains water of marginal quality, yielding small to large quantities of slightly saline to saline groundwater containing 1,000 to greater than 5,000 milligrams per liter of total dissolved solids. Water of the freshest quality, with total dissolved solids between 300 and 1,000 milligrams per liter, is present in the west near areas of recharge where the reef rock is exposed in several mountain ranges. Although most of the groundwater pumped from the aquifer in Texas is used for oil reservoir flooding in Ward and Winkler counties, a small amount is used to irrigate salt-tolerant crops in Pecos, Culberson, and Hudspeth counties. Over the last 70 years, water levels have declined in some areas as a result of localized production. The Far West Texas Regional Water Planning Group, in its 2006 Regional Water Plan, recommended several water management strategies for the Capitan Reef Complex Aquifer, including redeveloping an existing well field, desalinating the water, and transporting it to El Paso County.

The aquifer is in Brewster, Culberson, Hudspeth, and Jeff Davis counties in GMA 4 (Figure 8). It is classified as not relevant for purposes of joint planning in Hudspeth and Jeff Davis counties due to limited use and geographic isolation.

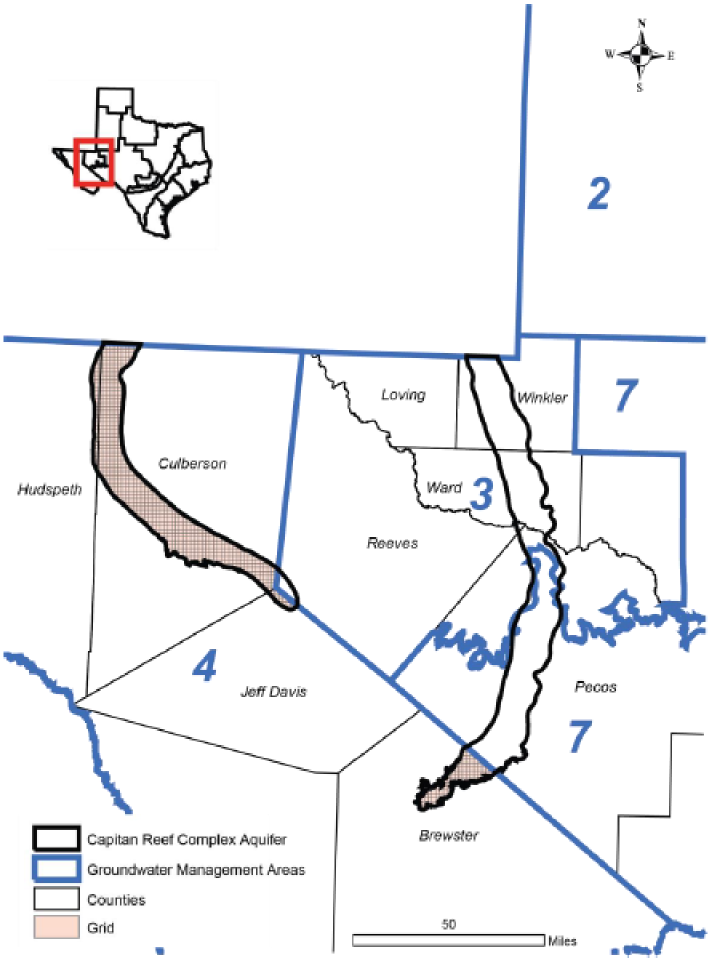


Figure 8. Location of Capitan Reef Complex Aquifer
From Boghici and others (2014)

6.2 Policy Justifications

As developed more fully in this report, the proposed desired future condition was adopted after considering:

- Aquifer uses and conditions within Groundwater Management Area 4
- Water supply needs and water management strategies included in the 2012 State Water Plan
- Hydrologic conditions within Groundwater Management Area 4 including total estimated recoverable storage, average annual recharge, inflows, and discharge
- Other environmental impacts, including spring flow and other interactions between groundwater and surface water
- The impact on subsidence
- Socioeconomic impacts reasonably expected to occur

- The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater as recognized under Texas Water Code Section 36.002
- The feasibility of achieving the desired future condition
- Other information

In addition, the proposed desired future condition provides a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater in Groundwater Management Area 4.

There is no set formula or equation for calculating groundwater availability. This is because an estimate of groundwater availability requires the blending of policy and science. Given that the tools for scientific analysis (groundwater models) contain limitations and uncertainty, policy provides the guidance and defines the bounds that science can use to calculate groundwater availability.

As developed more fully below, many of these factors could only be considered on a qualitative level since the available tools to evaluate these impacts have limitations and uncertainty.

6.3 Technical Justification

Wuerch and Davidson (2010a) completed an Aquifer Assessment for the Capitan Reef Complex that was the basis for the desired future condition adopted in 2010. An Aquifer Assessment was completed due the lack of a Groundwater Availability Model of the area (at the time) and limited data over the area. The analytical approach determined a pumping rate that was equal to the effective recharge plus the change in storage of the aquifer under an assumption of uniform water-level decline. Key assumptions in applying the method is that the aquifer is homogenous and isotropic, and that lateral inflow and lateral outflow are equal, and that future pumping will not alter this balance.

The Groundwater Availability Model of the Capitan Reef Complex Aquifer (Jones, 2016) was released in draft form in March 2016 and finalized in August 2016. Because of the timing of its release, GMA 4 did not consider results from this model prior to voting on the proposed desired future condition on March 31, 2016.

6.4 Factor Consideration

6.4.1 Aquifer Uses and Conditions

Tables 4, 5 and 6 summarize the TWDB estimates of groundwater demand and uses for the Capitan Reef Complex Aquifer in Brewster, Culberson, and Hudspeth counties, respectively.

Table 4. Groundwater Demands and Uses, 2004 to 2012, Capitan Reef Complex Aquifer, Brewster County

All Values in AF/yr

Year	Municipal	Livestock	Total
2004	0	21	21
2005	0	27	27
2006	3	25	28
2007	3	27	30
2008	3	30	33
2009	4	27	31
2010	5	29	34
2011	5	28	33
2012	5	25	30

Table 5. Groundwater Demands and Uses, 1993 to 2012, Capitan Reef Complex Aquifer, Culberson County

All Values in AF/yr

Year	Municipal	Irrigation	Livestock	Total
1993	6	6	29	41
1994	0	0	26	26
1995	5	0	21	26
1996	5	0	23	28
1997	4	0	25	29
1998	5	0	34	39
1999	6	0	37	43
2000	0	4,052	33	4,085
2001	0	2,707	30	2,737
2002	0	3,556	47	3,603
2003	0	3,601	25	3,626
2004	0	3,151	50	3,201
2005	0	3,594	41	3,635
2006	13	3,366	47	3,426
2007	10	2,749	53	2,812
2008	11	5,651	55	5,717
2009	11	6,313	50	6,374
2010	10	6,913	47	6,970
2011	11	5,827	47	5,885
2012	11	9,077	47	9,135

Table 6. Groundwater Demands and Uses, 1993 to 2012, Capitan Reef Complex Aquifer, Hudspeth County
All Values in AF/yr

Year	Municipal	Irrigation	Livestock	Total
1993	1	97	6	104
1994	1	2,797	8	2,806
1995	1	2,224	6	2,231
1996	1	2,084	5	2,090
1997	1	2,094	5	2,100
1998	1	2,436	9	2,446
1999	1	3,701	9	3,711
2000	0	4,085	8	4,093
2001	0	3,609	8	3,617
2002	0	3,203	8	3,211
2003	0	2,849	7	2,856
2004	0	2,828	6	2,834
2005	0	2,628	5	2,633
2006	4	1,533	6	1,543
2007	3	1,766	6	1,775
2008	4	1,713	6	1,723
2009	3	1,212	7	1,222
2010	3	1,158	6	1,167
2011	3	1,897	7	1,907
2012	3	2,106	5	2,114

6.4.2 Water Supply Needs and Water Management Strategies

Ashworth and others (2016, pg. 5-9) identified one water management strategy associated with the Capitan Reef Complex Aquifer. Strategy E-22 calls for the pumping 10,000 AF/yr of groundwater from the Diablo Farms area for supply to the City of El Paso starting in 2050 for a capital cost of about $273 million. This project does not necessarily result in an increased amount of pumping, but a change of use from irrigation to municipal.

6.4.3 Hydrologic Conditions, Including Total Estimated Recoverable Storage

The hydrologic conditions considered under this factor include:

- Total estimated recoverable storage
- Average annual recharge
- Average annual inflows

- Average annual discharge

The total estimated recoverable storage was reported by the Texas Water Development Board (Boghici and others, 2014). Table 7 summarizes the estimates. Boghici and others (2014) is presented in Appendix B.

Table 7. Total Estimated Recoverable Storage: Capitan Reef Complex Aquifer

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster	2,500,000	625,000	1,875,000
Culberson	21,000,000	5,250,000	15,750,000
Hudspeth	1,100,000	275,000	825,000
Jeff Davis	760,000	190,000	570,000
Total	**25,360,000**	**6,340,000**	**19,020,000**

Wuerch and Davidson (2010a) made the following estimates of effective recharge:

- Brewster County: 2,100 AF/yr
- Culberson County: 11,356 AF/yr
- Hudspeth County: 813 AF/yr
- Jeff Davis County: 341 AF/yr

Wuerch and Davidson (2010a) did not make specific estimates of annual inflow and outflow to and from the aquifer, just that these values were equal and assumed that the assumed future pumping would not affect the balance.

6.4.4 Other Environmental Impacts

Wuerch and Davidson (2010a) made no assumptions regarding the impacts to spring flow or groundwater-surface water interactions. Given the hydrogeologic setting, the generally arid conditions, and the locations of current and future pumping, these factors are not considered significant.

6.4.5 Subsidence

Subsidence is not an issue in the Capitan Reef Complex Aquifer.

6.4.6 Socioeconomic Impacts

The Texas Water Development Board prepared reports on the socioeconomic impacts of not meeting water needs for each of the Regional Planning Groups during development of the 2021 Regional Water Plans. Because the development of this desired future condition used the State Water Plan demands and water management strategies as an important foundation, it is reasonable to conclude that the socioeconomic impacts associated with this proposed desired future condition can be evaluated in the context of not meeting the listed water management strategies. Groundwater Management Area 4 is covered by Regional Planning Group E. The socioeconomic impact reports for Regions E is presented in Appendix C.

6.4.7 Impact on Private Property Rights

The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater is recognized under Texas Water Code Section 36.002.

The desired future conditions adopted by GMA 4 are consistent with protecting property rights of landowners who are currently pumping groundwater and landowners who have chosen to conserve groundwater by not pumping. As required by Chapter 36 of the Water Code, GMA 4 considered these impacts and balanced them with the increasing demand of water in the GMA 4 area, and concluded that, on balance and with appropriate monitoring and project specific review during the permitting process, all the Region E strategies can be included in the desired future condition.

At the April 30, 2015 meeting of GMA 4, the districts recognized that to protect all property rights, the districts have the authority to curb production and encourage conservation.

6.4.8 Feasibility of Achieving the Desired Future Conditions

Groundwater monitoring in terms of pumping and groundwater levels provide the means evaluate consistency with the desired future condition. Groundwater levels are routinely monitored by the districts and by TWDB in GMA 4. Evaluating the monitoring data is a routine task for the districts, and the comparison of these data with the desired future conditions is covered in each district's management plan. These comparisons are useful to guide the update of the DFCs that are required every five years.

6.4.9 Other Information

No other information was used in the development of the desired future conditions.

6.5 Discussion of Other Desired Future Conditions Considered

Prior to adopting the desired future condition in 2010, GMA 4 reviewed Bradley and George (2008) that analyzed five alternative drawdown conditions in an Aquifer Assessment. Alternative drawdowns considered included 10, 20, 30, 40, and 50 feet.

7.0 Edwards-Trinity (Plateau) Aquifer

7.1 Aquifer Description and Location

As described by George and others (2011, pg. 35):

> *The Edwards-Trinity (Plateau) Aquifer* is a major aquifer extending across much of the southwestern part of the state. The water-bearing units are composed predominantly of limestone and dolomite of the Edwards Group and sands of the Trinity Group. Although maximum saturated thickness of the aquifer is greater than 800 feet, freshwater saturated thickness averages 433 feet. Water quality ranges from fresh to slightly saline, with total dissolved solids ranging from 100 to 3,000 milligrams per liter, and water is characterized as hard within the Edwards Group. Water typically increases in salinity to the west within the Trinity Group. Elevated levels of fluoride in excess of primary drinking water standards occur within Glasscock and Irion counties. Springs occur along the northern, eastern, and southern margins of the aquifer primarily near the bases of the Edwards and Trinity groups where exposed at the surface. San Felipe Springs is the largest exposed spring along the southern margin. Of groundwater pumped from this aquifer, more than two-thirds is used for irrigation, with the remainder used for municipal and livestock supplies. Water levels have remained relatively stable because recharge has generally kept pace with the relatively low amounts of pumping over the extent of the aquifer. The regional water planning groups, in their 2006 Regional Water Plans, recommended water management strategies that use the Edwards Trinity (Plateau) Aquifer, including the construction of a well field in Kerr County and public supply wells in Real County.

The aquifer is in Brewster, Culberson, and Jeff Davis counties in GMA 4 (Figure 9). It is classified as not relevant for purposes of joint planning in Culberson and Jeff Davis counties due to limited use and geographic isolation.

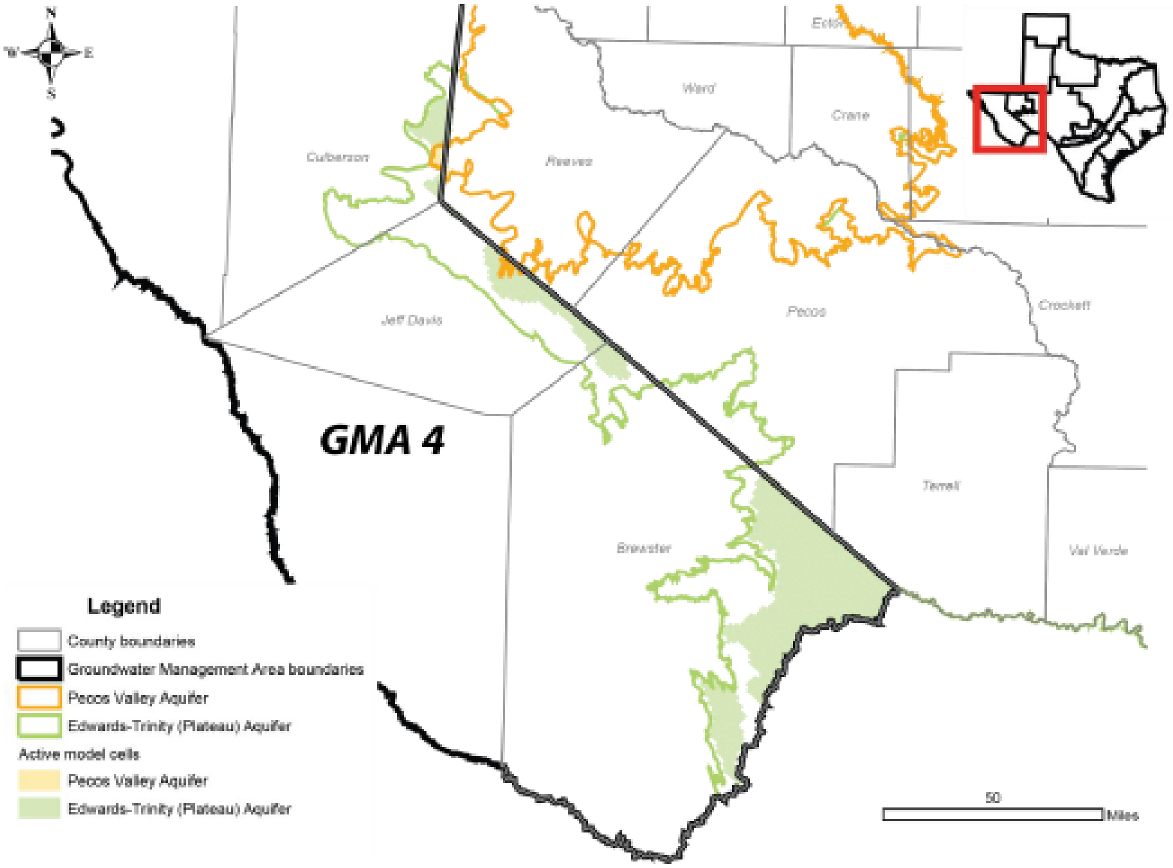


Figure 9. Location of Edwards-Trinity (Plateau) Aquifer
From Boghici and others (2014)

7.2 Policy Justifications

As developed more fully in this report, the proposed desired future condition was adopted after considering:

- Aquifer uses and conditions within Groundwater Management Area 4
- Water supply needs and water management strategies included in the 2012 State Water Plan
- Hydrologic conditions within Groundwater Management Area 4 including total estimated recoverable storage, average annual recharge, inflows, and discharge
- Other environmental impacts, including spring flow and other interactions between groundwater and surface water
- The impact on subsidence
- Socioeconomic impacts reasonably expected to occur

- The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater as recognized under Texas Water Code Section 36.002
- The feasibility of achieving the desired future condition
- Other information

In addition, the proposed desired future condition provides a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater in Groundwater Management Area 4.

There is no set formula or equation for calculating groundwater availability. This is because an estimate of groundwater availability requires the blending of policy and science. Given that the tools for scientific analysis (groundwater models) contain limitations and uncertainty, policy provides the guidance and defines the bounds that science can use to calculate groundwater availability.

As developed more fully below, many of these factors could only be considered on a qualitative level since the available tools to evaluate these impacts have limitations and uncertainty.

7.3 Technical Justification

The process of using the groundwater model in developing desired future conditions revolves around the concept of incorporating many of the elements of the nine factors (e.g. current uses and water management strategies in the regional plan). Some critics of the process asserted that the districts were "reverse-engineering" the desired future conditions by specifying pumping (e.g., the modeled available groundwater) and then adopting the resulting drawdown as the desired future condition. However, it must be remembered that among the input parameters for a predictive groundwater model run is pumping, and among the outputs of a predictive groundwater model run is drawdown. Thus, an iterative approach of running several predictive scenarios with models and then evaluating the results is a necessary (and time-consuming) step in the process of developing desired future conditions.

One part of the reverse-engineering critique of the process has been that "science" should be used in the development of desired future conditions. The critique plays on the unfortunate name of the groundwater models in Texas (Groundwater Availability Models) which could suggest that the models yield an availability number. This is simply a mischaracterization of how the models work (i.e. what is a model input and what is a model output).

The critique also relies on a fairly narrow definition of the term *science* and fails to recognize that the adoption of a desired future condition is primarily a policy decision. The call to use science in the development of desired future conditions seems to equate the term *science* with the terms *facts* and *truth*. Although the Latin origin of the word means knowledge, the term *science* also refers to the application of the scientific method. The scientific method is discussed in many textbooks and can be viewed as a means to quantify cause-and-effect relationships and to make useful predictions.

In the case of groundwater management, the scientific method can be used to understand the relationship between groundwater pumping and drawdown, or groundwater pumping and spring flow. A groundwater model is a tool that can be used to run "experiments" to better understand the cause-and-effect relationships within a groundwater system as they relate to groundwater management.

Much of the consideration of the nine statutory factors involves understanding the effects or the impacts of a desired future condition (e.g. groundwater-surface water interaction and property rights). The use of the models in this manner in evaluating the impacts of alternative futures is an effective means of developing information for the groundwater conservation districts as they develop desired future conditions.

As described in Oliver (2012), the original desired future condition adopted for Brewster County for the Edwards-Trinity (Plateau) Aquifer that was based on the Aquifer Assessment of Thorkildsen and Backhouse (2010b) was found to be not achievable when analyzed with the alternative groundwater availability model of the aquifer (Hutchison and others, 2011).

As described in Oliver (2012), on November 15, 2010, TWDB presented the results of alternative scenarios after finding that the originally adopted desired future condition of zero feet of drawdown was not achievable due to pumping in surrounding areas outside of Brewster County. Based on the updated analysis with the model, GMA 4 updated their desired future condition on May 19, 2011 to 3 feet of drawdown in Brewster County and 50 feet of drawdown in Culberson County.

In 2017, the desired future condition for Brewster County is unchanged at 3 feet of drawdown based on Oliver (2012), but the aquifer is classified as not relevant for purposes of joint planning in Culberson County.

7.4 Factor Consideration

7.4.1 Groundwater Demands and Uses

Tables 8, 9, and 10 present the groundwater demands and uses from 1993 to 2012 from the Edwards-Trinity (Plateau) Aquifer in Brewster County, Culberson County, and Jeff Davis County, respectively.

7.4.2 Water Supply Needs and Water Management Strategies

Ashworth and others (2016, pg. 5-11) identified no water management strategies associated with the Edwards-Trinity (Plateau) Aquifer in GMA 4.

Table 8. Groundwater Demands and Uses, 1993 to 2012, Edwards-Trinity (Plateau) Aquifer, Brewster County

All Values in AF/yr

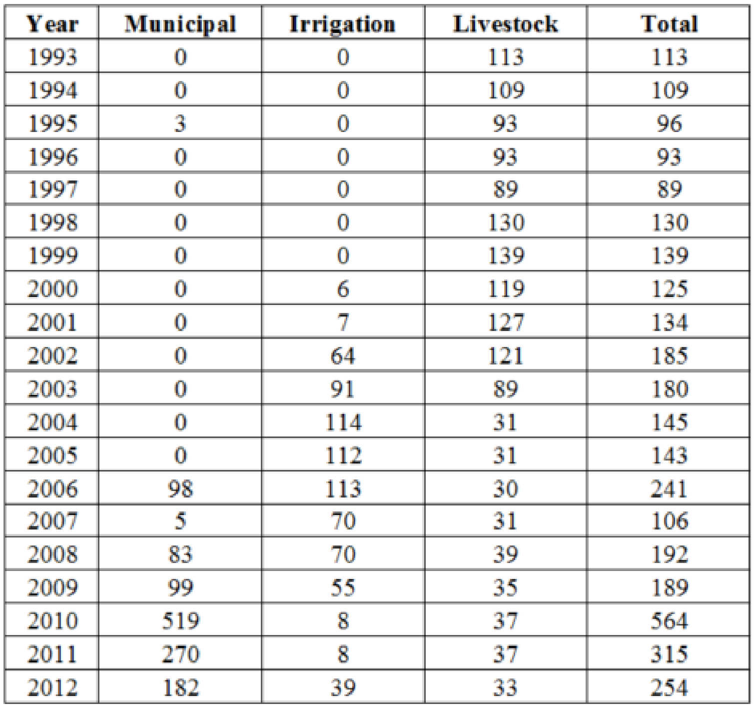
Year	Municipal	Irrigation	Livestock	Total
1993	146	191	270	607
1994	148	327	398	873
1995	157	327	357	841
1996	148	327	302	777
1997	149	327	310	786
1998	162	327	310	799
1999	162	327	350	839
2000	20	0	335	355
2001	20	0	304	324
2002	20	0	248	268
2003	21	0	128	149
2004	20	0	68	88
2005	21	0	89	110
2006	51	0	80	131
2007	68	0	89	157
2008	47	0	97	144
2009	61	0	88	149
2010	102	0	94	196
2011	96	0	92	188
2012	92	0	80	172

Table 9. Groundwater Demands and Uses, 1993 to 2012, Edwards-Trinity (Plateau) Aquifer, Culberson County

All Values in AF/yr

Year	Municipal	Irrigation	Livestock	Total
1993	6	2	29	37
1994	0	0	26	26
1995	5	0	21	26
1996	5	0	23	28
1997	4	0	25	29
1998	5	0	34	39
1999	6	0	37	43
2000	0	451	33	484
2001	0	301	30	331
2002	0	396	47	443
2003	0	401	25	426
2004	0	351	18	369
2005	0	400	15	415
2006	6	374	17	397
2007	5	306	19	330
2008	6	629	20	655
2009	5	702	18	725
2010	5	769	17	791
2011	6	648	17	671
2012	6	1,010	17	1,033

Table 10. Groundwater Demands and Uses, 1993 to 2012, Edwards-Trinity (Plateau) Aquifer, Jeff Davis County
All Values in AF/yr



Year	Municipal	Irrigation	Livestock	Total
1993	0	0	113	113
1994	0	0	109	109
1995	3	0	93	96
1996	0	0	93	93
1997	0	0	89	89
1998	0	0	130	130
1999	0	0	139	139
2000	0	6	119	125
2001	0	7	127	134
2002	0	64	121	185
2003	0	91	89	180
2004	0	114	31	145
2005	0	112	31	143
2006	98	113	30	241
2007	5	70	31	106
2008	83	70	39	192
2009	99	55	35	189
2010	519	8	37	564
2011	270	8	37	315
2012	182	39	33	254

7.4.3 Hydrologic Condition, Including Total Estimated Recoverable Storage

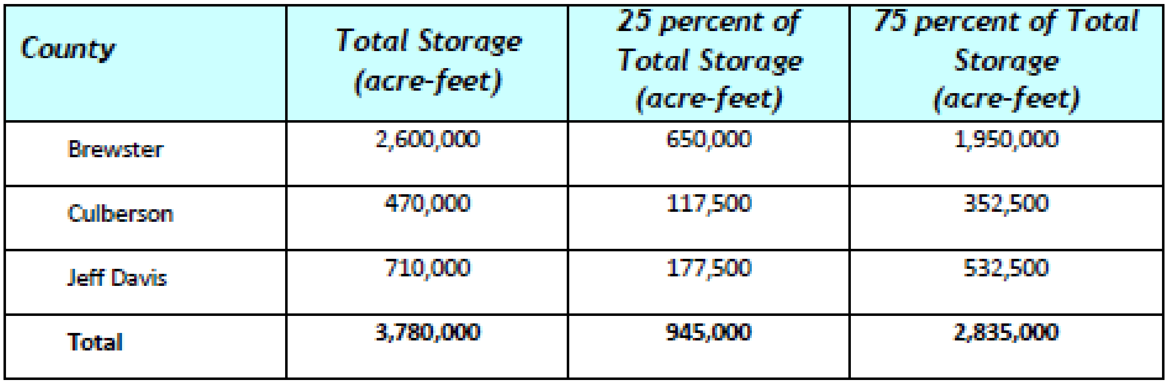
The hydrologic conditions considered under this factor include:

- Total estimated recoverable storage
- Average annual recharge
- Average annual inflows
- Average annual discharge

The total estimated recoverable storage was reported by the Texas Water Development Board (Boghici and others, 2014). Table 11 summarizes the estimates. Boghici and others (2014) is presented in Appendix B.

