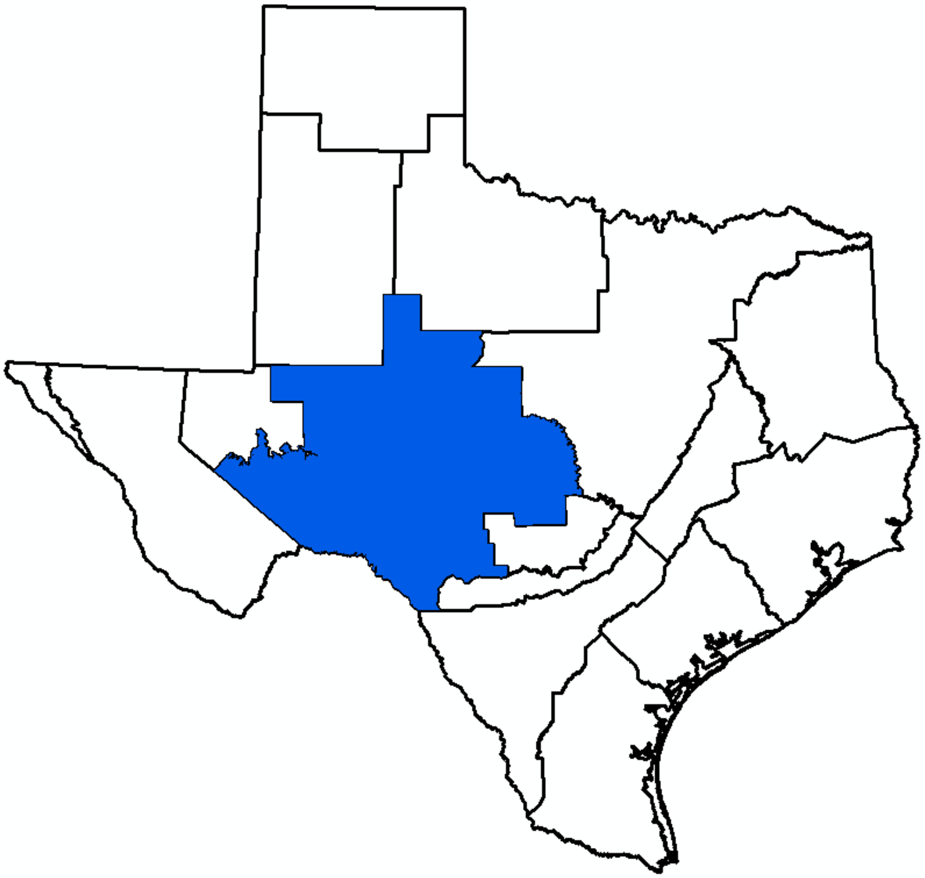
GMA 7 Explanatory Report - Final

Edward-Trinity (Plateau), Pecos Valley and Trinity Aquifers



Prepared for:

Groundwater Management Area 7

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GMA 7 Explanatory Report (Final)
Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Geoscientist and Engineering Seal

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1.0 Groundwater Management Area 7

Groundwater Management Area 7 is one of sixteen groundwater management areas in Texas, and covers that portion of west Texas that is underlain by the Edwards-Trinity (Plateau) Aquifer (Figure 1).

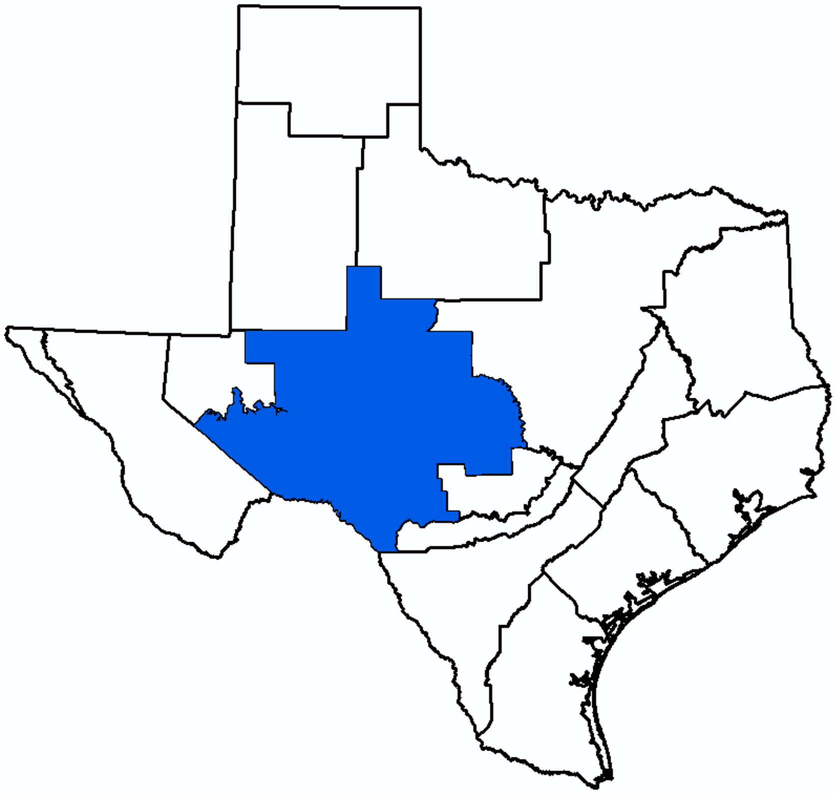


Figure 1. Groundwater Management Area 7

Groundwater Management Area 7 covers all or part of the following counties: Coke, Coleman, Concho, Crockett, Ector, Edwards, Gillespie, Glasscock, Irion, Kimble, Kinney, Llano, Mason, McCulloch, Menard, Midland, Mitchell, Nolan, Pecos, Reagan, Real, Runnels, San Saba, Schleicher, Scurry, Sterling, Sutton, Taylor, Terrell, Tom Green, Upton, and Uvalde (Figure 2).

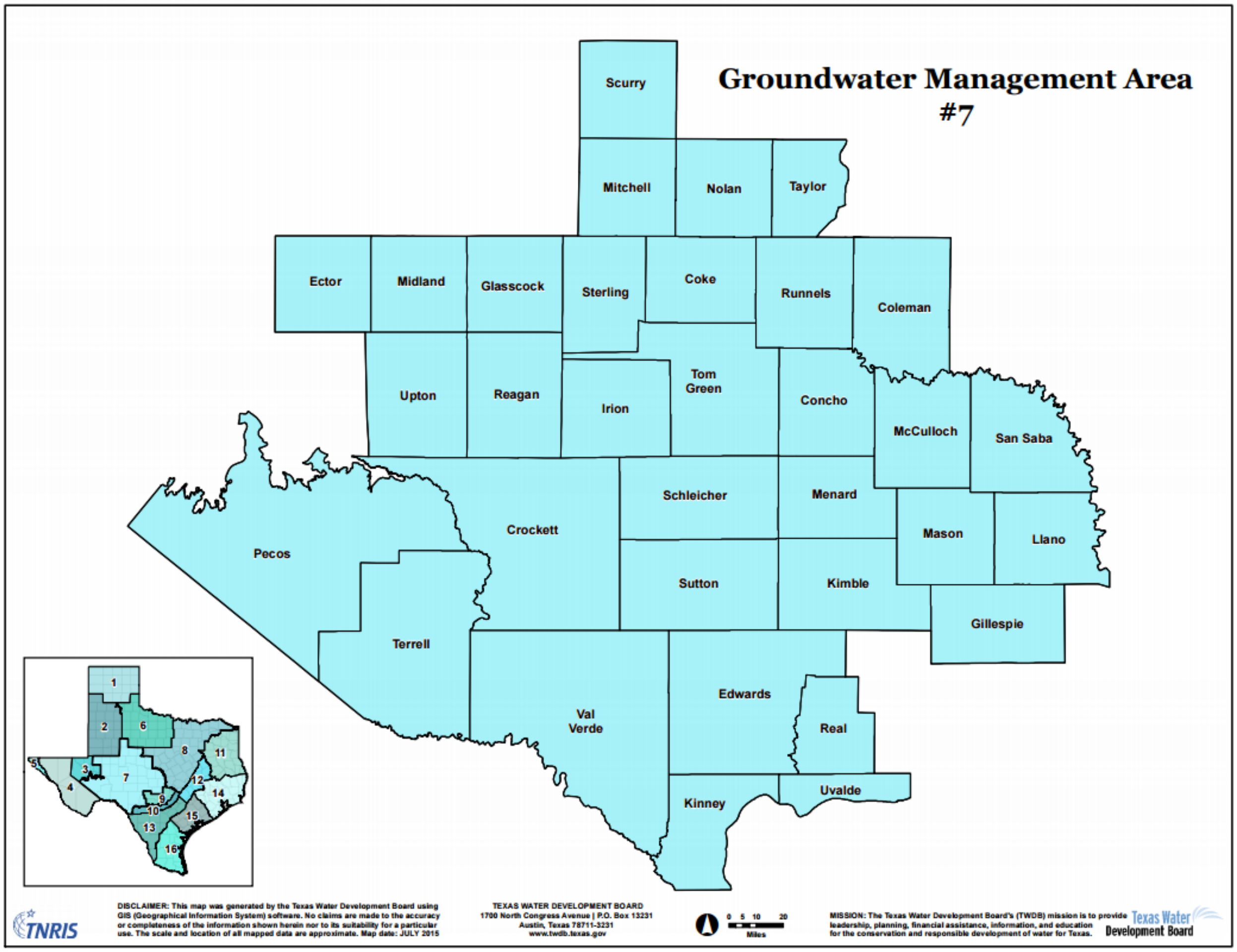


Figure 2. GMA 7 Counties (from TWDB)

There are 20 groundwater conservation districts in Groundwater Management Area 7: Coke County Underground Water Conservation District, Crockett County Groundwater Conservation District, Glasscock Groundwater Conservation District, Hickory Underground Water Conservation District No. 1, Hill County Underground Water Conservation District, Irion County Water Conservation District, Kimble County Groundwater Conservation District, Kinney County Groundwater Conservation District, Lipan-Kickapoo Water Conservation District, Lone Wolf Groundwater Conservation District, Menard County Underground Water District, Middle Pecos Groundwater Conservation District, Plateau Underground Water Conservation and Supply District, Real-Edwards Conservation and Reclamation District, Santa Rita Underground Water Conservation District, Sterling County Underground Water Conservation District, Sutton County Underground Water Conservation District, Terrell County Groundwater Conservation District, Uvalde County Underground Water Conservation District, and Wes-Tex Groundwater Conservation District (Figure 3).

The Edwards Aquifer Authority is also partially inside of the boundaries of GMA 7, but are exempt from participation in the joint planning process.

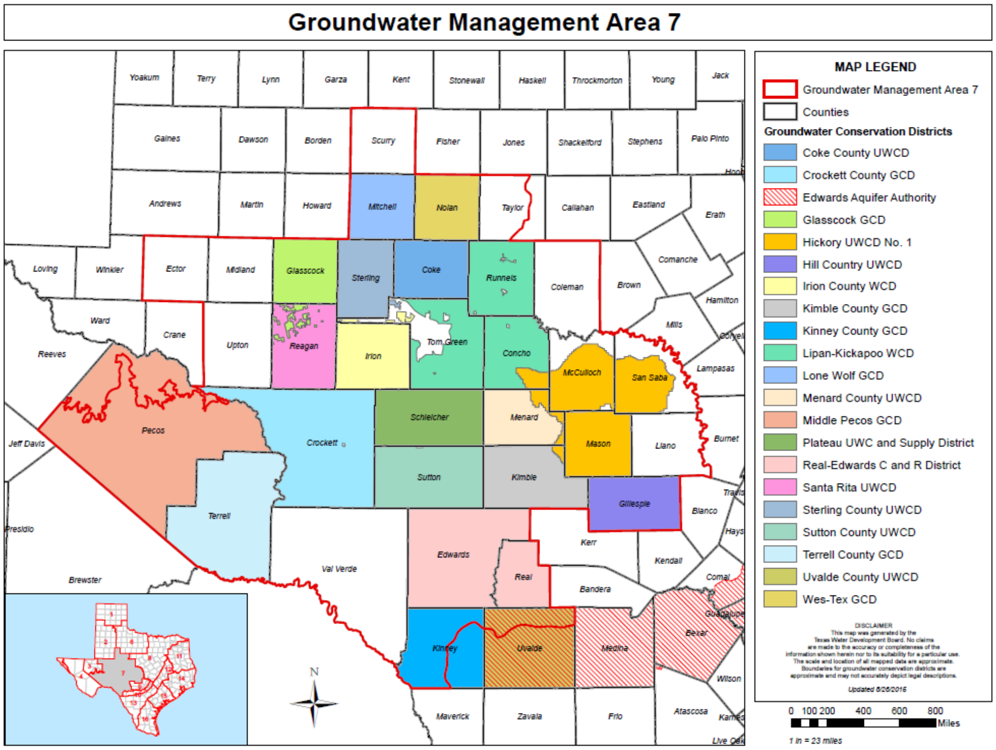


Figure 3. Groundwater Conservation Districts in GMA 7 (from TWDB)

The explanatory report covers the Edwards-Trinity (Plateau), Pecos Valley, and Trinity aquifers. As described in George and others (2011):

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

(Plateau) Aquifer, including the construction of a well field in Kerr County and public supply wells in Real County.

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

***The 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.*

2.0 Desired Future Condition

2.1 Desired Future Conditions

The desired future condition for the Edwards-Trinity (Plateau), Pecos Valley, and Trinity aquifers in GMA 7 is based on Scenario 2 as described in GMA 7 Technical Memorandum 15-06. During review of the materials for administrative completeness for GMA 3, the Texas Water Development Board could not reproduce the average drawdowns that were used as the desired future conditions with the model files that were submitted. After several meetings and emails, the differences were attributed to the use of different "grid files".

The groundwater model simulations that were completed in 2010 during the initial round of desired future conditions used a version of the grid file that was developed in 2009. Since then, a 2011 version, a 2014 version, and a 2015 version were developed.

Due to an oversight, the groundwater model simulation that was the basis for the adopted desired future conditions used the outdated grid file from 2009 to calculate average drawdowns in each of the counties that comprise GMA 3 (and GMA 7) instead of the most recent grid file developed by TWDB in 2015.

Because the GMA 3 files had used the same model files and post-processors as GMA 7, it was concluded that the same issues were present in GMA 7, and submittal of the materials to the Texas Water Development Board was delayed until GMA 7 met on March 22, 2018 to adopt updated desired future conditions based on the analyses presented in GMA 7 Technical Memorandum 18-01 that recalculated the average drawdowns from the GAM simulation using the 2015 grid file.

It is important to emphasize that the model run has not been changed, only the basis for calculating average drawdown. It is also important to note that the drawdown in individual cells has not changed, only the overall average in five counties.

The resolution that documents the adoption of the desired future condition on March 22, 2018 for the Edwards-Trinity (Plateau), Pecos Valley, and Trinity aquifers is presented in Appendix A. The desired future conditions are as follows:

Average drawdown in the following GMA 7 counties not to exceed drawdowns from 2010 to 2070, as set forth in Table 5 of GMA 7 Technical Memo 18-01 (based on the Alternative GAM):

County	Corrected Desired Future Conditions: Average Drawdowns from 2010 to 2070 (ft)
Coke	0
Crockett	10
Ector	4
Edwards	2
Gillespie	5
Glasscock	42
Irion	10
Kimble	1
Menard	1
Midland	12
Pecos	14
Reagan	42
Real	4
Schelicher	8
Sterling	7
Sutton	6
Taylor	0
Terrell	2
Upton	20
Uvalde	2

The desired future conditions adopted on March 23, 2017 for Kinney and Val Verde counties were reaffirmed in the March 22, 2018 resolution as follows:

a) Total net drawdown in Kinney County in 2070, as compared with 2010 aquifer levels, shall be consistent with maintenance of an annual average flow of 23.9 cfs and an annual median flow of 23.9 cfs at Las Moras Springs (Reference: Groundwater Flow Model of the Kinney County Area by W.R. Hutchison, Ph.D., P.E., P.G., Jerry Shi, Ph.D. and Marius Jigmond, TWDB, dated August 26, 2011).
b) Total net drawdown in Val Verde County in 2070, as compared with 2010 aquifer levels, shall be consistent with maintenance of an average annual flow of 73-75 mgd at San Felipe Springs

Finally, the March 22, 2018 resolution reaffirmed the previous finding of March 23, 2017 that the Edwards-Trinity (Plateau) aquifer is not relevant for purposes of joint planning within the boundaries of the Hickory UWCD No. 1, the Lipan-Kickapoo WCD, Lone Wolf GCD, and Wes-Tex GCD, this finding is reaffirmed in this resolution.

The desired future conditions were developed after considering the simulations from three different models. For most of the area, the alternative one-layer model of the Edwards-Trinity (Plateau) and Pecos Valley aquifers was used. For Kinney County, existing model runs using the alternative model for Kinney County was used. Finally, for Val Verde County, model runs from a model developed for Val Verde County and the City of Del Rio were used. These models are described in the next three sections of this report.

2.2 Alternative GAM of the Edwards-Trinity (Plateau) and Pecos Valley Aquifers

In 2010, GMA 7 evaluated the results of 11 alternative predictive scenarios using the alternative one-layer model of the Edwards-Trinity (Plateau) and Pecos Valley aquifers. The model is documented in Hutchison and others (2011), and the simulation results are documented in Hutchison (2010). GMA 7 based their 2010 DFC on Scenario 10 of Hutchison (2010).

Drawdowns calculated in Hutchison (2010) were for predictive simulations through the year 2060. The updated desired future conditions that was adopted in 2017 is expressed through the year 2070 in accordance with the requirements of the Texas Water Development Board.

GMA 7 Technical Memorandum 15-06 described two new simulations that built upon Scenario 10 of Hutchison (2010). Scenario 1 used the same pumping amounts, but extended the simulation to the year 2070. The results were reviewed with GMA 7 at the April 23, 2015 GMA 7 meeting. After discussion and review of the results, adjustments to pumping were made in Irion County, and the model was run again and designated as Scenario 2. These results were discussed at the January 14, 2016 and March 17, 2016 meetings of GMA 7.

The desired future conditions that were adopted were based on Scenario 2 of GMA 7 Technical Memorandum 15-06, and based on the calculation of average drawdown in GMA 7 Technical Memorandum 18-01 that are based on the 2015 grid file.

2.3 Alternative Model for Kinney County

In 2010, the adopted desired future condition for Kinney County was based on simulations with an alternative GAM developed by TWDB (Hutchison and others, 2011). The desired future condition was based on average spring flow in Las Moras Springs. GMA 7 (and the Kinney County GCD) has voted to keep the same DFC based on the 2010 analyses despite issues that have been identified with the model.

The simulations were documented in Draft GAM Task 10-027 (revised), referenced as Hutchison (2011). The adopted desired future condition is based on Scenario 3.

In 2014, the Kinney County GCD began an intensive effort to monitor groundwater elevations and spring flow in Kinney County. This effort began with instrumenting 13 wells with transducers in 2014, and now includes 33 wells with KCGCD transducers, one stream monitoring point with a KCGCD transducer, a well instrumented by TWDB, and Las Moras Spring (monitored by the USGS).

The wet year of 2015 resulted in a pause in model development because the recovery of groundwater elevations was significant, and resulted in additional analyses to better understand the differential response among the various wells.

The DFC for Kinney County was based on maintaining an average spring flow that is independent of the model used to calculate the MAG (modeled available groundwater). Although TWDB will ultimately calculate the MAG using the tool it deems most suitable, it is reasonable to expect that the alternative GAM previously used in 2010 and 2011 will be selected, the issues with the model could result in a significantly different MAG if a different method is chosen. It is possible that the resulting MAG would be lower if a different method is used. It is also reasonable to assume that that TWDB will move forward with preparing a MAG report before the new model is completed. Once the model is completed, it will be forwarded to TWDB for consideration in updating the MAG.

2.4 Val Verde County Model

The DFC for Val Verde County was based on maintaining an average spring flow that was based on simulations with a groundwater model that was developed for Val Verde County and the City of Del Rio as part of a hydrogeologic study completed by EcoKai Environmental, Inc. (EcoKai, 2014). The overall objective of the study was to determine the correlation and potential impacts of groundwater pumping on local spring flows, lake elevations, and groundwater levels. An understanding of these correlations is necessary to evaluate the potential effects that additional groundwater pumping for export would have on the overall groundwater system.

The groundwater model developed as part of this study was based on the alternative model for Kinney County referenced above (Hutchison and Shi, 2011). Specifically, the half-mile grid spacing, the geologic framework, and many of the boundary conditions of the Kinney County model were used as the foundation of this new model. The Kinney County model was developed using annual stress period. The new model was developed using monthly stress periods from 1968 to 2013.

Model calibration was completed using 3,605 groundwater elevations from 498 wells in Val Verde County from 1968 to 2013, and using spring flows from three springs (Cantu, McKee and San Felipe). Calibration of the model was considered sufficient to advance the objectives of the study with regard to providing technical information that could be used in developing groundwater management guidelines (e.g. identification and delineation of the boundaries of groundwater management areas, conservation triggers, exportation cessation triggers, and generally characterizing groundwater conditions based on groundwater elevations and spring flows).

Specific applications of the calibrated model included: 1) a simulation to estimate the effect of Lake Amistad on groundwater elevations in the area, 2) a series of runs that were designed to provide information useful for management zone delineation, and 3) a series of simulations to evaluate the effects of large-scale pumping in three different areas to develop a better understanding of the nature and character of potential impacts of groundwater pumping on spring flow, river baseflow, aquifer drawdown, and other changes to the groundwater flow system.

The simulations that considered pumping increases considered 6 different pumping scenarios and 3 well-field location scenarios. The adopted desired future condition was based on the pumping scenarios designated 50K (50,000 AF/yr of pumping). The listed range in average spring flow in the desired future condition reflects the range of average spring flow associated with different locations of pumping. The summary table and graph are that were used by GMA 7 at the April 21, 2016 meeting to propose the desired future condition are located on page 61of the EcoKai report (Table 23 and Figure 39).

3.0 Policy Justification

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

1. Aquifer uses and conditions within Groundwater Management Area 7
2. Water supply needs and water management strategies included in the 2012 State Water Plan
3. Hydrologic conditions within Groundwater Management Area 7 including total estimated recoverable storage, average annual recharge, inflows, and discharge
4. Other environmental impacts, including spring flow and other interactions between groundwater and surface water
5. The impact on subsidence
6. Socioeconomic impacts reasonably expected to occur
7. 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 7 in groundwater as recognized under Texas Water Code Section 36.002
8. The feasibility of achieving the desired future condition
9. 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 7.

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.

During the initial development of desired future conditions in 2010, there was no specific statutory guidance related to factor consideration or balancing. However, GMA 7 took a proactive approach in defining qualitative goals that were evaluated with the groundwater availability model at the time. The effort was rooted as a policy consideration, but tested and verified as a technical consideration. Details are discussed in the next section. This approach was extended to the process of updating the desired future conditions that were adopted in 2017.

4.0 Technical Justification

The process of using the groundwater model in developing desired future conditions revolves around the concept of incorporating many of the elements of the nine statutory factors listed in the previous section. For the Edwards-Trinity (Plateau), Pecos Valley, and Trinity aquifers, the initial 10 simulations completed in 2010 were evaluated as well as two new simulations. In Kinney County, the DFCs were based on an evaluation of 7 scenarios. In Val Verde County, the DFCs were based on an evaluation of 18 scenarios.

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

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

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

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

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

GMA 7 articulated a qualitative vision for desired future conditions in 2010: minimize drawdown in the eastern portion of GMA 7 (where baseflow to rivers is important) and provide for irrigation demands in the western portion of GMA 7 (where there would be significant drawdown). The key issue of the model simulations was to assess the compatibility of these qualitative goals. Given that groundwater models require pumping as inputs and calculate drawdowns as one of the outputs, this led to a series of simulations that evaluated increases in pumping on drawdown in various portions of GMA 7. Initially, six scenarios were run: a base case using 2005 pumping, and 5 scenarios where pumping was increased. The base case, or continuation of 2005 pumping was designated as Scenario 0. Scenario 1 was developed by polling each district to identify their expected pumping. Scenario 2 pumping was 110 percent of Scenario 1 pumping. Scenario 3 pumping was 120 percent of Scenario 1 pumping. Scenario 3 pumping was 120 percent of Scenario 1 pumping. Scenario 4 pumping was 130 percent of Scenario 1 pumping. Scenario 5 pumping was 140 percent of Scenario 1 pumping. These results were reviewed with GMA 7 at their meeting of July 28, 2010.

At the July 28, 2010 meeting, GMA 7 representatives then identified modifications to the pumping inputs and the model was re-run at the meeting, and the results were reviewed. These runs were labeled Scenarios 6 to 10. GMA 7 adopted DFCs based on Scenario 10. Based on the review, the GCD representatives found that Scenario 10 met the predefined qualitative vision of minimizing drawdown in the east while providing for irrigation demands in the west.

The evaluation of the eastern portion is exemplified by an analysis of San Saba River flow in Menard County. Figure 4 presents the flow of the San Saba River at Menard.

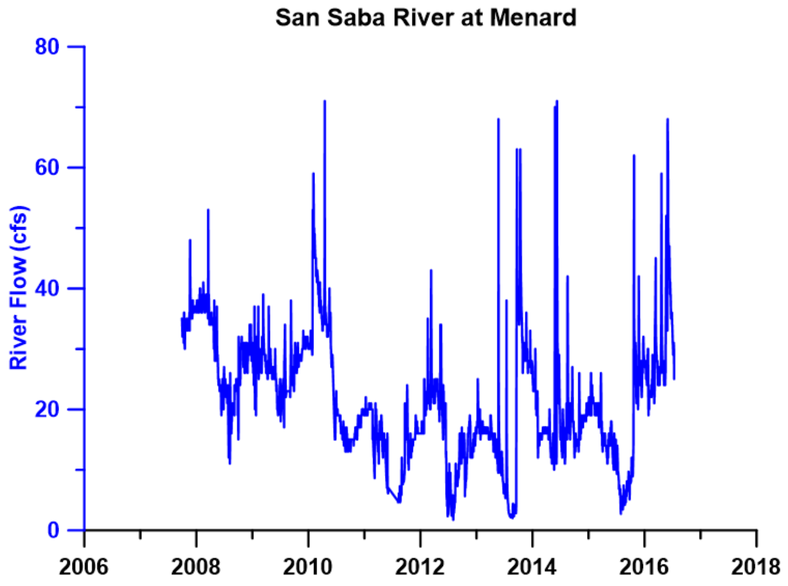


Figure 4. San Saba River at Menard

Please note that from about 2007 to 2010, minimum or base flow is about 30 cfs. From 2011 to 2014, minimum or base flow is about 10 cfs (during drought conditions), and after 2015, minimum or base flow return to about 30 cfs.

Figure 5 is a repeat of the river hydrograph and adds the hydrograph of a well completed in the Edwards-Trinity (Plateau) Aquifer several miles to the south of the stream gage.

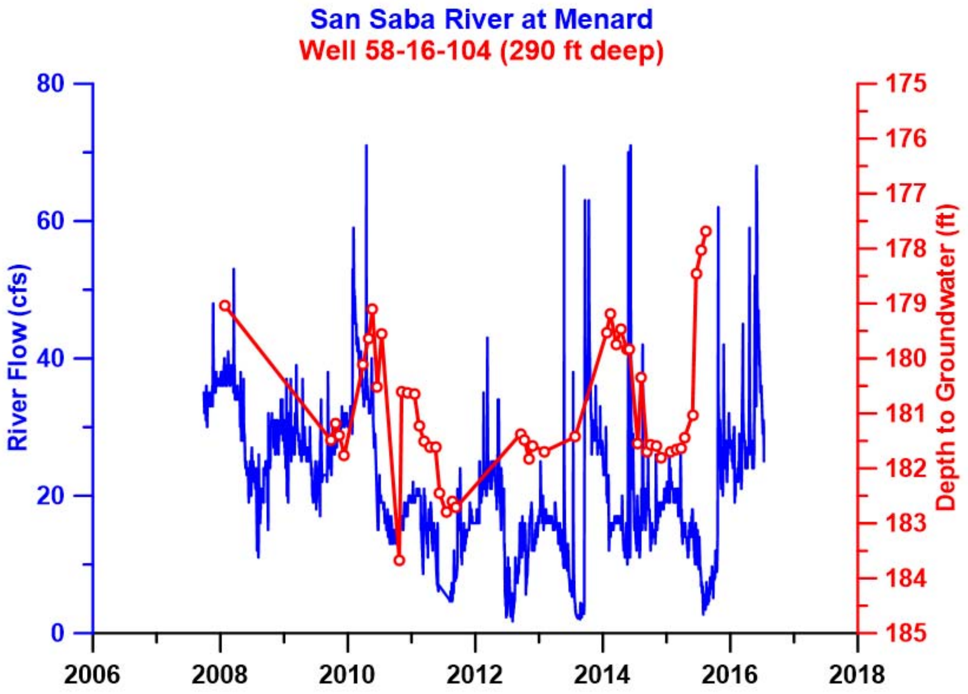


Figure 5. San Saba River at Menard and Well 58-16-104

Please note that the changes in the groundwater elevation in the well mimic the changes in river flow. The groundwater elevation from 1962 to 2016 in this well ranges from about 1,983 to 2,045 ft MSL. The stream gage elevation is 1,863 ft MSL, so it appears that this is a gaining reach of the river.

In general, the depth to water in the well is about 179 feet when river flow is high (i.e. during wet years), and the depth to water is about 182 feet when the river flow is low (i.e. during dry years). Thus, it was assumed that if, in wet periods, groundwater pumping resulted in a groundwater level decline of 3 feet, the river flow would be reduced. Thus, the pumping inputs into the GAM simulations were evaluated in the context of average drawdown that would be less than 3 feet to maintain base flow. In fact, the drawdown in Menard County under the desired future condition simulation was one foot suggested that impacts to baseflow would be minimal.

5.0 Factor Consideration

Senate Bill 660, adopted by the legislature in 2011, changed the process by which groundwater conservation districts within a groundwater management area develop and adopt desired future conditions. The new process includes nine steps as presented below:

- The groundwater conservation districts within a groundwater management area consider nine factors outlined in the statute.
- The groundwater conservation districts adopt a "proposed" desired future condition
- The "proposed" desired future condition is sent to each groundwater conservation district for a 90-day comment period, which includes a public hearing by each district
- After the comment period, each district compiles a summary report that summarizes the relevant comments and includes suggested revisions. This summary report is then submitted to the groundwater management area.
- The groundwater management area then meets to vote on a desired future condition.
- The groundwater management area prepares an "explanatory report".
- The desired future condition resolution and the explanatory report are then submitted to the Texas Water Development Board and the groundwater conservation districts within the groundwater management area.
- Districts then adopt desired future conditions that apply to that district.

The nine factors that must be considered before adopting a proposed desired future condition are:

1. Aquifer uses or conditions within the management area, including conditions that differ substantially from one geographic area to another.
2. The water supply needs and water management strategies included in the state water plan.
3. Hydrological conditions, including for each aquifer in the management area the total estimated recoverable storage as provided by the executive administrator (of the Texas Water Development Board), and the average annual recharge, inflows and discharge.
4. Other environmental impacts, including impacts on spring flow and other interactions between groundwater and surface water.
5. The impact on subsidence.
6. Socioeconomic impacts reasonably expected to occur.
7. 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 Section 36.002 (of the Texas Water Code).
8. The feasibility of achieving the desired future condition.
9. Any other information relevant to the specific desired future condition.

In addition to these nine factors, statute requires that the desired future condition provide a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater and control of subsidence in the management area.

5.1 Groundwater Demands and Uses

Groundwater demands and uses from 2000 to 2012 in the Edwards-Trinity (Plateau), Pecos Valley, and Trinity aquifers are presented in Appendix B. Data were obtained from the Texas Water Development Board historic pumping database:

http://www.twdb.state.tx.us/waterplanning/waterusesurvey/historical-pumpage.asp

The Modeled Available Groundwater values for the Edwards-Trinity Aquifer are summarized below in Table 1. In the Pecos Valley Aquifer, the modeled available groundwater in Crockett County is 31 AF/yr, is 113 AF/yr in Ector County, is 1,448 in Pecos County, and is 2 AF/yr in Upton County. In the Trinity Aquifer, the modeled available groundwater in Gillespie County is 2,482 AF/yr, and is 52 AF/yr in Real County.

Hydrographs that compare the historic pumping and the modeled available groundwater values are presented in Appendix C.

Table 1. Modeled Available Groundwater for the Edwards-Trinity (Aquifer)

County	Modeled Available Groundwater (2010 to 2070) (Acre-feet/yr)	County	Modeled Available Groundwater (2010 to 2070) (Acre-feet/yr)
Coke	998	Pecos	115,938
Crockett	5,426	Reagan	68,278
Ector	5,422	Real	7,477
Edwards	5,638	Schleicher	8,050
Gillespie	2,514	Sterling	2,497
Glasscock	65,213	Sutton	6,438
Irion	2,293	Taylor	489
Kimble	1,283	Terrell	1,421
Kinney	70,338	Tom Green	426
McCulloch	4	Upton	22,379
Menard	2,194	Uvalde	1,635
Midland	23,251	Val Verde	24,988
Nolan	693	Total	445,283

These data were discussed at the GMA 7 meeting of December 18, 2014 in San Angelo, Texas.

5.2 Groundwater Supply Needs and Strategies

Total future demand estimates from the Texas Water Development Board are summarized in Table 2. Recommended strategies in the 2011 Region F Water Plan for desalination, new groundwater, and well replacement are shown in Table 3.

Two alternative water supply strategies are listed for the Edwards-Trinity (Plateau) Aquifer in the 2011 Region F Water Plan. In Kimble County, a 1,000 AF/yr strategy for manufacturing is listed for the years 2010 to 2060. In Schleicher County, a 12,000 AF/yr strategy for municipal supply for the City of San Angelo is listed for the years 2040 to 2060.

5.3 Hydrologic Conditions, including Total Estimated Recoverable Storage

The groundwater budget as presented by Hutchison and others (2011) for the Edwards-Trinity (Plateau) Aquifer, Pecos Valley, and Trinity aquifers is presented in Table 4.

Jones and others (2013) documented the total estimated recoverable storage for the aquifers in GMA 7. Table 5 presents storage for the Edwards-Trinity (Plateau) Aquifer. Table 6 presents storage for the Pecos Aquifer. Table 7 presents storage for the Trinity.

5.4 Other Environmental Impacts, including Impacts on Spring Flow and Surface Water

Table 4 (referenced above) includes the entire groundwater budget for the Edwards-Trinity (Plateau) Aquifer, Pecos Valley, and Trinity aquifers.

The primary consideration for the desired future conditions in Val Verde and Kinney counties was the preservation of spring flow. The primary consideration in the northeastern portion of GMA 7 was the maintenance of groundwater levels to maintain baseflow to the tributaries of the Colorado River.

5.5 Subsidence

Subsidence is not an issue in the Edwards-Trinity (Plateau) Aquifer, Pecos Valley, and Trinity aquifers in GMA 7.

