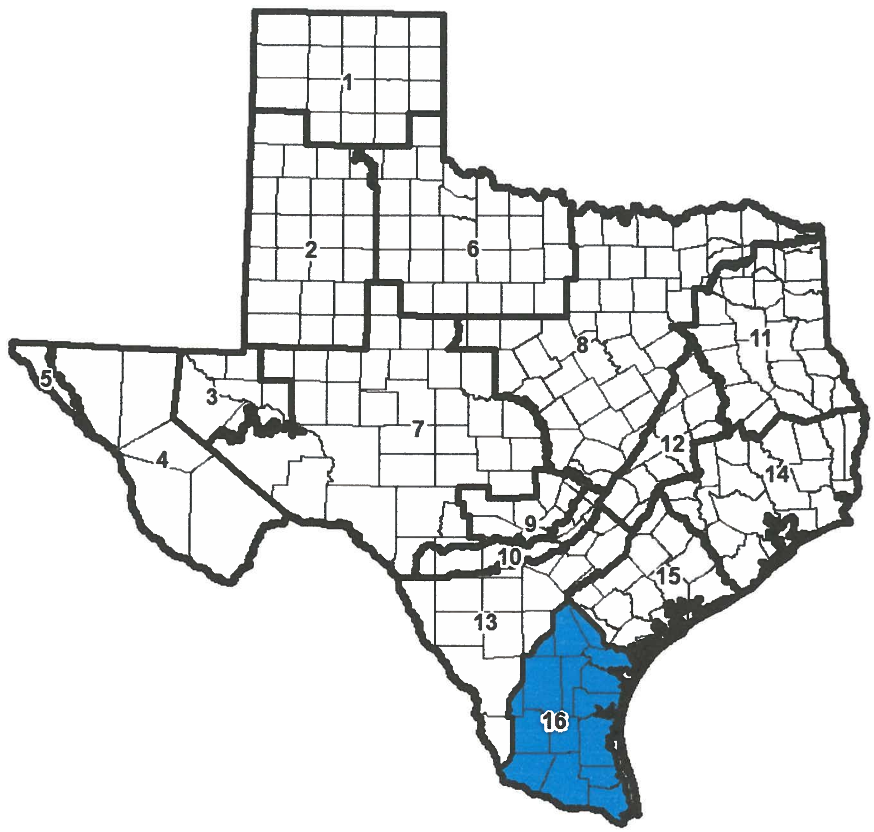
Proposed DFC Explanatory Report
Gulf Coast Aquifers
Groundwater Management Area 16



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This report was considered and approved by the member districts of Groundwater Management Area 16 on January 17, 2017.

Member Districts:

Bee Groundwater Conservation District
Live Oak Groundwater Conservation District
McMullen Groundwater Conservation District
San Patricio Groundwater Conservation District
Duval County Groundwater Conservation District
Kenedy County Groundwater Conservation District
Corpus Christi ASR Conservation District
Brush Country Groundwater Conservation District
Red Sands Groundwater Conservation District
Starr County Groundwater Conservation District

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3/30/17

Date

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1.0 Groundwater Management Area 16

Groundwater Management Areas (GMAs) were created "in order to provide for the conservation, preservation, protection, recharging, and prevention of waste of the groundwater, and of groundwater reservoirs or their subdivisions, and to control subsidence caused by withdrawal of water from those groundwater reservoirs or their subdivisions, consistent with the objectives of Section 59, Article XVI, Texas Constitution, groundwater management areas may be created..." (Texas Water Code §35.001). Groundwater Management Area 16 is one of sixteen groundwater management areas in Texas. It is the southernmost GMA in the state, and covers the southern Gulf of Mexico coastline in Texas. (Figure 1).

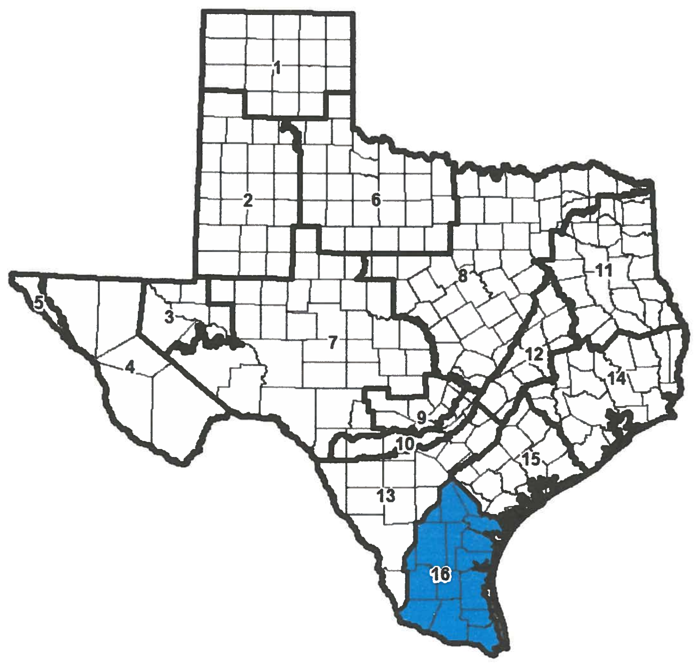

Figure 1 – Groundwater Management Area 16 Location

Groundwater Management Area 16 covers all or portions of the following sixteen counties: McMullen, Live Oak, Bee, Webb, Duval, Jim Wells, San Patricio, Nueces, Kleberg, Jim Hogg, Brooks, Kenedy, Starr, Hidalgo, Willacy, and Cameron (Figure 2). Table 1 lists the sixteen counties and their projected populations through 2060. In 2010, the sixteen counties had a combined population of 2,146,281 people, and the county with the largest population was Hidalgo County, with 775,857 people. The population of the fourteen counties is expected to grow to 4,669,273 people in 2070, with Hidalgo expanding to a population of 2,048,911 people.

Figure 2 – Counties in GMA-16

Table 1 – GMA 16 Counties and Population Projections

COUNTY	2000	2010	2020	2030	2040	2050	2060
BEE	32,359	34,298	36,099	37,198	37,591	37,598	36,686
BROOKS	7,976	8,607	9,303	9,909	10,288	10,399	10,349
CAMERON	335,227	424,762	510,697	599,672	688,532	777,607	862,511
DUVAL	13,120	13,881	14,528	14,882	14,976	14,567	13,819
HIDALGO	569,463	775,857	987,920	1,225,227	1,481,812	1,761,810	2,048,911
JIM HOGG	5,281	5,593	5,985	6,286	6,538	6,468	6,225
JIM WELLS	39,326	42,434	45,303	47,149	47,955	47,615	46,596
KENEDY	414	467	495	523	527	529	537
KLEBERG	31,549	36,959	40,849	43,370	44,989	47,118	47,212
LIVE OAK	12,309	13,735	14,929	15,386	15,018	13,808	12,424
MCMULLEN	851	920	957	918	866	837	793
STARR	53,597	69,379	83,583	98,262	113,102	127,802	141,961
SAN PATRICIO	67,138	80,701	95,381	109,518	122,547	134,806	146,131
NUECES	313,645	358,278	405,492	447,014	483,692	516,265	542,327
WEBB	193,117	257,647	333,451	418,332	511,710	613,774	721,586
WILLACY	20,082	22,763	25,212	27,455	29,276	30,542	31,205
TOTAL	**1,695,454**	**2,146,281**	**2,610,184**	**3,101,101**	**3,609,419**	**4,141,545**	**4,669,273**

Source: TWDB

There are ten groundwater conservation districts in Groundwater Management Area 16: McMullen GCD, Live Oak UWCD, Bee GCD, Duval County GCD, San Patricio County GCD, Corpus Christi Aquifer Storage and Recovery Conservation District, Brush Country GCD, Kenedy County GCD, Starr County GCD, Red Sands GCD (Figure 3). Please note that as shown in Figure 3, the Edwards Aquifer Authority overlaps other groundwater conservation districts in a small portion of Atascosa County, and larger parts of Caldwell, Guadalupe, Medina, and Uvalde counties.