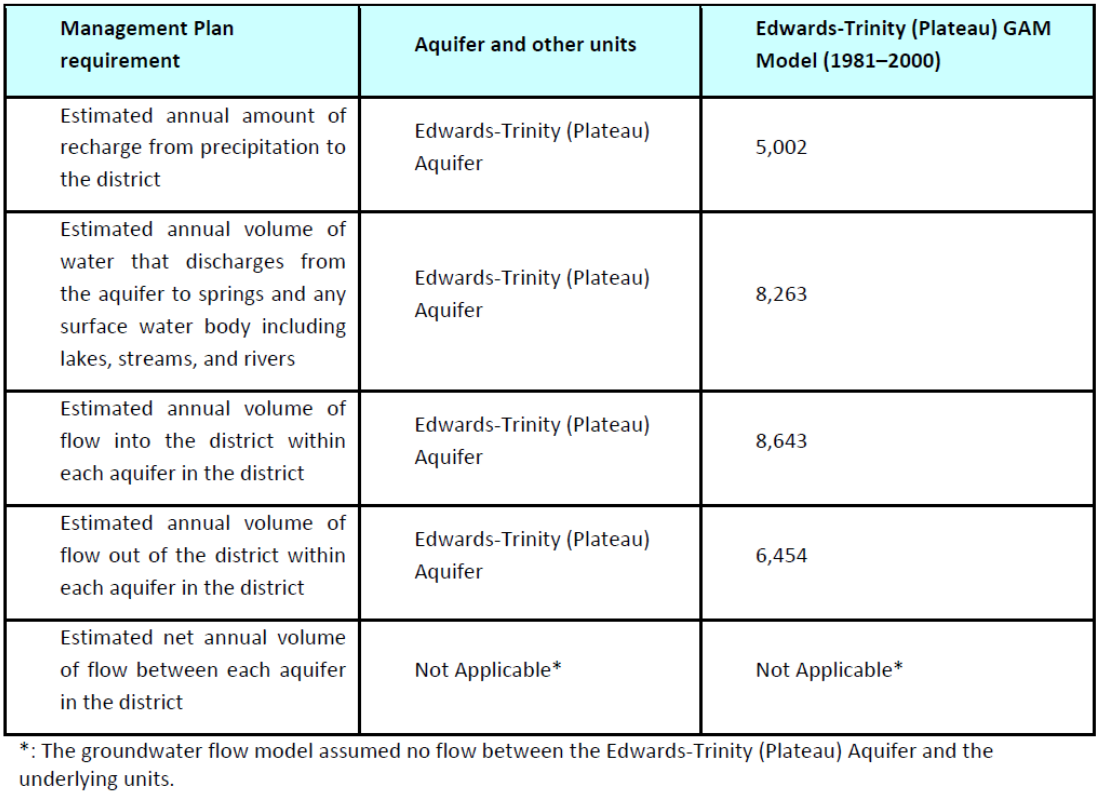
Shi (2013, pg.10) summarized the recharge, inflows and discharge for Brewster County. The estimates are presented in Table 12.

Table 11. Total Estimated Recoverable Storage: Edwards-Trinity (Plateau) Aquifer



County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster	2,600,000	650,000	1,950,000
Culberson	470,000	117,500	352,500
Jeff Davis	710,000	177,500	532,500
Total	**3,780,000**	**945,000**	**2,835,000**

Table 12. Recharge, Inflow, and Discharge Estimates: Edwards-Trinity (Plateau) Aquifer, Brewster County



Management Plan requirement	**Aquifer and other units**	**Edwards-Trinity (Plateau) GAM Model (1981–2000)**
Estimated annual amount of recharge from precipitation to the district	Edwards-Trinity (Plateau) Aquifer	5,002
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Edwards-Trinity (Plateau) Aquifer	8,263
Estimated annual volume of flow into the district within each aquifer in the district	Edwards-Trinity (Plateau) Aquifer	8,643
Estimated annual volume of flow out of the district within each aquifer in the district	Edwards-Trinity (Plateau) Aquifer	6,454
Estimated net annual volume of flow between each aquifer in the district	Not Applicable*	Not Applicable*

*: The groundwater flow model assumed no flow between the Edwards-Trinity (Plateau) Aquifer and the underlying units.

7.4.4 Other Environmental Impacts

The impacts under this factor include spring flow and other interactions between groundwater and surface water.

As presented previously in Table 12, Shi (2013) estimated that the annual volume of water that discharges from the aquifer to springs and surface water bodies is 8,263 AF/yr.

7.4.5 Subsidence

Subsidence is not an issue in the Edwards-Trinity (Plateau) Aquifer.

7.4.6 Socioeconomic Impacts

The Texas Water Development Board prepared reports on the socioeconomic impacts of not meeting water needs for each of the Regional Planning Groups during development of the 2021 Regional Water Plans. Because the development of this desired future condition used the State Water Plan demands and water management strategies as an important foundation, it is reasonable to conclude that the socioeconomic impacts associated with this proposed desired future condition can be evaluated in the context of not meeting the listed water management strategies. Groundwater Management Area 4 is covered by Regional Planning Group E. The socioeconomic impact reports for Regions E is presented in Appendix C.

7.4.7 Impact on Private Property Rights

The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater is recognized under Texas Water Code Section 36.002.

The desired future conditions adopted by GMA 4 are consistent with protecting property rights of landowners who are currently pumping groundwater and landowners who have chosen to conserve groundwater by not pumping. As required by Chapter 36 of the Water Code, GMA 4 considered these impacts and balanced them with the increasing demand of water in the GMA 4 area, and concluded that, on balance and with appropriate monitoring and project specific review during the permitting process, all the Region E strategies can be included in the desired future condition.

At the April 30, 2015 meeting of GMA 4, the districts recognized that to protect all property rights, the districts have the authority to curb production and encourage conservation.

7.4.8 Feasibility of Achieving the Desired Future Conditions

Groundwater monitoring in terms of pumping and groundwater levels provide the means evaluate consistency with the desired future condition. Groundwater levels are routinely monitored by the districts and by TWDB in GMA 4. Evaluating the monitoring data is a routine task for the districts, and the comparison of these data with the desired future conditions is covered in each district's management plan. These comparisons are useful to guide the update of the DFCs that are required every five years.

7.4.9 Other Information

No other information was used in the development of the desired future conditions.

7.5 Discussion of Other Desired Future Conditions Considered

As noted previously, Oliver (2012) noted that the original desired future condition adopted for Brewster County for the Edwards-Trinity (Plateau) Aquifer that was based on the Aquifer Assessment of Thorkildsen and Backhouse (2010b) was found to be not achievable when analyzed with the alternative groundwater availability model of the aquifer (Hutchison and others, 2011).

As described in Oliver (2012), on November 15, 2010, TWDB presented the results of alternative scenarios after finding that the originally adopted desired future condition of zero feet of drawdown was not achievable due to pumping in surrounding areas outside of Brewster County. Based on the updated analysis with the model, GMA 4 updated their desired future condition on May 19, 2011 to 3 feet of drawdown in Brewster County and 50 feet of drawdown in Culberson County.

8.0 Igneous Aquifer and Salt Basin Portion of the West Texas Bolsons Aquifer

Because these aquifers are both included in a single Groundwater Availability Model (GAM), and the desired future conditions were developed based on simulations with that GAM, this section of the explanatory report includes both aquifers.

8.1 Aquifer Description and Location

As described in George and others (2011, pg.115):

> The Igneous Aquifer, located in Far West Texas, is designated as a minor aquifer. The aquifer consists of volcanic rocks made up of a complex series of welded pyroclastic rock, lava, and volcaniclastic sediments and includes more than 40 different named units as much as 6,000 feet thick. Freshwater saturated thickness averages about 1,800 feet. The best water-bearing zones are found in igneous rocks with primary porosity and permeability, such as vesicular basalts, interflow zones in lava successions, sandstone, conglomerate, and breccia. Faulting and fracturing enhance aquifer productivity in less permeable rock units. Although water in the aquifer is fresh and contains less than 1,000 milligrams per liter of total dissolved solids, elevated levels of silica and fluoride have been found in water from some wells, reflecting the igneous origin of the rock. Water is primarily used to meet municipal needs for the cities of Alpine, Fort Davis, and Marfa, as well as some agricultural needs. There have been no significant water level declines in wells measured by the TWDB throughout the aquifer. The Far West Texas Water Planning Group, in its 2006 Regional Water Plan, did not recommend any water management strategies using the Igneous Aquifer.

As described by George and others (2011, pg. 153):

> The West Texas Bolsons Aquifer is a minor aquifer located in several basins, or bolsons, in Far West Texas. The aquifer occurs as water-bearing, basin-fill deposits as much as 3,000 feet thick. It is composed of eroded materials that vary depending on the mountains bordering the basins and the manner in which the sediments were deposited. Sediments range from the fine-grained silt and clay of lake deposits to the coarse-grained volcanic rock and limestone of alluvial fans. Freshwater saturated thickness averages about 580 feet. Groundwater quality varies depending on the basin, ranging from freshwater, containing less than 1,000 milligrams per liter of total dissolved solids, to slightly to moderately saline water, containing between 1,000 and 4,000 milligrams per liter of total dissolved solids. Groundwater is used for irrigation and livestock throughout the area and for municipal supply in the cities of Presidio, Sierra Blanca, Valentine, and Van Horn. From the 1950s to the present, water levels have been in decline in the West Texas Bolsons Aquifer, with the most significant declines occurring south of Van Horn in the Lobo Flats area and to the east in the Wild Horse Basin area. The Region E Planning Group, in its 2006 Regional Water Plan, did not recommend any water management strategies using the West Texas Bolsons Aquifer.

The aquifers are in Brewster, Culberson, Hudspeth, Jeff Davis, and Presidio counties (Figures 9 and 10).

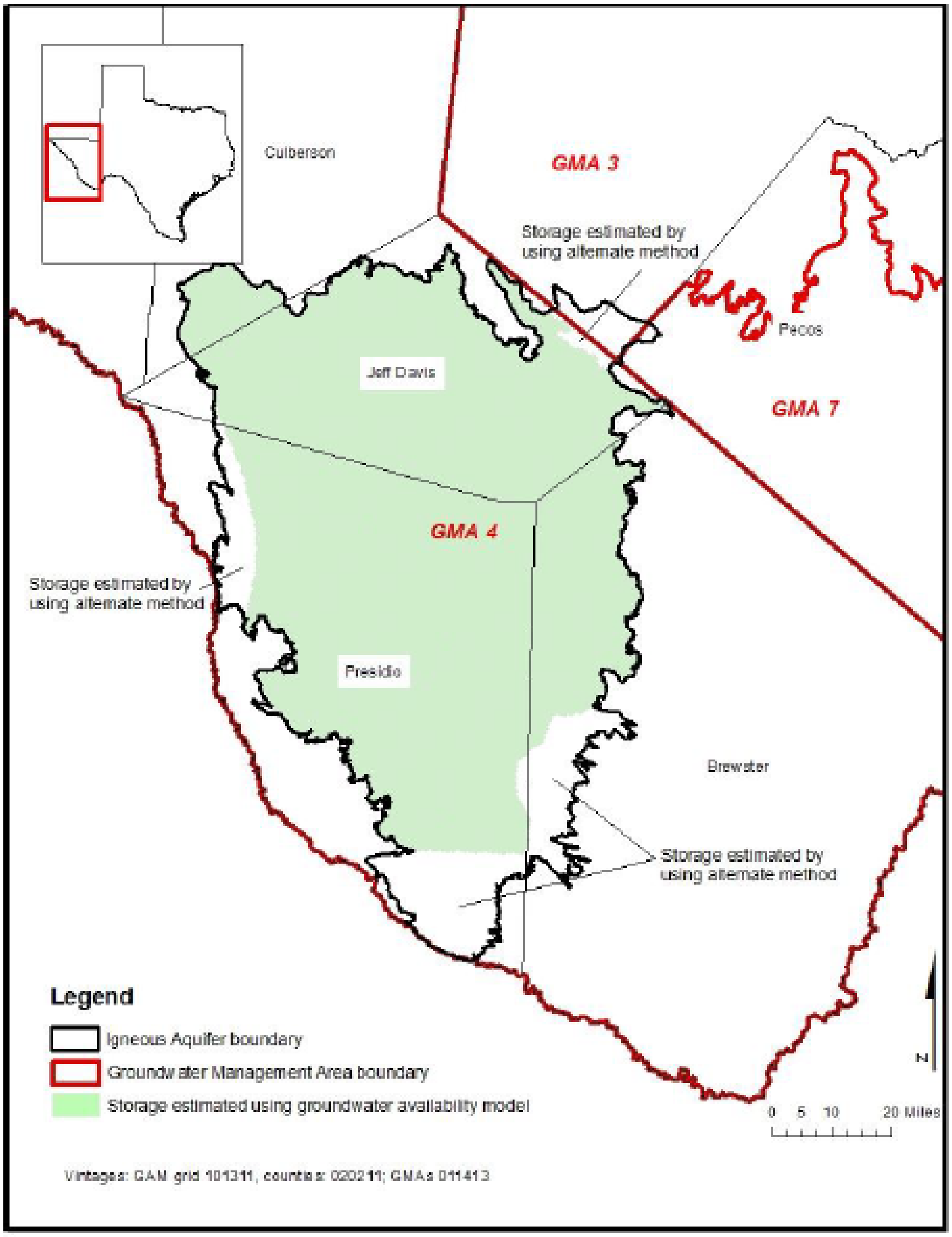


Figure 10. Location of Igneous Aquifer
From Boghici and others (2014)

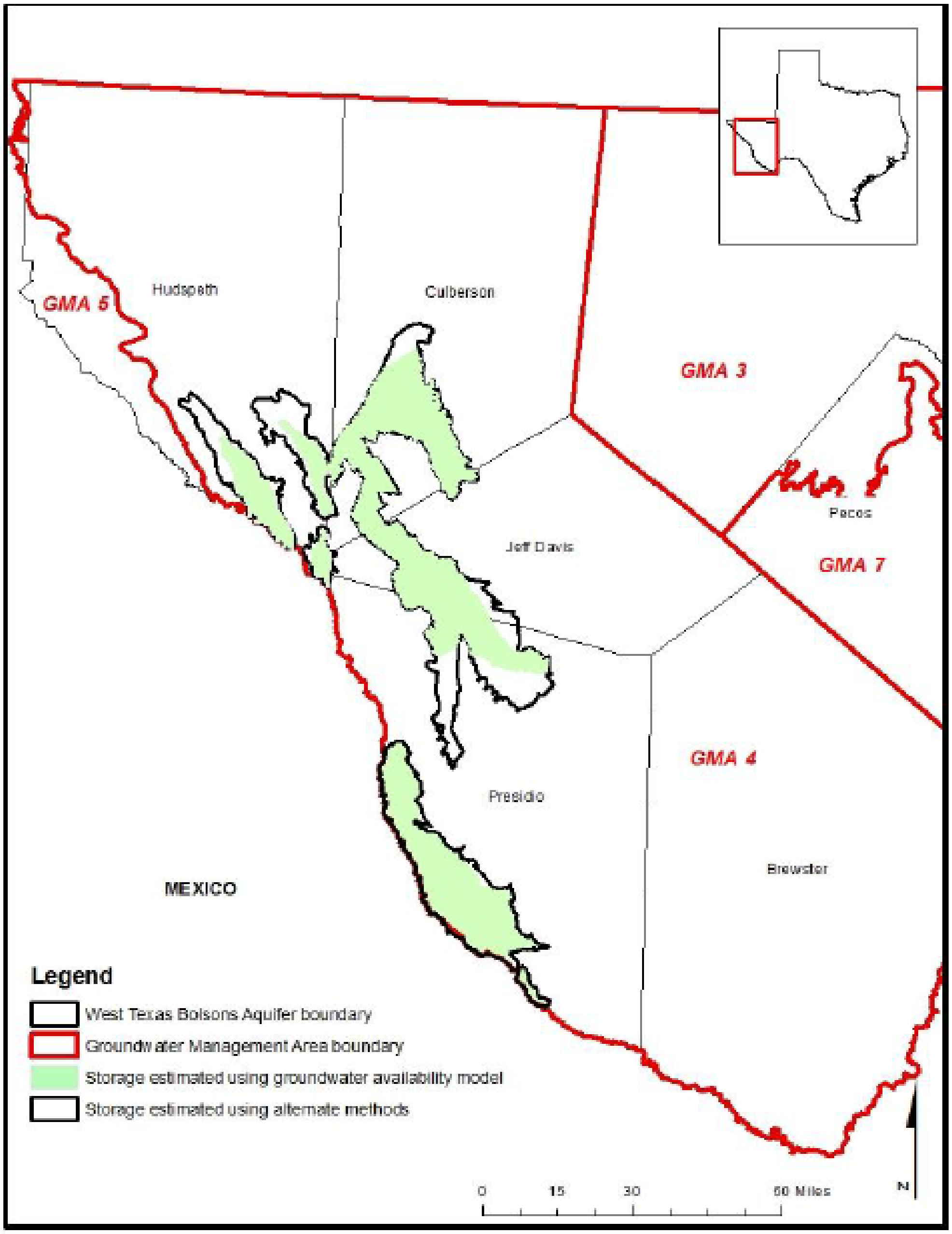


Figure 11. Location of West Texas Bolsons Aquifer
From Boghici and others (2014)

8.2 Policy Justifications

As developed more fully in this report, the proposed desired future condition was adopted after considering:

- Aquifer uses and conditions within Groundwater Management Area 4

- Water supply needs and water management strategies included in the 2012 State Water Plan
- Hydrologic conditions within Groundwater Management Area 4 including total estimated recoverable storage, average annual recharge, inflows, and discharge
- Other environmental impacts, including spring flow and other interactions between groundwater and surface water
- The impact on subsidence
- Socioeconomic impacts reasonably expected to occur
- The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater as recognized under Texas Water Code Section 36.002
- The feasibility of achieving the desired future condition
- Other information

In addition, the proposed desired future condition provides a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater in Groundwater Management Area 4.

There is no set formula or equation for calculating groundwater availability. This is because an estimate of groundwater availability requires the blending of policy and science. Given that the tools for scientific analysis (groundwater models) contain limitations and uncertainty, policy provides the guidance and defines the bounds that science can use to calculate groundwater availability.

As developed more fully below, many of these factors could only be considered on a qualitative level since the available tools to evaluate these impacts have limitations and uncertainty.

8.3 Technical Justification

The process of using the groundwater model in developing desired future conditions revolves around the concept of incorporating many of the elements of the nine factors (e.g. current uses and water management strategies in the regional plan). Some critics of the process asserted that the districts were “reverse-engineering” the desired future conditions by specifying pumping (e.g., the modeled available groundwater) and then adopting the resulting drawdown as the desired future condition. However, it must be remembered that among the input parameters for a predictive groundwater model run is pumping, and among the outputs of a predictive groundwater model run is drawdown. Thus, an iterative approach of running several predictive scenarios with models and then evaluating the results is a necessary (and time-consuming) step in the process of developing desired future conditions.

One part of the reverse-engineering critique of the process has been that “science” should be used in the development of desired future conditions. The critique plays on the unfortunate name of the groundwater models in Texas (Groundwater Availability Models) which could suggest that the models yield an availability number. This is simply a mischaracterization of how the models work (i.e. what is a model input and what is a model output).

The critique also relies on a fairly narrow definition of the term *science* and fails to recognize that the adoption of a desired future condition is primarily a policy decision. The call to use science in the development of desired future conditions seems to equate the term *science* with the terms *facts* and *truth*. Although the Latin origin of the word means knowledge, the term *science* also refers to the application of the scientific method. The scientific method is discussed in many textbooks and can be viewed to quantify cause-and-effect relationships and to make useful predictions.

In the case of groundwater management, the scientific method can be used to understand the relationship between groundwater pumping and drawdown, or groundwater pumping and spring flow. A groundwater model is a tool that can be used to run "experiments" to better understand the cause-and-effect relationships within a groundwater system as they relate to groundwater management.

Much of the consideration of the nine statutory factors involves understanding the effects or the impacts of a desired future condition (e.g. groundwater-surface water interaction and property rights). The use of the models in this manner in evaluating the impacts of alternative futures is an effective means of developing information for the groundwater conservation districts as they develop desired future conditions.

The desired future conditions for the Igneous Aquifer and West Texas Bolsons aquifers were developed based on simulations of alternative scenarios of future pumping using the Groundwater Availability Model (GAM) of the Igneous and West Texas Bolsons Aquifers (Beach and others, 2004). One of the stated purposes of the GAM was to "provide predictions of groundwater availability through the year 2050 based on current groundwater demand projections during an average and drought-of-record hydrologic conditions" (Beach and others, 2004, pg.13-1). The calibration period for the GAM was 1950 to 2000 (Beach and others, 2004, pg. 9-1). Simulations of approximately 50 years are, therefore, temporally consistent with the length of the calibration period.

The documentation for the GAM stated that the GAM "integrates all of the available hydrogeologic data for the study area into the flow model which can be used as a tool for the assessment of water management strategies" (Beach, 20014, pg.13-1). The GAM documentation notes that the Igneous Aquifer was included in the model in recognition that it is part of the regional flow system and is hydrologically connected to the Salt Basin Bolson (Beach and others, 2004, pg. 11-2). Specifically, model limitations include (Beach and others, 2004, pg. 11-2 and 11-3):

- The model is probably not a reasonable tool to assess spring flow in the Davis Mountains, stream-aquifer interaction, or assess localized water level conditions or aquifer dynamics of the Igneous Aquifer.
- The Igneous Aquifer portion of the model should be used with caution when attempting to simulate individual well dynamics, and possibly even wellfield conditions because the model was not developed with that goal in mind nor were the data available on a regional basis to construct a model for the entire Igneous Aquifer.
- The model simulates groundwater movement within the individual flats that comprise the Salt Basin Bolson aquifer relatively well. However, the simulation of lateral movement

between the flats is less defendable due to limited hydraulic property data and historic water level information.

Conceptually, the model simulates groundwater flow in three layers as shown in Figure 12, which is reproduced from Beach and others (2004, pg. 5-2). Due to the vertical interaction between aquifer units that is simulated in the GAM, the proposed desired future conditions for the Igneous Aquifer and the West Texas Bolsons were developed together.

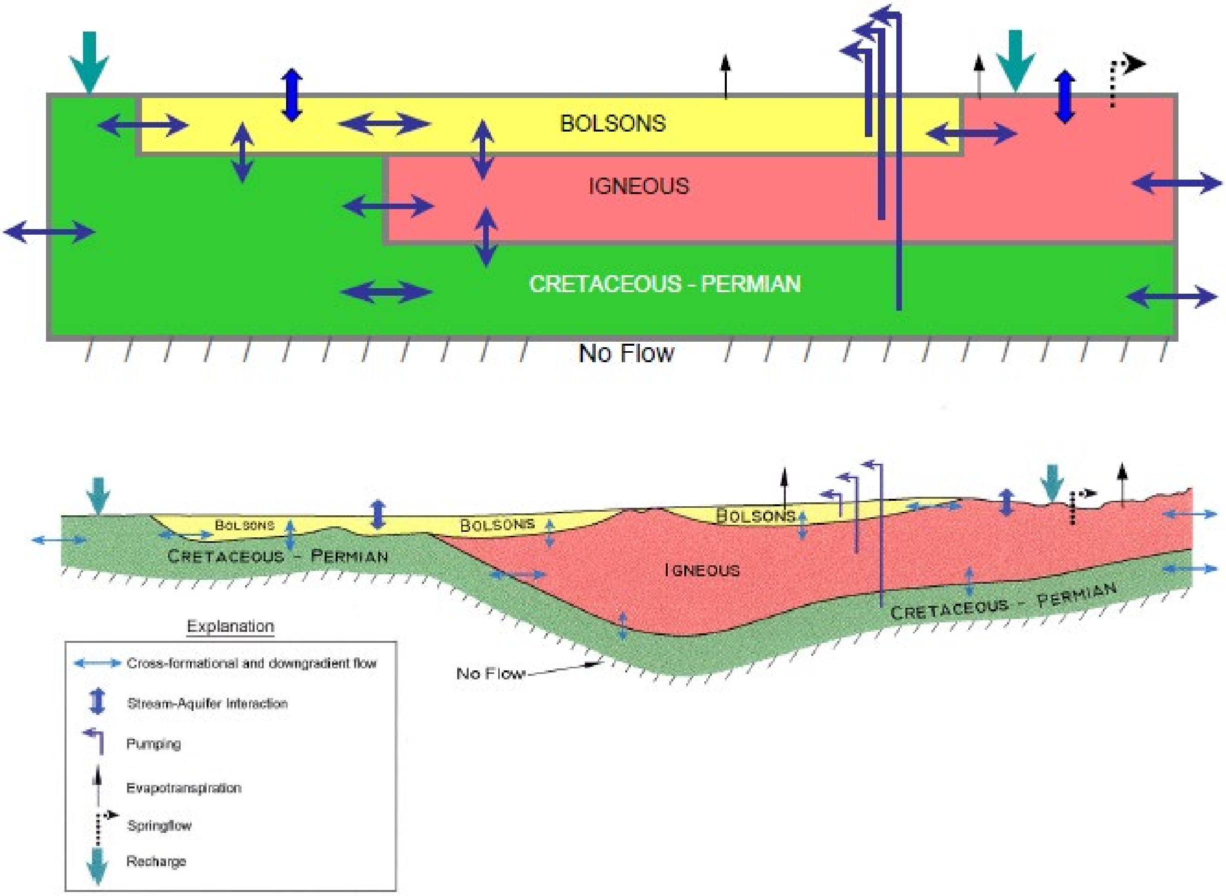


Figure 12. Schematic Conceptual Model (from Beach and others, 2004, pg. 5-2)

8.4 Factor Consideration

8.4.1 Aquifer Uses and Conditions

Appendix D presents the uses and demands for the Igneous Aquifer. Appendix E presents the uses and demands for the West Texas Bolsons Aquifer.

8.4.2 Water Supply Needs and Water Management Strategies

Ashworth and others (2016, pg. 5-11) identified three water management strategies associated with the Igneous Aquifer:

- Strategy E-58: Additional groundwater well for Fort Davis WSC (274 AF/yr starting in 2020 for a capital cost of $507,000).
- Strategy E-59: Additional transmission lines to connect Fort Davis WSC to Fort Davis Estates (114 AF/yr starting in 2020 for a capital cost of about $1.07 million).
- Strategy E-61: Additional groundwater well for the City of Marfa (785 AF/yr starting in 2020 for a capital cost of about $1.1 million).

