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

Prepared for:

Groundwater Management Area 4

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Groundwater Management Area 4

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Table of Contents

1.0 Groundwater Management Area 4 5
2.0 Desired Future Conditions 8
3.0 Summary of GMA 4 Meeting Discussions Related to Statutory Factors 11
  3.1 GMA 4 Meeting of June 19, 2014 11
  3.2 GMA 4 Meeting of November 20, 2014 11
  3.3 GMA 4 Meeting of January 29, 2015 11
  3.4 GMA 4 Meeting of April 30, 2015 12
  3.5 GMA 4 Meeting of September 17, 2015 12
  3.6 GMA 4 Meeting of January 14, 2016 13
  3.7 GMA 4 Meeting of February 18, 2016 13
  3.8 GMA 4 Meeting of March 31, 2016 13
4.0 Aquifers that are Not Relevant for Purposes of Joint Planning 14
  4.1 Pecos Valley Aquifer 14
  4.2 Rustler Aquifer 15
  4.3 Upper Salt Basin 17
5.0 Bone Spring-Victorio Peak Aquifer 19
  5.1 Aquifer Description and Location 19
  5.2 Policy Justifications 20
  5.3 Technical Justification 21
  5.4 Factor Consideration 22
    5.4.1 Groundwater Demands and Uses 22
    5.4.2 Water Supply Needs and Water Management Strategies 23
    5.4.3 Hydrologic Conditions, Including Total Estimated Recoverable Storage 23
    5.4.4 Other Environmental Impacts 23
    5.4.5 Subsidence 24
    5.4.6 Socioeconomic Impacts 24
    5.4.7 Impact on Private Property Rights 24
    5.4.8 Feasibility of Achieving the Desired Future Conditions 24
    5.4.9 Other Information 24
  5.5 Discussion of Other Desired Future Conditions Considered 25
6.0 Capitan Reef Complex 26
  6.1 Aquifer Description and Location 26
  6.2 Policy Justifications 27
  6.3 Technical Justification 28
  6.4 Factor Consideration 28
    6.4.1 Aquifer Uses and Conditions 28
    6.4.2 Water Supply Needs and Water Management Strategies 30
    6.4.3 Hydrologic Conditions, Including Total Estimated Recoverable Storage 30
    6.4.4 Other Environmental Impacts 31
    6.4.5 Subsidence 31
    6.4.6 Socioeconomic Impacts 32
    6.4.7 Impact on Private Property Rights 32
    6.4.8 Feasibility of Achieving the Desired Future Conditions 32
    6.4.9 Other Information 32
  6.5 Discussion of Other Desired Future Conditions Considered 32

7.0 Edwards-Trinity (Plateau) Aquifer 33
  7.1 Aquifer Description and Location 33
  7.2 Policy Justifications 34
  7.3 Technical Justification 35
  7.4 Factor Consideration 36
    7.4.1 Groundwater Demands and Uses 36
    7.4.2 Water Supply Needs and Water Management Strategies 36
    7.4.3 Hydrologic Condition, Including Total Estimated Recoverable Storage 38
    7.4.4 Other Environmental Impacts 40
    7.4.5 Subsidence 40
    7.4.6 Socioeconomic Impacts 40
    7.4.7 Impact on Private Property Rights 40
    7.4.8 Feasibility of Achieving the Desired Future Conditions 40
    7.4.9 Other Information 41
  7.5 Discussion of Other Desired Future Conditions Considered 41
8.0 Igneous Aquifer and Salt Basin Portion of the West Texas Bolsons Aquifer 42
  8.1 Aquifer Description and Location 42
  8.2 Policy Justifications 44
  8.3 Technical Justification 45
  8.4 Factor Consideration 47
    8.4.1 Aquifer Uses and Conditions 47
    8.4.2 Water Supply Needs and Water Management Strategies 48
    8.4.3 Hydrologic Conditions, Including Total Estimated Recoverable Storage 48
    8.4.4 Other Environmental Impacts 53
    8.4.5 Subsidence 53
    8.4.6 Socioeconomic Impacts 53
    8.4.7 Impact on Private Property Rights 54
    8.4.8 Feasibility of Achieving the Desired Future Conditions 54
    8.4.9 Other Information 54
  8.5 Discussion of Other Desired Future Conditions Considered 54
9.0 Marathon Aquifer 56
  9.1 Aquifer Description and Location 56
  9.2 Policy Justifications 57
  9.3 Technical Justification 57
  9.4 Factor Consideration 58
    9.4.1 Groundwater Demands and Uses 58
    9.4.3 Water Supply Needs and Water Management Strategies 58
    9.4.4 Hydrologic Conditions, Including Total Estimated Recoverable Storage 58
    9.4.5 Other Environmental Impacts 59
    9.4.5 Subsidence 59
    9.4.6 Socioeconomic Impacts 59
    9.4.7 Impact on Private Property Rights 60
    9.4.8 Feasibility of Achieving the Desired Future Conditions 60
    9.4.9 Other Information 60
  9.5 Discussion of Other Desired Future Conditions Considered 60
10.0 Presidio-Redford Bolson subdivision of the West Texas Bolsons Aquifer 61
  10.1 Aquifer Description and Location 61
  10.2 Policy Justifications 62

10.3 Technical Justification ... 62
10.4 Factor Consideration ... 63
10.4.1 Groundwater Demands and Uses ... 63
10.4.2 Water Supply Needs and Water Management Strategies ... 63
10.4.3 Hydrologic Conditions, Including Total Estimated Recoverable Storage ... 63
10.4.4 Other Environmental Impacts ... 64
10.4.5 Subsidence ... 64
10.4.6 Socioeconomic Impacts ... 64
10.4.7 Impact on Private Property Rights ... 65
10.4.8 Feasibility of Achieving the Desired Future Conditions ... 65
10.4.9 Other Information ... 65
10.5 Discussion of Other Desired Future Conditions ... 65
11.0 Public Comments and Discussion of Other Recommendations ... 66
11.1 Brewster County GCD Comments ... 66
11.2 Culberson County GCD Comments ... 67
11.3 Response to Comments ... 68
11.3.1 Model Output and Desired Future Conditions ... 68
11.3.2 Use of Total Estimated Recoverable Storage ... 69
11.3.3 Groundwater Use in the Oil and Gas Industry ... 69
12.0 References ... 70

List of Appendices

Appendix A – Resolution Adopting Desired Future Conditions
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

List of Tables

Table 1. Summary of Relevant and Non-Relevant Aquifers in Each GCD ... 9
Table 2. Total Estimated Recoverable Storage in GMA 4: Rustler Aquifer ... 17
Table 3. Groundwater Demands and Uses, 1993 to 2012, Bone Spring-Victorio Peak Aquifer ... 22
Table 4. Groundwater Demands and Uses, 2004 to 2012, Capitan Reef Complex Aquifer, Brewster County ... 29
Table 5. Groundwater Demands and Uses, 1993 to 2012, Capitan Reef Complex Aquifer, Culberson County ... 29
Table 6. Groundwater Demands and Uses, 1993 to 2012, Capitan Reef Complex Aquifer, Hudspeth County ... 30
Table 7. Total Estimated Recoverable Storage: Capitan Reef Complex Aquifer ... 31
Table 8. Groundwater Demands and Uses, 1993 to 2012, Edwards-Trinity (Plateau) Aquifer, Brewster County ... 37

Table 9. Groundwater Demands and Uses, 1993 to 2012, Edwards-Trinity (Plateau) Aquifer, Culberson County 37
Table 10. Groundwater Demands and Uses, 1993 to 2012, Edwards-Trinity (Plateau) Aquifer, Jeff Davis County 38
Table 11. Total Estimated Recoverable Storage: Edwards-Trinity (Plateau) Aquifer 39
Table 12. Recharge, Inflow, and Discharge Estimates: Edwards-Trinity (Plateau) Aquifer, Brewster County 39
Table 13. Total Estimated Recoverable Storage Estimates - Igneous Aquifer 49
Table 14. Total Estimated Recoverable Storage - West Texas Bolsons Aquifer 49
Table 15. Recharge, Inflow, and Discharge Estimates: Igneous Aquifer, Brewster County 50
Table 16. Recharge, Inflow, and Discharge Estimates: Igneous Aquifer, Culberson County 50
Table 17. Recharge, Inflow, and Discharge Estimates: West Texas Bolsons Aquifer, Culberson County 51
Table 18. Recharge, Inflow, and Discharge Estimates: Igneous Aquifer, Jeff Davis County 51
Table 19. Recharge, Inflow, and Discharge Estimates: West Texas Bolsons Aquifer, Jeff Davis County 52
Table 20. Recharge, Inflow, and Discharge Estimates: Igneous Aquifer, Presidio County 52
Table 21. Recharge, Inflow, and Discharge Estimates: West Texas Bolsons Aquifer, Presidio County .. 53
Table 22. Groundwater Demands and Uses, 1993 to 2012, Marathon Aquifer (Brewster County) 58

List of Figures

Figure 1. Groundwater Management Area 4 5
Figure 2. Counties in Groundwater Management Area 4 6
Figure 3. Groundwater Conservation Districts in GMA 4 7
Figure 4. Location of the Pecos Valley Aquifer in Jeff Davis County 15
Figure 5. Extent of the Rustler Aquifer in GMA 4 16
Figure 6. Location of Upper Salt Basin 18
Figure 7. Location of Bone Spring-Victorio Peak Aquifer 20
Figure 8. Location of Capitan Reef Complex Aquifer 27
Figure 9. Location of Edwards-Trinity (Plateau) Aquifer 34
Figure 10. Location of Igneous Aquifer 43
Figure 11. Location of West Texas Bolsons Aquifer 44
Figure 12. Schematic Conceptual Model (from Beach and others, 2004, pg. 5-2) 47
Figure 13. Location of Marathon Aquifer 56
Figure 14. Location of Presidio-Redford Bolson Aquifer 61

1.0 Groundwater Management Area 4

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 nearly all 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).

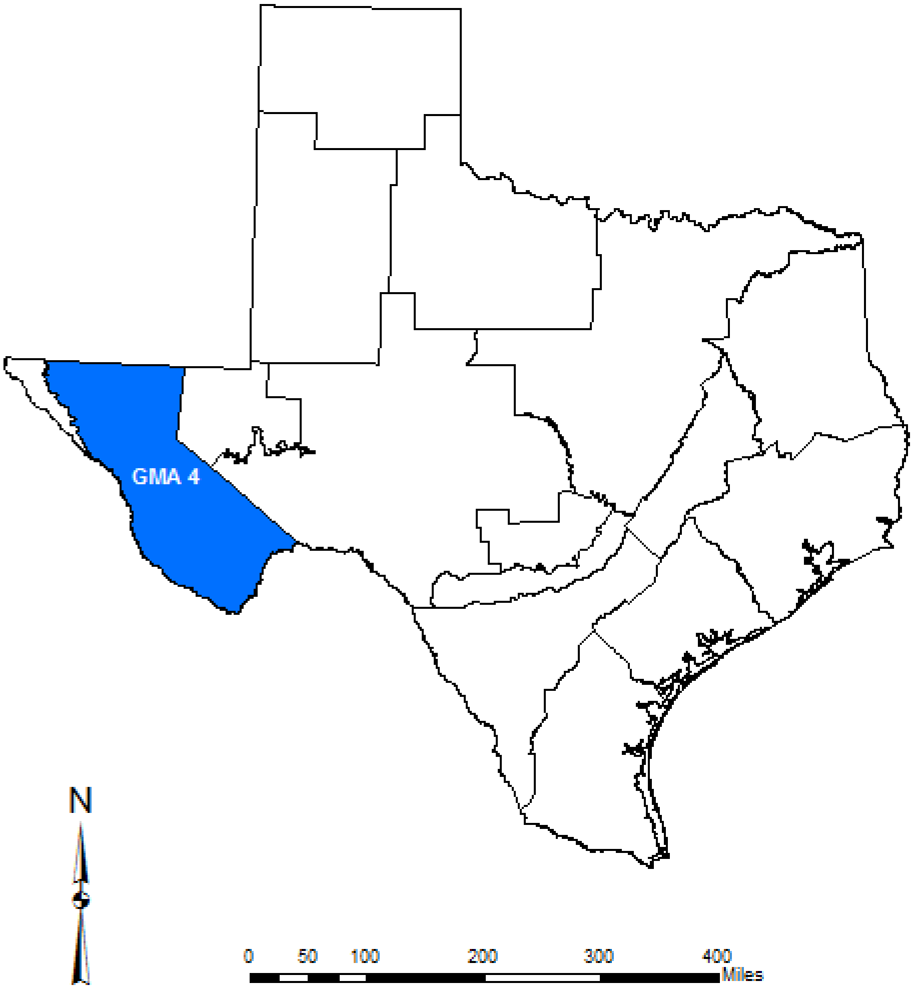


Figure 1. Groundwater Management Area 4

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.

2.0 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

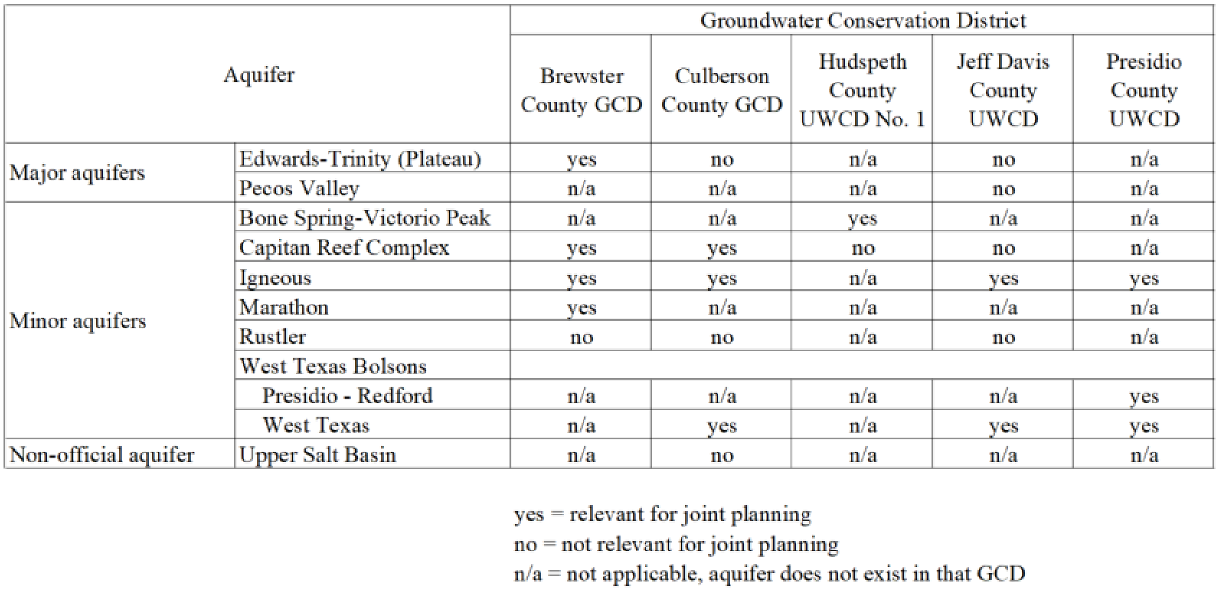
14-ft drawdown for the Igneous Aquifer
72-ft drawdown for the Salt Basin of the West Texas Bolsons
72-ft drawdown for the Presidio-Redford Bolson

A copy of the resolution is presented in Appendix A.

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. 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

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.

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.

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 or 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.

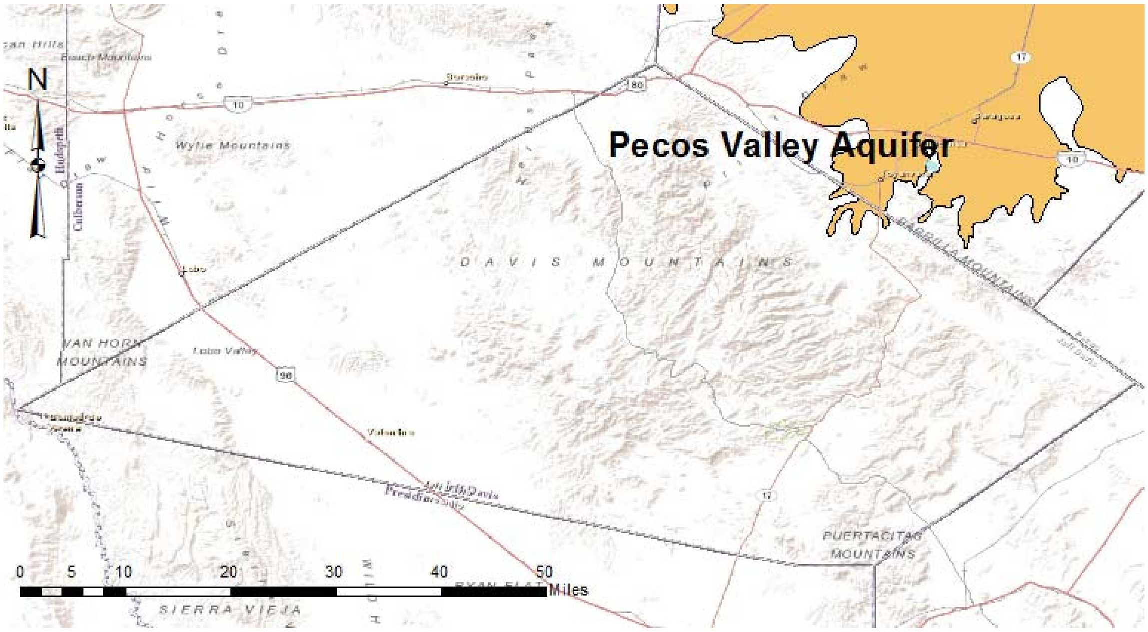


Figure 4. Location of the Pecos Valley Aquifer in Jeff Davis County

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).

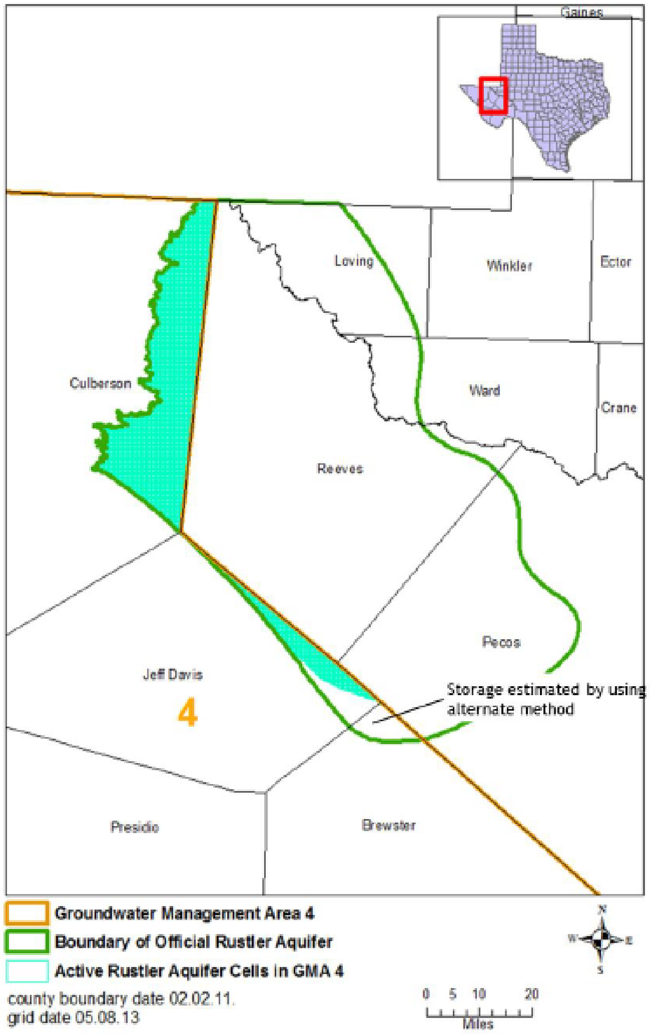


Figure 5. Extent of the Rustler Aquifer in GMA 4
From Boghici and others (2014)

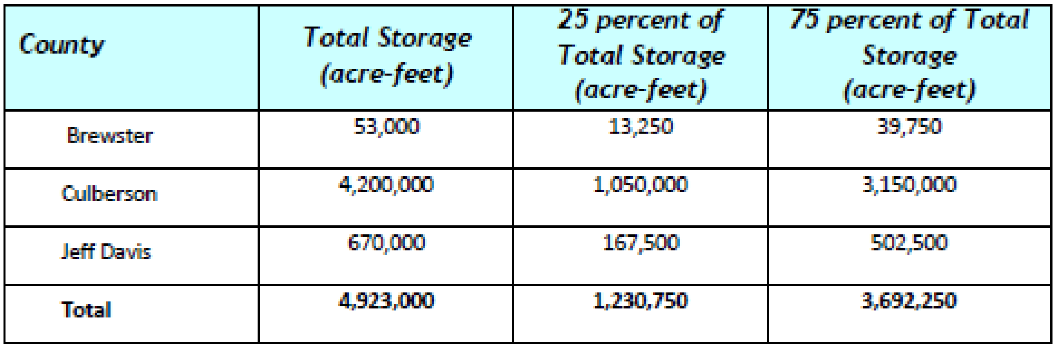
Based on the work of Ewing and others (2012, pg. 4-116) The Rustler outcrops in Culberson County and dips to the east. In Jeff Davis County, depth to the top of the Rustler Aquifer is generally between 1,000 and 2,000 feet, and is generally more than 2,000 feet in Brewster County.

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.

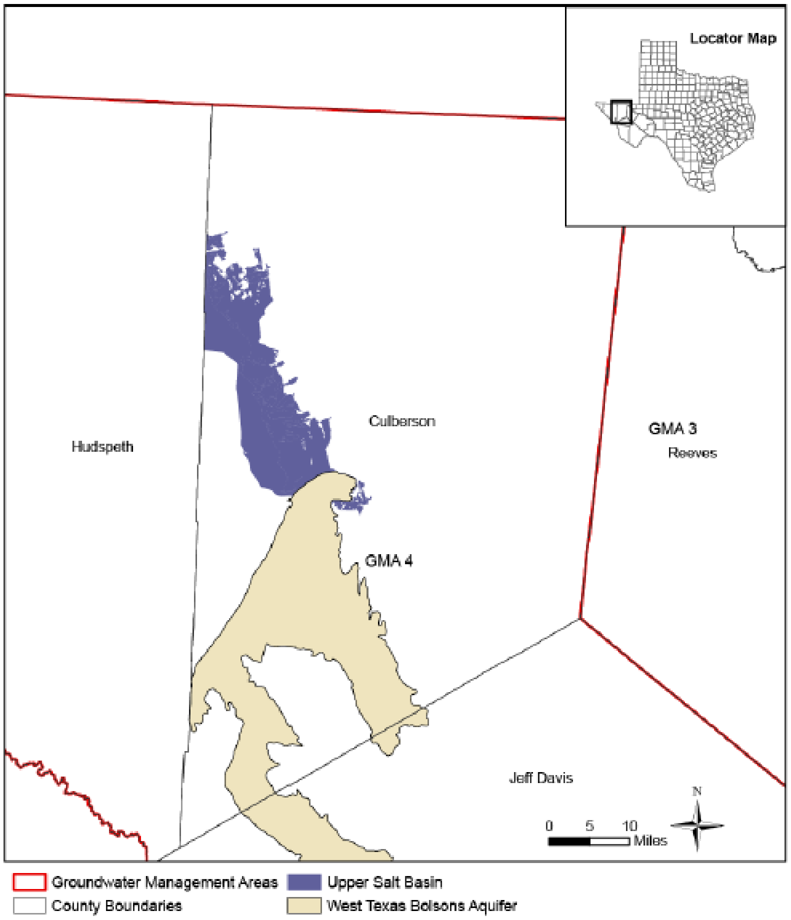


Figure 6. Location of Upper Salt Basin
From Boghici and others (2014)

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):

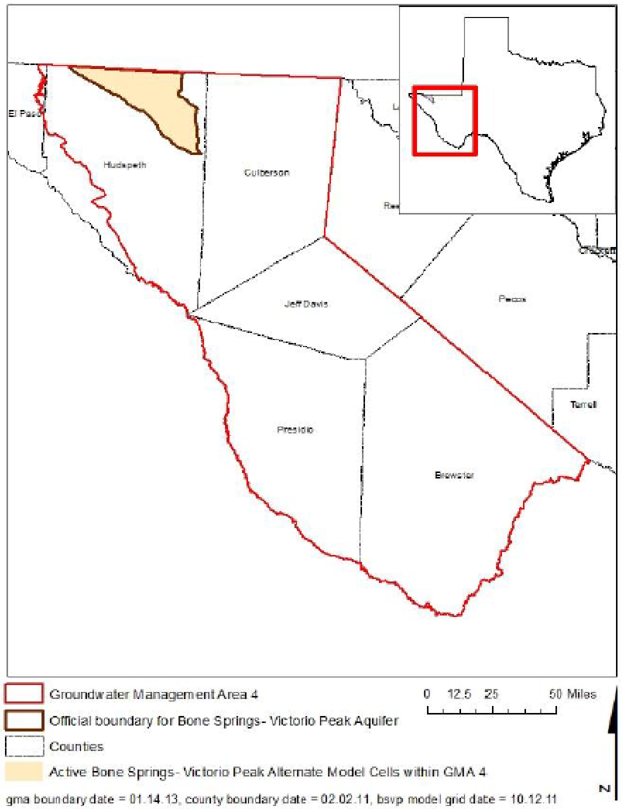


Figure 7. Location of Bone Spring-Victorio Peak Aquifer
From Boghici and others (2014)

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.

