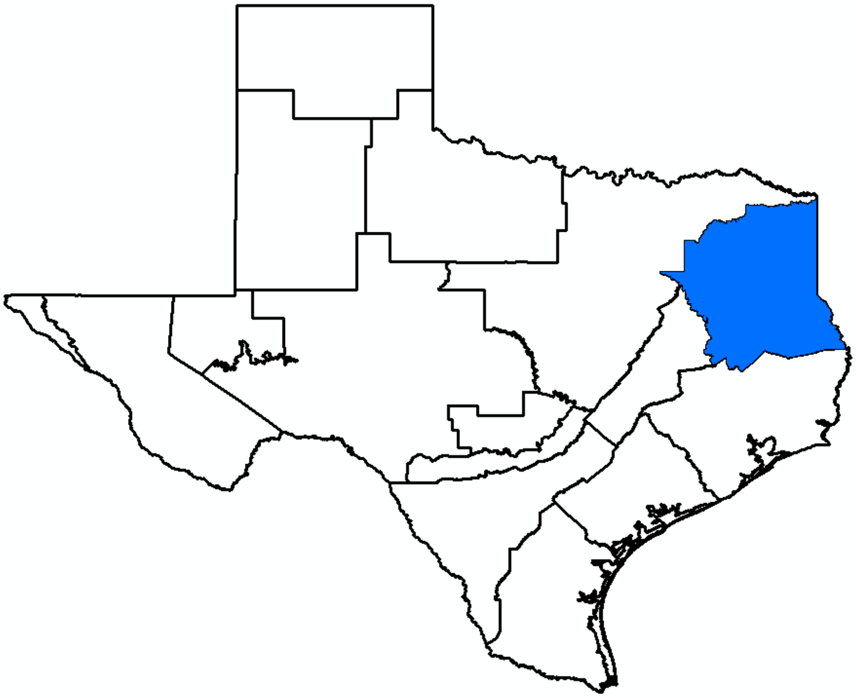
Desired Future Condition Explanatory Report (Final) Carrizo-Wilcox/Queen City/Sparta Aquifers for Groundwater Management Area 11



William R. Hutchison, Ph.D., P.E., P.G.
Independent Groundwater Consultant
9305 Jamaica Beach
Jamaica Beach, TX 77554
512-745-0599
billhutch@texasgw.com

August 24, 2021

Desired Future Condition Explanatory Report (Final) Carrizo-Wilcox/Queen City/Sparta Aquifers for Groundwater Management Area 11

Geoscientist and Engineering Seal

This report documents the work and supervision of work of the following licensed Texas Professional Geoscientist and licensed Texas Professional Engineers:

William R. Hutchison, Ph.D., P.E. (96287), P.G. (286)

Dr. Hutchison completed the analyses and model simulations described in this report, and was the principal author of the final report.

WILLIAM RAY HUTCHISON
96287

William R Hutchison
8/24/2021

WILLIAM R. HUTCHISON
GEOLOGY
286

William R Hutchison
8/24/2021

Table of Contents

List of Figures

List of Tables

List of Appendices

1.0 Groundwater Management Area 11

Groundwater Management Area 11 is one of sixteen groundwater management areas in Texas and covers a large portion of the northeast part of the state (Figure 1).

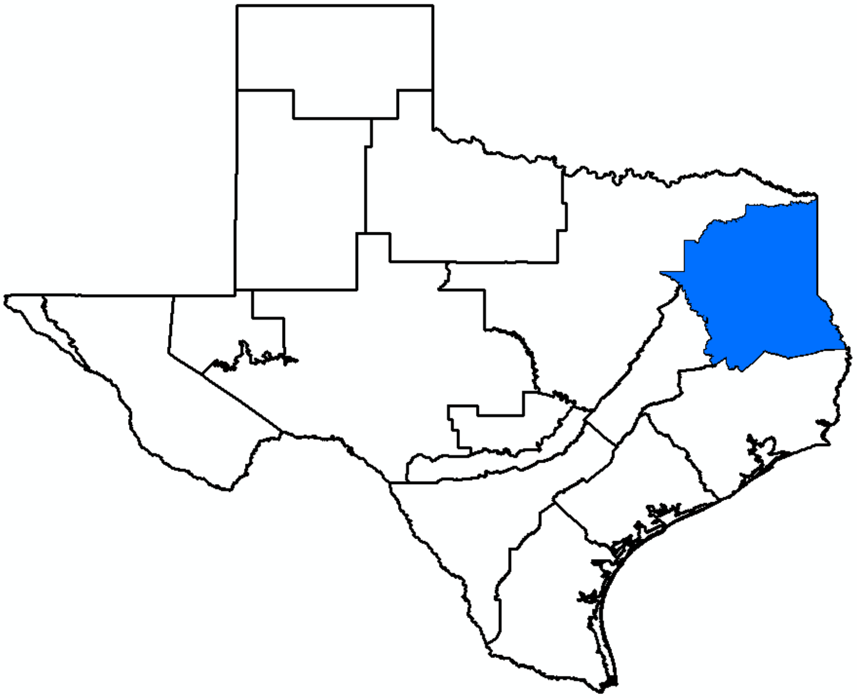
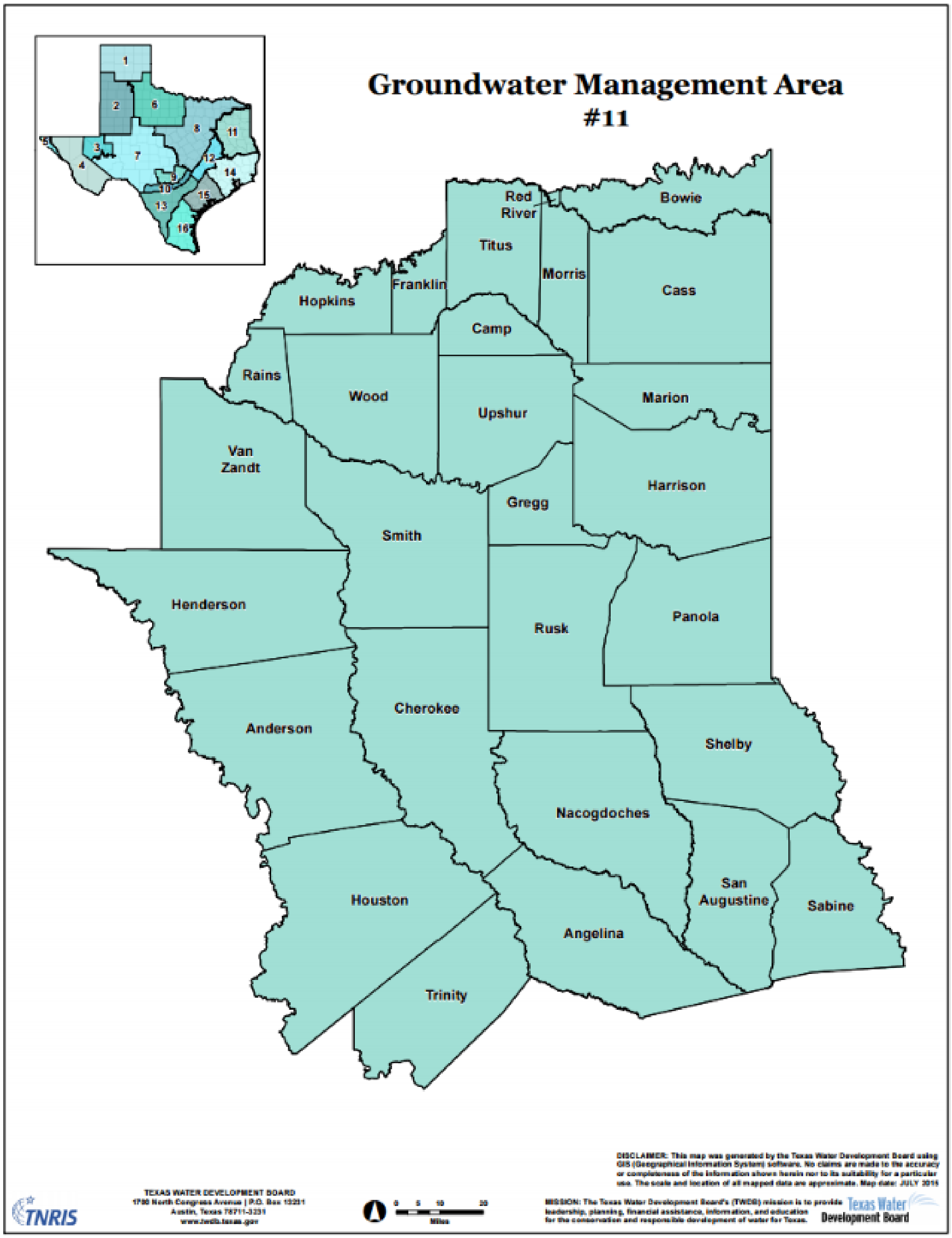


Figure 1. Groundwater Management Area 11

Groundwater Management Area 11 covers all or portions of the following counties: Anderson, Angelina, Bowie, Camp, Cass, Cherokee, Franklin, Gregg, Harrison, Henderson, Hopkins, Houston, Marion, Morris, Nacogdoches, Panola, Rains, Rusk, Sabine, San Augustine, Shelby, Smith, Titus, Trinity, Upshur, Van Zandt, and Wood (Figure 2).

There are four groundwater conservation districts in Groundwater Management Area 11: Neches & Trinity Valleys Groundwater Conservation District, Panola County Groundwater Conservation District, Pineywoods Groundwater Conservation District, and Rusk County Groundwater Conservation District (Figure 3).



DISCLAIMER: This map was generated by the Texas Water Development Board using GIS (Geographical Information System) software. No claims are made to the accuracy or completeness of the information shown herein nor to its suitability for a particular use. The scale and location of all mapped data are approximate. Map date: JULY 2015

TEXAS WATER DEVELOPMENT BOARD
1700 North Congress Avenue | P.O. Box 13231
Austin, Texas 78711-3231
www.twdb.texas.gov

MISSION: The Texas Water Development Board's (TWDB) mission is to provide leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas.

Figure 2. Counties Entirely or Partially in GMA 11 (from TWDB)

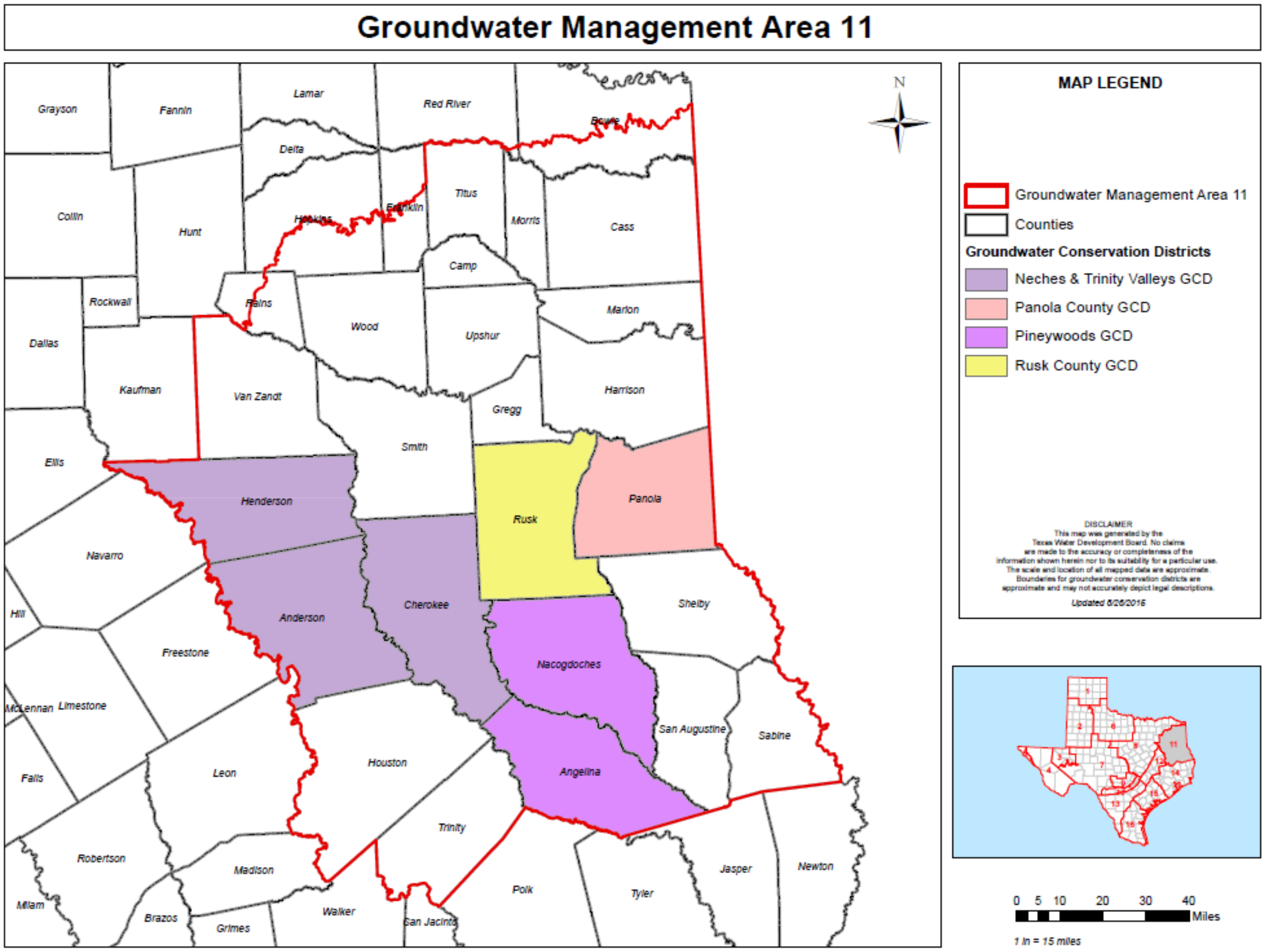


Figure 3. Groundwater Conservation Districts in GMA 11 (from TWDB)

2.0 Desired Future Condition History

2.1 Background

The joint planning process is a result of HB 1763 that was adopted by the Texas State Legislature in 2005. Every five years, groundwater conservation districts within a groundwater management area must adopt desired future conditions (DFCs) for relevant aquifers within the groundwater management area. Desired future conditions are defined as a quantified condition of groundwater at a specified time or times in the future. Once the desired future conditions are adopted, the Texas Water Development Board calculates the modeled available groundwater (MAG) for the aquifer, which is the amount of pumping that will achieve the desired future condition. The desired future condition is essentially a planning goal.

As a result of the definition of desired future condition (i.e. quantified condition), and the use of models to calculate the modeled available groundwater, groundwater availability models are an important aspect of developing desired future conditions. The Texas Water Development Board developed groundwater availability models for nearly all aquifers in the state. These are used by groundwater conservation districts and regional planning groups as tools to define groundwater availability. However, as with any model, there are limitations to their use. These limitations must be considered and understood when using the results or output from the model.

2.2 2010 Desired Future Conditions

In 2010, GMA 11 adopted desired future conditions for the Sparta, Queen City, and Carrizo-Wilcox aquifers. The desired future conditions were expressed in terms of average drawdown from 2000 to 2060. The overall average drawdown for GMA 11 for all aquifers was 17 feet. A table was also included in the desired future condition resolution that listed average drawdown for each county and each model layer unit. This table was generated from a simulation using the groundwater availability model of the area. This approach provided a means for the Texas Water Development Board to calculate modeled available groundwater values.

The use of average drawdown for purposes of developing desired future conditions is often confusing and misunderstood. Common misunderstandings include stating that the average drawdown is the same everywhere in the entire area of interest (i.e. county). Variations in pumping locations and amounts, and the natural variation of aquifer hydraulic conductivity and thickness will always result in varying drawdowns within the area of interest. In general, a regional average positive drawdown suggests that pumping has increased during the period of interest. Zero drawdown suggests that pumping is relatively constant. Negative drawdown suggests that there has been a pumping reduction. However, as is developed further in the technical memoranda that were developed as part of this proves, the presence of “negative drawdowns”, or groundwater level increases, are the result of model limitations.

In 2010, there were instances where simulated future pumping was less than historic pumping as defined in the calibrated model. This, as expected, resulted in groundwater level recoveries (i.e. negative drawdown). In other instances, (i.e. the Queen City Aquifer) pumping was significantly above historic amounts. The simulated pumping in the Queen City Aquifer is high (as compared to historic pumping) and was guided by evaluating the model output from alternative increases in pumping.

The development of the desired future conditions by GMA 11 in 2010 was based on evaluating a range of alternative model simulations and understanding the impacts of different amounts of pumping. During the development of the desired future condition in 2010, there was virtually no public input, despite numerous efforts to seek input from key stakeholders in GMA 11 by groundwater conservation district representatives.

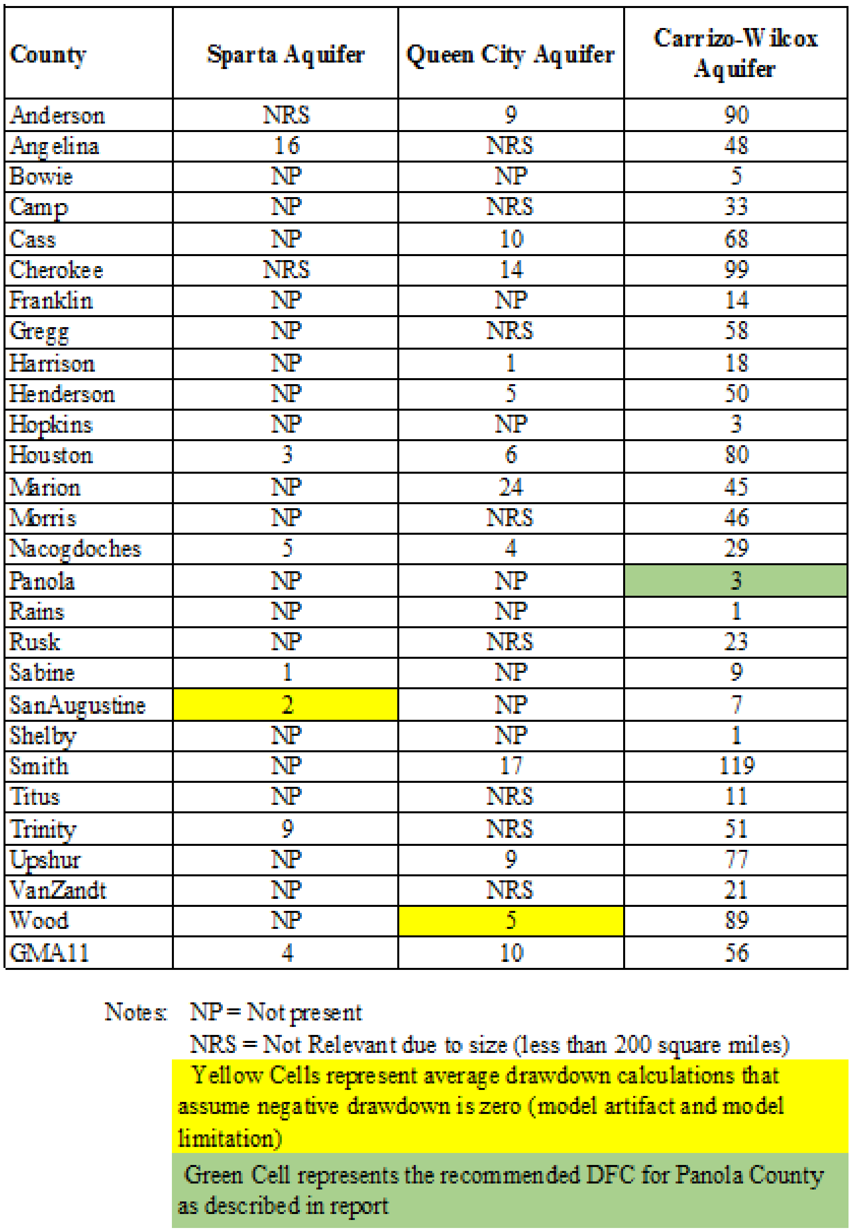
2.2 2016 Desired Future Conditions

In response to specific input from various stakeholders, the 2016 round of joint planning included integration of the planned Forestar project and all the recommended and alternative water management strategies in the regional water plans from Region D and Region I. This additional pumping was included as a base case, and the effects of decreasing and increasing the base pumping was evaluated.

The process also included a closer evaluation of the output of the model and addressing more fully the limitations of using the model to develop desired future conditions. A key objective of developing the base case was that all pumping was the same as or greater than historic pumping to reduce or eliminate planned groundwater level recoveries. However, as developed as described in the associated technical memoranda that were developed as part of this process, there continued to be instances of negative drawdown which are attributable to model limitations. Model limitations included recharge conceptualization problems and restrictions to the movement of groundwater from outcrop areas to downdip areas. These limitations resulted in rising groundwater levels in some of the outcrop areas.

The desired future conditions adopted in 2016 are summarized in Table 1. As described in the associated technical memorandum, the 2016 desired future conditions were expressed as average drawdown (in feet) from year 2000 conditions to 2070 conditions were largely based on GAM Scenario 4.

Table 1. Desired Future Conditions - Average Drawdown (ft) from 2000 to 2070



County	Sparta Aquifer	Queen City Aquifer	Carrizo-Wilcox Aquifer
Anderson	NRS	9	90
Angelina	16	NRS	48
Bowie	NP	NP	5
Camp	NP	NRS	33
Cass	NP	10	68
Cherokee	NRS	14	99
Franklin	NP	NP	14
Gregg	NP	NRS	58
Harrison	NP	1	18
Henderson	NP	5	50
Hopkins	NP	NP	3
Houston	3	6	80
Marion	NP	24	45
Morris	NP	NRS	46
Nacogdoches	5	4	29
Panola	NP	NP	3
Rains	NP	NP	1
Rusk	NP	NRS	23
Sabine	1	NP	9
SanAugustine	2	NP	7
Shelby	NP	NP	1
Smith	NP	17	119
Titus	NP	NRS	11
Trinity	9	NRS	51
Upshur	NP	9	77
VanZandt	NP	NRS	21
Wood	NP	5	89
GMA11	4	10	56

Notes: NP = Not present
NRS = Not Relevant due to size (less than 200 square miles)
Yellow Cells represent average drawdown calculations that assume negative drawdown is zero (model artifact and model limitation)
Green Cell represents the recommended DFC for Panola County as described in report

Based on an analysis of model output and model limitations, the output from the model was modified to develop the proposed desired future conditions as follows:

- Layers 2 and 4 (the confining units) were eliminated, and Table 1 includes only aquifer units. Areas that have no active cells are designated as NP (for not present).
- Layers 5, 6, 7, and 8 are combined, and a single drawdown value for the Carrizo-Wilcox Aquifer are listed
- All areas that are less than 200 square miles are eliminated (noted as NRS, or not relevant for purposes of joint planning due to size of area).

- Areas with negative drawdown that are greater than 200 square miles have had the negative drawdown cells eliminated from the average drawdown calculation, effectively assuming that those cells have a zero drawdown, and that the negative drawdown areas are a result of model limitations, as discussed (designated in yellow).
- The desired future condition in Panola County for the Carrizo-Wilcox Aquifer is listed as 3 feet. The actual average using all data from the model is 2 feet. If the areas with negative drawdown are assumed to be zero, the revised average is 4 feet. As presented at the March 22, 2016 GMA 11 meeting, Mr. Wade Oliver (representing the Panola County GCD) evaluated the average drawdown under Scenario 4 using an alternative analytical modeling approach and concluded that the drawdown was 3 feet. Thus, Mr. Oliver's result is consistent with the midpoint between the two GAM-based drawdown approaches.

2.3 2021 Desired Future Conditions

After considering the nine statutory factors, the groundwater conservation districts in Groundwater Management Area 11 voted to propose desired future conditions based on the Scenario 33 documented in Technical Memorandum 21-01 on April 28, 2021. After a public comment period, the groundwater conservation districts in Groundwater Management Area 11 discussed comments received and voted to adopt desired future conditions based on Scenario 33 documented in Technical Memorandum 21-01 on August 11, 2021. Appendix A is the resolution that was adopted by GMA 11 regarding the desired future conditions for the Carrizo-Wilcox, Queen City, and Sparta aquifers. Appendix A also includes the posted notices for the GMA 11 meeting.

As developed in the Technical Memorandum, the average drawdown from 2013 to 2080 for each county-aquifer unit are summarized in Table 2. Please note that the average drawdowns in Table 2 are generally higher than the previous desired future conditions that were adopted in 2010 and 2016. This is due to the updated GAM that has removed a limitation that caused unrealistic groundwater level increases due to the lack of ability for the model to move water from outcrop areas to downdip areas and issues with recharge conceptualization.

Also as documented in Technical Memoranda 20-05 and 21-01, the future pumping in Scenario 33 was less than the pumping assumed in 2010 and 2016 rounds of joint planning. This is also due to the improved model. As emphasized in Technical Memoranda 20-05 and 21-01, the pumping associated with the previous round of joint planning and the groundwater availability in the Region D and Region I water plans cannot be sustained with the assumed geographic distribution of pumping used in the predictive scenario. Thus, these lower pumping amounts are less than the current groundwater availability values in the regional plans. These are not arbitrary reductions, nor are the reductions based on regulation. These pumping amounts reflect the results of an updated and improved groundwater model to make such predictions.

Table 2. Desired Future Conditions for Each County-Aquifer Unit in GMA 11 Expressed at Average Drawdown from 2013 to 2080 (ft)

County	2013-2080 Average Drawdown (ft) Scenario 33, TM 21-01		
	Sparta Aquifer	Queen City Aquifer	Carrizo-Wilcox Aquifer
Anderson	30	44	155
Angelina	6	28	67
Bowie			12
Camp		11	85
Cass	66	34	79
Cherokee	7	31	176
Franklin			102
Gregg		49	109
Harrison		41	26
Henderson		33	106
Hopkins			61
Houston	3	12	86
Marion	123	32	32
Morris		39	78
Nacogdoches	7	22	73
Panola			21
Rains			17
Rusk	26	17	86
Sabine	1	3	9
San Augustine	2	7	22
Shelby	18	12	17
Smith	121	132	265
Titus		9	66
Trinity	5	18	56
Upshur	10	30	149
Van Zandt		73	55
Wood	9	16	122

3.0 Policy Justification

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

- Aquifer uses and conditions within Groundwater Management Area 11
- Water supply needs and water management strategies included in the 2021 Regional Water Plans
- Hydrologic conditions within Groundwater Management Area 11 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 11 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 11.

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.

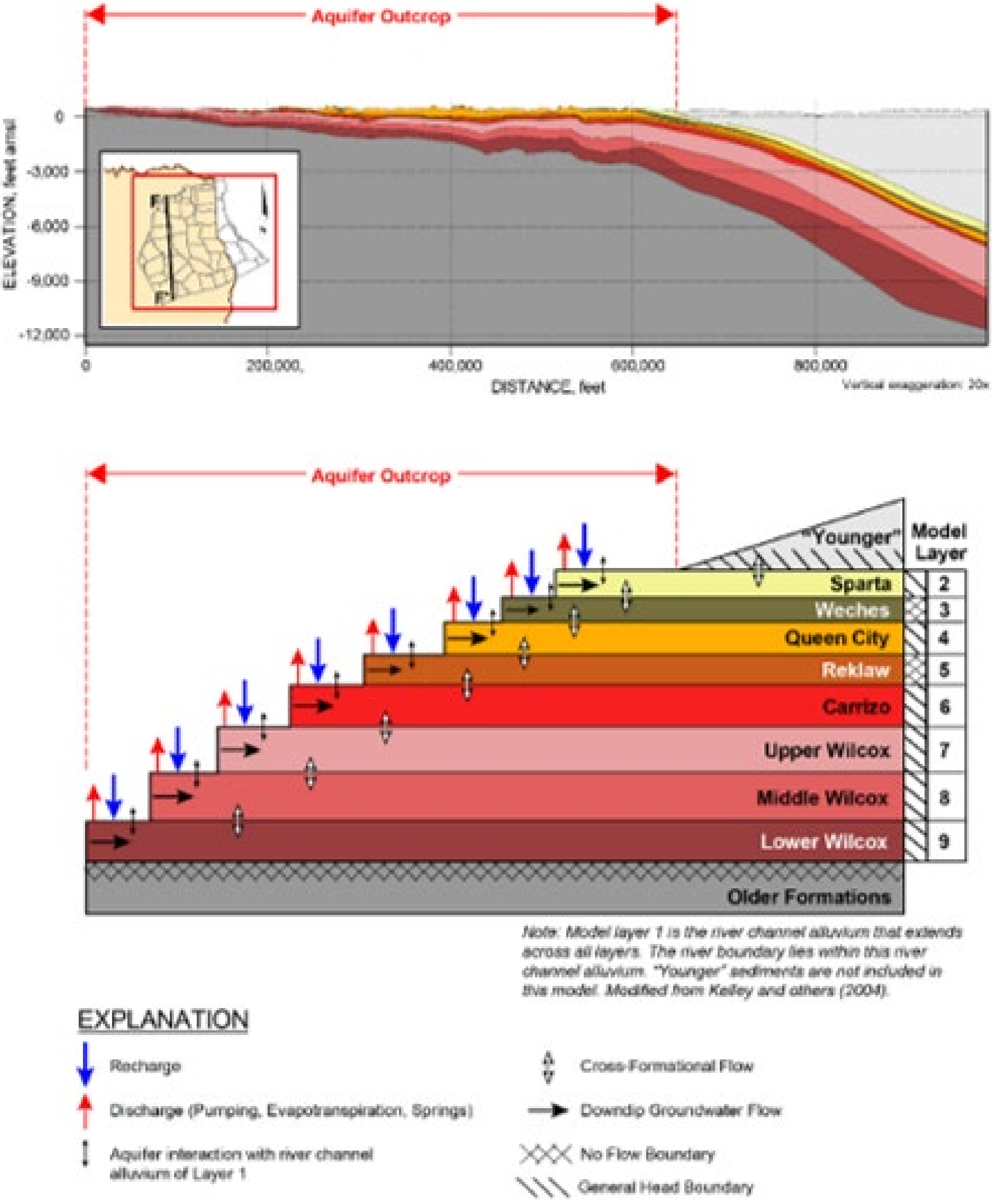
4.0 Technical Justification

4.1 Groundwater Availability Model

The desired future conditions for the Carrizo-Wilcox/Queen City/Sparta Aquifers were developed based on simulations of alternative scenarios of future pumping using the Groundwater Availability Model (GAM) of the northern Carrizo-Wilcox, Queen City, and Sparta aquifers (Panday and others, 2020). This updated GAM superseded the previous GAM of the northern Carrizo-Wilcox Aquifer (Kelley and others, 2004) that was used to support the joint planning process in 2010 and 2016. The calibration period for the GAM was 1980 to 2013.