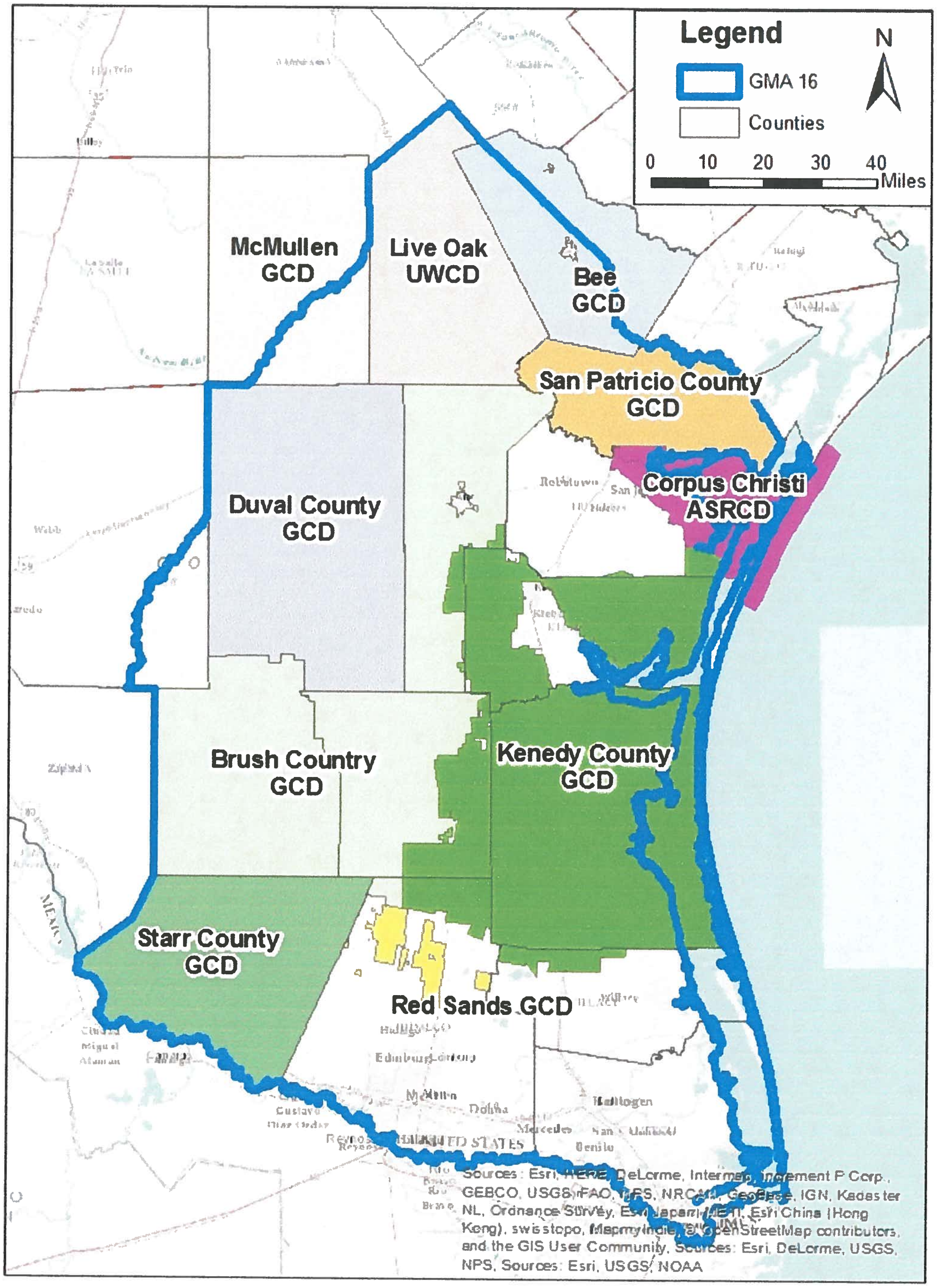

Figure 3 – Groundwater Conservation Districts in GMA-16

The primary aquifers in GMA-16 are the formations of the Gulf Coast Aquifer System: the Chicot Aquifer, the Evangeline Aquifer, the Burkeville confining unit, and the Jasper Aquifer. Small areas of the extreme downdip portion of the Carrizo-Wilcox aquifer are present in McMullen, Live Oak, and Bee County. A small area of Yegua-Jackson aquifer is present in Starr, Jim Hogg, McMullen (non GMA 16 area), and Live Oak County (Figure 4). These aquifers are discussed in more detail in Sections 2 and 4.