Table 2. Future Water Demands

County	Water Use (AF/yr)						Change (2020 to 2070)
	2020	2030	2040	2050	2060	2070	
Coke	2806	2823	2808	2811	2839	2848	42
Coleman	3335	3319	3274	3255	3241	3233	-102
Concho	11586	11535	11433	11335	11250	11173	-413
Crockett	5229	5563	5144	4770	4529	4541	-688
Ector	44084	48868	53855	59381	65707	72767	28,683
Edwards	1230	1211	1193	1184	1173	1166	-64
Gillespie	9142	9424	9658	9973	10338	10709	1,567
Glasscock	60554	59780	58603	57440	56409	55659	-4,895
Irion	5134	5261	4287	3317	2511	2109	-3,025
Kimble	4943	4871	4794	4722	4679	4647	-296
Kinney	8406	8397	8384	8380	8378	8378	-28
Llano	9499	9638	9563	9434	9543	9663	164
Mason	11493	11274	10907	10640	10412	10207	-1,286
McCulloch	15535	14986	13247	12230	11449	10830	-4,705
Menard	4468	4434	4298	4161	4043	3940	-528
Midland	75263	76803	79343	82052	85072	88465	13,202
Mitchell	19575	19622	19297	18942	18611	18347	-1,228
Nolan	25413	35845	35841	35883	35919	35979	10,566
Pecos	133971	134725	135119	135287	135455	135633	1,662
Reagan	24397	23330	22112	20785	19624	19007	-5,390
Real	913	890	870	855	843	835	-78
Runnels	6605	6581	6494	6441	6399	6363	-242
San Saba	9448	9323	8988	8740	8577	8442	-1,006
Schleicher	3453	3561	3371	3179	3005	2889	-564
Scurry	10891	11078	11015	10884	10785	10746	-145
Sterling	2394	2532	2349	2018	1726	1558	-836
Sutton	4134	4456	4488	4284	4081	3931	-203
Taylor	28806	29355	29801	30284	30868	31396	2,590
Terrell	1511	1604	1556	1416	1283	1178	-333
Tom Green	119070	120885	121841	122946	124361	125908	6,838
Upton	14974	14309	13442	12399	11515	11054	-3,920
Uvalde	75595	73694	71705	69993	68451	67179	-8,416
Val Verde	16777	17664	18519	19398	20262	21127	4,350
Total	770634	787641	787599	788819	793338	801907	31,273

Table 3. Recommended Groundwater Strategies in 2011 Region F Water Plan

Entity	County Used	Basin Used	Total Capital Cost	1st Decade Unit Cost	Supply (Ac-ft/yr)						2060 Unit Cost
					2010	2020	2030	2040	2050	2060	
Desalination											
City of Andrews	Andrews	Colorado	$6,717,000	$1,163	0	950	950	950	950	950	$546
CRMWD			$131,603,990	$0	0	0	0	9,500	9,500	9,500	$251
San Angelo			$75,440,000	$0	0	0	0	5,600	5,600	5,600	$473
Total			**$213,760,990**	**$1,163**	**0**	**950**	**950**	**16,050**	**16,050**	**16,050**	**$346**
New Groundwater											
Colorado City	Mitchell	Colorado	$17,855,000	$0	0	2,200	2,200	2,200	2,200	2,200	$445
City of Menard	Menard	Colorado	$1,684,000	$1,664	140	139	140	140	141	141	$610
County-Other	Menard	Colorado	$0	$0	20	21	20	20	19	19	$0
City of Midland	Midland	Colorado	$168,507,000	$0	0	0	13,600	13,600	13,600	13,600	$342
CRMWD	Multiple	Colorado	$76,268,000	$0	0	0	6,000	6,000	6,000	6,000	$251
San Angelo	Tom	Colorado	$173,307,000	$0	0	6,700	10,000	12,000	12,000	12,000	$1,670
Total			**$437,621,000**	**$1,664**	**160**	**9,060**	**31,960**	**33,960**	**33,960**	**33,960**	**$3,318**
Replacement Wells											
City of Eden	Concho	Colorado	$1,800,000	NA	0	0	0	0	0	0	NA
Richland SUD	McCulloc	Colorado	$1,701,000	NA	0	0	0	0	0	0	NA
CRMWD	Multiple	Colorado	$10,440,000	NA	0	0	0	0	0	0	NA
Total			**$13,941,000**	**NA**	**0**	**0**	**0**	**0**	**0**	**0**	**NA**

Table 4. Groundwater Budget of Edwards-Trinity (Plateau), Pecos Valley, and Trinity Aquifers from One-Layer Model

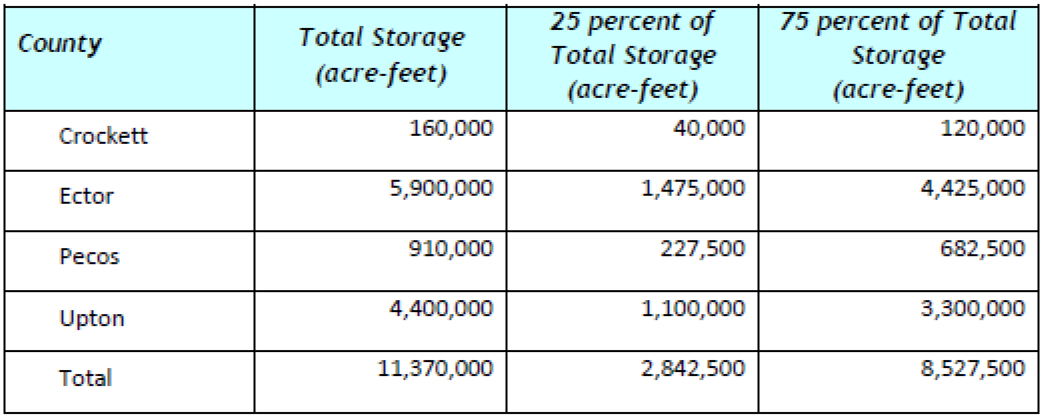
	Water Budget 1930-1939 (acre-feet per year)	Water Budget 1940-1949 (acre-feet per year)	Water Budget 1950-1959 (acre-feet per year)	Water Budget 1960-1969 (acre-feet per year)	Water Budget 1970-1979 (acre-feet per year)	Water Budget 1980-1989 (acre-feet per year)	Water Budget 1990-1999 (acre-feet per year)	Water Budget 2000-2005 (acre-feet per year)
Inflow								
Rivers	993,229	1,009,160	1,054,950	1,107,275	1,092,402	1,048,220	1,033,690	1,033,726
Inter-aquifer Flow	1,095,795	1,100,269	1,112,419	1,123,952	1,135,663	1,131,445	1,137,506	1,136,281
Recharge	1,641,803	1,688,928	1,545,021	1,621,125	1,680,625	1,671,631	1,669,556	1,703,227
Total Inflow	3,730,827	3,798,357	3,712,390	3,852,352	3,908,690	3,851,296	3,840,752	3,873,234
Outflow								
Pumpage	-194,233	-570,080	-947,024	-1,210,949	-935,718	-651,331	-706,359	-677,860
Springs	-1,216,432	-1,210,615	-1,129,334	-1,082,433	-1,092,612	-1,101,266	-1,120,187	-1,093,636
Rivers	-1,893,959	-1,841,710	-1,767,816	-1,722,471	-1,715,415	-1,741,168	-1,756,911	-1,755,300
Inter-aquifer Flow	-560,262	-557,538	-546,381	-532,124	-526,554	-531,894	-533,580	-535,091
Total Outflow	-3,864,885	-4,179,943	-4,390,555	-4,547,978	-4,270,298	-4,025,658	-4,117,038	-4,061,887
In-Out	-134,058	-381,585	-678,165	-695,626	-361,608	-174,362	-276,286	-188,653
Storage Change	-133,865	-372,190	-678,034	-695,534	-358,631	-166,175	-250,497	-188,648
Model Error	-194	-9,395	-131	-92	-2,977	-8,187	-25,789	-5
Model Error (Percent)	-0.01	-0.25	0.00	0.00	-0.08	-0.21	-0.67	0.00

Table 5. Total Estimated Recoverable Storage - Edwards-Trinity (Plateau) Aquifer

County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Coke	120,000	30,000	90,000
Concho	79,000	19,750	59,250
Crockett	1,500,000	375,000	1,125,000
Ector	220,000	55,000	165,000
Edwards	5,000,000	1,250,000	3,750,000
Gillespie	430,000	107,500	322,500
Glasscock	270,000	67,500	202,500
Irion	420,000	105,000	315,000
Kimble	1,100,000	275,000	825,000
Kinney[20]	4,400,000	1,100,000	3,300,000
Mason	51,000	12,750	38,250
McCulloch	93,000	23,250	69,750
Menard	250,000	62,500	187,500
Midland	240,000	60,000	180,000
Nolan	170,000	42,500	127,500
Pecos	3,100,000	775,000	2,325,000
Reagan	560,000	140,000	420,000
Real	1,600,000	400,000	1,200,000
Schleicher	890,000	222,500	667,500
Sterling	150,000	37,500	112,500
Sutton	1,800,000	450,000	1,350,000
Taylor	78,000	19,500	58,500
Terrell	4,500,000	1,125,000	3,375,000
Tom Green	250,000	62,500	187,500
Upton	550,000	137,500	412,500
Uvalde	1,000,000	250,000	750,000
Val Verde	10,000,000	2,500,000	7,500,000
Total	38,821,000	9,705,250	29,115,750

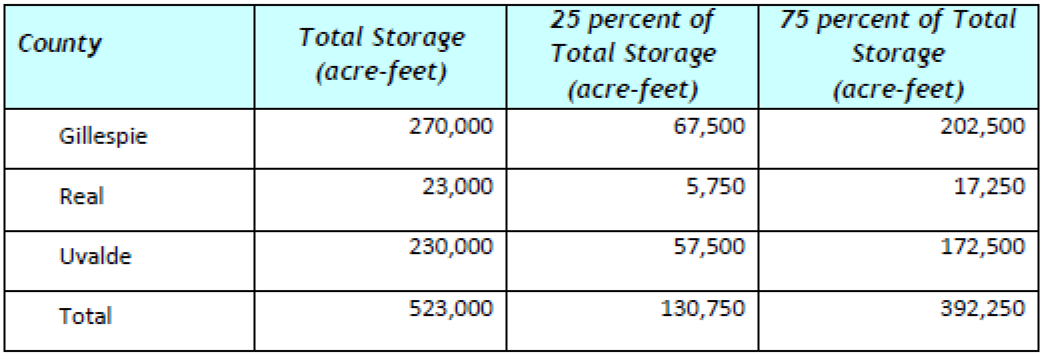
[20] Total storage values for Kinney County are based on the alternative model by Hutchison and others (2011), the other total storage values were based on the groundwater availability model by Anaya and Jones (2009).

Table 6. Total Estimated Recoverable Storage - Pecos Valley Aquifer



County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Crockett	160,000	40,000	120,000
Ector	5,900,000	1,475,000	4,425,000
Pecos	910,000	227,500	682,500
Upton	4,400,000	1,100,000	3,300,000
Total	11,370,000	2,842,500	8,527,500

Table 7. Total Estimated Recoverable Storage - Trinity Aquifer



County	*Total Storage (acre-feet)*	*25 percent of Total Storage (acre-feet)*	*75 percent of Total Storage (acre-feet)*
Gillespie	270,000	67,500	202,500
Real	23,000	5,750	17,250
Uvalde	230,000	57,500	172,500
Total	523,000	130,750	392,250

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 2011 Regional Water Plans. Because the development of this desired future condition used the State Water Plan demands and water management strategies as an important foundation, it is reasonable to conclude that the socioeconomic impacts associated with this proposed desired future condition can be evaluated in the context of not meeting the listed water management strategies. Groundwater Management Area 7 is covered by Regional Planning Group F. The socioeconomic impact report for Regions F is included in Appendix D.

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 7 in groundwater is recognized under Texas Water Code Section 36.002.

The desired future conditions adopted by GMA 7 are consistent with protecting property rights of landowners who are currently pumping groundwater and landowners who have chosen to conserve groundwater by not pumping. All current and projected uses (as defined in the 2015 Region F plan) can be met based on the simulations. In addition, the pumping associated with achieving the desired future condition (the modeled available groundwater) will cause impacts to exiting well owners and to surface water. However, as required by Chapter 36 of the Water Code, GMA 7 considered these impacts and balanced them with the increasing demand of water in the GMA 7 area, and concluded that, on balance and with appropriate monitoring and project specific review during the permitting process, the desired future condition is consistent with protection of private property rights.

5.8 Feasibility of Achieving the Desired Future Condition

Groundwater levels are routinely monitored by the districts and by the TWDB in GMA 7. Evaluating the monitoring data is a routine task for the districts, and the comparison of these data with the 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.

5.9 Other Information

GMA 7 did not consider any other information in developing these DFCs.

6.0 Discussion of Other Desired Future Conditions Considered

As discussed earlier in this explanatory report, desired future conditions were adopted after considering the nine statutory factors and after reviewing and discussing numerous model simulations. The simulations provided a foundation for the discussions and decisions. The Edwards-Trinity (Plateau), Pecos Valley, and Trinity aquifer simulation model was used in 12 simulations. The Kinney County simulation model was used in 7 simulations. The Val Verde County simulation model was used in 18 simulations.

7.0 Discussion of Other Recommendations

Public comments were invited and each district held a public hearing on the proposed desired future conditions for aquifers within their boundaries as follows:

District	Date of Public Meeting	Comments Received During Public Comment Period
Coke County UWCD	8/9/2016	none
Crockett County GCD	8/8/2016	none
Glasscock County GCD	7/22/2016	none
Hill Country GCD	7/22/2016	none
Irion County WCD	7/11/2016	none
Kimble County GCD	7/18/2016	none
Kinney County GCD	7/14/2016	none
Menard County UWD	7/12/2016	none
Middle Pecos GCD	7/19/2016	One letter, oral comments
Plateau UWC & SD	7/27/2016	none
Real-Edwards C & RD	7/13/2016	none
Santa Rita UWCD	7/19/2016	none
Sterling County UWCD	7/11/2016	none
Sutton County UWCD	7/12/2016	none
Terrell County GCD	7/27/2016	none
Uvalde County WCD	6/14/2016	none

The letter received by Middle Pecos GCD during the public comment period is included as Appendix E. Please note that this version of the letter includes large red numerals in the right-hand margin that correspond to a specific comment. Appendix F contains the responses to those comments that follows the numbering system of shown in Appendix E.

In addition to the letter (Appendix E) and the responses to the specific comments in the letter (Appendix F), an additional analysis was completed regarding the potential use of the USGS model for Pecos County (Clark and others, 2014). In response to that comment, a review of the model was completed and documented (Hutchison, 2017) and discussed at the GMA 7 meeting of February 16, 2017. In summary, the USGS model, as currently constructed, is not useful for predictive simulations, and is not an appropriate tool to evaluate and develop desired future conditions. The documentation of the model review is included as Appendix G.

8.0 References

Clark, B.R., Bumgarner, J.R., Houston, N.A., and Foster, A.L., 2014. Simulations of Groundwater Flow in the Edwards-Trinity and Related Aquifers in the Pecos County Region, Texas. USGS Scientific Investigations Report 2013-5228. Prepared in cooperation with the Middle Pecos Groundwater Conservation District, Pecos County, City of fort Stockton, Brewster County, and Pecos County Water Control and Improvement District No. 1, 67p.

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

EcoKai Environmental, Inc. and Hutchison, William R., 2014. Hydrogeological Study for Val Verde County and City of Del Rio, Texas. Final Report, November 2014. 168p.

Hutchison, W.R., 2010. Draft GAM Run 09-035 (Version 2). Texas Water Development Board, Groundwater Resources Division, 10p.

Hutchison, W.R., 2017. Simulations with USGS Groundwater Model of Pecos County Region. GMA 7 Technical Memorandum 17-01, Draft 2. February 13, 2017, 17p.

Hutchison, W.R., Jones, I.C., and Anaya, R., 2011. Update of the Groundwater Availability Model of the Edwards-Trinity (Plateau) and Pecos Valley Aquifers of Texas. Texas Water Development Board Report, January 21, 2011, 61p.

Hutchison, W.R., Shi, J., and Jigmond, M., 2011. Groundwater Flow Model of the Kinney County Area. TWDB Report, August 26, 2011. 219p.

Jones, I.C., Bradley, R., Boghici, R., Kohlrenken, W., Shi, J., 2013. GAM Task 13-030: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 7. Texas Water Development Board, Groundwater Resources Division, October 2, 2013, 53 p.

Appendix A

Desired Future Conditions Resolution

Groundwater Management Area 7
Resolution 03-22-2018-1a
Desired Future Conditions for the Edwards-Trinity (Plateau), Pecos Valley, and Trinity Aquifers in Groundwater Management Area 7

WHEREAS, Groundwater Conservation Districts (GCDs) located within or partially within Groundwater Management Area 7 (GMA 7) are required under Chapter 36.108, Texas Water Code to conduct joint planning and designate the Desired Future Conditions of aquifers within GMA 7 and;

WHEREAS, the Board Presidents or their Designated Representatives of GCDs in GMA 7 have met in various meetings and conducted joint planning in accordance with §36.108, Texas Water Code since September 2010; and

WHEREAS, the GMA 7 committee has received and considered Groundwater Availability Model runs and other technical advice regarding local aquifers, hydrology, geology, recharge characteristics, the nine factors set forth in§36.108(d) of the Texas Water Code, local groundwater demands and usage, population projections, total water supply and quality of water supply available from all aquifers within the respective GCDs, regional water plan water management strategies, ground and surface water interactions, that affect groundwater conditions through the year 2070; and

WHEREAS, the member GCDs in which the Edwards-Trinity (Plateau), Pecos Valley and Trinity aquifers are relevant for joint planning purposes held open meetings within each said district between June 14, 2016 and July 27, 2016 to take public comment on the proposed DFCs for that district; and

WHEREAS, the member GCDs of GMA 7, having given proper and timely notice, held an open meeting on March 23, 2017 at the Texas Research and Agri-Life Center, 7887 U.S. Highway 87 North, San Angelo, Texas to vote to adopt proposed Desired Future Conditions for the Edwards-Trinity (Plateau), Pecos Valley and Trinity aquifers within the boundaries of GMA 7; and

WHEREAS on this day of March 22, 2018, at an open meeting duly noticed and held in accordance with law at the Texas Research and Agri-Life Center, 7887 U.S. Highway 87 North, San Angelo, Texas, the GCDs within GMA 7, the calculations that were presented in GMA 7 Technical Memorandum 18-01, have voted, 19 districts in favor, 0 districts opposed, to correct the DFCs in the following counties and districts through the year 2070 as follows:

> Average drawdown in the following GMA 7 counties not to exceed drawdowns from 2010 to 2070, as set forth in Table 5 of GMA 7 Technical Memo 18-01, Draft 1) attached hereto and fully incorporated herein:

County	Corrected Desired Future Conditions: Average Drawdowns from 2010 to 2070 (ft)
Coke	0
Crockett	10
Ector	4
Edwards	2
Gillespie	5
Glasscock	42
Irion	10
Kimble	1
Menard	1
Midland	12
Pecos	14
Reagan	42
Real	4
Schelicher	8
Sterling	7
Sutton	6
Taylor	0
Terrell	2
Upton	20
Uvalde	2

WHEREAS the corrected desired future conditions do not affect the desired future conditions previously adopted for Kinney or Val Verde counties, the desired future conditions adopted on March 23, 2017 for Kinney and Val Verde counties are reaffirmed as follows:

a) Total net drawdown in Kinney County in 2070, as compared with 2010 aquifer levels, shall be consistent with maintenance of an annual average flow of 23.9 cfs and an annual median flow of 23.9 cfs at Las Moras Springs (Reference: Groundwater Flow Model of the Kinney County Area by W.R. Hutchison, Ph.D., P.E., P.G., Jerry Shi, Ph.D. and Marius Jigmond, TWDB, dated August 26, 2011).
b) Total net drawdown in Val Verde County in 2070, as compared with 2010 aquifer levels, shall be consistent with maintenance of an average annual flow of 73-75 mgd at San Felipe Springs

WHEREAS the corrected desired future conditions do not affect the previous finding of March 23, 2017 that the Edwards-Trinity (Plateau) aquifer is not relevant for purposes of joint planning within the boundaries of the Hickory UWCD No. 1, the Lipan-Kickapoo WCD, Lone Wolf GCD, and Wes-Tex GCD, this finding is reaffirmed in this resolution.

NOW THEREFORE BE IT RESOLVED, that Groundwater Management Area 7 does hereby document, record, and confirm the above-described Desired Future Conditions for the Edwards-Trinity (Plateau), Pecos Valley, and Trinity aquifers which were adopted by vote of the following Designated Representatives of Groundwater Conservation Districts present and voting on March 22, 2018:

Designated Representative – Coke County UWCD

Designated Representative – Crockett County GCD

Designated Representative – Glasscock GCD

Designated Representative – Hickory UWCD #1

Designated Representative – Hill Country UWCD

Designated Representative – Irion County WCD

Jerry

Designated Representative – Kimble County GCD

Gerald Hobbs

Designated Representative – Kinney County GCD

Allan J. Lange

Designated Representative – Lipan-Kickapoo WCD

Designated Representative – Lone Wolf GCD

Caroline Runge

Designated Representative – Menard County UWD

Designated Representative – Middle Pecos GCD

Jon Cartwright

Designated Representative – Plateau UWC & SD

Joel Pigg

Designated Representative – Real-Edwards Con & Rec Dist

Regina R Gomez

Designated Representative – Santa Rita UWCD

Designated Representative – Sterling County UWCD

Designated Representative – Sutton County UWCD

Designated Representative – Terrell County GCD

Designated Representative – Uvalde County UWCD

Designated Representative – Wes-Tex GCD

Nays:

Designated Representative –

Designated Representative –

Designated Representative –

Designated Representative –

Designated Representative –

Designated Representative –

Appendix B

Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley, and Trinity Aquifers

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2000	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	30	0	0	0	50	10	90
2001	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	30	0	0	0	50	12	92
2002	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	30	0	0	0	61	10	101
2003	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	30	0	0	0	26	6	62
2004	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	29	0	0	0	47	7	83
2005	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	32	0	0	0	47	61	140
2006	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	26	0	0	0	59	68	153
2007	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	21	0	0	0	38	62	121
2008	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	24	0	0	0	43	92	159
2009	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	25	0	0	0	25	88	138
2010	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	26	0	0	0	54	80	160
2011	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	51	0	0	0	56	82	189
2012	COKE	EDWARDS-TRINITY-PLATEAU AQUIFER	58	0	0	0	33	73	164
2000	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	1	0	0	0	0	144	145
2001	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	141	141
2002	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	144	144
2003	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	116	116
2004	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	303	303
2005	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	195	195
2006	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	17	0	0	0	0	241	258
2007	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	14	0	0	0	0	292	306
2008	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	15	0	0	0	0	204	219
2009	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	16	0	0	0	0	204	220
2010	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	16	0	0	0	0	187	203
2011	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	17	0	0	0	0	184	201
2012	CONCHO	EDWARDS-TRINITY-PLATEAU AQUIFER	13	0	0	0	0	163	176
2000	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,561	0	31	0	123	608	2,323
2001	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,240	0	22	0	165	572	1,999
2002	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,317	0	42	0	150	515	2,024

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2003	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,215	0	50	0	289	435	1,989
2004	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,209	0	50	0	242	487	1,988
2005	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,312	0	49	0	328	607	2,296
2006	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,366	0	40	0	373	641	2,420
2007	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,309	0	25	0	293	631	2,258
2008	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,331	0	30	0	279	612	2,252
2009	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,409	0	20	0	0	605	2,034
2010	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,426	0	20	0	115	557	2,118
2011	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,760	0	60	0	221	549	2,590
2012	CROCKETT	EDWARDS-TRINITY-PLATEAU AQUIFER	1,509	0	120	0	162	493	2,284
2000	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	1,809	2,479	99	0	304	151	4,842
2001	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	2,008	1,826	98	0	418	92	4,442
2002	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	2,079	2,278	98	0	392	78	4,925
2003	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	1,684	2,228	99	0	116	55	4,182
2004	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	1,662	3,510	98	0	717	62	6,049
2005	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	1,787	767	98	0	918	224	3,794
2006	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	2,781	1,965	98	0	17	210	5,071
2007	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	1,738	906	13	0	170	224	3,051
2008	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	1,959	938	13	0	0	202	3,112
2009	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	2,948	586	13	0	0	224	3,771
2010	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	4,420	584	12	0	748	211	5,975
2011	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	4,862	590	12	0	351	213	6,028
2012	ECTOR	EDWARDS-TRINITY-PLATEAU AQUIFER	4,455	587	12	0	100	185	5,339
2000	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	371	0	0	0	160	448	979
2001	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	383	0	0	0	130	143	656
2002	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	343	0	0	0	202	126	671
2003	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	294	0	0	0	137	122	553
2004	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	312	0	0	0	315	121	748
2005	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	355	0	0	0	347	416	1,118

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers
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Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2006	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	345	0	0	0	359	352	1,056
2007	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	286	0	0	0	104	280	670
2008	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	349	0	0	0	57	465	871
2009	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	327	0	0	0	0	463	790
2010	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	261	0	0	0	33	432	726
2011	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	387	0	0	0	257	425	1,069
2012	EDWARDS	EDWARDS-TRINITY-PLATEAU AQUIFER	329	0	0	0	97	372	798
2000	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	5	0	0	0	102	275	382
2001	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	2	0	0	0	116	261	379
2002	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	3	0	0	0	116	258	377
2003	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	3	0	0	0	116	242	361
2004	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	7	0	0	0	123	245	375
2005	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	14	0	0	0	100	374	488
2006	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	319	0	0	0	109	372	800
2007	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	257	0	0	0	9	388	654
2008	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	294	0	0	0	102	426	822
2009	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	289	0	0	0	99	398	786
2010	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	281	0	0	0	66	691	1,038
2011	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	311	0	0	0	163	711	1,185
2012	GILLESPIE	EDWARDS-TRINITY-PLATEAU AQUIFER	297	0	0	0	100	335	732
2000	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	156	0	0	0	30,528	135	30,819
2001	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	157	0	0	0	22,176	133	22,466
2002	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	148	0	0	0	22,729	122	22,999
2003	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	146	0	0	0	38,824	95	39,065
2004	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	124	0	0	0	38,147	86	38,357
2005	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	145	0	0	0	38,083	109	38,337
2006	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	134	0	0	0	40,105	119	40,358
2007	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	108	1	0	0	32,560	163	32,832
2008	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	122	0	0	0	36,919	84	37,125

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers
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Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2009	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	124	3	0	0	39,479	89	39,695
2010	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	126	3	0	0	49,218	107	49,454
2011	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	143	3	0	0	45,848	118	46,112
2012	GLASSCOCK	EDWARDS-TRINITY-PLATEAU AQUIFER	167	3	0	0	38,915	84	39,169
2000	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	179	0	0	0	808	248	1,235
2001	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	170	0	0	0	640	226	1,036
2002	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	206	0	0	0	640	218	1,064
2003	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	188	0	0	0	288	150	626
2004	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	185	0	0	0	104	148	437
2005	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	190	0	0	0	180	158	528
2006	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	185	0	0	0	573	169	927
2007	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	164	0	0	0	341	168	673
2008	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	168	0	0	0	542	202	912
2009	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	175	0	0	0	225	197	597
2010	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	186	0	0	0	43	208	437
2011	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	193	0	0	0	258	218	669
2012	IRION	EDWARDS-TRINITY-PLATEAU AQUIFER	212	0	0	0	47	158	417
2000	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	209	2	0	0	10	359	580
2001	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	211	2	0	0	11	347	571
2002	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	212	2	0	0	11	314	539
2003	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	210	2	0	0	11	278	501
2004	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	203	2	0	0	19	288	512
2005	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	221	2	0	0	35	259	517
2006	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	205	2	0	0	5	249	461
2007	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	171	2	0	0	98	268	539
2008	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	188	2	0	0	40	223	453
2009	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	195	2	0	0	165	222	584
2010	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	203	2	0	0	115	302	622
2011	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	229	2	0	0	66	306	603

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2012	KIMBLE	EDWARDS-TRINITY-PLATEAU AQUIFER	221	2	0	0	84	172	479
2000	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	7	0	0	0	10,454	236	10,697
2001	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	7	0	0	0	4,435	115	4,557
2002	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	7	0	0	0	4,357	106	4,470
2003	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	7	0	0	0	7,337	78	7,422
2004	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	7	0	0	0	3,355	36	3,398
2005	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	7	0	0	0	2,959	74	3,040
2006	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	14	0	0	0	3,551	67	3,632
2007	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	12	0	0	0	1,220	61	1,293
2008	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	13	0	0	0	1,519	87	1,619
2009	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	30	0	0	0	665	100	795
2010	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	536	0	0	0	640	50	1,226
2011	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	670	0	0	0	3,425	51	4,146
2012	KINNEY	EDWARDS-TRINITY-PLATEAU AQUIFER	621	0	0	0	1,663	46	2,330
2000	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	6	6
2001	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	7	7
2002	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	6	6
2003	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	9	9
2004	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	10	10
2005	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	14	14
2006	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	1	0	0	0	0	17	18
2007	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	1	0	0	0	0	14	15
2008	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	1	0	0	0	0	14	15
2009	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	1	0	0	0	0	12	13
2010	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	2	0	0	0	0	8	10
2011	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	2	0	0	0	0	12	14
2012	MASON	EDWARDS-TRINITY-PLATEAU AQUIFER	2	0	0	0	0	11	13
2000	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	17	17
2001	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	12	12

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2002	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	15	15
2003	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	11	11
2004	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	3	3
2005	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	4	4
2006	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	1	0	0	0	0	3	4
2007	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	1	0	0	0	0	3	4
2008	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	1	0	0	0	0	3	4
2009	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	3	0	0	0	0	4	7
2010	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	5	0	0	0	0	6	11
2011	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	6	0	0	0	0	3	9
2012	MCCULLOCH	EDWARDS-TRINITY-PLATEAU AQUIFER	5	0	72	0	0	3	80
2000	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	358	0	0	0	111	307	776
2001	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	338	0	0	0	126	306	770
2002	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	329	0	0	0	126	273	728
2003	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	315	0	0	0	56	292	663
2004	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	256	0	0	0	42	297	595
2005	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	261	0	0	0	65	304	630
2006	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	289	0	0	0	468	318	1,075
2007	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	255	0	0	0	318	326	899
2008	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	306	0	0	0	0	276	582
2009	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	339	0	0	0	244	314	897
2010	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	73	0	0	0	256	256	585
2011	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	81	0	0	0	100	245	426
2012	MENARD	EDWARDS-TRINITY-PLATEAU AQUIFER	79	0	0	0	301	211	591
2000	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	1,308	0	1	0	9,262	226	10,797
2001	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	1,717	0	1	0	8,382	223	10,323
2002	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	1,861	0	1	0	7,921	191	9,974
2003	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	1,257	0	1	0	5,828	102	7,188
2004	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	1,261	0	1	0	8,389	94	9,745

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2005	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	1,324	0	1	0	8,982	181	10,488
2006	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	1,643	0	1	0	9,851	216	11,711
2007	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	1,376	0	1	0	7,403	243	9,023
2008	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	1,636	0	0	0	9,584	157	11,377
2009	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	2,191	0	0	0	9,997	211	12,399
2010	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	2,112	0	0	0	7,128	158	9,398
2011	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	3,229	0	0	0	10,087	165	13,481
2012	MIDLAND	EDWARDS-TRINITY-PLATEAU AQUIFER	3,114	0	0	0	9,715	140	12,969
2000	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	669	70	0	0	39	22	800
2001	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	2,559	76	0	0	23	10	2,668
2002	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	2,908	79	0	0	23	10	3,020
2003	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	3,390	79	0	0	25	7	3,501
2004	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	2,454	79	0	0	33	11	2,577
2005	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	2,210	105	0	0	43	143	2,501
2006	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	3,108	105	0	0	42	165	3,420
2007	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	2,905	136	0	0	47	156	3,244
2008	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	2,945	132	0	0	81	150	3,308
2009	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	2,283	86	0	0	90	143	2,602
2010	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	1,927	11	0	0	65	131	2,134
2011	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	2,307	15	0	0	98	133	2,553
2012	NOLAN	EDWARDS-TRINITY-PLATEAU AQUIFER	2,046	19	0	0	100	117	2,282
2000	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	5,373	263	6	938	43,237	718	50,535
2001	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	4,235	143	5	908	38,367	757	44,415
2002	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	4,100	54	2	908	36,575	669	42,308
2003	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	4,171	52	0	647	22,477	573	27,920
2004	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	3,667	88	0	0	25,364	630	29,749
2005	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	4,656	92	0	0	24,722	669	30,139
2006	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	4,415	79	0	0	36,964	749	42,207
2007	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	4,831	129	0	0	32,579	581	38,120

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2008	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	5,533	75	0	0	33,983	654	40,245
2009	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	5,203	73	0	0	54,244	603	60,123
2010	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	5,369	149	0	0	73,249	594	79,361
2011	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	6,925	152	0	0	74,691	586	82,354
2012	PECOS	EDWARDS-TRINITY-PLATEAU AQUIFER	4,601	159	0	0	65,828	523	71,111
2000	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	148	0	0	0	15,735	167	16,050
2001	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	848	0	0	0	11,624	132	12,604
2002	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	849	0	0	0	14,746	132	15,727
2003	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	848	0	0	0	9,911	73	10,832
2004	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	845	0	0	0	10,300	79	11,224
2005	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	750	0	0	0	12,164	150	13,064
2006	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	879	0	0	0	18,599	120	19,598
2007	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	796	0	0	0	16,863	127	17,786
2008	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	751	0	0	0	19,305	223	20,279
2009	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	762	0	0	0	16,577	224	17,563
2010	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	603	0	0	0	19,238	189	20,030
2011	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	767	0	0	0	26,164	188	27,119
2012	REAGAN	EDWARDS-TRINITY-PLATEAU AQUIFER	717	0	0	0	19,681	167	20,565
2000	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	103	0	0	0	21	131	255
2001	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	89	0	0	0	22	85	196
2002	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	95	0	0	0	22	86	203
2003	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	105	0	0	0	17	76	198
2004	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	224	0	0	0	72	74	370
2005	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	251	0	0	0	92	118	461
2006	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	263	0	0	0	284	93	640
2007	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	214	0	0	0	0	105	319
2008	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	254	0	0	0	50	93	397
2009	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	269	0	0	0	0	98	367
2010	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	471	0	0	0	88	187	746

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2011	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	511	0	0	0	188	194	893
2012	REAL	EDWARDS-TRINITY-PLATEAU AQUIFER	442	0	0	0	99	79	620
2000	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	4	4
2001	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	4	4
2002	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	4	4
2003	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	3	3
2004	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	3	3
2005	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	0	0	0	0	0	15	15
2006	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	3	0	0	0	0	16	19
2007	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	2	0	0	0	0	15	17
2008	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	3	0	0	0	0	17	20
2009	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	3	0	0	0	0	16	19
2010	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	4	0	0	0	0	17	21
2011	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	4	0	0	0	0	18	22
2012	RUNNELS	EDWARDS-TRINITY-PLATEAU AQUIFER	4	0	0	0	0	11	15
2000	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	657	0	18	0	2,150	438	3,263
2001	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	552	0	18	0	1,294	273	2,137
2002	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	591	0	17	0	1,300	243	2,151
2003	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	461	0	18	0	964	222	1,665
2004	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	485	0	18	0	734	247	1,484
2005	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	473	0	18	0	762	477	1,730
2006	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	480	0	18	0	1,005	506	2,009
2007	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	484	0	17	0	500	508	1,509
2008	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	610	0	0	0	1,095	467	2,172
2009	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	613	0	0	0	1,432	463	2,508
2010	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	616	0	0	0	1,442	422	2,480
2011	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	806	0	0	0	1,941	414	3,161
2012	SCHLEICHER	EDWARDS-TRINITY-PLATEAU AQUIFER	652	0	0	0	2,020	364	3,036
2000	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	4	0	0	0	235	214	453

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2001	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	5	0	0	0	251	270	526
2002	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	5	0	0	0	264	236	505
2003	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	5	0	0	0	226	145	376
2004	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	5	0	0	0	183	164	352
2005	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	5	0	0	0	166	208	379
2006	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	20	0	0	0	221	217	458
2007	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	16	0	0	0	176	236	428
2008	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	19	0	0	0	272	196	487
2009	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	19	0	0	0	378	208	605
2010	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	20	0	0	0	253	183	456
2011	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	20	0	0	0	360	176	556
2012	STERLING	EDWARDS-TRINITY-PLATEAU AQUIFER	19	0	0	0	313	157	489
2000	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,389	0	0	0	1,234	440	3,063
2001	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,338	0	0	0	1,114	208	2,660
2002	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,339	0	0	0	1,114	188	2,641
2003	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,243	0	0	0	292	150	1,685
2004	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,108	0	0	0	292	141	1,541
2005	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,142	0	0	0	1,249	396	2,787
2006	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,247	0	0	0	1,407	363	3,017
2007	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,024	0	0	0	1,542	395	2,961
2008	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,141	0	0	0	342	469	1,952
2009	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	891	0	0	0	567	458	1,916
2010	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	928	0	0	0	958	477	2,363
2011	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,285	0	0	0	1,256	495	3,036
2012	SUTTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,267	0	0	0	859	360	2,486
2000	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	88	0	0	0	3	25	116
2001	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	88	0	0	0	8	10	106
2002	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	88	0	0	0	6	7	101
2003	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	87	0	0	0	1	6	94

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2004	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	85	0	0	0	1	11	97
2005	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	91	0	0	0	28	32	151
2006	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	123	0	0	0	26	42	191
2007	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	102	0	0	0	14	36	152
2008	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	113	0	0	0	0	90	203
2009	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	219	0	0	0	7	82	308
2010	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	328	0	0	0	21	44	393
2011	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	279	0	0	0	52	47	378
2012	TAYLOR	EDWARDS-TRINITY-PLATEAU AQUIFER	293	0	0	0	19	37	349
2000	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	217	0	5	0	0	292	514
2001	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	200	0	5	0	0	280	485
2002	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	178	0	5	0	0	234	417
2003	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	175	0	5	0	0	189	369
2004	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	147	0	5	0	0	207	359
2005	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	181	0	4	0	0	233	418
2006	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	196	0	5	0	0	211	412
2007	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	192	0	4	0	255	170	621
2008	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	178	0	4	0	0	193	375
2009	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	196	0	4	0	154	206	560
2010	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	202	0	4	0	173	182	561
2011	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	218	0	9	0	398	179	804
2012	TERRELL	EDWARDS-TRINITY-PLATEAU AQUIFER	186	0	9	0	41	163	399
2000	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	123	0	0	0	131	137	391
2001	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	75	0	0	0	171	125	371
2002	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	94	0	0	0	183	143	420
2003	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	95	0	0	0	166	122	383
2004	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	92	0	0	0	538	98	728
2005	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	97	0	0	0	615	841	1,553
2006	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	129	0	0	0	731	921	1,781

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2007	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	109	0	0	0	1,520	615	2,244
2008	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	199	0	0	0	1,896	844	2,939
2009	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	448	0	0	0	1,474	764	2,686
2010	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	613	0	0	0	836	786	2,235
2011	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	825	0	0	0	174	864	1,863
2012	TOM GREEN	EDWARDS-TRINITY-PLATEAU AQUIFER	672	0	0	0	1,166	747	2,585
2000	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,006	0	0	0	12,236	131	13,373
2001	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	1,051	0	0	0	8,553	60	9,664
2002	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	683	0	0	0	7,962	53	8,698
2003	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	779	0	0	0	7,792	35	8,606
2004	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	369	0	0	0	7,000	40	7,409
2005	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	759	0	0	0	6,584	98	7,441
2006	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	663	0	0	0	7,195	98	7,956
2007	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	297	0	0	0	6,253	94	6,644
2008	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	305	0	0	0	8,984	113	9,402
2009	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	411	0	0	0	7,873	111	8,395
2010	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	430	0	0	0	9,395	90	9,915
2011	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	450	0	0	0	13,651	87	14,188
2012	UPTON	EDWARDS-TRINITY-PLATEAU AQUIFER	286	0	0	0	10,033	75	10,394
2000	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	30	0	0	0	0	381	411
2001	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	39	0	0	0	0	351	390
2002	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	41	0	0	0	0	343	384
2003	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	42	0	0	0	0	374	416
2004	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	41	0	0	0	0	40	81
2005	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	44	0	0	0	0	61	105
2006	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	25	0	0	0	0	59	84
2007	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	21	0	0	0	0	60	81
2008	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	23	0	0	0	0	53	76
2009	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	95	0	0	0	0	45	140