The updated GAM was the first one developed with the objective of supporting the joint planning process. Previous GAMs of the area were developed prior to the adoption of HB 1763 in 2005 and were used as a default tool. Part of the development of the updated GAM included running predictive simulations to evaluate its use in the joint planning process. Specifically, the initial predictive simulations included testing various levels of constant pumping from 2014 to 2080 and various levels of constant recharge from 2014 to 2080. These simulations demonstrated that the updated GAM would reach an equilibrium condition and, thus, would not suffer from the problems of rising groundwater levels like the older GAM.

Conceptually, the model simulates groundwater flow in nine layers as shown in Figure 4. Due to the vertical interaction between aquifer units that is simulated in the GAM, the proposed desired future condition for all three aquifers were developed together.



Note: Model layer 1 is the river channel alluvium that extends across all layers. The river boundary lies within this river channel alluvium. "Younger" sediments are not included in this model. Modified from Kelley and others (2004).

Figure 4. Conceptual Model of Flow (from Panday and others, 2020, Figure 2.0-2)

4.2 Use of the Groundwater Availability Model in the Joint Planning Process

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). In GMA 11, several model runs were completed, 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 interactive or 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 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 *science* 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 numerical "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.

5.0 Factor Consideration

Section 36.108(d) of the Texas Water Code requires that groundwater conservation districts include documentation of how nine listed factors were considered prior to proposing a desired future condition, and how the proposed desired future condition impact each factor. This section of the explanatory report summarizes the information that the groundwater conservation districts used in its deliberations and discussions.

5.1 Aquifer Uses and Conditions

For purposes of joint planning, the aquifer uses, and conditions primarily relied on data and estimates from Panday and others (2020) rather than TWDB pumping estimates that had been used in previous rounds of joint planning.

During the development of the updated GAM, Panday and others (2020) identified limitations in the datasets associated with the TWDB pumping estimates. In many instances, using the TWDB pumping estimates were found to be unreliable. Specifically, TWDB pumping data did not show a general trend between 1980 and 2013 while groundwater levels showed declines. Groundwater data were deemed more reliable because they are directly measured values. In contrast, the TWDB groundwater pumping estimates are derived from indirect methods. In addition, the method of estimation appeared to change after 1999. The uncertainty and general inconsistency led Panday and others (2020) to rely on the previous GAM and calibration methods to develop more robust pumping estimates based on historic groundwater level data. This method can be generally summarized to ensure that historic groundwater level declines are associated with increases in pumping. However, the approach was limited in that variations in groundwater elevations and pumping were relatively small during the calibration period.

5.2 Water Supply Needs and Water Management Strategies

The 2016 joint planning process used this factor as its primary consideration to ensure that the desired future conditions resulted in modeled available groundwater values that fully supported the regional planning process in Region D and Region I.

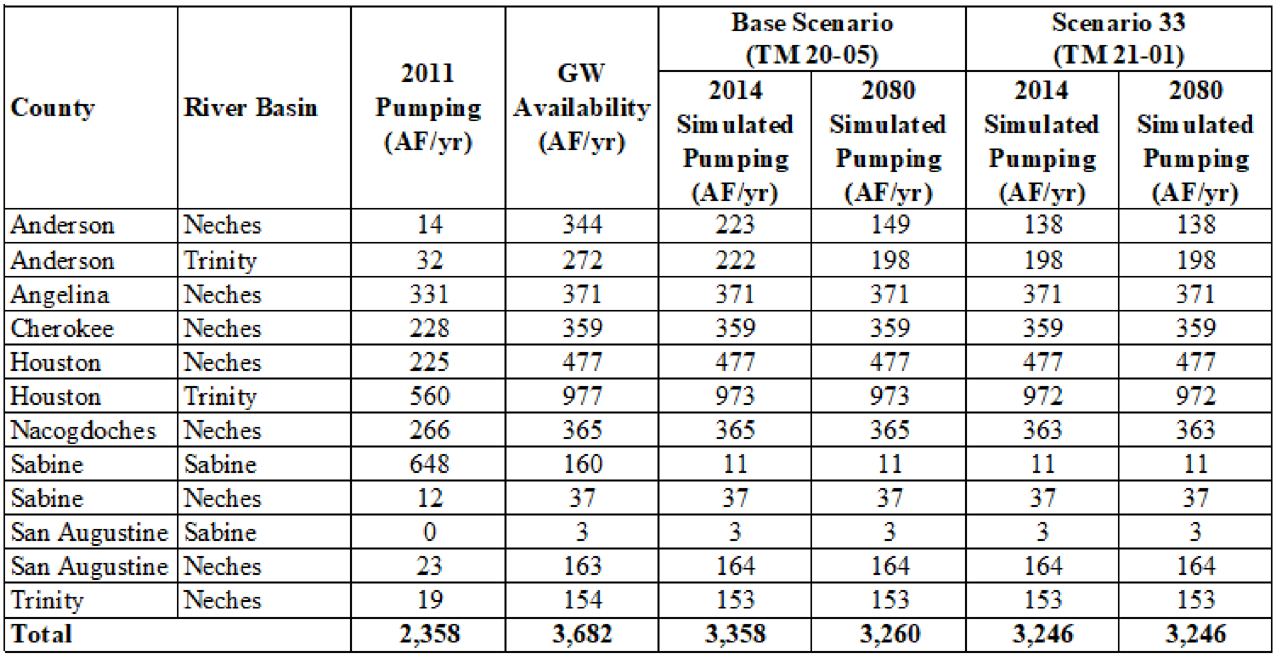
Technical Memorandum 20-03 documented the comparison of 2016 modeled available groundwater values and the recently released 2020 groundwater availability values in the initially prepared regional plans of Region D and Region I. As developed in Technical Memorandum 20-03 and based on the objective to fully support the regional planning process, the groundwater availability values formed the basis for the simulations in this round of joint planning.

As discussed in Technical Memorandum 20-05, however, the results of the updated GAM shows that these pumping amounts are not sustainable under the assumed geographic distribution of wells in the simulation. As noted earlier, these are not arbitrary reductions, nor are the reductions based on regulation. These pumping amounts reflect the results of an updated and improved groundwater model to make such predictions.

5.2.1 Sparta Aquifer

Table 3 summarizes the pumping for the Sparta Aquifer from Technical Memorandum 20-06.

Table 3. Sparta Aquifer Pumping Summary

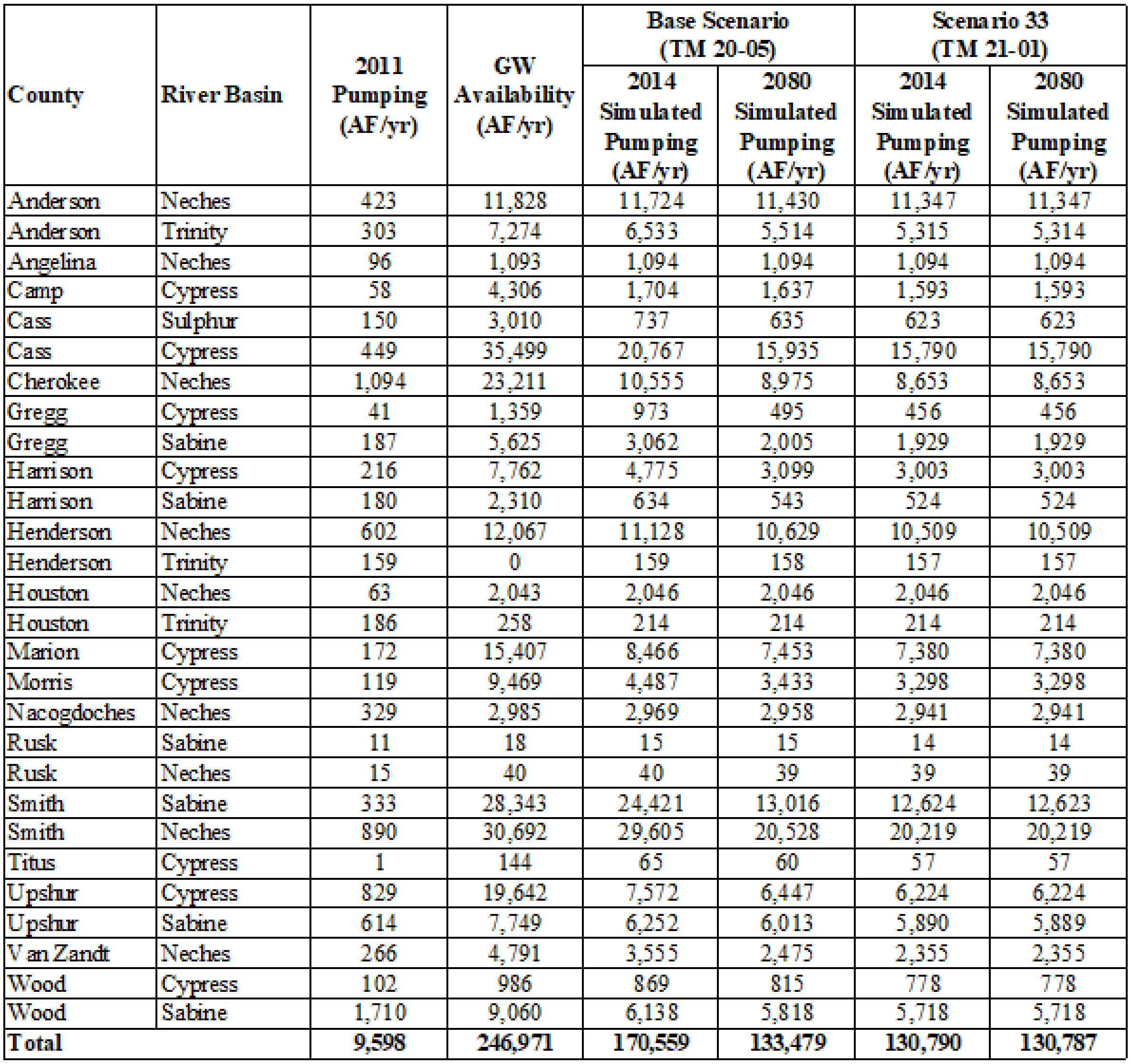


County	River Basin	2011 Pumping (AF/yr)	GW Availability (AF/yr)	Base Scenario (TM 20-05)		Scenario 33 (TM 21-01)	
				2014 Simulated Pumping (AF/yr)	2080 Simulated Pumping (AF/yr)	2014 Simulated Pumping (AF/yr)	2080 Simulated Pumping (AF/yr)
Anderson	Neches	14	344	223	149	138	138
Anderson	Trinity	32	272	222	198	198	198
Angelina	Neches	331	371	371	371	371	371
Cherokee	Neches	228	359	359	359	359	359
Houston	Neches	225	477	477	477	477	477
Houston	Trinity	560	977	973	973	972	972
Nacogdoches	Neches	266	365	365	365	363	363
Sabine	Sabine	648	160	11	11	11	11
Sabine	Neches	12	37	37	37	37	37
San Augustine	Sabine	0	3	3	3	3	3
San Augustine	Neches	23	163	164	164	164	164
Trinity	Neches	19	154	153	153	153	153
Total		**2,358**	**3,682**	**3,358**	**3,260**	**3,246**	**3,246**

5.2.2 Queen City Aquifer

Table 4 6 summarizes the pumping for the Queen City Aquifer from Technical Memorandum 20-06.

Table 4. Queen City Aquifer Pumping Summary



County	River Basin	2011 Pumping (AF/yr)	GW Availability (AF/yr)	Base Scenario (TM 20-05)		Scenario 33 (TM 21-01)	
				2014 Simulated Pumping (AF/yr)	2080 Simulated Pumping (AF/yr)	2014 Simulated Pumping (AF/yr)	2080 Simulated Pumping (AF/yr)
Anderson	Neches	423	11,828	11,724	11,430	11,347	11,347
Anderson	Trinity	303	7,274	6,533	5,514	5,315	5,314
Angelina	Neches	96	1,093	1,094	1,094	1,094	1,094
Camp	Cypress	58	4,306	1,704	1,637	1,593	1,593
Cass	Sulphur	150	3,010	737	635	623	623
Cass	Cypress	449	35,499	20,767	15,935	15,790	15,790
Cherokee	Neches	1,094	23,211	10,555	8,975	8,653	8,653
Gregg	Cypress	41	1,359	973	495	456	456
Gregg	Sabine	187	5,625	3,062	2,005	1,929	1,929
Harrison	Cypress	216	7,762	4,775	3,099	3,003	3,003
Harrison	Sabine	180	2,310	634	543	524	524
Henderson	Neches	602	12,067	11,128	10,629	10,509	10,509
Henderson	Trinity	159	0	159	158	157	157
Houston	Neches	63	2,043	2,046	2,046	2,046	2,046
Houston	Trinity	186	258	214	214	214	214
Marion	Cypress	172	15,407	8,466	7,453	7,380	7,380
Morris	Cypress	119	9,469	4,487	3,433	3,298	3,298
Nacogdoches	Neches	329	2,985	2,969	2,958	2,941	2,941
Rusk	Sabine	11	18	15	15	14	14
Rusk	Neches	15	40	40	39	39	39
Smith	Sabine	333	28,343	24,421	13,016	12,624	12,623
Smith	Neches	890	30,692	29,605	20,528	20,219	20,219
Titus	Cypress	1	144	65	60	57	57
Upshur	Cypress	829	19,642	7,572	6,447	6,224	6,224
Upshur	Sabine	614	7,749	6,252	6,013	5,890	5,889
Van Zandt	Neches	266	4,791	3,555	2,475	2,355	2,355
Wood	Cypress	102	986	869	815	778	778
Wood	Sabine	1,710	9,060	6,138	5,818	5,718	5,718
Total		**9,598**	**246,971**	**170,559**	**133,479**	**130,790**	**130,787**

5.2.3 Carrizo-Wilcox Aquifer

Table 5 summarizes the pumping for the Carrizo-Wilcox Aquifer from Technical Memorandum 20-06.

Table 5. Carrizo-Wilcox Aquifer Pumping Summary

County	River Basin	2011 Pumping (AF/yr)	GW Availability (AF/yr)	Base Scenario (TM 20-05)		Scenario 33 (TM 21-01)	
				2014 Simulated Pumping (AF/yr)	2080 Simulated Pumping (AF/yr)	2014 Simulated Pumping (AF/yr)	2080 Simulated Pumping (AF/yr)
Anderson	Neches	2,143	23,335	23,303	21,979	21,949	21,949
Anderson	Trinity	3,479	5,753	5,354	5,067	5,062	5,062
Angelina	Neches	25,214	27,591	27,592	27,592	27,592	27,592
Bowie	Sulphur	3,230	9,872	9,668	9,662	9,657	9,657
Camp	Cypress	1,323	4,050	3,997	3,770	3,766	3,766
Cass	Sulphur	856	2,864	775	775	775	775
Cass	Cypress	2,895	15,159	12,856	12,856	12,856	12,856
Cherokee	Neches	9,617	20,933	20,672	15,379	15,277	15,277
Franklin	Sulphur	202	2,021	883	477	432	432
Franklin	Cypress	454	7,765	6,404	5,586	5,551	5,551
Gregg	Cypress	274	862	863	729	728	728
Gregg	Sabine	2,959	7,179	6,850	5,412	5,348	5,347
Harrison	Cypress	2,462	6,183	4,749	4,635	4,635	4,635
Harrison	Sabine	2,113	4,851	4,702	4,469	4,457	4,457
Henderson	Neches	3,582	6,036	5,987	3,991	3,988	3,988
Henderson	Trinity	4,014	0	3,790	3,226	3,209	3,209
Hopkins	Sulphur	1,521	7,228	3,708	2,116	1,995	1,995
Hopkins	Cypress	102	313	313	294	292	292
Hopkins	Sabine	1,124	2,842	2,778	2,517	2,483	2,483
Houston	Neches	1,468	22,488	1,720	1,720	1,720	1,720
Houston	Trinity	5,139	3,806	634	634	634	634
Marion	Cypress	1,834	2,726	1,967	1,967	1,967	1,967
Morris	Sulphur	273	402	401	401	401	401
Morris	Cypress	1,013	2,166	2,161	2,154	2,154	2,154
Nacogdoches	Neches	17,949	24,181	21,171	20,880	20,855	20,855
Panola	Sabine	5,184	8,370	4,957	4,957	4,957	4,957
Rains	Sabine	700	1,839	1,584	1,462	1,433	1,433
Rusk	Sabine	3,355	9,068	8,897	6,989	6,936	6,936
Rusk	Neches	3,958	11,769	8,939	7,114	7,091	7,091
Sabine	Sabine	1,822	3,249	1,030	1,029	1,027	1,027
Sabine	Neches	254	356	355	355	355	355
San Augustine	Sabine	197	290	290	288	287	287
San Augustine	Neches	2,342	1,149	304	304	303	303
Shelby	Sabine	5,095	8,317	3,869	3,702	3,691	3,691
Shelby	Neches	496	2,577	2,577	2,577	2,577	2,577
Smith	Sabine	3,538	13,246	12,941	7,936	7,931	7,931
Smith	Neches	12,618	22,705	22,410	17,592	17,592	17,592
Titus	Sulphur	584	2,838	2,479	2,084	1,973	1,973
Titus	Cypress	1,299	7,252	6,790	5,497	5,411	5,410
Trinity	Neches	32	269	266	266	266	266
Trinity	Trinity	1	0	1	1	1	1
Upshur	Cypress	4,416	5,442	5,441	5,122	5,106	5,106
Upshur	Sabine	1,273	1,689	1,690	1,551	1,549	1,549
Van Zandt	Sabine	2,779	4,767	3,801	3,352	3,287	3,287
Van Zandt	Neches	1,198	4,317	4,095	2,635	2,618	2,618
Van Zandt	Trinity	910	1,384	1,251	1,095	1,050	1,050
Wood	Cypress	320	2,053	1,870	930	924	924
Wood	Sabine	5,556	19,404	18,931	16,971	16,919	16,919
Total		**153,167**	**342,956**	**288,066**	**252,097**	**251,067**	**251,065**

5.3 Hydrologic Conditions within Groundwater Management Area 11

As required by statute, the groundwater conservation districts in Groundwater Management Area 11 considered total estimated recoverable storage, average annual recharge, inflows, and discharge prior to adopting a proposed desired future condition.

5.3.1 Total Estimated Recoverable Storage

As required by statute, the Texas Water Development Board provided the groundwater conservation districts in Groundwater Management Area 11 with estimates of total recoverable storage (Wade and others, 2014). This report is included as Appendix B. Please note that these estimates are based on the outdated GAM. TWDB has not yet updated these estimates with the updated GAM.

A summary of total storage and the estimated range of recoverable storage for the three aquifers is presented in Table 6

Table 6. Summary of Total Storage and the Estimated Range of Recoverable Storage

Aquifer	Total Storage (million acre-feet)	Estimated Range of Recoverable Storage (million acre-feet)
Sparta	55.3	13.8 to 41.5
Queen City	142.0	35.5 to 106.5
Carrizo-Wilcox	2,070.6	517.7 to 1,553.0

These estimates are essentially the sum of three components: 1) the outcrop area, 2) the artesian portion of the downdip area, and 3) the saturated portion of the downdip area. The storage estimates were developed from the previous groundwater availability model of the area (Kelley and others, 2004)

In the outcrop area, the saturated thickness is the 1999 groundwater elevation minus the aquifer bottom elevation for each model cell. In each cell, the storage is then calculated as the saturated thickness times the area (640 acres) times the specific yield. The model estimates specific yield as either 0.1 or 0.15 depending on the specific cell. These cell storage values are then summed to arrive at a total storage for the Carrizo-Wilcox outcrop areas of 114 million acre-feet.

In the artesian portion of the downdip, the artesian zone thickness is the difference between the 1999 groundwater elevation and the elevation of the top of the aquifer. In each cell, the artesian storage is calculated as the artesian zone thickness times the area (640 acres) times the storativity. Storativity values range between 7.3E-05 to 9.93E-03. Total artesian zone storage is 65 million acre-feet for the Carrizo-Wilcox Aquifer.

In the saturated portion of the downdip area, saturated thickness is calculated differently depending on whether the head is above or below the top of the aquifer. If the head is below the top of the aquifer, the saturated thickness is the difference between the 1999 groundwater elevation and the elevation of the bottom of the aquifer. If the head is above the top of the aquifer, the saturated thickness is the thickness of the aquifer. The storage is then calculated as the saturated zone thickness times the area (640 acres) times the specific yield. The specific yield is either 0.1 or 0.15 depending on the layer. Total storage in the saturated portion of the downdip area is calculated to be 1,879 million acre-feet.

A key parameter in these calculations is the specific yield in the downdip portion of the aquifer. In most cases, the model's estimate of specific yield in the downdip area is never "used" in model. 23,320 cells of the 58,269 cells in the downdip area have an artesian head of over 500 feet, which is about 40 percent of the cells in the model. Unless heads drop below the top of the aquifer, these parameters are simply place holders, and were never calibrated.

In general, a specific yield values of 0.1 to 0.15 is representative of a clean sand. As drilling and electric logs show, interlayered sands and clays are common in the Carrizo-Wilcox. The model has thick layers (about 24 percent of the cells are over 500 feet thick). Thick cells increase the chance of interbedded clay, and this would result in reduced specific yield estimates. Although the higher specific yield values may be appropriate for individual sand units, the thicker layers increase the chance that the overall specific yield value is lower than the place-holder value in the model input files.

If the calculation is made with a specific yield value of 0.001 to reflect the interbedded clays, the total storage for the saturated portion of the downdip area is 188 million acre-feet (as compared to 1,879 million acre-feet reported by the TWDB).

When the model was developed in 2004, it is doubtful that the developers considered the possibility of using the model to calculate total aquifer storage, and simply used place holder values. As described in the technical memoranda and summarized above, the problems with future simulations in the outcrop area may be due flat gradients that restrict flow from the outcrop area to the downdip area. This restriction may be the result of underestimated drawdown due to pumping or drought conditions. If the specific yield were reduced in these areas, gradient might improve conditions to model water into the downdip area and prevent unrealistic increases in outcrop storage during the calibration period of the GAM.

In summary, the total estimated recoverable storage may be overestimated by one or two orders of magnitude, as evidenced by limitations of the GAM.

5.3.2 Average Annual Recharge, Inflows and Discharge

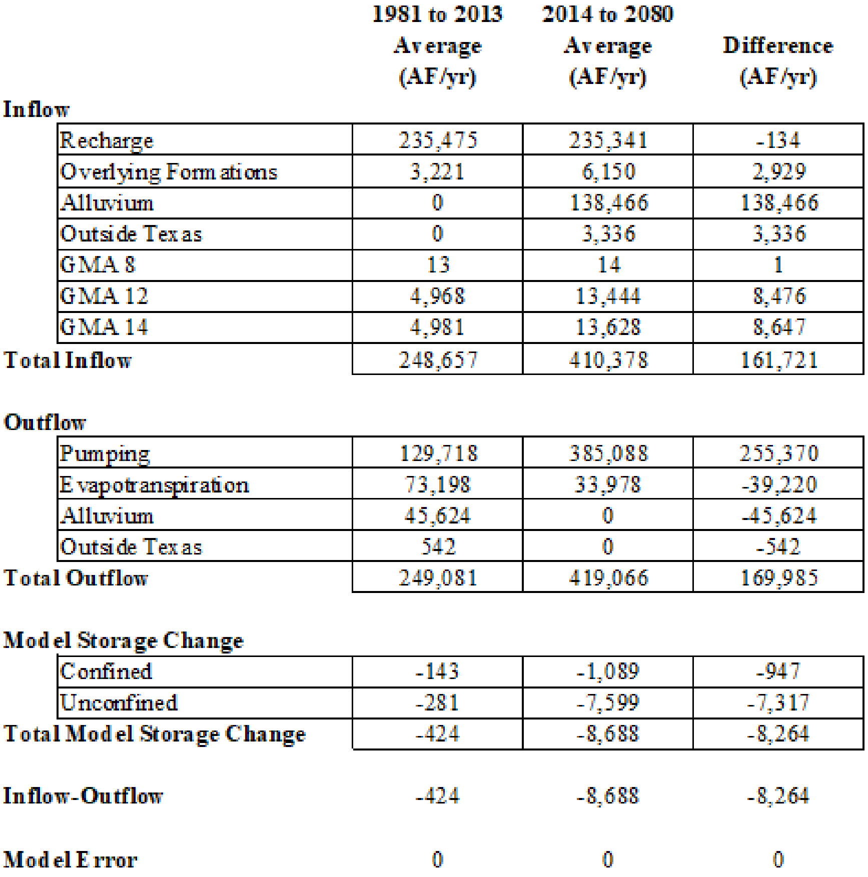
As documented in Technical Memorandum 21-01, the updated GAM was used to develop groundwater budgets of the historic period and the groundwater budget of the predictive simulation that is the basis of the desired future condition.

A groundwater budget is an accounting of all inflow components, all outflow components, and storage changes for a given area over a specified time period. For purposes of this analysis, the groundwater budget of the calibrated model (1980 to 2013) is compared to the groundwater budget of the base predictive simulation (2014 to 2080) to assess the source of the increased pumping simulated in the base predictive simulation.

When pumping is increased, the initial response is storage reduction. However, over an extended period, pumping will induce inflow and capture natural outflow. The pumping increases associated with the predictive simulation are discussed above. This analysis provides insight as to the source of that increased pumping.

The two groundwater budgets are presented in Table 7.

Table 7. Groundwater Budget Summary for GMA 11

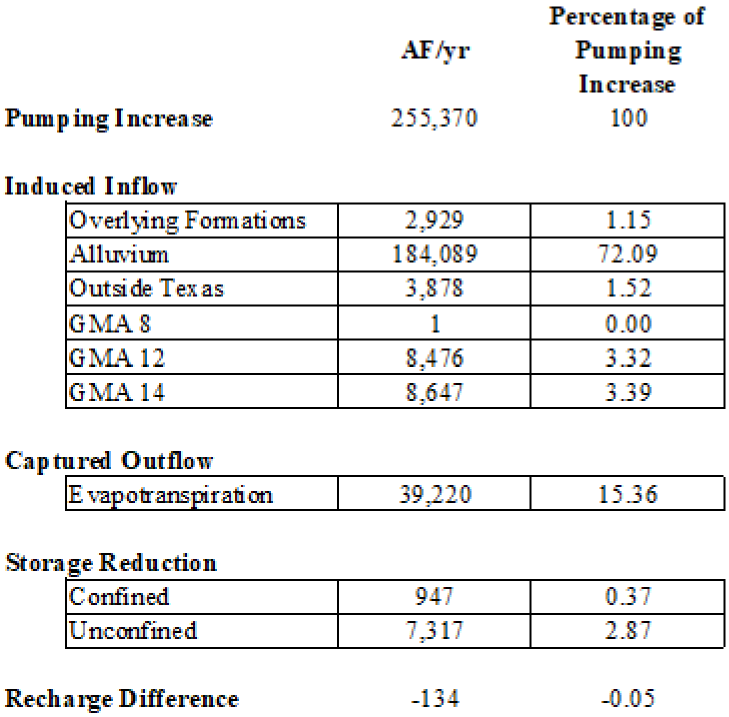


	1981 to 2013 Average (AF/yr)	2014 to 2080 Average (AF/yr)	Difference (AF/yr)
Inflow			
Recharge	235,475	235,341	-134
Overlying Formations	3,221	6,150	2,929
Alluvium	0	138,466	138,466
Outside Texas	0	3,336	3,336
GMA 8	13	14	1
GMA 12	4,968	13,444	8,476
GMA 14	4,981	13,628	8,647
Total Inflow	248,657	410,378	161,721
Outflow			
Pumping	129,718	385,088	255,370
Evapotranspiration	73,198	33,978	-39,220
Alluvium	45,624	0	-45,624
Outside Texas	542	0	-542
Total Outflow	249,081	419,066	169,985
Model Storage Change			
Confined	-143	-1,089	-947
Unconfined	-281	-7,599	-7,317
Total Model Storage Change	-424	-8,688	-8,264
Inflow-Outflow	-424	-8,688	-8,264
Model Error	0	0	0

5.4 Other Environmental Impacts, Including Spring Flow and Other Interactions between Groundwater and Surface Water

The impacts of increased pumping are documented in Technical Memorandum 21-01 by evaluating groundwater budgets as described above. Please note that the predictive scenario simulates average pumping that is over 250,000 AF/yr above the historic period. The differences in other components are useful to understand the source of the increased pumping and are summarized in Table 8.