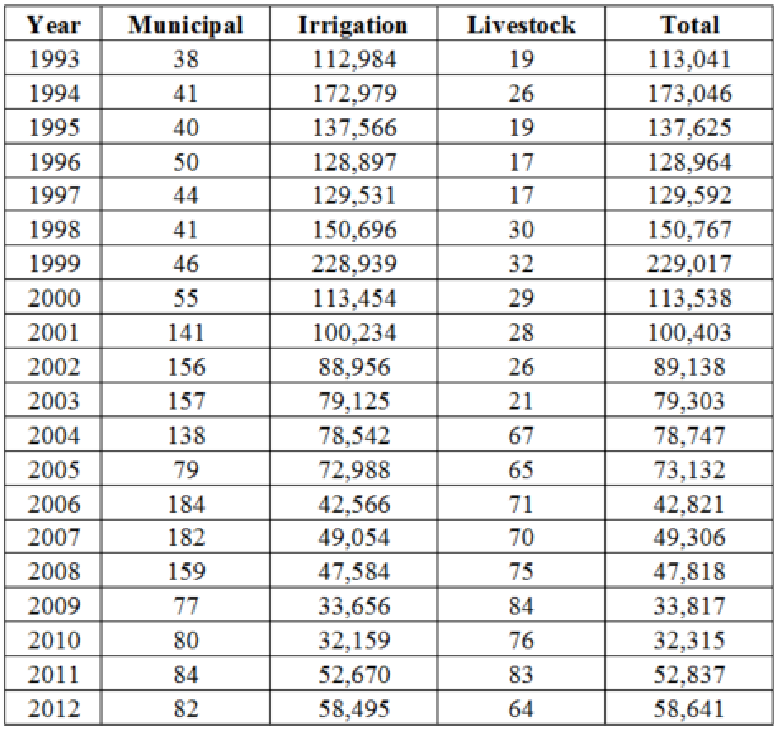
Much of the consideration of the nine statutory factors involves understanding the effects or the impacts of a desired future condition (e.g. groundwater-surface water interaction and property rights). The use of the models in this manner in evaluating the impacts of alternative futures is an effective 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 2011 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 this 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.

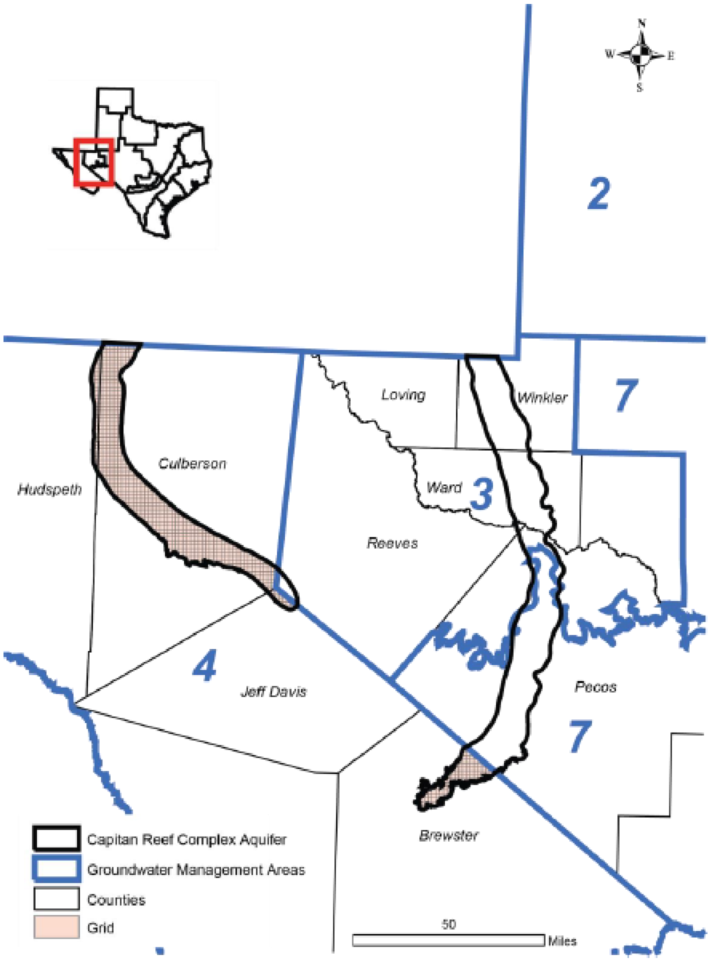


Figure 8. Location of Capitan Reef Complex Aquifer
From Boghici and others (2014)

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 2011 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.

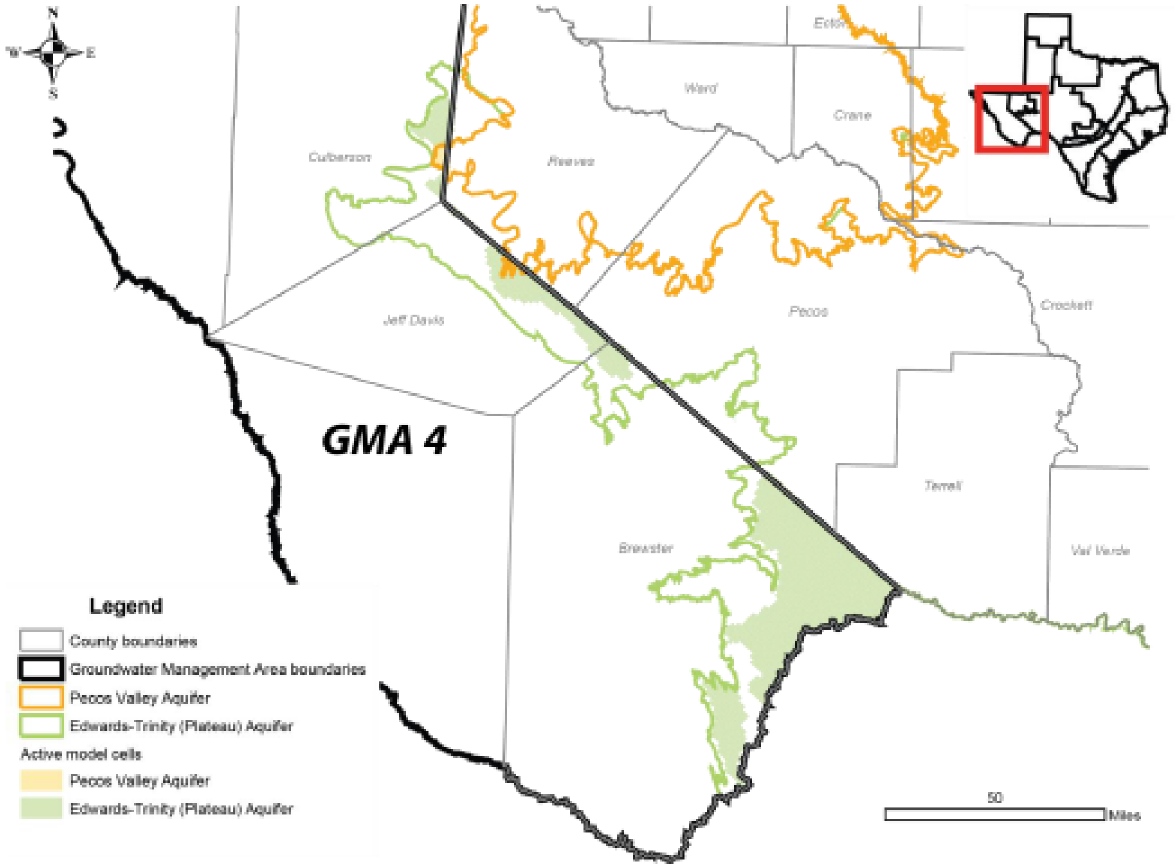


Figure 9. Location of Edwards-Trinity (Plateau) Aquifer
From Boghici and others (2014)

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

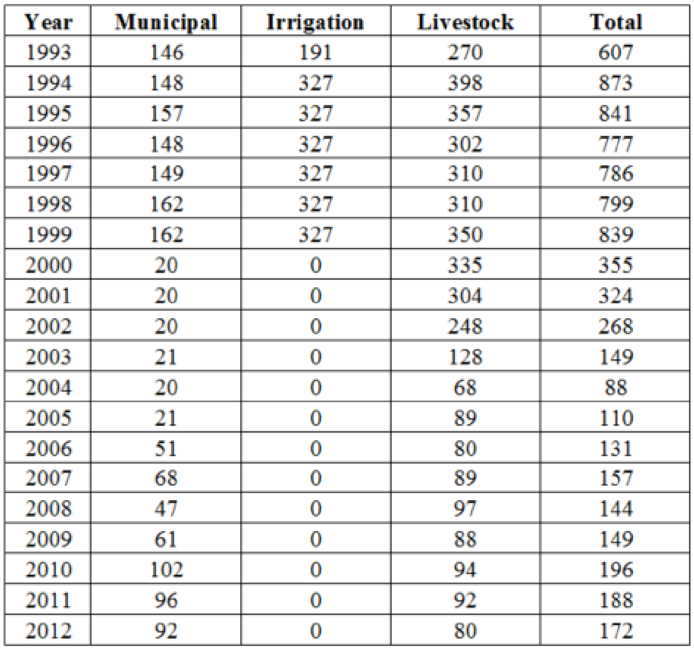
Tables 8, 9, and 10 present the groundwater demands and uses from 1993 to 2012 from the Edwards-Trinity (Plateau) Aquifer in Brewster County, Culberson County, and Jeff Davis County, respectively.

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

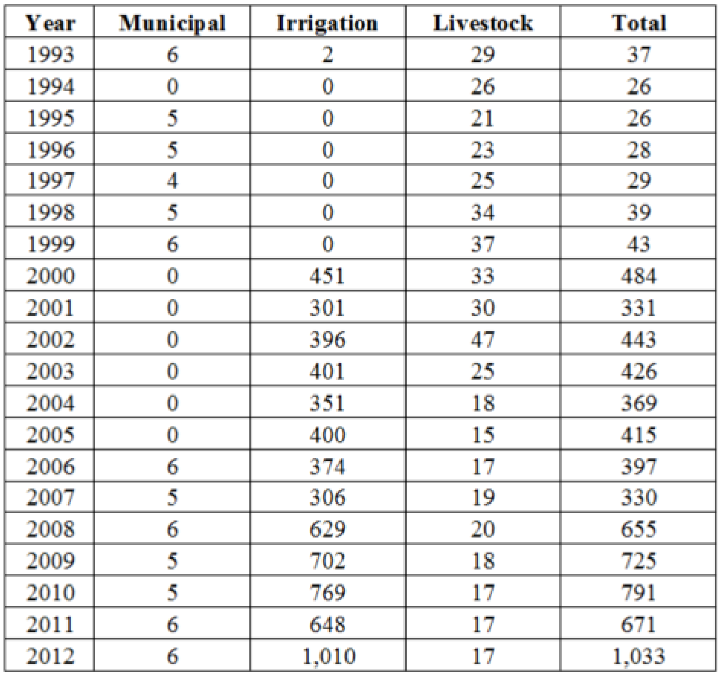
All Values in AF/yr



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

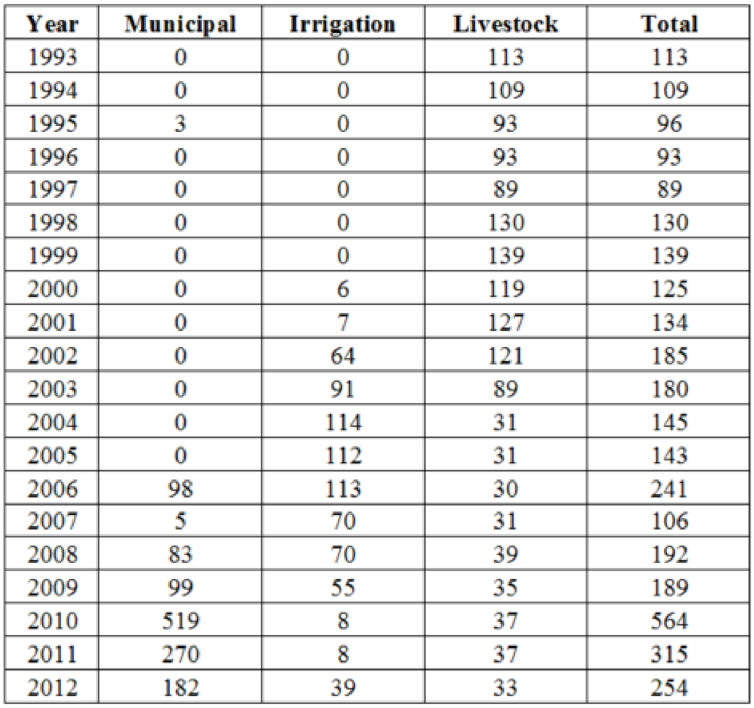
All Values in AF/yr



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 2011 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, GMA 4 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).

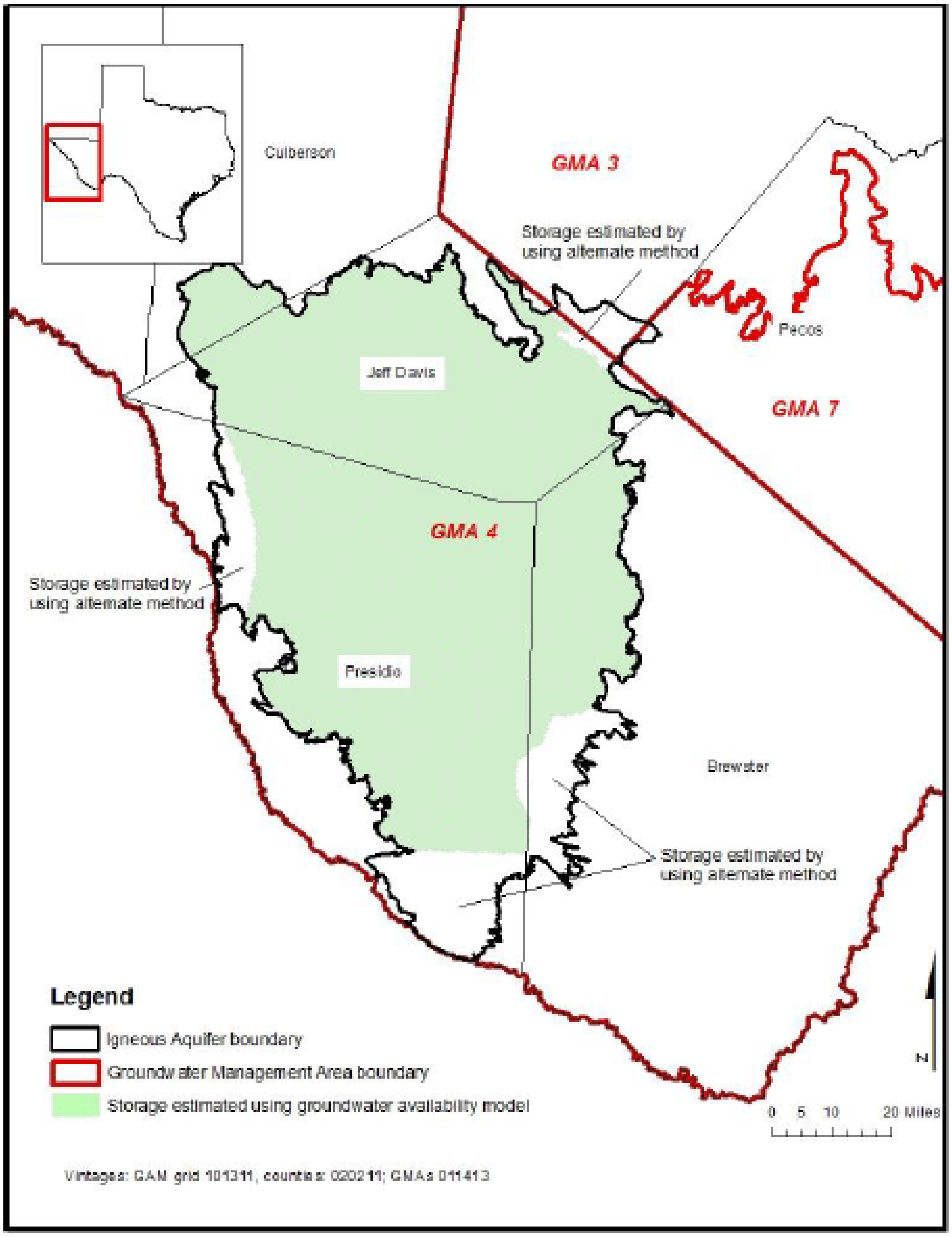


Figure 10. Location of Igneous Aquifer
From Boghici and others (2014)

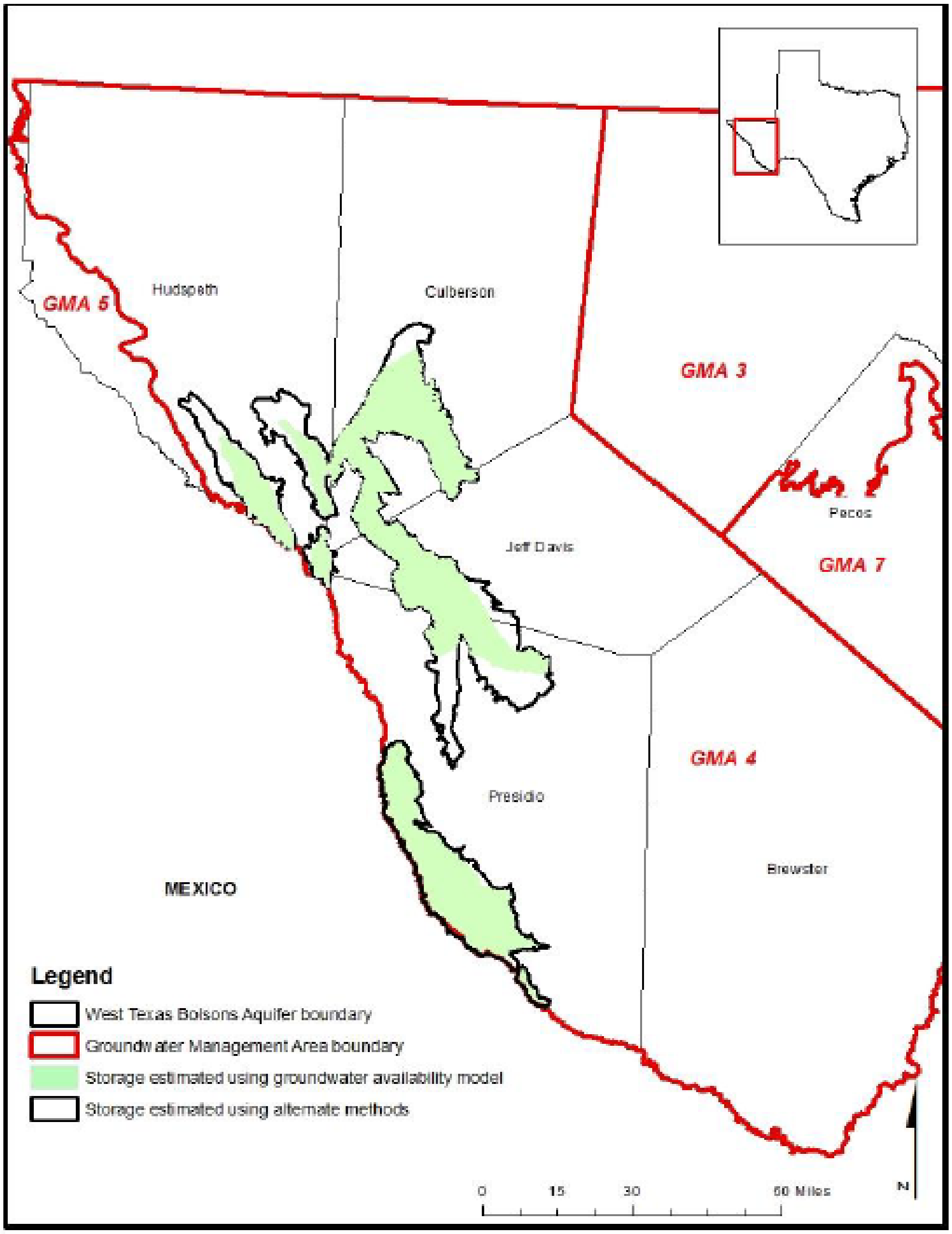


Figure 11. Location of West Texas Bolsons Aquifer
From Boghici and others (2014)

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.

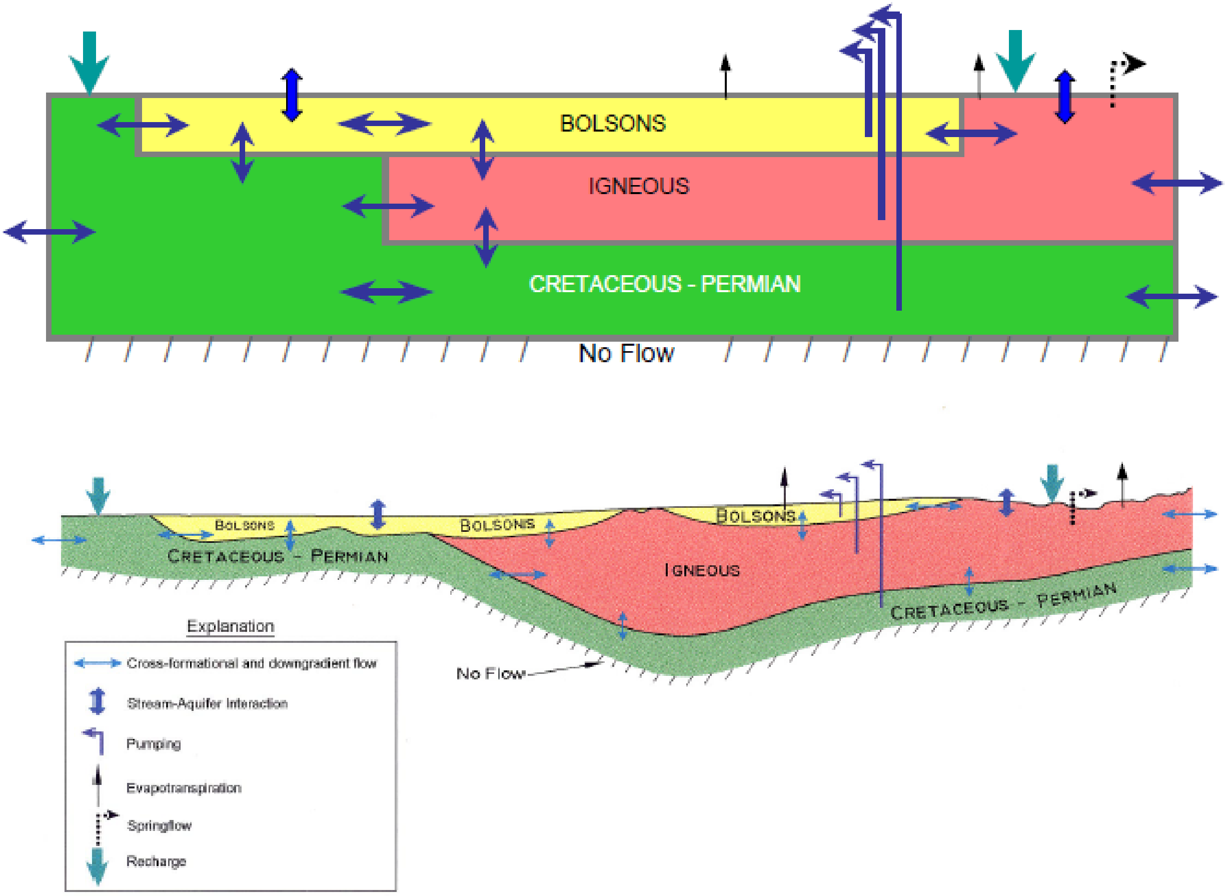


Figure 12. Schematic Conceptual Model (from Beach and others, 2004, pg. 5-2)

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 2011 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).