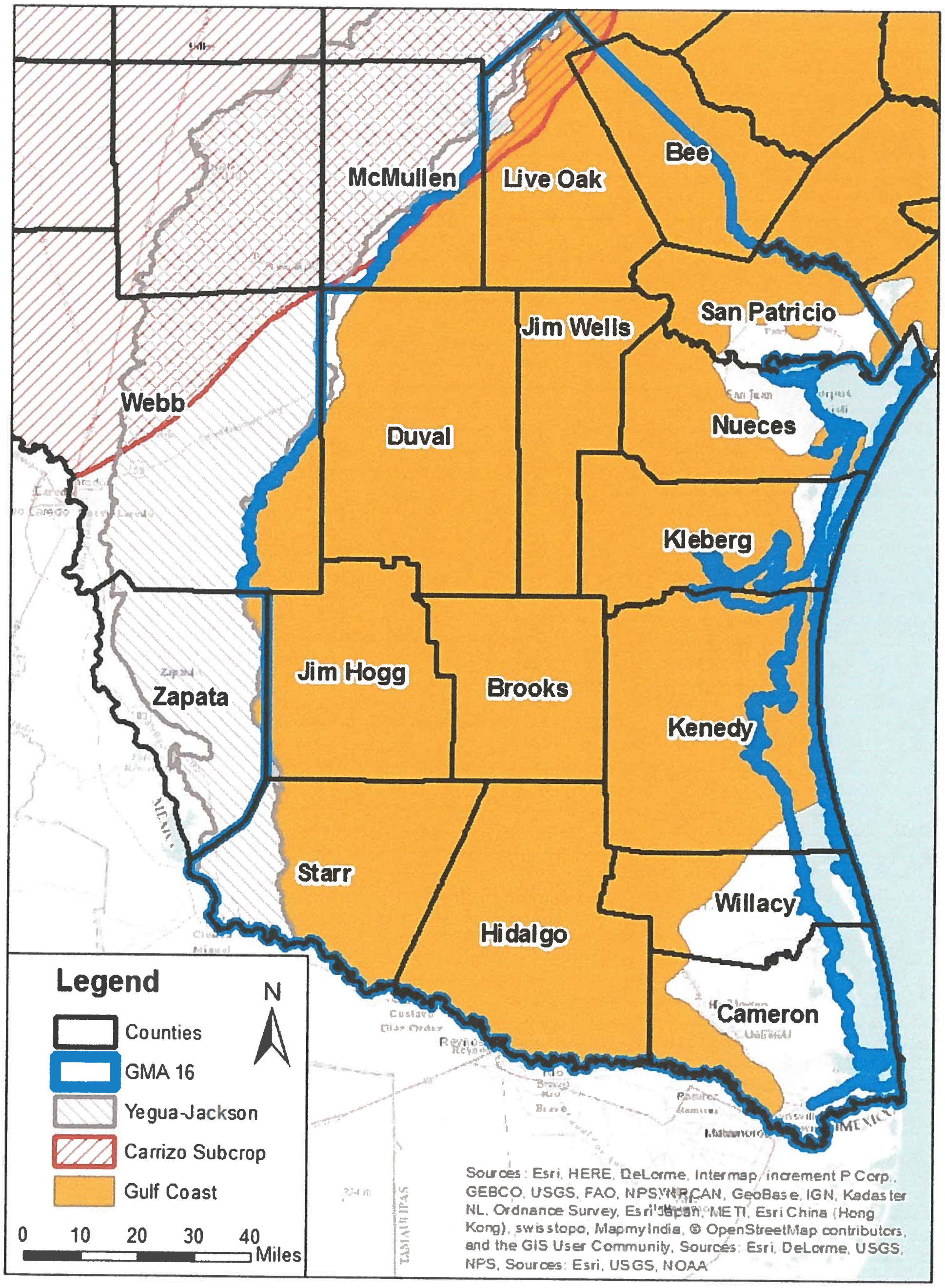

Figure 4 – Aquifers in GMA 16

As a component of the joint planning process promulgated by the Texas state legislature, multiple GCDs within a GMA are to coordinate their activities at meetings on at least an annual basis. In addition, GMAs that overlap more than one

Regional Water Planning Area (RWPA) are to coordinate with the respective RWPAs. GMA 16 intersects the areas of both Region M (Rio Grande Valley), and Region N (Coastal Bend). These RWPA areas are presented in Figure 5.

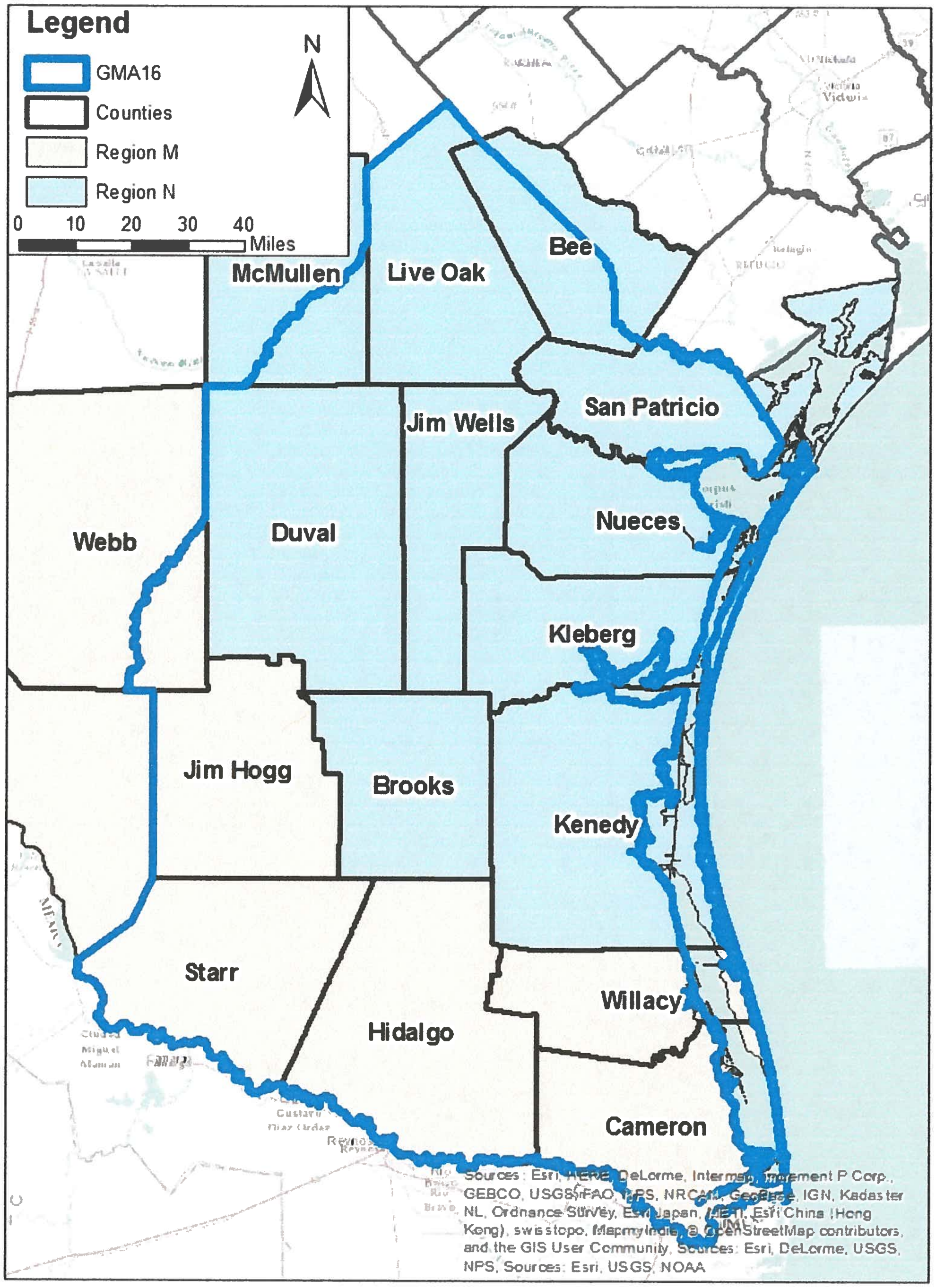

Figure 5 – Regional Water Planning Areas in GMA 16

After DFCs are adopted by a GMA, the TWDB calculates Modeled Available Groundwater (MAG) based on the DFCs. A MAG is defined in Title 31, Part 10, §356.10 (13) of the Texas Administrative Code as "the amount of water that the executive administrator determines may be produced on an average annual basis to achieve a DFC."