Table 8. Summary of Sources of Increased Pumping



		AF/yr	Percentage of Pumping Increase
Pumping Increase		255,370	100
Induced Inflow			
	Overlying Formations	2,929	1.15
	Alluvium	184,089	72.09
	Outside Texas	3,878	1.52
	GMA 8	1	0.00
	GMA 12	8,476	3.32
	GMA 14	8,647	3.39
Captured Outflow			
	Evapotranspiration	39,220	15.36
Storage Reduction			
	Confined	947	0.37
	Unconfined	7,317	2.87
Recharge Difference		-134	-0.05

Based on these results, 72 percent of the increased pumping is derived from the alluvium, and ultimately, from surface water. About 15 percent of the pumping is from decreased evapotranspiration. Only about 3 percent of the pumping is sourced from groundwater storage.

5.5 Subsidence

Subsidence has not been an issue historically in these aquifers. The Texas Water Development Board Subsidence Prediction Tool was used to assess the risk of subsidence in the future. This tool provides an overall risk score (0 is low risk and 10 is high risk). The application of this tool assumed the highest drawdown listed in Table 2 for each of the aquifers covered in this explanatory report.

For the Sparta Aquifer, it was assumed that the drawdown from 2010 to 2080 was 30 feet from Table 2 (Anderson County). The risk score was 3.91 and the predicted subsidence was 0.00 feet in 2080.

For the Queen City Aquifer, it was assumed that the drawdown from 2010 to 2080 was 132 feet from Table 2 (Smith County). The risk score was 4.22 and the predicted subsidence was 4.22 and the predicted subsidence in 2080 is 0.00 feet.

For the Carrizo-Wilcox Aquifer, it was assumed that the drawdown from 2010 to 2080 was 176 feet from Table 2 (Cherokee County). The risk score was 4.53 and the predicted subsidence was 0.16 feet in 2080.

5.6 Socioeconomic Impacts

The Texas Water Development Board prepared reports on the socioeconomic impacts of not meeting water needs for each of the Regional Planning Groups during development of the 2021 Regional Water Plans. Because the development of this desired future condition used the State Water Plan demands and water management strategies as an important foundation, it is reasonable to conclude that the socioeconomic impacts associated with this proposed desired future condition can be evaluated in the context of not meeting the listed water management strategies. Groundwater Management Area 11 is covered by Regional Planning Groups D and I. The socioeconomic impact reports for Regions D and I in Appendix C.

5.7 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 11 in groundwater is recognized under Texas Water Code Section 36.002.

The desired future conditions adopted by GMA 11 are consistent with protecting property rights of landowners who are currently pumping groundwater and landowners who have chosen to conserve groundwater by not pumping. In the 2016 DFC, all current and projected uses (as defined in the Region D plan and the Region I plan as well as the Forestar project) were included in Scenario 4 (the basis for the desired future condition). The increase in pumping associated with meeting the water management strategies will cause impacts to exiting well owners and to surface water.

The simulations with the new GAM demonstrated that the simulated pumping in the previous Scenario 4 was not possible to sustain due to limitations with the previous GAM. A more appropriate and sustainable increase in pumping was developed during the 2021 round of joint planning. The simulated increase in pumping will cause impacts to exiting well owners and to surface water. However, as required by Chapter 36 of the Water Code, GMA 11 considered these impacts and balanced them with the increasing demand of water in the GMA 11 area, and concluded that, on balance and with appropriate monitoring and project specific review during the permitting process, a pumping increase from about 130,000 AF/yr to about 385,000 AF/yr can be included in the desired future condition.

5.8 Feasibility of Achieving the Desired Future Condition

Groundwater levels are routinely monitored by the districts and by the TWDB in GMA 11. Evaluating the monitoring data is a routine task for the districts, and the comparison of these data with the desired future condition and model results that were used to develop the DFCs is covered in each district's management plan. These comparisons will be useful to guide the update of the DFCs that are required every five years.

Monitoring data must be interpreted with respect to changes in recharge conditions, changes in streamflow, and changes in pumping. An example of this was discussed at the GMA 11 meeting of August 11, 2021. The issue was raised by Pineywoods Groundwater Conservation District during the public comment period. At issue was the data collected from a Sparta Aquifer monitoring well in Angelina County (Well 37-44-403). A hydrograph (Figure 5) comparing drawdown from 1980 using actual data, calibrated model results, and the predictive run that was the basis for the desired future conditions (Run 33).

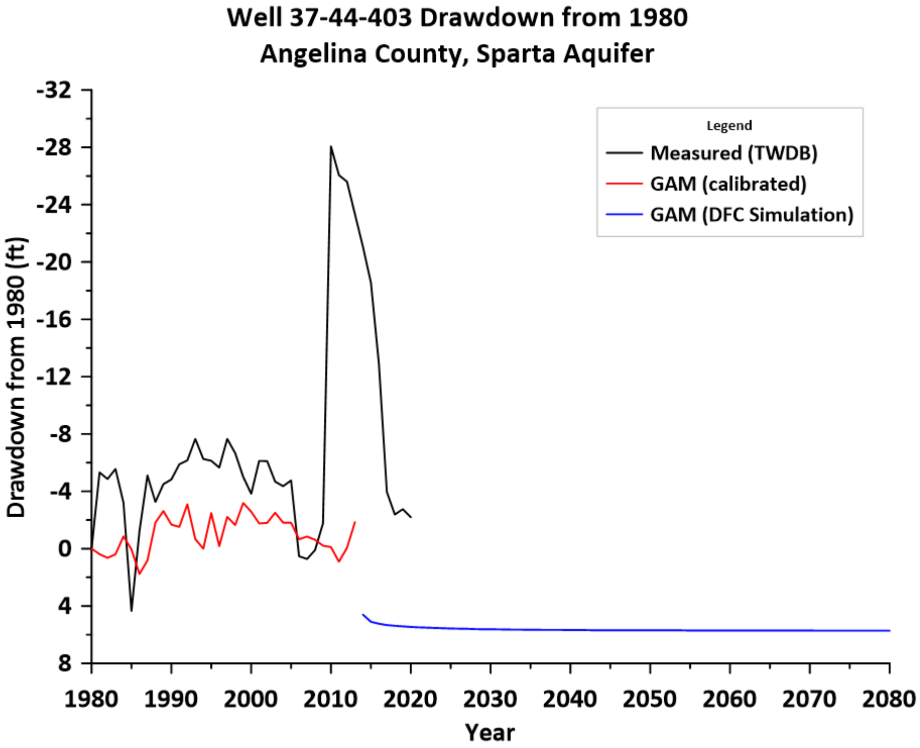


Figure 5. Comparison of Drawdown, Sparta Aquifer Well in Angelina County

Please note that there is an unexplained rise in the groundwater level in the measured data from about 2010 to about 2020. The groundwater level appears to have returned to a more historic level. Also, please note that the measured drawdown and calibrated GAM drawdown is in reasonably close agreement. The predicted drawdown is significantly higher than the calibrated model (about 6 feet). This is due to the assumed increase in groundwater pumping. The predictive simulation assumed a constant pumping of 371 AF/yr in the Sparta Aquifer in Angelina County. The predictive simulation starts in 2014, and the 2013 pumping in the Sparta Aquifer in Angelina County was 284 AF/yr, so this represents about a 30 percent increase in pumping that will result in drawdown. Predicted drawdown at the location of this well (cell 315040) is about 6 feet.

In the future, monitoring data will show fluctuations, some of which will be attributable to increased pumping or decreased pumping, some of which will be attributable to changes in recharge (wet years and dry years), and some of which will be attributable to streamflow given the intimate link between surface water and groundwater in this area. In order to provide some perspective to a wide range of interpretations that may be advanced to explain variations in groundwater level monitoring data in the future, a series of cross plots were developed from results from the calibrated model.

Figure 6 presents the relationship between Sparta Aquifer pumping in Angelina County and the drawdown in the well.

Please note that the r^2 value for the linear relationship is 0.40, which means that 40% of the variability in the drawdown results can be explained by variability in Angelina County pumping from the Sparta Aquifer.

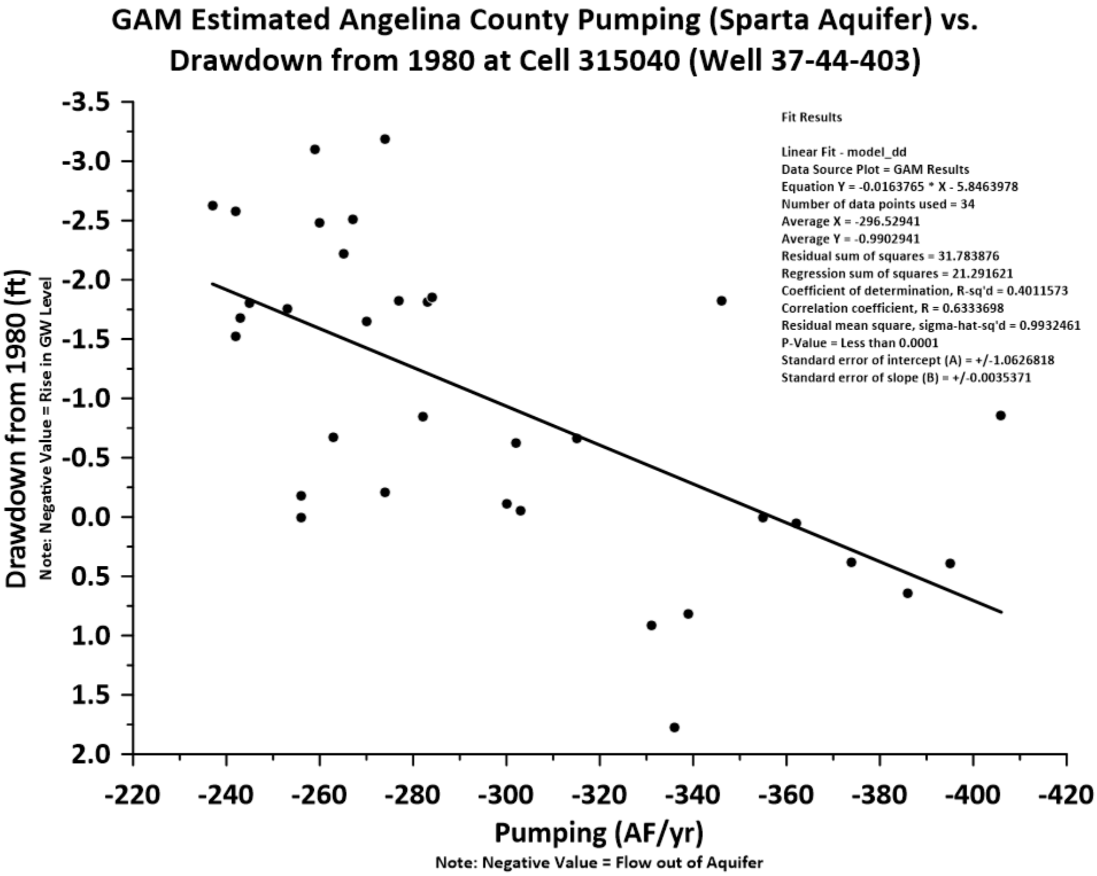


Figure 6. Angelina County Pumping vs. Well Drawdown

Figure 7 presents the relationship between Sparta Aquifer pumping within 1.5 miles of this well site and the drawdown in the well.

Please note that the r^2 value for the linear relationship is 0.22, which means that 22% of the variability in the drawdown results can be explained by the variability in Sparta Aquifer pumping within 1.5 miles of the well site.

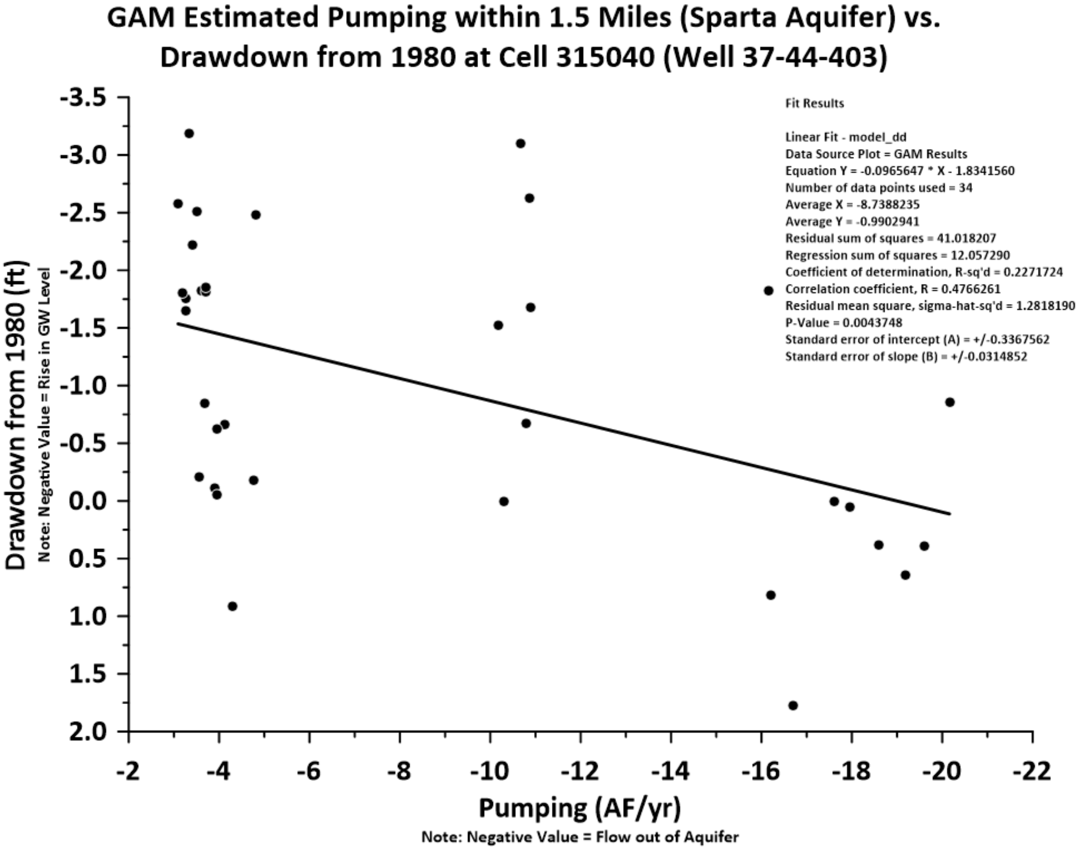


Figure 7. Pumping within 1.5 miles vs. Well Drawdown

Figure 8 presents the relationship between groundwater flow to surface water and the drawdown in the well.

Please note that the r^2 value for the linear relationship is 0.84, which means that 84% of the variability in the drawdown results can be explained by the variability in the groundwater flow to surface water. The x-axis has all negative number, which means that groundwater is flowing out of the model domain and into surface water. This may be an example of correlation and not necessarily causation. In this application, it is likely that the rise and fall of groundwater levels causes increases and decreases in the amount of groundwater outflow to surface water.

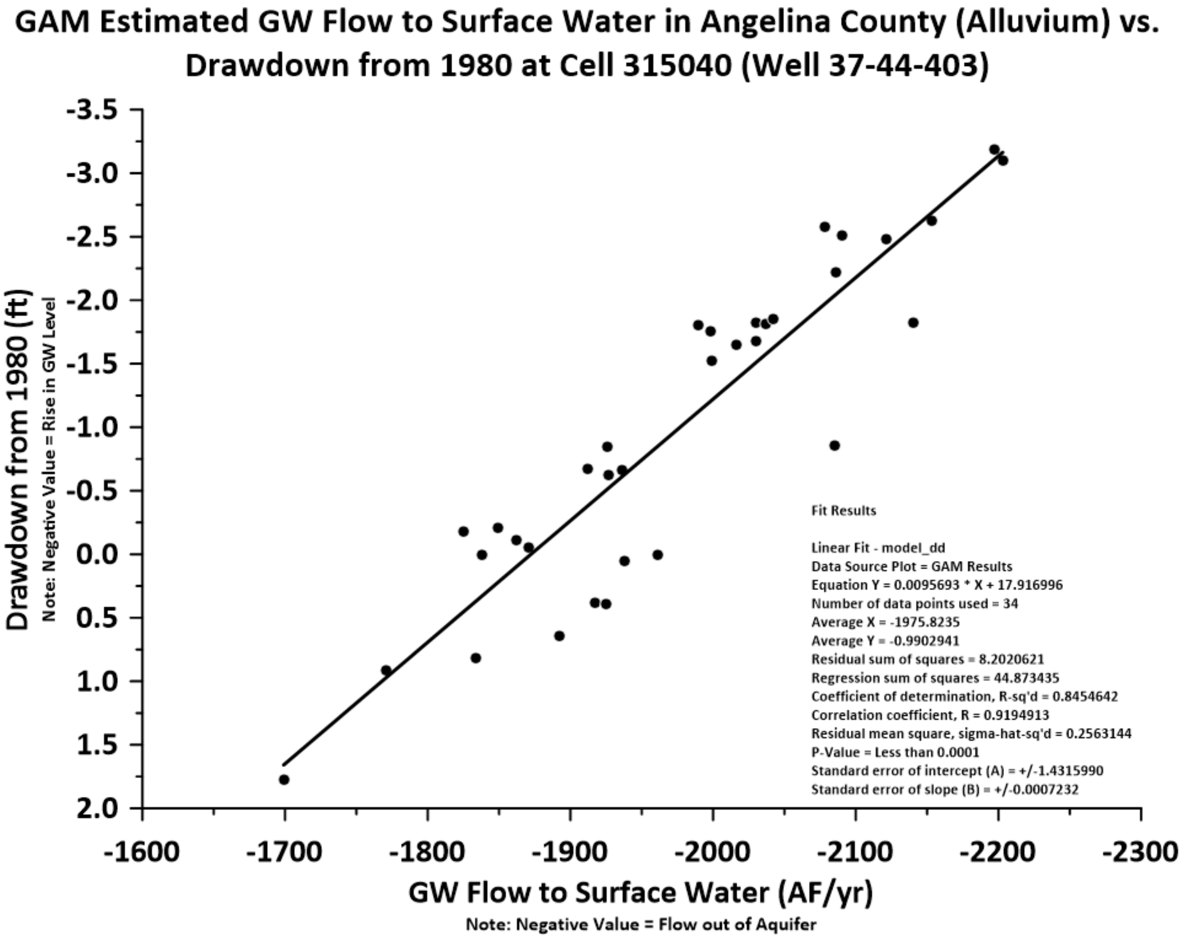
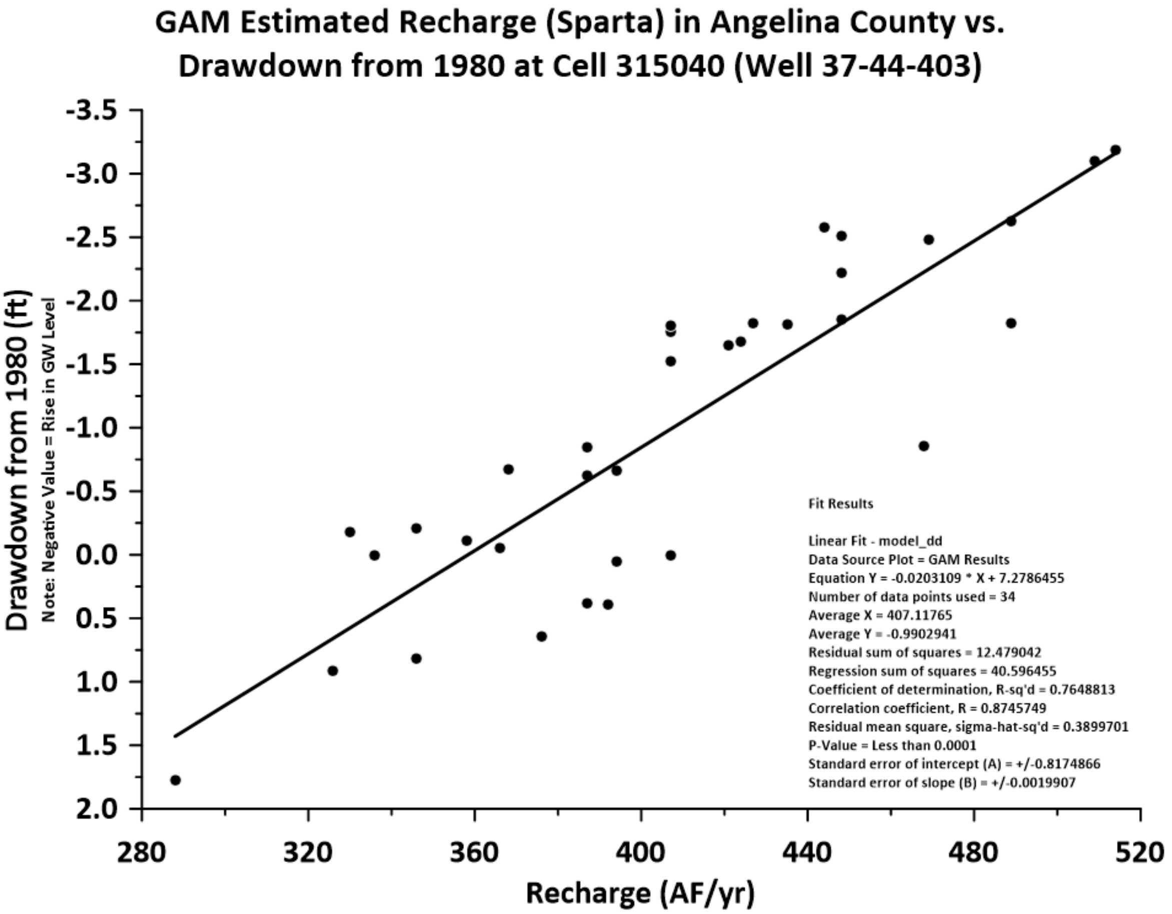


Figure 8. Groundwater Flow to Surface Water vs. Well Drawdown

Figure 9 presents the relationship between recharge to the Sparta Aquifer the drawdown in the well.

Please note that the r^2 value for the linear relationship is 0.76, which means that 76% of the variability in the drawdown results can be explained by the variability in the groundwater flow to surface water. This appears to be a case where recharge rises and falls because of wet years and dry years in terms of precipitation and results in variation in groundwater levels.



```
Fit Results

Linear Fit - model_dd
Data Source Plot = GAM Results
Equation Y = -0.0203109 * X + 7.2786455
Number of data points used = 34
Average X = 407.11765
Average Y = -0.9902941
Residual sum of squares = 12.479042
Regression sum of squares = 40.596455
Coefficient of determination, R-sq'd = 0.7648813
Correlation coefficient, R = 0.8745749
Residual mean square, sigma-hat-sq'd = 0.3899701
P-Value = Less than 0.0001
Standard error of intercept (A) = +/-0.8174866
Standard error of slope (B) = +/-0.0019907
```

Based on this analysis, future interpretations of actual groundwater monitoring data should include an analysis of annual precipitation to understand the relative contribution of recharge and pumping to variation in groundwater level.

5.9 Other Information

5.9.1 Aquifers Not Relevant for Purposes of Joint Planning

As documented in the resolution adopting desired future conditions, the groundwater conservation districts in Groundwater Management Area 11 have classified the following aquifers as not relevant for the purposes of joint planning:371

- Gulf Coast Aquifer
- Nacatoch Aquifer
- Trinity Aquifer
- Yegua-Jackson Aquifer

Documentation in support of the classification is presented in Appendix D.

6.0 Discussion of Other Desired Future Conditions Considered

Simulations associated with the joint planning process in 2010 and 2016 provided a basis for comparing various levels of pumping and the associated impacts to the nine statutory factors. Results of these simulations were presented at GMA 11 meetings and in technical memoranda.

The release of the updated GAM in late 2020 prevented the running of large number of simulations during this round of joint planning. However, the predictive simulations developed as part of the development of the updated GAM as documented in Panday and others (2020) provided a solid foundation to understand the impacts of alternative pumping and recharge scenarios.

Limitations associated with the old GAM resulted in an underprediction of average drawdowns due to the issues of recharge and the inability of water to move from the outcrop areas to the downdip areas of the aquifers. The updated GAM has corrected these limitations.

Based on the simulations with the new GAM, the pumping associated with the previous round of joint planning and the groundwater availability in the Region D and Region I water plans cannot be sustained with the assumed geographic distribution of pumping used in the predictive scenario. GMA 11 considered desired future conditions that would have resulted in decreasing pumping from 2020 to 2080. This option was rejected because it would complicate the regional planning process as groundwater availability would decrease each decade.

The modeled available groundwater values associated with these desired future conditions will be less than the groundwater availability values associated with the previous round of joint planning and lower than the values in the regional plans. This is not an arbitrary reduction, nor a reduction based on regulation. The reduction reflects the results of an updated and improved groundwater model to make such predictions.

7.0 Discussion of Other Recommendations

Public comments were invited, and each district held a public hearing on the proposed desired future condition as follows:

Groundwater Conservation District	Date of Public Hearing	Number of Comments Received
Neches & Trinity Valleys GCD	June 17, 2021	None
Panola County GCD	July 27, 2021	None
Pineywoods GCD	July 28, 2021	None
Rusk County GCD	July 26, 2021	None

8.0 References

Kelley, V.A., Deeds, N.E., Fryar, D.G., and Nicot, J.P., 2004. Groundwater Availability Model for the Queen City and Sparta Aquifers. INTERA Incorporated report prepared for the Texas Water Development Board, October 2004, 867p.

Panday, S., Rumbaugh, J., Hutchison, W.R., Schorr, S., 2020. Numerical Model Report: Groundwater Availability Model for the Northern Portion of the Queen City, Sparta, and Carrizo-Wilcox Aquifers. Final Report prepared for Texas Water Development Board, Contact Number #1648302063. 198p.

Wade, S., Shi, J., and Seiter-Weatherford, C., 2014. GAM Task 13-034: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 11. Texas Water Development Board, Groundwater Resources Division, April 2, 2014, 30 p.

Appendix A

Desired Future Conditions Resolution and Posted Notice

RESOLUTION TO ADOPT DESIRED FUTURE CONDITIONS FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 11

THE STATE OF TEXAS §
§
GROUNDWATER MANAGEMENT AREA 11 §
§
GROUNDWATER CONSERVATION DISTRICTS §

WHEREAS, Texas Water Code § 36.108 requires the groundwater conservation districts located in whole or in part in a groundwater management area ("GMA") designated by the Texas Water Development Board to adopt desired future conditions for the relevant aquifers located within the management area;

WHEREAS, the groundwater conservation districts located wholly or partially within Groundwater Management Area 11 ("GMA 11"), as designated by the Texas Water Development Board, as of the date of this resolution are as follows: Neches & Trinity Valleys Groundwater Conservation District, Panola County Groundwater Conservation District, Pineywoods Groundwater Conservation District, Rusk County Groundwater Conservation District (collectively hereinafter "the GMA 11 Districts");

WHEREAS, the GMA 11 Districts are each governmental agencies and bodies politic and corporate operating under Chapter 36, Water Code;

WHEREAS, the GMA 11 Districts desire to fulfill the requirements of Texas Water Code §36.108 through mutual cooperation and joint planning efforts;

WHEREAS, the GMA 11 Districts have had numerous public meetings, including stakeholder meetings for the specific purpose of receiving comments and input from stakeholders within GMA 11, and they have engaged in joint planning efforts to promote comprehensive management of the aquifers located in whole or in part in Groundwater Management Area 11;

WHEREAS, the GMA 11 Districts have considered the following factors, listed in §36.108(d), in establishing the desired future conditions for the aquifer(s),

(1) groundwater availability models and other data or information for the management area;

(2) aquifer uses or conditions within the management area, including conditions that differ substantially from one geographic area to another;

(3) the water supply needs and water management strategies included in the state water plan;

(4) hydrological conditions, including for each aquifer in the management area the total estimated recoverable storage as provided by the Texas Water Development Board Executive Administrator and the average annual recharge. inflows, and discharge;

(5) other environmental impacts, including impacts on spring flow and other interactions between groundwater and surface water;

(6) the impact of subsidence;

(7) socioeconomic impacts reasonably expected to occur;

(8) the impact on the interests and rights in private property, including ownership and the rights of management area landowners and their lessees and assigns in groundwater as recognized under Texas Water Code §36.002;

(9) the feasibility of achieving the desired future conditions; and

(10) any other information relevant to the specific desired future conditions;

WHEREAS, the desired future conditions provide a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater in the management area;

WHEREAS, after considering the factors listed in 36.108(d), Texas Water Code, the GMA 11 Districts may establish different desired future conditions for: (1) each aquifer, subdivision of an aquifer, or geologic strata located in whole or in part within the boundaries of GMA 11; or (2) each geographic area overlying an aquifer in whole or in part or subdivision of an aquifer within the boundaries of GMA 11;

WHEREAS, the GMA 11 Districts recognize that GMA 11 includes a geographically and hydrologically diverse area with a variety of land uses and a diverse mix of water users;

WHEREAS, the GMA 11 Districts voted to propose desired future conditions based on Scenario 33 documented in Technical Memorandum 21-01, at a meeting on April 28, 2021, followed by a 90-day public comment period during which no comments were received, and;

WHEREAS, it is the intent and purpose of the GMA 11 Districts, by adoption of this resolution, to meet the requirements of Texas Water Code §36.108, and establish "desired future conditions for the relevant aquifers" within GMA 11 for the Sparta, Queen City, and Carrizo-Wilcox aquifers as described in Table 1, attached hereto and incorporated herein for all purposes;

WHEREAS, it is the intent and purpose of the GMA 11 Districts, by adoption of this resolution, to meet the requirements of Texas Water Code §36.108, and declare that the following aquifers are classified as not relevant for the purposes of joint planning; Gulf Coast, Nacatoch, Trinity, and Yegua-Jackson aquifers;

WHEREAS, at the August 11, 2021 GMA 11 meeting, after a motion was duly made and seconded, the GMA 11 Districts adopt this resolution establishing desired future conditions for the aquifer(s) described in Table 1 by unanimous vote.