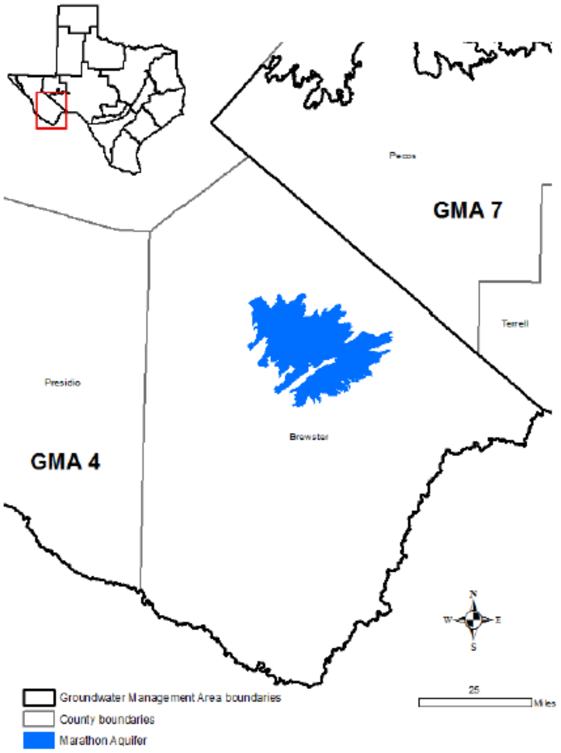


Figure 13. Location of Marathon Aquifer
From Boghici and others (2014)

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.

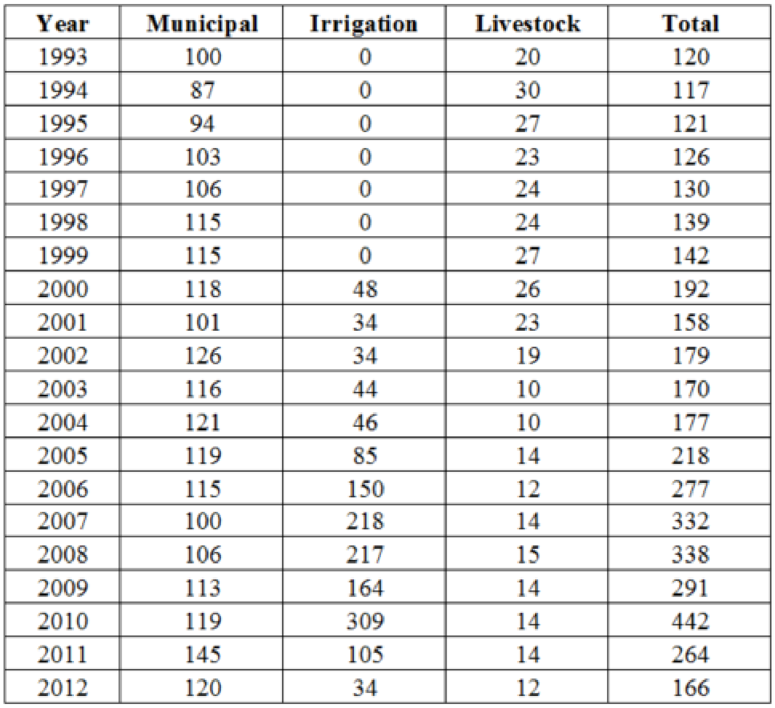
9.4 Factor Consideration

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 Bone Spring-Victorio Peak 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 2011 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

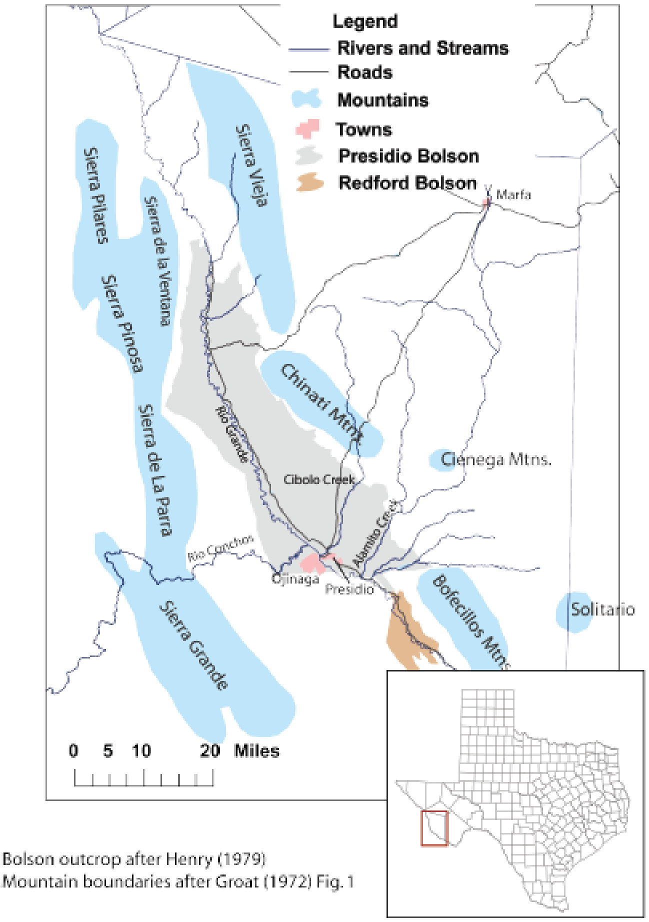
Prior to adopting the desired future condition in 2010, GMA 4 reviewed Thorkildsen and Backhouse (2010a) that analyzed four alternative drawdown conditions in an Aquifer Assessment. Alternative drawdowns considered included 0, 5, 10, and 20 feet.

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 2011 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.

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	June 23, 2016	1 oral, 3 written
Culberson County GCD	June 22, 2016	1 oral, 1 written
Hudspeth County UWCD No. 1	June 14, 2016	None
Jeff Davis UWCD	June 14, 2016	None
Presidio County UWCD	May 24, 2016	None

11.1 Brewster County GCD Comments

In a written comment dated June 16, 2016, Ms. Suzanne Bailey suggested that “new oil and gas activities” be considered because they may potentially affect the desired future conditions.

In a written comment dated June 22, 2016, Mr. Stephen Daugherty discussed concerns about the groundwater availability model of the area and suggested that the desired future condition for the Igneous Aquifer be the same for the entire aquifer “regardless of political boundary until better data exists (*sic*) to justify variations based on geology rather than political boundaries”.

In a written comment (undated), Mr. Matthew B. Lara, Volunteer Acting Executive Director for the Big Bend Conservation Alliance discussed groundwater use by the oil and gas industry in Brewster County. Specifically, the following were requested:

- Failure of the 2017 Texas Water Plan in accounting for the amount of water used by midstream natural gas facilities in the construction and hydrostatic testing of pipelines
- The ability of the Igneous Aquifer to support the water used for these purposes over a 5-year period without negatively impacting the production of municipal and private water wells in Brewster County
- Sudden drawdowns from unstudied sectors of the mining Water User Group, along with overly aggressive DFCs could affect the stream flow of creeks that are critically important to the ranching and recreational tourism industry that are the economic heart of the region.
- Lack of oversight and enforcement of wells involved in the construction of the Trans Pecos Pipeline
- The economic impact of drilling new wells for municipal use when a pipeline company is permitted to use the equivalent annual production of the new municipal well.

At the public hearing on June 23, 2016, Coyne Gibson stated that there was not adequate information to base a Desired Future Condition on and asked that the District have a 0 Drawdown on all aquifers until adequate science and information was available.

11.2 Culberson County GCD Comments

In a written comment dated June 22, 2016, Mr. Joseph B.C. Fitzsimmons of Uhl, Fitzsimmons, Jewett & Burton, PLLC, on behalf of Hughes Apache Ranch, L.P, and DAHJUR, L.P. (Culberson County Ranch owners) objects and formally protests the desired future conditions for the West Texas Bolsons and Capitan Reef Complex aquifers. Specific issues raised include:

- The desired future condition is the same as the last planning period, extrapolated to an additional 10-year period
- The West Texas Bolsons Aquifer are interconnected and contain varied zones and characteristics that are not sufficiently accounted for in the current groundwater availability model
- Drawdown will be centered at the cluster of historic users in the Wild Horse and Lobo Flat aquifers, making overall depletion difficult to measure. Property rights of landowners beneath other portions of these aquifers will be curtailed, and groundwater will migrate towards zones depleted by historic users.
- The Culberson County GCD failed to use the best available scientific modeling and, thus, the desired future condition will deprive landowners of private property rights.
- There is no groundwater availability model of the Capitan Reef Complex Aquifer, but TWDB has estimated that between 3,750,000 to 11,250,000 acre-feet of groundwater can potentially be recovered from the aquifer's permanent storage capacity of 15,000,000 acre-feet within Culberson County GCD boundaries.
- Given the unknown characteristics of the Capitan Reef Complex Aquifer, it is irresponsible of the Culberson County GCD to "issue DFCs based upon drawdown of the aquifer level at this time".

At the public hearing on June 22, 2016, Mr. Parks Brown, and attorney for the Hughes Apache Ranch provided the following comment on behalf of Mr. Joseph Fitzsimmons:

> *I brought a protest letter on his behalf. And essentially, you know, we think that there is a better scientific way to get information on what the appropriate draw out is for these aquifers. We don't feel there's really comprehensive information on Captain Reef. And, you know, we would just suggest that -- going forward, I know there are limited scientific models and data for these aquifers, but in order to protect people's property rights to the ground water, we really need to focus on using the best models. So we're just filing a general objection and we look forward to seeing the explanatory report.*

11.3 Response to Comments

All factual information was considered during the DFC process; however, it is recognized that more information is favored. The district continues to implement water use reporting and monitoring programs.

11.3.1 Model Output and Desired Future Conditions

The link between groundwater models and desired future conditions were the subject of some of the comments. The desired future conditions are expressed in terms of drawdown over a specified time period (e.g. 50 years). Drawdown is the difference between measured groundwater levels taken at two different times. All other things being equal, a positive drawdown connotes that pumping has increased over the time interval of interest, a zero drawdown connotes that pumping is essentially unchanged and an equilibrium has been reached, and a negative drawdown connotes that pumping has decreased over the time interval of interest.

Drawdown, is therefore, a measure in the change in storage. Storage calculations require knowledge of the geometry of the aquifer and groundwater levels. Change in storage calculation require knowledge of the geometry of the aquifer and the change in groundwater levels over a specific time interval. Drawdown-based desired future conditions have an advantage since a change in storage conditions can be tracked directly with measured data. Any storage-based desired future condition is saddled with the need to have knowledge of the aquifer geometry, the understanding of which changes as additional data are developed. From a regional planning perspective, it is entirely appropriate to use drawdown as a desired future condition.

Desired future conditions are planning goals, and not regulatory limits. There is a common misconception asserted in the tone of some of the comments that implies a regulatory context to desired future conditions that are not present. To the extent that groundwater conservation districts must manage to meet desired future conditions, there is the potential for misuse and blind application of desired future conditions to permitting decisions, but this is potentially true of any desired future condition whether based on drawdown, spring flow, or storage.

Model output can define drawdown or change in storage for the entire model area, individual groundwater management areas, subdivisions of groundwater management areas, individual counties, individual groundwater conservation districts, or any combination of these. It is true that drawdowns are commonly reported by county or by district for purposes of administrative convenience and, in part, due to the dual purpose of desired future conditions which is to develop modeled available groundwater numbers for the regional planning process that is organized by political boundaries as wells as river basin boundaries.

Beach and others (2004) discussed the variability of the Igneous and West Texas Bolsons aquifers and the variation in historic pumping. These variations lead to different drawdowns when reported by county. The assertion that the desired future conditions must be the same across all political boundaries ignores the natural variation in the aquifer, and the differences in pumping.

11.3.2 Use of Total Estimated Recoverable Storage

One comment asserted that the total estimated recoverable storage be the basis for desired future conditions, and not a drawdown-based desired future condition. The statute requires the consideration of nine factors when developing, proposing, and adopting desired future conditions. Total estimated recoverable storage is one of these factors. GMA 4 considered total estimated recoverable storage along with all the other factors when developing the desired future condition as detailed in this explanatory report.

11.3.3 Groundwater Use in the Oil and Gas Industry

Among the factors considered in the development of desired future conditions are the historic and future uses of groundwater. While the TWDB estimates may or may not have included the recent increase in groundwater use by the oil and gas industry, the local GCDs are certainly aware of changes in use. The estimates reported in this explanatory report provide a common framework to begin the process of developing desired future conditions, and are the same numbers used in the regional planning process and in the development of GCD management plans.

12.0 References

Ashworth, J.B., Herrera, J., and Albright, J.S., 2016. 2016 Far West Texas Water Plan. Prepared for Far West Texas Water Planning Group. January 2016, 452p.

Beach, J.A., Ashworth, J.B., Finch, S.T., Chastain-Howley, A., Calhoun, K., Urbancyk, K.M., Sharp, J.M., and Olson, J., 2004. Groundwater Availability Model for the Igneous and parts of the West Texas Bolsons (Wild Horse Flat, Ryan Flat and Lobo Flat) Aquifers. Report prepared for the Texas Water Development Board, 407p.

Boghici, R., Jones, I.C., Bradley, R.G., Shi, J., Goswami, R.R., Thorkildsen, D., and Backhouse, S., 2014. GAM Task 13-028: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 4. Texas Water Development Board, Groundwater Resources Division, Unpublished Report, January 15, 2014, 34p.

Bradley, R.G. and George, P., 2008. GTA Aquifer Assessment 06-01. Texas Water Development board, Groundwater Technical Assistance Section. June 10, 2008, 15p.

Donnelly, A.C.A., 2006a. GAM Run 05-40. Texas Water Development Board, Groundwater Availability Modeling Section, February 7, 2006, 26p.

Donnelly, A.C.A., 2006b. GAM Run 06-04. Texas Water Development Board, Groundwater Availability Modeling Section, March 8, 2006, 10p.

Donnelly, A.C.A., 2006c. GAM Run 06-17. Texas Water Development Board, Groundwater Availability Modeling Section, July 18, 2006, 17p.

Donnelly, A.C.A., 2007. GAM Run 06-32. Texas Water Development Board, Groundwater Availability Modeling Section, May 2, 2007, 18p.

Ewing, J.E., Kelley, V.A., Jones, T.L., Yan, T., Singh, A., Powers, D.W., Holt, R.M., Sharp, J.M., 2012. Final Groundwater Availability Model Report for the Rustler Aquifer. Prepared for Texas Water Development Board. 460p.

George, P.G., Mace, R.E., and Petrossian, R., 2011. Aquifers of Texas. Texas Water Development Board Report 380, July 2011, 182p.

Hutchison, W.R., 2010. GAM Task 10-006 (Bone Spring-Victorio Peak Aquifer). Texas Water Development Board, Groundwater Resources Division Task Report, September 3, 2010, 7p.

Hutchison, W.R., Jones, I.C., and Anaya, R.A., 2011, Update of the Groundwater Availability Model for the Edwards-Trinity (Plateau) and Pecos Valley Aquifers of Texas, Texas Water Development Board, 61 p.

Jigmond, M., 2012. GAM Run 12-023: Jeff Davis County Underground Water Conservation District Management Plan. Texas Water Development Board, Groundwater Availability Modeling Section, August 10, 2012, 15p.

Jones I.C., 2012a. GAM Run 11-018: Culberson County Groundwater Conservation District Management Plan. Texas Water Development Board, Groundwater Availability Modeling Section, January 23, 2012, 13p.

Jones, I.C., 2012b. GAM Run 11-020: Hudspeth County Underground Water Conservation District No. 1 Management Plan. Texas Water Development Board, Groundwater Availability Modeling Section, June 1, 2012, 9p.

Jones, Ian C., 2016. Groundwater Availability Model: Eastern Arm of the Capitan Reef Complex Aquifer of Texas. Texas Water Development Board, August 3, 2016. 503p.

Oliver, W., 2008. GAM Run 08-24, Texas Water Development Board, Groundwater Availability Modeling Section, December 19, 2008, 35p.

Oliver, W., 2010a. GAM Task 10-026 Model Run Report, Texas Water Development Board, Groundwater Availability Modeling Section, June 24, 2010, 7p.

Oliver, W., 2010b. GAM Task 10-028 Model Run Report, Texas Water Development Board, Groundwater Availability Modeling Section, July 29, 2010, 8p.

Oliver, W. 2012. GAM Run 10-048 MAG: Modeled Available Groundwater for the Edwards-Trinity (Plateau) Aquifer in Groundwater Management Area 4. Texas Water Development Board, Groundwater Availability Modeling Section, June 22, 2012 (edited and finalized by Jones, I. and Wade, S.), 10p.

Shi, J., GAM Run 13-020: Brewster County Groundwater Conservation District Groundwater Management Plan. Texas Water Development Board, Groundwater Availability Modeling Section, October 7, 2013, 15p.

Smith, R., 2001. Hydrogeology of the Marathon Basin, Brewster County, Texas. Chapter 14 of Mace, R.E., Mullican, W.F., and Angle, E.S., Aquifers of West Texas. Texas Water Development Board Report 356, December 2001, 281p.

Thorkildsen, D. and Backhouse, S., 2010a. GTA Aquifer Assessment 09-09. Texas Water Development Board, Groundwater Technical Assistance Section, Unpublished report, August 31, 2010, 7p.

Thorkildsen, D. and Backhouse, S., 2010b. GTA Aquifer Assessment 09-12. Texas Water Development Board, Groundwater Technical Assistance Section, Unpublished report, August 31, 2010, 8p.

Wade, S.C., 2010. GAM Run 10-003, Texas Water Development Board, Groundwater Availability Modeling Section, June 29, 2010. 18p.

Wade, S.C., 2013. GAM Run 12-026: Presidio County Underground Water Conservation District Management Plan. Texas Water Development Board, Groundwater Availability Modeling Section, March 21, 2013, 12p.

Wade, S.C., Hutchison, W.R., Chowdhury, A.H., and Coker, D., 2011. A Conceptual Model of Groundwater Flow in the Presidio-Redford Bolsons Aquifers. Texas Water Development Board Report, August 2011, 102p.

Wade, S.C. and Jigmond, M., 2013. Groundwater Availability Model of West Texas Bolsons (Presidio and Redford) Aquifer. Texas Water Development Board Report, February 2013, 100p.

Wuerch, D. and Davidson, S.C., 2010a. GTA Aquifer Assessment 09-08. Texas Water Development Board, Groundwater Technical Assistance Section, Unpublished report, September 21, 2010, 9p.

Wuerch, D. and Davidson, S.C., 2010b. GTA Aquifer Assessment 09-10. Texas Water Development Board, Groundwater Technical Assistance Section, Unpublished report, September 21, 2010, 9p.

Appendix A

Resolution Adopting Desired Future Conditions

Adopted September 20, 2017

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:

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 20st DAY OF SEPTEMBER 2017.

SIGNED Ike Roberts

~~Joan Johnson~~ **Brewster County GCD**
Ike Roberts

SIGNED Summer Webb

Summer Webb **Culberson County GCD**

SIGNED Randy Ba____

Randy Barker **Hudspeth County UWCD No 1**

SIGNED____

Janet Adams **Jeff Davis County UWCD**

SIGNED____

James R. Mustard, Jr **Presidio County UWCD**

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.,
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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).

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by Radu Boghici, P.G., Ian C. Jones, Ph.D., P.G., Robert G. Bradley P.G.,
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January 15, 2014

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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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(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

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

- for confined aquifers

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

  - confined part

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

or

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

  - unconfined part

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

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)

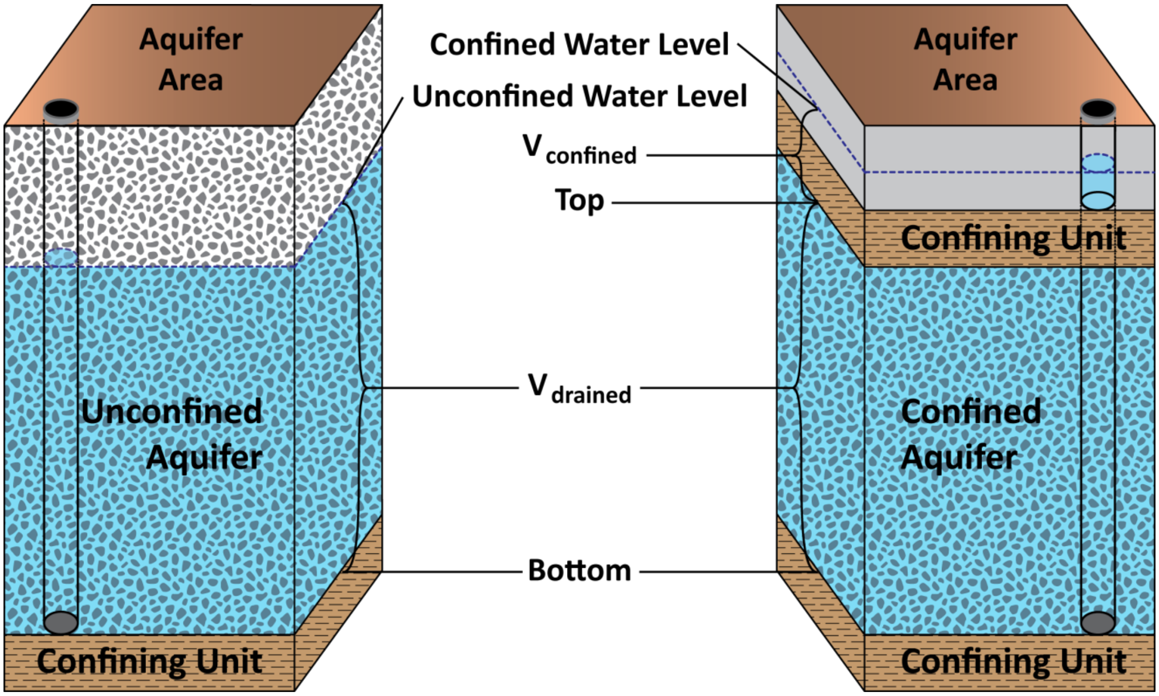

FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

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.

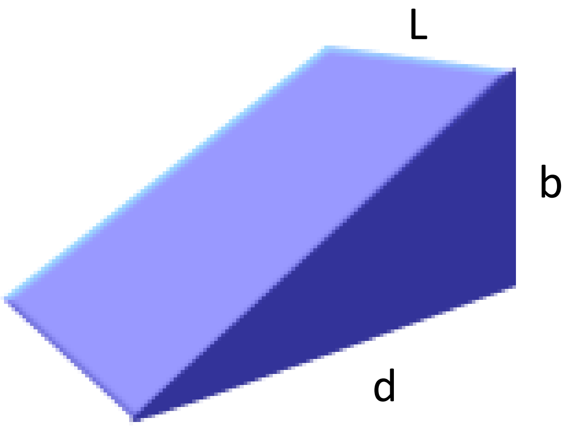

FIGURE 2. A SCHEMATIC OF THE RIGHT-WEDGE USED TO CALCULATE TOTAL STORAGE IN THE IGNEOUS AQUIFER IN GROUNDWATER MANAGEMENT AREA 4.