Ashworth and others (2016, pg. 5-9 and 5-11) identified four water management strategies associated with the West Texas Bolsons Aquifer:

- Strategy E-6: Additional groundwater well for "Culberson County Mining" (500 AF/yr starting in 2020 for a capital cost of $675,000).
- Strategy E-53: Additional transmission lines to supply connections outside of the Hudspeth Co. WCID No. 1 for the City of Sierra Blanca (351 AF/yr starting in 2020 for a capital cost of about $1.4 million).
- Strategy E-57: Additional groundwater well for "Hudspeth County Mining" (30 AF/yr starting in 2020 for a capital cost of $449,000)
- Strategy E-60: Additional groundwater well for the Town of Valentine (65 AF/yr starting in 2020 for a capital cost of about $400,000)

8.4.3 Hydrologic Conditions, Including Total Estimated Recoverable Storage

The hydrologic conditions considered under this factor include:

- Total estimated recoverable storage
- Average annual recharge
- Average annual inflows
- Average annual discharge

The total estimated recoverable storage was reported by the Texas Water Development Board (Boghici and others, 2014). Boghici and others (2014) is presented in Appendix B.

Table 13 presents the estimates for the Igneous Aquifer. Table 14 presents the estimates for the West Texas Bolsons Aquifer. Please note that the estimates in Table 14 include the Presidio-Redford Bolson subdivision in Presidio County.

Table 13. Total Estimated Recoverable Storage Estimates - Igneous Aquifer

County	Total Storage (acre-feet)	25 percent of Total Storage (acre-feet)	75 percent of Total Storage (acre-feet)
Brewster	5,300,000	1,325,000	3,975,000
Culberson	760,000	190,000	570,000
Jeff Davis	24,000,000	6,000,000	18,000,000
Presidio	34,000,000	8,500,000	25,500,000
Total	**64,060,000**	**16,015,000**	**48,045,000**

Table 14. Total Estimated Recoverable Storage - West Texas Bolsons Aquifer

County	Total Storage (acre-feet)	25 percent of Total Storage (acre-feet)	75 percent of Total Storage (acre-feet)
Culberson	5,400,000	1,350,000	4,050,000
Hudspeth	6,800,000	1,700,000	5,100,000
Jeff Davis	4,200,000	1,050,000	3,150,000
Presidio	35,000,000	8,750,000	26,250,000
Total	**51,400,000**	**12,850,000**	**38,550,000**

Shi (2013) summarized the recharge, inflows, and discharges for the Igneous Aquifer in Brewster County, and is reproduced in Table 15.

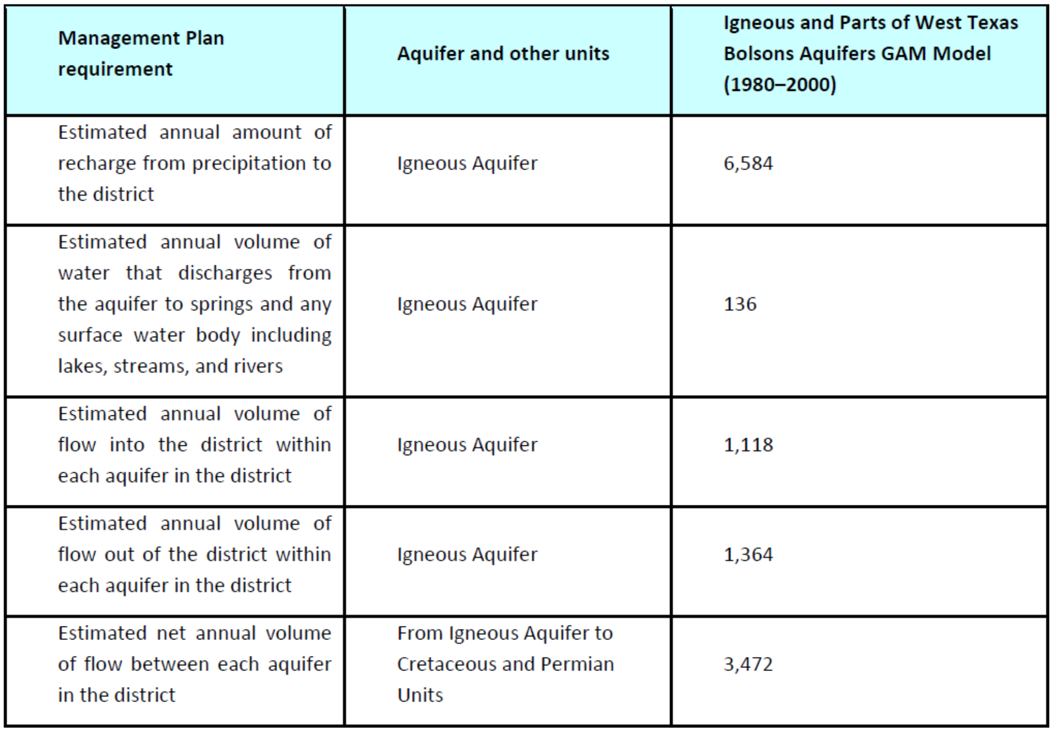
Jones (2012a) summarized the recharge, inflows, and discharges for the Igneous Aquifer and West Texas Bolsons Aquifer in Culberson County, and are reproduced in Table 16 (Igneous Aquifer) and Table 17 (West Texas Bolsons Aquifer).

Jigmond (2012) summarized the recharge, inflows, and discharges for the Igneous Aquifer and West Texas Bolsons Aquifer in Jeff Davis County, which are reproduced in Table 18 (Igneous Aquifer) and Table 19 (West Texas Bolsons Aquifer).

Wade (2013) summarized the recharge, inflows, and discharges for the Igneous Aquifer and West Texas Bolsons Aquifer in Presidio County, which are reproduced in Table 20 (Igneous Aquifer) and Table 21 (West Texas Bolsons Aquifer).

Table 15. Recharge, Inflow, and Discharge Estimates: Igneous Aquifer, Brewster County

(All Flows in AF/yr)

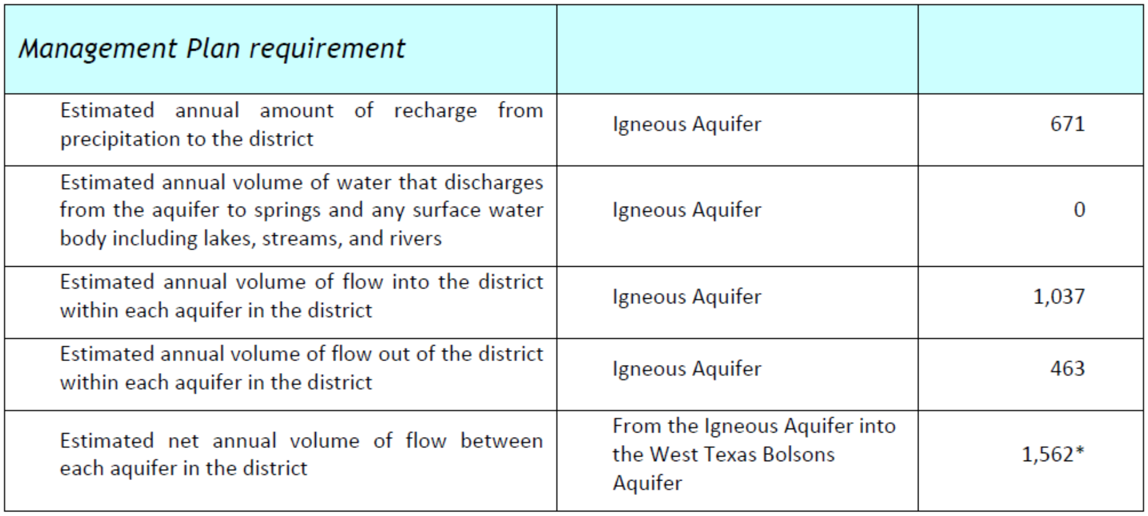


Management Plan requirement	**Aquifer and other units**	**Igneous and Parts of West Texas Bolsons Aquifers GAM Model (1980–2000)**
Estimated annual amount of recharge from precipitation to the district	Igneous Aquifer	6,584
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Igneous Aquifer	136
Estimated annual volume of flow into the district within each aquifer in the district	Igneous Aquifer	1,118
Estimated annual volume of flow out of the district within each aquifer in the district	Igneous Aquifer	1,364
Estimated net annual volume of flow between each aquifer in the district	From Igneous Aquifer to Cretaceous and Permian Units	3,472

Table 16. Recharge, Inflow, and Discharge Estimates: Igneous Aquifer, Culberson County

(All Flows in AF/yr)

* Some of the flow reported in Table 16 is included in Table 17 (see Jones, 2012a)



Management Plan requirement		
Estimated annual amount of recharge from precipitation to the district	Igneous Aquifer	671
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Igneous Aquifer	0
Estimated annual volume of flow into the district within each aquifer in the district	Igneous Aquifer	1,037
Estimated annual volume of flow out of the district within each aquifer in the district	Igneous Aquifer	463
Estimated net annual volume of flow between each aquifer in the district	From the Igneous Aquifer into the West Texas Bolsons Aquifer	1,562*

Table 17. Recharge, Inflow, and Discharge Estimates: West Texas Bolsons Aquifer, Culberson County

(All Flows in AF/yr)

* Some of the flow reported in Table 17 is included in Table 16 (see Jones, 2012a)

Management Plan requirement		
Estimated annual amount of recharge from precipitation to the district	West Texas Bolsons Aquifer	2,107
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	West Texas Bolsons Aquifer	494
Estimated annual volume of flow into the district within each aquifer in the district	West Texas Bolsons Aquifer	7,453
Estimated annual volume of flow out of the district within each aquifer in the district	West Texas Bolsons Aquifer	629
Estimated net annual volume of flow between each aquifer in the district	From the Igneous Aquifer and other underlying units into the West Texas Bolsons Aquifer	5,238*

Table 18. Recharge, Inflow, and Discharge Estimates: Igneous Aquifer, Jeff Davis County

(All Flows in AF/yr)

Management Plan requirement	*Aquifer*	*Results*
Estimated annual amount of recharge from precipitation to the district	Igneous Aquifer	26,043[3]
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Igneous Aquifer	2,566
Estimated annual volume of flow into the district within each aquifer in the district	Igneous Aquifer	611
Estimated annual volume of flow out of the district within each aquifer in the district	Igneous Aquifer	4,322
Estimated net annual volume of flow between each aquifer in the district[4]	From Igneous Aquifer into overlying West Texas Bolsons Aquifer	1,726
	From Igneous Aquifer into underlying Cretaceous and Permian units	14,342

Table 19. Recharge, Inflow, and Discharge Estimates: West Texas Bolsons Aquifer, Jeff Davis County

(All Flows in AF/yr)

Management Plan requirement	*Aquifer*	*Results*
Estimated annual amount of recharge from precipitation to the district	West Texas Bolsons Aquifer	153[5]
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	West Texas Bolsons Aquifer	0
Estimated annual volume of flow into the district within each aquifer in the district	West Texas Bolsons Aquifer	4,188
Estimated annual volume of flow out of the district within each aquifer in the district	West Texas Bolsons Aquifer	7,422
Estimated net annual volume of flow between each aquifer in the district[6]	From Igneous Aquifer into overlying West Texas Bolsons Aquifer	1,726
	From Cretaceous and Permian units into overlying West Texas Bolsons Aquifer	11

Table 20. Recharge, Inflow, and Discharge Estimates: Igneous Aquifer, Presidio County

(All Flows in AF/yr)

Management Plan requirement	*Aquifer*	*Results*
Estimated annual amount of recharge from precipitation to the district	Igneous Aquifer	9,409[1]
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	Igneous Aquifer	3,252
Estimated annual volume of flow into the district within each aquifer in the district	Igneous Aquifer	4,429
Estimated annual volume of flow out of the district within each aquifer in the district	Igneous Aquifer	1,783
Estimated net annual volume of flow between each aquifer in the district[2]	From Igneous Aquifer into overlying West Texas Bolsons Aquifer	1,611
	From Igneous Aquifer into underlying Cretaceous and Permian units	5,909

Table 21. Recharge, Inflow, and Discharge Estimates: West Texas Bolsons Aquifer, Presidio County
(All Flows in AF/yr)

Management Plan requirement	*Aquifer*	*Results*[3]
Estimated annual amount of recharge from precipitation to the district	West Texas Bolsons Aquifer	14,660
Estimated annual volume of water that discharges from the aquifer to springs and any surface water body including lakes, streams, and rivers	West Texas Bolsons Aquifer	9,117[4]
Estimated annual volume of flow into the district within each aquifer in the district	West Texas Bolsons Aquifer	22,987
Estimated annual volume of flow out of the district within each aquifer in the district	West Texas Bolsons Aquifer	39,097
Estimated net annual volume of flow between each aquifer in the district[5]	From West Texas Bolsons Aquifer into overlying river alluvium	911
	From Igneous Aquifer and other underlying units into West Texas Bolsons Aquifer	13,372

8.4.4 Other Environmental Impacts

As reported by Beach and others (2004), the groundwater availability of the model of the area is not well suited to evaluate spring flow and other interactions between groundwater and surface water. Due to the locations of the springs in the mountainous regions of the county and the location of most of the pumping at the lower elevations, the potential for pumping to impact spring flow is low. Due to the arid character of the region, and the intermittent flow of streams in Jeff Davis County, impacts to surface water resources are considered minor.

Despite this stated limitation, Tables 15 to 21, presented previously, include model developed estimates from the Texas Water Development Board for spring flow and other discharges to surface water.

8.4.5 Subsidence

Subsidence is not an issue in these aquifers.

8.4.6 Socioeconomic Impacts

The Texas Water Development Board prepared reports on the socioeconomic impacts of not meeting water needs for each of the Regional Planning Groups during development of the 2021 Regional Water Plans. Because the development of this desired future condition used the State Water Plan demands and water management strategies as an important foundation, it is reasonable to conclude that the socioeconomic impacts associated with this proposed desired future condition can be evaluated in the context of not meeting the listed water management strategies. Groundwater Management Area 4 is covered by Regional Planning Group E. The socioeconomic impact reports for Regions E is presented in Appendix C.

8.4.7 Impact on Private Property Rights

The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater is recognized under Texas Water Code Section 36.002.

The desired future conditions adopted by GMA 4 are consistent with protecting property rights of landowners who are currently pumping groundwater and landowners who have chosen to conserve groundwater by not pumping. As required by Chapter 36 of the Water Code, GMA 4 considered these impacts and balanced them with the increasing demand of water in the GMA 4 area, and concluded that, on balance and with appropriate monitoring and project specific review during the permitting process, all the Region E strategies can be included in the desired future condition.

At the April 30, 2015 meeting of GMA 4, the districts recognized that to protect all property rights, the districts have the authority to curb production and encourage conservation.

8.4.8 Feasibility of Achieving the Desired Future Conditions

Groundwater monitoring in terms of pumping and groundwater levels provide the means evaluate consistency with the desired future condition. Groundwater levels are routinely monitored by the districts and by TWDB in GMA 4. Evaluating the monitoring data is a routine task for the districts, and the comparison of these data with the desired future conditions is covered in each district's management plan. These comparisons are useful to guide the update of the DFCs that are required every five years.

8.4.9 Other Information

No other information was used in the development of the desired future conditions.

8.5 Discussion of Other Desired Future Conditions Considered

During the development of the desired future conditions in 2010, TWDB completed eight reports that summarized simulations with the groundwater availability model of the area that provided results that could be used for alternative desired future conditions. These reports are listed below:

- GAM Run 05-40 (Donnelly, 2006a) February 17, 2006
- GAM Run 06-04 (Donnelly, 2006b) March 8, 2006
- GAM Run 06-17 (Donnelly, 2006c) July 18, 2006
- GAM Run 06-32 (Donnelly, 2007) May 2, 2007
- GAM Run 08-24 (Oliver, 2008) December 19, 2008

- GAM Task 10-026 (Oliver, 2010a) June 24, 2010
- GAM Run 10-003 (Wade, 2010) June 29, 2010
- GAM Task 10-028 (Oliver, 2010b) July 29, 2010

9.0 Marathon Aquifer

9.1 Aquifer Description and Location

As described in George and others (2011, pg. 125):

> The Marathon Aquifer, a minor aquifer, occurs entirely within north-central Brewster County. The aquifer consists of tightly folded and faulted rocks of the Gaptank Formation, the Dimple Limestone, the Tesnus Formation, the Caballos Novaculite, the Maravillas Chert, the Fort Pena Formation, and the Marathon Limestone. Although maximum thickness of the aquifer is about 900 feet, well depths are commonly less than 250 feet. Water in the aquifer is under unconfined conditions in fractures, joints, and cavities; however, artesian conditions are common in areas where the aquifer rocks are buried beneath younger formations. The Marathon Limestone is at or near land surface and is the most productive part of the aquifer. Many of the shallow wells in the region actually produce water from alluvial deposits that cover parts of the rock formations. Total dissolved solids range from 500 to 1,000 milligrams per liter, and the water, although very hard, is generally suitable for most uses. Groundwater is used primarily for municipal water supply by the city of Marathon and for domestic and livestock purposes. The Region E Planning Group, in its 2006 Regional Water Plan, did not recommend any water management strategies using the Marathon Aquifer.

The aquifer is in Brewster County (Figure 13).

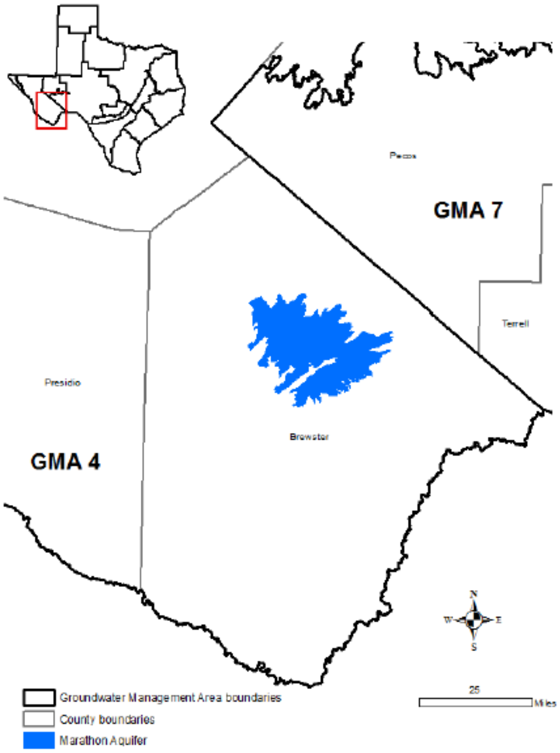


Figure 13. Location of Marathon Aquifer
From Boghici and others (2014)

9.2 Policy Justifications

As developed more fully in this report, the proposed desired future condition was adopted after considering:

- Aquifer uses and conditions within Groundwater Management Area 4
- Water supply needs and water management strategies included in the 2012 State Water Plan
- Hydrologic conditions within Groundwater Management Area 4 including total estimated recoverable storage, average annual recharge, inflows, and discharge
- Other environmental impacts, including spring flow and other interactions between groundwater and surface water
- The impact on subsidence
- Socioeconomic impacts reasonably expected to occur
- The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater as recognized under Texas Water Code Section 36.002
- The feasibility of achieving the desired future condition
- Other information

In addition, the proposed desired future condition provides a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater in Groundwater Management Area 4.

There is no set formula or equation for calculating groundwater availability. This is because an estimate of groundwater availability requires the blending of policy and science. Given that the tools for scientific analysis (groundwater models) contain limitations and uncertainty, policy provides the guidance and defines the bounds that science can use to calculate groundwater availability.

As developed more fully below, many of these factors could only be considered on a qualitative level since the available tools to evaluate these impacts have limitations and uncertainty.

9.3 Technical Justification

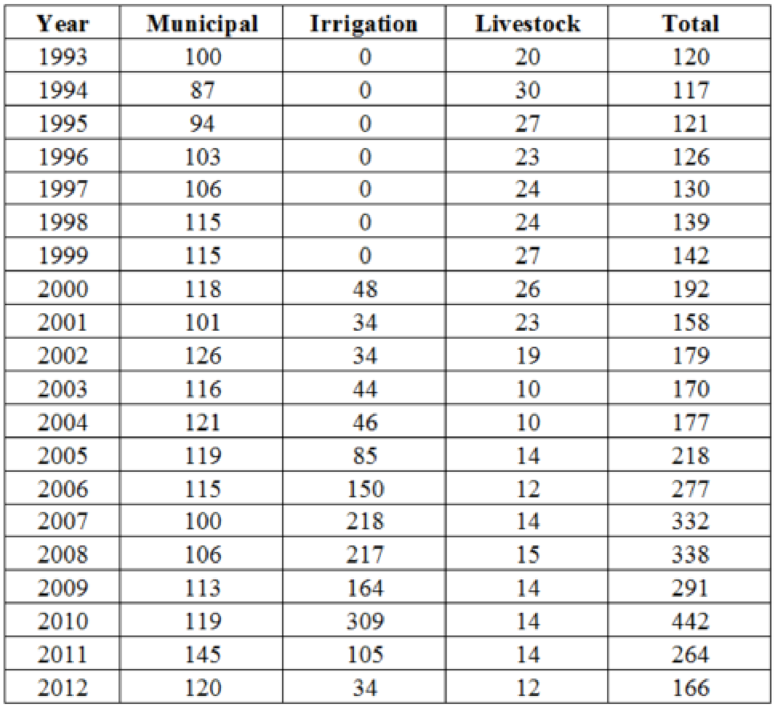
Thorkildsen and Backhouse (2010a) completed an Aquifer Assessment for the Marathon Aquifer that was the basis for the desired future condition adopted in 2010. An Aquifer Assessment was completed due the lack of a Groundwater Availability Model of the area (at the time) and limited data over the area. The analytical approach determined a pumping rate that was equal to the effective recharge plus the change in storage of the aquifer under an assumption of uniform water-level decline. Key assumptions in applying the method is that the aquifer is homogenous and isotropic, and that lateral inflow and lateral outflow are equal, and that future pumping will not alter this balance.

9.4 Factor Consideration

9.4.1 Groundwater Demands and Uses

Table 22 summarizes the TWDB estimates of groundwater demands and uses for the Marathon Aquifer in Brewster County.

Table 22. Groundwater Demands and Uses, 1993 to 2012, Marathon Aquifer (Brewster County)
All Values in AF/yr



Year	Municipal	Irrigation	Livestock	Total
1993	100	0	20	120
1994	87	0	30	117
1995	94	0	27	121
1996	103	0	23	126
1997	106	0	24	130
1998	115	0	24	139
1999	115	0	27	142
2000	118	48	26	192
2001	101	34	23	158
2002	126	34	19	179
2003	116	44	10	170
2004	121	46	10	177
2005	119	85	14	218
2006	115	150	12	277
2007	100	218	14	332
2008	106	217	15	338
2009	113	164	14	291
2010	119	309	14	442
2011	145	105	14	264
2012	120	34	12	166

9.4.3 Water Supply Needs and Water Management Strategies

Ashworth and others (2016) identified no water management strategies associated with the Marathon Aquifer.

9.4.4 Hydrologic Conditions, Including Total Estimated Recoverable Storage

The hydrologic conditions considered under this factor include:

- Total estimated recoverable storage
- Average annual recharge
- Average annual inflows
- Average annual discharge

The total estimated recoverable storage was reported by the Texas Water Development Board (Boghici and others, 2014). Total estimated storage was reported as 1.5 million acre-feet. Total estimated recoverable storage was reported as a range (25 to 75 percent of the total storage) between 375,000 acre-feet to 1.125 million acre-feet. Boghici and others (2014) is presented in Appendix B.

Smith (2001) estimated recharge of less than 5 percent of the annual precipitation for a recharge rate to the Marathon area of about 25,000 AF/yr. Thorkildsen and Backhouse (2010a) estimated effective recharge from precipitation to be 2.5 percent of annual precipitation, or 7,327 AF/yr.

Smith (2001) reported that recharge from underflow is only likely from the east, and any water entering the basin from this direction would most likely move southwestward, along San Francisco Creek. No quantitative estimate of the inflow was provided.

Smith (2001) reported that underflow out of the basin through the alluvium and permeable Paleozoic rocks in preferential stream valleys (Maravillas, Woods Hollow, Hackberry, and San Francisco Creeks). No quantitative estimate of the outflow was provided.

9.4.5 Other Environmental Impacts

The impacts under this factor include spring flow and other interactions between groundwater and surface water.

Smith (2001) estimated spring discharge in 1957 was 880 AF/yr and 902 AF/yr in 1976. Smith (2001) also reported that groundwater is also discharged via evapotranspiration and direct evaporation, but provided no quantitative estimates.

9.4.5 Subsidence

Subsidence is not an issue in the Marathon Aquifer.

9.4.6 Socioeconomic Impacts

The Texas Water Development Board prepared reports on the socioeconomic impacts of not meeting water needs for each of the Regional Planning Groups during development of the 2021 Regional Water Plans. Because the development of this desired future condition used the State Water Plan demands and water management strategies as an important foundation, it is reasonable to conclude that the socioeconomic impacts associated with this proposed desired future condition can be evaluated in the context of not meeting the listed water management strategies. Groundwater Management Area 4 is covered by Regional Planning Group E. The socioeconomic impact reports for Regions E is presented in Appendix C.

9.4.7 Impact on Private Property Rights

The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater is recognized under Texas Water Code Section 36.002.

The desired future conditions adopted by GMA 4 are consistent with protecting property rights of landowners who are currently pumping groundwater and landowners who have chosen to conserve groundwater by not pumping. As required by Chapter 36 of the Water Code, GMA 4 considered these impacts and balanced them with the increasing demand of water in the GMA 4 area, and concluded that, on balance and with appropriate monitoring and project specific review during the permitting process, all the Region E strategies can be included in the desired future condition.

At the April 30, 2015 meeting of GMA 4, the districts recognized that to protect all property rights, the districts have the authority to curb production and encourage conservation.

9.4.8 Feasibility of Achieving the Desired Future Conditions

Groundwater monitoring in terms of pumping and groundwater levels provide the means evaluate consistency with the desired future condition. Groundwater levels are routinely monitored by the districts and by TWDB in GMA 4. Evaluating the monitoring data is a routine task for the districts, and the comparison of these data with the desired future conditions is covered in each district's management plan. These comparisons are useful to guide the update of the DFCs that are required every five years.

9.4.9 Other Information

No other information was used in the development of the desired future conditions.