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2010	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	466	0	0	0	0	47	513
2011	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	417	0	0	0	0	49	466
2012	UVALDE	EDWARDS-TRINITY-PLATEAU AQUIFER	440	0	0	0	0	42	482
2000	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	15,766	0	0	0	245	604	16,615
2001	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	15,769	0	0	0	287	607	16,663
2002	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	15,783	0	0	0	293	541	16,617
2003	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	15,778	0	0	0	209	464	16,451
2004	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	15,746	0	0	0	97	419	16,262
2005	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	15,828	0	0	0	133	482	16,443
2006	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	11,297	0	0	0	136	464	11,897
2007	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	834	0	0	0	31	408	1,273
2008	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	903	0	0	0	16	497	1,416
2009	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	1,755	0	0	0	0	488	2,243
2010	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	11,292	0	0	0	251	458	12,001
2011	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	13,053	0	0	0	130	459	13,642
2012	VAL VERDE	EDWARDS-TRINITY-PLATEAU AQUIFER	12,677	0	0	0	61	407	13,145
2000	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2001	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2002	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2003	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2004	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2005	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2006	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2007	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2008	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2009	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2010	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2011	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2012	CROCKETT	PECOS AQUIFER	0	0	0	0	0	0	0
2000	ECTOR	PECOS AQUIFER	158	0	24	0	0	19	201

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2001	ECTOR	PECOS AQUIFER	209	0	24	0	0	6	239
2002	ECTOR	PECOS AQUIFER	213	0	13	0	0	5	231
2003	ECTOR	PECOS AQUIFER	214	0	13	0	0	4	231
2004	ECTOR	PECOS AQUIFER	207	0	13	0	0	0	220
2005	ECTOR	PECOS AQUIFER	222	0	13	0	0	0	235
2006	ECTOR	PECOS AQUIFER	0	0	13	0	0	0	13
2007	ECTOR	PECOS AQUIFER	0	0	13	0	0	0	13
2008	ECTOR	PECOS AQUIFER	0	0	13	0	0	0	13
2009	ECTOR	PECOS AQUIFER	0	0	13	0	0	0	13
2010	ECTOR	PECOS AQUIFER	0	0	13	0	0	0	13
2011	ECTOR	PECOS AQUIFER	0	0	13	0	0	0	13
2012	ECTOR	PECOS AQUIFER	0	0	13	0	0	0	13
2000	PECOS	PECOS AQUIFER	411	0	9	0	19,797	188	20,405
2001	PECOS	PECOS AQUIFER	382	0	7	0	17,567	198	18,154
2002	PECOS	PECOS AQUIFER	361	0	6	0	16,747	175	17,289
2003	PECOS	PECOS AQUIFER	328	0	6	0	10,292	149	10,775
2004	PECOS	PECOS AQUIFER	327	0	5	0	11,613	58	12,003
2005	PECOS	PECOS AQUIFER	328	0	5	0	11,320	61	11,714
2006	PECOS	PECOS AQUIFER	331	0	5	0	16,925	69	17,330
2007	PECOS	PECOS AQUIFER	351	0	5	0	14,917	53	15,326
2008	PECOS	PECOS AQUIFER	425	63	2	0	15,560	60	16,110
2009	PECOS	PECOS AQUIFER	431	63	2	0	24,837	55	25,388
2010	PECOS	PECOS AQUIFER	45	65	0	0	33,539	54	33,703
2011	PECOS	PECOS AQUIFER	241	75	0	0	34,200	54	34,570
2012	PECOS	PECOS AQUIFER	208	76	13	0	30,142	48	30,487
2000	UPTON	PECOS AQUIFER	0	0	0	0	0	1	1
2001	UPTON	PECOS AQUIFER	0	0	0	0	0	0	0
2002	UPTON	PECOS AQUIFER	0	0	0	0	0	0	0
2003	UPTON	PECOS AQUIFER	0	0	0	0	0	0	0
2004	UPTON	PECOS AQUIFER	0	0	0	0	0	0	0
2005	UPTON	PECOS AQUIFER	0	0	0	0	0	1	1
2006	UPTON	PECOS AQUIFER	0	0	0	0	0	1	1

Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

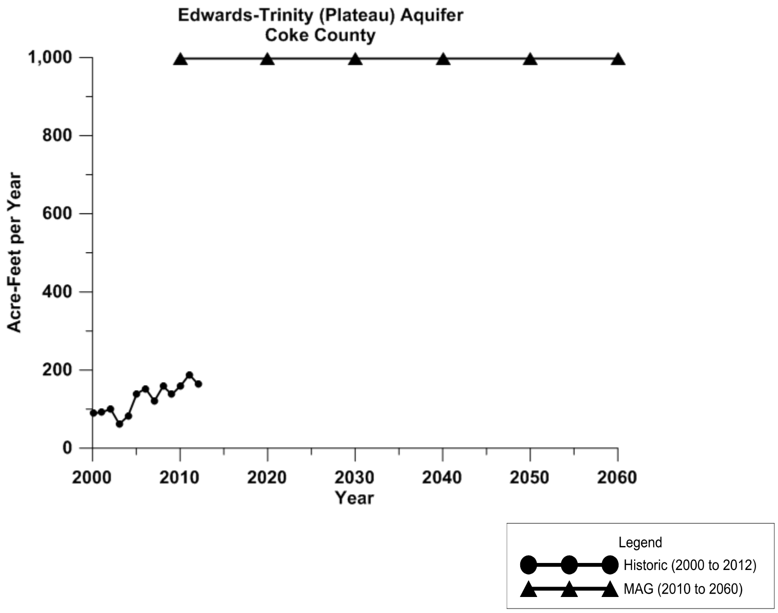
Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2007	UPTON	PECOS AQUIFER	0	0	0	0	0	1	1
2008	UPTON	PECOS AQUIFER	0	0	0	0	0	0	0
2009	UPTON	PECOS AQUIFER	0	0	0	0	0	0	0
2010	UPTON	PECOS AQUIFER	0	0	0	0	0	0	0
2011	UPTON	PECOS AQUIFER	0	0	0	0	0	0	0
2012	UPTON	PECOS AQUIFER	0	0	0	0	0	0	0
2000	GILLESPIE	TRINITY AQUIFER	542	0	0	0	982	148	1,672
2001	GILLESPIE	TRINITY AQUIFER	517	0	0	0	1,123	128	1,768
2002	GILLESPIE	TRINITY AQUIFER	553	0	0	0	1,123	127	1,803
2003	GILLESPIE	TRINITY AQUIFER	629	0	0	0	1,123	119	1,871
2004	GILLESPIE	TRINITY AQUIFER	610	0	0	0	1,189	73	1,872
2005	GILLESPIE	TRINITY AQUIFER	666	0	0	0	968	111	1,745
2006	GILLESPIE	TRINITY AQUIFER	719	0	0	0	1,059	110	1,888
2007	GILLESPIE	TRINITY AQUIFER	616	0	0	0	90	115	821
2008	GILLESPIE	TRINITY AQUIFER	681	0	0	0	985	127	1,793
2009	GILLESPIE	TRINITY AQUIFER	653	0	0	0	958	118	1,729
2010	GILLESPIE	TRINITY AQUIFER	706	0	0	0	638	245	1,589
2011	GILLESPIE	TRINITY AQUIFER	774	0	0	0	1,577	252	2,603
2012	GILLESPIE	TRINITY AQUIFER	748	0	0	0	971	119	1,838
2000	REAL	TRINITY AQUIFER	0	0	0	0	2	9	11
2001	REAL	TRINITY AQUIFER	0	0	0	0	2	7	9
2002	REAL	TRINITY AQUIFER	0	0	0	0	2	7	9
2003	REAL	TRINITY AQUIFER	0	0	0	0	1	6	7
2004	REAL	TRINITY AQUIFER	0	0	0	0	6	6	12
2005	REAL	TRINITY AQUIFER	0	0	0	0	8	10	18
2006	REAL	TRINITY AQUIFER	0	0	0	0	24	8	32
2007	REAL	TRINITY AQUIFER	0	0	0	0	0	9	9
2008	REAL	TRINITY AQUIFER	0	0	0	0	4	8	12
2009	REAL	TRINITY AQUIFER	0	0	0	0	0	8	8
2010	REAL	TRINITY AQUIFER	0	0	0	0	7	15	22
2011	REAL	TRINITY AQUIFER	31	0	0	0	15	15	61
2012	REAL	TRINITY AQUIFER	2	0	0	0	8	6	16

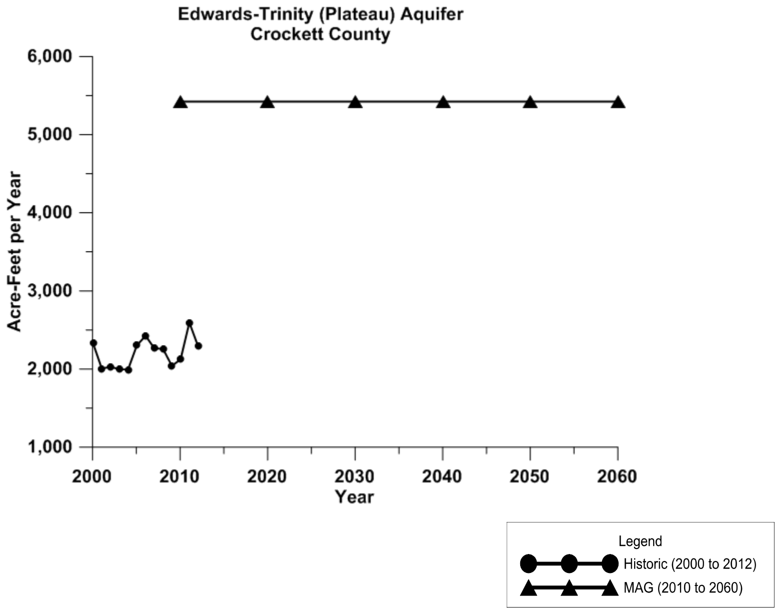
Appendix B - Historic Pumping from the Edwards-Trinity (Plateau), Pecos Valley and Trinity Aquifers

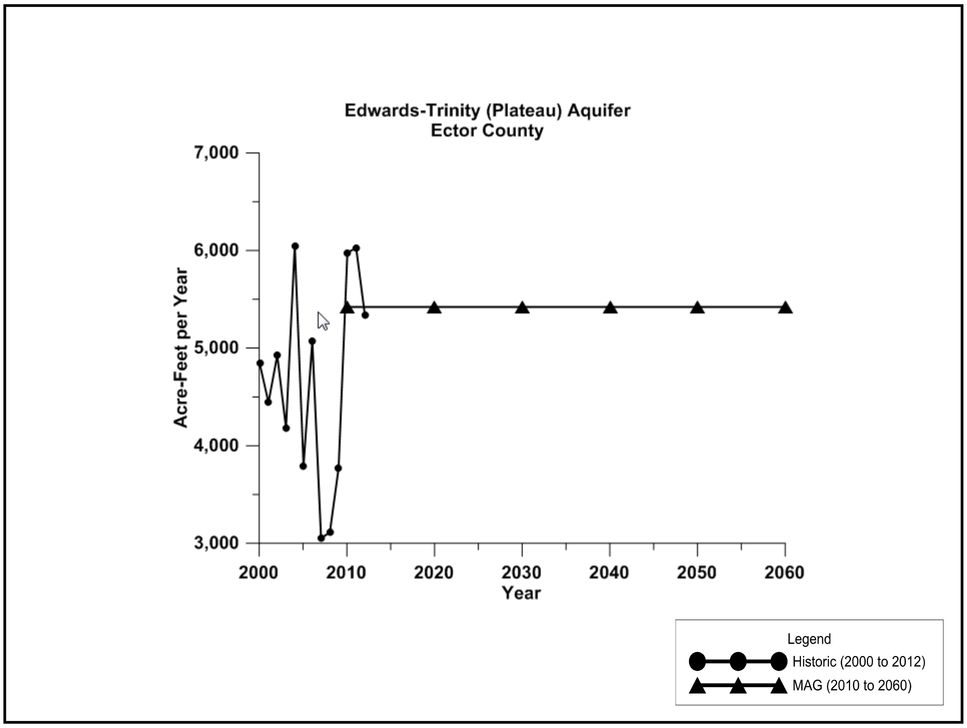
Year	County	Aquifer	Municipal	Manufacturing	Mining	Steam Electric Power	Irrigation	Livestock	Total
2000	UVALDE	TRINITY AQUIFER	0	0	0	0	0	49	49
2001	UVALDE	TRINITY AQUIFER	0	0	0	0	0	46	46
2002	UVALDE	TRINITY AQUIFER	0	0	0	0	0	45	45
2003	UVALDE	TRINITY AQUIFER	0	0	0	0	0	43	43
2004	UVALDE	TRINITY AQUIFER	0	0	0	0	0	40	40
2005	UVALDE	TRINITY AQUIFER	0	0	0	0	0	61	61
2006	UVALDE	TRINITY AQUIFER	37	0	0	0	0	59	96
2007	UVALDE	TRINITY AQUIFER	31	0	0	0	0	60	91
2008	UVALDE	TRINITY AQUIFER	117	0	0	0	0	53	170
2009	UVALDE	TRINITY AQUIFER	118	0	0	0	0	45	163
2010	UVALDE	TRINITY AQUIFER	199	0	0	0	0	47	246
2011	UVALDE	TRINITY AQUIFER	208	0	0	0	0	49	257
2012	UVALDE	TRINITY AQUIFER	153	0	0	0	0	42	195

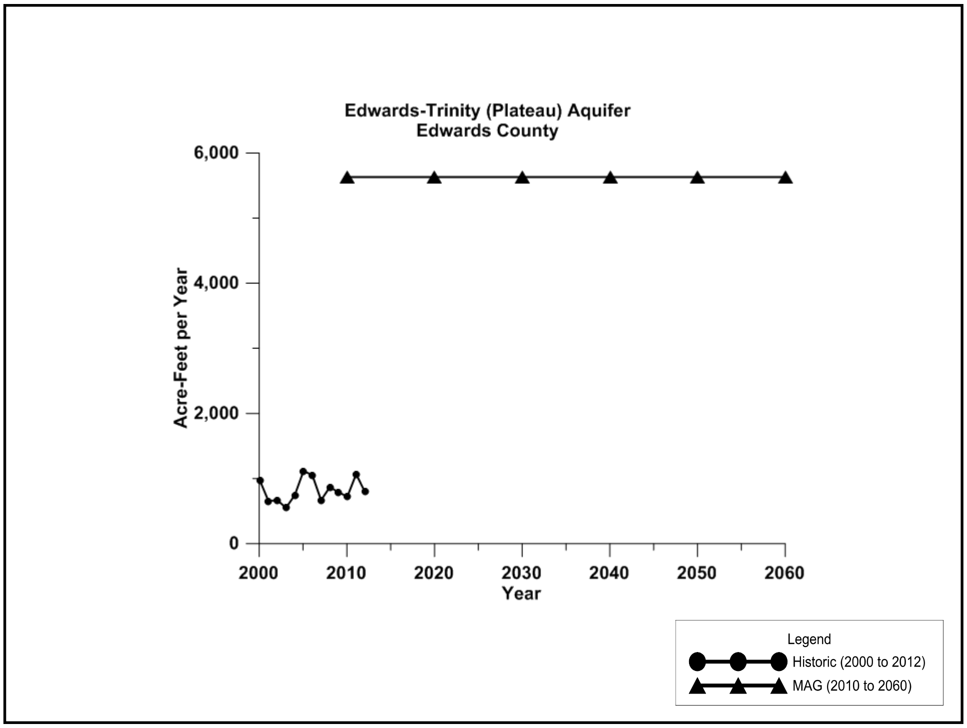
Appendix C

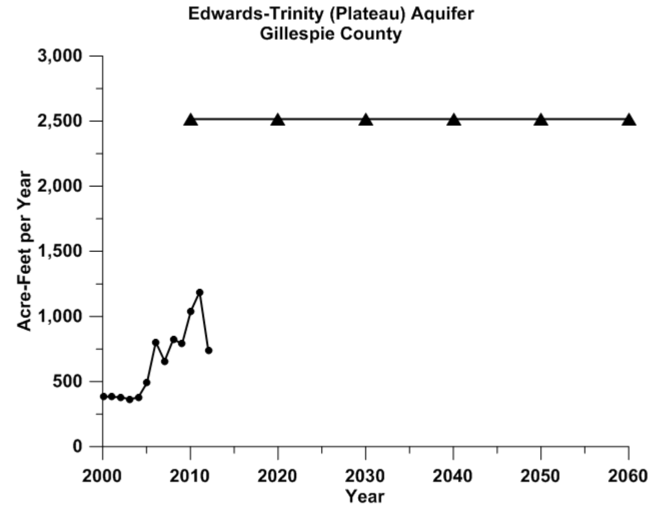
Hydrographs Comparing Historic Pumping and Modeled Available Groundwater from the Edwards-Trinity (Plateau), Pecos Valley, and Trinity Aquifers


Edwards-Trinity (Plateau) Aquifer
Coke County
Acre-Feet per Year
1,000
800
600
400
200
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Edwards-Trinity (Plateau) Aquifer
Crockett County
Acre-Feet per Year
6,000
5,000
4,000
3,000
2,000
1,000
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Edwards-Trinity (Plateau) Aquifer
Ector County
Acre-Feet per Year
7,000
6,000
5,000
4,000
3,000
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Edwards-Trinity (Plateau) Aquifer
Edwards County
Acre-Feet per Year
6,000
4,000
2,000
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Edwards-Trinity (Plateau) Aquifer
Gillespie County
Acre-Feet per Year
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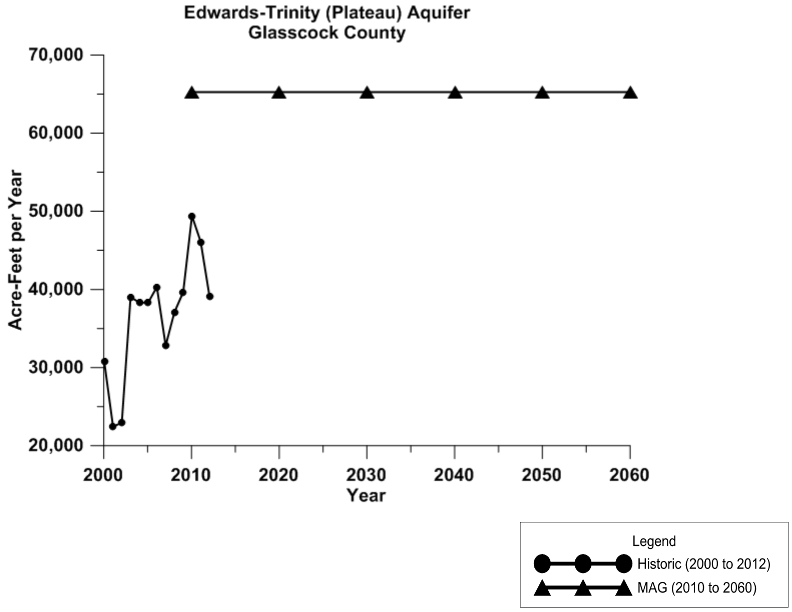
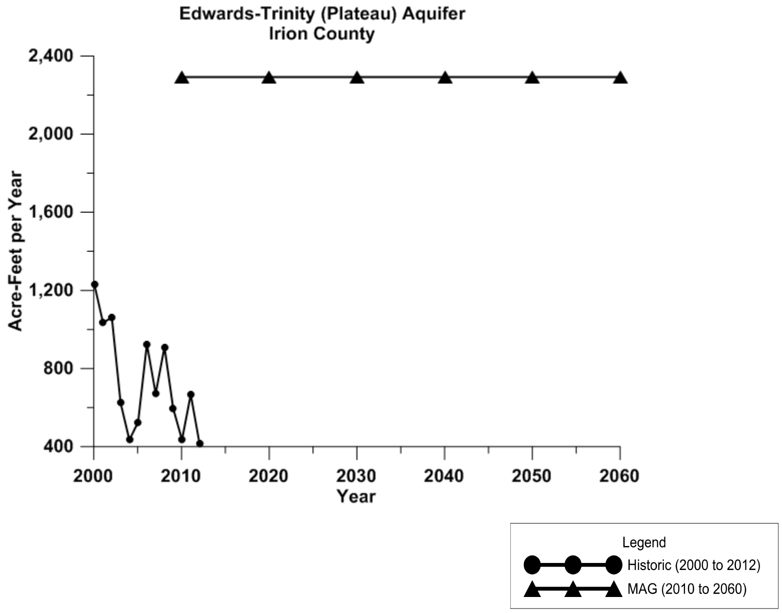
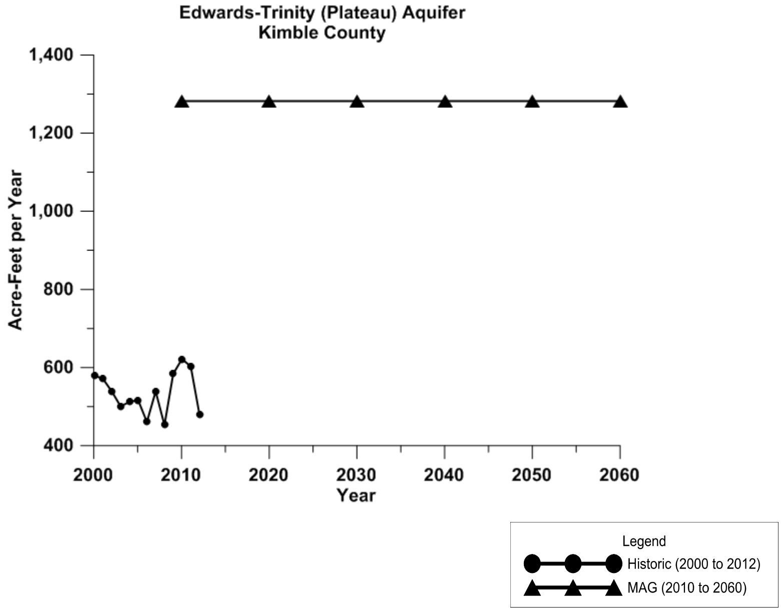
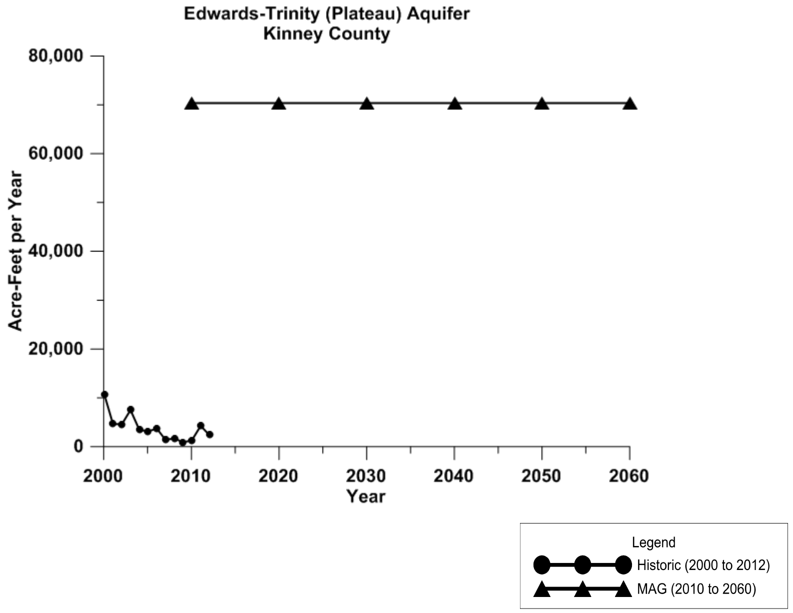
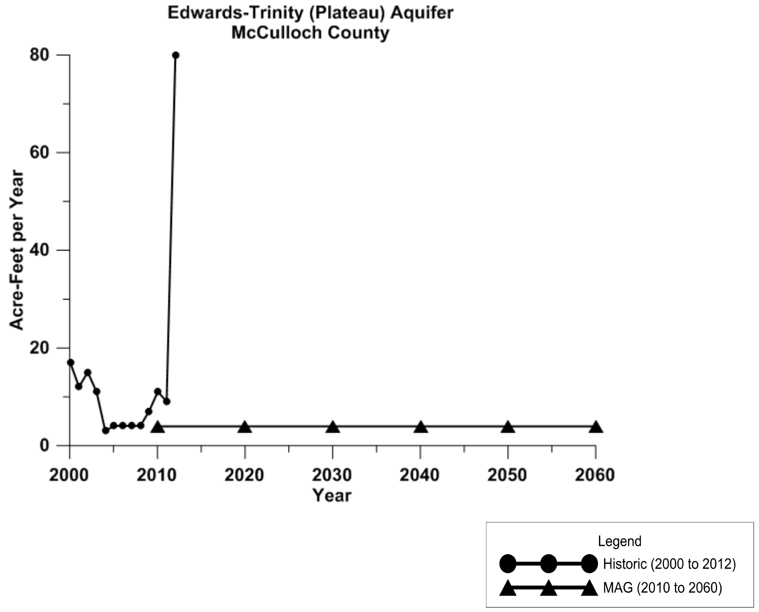
500
1,000
1,500
2,000
2,500
3,000
2000
2010
2020
2030
2040
2050
2060
Year

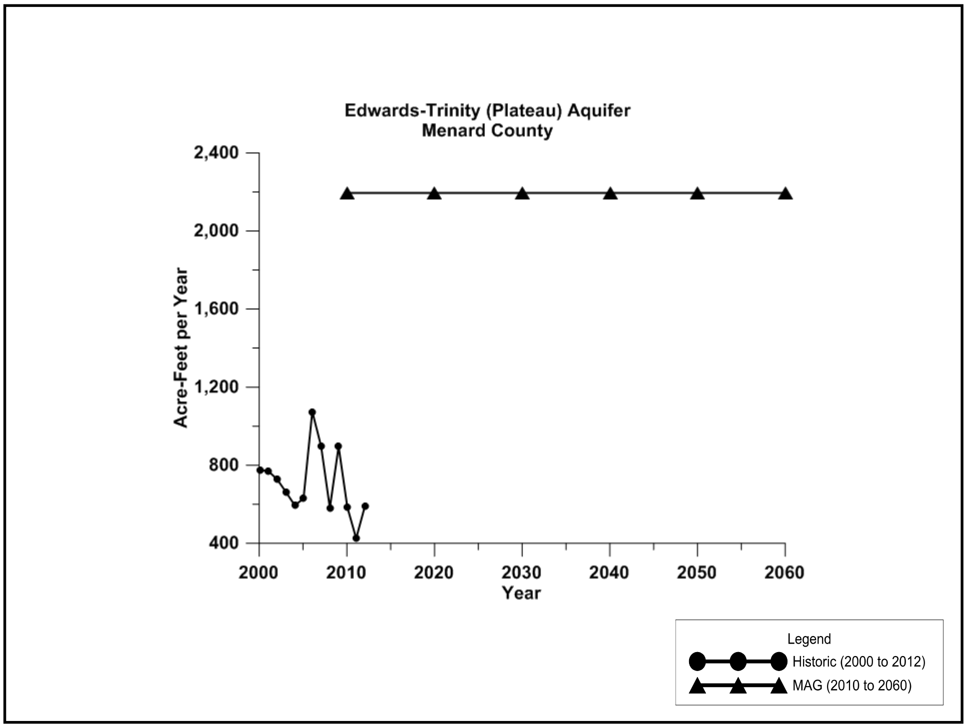

Edwards-Trinity (Plateau) Aquifer
Glasscock County
Acre-Feet per Year
20,000
30,000
40,000
50,000
60,000
70,000
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

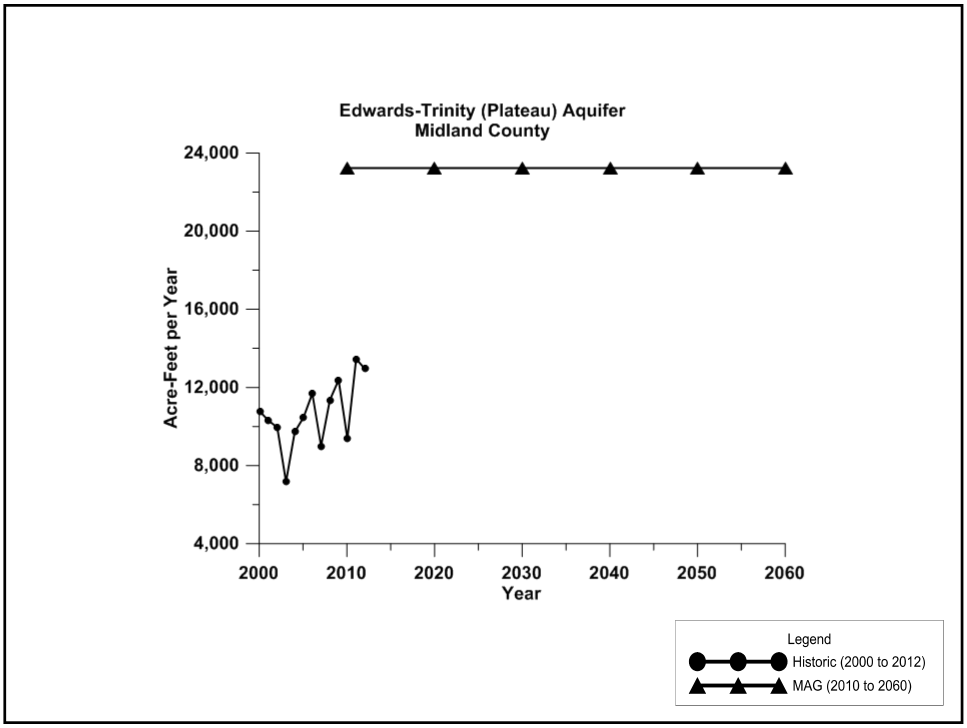

Edwards-Trinity (Plateau) Aquifer
Irion County
Acre-Feet per Year
2,400
2,000
1,600
1,200
800
400
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

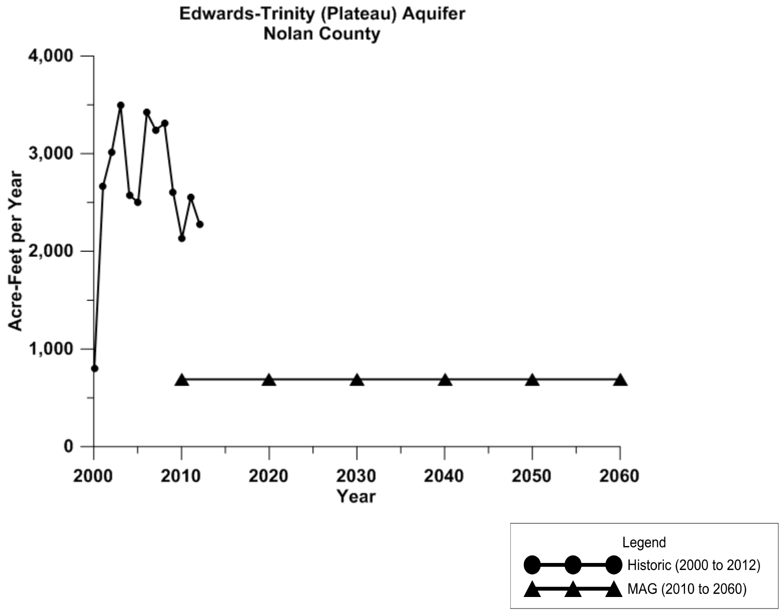

Edwards-Trinity (Plateau) Aquifer
Kimble County
Acre-Feet per Year
1,400
1,200
1,000
800
600
400
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

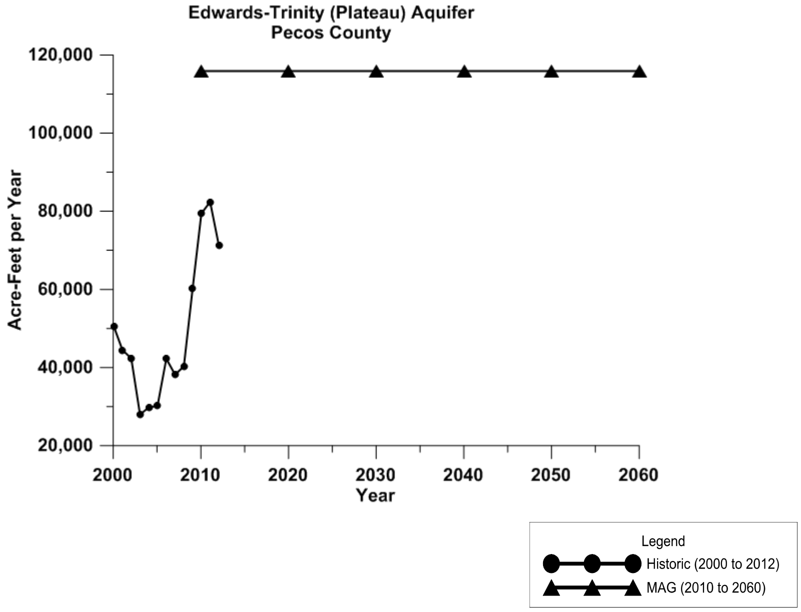

Edwards-Trinity (Plateau) Aquifer
Kinney County
80,000
60,000
40,000
20,000
0
Acre-Feet per Year
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

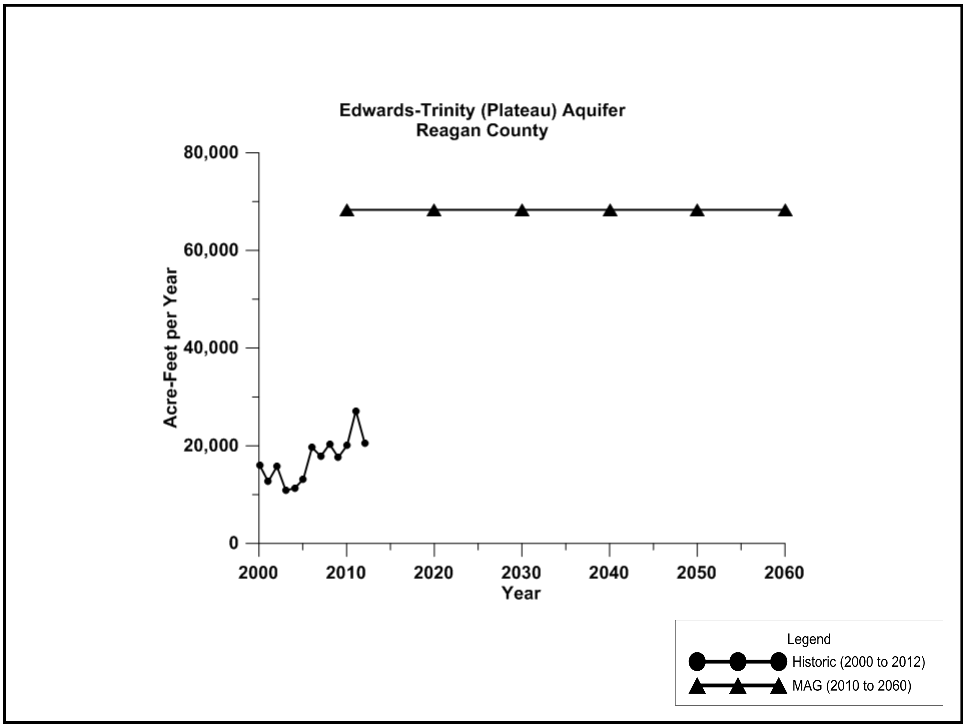

Edwards-Trinity (Plateau) Aquifer
McCulloch County
80
60
40
20
0
Acre-Feet per Year
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Edwards-Trinity (Plateau) Aquifer
Menard County
Acre-Feet per Year
2,400
2,000
1,600
1,200
800
400
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

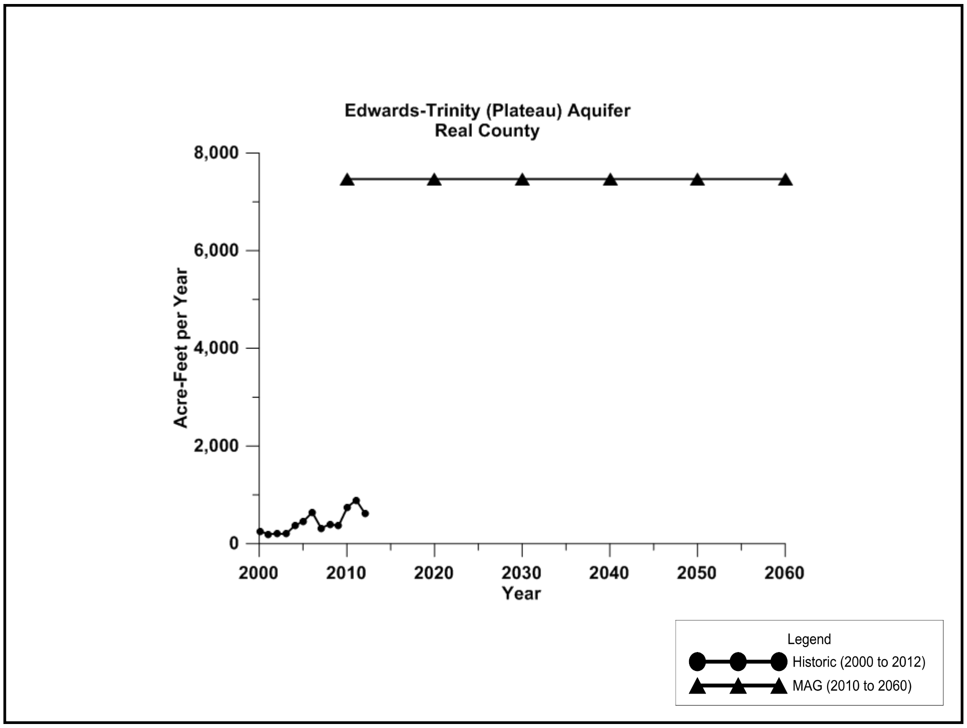

Edwards-Trinity (Plateau) Aquifer
Midland County
Acre-Feet per Year
24,000
20,000
16,000
12,000
8,000
4,000
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Edwards-Trinity (Plateau) Aquifer
Nolan County
Acre-Feet per Year
4,000
3,000
2,000
1,000
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