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

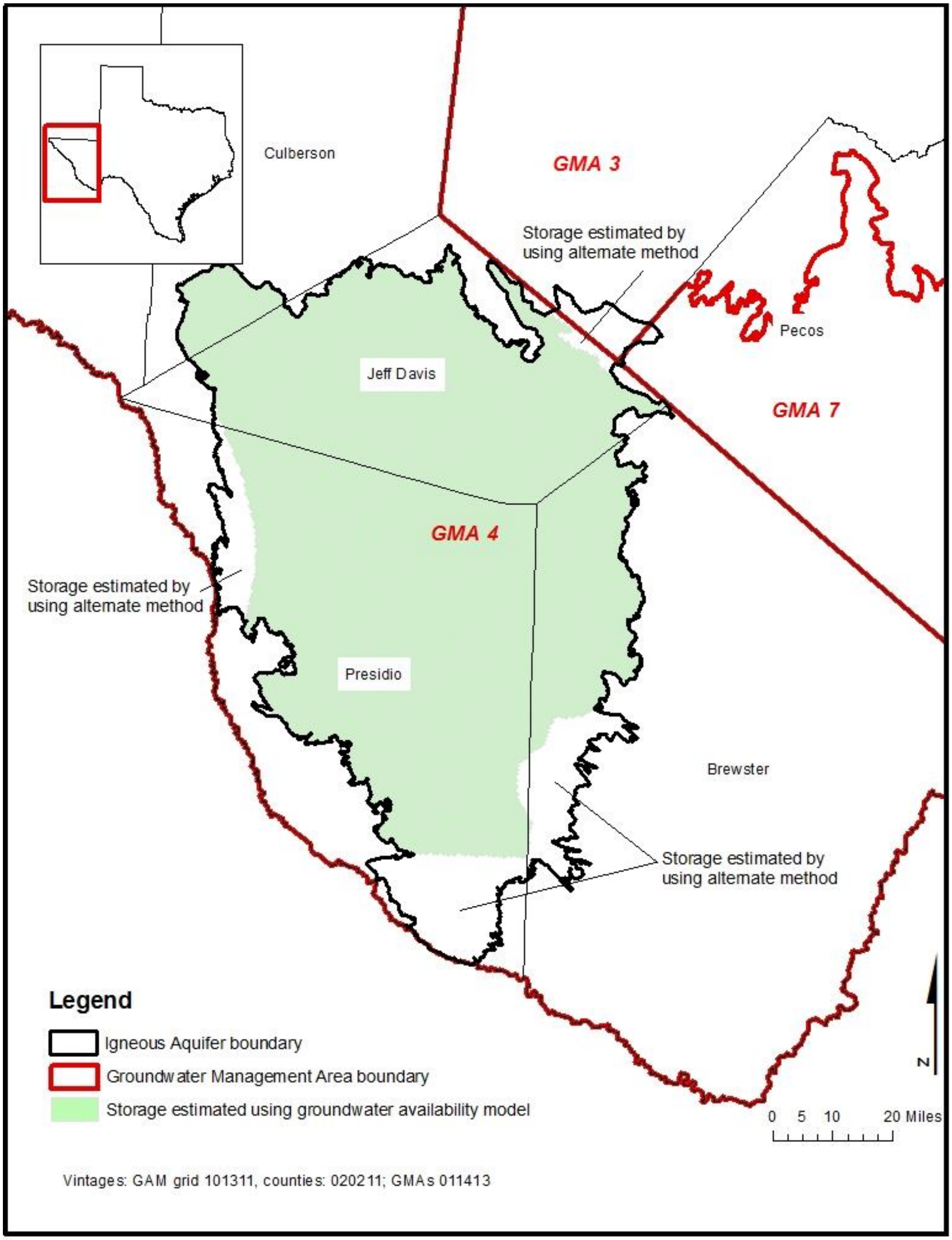

FIGURE 3. EXTENT OF THE IGNEOUS AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 4.

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

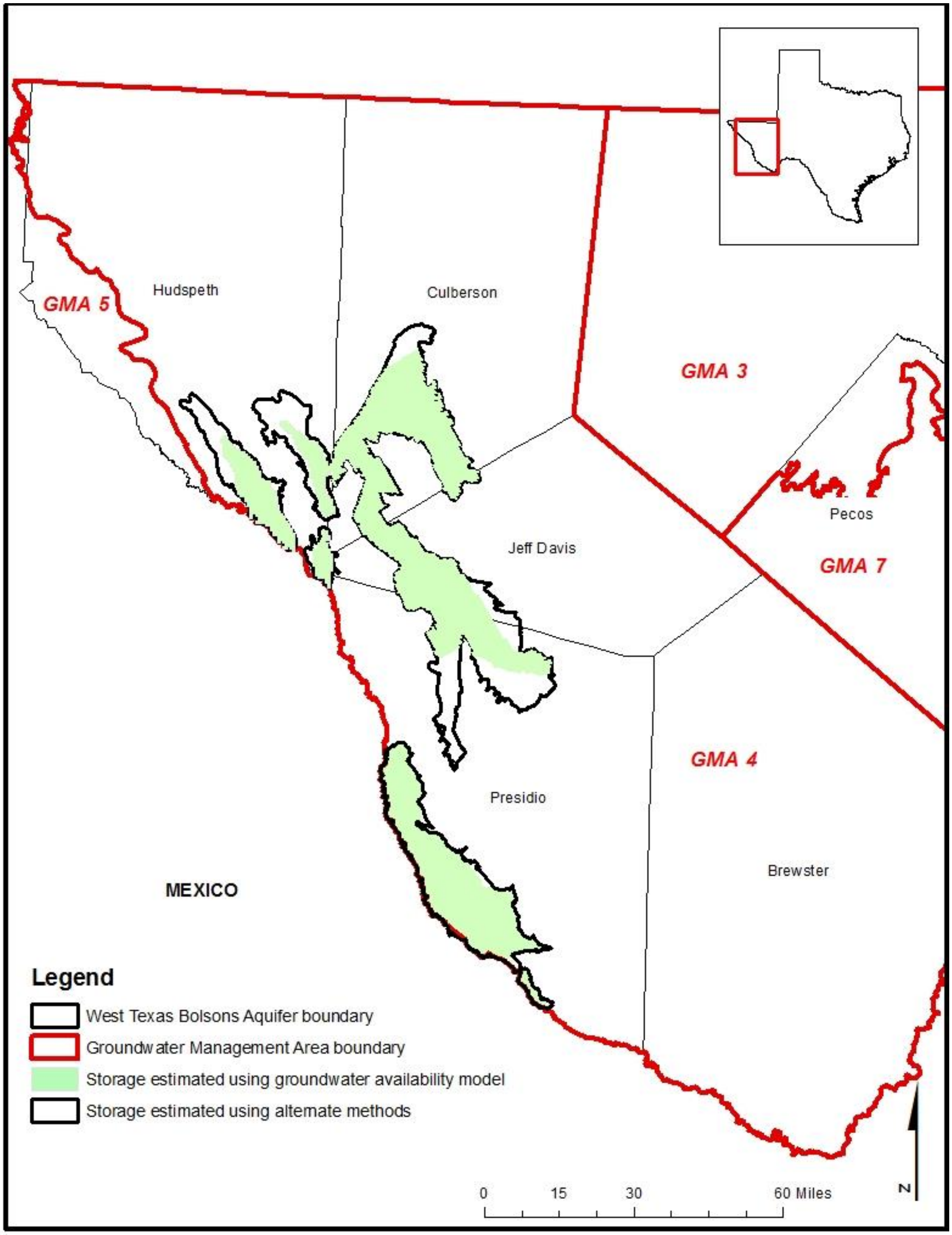

FIGURE 4. EXTENT OF THE WEST TEXAS BOLSONS AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA 4.

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

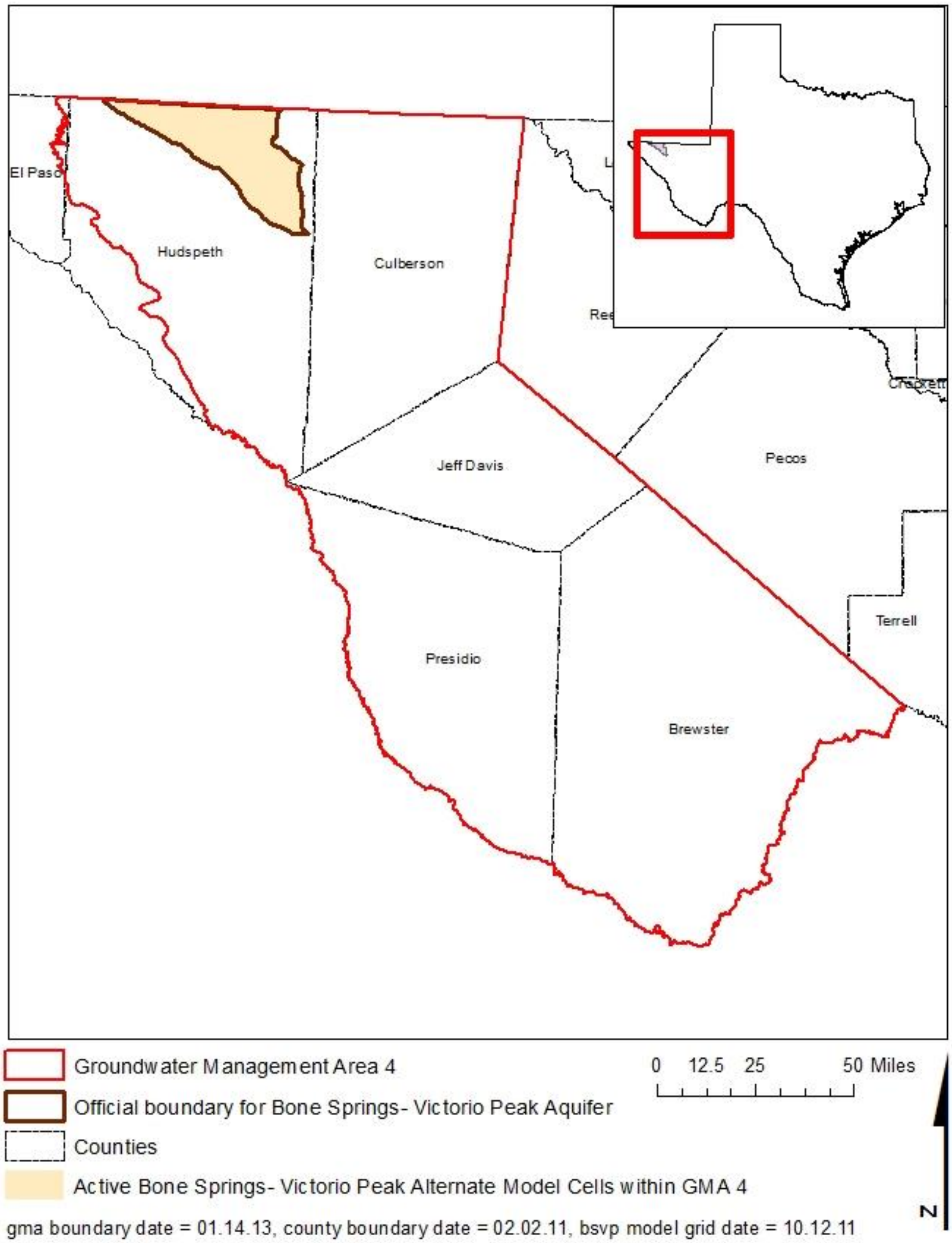

FIGURE 5. EXTENT OF THE BONE SPRING-VICTORIO PEAK AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

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.

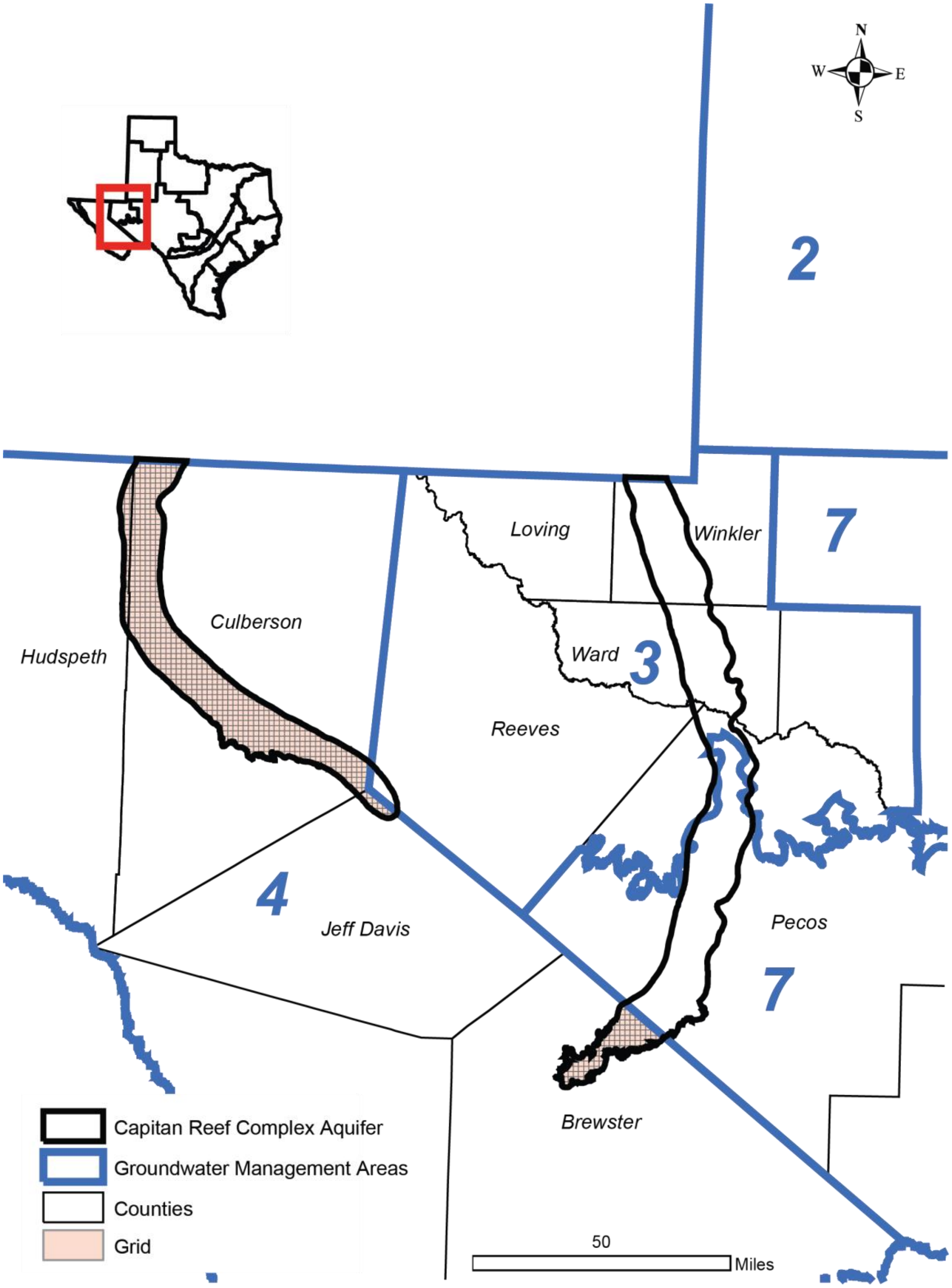

FIGURE 6. EXTENT OF THE THE CAPITAN REEF COMPLEX AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

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**

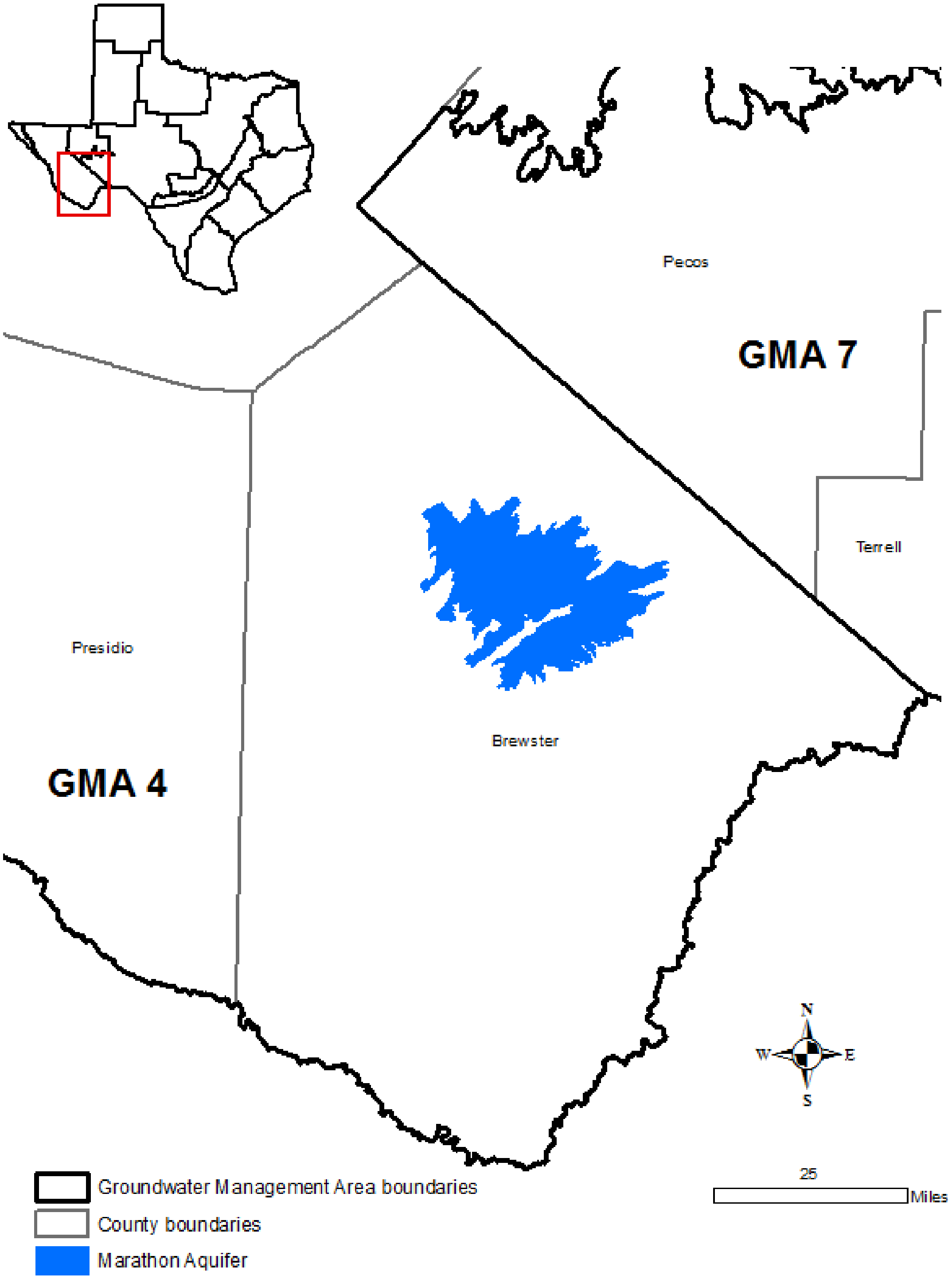

FIGURE 7. EXTENT OF THE MARATHON AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 9 AND 10) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

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**

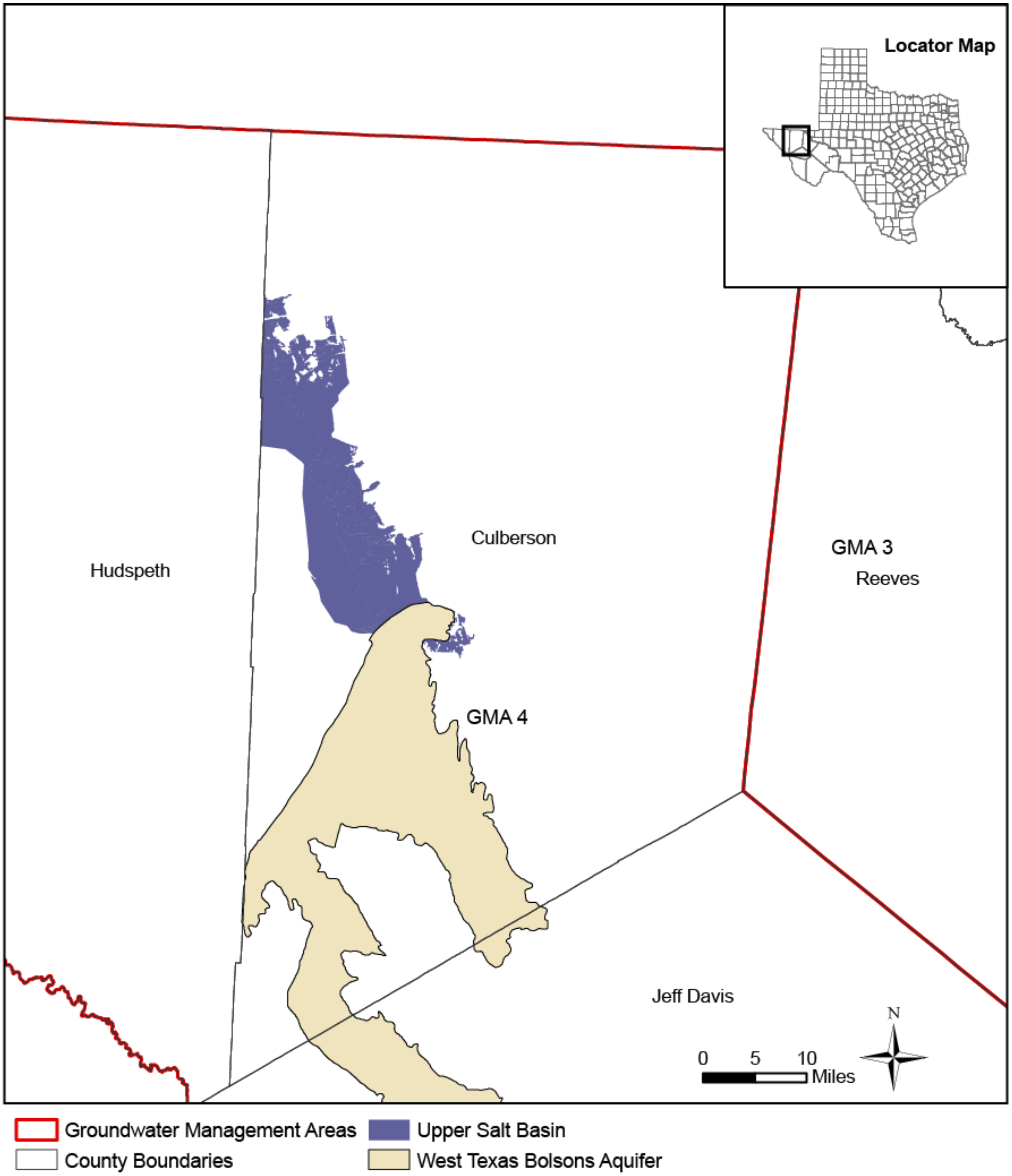

FIGURE 8. EXTENT OF THE UPPER SALT BASIN USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 11 AND 12) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

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**

---

[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

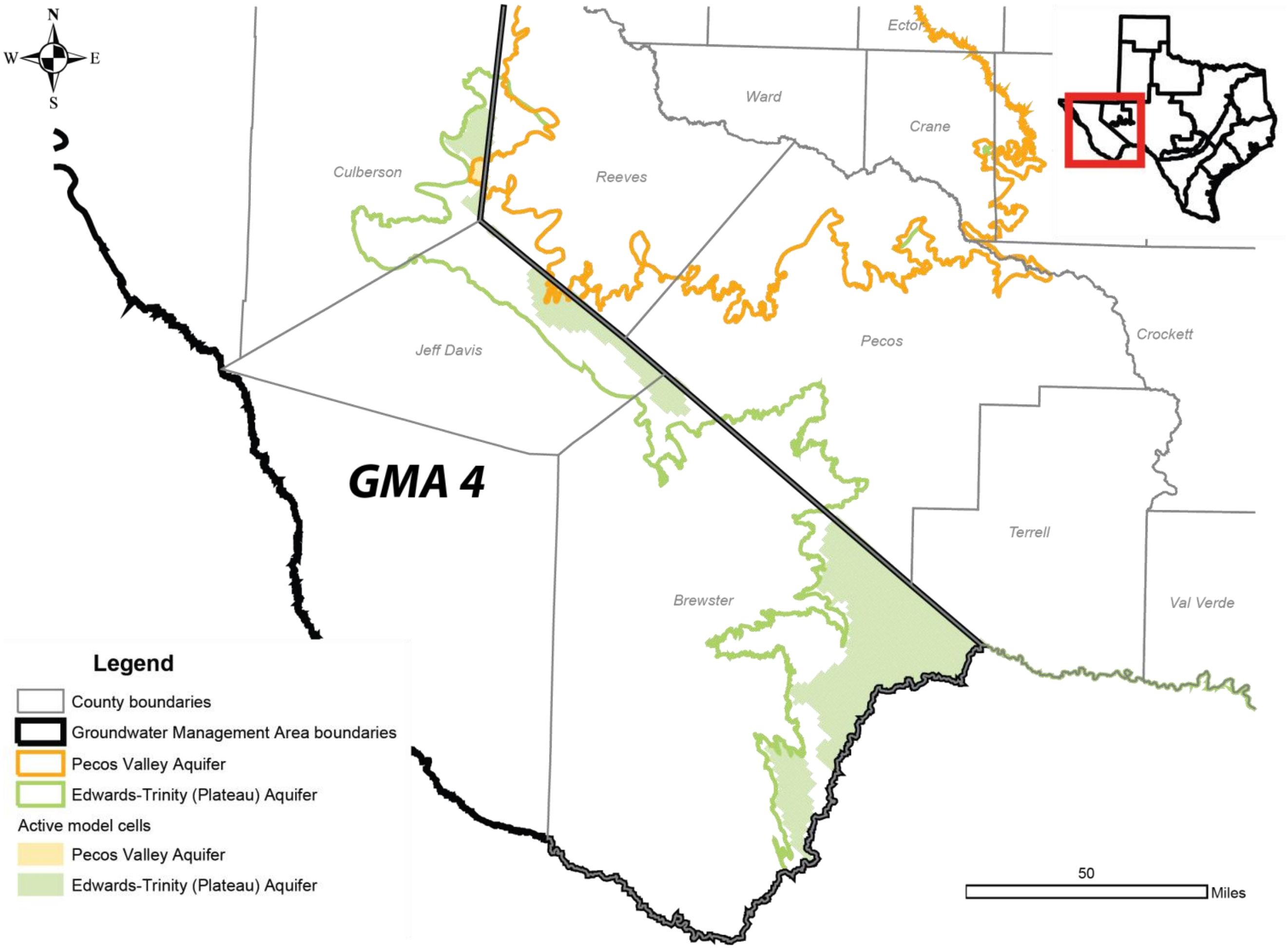

FIGURE 9. EXTENT OF THE EDWARDS-TRINITY (PLATEAU) AND PECOS VALLEY AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 13 THROUGH 16) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