9.5 Discussion of Other Desired Future Conditions Considered

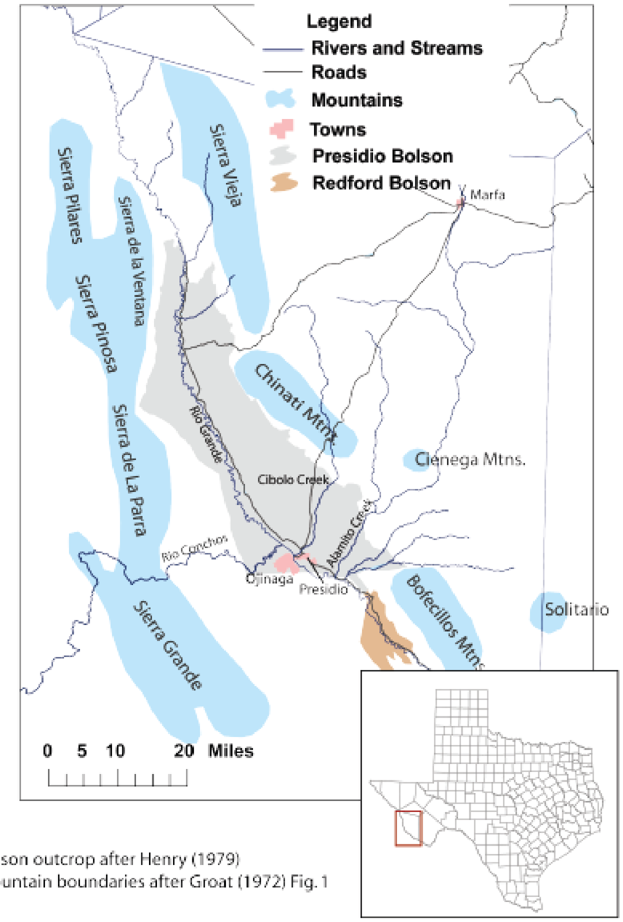
Prior to adopting the desired future condition in 2010, GMA 4 reviewed Thorkildsen and Backhouse (2010a) that analyzed four alternative drawdown conditions in an Aquifer Assessment. Alternative drawdowns considered included 0, 5, 10, and 20 feet.

10.0 Presidio-Redford Bolson subdivision of the West Texas Bolsons Aquifer

10.1 Aquifer Description and Location

The Presidio-Redford Bolson is a subdivision of the West Texas Bolsons Aquifer. Wade and others (2011) completed a conceptual model of the area, and Wade and Jigmond (2013) completed a Groundwater Availability Model of the area. The Presidio-Redford Bolson straddles the Rio Grande Valley. Groundwater occurs in Quaternary-age Rio Grande alluvium and side-stream alluvium deposits, Quaternary-Tertiary age Presidio and Redford Bolsons, and in underlying and surrounding Tertiary igneous, and Cretaceous age rocks (Wade and Jigmond, 2013, pg. 15). The alluvial portion and Bolson portion of the aquifer is geographically isolated from the rest of the West Texas Bolsons Aquifer.

The subdivision of the aquifer is in Presidio County (Figure 14).



Bolson outcrop after Henry (1979)
Mountain boundaries after Groat (1972) Fig. 1

Figure 14. Location of Presidio-Redford Bolson Aquifer

10.2 Policy Justifications

As developed more fully in this report, the proposed desired future condition was adopted after considering:

- Aquifer uses and conditions within Groundwater Management Area 4
- Water supply needs and water management strategies included in the 2012 State Water Plan
- Hydrologic conditions within Groundwater Management Area 4 including total estimated recoverable storage, average annual recharge, inflows, and discharge
- Other environmental impacts, including spring flow and other interactions between groundwater and surface water
- The impact on subsidence
- Socioeconomic impacts reasonably expected to occur
- The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater as recognized under Texas Water Code Section 36.002
- The feasibility of achieving the desired future condition
- Other information

In addition, the proposed desired future condition provides a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater in Groundwater Management Area 4.

There is no set formula or equation for calculating groundwater availability. This is because an estimate of groundwater availability requires the blending of policy and science. Given that the tools for scientific analysis (groundwater models) contain limitations and uncertainty, policy provides the guidance and defines the bounds that science can use to calculate groundwater availability.

As developed more fully below, many of these factors could only be considered on a qualitative level since the available tools to evaluate these impacts have limitations and uncertainty.

10.3 Technical Justification

Wuerch and Davidson (2010b) completed an Aquifer Assessment for the Presidio-Redford Bolson Aquifer that was the basis for the desired future condition adopted in 2010. An Aquifer Assessment was completed due the lack of a Groundwater Availability Model of the area (at the time) and limited data over the area. The analytical approach determined a pumping rate that was equal to the effective recharge plus the change in storage of the aquifer under an assumption of uniform water-level decline. Key assumptions in applying the method is that the aquifer is homogenous and isotropic, and that lateral inflow and lateral outflow are equal, and that future pumping will not alter this balance.

The DFC adopted in 2010 has been updated since then as summarized on the timeline provided by Robert Bradley of TWDB:

- January 15, 2015 – Presidio County UWCD 2015 management plan approved which combined the DFCs for all West Texas Bolsons at 72 feet. http://www.twdb.texas.gov/groundwater/docs/GCD/pcuwcd/pcuwcd_mgmt_plan2015.pdf
- January 29, 2015 – GMA 4 meeting, Robert Bradley presented table of aquifers listing relevant and non-relevant to GMA 4 members.
- April 30, 2015 – GMA 4 meeting, Rudy Garcia showed up for Presidio County UWCD
- September 17, 2015 – GMA 4 meeting, GMA 4 members and Robert Bradley requested Presidio County UWCD DFC listed (72 feet) in management plan to be adopted as PCUWCD board resolution.
- February 18, 2016 – GMA 4 meeting, Rudy Garcia stated that he had made a mistake in the original resolution to his board, and the district will modify this to 72 feet to match the other aquifers in Presidio County.

10.4 Factor Consideration

10.4.1 Groundwater Demands and Uses

The Presidio-Redford Bolson Aquifer is a subdivision of the West Texas Bolsons Aquifer. The Texas Water Development Board reports uses and demands on an aquifer-wide basis, and does not provide estimates at the aquifer subdivision level. Appendix E (previously discussed in the section on the West Texas Bolsons Aquifer) presents the combined data for all subdivisions of the West Texas Bolsons Aquifer in Presidio County. Wade and Jigmond (2013) estimated that pumping in the Presidio-Redford Bolson Aquifer in Presidio County averaged 3,168 AF/yr from 1948 to 2008.

10.4.2 Water Supply Needs and Water Management Strategies

Ashworth and others (2016, pg. 5-11) identified one water management strategy associated with the Presidio-Redford Bolson Aquifer. Strategy E-63 calls for an additional groundwater well with a supply of 120 AF/yr starting in 2020, for a capital cost of about $1.8 million.

10.4.3 Hydrologic Conditions, Including Total Estimated Recoverable Storage

The hydrologic conditions considered under this factor include:

- Total estimated recoverable storage
- Average annual recharge
- Average annual inflows
- Average annual discharge

The total estimated recoverable storage was reported by the Texas Water Development Board (Boghici and others, 2014). The Presidio-Redford Bolson Aquifer is a subdivision of the West

Texas Bolsons Aquifer. The Texas Water Development Board reported the total estimated recoverable storage for all subdivisions of the West Texas Bolsons Aquifer in Presidio County on an aquifer-wide basis, and did not provide estimates at the aquifer subdivision level.

Total estimated storage for all of Presidio County was reported as 35 million acre-feet. Total estimated recoverable storage was reported as a range (25 to 75 percent of the total storage) between 8.75 million acre-feet to 26.225 million acre-feet. Boghici and others (2014) is presented in Appendix B.

Wuerch and Davidson (2010b) estimated that effective recharge was 3,630 AF/yr as part of its Aquifer Assessment.

Wade and Jigmond (2013, pg. 57) reported the following:

- Average recharge inflow from 1948 to 2008 = 33,110 AF/yr
- Average net regional inflow from outside the model domain from 1948 to 2008 = 13,172 AF/yr

10.4.4 Other Environmental Impacts

The impacts under this factor include spring flow and other interactions between groundwater and surface water.

Wade and Jigmond (2013, pg. 57) reported that the average net discharge to rivers and evapotranspiration from 1948 to 2002 was 26,849 AF/yr, and that spring discharge from 1948 to 2008 was 2,263 AF/yr.

10.4.5 Subsidence

Subsidence is not an issue in the Presidio-Redford Bolson Aquifer

10.4.6 Socioeconomic Impacts

The Texas Water Development Board prepared reports on the socioeconomic impacts of not meeting water needs for each of the Regional Planning Groups during development of the 2021 Regional Water Plans. Because the development of this desired future condition used the State Water Plan demands and water management strategies as an important foundation, it is reasonable to conclude that the socioeconomic impacts associated with this proposed desired future condition can be evaluated in the context of not meeting the listed water management strategies. Groundwater Management Area 4 is covered by Regional Planning Group E. The socioeconomic impact report for Regions E is presented in Appendix C.

10.4.7 Impact on Private Property Rights

The impact on the interests and rights in private property, including ownership and the rights of landowners and their lessees and assigns in Groundwater Management Area 4 in groundwater is recognized under Texas Water Code Section 36.002.

The desired future conditions adopted by GMA 4 are consistent with protecting property rights of landowners who are currently pumping groundwater and landowners who have chosen to conserve groundwater by not pumping. As required by Chapter 36 of the Water Code, GMA 4 considered these impacts and balanced them with the increasing demand of water in the GMA 4 area, and concluded that, on balance and with appropriate monitoring and project specific review during the permitting process, all the Region E strategies can be included in the desired future condition.

At the April 30, 2015 meeting of GMA 4, the districts recognized that to protect all property rights, the districts have the authority to curb production and encourage conservation.

10.4.8 Feasibility of Achieving the Desired Future Conditions

Groundwater monitoring in terms of pumping and groundwater levels provide the means evaluate consistency with the desired future condition. Groundwater levels are routinely monitored by the districts and by TWDB in GMA 4. Evaluating the monitoring data is a routine task for the districts, and the comparison of these data with the desired future conditions is covered in each district's management plan. These comparisons are useful to guide the update of the DFCs that are required every five years.

10.4.9 Other Information

No other information was used in the development of the desired future conditions.

10.5 Discussion of Other Desired Future Conditions

There were no other alternatives discussed.

11.0 Public Comments and Discussion of Other Recommendations

Public comments were invited, and each district held a public hearing on the proposed desired future condition for aquifers within their boundaries. The five GCDs in GMA 4 held public hearings as follows:

Groundwater Conservation District	Date of Public Hearing	Number of Comments Received
Brewster County GCD	March 18, 2021	None
Culberson County GCD	March 10, 2021	None
Hudspeth County UWCD No. 1	March 8, 2021	None
Jeff Davis UWCD	February 9, 2021	None
Presidio County UWCD	March 11, 2021	None

12.0 References

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Appendix A

Resolution Adopting Desired Future Conditions
and
Posted Agendas for GMA 4 Meeting of
June 17, 2021

Adopted June 17, 2021

RESOLUTION FOR ADOPTION OF THE DESIRED FUTURE CONDITIONS FOR THE AQUIFERS IN GROUNDWATER MANAGEMENT AREA 4

WHEREAS: Groundwater Management Area (GMA) 4 comprised of the following Groundwater Conservation Districts: Brewster County GCD, Culberson County GCD, Hudspeth County UWCD No. 1, Jeff Davis County UWCD, Presidio County UWCD have reviewed and discussed groundwater availability models and considered the nine statutory factors set forth in Section 36.108(d) of the Texas Water Code

NOW, THEREFORE, BE IT RESOLVED THAT: That the District members of Groundwater Management Area 4 have adopted the following proposed DFCs:

Brewster County GCD: for the period from 2010-2060

3 foot drawdown for the Edwards-Trinity (Plateau) Aquifer

10 foot drawdown for the Igneous Aquifer

0 foot drawdown for the Marathon Aquifer

0 foot drawdown for the Capitan Reef Complex

The Rustler was deemed non-relevant for joint planning purposes.

Culberson County GCD: for the period from 2010-2060

50 foot drawdown for the Capitan Reef Complex

78 foot drawdown for the West Texas Bolsons

66 foot drawdown for the Igneous Aquifer

The Edwards Trinity (Plateau) and Upper Salt Basin were deemed non-relevant for joint planning purposes.

Hudspeth County UWCD No. 1: for the period from 2010-2060

0 foot drawdown for the period from 2010 until 2060 for the Bone Springs-Victorio Peak Aquifer, averaged across the portion of the aquifer within the boundaries of the District.

The Capitan Reef has been deemed non-relevant for joint panning purpose.

Jeff Davis County UWCD: for the period from 2010-2060

20 foot drawdown for the Igneous Aquifer

72 foot drawdown for the West Texas Bolsons

The Edwards-Trinity (Plateau), Pecos Valley Aquifer, Capitan Reef Complex, and the Rustler were deemed non-relevant for joint planning purposes.

Presidio County UWCD: for the period from 2010-2060

14 foot drawdown for the Igneous Aquifer

72 foot drawdown for the West Texas Bolsons

72 foot drawdown for the Presidio-Redford Bolson

AND IT IS SO ORDERED AND PASSED THIS 17th DAY OF JUNE 2021.

SIGNED 6-17-21

Joan Johnson **Brewster County GCD**

SIGNED Summer Webb 6-17-21

Summer Webb **Culberson County GCD**

SIGNED 6-17-2021

Randy Barker **Hudspeth County UWCD No 1**

SIGNED 6-17-21

Janet Adams **Jeff Davis County UWCD**

SIGNED 6.17-2021

Carolyn Macartney **Presidio County UWCD**

Hudspeth County Underground Water Conservation District #1
P.O. Box 212, 107 S. Dodson
Dell City TX 79837
(915) 964-2932
hcuwcd1@dellcity.com

NOTICE OF JOINT PLANNING MEETING OF THE GOVERNING BODY OF THE GROUNDWATER MANAGEMENT AREA #4

June 17, 2021, 10:00 AM (Central Time)

Join Zoom Meeting
https://zoom.us/j/93624829557?pwd=eTVRVEJIbUkrWjBnRitReHlZQ1F1dz09
Meeting ID: 936 2482 9557
Passcode: 6pQrWn

As required by section 36.108(e), Texas Water Code, a meeting of the Groundwater Management Area Joint Planning Group, comprised of delegates from the following groundwater conservation districts located wholly or partially within Groundwater Management Area #4: Brewster County GCD, Jeff Davis UWCD, Culberson County GCD, Hudspeth County UWCD #1, and Presidio County UWCD.

At this meeting, the following business may be considered and recommended for Joint Planning Group action:

1. Call to Order
2. Introduction of member Districts.
3. Public comment
4. Approval of minutes February 3, 2021.
5. Report from Evan Strickland, on TWDB Edwards-Trinity (Plateau) brackish groundwater study
6. Report from TWDB staff
7. Report from Bill Hutchison
8. Adopt Final DFCs
9. Start new DFC planning
10. Timeline for next report
11. Discussion of Similar Rules
12. Discuss items for future agenda items.
13. Set next meeting date.
14. Adjournment.

Janet Adams GMA 4 Representative

I, the undersigned authority of the District, do hereby certify that the above notice is a true and correct copy of said notice and that such notice was posted on the main entrance of the District's office located at 105 S. Dodson, Dell City, Texas, at least 72 hours prior to the time of said meeting, and that copy of said notice was furnished via facsimile to the Clerk of Hudspeth County, Texas at least 72 hours prior to the time of said meeting.

Date: 6-27-2021 Time: 11:20 AM

Randy L. Barker, General Manager

I, the Clerk of Hudspeth County, Texas do hereby certify that the above notice of meeting is a true and correct copy of said notice and that such notice has been posted on the bulletin board at the Hudspeth County Court House in Sierra Blanca, Texas, at least 72 hours prior to the time of said meeting.

Date: ____________________ Time: ____________

____

Brenda Sanchez, County Clerk/Hudspeth County, Texas

Groundwater Management Area # 4
Joint Planning Meeting
June 17, 2021, 10:00 a.m.

In Person: Val Clark Beard County Office Building, Conference Room,
203 N. 7th Street, Alpine, TX

Time: Jun 17, 2021 10:00 AM Central Time (US and Canada)

Join Zoom Meeting
https://zoom.us/j/93624829557?pwd=eTVRVEJIbUkrWjBnRitReHlZQ1F1dz09

Meeting ID: 936 2482 9557
Passcode: 6pQrWn

As required by section 36.108(e), Texas Water Code, a meeting of the Groundwater Management Area Joint Planning Group, comprised of delegates from the following groundwater conservation districts located wholly or partially within Groundwater Management Area #4: Brewster County GCD, Jeff Davis UWCD, Culberson County GCD, Hudspeth County UWCD #1, and Presidio County UWCD.
At this meeting, the following business may be considered and recommended for Joint Planning Group action:

1. Call to Order
2. Introduction of member Districts.
3. Public comment
4. Approval of minutes February 3, 2021.
5. Report from Evan Strickland, on TWDB Edwards-Trinity (Plateau) brackish groundwater study
6. Report from TWDB staff.
7. Report from Bill Hutchison
8. Adopt Final DFCs
9. Start new DFC planning
10. Timeline for next report

FILED FOR RECORD at 10:42A M.

JUN 02 2021

Virginia Pallarez
COUNTY CLK, PRESIDIO CO.

AT 1:40 O'CLOCK P M
FILED
JUN - 1 2021
JENNIFER WRIGHT
CLERK OF COUNTY COURT
JEFF DAVIS COUNTY, TEXAS
BY Ashlie DEPUTY

Groundwater Management Area # 4
Joint Planning Meeting
June 17, 2021, 10:00 a.m.

In Person: Val Clark Beard County Office Building, Conference Room,
203 N. 7th Street, Alpine, TX

Time: Jun 17, 2021 10:00 AM Central Time (US and Canada)

Join Zoom Meeting
https://zoom.us/j/93624829557?pwd=eTVRVEJIbUkrWjBnRitReHlZQ1F1dz09

Meeting ID: 936 2482 9557
Passcode: 6pQrWn

As required by section 36.108(e), Texas Water Code, a meeting of the Groundwater Management Area Joint Planning Group, comprised of delegates from the following groundwater conservation districts located wholly or partially within Groundwater Management Area #4: Brewster County GCD, Jeff Davis UWCD, Culberson County GCD, Hudspeth County UWCD #1, and Presidio County UWCD.
At this meeting, the following business may be considered and recommended for Joint Planning Group action:

1. Call to Order
2. Introduction of member Districts.
3. Public comment
4. Approval of minutes February 3, 2021.
5. Report from Evan Strickland, on TWDB Edwards-Trinity (Plateau) brackish groundwater study
6. Report from TWDB staff.
7. Report from Bill Hutchison
8. Adopt Final DFCs
9. Start new DFC planning
10. Timeline for next report

11. Discussion of Similar Rules

12. Discuss items for future agenda items.

13. Set next meeting date.

14. Adjournment.

Janet Adams
GMA 4 Representative

Groundwater Management Area # 4
Joint Planning Meeting
June 17, 2021, 10:00 a.m.

In Person: Val Clark Beard County Office Building, Conference Room,
203 N. 7th Street, Alpine, TX

Time: Jun 17, 2021 10:00 AM Central Time (US and Canada)

Join Zoom Meeting
https://zoom.us/j/93624829557?pwd=eTVRVEJIbUkrWjBnRitReHlZQ1F1dz09

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Passcode: 6pQrWn

As required by section 36.108(e), Texas Water Code, a meeting of the Groundwater Management Area Joint Planning Group, comprised of delegates from the following groundwater conservation districts located wholly or partially within Groundwater Management Area #4: Brewster County GCD, Jeff Davis UWCD, Culberson County GCD, Hudspeth County UWCD #1, and Presidio County UWCD.
At this meeting, the following business may be considered and recommended for Joint Planning Group action:

1. Call to Order
2. Introduction of member Districts.
3. Public comment
4. Approval of minutes February 3, 2021.
5. Report from Evan Strickland, on TWDB Edwards-Trinity (Plateau) brackish groundwater study
6. Report from TWDB staff.
7. Report from Bill Hutchison
8. Adopt Final DFCs
9. Start new DFC planning
10. Timeline for next report

11. Discussion of Similar Rules

12. Discuss items for future agenda items.

13. Set next meeting date.

14. Adjournment.

Janet Adams
GMA 4 Representative

I, the undersigned authority of the District, do hereby certify that the above notice is a true and correct copy of said notice and that such notice was posted on the District website at westtexasgroundwater.com at least 72 hours prior to the time of said public hearing.

Date: 6/13/2021

Summer Webb
Summer Webb, General Manager

Groundwater Management Area # 4
Joint Planning Meeting
June 17, 2021, 10:00 a.m.

In Person: Val Clark Beard County Office Building, Conference Room,
203 N. 7th Street, Alpine, TX

Time: Jun 17, 2021 10:00 AM Central Time (US and Canada)

Join Zoom Meeting
https://zoom.us/j/93624829557?pwd=eTVRVEJIbUkrWjBnRitReHlZQ1F1dz09

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GMA 4 Representative

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Date: 6/13/2021

Summer Webb

Summer Webb, General Manager

Appendix B

Total Estimated Recoverable Storage Report
(TWDB Task 13-028)

GAM TASK 13-028: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 4

by Radu Boghici, P.G., Ian C. Jones, Ph.D., P.G., Robert G. Bradley P.G.,
Jerry Shi, Ph.D., P.G., Rohit Raj Goswami, Ph.D.,
David Thorkildsen, P.G., and Sarah Backhouse
Texas Water Development Board
Groundwater Resources Division
(512) 463-5808[1]
January 15, 2014

IAN C. JONES
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1/15/14

RADU BOGHICI
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1/15/14

CYNTHIA K. RIDGEWAY
GEOLOGY
No. 471
1/15/14

RIMA PETROSSIAN
GEOLOGY
No. 467
1/15/2014

JIANYOU SHI
GEOLOGY
11113

ROBERT G. BRADLEY
GEOLOGY
No. 707
1/15/14

DAVID THORKILDSEN
GEOLOGY
No. 705
1/15/14

The seals appearing on this document were authorized on January 10, 2014 by Radu Boghici, P.G. 482; Robert G. Bradley, P.G. 707; Ian C. Jones, P.G. 477; Jerry Shi, P.G. 11113; David Thorkildsen, P.G. 705; Cynthia K. Ridgeway, P.G. 471; and Rima Petrossian, P.G. 467. Cynthia K. Ridgeway is the Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by Rohit Raj Goswami under her direct supervision. Rima Petrossian is the Manager of the Groundwater Technical Assistance Section and is responsible for oversight of work performed by Sarah Backhouse under her direct supervision.

The total estimated recoverable storage in this report was calculated as follows: the Igneous and West Texas Bolsons aquifers (Radu Boghici); the Edwards-Trinity (Plateau) and Capitan Reef Complex aquifers (Ian C. Jones); the Upper Salt Basin (Robert G. Bradley); the Rustler Aquifer (Jerry Shi); the Bone Spring-Victorio Peak Aquifer (Rohit Raj Goswami); and the Marathon Aquifer (David Thorkildsen and Sarah Backhouse).

---

[1] This is the office telephone number for Radu Boghici

GAM TASK 13-028: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 4

by Radu Boghici, P.G., Ian C. Jones, Ph.D., P.G., Robert G. Bradley P.G.,
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David Thorkildsen, P.G., and Sarah Backhouse
Texas Water Development Board
Groundwater Resources Division
(512) 463-5808[1]
January 15, 2014

The seals appearing on this document were authorized on January 15, 2014 by Radu Boghici, P.G. 482; Robert G. Bradley, P.G. 707; Ian C. Jones, P.G. 477; Jerry Shi, P.G. 11113; David Thorkildsen, P.G. 705; Cynthia K. Ridgeway, P.G. 471; and Rima Petrossian, P.G. 467. Cynthia K. Ridgeway is the Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by Rohit Raj Goswami under her direct supervision. Rima Petrossian is the Manager of the Groundwater Technical Assistance Section and is responsible for oversight of work performed by Sarah Backhouse under her direct supervision.

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David Thorkildsen, P.G., and Sarah Backhouse
Texas Water Development Board
Groundwater Resources Division
(512) 463-5808
January 15, 2014

EXECUTIVE SUMMARY:

Texas Water Code, § 36.108 (d) (Texas Water Code, 2011) states that, before voting on the proposed desired future conditions for a relevant aquifer within a groundwater management area, the groundwater conservation districts shall consider the total estimated recoverable storage as provided by the executive administrator of the Texas Water Development Board (TWDB) along with other factors listed in §36.108 (d). Texas Administrative Code Rule §356.10 (Texas Administrative Code, 2011) defines the total estimated recoverable storage as the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume.

This report discusses the methods, assumptions, and results of an analysis to estimate the total recoverable storage for the Igneous, West Texas Bolsons, Bone Spring-Victorio Peak, Capitan Reef Complex, Marathon, Upper Salt Basin, Edwards Trinity (Plateau), Pecos Valley, and Rustler aquifers within Groundwater Management Area 4. Tables 1 through 18 summarize the total estimated recoverable storage required by the statute. Figures 3 through 10 indicate the extent of the groundwater availability models, and/or of the non-modeled areas, used to estimate the total recoverable storage.

DEFINITION OF TOTAL ESTIMATED RECOVERABLE STORAGE:

The total estimated recoverable storage is defined as the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume. In other words, we assume that between 25 and 75 percent of groundwater held within an aquifer can be removed by pumping.

The total recoverable storage was estimated for the portion of each aquifer within Groundwater Management Area 4 that lies within the official lateral aquifer boundaries as delineated by George and others (2011). Total estimated recoverable storage values may include a mixture of water quality types, including fresh, brackish, and saline groundwater, because the available data and the existing groundwater availability models do not permit the differentiation of different water quality types. These values do not take into account the effects of land surface subsidence, degradation of water quality, or any changes to surface water-groundwater interaction as the result of extracting groundwater from the aquifer.

METHODS, PARAMETERS, AND ASSUMPTIONS:

To estimate the total recoverable storage of an aquifer, we calculated the total volume of water within the official aquifer boundary in the groundwater management area.