NOW, THEREFORE, BE IT RESOLVED BY THE AUTHORIZED VOTING REPRESENTATIVES OF THE GMA 11 DISTRICTS AS FOLLOWS:

1. The above recitals are true and correct.

2. The authorized voting representatives of the GMA 11 Districts hereby establish the desired future conditions of the aquifer(s) as set forth in Table 1 by unanimous vote reflected in the above recitals.

3. The GMA 11 Districts and their agents and representatives, individually and collectively, are further authorized to take all actions necessary to implement this resolution.

AND IT IS SO ORDERED.

PASSED AND ADOPTED on this 11th day of August, 2021.

ATTEST:

Neches & Trinity Valleys Groundwater Conservation District

Panola County Groundwater Conservation District

John McFarland

Pineywoods Groundwater Conservation District

Rusk County Groundwater Conservation District

Table 1
Desired Future Conditions for Each County-Aquifer Unit in GMA 11 Expressed at Average Drawdown from 2013 to 2080 (ft)

County	**2013-2080 Average Drawdown (ft) Scenario 33, TM 21-01**		
	Sparta Aquifer	**Queen City Aquifer**	**Carrizo-Wilcox Aquifer**
Anderson	30	44	155
Angelina	6	28	67
Bowie			12
Camp		11	85
Cass	66	34	79
Cherokee	7	31	176
Franklin			102
Gregg		49	109
Harrison		41	26
Henderson		33	106
Hopkins			61
Houston	3	12	86
Marion	123	32	32
Morris		39	78
Nacogdoches	7	22	73
Panola			21
Rains			17
Rusk	26	17	86
Sabine	1	3	9
San Augustine	2	7	22
Shelby	18	12	17
Smith	121	132	265
Titus		9	66
Trinity	5	18	56
Upshur	10	30	149
Van Zandt		73	55
Wood	9	16	122

tgriffin pcgcd.org

From:	TexReg@sos.texas.gov
Sent:	Monday, July 26, 2021 10:59 AM
To:	tgriffin pcgcd.org
Subject:	S.O.S. Acknowledgment of Receipt

Acknowledgment of Receipt

Agency: Groundwater Management Area 11

Liaison: Teresa Griffin

The Office of the Secretary of State has posted

notice of the following meeting:

Board: GMA 11

Committee: GMA 11

Date: 08/11/2021 10:00 AM "TRD# 2021004478"

Notice posted: 07/26/21 10:58 AM

Proofread your current open meeting notice at:

http://texreg.sos.state.tx.us/public/pub_om_lookup$.startup?Z_TRD=2021004478

Open Meeting Submission

TRD:	2021004478
Date Posted:	07/26/2021
Status:	Accepted
Agency Id:	1148
Date of Submission:	07/26/2021
Agency Name:	Groundwater Management Area 11
Board:	GMA 11
Committee:	GMA 11
Date of Meeting:	08/11/2021
Time of Meeting:	10:00 AM (**##:## AM Local Time)**
Street Location:	202 E. Pilar
City:	Nacogdoches
State:	TX
Liaison Name:	Teresa Griffin
Liaison Id:	2
Additional Information Obtained From:	Teresa Griffin 903-690-0143

Agenda: GROUNDWATER MANAGEMENT AREA 11
NOTICE OF OPEN MEETING

Notice is hereby given that the groundwater conservation districts (GCDs) located wholly or partially within the Groundwater Management Area 11 (GMA-11) as designated by the Texas Water Development Board (TWDB) consisting of:

Neches and Trinity Valleys Groundwater Conservation District (NTVGCD),
Panola County Groundwater Conservation District (PCGCD),
Pineywoods Groundwater Conservation District (PGCD), and
Rusk County Groundwater Conservation District (RCGCD);

Will hold a Joint Planning Meeting at 10:00 a.m. on August 11, 2021, in room 119 (Commissioners Room) in Nacogdoches City Hall at 202 E. Pilar, Nacogdoches, TX, and via Zoom at: https://zoom.us/j/95002156603?pwd=Qm5WZm01TS8xcERFWVVnUmJzK3huZz09
Via telephone (346)248-7799 Meeting ID: 950 0215 6603 Passcode: 386379
For the following purpose:

1. Call to order.
2. Public comments. i
3. Discussion and possible action to approve the minutes of the April 28, 2021, meeting.
4. Discussion of representatives and alternate appointments from Rusk County.

5. Nominations and election of officers in accordance with Section 4.05 of the GMA 11 Bylaws
6. Discussion and possible action regarding the public comments received by each District during the DFC comment period.
7. Discussion and possible action to approve final proposed DFC's via Resolution.
8. Discussion of possible agenda items for the next GMA-11 meeting.
9. Set date, time, and place of next meeting.
10. Adjourn meeting.

Dated and posted prior to 5:00 PM on or before the 30th day of July 2021.

____
Teresa Griffin, GMA-11 Contact
Panola County Groundwater Conservation District

This meeting is available to all persons regardless of disability. If you require special assistance to attend or participate in the meeting, please contact the Panola County GCD at (903) 690-0143 at least 24 hours in advance of the meeting.

i PUBLIC COMMENTS: Citizens who desire to address GMA-11 on any matter may sign up to do so prior to this meeting. Public comments will be received during this portion of the meeting. Please limit comments to 3 (three) minutes. No discussion or final action will be taken by GMA-11.

Questions, Requests for Information and Comments Submission: Citizens who wish to ask questions, to request additional information, or to submit comments may do so by submitting such information to the following person:
Teresa Griffin | Panola County GCD | 419 W. Sabine, Cart

New Submission

HOME | TEXAS REGISTER | TEXAS ADMINISTRATIVE CODE | OPEN MEETINGS

GROUNDWATER MANAGEMENT AREA 11
NOTICE OF OPEN MEETING

Notice is hereby given that the groundwater conservation districts (GCDs) located wholly or partially within the **Groundwater Management Area 11** (GMA-11) as designated by the Texas Water Development Board (TWDB) consisting of:

Neches and Trinity Valleys Groundwater Conservation District (NTVGCD),
Panola County Groundwater Conservation District (PCGCD),
Pineywoods Groundwater Conservation District (PGCD), and
Rusk County Groundwater Conservation District (RCGCD);

Will hold a **Joint Planning Meeting at 10:00 a.m. on August 11, 2021,** in room 119 (Commissioners Room) in Nacogdoches City Hall at 202 E. Pilar, Nacogdoches, TX, and via Zoom at: https://zoom.us/j/95002156603?pwd=Qm5WZm01TS8xcERFWVVnUmJzK3huZz09

Via telephone (346)248-7799 Meeting ID: 950 0215 6603 Passcode: 386379

FILED
NACOGDOCHES COUNTY
TEXAS
2021 JUL 21 AM 9:38
COUNTY CLERK

For the following purpose:

1. Call to order.
2. Public comments. [i]
3. Discussion and possible action to approve the minutes of the April 28, 2021, meeting.
4. Discussion of representatives and alternate appointments from Rusk County.
5. Nominations and election of officers in accordance with Section 4.05 of the GMA 11 Bylaws
6. Discussion and possible action regarding the public comments received by each District during the DFC comment period.
7. Discussion and possible action to approve final proposed DFC's via Resolution.
8. Discussion of possible agenda items for the next GMA-11 meeting.
9. Set date, time, and place of next meeting.
10. Adjourn meeting.

Dated and posted prior to 5:00 PM on or before the 30th day of July 2021.

Teresa Griffin

Teresa Griffin, GMA-11 Contact
Panola County Groundwater Conservation District

This meeting is available to all persons regardless of disability. If you require special assistance to attend or participate in the meeting, please contact the Panola County GCD at (903) 690-0143 at least 24 hours in advance of the meeting.

---

[i] **PUBLIC COMMENTS**: Citizens who desire to address GMA-11 on any matter may sign up to do so prior to this meeting. Public comments will be received during this portion of the meeting. Please limit comments to 3 (three) minutes. No discussion or final action will be taken by GMA-11.

Questions, Requests for Information and Comments Submission: Citizens who wish to ask questions, to request additional information, or to submit comments may do so by submitting such information to the following person:
Teresa Griffin | Panola County GCD | 419 W. Sabine, Carthage, TX 75633 | (903) 690-0143 / tgriffin@pcgcd.org

FILED
AT 1051 O'CLOCK A M
JUL 21 2021
AMY FINCHER
County Clerk, County Court at Law
Angelina County, Texas
By MO

GROUNDWATER MANAGEMENT AREA 11
NOTICE OF OPEN MEETING

Notice is hereby given that the groundwater conservation districts (GCDs) located wholly or partially within the **Groundwater Management Area 11** (GMA-11) as designated by the Texas Water Development Board (TWDB) consisting of:

Neches and Trinity Valleys Groundwater Conservation District (NTVGCD),
Panola County Groundwater Conservation District (PCGCD),
Pineywoods Groundwater Conservation District (PGCD), and
Rusk County Groundwater Conservation District (RCGCD);

Will hold a **Joint Planning Meeting at 10:00 a.m. on August 11, 2021,** in room 119 (Commissioners Room) in Nacogdoches City Hall at 202 E. Pilar, Nacogdoches, TX, and via Zoom at: https://zoom.us/j/95002156603?pwd=Qm5WZm01TS8xcERFWVVnUmJzK3huZz09

Via telephone (346)248-7799 Meeting ID: 950 0215 6603 Passcode: 386379

For the following purpose:

1. Call to order.
2. Public comments. [i]
3. Discussion and possible action to approve the minutes of the April 28, 2021, meeting.
4. Discussion of representatives and alternate appointments from Rusk County.
5. Nominations and election of officers in accordance with Section 4.05 of the GMA 11 Bylaws
6. Discussion and possible action regarding the public comments received by each District during the DFC comment period.
7. Discussion and possible action to approve final proposed DFC's via Resolution.
8. Discussion of possible agenda items for the next GMA-11 meeting.
9. Set date, time, and place of next meeting.
10. Adjourn meeting.

Dated and posted prior to 5:00 PM on or before the 30th day of July 2021.

Teresa Griffin, GMA-11 Contact
Panola County Groundwater Conservation District

This meeting is available to all persons regardless of disability. If you require special assistance to attend or participate in the meeting, please contact the Panola County GCD at (903) 690-0143 at least 24 hours in advance of the meeting.

[i] **PUBLIC COMMENTS**: Citizens who desire to address GMA-11 on any matter may sign up to do so prior to this meeting. Public comments will be received during this portion of the meeting. Please limit comments to 3 (three) minutes. No discussion or final action will be taken by GMA-11.

Questions, Requests for Information and Comments Submission: Citizens who wish to ask questions, to request additional information, or to submit comments may do so by submitting such information to the following person: Teresa Griffin | Panola County GCD | 419 W. Sabine, Carthage, TX 75633 | (903) 690-0143 / tgriffin@pcgcd.org

GROUNDWATER MANAGEMENT AREA 11
NOTICE OF OPEN MEETING

Notice is hereby given that the groundwater conservation districts (GCDs) located wholly or partially within the **Groundwater Management Area 11** (GMA-11) as designated by the Texas Water Development Board (TWDB) consisting of:

Neches and Trinity Valleys Groundwater Conservation District (NTVGCD),
Panola County Groundwater Conservation District (PCGCD),
Pineywoods Groundwater Conservation District (PGCD), and
Rusk County Groundwater Conservation District (RCGCD);

Will hold a **Joint Planning Meeting at 10:00 a.m. on August 11, 2021,** in room 119 (Commissioners Room) in Nacogdoches City Hall at 202 E. Pilar, Nacogdoches, TX, and via Zoom at: https://zoom.us/j/95002156603?pwd=Qm5WZm01TS8xcERFWVVnUmJzK3huZz09

FILED FOR RECORD
IN MY OFFICE
AT 1:11 O'CLOCK P M
JUL 22 2021
BOBBIE DAVIS
COUNTY CLERK, PANOLA COUNTY, TEXAS
BY DEPUTY

Via telephone (346)248-7799 Meeting ID: 950 0215 6603 Passcode: 386379

For the following purpose:

1. Call to order.
2. Public comments. [i]
3. Discussion and possible action to approve the minutes of the April 28, 2021, meeting.
4. Discussion of representatives and alternate appointments from Rusk County.
5. Nominations and election of officers in accordance with Section 4.05 of the GMA 11 Bylaws
6. Discussion and possible action regarding the public comments received by each District during the DFC comment period.
7. Discussion and possible action to approve final proposed DFC's via Resolution.
8. Discussion of possible agenda items for the next GMA-11 meeting.
9. Set date, time, and place of next meeting.
10. Adjourn meeting.

Dated and posted prior to 5:00 PM on or before the 30th day of July 2021.

Teresa Griffin, GMA-11 Contact
Panola County Groundwater Conservation District

This meeting is available to all persons regardless of disability. If you require special assistance to attend or participate in the meeting, please contact the Panola County GCD at (903) 690-0143 at least 24 hours in advance of the meeting.

[i] **PUBLIC COMMENTS**: Citizens who desire to address GMA-11 on any matter may sign up to do so prior to this meeting. Public comments will be received during this portion of the meeting. Please limit comments to 3 (three) minutes. No discussion or final action will be taken by GMA-11.

Questions, Requests for Information and Comments Submission: Citizens who wish to ask questions, to request additional information, or to submit comments may do so by submitting such information to the following person: Teresa Griffin | Panola County GCD | 419 W. Sabine, Carthage, TX 75633 | (903) 690-0143 / tgriffin@pcgcd.org

GROUNDWATER MANAGEMENT AREA 11
NOTICE OF OPEN MEETING

Notice is hereby given that the groundwater conservation districts (GCDs) located wholly or partially within the **Groundwater Management Area 11** (GMA-11) as designated by the Texas Water Development Board (TWDB) consisting of:

Neches and Trinity Valleys Groundwater Conservation District (NTVGCD),
Panola County Groundwater Conservation District (PCGCD),
Pineywoods Groundwater Conservation District (PGCD), and
Rusk County Groundwater Conservation District (RCGCD);

Will hold a **Joint Planning Meeting at 10:00 a.m. on August 11, 2021,** in room 119 (Commissioners Room) in Nacogdoches City Hall at 202 E. Pilar, Nacogdoches, TX, and via Zoom at: https://zoom.us/j/95002156603?pwd=Qm5WZm01TS8xcERFWVVnUmJzK3huZz09

Via telephone (346)248-7799 Meeting ID: 950 0215 6603 Passcode: 386379

For the following purpose:

1. Call to order.
2. Public comments. [i]
3. Discussion and possible action to approve the minutes of the April 28, 2021, meeting.
4. Discussion of representatives and alternate appointments from Rusk County.
5. Nominations and election of officers in accordance with Section 4.05 of the GMA 11 Bylaws
6. Discussion and possible action regarding the public comments received by each District during the DFC comment period.
7. Discussion and possible action to approve final proposed DFC's via Resolution.
8. Discussion of possible agenda items for the next GMA-11 meeting.
9. Set date, time, and place of next meeting.
10. Adjourn meeting.

FILED FOR RECORD
at 1:14 o'clock P M.

JUL 16 2021

MARK STAPLES
County Clerk, Anderson County, Texas
By ____ Deputy

Dated and posted prior to 5:00 PM on or before the 30th day of July 2021.

Teresa Griffin, GMA-11 Contact
Panola County Groundwater Conservation District

This meeting is available to all persons regardless of disability. If you require special assistance to attend or participate in the meeting, please contact the Panola County GCD at (903) 690-0143 at least 24 hours in advance of the meeting.

[i] **PUBLIC COMMENTS**: Citizens who desire to address GMA-11 on any matter may sign up to do so prior to this meeting. Public comments will be received during this portion of the meeting. Please limit comments to 3 (three) minutes. No discussion or final action will be taken by GMA-11.

Questions, Requests for Information and Comments Submission: Citizens who wish to ask questions, to request additional information, or to submit comments may do so by submitting such information to the following person:
Teresa Griffin | Panola County GCD | 419 W. Sabine, Carthage, TX 75633 | (903) 690-0143 / tgriffin@pcgcd.org

a575

GROUNDWATER MANAGEMENT AREA 11
NOTICE OF OPEN MEETING

Notice is hereby given that the groundwater conservation districts (GCDs) located wholly or partially within the **Groundwater Management Area 11** (GMA-11) as designated by the Texas Water Development Board (TWDB) consisting of:

Neches and Trinity Valleys Groundwater Conservation District (NTVGCD),
Panola County Groundwater Conservation District (PCGCD),
Pineywoods Groundwater Conservation District (PGCD), and
Rusk County Groundwater Conservation District (RCGCD);

Will hold a **Joint Planning Meeting at 10:00 a.m. on August 11, 2021,** in room 119 (Commissioners Room) in Nacogdoches City Hall at 202 E. Pilar, Nacogdoches, TX, and via Zoom at: https://zoom.us/j/95002156603?pwd=Qm5WZm01TS8xcERFWVVnUmJzK3huZz09

Via telephone (346)248-7799 Meeting ID: 950 0215 6603 Passcode: 386379

For the following purpose:

1. Call to order.
2. Public comments.[1]
3. Discussion and possible action to approve the minutes of the April 28, 2021, meeting.
4. Discussion of representatives and alternate appointments from Rusk County.
5. Nominations and election of officers in accordance with Section 4.05 of the GMA 11 Bylaws
6. Discussion and possible action regarding the public comments received by each District during the DFC comment period.
7. Discussion and possible action to approve final proposed DFC's via Resolution.
8. Discussion of possible agenda items for the next GMA-11 meeting.
9. Set date, time, and place of next meeting.
10. Adjourn meeting.

FILED
FOR RECORD
2021 JUL 16 PM 3:06
LAVERNE LUSK COUNTY CLERK
CHEROKEE COUNTY, TEXAS
DEPUTY

Dated and posted prior to 5:00 PM on or before the 30th day of July 2021.

Teresa Griffin, GMA-11 Contact
Panola County Groundwater Conservation District

This meeting is available to all persons regardless of disability. If you require special assistance to attend or participate in the meeting, please contact the Panola County GCD at (903) 690-0143 at least 24 hours in advance of the meeting.

---

[1] **PUBLIC COMMENTS**: Citizens who desire to address GMA-11 on any matter may sign up to do so prior to this meeting. Public comments will be received during this portion of the meeting. Please limit comments to 3 (three) minutes. No discussion or final action will be taken by GMA-11.

Questions, Requests for Information and Comments Submission: Citizens who wish to ask questions, to request additional information, or to submit comments may do so by submitting such information to the following person:
Teresa Griffin | Panola County GCD | 419 W. Sabine, Carthage, TX 75633 | (903) 690-0143 / tgriffin@pcgcd.org

GROUNDWATER MANAGEMENT AREA 11
NOTICE OF OPEN MEETING

Notice is hereby given that the groundwater conservation districts (GCDs) located wholly or partially within the **Groundwater Management Area 11** (GMA-11) as designated by the Texas Water Development Board (TWDB) consisting of:

Neches and Trinity Valleys Groundwater Conservation District (NTVGCD),
Panola County Groundwater Conservation District (PCGCD),
Pineywoods Groundwater Conservation District (PGCD), and
Rusk County Groundwater Conservation District (RCGCD);

Will hold a **Joint Planning Meeting at 10:00 a.m. on August 11, 2021,** in room 119 (Commissioners Room) in Nacogdoches City Hall at 202 E. Pilar, Nacogdoches, TX, and via Zoom at: https://zoom.us/j/95002156603?pwd=Qm5WZm01TS8xcERFWVVnUmJzK3huZz09

Via telephone (346)248-7799 Meeting ID: 950 0215 6603 Passcode: 386379

For the following purpose:

1. Call to order.
2. Public comments. [i]
3. Discussion and possible action to approve the minutes of the April 28, 2021, meeting.
4. Discussion of representatives and alternate appointments from Rusk County.
5. Nominations and election of officers in accordance with Section 4.05 of the GMA 11 Bylaws
6. Discussion and possible action regarding the public comments received by each District during the DFC comment period.
7. Discussion and possible action to approve final proposed DFC's via Resolution.
8. Discussion of possible agenda items for the next GMA-11 meeting.
9. Set date, time, and place of next meeting.
10. Adjourn meeting.

FILED FOR RECORD
2021 JUL 19 PM 4:32
[illegible]
COUNTY CLERK
HENDERSON COUNTY, TEXAS

Dated and posted prior to 5:00 PM on or before the 30th day of July 2021.

Teresa Griffin, GMA-11 Contact
Panola County Groundwater Conservation District

This meeting is available to all persons regardless of disability. If you require special assistance to attend or participate in the meeting, please contact the Panola County GCD at (903) 690-0143 at least 24 hours in advance of the meeting.

---

[i] **PUBLIC COMMENTS**: Citizens who desire to address GMA-11 on any matter may sign up to do so prior to this meeting. Public comments will be received during this portion of the meeting. Please limit comments to 3 (three) minutes. No discussion or final action will be taken by GMA-11.

Questions, Requests for Information and Comments Submission: Citizens who wish to ask questions, to request additional information, or to submit comments may do so by submitting such information to the following person: Teresa Griffin | Panola County GCD | 419 W. Sabine, Carthage, TX 75633 | (903) 690-0143 / tgriffin@pcgcd.org

FILED FOR RECORD
RUSK COUNTY, TEXAS
2021 JUL 16 PM 1:36
TRUDY McGILL
COUNTY CLERK
BY SW DEPUTY

GROUNDWATER MANAGEMENT AREA 11
NOTICE OF OPEN MEETING

Notice is hereby given that the groundwater conservation districts (GCDs) located wholly or partially within the **Groundwater Management Area 11** (GMA-11) as designated by the Texas Water Development Board (TWDB) consisting of:

Neches and Trinity Valleys Groundwater Conservation District (NTVGCD),
Panola County Groundwater Conservation District (PCGCD),
Pineywoods Groundwater Conservation District (PGCD), and
Rusk County Groundwater Conservation District (RCGCD);

Will hold a **Joint Planning Meeting at 10:00 a.m. on August 11, 2021,** in room 119 (Commissioners Room) in Nacogdoches City Hall at 202 E. Pilar, Nacogdoches, TX, and via Zoom at: https://zoom.us/j/95002156603?pwd=Qm5WZm01TS8xcERFWVVnUmJzK3huZz09

Via telephone (346)248-7799 Meeting ID: 950 0215 6603 Passcode: 386379

For the following purpose:

1. Call to order.
2. Public comments. [i]
3. Discussion and possible action to approve the minutes of the April 28, 2021, meeting.
4. Discussion of representatives and alternate appointments from Rusk County.
5. Nominations and election of officers in accordance with Section 4.05 of the GMA 11 Bylaws
6. Discussion and possible action regarding the public comments received by each District during the DFC comment period.
7. Discussion and possible action to approve final proposed DFC's via Resolution.
8. Discussion of possible agenda items for the next GMA-11 meeting.
9. Set date, time, and place of next meeting.
10. Adjourn meeting.

Dated and posted prior to 5:00 PM on or before the 30th day of July 2021.

Teresa Griffin
Teresa Griffin, GMA-11 Contact
Panola County Groundwater Conservation District

This meeting is available to all persons regardless of disability. If you require special assistance to attend or participate in the meeting, please contact the Panola County GCD at (903) 690-0143 at least 24 hours in advance of the meeting.

[i] **PUBLIC COMMENTS**: Citizens who desire to address GMA-11 on any matter may sign up to do so prior to this meeting. Public comments will be received during this portion of the meeting. Please limit comments to 3 (three) minutes. No discussion or final action will be taken by GMA-11.

Questions, Requests for Information and Comments Submission: Citizens who wish to ask questions, to request additional information, or to submit comments may do so by submitting such information to the following person: Teresa Griffin | Panola County GCD | 419 W. Sabine, Carthage, TX 75633 | (903) 690-0143 / tgriffin@pcgcd.org

Appendix B

TWDB GAM Task 13-034: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 11

GAM TASK 13-034: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 11

by Shirley Wade, Ph.D., P.G., Jerry Shi, Ph.D., P.G.,
and Chelsea Seiter-Weatherford
Texas Water Development Board
Groundwater Resources Division
(512) 936-0883
April 2, 2014

SHIRLEY C. WADE
GEOLOGY
No. 525

Shirley C. Wade
4/2/14

JIANYOU SHI
GEOLOGY
11113

4/2/2014

CYNTHIA K. RIDGEWAY
GEOLOGY
No. 471

Cynthia K. Ridgeway
4/2/2014

The seals appearing on this document were authorized by Shirley C. Wade, P.G. 525, Jianyou (Jerry) Shi, P.G. 11113, and Cynthia K. Ridgeway, P.G. 471 on April 2, 2014. Cynthia K. Ridgeway is the Manager of the Groundwater Availability Modeling Section and is responsible for oversight of work performed by Chelsea Seiter-Weatherford under her direct supervision.

The total estimated recoverable storage in this report was calculated as follows: the Trinity Aquifer (Jerry Shi), the Nacatoch Aquifer (Chelsea Seiter-Weatherford), and the Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, and Gulf Coast aquifers (Shirley Wade).

This page is intentionally blank

GAM TASK 13-034: TOTAL ESTIMATED RECOVERABLE STORAGE FOR AQUIFERS IN GROUNDWATER MANAGEMENT AREA 11

by Shirley Wade, Ph.D., P.G., Jerry Shi, Ph.D., P.G.,
and Chelsea Seiter-Weatherford
Texas Water Development Board
Groundwater Resources Division
(512) 936-0883
April 2, 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(24) (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 Trinity, Nacatoch, Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, and Gulf Coast aquifers within Groundwater Management Area 11. Tables 1 through 14 summarize the total estimated recoverable storage required by the statute. Figures 2 through 8 indicate the official extent of the aquifers in Groundwater Management Area 11 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 only 25 to 75 percent of groundwater held within an aquifer can be removed by pumping.

The total recoverable storage was estimated for the portion of the aquifer within Groundwater Management Area 11 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 between different water quality types. The total estimated recoverable storage values do not take into account the effects of land surface subsidence, degradation of water quality, or any changes to surface water-groundwater interaction that may occur as the result of extracting groundwater from the aquifer.

METHODS:

To estimate the total recoverable storage of an aquifer, we first calculated the total storage in an aquifer within the official aquifer boundary. The total storage is the volume of groundwater removed by pumping that completely drains the aquifer.

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. A confined aquifer is bounded by low permeable geologic units at the top and bottom, and the aquifer is under hydraulic pressure above the ambient atmospheric pressure. The water level in a well screened in a confined aquifer will be above the top of the aquifer. As a result, calculation of total storage is different between unconfined and confined aquifers. For an unconfined aquifer, the total storage is equal to the volume of groundwater removed by pumping 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 aquifers and specific yield related to unconfined aquifers. 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

$$Total\ Storage\ =\ V_{drained} = Area \times S_y \times (Water\ Level - Bottom)$$

- for confined aquifers

$$Total\ Storage\ =\ V_{confined} + V_{drained}$$

  - confined part

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

or

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

  - unconfined part

$$V_{drained} =\ Area \times \left[S_y \times (Top - Bottom)\right]$$

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)

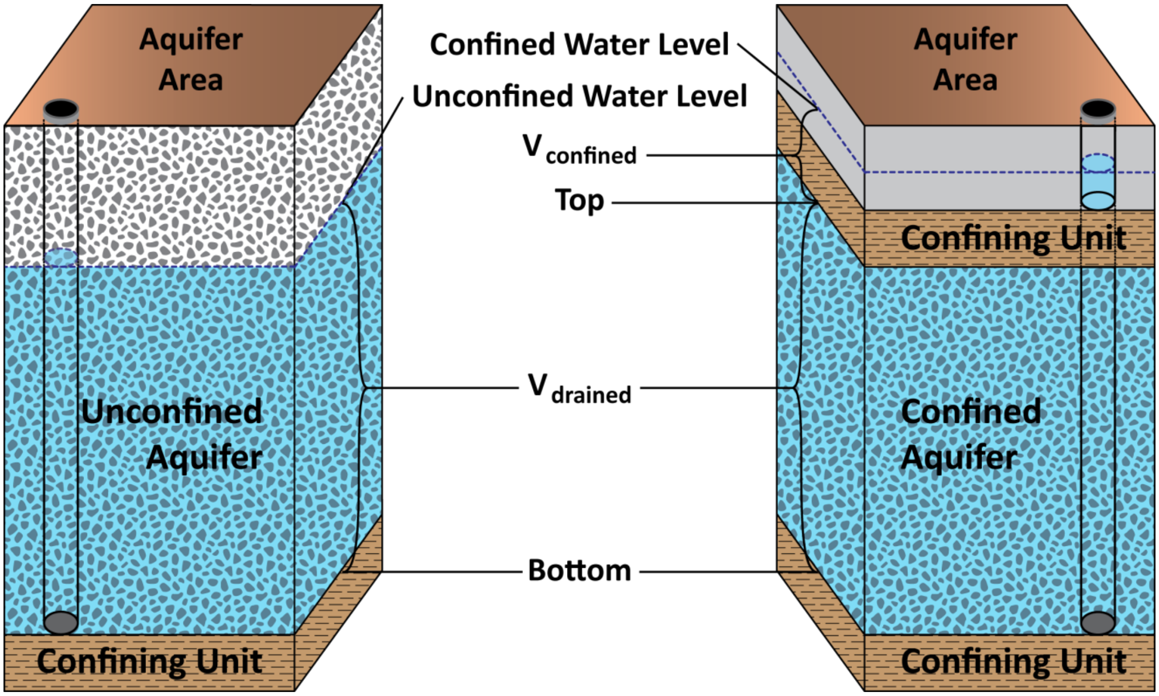


FIGURE 1. SCHEMATIC GRAPH SHOWING THE DIFFERENCE BETWEEN UNCONFINED AND CONFINED AQUIFERS.