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

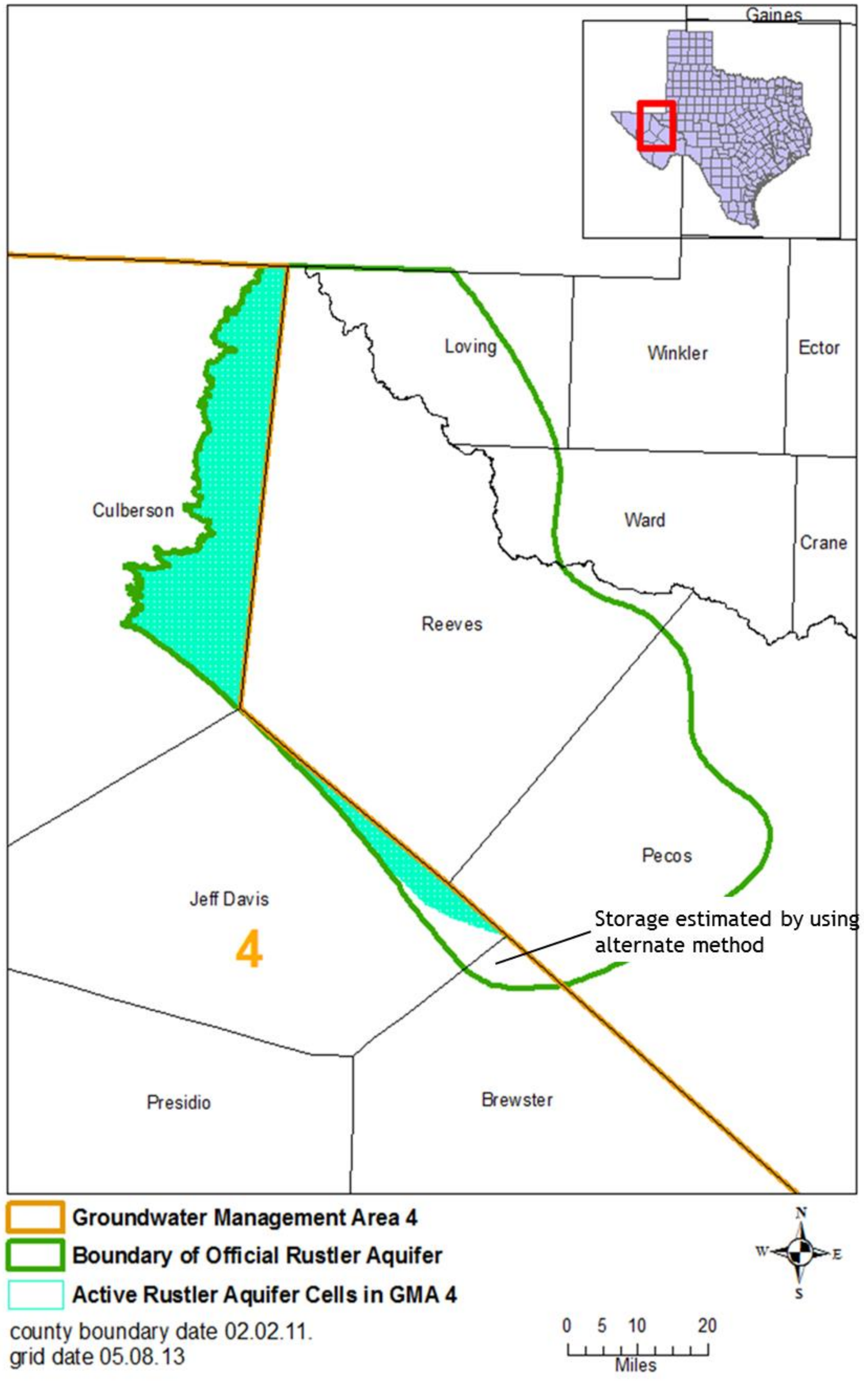

FIGURE 10. EXTENT OF THE RUSTLER AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 17 AND 18) WITHIN GROUNDWATER MANAGEMENT AREA (GMA) 4.

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.

REFERENCES:

Beach, J. A., Ashworth, J. B., Finch, S. T., Chastain-Howley, A. C., Calhoun, K., Urbanczyk, K. M., Sharp, J. M., Olson, J., 2004, Groundwater Availability Model for the Igneous and parts of the West Texas Bolsons, (Wild Horse Flat, Michigan Flat, Ryan Flat and Lobo Flat) Aquifers, 407 p., http://www.twdb.texas.gov/groundwater/models/gam/igbl/IGBL_Model_Report.pdf

Beach, J. A., Symank, L., Huang, Y., Ashworth, J. B., Davidson, T., Collins, E. W., Hibbs, B. J., Darling, B. K., Urbanczyk, K., Calhoun, K., Finch, S, 2008, Groundwater Availability Model for the Igneous and parts of the West Texas Bolsons, (Red Light Draw, Green River Valley, and Eagle Flat) Aquifers, 320 p., http://www.twdb.texas.gov/groundwater/models/gam/wtbl/WTBL_Model_Report.pdf

Ewing, J.E., Kelley, V.A., Jones, T.L., Yan, T., Singh, A., Powers, D.W., Holt, R.M., and Sharp, J.M., 2012. Groundwater Availability Model Report for the Rustler Aquifer. http://www.twdb.texas.gov/groundwater/models/gam/rslr/RSLR_GAM_Report.pdf.

Far West Texas Regional Water Planning Group (RWPG), 2001, Far west Texas regional water plan: Far West Texas Regional Water Planning Group, variously paginated.

Gates, J. S, White, D. E., Stanley, W. D., and Ackerman H. D., 1980, Availability of fresh and slightly saline ground water in the basins of westernmost Texas: Texas Department of Water Resources Report 256, 108p.

Garber, R. A., Grover, G. A., and Harris, P. M., 1989, Geology of the Capitan Shelf Margin—subsurface data from the northern Delaware Basin: in Harris, P. M., and Grover, G. A., eds., Subsurface and outcrop examination of the Capitan Shelf Margin, northern Delaware Basin: Society of Economic Paleontologists and Mineralogists, SEPM Core Workshop no. 13, p. 3-269.

George, P. G., Mace, R. E., and Petrossian, R, 2011, Aquifers of Texas, Texas Water Development Board Report 380, http://www.twdb.texas.gov/groundwater/aquifer/index.asp

Hutchison, W. R., 2008, Preliminary Groundwater Flow Model, Dell City Area, Hudspeth and Culberson Counties, Texas, 480 p., http://www.twdb.texas.gov/groundwater/models/alt/bsvp/bsvp_report.pdf

Hutchison, W. R., Jones, I. C., and Anaya, R., 2011, Update of the Groundwater Availability Model for the Edwards-Trinity (Plateau) and Pecos Valley Aquifers of Texas: Unpublished report, Texas Water Development Board, 60 p., http://www.twdb.texas.gov/groundwater/models/alt/eddt_p_2011/ETP_PV_One_Layer_Model.pdf

LBG-Guyton Associates, 2003. Brackish Groundwater Manual for Texas Regional Water Planning Groups: Texas Water Development Board contract report, 188 p.

National Research Council, 2007, Models in Environmental Regulatory Decision Making Committee on Models in the Regulatory Decision Process, National Academies Press, Washington D.C., 287 p., http://www.nap.edu/catalog.php?record_id=11972.

Standen, A. R., Finch, S., Williams, R., and Lee-Brand, B., 2009, Capitan Reef Complex Structure and Stratigraphy, Texas Water Development Board (TWDB) contracted report, 0804830794, 71 p. http://www.twdb.state.tx.us/groundwater/models/gam/crcx/CapitanReefComplex_Framework_finalwErrata.pdf

Texas Water Development Board, 2013, Groundwater database: Texas Water Development Board, Water Science and Conservation Division.

Texas Administrative Code, 2011, http://info.sos.state.tx.us/pls/pub/readtac$ext.viewtac

Texas Water Code, 2011, http://www.statutes.legis.state.tx.us/docs/WA/pdf/WA.36.pdf

Wade, Shirley C., and Jigmond M., 2013, Groundwater Availability Model of West Texas Bolsons (Presidio and Redford) Aquifer, 100 p., http://www.twdb.texas.gov/groundwater/models/gam/prbl/PRBL_ModelFinalReport.pdf

Appendix C

Region E Socioeconomic Report

TEXAS WATER DEVELOPMENT BOARD

April 30, 2010

Mr. Tom Beard, Chairman
Far West Texas Regional Water Planning Group
P.O. Box 668
Alpine, Texas 79831

Re: Socioeconomic Impact Analysis of Not Meeting Water Needs for the 2011 Far West Texas (Region E) Regional Water Plan

Dear Chairman Beard:

We have received your request for technical assistance to complete the socioeconomic impact analysis of not meeting water needs. In response, enclosed is a report that describes our methodology and presents the results. Section 1 provides an overview of the methodology, and Section 2 presents results for each water user group.

If you have any questions or comments, please feel free to contact me at (512) 463-7928 or by email at stuart.norvell@twdb.state.tx.us.

Sincerely,

Stuart Norvell
Manager, Water Planning Research and Analysis
Water Resources Planning Division

SN/ao

Enclosure

c. Barbara Kauffman, RGCOG
John Ashworth, LBG-Guyton
Connie Townsend, TWDB
S. Doug Shaw, TWDB

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

Prepared in Support of the 2011 Far West Texas Regional Water Plan

Stuart D. Norvell, Managing Economist
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Austin, Texas

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Water Resources Planning Division
Texas Water Development Board
Austin, Texas

April 2010

Table of Contents

Section Title **Page**

Introduction 3
1.0 Methodology 3
1.1 Economic Impacts of Water Shortages 3
1.1.1 General Approach 8
General Assumptions and Clarifications of the Methodology 9
1.1.2 Impacts to Agriculture 9
Irrigation 9
Livestock 13
1.1.3 Impacts to Municipal Water User Groups 13
Disaggregation of Municipal Water Demands 13
Domestic Water Uses 14
Commercial Businesses 18
Water Utility Revenues 18
Horticulture and Landscaping 18
Recreational Impacts 19
1.1.4 Impacts to Industrial Water User Groups 20
Manufacturing 20
Mining 20
Steam-electric 21
1.2 Social Impacts of Water Shortages 22
2.0 Results 23
2.1 Overview of Regional Economy 23
2.2 Impacts to Agricultural Water User Groups 24
2.3 Impacts to Municipal Water User Groups 25
2.4 Impacts to Manufacturing Water User Groups 27
2.6 Impacts to Steam-electric Water User Groups 28
2.7 Social Impacts 28

Appendix: Economic Data for Individual IMPLAN Sectors 30

Tables

1 Crop Classifications and Corresponding IMPLAN Crop Sectors 10
2 Summary of Irrigated Crop Acreage and Water Demand 10
3 Average Gross Sales Revenues per Acre for Irrigated Crops 11
4 Description of Livestock Sectors 13
5 Water Use and Costs Parameters Used to Estimated Domestic Water Demand Functions 15
6 Economic Losses Associated with Domestic Water Shortages 17
7 Impacts of Municipal Water Shortages at Different Magnitudes of Shortages 20
8 Regional Baseline Economy by Water User Group 24
9 Economic Impacts of Water Shortages for Irrigation Water User Groups 25
10 Economic Impacts of Water Shortages for Municipal Water User Groups 26
11 Economic Impacts of Water Shortages for Manufacturing Water User Groups 28
12 Economic Impacts of Water Shortages for Steam-electric Water User Groups 28
13 Social Impact of Water Shortages 29

Introduction

Water shortages during drought would likely curtail or eliminate economic activity in business and industries reliant on water. For example, without water farmers cannot irrigate; refineries cannot produce gasoline, and paper mills cannot make paper. Unreliable water supplies would not only have an immediate and real impact on existing businesses and industry, but they could also adversely affect economic development in Texas. From a social perspective, water supply reliability is critical as well. Shortages would disrupt activity in homes, schools and government and could adversely affect public health and safety. For all of the above reasons, it is important to analyze and understand how restricted water supplies during drought could affect communities throughout the state.

Administrative rules require that regional water planning groups evaluate the impacts of not meeting water needs as part of the regional water planning process, and rules direct TWDB staff to provide technical assistance: "*The executive administrator shall provide available technical assistance to the regional water planning groups, upon request, on water supply and demand analysis, including methods to evaluate the social and economic impacts of not meeting needs*" [(§357.7 (4)(A)]. Staff of the TWDB's Water Resources Planning Division designed and conducted this report in support of the Far West Texas Regional Water Planning Group (Region E).

This document summarizes the results of our analysis and discusses the methodology used to generate the results. Section 1 outlines the overall methodology and discusses approaches and assumptions specific to each water use category (i.e., irrigation, livestock, mining, steam-electric, municipal and manufacturing). Section 2 presents the results for each category where shortages are reported at the regional planning area level and river basin level. Results for individual water user groups are not presented, but are available upon request.

1. Methodology

Section 1 provides a general overview of how economic and social impacts were measured. In addition, it summarizes important clarifications, assumptions and limitations of the study.

1.1 Economic Impacts of Water Shortages

1.1.1 General Approach

Economic analysis as it relates to water resources planning generally falls into two broad areas. Supply side analysis focuses on costs and alternatives of developing new water supplies or implementing programs that provide additional water from current supplies. Demand side analysis concentrates on impacts or benefits of providing water to people, businesses and the environment. Analysis in this report focuses strictly on demand side impacts. When analyzing the economic impacts of water shortages as defined in Texas water planning, three potential scenarios are possible:

1) Scenario 1 involves situations where there are physical shortages of raw surface or groundwater due to drought of record conditions. For example, City A relies on a reservoir with average conservation storage of 500 acre-feet per year and a firm yield of 100 acre feet. In 2010, the city uses about 50 acre-feet per year, but by 2030 their demands are expected to increase to 200 acre-feet. Thus, in 2030 the reservoir would not have enough water to meet the city's demands,

and people would experience a shortage of 100 acre-feet assuming drought of record conditions. Under normal or average climatic conditions, the reservoir would likely be able to provide reliable water supplies well beyond 2030.

2) Scenario 2 is a situation where despite drought of record conditions, water supply sources can meet existing use requirements; however, limitations in water infrastructure would preclude future water user groups from accessing these water supplies. For example, City B relies on a river that can provide 500 acre-feet per year during drought of record conditions and other constraints as dictated by planning assumptions. In 2010, the city is expected to use an estimated 100 acre-feet per year and by 2060 it would require no more than 400 acre-feet. But the intake and pipeline that currently transfers water from the river to the city's treatment plant has a capacity of only 200 acre-feet of water per year. Thus, the city's water supplies are adequate even under the most restrictive planning assumptions, but their conveyance system is too small. This implies that at some point – perhaps around 2030 - infrastructure limitations would constrain future population growth and any associated economic activity or impacts.

3) Scenario 3 involves water user groups that rely primarily on aquifers that are being depleted. In this scenario, projected and in some cases existing demands may be unsustainable as groundwater levels decline. Areas that rely on the Ogallala aquifer are a good example. In some communities in the region, irrigated agriculture forms a major base of the regional economy. With less irrigation water from the Ogallala, population and economic activity in the region could decline significantly assuming there are no offsetting developments.

Assessing the social and economic effects of each of the above scenarios requires various levels and methods of analysis and would generate substantially different results for a number of reasons; the most important of which has to do with the time frame of each scenario. Scenario 1 falls into the general category of static analysis. This means that models would measure impacts for a small interval of time such as a drought. Scenarios 2 and 3, on the other hand imply a dynamic analysis meaning that models are concerned with changes over a much longer time period.

Since administrative rules specify that planning analysis be evaluated under drought of record conditions (a static and random event), socioeconomic impact analysis developed by the TWDB for the state water plan is based on assumptions of Scenario 1. Estimated impacts under scenario 1 are point estimates for years in which needs are reported (2010, 2020, 2030, 2040, 2050 and 2060). They are independent and distinct "what if" scenarios for a particular year and shortages are assumed to be temporary events resulting from drought of record conditions. Estimated impacts measure what would happen if water user groups experience water shortages for a period of one year.

The TWDB recognize that dynamic models may be more appropriate for some water user groups; however, combining approaches on a statewide basis poses several problems. For one, it would require a complex array of analyses and models, and might require developing supply and demand forecasts under "normal" climatic conditions as opposed to drought of record conditions. Equally important is the notion that combining the approaches would produce inconsistent results across regions resulting in a so-called "apples to oranges" comparison.

A variety tools are available to estimate economic impacts, but by far, the most widely used today are input-output models (IO models) combined with social accounting matrices (SAMs). Referred to as IO/SAM models, these tools formed the basis for estimating economic impacts for agriculture (irrigation and livestock water uses) and industry (manufacturing, mining, steam-electric and commercial business activity for municipal water uses).

Since the planning horizon extends through 2060, economic variables in the baseline are adjusted in accordance with projected changes in demographic and economic activity. Growth rates for municipal water use sectors (i.e., commercial, residential and institutional) are based on TWDB population forecasts. Future values for manufacturing, agriculture, and mining and steam-electric activity are based on the same underlying economic forecasts used to estimate future water use for each category.

The following steps outline the overall process.

Step 1: *Generate IO/SAM Models and Develop Economic Baseline*

IO/SAM models were estimated using propriety software known as IMPLAN PRO^{TM} (Impact for Planning Analysis). IMPLAN is a modeling system originally developed by the U.S. Forestry Service in the late 1970s. Today, the Minnesota IMPLAN Group (MIG Inc.) owns the copyright and distributes data and software. It is probably the most widely used economic impact model in existence. IMPLAN comes with databases containing the most recently available economic data from a variety of sources.[1] Using IMPLAN software and data, transaction tables conceptually similar to the one discussed previously were estimated for each county in the region and for the region as a whole. Each transaction table contains 528 economic sectors and allows one to estimate a variety of economic statistics including:

- **total sales** - total production measured by sales revenues;
- **intermediate sales** - sales to other businesses and industries within a given region;
- **final sales** – sales to end users in a region and exports out of a region;
- **employment** - number of full and part-time jobs (annual average) required by a given industry including self-employment;
- **regional income** - total payroll costs (wages and salaries plus benefits) paid by industries, corporate income, rental income and interest payments; and
- **business taxes** - sales, excise, fees, licenses and other taxes paid during normal operation of an industry (does not include income taxes).

TWDB analysts developed an economic baseline containing each of the above variables using year 2000 data. Since the planning horizon extends through 2060, economic variables in the baseline were allowed to change in accordance with projected changes in demographic and economic activity. Growth rates for municipal water use sectors (i.e., commercial, residential and institutional) are based on TWDB population forecasts. Projections for manufacturing, agriculture, and mining and steam-electric activity are based on the same underlying economic forecasts used to estimate future water use for each category. Monetary impacts in future years are reported in constant year 2006 dollars.

It is important to stress that employment, income and business taxes are the most useful variables when comparing the relative contribution of an economic sector to a regional economy. Total sales as reported in IO/SAM models are less desirable and can be misleading because they include sales to other industries in the region for use in the production of other goods. For example, if a mill buys grain from local farmers and uses it to produce feed, sales of both the processed feed and raw corn are counted as "output" in an IO model. Thus, total sales double-count or overstate the true economic value of goods

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[1] The IMPLAN database consists of national level technology matrices based on benchmark input-output accounts generated by the U.S. Bureau of Economic Analysis and estimates of final demand, final payments, industry output and employment for various economic sectors. IMPLAN regional data (i.e. states, a counties or groups of counties within a state) are divided into two basic categories: 1) data on an industry basis including value-added, output and employment, and 2) data on a commodity basis including final demands and institutional sales. State-level data are balanced to national totals using a matrix ratio allocation system and county data are balanced to state totals.

and services produced in an economy. They are not consistent with commonly used measures of output such as Gross National Product (GNP), which counts only final sales.

Another important distinction relates to terminology. Throughout this report, the term *sector* refers to economic subdivisions used in the IMPLAN database and resultant input-output models (528 individual sectors based on Standard Industrial Classification Codes). In contrast, the phrase *water use category* refers to water user groups employed in state and regional water planning including irrigation, livestock, mining, municipal, manufacturing and steam electric. Each IMPLAN sector was assigned to a specific water use category.

Step 2: *Estimate Direct and Indirect Economic Impacts of Water Needs*

Direct impacts are reductions in output by sectors experiencing water shortages. For example, without adequate cooling and process water a refinery would have to curtail or cease operation, car washes may close, or farmers may not be able to irrigate and sales revenues fall. Indirect impacts involve changes in inter-industry transactions as supplying industries respond to decreased demands for their services, and how seemingly non-related businesses are affected by decreased incomes and spending due to direct impacts. For example, if a farmer ceases operations due to a lack of irrigation water, they would likely reduce expenditures on supplies such as fertilizer, labor and equipment, and businesses that provide these goods would suffer as well.

Direct impacts accrue to immediate businesses and industries that rely on water and without water industrial processes could suffer. However, output responses may vary depending upon the severity of shortages. A small shortage relative to total water use would likely have a minimal impact, but large shortages could be critical. For example, farmers facing small shortages might fallow marginally productive acreage to save water for more valuable crops. Livestock producers might employ emergency culling strategies, or they may consider hauling water by truck to fill stock tanks. In the case of manufacturing, a good example occurred in the summer of 1999 when Toyota Motor Manufacturing experienced water shortages at a facility near Georgetown, Kentucky.[2] As water levels in the Kentucky River fell to historic lows due to drought, plant managers sought ways to curtail water use such as reducing rinse operations to a bare minimum and recycling water by funneling it from paint shops to boilers. They even considered trucking in water at a cost of 10 times what they were paying. Fortunately, rains at the end of the summer restored river levels, and Toyota managed to implement cutbacks without affecting production, but it was a close call. If rains had not replenished the river, shortages could have severely reduced output.[3]

To account for uncertainty regarding the relative magnitude of impacts to farm and business operations, the following analysis employs the concept of elasticity. Elasticity is a number that shows how a change in one variable will affect another. In this case, it measures the relationship between a percentage reduction in water availability and a percentage reduction in output. For example, an elasticity of 1.0 indicates that a 1.0 percent reduction in water availability would result in a 1.0 percent reduction in economic output. An elasticity of 0.50 would indicate that for every 1.0 percent of unavailable water, output is reduced by 0.50 percent and so on. Output elasticities used in this study are:[4]

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[2] Royal, W. *"High And Dry - Industrial Centers Face Water Shortages."* in Industry Week, Sept, 2000.

[3] The efforts described above are not planned programmatic or long-term operational changes. They are emergency measures that individuals might pursue to alleviate what they consider a temporary condition. Thus, they are not characteristic of long-term management strategies designed to ensure more dependable water supplies such as capital investments in conservation technology or development of new water supplies.