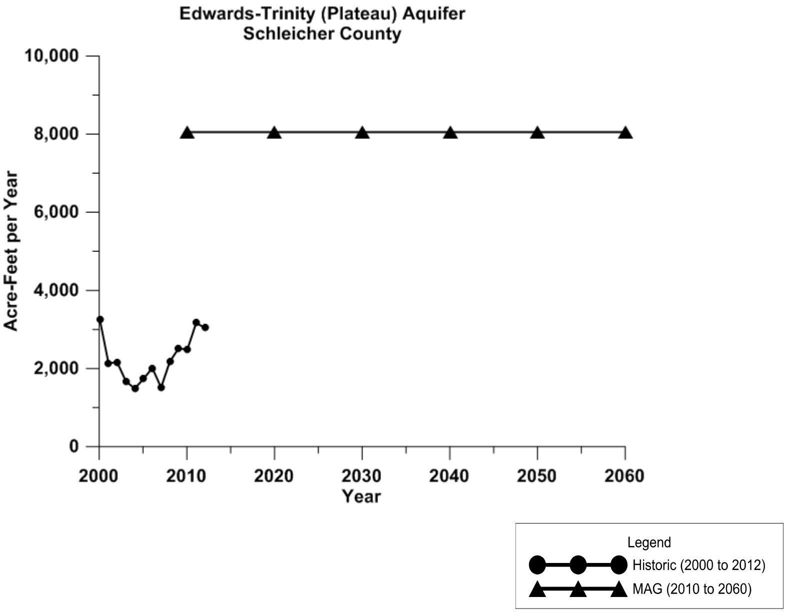

Edwards-Trinity (Plateau) Aquifer
Pecos County
Acre-Feet per Year
120,000
100,000
80,000
60,000
40,000
20,000
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

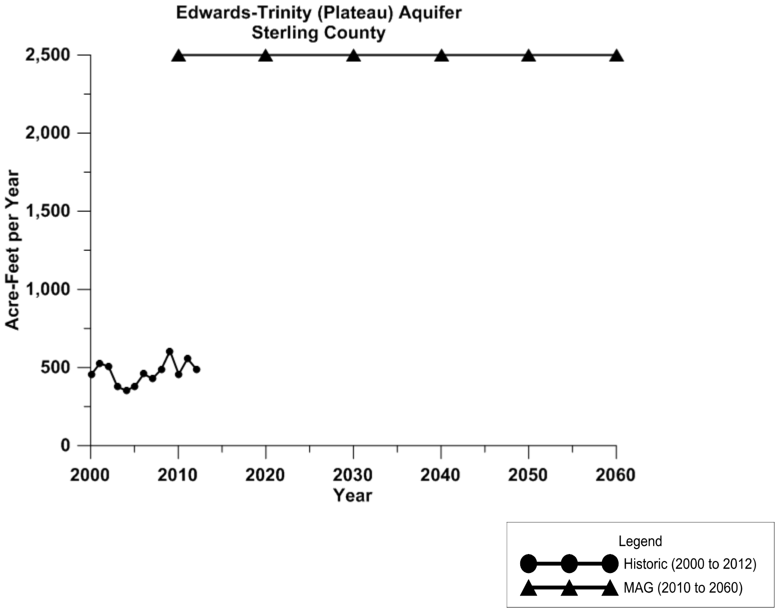


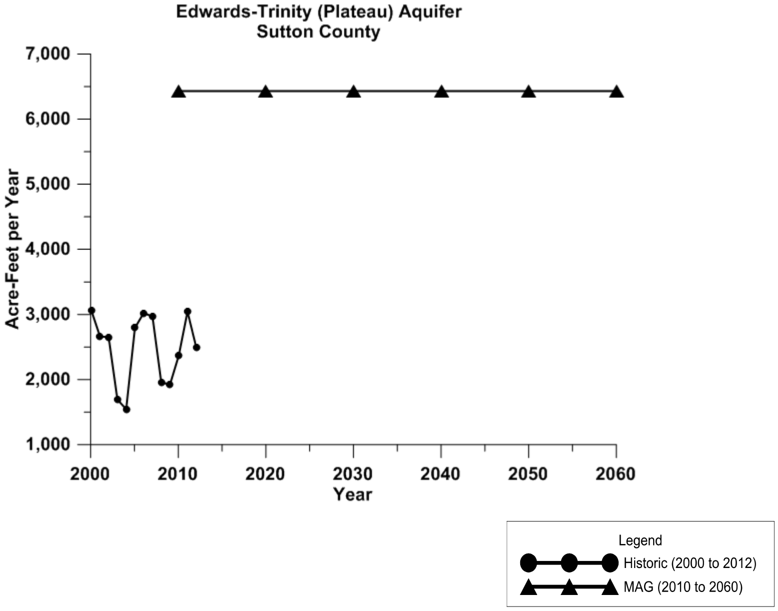
Edwards-Trinity (Plateau) Aquifer
Reagan County

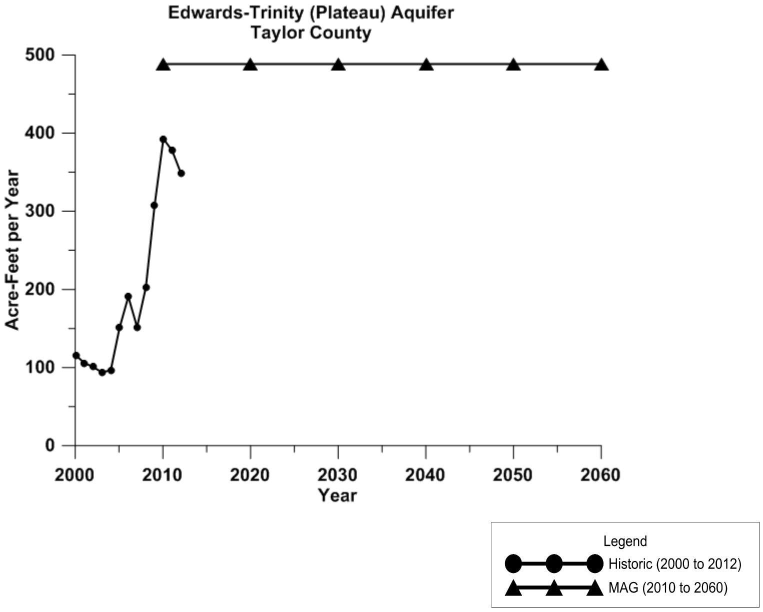


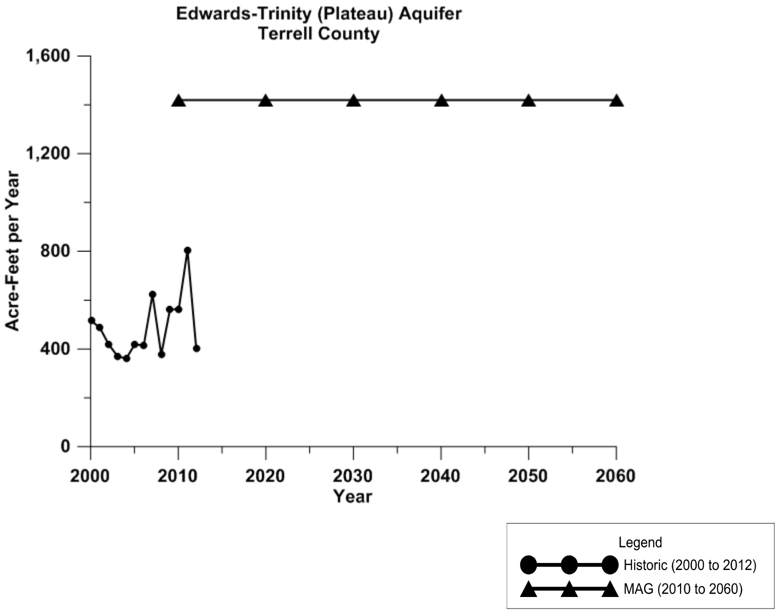
Edwards-Trinity (Plateau) Aquifer
Real County

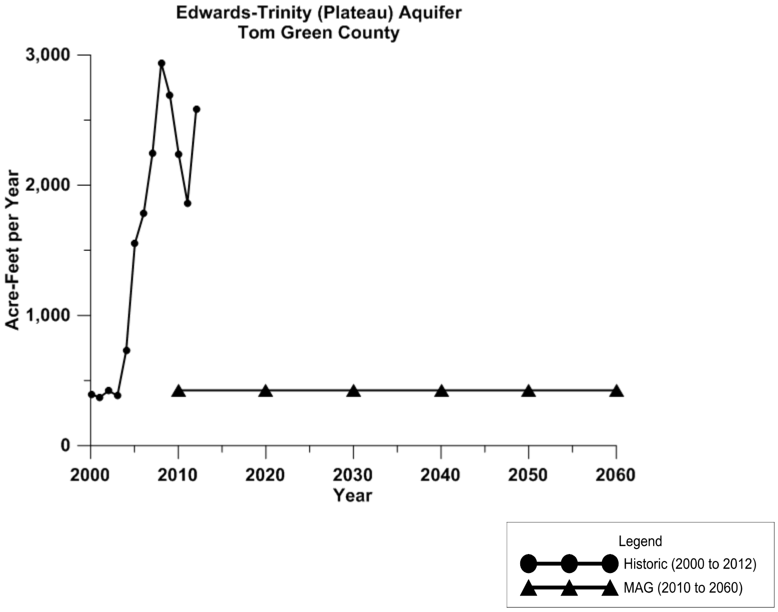

Edwards-Trinity (Plateau) Aquifer
Schleicher County
Acre-Feet per Year
10,000
8,000
6,000
4,000
2,000
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

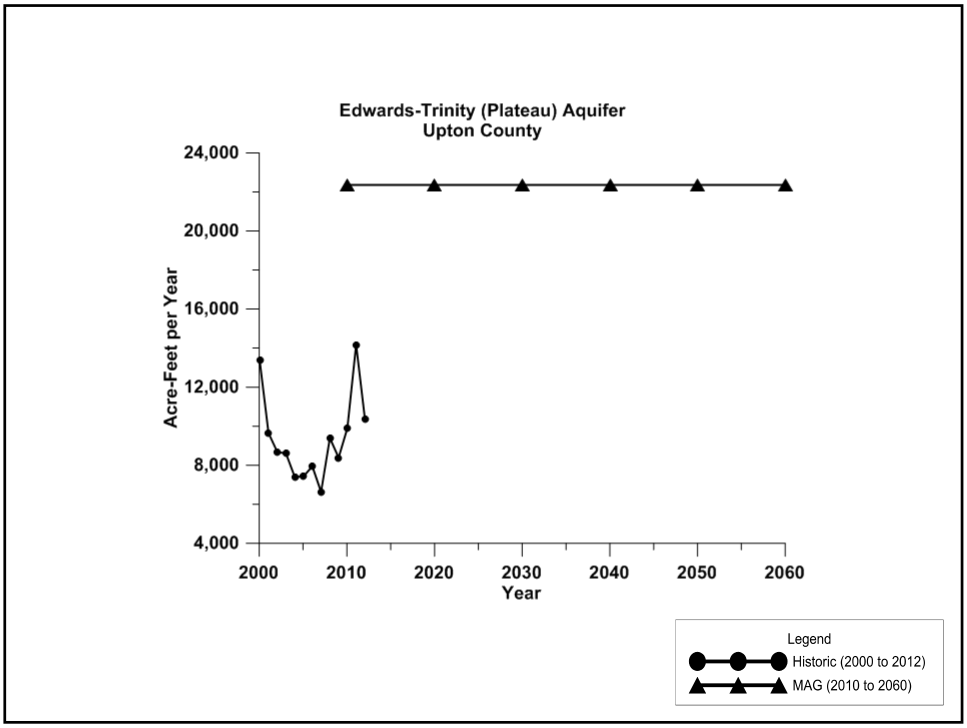

Edwards-Trinity (Plateau) Aquifer
Sterling County
Acre-Feet per Year
2,500
2,000
1,500
1,000
500
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

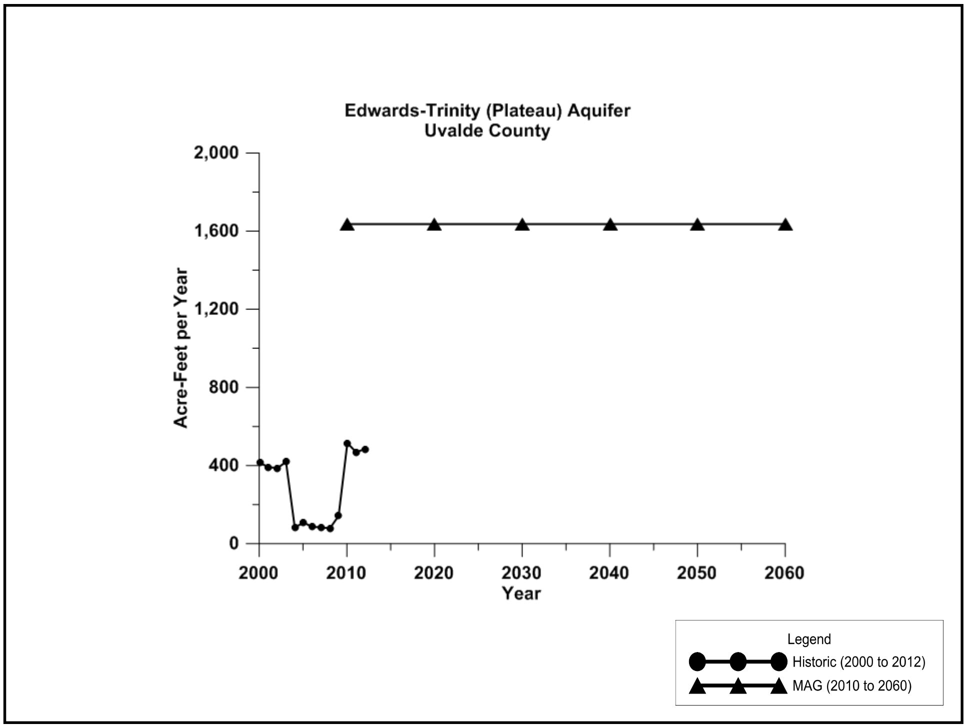

Edwards-Trinity (Plateau) Aquifer
Sutton County
Acre-Feet per Year
7,000
6,000
5,000
4,000
3,000
2,000
1,000
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Edwards-Trinity (Plateau) Aquifer
Taylor County
Acre-Feet per Year
500
400
300
200
100
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

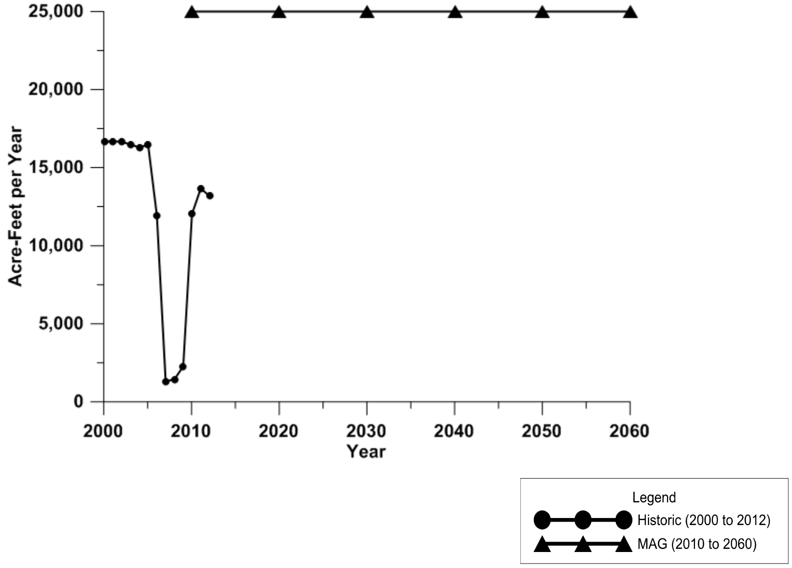

Edwards-Trinity (Plateau) Aquifer
Terrell County
Acre-Feet per Year
1,600
1,200
800
400
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Edwards-Trinity (Plateau) Aquifer
Tom Green County
Acre-Feet per Year
3,000
2,000
1,000
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

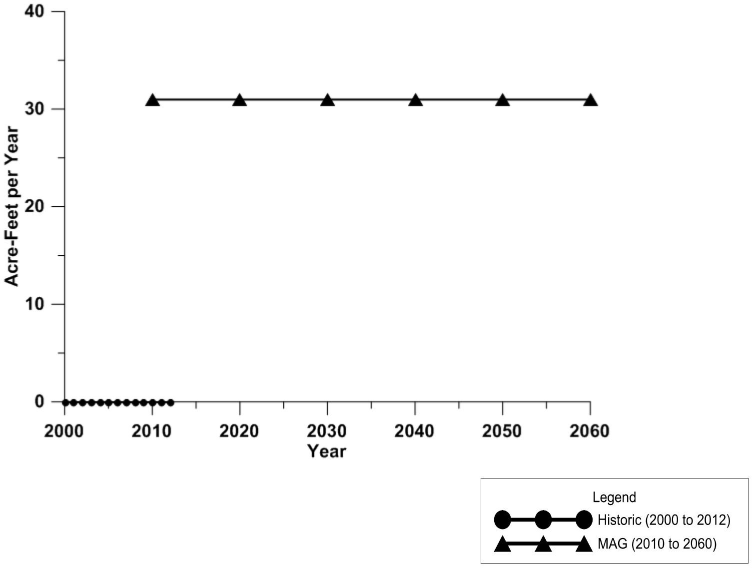

Edwards-Trinity (Plateau) Aquifer
Upton County
Acre-Feet per Year
24,000
20,000
16,000
12,000
8,000
4,000
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

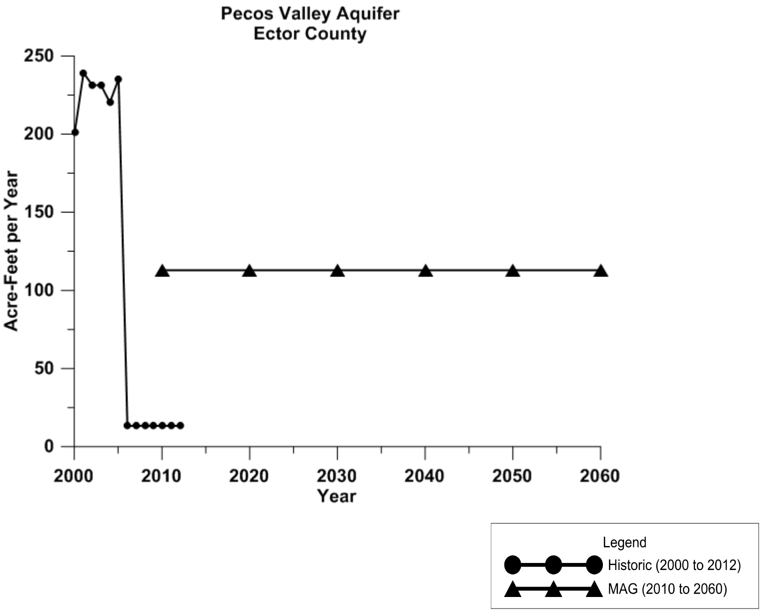

Edwards-Trinity (Plateau) Aquifer
Uvalde County
Acre-Feet per Year
2,000
1,600
1,200
800
400
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

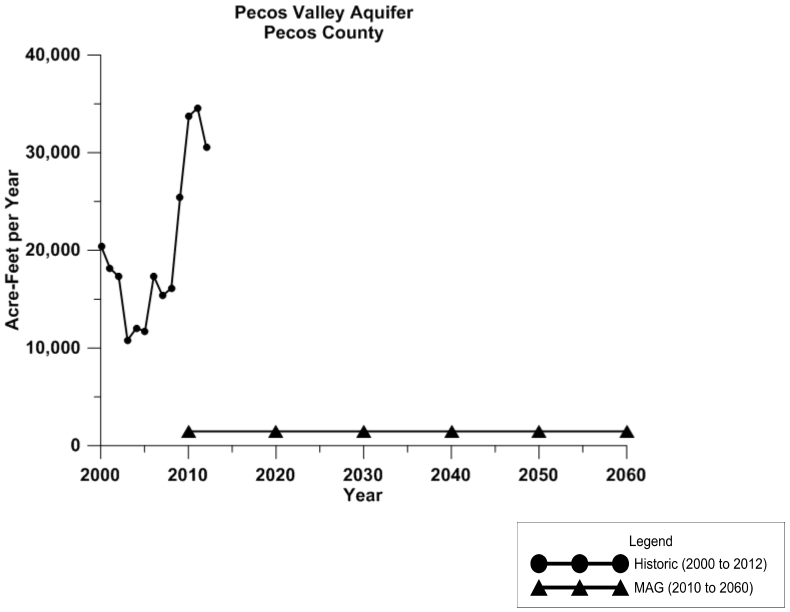
Edwards-Trinity (Plateau) Aquifer
Val Verde County

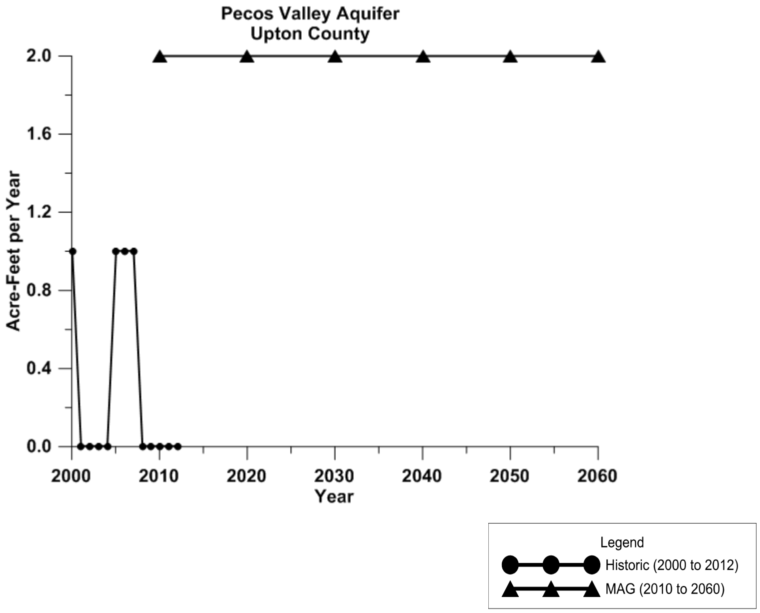


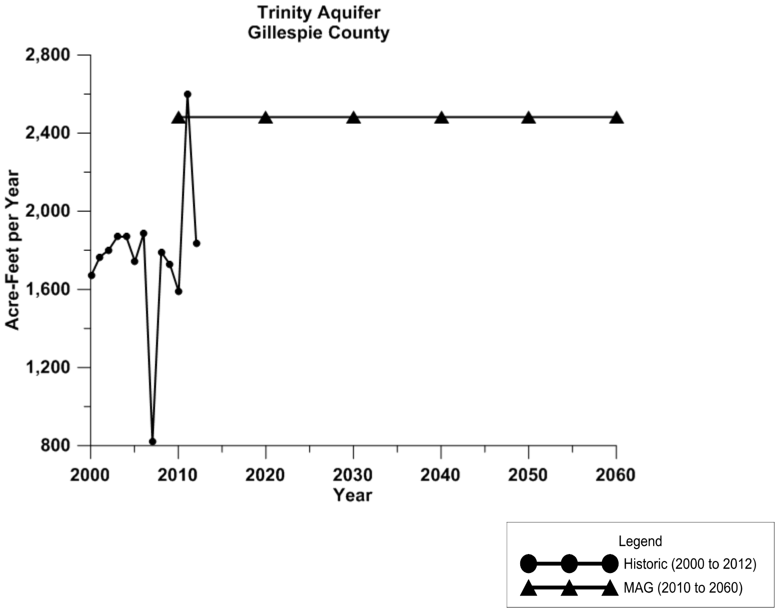
Pecos Valley Aquifer
Crockett County

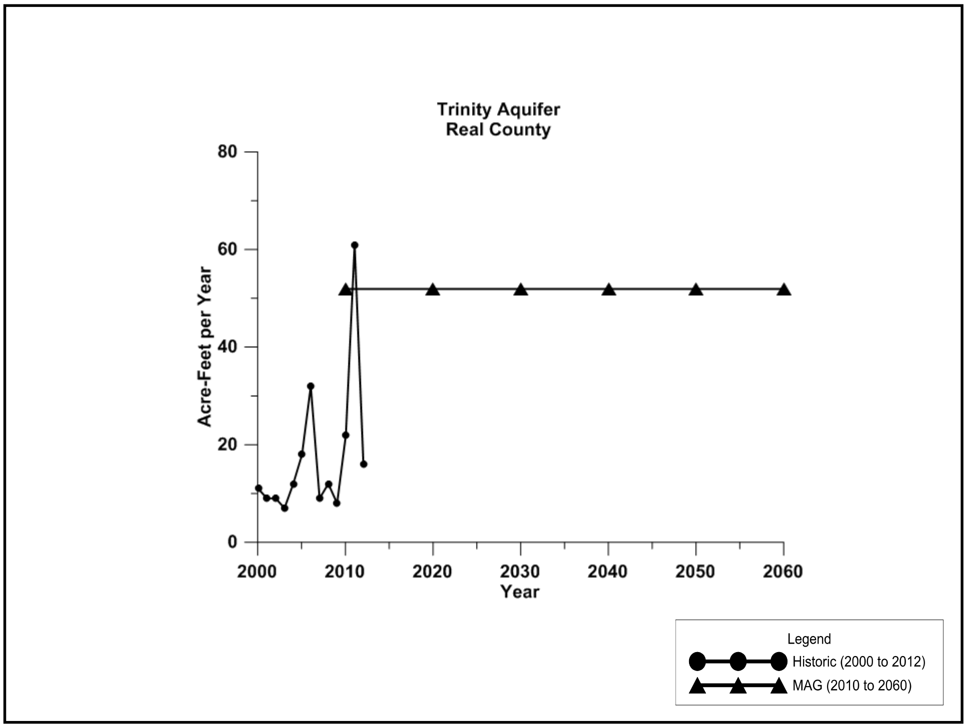



Pecos Valley Aquifer
Ector County
Acre-Feet per Year
250
200
150
100
50
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Pecos Valley Aquifer
Pecos County
Acre-Feet per Year
40,000
30,000
20,000
10,000
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Pecos Valley Aquifer
Upton County
Acre-Feet per Year
2.0
1.6
1.2
0.8
0.4
0.0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Trinity Aquifer
Gillespie County
Acre-Feet per Year
2,800
2,400
2,000
1,600
1,200
800
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)


Trinity Aquifer
Real County
Acre-Feet per Year
80
60
40
20
0
2000
2010
2020
2030
2040
2050
2060
Year
Legend
Historic (2000 to 2012)
MAG (2010 to 2060)

Appendix D

Region F Socioeconomic Impact Reports from TWDB

TEXAS WATER DEVELOPMENT BOARD

James E. Herring, *Chairman*
Lewis H. McMahan, *Member*
Edward G. Vaughan, *Member*

J. Kevin Ward
Executive Administrator

Jack Hunt, *Vice Chairman*
Thomas Weir Labatt III, *Member*
Joe M. Crutcher, *Member*

July 22, 2010

Mr. John Grant
Chairman, Region F Regional Water Planning Group
c/o Colorado River Municipal Water District
P.O. Box 869
Big Spring, Texas 79721-0869

Re: Socioeconomic Impact Analysis of Not Meeting Water Needs for the 2011 Region F Regional Water Plan

Dear Chairman Grant:

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

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

Sincerely,

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

SN/ao

Enclosure

c. Angela Kennedy, TWDB
S. Doug Shaw, TWDB

Our Mission
To provide leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas.

P.O. Box 13231 • 1700 N. Congress Avenue • Austin, Texas 78711-3231
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TNRIS - Texas Natural Resources Information System • www.tnris.state.tx.us
A Member of the Texas Geographic Information Council (TGIC)

TNRIS

Economic Impacts of Projected Water Shortages for the Region F Regional Water Planning Area

Prepared in Support of the 2011 Region F Regional Water Plan

Stuart D. Norvell, Managing Economist
Water Resources Planning Division
Texas Water Development Board
Austin, Texas

S. Doug Shaw, Agricultural Economist
Water Resources Planning Division
Texas Water Development Board
Austin, Texas

July 2010

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Introduction

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

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

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

1. Methodology

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

1.1 Economic Impacts of Water Shortages

1.1.1 General Approach

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

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

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

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

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

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

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

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

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

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

The following steps outline the overall process.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

- if water needs are 0 to 5 percent of total water demand, no corresponding reduction in output is assumed;
- if water needs are 5 to 30 percent of total water demand, for each additional one percent of water need that is not met, there is a corresponding 0.50 percent reduction in output;
- if water needs are 30 to 50 percent of total water demand, for each additional one percent of water need that is not met, there is a corresponding 0.75 percent reduction in output; and
- if water needs are greater than 50 percent of total water demand, for each additional one percent of water need that is not met, there is a corresponding 1.0 percent (i.e., a proportional reduction).

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

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

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

where:

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

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

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

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

E_Q = elasticity of output and water use

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

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

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

General Assumptions and Clarification of the Methodology

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

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

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

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

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

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

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

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

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

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

1.1.2 Impacts to Agriculture

Irrigated Crop Production

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

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

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

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

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

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

Table 2: Summary of Irrigated Crop Acreage and Water Demand for the Region F Water Planning Area (average 2003-2007)

Sector	Acres (1000s)	Distribution of acres	Water use (1000s of AF)	Distribution of water use
Oilseeds	<1	<1%	<1	<1%
Grains	45	20%	62	17%
Vegetable and melons	5	2%	9	<1%
Tree nuts	6	3%	13	<1%
Fruits	<1	<1%	1	<1%
Cotton	104	47%	154	42%
All "other" crops	61	28%	123	34%
Total	221	100%	363	100%

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

Table 3: Average Gross Sales Revenues per Acre for Irrigated Crops for the Region F Water Planning Area (2003-2007)		
IMPLAN Sector	**Gross revenues per acre**	**Crops included in estimates**
Oilseeds	$177	Irrigated figure is based on five-year (2003-2007) average weighted by acreage for “irrigated soybeans” and “irrigated ‘other’ oil crops.”
Grains	$199	Based on five-year (2003-2007) average weighted by acreage for “irrigated grain sorghum,” “irrigated corn”, “irrigated wheat” and “irrigated ‘other’ grain crops.”
Vegetable and melons	$6,053	Based on five-year (2003-2007) average weighted by acreage for “irrigated shallow and deep root vegetables”, “irrigated Irish potatoes” and “irrigated melons.”
Tree nuts	$3,451	Based on five-year (2003-2007) average weighted by acreage for “irrigated pecans.”
Fruits	$5,902	Based on five-year (2003-2007) average weighted by acreage for “irrigated citrus”, “irrigated vineyards” and “irrigated ‘other’ orchard.”
Cotton	$488	Based on five-year (2003-2007) average weighted by acreage for “irrigated cotton.”
All other crops	$335	Irrigated figure is based on five-year (2003-2007) average weighted by acreage for “irrigated ‘forage’ crops”, “irrigated peanuts”, “irrigated alfalfa”, “irrigated ‘hay’ and pasture” and “irrigated ‘all other’ crops.”

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

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

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

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

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

Livestock

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

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

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

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

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

Table 4: Description of Livestock Sectors

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

1.1.3 Impacts to Municipal Water User Groups

Disaggregation of Municipal Water Demands

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

The amount of commercial water use as a percentage of total municipal demand was estimated based on "GED" coefficients (gallons per employee per day) published in secondary sources.[8] For example, if year 2006 baseline data for a given economic sector (e.g., amusement and recreation services) shows employment at 30 jobs and the GED coefficient is 200, then average daily water use by that sector is (30 x 200 = 6,000 gallons) or 6.7 acre-feet per year. Water not attributed to commercial use is considered

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

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

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

domestic, which includes single and multi-family residential consumption, institutional uses and all use designated as "county-other." Based on our analysis, commercial water use is about 5 to 35 percent of municipal demand. Less populated rural counties occupy the lower end of the spectrum, while larger metropolitan counties are at the higher end.

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

Domestic Water Uses

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

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

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

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

where:

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

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

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

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

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

Community Population	Water	Wastewater	Total monthly cost	Avg. monthly use (gallons)
Less than or equal to 5,000	$1,335	$1,228	$2,563	6,204
5,000 to 100,000	$1,047	$1,162	$2,209	7,950
Great than or equal to 100,000	$718	$457	$1,190	8,409

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

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

> 1) Reported values are net of the variable costs of treatment and distribution such as expenses for chemicals and electricity since using less water involves some savings to consumers and utilities alike; and for outdoor uses we do not include any value for wastewater.
>
> 2) Outdoor and “non-essential” water uses would be eliminated before indoor water consumption was affected, which is logical because most water utilities in Texas have drought contingency plans that generally specify curtailment or elimination of outdoor water use during droughts.[11] Determining how much water is used for outdoor purposes is based on several secondary sources. The first is a major study sponsored by the American Water Works Association, which surveyed cities in states including Colorado, Oregon, Washington, California, Florida and Arizona. On average across all cities surveyed 58 percent of single family residential water use was for outdoor activities. In cities with climates comparable to large metropolitan areas of Texas, the average was 40 percent.[12] Earlier findings of the U.S. Water Resources Council showed a national

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

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

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

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

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

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

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

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

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

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

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

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

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

Commercial Businesses

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

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

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

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

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

Water Utility Revenues

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

Horticultural and Landscaping Industry

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

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

Recreational Impacts

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

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

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

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

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

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

*Figures are rounded

1.1.4 Industrial Water User Groups

Manufacturing

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

Mining

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

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

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

Other considerations with respect to mining include:

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

Steam-electric

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

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

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

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

1.2 Social Impacts of Water Shortages

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

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

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

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

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

2. Results

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

2.1 Overview of Regional Economy

On an annual basis, the Region F economy generates $20.8 billion worth of gross state product for Texas ($19.1 billion in income and $1.7 billion in business taxes) and supports nearly 227,000 jobs (Table 8). Generating about $9.8 billion in gross state product, agriculture, manufacturing, and mining are the region's primary base economic sectors.[22] Municipal sectors also generate substantial amounts of income and are major employers in the region; however, many businesses that make up the municipal category such as restaurants and retail stores are non-basic industries meaning they exist to provide services to people who work would in base industries. In other words, without base industries, many jobs categorized as municipal would not exist.

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

Table 8: The Region F Economy by Water User Group ($millions)*

Water Use Category	Total sales	Intermediate sales	Final sales	Jobs	Income	Business taxes
Irrigation	$131.11	$21.48	$109.67	2,267	$68.24	$1.79
Livestock	$801.61	$432.80	$368.82	11,083	$78.45	$11.11
Manufacturing	$8,793.15	$1,386.66	$7,406.49	36,089	$2,613.94	$51.57
Mining	$11,507.80	$5,279.12	$6,228.68	27,668	$6,415.53	$563.76
Steam-electric	$376.64	$105.96	$270.68	932	$261.54	$44.63
Municipal	$15,709.07	$3,801.30	$11,907.77	148,786	$9,682.07	$981.89
Regional total	$37,319.38	$11,027.32	$26,292.11	226,825	$19,119.77	$1,654.75

[a] Appendix 1 displays data for individual IMPLAN sectors that make up each water use category. Based on data from the Texas Water Development Board, and year 2006 data from the Minnesota IMPLAN Group, Inc.

2.2 Impacts of Agricultural Water Shortages

According to the 2011 *Region F Regional Water Plan*, during severe drought most counties in the region would experiences shortages of irrigation water ranging anywhere from about 5 to 90 percent of total annual irrigation demands. Shortages of these magnitudes would reduce gross state product (income plus state and local business taxes) by about $30 to 35 million depending upon the decade Table 9).

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

Decade	Lost income from reduced crop production *	Lost state and local tax revenues from reduced crop production	Lost jobs from reduced crop production
2010	$34.97	$1.70	454
2020	$34.45	$1.68	448
2030	$33.89	$1.65	442
2040	$33.02	$1.61	432
2050	$32.48	$1.58	426
2060	$31.97	$1.56	419

*Changes to income and business taxes are collectively equivalent to a decrease in gross state product, which is analogous to gross domestic product measured at the state rather than national level. Appendix 2 shows results by water user group.

2.3 Impacts of Municipal Water Shortages

Water shortages are projected to occur in a significant number of communities throughout the region, and deficits range anywhere from 1 to 100 percent of total annual water demands. At the regional level, the estimated economic value of domestic water shortages totals $164 million in 2010 and $446 million in 2060 (Table 10). Due to curtailment of commercial business activity, municipal shortages would also reduce gross state product (income plus taxes) by $40 million in 2010 and $433 million in 2060.

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

Decade	Monetary value of domestic water shortages	Lost income from reduced commercial business activity*	Lost state and local taxes from reduced commercial business activity	Lost jobs from reduced commercial business activity	Lost water utility revenues
2010	$164.31	$35.84	1,165	$3.58	$22.60
2020	$244.46	$36.34	1,180	$3.64	$38.89
2030	$275.39	$119.12	3,208	$9.52	$48.62
2040	$363.08	$366.53	9,367	$27.34	$62.99
2050	$432.97	$386.74	9,940	$29.00	$67.58
2060	$446.11	$403.41	10,360	$30.22	$72.94

*Changes to Income and business taxes are collectively equivalent to a decrease in gross state product, which is analogous to gross domestic product measured at the state rather than national level. Appendix 2 shows results by water user group.