Table 2 lists the dates and the major discussion topics of the GMA 16 joint planning meetings from March 2013 through November 2016. The minutes for each of these meetings is included as Appendix B of this report.

Table 2 – GMA 16 Board Meeting Dates and Primary Topics of Discussion

Date	Major Discussion Topics
3/5/2013	TWDB discussed DFC guidance documents. Bar W discussed pumping data.
4/30/2013	TWDB- TERS reports available, guidance docs in summer 2013. Bar W- discussion of pumping distribution etc, in GCD and non-GCD areas
8/26/2013	TWDB - guidance docs on DFCs and TWDB review, non-relevant aquifers. Bar W - Run 1 groundwater model results 1. Region M plans 3 desalination plants, Alice 19 wells.
9/24/2013	Discussion regarding non-relevant aquifers, additional model runs.
10/22/2013	Agreement to consider the Carrizo-Wilcox and Yegua-Jackson aquifers as non-relevant for DFCs. More model runs/pumping revisions. Discuss consideration of aquifer uses or conditions. Format for DFCs should match previous 2011 DFC.
1/27/2014	SB-TWDB has started SWIFT application process, exemptions. Bar W – Carrizo-Wilcox too deep to be relevant
3/25/2014	New TWDB representative Robert Bradley. Bar W - no additional model runs. Yegua-Jackson non-relevant. Reviewed factors 1-5.
4/22/2014	TWDB indicates need for documentation on non-relevant aquifers. Bar W - model scenario 1.4. Discussed socioeconomic impacts, impacts on property rights, and feasibility of achieving DFCs
6/24/2014	New TWDB representative Nathan van Oort. James Dodson requests additional pumping in San Patricio County. Alice plans ~ 4000 ac-ft brackish groundwater production. New GAM planned for GMA 15-16.
9/23/2014	TWDB -request for data for new GMA 15-16 GAM. Checklist for explanatory reports upcoming. J Dodson discussed San Patricio pumping. Steve Young discusses drawdown. Scotty Bledsoe-maybe adopt DFC next meeting. Alice maybe desalination.

11/18/2014	TWDB-GMA 16 consultant modelers should coordinate with TWDB modelers. Bar W-model run revisions discussed, talked to Alice re plans (7000-19000 ac ft/yr in 2060).
6/23/2015	TWDB - final date for proposing revised is conveyed. RW-review model runs 1.7 and 1.8,
9/22/2015	Bar W-reviewed factors, report, appendices. Results from run 1.8 are recommended DFCs.
10/28/2015	Bar W -reviewed factors again, and draft report. Presented drawdown table 1.8, adopted as proposed DFC.
3/22/2016	Model review by TWDB found errors in grid file, will provide draft report in a week. GCDs should establish monitoring networks. Scotty Bledsoe-no revisions from public comment. No DFC adopted due to errors.
11/15/2016	Terminate Bar W, hire Dave O'Rourke to complete DFC explanatory report.

After the adoption of the proposed DFC at the 10/28/2015 meeting, each of the GCDs within GMA 16 held public meetings to present and discuss the proposed DFCs in accordance with all requirements for public meetings and public comments. None of the GCDs received public comment. Therefore, no revisions were made to the DFCs in response to public comment.

2.0 GMA 16 DFCS

This section discusses the adopted DFCs for each of the aquifers within GMA 16.

GMA 16's approach to developing DFCs for this round of joint planning duplicates the approach that was used in the development of the DFCs approved in 2011. The proposed DFCs for the Gulf Coast Aquifers were developed based on iterative simulations of alternative scenarios of future pumping using the GMA 16 Groundwater Availability Model (GAM) (Hutchison et al, 2011). The process of using the groundwater model in developing DFCs incorporates many of the elements of the nine factors (for example, consideration of current uses and water management strategies in the regional plan). An iterative approach of running several predictive model scenarios and evaluating the results is a necessary step in the process of developing DFCs, and is the most time-consuming task in the DFC development process. In GMA 16, several model runs were completed that considered various future pumping scenarios and identified water management strategies, and the results were discussed in public meetings prior to adopting a DFC (Appendix B). Technical memos documenting the details of these model runs conducted by Bar W Consulting/QEA Anchor Engineering are included in Appendix C.

2.1 Gulf Coast Aquifer

The formations of the Gulf Coast aquifer of primary interest in GMA 16 are the Chicot Aquifer, the Evangeline Aquifer, the Burkeville Confining Unit, and the Jasper Aquifer. The Burkeville Confining Unit lies between and separates the Evangeline and the Jasper aquifers. For the purpose of establishing DFCs, GMA 16 has adopted the boundaries defined in the grid file "alt1_gma16_grid_poly050114.shp" provided by the TWDB, and the aquifer layers defined in the GMA 16 GAM to define the areas and volumes associated with the Gulf Coast Aquifer.

On January 17, 2017, GMA 16 representatives approved a resolution titled Resolution to Adopt the DFCs for Groundwater Management Area 16. Appendix A contains the resolution. The adopted DFCs are based on acceptable levels of drawdown for each county and the entire groundwater management area from 2010 to 2060.

Gulf Coast Aquifer System – The proposed DFC represents an average drawdown for the Chicot Aquifer, the Evangeline Aquifer, the Burkeville Confining Unit, and the Jasper Aquifer that is weighted by the area of each hydrogeological unit in the GMA 16 GAM (Hutchison and others, 2011).

Groundwater Management Area 16 adopts DFCs for each county within the groundwater management area (county-specific DFCs) and adopts a DFC for the counties in the groundwater management area (GMA-specific DFC). The DFC for the counties in the groundwater management area shall not exceed an average drawdown of 62 feet for the Gulf Coast Aquifer System in December 2060. DFCs for the Gulf Coast Aquifer in each county within the groundwater management area (county-specific DFCs) shall not exceed the values specified in Table 3 by the year 2060.

Table 3 – DFCs for GMA 16 as an Average Drawdown from 2010 – 2060

GCD or Region	Simulated Drawdown (ft) 2010-2060				
	Chicot	Evangeline	Burkeville	Jasper	Combined
Bee GCD	106	84	73	60	76
Live Oak UWCD	79	64	60	19	34
McMullen GCD	0	0	0	9	9
Red Sands GCD	38	41	40	39	40
Kenedy County GCD	15	104	21	21	40
Brush Country GCD	47	76	68	69	69
Duval County GCD	78	133	95	85	104
San Patricio County GCD	88	60	23	22	48
Starr County GCD	0	83	74	55	69
Non-district Cameron	62	122	48	48	70
Non-district Hidalgo	143	151	96	94	118
Non-district Kleberg	7	85	10	9	28
Non-district Nueces	22	39	11	11	21
Non-district Webb	0	151	0	71	113
Non-district Willacy	28	85	23	23	40
GMA 16	47	97	49	49	62

2.2 Carrizo-Wilcox Aquifer

GMA 16 considers the portion of the Carrizo-Wilcox Aquifer within boundary of GMA 16 non-relevant for joint planning purposes. This subject was discussed at the 1/27/14 GMA 16 Board meeting. Developing a DFC will require monitoring of the Carrizo-Wilcox aquifer to ensure that the DFC is achieved. The area of the Carrizo-Wilcox within the GMA is small (Figure 4), and it occurs only at depths of greater than 5000 feet in GMA 16 (Kelley et al., 2004). This is below the depth that is generally considered economically feasible to construct a water well. There are likely very few wells producing water from the Carrizo-Wilcox aquifer in GMA 16. Consequently, the estimated use of the Carrizo-Wilcox aquifer in the GMA is considered insignificant. The depth and lack of wells in the Carrizo-Wilcox aquifer increase the difficulty and cost of monitoring the aquifer. Therefore, the Carrizo-Wilcox aquifer should not be considered relevant for planning purposes at this time.