[4] Elasticities are based on one of the few empirical studies that analyze potential relationships between economic output and water shortages in the United States. The study, conducted in California, showed that a significant number of industries would suffer reduced output during water shortages. Using a survey based approach researchers posed two scenarios to different industries. In

- if water needs are 0 to 5 percent of total water demand, no corresponding reduction in output is assumed;

- if water needs are 5 to 30 percent of total water demand, for each additional one percent of water need that is not met, there is a corresponding 0.50 percent reduction in output;

- if water needs are 30 to 50 percent of total water demand, for each additional one percent of water need that is not met, there is a corresponding 0.75 percent reduction in output; and

- if water needs are greater than 50 percent of total water demand, for each additional one percent of water need that is not met, there is a corresponding 1.0 percent (i.e., a proportional reduction).

In some cases, elasticities are adjusted depending upon conditions specific to a given water user group.

Once output responses to water shortages were estimated, direct impacts to total sales, employment, regional income and business taxes were derived using regional level economic multipliers estimating using IO/SAM models. The formula for a given IMPLAN sector is:

$$D_{i,t} = Q_{i,t} *, S_{i,t} * E_Q * RFD_i * DM_{i(Q, L, I, T)}$$

where:

$D_{i,t}$ = direct economic impact to sector *i* in period *t*

$Q_{i,t}$ = total sales for sector *i* in period *t* in an affected county

$RFD_{i,}$ = ratio of final demand to total sales for sector *i* for a given region

$S_{i,t}$ = water shortage as percentage of total water use in period *t*

E_Q = elasticity of output and water use

$DM_{i(L, I, T)}$ = direct output multiplier coefficients for labor (L), income (I) and taxes (T) for sector *i*.

Secondary impacts were derived using the same formula used to estimate direct impacts; however, indirect multiplier coefficients are used. Methods and assumptions specific to each water use sector are discussed in Sections 1.1.2 through 1.1.4.

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the first scenario, they asked how a 15 percent cutback in water supply lasting one year would affect operations. In the second scenario, they asked how a 30 percent reduction lasting one year would affect plant operations. In the case of a 15 percent shortage, reported output elasticities ranged from 0.00 to 0.76 with an average value of 0.25. For a 30 percent shortage, elasticities ranged from 0.00 to 1.39 with average of 0.47. For further information, see, California Urban Water Agencies, *"Cost of Industrial Water Shortages,"* Spectrum Economics, Inc. November, 1991.

General Assumptions and Clarification of the Methodology

As with any attempt to measure and quantify human activities at a societal level, assumptions are necessary and every model has limitations. Assumptions are needed to maintain a level of generality and simplicity such that models can be applied on several geographic levels and across different economic sectors. In terms of the general approach used here several clarifications and cautions are warranted:

1. Shortages as reported by regional planning groups are the starting point for socioeconomic analyses.

2. Estimated impacts are point estimates for years in which needs are reported (i.e., 2010, 2020, 2030, 2040, 2050 and 2060).They are independent and distinct "what if" scenarios for each particular year and water shortages are assumed to be temporary events resulting from severe drought conditions combined with infrastructure limitations. In other words, growth occurs and future shocks are imposed on an economy at 10-year intervals and resultant impacts are measured. Given, that reported figures are not cumulative in nature, it is inappropriate to sum impacts over the entire planning horizon. Doing so, would imply that the analysis predicts that drought of record conditions will occur every ten years in the future, which is not the case. Similarly, authors of this report recognize that in many communities needs are driven by population growth, and in the future total population will exceed the amount of water available due to infrastructure limitations, regardless of whether or not there is a drought. This implies that infrastructure limitations would constrain economic growth. However, since needs as defined by planning rules are based upon water supply and demand under the assumption of drought of record conditions, it improper to conduct economic analysis that focuses on growth related impacts over the planning horizon. Figures generated from such an analysis would presume a 50-year drought of record, which is unrealistic. Estimating lost economic activity related to constraints on population and commercial growth due to lack of water would require developing water supply and demand forecasts under "normal" or "most likely" future climatic conditions.

3. While useful for planning purposes, this study is not a benefit-cost analysis. Benefit cost analysis is a tool widely used to evaluate the economic feasibility of specific policies or projects as opposed to estimating economic impacts of unmet water needs. Nevertheless, one could include some impacts measured in this study as part of a benefit cost study if done so properly. Since this is not a benefit cost analysis, future impacts are not weighted differently. In other words, estimates are not discounted. If used as a measure of economic benefits, one should incorporate a measure of uncertainty into the analysis. In this type of analysis, a typical method of discounting future values is to assign probabilities of the drought of record recurring again in a given year, and weight monetary impacts accordingly. This analysis assumes a probability of one.

4. IO multipliers measure the strength of backward linkages to supporting industries (i.e., those who sell inputs to an affected sector). However, multipliers say nothing about forward linkages consisting of businesses that purchase goods from an affected sector for further processing. For example, ranchers in many areas sell most of their animals to local meat packers who process animals into a form that consumers ultimately see in grocery stores and restaurants. Multipliers do not capture forward linkages to meat packers, and since meat packers sell livestock purchased from ranchers as "final sales," multipliers for the ranching sector do fully account for all losses to a region's economy. Thus, as mentioned previously, in some cases closely linked sectors were moved from one water use category to another.

5. Cautions regarding interpretations of direct and secondary impacts are warranted. IO/SAM multipliers are based on "fixed-proportion production functions," which basically means that input use - including labor - moves in lockstep fashion with changes in levels of output. In a

scenario where output (i.e., sales) declines, losses in the immediate sector or supporting sectors could be much less than predicted by an IO/SAM model for several reasons. For one, businesses will likely expect to continue operating so they might maintain spending on inputs for future use; or they may be under contractual obligations to purchase inputs for an extended period regardless of external conditions. Also, employers may not lay-off workers given that experienced labor is sometimes scarce and skilled personnel may not be readily available when water shortages subside. Lastly people who lose jobs might find other employment in the region. As a result, direct losses for employment and secondary losses in sales and employment should be considered an upper bound. Similarly, since projected population losses are based on reduced employment in the region, they should be considered an upper bound as well.

6. IO models are static. Models and resultant multipliers are based upon the structure of the U.S. and regional economies in 2006. In contrast, water shortages are projected to occur well into the future. Thus, the analysis assumes that the general structure of the economy remains the same over the planning horizon, and the farther out into the future we go, this assumption becomes less reliable.

7. Impacts are annual estimates. If one were to assume that conditions persisted for more than one year, figures should be adjusted to reflect the extended duration. The drought of record in most regions of Texas lasted several years.

8. Monetary figures are reported in constant year 2006 dollars.

1.1.2 Impacts to Agriculture

Irrigated Crop Production

The first step in estimating impacts to irrigation required calculating gross sales for IMPLAN crop sectors. Default IMPLAN data do not distinguish irrigated production from dry-land production. Once gross sales were known other statistics such as employment and income were derived using IMPLAN direct multiplier coefficients. Gross sales for a given crop are based on two data sources:

1) county-level statistics collected and maintained by the TWDB and the USDA Farm Services Agency (FSA) including the number of irrigated acres by crop type and water application per acre, and

2) regional-level data published by the Texas Agricultural Statistics Service (TASS) including prices received for crops (marketing year averages), crop yields and crop acreages.

Crop categories used by the TWDB differ from those used in IMPLAN datasets. To maintain consistency, sales and other statistics are reported using IMPLAN crop classifications. Table 1 shows the TWDB crops included in corresponding IMPLAN sectors, and Table 2 summarizes acreage and estimated annual water use for each crop classification (five-year average from 2003-2007). Table 3 displays average (2003-2007) gross revenues per acre for IMPLAN crop categories.

Table 1: Crop Classifications Used in TWDB Water Use Survey and Corresponding IMPLAN Crop Sectors

IMPLAN Category	TWDB Category
Oilseeds	Soybeans and other oil crops
Grains	Grain sorghum, corn, wheat and other grain crops
Vegetable and melons	Vegetables and potatoes
Tree nuts	Pecans
Fruits	Citrus, vineyard and other orchard
Cotton	Cotton
Sugarcane and sugar beets	Sugarcane and sugar beets
All "other" crops	Forage crops, peanuts, alfalfa, hay and pasture, rice and all other crops

Table 2: Summary of Irrigated Crop Acreage and Water Demand for the Far West Texas Regional Water Planning Area (average 2003-2007)

Sector	Acres (1000s)	Distribution of acres	Water use (1000s of AF)	Distribution of water use
Oilseeds	0.014	< 1%	0.034	<1%
Grains	5.19	5%	12.67	4%
Vegetable and melons	6.02	6%	15.62	4%
Tree nuts	12.26	13%	57.52	16%
Fruits	1.62	2%	3.7	1%
Cotton	32.57	34%	119.49	33%
Sugarcane and sugar beets	0.00	0%	0.00	0%
All other crops	37.51	39%	152.07	42%
Total	95.18	100%	361.12	100%

Source: Water demand figures are a 5- year average (2003-2007) of the TWDB's annual Irrigation Water Use Estimates. Statistics for irrigated crop acreage are based upon annual survey data collected by the TWDB and the Farm Service Agency. Values do not include acreage or water use for the TWDB categories classified by the Farm Services Agency as "failed acres," "golf course" or "waste water."

Table 3: Average Gross Sales Revenues per Acre for Irrigated Crops for the Far West Texas Regional Water Planning Area (2003-2007)

IMPLAN sector	Gross revenues per acre	Crops included in estimates
Oilseeds	$437	Based on five-year (2003-2007) average weighted by acreage for "irrigated soybeans" and "irrigated other oil crops."
Grains	$175	Based on five-year (2003-2007) average weighted by acreage for "irrigated grain sorghum," "irrigated corn", "irrigated wheat" and "irrigated 'other' grain crops."
Vegetable and melons	$6,265	Based on five-year (2003-2007) average weighted by acreage for "irrigated shallow and deep root vegetables," "irrigated Irish potatoes" and "irrigated melons."
Tree nuts	$3,558	Based on five-year (2003-2007) average weighted by acreage for "irrigated pecans."
Fruits	$6,134	Based on five-year (2003-2007) average weighted by acreage for "irrigated citrus," "irrigated vineyards" and "irrigated 'other' orchard."
Cotton	$513	Based on five-year (2003-2007) average weighted by acreage for "irrigated cotton."
Sugarcane and sugar beets	$528	Irrigated figure is based on five-year (2003-2007) average weighted by acreage for "irrigated 'forage' crops", "irrigated peanuts", "irrigated alfalfa," "irrigated 'hay' and pasture" and "irrigated 'all other' crops."

*Figures are rounded. Source: Based on data from the Texas Agricultural Statistics Service, Texas Water Development Board, and Texas A&M University.

An important consideration when estimating impacts to irrigation was determining which crops are affected by water shortages. One approach is the so-called rationing model, which assumes that farmers respond to water supply cutbacks by fallowing the lowest value crops in the region first and the highest valued crops last until the amount of water saved equals the shortage.[5] For example, if farmer A grows vegetables (higher value) and farmer B grows wheat (lower value) and they both face a proportionate cutback in irrigation water, then farmer B will sell water to farmer A. Farmer B will fallow her irrigated acreage before farmer A fallows anything. Of course, this assumes that farmers can and do transfer enough water to allow this to happen. A different approach involves constructing farm-level profit maximization models that conform to widely-accepted economic theory that farmers make decisions based on marginal net returns. Such models have good predictive capability, but data requirements and complexity are high. Given that a detailed analysis for each region would require a substantial amount of farm-level data and analysis, the following investigation assumes that projected shortages are distributed equally across predominant crops in the region. Predominant in this case are crops that comprise at least one percent of total acreage in the region.

The following steps outline the overall process used to estimate direct impacts to irrigated agriculture:

1. *Distribute shortages across predominant crop types in the region.* Again, unmet water needs were distributed equally across crop sectors that constitute one percent or more of irrigated acreage.

2. *Estimate associated reductions in output for affected crop sectors.* Output reductions are based on elasticities discussed previously and on estimated values per acre for different crops. Values per acre stem from the same data used to estimate output for the year 2006 baseline. Using multipliers, we then generate estimates of forgone income, jobs, and tax revenues based on reductions in gross sales and final demand.

Livestock

The approach used for the livestock sector is basically the same as that used for crop production. As is the case with crops, livestock categorizations used by the TWDB differ from those used in IMPLAN datasets, and TWDB groupings were assigned to a given IMPLAN sector (Table 4). Then we:

1) *Distribute projected water needs equally among predominant livestock sectors and estimate lost output*: As is the case with irrigation, shortages are assumed to affect all livestock sectors equally; however, the category of "other" is not included given its small size. If water needs were small relative to total demands, we assume that producers would haul in water by truck to fill stock tanks. The cost per acre-foot ($24,000) is based on 2008 rates charged by various water haulers in Texas, and assumes that the average truck load is 6,500 gallons at a hauling distance of 60 miles.

3) *Estimate reduced output in forward processors for livestock sectors.* Reductions in output for livestock sectors are assumed to have a proportional impact on forward processors in the region such as meat packers. In other words, if the cows were gone, meat-packing plants or fluid milk manufacturers) would likely have little to process. This is not an unreasonable premise. Since the

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[5] The rationing model was initially proposed by researchers at the University of California at Berkeley, and was then modified for use in a study conducted by the U.S. Environmental Protection Agency that evaluated how proposed water supply cutbacks recommended to protect water quality in the Bay/Delta complex in California would affect farmers in the Central Valley. See, Zilberman, D., Howitt, R. and Sunding, D. *"Economic Impacts of Water Quality Regulations in the San Francisco Bay and Delta."* Western Consortium for Public Health. May 1993.

1950s, there has been a major trend towards specialized cattle feedlots, which in turn has decentralized cattle purchasing from livestock terminal markets to direct sales between producers and slaughterhouses. Today, the meat packing industry often operates large processing facilities near high concentrations of feedlots to increase capacity utilization.[6] As a result, packers are heavily dependent upon nearby feedlots. For example, a recent study by the USDA shows that on average meat packers obtain 64 percent of cattle from within 75 miles of their plant, 82 percent from within 150 miles and 92 percent from within 250 miles.[7]

Table 4: Description of Livestock Sectors

IMPLAN category	TWDB category
Cattle ranching and farming	Cattle, cow calf, feedlots and dairies
Poultry and egg production	Poultry production.
Other livestock	Livestock other than cattle and poultry (i.e., horses, goats, sheep, hogs)
Milk manufacturing	Fluid milk manufacturing, cheese manufacturing, ice cream manufacturing etc.
Meat packing	Meat processing present in the region from slaughter to final processing

1.1.3 Impacts to Municipal Water User Groups

Disaggregation of Municipal Water Demands

Estimating the economic impacts for the municipal water user groups is complicated for a number of reasons. For one, municipal use comprises a range of consumers including commercial businesses, institutions such as schools and government and households. However, reported water needs are not distributed among different municipal water users. In other words, how much of a municipal need is commercial and how much is residential (domestic)?

The amount of commercial water use as a percentage of total municipal demand was estimated based on "GED" coefficients (gallons per employee per day) published in secondary sources.[8] For example, if year 2006 baseline data for a given economic sector (e.g., amusement and recreation services) shows employment at 30 jobs and the GED coefficient is 200, then average daily water use by that sector is (30 x

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[6] Ferreira, W.N. "*Analysis of the Meat Processing Industry in the United States.*" Clemson University Extension Economics Report ER211, January 2003.

[7] Ward, C.E. "*Summary of Results from USDA's Meatpacking Concentration Study.*" Oklahoma Cooperative Extension Service, OSU Extension Facts WF-562.

[8] Sources for GED coefficients include: Gleick, P.H., Haasz, D., Henges-Jeck, C., Srinivasan, V., Wolff, G. Cushing, K.K., and Mann, A. "*Waste Not, Want Not: The Potential for Urban Water Conservation in California.*" Pacific Institute. November 2003. U.S. Bureau of the Census. 1982 Census of Manufacturers: Water Use in Manufacturing. USGPO, Washington D.C. See also: "*U.S. Army Engineer Institute for Water Resources, IWR Report 88-R-6.,*" Fort Belvoir, VA. See also, Joseph, E. S., 1982, "*Municipal and Industrial Water Demands of the Western United States.*" Journal of the Water Resources Planning and Management Division, Proceedings of the American Society of Civil Engineers, v. 108, no. WR2, p. 204-216. See also, Baumann, D. D., Boland, J. J., and Sims, J. H., 1981, "*Evaluation of Water Conservation for Municipal and Industrial Water Supply.*" U.S. Army Corps of Engineers, Institute for Water Resources, Contract no. 82-C1.

200 = 6,000 gallons) or 6.7 acre-feet per year. Water not attributed to commercial use is considered domestic, which includes single and multi-family residential consumption, institutional uses and all use designated as "county-other." Based on our analysis, commercial water use is about 5 to 35 percent of municipal demand. Less populated rural counties occupy the lower end of the spectrum, while larger metropolitan counties are at the higher end.

After determining the distribution of domestic versus commercial water use, we developed methods for estimating impacts to the two groups.

Domestic Water Uses

Input output models are not well suited for measuring impacts of shortages for domestic water uses, which make up the majority of the municipal water use category. To estimate impacts associated with domestic water uses, municipal water demand and needs are subdivided into residential, and commercial and institutional use. Shortages associated with residential water uses are valued by estimating proxy demand functions for different water user groups allowing us to estimate the marginal value of water, which would vary depending upon the level of water shortages. The more severe the water shortage, the more costly it becomes. For instance, a 2 acre-foot shortage for a group of households that use 10 acre-feet per year would not be as severe as a shortage that amounted to 8 acre-feet. In the case of a 2 acre-foot shortage, households would probably have to eliminate some or all outdoor water use, which could have implicit and explicit economic costs including losses to the horticultural and landscaping industry. In the case of an 8 acre-foot shortage, people would have to forgo all outdoor water use and most indoor water consumption. Economic impacts would be much higher in the latter case because people, and would be forced to find emergency alternatives assuming alternatives were available.

To estimate the value of domestic water uses, TWDB staff developed marginal loss functions based on constant elasticity demand curves. This is a standard and well-established method used by economists to value resources such as water that have an explicit monetary cost.

A constant price elasticity of demand is estimated using a standard equation:

$$w = kc^{(-\varepsilon)}$$

where:

- w is equal to average monthly residential water use for a given water user group measured in thousands of gallons;
- k is a constant intercept;
- c is the average cost of water per 1,000 gallons; and
- ε is the price elasticity of demand.

Price elasticities (-0.30 for indoor water use and -0.50 for outdoor use) are based on a study by Bell et al.[9] that surveyed 1,400 water utilities in Texas that serve at least 1,000 people to estimate demand elasticity for several variables including price, income, weather etc. Costs of water and average use per month per household are based on data from the Texas Municipal League's annual water and

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[9] Bell, D.R. and Griffin, R.C. "*Community Water Demand in Texas as a Century is Turned.*" Research contract report prepared for the Texas Water Development Board. May 2006.

wastewater rate surveys - specifically average monthly household expenditures on water and wastewater in different communities across the state. After examining variance in costs and usage, three different categories of water user groups based on population (population less than 5,000, cities with populations ranging from 5,000 to 99,999 and cities with populations exceeding 100,000) were selected to serve as proxy values for municipal water groups that meet the criteria (Table 5).[10]

Table 5: Water Use and Costs Parameters Used to Estimated Water Demand Functions
(average monthly costs per acre-foot for delivered water and average monthly use per household)

Community population	Water	Wastewater	Total monthly cost	Avg. monthly use (gallons)
Less than or equal to 5,000	$1,335	$1,228	$2,563	6,204
5,000 to 100,000	$718	$1,162	$1,880	7,950
Great than or equal to 100,000	$1,047	$457	$1,504	8,409

Source: Based on annual water and wastewater rate surveys published by the Texas Municipal League.

As an example, Table 6 shows the economic impact per acre-foot of domestic water needs for municipal water user groups with population exceeding 100,000 people. There are several important assumptions incorporated in the calculations:

1) Reported values are net of the variable costs of treatment and distribution such as expenses for chemicals and electricity since using less water involves some savings to consumers and utilities alike; and for outdoor uses we do not include any value for wastewater.

2) Outdoor and "non-essential" water uses would be eliminated before indoor water consumption was affected, which is logical because most water utilities in Texas have drought contingency plans that generally specify curtailment or elimination of outdoor water use during droughts.[11] Determining how much water is used for outdoor purposes is based on several secondary sources. The first is a major study sponsored by the American Water Works Association, which surveyed cities in states including Colorado, Oregon, Washington, California, Florida and Arizona. On average across all cities surveyed 58 percent of single family residential water use was for outdoor activities. In cities with climates comparable to large metropolitan areas of Texas, the average was 40 percent.[12] Earlier findings of the U.S. Water Resources Council showed a national

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[10] Ideally, one would want to estimate demand functions for each individual utility in the state. However, this would require an enormous amount of time and resources. For planning purposes, we believe the values generated from aggregate data are more than sufficient.

[11] In Texas, state law requires retail and wholesale water providers to prepare and submit plans to the Texas Commission on Environmental Quality (TCEQ). Plans must specify demand management measures for use during drought including curtailment of "non-essential water uses." Non-essential uses include, but are not limited to, landscape irrigation and water for swimming pools or fountains. For further information see the Texas Environmental Quality Code §288.20.

[12] See, Mayer, P.W., DeOreo, W.B., Opitz, E.M., Kiefer, J.C., Davis, W., Dziegielewski, D., Nelson, J.O. *"Residential End Uses of Water."* Research sponsored by the American Water Works Association and completed by Aquacraft, Inc. and Planning and Management Consultants, Ltd. (PMCL@CDM).

average of 33 percent. Similarly, the United States Environmental Protection Agency (USEPA) estimated that landscape watering accounts for 32 percent of total residential and commercial water use on annual basis.[13] A study conducted for the California Urban Water Agencies (CUWA) calculated average annual values ranging from 25 to 35 percent.[14] Unfortunately, there does not appear to be any comprehensive research that has estimated non-agricultural outdoor water use in Texas. As an approximation, an average annual value of 30 percent based on the above references was selected to serve as a rough estimate in this study.

3) As shortages approach 100 percent values become immense and theoretically infinite at 100 percent because at that point death would result, and willingness to pay for water is immeasurable. Thus, as shortages approach 80 percent of monthly consumption, we assume that households and non-water intensive commercial businesses (those that use water only for drinking and sanitation would have water delivered by tanker truck or commercial water delivery companies. Based on reports from water companies throughout the state, we estimate that the cost of trucking in water is around $21,000 to $27,000 per acre-feet assuming a hauling distance of between 20 to 60 miles. This is not an unreasonable assumption. The practice was widespread during the 1950s drought and recently during droughts in this decade. For example, in 2000 at the heels of three consecutive drought years Electra - a small town in North Texas - was down to its last 45 days worth of reservoir water when rain replenished the lake, and the city was able to refurbish old wells to provide supplemental groundwater. At the time, residents were forced to limit water use to 1,000 gallons per person per month - less than half of what most people use - and many were having water delivered to their homes by private contractors.[15] In 2003 citizens of Ballinger, Texas, were also faced with a dwindling water supply due to prolonged drought. After three years of drought, Lake Ballinger, which supplies water to more than 4,300 residents in Ballinger and to 600 residents in nearby Rowena, was almost dry. Each day, people lined up to get water from a well in nearby City Park. Trucks hauling trailers outfitted with large plastic and metal tanks hauled water to and from City Park to Ballinger.[16]

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[13] U.S. Environmental Protection Agency. *"Cleaner Water through Conservation."* USEPA Report no. 841-B-95-002. April, 1995.

[14] Planning and Management Consultants, Ltd. *"Evaluating Urban Water Conservation Programs: A Procedures Manual."* Prepared for the California Urban Water Agencies. February 1992.

[15] Zewe, C. *"Tap Threatens to Run Dry in Texas Town."* July 11, 2000. CNN Cable News Network.

[16] Associated Press, *"Ballinger Scrambles to Finish Pipeline before Lake Dries Up."* May 19, 2003.