2.4 Impacts of Manufacturing Water Shortages

Manufacturing water shortages are projected to occur in the counties of Coleman, Ector, Howard, Kimble, Runnels, and Tom Green. Projected shortages would reduce gross state product (income plus taxes) by an estimated $891 million in 2020 and $1,356 million in 2060 (Table 11).

Table 11: Economic Impacts of Water Shortages for Manufacturing Water User Groups ($millions)

Decade	Lost income due to reduced manufacturing output*	Lost state and local business tax revenues due to reduced manufacturing output	Lost jobs due to reduced manufacturing output
2010	$829.61	$62.12	15,723
2020	$936.77	$69.97	17,705
2030	$994.28	$75.07	19,076
2040	$1,092.03	$82.10	20,836
2050	$1,166.59	$87.70	22,261
2060	$1,261.31	$94.74	24,041

*Changes to Income and business taxes are collectively equivalent to a decrease in gross state product, which is analogous to gross domestic product measured at the state rather than national level. Appendix 2 shows results by water user group.

2.5 Impacts of Mining Water Shortages

Mining water shortages are projected to occur in Coleman, Coke, and Howard counties, and would primarily affect oil extraction. Combined shortages for each county would result in estimated losses of gross state product totaling $13.5 million dollars in 2010 and $11.0 million 2060 (Table 12).

Table 12: Economic Impacts of Water Shortages for Mining Water User Groups ($millions)

Decade	Lost income due to reduced mining output*	Lost state and local business tax revenues due to reduced mining output	Lost jobs due to reduced mining output
2010	$12.50	$0.94	78
2020	$16.04	$1.21	101
2030	$2.26	$0.14	13
2040	$4.75	$0.33	29
2050	$6.70	$0.49	41
2060	$9.83	$0.73	61

*Changes to Income and business taxes are collectively equivalent to a decrease in gross state product, which is analogous to gross domestic product measured at the state rather than national level. Appendix 2 shows results by water user group.

2.6 Impacts of Steam-electric Water Shortages

Water shortages for electrical generating units are projected in Coke, Ector, Mitchell, Tom Green and Ward counties resulting in estimated losses of gross state product totaling $607 million dollars in 2010, and $2,017 billion in 2060 (Table 13).

Table 13: Economic Impacts of Water Shortages for Steam-electric Water User Groups ($millions)

Decade	Lost income due to reduced electrical generation*	Lost state and local business tax revenues due to reduced electrical generation	Lost jobs due to reduced electrical generation
2010	$530.83	$76.19	1,805
2020	$691.34	$99.23	2,350
2030	$1,045.50	$150.07	3,554
2040	$1,232.24	$176.87	4,189
2050	$1,468.65	$210.80	4,993
2060	$1,763.75	$253.16	5,996

*Changes to Income and business taxes are collectively equivalent to a decrease in gross state product, which is analogous to gross domestic product measured at the state rather than national level. Appendix 2 shows results by water user group.

2.7 Social Impacts of Water Shortages

As discussed previously, social impacts focus on changes in population and school enrollment in the region. In 2010, estimated population losses total 25,050 with corresponding reductions in school enrollment of 7,065 students (Table 15). In 2060, population would decline by 49,236 and school enrollment would fall by 9,106.

Table 15: Social Impacts of Water Shortages (2010-2060)

Year	Population Losses	Declines in School Enrollment
2010	25,050	7,065
2020	26,239	7,444
2030	31,670	8,389
2040	41,980	7,759
2050	45,362	8,378
2060	49,236	9,106

2.8 Distribution of Impacts by Major River Basin

Administrative rules require that impacts are presented by both planning region and major river basin. To meet rule requirements, impacts were allocated among basins based on the distribution of water shortages in relevant basins. For example, if 50 percent of water shortages in River Basin A and 50 percent occur in River Basin B, then impacts were split equally among the two basins. Table 16 displays the results.

Table 16: Distribution of Impacts by Major River Basin (2010-2060)

River Basin	2010	2020	2030	2040	2050	2060
Brazos	1%	1%	1%	1%	1%	1%
Colorado	80%	82%	82%	83%	83%	83%
Rio Grande	19%	17%	17%	16%	16%	16%
Total	**100%**	**100%**	**100%**	**100%**	**100%**	**100%**

Appendix 1: Economic Data for Individual IMPLAN Sectors

Economic Data for Agricultural Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Irrigation	Cotton Farming	8	$53.73	$0.73	$53.04	919	$19.78	$0.48
Irrigation	Vegetable and Melon Farming	3	$27.14	$0.97	$26.17	233	$19.84	$0.24
Irrigation	Tree Nut Farming	4	$19.17	$1.01	$18.16	376	$13.34	$0.46
Irrigation	All “Other” Crop Farming	10	$18.30	$16.92	$1.38	206	$8.98	$0.35
Irrigation	Grain Farming	2	$8.96	$1.29	$7.67	446	$4.14	$0.16
Irrigation	Fruit Farming	5	$3.75	$0.57	$3.18	85	$2.13	$0.08
Irrigation	Oilseed Farming	1	$0.07	$0.00	$0.07	2	$0.03	$0.00
Livestock	Cattle ranching and farming	11	$401.54	$278.43	$123.11	7,838	$31.72	$8.44
Livestock	Animal- except poultry- slaughtering	67	$315.06	$84.24	$230.82	832	$31.15	$1.73
Livestock	Animal production- except cattle and poultry	13	$54.48	$46.20	$8.29	2,237	$5.30	$0.84
Livestock	Poultry and egg production	12	$30.53	$23.93	$6.60	176	$10.28	$0.10
	Total Agriculture		$932.73	$454.27	$478.50	13,350	$146.68	$12.90

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

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

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Mining	Oil and gas extraction	19	$5,205.54	$4,834.32	$371.22	8,214	$3,001.63	$308.29
Mining	Drilling oil and gas wells	27	$3,371.52	$16.83	$3,354.69	5,299	$997.63	$131.53
Mining	Support activities for oil and gas operations	28	$2,408.86	$334.58	$2,074.28	11,698	$2,184.47	$98.47
Mining	Stone mining and quarrying	24	$348.51	$35.86	$312.65	2,055	$178.44	$13.95
Mining	Natural gas distribution	31	$134.21	$53.79	$80.42	261	$31.27	$10.24
Mining	Sand- gravel- clay- and refractory mining	25	$22.60	$2.39	$20.21	85	$13.55	$0.67
Mining	Other nonmetallic mineral mining	26	$13.05	$1.30	$11.74	30	$7.39	$0.49
Mining	Support activities for other mining	29	$3.52	$0.05	$3.47	26	$1.16	$0.14
Total Mining	NA		$11,507.80	$5,279.12	$6,228.68	27,668	$6,415.53	$563.76
Steam-electric	Power generation and supply		$376.64	$105.96	$270.68	932	$261.54	$44.63

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

Economic Data for Manufacturing Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Manufacturing	Petroleum refineries	142	$1,416.82	$526.63	$890.19	156	$154.70	$5.98
Manufacturing	New residential one-unit structures- all	33	$851.38	$0.00	$851.38	5,727	$282.36	$4.44
Manufacturing	Oil and gas field machinery and equipment	261	$523.73	$19.50	$504.22	1,465	$124.96	$2.54
Manufacturing	Other aluminum rolling and drawing	213	$482.71	$13.42	$469.30	642	$68.79	$2.74
Manufacturing	Commercial and institutional buildings	38	$479.41	$0.00	$479.41	4,993	$242.23	$2.98
Manufacturing	Air and gas compressor manufacturing	289	$392.54	$4.04	$388.51	911	$128.34	$2.41
Manufacturing	Vitreous china plumbing fixture manufacturing	182	$370.11	$19.16	$350.94	1,581	$194.11	$3.58
Manufacturing	Prefabricated metal buildings and components	232	$244.97	$12.30	$232.68	1,032	$50.43	$1.18
Manufacturing	Other new construction	41	$209.12	$0.00	$209.12	2,290	$112.29	$0.88
Manufacturing	Other miscellaneous chemical products	171	$149.55	$78.24	$71.31	333	$26.61	$0.65
Manufacturing	Synthetic rubber manufacturing	153	$148.58	$3.64	$144.94	199	$34.04	$0.82
Manufacturing	Asphalt paving mixture and blocks	143	$140.29	$125.83	$14.46	211	$27.81	$0.15
Manufacturing	Machine shops	243	$134.79	$32.53	$102.26	860	$70.03	$1.12
Manufacturing	Fabricated structural metal manufacturing	233	$121.00	$6.27	$114.74	482	$41.45	$0.67
Manufacturing	New residential additions and alterations-all	35	$120.95	$0.00	$120.95	682	$44.73	$0.63
Manufacturing	Cement manufacturing	191	$120.37	$0.32	$120.05	202	$53.57	$1.09
Manufacturing	Plastics pipe- fittings- and profile shapes	173	$116.14	$71.44	$44.70	310	$35.38	$0.80
Manufacturing	Plate work manufacturing	234	$110.15	$6.93	$103.21	446	$43.92	$0.57
Manufacturing	Iron- steel pipe and tubes	205	$107.02	$7.47	$99.55	209	$37.69	$0.96
Manufacturing	Motor vehicle parts manufacturing	350	$104.97	$8.44	$96.53	279	$26.82	$0.49
Manufacturing	Highway- street- bridge- and tunnel construct	39	$103.00	$0.00	$103.00	967	$51.86	$0.66
Manufacturing	Soft drink and ice manufacturing	85	$93.76	$5.24	$88.52	161	$7.92	$0.35
Manufacturing	New multifamily housing structures	34	$92.77	$0.00	$92.77	832	$43.47	$0.25
Manufacturing	Cut and sew apparel manufacturing	107	$76.34	$2.07	$74.27	541	$26.77	$0.43
Manufacturing	Water- sewer- and pipeline construction	40	$74.90	$0.00	$74.90	630	$33.22	$0.48
Manufacturing	Paperboard container manufacturing	126	$74.18	$0.79	$73.39	241	$18.19	$0.71
Manufacturing	Household vacuum cleaner manufacturing	328	$73.63	$2.78	$70.84	263	$24.46	$0.55
Manufacturing	All other manufacturing	various	$1,859.96	$439.61	$1,420.35	9,444	$607.80	$13.47
	Total manufacturing		**$8,793.15**	**$1,386.66**	**$7,406.49**	**36,089**	**$2,613.94**	**$51.57**

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

Economic Data for Municipal Water User Groups ($millions)

Water Use Category	IMPLAN Sector	IMPLAN Code	Total Sales	Intermediate Sales	Final Sales	Jobs	Income	Business Taxes
Municipal	Wholesale trade	390	$2,098.95	$1,004.90	$1,094.05	12,934	$1,105.37	$310.12
Municipal	Owner-occupied dwellings	509	$1,892.34	$0.00	$1,892.34	0	$1,465.93	$223.76
Municipal	State & Local Education	503	$1,254.80	$0.00	$1,254.79	31,837	$1,254.80	$0.00
Municipal	Telecommunications	422	$965.38	$331.59	$633.79	3,360	$362.46	$60.38
Municipal	Food services and drinking places	481	$928.45	$118.56	$809.89	19,811	$373.53	$43.64
Municipal	Monetary authorities and depository credit in	430	$736.91	$242.70	$494.21	4,003	$517.47	$9.43
Municipal	State & Local Non-Education	504	$729.16	$0.00	$729.16	13,857	$729.16	$0.00
Municipal	Offices of physicians- dentists- and other he	465	$692.35	$0.00	$692.35	6,505	$486.53	$4.26
Municipal	Pipeline transportation	396	$617.24	$269.94	$347.30	801	$204.11	$43.20
Municipal	Truck transportation	394	$524.82	$284.17	$240.64	4,007	$240.77	$5.45
Municipal	Hospitals	467	$508.85	$0.00	$508.85	4,933	$252.98	$3.23
Municipal	Motor vehicle and parts dealers	401	$498.77	$54.24	$444.54	4,626	$257.34	$72.89
Municipal	Machinery and equipment rental and leasing	434	$433.59	$235.80	$197.78	1,401	$175.66	$6.14
Municipal	Real estate	431	$414.65	$164.14	$250.51	2,447	$240.10	$50.89
Municipal	Commercial machinery repair and maintenance	485	$413.71	$217.81	$195.90	2,466	$216.38	$15.81
Municipal	Architectural and engineering services	439	$402.20	$253.54	$148.67	3,640	$201.97	$1.68
Municipal	General merchandise stores	410	$375.62	$39.59	$336.03	7,016	$167.88	$53.50
Municipal	Other State and local government enterprises	499	$356.82	$116.19	$240.62	1,797	$121.61	$0.04
Municipal	Federal Military	505	$312.73	$0.00	$312.73	4,027	$312.73	$0.00
Municipal	Food and beverage stores	405	$283.68	$37.93	$245.75	5,296	$142.16	$31.15
Municipal	Federal Non-Military	506	$261.85	$0.00	$261.84	1,655	$261.84	$0.00
Municipal	Nursing and residential care facilities	468	$260.81	$0.00	$260.81	5,608	$161.88	$3.82
Municipal	Legal services	437	$258.66	$164.16	$94.50	2,162	$161.43	$5.06
Municipal	Management of companies and enterprises	451	$243.64	$229.12	$14.52	1,331	$136.89	$2.19
Municipal	Gasoline stations	407	$243.12	$36.92	$206.19	3,266	$131.09	$35.27
Municipal	All other municipal	various	$5,964.80	$2,337.40	$3,627.40	95,011	$2,952.30	$228.33
Municipal	Total municipal		$15,709.07	$3,801.30	$11,907.77	148,786	$9,682.07	$981.89

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

Appendix 2: Impacts by Water User Group

Irrigation cont. ($millions)	2010	2020	2030	2040	2050	2060
Andrews County						
Reduced income from curtailed crop production	$2.6873	$2.6810	$2.6522	$2.3621	$2.3197	$2.2847
Reduced business taxes from curtailed crop production	$0.1093	$0.1090	$0.1079	$0.0961	$0.0943	$0.0929
Reduced jobs from curtailed crop production	33	33	33	29	29	28
Borden County						
Reduced income from curtailed crop production	$0.49	$0.49	$0.49	$0.49	$0.49	$0.49
Reduced business taxes from curtailed crop production	$0.02	$0.02	$0.02	$0.02	$0.02	$0.02
Reduced jobs from curtailed crop production	6	6	6	6	6	6
Brown County						
Reduced income from curtailed crop production	$1.31	$1.31	$1.31	$1.30	$1.30	$1.30
Reduced business taxes from curtailed crop production	$0.06	$0.06	$0.06	$0.06	$0.06	$0.06
Reduced jobs from curtailed crop production	31	31	31	31	31	31
Coke County						
Reduced income from curtailed crop production	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03
Reduced business taxes from curtailed crop production	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Reduced jobs from curtailed crop production	1	1	1	1	1	1
Coleman County						
Reduced income from curtailed crop production	$0.23	$0.23	$0.23	$0.23	$0.23	$0.23
Reduced business taxes from curtailed crop production	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
Reduced jobs from curtailed crop production	6	6	6	6	6	6
Glasscock County						
Reduced income from curtailed crop production	$12.24	$12.06	$11.88	$11.69	$11.51	$11.33
Reduced business taxes from curtailed crop production	$0.60	$0.59	$0.58	$0.57	$0.56	$0.55
Reduced jobs from curtailed crop production	142	140	138	136	134	132

Irrigation cont. ($millions)	2010	2020	2030	2040	2050	2060
Irion County						
Reduced income from curtailed crop production	$0.13	$0.12	$0.12	$0.11	$0.11	$0.10
Reduced business taxes from curtailed crop production	$0.003	$0.003	$0.003	$0.003	$0.003	$0.003
Reduced jobs from curtailed crop production	2	2	2	1	1	1
Martin County						
Reduced income from curtailed crop production	$0.26	$0.19	$0.11	$0.00	$0.00	$0.00
Reduced business taxes from curtailed crop production	$0.01	$0.01	$0.00	$0.00	$0.00	$0.00
Reduced jobs from curtailed crop production	5	5	5	5	4	4
Menard County						
Reduced income from curtailed crop production	$0.46	$0.46	$0.45	$0.45	$0.44	$0.44
Reduced business taxes from curtailed crop production	$0.03	$0.03	$0.03	$0.02	$0.02	$0.02
Reduced jobs from curtailed crop production	10	10	10	10	10	10
Midland County						
Reduced income from curtailed crop production	$1.72	$1.73	$1.73	$1.72	$1.71	$1.69
Reduced business taxes from curtailed crop production	$0.09	$0.09	$0.09	$0.09	$0.08	$0.08
Reduced jobs from curtailed crop production	22	22	22	22	22	22
Reagan County						
Reduced income from curtailed crop production	$1.36	$1.31	$1.25	$1.18	$1.11	$1.04
Reduced business taxes from curtailed crop production	$0.07	$0.07	$0.06	$0.06	$0.06	$0.05
Reduced jobs from curtailed crop production	15	14	14	13	12	11
Runnels County						
Reduced income from curtailed crop production	$3.17	$3.09	$3.02	$2.94	$2.87	$2.79
Reduced business taxes from curtailed crop production	$0.16	$0.15	$0.15	$0.15	$0.14	$0.14
Reduced jobs from curtailed crop production	45	44	43	42	41	40
Tom Green County						
Reduced income from curtailed crop production	$0.20	$0.20	$0.20	$0.20	$0.19	$0.19
Reduced business taxes from curtailed crop production	$0.01	$0.01	$0.01	$0.01	$0.01	$0.01
Reduced jobs from curtailed crop production	3	3	3	3	3	3
Upton County						
Reduced income from curtailed crop production	$5.99	$5.96	$5.93	$5.90	$5.86	$5.83
Reduced business taxes from curtailed crop production	$0.30	$0.30	$0.30	$0.29	$0.29	$0.29
Reduced jobs from curtailed crop production	79	78	78	77	77	77

Irrigation cont. ($millions)						
	2010	**2020**	**2030**	**2040**	**2050**	**2060**
Ward County						
Reduced income from curtailed crop production	$0.09	$0.08	$0.10	$0.11	$0.11	$0.11
Reduced business taxes from curtailed crop production	$0.004	$0.004	$0.005	$0.01	$0.01	$0.01
Reduced jobs from curtailed crop production	2	1	2	2	2	2

Manufacturing ($millions)

	2010	2020	2030	2040	2050	2060
Coleman County						
Reduced income from reduced manufacturing output	$0.78	$0.78	$0.78	$0.78	$0.78	$0.78
Reduced business taxes from reduced manufacturing output	$0.11	$0.11	$0.11	$0.11	$0.11	$0.11
Reduced jobs from reduced manufacturing output	55	55	55	55	55	55
Ector County						
Reduced income from reduced manufacturing output	$14.56	$19.85	$4.30	$15.75	$15.36	$16.23
Reduced business taxes from reduced manufacturing output	$0.71	$0.97	$0.21	$0.77	$0.75	$0.80
Reduced jobs from reduced manufacturing output	147	201	43	159	155	164
Howard County						
Reduced income from reduced manufacturing output	$7.04	$11.97	$0.00	$2.82	$4.93	$8.75
Reduced business taxes from reduced manufacturing output	$0.35	$0.59	$0.00	$0.14	$0.24	$0.43
Reduced jobs from reduced manufacturing output	71	121	0	29	50	89
Kimble County						
Reduced income from reduced manufacturing output	$50.42	$55.11	$59.15	$63.27	$67.02	$72.07
Reduced business taxes from reduced manufacturing output	$2.69	$2.94	$3.16	$3.38	$3.58	$3.84
Reduced jobs from reduced manufacturing output	163	179	192	205	217	234
Runnels County						
Reduced income from reduced manufacturing output	$20.83	$23.14	$25.13	$27.11	$28.76	$31.08
Reduced business taxes from reduced manufacturing output	$1.60	$1.78	$1.93	$2.09	$2.21	$2.39
Reduced jobs from reduced manufacturing output	421	467	508	548	581	628
Tom Green County						
Reduced income from reduced manufacturing output	$735.98	$825.91	$904.93	$982.30	$1,049.74	$1,132.40
Reduced business taxes from reduced manufacturing output	$56.65	$63.58	$69.66	$75.61	$80.81	$87.17
Reduced jobs from reduced manufacturing output	14,865	16,682	18,278	19,840	21,203	22,872

Mining ($millions)						
	2010	2020	2030	2040	2050	2060
Coke County						
Reduced income from reduced mining activity	$2.12	$2.93	$0.05	$0.59	$1.06	$1.77
Reduced business taxes from reduced mining activity	$0.15	$0.20	$0.00	$0.04	$0.07	$0.12
Reduced jobs from reduced mining activity	13	18	0	4	6	11
Coleman County						
Reduced income from reduced mining activity	$1.91	$2.02	$2.02	$2.02	$2.02	$2.02
Reduced business taxes from reduced mining activity	$0.11	$0.12	$0.12	$0.12	$0.12	$0.12
Reduced jobs from reduced mining activity	11	12	12	12	12	12
Howard County						
Reduced income from reduced mining activity	$8.48	$11.09	$0.19	$2.14	$3.63	$6.04
Reduced business taxes from reduced mining activity	$0.68	$0.89	$0.02	$0.17	$0.29	$0.49
Reduced jobs from reduced mining activity	54	71	1	14	23	39

Steam-electric ($millions)						
	2010	**2020**	**2030**	**2040**	**2050**	**2060**
Coke County						
Reduced income from reduced electrical generation	$23.08	$18.39	$21.52	$25.24	$29.86	$35.52
Reduced business taxes from reduced electrical generation	$3.31	$2.64	$3.09	$3.62	$4.29	$5.10
Reduced jobs from reduced electrical generation	78	63	73	86	102	121
Ector County						
Reduced income from reduced electrical generation	$31.29	$203.76	$565.96	$759.10	$994.54	$1,281.52
Reduced business taxes from reduced electrical generation	$4.49	$29.25	$81.23	$108.96	$142.75	$183.94
Reduced jobs from reduced electrical generation	106	693	1,924	2,580	3,381	4,356
Mitchell County						
Reduced income from reduced electrical generation	$456.24	$440.25	$424.18	$408.10	$392.11	$376.04
Reduced business taxes from reduced electrical generation	$65.49	$63.19	$60.88	$58.58	$56.28	$53.97
Reduced jobs from reduced electrical generation	1,551	1,497	1,442	1,387	1,333	1,278
Tom Green County						
Reduced income from reduced electrical generation	$20.22	$28.93	$33.85	$39.80	$47.06	$55.92
Reduced business taxes from reduced electrical generation	$2.90	$4.15	$4.86	$5.71	$6.76	$8.03
Reduced jobs from reduced electrical generation	69	98	115	135	160	190
Ward County						
Reduced income from reduced electrical generation	$0.00	$0.00	$0.00	$0.00	$5.07	$14.74
Reduced business taxes from reduced electrical generation	$0.00	$0.00	$0.00	$0.00	$0.73	$2.12
Reduced jobs from reduced electrical generation	0	0	0	0	17	50

Municipal ($millions)	2010	2020	2030	2040	2050	2060
Andrews						
Monetary value of domestic water shortages	$0.00	$0.00	$0.00	$0.96	$0.98	$0.99
Lost utility revenues	$0.00	$0.00	$0.00	$1.49	$1.51	$1.53
Ballinger						
Monetary value of domestic water shortages	$7.38	$10.75	$7.67	$8.54	$23.75	$24.94
Lost income from reduced commercial business activity	$3.51	$4.15	$1.67	$1.95	$7.52	$7.90
Lost jobs due to reduced commercial business activity	132	156	63	74	284	298
Lost state and local taxes from reduced commercial business activity	$0.38	$0.45	$0.18	$0.21	$0.82	$0.86
Lost utility revenues	$1.31	$1.49	$1.35	$1.51	$2.33	$2.45
Brady						
Monetary value of domestic water shortages	$8.03	$8.13	$7.99	$7.84	$7.75	$7.75
Lost income from reduced commercial business activity	$1.06	$1.09	$1.05	$1.02	$1.00	$1.00
Lost jobs due to reduced commercial business activity	41	42	40	39	38	38
Lost state and local taxes from reduced commercial business activity	$0.12	$0.13	$0.12	$0.12	$0.12	$0.12
Lost utility revenues	$1.97	$2.00	$1.96	$1.92	$1.90	$1.90
Bronte Village						
Monetary value of domestic water shortages	$0.00	$0.02	$0.03	$0.05	$0.07	$0.09
Lost utility revenues	$0.00	$0.04	$0.06	$0.07	$0.09	$0.11
Coahoma						
Monetary value of domestic water shortages	$0.10	$0.12	$0.001	$0.01	$0.02	$0.04
Lost utility revenues	$0.10	$0.12	$0.002	$0.02	$0.04	$0.06
Coleman						
Monetary value of domestic water shortages	$25.91	$25.58	$25.24	$24.90	$24.66	$24.66
Lost income from reduced commercial business activity	$12.43	$12.28	$12.11	$11.95	$11.83	$11.83
Lost jobs due to reduced commercial business activity	348	344	339	335	332	332
Lost state and local taxes from reduced commercial business activity	$0.96	$0.95	$0.94	$0.92	$0.91	$0.91
Lost utility revenues	$2.54	$2.51	$2.48	$2.45	$2.42	$2.42

Municipal ($millions)

	2010	2020	2030	2040	2050	2060
County-other (Coke)						
Monetary value of domestic water shortages	$0.04	$0.05	$0.00	$0.01	$0.01	$0.02
County-other (Coleman)						
Monetary value of domestic water shortages	$0.46	$0.43	$0.43	$0.43	$0.43	$0.46
County-other (Kimble)						
Monetary value of domestic water shortages	$0.01	$0.01	$0.003	$0.00	$0.00	$0.00
County-other (Menard)						
Monetary value of domestic water shortages	$0.03	$0.03	$0.03	$0.02	$0.02	$0.03
County-other (Runnels)						
Monetary value of domestic water shortages	$7.92	$6.38	$5.21	$3.96	$3.00	$1.85
County-other (Scurry)						
Monetary value of domestic water shortages	$0.07	$0.08	$0.00	$0.01	$0.03	$0.04
County-other (Tom Green)						
Monetary value of domestic water shortages	$0.04	$0.00	$0.00	$0.00	$0.00	$0.00
County-other (Ward)						
Monetary value of domestic water shortages	$0.00	$3.60	$3.60	$3.60	$3.60	$3.60
Junction						
Monetary value of domestic water shortages	$18.87	$18.85	$18.67	$18.49	$18.35	$18.35
Lost income from reduced commercial business activity	$9.58	$9.57	$9.48	$9.38	$9.31	$9.31
Lost jobs due to reduced commercial business activity	373	373	369	365	363	363
Lost state and local taxes from reduced commercial business activity	$1.22	$1.22	$1.21	$1.19	$1.19	$1.19
Lost utility revenues	$1.85	$1.85	$1.83	$1.82	$1.80	$1.80
Menard						
Monetary value of domestic water shortages	$0.07	$0.07	$0.05	$0.05	$0.04	$0.04
Lost utility revenues	$0.10	$0.10	$0.09	$0.07	$0.07	$0.07

Municipal ($millions)						
	2010	**2020**	**2030**	**2040**	**2050**	**2060**
Midland						
Monetary value of domestic water shortages	$1.06	$3.01	$95.81	$201.95	$244.36	$251.36
Lost income from reduced commercial business activity	$0.00	$0.00	$85.32	$311.55	$324.80	$339.87
Lost jobs due to reduced commercial business activity	0	0	2,125	7,760	8,090	8,466
Lost state and local taxes from reduced commercial business activity	$0.00	$0.00	$6.16	$22.49	$23.45	$24.54
Lost utility revenues	$2.29	$4.88	$30.91	$41.59	$42.80	$44.20
Miles						
Monetary value of domestic water shortages	$5.12	$5.60	$5.97	$3.50	$3.71	$3.91
Lost income from reduced commercial business activity	$1.54	$1.69	$1.80	$1.91	$2.03	$2.14
Lost jobs due to reduced commercial business activity	41	45	48	51	54	57
Lost state and local taxes from reduced commercial business activity	$0.19	$0.21	$0.23	$0.24	$0.26	$0.27
Lost utility revenues	$0.28	$0.30	$0.32	$0.34	$0.36	$0.38
Millersview-Doole WSC						
Monetary value of domestic water shortages	$0.02	$0.03	$0.00	$0.00	$1.66	$2.91
Lost utility revenues	$0.03	$0.05	$0.00	$0.00	$0.47	$0.57
Odessa						
Monetary value of domestic water shortages	$4.36	$61.75	$5.35	$6.24	$7.22	$10.05
Lost utility revenues	$7.35	$18.65	$7.94	$9.18	$10.61	$13.16
Robert Lee						
Monetary value of domestic water shortages	$0.16	$0.22	$0.00	$0.01	$0.03	$0.07
Lost utility revenues	$0.17	$0.21	$0.00	$0.03	$0.05	$0.10
San Angelo						
Monetary value of domestic water shortages	$64.65	$79.05	$83.30	$65.88	$76.44	$77.63
Lost income from reduced commercial business activity	$0.00	$0.00	$0.00	$21.05	$22.71	$24.02
Lost jobs due to reduced commercial business activity	0	0	0	519	559	592
Lost state and local taxes from reduced commercial business activity	$0.00	$0.00	$0.00	$1.46	$1.58	$1.67
Lost utility revenues	$0.17	$0.56	$0.30	$0.39	$0.46	$0.57

Municipal ($millions)						
	2010	2020	2030	2040	2050	2060
Snyder						
Monetary value of domestic water shortages	$0.66	$0.92	$0.01	$0.11	$0.20	$0.32
Lost utility revenues	$0.31	$0.39	$0.01	$0.07	$0.12	$0.19
Stanton						
Monetary value of domestic water shortages	$7.93	$8.54	$8.68	$8.70	$8.40	$7.95
Lost income from reduced commercial business activity	$4.90	$5.29	$5.38	$5.39	$5.20	$4.92
Lost jobs due to reduced commercial business activity	127	137	139	140	135	127
Lost state and local taxes from reduced commercial business activity	$0.40	$0.43	$0.44	$0.44	$0.42	$0.40
Lost utility revenues	$0.78	$0.84	$0.85	$0.85	$0.82	$0.78
Winters						
Monetary value of domestic water shortages	$8.90	$7.24	$7.30	$7.37	$7.42	$7.63
Lost income from reduced commercial business activity	$2.82	$2.29	$2.31	$2.33	$2.35	$2.41
Lost jobs due to reduced commercial business activity	102	83	84	85	85	88
Lost state and local taxes from reduced commercial business activity	$0.30	$0.24	$0.25	$0.25	$0.25	$0.26
Lost utility revenues	$1.09	$1.11	$1.12	$1.13	$1.14	$1.17

Appendix E

Thornhill Group, Inc. Comment Letter of August 11, 2016

THORNHILL GROUP, INC.

Professional Hydrogeologists • Water Resources Specialists

August 11, 2016

Mr. Paul Weatherby, General Manager
Middle Pecos Groundwater Conservation District
405 North Spring Drive
Fort Stockton, Texas 79735

Re: Stakeholder Comments, Recommendations, and Requests for the Proposed Desired Future Conditions Determinations — The Aquifer Systems in Groundwater Management Area 7

Dear Mr. Weatherby,

Thornhill Group, Inc. (TGI) appreciates this opportunity to, on behalf of Fort Stockton Holdings, L.P. (FSH), provide comments, recommendations, and requests pertaining to the adoption of the recently proposed 2016 Desired Future Conditions (DFCs) for Groundwater Management Area 7 (GMA 7), and specifically the DFCs as applied to the Edwards-Trinity (Plateau) within GMA 7 in Pecos County. These written comments are provided during the Public Comment Period as set in the notice published by the Middle Pecos Groundwater Conservation District (MPGCD) in GMA 7. TGI's recommendations provided herein are relevant to GMA 7, MPGCD, all GCDs across Texas, the Texas Water Development Board (TWDB), and the State of Texas Legislature.

TGI and FSH believe that the DFCs adopted in 2010 for GMA 7 and the proposed 2016 DFCs and the resulting managed available groundwater (MAG) are severely flawed constitutionally, legally and scientifically. Therefore, TGI on behalf of FSH respectfully requests that an alternative DFC be considered and adopted by GMA 7 beginning in 2016 for the Capitan Reef, Dockum, Edwards-Trinity (Plateau)/Pecos Valley Alluvium, and Rustler aquifers. This letter serves to provide for the consideration of MPGCD and GMA 7 alternative DFCs and management strategies that are based on sound science and honor Texas Water Law.

Fort Stockton Holdings, L.P. – A Vested Stakeholder

FSH is a stakeholder in GMA 7, with approximately 18,000 acres of land and 47 wells permitted by MPGCD within GMA 7. FSH clearly meets the definition of "affected person" presented by Texas Water Code Section 36.1083.(1) and Section 36.1082. – "Appeal of Desired Future Conditions" regarding the potential outcome of the proposed 2016 DFCs. The consequences of GMA 7 actions regarding determining the availability and management of 1 groundwater directly affect the private property rights and investment-backed expectations of FSH.

Purpose, Objectives and Goals

The purpose of this letter is twofold:

(i) to express to the MPGCD that the proposed DFCs fail to meet the definitions and requirements of the Texas Regulatory Code as set forth by Title 31 of The Texas Administrative Code, and Chapter 36 of the Texas Water Code as well as the mandate of the state legislature as defined in Senate Bill 660 (SB660 2011), and

(ii) to offer a DFC metric that meets the mandate of SB660.

Specifically, the Texas Water Code and Texas Administrative Code provide the following definitions:

"Desired future condition – the desired, quantified condition of groundwater resources (such as water levels, spring flows, or volumes) within a management area at one or more specified future times as defined by participating groundwater conservation district within a groundwater management area as part of the joint planning process."

(Title 31, Part 10, §356.10(6) of the Texas Administrative Code)

"'Modeled available groundwater' means the amount of water that the executive administrator determines may be produced on an average annual basis to achieve a desired future condition established under 36.108."

(Texas Water Code 36.001(25))

"Before voting on the proposed desired future conditions of the aquifers under Subsection (d-2), the districts shall consider: … (3) hydrological conditions, including for each aquifer in the management area the total estimated recoverable storage as provided by the executive administrator, and the average annual recharge, inflows, and discharge." 2

(Senate Bill 660, §36.108(d)(3))

The Current and Proposed DFC and MAG are Flawed

TGI has extensively reviewed the proposed DFCs and based on these reviews, the proposed
DFCs (2016) are legally and scientifically flawed because they do not consider “a balance
between the highest practicable level of groundwater production and the conservation, 3
preservation, protection, recharging, and prevention of waste of groundwater and control of
subsidence in the management area” (Code §36.108 (d)(d-2)). Basing DFCs on drawdown
based on prescribed or preset pumping conditions does not meet the definition of DFCs from 4
Title 31 of the Texas Administrative Code. Drawdown levels are not equivalent to measured
water levels, spring flows or volumes, the three metrics identified in the regulation. Even
though drawdown is a measure of a change in water levels in a well, drawdown (particularly
drawdown due to reduction of artesian pressure) is not reflective of the condition of water
availability in an aquifer. The use of drawdown to develop DFCs which are based on
prescribed pumping from existing permit information or water planning data unnecessarily 5
results in arbitrary and discriminatory artificial water shortages.

Arbitrary and Discriminatory Considerations

Neither the TWDB nor the Texas Legislature provided substantial technical guidance to GCDs
and GMAs in deriving DFCs. In fact, the TWDB seems to promote a subjective approach to
DFCs with such statements as: **“What do you want your aquifer to look like in the future?”**
(Mace, Petrossian, et al. 2008)**.** Likewise, in a previous paper the TWDB leadership stated
when discussing a **consensus-based** groundwater management framework, “Like beauty,
availability is in the eye of the beholder” (Mace, Mullican and Way 2001, 9). Following such
guidance apparently leads GMAs in deriving DFCs that are illegal and scientifically flawed
because they do not consider “a balance between the highest practicable level of 6
groundwater production and the conservation, preservation, protection, recharging, and
prevention of waste of groundwater and control of subsidence in the management area”
(Code §36.108 (d)(d-2)). Basing MAGs on DFCs derived from prescribed pumpage data from
water planning projections of future water needs within political boundaries “reverse
engineering” and; (i) amounts to “regulation by planning”, (ii) fails to account for the real- 7
world hydrologic conditions; and, (iii) is contrary to the legislature changes to Chapter 36
since 2008.