A technical memo more fully discussing the rationale for considering the Carrizo-Wilcox Aquifer non-relevant is included in Appendix C.

2.3 Yegua-Jackson

GMA 16 considers the portions of the Yegua-Jackson within the boundary of GMA 16 non-relevant for joint planning purposes. This subject was discussed at the 3/25/14 GAM 16 Board meeting. The Yegua-Jackson occurs only in very limited areas of GMA 16. The majority of fresh water occurs in or near the outcrop region. In general, concentrations of total dissolved solids increase rapidly moving downdip into the confined portion of the aquifer. There are likely very few wells producing water from the Yegua-Jackson aquifer in GMA 16. Use of the Yegua-Jackson aquifer in GMA 16 is likely very low. The limited area and lack of wells in the Yegua-Jackson aquifer in GMA 16 increases the difficulty and reduces the efficacy of monitoring the aquifer. Developing a DFC will require monitoring of the Yegua-Jackson aquifer to ensure that the DFC is achieved. The current and projected low use of the Yegua-Jackson aquifer within the current round of GMA planning does not justify development of a DFC for the Yegua-Jackson aquifer. The Yegua-Jackson aquifer should not be considered relevant for planning purposes at this time.

A technical memo more fully discussing the rationale for considering the Yegua-Jackson Aquifer non-relevant is included in Appendix C.

3.0 Policy Justification

As discussed more fully in this report, the proposed DFCs were adopted after discussing and considering the following factors in public meetings:

1. Aquifer uses and conditions within Groundwater Management Area 16.
2. Water supply needs and water management strategies included in the 2012 State Water Plan.
3. Hydrologic conditions within Groundwater Management Area 16 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 16 in groundwater as recognized under Texas Water Code Section 36.002.
8. The feasibility of achieving the DFC.
9. Other information.

GMA 16 and each of its member districts evaluated DFCs with regard to these nine factors. In addition to these nine factors, GMA 16 and the individual districts evaluated DFCs with regard to providing a balance between the highest practicable level of groundwater production and the conservation, preservation, protection, and recharging, and prevention of waste of groundwater in GMA 15.

The proposed DFC attempts to provide 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 16.

There is no state-defined formula or equation for calculating groundwater availability. This is because an estimate of groundwater availability requires the blending of policy and science. The groundwater models employed as tools for scientific analysis contain inherent limitations and uncertainty. The adoption of policies by the GMAs provides the guidance that science can use to calculate groundwater availability.

4.0 Technical Justification

In the case of groundwater management, a groundwater model is a tool that can be used 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 DFC (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 DFCs.

As discussed in Section 2, the proposed DFC for the Gulf Coast Aquifers in GMA 16 was developed based on iterative simulations of alternative scenarios of future pumping using the GMA 16 Groundwater Availability Model (GAM) (Hutchison et al, 2011). The GMA 16 GAM used in this process was developed specifically to assist with the development of initial DFCs for GMA-16, and it remains the most appropriate tool to use for this purpose.

Conceptually, the model simulates groundwater flow in six layers as shown in Figure 4. Layers 1 through 4 represent the Gulf Coast strata of the Chicot Aquifer, Evangeline Aquifer, Burkeville Confining Unit, and the Jasper Aquifer, respectively. Layer 5 represents the combined strata of the Yegua-Jackson Aquifer, including some portions of the Catahoula Formation. Layer 6 represents the combined strata of the Sparta, Queen City, and Carrizo-Wilcox Aquifers. The primary input of water to the system is recharge from precipitation. The primary outflow is pumping from wells. Vertical flow between layers is simulated. Due to the vertical interaction between aquifer units that is simulated in the GAM, the proposed DFC for all Gulf Coast strata were developed simultaneously during the iterative model simulations. During its development, the GMA 16 GAM used a calibration period from 1963 to 1999.

The GMA 16 GAM is the most appropriate tool for use in the development of DFCs for the area. However, it is important to bear in mind that all groundwater models have inherent uncertainty due to various factors including sparse field data, inaccurate input parameters, errors associated with numerical computations and spatial resolution, and others. Groundwater models are best viewed as a tool to help develop estimates to support decisions, rather than a quantitative machine to generate decisions.

GMA 16 performed a series of eight groundwater model simulations using pumping files as approved by the GMA 16 Board after discussion in public meetings. After discussions from various member districts, their representatives, and members of the public, pumping files were iteratively revised to address questions, comments, concerns, and requests from the various stakeholders.