Aquifers can be either unconfined or confined (Figure 1). A well screened in an unconfined aquifer will have a water level equal to the water level in the aquifer outside the well. Thus, unconfined aquifers have water levels less than the top of the aquifers. A confined aquifer is bounded by low permeable geologic units at the top and bottom, and the aquifer is under hydraulic pressure higher than the ambient atmospheric pressure. The water level at a well screened in a confined aquifer will be above the top of the aquifer. As a result, calculation of total storage is also different between unconfined and confined aquifers. For an unconfined aquifer, the total storage is equal to the volume of groundwater that makes the water level fall to the aquifer bottom. For a confined aquifer, the total storage contains two parts. The first part is the groundwater released from the aquifer when the water level falls from above the top of the aquifer to the top of the aquifer. The reduction of hydraulic pressure in the aquifer by pumping causes expansion of groundwater and deformation of aquifer solids. The aquifer is still fully saturated to this point. The second part, just like unconfined aquifer, is the groundwater released from the aquifer when the water level falls from the top to the bottom of the aquifer. Given the same aquifer area and water level drop, the amount of water released in the second part is much greater than the first part. The difference is quantified by two parameters: storativity related to confined aquifer and specific yield related to unconfined aquifer. For example, storativity values range from 10^{-5} to 10^{-3} for most confined aquifers, while the specific yield values can be 0.01 to 0.3 for most unconfined aquifers. The equations for calculating the total storage are presented below:

- for unconfined aquifers

$$Total\ Storage \qquad V_{drained} \qquad Area \qquad S \qquad (Water\ Level - Bottom)$$

- for confined aquifers

$$Total\ Storage \qquad V_{confined} \qquad V_{drained}$$

  - confined part

$$V_{confined} \qquad Area \qquad [S \qquad (Water\ Level - Top)]$$

or

$$V_{confined} \qquad Area \qquad [S_s \qquad (\ \mathrm{op} - \mathrm{Bottom}) \qquad (Water\ Level - Top)]$$

  - unconfined part

$$V_{drained} \qquad Area \qquad \left[S \qquad (Top - Bottom)\right]$$

where:

- $V_{drained}$ = storage volume due to water draining from the formation (acre-feet)
- $V_{confined}$ = storage volume due to elastic properties of the aquifer and water(acre-feet)
- *Area* = area of aquifer (acre)
- *Water Level* = groundwater elevation (feet above mean sea level)
- *Top* = elevation of aquifer top (feet above mean sea level)
- *Bottom* = elevation of aquifer bottom (feet above mean sea level)
- S_y = specific yield (no units)
- S_s = specific storage (1/feet)
- *S* = storativity or storage coefficient (no units)

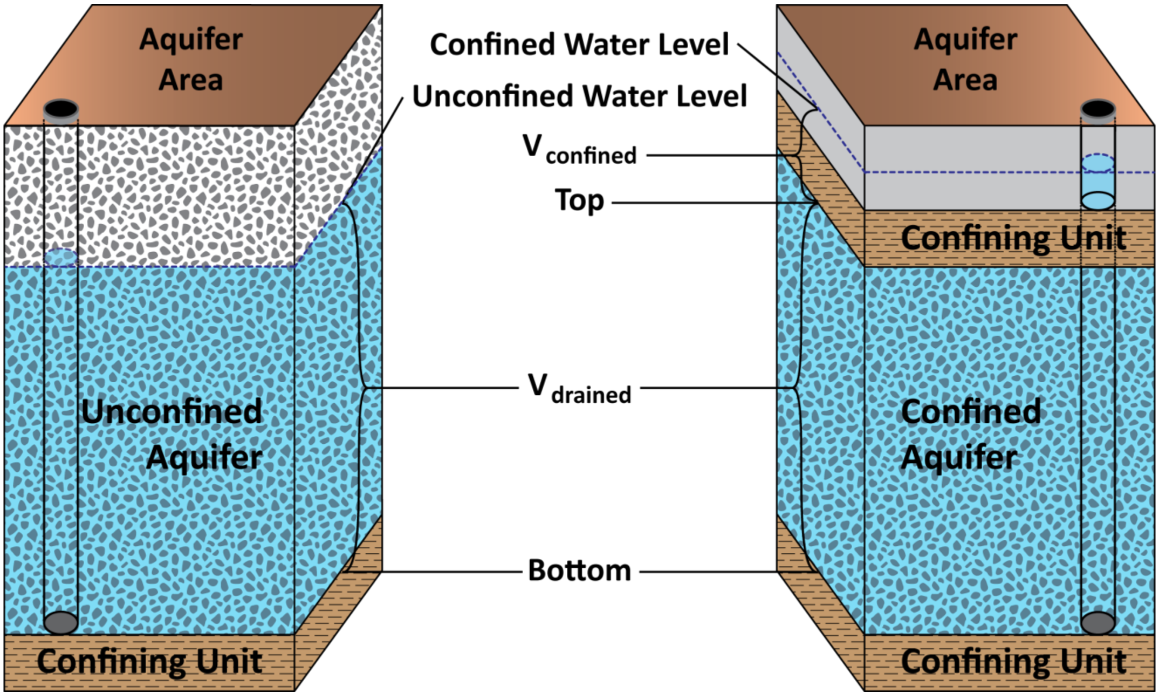

FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

As presented in the equations, calculation of the total storage requires data, such as aquifer top, aquifer bottom, aquifer storage properties, and water level. For the aquifers that had groundwater availability models in Groundwater Management Area 4, we extracted this information from existing groundwater availability model input and output files on a cell-by-cell basis. Python scripts and a FORTRAN-90 program were developed and used to expedite the storage calculation. The total recoverable storage was calculated as the product of the total storage and an estimated factor ranging from 25 percent to 75 percent of the total storage.

In the absence of groundwater availability models, the total storage was calculated using other approaches (see the methodologies used for the Capitan Reef Complex Aquifer, Marathon Aquifer, the Upper Salt Basin Formation, and marginal parts of the Igneous, West Texas Bolsons, Pecos Valley, Edwards-Trinity (Plateau), and Rustler aquifers). These approaches and methods are described on the following pages for each aquifer or set of multiple aquifers, as appropriate.

IGNEOUS AND WEST TEXAS BOLSONS (WILD HORSE FLAT, MICHIGAN FLAT, RYAN FLAT, LOBO FLAT, PRESIDIO AND REDFORD) AQUIFERS

To determine the total estimated recoverable storage in the areas covered by groundwater availability models, we used version 1.01 of the groundwater availability model for the Igneous Aquifer and West Texas Bolsons (Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat) Aquifer and version 1.01 of the groundwater availability model for the West Texas Bolsons (Presidio and Redford) Aquifer. See Beach and others (2004), and Wade and Jigmond (2013) for assumptions and limitations of these models. The groundwater availability model for the Igneous Aquifer and West Texas Bolsons (Wild Horse Flat, Michigan Flat, Ryan Flat, and Lobo Flat) Aquifer includes three layers, representing the West Texas Bolsons (layer 1) and Igneous (layer 2) aquifers, and the underlying units (layer 3). Total estimated recoverable storage was determined using the cells in the model that represent the West Texas Bolsons (layer 1) and Igneous Aquifer (layer 2). The groundwater availability model for the West Texas Bolsons (Presidio and Redford) Aquifer includes three layers which generally represent the Rio Grande Alluvium (layer 1), the Presidio and Redford Bolsons (layer 2), and the underlying older rocks (layer 3). To develop the estimates for the total estimated recoverable storage, we used layer2 (the Presidio and Redford Bolsons).

We employed an alternate method, herein named *“The Method of the Wedges”*, to calculate total storage for parts of the Igneous Aquifer and West Texas Bolsons (Wild Horse Flat, Michigan Flat, Ryan Flat, Lobo Flat, Presidio and Redford) Aquifer in Groundwater Management Area 4 that are within the official aquifer boundaries, but are not within the area of a groundwater availability model. The “Method of the Wedges” is based on the assumption that the non-modeled areas approximate the form of a right-wedge (Figure 2). These areas were not included in their respective groundwater availability models because they occur along the margins of the aquifers where the aquifer pinches out and is difficult to model (see Figures 3 and 4). Total storage was calculated by multiplying the volume of the assumed right-wedge by specific yields extracted from the model files, values ranging from 0.01 to 0.15.

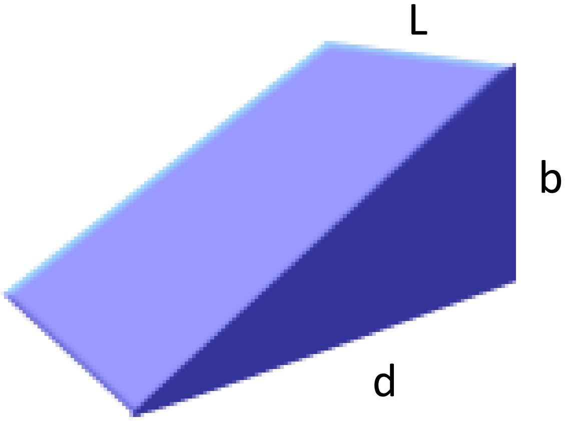

FIGURE 2. A SCHEMATIC OF THE RIGHT-WEDGE USED TO CALCULATE TOTAL STORAGE IN THE IGNEOUS AQUIFER IN GROUNDWATER MANAGEMENT AREA 4.

The volume of the right-edge was calculated using the formula:

$$V \quad 0.5 \quad b \quad L \quad d$$

Where:

- *b* = the average saturated thickness of the last row of active model cells bordering the "wedge";
- *L* = the length of the last row of active model cells bordering the "wedge"; and
- *d* = the average distance between the last row of active model cells and the aquifer boundary.

We computed the non-modeled areas' storage as by using *The Method of the Wedges*, and we added it to the groundwater availability model-derived storage.

WEST TEXAS BOLSONS (RED LIGHT DRAW, GREEN RIVER VALLEY, AND EAGLE FLAT) AQUIFER

To determine the total estimated recoverable storage in the areas covered by groundwater availability models, we used version 1.01 of the groundwater availability model for the West Texas Bolsons (Red Light Draw, Green River Valley, and Eagle Flat) Aquifer. See Beach and others (2008) for assumptions and limitations of the groundwater availability model. This groundwater availability model includes three layers. Layer 1 represents the bolson aquifer, while layers 2 and 3 represent strata underlying the bolson deposits of layer 1. Of the three layers, total estimated recoverable storage was determined for layer 1.

For the non-modeled portions of the West Texas Bolsons (Red Light Draw, Green River Valley, and Eagle Flat) aquifers, the aquifer structure and water level data were projected from modeled areas into the non-modeled areas. Recoverable storage in areas outside of the model but within the official aquifer boundaries (see Figure 4) was estimated by first establishing a relationship between aquifer thickness and saturated thickness. The aquifer thickness is the difference between the elevations of the aquifer top and base, and saturated thickness is the difference between the water table and aquifer base elevations. We determined that there is a polynomial relationship between aquifer thickness and saturated thickness in the West Texas Bolsons (Red Light Draw, Green River Valley, and Eagle Flat) Aquifer. The relationship between saturated thickness ($Hsat$) and aquifer thickness (H) is described by the following equation:

$$Hsat = 0.0001 \times H^2 + 0.485 \times H$$

We computed the non-modeled areas' storage by multiplying *Hsat* by the aquifer surface area by a specific yield of 0.06, which was derived from the model files. We added the non-modeled areas storage to the groundwater availability model-derived storage.

The combined storage estimates for West Texas Bolsons (Red Light Draw, Green River Valley, Eagle Flat, Wild Horse Flat, Michigan Flat, Ryan Flat, Lobo Flat, Presidio and Redford) Aquifer, calculated as described here and in the preceding section, are shown in Tables 3 and 4.

BONE SPRING-VICTORIO PEAK AQUIFER

We used the preliminary groundwater flow model for the Dell City Area (Hudspeth and Culberson counties, Texas) developed by El Paso Water Utilities (Hutchinson, 2008) to estimate the total recoverable storage for the Bone Spring-Victorio Peak Aquifer (Figure 5). See Hutchison (2008) for assumptions and limitations of this groundwater flow model. This groundwater flow model includes one layer, which represents the confined Bone Spring-Victorio Peak Aquifer. The specific yield values were not included in the model Layer-Property Flow package as the groundwater flow model simulated all hydrostratigraphic units as confined aquifers. The specific yield values for the Bone Springs-Victorio Peak Aquifer were obtained from groundwater storage zones database provided with groundwater modeling files by

Hutchison (2008). The specific yield values ranged from 0.01 to 0.019 and were assigned to the various cells as per their respective zonation.

The total estimated recoverable storage was initially determined for the Bone Spring-Victorio Peak Aquifer (layer 1) as volumes for three alternative scenarios (see Hutchison, 2008). These alternative-scenario volumes were then averaged to obtain the total estimated recoverable storage presented in this report, as product of storage volume and an estimated factor ranging from 25 percent to 75 percent.

CAPITAN REEF COMPLEX AQUIFER

The Capitan Reef Complex Aquifer in Groundwater Management Area 4 does not yet have a groundwater availability model. For this aquifer, we used surfaces for the aquifer top and base constructed by Standen and others (2009). Due to insufficient water-level data to construct a water-level map we calculated total storage for the Capitan Reef Complex Aquifer assuming that $V_{confined}$ is very small relative to $V_{drained}$ and is, therefore, insignificant. The justification for this assumption is that the aquifer thickness and specific yield used to calculate the unconfined part of the total storage are much larger than the confined head—difference between the water level and aquifer top elevations—and the storativity or specific storage used to calculate the confined part of the total storage. No storage data were available for the area. We estimated the specific yield to be 0.05 based on borehole geophysics data for the Capitan Reef Complex Aquifer (Garber and others, 1989).

The total storage was calculated for each cell by multiplying cell area, aquifer thickness and the specific yield of 0.05.We extracted the aquifer top and base data using a grid with 1 square mile cells (Figure 6) and calculated total storage for each cell.

MARATHON AQUIFER

The Marathon Aquifer (Figure 7) occurs entirely within north-central Brewster County within Groundwater Management Area 4.Water in the aquifer is under unconfined conditions within fractures, joints, and cavities (George and others, 2011).

We used an estimated average saturated thickness of 200 feet and specific yield of 0.03 (Far West Texas RWPG, 2001) to calculate total estimated recoverable storage by multiplying the aquifer areal extent by the saturated thickness and by the specific yield.

THE UPPER SALT BASIN FORMATION

The delineation of the Upper Salt Basin Formation (Figure 8) was based on information provided by the Culberson County Underground Water Conservation District. The Upper Salt Basin Formation does not have a groundwater availability model.

The Upper Salt Basin Formation within Groundwater Management Area 4 is assumed to be under water-table conditions within Culberson County. The aquifer-wide saturated thickness was estimated to be 440 feet, based on the minimum saturated thickness calculated in each well. The specific yield of the aquifer was estimated as 0.06 based on values from the adjacent groundwater availability model for the Igneous and parts of the West Texas Bolsons aquifers (Beach and others 2004). The saturated thickness of the aquifer was calculated by subtracting the elevation of the base of the Upper Salt Basin (see Beach and others 2004; Gates and others, 1980; Standen and others, 2009; and TWDB, 2013 for base elevations) from the elevation of each water level measurement available in the TWDB groundwater database wells (2013).

The total estimated recoverable storage was calculated by multiplying the aquifer areal extent by the saturated thickness and by the specific yield.

EDWARDS-TRINITY (PLATEAU) AND PECOS VALLEY AQUIFERS

We first used the alternative one-layer numerical flow model (Hutchison and others, 2011) to compute the recoverable storage in the modeled areas of the Edwards-Trinity (Plateau) and Pecos Valley Aquifers. Specific yield values were obtained from the storage values database from groundwater modeling files (Hutchison and others, 2011).

Some portions of the Pecos Valley and Edwards-Trinity (Plateau) aquifers in Groundwater Management Area 4 were not included in the one-layer alternative groundwater flow model covering these aquifers (Hutchison and others, 2011). The aquifers in these areas (see Figure 9) are relatively thin and mostly restricted to the western margins of the area. As was done for the West Texas Bolsons, the recoverable storage in the Pecos Valley and Edwards-Trinity

(Plateau) aquifers outside of the model but within the official aquifer boundaries was estimated by first establishing a relationship between aquifer thickness and saturated thickness. In the Edwards-Trinity (Plateau) and Pecos Valley aquifers there is a generally linear relationship between aquifer thickness (*H*) and saturated thickness (*Hsat*). We found that the relationship between saturated thickness (*Hsat*)and aquifer thickness (*H*) is described by the following equation for the Edwards-Trinity (Plateau) Aquifer:

$$Hsat = 0.9 \times H$$

and by the following equation for the Pecos Valley Aquifer:

$$Hsat = 0.8 \times H$$

The non-modeled portions of the Pecos Valley and Edwards-Trinity (Plateau) aquifers were assumed to be unconfined. Consequently, storage in each model cell representing parts of the respective aquifers excluded from the groundwater flow model was estimated using the following equation:

$$Total\ Storage = V_{drained} = Area \times S_y \times H_{sat}$$

where:

- $V_{drained}$ = storage volume due to water draining from the formation (acre-feet)
- $Area$ = area of aquifer (acre)
- S_y = specific yield (no units)
- H_{sat} = estimated saturated thickness (feet)

Storage volumes estimated using this method were added to the storage volumes from the modeled area, where applicable, to estimate the total recoverable storage for the entire aquifers.

RUSTLER AQUIFER

For the Rustler Aquifer, we used version 1.01 of the groundwater availability model for the Rustler Aquifer to estimate the total recoverable storage. See Ewing and others (2012) for assumptions and limitations of the groundwater availability model. This groundwater availability model includes two numerical layers which represent Dockum Aquifer/Dewey Lake

Formation (Layer 1) and Rustler Aquifer (Layer 2). Model Layer 2 was used to calculate the total estimated recoverable storage for the Rustler Aquifer.

Parts of the Rustler Aquifer in Brewster and Jeff Davis counties that are not included in the modeled area in Groundwater Management Area 4 (see Figure 10) were addressed using an analytical method as follows:

First, we calculated the total aquifer volume by using the equation:

$$\textit{Total Aquifer Volume} = \textit{Aquifer Area} \times \textit{Aquifer Average Thickness}$$

The aquifer area was estimated using ArcGIS 10 and the aquifer average thickness was estimated to be approximately 50 feet, based on the Rustler Groundwater Availability Model report. Next, we calculated the total aquifer storage using the following equation:

$$\textit{Total Aquifer Storage} = \textit{Total Aquifer Volume} \times \textit{Aquifer Specific Yield}$$

The specific yield was assigned a value of 0.03 (see LBG-Guyton Associates, 2003).

We computed the non-modeled areas’ storage as by using the analytical method described above, and we added it to the groundwater availability model-derived storage.

RESULTS:

Tables 1 through 18 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total estimates are rounded to two significant figures. Figures 3 through 10 indicate the extent of the groundwater availability models and/or of the non-modeled areas in Groundwater Management Area 4 for the Igneous Aquifer and West Texas Bolsons Aquifer (Wild Horse Flat, Michigan Flat, Ryan Flat, Lobo Flat, Red Light Draw, Green River Valley, Eagle Flat, Presidio and Redford bolsons), Bone Spring-Victorio Peak Aquifer, Capitan Reef Complex, Marathon Aquifer, Upper Salt Basin, Edwards-Trinity (Plateau) Aquifer, Pecos Valley Aquifer, and Rustler Aquifer from which the storage information was calculated.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE IGNEOUS AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster	5,300,000	1,325,000	3,975,000
Culberson	760,000	190,000	570,000
Jeff Davis	24,000,000	6,000,000	18,000,000
Presidio	34,000,000	8,500,000	25,500,000
Total	**64,060,000**	**16,015,000**	**48,045,000**

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE IGNEOUS AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster County GCD	5,300,000	1,325,000	3,975,000
Culberson County GCD	760,000	190,000	570,000
Jeff Davis Co. UWCD[2]	24,000,000	6,000,000	18,000,000
Presidio County UWCD	34,000,000	8,500,000	25,500,000
Total	**64,060,000**	**16,015,000**	**48,045,000**

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[2] UWCD is the abbreviation for Underground Water Conservation District

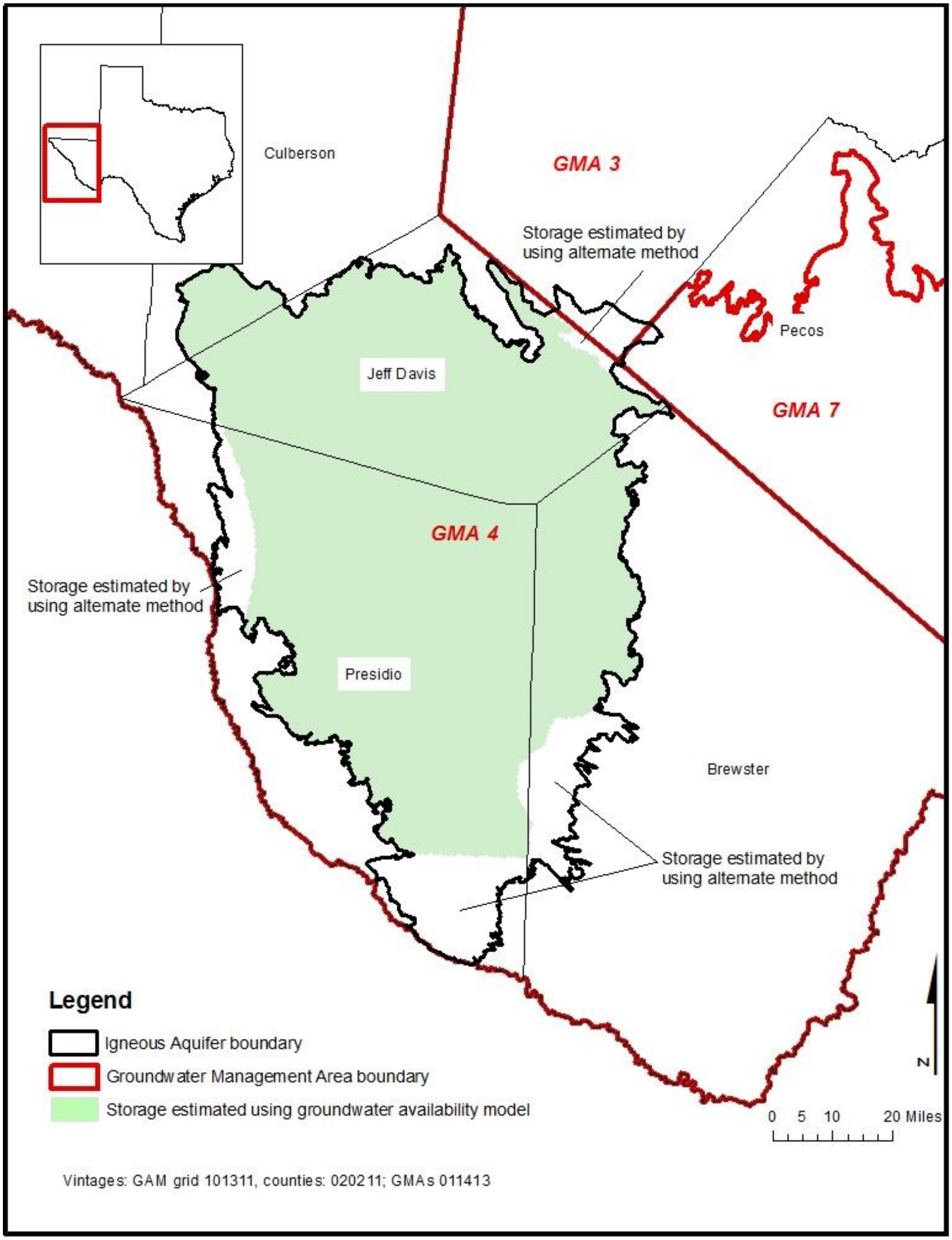

FIGURE 3. EXTENT OF THE IGNEOUS AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 4.