Table 6: Economic Losses Associated with Domestic Water Shortages in Communities with Populations Exceeding 100,000 people

Water shortages as a percentage of total monthly household demands	No. of gallons remaining per household per day	No of gallons remaining per person per day	Economic loss (per acre-foot)	Economic loss (per gallon)
1%	278	93	$748	$0.00005
5%	266	89	$812	$0.0002
10%	252	84	$900	$0.0005
15%	238	79	$999	$0.0008
20%	224	75	$1,110	$0.0012
25%	210	70	$1,235	$0.0015
30%[a]	196	65	$1,699	$0.0020
35%	182	61	$3,825	$0.0085
40%	168	56	$4,181	$0.0096
45%	154	51	$4,603	$0.011
50%	140	47	$5,109	$0.012
55%	126	42	$5,727	$0.014
60%	112	37	$6,500	$0.017
65%	98	33	$7,493	$0.02
70%	84	28	$8,818	$0.02
75%	70	23	$10,672	$0.03
80%	56	19	$13,454	$0.04
85%	42	14	$18,091 ($24,000)[b]	$0.05 ($0.07)[b]
90%	28	9	$27,363 ($24,000)	$0.08 ($0.07)
95%	14	5	$55,182 ($24,000)	$0.17 ($0.07)
99%	3	0.9	$277,728 ($24,000)	$0.85 ($0.07)
99.9%	1	0.5	$2,781,377 ($24,000)	$8.53 ($0.07)
100%	0	0	Infinite ($24,000)	Infinite ($0.07)

[a] The first 30 percent of needs are assumed to be restrictions of outdoor water use; when needs reach 30 percent of total demands all outdoor water uses would be restricted. Needs greater than 30 percent include indoor use.

[b] As shortages approach 100 percent the value approaches infinity assuming there are not alternatives available; however, we assume that communities would begin to have water delivered by tanker truck at an estimated cost of $24,000 per acre-foot when shortages breached 85 percent.

Commercial Businesses

Effects of water shortages on commercial sectors were estimated in a fashion similar to other business sectors meaning that water shortages would affect the ability of these businesses to operate. This is particularly true for "water intensive" commercial sectors that are need large amounts of water (in addition to potable and sanitary water) to provide their services. These include:

- car-washes,
- laundry and cleaning facilities,
- sports and recreation clubs and facilities including race tracks,
- amusement and recreation services,
- hospitals and medical facilities,
- hotels and lodging places, and
- eating and drinking establishments.

A key assumption is that commercial operations would not be affected until water shortages were at least 50 percent of total municipal demand. In other words, we assume that residential water consumers would reduce water use including all non-essential uses before businesses were affected.

An example will illustrate the breakdown of municipal water needs and the overall approach to estimating impacts of municipal needs. Assume City A experiences an unexpected shortage of 50 acre-feet per year when their demands are 200 acre-feet per year. Thus, shortages are only 25 percent of total municipal use and residents of City A could eliminate needs by restricting landscape irrigation. City B, on the other hand, has a deficit of 150 acre-feet in 2020 and a projected demand of 200 acre-feet. Thus, total shortages are 75 percent of total demand. Emergency outdoor and some indoor conservation measures could eliminate 50 acre-feet of projected needs, yet 50 acre-feet would still remain. To eliminate" the remaining 50 acre-feet water intensive commercial businesses would have to curtail operations or shut down completely.

Three other areas were considered when analyzing municipal water shortages: 1) lost revenues to water utilities, 2) losses to the horticultural and landscaping industries stemming for reduction in water available for landscape irrigation, and 3) lost revenues and related economic impacts associated with reduced water related recreation.

Water Utility Revenues

Estimating lost water utility revenues was straightforward. We relied on annual data from the "*Water and Wastewater Rate Survey*" published annually by the Texas Municipal League to calculate an average value per acre-foot for water and sewer. For water revenues, average retail water and sewer rates multiplied by total water needs served as a proxy. For lost wastewater, total unmet needs were adjusted for return flow factor of 0.60 and multiplied by average sewer rates for the region. Needs reported as "county-other" were excluded under the presumption that these consist primarily of self-supplied water uses. In addition, 15 percent of water demand and needs are considered non-billed or "unaccountable" water that comprises things such as leakages and water for municipal government functions (e.g., fire departments). Lost tax receipts are based on current rates for the "miscellaneous gross receipts tax, "which the state collects from utilities located in most incorporated cities or towns in Texas. We do not include lost water utility revenues when aggregating impacts of municipal water shortages to regional and state levels to prevent double counting.

Horticultural and Landscaping Industry

The horticultural and landscaping industry, also referred to as the "green Industry," consists of businesses that produce, distribute and provide services associated with ornamental plants, landscape and garden supplies and equipment. Horticultural industries often face big losses during drought. For example, the recent drought in the Southeast affecting the Carolinas and Georgia horticultural and landscaping businesses had a harsh year. Plant sales were down, plant mortality increased, and watering costs increased. Many businesses were forced to close locations, lay off employees, and even file for bankruptcy. University of Georgia economists put statewide losses for the industry at around $3.2 billion during the 3-year drought that ended in 2008.[17] Municipal restrictions on outdoor watering play a significant role. During drought, water restrictions coupled with persistent heat has a psychological effect on homeowners that reduces demands for landscaping products and services. Simply put, people were afraid to spend any money on new plants and landscaping.

In Texas, there do not appear to be readily available studies that analyze the economic effects of water shortages on the industry. However, authors of this report believe negative impacts do and would result in restricting landscape irrigation to municipal water consumers. The difficulty in measuring them is two-fold. First, as noted above, data and research for these types of impacts that focus on Texas are limited; and second, economic data provided by IMPLAN do not disaggregate different sectors of the green industry to a level that would allow for meaningful and defensible analysis.[18]

Recreational Impacts

Recreational businesses often suffer when water levels and flows in rivers, springs and reservoirs fall significantly during drought. During droughts, many boat docks and lake beaches are forced to close, leading to big losses for lakeside business owners and local communities. Communities adjacent to popular river and stream destinations such as Comal Springs and the Guadalupe River also see their business plummet when springs and rivers dry up. Although there are many examples of businesses that have suffered due to drought, dollar figures for drought-related losses to the recreation and tourism industry are not readily available, and very difficult to measure without extensive local surveys. Thus, while they are important, economic impacts are not measured in this study.

Table 7 summarizes impacts of municipal water shortages at differing levels of magnitude, and shows the ranges of economic costs or losses per acre-foot of shortage for each level.

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[17] Williams, D. *"Georgia landscapers eye rebound from Southeast drought."* Atlanta Business Chronicle, Friday, June 19, 2009

[18] Economic impact analyses prepared by the TWDB for 2006 regional water plans did include estimates for the horticultural industry. However, year 2000 and prior IMPLAN data were disaggregated to a finer level. In the current dataset (2006), the sector previously listed as "Landscaping and Horticultural Services" (IMPLAN Sector 27) is aggregated into "Services to Buildings and Dwellings" (IMPLAN Sector 458).

Table 7: Impacts of Municipal Water Shortages at Different Magnitudes of Shortages

Water shortages as percent of total municipal demands	Impacts	Economic costs per acre-foot*
0-30%	✓ Lost water utility revenues ✓ Restricted landscape irrigation and non-essential water uses	$730 - $2,040
30-50%	✓ Lost water utility revenues ✓ Elimination of landscape irrigation and non-essential water uses ✓ Rationing of indoor use	$2,040 - $10,970
>50%	✓ Lost water utility revenues ✓ Elimination of landscape irrigation and non-essential water uses ✓ Rationing of indoor use ✓ Restriction or elimination of commercial water use ✓ Importing water by tanker truck	$10,970 - varies

*Figures are rounded

1.1.4 Industrial Water User Groups

Manufacturing

Impacts to manufacturing were estimated by distributing water shortages among industrial sectors at the county level. For example, if a planning group estimates that during a drought of record water supplies in County A would only meet 50 percent of total annual demands for manufactures in the county, we reduced output for each sector by 50 percent. Since projected manufacturing demands are based on TWDB Water Uses Survey data for each county, we only include IMPLAN sectors represented in the TWBD survey database. Some sectors in IMPLAN databases are not part of the TWDB database given that they use relatively small amounts of water - primarily for on-site sanitation and potable purposes. To maintain consistency between IMPLAN and TWDB databases, Standard Industrial Classification (SIC) codes both databases were cross referenced in county with shortages. Non-matches were excluded when calculating direct impacts.

Mining

The process of mining is very similar to that of manufacturing. We assume that within a given county, shortages would apply equally to relevant mining sectors, and IMPLAN sectors are cross referenced with TWDB data to ensure consistency.

In Texas, oil and gas extraction and sand and gravel (aggregates) operations are the primary mining industries that rely on large volumes of water. For sand and gravel, estimated output reductions are straightforward; however, oil and gas is more complicated for a number of reasons. IMPLAN does not necessarily report the physical extraction of minerals by geographic local, but rather the sales revenues reported by a particular corporation.

For example, at the state level revenues for IMPLAN sector 19 (oil and gas extraction) and sector 27 (drilling oil and gas wells) totals $257 billion. Of this, nearly $85 billion is attributed to Harris County. However, only a very small fraction (less than one percent) of actual production takes place in the county. To measure actual potential losses in well head capacity due to water shortages, we relied on county level production data from the Texas Railroad Commission (TRC) and average well-head market prices for crude and gas to estimate lost revenues in a given county. After which, we used to IMPLAN ratios to estimate resultant losses in income and employment.

Other considerations with respect to mining include:

> 1) Petroleum and gas extraction industry only uses water in significant amounts for secondary recovery. Known in the industry as enhanced or water flood extraction, secondary recovery involves pumping water down injection wells to increase underground pressure thereby pushing oil or gas into other wells. IMPLAN output numbers do not distinguish between secondary and non-secondary recovery. To account for the discrepancy, county-level TRC data that show the proportion of barrels produced using secondary methods were used to adjust IMPLAN data to reflect only the portion of sales attributed to secondary recovery.
>
> 2) A substantial portion of output from mining operations goes directly to businesses that are classified as manufacturing in our schema. Thus, multipliers measuring backward linkages for a given manufacturer might include impacts to a supplying mining operation. Care was taken not to double count in such situations if both a mining operation and a manufacturer were reported as having water shortages.

Steam-electric

At minimum without adequate cooling water, power plants cannot safely operate. As water availability falls below projected demands, water levels in lakes and rivers that provide cooling water would also decline. Low water levels could affect raw water intakes and outfalls at electrical generating units in several ways. For one, power plants are regulated by thermal emission guidelines that specify the maximum amount of heat that can go back into a river or lake via discharged cooling water. Low water levels could result in permit compliance issues due to reduced dilution and dispersion of heat and subsequent impacts on aquatic biota near outfalls.[19] However, the primary concern would be a loss of head (i.e., pressure) over intake structures that would decrease flows through intake tunnels. This would affect safety related pumps, increase operating costs and/or result in sustained shut-downs. Assuming plants did shutdown, they would not be able to generate electricity.

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[19] Section 316 (b) of the Clean Water Act requires that thermal wastewater discharges do not harm fish and other wildlife.

Among all water use categories steam-electric is unique and cautions are needed when applying methods used in this study. Measured changes to an economy using input-output models stem directly from changes in sales revenues. In the case of water shortages, one assumes that businesses will suffer lost output if process water is in short supply. For power generation facilities this is true as well. However, the electric services sector in IMPLAN represents a corporate entity that may own and operate several electrical generating units in a given region. If one unit became inoperable due to water shortages, plants in other areas or generation facilities that do not rely heavily on water such as gas powered turbines might be able to compensate for lost generating capacity. Utilities could also offset lost production via purchases on the spot market.[20] Thus, depending upon the severity of the shortages and conditions at a given electrical generating unit, energy supplies for local and regional communities could be maintained. But in general, without enough cooling water, utilities would have to throttle back plant operations, forcing them to buy or generate more costly power to meet customer demands.

Measuring impacts end users of electricity is not part of this study as it would require extensive local and regional level analysis of energy production and demand. To maintain consistency with other water user groups, impacts of steam-electric water shortages are measured in terms of lost revenues (and hence income) and jobs associated with shutting down electrical generating units.

1.2 Social Impacts of Water Shortages

As the name implies, the effects of water shortages can be social or economic. Distinctions between the two are both semantic and analytical in nature – more so analytic in the sense that social impacts are harder to quantify. Nevertheless, social effects associated with drought and water shortages are closely tied to economic impacts. For example, they might include:

- demographic effects such as changes in population,
- disruptions in institutional settings including activity in schools and government,
- conflicts between water users such as farmers and urban consumers,
- health-related low-flow problems (e.g., cross-connection contamination, diminished sewage flows, increased pollutant concentrations),
- mental and physical stress (e.g., anxiety, depression, domestic violence),
- public safety issues from forest and range fires and reduced fire fighting capability,
- increased disease caused by wildlife concentrations,
- loss of aesthetic and property values, and
- reduced recreational opportunities.[21]

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[20] Today, most utilities participate in large interstate "power pools" and can buy or sell electricity "on the grid" from other utilities or power marketers. Thus, assuming power was available to buy, and assuming that no contractual or physical limitations were in place such as transmission constraints; utilities could offset lost power that resulted from waters shortages with purchases via the power grid.

[21] Based on information from the website of the National Drought Mitigation Center at the University of Nebraska Lincoln. Available online at: http://www.drought.unl.edu/risk/impacts.htm. See also, Vanclay, F. *"Social Impact Assessment."* in Petts, J. (ed) International Handbook of Environmental Impact Assessment. 1999.

Social impacts measured in this study focus strictly on demographic effects including changes in population and school enrollment. Methods are based on demographic projection models developed by the Texas State Data Center and used by the TWDB for state and regional water planning. Basically, the social impact model uses results from the economic component of the study and assesses how changes in labor demand would affect migration patterns in a region. Declines in labor demand as measured using adjusted IMPLAN data are assumed to affect net economic migration in a given regional water planning area. Employment losses are adjusted to reflect the notion that some people would not relocate but would seek employment in the region and/or public assistance and wait for conditions to improve. Changes in school enrollment are simply the proportion of lost population between the ages of 5 and 17.

2.0 Results

Section 2 presents the results of the analysis at the regional level. Included are baseline economic data for each water use category, and estimated economic impacts of water shortages for water user groups with deficits. According to the 2011 *Far West Texas Regional Water Plan*, during severe drought irrigation, municipal, manufacturing, mining and steam-electric water user groups would experience water shortages in the absence of new water management strategies.

2.1 Overview of Regional Economy

The Region E economy generates about $33 billion in gross state product for Texas ($30 billion worth of income and $3 billion in business taxes), and supports 377,702 jobs (Table 8). Agriculture and manufacturing (particularly petroleum refining, copper smelting and automotive parts), are the primary base economic sectors.[22] Municipal sectors also generate substantial amounts of income – about $25 billion per year. While municipal sectors are the largest employer and source of income, many businesses that make up the municipal category such as restaurants and retail stores are non-basic industries meaning they exist to provide services to people who work would in base industries such as manufacturing, agriculture and mining. In other words, without base industries such agriculture, many municipal jobs in the region would not exist.

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[22] Base industries are those that supply markets outside of the region. These industries are crucial to the local economy and are called the economic base of a region. Appendix A shows how IMPLAN's 529 sectors were allocated to water use category, and shows economic data for each sector.

Table 8: The Far West Texas Regional Economy by Water User Group ($millions)

Water Use Category	Total sales	Intermediate sales	Final sales	Jobs	Income	Business taxes
Irrigation	$141.10	$62.28	$76.67	1,694	$87.73	$2.38
Livestock	$196.88	$46.10	$150.78	236	$47.11	$1.44
Manufacturing	$13,039.47	$2,747.78	$10,291.68	41,061	$3,788.27	$114.36
Mining	$184.65	$116.35	$68.30	$360.00	$98.28	$10.02
Steam-electric	$384.76	$108.24	$276.52	837	$267.12	$45.65
Municipal	$45,429.48	$16,572.52	$28,856.96	333,514	$25,501.39	$2,442.99
Regional total	$59,376.34	$19,653.27	$39,720.91	377,702	$29,789.90	$2,616.84

Based on data from the Texas Water Development Board, and year 2006 data from the Minnesota IMPLAN Group, Inc.

2.2 Impacts of Agricultural Water Shortages

According to the 2011 *Far West Texas Regional Water Plan*, during severe drought Hudspeth and El Paso counties would experiences irrigation shortages. In 2010, shortages range from 23 to 54 percent of annual irrigation demands. Deficits of this magnitude would decrease gross state product (income plus taxes) by an estimated $40 million dollars in 2010 and $23 million in 2060 (Table 9).

Table 9: Economic Impacts of Water Shortages for Irrigation Water User Groups ($millions)

Decade	Lost income from reduced crop production [a]	Lost state and local tax revenues from reduced crop production	Lost jobs from reduced crop production
		Hudspeth County	
2010	$23.76	$1.37	142
2020	$11.42	$0.66	136
2030	$10.98	$0.63	131
2040	$10.54	$0.61	126
2050	$10.11	$0.58	120
2060	$9.69	$0.56	115
		El Paso County	
2010	$16.80	$1.03	198
2020	$15.82	$0.97	187
2030	$15.37	$0.95	181
2040	$13.43	$0.83	158
2050	$12.56	$0.77	148
2060	$11.70	$0.72	138
		Regional Totals	
2010	$40.56	$2.40	340
2020	$27.24	$1.63	323
2030	$26.35	$1.58	312
2040	$23.97	$1.43	284
2050	$22.67	$1.36	269
2060	$21.39	$1.28	254

[a] Changes to income and business taxes are collectively equivalent to a decrease in gross state product, which is analogous to gross domestic product measured at the state rather than national level.

2.3 Impacts of Municipal Water Shortages

Water shortages are projected to occur in eight municipal water user groups in the planning region. Deficits range from 5 to 69 percent of total annual water use. At a regional level, monetary losses associated with domestic water shortages total $48 million in 2020 and rise to nearly $402 million in 2060 (Table 10). Curtailment of commercial business activity would reduce gross state product by an estimated $2 million in 2030 and $55 million in 2060.

Table 10: Economic Impacts of Water Shortages for Municipal Water User Groups ($millions)

Decade	Monetary value of domestic water shortages	Lost income from reduced commercial business activity	Lost state and local taxes from reduced commercial business activity	Lost jobs from reduced commercial business activity	Lost water utility revenues
City of El Paso					
2010	$0.00	$0.00	$0.00	0	$0.00
2020	$0.00	$0.00	$0.00	0	$0.00
2030	$0.00	$0.00	$0.00	0	$0.00
2040	$0.00	$0.00	$0.00	0	$0.00
2050	$3.94	$0.00	$0.00	0	$1.51
2060	$12.33	$0.00	$0.00	0	$4.26
County-other					
2010	$0.00	$0.00	$0.00	0	$0.00
2020	$25.71	$0.00	$0.00	0	$0.00
2030	$61.69	$0.00	$0.00	0	$0.00
2040	$93.13	$0.00	$0.00	0	$0.00
2050	$133.24	$0.00	$0.00	0	$0.00
2060	$190.00	$0.00	$0.00	0	$0.00
Horizon Regional Municipal Utility District					
2010	$0.00	$0.00	$0.00	0	$0.00
2020	$8.49	$0.00	$0.00	0	$0.32
2030	$25.84	$0.00	$0.00	0	$0.66
2040	$39.17	$4.94	$0.53	110	$0.95
2050	$69.15	$16.68	$1.78	371	$1.25
2060	$84.74	$23.49	$2.50	523	$1.55
Lower Valley Water District					
2010	$0.00	$0.00	$0.00	0	$0.00
2020	$4.26	$0.00	$0.00	0	$0.12
2030	$9.05	$0.85	$0.12	27	$0.23
2040	$13.72	$3.04	$0.43	96	$0.32
2050	$21.34	$4.48	$0.64	141	$0.42
2060	$31.28	$11.83	$1.69	373	$0.51
San Elizario					
2010	$0.00	$0.00	$0.00	0	$0.00
2020	$5.93	$0.00	$0.00	0	$0.19
2030	$15.13	$1.17	$0.12	26	$0.36
2040	$23.36	$5.50	$0.59	122	$0.50
2050	$36.43	$8.87	$0.94	197	$0.64
2060	$57.69	$12.24	$1.30	272	$0.79
Socorro					
2010	$0.00	$0.00	$0.00	0	$0.00
2020	$0.58	$0.00	$0.00	0	$0.10
2030	$1.47	$0.00	$0.00	0	$0.20
2040	$2.27	$0.00	$0.00	0	$0.28
2050	$10.60	$0.00	$0.00	0	$0.37
2060	$13.11	$0.00	$0.00	0	$0.45

Table 10: Economic Impacts of Water Shortages for Municipal Water User Groups ($millions)

Decade	Monetary value of domestic water shortages	Lost income from reduced commercial business activity	Lost state and local taxes from reduced commercial business activity	Lost jobs from reduced commercial business activity	Lost water utility revenues
Tornillo WCID					
2010	$0.00	$0.00	$0.00	0	$0.00
2020	$0.00	$0.00	$0.00	0	$0.00
2030	$0.00	$0.00	$0.00	0	$0.00
2040	$0.08	$0.00	$0.00	0	$0.01
2050	$0.26	$0.00	$0.00	0	$0.06
2060	$0.82	$0.00	$0.00	0	$0.10
Vinton					
2010	$0.00	$0.00	$0.00	0	$0.00
2020	$2.12	$0.00	$0.00	0	$0.04
2030	$5.53	$0.00	$0.00	0	$0.08
2040	$7.22	$0.60	$0.09	19	$0.11
2050	$9.68	$0.93	$0.13	29	$0.15
2060	$11.81	$1.26	$0.18	40	$0.18
Regional Totals					
2010	$0.00	$0.00	$0.00	0	$0.00
2020	$47.09	$0.00	$0.00	0	$1.20
2030	$118.70	$2.02	$0.25	53	$2.39
2040	$178.96	$14.08	$1.63	347	$3.38
2050	$284.64	$30.96	$3.49	739	$5.98
2060	$401.77	$48.82	$5.67	1,208	$9.82

[a] Changes to income and business taxes are collectively equivalent to a decrease in gross state product, which is analogous to gross domestic product measured at the state rather than national level.

2.4 Impacts of Manufacturing Water Shortages

The Region E planning group estimates that manufacturers in El Paso County would be short about 800 acre-feet in 2020 (8 percent of projected manufacturing demands); and roughly 3,670 acre-feet (30 percent of projected demands) in 2060. The adverse impacts of these shortages would be substantial. In 2020, manufacturing water deficits would reduce gross state product by an estimated $456 million and threaten 1,450 jobs. By 2060, losses grow to nearly $1.7 billion with 6,572 jobs at stake (Table 11).

Table 11: Economic Impacts of Water Shortages for Manufacturing in El Paso County ($millions)

Decade	Lost income due to reduced manufacturing output	Lost state and local business tax revenues due to reduced manufacturing output	Lost jobs due to reduced manufacturing output
2010	$0.00	$0.00	0
2020	$435.43	$21.73	1,454
2030	$809.28	$40.39	2,703
2040	$1,170.80	$58.43	3,910
2050	$1,478.23	$73.77	4,937
2060	$1,967.76	$98.20	6,572

[a] Changes to income and business taxes are collectively equivalent to a decrease in gross state product, which is analogous to gross domestic product measured at the state rather than national level.

2.5 Impacts of Steam-electric Water Shortages

Water shortages for steam-electric water user groups are also projected to occur in El Paso County resulting in reduced income worth $286 million in 2020, and $772 million in 2060 (Table 12). Estimated jobs losses total 670 in 2020 and 1,809 in 2060.

Table 12: Economic Impacts of Water Shortages for Steam-electric Water User Groups in El Paso County ($millions)

Decade	Lost income due to reduced electrical generation	Lost state and local business tax revenues due to reduced electrical generation	Lost jobs due to reduced electrical generation
2010	$0.00	$0.00	0
2020	$285.84	$27.24	670
2030	$374.02	$35.65	876
2040	$481.41	$45.88	1,128
2050	$612.32	$58.36	1,435
2060	$771.99	$73.58	1,809

[a] Changes to income and business taxes are collectively equivalent to a decrease in gross state product, which is analogous to gross domestic product measured at the state rather than national level.

2.6 Social Impacts of Water Shortages

As discussed previously, estimated social impacts focus on changes in regional population and school enrollment. In 2010, estimated population losses total 409 with corresponding reductions in school enrollment of 115 students (Table 13). In 2060, population would decline by 11,750 people and school enrollment would fall by 2,173 students.