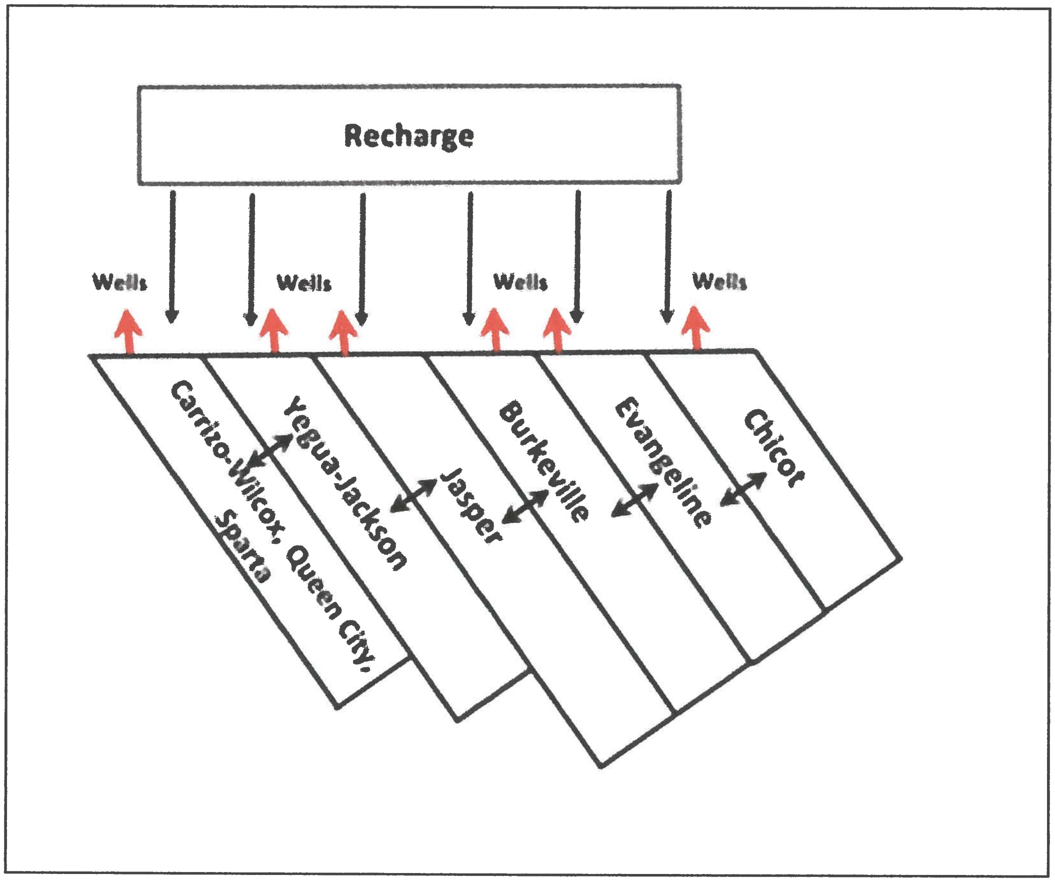

Figure 6 – Conceptual Model of Flow in GMA 16 GAM (Adapted from Hutchison et al, 2011)

There are some technical details regarding the GMA 16 DFC simulations that were addressed by the TWDB in their review of model files submitted for review that are of note when evaluating these model results.

The DFC simulations were set up as 61-year simulations, representing the period 2000-2060. Fifty-year drawdown was calculated using year 2010 as the initial conditions for calculations. The use of year 2010 conditions as initial conditions was reviewed and verified by the TWDB.

The GMA 16 GAM represents all model layers as fully confined, rather than representing the outcrop areas accurately as unconfined areas. The significance of this is that confined aquifers respond more quickly to pumping, due to smaller storage coefficients (typically in the 10^{-4} magnitude), while unconfined aquifers respond more slowly to equivalent pumping due to a higher storage coefficient, or specific yield, typically in the 10^{-1} magnitude. The draining of unconfined pore space occurs more slowly than the reduction of potentiometric pressure in a confined aquifer. As a result, simulated drawdowns in the outcrop areas of the Gulf Coast Aquifer may be greater than expected in the field. Therefore, these simulated drawdowns may be viewed as being conservative; i.e., model results may generate greater drawdowns than may be expected to be observed in the outcrop areas.

Another factor noted that is also related to the fact that all model layers are represented as confined is that MODFLOW allows confined cells to continue pumping even when the potentiometric surface falls below the bottom elevation of the pumping cell. During the simulations, dry cells were observed to occur in updip (i.e., outcrop) areas in many of the model layers in GMA 16. In effect, this will yield physically unrealistic model results that indicate greater drawdown than may be expected to be observed in the outcrop areas. This was noted in the TWDB model review. However, this does not affect the overall validity of the model results.

It should be noted that the TWDB has initiated work on a new GAM encompassing the combined areas of GMA 15 and GMA 16. This model will likely contain several technical improvements, and is expected to be available for the next round of DFC revisions.

5.0 Factor Consideration

GCDs are required to include documentation of how nine listed factors were considered prior to proposing a DFC, and how the proposed DFC impact each factor. This section of the explanatory report summarizes the information that the groundwater conservation districts used in its deliberations and discussions.

5.1 Aquifer Uses and Conditions

In developing a DFC, the GCDs of GMA 16 considered the following information regarding aquifer uses and conditions:

- Estimates of pumping from 2000 to 2011 from the TWDB Water Uses Survey database
- Estimates of pumping from Bee GCD for the years 2000 to 2011
- Estimates of pumping from Live Oak UWCD for the years 2000 to 2011
- Estimates of pumping from McMullen County GCD for the years 2000 to 2011
- A comparison of TWDB pumping estimates to proposed future pumping values
- Groundwater Monitoring Data (aquifer water-level elevations) from the TWDB Groundwater database for the years 2000 to 2011
- Calibration water level hydrographs in the GMA 16 GAM report.

These data provide data on baseline hydrogeologic conditions prior to the start of the fifty-year period being considered for the new DFC. The aquifers in GMA 16 have not been heavily developed, historically. Pumping demands from the Gulf Coast Aquifer in GMA 16 have been modest compared to other areas of the state. Examination of monitoring well water level hydrographs do not indicate any trends of declining water levels in the period before 2010. In wells that have multiple water level measurements spanning decades, the hydrographs indicate water levels that are essentially static.

The information on aquifer uses and conditions considered by the GCDs of GMA 16 are included in Appendix D. These data were presented to and discussed by the GMA 16 Board in public meetings on September 24 and October 22, 2013.

5.2 Water Supply Needs and Water Management Strategies

The GCDs of GMA 16 considered the following information regarding water supply needs and water management strategies in developing a DFC:

- Data from the 2012 State Water Plan on;
- Identified groundwater sources
- Identified needs
- Water management strategies using a groundwater source
- Modeled Available Groundwater Report; GAM Run 10-047 (Hassan and Jigmond, 2011)
- A tabular summary of the range of future pumping estimates used in developing the proposed DFC

The Rio Grande Valley is expected to have a significant increase in growth and water demands over the next 50 years. The GMA 16 counties in Region N are also expected to grow, although the rate of growth will not be as great as in the Rio Grande Valley (Table 1). A significant part of anticipated new water supplies for portions of these planning regions are expected to be met by increased groundwater production. The Gulf Coast Aquifer is the primary groundwater supply source for these regions. Much of the groundwater in this region is brackish, and may need to be treated to drinking water standards if intended for drinking water supply.

The information on water supply needs and water management strategies considered by the GCDs of GMA 16 are included in Appendix E. Also included in Appendix E is the Modeled Available Groundwater Report (Wade, 2012) that was developed by TWDB associated with the previously developed DFC adopted in 2011. These data were presented to the GMA 16 Board and discussed in the public meeting on March 25, 2014. Revisions to proposed pumping scenarios in light of developing water management strategies discussed by the Board represented a large part of the public meetings conducted from March 5, 2013, through June 23, 2014. Details regarding these alternative pumping scenarios are presented in the technical memos included in Appendix C.

5.3. Hydrologic Conditions within GMA 16

In developing a DFC, the GCDs of GMA 16 considered the total estimated recoverable storage, average annual recharge, inflows, and discharge during their deliberations prior to adopting a new DFC. These data were discussed at the public meeting on March 25, 2014.

5.3.1 Total Estimated Recoverable Storage

As required by the state, the Texas Water Development Board provided the groundwater conservation districts in Groundwater Management Area 16 with estimates of total recoverable storage (Jigmond and Wade, 2013). A copy of this report is included as Appendix F.