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 Trinity, Nacatoch, Carrizo-Wilcox, Queen City, Sparta, Yegua-Jackson, and Gulf Coast aquifers within Groundwater Management Area 11 we extracted this information from existing groundwater availability model input and output files on a cell-by-cell basis.

The recoverable storage for each of the aquifers listed above was the product of its total storage and an estimated factor ranging from 25 percent to 75 percent.

PARAMETERS AND ASSUMPTIONS:

Trinity Aquifer

- We used version 1.01 of the groundwater availability model for the northern part of the Trinity Aquifer and the Woodbine Aquifer to estimate the total recoverable storage for the Trinity Aquifer. The Woodbine Aquifer is not present in Groundwater

Management Area 11. See Bené and others (2004) for assumptions and limitations of the groundwater availability model.

- This groundwater availability model includes seven layers which generally represent the Woodbine Aquifer (Layer 1), the Washita and Fredericksburg Confining Unit (Layer 2), the Paluxy Aquifer Unit of the Trinity Aquifer (Layer 3), the Glen Rose Confining Unit of the Trinity Aquifer (Layer 4), the Hensell Sand Aquifer Unit of the Trinity Aquifer (Layer 5), the Twin Mountains Confining Units of the Trinity Aquifer (Layer 6), and the Hosston Aquifer Unit of the Trinity Aquifer (Layer 7). To develop the estimates for the total estimated recoverable storage, we used Layers 3 through 7 (the Trinity Aquifer).
- The down-dip boundary of the model is the Luling-Mexia-Talco Fault Zone, which probably allows minimal groundwater flow across the fault zone (Bené and others, 2004). The groundwater in the official extent of the northern portion of the Trinity Aquifer aquifers ranges from fresh to moderately saline (brackish) in composition (Bené and others, 2004).

Nacatoch Aquifer

- We used version 1.01 of the groundwater availability model for the Nacatoch Aquifer. See Beach and others (2009) for assumptions and limitations of the groundwater availability model for the Nacatoch Aquifer.
- This groundwater availability model includes two layers which represent the Midway Group, and alluvium and terrace deposits (Layer 1), and the Nacatoch Aquifer (Layer 2).
- The total estimated recoverable storage for the Nacatoch Aquifer was calculated using Layer 2.
- Groundwater in the Nacatoch Aquifer is generally fresh within Groundwater Management Area 11 (Beach and others, 2009). Groundwater with total dissolved solids of less than 1,000 milligrams per liter is defined as fresh. Groundwater with total dissolved solids between 1,000 to 10,000 milligrams per liter is defined as brackish, and groundwater with total dissolved solids between 10,000 and 35,000 milligrams per liter is defined as saline (George and others, 2011).

Carrizo-Wilcox, Queen City, and Sparta aquifers

- We used Version 2.01 of the groundwater availability model for the northern part of the Carrizo-Wilcox, Queen City, and Sparta aquifers. See Fryar and others (2003) and Kelley and others (2004) for assumptions and limitations of the groundwater availability model for the northern part of the Carrizo-Wilcox, Queen City, and Sparta aquifers.
- The groundwater availability model includes eight layers that generally correspond to the Sparta Aquifer (Layer 1), the Weches Confining Unit (Layer 2), the Queen City Aquifer (Layer 3), the Reklaw Confining Unit (Layer 4), the Carrizo Aquifer (Layer 5), the Upper Wilcox Aquifer (Layer 6), the Middle Wilcox Aquifer (Layer 7), and the Lower Wilcox Aquifer (Layer 8).
- In the Sabine Uplift area, the Simsboro Formation (Middle Wilcox Aquifer) is not distinguishable and the Wilcox Group is informally divided into the Upper Wilcox and the Lower Wilcox aquifers (Fryar and others, 2003). In the current version of the groundwater availability model, layers 6 and 7 represent the Upper Wilcox and Lower Wilcox aquifers in this area. Layer 8 is included in the model in this area, but it is of nominal thickness and is not intended to represent the Lower Wilcox aquifer.

Yegua-Jackson Aquifer and the Catahoula Formation portion of the Gulf Coast Aquifer System

- We used version 1.01 of the groundwater availability model for the Yegua-Jackson Aquifer to estimate the total recoverable storages of the Yegua-Jackson Aquifer and parts of the Catahoula Formation. See Deeds and others (2010) for assumptions and limitations of the groundwater availability model.
- This groundwater availability model includes five layers which represent the outcrop section for the Yegua-Jackson Aquifer and the Catahoula Formation and other younger overlying units (Layer 1), the upper portion of the Jackson Group (Layer 2), the lower portion of the Jackson Group (Layer 3), the upper portion of the Yegua Group (Layer 4), and the lower portion of the Yegua Group (Layer 5). To develop the estimates for the total estimated recoverable storage in the Yegua-Jackson Aquifer, we used layers

1 through 5. However, we only used model cells in Layer 1 to evaluate the outcrop area of the Yegua-Jackson Aquifer.

- The down-dip boundary for the Yegua-Jackson Aquifer in this model was set to approximately coincide with the extent of the available geologic data, much deeper than any portion of the aquifer that is used for groundwater supply (Deeds and others, 2010). Consequently, the model extends into zones of brackish and saline groundwater. The groundwater in the official extent of the Yegua-Jackson Aquifer ranges from fresh to brackish in composition (Deeds and others, 2010).

Gulf Coast Aquifer System

- We used version 3.01 of the groundwater availability model for the northern portion of the Gulf Coast Aquifer system for this analysis. See Kasmarek (2013) for assumptions and limitations of the model.
- The model has four layers which represent the Chicot Aquifer (Layer 1), the Evangeline Aquifer (Layer 2), the Burkeville confining unit (Layer 3), and the Jasper Aquifer and parts of the Catahoula Formation in direct hydrologic communication with the Jasper Aquifer (Layer 4).
- The southeastern boundary of flow in each hydrogeologic unit of the model was set at the down-dip limit of freshwater (up to 10,000 milligrams per liter of total dissolved solids; Kasmarek, 2013).

RESULTS:

Tables 1 through 14 summarize the total estimated recoverable storage required by statute. The county and groundwater conservation district total storage estimates are rounded to two significant digits. Figures 2 through 8 indicate the extent of the groundwater availability models in Groundwater Management Area 11 from which the storage information was extracted.

TABLE 1. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

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

TABLE 2. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT FOR THE TRINITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Neches & Trinity Valleys GCD	500,000	125,000	375,000
Total	**500,000**	**125,000**	**375,000**

FIGURE 2 EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE NORTHERN TRINITY AND WOODBINE AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE TRINITY AQUIFER (TABLES 1 AND 2) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 3. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE NACATOCH AQUIFER IN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

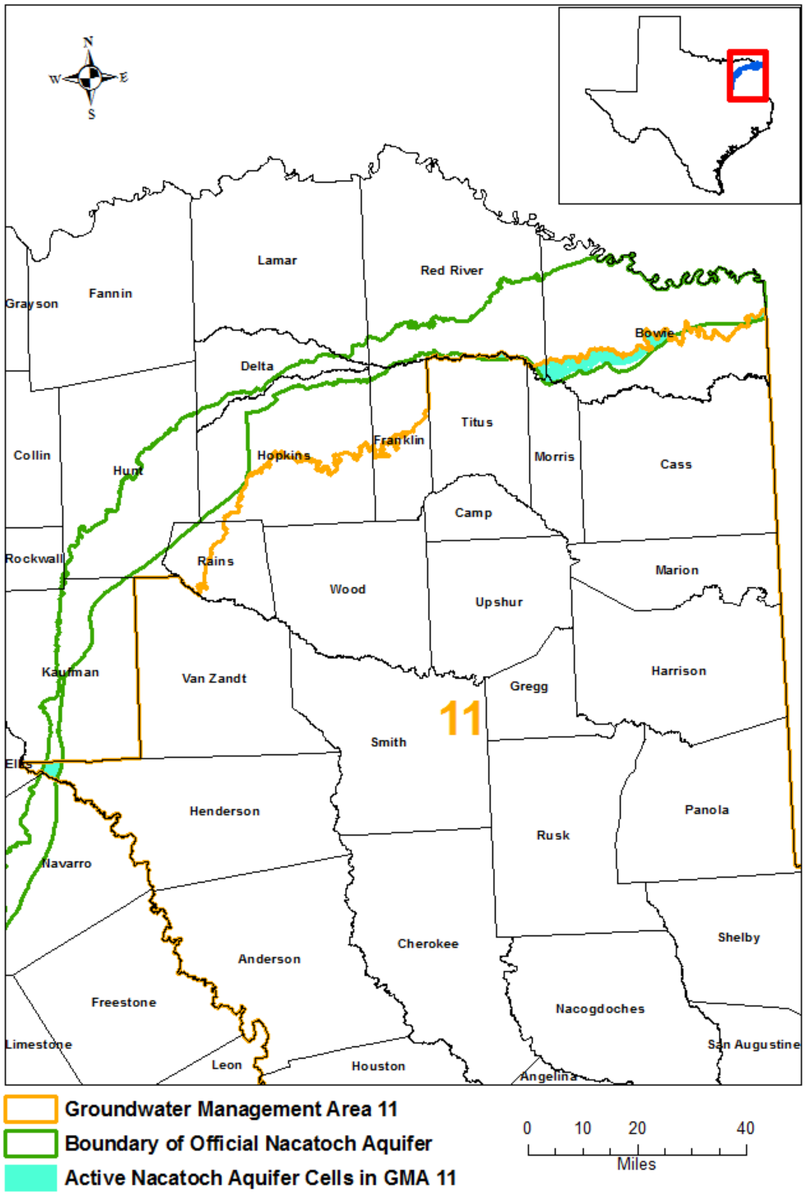
County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Bowie	140,000	35,000	105,000
Henderson	9,800	2,450	7,350
Morris	2,900	725	2,175
Red River	11,000	2,750	8,250
Titus	15,000	3,750	11,250
Total	**178,700**	**44,675**	**134,025**

TABLE 4. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[1] FOR THE NACATOCH AQUIFER IN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	160,000	40,000	120,000
Neches & Trinity Valleys GCD	9,800	2,450	7,350
Total	**169,800**	**42,450**	**127,350**

---

[1] The total estimated recoverable storage values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.



county boundary date 02.02.11. nctc model grid date 10.13.11

FIGURE 3. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE NACATOCH AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE NACATOCH AQUIFER (TABLES 3 AND 4) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 5. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Anderson	170,000,000	42,500,000	127,500,000
Angelina	130,000,000	32,500,000	97,500,000
Bowie	6,400,000	1,600,000	4,800,000
Camp	15,000,000	3,750,000	11,250,000
Cass	60,000,000	15,000,000	45,000,000
Cherokee	200,000,000	50,000,000	150,000,000
Franklin	6,000,000	1,500,000	4,500,000
Gregg	21,000,000	5,250,000	15,750,000
Harrison	40,000,000	10,000,000	30,000,000
Henderson	66,000,000	16,500,000	49,500,000
Hopkins	7,000,000	1,750,000	5,250,000
Houston	390,000,000	97,500,000	292,500,000
Marion	25,000,000	6,250,000	18,750,000
Morris	16,000,000	4,000,000	12,000,000
Nacogdoches	210,000,000	52,500,000	157,500,000
Panola	33,000,000	8,250,000	24,750,000
Rains	3,200,000	800,000	2,400,000
Red River	33,000	8,250	24,750
Rusk	100,000,000	25,000,000	75,000,000
Sabine	78,000,000	19,500,000	58,500,000

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
San Augustine	110,000,000	27,500,000	82,500,000
Shelby	85,000,000	21,250,000	63,750,000
Smith	100,000,000	25,000,000	75,000,000
Titus	13,000,000	3,250,000	9,750,000
Trinity	43,000,000	10,750,000	32,250,000
Upshur	45,000,000	11,250,000	33,750,000
Van Zandt	35,000,000	8,750,000	26,250,000
Wood	54,000,000	13,500,000	40,500,000
Total	**2,061,633,000**	**515,408,250**	**1,546,224,750**

TABLE 6. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT [2] FOR THE CARRIZO-WILCOX AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

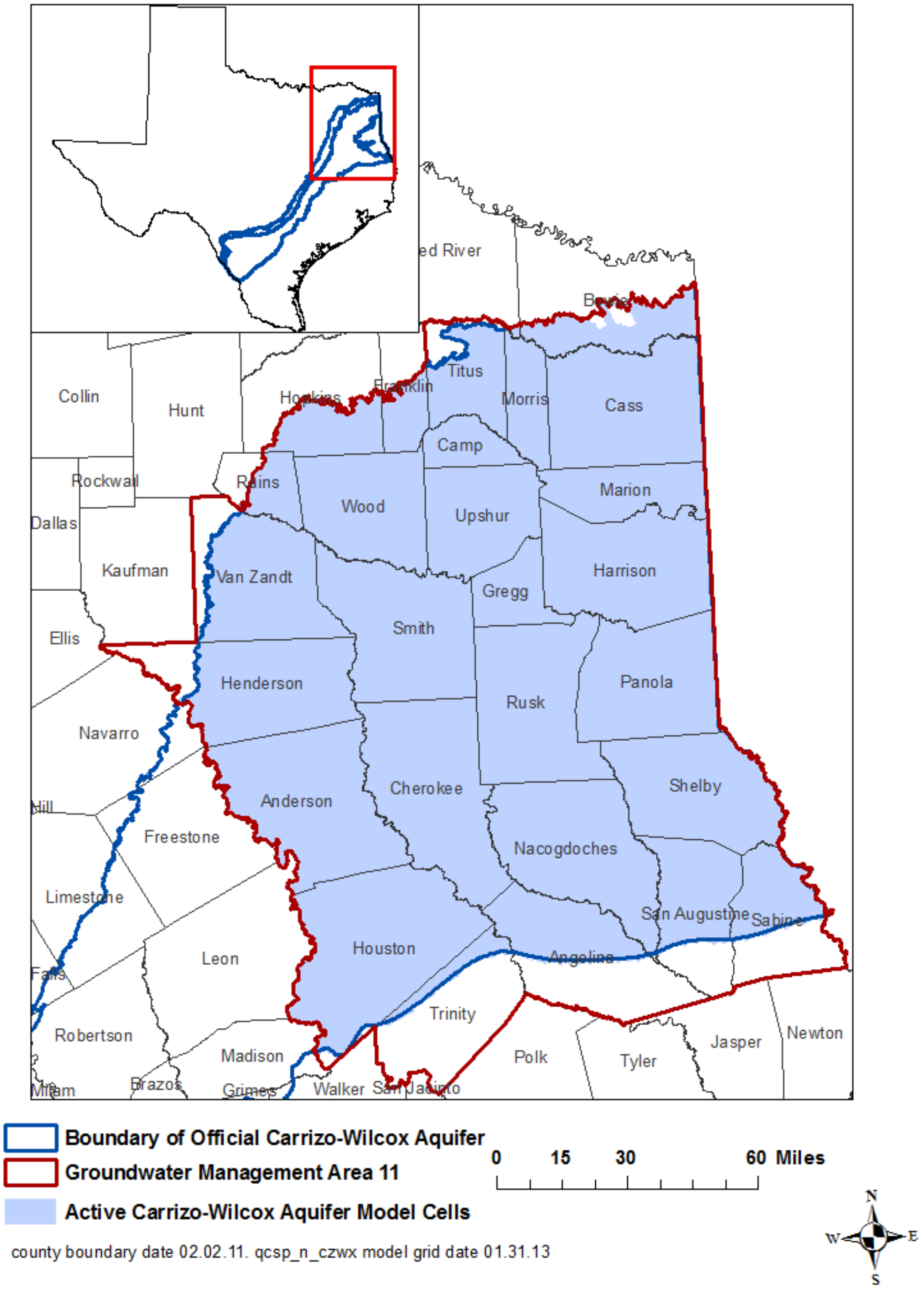
Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	890,000,000	222,500,000	667,500,000
Anderson County UWCD[3]	7,600,000	1,900,000	5,700,000
Deep East Texas GCD[4]	270,000,000	67,500,000	202,500,000
Neches & Trinity Valleys GCD	430,000,000	107,500,000	322,500,000
Panola County GCD	33,000,000	8,250,000	24,750,000
Pineywoods GCD	340,000,000	85,000,000	255,000,000
Rusk County GCD	100,000,000	25,000,000	75,000,000
Total	**2,070,600,000**	**517,650,000**	**1,552,950,000**

---

[2] The total estimated recoverable storage values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.

[3] UWCD stands for Underground Water Conservation District

[4] Deep East Texas Groundwater Conservation District is pending confirmation.



county boundary date 02.02.11. qcsp_n_czwx model grid date 01.31.13

FIGURE 4. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE NORTHERN PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE CARRIZO-WILCOX AQUIFER (TABLES 5 AND 6) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 7. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE QUEEN CITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Anderson	19,000,000	4,750,000	14,250,000
Angelina	2,000,000	500,000	1,500,000
Camp	600,000	150,000	450,000
Cass	8,000,000	2,000,000	6,000,000
Cherokee	15,000,000	3,750,000	11,250,000
Gregg	1,500,000	375,000	1,125,000
Harrison	1,200,000	300,000	900,000
Henderson	6,700,000	1,675,000	5,025,000
Houston	37,000,000	9,250,000	27,750,000
Marion	2,500,000	625,000	1,875,000
Morris	1,300,000	325,000	975,000
Nacogdoches	4,500,000	1,125,000	3,375,000
Rusk	58,000	14,500	43,500
Smith	23,000,000	5,750,000	17,250,000
Titus	63,000	15,750	47,250
Trinity	1,900,000	475,000	1,425,000
Upshur	7,800,000	1,950,000	5,850,000
Van Zandt	1,200,000	300,000	900,000
Wood	8,700,000	2,175,000	6,525,000
Total	**142,021,000**	**35,505,250**	**106,515,750**

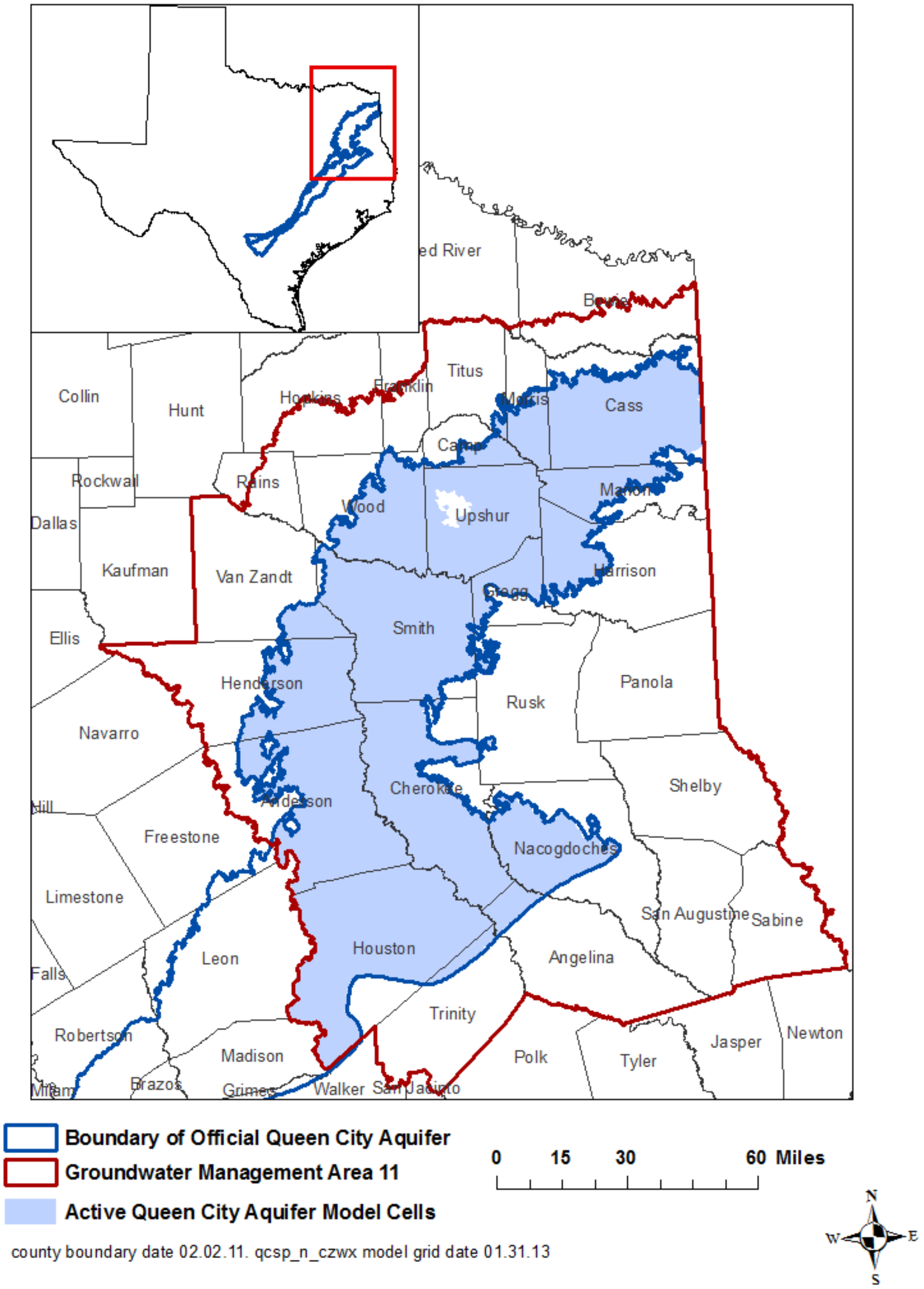
TABLE 8. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[5] FOR THE QUEEN CITY AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	***Total Storage (acre-feet)***	***25 percent of Total Storage (acre-feet)***	***75 percent of Total Storage (acre-feet)***
No District	95,000,000	23,750,000	71,250,000
Anderson County UWCD[6]	550,000	137,500	412,500
Neches & Trinity Valleys GCD	40,000,000	10,000,000	30,000,000
Pineywoods GCD	6,500,000	1,625,000	4,875,000
Rusk County GCD	58,000	14,500	43,500
Total	**142,108,000**	**35,527,000**	**106,581,000**

---

[5] The total estimated recoverable storage values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.

[6] UWCD stands for Underground Water Conservation District



county boundary date 02.02.11. qcsp_n_czwx model grid date 01.31.13

FIGURE 5. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE NORTHERN PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE QUEEN CITY AQUIFER (TABLES 7 AND 8) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 9. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE SPARTA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

County	***Total Storage (acre-feet)***	***25 percent of Total Storage (acre-feet)***	***75 percent of Total Storage (acre-feet)***
Anderson	640,000	160,000	480,000
Angelina	5,200,000	1,300,000	3,900,000
Cherokee	1,700,000	425,000	1,275,000
Houston	25,000,000	6,250,000	18,750,000
Nacogdoches	3,900,000	975,000	2,925,000
Sabine	6,000,000	1,500,000	4,500,000
San Augustine	6,800,000	1,700,000	5,100,000
Trinity	6,100,000	1,525,000	4,575,000
Total	**55,340,000**	**13,835,000**	**41,505,000**

TABLE 10. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[7] FOR THE SPARTA AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
No District	32,000,000	8,000,000	24,000,000
Deep East Texas GCD[8]	13,000,000	3,250,000	9,750,000
Neches & Trinity Valleys GCD	2,300,000	575,000	1,725,000
Pineywoods GCD	9,100,000	2,275,000	6,825,000
Total	**56,400,000**	**14,100,000**	**42,300,000**

---

[7] The total estimated recoverable storage values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.

[8] Deep East Texas Groundwater Conservation District is pending confirmation.

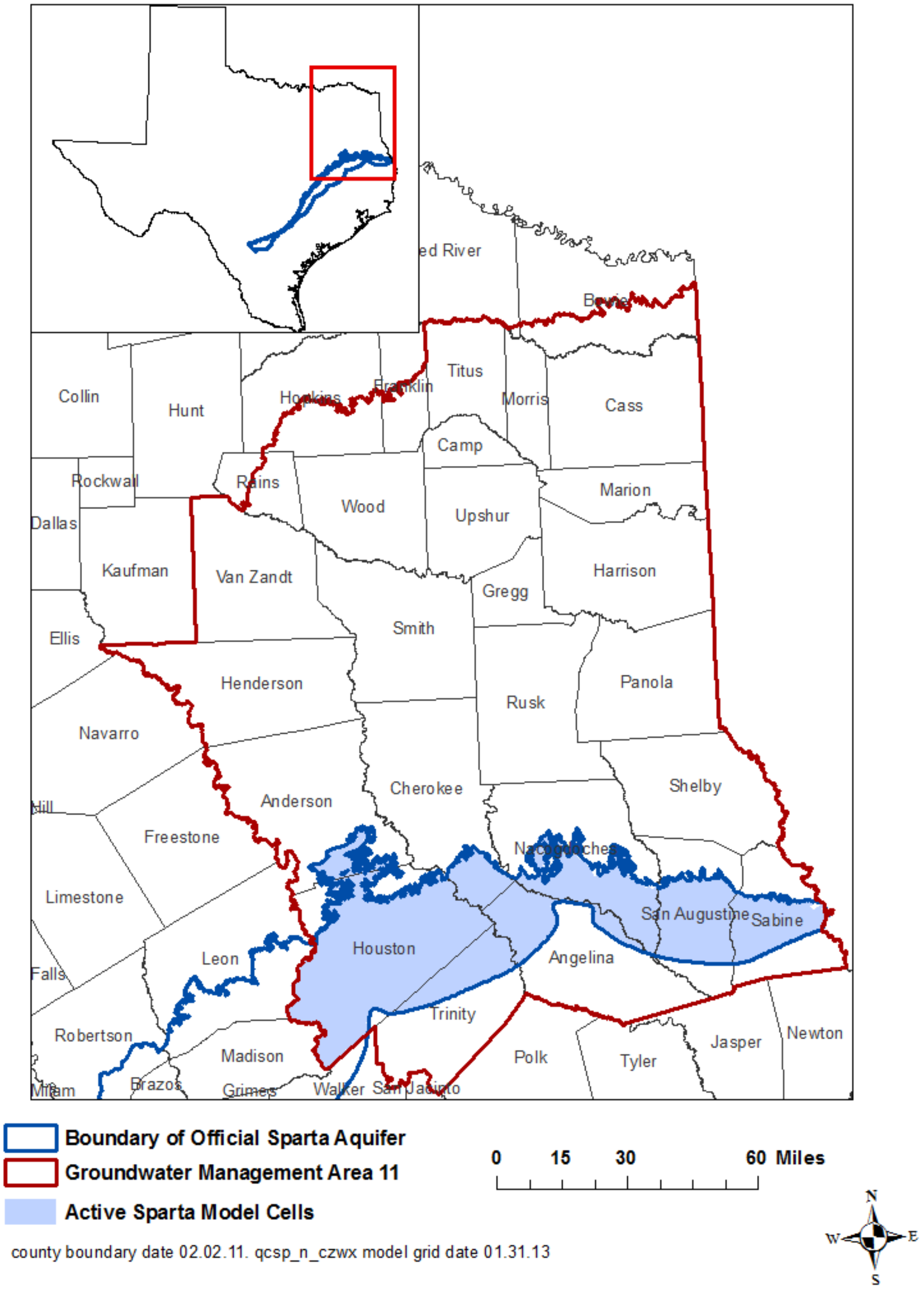


FIGURE 6. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE CENTRAL PART OF THE CARRIZO-WILCOX, QUEEN CITY, AND SPARTA AQUIFERS USED TO ESTIMATE TOTAL RECOVERABLE STORAGE FOR THE SPARTA AQUIFER (TABLES 9 AND 10) WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 11. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

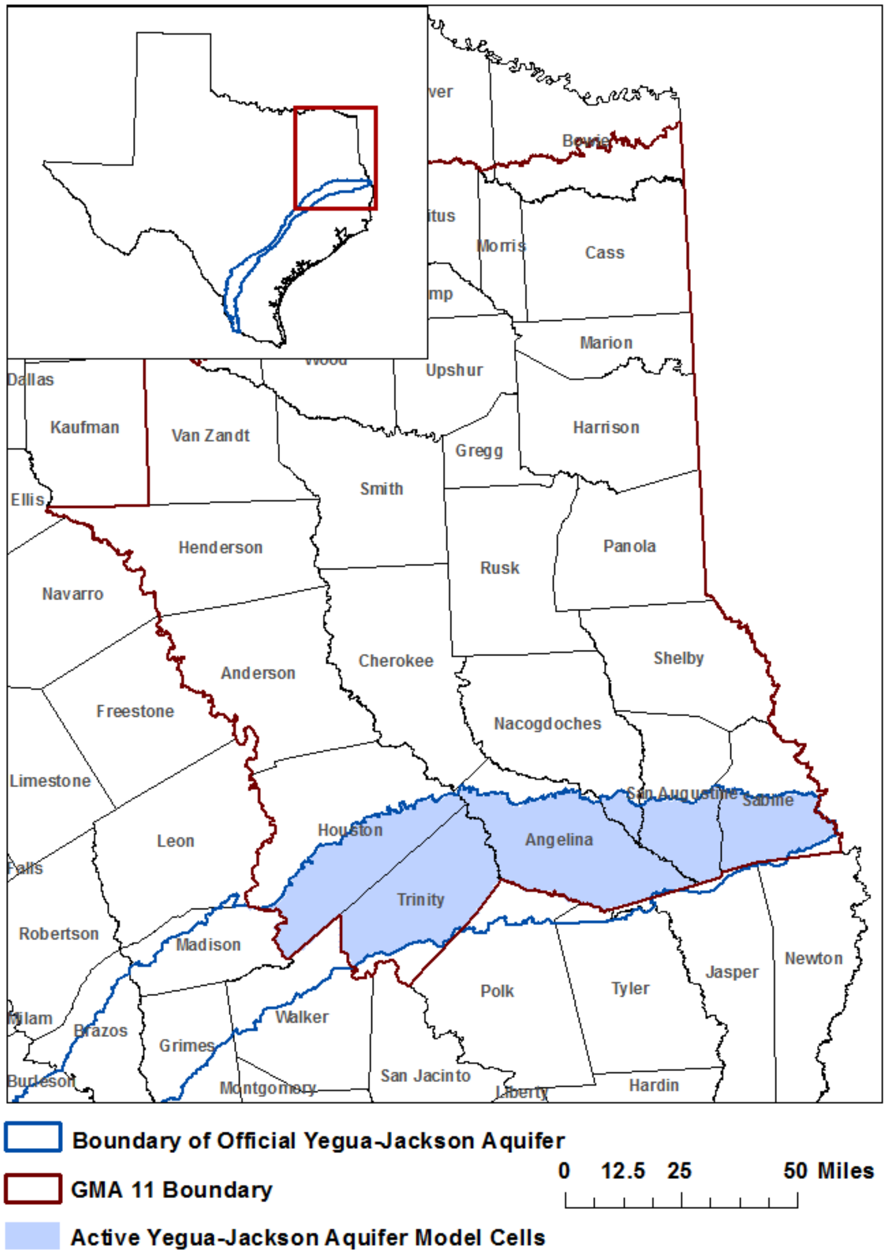
County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Angelina	72,000,000	18,000,000	54,000,000
Houston	21,000,000	5,250,000	15,750,000
Nacogdoches	1,400,000	350,000	1,050,000
Sabine	30,000,000	7,500,000	22,500,000
San Augustine	19,000,000	4,750,000	14,250,000
Trinity	83,000,000	20,750,000	62,250,000
Total	**226,400,000**	**56,600,000**	**169,800,000**

TABLE 12. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[9] FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	*Total Storage (acre-feet)*	*25percent of Total Storage (acre-feet)*	*75percent of Total Storage (acre-feet)*
No District	100,000,000	25,000,000	75,000,000
Deep East Texas GCD[10]	49,000,000	12,250,000	36,750,000
Pineywoods GCD	74,000,000	18,500,000	55,500,000
Total	**223,000,000**	**55,750,000**	**167,250,000**

---

[9] The total estimated recoverable storages values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.
[10] Deep East Texas Groundwater Conservation District is pending confirmation.



county boundary date 02.02.11. ygjk model grid date 10.14.11

FIGURE 7. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE YEGUA-JACKSON AQUIFER USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 11 AND 12) FOR THE YEGUA-JACKSON AQUIFER WITHIN GROUNDWATER MANAGEMENT AREA 11.