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE WEST TEXAS BOLSONS AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Culberson	5,400,000	1,350,000	4,050,000
Hudspeth	6,800,000	1,700,000	5,100,000
Jeff Davis	4,200,000	1,050,000	3,150,000
Presidio	35,000,000	8,750,000	26,250,000
Total	**51,400,000**	**12,850,000**	**38,550,000**

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE WEST TEXAS BOLSONS AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Culberson County GCD	5,400,000	1,350,000	4,050,000
Jeff Davis Co. UWCD[3]	4,200,000	1,050,000	3,150,000
Presidio County UWCD	35,000,000	8,750,000	26,250,000
No District	6,800,000	1,700,000	5,100,000
Total	**51,400,000**	**12,850,000**	**38,550,000**

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[3] UWCD is the abbreviation for Underground Water Conservation District

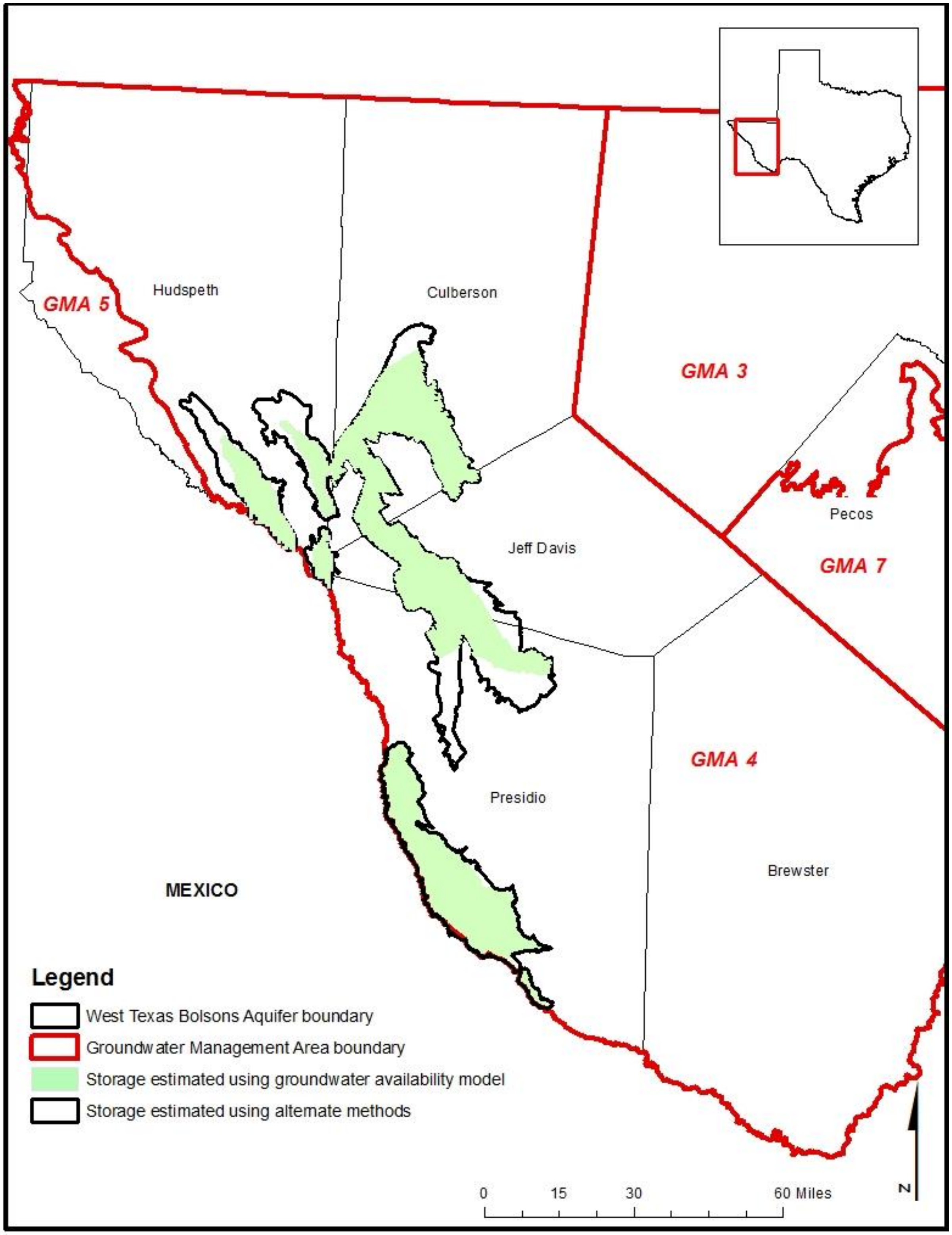

FIGURE 4. EXTENT OF THE WEST TEXAS BOLSONS AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA 4.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE BONE SPRING-VICTORIO PEAK AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Hudspeth	3,700,000	925,000	2,775,000
Total	**3,700,000**	**925,000**	**2,775,000**

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE BONE SPRING-VICTORIO PEAK AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Hudspeth County UWCD[4] No. 1	3,700,000	925,000	2,775,000
Total	**3,700,000**	**925,000**	**2,775,000**

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[4] UWCD is the abbreviation for Underground Water Conservation District

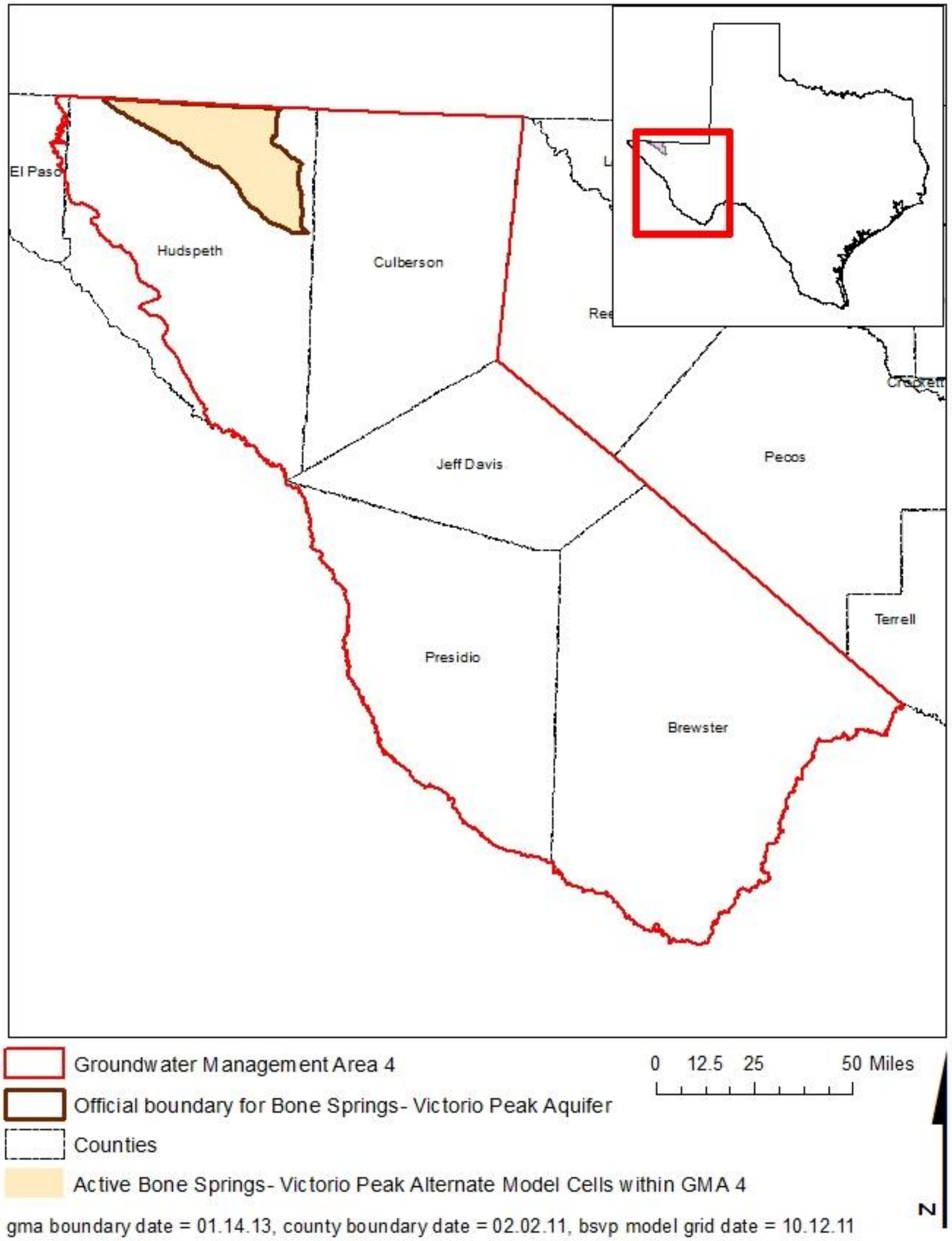

FIGURE 5. EXTENT OF THE BONE SPRING-VICTORIO PEAK AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE CAPITAN AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster	2,500,000	625,000	1,875,000
Culberson	21,000,000	5,250,000	15,750,000
Hudspeth	1,100,000	275,000	825,000
Jeff Davis	760,000	190,000	570,000
Total	**25,360,000**	**6,340,000**	**19,020,000**

TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE CAPITAN AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster County GCD	2,500,000	625,000	1,875,000
Culberson County GCD	15,000,000	3,750,000	11,250,000
Jeff Davis Co. UWCD[5]	760,000	190,000	570,000
No District	7,300,000	1,825,000	5,475,000
Total	**25,560,000**[6]	**6,390,000**	**19,170,000**

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[5] UWCD is the abbreviation for Underground Water Conservation District

[6] Note: Due to rounding to two significant figures, the total storage by county differs from the total storage by groundwater conservation district.

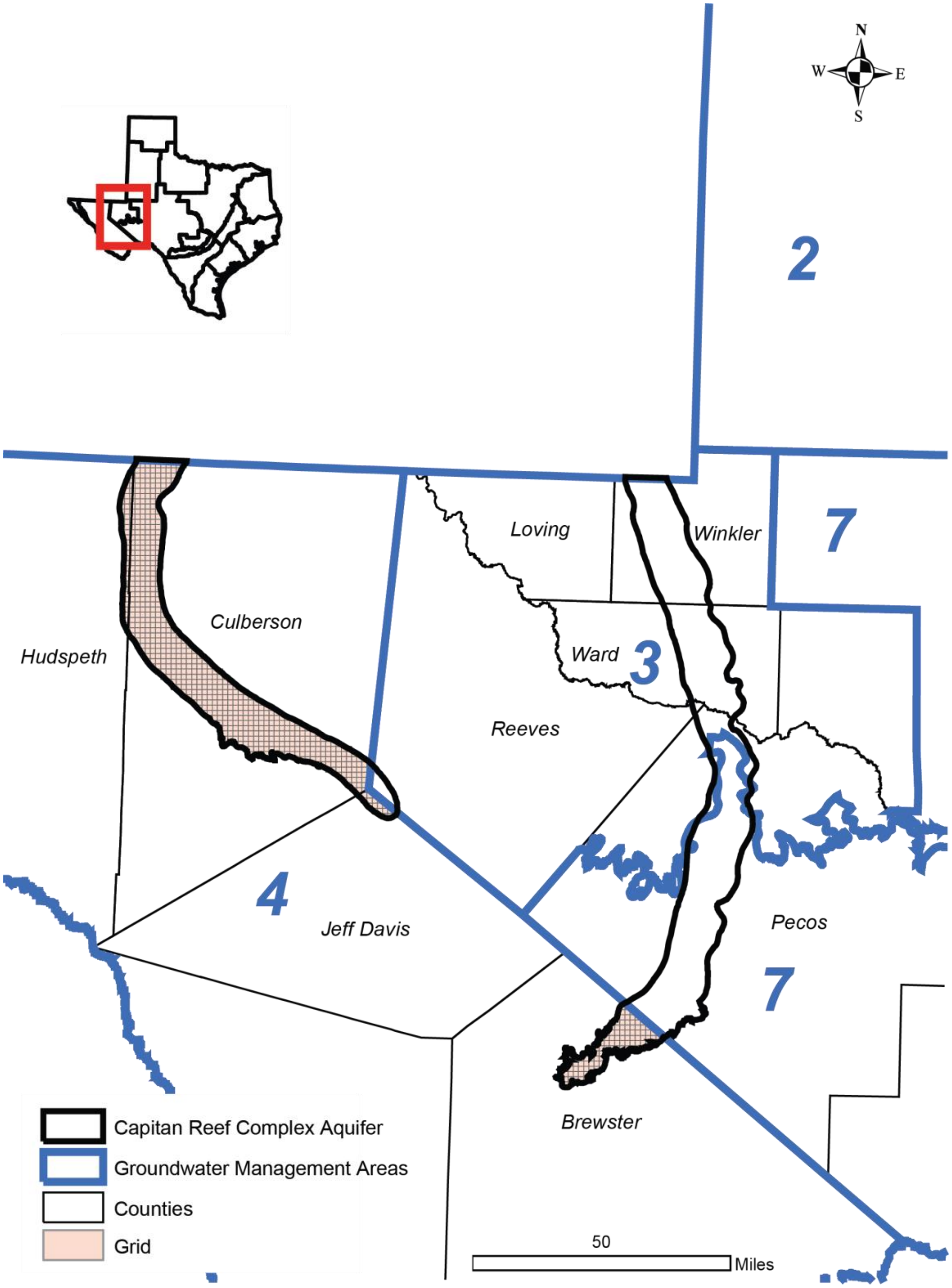

FIGURE 6. EXTENT OF THE THE CAPITAN REEF COMPLEX AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 9. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE MARATHON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster	1,500,000	375,000	1,125,000
Total	**1,500,000**	**375,000**	**1,125,000**

TABLE 10. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT (GCD) FOR THE MARATHON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster County GCD	1,500,000	375,000	1,125,000
Total	**1,500,000**	**375,000**	**1,125,000**

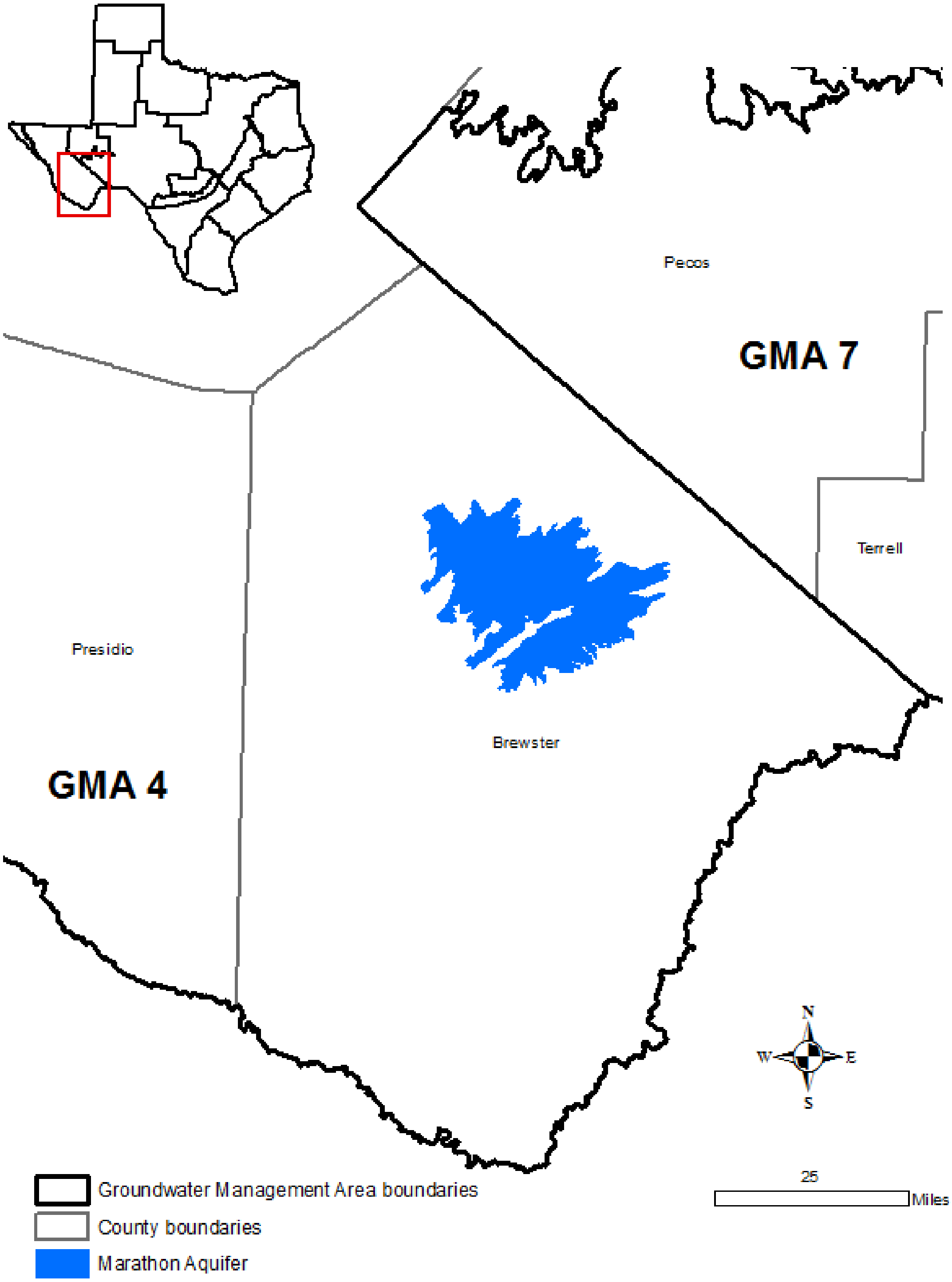

FIGURE 7. EXTENT OF THE MARATHON AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 9 AND 10) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 11. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE UPPER SALT BASIN WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Culberson	3,700,000	925,000	2,775,000
Total	**3,700,000**	**925,000**	**2,775,000**

TABLE 12. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE UPPER SALT BASIN WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Culberson County GCD	3,700,000	925,000	2,775,000
Total	**3,700,000**	**925,000**	**2,775,000**

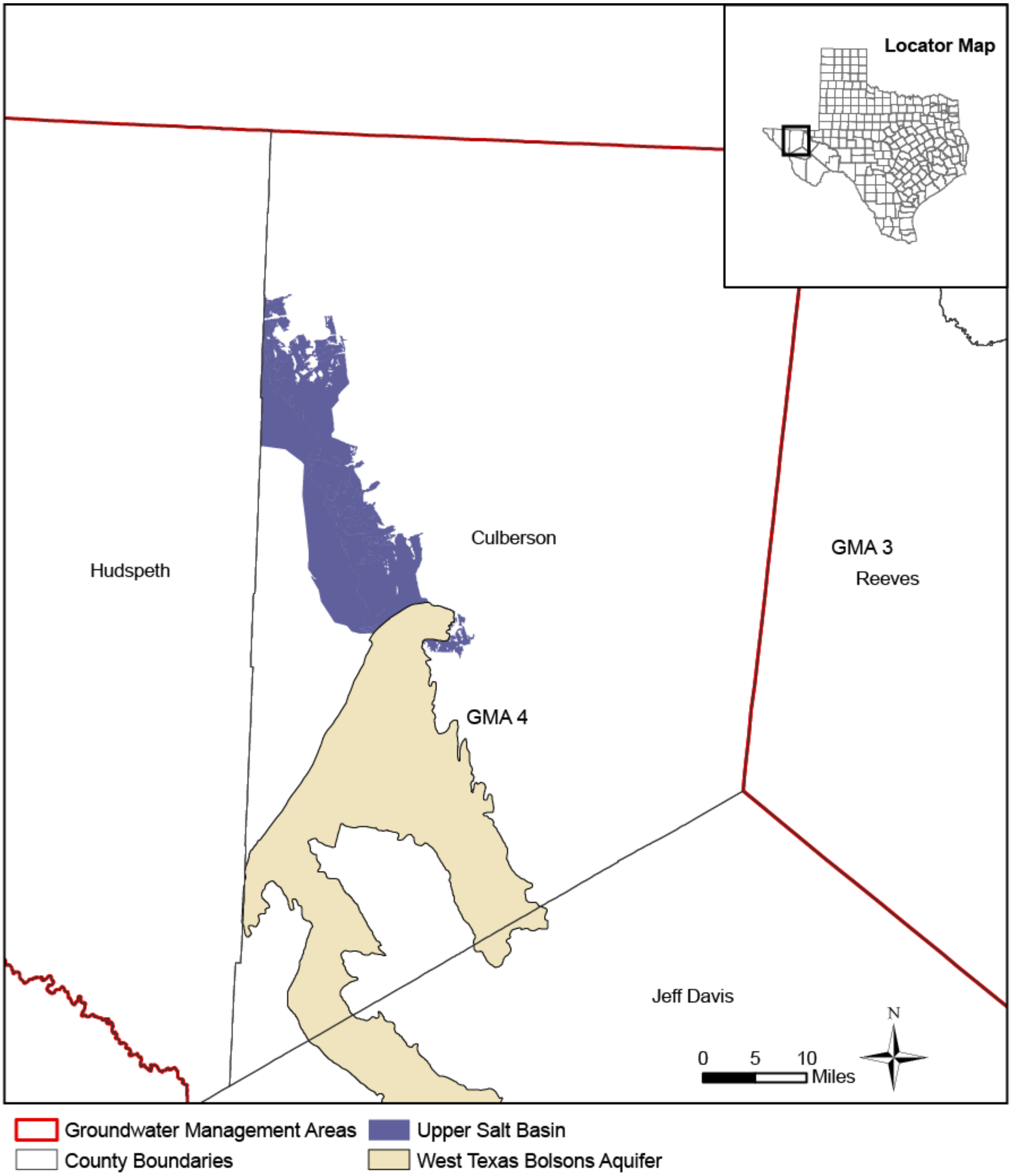

FIGURE 8. EXTENT OF THE UPPER SALT BASIN USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 11 AND 12) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 13. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE EDWARDS-TRINITY (PLATEAU) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster	2,600,000	650,000	1,950,000
Culberson	470,000	117,500	352,500
Jeff Davis	710,000	177,500	532,500
Total	**3,780,000**	**945,000**	**2,835,000**

TABLE 14. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR EDWARDS-TRINITY (PLATEAU) AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster County GCD	2,600,000	650,000	1,950,000
Culberson County GCD	210,000	52,500	157,500
Jeff Davis Co. UWCD[7]	710,000	177,500	532,500
No District	260,000	65,000	195,000
Total	**3,780,000**	**945,000**	**2,835,000**

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[7] UWCD is the abbreviation for Underground Water Conservation District

TABLE 15. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE PECOS VALLEY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Culberson	750,000	187,500	562,500
Jeff Davis	740,000	185,000	555,000
Total	**1,490,000**	**372,500**	**1,117,500**

TABLE 16. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE PECOS VALLEY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Jeff Davis Co. UWCD[8]	740,000	185,000	555,000
No District	750,000	187,500	562,500
Total	**1,490,000**	**372,500**	**1,117,500**

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[8] UWCD is the abbreviation for Underground Water Conservation District

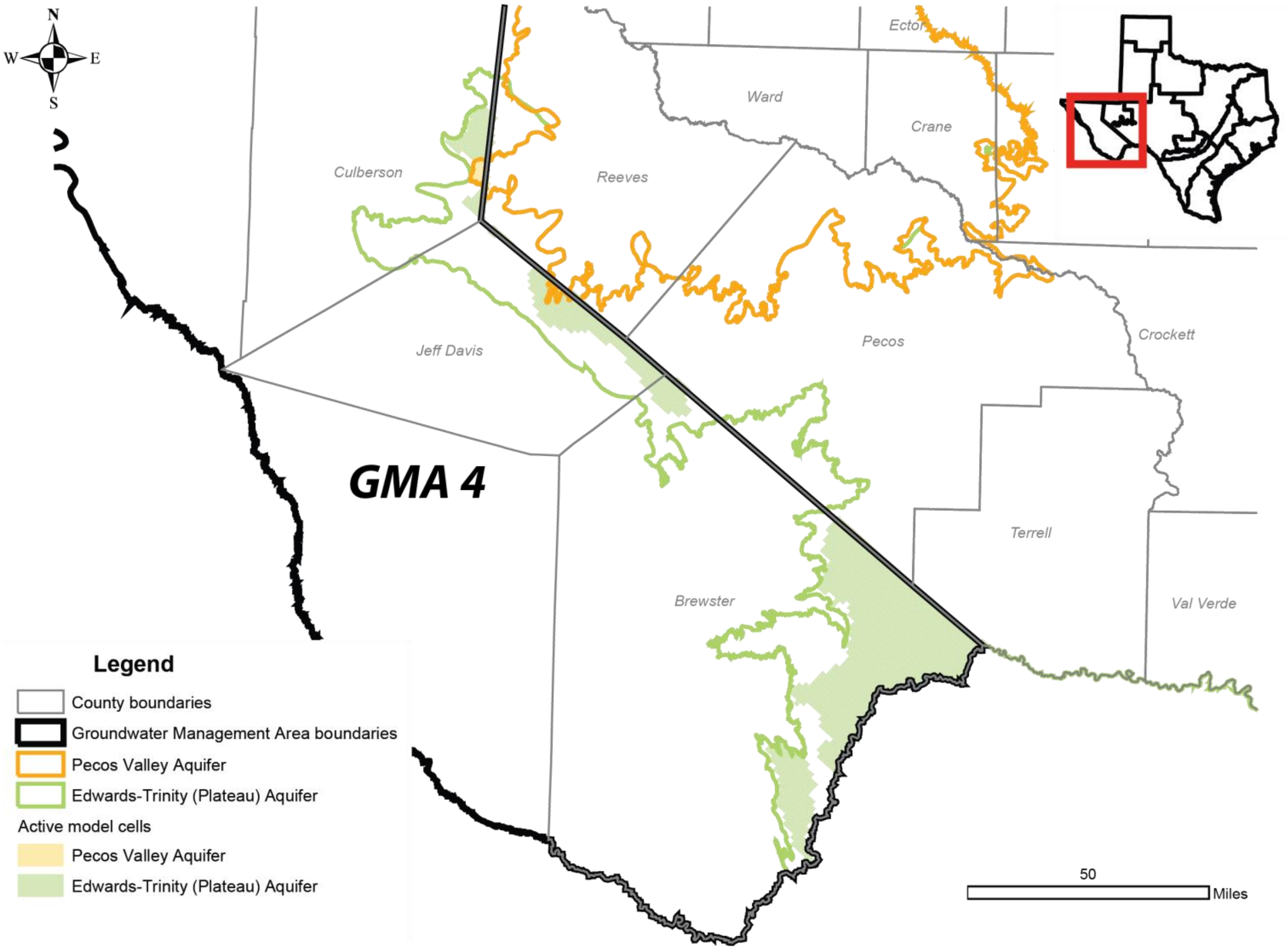

FIGURE 9. EXTENT OF THE EDWARDS-TRINITY (PLATEAU) AND PECOS VALLEY AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 13 THROUGH 16) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

TABLE 17. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE RUSTLER AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster	53,000	13,250	39,750
Culberson	4,200,000	1,050,000	3,150,000
Jeff Davis	670,000	167,500	502,500
Total	**4,923,000**	**1,230,750**	**3,692,250**

TABLE 18. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE RUSTLER AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 4. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT FIGURES.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Brewster County GCD	53,000	13,250	39,750
Jeff Davis Co. UWCD[9]	670,000	167,500	502,500
No District	4,200,000	1,050,000	3,150,000
Total	**4,923,000**	**1,230,750**	**3,692,250**

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[9] UWCD is the abbreviation for Underground Water Conservation District

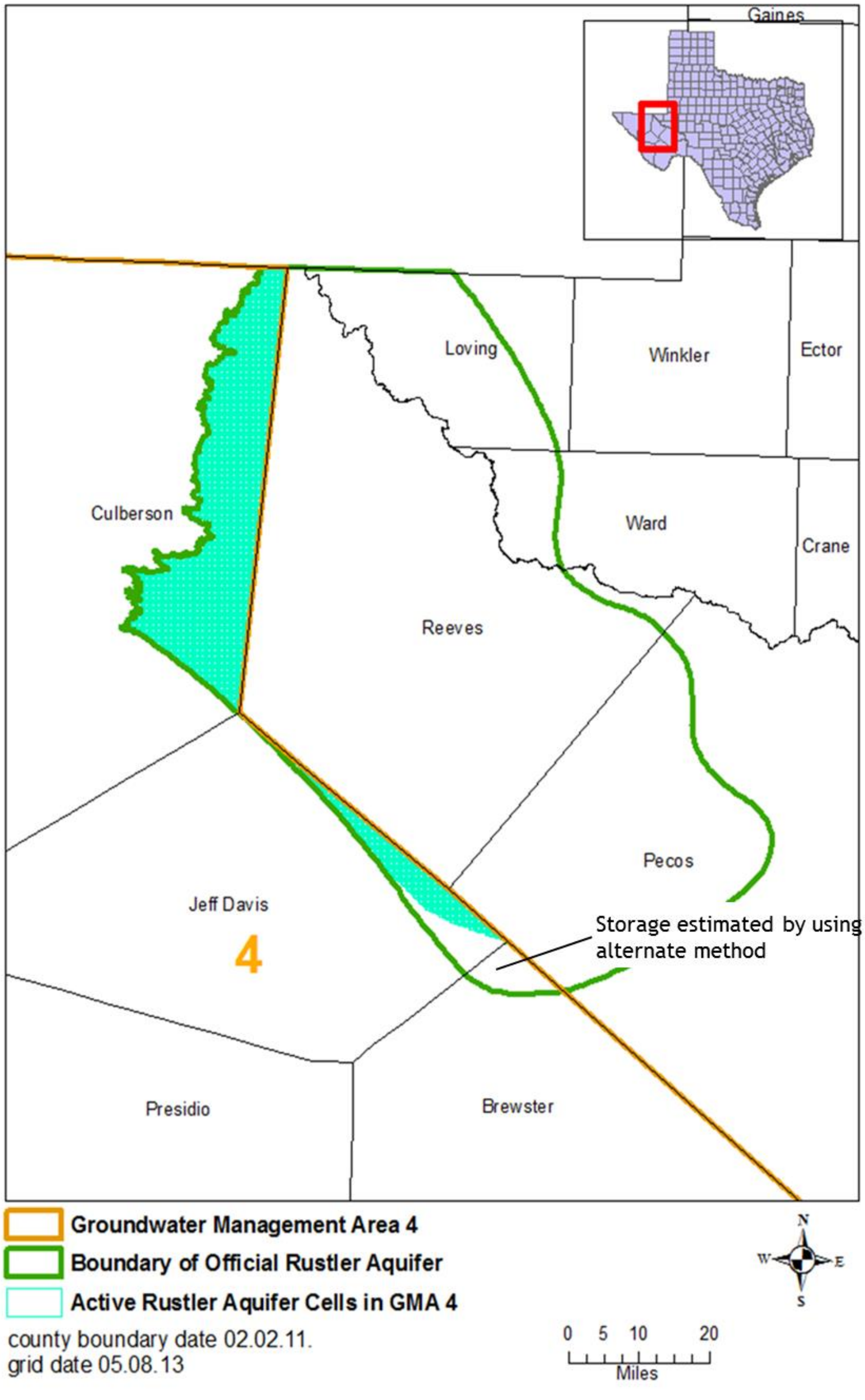

FIGURE 10. EXTENT OF THE RUSTLER AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 17 AND 18) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

LIMITATIONS

The groundwater models used in completing this analysis are the best available scientific tools that can be used to meet the stated objective(s). To the extent that this analysis will be used for planning purposes and/or regulatory purposes related to pumping in the past and into the future, it is important to recognize the assumptions and limitations associated with the use of the results. In reviewing the use of models in environmental regulatory decision making, the National Research Council (2007) noted:

> *"Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results."*

Because the application of the groundwater model was designed to address regional scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations relating to the actual conditions of any aquifer at a particular location or at a particular time.