Table 13: Social Impacts of Water Shortages (2010-2060)

Year	Population Losses	Declines in School Enrollment
2010	409	115
2020	2,947	836
2030	4,745	1,257
2040	6,787	1,254
2050	8,814	1,628
2060	11,750	2,173

Appendix: Economic Data for Individual IMPLAN Sectors for the Far West Texas Regional Water Planning Area

Economic Data for Agricultural Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Irrigation	Oilseed Farming	1	$0.01	$0	$0.06	1	$0.00	$0.00
Irrigation	Grain Farming	2	$0.95	$0.24	$0.71	43	$0.46	$0.02
Irrigation	Vegetable and Melon Farming	3	$39.79	$2.28	$34.25	427	$29.28	$0.36
Irrigation	Tree Nut Farming	4	$50.69	$39.71	$11.83	601	$35.12	$1.22
Irrigation	Fruit Farming	5	$9.89	$0.97	$8.76	158	$5.62	$0.22
Irrigation	Cotton Farming	8	$19.33	$0.14	$19.26	243	$7.11	$0.17
Irrigation	All "Other" Crop Farming	10	$20.44	$18.94	$1.80	221	$10.14	$0.39
Livestock	Cattle ranching and farming	11	$94.95	$65.84	$29.11	1,593	$7.50	$2.00
Livestock	Poultry and egg production	12	$1.90	$1.49	$0.41	15	$0.65	$0.01
Livestock	Animal production- except cattle and poultry	13	$4.75	$4.03	$0.72	305	$0.46	$0.07
Livestock	Dog and cat food manufacturing	46	$10.56	$1.02	$9.54	10	$1.47	$0.05
Livestock	Other animal food manufacturing	47	$25.32	$3.05	$22.26	37	$1.24	$0.09
Livestock	Fluid milk manufacturing	62	$139.01	$33.44	$105.57	240	$12.55	$0.81
	Total Agricultural	**NA**	**$337.98**	**$108.38**	**$227.45**	**1,930**	**$134.84**	**$3.82**

Based on year 2006 data from the Minnesota IMPLAN Group, Inc.

Economic Data for Mining and Steam-electric Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Mining	Oil and gas extraction	19	$121.59	$112.91	$8.67	150	$69.67	$7.64
Mining	Coal mining	20	$0.00	$0.00	$0.00	0	$0.00	$0.00
Mining	Iron ore mining	21	$0.00	$0.00	$0.00	0	$0.00	$0.00
Mining	Copper- nickel- lead- and zinc mining	22	$0.00	$0.00	$0.00	0	$0.00	$0.00
Mining	Gold- silver- and other metal ore mining	23	$0.00	$0.00	$0.00	0	$0.00	$0.00
Mining	Stone mining and quarrying	24	$1.00	$0.10	$0.89	5	$0.55	$0.01
Mining	Sand- gravel- clay- and refractory mining	25	$7.66	$0.81	$6.85	39	$4.51	$0.25
Mining	Other nonmetallic mineral mining	26	$13.11	$1.31	$11.80	76	$5.42	$0.31
Mining	Support activities for oil and gas operations	28	$7.50	$1.04	$6.46	41	$6.79	$0.32
Mining	Support activities for other mining	29	$0.23	$0.00	$0.23	2	$0.08	$0.01
Total Mining	NA		$184.65	$116.35	$68.30	$360.00	$98.28	$10.02
Steam-electric	Power generation and supply	30	$384.76	$108.24	$276.52	837	$267.12	$45.65

Based on year 2006 data from the Minnesota IMPLAN Group, Inc.

Economic Data for Manufacturing Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Manufacturing	Petroleum refineries	142	$3,795.98	$1,410.97	$2,385.01	322	$1,067.39	$40.63
Manufacturing	New residential 1-unit structures- all	33	$833.32	$0.00	$833.32	5,908	$252.93	$3.98
Manufacturing	Primary smelting and refining of copper	214	$560.08	$50.08	$510.00	160	$45.92	$5.87
Manufacturing	Commercial and institutional buildings	38	$452.88	$0.00	$452.88	5,150	$216.40	$2.67
Manufacturing	Motor vehicle parts manufacturing	350	$443.81	$35.69	$408.12	1,289	$86.33	$1.41
Manufacturing	Semiconductors and related device manufacturing	311	$429.72	$228.71	$201.01	547	$45.46	$1.28
Manufacturing	Iron and steel mills	203	$416.00	$29.97	$386.03	517	$70.72	$2.60
Manufacturing	Ready-mix concrete manufacturing	192	$368.74	$1.79	$366.95	787	$190.83	$5.63
Manufacturing	Copper wire- except mechanical- drawing	217	$342.76	$22.66	$320.10	381	$68.87	$3.25
Manufacturing	Soft drink and ice manufacturing	85	$267.58	$14.95	$252.64	434	$35.06	$1.55
Manufacturing	Household vacuum cleaner manufacturing	328	$233.91	$8.85	$225.06	867	$73.50	$1.65
Manufacturing	Plastics plumbing fixtures and all other plastics	177	$229.01	$165.90	$63.11	1,188	$83.98	$1.45
Manufacturing	Paperboard container manufacturing	126	$212.37	$2.25	$210.12	671	$55.43	$2.21
Manufacturing	Cut and sew apparel manufacturing	107	$202.21	$5.47	$196.74	1,409	$72.54	$1.17
Manufacturing	Other new construction	41	$196.41	$0.00	$196.41	2,363	$100.40	$0.79
Manufacturing	Electric housewares and household fan manufacturing	327	$185.41	$16.39	$169.01	456	$75.58	$2.06
Manufacturing	Footwear manufacturing	110	$171.76	$1.42	$170.34	1,230	$67.96	$1.56
Manufacturing	Natural gas distribution	31	$166.43	$66.71	$99.73	331	$37.68	$12.31
Manufacturing	Roasted nuts and peanut butter manufacturing	78	$152.57	$4.18	$148.39	337	$18.61	$0.69
Manufacturing	All other electronic component manufacturing	312	$141.25	$80.94	$60.31	669	$37.46	$0.64
Manufacturing	Lawn and garden equipment manufacturing	258	$140.95	$27.22	$113.73	328	$25.73	$0.79
Manufacturing	Soap and other detergent manufacturing	163	$137.76	$36.80	$100.96	120	$46.61	$1.32
Manufacturing	Ornamental and architectural metal work manufacturing	237	$118.25	$6.82	$111.42	779	$34.46	$0.51
Manufacturing	New residential additions and alterations-all	35	$117.01	$0.00	$117.01	703	$40.04	$0.57
Manufacturing	Hand and edge tool manufacturing	229	$98.25	$12.94	$85.31	399	$47.55	$0.68
Manufacturing	Copper rolling- drawing- and extruding	216	$97.11	$2.38	$94.73	142	$11.91	$0.61
Manufacturing	Highway- street- bridge- and tunnel construct	39	$97.09	$0.00	$97.09	997	$46.33	$0.59
Manufacturing	Other engine equipment manufacturing	286	$94.30	$56.13	$38.17	145	$12.74	$0.14

Based on year 2006 data from the Minnesota IMPLAN Group, Inc.

Economic Data for Manufacturing Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Manufacturing	Fruit and vegetable canning and drying	61	$90.82	$3.36	$87.46	221	$14.05	$0.44
Manufacturing	New multifamily housing structures- all	34	$88.49	$0.00	$88.49	858	$39.11	$0.23
Manufacturing	Plastics material and resin manufacturing	152	$76.90	$3.05	$73.85	46	$22.00	$0.69
Manufacturing	Water- sewer- and pipeline construction	40	$71.66	$0.00	$71.66	652	$29.73	$0.43
Manufacturing	Custom roll forming	226	$67.37	$1.87	$65.50	181	$13.95	$0.29
Manufacturing	Commercial printing	139	$66.25	$32.91	$33.33	858	$46.18	$0.58
Manufacturing	Other aluminum rolling and drawing	213	$65.03	$1.81	$63.22	93	$5.84	$0.21
Manufacturing	Ceramic wall and floor tile manufacturing	186	$62.88	$33.50	$29.38	311	$26.25	$0.73
Manufacturing	Miscellaneous nonmetallic mineral products	202	$57.49	$1.06	$56.43	170	$28.09	$0.63
Manufacturing	Fabricated structural metal manufacturing	233	$45.50	$2.36	$43.15	186	$15.02	$0.24
Manufacturing	Tortilla manufacturing	77	$44.84	$4.77	$40.07	295	$13.27	$0.30
Manufacturing	Electric lamp bulb and part manufacturing	325	$41.83	-$0.01	$41.84	186	$15.74	$0.28
Manufacturing	Metal valve manufacturing	248	$40.94	$4.43	$36.50	100	$22.33	$0.29
Manufacturing	All other forging and stamping	227	$40.68	$2.09	$38.59	197	$15.87	$0.23
Manufacturing	Broom- brush- and mop manufacturing	387	$40.50	$2.19	$38.31	183	$18.75	$0.25
Manufacturing	Plastics packaging materials- film and sheet	172	$39.79	$21.54	$18.24	140	$8.68	$0.24
Manufacturing	Other millwork- including flooring	119	$38.86	$30.18	$8.67	263	$7.38	$0.15
Manufacturing	Ferrous metal foundaries	221	$38.56	$0.04	$38.52	238	$10.59	$0.21
Manufacturing	Bread and bakery product- except frozen- manufacturing	73	$37.92	$8.47	$29.46	285	$13.84	$0.23
Manufacturing	Paint and coating manufacturing	161	$37.69	$0.48	$37.21	45	$14.03	$0.43
Manufacturing	Frozen food manufacturing	60	$36.07	$1.13	$34.94	144	$4.91	$0.14
Manufacturing	Narrow fabric mills and schiffli embroidery	94	$35.90	$1.39	$34.50	274	$14.39	$0.28
Manufacturing	Manufacturing and industrial buildings	37	$35.62	$0.00	$35.62	448	$18.00	$0.19
Manufacturing	Automobile and light truck manufacturing	344	$32.83	$0.04	$32.79	25	$1.09	$0.03
Manufacturing	Wood kitchen cabinet and countertop manufacturing	362	$32.62	$25.41	$7.21	312	$11.63	$0.19
Manufacturing	Plastics pipe- fittings- and profile shapes	173	$31.71	$19.50	$12.20	99	$6.92	$0.16
Manufacturing	Foam product manufacturing	178	$31.38	$23.89	$7.49	130	$8.56	$0.17
Manufacturing	Concrete block and brick manufacturing	193	$30.97	$0.13	$30.83	111	$12.67	$0.38

Based on year 2006 data from the Minnesota IMPLAN Group, Inc.

Economic Data for Manufacturing Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Manufacturing	Other snack food manufacturing	79	$30.15	$5.08	$25.07	42	$11.09	$0.28
Manufacturing	Surgical appliance and supplies manufacturing	376	$28.92	$7.22	$21.70	93	$14.93	$0.13
Manufacturing	Surgical and medical instrument manufacturing	375	$28.89	$9.78	$19.10	59	$16.52	$0.14
Manufacturing	Agriculture and forestry support activities	18	$28.01	$15.92	$12.09	1,204	$18.03	$0.24
Manufacturing	Asphalt shingle and coating materials manufacturing	144	$27.37	$14.76	$12.61	37	$8.58	$0.06
Manufacturing	Machine shops	243	$26.64	$6.43	$20.21	243	$9.53	$0.15
Manufacturing	Hunting and trapping	17	$24.67	$2.02	$22.65	128	$8.26	$1.61
Manufacturing	All other converted paper product manufacturing	135	$23.50	$0.27	$23.24	94	$7.63	$0.23
Manufacturing	Other computer peripheral equipment manufacturing	305	$23.42	$7.26	$16.15	56	$3.41	$0.09
Manufacturing	Other basic organic chemical manufacturing	151	$22.10	$4.12	$17.98	16	$5.71	$0.25
Manufacturing	Office furniture- except wood- manufacturing	370	$20.86	$0.19	$20.67	117	$11.80	$0.06
Manufacturing	Electronic computer manufacturing	302	$20.45	$4.76	$15.69	8	$1.02	$0.08
Manufacturing	Metal tank- heavy gauge- manufacturing	239	$19.73	$0.81	$18.92	70	$10.47	$0.14
Manufacturing	Rubber and plastics hose and belting manufacturing	180	$19.55	$0.49	$19.06	90	$7.39	$0.12
Manufacturing	Cut stone and stone product manufacturing	199	$19.36	$15.99	$3.37	111	$11.17	$0.22
Manufacturing	Electroplating- anodizing- and coloring metal	247	$19.18	$6.76	$12.41	106	$9.38	$0.11
Manufacturing	Aircraft manufacturing	351	$18.46	$0.94	$17.52	29	$6.14	$0.06
Manufacturing	Motor and generator manufacturing	334	$18.23	$1.73	$16.49	49	$8.43	$0.18
Manufacturing	Special tool- die- jig- and fixture manufacturing	282	$17.85	$10.23	$7.62	156	$7.10	$0.08
Manufacturing	Metal household furniture manufacturing	365	$17.81	$0.03	$17.78	124	$9.63	$0.06
Manufacturing	Meat processed from carcasses	68	$17.27	$5.09	$12.17	41	$1.35	$0.07
Manufacturing	AC- refrigeration- and forced air heating	278	$17.04	$0.00	$17.04	60	$2.36	$0.06
Manufacturing	Wood container and pallet manufacturing	120	$16.12	$10.72	$5.40	164	$4.51	$0.07
Manufacturing	Miscellaneous fabricated metal product manufacturing	255	$15.77	$0.08	$15.69	50	$8.67	$0.14
Manufacturing	Textile and fabric finishing mills	97	$15.18	$6.41	$8.77	65	$2.99	$0.09
Manufacturing	Jewelry and silverware manufacturing	380	$15.13	$0.31	$14.83	58	$5.20	$0.08
Manufacturing	Watch- clock- and other measuring and control	321	$14.71	$1.42	$13.30	66	$1.76	$0.03
Manufacturing	Plate work manufacturing	234	$14.24	$0.90	$13.35	72	$4.43	$0.06

Based on year 2006 data from the Minnesota IMPLAN Group, Inc.

Economic Data for Manufacturing Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Manufacturing	Spring and wire product manufacturing	242	$12.97	$1.38	$11.58	75	$4.27	$0.07
Manufacturing	Sign manufacturing	384	$12.77	$4.14	$8.64	109	$6.88	$0.08
Manufacturing	Turned product and screw- nut- and bolt manufacturing	244	$12.61	$2.60	$10.01	88	$4.38	$0.05
Manufacturing	Search- detection- and navigation instruments	314	$11.96	$3.97	$7.99	40	$3.15	$0.04
Manufacturing	Adhesive manufacturing	162	$11.84	$9.11	$2.73	17	$4.79	$0.12
Manufacturing	Scales- balances- and miscellaneous general p	301	$11.41	$2.46	$8.95	46	$3.48	$0.06
Manufacturing	Accessories and other apparel manufacturing	108	$11.32	$0.79	$10.53	71	$5.44	$0.08
Manufacturing	Textile bag and canvas mills	101	$10.88	$0.12	$10.75	94	$2.17	$0.03
Manufacturing	Secondary smelting and alloying of aluminum	210	$10.68	$0.17	$10.51	15	$0.87	$0.04
Manufacturing	All other food manufacturing	84	$8.74	$0.74	$8.00	37	$1.01	$0.03
Manufacturing	Wood windows and door manufacturing	117	$8.60	$7.83	$0.77	60	$2.81	$0.04
Manufacturing	Nonupholstered wood household furniture manufacturing	364	$7.91	$0.23	$7.68	80	$2.59	$0.02
Manufacturing	Logging	14	$1.76	$1.31	$0.44	7	$0.47	$0.02
Manufacturing	Mattress manufacturing	372	$7.38	$0.01	$7.37	35	$2.28	$0.02
Manufacturing	Pharmaceutical and medicine manufacturing	160	$7.14	$1.30	$5.83	8	$1.85	$0.04
Manufacturing	Other leather product manufacturing	111	$7.11	$1.12	$5.99	49	$3.11	$0.06
Manufacturing	Other communication and energy wire manufacturing	340	$7.09	$3.32	$3.77	15	$2.62	$0.08
Manufacturing	Engineered wood member and truss manufacturing	116	$7.00	$6.57	$0.43	54	$2.40	$0.03
Manufacturing	Other major household appliance manufacturing	332	$6.92	$0.42	$6.50	20	$1.46	$0.04
Manufacturing	Toilet preparation manufacturing	166	$6.84	$0.74	$6.10	8	$2.80	$0.02
Manufacturing	Cutting tool and machine tool accessory manufacturing	283	$6.79	$4.73	$2.06	50	$2.41	$0.03
Manufacturing	Electric power and specialty transformers	333	$6.60	$3.49	$3.12	26	$2.14	$0.05
Manufacturing	All other industrial machinery manufacturing	269	$6.37	$1.62	$4.75	34	$1.26	$0.01
Manufacturing	Custom compounding of purchased resins	169	$5.50	$5.25	$0.25	9	$2.25	$0.02
Manufacturing	Sheet metal work manufacturing	236	$5.24	$0.29	$4.96	33	$1.74	$0.02
Manufacturing	Other miscellaneous chemical products	171	$5.23	$2.74	$2.50	7	$2.33	$0.07
Manufacturing	Custom architectural woodwork and millwork	369	$5.21	$4.58	$0.62	52	$2.94	$0.01
Manufacturing	All other manufacturing	NA	$104.89	$20.14	$84.75	556	$34.88	$0.60

Based on year 2006 data from the Minnesota IMPLAN Group, Inc.

Economic Data for Municipal Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Municipal	Lessors of nonfinancial intangible assets	436	$16,164.50	$8,815.05	$7,349.45	470	$7,581.26	$744.98
Municipal	Real estate	431	$4,377.11	$1,732.70	$2,644.42	27,461	$2,529.79	$542.02
Municipal	Wholesale trade	390	$1,834.11	$878.11	$956.01	13,132	$965.13	$271.77
Municipal	Owner-occupied dwellings	509	$1,776.08	$0.00	$1,776.08	0	$1,375.87	$210.01
Municipal	State & Local Education	503	$1,662.99	$0.00	$1,662.99	40,669	$1,662.99	$0.00
Municipal	Federal Military	505	$1,323.79	$0.00	$1,323.79	12,576	$1,323.78	$0.00
Municipal	Federal Non-Military	506	$1,170.87	$0.00	$1,170.87	7,660	$1,170.87	$0.00
Municipal	Food services and drinking places	481	$1,129.62	$144.25	$985.36	25,025	$439.36	$51.39
Municipal	Truck transportation	394	$1,103.99	$597.78	$506.21	9,133	$474.22	$10.78
Municipal	Telecommunications	422	$850.60	$292.17	$558.44	2,417	$349.02	$58.07
Municipal	Offices of physicians- dentists- and other he	465	$846.47	$0.00	$846.47	7,077	$601.41	$5.29
Municipal	Hospitals	467	$753.57	$0.00	$753.56	6,528	$403.89	$5.16
Municipal	State & Local Non-Education	504	$734.91	$0.00	$734.91	11,882	$734.91	$0.00
Municipal	Motor vehicle and parts dealers	401	$577.61	$62.81	$514.80	5,722	$296.26	$84.15
Municipal	Monetary authorities and depository credit in	430	$566.34	$186.53	$379.81	3,044	$397.69	$7.25
Municipal	General merchandise stores	410	$459.91	$48.47	$411.43	9,013	$201.74	$64.18
Municipal	Business support services	455	$425.06	$198.93	$226.13	7,484	$231.11	$8.78
Municipal	Other State and local government enterprises	499	$387.33	$126.13	$261.20	1,831	$143.84	$0.05
Municipal	Home health care services	464	$347.16	$0.00	$347.16	9,538	$212.39	$1.25
Municipal	Insurance carriers	427	$337.50	$98.41	$239.09	1,634	$93.38	$11.58
Municipal	All other miscellaneous professional and tech	450	$329.52	$294.20	$35.32	1,193	$45.59	$0.92
Municipal	Other ambulatory health care services	466	$283.92	$18.47	$265.45	1,867	$143.91	$2.15
Municipal	Rail transportation	392	$279.25	$135.01	$144.23	809	$170.40	$5.40
Municipal	Social assistance- except child day care serv	470	$266.25	$0.05	$266.20	10,047	$119.83	$0.83
Municipal	Food and beverage stores	405	$265.89	$35.55	$230.34	4,999	$132.91	$29.20
Municipal	Clothing and clothing accessories stores	408	$253.87	$31.79	$222.08	5,047	$130.06	$36.93
Municipal	Legal services	437	$247.26	$156.93	$90.34	2,240	$152.43	$4.76

Based on year 2006 data from the Minnesota IMPLAN Group, Inc.

Economic Data for Municipal Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Municipal	Automotive equipment rental and leasing	432	$235.34	$96.25	$139.10	1,523	$85.87	$4.31
Municipal	Architectural and engineering services	439	$233.24	$147.03	$86.21	2,134	$116.22	$0.97
Municipal	Building material and garden supply stores	404	$231.70	$35.93	$195.77	2,696	$109.45	$33.26
Municipal	Scenic and sightseeing transportation and sup	397	$208.96	$78.39	$130.56	1,803	$141.75	$24.24
Municipal	Employment services	454	$202.34	$167.46	$34.88	9,684	$166.60	$0.95
Municipal	Automotive repair and maintenance- except car	483	$193.71	$46.01	$147.70	2,815	$66.93	$13.32
Municipal	Insurance agencies- brokerages- and related	428	$189.17	$111.01	$78.16	1,831	$160.44	$1.01
Municipal	Nondepository credit intermediation and rela	425	$186.53	$114.19	$72.34	1,767	$98.65	$7.55
Municipal	Gasoline stations	407	$176.43	$26.80	$149.64	2,626	$95.32	$25.41
Municipal	Nonstore retailers	412	$175.49	$27.11	$148.38	4,596	$110.49	$19.84
Municipal	Health and personal care stores	406	$169.85	$27.11	$142.74	2,613	$83.57	$24.32
Municipal	Hotels and motels- including casino hotels	479	$161.99	$83.45	$78.54	2,801	$86.63	$14.85
Municipal	Accounting and bookkeeping services	438	$160.87	$130.64	$30.23	2,162	$69.49	$0.56
Municipal	Maintenance and repair of nonresidential buil	43	$148.27	$98.24	$50.03	1,321	$53.28	$0.99
Municipal	Civic- social- professional and similar organ	493	$148.16	$52.06	$96.10	4,485	$70.66	$0.45
Municipal	Nursing and residential care facilities	468	$144.05	$0.00	$144.05	2,921	$91.74	$2.18
Municipal	Other educational services	463	$139.05	$11.74	$127.31	2,550	$75.52	$4.29
Municipal	Grantmaking and giving and social advocacy or	492	$132.70	$0.00	$132.70	3,247	$44.41	$0.23
Municipal	Office administrative services	452	$123.32	$54.86	$68.46	793	$64.10	$1.10
Municipal	Pipeline transportation	396	$121.86	$53.29	$68.56	24	$59.37	$12.94
Municipal	Securities- commodity contracts- investments	426	$117.77	$78.21	$39.56	968	$43.33	$1.28
Municipal	Services to buildings and dwellings	458	$117.67	$86.82	$30.85	2,634	$49.37	$1.77
Municipal	Radio and television broadcasting	420	$111.52	$88.53	$22.99	610	$36.16	$0.46
Municipal	Air transportation	391	$109.29	$12.17	$97.12	519	$28.79	$3.67
Municipal	Furniture and home furnishings stores	402	$105.25	$16.09	$89.16	1,391	$50.70	$14.95
Municipal	Miscellaneous store retailers	411	$105.07	$13.04	$92.03	3,045	$63.60	$15.29

Based on year 2006 data from the Minnesota IMPLAN Group, Inc.

Economic Data for Municipal Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Municipal	Postal service	398	$104.28	$71.00	$33.29	1,614	$82.48	$0.00
Municipal	Management of companies and enterprises	451	$97.58	$91.76	$5.81	688	$46.15	$0.74
Municipal	State and local government electric utilities	498	$92.43	$24.97	$67.46	252	$46.58	$0.24
Municipal	Management consulting services	444	$87.14	$67.08	$20.06	809	$37.47	$0.29
Municipal	Couriers and messengers	399	$84.33	$76.67	$7.66	998	$55.47	$1.29
Municipal	Other maintenance and repair construction	45	$80.87	$28.19	$52.68	1,375	$48.94	$0.47
Municipal	Investigation and security services	457	$80.78	$51.66	$29.13	2,558	$54.34	$1.28
Municipal	Data processing services	424	$80.65	$16.55	$64.10	479	$34.21	$0.44
Municipal	Advertising and related services	447	$80.00	$74.58	$5.42	632	$33.56	$0.56
Municipal	Child day care services	469	$77.03	$0.00	$77.03	2,981	$43.08	$0.51
Municipal	Waste management and remediation services	460	$75.07	$42.20	$32.88	481	$34.77	$2.76
Municipal	Scientific research and development services	446	$75.05	$57.67	$17.38	638	$38.15	$0.31
Municipal	All other municipal		$1,479.99	$459.64	$1,020.35	26,862	$721.51	$45.51

Based on year 2006 data from the Minnesota IMPLAN Group, Inc.

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