TABLE 13. TOTAL ESTIMATED RECOVERABLE STORAGE BY COUNTY FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 11. COUNTY TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

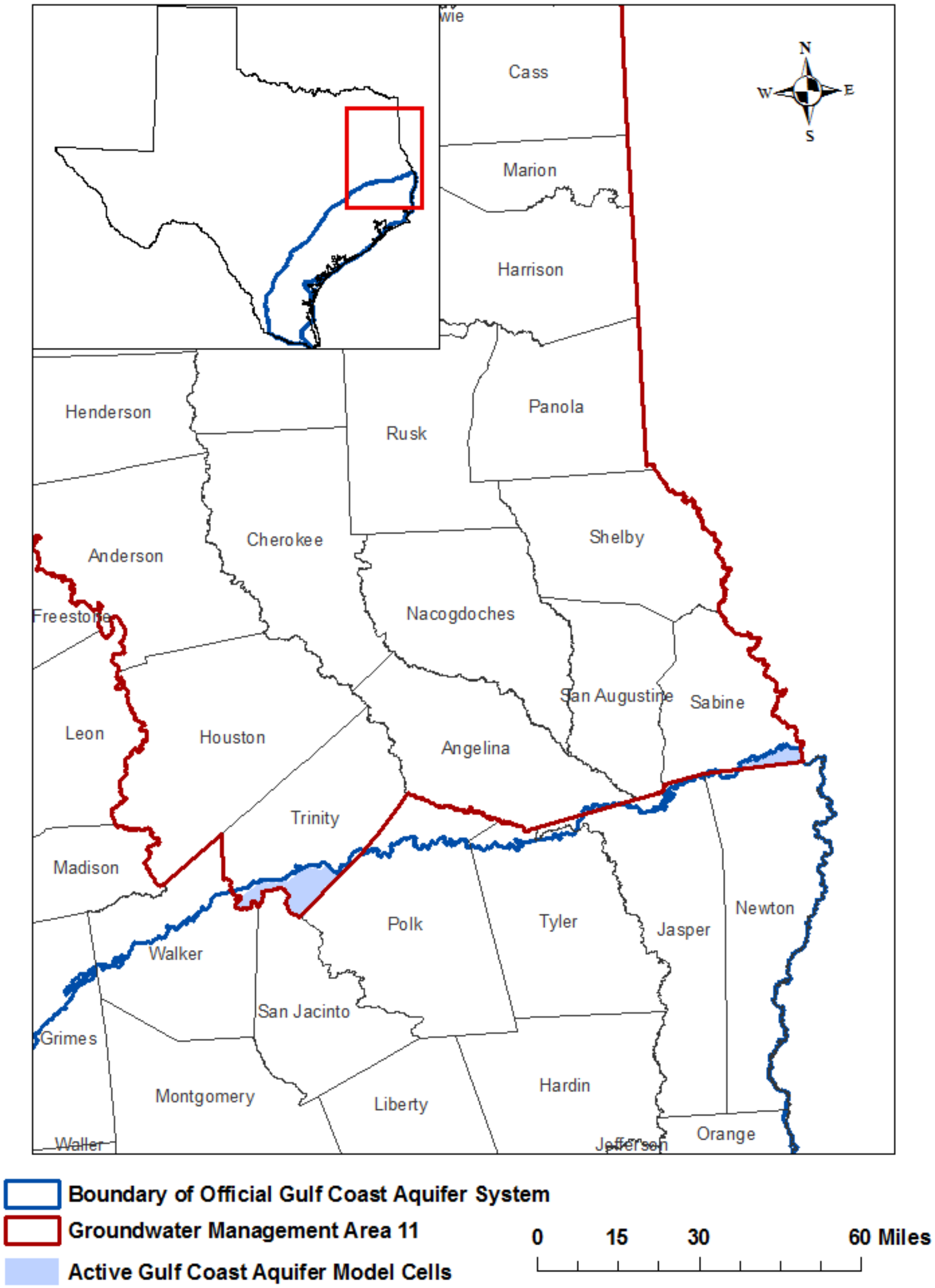
County	***Total Storage (acre-feet)***	***25 percent of Total Storage (acre-feet)***	***75 percent of Total Storage (acre-feet)***
Angelina	27,000	6,750	20,250
Sabine	120,000	30,000	90,000
Trinity	1,300,000	325,000	975,000
Total	**1,447,000**	**361,750**	**1,085,250**

TABLE 14. TOTAL ESTIMATED RECOVERABLE STORAGE BY GROUNDWATER CONSERVATION DISTRICT[11] FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 11. GROUNDWATER CONSERVATION DISTRICT TOTAL ESTIMATES ARE ROUNDED TO TWO SIGNIFICANT DIGITS.

Groundwater Conservation District (GCD)	***Total Storage (acre-feet)***	***25percent of Total Storage (acre-feet)***	***75percent of Total Storage (acre-feet)***
No District	1,400,000	350,000	1,050,000
Pineywoods GCD	27,000	6,750	20,250
Total	**1,427,000**	**356,750**	**1,070,250**

---

[11] The total estimated recoverable storages values by groundwater conservation district and county for an aquifer may not be the same because the numbers have been rounded to two significant digits.



county boundary date 02.02.11. glfc_n model grid date 08.20.13

FIGURE 8. EXTENT OF THE GROUNDWATER AVAILABILITY MODEL FOR THE GULF COAST AQUIFER SYSTEM USED TO ESTIMATE TOTAL RECOVERABLE STORAGE (TABLES 13 AND 14) FOR THE GULF COAST AQUIFER SYSTEM WITHIN GROUNDWATER MANAGEMENT AREA 11.

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., Huang, Y., Symank, L., Ashworth, J.B., Davidson, T., Vreugdenhil, A.M., and Deeds, N.E., 2009, Nacatoch Aquifer Groundwater Availability Model: contract report to the Texas Water Development Board, 304 p., http://www.twdb.texas.gov/groundwater/models/gam/nctc/NCTC_Model_Report.pdf

Bené, J., Harden, B., O'Rourke, D., Donnelly, A., and Yelderman, J., 2004, Northern Trinity/Woodbine Groundwater Availability Model: contract report to the Texas Water Development Board by R.W. Harden and Associates, 391 p., http://www.twdb.texas.gov/groundwater/models/gam/trnt_n/TRNT_N_Model_Report.pdf

Deeds, N.E., Yan, T., Singh, A., Jones, T.L., Kelley, V.A., Knox, P.R., Young, S.C., 2010, Groundwater availability model for the Yegua-Jackson Aquifer: Final report prepared for the Texas Water Development Board by INTERA, Inc., 582 p., http://www.twdb.texas.gov/groundwater/models/gam/ygjk/YGJK_Model_Report.pdf.

Fryar, D., Senger, R., Deeds, N., Pickens, J., Jones, T., Whallon, A.J., Dean, K.E., 2003, Groundwater availability model for the northern Carrizo-Wilcox aquifer: Contract report to the Texas Water Development Board, 529 p., http://www.twdb.texas.gov/groundwater/models/gam/czwx_n/czwx_n.asp

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.

Kasmarek, M.C., 2013, Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System, Texas, 1891-2009: United States Geological Survey Scientific investigations Report 2012-5154 Version 1.1, 55 p., http://www.twdb.texas.gov/groundwater/models/gam/glfc_n/HAGM.SIR.Version1.1.November2013.pdf

Kelley, V.A., Deeds, N.E., Fryar, D.G., and Nicot, J.P., 2004, Groundwater availability models for the Queen City and Sparta aquifers: Contract report to the Texas Water Development Board, 867 p., http://www.twdb.texas.gov/groundwater/models/gam/qcsp/QCSP_Model_Report.pdf.

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.

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

Appendix C

Region D and Region I Socioeconomic Impact Reports from TWDB

Socioeconomic Impacts of Projected Water Shortages for the North East Texas (Region D) Regional Water Planning Area

Prepared in Support of the 2021 Region D Regional Water Plan

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

November 2019

Table of Contents

Executive Summary

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

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

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

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

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

IMPLAN data reported that Region D generated more than $30 billion in GDP (2018 dollars) and supported more than 393,000 jobs in 2016. The Region D estimated total population was approximately 783,000 in 2016.

It is estimated that not meeting the identified water needs in Region D would result in an annually combined lost income impact of approximately $5.9 billion in 2020, increasing to $6.1 billion in 2070 (Table ES-1). In 2020, the region would lose approximately 46,000 jobs, and by 2070 job losses would increase to approximately 60,000 if anticipated needs are not mitigated.

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

Table ES-1 Region D socioeconomic impact summary

Regional Economic Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Income losses ($ millions)*	$5,868	$7,000	$6,602	$6,211	$6,068	$6,148
Job losses	46,069	57,405	55,266	54,160	56,434	59,710
Financial Transfer Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Tax losses on production and imports ($ millions)*	$445	$548	$500	$454	$440	$450
Water trucking costs ($ millions)*	$92	$94	$97	$101	$105	$114
Utility revenue losses ($ millions)*	$44	$46	$52	$69	$96	$139
Utility tax revenue losses ($ millions)*	$1	$1	$1	$1	$1	$2
Social Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Consumer surplus losses ($ millions)*	$141	$146	$155	$173	$220	$300
Population losses	8,458	10,540	10,147	9,944	10,361	10,963
School enrollment losses	1,618	2,016	1,941	1,902	1,982	2,097

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

1 Introduction

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

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

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

1.1 Regional Economic Summary

The Region D Regional Water Planning Area generated more than $30 billion in gross domestic product (2018 dollars) and supported more than 393,000 jobs in 2016, according to the IMPLAN dataset utilized in this socioeconomic analysis. This activity accounted for nearly 2 percent of the state's total gross domestic product of 1.73 trillion dollars for the year based on IMPLAN. Table 1-1 lists all economic sectors ranked by the total value-added to the economy in Region D. The manufacturing sector (including agribusiness and timber production) generated 18 percent of the region's total value-added and was also a significant source of tax revenue. The top employers in the region were in the public administration, health care, retail trade, and manufacturing sectors. Region D's estimated total population was approximately 783,000 in 2016, close to 3 percent of the state's total.

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

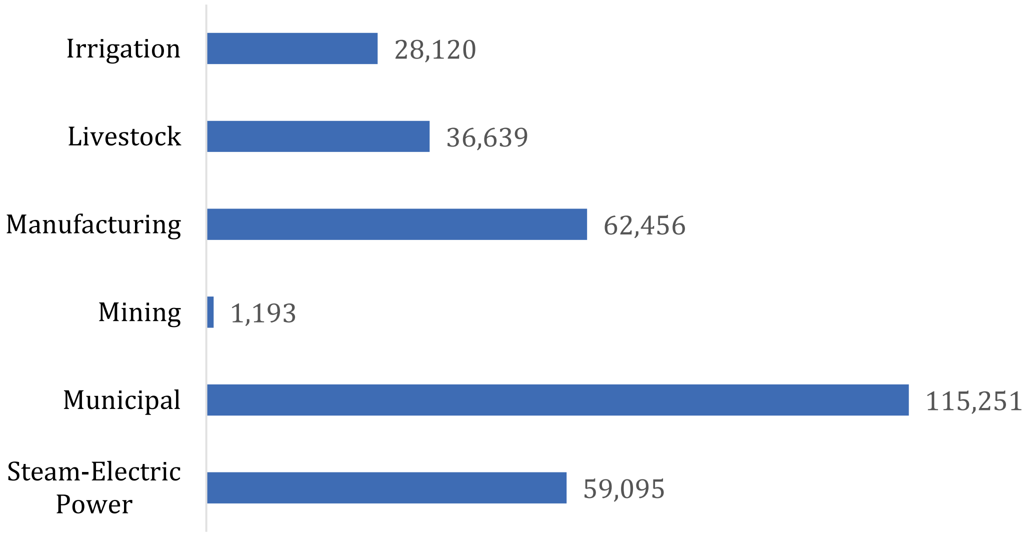
Table 1-1 Region D regional economy by economic sector*

Economic sector	Value-added ($ millions)	Tax ($ millions)	Jobs
Manufacturing	$5,446.6	$240.3	38,589
Public Administration	$3,360.9	$(14.8)	46,555
Real Estate and Rental and Leasing	$2,676.3	$465.8	11,460
Health Care and Social Assistance	$2,136.7	$39.1	42,208
Retail Trade	$2,120.1	$562.8	39,363
Wholesale Trade	$2,105.1	$405.9	13,804
Construction	$1,974.9	$32.3	29,218
Mining, Quarrying, and Oil and Gas Extraction	$1,940.3	$519.4	15,703
Utilities	$1,424.3	$265.9	2,452
Professional, Scientific, and Technical Services	$1,102.8	$38.6	17,643
Accommodation and Food Services	$974.6	$171.6	27,595
Other Services (except Public Administration)	$964.3	$106.9	23,534
Transportation and Warehousing	$922.6	$47.8	13,758
Finance and Insurance	$910.1	$66.8	15,397
Administrative and Support and Waste Management and Remediation Services	$664.1	$28.6	17,688
Agriculture, Forestry, Fishing and Hunting	$539.9	$23.6	24,728
Information	$500.2	$162.6	3,105
Management of Companies and Enterprises	$126.6	$7.2	2,555
Educational Services	$93.7	$6.8	3,988
Arts, Entertainment, and Recreation	$83.7	$25.6	3,793
Grand Total	$30,067.9	$3,202.7	393,138

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

While the manufacturing sector led the region in economic output, the municipal category used the most water in 2016 (38 percent of the region's total). Notably, nearly 13 percent of the state's water use for steam-electric power generation occurred in Region D. Figure 1-1 illustrates Region D's breakdown of the 2016 water use estimates by TWDB water use category.

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



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

1.2 Identified Regional Water Needs (Potential Shortages)

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

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

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

Water Use Category		2020	2030	2040	2050	2060	2070
Irrigation	water needs (acre-feet per year)	13,696	13,696	13,696	13,696	13,696	13,696
	% of the category's total water demand	39%	39%	39%	39%	39%	39%
Livestock	water needs (acre-feet per year)	15,005	15,015	15,003	14,918	14,940	14,954
	% of the category's total water demand	42%	42%	42%	42%	42%	43%
Manufacturing	water needs (acre-feet per year)	2,683	5,308	5,159	5,148	5,380	5,489
	% of the category's total water demand	3%	5%	5%	5%	5%	5%
Mining	water needs (acre-feet per year)	2,250	2,138	1,776	1,423	1,113	928
	% of the category's total water demand	32%	28%	23%	20%	16%	14%
Municipal*	water needs (acre-feet per year)	15,034	15,716	17,594	23,230	31,981	45,627
	% of the category's total water demand	12%	11%	12%	14%	18%	22%
Steam-electric power	water needs (acre-feet per year)	30,066	30,866	31,766	32,566	32,814	33,083
	% of the category's total water demand	32%	33%	34%	35%	35%	35%
Total water needs (acre-feet per year)		**78,734**	**82,739**	**84,994**	**90,981**	**99,924**	**113,777**

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

2 Impact Assessment Measures

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

Table 2-1 Socioeconomic impact analysis measures

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

2.1 Regional Economic Impacts

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

Income Losses - Value-added Losses

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

Income Losses - Electric Power Purchase Costs

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

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

Job Losses

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

2.2 Financial Transfer Impacts

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

Tax Losses on Production and Imports

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

Water Trucking Costs

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

Utility Revenue Losses

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

Utility Tax Losses

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

2.3 Social Impacts

Consumer Surplus Losses for Municipal Water Users

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

---

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

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

Population and School Enrollment Losses

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

---

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

3 Socioeconomic Impact Assessment Methodology

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

3.1 Analysis Context

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

3.2 IMPLAN Model and Data

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

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

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

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

3.3 Elasticity of Economic Impacts

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

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

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

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

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

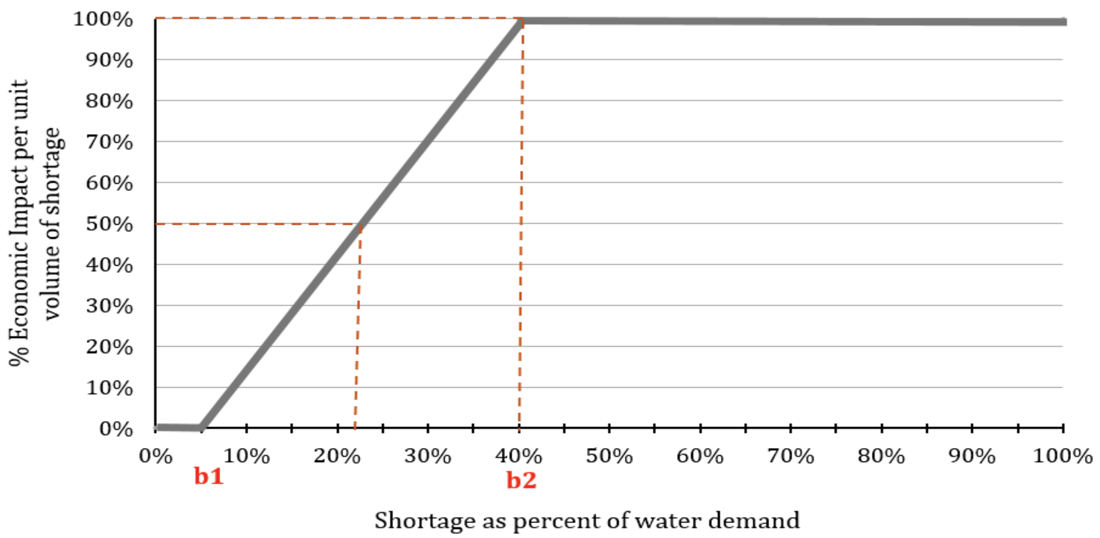


Table 3-1 Economic impact elasticity function lower and upper bounds

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

3.4 Analysis Assumptions and Limitations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4 Analysis Results

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

4.1 Impacts for Irrigation Water Shortages

Eight of the 19 counties in the region are projected to experience water shortages in the irrigated agriculture water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-1. Note that tax collection impacts were not estimated for this water use category. IMPLAN data indicates a negative tax impact (i.e., increased tax collections) for the associated production sectors, primarily due to past subsidies from the federal government. However, it was not considered realistic to report increasing tax revenues during a drought of record.

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

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$3	$3	$3	$3	$3	$3
Job losses	94	94	94	94	94	94

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

4.2 Impacts for Livestock Water Shortages

Fourteen of the 19 counties in the region are projected to experience water shortages in the livestock water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-2.

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

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$523	$523	$524	$522	$524	$525
Jobs losses	13,614	13,618	13,596	13,514	13,523	13,530
Tax losses on production and imports ($ millions)*	$31	$31	$31	$31	$31	$31

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

4.3 Impacts of Manufacturing Water Shortages

Manufacturing water shortages in the region are projected to occur in eight of the 19 counties in the region for at least one decade of the planning horizon. Estimated impacts to this water use category appear in Table 4-3.

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

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$2,627	$3,843	$3,769	$3,754	$3,841	$3,881
Job losses	21,846	33,544	32,571	32,428	33,771	34,407
Tax losses on production and Imports ($ millions)*	$189	$303	$295	$294	$308	$315

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

4.4 Impacts of Mining Water Shortages

Mining water shortages in the region are projected to occur in five of the 19 counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use type appear in Table 4-4.

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

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$1,791	$1,682	$1,327	$900	$561	$453
Job losses	6,779	6,300	4,983	3,411	2,171	1,814
Tax losses on production and Imports ($ millions)*	$206	$195	$154	$105	$66	$54

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

4.5 Impacts for Municipal Water Shortages

Sixteen of the 19 counties in the region are projected to experience water shortages in the municipal water use category for one or more decades within the planning horizon.

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

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

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

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses[1] ($ millions)*	$176	$181	$189	$222	$324	$464
Job losses[1]	3,736	3,849	4,022	4,712	6,876	9,866
Tax losses on production and imports[1] ($ millions)*	$19	$20	$20	$24	$35	$50
Trucking costs ($ millions)*	$92	$94	$97	$101	$105	$114
Utility revenue losses ($ millions)*	$44	$46	$52	$69	$96	$139
Utility tax revenue losses ($ millions)*	$1	$1	$1	$1	$1	$2

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

4.6 Impacts of Steam-Electric Water Shortages

Steam-electric water shortages in the region are projected to occur in one of the 19 counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-6.

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

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

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

Impacts measure	2020	2030	2040	2050	2060	2070
Income Losses ($ millions)*	$748	$768	$790	$810	$816	$823

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

4.7 Regional Social Impacts

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

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

Impacts measure	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)*	$141	$146	$155	$173	$220	$300
Population losses	8,458	10,540	10,147	9,944	10,361	10,963
School enrollment losses	1,618	2,016	1,941	1,902	1,982	2,097

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

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

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

		Income losses (Million $)*						Job losses					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
BOWIE	IRRIGATION	$0.82	$0.82	$0.82	$0.82	$0.82	$0.82	23	23	23	23	23	23
BOWIE	LIVESTOCK	$15.18	$15.18	$13.77	$11.82	$10.12	$9.44	646	646	586	503	431	402
BOWIE	MANUFACTURING	$1,779.61	$2,269.87	$2,269.87	$2,269.87	$2,269.87	$2,269.87	15,731	20,065	20,065	20,065	20,065	20,065
BOWIE	MUNICIPAL	$169.95	$173.24	$176.26	$180.55	$185.61	$190.83	3,616	3,685	3,750	3,841	3,949	4,060
BOWIE Total		**$1,965.55**	**$2,459.10**	**$2,460.72**	**$2,463.06**	**$2,466.42**	**$2,470.96**	**20,016**	**24,420**	**24,424**	**24,433**	**24,468**	**24,550**
CAMP	LIVESTOCK	$147.01	$147.01	$147.01	$147.01	$147.01	$147.01	3,628	3,628	3,628	3,628	3,628	3,628
CAMP	MANUFACTURING	-	$0.31	-	-	-	-	-	3	-	-	-	-
CAMP Total		**$147.01**	**$147.32**	**$147.01**	**$147.01**	**$147.01**	**$147.01**	**3,628**	**3,630**	**3,628**	**3,628**	**3,628**	**3,628**
CASS	LIVESTOCK	$62.51	$62.51	$62.51	$62.44	$62.44	$62.44	1,728	1,728	1,728	1,727	1,727	1,727
CASS	MUNICIPAL	$0.58	$0.41	$0.26	$0.17	$0.17	$0.17	12	9	5	4	4	4
CASS Total		**$63.09**	**$62.92**	**$62.77**	**$62.61**	**$62.61**	**$62.61**	**1,741**	**1,737**	**1,734**	**1,730**	**1,730**	**1,730**
DELTA	LIVESTOCK	$4.90	$4.67	$4.67	$4.67	$4.67	$4.67	276	264	264	264	264	264
DELTA	MUNICIPAL	$0.00	$0.00	$0.00	$0.00	$0.01	$0.01	0	0	0	0	0	0
DELTA Total		**$4.90**	**$4.68**	**$4.68**	**$4.68**	**$4.68**	**$4.68**	**276**	**264**	**264**	**264**	**264**	**264**
FRANKLIN	LIVESTOCK	$70.65	$70.65	$70.65	$70.65	$70.65	$70.65	1,492	1,492	1,492	1,492	1,492	1,492
FRANKLIN Total		**$70.65**	**$70.65**	**$70.65**	**$70.65**	**$70.65**	**$70.65**	**1,492**	**1,492**	**1,492**	**1,492**	**1,492**	**1,492**
GREGG	MUNICIPAL	-	-	-	-	-	$0.01	-	-	-	-	-	0
GREGG Total		**-**	**-**	**-**	**-**	**-**	**$0.01**	**-**	**-**	**-**	**-**	**-**	**0**
HARRISON	IRRIGATION	$0.11	$0.11	$0.11	$0.11	$0.11	$0.11	6	6	6	6	6	6
HARRISON	MINING	$1,331.43	$958.19	$656.36	$330.47	$73.77	-	5,122	3,686	2,525	1,271	284	-
HARRISON	MUNICIPAL	$0.57	$0.88	$1.64	$3.55	$5.48	$7.57	12	19	35	75	117	161
HARRISON Total		**$1,332.12**	**$959.19**	**$658.12**	**$334.13**	**$79.37**	**$7.68**	**5,140**	**3,710**	**2,565**	**1,352**	**406**	**167**
HOPKINS	IRRIGATION	$1.13	$1.13	$1.13	$1.13	$1.13	$1.13	30	30	30	30	30	30
HOPKINS	LIVESTOCK	$33.47	$34.16	$35.73	$35.82	$37.48	$38.21	818	835	873	875	916	933
HOPKINS	MINING	$35.15	$51.97	$80.13	$114.79	$154.54	$203.53	160	237	365	523	704	927
HOPKINS	MUNICIPAL	$0.01	$0.07	$0.17	$0.29	$0.58	$0.96	0	2	4	6	12	20
HOPKINS Total		**$69.77**	**$87.33**	**$117.17**	**$152.03**	**$193.74**	**$243.83**	**1,008**	**1,102**	**1,271**	**1,434**	**1,662**	**1,910**
HUNT	IRRIGATION	$0.06	$0.06	$0.06	$0.06	$0.06	$0.06	3	3	3	3	3	3