The Water Code seems to favor and even emphasize the concept of managing aquifers on
the basis of hydrogeologic and hydrologic characteristics, rather than simply on the basis of
political subdivision. **“Groundwater reservoir”** means a specified subsurface water-bearing
reservoir having ascertainable boundaries containing groundwater” (Texas Water Code
36.001(6)). **“Subdivision of a groundwater reservoir”** means a definable part of a
groundwater reservoir in which the groundwater supply will not be appreciably affected by
withdrawing water from any other part of the reservoir, as indicated by known geological and 8

hydrological conditions and relationships and on foreseeable economic development at the time the subdivision is designated or altered." (Texas Water Code 36.001(7)). Dr. Bill Hutchison and Kenneth L. Peterson wrote in a TWDB memorandum in 2010 that arguments against using political subdivisions to determine DFCs are not persuasive "…as long as the groundwater conservation districts do not appear to be using county or other political subdivision lines to gerrymander DFCs for purposes other than accommodating discernible, substantial differences in uses or other aquifer conditions within the GMA." DFCs based on political boundaries are likely contrary to the original philosophy of the Texas Legislature in the development of GMAs, and typically do not honor the hydrogeologic and hydrologic conditions of aquifers. Such thinking allows for inequity in the opportunity to exercise property rights. Again, amendments to Chapter 36 in 2011 and 2013 corrected the errors in Mr. Peterson's thinking. 9

DFCs should be based on the full water balance of the coterminous aquifer (or groundwater reservoir). Such a water balance accounts for the outflows (production/discharge) of the aquifer, as well as the inflows (including average annual recharge), which are only an extremely small percentage of the water balance of the aquifers within GMA 7. In addition to outflows and inflows, the water balance includes **storage,** the largest volumetric factor within the water balance of the aquifers within GMA 7, that has been ignored in the development of previous DFCs and the proposed DFCs. Such a water balance must also include the **total estimated recoverable storage** as determined by the executive administrator of the TWDB. 10

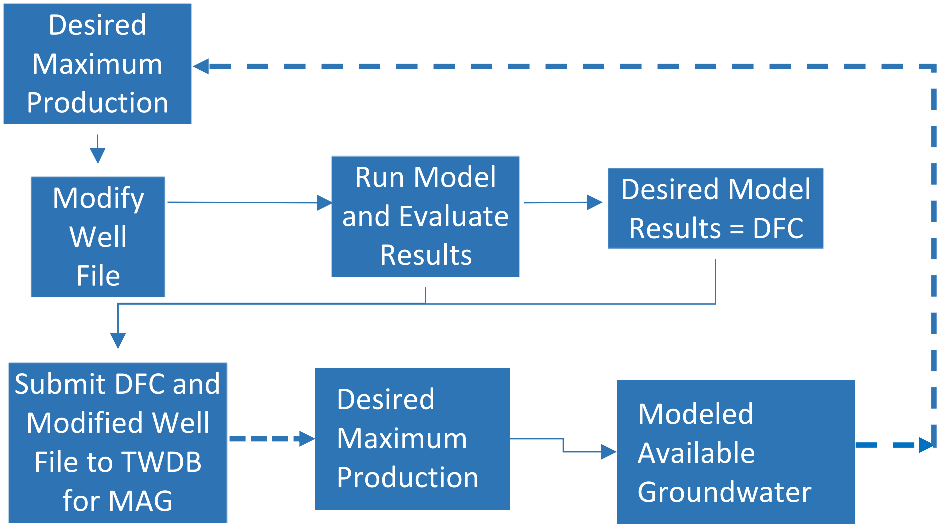
Reverse Engineered DFCs Based on Prescribed Pumping

In most cases, DFCs were determined based on the amount of drawdown resulting from a prescribed amount of planned future pumping. Many of these planned future pumping estimates utilized in the initial round of DFC adoption were based on 2006/2007 regional and state water planning efforts. Groundwater "availability" was limited based on a definition of "sustainability" that was erroneously characterized as the amount of recharge to an aquifer within a certain geographic area (e.g., county). **Importantly, however, the TWDB has clearly stated that pumping is not a desired future condition, but is a means to achieve a desired future condition** (Petrossian, Ridgeway and Donnelly, 2007). The Texas Water Code and TWDB rules state that the TWDB, not GCDs and GMAs, determine the modeled available groundwater or MAG, based on DFC. Texas Water Code defines DFC and MAG as follows:

> "Desired [F]uture [C]ondition – The desired, quantified condition of groundwater resources (such as water levels, spring flows, or volumes) within **a management area** at one or more specified future times as defined by participating groundwater

> conservation districts within a **groundwater management area** as part of the joint planning process."
>
> "Modeled [A]vailable [G]roundwater" means the amount of water that the executive administrator determines may be produced on an average annual basis to achieve a desired future condition established under 36.108" (Texas Water Code 36.001 (25)).

These predicted sustainable pumping rates were utilized as the pumping files for GAMs, and the resulting aquifer drawdown was called the "DFC". Then, the prescribed pumping amounts were plugged into the GAM to calculate average drawdowns which became the DFCs. These DFCs were then sent to TWDB and the GAM was used to derive the MAG – **classic reverse engineering** as illustrated below:

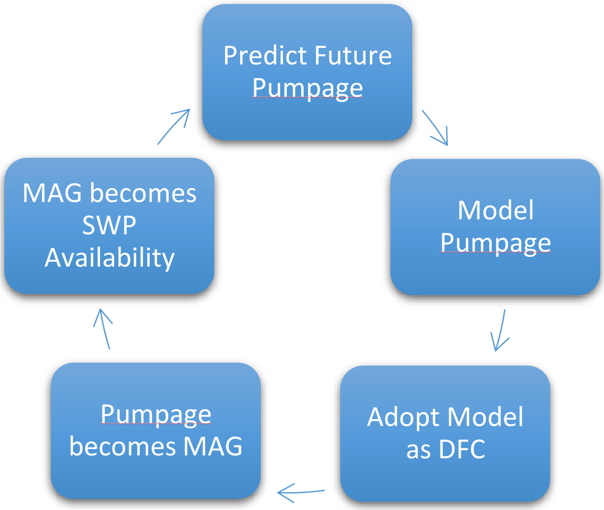


For example, based on the agenda, meeting minutes, notes and audio recordings from the GMA 7 July 29, 2010 meeting, and from GMA 7 Resolution # 07-29-10-9, it is clear that the Edwards-Trinity (Plateau) aquifer DFCs for most of GMA 7 were back-calculated (or reverse engineered) from prescribed pumping amounts (desired maximum production). 11

Rather than first selecting an aquifer condition (remaining available storage or water levels), GMA 7 chose initial pumping scenarios for each county based initially on pumping called "a continuation of 2005", and generally slightly modified that initial pumping and calculated from those model runs the average drawdown across individual counties. Prior to the July 29, 2010 meeting, there had been five (5) pumping scenarios assessed for the Edwards-Trinity aquifer within GMA 7. During the GMA 7 meeting of July 29, 2010, the day the DFCs were adopted, the GCD general managers and representatives provided various pumping values to Dr. Bill Hutchison, who entered them into a spreadsheet based on GAM results that recalculated average drawdown with varied pumping. It is evident from discussions during

the meeting and the results from the modeling that the district general managers or
representatives did not truly consider aquifer conditions in setting various pumping amounts. 12
Based on minutes from the meeting, "Additional scenarios 6 and 7 were drafted at this time
based on **pumping changes recommended by GMA members**" (emphasis added). Later that
day at the Public Meeting, the minutes show that an additional three (3) scenarios were
developed for consideration, including draft scenarios 9 and 10 of GAM 09-35 "…utilizing
different pumping rates and the setting of individual district DFCs versus an aquifer-wide
DFC" (GMA 7 Meeting Minutes). Therefore, the initial and primary consideration in the
meeting appeared to be prescribing pumping amounts, rather than selecting aquifer
conditions to assess using the GAM. The TWDB has clearly stated that pumping is not a 13
desired future condition, but is a means to achieve a desired future conditions (Petrossian,
Ridgeway and Donnelly, 2007).

HB 1763 (2005) mandated that the
MAG be used as the groundwater
availability numbers in the regional and
state water plans. GCDs and GMAs
have a combined propensity to reverse
engineer DFCs based on water planning
projections, as a result the current
DFC/MAG process is largely a 14
"regulation by planning" process that
creates a "regulatory feedback loop" as
illustrated here by Mr. James Bené,
P.G. of R.W. Harden & Associates, Inc.,
diagram of the DFC/MAG:



James Bene', R.W. Harden & Associates, Inc.

The initial DFC process has resulted in
considerable regulatory, management
and planning confusion. Across Texas,
the DFC process has resulted in
arbitrary permit denials or restrictions, 15
false "paper", "digital" and/or "political" water shortages, unnecessary restrictions on
groundwater production, stifling of groundwater supply development, uncertainty, and
considerable taking of private property rights resulting in devaluing of private property in
regards to groundwater availability.

Political Subdivisions Are Not Valid Unless They Match Hydrogeologic Management Areas

Clearly, aquifers do not conform to county lines and groundwater flows across political subdivision boundaries. The original legislation providing for districts stated:

> "No petition for the creation of a District to exercise the powers and functions set forth in Subsection B of this Section 3c shall be considered by a Commissioners Court or the Board, as the case may be, unless the area to be included therein is **coterminous** with an **underground water reservoir** or **subdivision** thereof which theretofore has been defined and designated by the Board as an underground water reservoir or subdivision thereof. Such district, in conforming to a defined reservoir or subdivision, may include all or parts of a county or counties, municipal corporations or other political subdivisions, including but not limited to Water Control and Improvement Districts." (HB 162, Acts 1949, 51st R.S., ch. 306, General and Special Laws of Texas). 16

Single-county districts were allowed in the Water Code only after the mid-1980s, and were greatly proliferated between 1999 and 2001 after the passage of SB 1 (1997). It appears that the legislature attempted to mitigate the chaos caused by attempting to manage regional aquifers through single-county and small districts covering parts of a single groundwater reservoir with the passing of SB 2 (2001), and the re-establishment of GMAs. The designation of groundwater management areas is codified in the Texas Water Code §35.004, which states the following:

> "…Each groundwater management area **<u>shall</u>** be designated with the **objective of *providing the most suitable area for the management of the groundwater resources***. *To the extent feasible, the groundwater management area shall coincide with the boundaries of a groundwater reservoir or a subdivision of a groundwater reservoir. The Texas Water Development Board also <u>may</u> consider other factors, including the boundaries of political subdivision"* (emphasis added).

MPGCD has taken the erroneous political subdivision concept even further in the wrong direction by creating gerrymandered management zones within the district boundaries that already fail to meet the requirements of a groundwater management area based on a reservoir boundary. The use of "geographic areas", rather than actual underground reservoirs in establishing DFCs violates Texas Water Code §35.004 and §36.116(d) as referenced in the January 20, 2016 version of the district's rules in defining "Management Zone". The MPGCD rules relied upon to create these artificial sub-district DFCs misinterpret Texas Water Code §36.116(d) as allowing the creation of geographic boundaries for management of spacing and production by not including the full context of development of 17 geographic boundaries at the surface that correspond to the aquifer that lies in whole within the district or subdivisions of an aquifer located in part within the district. The only clearly defined subdivision allowed in the Texas Water Code for groundwater management areas relates to hydrogeologic boundaries of the groundwater reservoir or hydrological based subdivisions of the groundwater reservoirs. 18

These concepts of aquifer based subdivisions for management of resources were further confirmed by the Texas Supreme Court in regards to regulation of groundwater in the decision of the Edwards Aquifer Authority v. Day. The court's decision stated:

> "one purpose of groundwater regulation is to afford each owner in a _common, subsurface reservoir_ a _fair share_" (emphasis added).

The language used by the Texas Supreme Court of a common, subsurface reservoir falls in line with previous language quoted above in regards to defining the area of a groundwater conservation district "the area to be included therein is **coterminous** with an **underground water reservoir** or **subdivision** thereof which theretofore "has been defined and designated by the Board as an underground water reservoir or subdivision thereof (HB 162, Acts 1949, 51st R.S., ch. 306, General and Special Laws of Texas). The Texas Water Code has purposely recognized that the most suitable manner in which to manage groundwater resources is by aquifer or aquifer subdivision and not gerrymandered geopolitical boundaries. 19

Proposed DFCs Do Not Consider Hydrogeology or Aquifer Capability

The DFCs proposed by GMA 7 are reported as decreases in average saturated thickness for unconfined aquifers and average drawdown that is determined by modeling results of the drawdown this ignores the aquifer response as demonstrated through historic water level measurements and the true physical availability of an aquifer to recharge. As stated by a former board member of the TWDB, **"Some of the desired future conditions are being driven by…a fundamental misunderstanding of how groundwater aquifers behave…"**; and **"…groundwater districts now have the power to enforce resulting managed available groundwater determination that may, in effect, ignore the capability of the aquifer to produce water"** (Mr. Jack Hunt, 2009). 20

Average drawdown alone is a very poor metric in assessing the availability of groundwater, particularly in the oftentimes karst Edwards-Trinity (Plateau) aquifer. Similarly, estimating recharge within a county or a subarea of an aquifer or aquifer subdivision is essentially meaningless with respect to assessing groundwater availability or providing a metric for groundwater management. 21

As the legislature directed in Senate Bill 660 (SB 660), the entire water balance of an aquifer should be considered in assessing groundwater availability. The water balance includes all 22 inflows, all outflows and storage of the aquifer or subdivision of the aquifer being considered. DFCs should be based on the full water balance of the coterminous aquifer, and **not** based on political boundaries including MPGCD's management zones. A full water balance of the coterminous aquifer accounts for the outflows (production/discharge) of the aquifer, as well as the inflows (including average annual recharge). Importantly, such a water balance must also include the total estimated recoverable storage (TERs) determined by the executive 23 administrator of the TWDB. Analyses relying on planned outflows from specific areas (e.g., management zones, or the principal areas of irrigation) used for the development of the proposed DFCs creates man-made, false groundwater shortages. This results in dysfunctional inaccurate water planning, and results in predicting premature adverse economic impacts forcing GCDs to create rules that infringe on private property rights, ultimately resulting in a regulatory taking.

Ramifications of the DFC

The current and proposed DFCs are not scientifically and legally defensible primarily because they are based on modeled average artesian drawdown over a political boundary that is back-calculated from prescribed pumping amounts. And because separate DFCs are provided for geopolitical subdivisions and not the overly large, contiguous and hydraulically continuous aquifers, the current DFCs:

- May not be achievable as defined;
- Create false groundwater shortages;
- Lead to dysfunctional and inaccurate water planning; 24
- Can result in unnecessary or premature adverse economic impacts; and,
- Likely result in GCD rules and management procedures that infringe on private property rights, as artesian drawdown is not a viable management criterion to assign "fair chance".

In developing the GAMs used to develop the DFCs very clear limitations are defined for the 25 models, and these limitations must be considered and taken seriously.

Regional Groundwater Model Limitations

The above general comments reflect assessments that can be applied to all aquifers and the proposed DFCs, below is a detailed look into the specific details related to the limitations of the groundwater models that have been misused to develop the proposed drawdown DFCs for the specific aquifers; the Capitan Reef and the Edwards-Trinity (Plateau)/Pecos Valley Alluvium. The TWDB and contracted regional groundwater model developers have clearly defined the limitations of the GAMs in the reports summarizing the Capitan Reef Complex Aquifer (Jones, 2016) and the Edwards-Trinity (Plateau)/Pecos Valley Alluvium modeling efforts (Hutchinson, et.al., 2011). Further discussion of additional limitations of the Edwards-Trinity (Plateau)/Pecos Valley Alluvium modeling efforts are presented in the April 2011 letter from Robert Mace (TWDB) to Edmond McCarthy and Michael Gerson regarding additional model efforts reported in GAM Task 10-033 (Attachment 1 is the letter from Dr. Mace).

The limitations of the regional groundwater models have been inherently ignored by GCDs in the development of drawdown based DFCs and in particular when GCDs utilize the results of the GAM models to assess site-specific permits. Below are prescribed limits of the GAM models as quoted directly from the TWDB GAM Reports: 26

- "*Model users should consider several limitations when using this model. To a certain extent this model is interpretive rather than being a fully predictive model because of: the limited historical stresses on the aquifer, limited amount of measured water levels, and limited hydraulic property data. In addition, because of the lack of historical stresses, it was not possible to fully calibrate the storage coefficient. The use of a constant transmissivity in the model requires that model users carefully evaluate whether it is appropriate to assume that water-level drawdown is insignificant relative to the total aquifer thickness*" (Jones, 2016).
- "***Several*** *input parameter data sets for the model are based on* ***limited*** *information. These include geologic framework, recharge, water level and streamflow data, hydraulic conductivity, specific storage, and specific yield*" (Hutchinson, et.al., 2011) (**empahsis added**). In summation nearly every input related to the solution of groundwater flow in this regional MODFLOW model are based on limited information making any analysis performed using this model a general estimation of regional groundwater flow. Applying this model in a predictive capacity means not only are any predictive assessments limited by the generalized inputs of future development, but also verty limited by the general nature of the hydrogeologic properties that have been used to create this model.
- "*There is model uncertainty associated with using annual stress periods in the model. The use of annual stress periods results in the model not simulating seasonal effects of recharge and pumping. However, attempting to simulate seasonal effects would be impractical due to the paucity of wells and frequent water level measurements needed for calibration and the fact that seasonal fluctuations may be too small to simulate with certainty at the regional scale. This updated model lumps together the two layers in the original model and thus potentially introduces uncertainty related to head differences between the Trinity and Edwards Groups*" (Hutchinson, et.al., 2011). Application of the pumping scenarios in an annual time step fashion ignores the

seasonal nature of historic pumping especially in the three irrigation districts. These areas have historically had pumping during a shortened irrigation season which lasted between five to eight months annually. During non-irrigation season months pumping is much lower and these months typically correspond to the months when weather patterns produce regional recharge primarily in the form of precipitation and the associated increase in surface water flows.

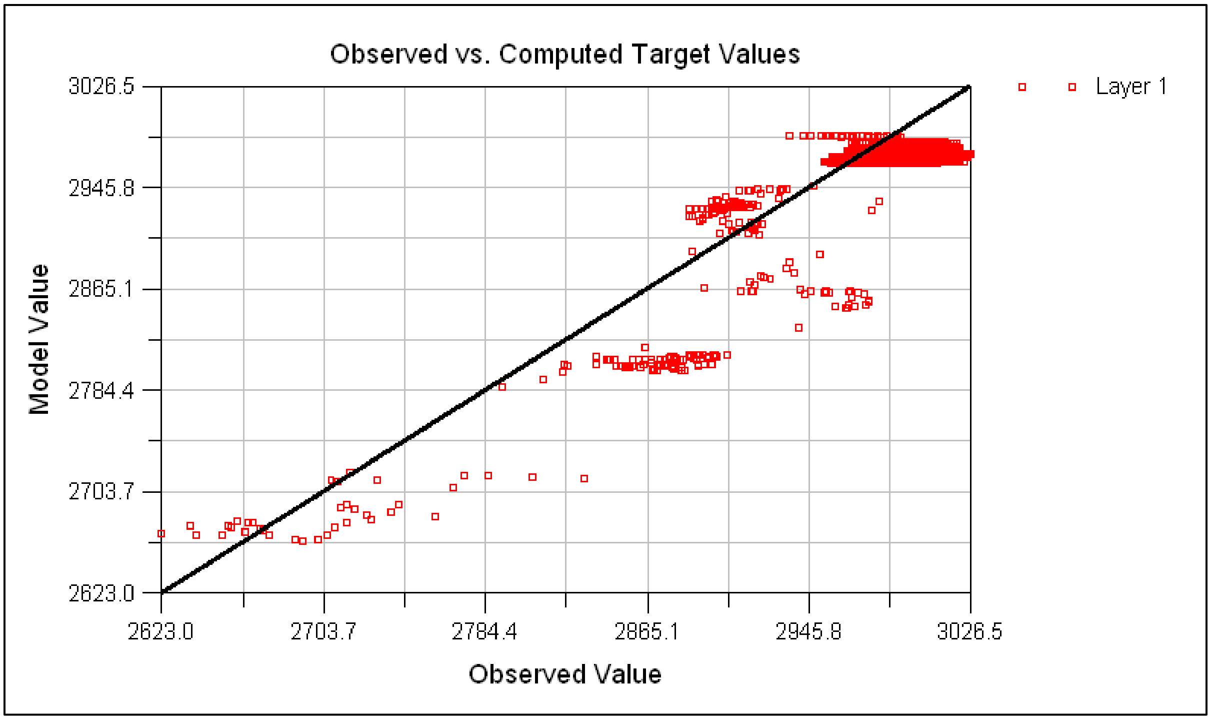
- "*There is uncertainty with simulating base flow and spring discharge at the spatial and temporal scale of this model. Actual discharge to streams occurs within small areas averaging 50 feet wide, compared to the 1 square mile of the model cells, and base flow is more variable within the annual time steps of the model. Therefore, uncertainty occurs because modeled discharge to streams is averaged over a 1-year stress period and 1 square-mile cell*" (Hutchinson, et.al., 2011). Model scale is a critical component in determining the scale at which assessment from a model can be applied. As noted in the above quoted text the scale of the model makes assessment of a critical model outlfow uncertain even with that outflow occuring at the scale of 50 feet in real world space. The uncertainty of scale is magnified at smaller scales, so any attempt to assess single well scale impacts to aquifers using this model when those wells are 33 times smaller are sure to contain a greater uncertainty.
- "*Available transmissivity and hydraulic conductivity data for the Edwards-Trinity (Plateau) and Pecos Valley aquifers is derived primarily from specific-capacity data obtained from wells scattered throughout the model area. However, these data are not located close enough to indicate more localized heterogeneity within the zones used in the model*" (Hutchinson, et.al., 2011). On a local site specific well or well field level the above model limitation represents one of the greatest inherent errors when applying MODFLOW regional models to assessment of the Edwards Aquifer. The karst nature of the Edwards Aquifer is well documented and therefore not referenced in detail in this response but specific capacity and the relationship to transmissivity are less correlative in fracture and conduit flow systems which have been observed at local levels within the modeled area. Downhole wellbore videos from the Leon-Belding Area document the presence of large subsurface solution features which cannot be represented in the model as developed, but these large transimissive features are critical to understanding the response at the well or well field level where permit decisions occur and represent a **fundamental flaw** in applying this analysis for determining DFCs that should prevent the use of this model by GMA 7 and all related GCDs.
- "*Groundwater flow between the Edwards-Trinity (Plateau) and Pecos Valley aquifers and the underlying aquifers is assumed to be negligible. This assumption is based partially on successfully calibrating the model without the need to factor in flows to or from the underlying aquifers. It was difficult for us to consider this inter-aquifer*

groundwater flow because of the paucity of water level and hydraulic property data to constrain such flow. Additionally, groundwater geochemistry studies in the Pecos Valley Aquifer, which would potentially be impacted the most by groundwater interaction with underlying aquifers, indicate only minor amounts of groundwater flow from underlying saline aquifers (Jones, 2004)" (Hutchinson, et.al., 2011). Again, TGI wants to identify that this model is being identified as having been developed with limited data at a large scale (1-mile grid), AND in this case the limited data of the model is used as justification for not including additional recharge components. The inter-aquifer flow was determined to not be a necessary component of this model because of the limited data that was used to develop this model. And since limited data was used to develop the model it was possible to achieve model calibration and adding inter-aquifer flow was not a needed component regardless of whether or not real world data shows inter-aquifer flow to be present in this area.

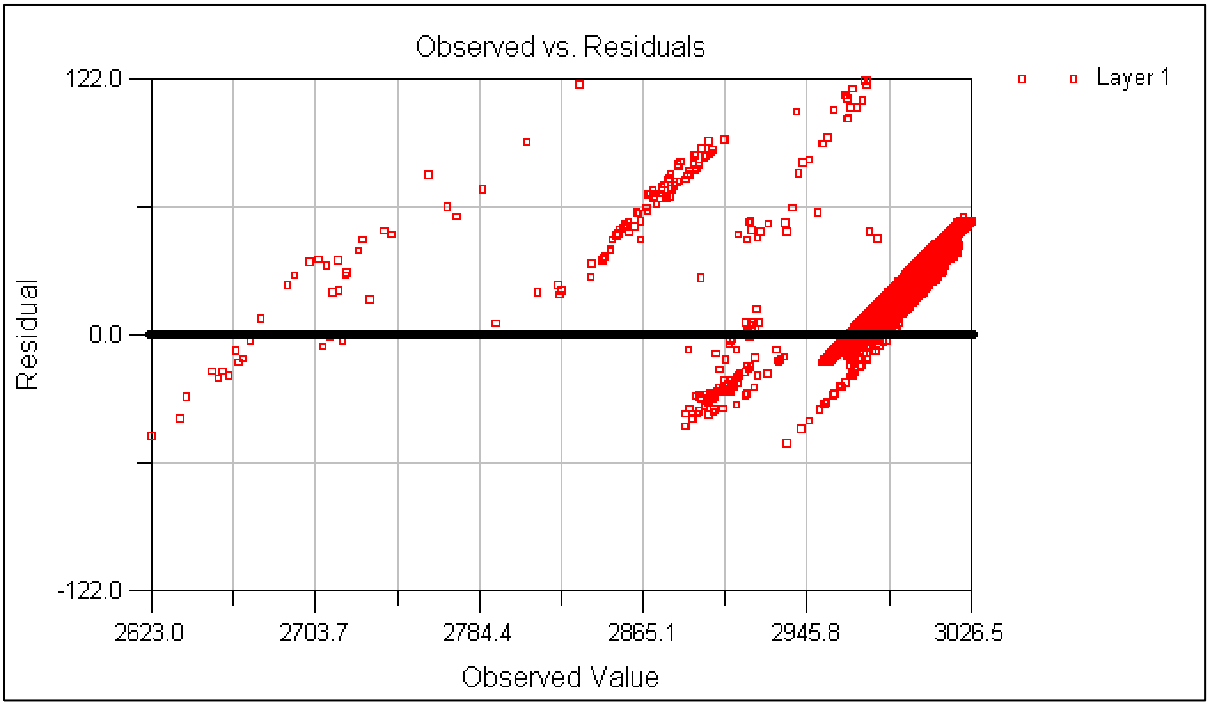
- "*The limitations described earlier and the nature of regional groundwater flow models affect the scale of application of the model. This model is most accurate in assessing larger regional-scale groundwater issues, such as predicting aquifer-wide water level changes and trends over the next 50 years that may result from different proposed water management strategies. Accuracy and applicability of the model decreases when using it to address more local-scale issues because of limitations of the information used in model construction and the model cell size that determines spatial resolution of the model. Consequently, this model is not likely to accurately predict water level declines associated with a single well or spring because (1) these water level declines depend on site-specific hydrologic properties not included in detail in regional-scale models, and (2) the cell size used in the model is too large to resolve changes in water levels that occur over relatively short distances. Addressing local-scale issues requires a more detailed model, with local estimates of hydrologic properties, or an analytical model. This model is more useful in determining the impacts of groups of wells distributed over many square miles. The model predicts changes in ambient water levels rather than actual water level changes at specific locations, such as an individual well"* (Hutchinson, et.al., 2011). The paragraph above succintly defines two key points of why this model is not appropriate for the development of DFCs for the MPGCD, the irrigation management areas, and overall why regional drawdown developed from models is not an appropriate measure to assess DFCs. The overall lack of location scale data in the development of this model and the development of model cells at large scale (1 mile by 1 mile) precelude reasonable analysis at a permit or well level. Combined with the overall lack of data used in development of the model, the generalized assumptions of the aquifer parameters that must occur for three separate confined aquifer units to be modeled as one layer, and the lack of seasonal pumping assessments make this model a poor simulation of the regional aquifer and future groundwater conditions.

Additionally, in terms of the GMA 7 Edwards-Trinity (Plateau)/Pecos Valley Alluvium GAM runs, the calibration pumping scenario inputs could not be matched to historic existing use (see Attachment 2). For example, Attachment 2 illustrates the total Historic and Existing Use (HEU) Permit amount within MPGCD Management Zone 1. This HEU permit amount totaled 90,753.0 acre-feet per year and can be compared to the total amount of pumping that was included in the GMA 7 Scenario 10 (and the extended version of Scenario 10), which is 123,341.4 acre-feet per year resulting in an over estimation of pumping by 32,588.4 acre-feet per year. In summary, the distribution of pumping in the GMA 7 Scenario 10 (and the Scenario 10 extended) Edwards-Trinity (Plateau)/Pecos Valley Alluvium GAM run includes a pumping distribution that cannot be correlated with historic or known proposed future pumping scenarios making the use of this model run for development of DFCs a poor choice. 27

Furthermore, the Leon Belding Area is an area where HEU permits are known and historical monitored water levels are available that provide an accurate water level data set to calibrate the model to and provide a base to assess future pumping scenarios against. However, this data does not appear to have been effectively used in the modeling efforts as illustrated in Attachment 3 (Hydrograph Map). As applied, the model inputs and modeled pumping scenarios used for calibration provided a poor representation of historic activity and represent another flaw in the development of this MODFLOW model. The poor quality of the calibration of the GAM model for the Leon Belding Area (using the measured and simulated values shown in Attachment 3 for the six monitor wells) can be seen by assessing the modeled calibration head levels versus measured (observed) water level records, as shown in the figure below. 28



This comparison facilitates an assessment of the regional models calibration within the local area (i.e., MPGCD Management Zone 1) to assess how well the history match is within this particular area. Based on these results the simulated versus observed water levels do not closely match based on their proximity to the one-to-one line. Additionally, the results appear biased in the positive direction when plotting the residual versus the measured (observed) values. Positive residuals indicate higher observed elevations, meaning the simulated modeled elevations are lower and not representative of aquifer conditions in the Leon Belding Area.



Requested Alternative DFC Assessment

In 2015, the Legislature took notice of the confusion, technical fallacies, understated groundwater availability and hydropolitical gridlock caused by the first cycle of setting DFCs. Additionally, new legislation (SB 332) and the Texas Supreme Court ruling in the Day Case have clarified and strengthened the understanding of **absolute groundwater ownership as a property right and the Rule of Capture.** SB 660 and the associated TWDB rules set forth some important and relevant new considerations for GCDs and GMAs in determining desired future conditions. In establishing DFCs, the following factors as identified in Texas Water Code §36.108 (d) must be considered:

"1. aquifer uses or conditions within the management area, including conditions that differ substantially from one geographic area to another;
  a. for each aquifer, subdivision of an aquifer, or geologic strata and
  b. for each geographic area overlying an aquifer

"2. the water supply needs and water management strategies included in the state water plan;

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

“4. other environmental impacts on spring flow and other interactions between groundwater and surface water;
“5. the impact on subsidence;
“6. socioeconomic impacts reasonably expected to occur;
“7. 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 Section 36.002;
“8. the feasibility of achieving the desired future condition; and,
“9. **any other information relevant to the specific desired future conditions**.”

29 DFCs proposed under Texas Water Code §36.108 (d) must also:

“a. be established for each aquifer, subdivision of aquifer, or geologic strata, or
“b. be established for each geographic area overlying an aquifer in whole or in part or subdivisions of an aquifer, and,
“c. provide a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, recharging, and prevention of waste of groundwater and control of subsidence in the management area” (Texas Water Code 36.108(d-1) and (d-2)).

The considerations that are new and significant with respect to the current cycle of establishing DFCs and MAGs via the joint-planning process are highlighted in bold letters above. Since the implementation of SB 660, the Supreme Court of Texas has reaffirmed the absolute ownership of groundwater (*Day Case*), and that groundwater conservation districts cannot cause a regulatory taking without applicable compensation (*Bragg Case*). 30

Recommended Alternative Management Strategy

The Texas Legislature mandated in SB 660 that GMAs and GCDs consider aquifer storage, inflows and outflows – the 3 components of a water balance – when adopting DFCs. The total water balance is the only true way to measure groundwater availability, and in confined aquifers, storage is the largest component of the water balance. The record of historic water levels in much of the MPGCD area is a great tool to use for the assessment of groundwater availability in the Edwards-Trinity (Plateau)/Pecos Valley Alluvium, and can be assessed through an established water level monitoring program. 31

Based on Texas water law, the history of groundwater management in Texas, the hydrogeologic and hydrologic conditions in the aquifer, and the methods, processes, procedures and results of the initial (2010) DFC adoption by GMA 7, TGI on behalf of FSH proposes the following alternative DFC, or Management Strategy for the portion of the 32

Edwards-Trinity (Plateau) aquifer in the Leon-Belding Area, which can be further applied to almost all the aquifers within and across GMA 7:

- **Delineation of groundwater reservoirs and subdivisions –** As stated previously, the Water Code seems to favor and even emphasize the concept of managing aquifers on the basis of hydrogeologic and hydrologic characteristics, rather than simply on the basis of political subdivision. **"Groundwater reservoir"** means a specified subsurface water-bearing reservoir having ascertainable boundaries containing groundwater" (Texas Water Code 36.001(6)). **"Subdivision of a groundwater reservoir"** means a definable part of a groundwater reservoir in which the groundwater supply will not be appreciably affected by withdrawing water from any other part of the reservoir, as indicated by known geological and hydrological conditions and relationships and on foreseeable economic development at the time the subdivision is designated or altered." (Texas Water Code 36.001(7)). Various reports have illustrated that the Leon-Belding Area is hydrogeologically different from surrounding areas. These difference are perhaps best represented in a map of water level declines across MPGCD's gerrymandered Management Zone 1 from a 2009 report by TGI titled the Ground-Water Supply Assessment City of Fort Stockton, Texas. Attachment 4 is a map that includes contours of water level declines across the Leon-Belding Area, Coyanosa Area, and Fort Stockton in the mid 1970's reflecting changes resulting from pumping activity that occurred between the 1950's and the early 1970's. Reported approximation of pumping from the time period indicate the Leon-Belding Area had at least 500-percent or more pumping during this time frame in comparison to the Coyanosa Area, but water level declines in the Coyanosa area were approximately 75-percent greater than in the Leon-Belding Area. The reason for the greater water level declines can only be attributed to a fundamental difference in the hydrogeologic conditions between the two areas. **This difference in water level declines suggests an aquifer subdivision could be identified to assess these two areas based on hydrogeologic differences and not include these two areas in the same gerrymandered management zone.**
- **Leon-Belding Aquifer Subdivision** - Geologic features have been identified in various well logs and geologic models that show a large trough like structure in the Leon-Belding Area. This structure dates back far enough into geologic time that much of the present day groundwater flow system in the Leon-Belding Area is a direct result of this feature. While the single layer model developed by the TWDB tried to develop model parameters to reflect this structure, the model does not truly reflect the hydrogeologic conditions and importance this feature plays in distinguishing this trough area in the model.

  The unique nature of this area should be evaluated to determine whether it meets the distinct aquifer subdivision defined in the bullet above. This would allow this area to be assigned DFCs based on water levels due to the number of water wells with historic water level data and historic pumping at rates higher than current rates which can be used to document how the aquifer has historically responded. Monitoring data shows that the aquifer is capable of recovery as it has recovered from this historic pumping and the nature of this recovery could serve as guidelines for when water levels within the aquifer indicate that pumping should be curtailed to allow recovery. A detailed study reviewing historic pumping and water levels of various wells in the area could be performed that would result in the identification of an "alert or action" water levels. A DFC or aquifer management strategy based on the historic water level data in and around the Leon-Belding irrigation area in Pecos County, Texas is recommended. Specific monitor wells that have the best available hydraulic information over a period of time with continuation of monitoring and analyses should be identified and utilized.

- **Storage Based Management Conditions–** The Texas Legislature mandated in SB 660 that GMAs and GCDs consider aquifer storage, inflows and outflows – the 3 components of a water balance – when adopting DFCs. As stated previously, the total water balance is the only true way to measure groundwater availability, and in confined aquifers, storage is the largest component of the water balance. The fact that the majority of groundwater in confined aquifers is located in storage is precisely what the legislature identified in mandating that GCDs and GMAs consider total estimated recoverable storage (TERS) and recharge, inflows and discharge when developing DFCs. Storage **must** be considered in context of the Texas Water Code and Texas Administrative Code, as well as hydrogeologically. The Texas Water Law defines total aquifer storage and total estimated recoverable storage (TERS) as follows:

  - "**total aquifer storage"** means the total calculated volume of groundwater that an aquifer is capable of producing (Texas Water Code, §36.001 (24)).
  - **Total Estimated Recoverable Storage –** the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range from 25% to 75% of the porosity adjusted aquifer volume (Texas Administrative Code §356.10 (24)).

It is important that the GCDs developing DFCs understand that large artesian water-level declines can occur locally while having essentially no impact on groundwater availability because of the large capacity of water presently in aquifer storage. Artesian drawdown is not directly tied to aquifer hydraulics (e.g., transmissivity) and is practically not affected by aquifer storage or recharge. Most importantly to the development of DFCs, very small (five percent) reductions in aquifer storage can result in large available aquifer production volumes without causing harm to aquifers. Therefore, it is recommended for all aquifers but the Edwards-Trinity (Plateau) aquifer in GMA 7 that storage-based DFCs be developed. 33

Additional Recommendations

TGI and FSH requests that the MPGCD work with other GCDs within GMA 7 to propose alternative DFCs for the GMA 7 aquifers that meet the requirements of SB 660 by developing DFCs based on scientific assessments of real world aquifer data considering the following criteria as objectives: Ensure that a DFC can be achieved while honoring **law** and **private property rights**, and a DFC that accurately reflects the physical availability of groundwater in the aquifer;

1. Require the assessment of whether a DFC has been impaired based on valid scientific methods that utilize actual water-level monitoring data, specifically in the outcrop areas. Equally important ensure that DFCs are NOT developed relying on the utilization of model runs that contain substantial limitations and assumptions that result in egregious errors when applied on the level of an individual permit, as the errors in the assumptions of the models can be identified and demonstrated through new data collection from exploration, discovery, and aquifer monitoring as *not reflective of current real world conditions* let alone being applicable 60 years in the future; 34
2. Accurately establish an effective water-level monitoring program that has acceptable spatial and temporal coverage across the conterminous aquifers (water-table and artesian portions as appropriate). Existing conditions will serve as the baseline for future assessments of whether storage DFCs are being achieved; 35
3. Recognize that aquifer water table levels and storage change ***very slowly***. Therefore, extending permit terms can be done without adverse ramifications; 36
4. As recommended in TWDB GAM reports, prohibit ***regional*** GAM runs from being utilized outside the clearly defined (by TWDB) limitations of the model such as using site specific levels derived from applying modeled drawdowns to form the basis to grant and deny permits; and, 37
5. Do not base groundwater availability on regional groundwater models developed using production "needs assessments" for regional water planning determinations that have been projected 60 years into the future. 38

GMA 7 Must Address Proposed DFCs per Statutory Requirements

SB660 and subsequent rules in the Texas Water Code have added requirement to GCDs and GMAs in establishing DFCs. DFC submittals must now include:

> "A copy of the adopted desired conditions and **the explanatory report** addressing the information required by Texas Water Code §36.108(d-3) and

> the criteria in Texas Water Code §36.108(d)" (31 Texas Administrative Code §356.32).