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Appendix C

Region E Socioeconomic Report

Socioeconomic Impacts of Projected Water Shortages for the Far West Texas (Region E) Regional Water Planning Area

Prepared in Support of the 2021 Region E Regional Water Plan

Dr. John R. Ellis
Water Use, Projections, & Planning Division
Texas Water Development Board

November 2019

Table of Contents

Executive Summary

Evaluating the social and economic impacts of not meeting identified water needs is a required analysis in the regional water planning process. The Texas Water Development Board (TWDB) estimates these impacts for regional water planning groups (RWPGs) and summarizes the impacts in the state water plan. The analysis presented is for the Far West Texas Regional Water Planning Group (Region E).

Based on projected water demands and existing water supplies, Region E identified water needs (potential shortages) that could occur within its region under a repeat of the drought of record for six water use categories (irrigation, livestock, manufacturing, mining, municipal and steam-electric power). The TWDB then estimated the annual socioeconomic impacts of those needs—if they are not met—for each water use category and as an aggregate for the region.

This analysis was performed using an economic impact modeling software package, IMPLAN (Impact for Planning Analysis), as well as other economic analysis techniques, and represents a snapshot of socioeconomic impacts that may occur during a single year repeat of the drought of record with the further caveat that no mitigation strategies are implemented. Decade specific impact estimates assume that growth occurs, and future shocks are imposed on an economy at 10-year intervals. The estimates presented are not cumulative (i.e., summing up expected impacts from today up to the decade noted), but are simply snapshots of the estimated annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated water supplies and demands for that same decade.

For regional economic impacts, income losses and job losses are estimated within each planning decade (2020 through 2070). The income losses represent an approximation of gross domestic product (GDP) that would be foregone if water needs are not met.

The analysis also provides estimates of financial transfer impacts, which include tax losses (state, local, and utility tax collections); water trucking costs; and utility revenue losses. In addition, social impacts are estimated, encompassing lost consumer surplus (a welfare economics measure of consumer wellbeing); as well as population and school enrollment losses.

IMPLAN data reported that Region E generated close to $35 billion in GDP (2018 dollars) and supported roughly 435,000 jobs in 2016. Region E estimated total population was approximately 863,000 in 2016.

It is estimated that not meeting the identified water needs in Region E would result in an annually combined lost income impact of approximately $883 million in 2020, increasing to $1.75 billion in 2070 (Table ES-1). In 2020, the region would lose approximately 3,600 jobs, and by 2070 job losses would increase to approximately 12,000 if anticipated needs are not mitigated.

All impact estimates are in year 2018 dollars and were calculated using a variety of data sources and tools including the use of a region-specific IMPLAN model, data from TWDB annual water use estimates, the U.S. Census Bureau, Texas Agricultural Statistics Service, and the Texas Municipal League.

Table ES-1 Region E socioeconomic impact summary

Regional Economic Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Income losses ($ millions)*	$883	$1,143	$1,287	$1,386	$1,538	$1,753
Job losses	3,635	5,443	6,606	7,592	9,422	11,989
Financial Transfer Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Tax losses on production and imports ($ millions)*	$58	$80	$93	$103	$118	$139
Water trucking costs ($ millions)*	$-	$-	$-	$-	$-	$-
Utility revenue losses ($ millions)*	$11	$21	$31	$60	$93	$123
Utility tax revenue losses ($ millions)*	$0	$0	$1	$1	$2	$2
Social Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Consumer surplus losses ($ millions)*	$3	$15	$40	$79	$133	$201
Population losses	667	999	1,213	1,394	1,730	2,201
School enrollment losses	128	191	232	267	331	421

* Year 2018 dollars, rounded**.** Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

1 Introduction

Water shortages during a repeat of the drought of record would likely curtail or eliminate certain economic activity in businesses and industries that rely heavily on water. Insufficient water supplies could not only have an immediate and real impact on the regional economy in the short term, but they could also adversely and chronically affect economic development in Texas. From a social perspective, water supply reliability is critical as well. Shortages could disrupt activity in homes, schools and government, and could adversely affect public health and safety. For these reasons, it is important to evaluate and understand how water supply shortages during drought could impact communities throughout the state.

As part of the regional water planning process, RWPGs must evaluate the social and economic impacts of not meeting water needs (31 Texas Administrative Code §357.33 (c)). Due to the complexity of the analysis and limited resources of the planning groups, the TWDB has historically performed this analysis for the RWPGs upon their request. Staff of the TWDB's Water Use, Projections, & Planning Division designed and conducted this analysis in support of Region E, and those efforts for this region as well as the other 15 regions allow consistency and a degree of comparability in the approach.

This document summarizes the results of the analysis and discusses the methodology used to generate the results. Section 1 provides a snapshot of the region's economy and summarizes the identified water needs in each water use category, which were calculated based on the RWPG's water supply and demand established during the regional water planning process. Section 2 defines each of ten impact assessment measures used in this analysis. Section 3 describes the methodology for the impact assessment and the approaches and assumptions specific to each water use category (i.e., irrigation, livestock, manufacturing, mining, municipal, and steam-electric power). Section 4 presents the impact estimates for each water use category with results summarized for the region as a whole. Appendix A presents a further breakdown of the socioeconomic impacts by county.

1.1 Regional Economic Summary

The Region E Regional Water Planning Area generated close to $35 billion in gross domestic product (2018 dollars) and supported roughly 435,000 jobs in 2016, according to the IMPLAN dataset utilized in this socioeconomic analysis. This activity accounted for approximately 2 percent of the state's total gross domestic product of 1.73 trillion dollars for the year based on IMPLAN. Table 1-1 lists all economic sectors ranked by the total value-added to the economy in Region E. The real estate, manufacturing, and retail trade sectors generated close to 25 percent of the region's total value-added and were also significant sources of tax revenue. The top employers in the region were in the public administration, retail trade, and health care sectors. Region E's estimated total population was approximately 863,000 in 2016, comprising 3 percent of the state's total.

This represents a snapshot of the regional economy as a whole, and it is important to note that not all economic sectors were included in the TWDB socioeconomic impact analysis. Data considerations prompted use of only the more water-intensive sectors within the economy because damage estimates could only be calculated for those economic sectors which had both reliable income and water use estimates.

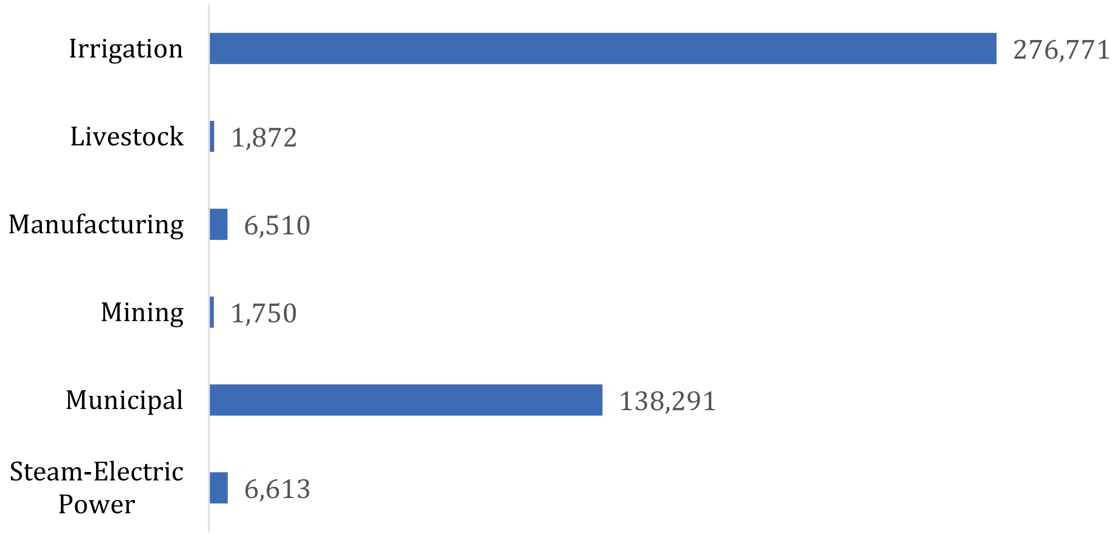
Table 1-1 Region E regional economy by economic sector*

Economic sector	Value-added ($ millions)	Tax ($ millions)	Jobs
Public Administration	$10,871.7	$(105.1)	101,104
Real Estate and Rental and Leasing	$3,358.3	$514.2	15,728
Manufacturing	$2,628.6	$88.5	18,922
Retail Trade	$2,518.5	$648.9	46,183
Health Care and Social Assistance	$2,245.4	$29.6	45,413
Wholesale Trade	$1,907.6	$420.0	14,273
Transportation and Warehousing	$1,708.2	$53.0	21,793
Information	$1,398.5	$479.4	5,131
Professional, Scientific, and Technical Services	$1,285.7	$43.3	17,931
Accommodation and Food Services	$1,257.6	$220.7	37,186
Administrative and Support and Waste Management and Remediation Services	$1,196.6	$35.8	31,879
Construction	$1,182.7	$29.1	26,328
Finance and Insurance	$936.0	$74.6	15,900
Other Services (except Public Administration)	$870.7	$106.9	20,143
Utilities	$806.7	$160.1	1,572
Arts, Entertainment, and Recreation	$128.0	$34.8	5,220
Management of Companies and Enterprises	$113.4	$5.4	1,914
Agriculture, Forestry, Fishing and Hunting	$105.8	$4.0	2,929
Educational Services	$104.1	$5.2	3,959
Mining, Quarrying, and Oil and Gas Extraction	$64.7	$39.3	1,171
Grand Total	$34,688.8	$2,887.5	434,680

*Source: 2016 IMPLAN for 536 sectors aggregated by 2-digit NAICS (North American Industry Classification System)

While municipal and manufacturing sectors led the region in economic output, the majority (64 percent) of water use in 2016 occurred in irrigated agriculture. In fact, more than 3 percent of the state's irrigation water use occurred within Region E. Figure 1-1 illustrates Region E's breakdown of the 2016 water use estimates by TWDB water use category.

Figure 1-1 Region E 2016 water use estimates by water use category (in acre-feet)



Source: TWDB Annual Water Use Estimates (all values in acre-feet)

1.2 Identified Regional Water Needs (Potential Shortages)

As part of the regional water planning process, the TWDB adopted water demand projections for water user groups (WUG) in Region E with input from the planning group. WUG-level demand projections were established for utilities that provide more than 100 acre-feet of annual water supply, combined rural areas (designated as county-other), and county-wide water demand projections for five non-municipal categories (irrigation, livestock, manufacturing, mining and steam-electric power). The RWPG then compared demands to the existing water supplies of each WUG to determine potential shortages, or needs, by decade.

Table 1-2 summarizes the region's identified water needs in the event of a repeat of the drought of record. Demand management, such as conservation, or the development of new infrastructure to increase supplies, are water management strategies that may be recommended by the planning group to address those needs. This analysis assumes that no strategies are implemented, and that the identified needs correspond to future water shortages. Note that projected water needs generally increase over time, primarily due to anticipated population growth, economic growth, or declining supplies. To provide a general sense of proportion, total projected needs as an overall percentage of total demand by water use category are also presented in aggregate in Table 1-2. Projected needs for individual water user groups within the aggregate can vary greatly and may reach 100% for a given WUG and water use category. A detailed summary of water needs by WUG and county appears in Chapter 4 of the 2021 Region E Regional Water Plan.

Table 1-2 Regional water needs summary by water use category *

Water Use Category		2020	2030	2040	2050	2060	2070
Irrigation	water needs (acre-feet per year)	16,903	13,375	13,375	13,375	13,375	13,375
	% of the category's total water demand	5%	4%	4%	4%	4%	4%
Livestock	water needs (acre-feet per year)	-	-	-	-	-	-
	% of the category's total water demand	0%	0%	0%	0%	0%	0%
Manufacturing	water needs (acre-feet per year)	-	860	860	860	860	860
	% of the category's total water demand	0%	11%	11%	11%	11%	11%
Mining	water needs (acre-feet per year)	2,530	3,223	3,840	4,407	5,038	5,796
	% of the category's total water demand	32%	36%	40%	44%	49%	54%
Municipal**	water needs (acre-feet per year)	4,102	8,061	11,815	24,605	38,953	52,666
	% of the category's total water demand	3%	5%	7%	13%	19%	24%
Steam-electric power	water needs (acre-feet per year)	7,260	7,260	7,260	7,260	7,260	7,260
	% of the category's total water demand	69%	69%	69%	69%	69%	69%
Total water needs (acre-feet per year)		**30,795**	**32,779**	**37,150**	**50,507**	**65,486**	**79,957**

*Entries denoted by a dash (-) indicate no identified water need for a given water use category.

** Municipal category consists of residential and non-residential (commercial and institutional) subcategories.

2 Impact Assessment Measures

A required component of the regional and state water plans is to estimate the potential economic and social impacts of potential water shortages during a repeat of the drought of record. Consistent with previous water plans, ten impact measures were estimated and are described in Table 2-1.

Table 2-1 Socioeconomic impact analysis measures

Regional economic impacts	Description
Income losses - value-added	The value of output less the value of intermediate consumption; it is a measure of the contribution to gross domestic product (GDP) made by an individual producer, industry, sector, or group of sectors within a year. Value-added measures used in this report have been adjusted to include the direct, indirect, and induced monetary impacts on the region.
Income losses - electrical power purchase costs	Proxy for income loss in the form of additional costs of power as a result of impacts of water shortages.
Job losses	Number of part-time and full-time jobs lost due to the shortage. These values have been adjusted to include the direct, indirect, and induced employment impacts on the region.
Financial transfer impacts	**Description**
Tax losses on production and imports	Sales and excise taxes not collected due to the shortage, in addition to customs duties, property taxes, motor vehicle licenses, severance taxes, other taxes, and special assessments less subsidies. These values have been adjusted to include the direct, indirect and induced tax impacts on the region.
Water trucking costs	Estimated cost of shipping potable water.
Utility revenue losses	Foregone utility income due to not selling as much water.
Utility tax revenue losses	Foregone miscellaneous gross receipts tax collections.
Social impacts	**Description**
Consumer surplus losses	A welfare measure of the lost value to consumers accompanying restricted water use.
Population losses	Population losses accompanying job losses.
School enrollment losses	School enrollment losses (K-12) accompanying job losses.

2.1 Regional Economic Impacts

The two key measures used to assess regional economic impacts are income losses and job losses. The income losses presented consist of the sum of value-added losses and the additional purchase costs of electrical power.

Income Losses - Value-added Losses

Value-added is the value of total output less the value of the intermediate inputs also used in the production of the final product. Value-added is similar to GDP, a familiar measure of the productivity of an economy. The loss of value-added due to water shortages is estimated by input-output analysis using the IMPLAN software package, and includes the direct, indirect, and induced monetary impacts on the region. The indirect and induced effects are measures of reduced income as well as reduced employee spending for those input sectors which provide resources to the water shortage impacted production sectors.

Income Losses - Electric Power Purchase Costs

The electrical power grid and market within the state is a complex interconnected system. The industry response to water shortages, and the resulting impact on the region, are not easily modeled using traditional input/output impact analysis and the IMPLAN model. Adverse impacts on the region will occur and are represented in this analysis by estimated additional costs associated with power purchases from other generating plants within the region or state. Consequently, the analysis employs additional power purchase costs as a proxy for the value-added impacts for the steam-electric power water use category, and these are included as a portion of the overall income impact for completeness.

For the purpose of this analysis, it is assumed that power companies with insufficient water will be forced to purchase power on the electrical market at a projected higher rate of 5.60 cents per kilowatt hour. This rate is based upon the average day-ahead market purchase price of electricity in Texas that occurred during the recent drought period in 2011. This price is assumed to be comparable to those prices which would prevail in the event of another drought of record.

Job Losses

The number of jobs lost due to the economic impact is estimated using IMPLAN output associated with each TWDB water use category. Because of the difficulty in predicting outcomes and a lack of relevant data, job loss estimates are not calculated for the steam-electric power category.

2.2 Financial Transfer Impacts

Several impact measures evaluated in this analysis are presented to provide additional detail concerning potential impacts on a portion of the economy or government. These financial transfer impact measures include lost tax collections (on production and imports), trucking costs for imported water, declines in utility revenues, and declines in utility tax revenue collected by the state. These measures are not solely adverse, with some having both positive and negative impacts. For example, cities and residents would suffer if forced to pay large costs for trucking in potable water. Trucking firms, conversely, would benefit from the transaction. Additional detail for each of these measures follows.

Tax Losses on Production and Imports

Reduced production of goods and services accompanying water shortages adversely impacts the collection of taxes by state and local government. The regional IMPLAN model is used to estimate reduced tax collections associated with the reduced output in the economy. Impact estimates for this measure include the direct, indirect, and induced impacts for the affected sectors.

Water Trucking Costs

In instances where water shortages for a municipal water user group are estimated by RWPGs to exceed 80 percent of water demands, it is assumed that water would need to be trucked in to support basic consumption and sanitation needs. For water shortages of 80 percent or greater, a fixed, maximum of $35,000[1] per acre-foot of water applied as an economic cost. This water trucking cost was utilized for both the residential and non-residential portions of municipal water needs.

Utility Revenue Losses

Lost utility income is calculated as the price of water service multiplied by the quantity of water not sold during a drought shortage. Such estimates are obtained from utility-specific pricing data provided by the Texas Municipal League, where available, for both water and wastewater. These water rates are applied to the potential water shortage to estimate forgone utility revenue as water providers sold less water during the drought due to restricted supplies.

Utility Tax Losses

Foregone utility tax losses include estimates of forgone miscellaneous gross receipts taxes. Reduced water sales reduce the amount of utility tax that would be collected by the State of Texas for water and wastewater service sales.

2.3 Social Impacts

Consumer Surplus Losses for Municipal Water Users

Consumer surplus loss is a measure of impact to the wellbeing of municipal water users when their water use is restricted. Consumer surplus is the difference between how much a consumer is

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[1] Based on staff survey of water hauling firms and historical data concerning transport costs for potable water in the recent drought in California for this estimate. There are many factors and variables that would determine actual water trucking costs including distance to, cost of water, and length of that drought.

willing and able to pay for a commodity (i.e., water) and how much they actually have to pay. The difference is a benefit to the consumer's wellbeing since they do not have to pay as much for the commodity as they would be willing to pay. Consumer surplus may also be viewed as an estimate of how much consumers would be willing to pay to keep the original quantity of water which they used prior to the drought. Lost consumer surplus estimates within this analysis only apply to the residential portion of municipal demand, with estimates being made for reduced outdoor and indoor residential use. Lost consumer surplus estimates varied widely by location and degree of water shortage.

Population and School Enrollment Losses

Population loss due to water shortages, as well as the associated decline in school enrollment, are based upon the job loss estimates discussed in Section 2.1. A simplified ratio of job and net population losses are calculated for the state as a whole based on a recent study of how job layoffs impact the labor market population.[2] For every 100 jobs lost, 18 people were assumed to move out of the area. School enrollment losses are estimated as a proportion of the population lost based upon public school enrollment data from the Texas Education Agency concerning the age K-12 population within the state (approximately 19%).

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[2] Foote, Andrew, Grosz, Michel, Stevens, Ann. "Locate Your Nearest Exit: Mass Layoffs and Local Labor Market Response." University of California, Davis. April 2015, http://paa2015.princeton.edu/papers/150194. The study utilized Bureau of Labor Statistics data regarding layoffs between 1996 and 2013, as well as Internal Revenue Service data regarding migration, to model the change in the population as the result of a job layoff event. The study found that layoffs impact both out-migration and in-migration into a region, and that a majority of those who did move following a layoff moved to another labor market rather than an adjacent county.

3 Socioeconomic Impact Assessment Methodology

This portion of the report provides a summary of the methodology used to estimate the potential economic impacts of future water shortages. The general approach employed in the analysis was to obtain estimates for income and job losses on the smallest geographic level that the available data would support, tie those values to their accompanying historic water use estimate, and thereby determine a maximum impact per acre-foot of shortage for each of the socioeconomic measures. The calculations of economic impacts are based on the overall composition of the economy divided into many underlying economic sectors. Sectors in this analysis refer to one or more of the 536 specific production sectors of the economy designated within IMPLAN, the economic impact modeling software used for this assessment. Economic impacts within this report are estimated for approximately 330 of these sectors, with the focus on the more water-intensive production sectors. The economic impacts for a single water use category consist of an aggregation of impacts to multiple, related IMPLAN economic sectors.

3.1 Analysis Context

The context of this socioeconomic impact analysis involves situations where there are physical shortages of groundwater or surface water due to a recurrence of drought of record conditions. Anticipated shortages for specific water users may be nonexistent in earlier decades of the planning horizon, yet population growth or greater industrial, agricultural or other sector demands in later decades may result in greater overall demand, exceeding the existing supplies. Estimated socioeconomic impacts measure what would happen if water user groups experience water shortages for a period of one year. Actual socioeconomic impacts would likely become larger as drought of record conditions persist for periods greater than a single year.

3.2 IMPLAN Model and Data

Input-Output analysis using the IMPLAN software package was the primary means of estimating the value-added, jobs, and tax related impact measures. This analysis employed regional level models to determine key economic impacts. IMPLAN is an economic impact model, originally developed by the U.S. Forestry Service in the 1970's to model economic activity at varying geographic levels. The model is currently maintained by the Minnesota IMPLAN Group (MIG Inc.) which collects and sells county and state specific data and software. The year 2016 version of IMPLAN, employing data for all 254 Texas counties, was used to provide estimates of value-added, jobs, and taxes on production for the economic sectors associated with the water user groups examined in the study. IMPLAN uses 536 sector-specific Industry Codes, and those that rely on water as a primary input were assigned to their appropriate planning water user categories (irrigation, livestock, manufacturing, mining, and municipal). Estimates of value-added for a water use category were obtained by summing value-added estimates across the relevant IMPLAN sectors associated with that water use category. These calculations were also performed for job losses as well as tax losses on production and imports.

The adjusted value-added estimates used as an income measure in this analysis, as well as the job and tax estimates from IMPLAN, include three components:

- ***Direct effects*** representing the initial change in the industry analyzed;
- ***Indirect effects*** that are changes in inter-industry transactions as supplying industries respond to reduced demands from the directly affected industries; and,
- ***Induced effects*** that reflect changes in local spending that result from reduced household income among employees in the directly and indirectly affected industry sectors.

Input-output models such as IMPLAN only capture backward linkages and do not include forward linkages in the economy.

3.3 Elasticity of Economic Impacts

The economic impact of a water need is based on the size of the water need relative to the total water demand for each water user group. Smaller water shortages, for example, less than 5 percent, are generally anticipated to result in no initial negative economic impact because water users are assumed to have a certain amount of flexibility in dealing with small shortages. As a water shortage intensifies, however, such flexibility lessens and results in actual and increasing economic losses, eventually reaching a representative maximum impact estimate per unit volume of water. To account for these characteristics, an elasticity adjustment function is used to estimate impacts for the income, tax and job loss measures. Figure 3-1 illustrates this general relationship for the adjustment functions. Negative impacts are assumed to begin accruing when the shortage reaches the lower bound 'b1' (5 percent in Figure 3-1), with impacts then increasing linearly up to the 100 percent impact level (per unit volume) once the upper bound reaches the 'b2' level shortage (40 percent in Figure 3-1).

To illustrate this, if the total annual value-added for manufacturing in the region was $2 million and the reported annual volume of water used in that industry is 10,000 acre-feet, the estimated economic measure of the water shortage would be $200 per acre-foot. The economic impact of the shortage would then be estimated using this value-added amount as the maximum impact estimate ($200 per acre-foot) applied to the anticipated shortage volume and then adjusted by the elasticity function. Using the sample elasticity function shown in Figure 3-1, an approximately 22 percent shortage in the livestock category would indicate an economic impact estimate of 50% of the original $200 per acre-foot impact value (i.e., $100 per acre-foot).

Such adjustments are not required in estimating consumer surplus, utility revenue losses, or utility tax losses. Estimates of lost consumer surplus rely on utility-specific demand curves with the lost consumer surplus estimate calculated based on the relative percentage of the utility's water shortage. Estimated changes in population and school enrollment are indirectly related to the elasticity of job losses.

Assumed values for the lower and upper bounds 'b1' and 'b2' vary by water use category and are presented in Table 3-1.