		Income losses (Million $)*						Job losses					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
HUNT	MINING	$74.10	$64.96	$35.29	$11.99	$1.44	-	249	218	119	40	5	-
HUNT	MUNICIPAL	$1.28	$2.73	$5.59	$29.22	$117.52	$240.13	27	58	118	619	2,495	5,100
HUNT Total		**$75.43**	**$67.75**	**$40.94**	**$41.27**	**$119.01**	**$240.19**	**279**	**279**	**239**	**662**	**2,502**	**5,103**
LAMAR	IRRIGATION	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	3	3	3	3	3	3
LAMAR	LIVESTOCK	$12.86	$12.86	$12.86	$12.86	$12.86	$12.86	598	598	598	598	598	598
LAMAR	MUNICIPAL	$1.52	$1.52	$1.58	$1.66	$1.74	$1.81	32	32	34	35	37	39
LAMAR Total		**$14.46**	**$14.46**	**$14.52**	**$14.61**	**$14.69**	**$14.76**	**634**	**634**	**635**	**637**	**638**	**640**
MARION	MINING	$350.77	$606.56	$554.84	$442.93	$331.02	$249.21	1,249	2,159	1,975	1,577	1,178	887
MARION	MUNICIPAL	$0.03	$0.04	$0.06	$0.13	$0.23	$0.38	1	1	1	3	5	8
MARION Total		**$350.80**	**$606.61**	**$554.91**	**$443.06**	**$331.25**	**$249.59**	**1,249**	**2,160**	**1,976**	**1,579**	**1,183**	**895**
MORRIS	LIVESTOCK	$34.19	$34.19	$34.19	$34.19	$34.19	$34.19	931	931	931	931	931	931
MORRIS	MUNICIPAL	$0.02	$0.02	$0.01	$0.01	$0.01	$0.01	0	0	0	0	0	0
MORRIS Total		**$34.21**	**$34.21**	**$34.21**	**$34.21**	**$34.21**	**$34.21**	**931**	**931**	**931**	**931**	**931**	**931**
RAINS	MANUFACTURING	$13.09	$13.09	$13.09	$13.09	$13.09	$13.09	139	139	139	139	139	139
RAINS	MUNICIPAL	$1.06	$0.73	$0.78	$0.84	$0.92	$1.04	22	16	17	18	20	22
RAINS Total		**$14.15**	**$13.82**	**$13.88**	**$13.93**	**$14.01**	**$14.14**	**161**	**154**	**156**	**157**	**158**	**161**
RED RIVER	IRRIGATION	$0.41	$0.41	$0.41	$0.41	$0.41	$0.41	16	16	16	16	16	16
RED RIVER	LIVESTOCK	$4.09	$4.09	$4.09	$4.09	$4.09	$4.09	190	190	190	190	190	190
RED RIVER	MUNICIPAL	$0.49	$0.48	$0.45	$0.44	$0.44	$0.44	10	10	9	9	9	9
RED RIVER Total		**$4.98**	**$4.97**	**$4.94**	**$4.94**	**$4.93**	**$4.93**	**217**	**217**	**216**	**216**	**216**	**216**
SMITH	IRRIGATION	$0.33	$0.33	$0.33	$0.33	$0.33	$0.33	12	12	12	12	12	12
SMITH	LIVESTOCK	$11.52	$11.52	$11.52	$11.52	$11.52	$11.52	473	473	473	473	473	473
SMITH	MUNICIPAL	$0.02	$0.67	$2.12	$4.43	$9.83	$18.91	0	14	45	94	209	402
SMITH Total		**$11.86**	**$12.52**	**$13.96**	**$16.27**	**$21.67**	**$30.75**	**485**	**499**	**530**	**579**	**694**	**887**
TITUS	LIVESTOCK	$84.02	$84.02	$84.02	$84.02	$85.97	$86.88	1,752	1,752	1,752	1,752	1,793	1,812
TITUS	MANUFACTURING	-	$268.59	$220.36	$224.10	$331.98	$385.55	-	3,904	3,203	3,258	4,826	5,605
TITUS	STEAM ELECTRIC POWER	$748.02	$767.93	$790.32	$810.22	$816.39	$823.08	-	-	-	-	-	-
TITUS Total		**$832.05**	**$1,120.53**	**$1,094.70**	**$1,118.35**	**$1,234.34**	**$1,295.52**	**1,752**	**5,657**	**4,956**	**5,010**	**6,619**	**7,417**
UPSHUR	LIVESTOCK	$2.42	$2.42	$2.42	$2.42	$2.42	$2.42	89	89	89	89	89	89
UPSHUR	MANUFACTURING	$227.70	$253.00	$253.00	$253.00	$253.00	$253.00	2,052	2,280	2,280	2,280	2,280	2,280
UPSHUR	MUNICIPAL	$0.00	$0.00	$0.00	$0.03	$0.42	$1.05	0	0	0	1	9	22
UPSHUR Total		**$230.12**	**$255.42**	**$255.42**	**$255.45**	**$255.84**	**$256.47**	**2,141**	**2,369**	**2,369**	**2,370**	**2,378**	**2,391**
VAN ZANDT	IRRIGATION	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02	2	2	2	2	2	2
VAN ZANDT	MANUFACTURING	-	$106.62	$81.01	$62.33	$40.92	$27.31	-	1,123	853	656	431	288
VAN ZANDT	MUNICIPAL	$0.14	$0.20	$0.25	$0.43	$0.72	$1.14	2	3	4	6	11	17
VAN ZANDT Total		**$0.17**	**$106.85**	**$81.29**	**$62.78**	**$41.67**	**$28.48**	**4**	**1,127**	**858**	**664**	**443**	**307**

		Income losses (Million $)*						Job losses					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
WOOD	LIVESTOCK	$40.14	$40.14	$40.14	$40.14	$40.14	$40.14	991	991	991	991	991	991
WOOD	MANUFACTURING	$606.23	$931.71	$931.71	$931.71	$931.71	$931.71	3,924	6,031	6,031	6,031	6,031	6,031
WOOD	MUNICIPAL	$0.00	-	-	-	-	-	0	-	-	-	-	-
WOOD Total		**$646.37**	**$971.85**	**$971.85**	**$971.85**	**$971.85**	**$971.85**	**4,915**	**7,022**	**7,022**	**7,022**	**7,022**	**7,022**
REGION D Total		**$5,867.69**	**$7,000.18**	**$6,601.72**	**$6,210.89**	**$6,067.93**	**$6,148.30**	**46,069**	**57,405**	**55,266**	**54,160**	**56,434**	**59,710**

Socioeconomic Impacts of Projected Water Shortages for the East Texas (Region I) Regional Water Planning Area

Prepared in Support of the 2021 Region I Regional Water Plan

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

November 2019

Table of Contents

Executive Summary

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

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

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

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

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

IMPLAN data reported that Region I generated nearly $59 billion in GDP (2018 dollars) and supported roughly 593,000 jobs in 2016. The Region I estimated total population was approximately 1.1 million in 2016.

It is estimated that not meeting the identified water needs in Region I would result in an annually combined lost income impact of approximately $9.3 billion in 2020, and $3.9 billion in 2070 (Table ES-1). It is also estimated that the region would lose approximately 68,000 jobs in 2020, and 52,000 in 2070.

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

Table ES-1 Region I socioeconomic impact summary

Regional Economic Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Income losses ($ millions)*	$9,314	$6,786	$3,515	$3,651	$3,892	$3,920
Job losses	68,468	57,221	42,058	45,480	50,164	51,585
Financial Transfer Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Tax losses on production and imports ($ millions)*	$1,061	$704	$248	$242	$243	$239
Water trucking costs ($ millions)*	$3	$3	$3	$3	$3	$3
Utility revenue losses ($ millions)*	$12	$13	$18	$28	$42	$59
Utility tax revenue losses ($ millions)*	$0	$0	$0	$0	$1	$1
Social Impacts	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
Consumer surplus losses ($ millions)*	$34	$35	$35	$36	$42	$52
Population losses	12,571	10,506	7,722	8,350	9,210	9,471
School enrollment losses	2,405	2,010	1,477	1,597	1,762	1,812

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

1 Introduction

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

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

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

1.1 Regional Economic Summary

The Region I Regional Water Planning Area generated nearly $59 billion in gross domestic product (2018 dollars) and supported roughly 593,000 jobs in 2016, according to the IMPLAN dataset utilized in this socioeconomic analysis. This activity accounted for 3.4 percent of the state's total gross domestic product of 1.73 trillion dollars for the year based on IMPLAN. Table 1-1 lists all economic sectors ranked by the total value-added to the economy in Region I. The manufacturing sector generated more than 27 percent of the region's total value-added and was also a significant source of tax revenue. The top employers in the region were in the public administration, health care, and retail trade sectors. Region I's estimated total population was roughly 1.1 million in 2016, approximately 4 percent of the state's total.

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

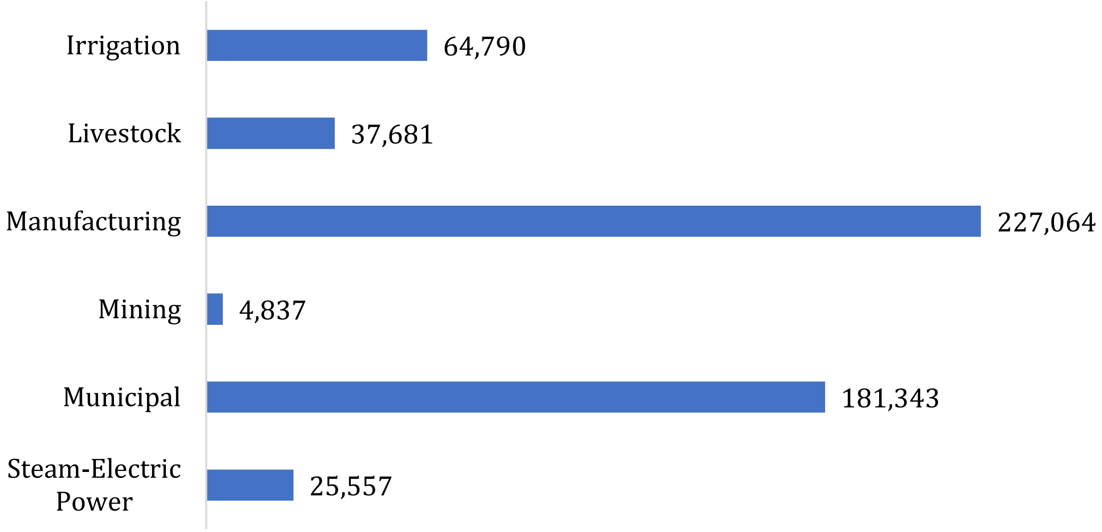
Table 1-1 Region I regional economy by economic sector*

Economic sector	Value-added ($ millions)	Tax ($ millions)	Jobs
Manufacturing	$16,152.9	$507.3	47,857
Public Administration	$5,419.7	$(20.8)	72,259
Mining, Quarrying, and Oil and Gas Extraction	$4,789.2	$732.1	16,819
Real Estate and Rental and Leasing	$4,278.7	$682.2	17,085
Health Care and Social Assistance	$4,265.8	$63.9	71,846
Construction	$3,470.9	$48.6	44,007
Retail Trade	$3,457.2	$821.9	59,420
Wholesale Trade	$2,835.7	$496.2	16,876
Professional, Scientific, and Technical Services	$2,168.8	$55.3	27,527
Transportation and Warehousing	$2,102.9	$95.5	22,237
Other Services (except Public Administration)	$1,892.8	$172.1	55,611
Utilities	$1,654.3	$249.9	2,743
Finance and Insurance	$1,564.8	$77.2	26,010
Accommodation and Food Services	$1,526.2	$250.3	40,573
Administrative and Support and Waste Management and Remediation Services	$1,159.7	$45.7	30,764
Information	$911.3	$292.2	5,543
Agriculture, Forestry, Fishing and Hunting	$710.1	$30.1	22,427
Management of Companies and Enterprises	$295.9	$9.3	3,303
Arts, Entertainment, and Recreation	$153.0	$33.8	5,874
Educational Services	$103.6	$5.8	4,152
Grand Total	$58,913.5	$4,648.6	592,934

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

Figure 1-1 illustrates Region I's breakdown of the 2016 water use estimates by TWDB water use category. The categories with the highest use in Region I in 2016 were manufacturing (42 percent) and municipal (34 percent). Notably, more than 21 percent of the state's manufacturing water use occurred within Region I.

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



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

1.2 Identified Regional Water Needs (Potential Shortages)

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

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

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

Water Use Category		2020	2030	2040	2050	2060	2070
Irrigation	water needs (acre-feet per year)	577	587	602	618	670	700
	% of the category's total water demand	1%	1%	1%	1%	1%	1%
Livestock	water needs (acre-feet per year)	25,447	28,441	32,048	36,404	41,618	42,766
	% of the category's total water demand	54%	57%	59%	62%	65%	66%
Manufacturing	water needs (acre-feet per year)	1,452	1,710	1,710	1,710	1,710	1,710
	% of the category's total water demand	0%	0%	0%	0%	0%	0%
Mining	water needs (acre-feet per year)	9,596	6,901	2,593	2,196	1,965	1,837
	% of the category's total water demand	35%	28%	14%	14%	15%	15%
Municipal*	water needs (acre-feet per year)	3,556	4,002	5,506	8,850	13,364	18,842
	% of the category's total water demand	2%	2%	3%	4%	6%	8%
Steam-electric power	water needs (acre-feet per year)	3,494	3,494	3,494	3,494	3,494	3,494
	% of the category's total water demand	5%	5%	5%	5%	5%	5%
Total water needs (acre-feet per year)		**44,122**	**45,135**	**45,953**	**53,272**	**62,821**	**69,349**

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

2 Impact Assessment Measures

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

Table 2-1 Socioeconomic impact analysis measures

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

2.1 Regional Economic Impacts

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

Income Losses - Value-added Losses

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

Income Losses - Electric Power Purchase Costs

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

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

Job Losses

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

2.2 Financial Transfer Impacts

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

Tax Losses on Production and Imports

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

Water Trucking Costs

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

Utility Revenue Losses

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

Utility Tax Losses

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

---

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

2.3 Social Impacts

Consumer Surplus Losses for Municipal Water Users

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

Population and School Enrollment Losses

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

---

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

3 Socioeconomic Impact Assessment Methodology

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

3.1 Analysis Context

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

3.2 IMPLAN Model and Data

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

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

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

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

3.3 Elasticity of Economic Impacts

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

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

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

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

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

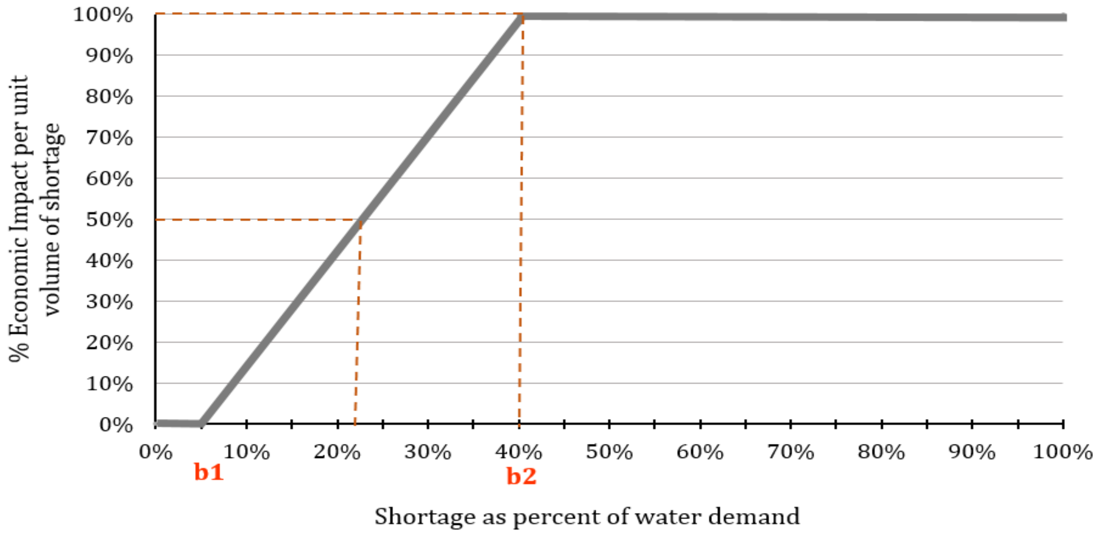


Table 3-1 Economic impact elasticity function lower and upper bounds

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

3.4 Analysis Assumptions and Limitations

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

4 Analysis Results

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

4.1 Impacts for Irrigation Water Shortages

Two of the 20 counties in the region are projected to experience water shortages in the irrigated agriculture water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-1. Note that tax collection impacts were not estimated for this water use category. IMPLAN data indicates a negative tax impact (i.e., increased tax collections) for the associated production sectors, primarily due to past subsidies from the federal government. However, it was not considered realistic to report increasing tax revenues during a drought of record.

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

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$0	$0	$0	$0	$0	$1
Job losses	2	3	4	6	14	21

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

4.2 Impacts for Livestock Water Shortages

Seven of the 20 counties in the region are projected to experience water shortages in the livestock water use category for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-2.

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

Impact measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$1,520	$1,722	$1,964	$2,255	$2,605	$2,679
Jobs losses	26,195	29,120	32,545	36,679	41,626	42,730
Tax losses on production and imports ($ millions)*	$74	$84	$96	$110	$127	$131

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

4.3 Impacts of Manufacturing Water Shortages

Manufacturing water shortages in the region are projected to occur in three of the 20 counties in the region for at least one decade of the planning horizon. Estimated impacts to this water use category appear in Table 4-3.

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

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$386	$438	$438	$438	$438	$438
Job losses	3,936	4,463	4,463	4,463	4,463	4,463
Tax losses on production and Imports ($ millions)*	$31	$36	$36	$36	$36	$36

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

4.4 Impacts of Mining Water Shortages

Mining water shortages in the region are projected to occur in nine of the 20 counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use type appear in Table 4-4.

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

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses ($ millions)*	$7,174	$4,390	$877	$712	$578	$491
Job losses	38,070	23,347	4,720	3,836	3,124	2,659
Tax losses on production and Imports ($ millions)*	$954	$583	$116	$94	$76	$64

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

4.5 Impacts for Municipal Water Shortages

Twelve of the 20 counties in the region are projected to experience water shortages in the municipal water use category for one or more decades within the planning horizon.

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

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

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

Impacts measure	2020	2030	2040	2050	2060	2070
Income losses[1] ($ millions)*	$14	$16	$18	$27	$51	$93
Job losses[1]	265	288	326	497	937	1,711
Tax losses on production and imports[1] ($ millions)*	$1	$1	$2	$2	$5	$8
Trucking costs ($ millions)*	$3	$3	$3	$3	$3	$3
Utility revenue losses ($ millions)*	$12	$13	$18	$28	$42	$59
Utility tax revenue losses ($ millions)*	$0	$0	$0	$0	$1	$1

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

4.6 Impacts of Steam-Electric Water Shortages

Steam-electric water shortages in the region are projected to occur in two of the 20 counties in the region for one or more decades within the planning horizon. Estimated impacts to this water use category appear in Table 4-6.

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

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

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

Impacts measure	2020	2030	2040	2050	2060	2070
Income Losses ($ millions)*	$219	$219	$219	$219	$219	$219

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

4.7 Regional Social Impacts

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

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

Impacts measure	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)*	$34	$35	$35	$36	$42	$52
Population losses	12,571	10,506	7,722	8,350	9,210	9,471
School enrollment losses	2,405	2,010	1,477	1,597	1,762	1,812

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

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

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

		Income losses (Million $)*						Job losses					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
ANDERSON	MUNICIPAL	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01	0	0	0	0	0	0
ANDERSON Total		**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**$0.01**	**0**	**0**	**0**	**0**	**0**	**0**
ANGELINA	MANUFACTURING	$386.27	$438.04	$438.04	$438.04	$438.04	$438.04	3,936	4,463	4,463	4,463	4,463	4,463
ANGELINA	MINING	$394.15	$476.64	$330.82	$249.15	$186.66	$139.16	2,089	2,526	1,753	1,321	989	738
ANGELINA Total		**$780.41**	**$914.68**	**$768.86**	**$687.20**	**$624.70**	**$577.20**	**6,025**	**6,990**	**6,217**	**5,784**	**5,452**	**5,201**
CHEROKEE	MINING	$198.32	$205.82	$174.99	$122.49	$70.00	$33.33	1,051	1,091	928	649	371	177
CHEROKEE	MUNICIPAL	$0.00	$0.02	$0.03	$0.07	$0.27	$0.73	0	0	1	1	5	13
CHEROKEE Total		**$198.33**	**$205.84**	**$175.02**	**$122.56**	**$70.27**	**$34.06**	**1,051**	**1,091**	**928**	**651**	**376**	**190**
HENDERSON	IRRIGATION	$0.01	$0.02	$0.05	$0.10	$0.32	$0.51	0	1	2	4	12	19
HENDERSON	MINING	-	$0.79	-	-	-	-	-	4	-	-	-	-
HENDERSON	MUNICIPAL	$0.00	$0.00	$0.01	$0.01	$0.31	$0.77	0	0	0	0	4	12
HENDERSON Total		**$0.01**	**$0.82**	**$0.06**	**$0.11**	**$0.63**	**$1.28**	**0**	**5**	**2**	**4**	**17**	**31**
HOUSTON	LIVESTOCK	-	$5.63	$9.08	$12.86	$16.94	$22.16	-	191	309	437	576	753
HOUSTON	MUNICIPAL	$12.99	$12.56	$11.93	$11.63	$11.57	$11.57	238	230	219	213	212	212
HOUSTON Total		**$12.99**	**$18.19**	**$21.01**	**$24.49**	**$28.51**	**$33.73**	**238**	**421**	**527**	**650**	**788**	**965**
JASPER	LIVESTOCK	$419.22	$419.22	$419.22	$419.22	$419.22	$419.22	10,573	10,573	10,573	10,573	10,573	10,573
JASPER	MUNICIPAL	$0.25	$0.27	$0.30	$0.32	$0.32	$0.32	5	5	6	6	6	6
JASPER Total		**$419.48**	**$419.49**	**$419.52**	**$419.54**	**$419.55**	**$419.55**	**10,578**	**10,578**	**10,579**	**10,579**	**10,579**	**10,579**
JEFFERSON	MUNICIPAL	-	-	-	$6.24	$25.95	$61.81	-	-	-	114	475	1,133
JEFFERSON	STEAM ELECTRIC POWER	$149.89	$149.89	$149.89	$149.89	$149.89	$149.89	-	-	-	-	-	-
JEFFERSON Total		**$149.89**	**$149.89**	**$149.89**	**$156.14**	**$175.84**	**$211.71**	**-**	**-**	**-**	**114**	**475**	**1,133**
NACOGDOCHES	LIVESTOCK	$415.89	$445.78	$480.40	$520.53	$566.44	$634.85	5,636	6,041	6,510	7,054	7,676	8,603
NACOGDOCHES	MINING	$4,562.26	$2,479.04	$6.13	-	-	-	24,182	13,140	32	-	-	-

		Income losses (Million $)*						Job losses					
County	**Water Use Category**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**	**2020**	**2030**	**2040**	**2050**	**2060**	**2070**
NACOGDOCHES	MUNICIPAL	-	-	-	$0.02	$0.08	$0.21	-	-	-	0	1	4
NACOGDOCHES Total		**$4,978.16**	**$2,924.82**	**$486.53**	**$520.55**	**$566.52**	**$635.06**	**29,818**	**19,181**	**6,543**	**7,054**	**7,678**	**8,607**
NEWTON	MINING	$59.71	$15.20	-	-	-	-	316	81	-	-	-	-
NEWTON Total		**$59.71**	**$15.20**	**-**	**-**	**-**	**-**	**316**	**81**	**-**	**-**	**-**	**-**
ORANGE	IRRIGATION	$0.06	$0.06	$0.06	$0.06	$0.06	$0.06	2	2	2	2	2	2
ORANGE Total		**$0.06**	**$0.06**	**$0.06**	**$0.06**	**$0.06**	**$0.06**	**2**	**2**	**2**	**2**	**2**	**2**
PANOLA	LIVESTOCK	$50.21	$50.21	$50.21	$50.21	$50.21	$50.21	986	986	986	986	986	986
PANOLA	MUNICIPAL	-	$0.00	$0.02	$0.09	$0.13	$0.16	-	0	1	2	3	3
PANOLA Total		**$50.21**	**$50.21**	**$50.23**	**$50.30**	**$50.33**	**$50.36**	**986**	**986**	**986**	**988**	**988**	**989**
RUSK	LIVESTOCK	$9.33	$8.73	$8.83	$9.47	$10.12	$10.12	206	192	194	209	223	223
RUSK	MINING	$189.30	$361.19	$347.06	$331.92	$319.18	$318.18	1,037	1,979	1,902	1,819	1,749	1,744
RUSK	MUNICIPAL	$0.02	$0.02	$0.02	$0.02	$0.06	$0.16	0	0	0	0	1	3
RUSK	STEAM ELECTRIC POWER	$69.15	$69.15	$69.15	$69.15	$69.15	$69.15	-	-	-	-	-	-
RUSK Total		**$267.80**	**$439.09**	**$425.05**	**$410.56**	**$398.51**	**$397.61**	**1,243**	**2,172**	**2,097**	**2,028**	**1,973**	**1,970**
SAN AUGUSTINE	LIVESTOCK	$81.67	$94.37	$108.87	$125.77	$144.33	$144.33	1,278	1,477	1,704	1,969	2,260	2,260
SAN AUGUSTINE	MINING	$1,751.58	$832.58	-	-	-	-	9,284	4,413	-	-	-	-
SAN AUGUSTINE	MUNICIPAL	$0.72	$0.54	$0.41	$0.38	$0.38	$0.38	13	10	7	7	7	7
SAN AUGUSTINE Total		**$1,833.96**	**$927.50**	**$109.28**	**$126.15**	**$144.71**	**$144.71**	**10,576**	**5,900**	**1,712**	**1,976**	**2,266**	**2,266**
SHELBY	LIVESTOCK	$543.43	$698.41	$887.04	$1,117.25	$1,397.84	$1,397.84	7,516	9,659	12,268	15,452	19,332	19,332
SHELBY	MUNICIPAL	$0.15	$0.38	$1.08	$2.24	$3.77	$5.51	3	7	20	41	69	101
SHELBY Total		**$543.59**	**$698.79**	**$888.12**	**$1,119.49**	**$1,401.61**	**$1,403.36**	**7,519**	**9,666**	**12,288**	**15,493**	**19,401**	**19,433**
SMITH	MINING	$18.62	$19.08	$17.80	$7.97	$2.45	$0.20	110	112	105	47	14	1
SMITH	MUNICIPAL	$0.33	$1.88	$3.80	$5.73	$7.85	$11.19	6	36	73	111	153	218
SMITH Total		**$18.95**	**$20.96**	**$21.60**	**$13.70**	**$10.30**	**$11.40**	**116**	**148**	**178**	**158**	**167**	**219**
REGION I Total		**$9,313.56**	**$6,785.54**	**$3,515.24**	**$3,650.85**	**$3,891.54**	**$3,920.09**	**68,468**	**57,221**	**42,058**	**45,480**	**50,164**	**51,585**

Appendix D

Documentation for Aquifers Classified as Not Relevant for Purposes of Joint Planning

Tech Memo 16-03: Gulf Cost Aquifer
Tech Memo 16-04: Nacatoch Aquifer
Tech Memo 16-05: Trinity Aquifer
Tech Memo 16-06: Yegua-Jackson Aquifer

Gulf Coast Aquifer: Not Relevant for Purposes of Joint Planning
GMA 11 Technical Memorandum 16-03

Nacatoch Aquifer: Not Relevant for Purposes of Joint Planning
GMA 11 Technical Memorandum 16-04

Trinity Aquifer: Not Relevant for Purposes of Joint Planning
GMA 11 Technical Memorandum 16-05

Yegua-Jackson Aquifer: Not Relevant for Purposes of Joint Planning
GMA 11 Technical Memorandum 16-06

Geoscientist and Engineering Seal

This report documents the work and supervision of work of the following licensed Texas Professional Geoscientist and licensed Texas Professional Engineers:

William R. Hutchison, Ph.D., P.E. (96287), P.G. (286)

Dr. Hutchison completed the analyses and model simulations described in this report, and was the principal author of the final report.

WILLIAM RAY HUTCHISON
96287

William R Hutchison
11/17/2016

WILLIAM R. HUTCHISON
286

William R Hutchison
11/17/2016

Gulf Coast Aquifer: Not Relevant for Purposes of Joint Planning

GMA 11 Technical Memorandum 16-03, Final

William R. Hutchison, Ph.D., P.E., P.G.

November 17, 2016

Introduction

The Texas Water Development Board, in its July 2013 document, Explanatory Report for Submittal of Desired Future Conditions to the Texas Water Development Board, offers the following guidance regarding documentation for aquifers that are to be classified not relevant for purposes of joint planning:

> *Districts in a groundwater management area may, as part of the process for adopting and submitting desired future conditions, propose classification of a portion or portions of a relevant aquifer as non-relevant (31 Texas Administrative Code 356.31 (b)). This proposed classification of an aquifer may be made if the districts determine that aquifer characteristics, groundwater demands, and current groundwater uses do not warrant adoption of a desired future condition.*
>
> *The districts must submit to the TWDB the following documentation for the portion of the aquifer proposed to be classified as non-relevant:*
>
> 1. *A description, location, and/or map of the aquifer or portion of the aquifer;*
> 2. *A summary of aquifer characteristics, groundwater demands, and current groundwater uses, including the total estimated recoverable storage as provided by the TWDB, that support the conclusion that desired future conditions in adjacent or hydraulically connected relevant aquifer(s) will not be affected; and*
> 3. *An explanation of why the aquifer or portion of the aquifer is non-relevant for joint planning purposes.*

This technical memorandum provides the required documentation to classify the Gulf Coast Aquifer as not relevant for purposes of joint planning.

Aquifer Description and Location

As described in George and others (2011):

> ***The Gulf Coast Aquifer*** *is a major aquifer paralleling the Gulf of Mexico coastline from the Louisiana border to the border of Mexico. It consists of several aquifers, including the Jasper, Evangeline, and Chicot aquifers, which are composed of discontinuous sand, silt, clay, and gravel beds. The maximum total sand thickness of the Gulf Coast Aquifer ranges from 700 feet in the south to 1,300 feet in the north. Freshwater saturated thickness averages about 1,000 feet. Water quality varies with depth and locality: it is generally good in the*

> *central and northeastern parts of the aquifer, where the water contains less than 500 milligrams per liter of total dissolved solids, but declines to the south, where it typically contains 1,000 to more than 10,000 milligrams per liter of total dissolved solids and where the productivity of the aquifer decreases. High levels of radionuclides, thought mainly to be naturally occurring, are found in some wells in Harris County in the outcrop and in South Texas. The aquifer is used for municipal, industrial, and irrigation purposes. In Harris, Galveston, Fort Bend, Jasper, and Wharton counties, water level declines of as much as 350 feet have led to land subsidence. The regional water planning groups, in their 2006 Regional Water Plans, recommended several water management strategies that use the Gulf Coast Aquifer, including drilling more wells, pumping more water from existing wells, temporary overdrafting, constructing new or expanded treatment plants, desalinating brackish groundwater, developing conjunctive use projects, and reallocating supplies.*

Figure 1 (taken from Wade and others, 2014) shows the limited extent of the Gulf Coast Aquifer in GMA 11. Note that it occurs only in a small portion of Angelina, Sabine, and Trinity counties.