The TWDB states that the required **EXPLANATORY REPORT** "…will also be a key document if a petition is filed challenging the reasonableness of a desired future condition" (TWDB 2013). The TWDB also recommends that the explanatory report "…be organized in such a way as to facilitate use by groundwater stakeholders and district conditions" (TWDB 2013). The TWDB notes that, according to Texas Water Code § 36.108 (d-3), "…the district representatives shall produce a desired future conditions explanatory report for the management area and submit to the TWDB and each district in the management area proof that notice was posted for the joint planning meeting, a copy of the resolution, and a copy of the explanatory report. The report must:

> "1. identify each desired future condition;
> 2. provide the policy and technical justifications for each desired future condition;
> 3. include documentation that the factors under Texas Water Code §36.108 (d) were considered by the districts and a discussion of how the adopted desired future conditions impact each factor;
> 4. list other desired future condition options considered, if any, and the reasons why those options were not adopted; and,
> 5. discuss reasons why recommendations made by advisory committees and relevant public comments received by the districts were or were not incorporated into the DFCs."

Exclusion of the Proposed Alternative DFCs submitted herein as *relevant public comments* would be justification for filing an appeal of the reasonableness of any DFCs presented. HB200 passed in 2015 allows affected persons to file appeals challenging the reasonableness of desired future conditions through the State Office of Administrative Hearings. 39

Conclusion

TGI appreciates the opportunity to provide you this assessment of the currently proposed GMA 7 DFCs, and to present you with an alternative DFC methodology for formal consideration. TGI believes the alternative DFC methodology recommended herein to GMA 7 and MPGCD should be given serious consideration, and fully evaluated before the GMA and MPGCD, finalize the adoption of the proposed 2016 DFCs that are legally and scientifically flawed.

The alternative DFC proposed herein best honors Texas Water Law, private property rights associated with the absolute ownership of groundwater, the Rule of Capture, and represents a true assessment of the aquifer's capability to produce long-term groundwater supplies based on coterminous aquifer's water balance. The development of storage based DFCs for Capitan Reef, Dockum, and Rustler aquifers as well as aquifer condition based DFCs evaluated against historic water levels specific to the Edwards-Trinity (Plateau) aquifer in the Leon-Belding Area in Pecos County.

On behalf of FSH, TGI looks forward to working with GMA 7 and its consultants in evaluating an alternative DFC as described herein, and in improving groundwater management in the region and in our State.

If you have any questions, please call.

STATE OF TEXAS
BRIAN K. BOHM
GEOLOGY
10141
LICENSED PROFESSIONAL GEOSCIENTIST

Sincerely,
THORNHILL GROUP, INC.

Brian K. Bohm, P.G.
Managing Associate

STATE OF TEXAS
ELIZABETH FERRY
GEOLOGY
11011
LICENSED PROFESSIONAL GEOSCIENTIST

The seal appearing on this document was authorized by Elizabeth Ferry, P.G. on August 11, 2016.

Elizabeth Ferry, P.G.
Senior Hydrogeologist

cc: Mr. Jeff Williams, Fort Stockton Holdings, L.P.
Mr. Ed McCarthy, Jackson, Sjoberg, McCarthy & Townsend, L.L.P.
Ms. Carolyn Runge, GMA 7 Administrator
Dr. Bill Hutchinson, P.E., P.G.

Attachments

Attachment 1

Texas Water
Development Board

P.O. Box 13231, 1700 N. Congress Ave.
Austin, TX 78711-3231, www.twdb.state.tx.us
Phone (512) 463-7847, Fax (512) 475-2053

April 28, 2011

Edmond R. McCarthy, Jr., Esq.
Jackson, Sjoberg, McCarthy & Wilson, L.L.P.
711 West 7th Street
Austin, Texas 78701

Michael A. Gershon, Esq.
Lloyd Gosselink, Attorneys at Law
816 Congress Avenue, Suite 1900
Austin, Texas 78701

Gentlemen:

Our chairman asked me to respond to your letters concerning the use of the groundwater model for the Edwards-Trinity (Plateau) Aquifer in the Middle Pecos Groundwater Conservation District (letters from Mr. McCarthy dated March 16, 2011, and April 1, 2011, and a letter from Mr. Gershon dated March 26, 2011).

Mr. Randy Williams, on behalf of the Middle Pecos Groundwater Conservation District, requested that we provide average drawdown values for proposed management zones in Pecos County. Our response to that request was GAM Task 10-033. GAM Task 10-033 simply reports those drawdown values, based on the groundwater model simulations used to develop the desired future conditions for groundwater management areas 3 and 7. GAM Task 10-033 is not a Texas Water Development Board (TWDB) endorsement of the district's management approach or an indication that the model is the appropriate tool to guide the regulation of the aquifer in the management zones.

The development of a groundwater model is an objective-driven process. Models are developed with a specific objective in mind and are calibrated accordingly. We developed the groundwater availability models as regional tools to assist stakeholders in estimating groundwater availability, a task presently accomplished through the desired future conditions process. This does not mean that a model would not be useful for a different purpose or at a sub-regional scale.

Our Mission

To provide leadership, planning, financial assistance, information, and education for the conservation and responsible development of water for Texas

Board Members

Edward G. Vaughan, Chairman
Thomas Weir Labatt III, Member
Joe M. Crutcher, Member
Lewis H. McMahan, Member
Billy R. Bradford Jr., Member
Monte Cluck, Member

Melanie Callahan, Interim Executive Administrator

An appropriate analysis, using appropriate data, would need to be completed to determine whether or not use of the model for a different purpose or at a different scale is appropriate. We did not do this analysis as part of GAM Task 10-033.

It is generally appropriate to use the results of a predictive run of a regional groundwater model to provide a framework or overview of results at a more local scale. A common example of this is interpreting groundwater elevation or drawdown contours derived from the results of a regional model on a county or sub-county scale. In this case, GAM Task 10-033 provides at least a framework or overview of potential future drawdowns in each of the management zones. However, it is not possible to determine whether it is appropriate to use these results for regulatory purposes without first (1) assessing the calibration of the model at the scale of the question (the management zones) and (2) assessing the assumed amount and distribution of predicted pumping within the management zones that is associated with the predicted drawdown. In response to questions in early February, Dr. Bill Hutchison of my staff discussed the need for this type of analysis with Mr. Williams. He also discussed the same issues with Mr. Mike Thornhill.

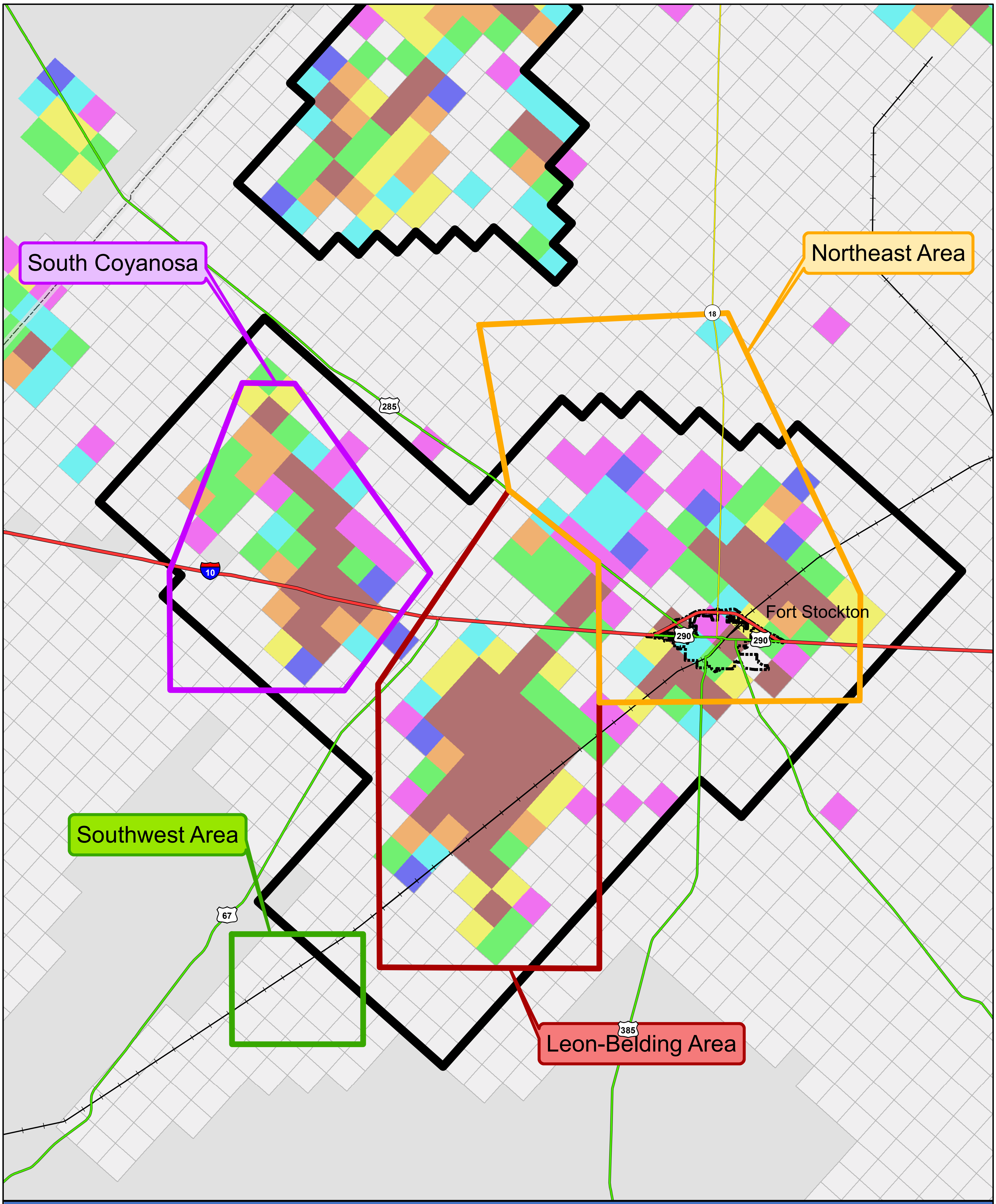
Please let me know if you have any questions or comments.

Respectfully,

Robert E. Mace, Ph.D., P.G.
Deputy Executive Administrator
Water Science and Conservation

c: Edward G. Vaughan, Chairman, TWDB
Melanie Callahan, Interim Executive Administrator, TWDB
Ken Petersen, General Counsel

Attachment 2



Area	Historic and Existing Use Permit Amount (ac-ft/yr)	GAM Run: GMA 7 Scenario 10 Pumpage Amount (ac-ft/yr)	Difference Between GAM Run and HEU Permits
Leon-Belding	69,342.8	59,045.4	(10,297.4)
Northeast	3,297.5	31,213.7	27,916.2
Southwest	210.0	3.6	(206.4)
South Coyanosa	12,554.8	29,373.7	16,818.9
MPGCD Management Zone 1 per Cell Identification Table	90,753.0	123,341.4	32,588.4

Explanation

Pumpage (ac-ft/yr)

⬜	0 - 25	🟩	251 - 500
🟪	26 - 50	🟨	501 - 750
🟦	51 - 100	🟧	751 - 1,000
🟦	101 - 250	🟥	1,001 - 9,410

MPGCD Management Zone per Cell Identification Tables

Interstate

US Highway

State Highway

Rail Road

City Limits

Texas Counties

N

0 40,000

Feet

Fort Stockton Holdings, L.P.

Pumpage Distribution in
Management Zone 1 for
GAM Run: GMA 7 Scenario 10

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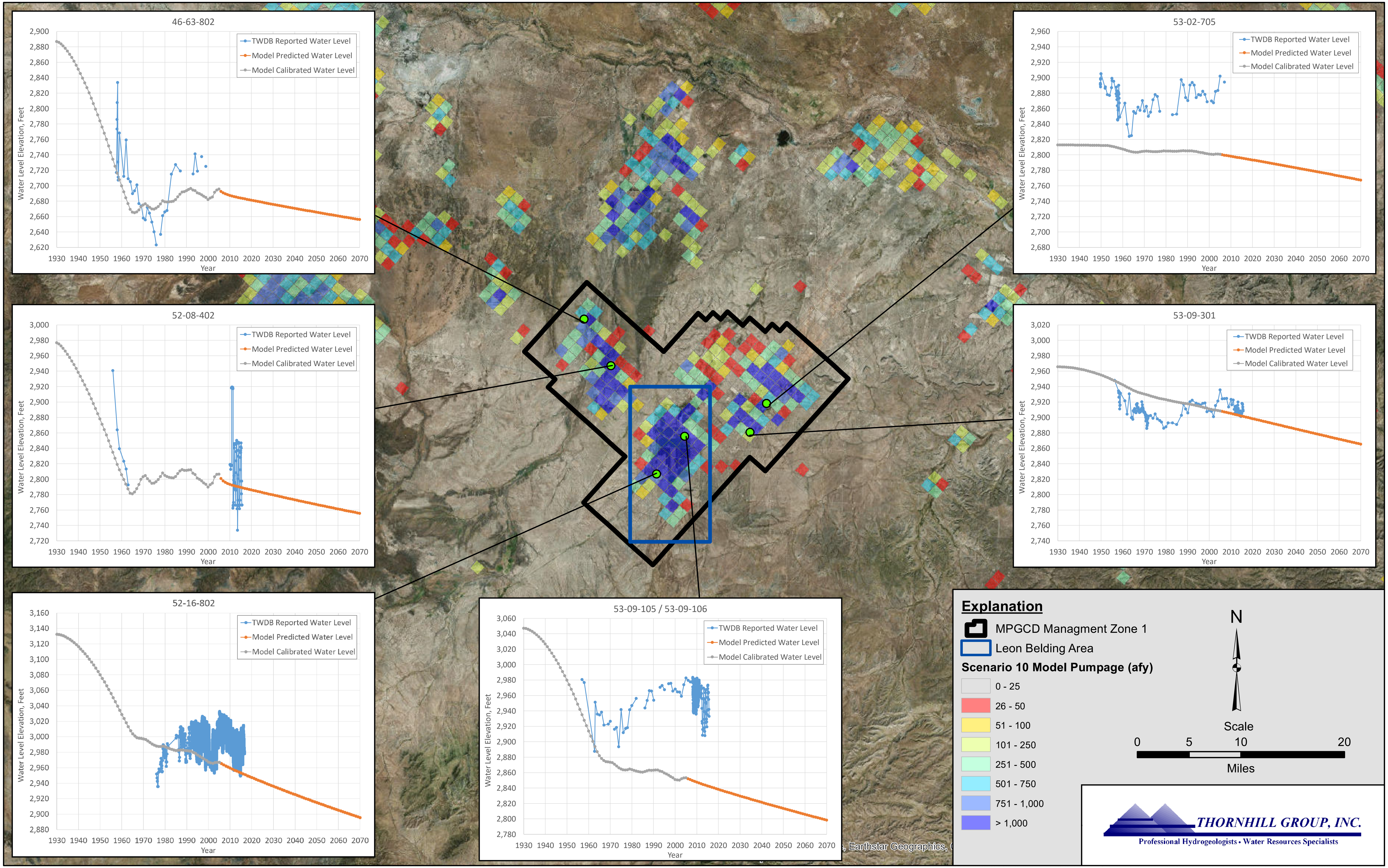
Attachment 3


46-63-802
Water Level Elevation, Feet
2,900
2,880
2,860
2,840
2,820
2,800
2,780
2,760
2,740
2,720
2,700
2,680
2,660
2,640
2,620
1930 1940 1950 1960 1970 1980 1990 2000 2010 2020 2030 2040 2050 2060 2070
Year
TWDB Reported Water Level
Model Predicted Water Level
Model Calibrated Water Level
52-08-402
3,000
2,980
2,960
2,940
2,920
2,900
2,880
2,860
2,840
2,820
2,800
2,780
2,760
2,740
2,720
52-16-802
3,160
3,140
3,120
3,100
3,080
3,060
3,040
3,020
3,000
2,980
2,960
2,940
2,920
2,900
2,880
53-09-105 / 53-09-106
3,060
3,040
3,020
3,000
2,980
2,960
2,940
2,920
2,900
2,880
2,860
2,840
2,820
2,800
2,780
53-02-705
2,960
2,940
2,920
2,900
2,880
2,860
2,840
2,820
2,800
2,780
2,760
2,740
2,720
2,700
2,680
53-09-301
3,020
3,000
2,980
2,960
2,940
2,920
2,900
2,880
2,860
2,840
2,820
2,800
2,780
2,760
2,740
, Earthstar Geographics, (
Explanation
MPGCD Managment Zone 1
Leon Belding Area
Scenario 10 Model Pumpage (afy)
0 - 25
26 - 50
51 - 100
101 - 250
251 - 500
501 - 750
751 - 1,000
> 1,000
N
Scale
0 5 10 20
Miles
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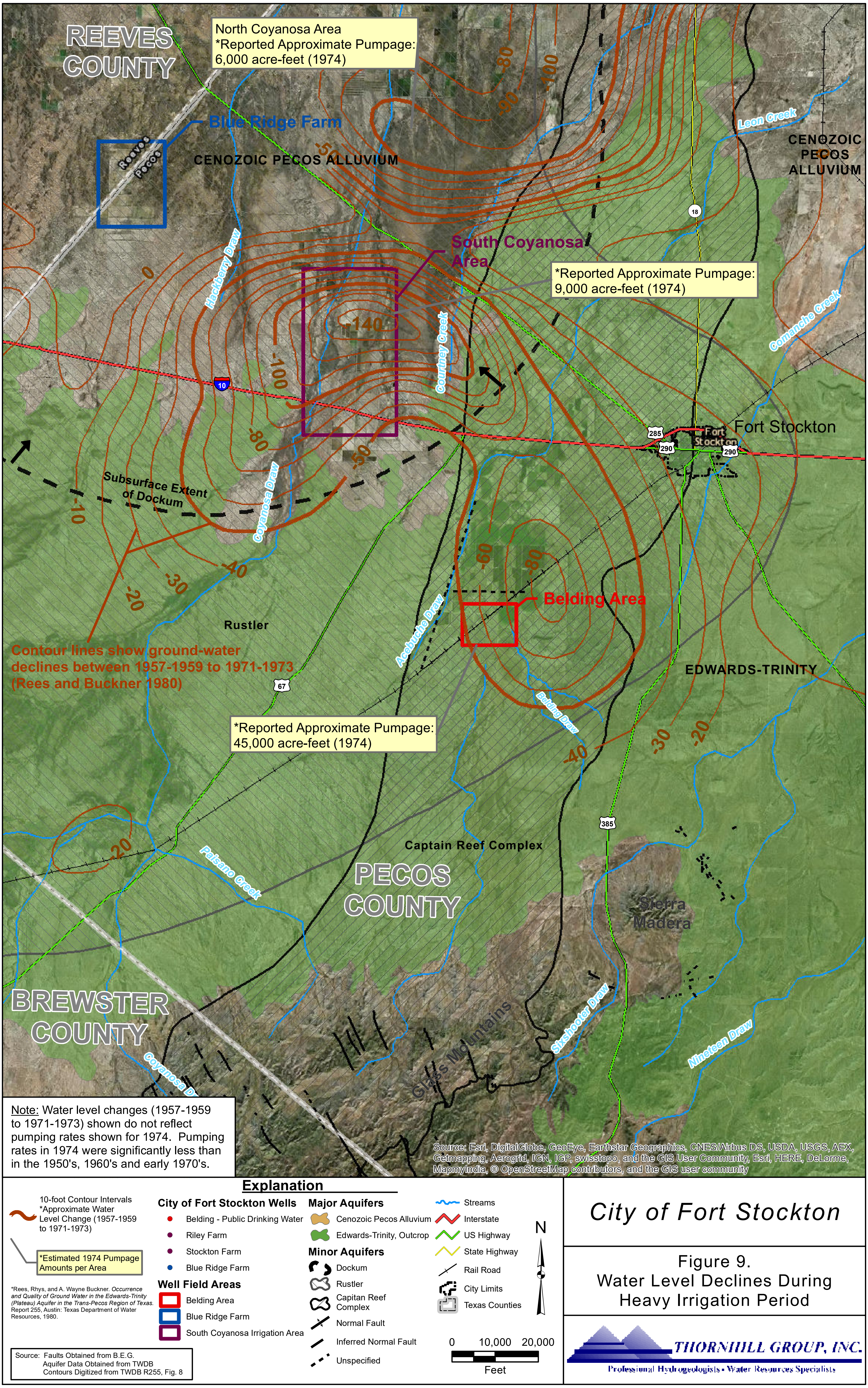
Attachment 4



Note: Water level changes (1957-1959 to 1971-1973) shown do not reflect pumping rates shown for 1974. Pumping rates in 1974 were significantly less than in the 1950's, 1960's and early 1970's.

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community, Esri, HERE, DeLorme, MapmyIndia, © OpenStreetMap contributors, and the GIS user community

*Rees, Rhys, and A. Wayne Buckner. *Occurrence and Quality of Ground Water in the Edwards-Trinity (Plateau) Aquifer in the Trans-Pecos Region of Texas.* Report 255, Austin: Texas Department of Water Resources, 1980.

Source: Faults Obtained from B.E.G.
Aquifer Data Obtained from TWDB
Contours Digitized from TWDB R255, Fig. 8

City of Fort Stockton

Figure 9.
Water Level Declines During Heavy Irrigation Period

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Appendix F

Responses to August 11, 2016 Comments Contained in Letter from Thornhill Group, Inc.

This appendix details responses to the comments contained in the August 11, 2016 letter to Mr. Paul Weatherby of the Middle Pecos GCD. The comments were made on the proposed desired future conditions in GMA 7, specifically in Middle Pecos GCD. A copy of the letter appears at the end of this appendix with numerical notations in the right margin. Specific responses to the comments are presented below.

Comment 1

The comment simply stated that the letter was written on behalf of Fort Stockton Holdings, a stakeholder.

Comment 2

The comment is incorrect. GMA 7 did consider all factors, including the total estimated recoverable storage prior to voting on a proposed desired future condition.

Comment 3

The comment is incorrect. GMA 7 did consider a “balance between the highest practicable level of groundwater production and the conservation, preservation, recharging, and prevention of waste of groundwater and the control of subsidence in the management area”. This is evidenced by the numerous model runs that were considered in 2010 for the initial desired future condition and the proposed desired future condition (2016).

Comment 4

Drawdown is the difference between measured groundwater levels taken at two different times. All other things being equal, a positive drawdown connotes that pumping has increased over the time interval of interest, a zero drawdown connotes that pumping is essentially unchanged and an equilibrium has been reached, and a negative drawdown connotes that pumping has decreased over the time interval of interest. The Texas Water Development Board has approved as administratively complete drawdown-based desired future conditions.

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

Comment 5

Desired future conditions are planning goals, and not regulatory limits. This comment imputes a regulatory context to desired future conditions that are not present. To the extent that groundwater conservation districts must manage to meet desired future conditions, there is the potential for misuse and blind application of desired future conditions to permitting decisions, but this is potentially true of any desired future condition whether based on drawdown, spring flow, or storage. This comment is not relevant since it has nothing to do with the establishment of desired future conditions.

Comment 6

Citation of guidance documents from 2001 and 2008 is now irrelevant since the changes to the desired future condition process in 2011 in accordance with SB 660.

Comment 7

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), and evaluating the impacts of changes in pumping (e.g. spring flow, surface water-groundwater interactions). For the Edwards-Trinity (Plateau) and Pecos Valley aquifers, numerous scenarios were completed, and the results discussed prior to voting on a proposed desired future condition.

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

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

The critique also relies on a 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 is a process to quantify cause-and-effect relationships and to make useful predictions.

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

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

Comment 8

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

However, the mere reporting of the drawdowns on a county level and the thrust of this comment ignore the process that has been ongoing in GMA 7 since 2010. The districts in Groundwater Management Area 7 initiated the process with a county-by-county estimate of future pumping, and this represented Scenario 1. Scenario 2 represented a 10 percent increase in pumping in each county of Groundwater Management Area 7 as compared to Scenario 1. Scenarios 3, 4, and 5 represented 20, 30, and 40 percent pumping increases in each county of Groundwater Management Area 7, respectively. The results of Scenarios 1 to 5 were summarized, distributed to the district representatives, and discussed at the July 29, 2010, meeting of Groundwater Management Area 7. The discussion focused on the districts' "vision" of groundwater conditions that qualitatively described the need to minimize drawdown in the eastern portion of Groundwater Management Area 7 to maintain spring flow and river baseflow and allow for drawdown in the western portion of Groundwater Management Area 7 where irrigated agriculture used large amounts of groundwater. The primary issue that needed to be resolved was the compatibility of these two qualitative goals. Recall that the purpose of joint planning was to regionalize groundwater management decisions among neighboring districts within a groundwater management area. Groundwater Management Area 7 included twenty groundwater conservation districts (the most in any groundwater management area), and the dynamics of discussing the impacts of various pumping scenarios was unique given the large number of stakeholders.

At the meeting, and after the general relationship between pumping and drawdown was presented and discussed, the district representatives provided updates to pumping on a county-by-county basis. Those updated pumping amounts were input into the model and runs were completed at the meeting, and the results summarized and discussed. Scenarios 6 to 10 were run during the meeting in this iterative fashion based on this input from the district representatives. After review of these model runs, the districts adopted Scenario 10 as meeting their qualitative vision of future drawdown conditions as their desired future condition.

Comment 9

As described above, in 2010, GMA 7 focused on the qualitative goal to minimize drawdown in the eastern portion of GMA 7 and provide for increased pumping in the western portion of GMA 7. The key aspects of using the model was to quantitatively evaluate the compatibility of these separate goals. The proposed desired future condition adopted in 2016 was based on the desired future condition adopted in 2010, after an updated assessment of uses and needs which are included among the nine statutory factors that have to be considered before voting on a proposed desired future condition.

The assertion in the comment that the proposed desired future condition is "based on political boundaries" is simply not true.

Comment 10

The full water balance was considered as required. However, the comment incorrectly defines the components of a water balance. The correct definition is the accounting of all inflows, all outflows, and the ***change*** in storage. The comment seems to confuse the concept of change in storage with total storage.

Total storage is a required factor to consider, and GMA 7 received and reviewed the Total Estimated Recoverable Storage estimates from the TWDB. However, the total storage is not a component of the water budget.

Comment 11

This subject has been covered in the response to Comments 8 and 9 (reverse engineering). It should be noted that the representatives of the Thornhill Group were present and actively participated at the July 29, 2010 GMA 7 meeting. Their participation included assisting the substitute representative of the Middle Pecos GCD in formulating the assumed pumping for input in the model simulations at the meeting after some initial confusion by the substitute representative of Middle Pecos GCD.

Comment 12

A description of the model runs, the underlying goals of the simulations, and the context of the discussion of the results in 2010 and again in 2016 have been covered in the response to comments 8 and 9.

Comment 13

The characterization of what the "initial and primary consideration" is not accurate. As stated above, models require pumping as input and one of the outputs is drawdown. As discussed above, the simulations were completed to evaluate the impacts of alternative pumping amounts. The primary consideration was the evaluation of GMA 7's qualitative vision of minimal drawdown in the eastern part of GMA 7 to protect spring flow and river base flow, and provide for increased pumping in the western portion of GMA 7.

Comment 14

The reference to the original legislation regarding MAGs is not relevant since:

- The term has since been changed (modeled available groundwater now versus managed available groundwater in the original legislation),
- The specifics of what a MAG is has changed in subsequent legislative sessions, and
- How the TWDB views MAGs has changed in the regional planning process.

Also, as stated above in the response to Comment 5, to the extent that GCDs must manage to meet desired future conditions, there is the potential for misuse and blind application of desired future conditions to permitting decisions, but this is potentially true of any desired future condition whether based on drawdown, spring flow, or storage. This comment is not relevant since it has nothing to do with the establishment of desired future conditions.

Comment 15

As stated above in the response to Comment 5 and Comment 14, the potential for misuse of the desired future condition is a valid concern, but this is more of a criticism of the process and not a specific comment on the proposed desired future conditions themselves.

Comment 16

This comment relies on statutory language regarding the creation of a groundwater conservation district (not the joint planning process). The incorrect assertion that the proposed desired future conditions were developed primarily along political boundaries has been discussed above in the response to Comments 8, 9, 12 and 13.

Comment 17

This comment is primarily about the management zones in Middle Pecos GCD. The proposed desired future condition has not been further subdivided into these management zones at the GMA 7 level, and it is therefore not possible to specifically respond to the issues raised.

An evaluation was of these management zones was attempted using the USGS groundwater model of Pecos County, the results of which are summarized in Technical Memorandum 17-01. Unfortunately, the model limitations prevent reliable predictive simulations or the evaluation of the management zone concept in Middle Pecos GCD.

Comment 18

As stated above in the responses to Comments 8, 9, 12, 13, and 16, this is a mischaracterization of the basis for the proposed desired future condition.

Comment 19

This is not a specific comment on the desired future condition, but rather an interpretation of statutory intent on the appropriate scale of groundwater management. Desired future conditions are planning goals, and are largely policy decisions made after considering nine statutory factors. The legislature has created the groundwater conservation districts to manage groundwater, and has required the districts to meet within designated groundwater management areas to conduct joint planning.

Comment 20

Mr. Hunt's comments were made in 2009, which was during the time that the initial desired future conditions were being developed. The first round had minimal statutory guidance as to what should be considered when establishing desired future conditions. Since then, the legislature has better defined the process by requiring groundwater conservation districts to consider nine specific factors (some that are technical and some that are more rooted in planning and policy). The proposed desired future conditions that are the subject of the comment letter were proposed after considering those statutory factors.

Mr. Hunt's discussion was focused on a single factor: the physical capability of the aquifer to produce water. This is only one of the factors that groundwater conservation districts in GMA 7 considered prior to voting on the proposed desired future conditions. In the context of the lack of specific statutory guidance at that time (2009), Mr. Hunt's was advocating that the physical capability of the aquifer to produce groundwater should be the dominant issue when establishing desired future conditions. Since then, the legislature updated the process to include nine factors, only one of which involves the physical ability of the aquifer to produce groundwater. Thus, given the current statutory language regarding the nine factors, the comment is not relevant.

Comment 21

Average drawdown is an appropriate means to quantify a planning goal. As stated in the response to Comment 4, drawdown is the difference between measured groundwater levels taken at two different times. All other things being equal, a positive drawdown connotes that pumping has increased over the time interval of interest, a zero drawdown connotes that pumping is essentially unchanged and an equilibrium has been reached, and a negative drawdown connotes that pumping has decreased over the time interval of interest. Thus, the result of the planning goal can be broadly interpreted as, over the planning period, pumping will increase, pumping will remain the same, or pumping will decrease.

This comment letter is an example of disagreements on a policy level as to how much pumping should increase. However, the joint planning process in GMA 7 began with an overall qualitative “vision” (minimal drawdown in the east and provide for increased drawdown in the west), considered a wide range of alternatives, and the potential impacts of the alternatives have been evaluated with the assistance of model simulations. The alternatives were developed, in part, based on the historic and future use of the aquifer (as required by statute).

Comment 22

This comment misstates the statutory requirements, and misstates the components of a water balance. The specific requirements in statute include total estimated recoverable storage as provided by TWDB and the average annual recharge, inflows and discharge. These are included in the third factor. In addition, the fourth factor requires consideration of the impacts on spring flow and other interactions between groundwater and surface water. These factors were considered.

As stated in the response to Comment 10, the correct definition of a water balance is the accounting of all inflows, all outflows, and the ***change*** in storage. The comment seems to confuse the concept of change in storage with total storage. Change in storage is an important factor since it can be used to characterize pumping increases, pumping stability, or pumping decreases over a specified interval of time.

As stated in the response to Comment 4 and 21, change in storage can be calculated by drawdown, which is the difference between measured groundwater levels taken at two different times. All other things being equal, a positive drawdown connotes that pumping has increased over the time interval of interest (and storage has decreased), a zero drawdown connotes that pumping is essentially unchanged and an equilibrium has been reached (and storage is unchanged), and a negative drawdown connotes that pumping has decreased over the time interval of interest (and storage has increased).

Comment 23

The total estimated recoverable storage is not part of the water budget. Also, when developing desired future conditions, the statute requires that other factors also be considered (e.g. impacts on spring flow and impacts to groundwater-surface water interactions). The consideration of these other factors will tend to result in a desired future condition that is different than a desired future condition that is only based on the physical ability of the aquifer to produce groundwater.

Comment 24

This comment is predicated on the false assertion that the proposed desired future conditions were primarily based on political boundaries and were reverse-engineered. Responses to comments 8, 9, 12, 13, 16, and 18 have covered this subject.

Comment 25

Model limitations were taken into consideration, and were an important part of the discussion at GMA 7 meetings.

Comment 26

Model limitations were taken into consideration. The potential misuse of models by individual districts in permitting decisions is not a relevant comment on the development of desired future conditions.

Comment 27

There are two issues raised in this comment: 1) historic pumping total versus Scenario 10 pumping, and 2) historic pumping distribution versus Scenario 10 pumping distribution.

As stated in the comment, the Scenario 10 pumping (i.e. simulated future pumping) is about 32,000 AF/yr more than historic pumping, and characterized this as an "overestimation". The simple matter is that Scenario 10 simulated an increase in future pumping over the historic to evaluate the potential impacts of that pumping.

The pumping distribution issue is acknowledged. The regional model used the best available information to distribute the pumping. To the extent that the distribution is inaccurate, this is a model limitation that is well known. This is one of the reasons that the models should only be used for regional assessments, and not local-scale simulations, which was done in this case.

The overall tone of the comments up to this point in the letter has been that the desired future conditions do not provide for sufficient pumping increases, will cause "paper shortages" and infringe on property rights. This comment is therefore confusing since the specific outcome of the proposed desired future condition will be a greater than 30 percent increase in pumping in Management Zone 1 of Pecos County over historic uses.

Comment 28

This comment points out a limitation in the regional model regarding the Leon Belding area. As discussed in the response to Comment 27, this limitation is well known. The model was used on a regional basis. It is agreed that this limitation is serious in the context of using the regional model for site-specific analyses (i.e. analyses associated with permitting decisions in the Leon Belding area). However, that comment is not relevant to the use of the model to evaluate regional conditions.

Comment 29

This comment is simply repeating the factors that must be considered prior to voting on a proposed desired future condition, which was done.

Comment 30

This comment mischaracterizes the "new joint planning process". The bolded items were added to the statute at the same time as the non-bolded items, all in SB 660.

The comment incorrectly suggests that the most important factors are the physical ability of the aquifer to produce water (factor 3) and the property rights (factor 7). However, there is no statutory language regarding the relative importance of one factor over another.

Comment 31

Again, the comment mischaracterizes the components of a water balance. Total storage was considered as required, and the inflows, outflows and change in storage were considered as required. However, total storage is not part of a water balance.

Comment 32

This comment offers an alternative desired future condition. The individual parts of the recommendation are discussed below:

Delineation of groundwater reservoirs and subdivisions – This comment is focused on the Leon Belding area in Pecos County, and not on the entirety of GMA 7. As discussed in the responses to previous comments, GMA 7 did qualitatively view GMA 7 in areas (east and west), and provided for minimal drawdown in the east to protect spring flow and river base flow, and provide for drawdown in the west. The model was used to evaluate the compatibility of the two separate goals. The desired future conditions are reported on a county and district basis for administrative convenience. The comment goes more to the specifics of a Pecos County, which is more appropriate for groundwater management at a district level. Based on the comment, it appears that there is disagreement on how the Leon Belding area should be defined. The comment recognizes that it is "hydrogeologically different", but disagrees with the way Middle Pecos GCD has defined Management Area 1. This is not a relevant comment for purposes of the desired future condition.

Leon Belding Aquifer Subdivision - This comment recommends that the Leon Belding area be designated as a subdivision and a separate desired future condition be established based on water levels since the regional model has limitations. Furthermore, the comment recommends detailed study to establish "alert or action" levels in water levels to curtail pumping. This recommendation is more appropriate for district-level groundwater management, and not appropriate for desired future conditions that are regional in nature. It is also confusing since the proposed desired future condition would result in over 30 percent increase in historic pumping (please see the response to Comment 27).

Storage Based Management Conditions – This comment (again) mischaracterizes the components of a water balance, which is an accounting of all inflows, outflows and ***change*** in storage (not total storage as stated in the comment). The comment also emphasizes the physical ability of the aquifer to produce groundwater, and states that the water balance is the "only true way to measure groundwater availability". The comment attempts to define the term “groundwater availability” as meaning only physical availability. However, as defined by statute, groundwater availability is largely a policy decision, and is defined and constrained by many factors. Physical availability is only one of these factors. The use of average drawdowns for desired future conditions is appropriate and can be assessed based on changes in measured groundwater levels. Measured groundwater levels would also be needed to assess storage-based desired future conditions, but with additional assumptions and calculations on aquifer geometry. Thus, the use of drawdown-based desired future conditions is superior since their evaluation require less in the way of assumptions and calculations.

Comment 33

This recommendation to establish a desired future condition of five percent reduction in storage ignores issues related the other factors, ignores the balancing requirements of the statute, and, in some cases, is not even achievable.

Comment 34

Monitoring of groundwater levels is a routine activity of the groundwater conservation districts and the Texas Water Development Board. These data provide the foundation to evaluating management decisions related to desired future conditions. The use of models in evaluating alternatives and analyzing the impacts of the alternatives in the context of the nine factors is appropriate.

Comments regarding the misuse of models in permitting decisions are not relevant to the establishment of desired future conditions.

Comment 35

As discussed in the response to Comment 34, monitoring of groundwater levels is a routine activity of the groundwater conservation districts and the Texas Water Development Board. These data provide the foundation to evaluating management decisions related to desired future conditions.

Comment 36

The comment is not relevant since permit terms have nothing to do with desired future conditions.

Comment 37

The comment is not relevant since the misuse of models in permitting decisions has nothing to do with desired future conditions.

Comment 38

One of the factors that need to be considered by statute is the “water supply needs and water management strategies included in the state water plan” (factor 2). This factor was even quoted in an earlier part of the comment letter. However, this comment seems to recommend that GMA 7 ignore this factor, and that no consideration be given to future needs in a long-term planning process. This comment is neither appropriate nor relevant since GMA 7 has endeavored to comply with the statutory requirements of the Texas Water Code and the Administrative Rules of the Texas Water Development Board in the joint planning process.