The estimate of total recoverable storage is an estimate of physical availability, but it includes numerous simplifying assumptions, and should be viewed with these assumptions in mind. It does not distinguish between fresh and brackish or saline water quality; it assumes the full thickness of GAM aquifer layers to have sand-like porosity values; it may include groundwater volumes at depths that are economically infeasible to develop. Therefore, in many cases, the total estimated recoverable storage is greater than the highest practicable level of groundwater production. However, it is useful in educating the public to the large volumes of groundwater in storage in the state, and therefore is to be considered in the DFC adoption process.

The total calculated storage value for the Gulf Coast Aquifer in GMA 16 is over a billion acre-feet (Table 4). The TERS is defined as between 25% and 75% of the total storage volume, which ranges from approximately 254 million to 761 million acre-feet of groundwater.

5.3.2 Average Annual Recharge, Inflows and Discharge

GMA 16 used the GMA 16 GAM to evaluate water budget components such as recharge, inflows, and discharge as part of the evaluation of hydrologic conditions in the area. The DFC simulations cover a 61-year period from 2000-2060. Water budgets are reviewed for the year 2010 (the initial conditions for the purpose of calculating drawdown) and 2060 (the final stress period of the DFC simulations).

Table 4 - Estimated Recoverable Storage of Gulf Coast Aquifer in GMA 16

County	*Total Storage (acre-feet)*	*25% of Total Storage (acre-feet)*	*75% of Total Storage (acre-feet)*
Bee	25,000,000	6,250,000	18,750,000
Brooks	90,000,000	22,500,000	67,500,000
Cameron	49,000,000	12,250,000	36,750,000
Duval	45,000,000	11,250,000	33,750,000
Hidalgo	160,000,000	40,000,000	120,000,000
Jim Hogg	40,000,000	10,000,000	30,000,000
Jim Wells	61,000,000	15,250,000	45,750,000
Kenedy	210,000,000	52,500,000	157,500,000
Kleberg	110,000,000	27,500,000	82,500,000
Live Oak	35,000,000	8,750,000	26,250,000
McMullen	2,100,000	525,000	1,575,000
Nueces	76,000,000	19,000,000	57,000,000
San Patricio	51,000,000	12,750,000	38,250,000
Starr	15,000,000	3,750,000	11,250,000
Webb	250,000	62,500	187,500
Willacy	45,000,000	11,250,000	33,750,000
Total	**1,014,350,000**	**253,587,500**	**760,762,500**

The only change in input between year 2010 and 2060 is pumping volume, which increases from 149,069 ac-ft/yr in 2010 to 393,898 ac-ft/yr in 2060. This is an increase of 244,829 ac-ft/yr. Recharge remains constant for the simulation period. A review of the other components of the water budget will give insight into how the aquifer system will respond to the increased pumping stress (Table 5).

In year 2010, which represents initial conditions for the DFC drawdown calculations, the aquifers are discharging to rivers and streams at 11,768 ac-ft/yr. In year 2060 at the end of the simulation, the aquifers are being recharged by streamflow at 18,775 acre-feet per year, a net change of 30,543 acre-feet per year.

Gulf Coast Aquifer discharge to springs decreases from 1,844 ac-ft/yr to 445 ac-ft/yr between 2010 and 2060, a net change of 1,399 ac-ft/yr.

Lateral inflow from GMA 15 and from Mexico increases in response to the increased pumping. In 2010, the aquifer has outflow to the Gulf of Mexico, but in 2060 the flow direction has reversed to inflow from the Gulf in response to the increased pumping. Inflow from strata beneath the Gulf Coast Aquifer increases from 8,639 acre-feet per year in 2010 to 25,959 ac-ft/yr in 2060, a net change of 16,320 acre-feet per year.

Reduction of storage changes from 84,550 ac-ft/yr in 2010 to 189,698 ac-ft/yr in 2060, an increase of 105,148 ac-ft/yr.

Regarding the quantification of groundwater-surface water interaction, it should be noted that the GAM is not calibrated to a degree where surface water impacts are particularly reliable or can be viewed as quantitative. The square mile model cell size is more suited to evaluating regional drawdown than stream or spring interaction. However, the GAM is the best tool to address this issue. Since the GAM has inherent uncertainty in this regard, the conclusion of this analysis is that the increased pumping will cause impacts beyond the reduction in storage, including increased lateral and vertical inflow, and possible deceased discharge to rivers and springs.

Table 5 – DFC Groundwater Simulation Water Budgets

To/From	2010		2060	
	In	Out	In	Out
Wells	--	149,069	--	393,898
Recharge	51,309	--	51,309	--
Storage	84,550	--	189,698	--
GMA 13	1,897	--	--	817
Gulf of Mexico	--	1,673	7,812	--
GMA 15	6,507	--	22,890	--
Mexico	8,806	--	49,163	--
Underlying Units	8,639	--	25,959	--
Rivers	--	11,768	18,775	--
Springs	--	1,844	--	445
GHB	3,138		30,308	
Total	**164,846**	**164,354**	**395,914**	**395,160**
Note: All values in acre-feet/year				

Based on a review of the TERS and simulated water budgets associated with the model run, the adoption of the recommended DFCs of GMA 16 are not anticipated to impact the hydrological conditions within GMA significantly during the planning horizon. They are intended to 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.

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

The relevant GAM water budget values are presented in Section 5.3.2 above.

As discussed previously, the purpose of the GMA 16 GAM is to evaluate regional drawdown in support of developing DFCs. It may not be suited to adequately predict groundwater-surface water interaction in a quantitative fashion. Water budgets presented previously indicate that reduced water levels may affect streams in the GMA. However, GMA 16 anticipates that the pumping rates associated with the DFC scenario will not impact environmental conditions significantly during the planning horizon and would 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.

5.5 Subsidence

Historically, subsidence has not been identified as an issue in GMA 16. However, it is well documented that dewatering of the clay layers in the Gulf Coast Aquifer can lead to compaction of those strata, ultimately leading to observable subsidence if the dewatering is significant enough in time and volume. Heavy pumping of the Gulf Coast Aquifer in the Houston area has resulted in over 7 feet of subsidence over much of Harris County, with a maximum subsidence of approximately 10 feet over predevelopment conditions along the Houston Ship Channel (Kasmarek et al, 2012). The Gulf Coast Aquifer in GMA 16 is similar in character to the strata in the Houston area, with multiple interlayered strata of clays and sands. Dewatering of clay layers can lead to compaction and ultimately subsidence. Most of the subsidence observed in Texas has been caused by production of oil and gas, and the withdrawal of groundwater.

A study of subsidence along the Texas Gulf Coast, including in the GMA 16 area, was documented in the Texas Department of Water Resources Report 272 (Ratzlaff 1982). The report indicates that measured subsidence of 5.28 feet was observed in western Corpus Christi between 1942 and 1975. The estimated area of subsidence closely approximates the boundaries of the Saxet Oil and Gas field. Subsidence in this area is likely associated with historical oil and gas production. There was no other significant subsidence documented between 1918 and 1975 in the counties of San Patricio, Nueces, Kleberg, and Jim Wells. In the area encompassing Kenedy, Willacy, Cameron, Brooks, and Hidalgo Counties, maximum measured subsidence was 0.42 feet between 1918 and 1951, with 90 percent of the subsidence occurring before 1943.