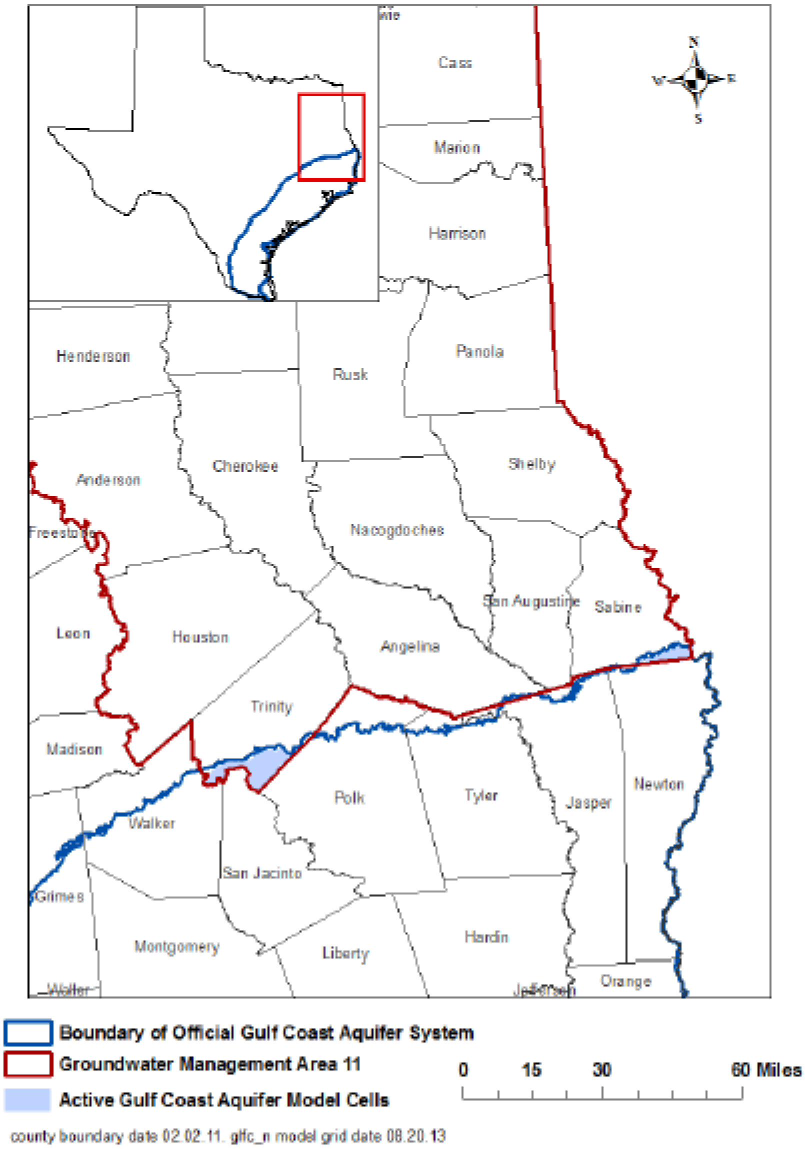


Figure 1. Location of Gulf Coast Aquifer in GMA 11

Aquifer Characteristics

The Jasper Aquifer is the relevant formation within the Gulf Coast Aquifer system in GMA 11. Previous studies (i.e. Chowdhury and others, 2004, pg. 36) noted that hydraulic conductivity in the Jasper is about 1 ft/day.

Gulf Coast Aquifer: Not Relevant for Purposes of Joint Planning

GMA 11 Technical Memorandum 16-03, Final

William R. Hutchison, Ph.D., P.E., P.G.
November 17, 2016

Groundwater Demands and Current Groundwater Uses

The Texas Water Development Board pumping database shows 2012 groundwater pumping for the Gulf Coast Aquifer as follows:

- Sabine: 18 AF/yr
- Trinity: 333 AF/yr

No pumping was listed for Angelina County.

Total Estimated Recoverable Storage

Wade and others (2013) documented the total estimated recoverable storage for the Gulf Coast Aquifer in GMA 11 as follows:

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Angelina	27,000	6,750	20,250
Sabine	120,000	30,000	90,000
Trinity	1,300,000	325,000	975,000
Total	1,447,000	361,750	1,085,250

Total storage is given in the first column. The recoverable storage is assumed to be between 25 and 75 percent of the total storage.

Explanation of Non-Relevance

Due to its limited areal extent and generally low use, the Gulf Coast Aquifer is classified as not relevant for purposes of joint planning in Groundwater Management Area 11.

References

Chowdhury, A.H., Wade, S., Mace, R.E., Ridgeway, C., 2004. Groundwater Availability Model of the Central Gulf Coast Aquifer System: Numerical Simulations through 1999. Texas Water Development Board, Groundwater Availability Modeling Section, September 27, 2004, 114p.

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

Wade, S., Shi, J., and Seiter-Weatherford, C. 2014. GAM Task 13-034: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 11. Texas Water Development Board, Groundwater Resources Division, April 2, 2014, 30p.

Nacatoch Aquifer: Not Relevant for Purposes of Joint Planning

GMA 11 Technical Memorandum 16-04, Final

William R. Hutchison, Ph.D., P.E., P.G.
November 17, 2016

Introduction

The Texas Water Development Board, in its July 2013 document, Explanatory Report for Submittal of Desired Future Conditions to the Texas Water Development Board, offers the following guidance regarding documentation for aquifers that are to be classified not relevant for purposes of joint planning:

> *Districts in a groundwater management area may, as part of the process for adopting and submitting desired future conditions, propose classification of a portion or portions of a relevant aquifer as non-relevant (31 Texas Administrative Code 356.31 (b)). This proposed classification of an aquifer may be made if the districts determine that aquifer characteristics, groundwater demands, and current groundwater uses do not warrant adoption of a desired future condition.*
>
> *The districts must submit to the TWDB the following documentation for the portion of the aquifer proposed to be classified as non-relevant:*
>
> 1. *A description, location, and/or map of the aquifer or portion of the aquifer;*
> 2. *A summary of aquifer characteristics, groundwater demands, and current groundwater uses, including the total estimated recoverable storage as provided by the TWDB, that support the conclusion that desired future conditions in adjacent or hydraulically connected relevant aquifer(s) will not be affected; and*
> 3. *An explanation of why the aquifer or portion of the aquifer is non-relevant for joint planning purposes.*

This technical memorandum provides the required documentation to classify the Nacatoch Aquifer as not relevant for purposes of joint planning.

Aquifer Description and Location

As described in George and others (2011):

> ***The Nacatoch Aquifer*** *is a minor aquifer occurring in a narrow band across northeast Texas. The aquifer consists of the Nacatoch Sand, composed of sequences of sandstone separated by impermeable layers of mudstone or clay. These sandstones are marine in origin, coarsen upward, and are laterally discontinuous. The number of sand layers varies throughout the Nacatoch's extent, and the thickness of individual sand units ranges from more than 100 feet in the north to less than 20 feet to the south. Thickness of intervening mudstone*

> *units similarly ranges from more than 100 feet to only a few feet. Freshwater saturated thickness averages about 50 feet. The aquifer also includes a hydraulically connected cover of alluvium that is as much as 80 feet thick along major drainages. Groundwater in this aquifer is usually under artesian conditions except in shallow wells where the Nacatoch Formation crops out and water table conditions exist. The Mexia-Talco Fault Zone generally delineates the subsurface limit of the aquifer. The groundwater in the aquifer is typically alkaline, high in sodium bicarbonate, and soft. Total dissolved solids in the subsurface increase and are significantly higher south of the Mexia-Talco Fault Zone, where the water contains between 1,000 and 3,000 milligrams per liter of total dissolved solids. Water from the aquifer is extensively used for domestic and livestock purposes. The city of Commerce historically pumped the greatest amount from the Nacatoch Aquifer but has recently attempted to convert to surface water; however, because of recent droughts, the city has pumped 30 to 50 percent of its water from the aquifer. As a result of Commerce's reduced pumping, the declining water levels that had developed around Commerce in Delta and Hunt counties are stabilizing. The North East Texas Regional Water Planning Group, in its 2006 Regional Water Plan, recommended new and supplemental groundwater wells in the Nacatoch Aquifer as a water management strategy.*

Figure 1 (taken from Wade and others, 2014) shows the limited extent of the Nacatoch Aquifer in GMA 11. Note that it occurs only in a small portion of Bowie, Henderson, Morris, Red River, and Titus counties.

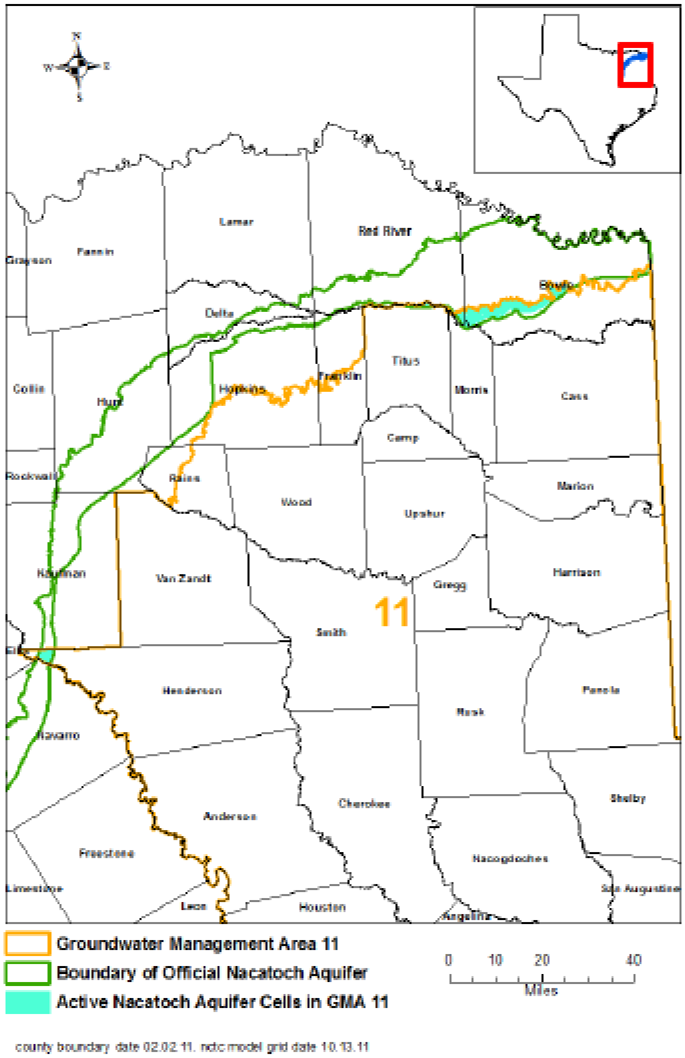


Figure 1. Location of Nacatoch Aquifer in GMA 11

Aquifer Characteristics

Beach and others (2009) developed a groundwater availability model for the Nacatoch Aquifer for the Texas Water Development Board. This study appears to document only two estimates of hydraulic conductivity in GMA 11 (Beach and others, 2009, pg. 4-57) in Bowie County (1 to 3 ft/day). The groundwater modeling effort included developing estimates of hydraulic conductivity throughout the area (Beach and others, 2009, pp 8-4 and 8-5).

Nacatoch Aquifer: Not Relevant for Purposes of Joint Planning

GMA 11 Technical Memorandum 16-04, Final

William R. Hutchison, Ph.D., P.E., P.G.
November 17, 2016

Groundwater Demands and Current Groundwater Uses

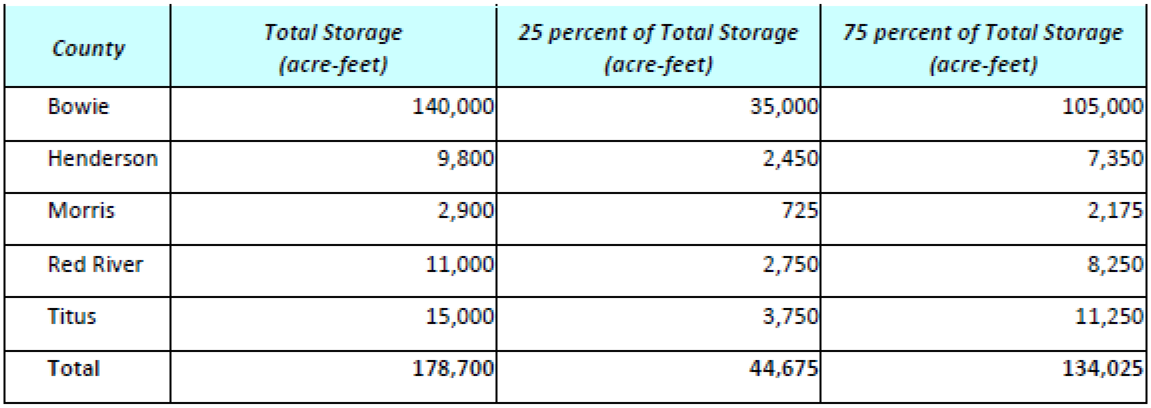
The Texas Water Development Board pumping database shows 2012 groundwater pumping for the Nacatoch Aquifer as follows:

- Bowie: 1,466 AF/yr
- Henderson: 12 AF/yr
- Hopkins: 1,113 AF/yr
- Titus: 100 AF/yr

No pumping estimates are listed for Morris or Red River counties.

Total Estimated Recoverable Storage

Wade and others (2013) documented the total estimated recoverable storage for the Nacatoch Aquifer in GMA 11 as follows:



County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Bowie	140,000	35,000	105,000
Henderson	9,800	2,450	7,350
Morris	2,900	725	2,175
Red River	11,000	2,750	8,250
Titus	15,000	3,750	11,250
Total	178,700	44,675	134,025

Total storage is given in the first column. The recoverable storage is assumed to be between 25 and 75 percent of the total storage.

Explanation of Non-Relevance

Due to its limited areal extent and generally low use, the Nacatoch Aquifer is classified as not relevant for purposes of joint planning in Groundwater Management Area 11.

References

Beach, J.A., Huang, Y., Symank, L., Ashworth, J.B., Davidson, T., Vreugdenhil, A.M., and Deeds, N.E., 2009. Final Report: Nacatoch Aquifer Groundwater Availability Model. Prepared for the Texas Water Development Board, January 2009, 304p.

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

Wade, S., Shi, J., and Seiter-Weatherford, C. 2014. GAM Task 13-034: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 11. Texas Water Development Board, Groundwater Resources Division, April 2, 2014, 30p.

Trinity Aquifer: Not Relevant for Purposes of Joint Planning

GMA 11 Technical Memorandum 16-05, Final

William R. Hutchison, Ph.D., P.E., P.G.
November 17, 2016

Introduction

The Texas Water Development Board, in its July 2013 document, Explanatory Report for Submittal of Desired Future Conditions to the Texas Water Development Board, offers the following guidance regarding documentation for aquifers that are to be classified not relevant for purposes of joint planning:

> *Districts in a groundwater management area may, as part of the process for adopting and submitting desired future conditions, propose classification of a portion or portions of a relevant aquifer as non-relevant (31 Texas Administrative Code 356.31 (b)). This proposed classification of an aquifer may be made if the districts determine that aquifer characteristics, groundwater demands, and current groundwater uses do not warrant adoption of a desired future condition.*
>
> *The districts must submit to the TWDB the following documentation for the portion of the aquifer proposed to be classified as non-relevant:*
>
> 1. *A description, location, and/or map of the aquifer or portion of the aquifer;*
> 2. *A summary of aquifer characteristics, groundwater demands, and current groundwater uses, including the total estimated recoverable storage as provided by the TWDB, that support the conclusion that desired future conditions in adjacent or hydraulically connected relevant aquifer(s) will not be affected; and*
> 3. *An explanation of why the aquifer or portion of the aquifer is non-relevant for joint planning purposes.*

This technical memorandum provides the required documentation to classify the Trinity Aquifer as not relevant for purposes of joint planning.

Aquifer Description and Location

As described in George and others (2011):

> ***The Trinity Aquifer,*** *a major aquifer, extends across much of the central and northeastern part of the state. It is composed of several smaller aquifers contained within the Trinity Group. Although referred to differently in different parts of the state, they include the Antlers, Glen Rose, Paluxy, Twin Mountains, Travis Peak, Hensell, and Hosston aquifers. These aquifers consist of limestones, sands, clays, gravels, and conglomerates. Their combined freshwater saturated thickness averages about 600 feet in North Texas and about 1,900 feet in Central Texas. In*

> *general, groundwater is fresh but very hard in the outcrop of the aquifer. Total dissolved solids increase from less than 1,000 milligrams per liter in the east and southeast to between 1,000 and 5,000 milligrams per liter, or slightly to moderately saline, as the depth to the aquifer increases. Sulfate and chloride concentrations also tend to increase with depth. The Trinity Aquifer discharges to a large number of springs, with most discharging less than 10 cubic feet per second. The aquifer is one of the most extensive and highly used groundwater resources in Texas. Although its primary use is for municipalities, it is also used for irrigation, livestock, and other domestic purposes. Some of the state's largest water level declines, ranging from 350 to more than 1,000 feet, have occurred in counties along the IH-35 corridor from McLennan County to Grayson County. These declines are primarily attributed to municipal pumping, but they have slowed over the past decade as a result of increasing reliance on surface water. The regional water planning groups, in their 2006 Regional Water Plans, recommended numerous water management strategies for the Trinity Aquifer, including developing new wells and well fields, pumping more water from existing wells, overdrafting, reallocating supplies, and using surface water and groundwater conjunctively.*

Figure 1 (taken from Wade and others, 2014) shows the limited extent of the Trinity Aquifer in GMA 11. Note that it occurs only in a small portion of Henderson County.

Figure 1. Location of Trinity Aquifer in GMA 11

Aquifer Characteristics

Kelley and others (2014) developed an updated groundwater availability model of the Northern Trinity and Woodbine aquifers for four groundwater conservation districts in north Texas. This model covered the entire Northern Trinity Aquifer, including the small portion in Henderson County. Maps of calibrated horizontal hydraulic conductivity are provided in Kelley and others (2014, pg. 8:1-6, 8:1-7, 8:1-8, 8:1-9, 8:1-10, 8:1-11, 8:1-12). Estimated values are typically 0.1 ft/day or less, except for the Hosston Aquifer, which was shown as between 3 and 10 ft/day.

Trinity Aquifer: Not Relevant for Purposes of Joint Planning

GMA 11 Technical Memorandum 16-05, Final

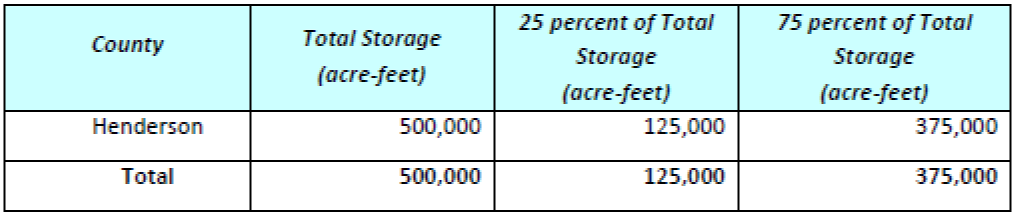
William R. Hutchison, Ph.D., P.E., P.G.
November 17, 2016

Groundwater Demands and Current Groundwater Uses

The Texas Water Development Board pumping database does not list any pumping from the Trinity Aquifer in Henderson County. However, the database shows 42 AF/yr was pumping from the Trinity Aquifer in Trinity County in 2012.

Total Estimated Recoverable Storage

Wade and others (2013) documented the total estimated recoverable storage for the Trinity Aquifer in GMA 11 as follows:



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

Total storage is given in the first column. The recoverable storage is assumed to be between 25 and 75 percent of the total storage.

Explanation of Non-Relevance

Due to its limited areal extent and generally low use, the Trinity Aquifer is classified as not relevant for purposes of joint planning in Groundwater Management Area 11.

References

Kelley, V.A., Ewing, J., Jones, T.L., Young, S.C., Deeds, N., Hamlin, S., Jigmond, M., Harding, J., Pinkard, J., Yan, T.T., Scanlon, B., Beach, J., Davidson, T., Laughlin, K., 2014, Final Report: Updated Groundwater Availability Model of the Northern Trinity and Woodbine Aquifers. Report prepared for North Texas GCD, Northern Trinity GCD, Prairielands GCD, and Upper Trinity GCD. August 2014, Volume 1, 990p.

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

Wade, S., Shi, J., and Seiter-Weatherford, C. 2014. GAM Task 13-034: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 11. Texas Water Development Board, Groundwater Resources Division, April 2, 2014, 30p.

Yegua-Jackson Aquifer: Not Relevant for Purposes of Joint Planning

GMA 11 Technical Memorandum 16-06, Final

William R. Hutchison, Ph.D., P.E., P.G.
November 17, 2016

Introduction

The Texas Water Development Board, in its July 2013 document, Explanatory Report for Submittal of Desired Future Conditions to the Texas Water Development Board, offers the following guidance regarding documentation for aquifers that are to be classified not relevant for purposes of joint planning:

> *Districts in a groundwater management area may, as part of the process for adopting and submitting desired future conditions, propose classification of a portion or portions of a relevant aquifer as non-relevant (31 Texas Administrative Code 356.31 (b)). This proposed classification of an aquifer may be made if the districts determine that aquifer characteristics, groundwater demands, and current groundwater uses do not warrant adoption of a desired future condition.*
>
> *The districts must submit to the TWDB the following documentation for the portion of the aquifer proposed to be classified as non-relevant:*
>
> 1. *A description, location, and/or map of the aquifer or portion of the aquifer;*
> 2. *A summary of aquifer characteristics, groundwater demands, and current groundwater uses, including the total estimated recoverable storage as provided by the TWDB, that support the conclusion that desired future conditions in adjacent or hydraulically connected relevant aquifer(s) will not be affected; and*
> 3. *An explanation of why the aquifer or portion of the aquifer is non-relevant for joint planning purposes.*

This technical memorandum provides the required documentation to classify the Yegua-Jackson Aquifer as not relevant for purposes of joint planning.

Aquifer Description and Location

As described in George and others (2011):

> ***The Yegua-Jackson Aquifer*** *is a minor aquifer stretching across the southeast part of the state. It includes water-bearing parts of the Yegua Formation (part of the upper Claiborne Group) and the Jackson Group (comprising the Whitsett, Manning, Wellborn, and Caddell formations). These geologic units consist of interbedded sand, silt, and clay layers originally deposited as fluvial and deltaic sediments. Freshwater saturated thickness averages about 170 feet. Water quality*

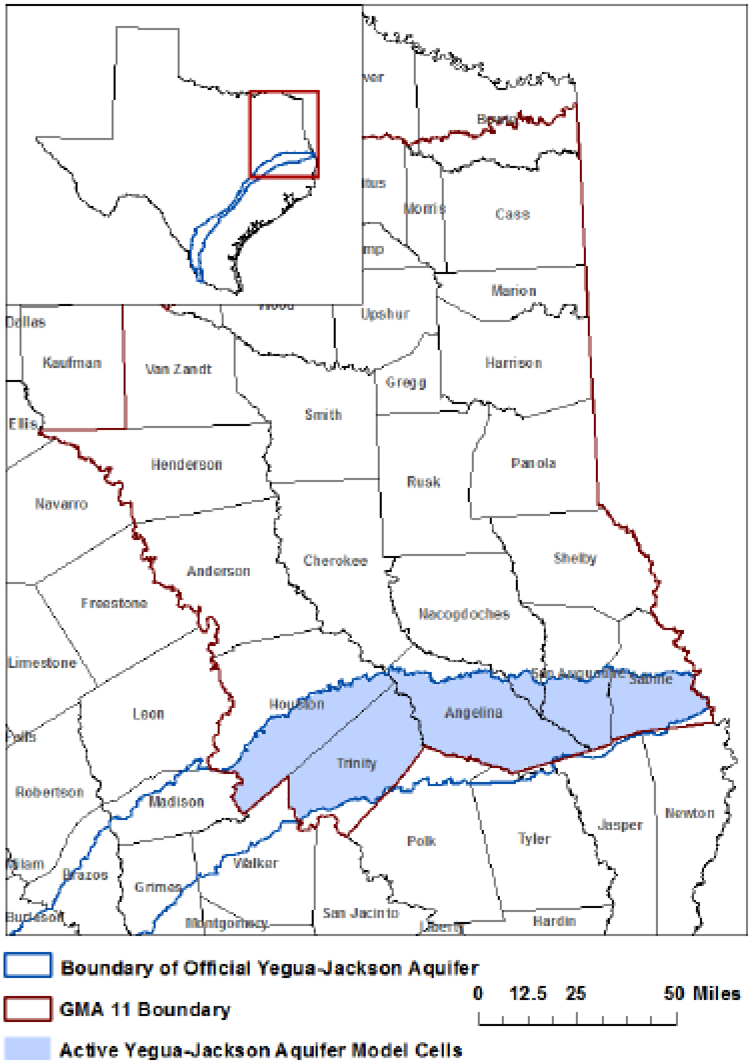
> *varies greatly owing to sediment composition in the aquifer formations, and in all areas the aquifer becomes highly mineralized with depth. Most groundwater is produced from the sand units of the aquifer, where the water is fresh and ranges from less than 50 to 1,000 milligrams per liter of total dissolved solids. Some slightly to moderately saline water, with concentrations of total dissolved solids ranging from 1,000 to 10,000 milligrams per liter, also occurs in the aquifer. No significant water level declines have occurred in wells measured by the TWDB. Groundwater for domestic and livestock purposes is available from shallow wells over most of the aquifer's extent. Water is also used for some municipal, industrial, and irrigation purposes. The regional water planning groups, in their 2006 Regional Water Plans, recommended several water management strategies that use the Yegua-Jackson Aquifer, including drilling more wells and desalinating the water.*

Figure 1 (taken from Wade and others, 2014) shows the limited extent of the Yegua-Jackson Aquifer in GMA 11.

Yegua-Jackson Aquifer: Not Relevant for Purposes of Joint Planning

GMA 11 Technical Memorandum 16-06, Final

William R. Hutchison, Ph.D., P.E., P.G.
November 17, 2016



county boundary date 02.02.11. ygjk model grid date 10.14.11

Figure 1. Location of Yegua-Jackson Aquifer in GMA 11

Aquifer Characteristics

Deeds and others (2010) developed a groundwater availability model of the Yegua-Jackson Aquifer for the Texas Water Development Board. Maps of calibrated horizontal hydraulic conductivity are provided on pages 8-7, to 8-11. Estimated values in the GMA 11 area vary considerably from less than 1ft/day to over 30 ft/day, depending on the unit and location.

Yegua-Jackson Aquifer: Not Relevant for Purposes of Joint Planning

GMA 11 Technical Memorandum 16-06, Final

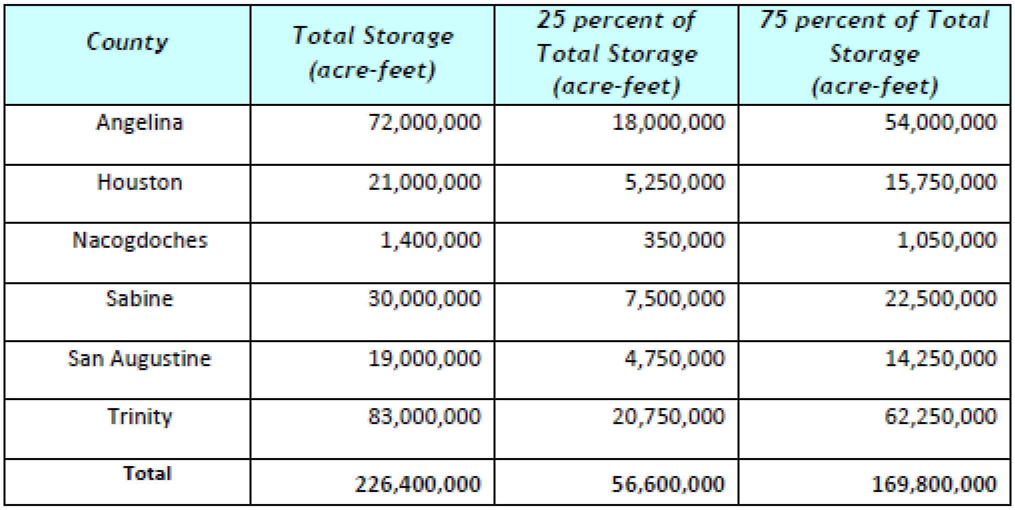
William R. Hutchison, Ph.D., P.E., P.G.
November 17, 2016

Groundwater Demands and Current Groundwater Uses

The Texas Water Development Board pumping database does not list any pumping from the Trinity Aquifer in Henderson County. However, the database shows 42 AF/yr was pumping from the Trinity Aquifer in Trinity County in 2012.

Total Estimated Recoverable Storage

Wade and others (2013) documented the total estimated recoverable storage for the Yegua-Jackson Aquifer in GMA 11 as follows:



County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Angelina	72,000,000	18,000,000	54,000,000
Houston	21,000,000	5,250,000	15,750,000
Nacogdoches	1,400,000	350,000	1,050,000
Sabine	30,000,000	7,500,000	22,500,000
San Augustine	19,000,000	4,750,000	14,250,000
Trinity	83,000,000	20,750,000	62,250,000
Total	226,400,000	56,600,000	169,800,000

Total storage is given in the first column. The recoverable storage is assumed to be between 25 and 75 percent of the total storage.

Explanation of Non-Relevance

Due to its limited areal extent and generally low use, the Yegua-Jackson Aquifer is classified as not relevant for purposes of joint planning in Groundwater Management Area 11.

References

Deeds, N.E., Yan, T., Singh, A., Jones, T.L., Kelley, V.A., Knox, P.R., and Young, S.C., 2010. Final Report: Groundwater Availability Model for the Yegua-Jackson Aquifer. Prepared for the Texas Water Development Board, March 2010, 582p.

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

Wade, S., Shi, J., and Seiter-Weatherford, C. 2014. GAM Task 13-034: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 11. Texas Water Development Board, Groundwater Resources Division, April 2, 2014, 30p.