Comment 39

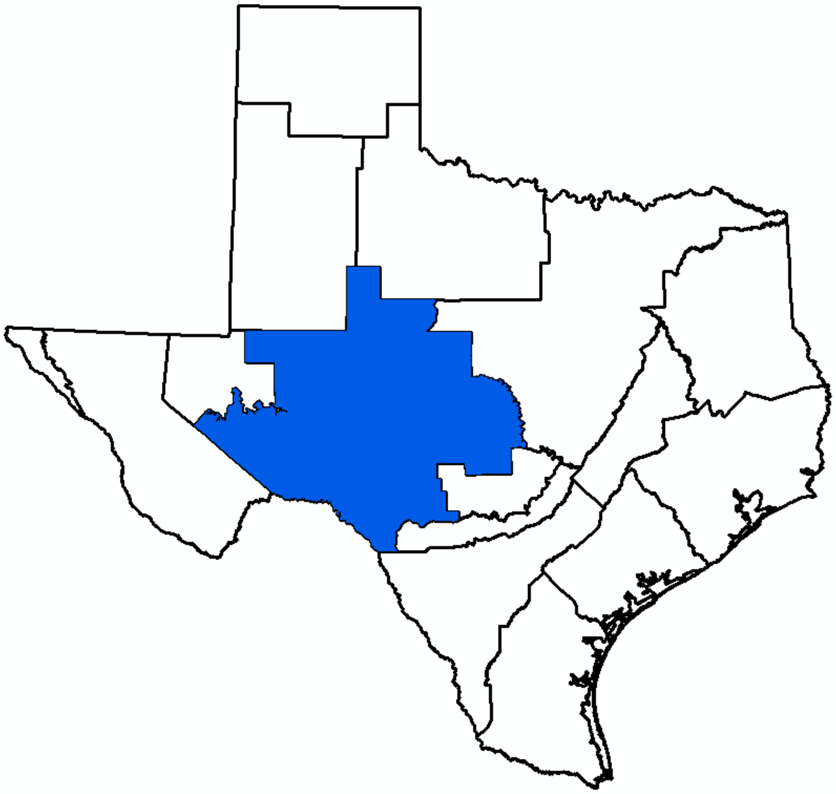
The explanatory report is not required until after the final desired future condition is adopted. This appendix is included in the explanatory report to respond to the comments provided, and to discuss the reasons the recommended desired future conditions were not incorporated into the desired future condition.

Appendix G

Simulations with USGS Groundwater Model of Pecos County Region
(GMA 7 Technical Memorandum 17-01)

GMA 7 Technical Memorandum 17-01
Draft 2

Simulations with USGS Groundwater Model of Pecos County Region



Prepared for:
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February 13, 2017

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1.0 Introduction

This technical memorandum documents simulations using the USGS Groundwater Model for the Pecos County region. These simulations were completed in response to public comments of the proposed desired future condition for the Edwards-Trinity (Plateau) and Pecos Valley Aquifers.

The proposed desired future conditions were approved by GMA 7 on April 21, 2016. During the public comment period, Middle Pecos GCD received oral and written comments that included the possible use of the USGS model (Clark and others, 2014) in the development of desired future conditions. This model had not been used in the process of developing the proposed desired future condition from 2014 to 2016.

Initial review of the model suggested that it may be a better tool since it explicitly simulated flow from Comanche Springs, divided the flow system into multiple layers, had a more refined model grid, and had a more detailed and realistic specification of pumping. However, as detailed in this technical memorandum, the model, as currently constructed, is not useful for predictive simulations.

2.0 USGS Groundwater Model for the Pecos County Region

As stated in Clark and others (2014), the USGS report

> *"documents the development of a numerical model describing groundwater flow of the Edwards-Trinity and related aquifers in the Pecos County region, Tex., and summarizes potential future pumping scenarios simulated with the model. The sustainability of recent (2008) and projected water-use demands on groundwater resources in the Pecos County region study area were evaluated through the year 2040."*

2.1 Discretization

The model code used for this effort was MODFLOW-2005, a finite difference code developed by the USGS that requires the model domain to be discretized into a regular grid of cells. As described in Clark and others (2014), the Pecos County region was discretized into a 5-layer grid of cells. The grid consisted of 156 rows and 174 columns with uniform cells size of ½ mile by ½ mile. From top to bottom, the five layers represented: 1) the Pecos Valley Aquifer, or the alluvial layer, 2) the Edwards formation, 3) the Trinity formation, 4) the Dockum Aquifer, and 5) the Rustler Aquifer.

2.2 Lateral and Vertical Boundary Conditions

Of note in the construction of the model are the lateral flow boundary conditions (simulated with the general head boundary package of MODFLOW) and the use of time-variant constant heads to simulate heads in the Rustler Aquifer.

The lateral boundary conditions using the general head boundary (GHB) package were placed on the western, northwestern, north, and southeastern perimeters of the model area in layer 3 (Trinity layer) (Clark and others, 2014, pg. 10). Heads assigned to the boundary condition varied with space and time as described in Clark and others (2014, pg. 10).

The use of the time-variant constant head (CHD) package was intended "to represent water levels in the Rustler Aquifer" (Clark and others, 2014, pg. 12). The CHD input file lists 650 cells, all in layer 5, that allow interaction between the boundary and the aquifer system. Since layer 5 of the model is the Rustler Aquifer, these boundaries are, in effect, a means to specify heads in layer 5 (in cells where the CHD package is used), and allow for inflows and outflows outside the model domain (effectively with formations below layer 5).

A key feature of the implementation of the CHD package was how the heads changed with time during the calibration period. Clark and others (2014, pg. 29) noted that simulated flow at Comanche Springs did not gradually decline and then cease until addition of these boundaries in layer 5. In support of this approach, Clark and others (2014, pg. 29) cited Ewing and others (2012). Furthermore, Clark and others (2012, pg. 29) cited a geochemical analysis by Bumgarner and others (2012) that suggested “upwelling of groundwater from the Rustler Aquifer in localized areas”.

Ewing and others (2012) is a model of the Rustler Aquifer. The Rustler model is a two-layer model where layer 2 is the Rustler Aquifer and layer 1 represents all the younger overlying layers. Ewing and others used the GHB package to simulate overlying formations (in layer 1) to interact with the aquifer of interest in layer 2 (the Rustler Aquifer). A detailed description of how to use the GHB package in a predictive simulation is presented in Ewing and others (2012, pg. 11-3 and 11-4). A similar approach was used by Ewing and others (2008) for the Dockum Aquifer.

The use of GHBs for these models simply allowed interaction with overlying formations by specifying a temporally changing set of heads to simulate the interaction between the overlying formations and the aquifer of interest (either the Dockum or the Rustler). An important consideration in applying GHBs to simulate interactions with formation that overlie the area of interest is how to specify heads for predictive simulations. Hutchison (2016) described how the GHB package was applied in the Rustler Aquifer for predictive simulations for GMA 7. The issue of use of GHBs for the Dockum Aquifer in 2010 for predictive simulations resulted in modifying and recalibrating the model as described in Oliver and Hutchison (2010).

Clark and others (2014) completed predictive simulations that simply used the specified heads in the CHD package from the last stress period of the calibration period, and did not provide for any change during the 30-year predictive runs (years 2010 to 2040). Initial simulations using the USGS model in response to the public comments using the approach employed by Clark and others (2014) yielded results that were inconsistent with a conceptual understanding of the groundwater flow system and, to a certain extent, by anecdotal observations (i.e. large reductions in pumping should result in increases in spring flow). Thus, a more detailed review was completed to understand the USGS model.

2.3 Summary of CHD Specifications

CHD boundary specifications included 650 cells in layer 5. Cell-by-cell boundary heads changed for each of the 144 stress periods as described in Clark and others (2014). Because Clark and others (2014, pg. 29) stated that the CHD package was needed to simulate the reduction and cessation of spring flow during the calibration period the initial review focused on CHD boundary cells that underlie the Comanche Springs area. Comanche Springs is simulated in nine cells in layer 2 of the USGS model using the Streamflow Routing Package (SFR). Two of these SFR cells directly overlie two of the CHD cells in layer 5. Figure 1 presents the time-history of the head specification of these two CHD cells.

Please note that each of these cells included a sharp drop from 1940 to about 1960, and a more gradual decline from 1960 to 2010. Overall, total head decline for these two cells was estimated to be about 67 or 68 feet from 1940 to 2010, or just under 1 foot per year, on average. A cursory review of Ewing and others (2012, pg. 9-47) suggest that, based on measured groundwater elevations in two wells in the Rustler Aquifer in Pecos County, the continued drop specified in the CHD boundary may not be accurate. These two wells suggest a decline followed by a recovery in more recent years to elevations similar to the early 1960s.

Additional analyses were completed to gain additional perspective on the CHD specification, and the effect on spring flow.

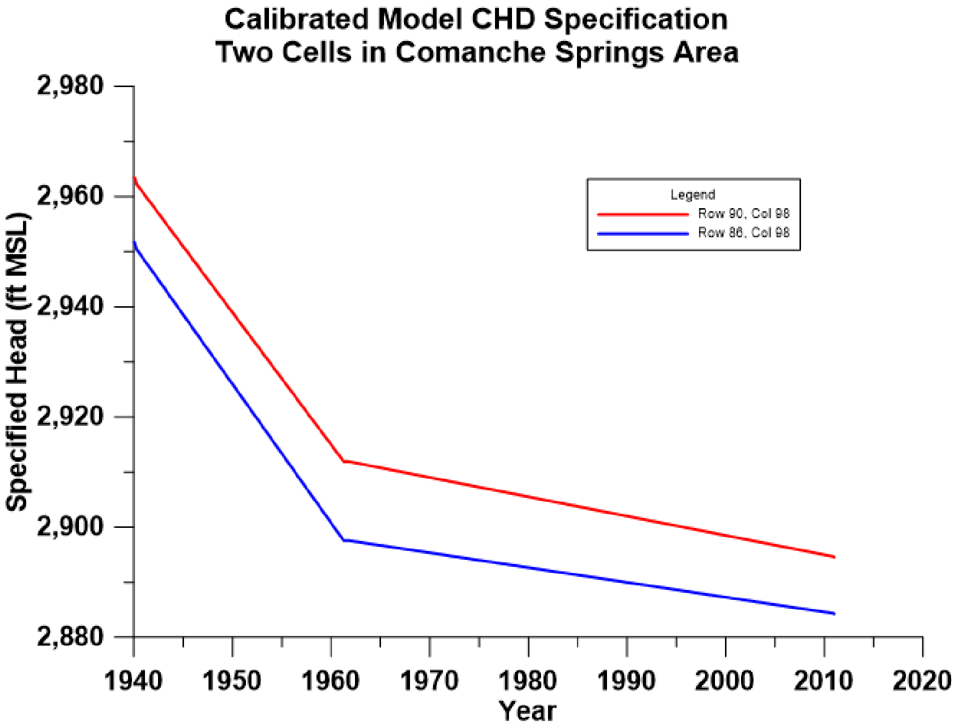

Figure 1. CHD Specification for Two Cells in Comanche Springs Area

2.4 Link Between CHD Specification and Spring Flow

Figure 2 presents model input and output data for the downstream cell associated with Comanche Springs (row 86, column 98). The model specified top elevation of layer 1 and layer 2 are shown. Also shown are the specified SFR elevation (specified for layer 2), the calibrated model head in layer 2, and the CHD boundary specification for layer 5.

Please note that when the aquifer head (black line) is above the SFR elevation (red line), groundwater flows out of the aquifer and becomes spring flow. From 1940 to about 1960, the black line is above the red line, and spring flow was noted (Clark and others, 2014, pg. 31).

Also, please note that the head in layer 2 (black line) and the CHD specification in layer 5 (blue line) are very similar after the early 1960s. This results in a situation where the specification of the CHD boundary in layer 5 will have a controlling influence on the head in layer 2. The head in layer 2 is important since it will determine whether there is spring flow or not, depending on whether the head is above or below the SFR specification for spring elevation. Another consideration is that, due to the CHD boundary, the upwelling of water from formations below layer 5 is an inflow component to the model. Clark and others (2014, pg.40) summarize the overall water budget of the calibration period, and includes a hydrograph of the "upwelling from lower units". For most years, this upwelling is the highest inflow component (up to about 400 million gallons per day). The upwelling peaks in the 1960s, and gradually declines from the 1960s to 2010, apparently due to the change in rate of decline of the CHD boundary heads specified in the input.

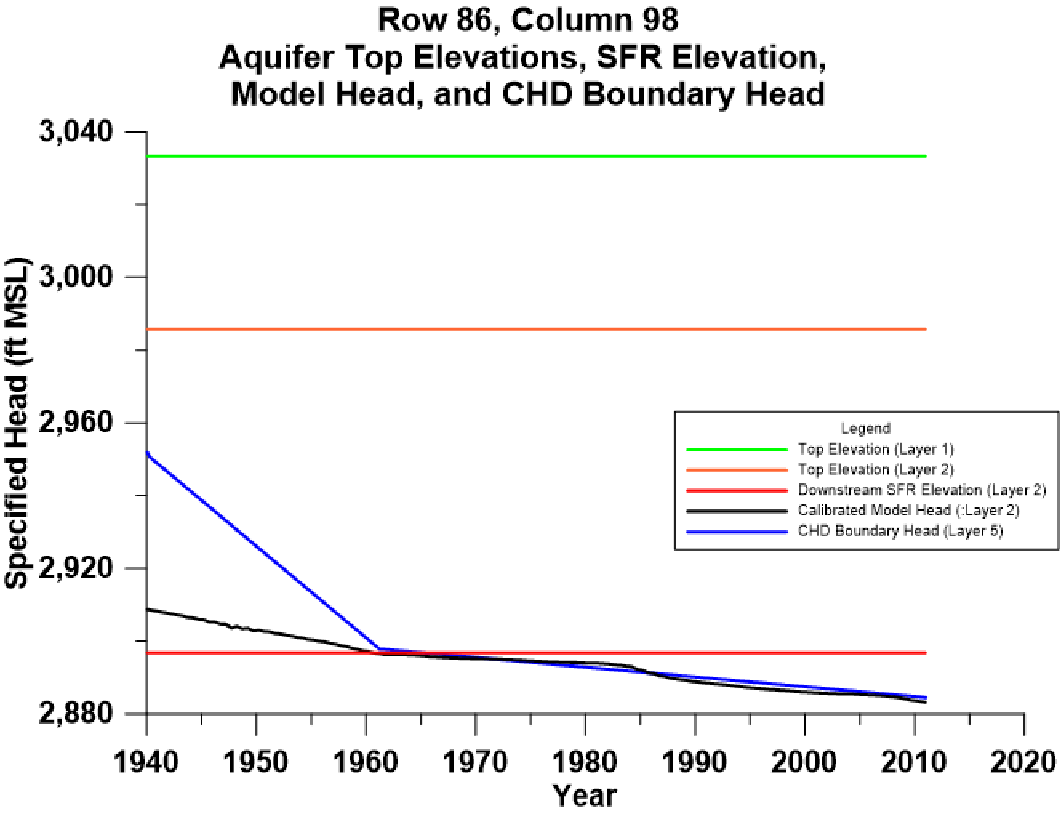

Figure 2. Model Input and Output Data for Downstream Cell of Comanche Springs

The top elevations for layer 1 and layer 2 are not directly involved in these calculations, but are presented to show an apparent inconsistency in the model input since the SFR elevation is substantially below the aquifer top elevation. Given that the model input for the LPF package is for "confined aquifers" (Clark and others, 2014, pg. 40) the top and bottom elevations are only used for calculation of aquifer transmissivity which is constant for the entire calibration period, and have no bearing on any other calculations.

3.0 Simulations with the USGS Model

The initial objective of these simulations was to test the usefulness of the USGS model in the development of desired future conditions. Spring flow is generally considered a good indicator of aquifer conditions on a regional scale, and the USGS model was reported to have been calibrated, in part, with data from Comanche Springs. As stated in some of the public comments, there was an interest in developing a desired future condition on something other than drawdown. In GMA 7, two proposed desired future conditions in the Edwards-Trinity (Plateau) Aquifer are specified with spring flow (Val Verde County and Kinney County). Thus, it seemed that if the USGS model was a suitable tool, the potential for establishing a desired future condition based on spring flow could be considered.

3.1 Initial Simulations

Initially, a set of 14 simulations were developed based on the varying pumping within each management zone in Middle Pecos GCD. Although the management zones are not included in the proposed desired future condition, the management zones were the subject of some of the comments received, and part of this effort included the review of pumping in each of the management zones and the impacts of pumping across management zones.

3.1.1 Historic Pumping, Permit Totals, and Modeled Available Groundwater

The simulations were developed from a foundation of historic pumping, permit totals and current modeled available groundwater (MAG) organized by management zone. Middle Pecos GCD has formally designated Management Zones 1, 2 and 3. For purposes of this technical memorandum, Management Zone 4 is the area of Middle Pecos GCD that is not in Management Zones 1, 2, or 3. Figure 3 presents the locations of Management Zones 1, 2, and 3.

A summary of pumping from each management zone is presented in Figures 4 to 7. Please note that each graph of pumping is from output from the USGS model, and presents the pumping from each of the top 3 layers (alluvium, Edwards, and Trinity) from 1940 to 2010. In addition, the total permitted pumping and the 2010 Modeled Available Groundwater (MAG) are shown for comparative purposes.

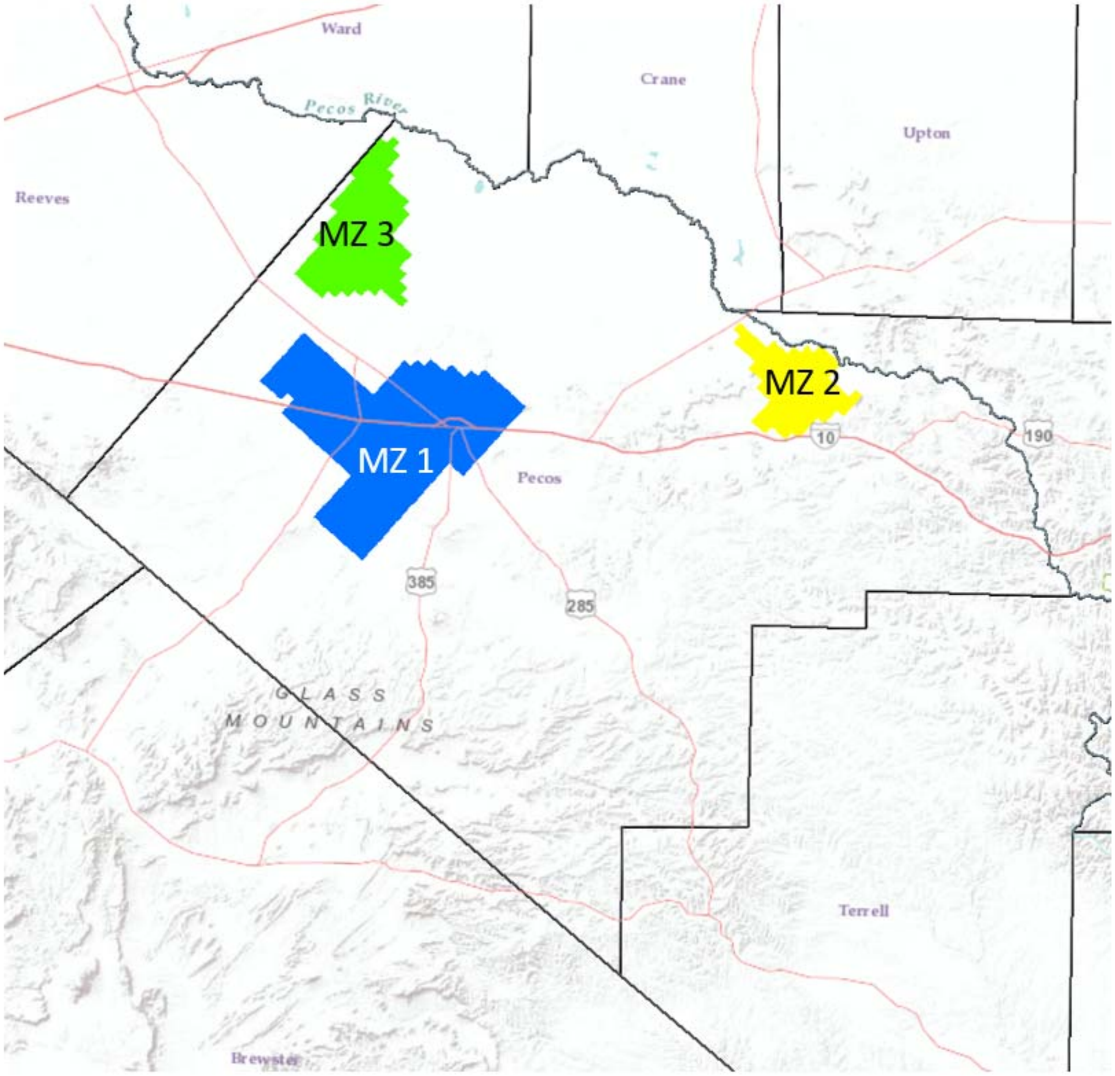

Figure 3. Locations of Management Zones 1, 2, and 3

Please note that Management Zone is labeled MZ in figure

Areas in Pecos County not in Management Zone 1, 2, or 3 are informally designated Management Zone 4 in this Technical Memorandum (please see Figure 7)

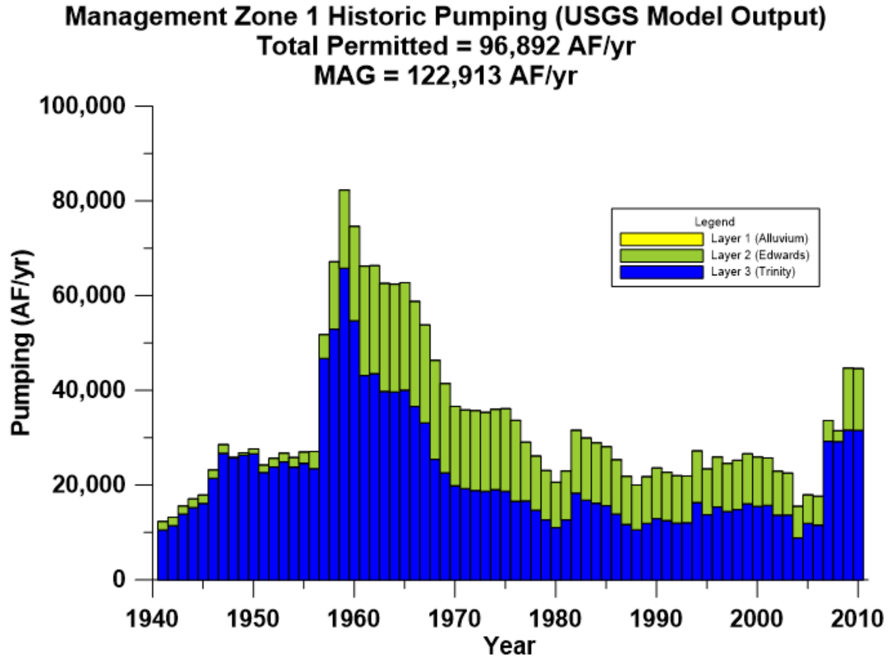

Figure 4. Management Zone 1 Historic Pumping

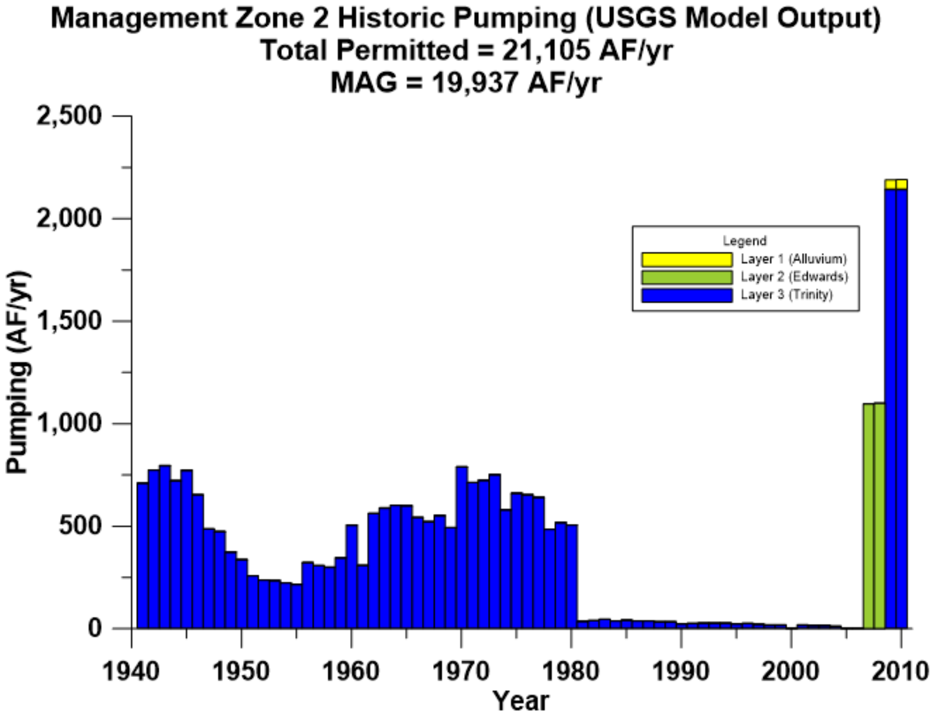

Figure 5. Management Zone 2 Historic Pumping

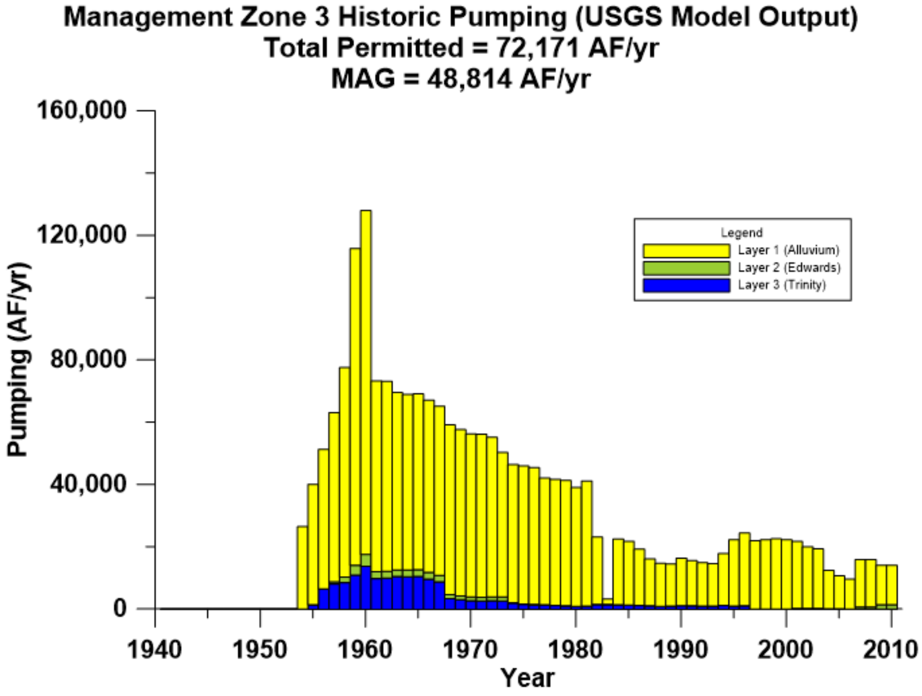

Figure 6. Management Zone 3 Historic Pumping

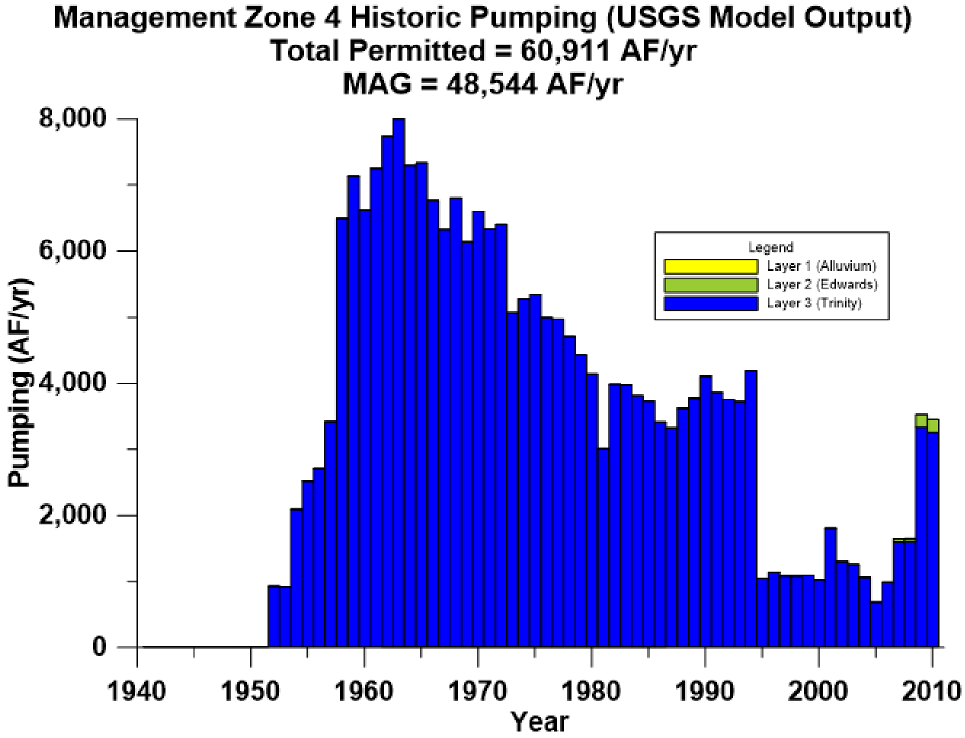

Figure 7. Management Zone 4 Historic Pumping

Based on an evaluation of the historic pumping, a base scenario was developed using stress period 41 (March to September, 1959) for Management Zones 1, 3, and 4, and stress period 139 (March to September, 2008) for Management Zone 2. This approach allowed the use of the specific well locations and completion intervals used in the calibrated USGS model for the simulations by simply assigning alternative pumping rates.

Table 1 summarizes the pumping amounts used for input for the base scenario, and the permit totals and 2010 modeled available groundwater (MAG) for comparative purposes.

Table 1. Summary of Base Scenario Input, Permit Totals, and 2010 MAG by Management Zone

Management Zone	Base Scenario Pumping Input (AF/yr)	Permit Total (AF/yr)	2010 MAG (AF/yr)
1	75,490	96,892	122,913
2	2,180	21,105	19,937
3	149,146	72,171	48,814
4	6,214	60,911	48,544

3.1.2 Development of Initial Scenarios

The initial scenarios were developed as follows:

- Scenario 1 is the baseline pumping presented in Table 1.
- Scenario 2 scaled the baseline pumping to match the permitted total in each management zone.
- Scenario 3 scaled the baseline pumping to match the 2010 MAG for each management zone.
- Scenarios 4, 5, and 6 scaled the baseline pumping to evaluate the effects of reduced pumping in Management Zone 1.
- Scenarios 7, 8, and 9 scaled the baseline pumping to evaluate the effects of increased pumping in Management Zone 2.
- Scenarios 10 and 11 scaled the baseline pumping to evaluate the effects of increased and decreased pumping in Management Zone 3.
- Scenarios 12, 13, and 14 scaled the baseline pumping to evaluate the effects of increased pumping in Management Zone 4.

Table 2 summarizes the 14 initial scenarios and the scaling factors used.

Table 2. Summary of Scaling Factors for Pumping in the 14 Scenarios

Scenario	Description	MZ1	MZ2	MZ3	MZ4
1	Baseline	1.00	1.00	1.00	1.00
2	Permit	1.28	9.68	0.48	9.80
3	MAG	1.63	9.15	0.33	7.81
4	MZ1-1	0.25	1.00	0.50	1.00
5	MZ1-2	0.50	1.00	0.50	1.00
6	MZ1-3	0.75	1.00	0.50	1.00
7	MZ2-1	1.00	2.00	0.50	1.00
8	MZ2-2	1.00	4.00	0.50	1.00
9	MZ2-3	1.00	6.00	0.50	1.00
10	MZ3-1	1.00	1.00	1.25	1.00
11	MZ3-2	1.00	1.00	0.75	1.00
12	MZ4-1	1.00	1.00	0.50	2.00
13	MZ4-2	1.00	1.00	0.50	4.00
14	MZ4-3	1.00	1.00	0.50	6.00

Scenarios were developed to run with annual stress periods from 2011 to 2070. Heads from the calibrated model in 2010 were used as initial conditions. Clark and others (2014) used GHB and CHD input from the last stress period (2010) for their predictive simulations, and this convention was followed for these initial simulations. All other inputs also followed the concepts of the USGS predictive runs (e.g. RIV, SFR, and RCH), but the time of the simulation was extended to 2070.

3.1.3 Results of Initial Simulations

The spring flow output from the initial simulations was evaluated from each of the 14 scenarios. In all cases, even the ones where pumping was reduced dramatically in Management Zone 1 (e.g. Scenario 4), there was no spring flow. This means that the heads in layer 2 did not rise above the SFR boundary elevations to cause groundwater to discharge from the spring. It would be expected that pumping reductions would result in a recovery of heads sufficient to result in at least some spring flow in Comanche Springs, so additional simulations were completed to gain an understanding of model behavior.

Specifically, the role of the GHB and CHD boundaries were evaluated since these were the only model inputs that varied with time during the calibration period.

3.2 Simulations with Alternative GHB Boundaries

The same of 14 scenarios were run in this set of simulations, but with a GHB package that had head values equal to the first stress period of the calibrated model rather than the last as was used in the initial simulations described above and in the USGS predictive simulations.

Results of these simulations also showed no spring flow in any of the scenarios, again which is not expected in scenarios where pumping in Management Zone 1 is reduced.

3.3 Simulations with Alternative CHD Boundaries

The same set of 14 scenarios were run in this set of simulations, but with a CHD package that had head values equal to the first stress period of the calibrated model rather than the last as was used in the initial simulations described above and in the USGS predictive simulations.

The estimated spring flow in 2011 and 2070 are summarized for each scenario in Table 3.

Table 3. Summary of Estimated Spring Flow for Alternative CHD Scenarios

Scenario	Description	Spring Flow in 2011 (cfs)	Spring Flow in 2070 (cfs)
1	Baseline	20.70	32.81
2	Permit	20.34	32.05
3	MAG	19.89	31.10
4	MZ1-1	21.67	34.85
5	MZ1-2	21.35	34.17
6	MZ1-3	21.02	33.49
7	MZ2-1	20.70	32.81
8	MZ2-2	20.70	32.81
9	MZ2-3	20.70	32.81
10	MZ3-1	20.70	32.81
11	MZ3-2	20.70	32.81
12	MZ4-1	20.70	32.81
13	MZ4-2	20.70	32.81
14	MZ4-3	20.70	32.81

Please note the following:

- Spring flow increases from 2011 to 2070 due to an overall recovery of groundwater levels associated with the higher CHD specification.
- Spring flows vary with pumping changes in Management Zone 1 pumping, but not to changes in pumping in Management Zones 2, 3 and 4.
- Spring flow is relatively high in pumping scenarios with high pumping, which is inconsistent with observations.

The specification of higher boundary elevations in layer 5 resulted in heads to rise above the SFR boundary elevation. This recovery occurred over a 15- to 20-year period, resulting in increasing spring flows during this transition period. After this transition period, spring flows were essentially constant.

3.4 Simulations with Alternative GHB and CHD Boundaries

The final set of simulations used alternative GHB and CHD boundaries that were evaluated individually as described above. The objective of this set of simulations was to test the sensitivity of the GHB boundary conditions when the CHD boundaries are set to the higher first stress period values.

Spring flow results are summarized in Table 4, and are similar to Table 3. Thus, the change in GHB head specification does not result in changes to spring flow.

Table 4. Summary of Estimated Spring Flow for Alternative GHB and CHD Scenarios

Scenario	Description	Spring Flow in 2011 (cfs)	Spring Flow in 2070 (cfs)
1	Baseline	20.71	32.99
2	Permit	20.35	32.23
3	MAG	19.91	31.28
4	MZ1-1	21.69	35.03
5	MZ1-2	21.36	34.35
6	MZ1-3	21.04	33.67
7	MZ2-1	20.71	32.99
8	MZ2-2	20.71	32.99
9	MZ2-3	20.71	32.99
10	MZ3-1	20.71	32.99
11	MZ3-2	20.71	32.99
12	MZ4-1	20.71	32.99
13	MZ4-2	20.71	32.99
14	MZ4-3	20.71	32.99

4.0 Discussion of Results

The results of the simulations show that spring flow is sensitive to the selection of CHD boundary heads in layer 5. The use of CHD boundary heads from 2010 in predictive simulations results in no spring flow since the heads in layer 2 have equilibrated to the CHD boundary head, and remain below the SFR elevation. Essentially, changes in pumping in layer 2 or layer 3 near Comanche Springs will cause little or no change to the spring flow. Because of the sensitivity of spring flow to the CHD boundary heads, it is not a useful tool for predictive simulations.

This limitation also extends to using the model to drawdown estimates using the model. Because the CHD boundary head specification causes layer 2 heads to equilibrate to essentially the same value, the resulting drawdown calculations would be tied more to layer 5 CHD boundary specification than to evaluating the drawdown effects of pumping.

The USGS model needs to be reconceptualized and recalibrated to be useful for predictive simulations. The choice of using CHD boundaries to essentially drive the heads in layer 5 needs to be reevaluated.

Clark and others (2014) noted that the CHD boundary was needed to achieve model-estimated spring flows that approximated actual spring flow data. This choice, however, has resulted in a model that requires specification of CHD boundaries for predictive simulations that control spring flow estimates to such an extent that the predictions are not useful to evaluate impacts of pumping on spring flow.

Based on these simulations, the USGS model is not an appropriate tool to evaluate and develop desired future conditions.

5.0 References

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