For this joint-planning session, no district proposed a DFC for land subsidence. However, additional information may be available for the next round of DFC revisions that could provide additional data for consideration. The TWDB has sponsored a research project into the vulnerability of the major and minor aquifers of Texas to subsidence. As information becomes available, GCDs are able to adjust their management plans and groundwater rules to address land subsidence, if so desired

5.6 Socioeconomic Impacts

The Texas Water Development Board prepared reports on the socioeconomic impacts of not meeting the water needs identified for each of the Regional Water Planning Groups. The socioeconomic impact reports were prepared to support the development of the 2011 Regional Water Plans. The GMA considered the socioeconomic impact reports in developing the DFC. GMA 16 evaluated the development of a DFC in the context of potentially not meeting the identified needs in Regions N and M because certain recommended water management strategies may not be possible.

In general the GMA considered the socioeconomic impacts by projecting future uses of groundwater and incorporating the projections into the development of the DFC. However, the GMA additionally incorporated the Region M water management strategy for groundwater desalination and the Region N water management strategy for groundwater supply development for the City of Alice in the adopted DFC. The approach to simulating the Region M water management strategy for groundwater desalination and the City of Alice groundwater supply development is described in the GAM-run narrative report given in Appendix C.

The socioeconomic impact reports considered by the GCDs of GMA 16 are provided in Appendix G. The information on the Region M water management strategy for groundwater desalination and the City of Alice groundwater supply development considered by GMA 16 is given in Appendix H. These factors were discussed at the public meeting April 22, 2014.

5.7 Impact on Private Property Rights

The GCDs of GMA 16 considered the potential impact on private property, including the ownership and the rights of landowners and their lessees and assigns in groundwater within the GMA as recognized under Texas Water Code Section 36.002. These impacts were discussed at the public meeting held on April 22, 2014.

In general, the GMA considered estimates of the existing uses of groundwater and projections of future uses of groundwater in developing a DFC. The projections of future groundwater use considered by the GMA in developing the DFC reflects the balance of making water available for permitting and protecting the interests of existing users considered appropriate by each GCD of the GMA. Additionally the GMA considered the investment backed expectations for private groundwater development that were brought to the attention of the GMA during the development of the DFC. The estimates of current groundwater use and projections of future groundwater use used by the GMA as well as the approach to incorporating private groundwater developments brought to the attention of the GMA appear in the GAM-run narrative report given in Appendix C.

The information on investment backed expectations for private groundwater development considered by the GMA during development of the DFC are included in Appendix H.

5.8 Feasibility of Achieving the DFC

The GCDs of GMA 16 monitor the water-level conditions of aquifers within their area of jurisdiction on a regular basis by measuring the water levels of wells identified as producing water from specific aquifers. On a schedule defined by their Management Plans, the GCDs will periodically compile the monitoring data and assess the change in the water-level condition of the monitored aquifers to determine if the DFC is being achieved. To facilitate comparison with GCD monitoring data, the GCDs of the GMA developed a methodology for averaging the predicted drawdown of aquifers under the adopted DFC in each GCD area of jurisdiction,. The averaging methodology incorporates a weighting approach to account for the potentially large or small area of occurrence of an aquifer subdivision within a GCD. As required by statute the GMA will convene to consider what (if any) changes may be needed to the DFC at least every 5 years.

5.9 Other Information

As described in other sections the general approach of the GMA to developing the DFC used estimates of current groundwater use and projections of future groundwater use in a series of iterative GAM-runs. After establishing the estimates of use, projections of future use and completing the initial GAM-runs, the GMA considered additional information in developing the DFC. The additional information considered by the GMA in developing the DFC related to:

1. Region M water management strategy for groundwater desalination;
2. Investment backed expectations for private groundwater development in San Patricio County GCD;
3. Groundwater development for the City of Alice, Texas municipal water supply.

The additional information was iteratively incorporated into the series of GAM runs performed by the GMA in developing the DFC.

The additional information considered by the GMA in developing the DFC is given in Appendix H.

6.0 Discussion of Other DFCs Considered

There were 8 scenarios and numerous simulations completed as part of the development of the DFCs. Results of these simulations were presented at GMA 16 meetings and in technical memoranda (Appendix C) as follows:

Scenarios 1 to 3 were iterations of adjusting future pumping upwards using the area-specific multiplication factors based on input from GMA 16 members and the public. The general approach for increasing pumping rates was refined in these runs, and initial errors in various member district pumping files were addressed.

Scenario 4 increased pumping volumes in Duval and Nueces Counties. New pumping centers were simulated in Cameron and Hidalgo County to represent brackish groundwater desalination facilities anticipated by Region M.

Scenarios 5 and 6 established a new pumping center in San Patricio County to represent market production of groundwater by a private interest group. This pumping center was simulated at two different production scenarios.

Scenarios 7 and 8 established a new pumping center to represent a new public water supply project for the City of Alice, Texas beginning in the year 2017. Scenario 7 added this pumping to Scenario 5, and Scenario 8 added this pumping to Scenario 6.

7.0 References

Hassan, M.M., December 8, 2011, GAM Run 10-047 MAG: Groundwater Management Area 16 Model Runs to Estimate Drawdowns Under Assumed Future Pumping for the Gulf Coast Aquifer, Texas Water Development Board Report, 14 p.

Jigmond, M., and Wade, S., GAM Run 12-025: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 16. Texas Water Development Board Report, 19 p.

Kasmarek, M., Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System, Texas, 1891–2009, USGS Scientific Investigations Report 2012-5154, Version 1.1, November 2013, 55 p.

Kelley, V. A., Deeds, N. E., Fryar, D. G., and Nicot, J. P., 2004, Groundwater availability models for the Queen City and Sparta aquifers: contract report to the Texas Water Development Board, 867 p.

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Final Report Groundwater Availability Model for the Yegua-Jackson Aquifer, Deeds N., Yan T., Singh A., Jones T., Kelley V., Knox P., Young S.

Ratzlaff K.W., Land-Surface Subsidence in the Texas Coastal Region, Texas Department of Water Resources Report 272, November 1982.

APPENDIX A – GMA 16 PROPOSED DFC RESOLUTION

(delivered electronically)

APPENDIX B – GMA 16 PUBLIC MEETING MINUTES

(delivered electronically)

APPENDIX C – TECHNICAL MEMOS DOCUMENTING GAM RUNS AND NON-RELEVANT AQUIFERS

(delivered electronically)

APPENDIX D – AQUIFER USES AND CONDITIONS SUPPORTING DATA

(delivered electronically)

APPENDIX E – Water Supply Needs and Water Management Strategies Supporting Data

(delivered electronically)

APPENDIX F – GAM Run 12-025: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 16

(delivered electronically)

APPENDIX G – SOCIOECONOMIC IMPACT ANALYSES FOR REGIONS M AND N

(delivered electronically)

APPENDIX H – Impacts on Private Property Rights Supporting Materials

(delivered electronically)

APPENDIX I – Groundwater Model Files

(delivered electronically)