Figure 3-1 Example economic impact elasticity function (as applied to a single water user's shortage)

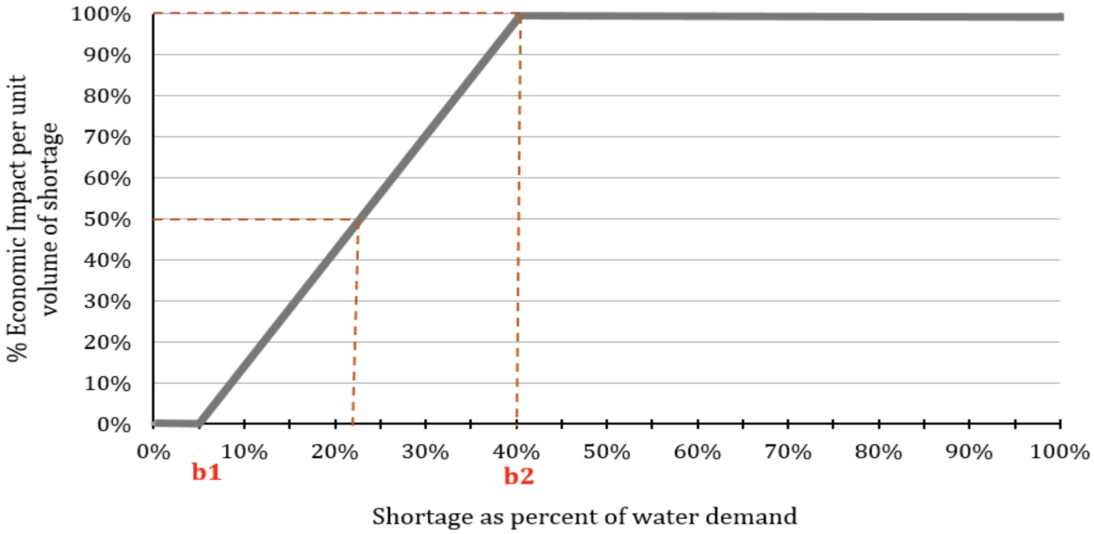

Table 3-1 Economic impact elasticity function lower and upper bounds

Water use category	Lower bound (b1)	Upper bound (b2)
Irrigation	**5%**	**40%**
Livestock	**5%**	**10%**
Manufacturing	**5%**	**40%**
Mining	**5%**	**40%**
Municipal (non-residential water intensive subcategory)	**5%**	**40%**
Steam-electric power	**N/A**	**N/A**

3.4 Analysis Assumptions and Limitations

The modeling of complex systems requires making many assumptions and acknowledging the model's uncertainty and limitations. This is particularly true when attempting to estimate a wide range of socioeconomic impacts over a large geographic area and into future decades. Some of the key assumptions and limitations of this methodology include:

1. The foundation for estimating the socioeconomic impacts of water shortages resulting from a drought are the water needs (potential shortages) that were identified by RWPGs as part of the

regional water planning process. These needs have some uncertainty associated with them but serve as a reasonable basis for evaluating the potential impacts of a drought of record event.

2. All estimated socioeconomic impacts are snapshots for years in which water needs were identified (i.e., 2020, 2030, 2040, 2050, 2060, and 2070). The estimates are independent and distinct "what if" scenarios for each particular year, and water shortages are assumed to be temporary events resulting from a single year recurrence of drought of record conditions. The evaluation assumed that no recommended water management strategies are implemented. In other words, growth occurs and future shocks are imposed on an economy at 10-year intervals, and the resulting impacts are estimated. Note that the estimates presented are not cumulative (i.e., summing up expected impacts from today up to the decade noted), but are simply snapshots of the estimated annual socioeconomic impacts should a drought of record occur in each particular decade based on anticipated water supplies and demands for that same decade.

3. Input-output models such as IMPLAN rely on a static profile of the structure of the economy as it appears today. This presumes that the relative contributions of all sectors of the economy would remain the same, regardless of changes in technology, availability of limited resources, and other structural changes to the economy that may occur in the future. Changes in water use efficiency will undoubtedly take place in the future as supplies become more stressed. Use of the static IMPLAN structure was a significant assumption and simplification considering the 50-year time period examined in this analysis. To presume an alternative future economic makeup, however, would entail positing many other major assumptions that would very likely generate as much or more error.

4. This is not a form of cost-benefit analysis. That approach to evaluating the economic feasibility of a specific policy or project employs discounting future benefits and costs to their present value dollars using some assumed discount rate. The methodology employed in this effort to estimate the economic impacts of future water shortages did not use any discounting methods to weigh future costs differently through time.

5. All monetary values originally based upon year 2016 IMPLAN and other sources are reported in constant year 2018 dollars to be consistent with the water management strategy requirements in the State Water Plan.

6. IMPLAN based loss estimates (income-value-added, jobs, and taxes on production and imports) are calculated only for those IMPLAN sectors for which the TWDB's Water Use Survey (WUS) data was available and deemed reliable. Every effort is made in the annual WUS effort to capture all relevant firms who are significant water users. Lack of response to the WUS, or omission of relevant firms, impacts the loss estimates.

7. Impacts are annual estimates. The socioeconomic analysis does not reflect the full extent of impacts that might occur as a result of persistent water shortages occurring over an extended duration. The drought of record in most regions of Texas lasted several years.

8. Value-added estimates are the primary estimate of the economic impacts within this report. One may be tempted to add consumer surplus impacts to obtain an estimate of total adverse economic impacts to the region, but the consumer surplus measure represents the change to the wellbeing of households (and other water users), not an actual change in the flow of dollars through the economy. The two measures (value-added and consumer surplus) are both valid impacts but ideally should not be summed.

9. The value-added, jobs, and taxes on production and import impacts include the direct, indirect and induced effects to capture backward linkages in the economy described in Section 2.1. Population and school enrollment losses also indirectly include such effects as they are based on the associated losses in employment. The remaining measures (consumer surplus, utility revenue, utility taxes, additional electrical power purchase costs, and potable water trucking costs), however, do not include any induced or indirect effects.

10. The majority of impacts estimated in this analysis may be more conservative (i.e., smaller) than those that might actually occur under drought of record conditions due to not including impacts in the forward linkages in the economy. Input-output models such as IMPLAN only capture backward linkages on suppliers (including households that supply labor to directly affected industries). While this is a common limitation in this type of economic modeling effort, it is important to note that forward linkages on the industries that use the outputs of the directly affected industries can also be very important. A good example is impacts on livestock operators. Livestock producers tend to suffer substantially during droughts, not because there is not enough water for their stock, but because reductions in available pasture and higher prices for purchased hay have significant economic effects on their operations. Food processors could be in a similar situation if they cannot get the grains or other inputs that they need. These effects are not captured in IMPLAN, resulting in conservative impact estimates.

11. The model does not reflect dynamic economic responses to water shortages as they might occur, nor does the model reflect economic impacts associated with a recovery from a drought of record including:
    a. The likely significant economic rebound to some industries immediately following a drought, such as landscaping;
    b. The cost and time to rebuild liquidated livestock herds (a major capital investment in that industry);
    c. Direct impacts on recreational sectors (i.e., stranded docks and reduced tourism); or,
    d. Impacts of negative publicity on Texas’ ability to attract population and business in the event that it was not able to provide adequate water supplies for the existing economy.

12. Estimates for job losses and the associated population and school enrollment changes may exceed what would actually occur. In practice, firms may be hesitant to lay off employees, even in difficult economic times. Estimates of population and school enrollment changes are based on regional evaluations and therefore do not necessarily reflect what might occur on a statewide basis.

13. **The results must be interpreted carefully. It is the general and relative magnitudes of impacts as well as the changes of these impacts over time that should be the focus rather than the absolute numbers.** Analyses of this type are much better at predicting relative percent differences brought about by a shock to a complex system (i.e., a water shortage) than the precise size of an impact. To illustrate, assuming that the estimated economic impacts of a drought of record on the manufacturing and mining water user categories are $2 and $1 million, respectively, one should be more confident that the economic impacts on manufacturing are twice as large as those on mining and that these impacts will likely be in the millions of dollars. But one should have less confidence that the actual total economic impact experienced would be $3 million.

14. The methodology does not capture “spillover” effects between regions – or the secondary impacts that occur outside of the region where the water shortage is projected to occur.

15. The methodology that the TWDB has developed for estimating the economic impacts of unmet water needs, and the assumptions and models used in the analysis, are specifically designed to estimate potential economic effects at the regional and county levels. Although it may be tempting to add the regional impacts together in an effort to produce a statewide result, the TWDB cautions against that approach for a number of reasons. The IMPLAN modeling (and corresponding economic multipliers) are all derived from regional models – a statewide model of Texas would produce somewhat different multipliers. As noted in point 14 within this section, the regional modeling used by TWDB does not capture spillover losses that could result in other regions from unmet needs in the region analyzed, or potential spillover gains if decreased production in one region leads to increases in production elsewhere. The assumed drought of record may also not occur in every region of Texas at the same time, or to the same degree.

4 Analysis Results

This section presents estimates of potential economic impacts that could reasonably be expected in the event of water shortages associated with a drought of record and if no recommended water management strategies were implemented. Projected economic impacts for the six water use categories (irrigation, livestock, manufacturing, mining, municipal, and steam-electric power) are reported by decade.

4.1 Impacts for Irrigation Water Shortages

Two of the seven counties in the region are projected to experience water shortages in the irrigated agriculture water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-1. Note that tax collection impacts were not estimated for this water use category. IMPLAN data indicates a negative tax impact (i.e., increased tax collections) for the associated production sectors, primarily due to past subsidies from the federal government. However, it was not considered realistic to report increasing tax revenues during a drought of record.

Table 4-1 Impacts of water shortages on irrigation in Region E

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$2	$1	$1	$1	$1	$1
Job losses	36	18	18	18	18	18

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.2 Impacts for Livestock Water Shortages

None of the seven counties in the region are projected to experience water shortages in the livestock water use category. Estimated impacts to this water use category appear in Table 4-2.

Table 4-2 Impacts of water shortages on livestock in Region E

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$-	$-	$-	$-	$-	$-
Jobs losses	-	-	-	-	-	-
Tax losses on production and imports ($ millions)*	$-	$-	$-	$-	$-	$-

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.3 Impacts of Manufacturing Water Shortages

Manufacturing water shortages in the region are projected to occur in one of the seven counties in the region for at least one decade of the planning horizon. Estimated impacts to this water use category appear in Table 4-3.

Table 4-3 Impacts of water shortages on manufacturing in Region E

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$-	$41	$41	$41	$41	$41
Job losses	-	270	270	270	270	270
Tax losses on production and Imports ($ millions)*	$-	$3	$3	$3	$3	$3

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.4 Impacts of Mining Water Shortages

Mining water shortages in the region are projected to occur in three of the seven counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use type appear in Table 4-4.

Table 4-4 Impacts of water shortages on mining in Region E

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$680	$866	$980	$1,047	$1,133	$1,254
Job losses	3,135	3,970	4,502	4,821	5,221	5,783
Tax losses on production and Imports ($ millions)*	$56	$72	$81	$87	$95	$105

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.5 Impacts for Municipal Water Shortages

Two of the seven counties in the region are projected to experience water shortages in the municipal water use category for one or more decades within the planning horizon.

Impact estimates were made for two sub-categories within municipal water use: residential and non-residential. Non-residential municipal water use includes commercial and institutional users, which are further divided into non-water-intensive and water-intensive subsectors including car wash, laundry, hospitality, health care, recreation, and education. Lost consumer surplus estimates were made only for needs in the residential portion of municipal water use. Available IMPLAN and TWDB Water Use Survey data for the non-residential, water-intensive portion of municipal demand allowed these sectors to be included in income, jobs, and tax loss impact estimate.

Trucking cost estimates, calculated for shortages exceeding 80 percent, assumed a fixed, maximum cost of $35,000 per acre-foot to transport water for municipal use. The estimated impacts to this water use category appear in Table 4-5.

Table 4-5 Impacts of water shortages on municipal water users in Region E

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses[1] ($ millions)*	$22	$56	$85	$116	$183	$278
Job losses[1]	464	1,186	1,817	2,483	3,913	5,919
Tax losses on production and imports[1] ($ millions)*	$2	$6	$9	$13	$20	$30
Trucking costs ($ millions)*	$-	$-	$-	$-	$-	$-
Utility revenue losses ($ millions)*	$11	$21	$31	$60	$93	$123
Utility tax revenue losses ($ millions)*	$0	$0	$1	$1	$2	$2

[1] Estimates apply to the water-intensive portion of non-residential municipal water use.
* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.6 Impacts of Steam-Electric Water Shortages

Steam-electric water shortages in the region are projected to occur in one of the seven counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-6.

Note that estimated economic impacts to steam-electric water users:

- Are reflected as an income loss proxy in the form of estimated additional purchasing costs for power from the electrical grid to replace power that could not be generated due to a shortage;
- Do not include estimates of impacts on jobs. Because of the unique conditions of power generators during drought conditions and lack of relevant data, it was assumed that the industry would retain, perhaps relocating or repurposing, their existing staff in order to manage their ongoing operations through a severe drought.
- Do not presume a decline in tax collections. Associated tax collections, in fact, would likely increase under drought conditions since, historically, the demand for electricity increases during times of drought, thereby increasing taxes collected on the additional sales of power.

Table 4-6 Impacts of water shortages on steam-electric power in Region E

Impacts measure	2020	2030	2040	2050	2060	2070
Income Losses ($ millions)*	$180	$180	$180	$180	$180	$180

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

4.7 Regional Social Impacts

Projected changes in population, based upon several factors (household size, population, and job loss estimates), as well as the accompanying change in school enrollment, were also estimated and are summarized in Table 4-7.

Table 4-7 Region-wide social impacts of water shortages in Region E

Impacts measure	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)*	$3	$15	$40	$79	$133	$201
Population losses	667	999	1,213	1,394	1,730	2,201
School enrollment losses	128	191	232	267	331	421

* Year 2018 dollars, rounded. Entries denoted by a dash (-) indicate no estimated economic impact. Entries denoted by a zero ($0) indicate estimated income losses less than $500,000.

Appendix A - County Level Summary of Estimated Economic Impacts for Region E

County level summary of estimated economic impacts of not meeting identified water needs by water use category and decade (in 2018 dollars, rounded). Values are presented only for counties with projected economic impacts for at least one decade.
(* Entries denoted by a dash (-) indicate no estimated economic impact)

		Income losses (Million $)*						**Job losses**					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
EL PASO	IRRIGATION	$1.69	$0.82	$0.82	$0.82	$0.82	$0.82	36	18	18	18	18	18
EL PASO	MANUFACTURING	-	$41.35	$41.35	$41.35	$41.35	$41.35	-	270	270	270	270	270
EL PASO	MINING	$386.81	$515.95	$648.86	$792.22	$947.90	$1,124.69	1,773	2,365	2,974	3,631	4,344	5,155
EL PASO	MUNICIPAL	$21.67	$55.51	$85.12	$116.36	$183.41	$277.45	462	1,184	1,815	2,482	3,912	5,917
EL PASO	STEAM ELECTRIC POWER	$179.59	$179.59	$179.59	$179.59	$179.59	$179.59	-	-	-	-	-	-
EL PASO Total		**$589.77**	**$793.23**	**$955.75**	**$1,130.34**	**$1,353.08**	**$1,623.90**	**2,271**	**3,836**	**5,076**	**6,400**	**8,543**	**11,359**
HUDSPETH	MINING	$14.88	$11.75	$13.85	$15.18	$15.86	$16.62	110	87	102	112	117	123
HUDSPETH	MUNICIPAL	$0.07	$0.08	$0.08	$0.08	$0.08	$0.08	1	2	2	2	2	2
HUDSPETH Total		**$14.95**	**$11.83**	**$13.93**	**$15.26**	**$15.94**	**$16.71**	**111**	**89**	**104**	**114**	**119**	**125**
TERRELL	MINING	$278.59	$337.99	$317.23	$239.94	$169.00	$112.47	1,252	1,519	1,426	1,078	759	505
TERRELL Total		**$278.59**	**$337.99**	**$317.23**	**$239.94**	**$169.00**	**$112.47**	**1,252**	**1,519**	**1,426**	**1,078**	**759**	**505**
REGION E Total		**$883.30**	**$1,143.05**	**$1,286.91**	**$1,385.54**	**$1,538.02**	**$1,753.08**	**3,635**	**5,443**	**6,606**	**7,592**	**9,422**	**11,989**

Appendix D

Igneous Aquifer Groundwater Uses and Demands

Appendix D - Igneous Aquifer Uses and Demands

Year	County	Municipal	Mining	Irrigation	Livestock	Total
1993	BREWSTER	1,301	696	116	180	2,293
1994	BREWSTER	1,364	696	0	266	2,326
1995	BREWSTER	1,338	696	0	239	2,273
1996	BREWSTER	1,302	696	0	202	2,200
1997	BREWSTER	1,646	696	0	207	2,549
1998	BREWSTER	1,787	696	0	207	2,690
1999	BREWSTER	1,787	696	0	234	2,717
2000	BREWSTER	1,974	0	191	224	2,389
2001	BREWSTER	1,985	0	137	202	2,324
2002	BREWSTER	2,019	0	137	165	2,321
2003	BREWSTER	2,025	0	177	86	2,288
2004	BREWSTER	1,839	0	186	79	2,104
2005	BREWSTER	1,855	0	339	103	2,297
2006	BREWSTER	1,712	0	598	93	2,403
2007	BREWSTER	844	0	873	103	1,820
2008	BREWSTER	1,695	0	867	112	2,674
2009	BREWSTER	1,270	0	657	102	2,029
2010	BREWSTER	189	0	1,236	109	1,534
2011	BREWSTER	245	0	418	107	770
2012	BREWSTER	274	0	137	93	504
2000	CULBERSON	0	0	451	17	468
2001	CULBERSON	0	0	301	15	316
2002	CULBERSON	0	0	396	24	420
2003	CULBERSON	0	0	401	13	414
2004	CULBERSON	0	0	351	14	365
2005	CULBERSON	0	0	400	11	411
2006	CULBERSON	3	0	374	13	390
2007	CULBERSON	2	0	306	15	323
2008	CULBERSON	2	0	629	15	646
2009	CULBERSON	2	0	702	14	718
2010	CULBERSON	2	0	769	13	784
2011	CULBERSON	2	0	648	13	663
2012	CULBERSON	2	0	1,010	13	1,025
2004	HUDSPETH	0	0	0	6	6
2005	HUDSPETH	0	0	0	5	5
2006	HUDSPETH	0	0	0	6	6
2007	HUDSPETH	0	0	0	6	6
2008	HUDSPETH	0	0	0	6	6
2009	HUDSPETH	0	0	0	7	7
2010	HUDSPETH	0	0	0	6	6
2011	HUDSPETH	0	0	0	7	7
2012	HUDSPETH	0	0	0	5	5
1993	JEFF DAVIS	212	0	21	68	301
1994	JEFF DAVIS	238	0	132	66	436

Appendix D - Igneous Aquifer Uses and Demands

Year	County	Municipal	Mining	Irrigation	Livestock	Total
1995	JEFF DAVIS	248	0	120	56	424
1996	JEFF DAVIS	253	0	120	56	429
1997	JEFF DAVIS	245	0	120	54	419
1998	JEFF DAVIS	207	0	120	79	406
1999	JEFF DAVIS	267	0	120	84	471
2000	JEFF DAVIS	355	0	394	72	821
2001	JEFF DAVIS	349	0	433	77	859
2002	JEFF DAVIS	360	0	1,623	73	2,056
2003	JEFF DAVIS	344	0	2,184	54	2,582
2004	JEFF DAVIS	305	0	2,683	240	3,228
2005	JEFF DAVIS	329	0	2,700	239	3,268
2006	JEFF DAVIS	413	0	2,709	228	3,350
2007	JEFF DAVIS	482	0	1,820	239	2,541
2008	JEFF DAVIS	431	0	1,776	299	2,506
2009	JEFF DAVIS	465	0	1,463	268	2,196
2010	JEFF DAVIS	1,430	0	455	282	2,167
2011	JEFF DAVIS	2,335	0	467	284	3,086
2012	JEFF DAVIS	1,868	0	1,118	251	3,237
1993	PRESIDIO	794	0	130	102	1,026
1994	PRESIDIO	831	0	575	123	1,529
1995	PRESIDIO	811	0	656	102	1,569
1996	PRESIDIO	788	0	672	78	1,538
1997	PRESIDIO	716	0	1,059	78	1,853
1998	PRESIDIO	784	0	1,065	128	1,977
1999	PRESIDIO	790	0	704	140	1,634
2000	PRESIDIO	808	0	542	128	1,478
2001	PRESIDIO	693	0	513	128	1,334
2002	PRESIDIO	657	0	1,085	112	1,854
2003	PRESIDIO	659	0	869	74	1,602
2004	PRESIDIO	580	0	930	198	1,708
2005	PRESIDIO	600	0	791	202	1,593
2006	PRESIDIO	641	0	687	192	1,520
2007	PRESIDIO	571	0	317	174	1,062
2008	PRESIDIO	552	0	490	224	1,266
2009	PRESIDIO	524	0	605	217	1,346
2010	PRESIDIO	526	0	574	205	1,305
2011	PRESIDIO	649	0	256	207	1,112
2012	PRESIDIO	582	0	264	184	1,030

Appendix E

West Texas Bolsons Aquifer Groundwater Uses and Demands

Appendix E - West Texas Bolsons Aquifer Uses and Demands

Year	County	Municipal	Manufacturing	Mining	Irrigation	Livestock	Total
1993	CULBERSON	883	0	1,944	4,737	127	7,691
1994	CULBERSON	966	0	2,004	5,583	113	8,666
1995	CULBERSON	708	0	2,139	5,885	92	8,824
1996	CULBERSON	817	0	2,139	6,196	99	9,251
1997	CULBERSON	669	0	2,201	6,751	106	9,727
1998	CULBERSON	802	0	1,380	11,702	144	14,028
1999	CULBERSON	1,078	0	2,201	11,702	155	15,136
2000	CULBERSON	678	0	0	19,361	123	20,162
2001	CULBERSON	930	0	0	12,936	111	13,977
2002	CULBERSON	817	0	0	16,995	168	17,980
2003	CULBERSON	867	0	0	17,208	91	18,166
2004	CULBERSON	1,194	0	0	15,058	85	16,337
2005	CULBERSON	836	0	0	17,174	70	18,080
2006	CULBERSON	743	0	0	16,083	80	16,906
2007	CULBERSON	578	0	0	13,136	90	13,804
2008	CULBERSON	697	0	0	27,004	93	27,794
2009	CULBERSON	913	0	0	30,169	85	31,167
2010	CULBERSON	889	0	0	33,033	80	34,002
2011	CULBERSON	819	5	0	27,845	80	28,749
2012	CULBERSON	741	0	0	43,376	80	44,197
1993	HUDSPETH	1	0	0	0	33	34
1994	HUDSPETH	1	0	0	0	45	46
1995	HUDSPETH	1	0	2	0	34	37
1996	HUDSPETH	1	0	2	0	30	33
1997	HUDSPETH	1	0	2	0	29	32
1998	HUDSPETH	1	0	1	0	51	53
1999	HUDSPETH	1	0	2	0	55	58
2000	HUDSPETH	0	1	0	0	51	52
2001	HUDSPETH	0	1	0	0	48	49
2002	HUDSPETH	0	1	0	0	45	46
2003	HUDSPETH	0	1	0	0	35	36
2004	HUDSPETH	0	0	0	0	55	55
2005	HUDSPETH	114	0	0	0	54	168
2006	HUDSPETH	121	0	0	0	59	180
2007	HUDSPETH	120	0	0	0	58	178
2008	HUDSPETH	143	0	0	0	62	205
2009	HUDSPETH	143	0	0	0	70	213
2010	HUDSPETH	142	0	0	0	64	206
2011	HUDSPETH	143	0	0	0	69	212
2012	HUDSPETH	142	0	0	0	53	195
1993	JEFF DAVIS	22	0	0	152	71	245
1994	JEFF DAVIS	24	0	0	59	69	152
1995	JEFF DAVIS	32	0	0	53	59	144
1996	JEFF DAVIS	24	0	0	53	59	136

Appendix E - West Texas Bolsons Aquifer Uses and Demands

Year	County	Municipal	Manufacturing	Mining	Irrigation	Livestock	Total
1997	JEFF DAVIS	24	0	0	53	56	133
1998	JEFF DAVIS	20	0	0	53	82	155
1999	JEFF DAVIS	26	0	0	53	88	167
2000	JEFF DAVIS	35	0	0	45	75	155
2001	JEFF DAVIS	33	0	0	60	80	173
2002	JEFF DAVIS	42	0	0	513	76	631
2003	JEFF DAVIS	37	0	0	727	56	820
2004	JEFF DAVIS	37	0	0	917	50	1,004
2005	JEFF DAVIS	38	0	0	899	50	987
2006	JEFF DAVIS	38	0	0	902	48	988
2007	JEFF DAVIS	35	0	0	564	50	649
2008	JEFF DAVIS	41	0	0	561	63	665
2009	JEFF DAVIS	47	0	0	441	56	544
2010	JEFF DAVIS	52	0	0	62	59	173
2011	JEFF DAVIS	53	0	0	67	60	180
2012	JEFF DAVIS	52	0	0	315	53	420
1993	PRESIDIO	594	0	10	1,809	185	2,598
1994	PRESIDIO	710	0	10	1,150	223	2,093
1995	PRESIDIO	817	0	10	1,313	185	2,325
1996	PRESIDIO	710	0	10	1,344	141	2,205
1997	PRESIDIO	677	0	10	2,119	141	2,947
1998	PRESIDIO	716	0	10	2,131	231	3,088
1999	PRESIDIO	796	0	10	1,407	253	2,466
2000	PRESIDIO	895	0	0	759	229	1,883
2001	PRESIDIO	931	0	0	735	229	1,895
2002	PRESIDIO	933	0	0	888	202	2,023
2003	PRESIDIO	932	0	0	711	133	1,776
2004	PRESIDIO	777	0	0	761	93	1,631
2005	PRESIDIO	773	0	0	647	95	1,515
2006	PRESIDIO	740	0	0	562	90	1,392
2007	PRESIDIO	650	0	0	260	82	992
2008	PRESIDIO	660	0	0	401	105	1,166
2009	PRESIDIO	663	0	0	495	102	1,260
2010	PRESIDIO	753	0	0	469	96	1,318
2011	PRESIDIO	753	0	0	209	97	1,059
2012	PRESIDIO	979	0	0	216	86	1,281