DESIRED FUTURE CONDITION EXPLANATORY REPORT FOR GROUNDWATER MANAGEMENT AREA 15

This report was considered and approved by the member districts of Groundwater Management Area 15 on June 14, 2016.

Member Districts:

1. Aransas County Groundwater Conservation District
2. Bee Groundwater Conservation District
3. Calhoun County Groundwater Conservation District
4. Coastal Bend Groundwater Conservation District
5. Coastal Plains Groundwater Conservation District
6. Colorado County Groundwater Conservation District
7. Corpus Christi ASR Conservation District
8. Evergreen Underground Water Conservation District
9. Fayette County Groundwater Conservation District
10. Goliad County Groundwater Conservation District
11. Pecan Valley Groundwater Conservation District
12. Refugio Groundwater Conservation District
13. Texana Groundwater Conservation District
14. Victoria County Groundwater Conservation District

Technical Consultancy and Support Provided by:

INTERA
GEOSCIENCE & ENGINEERING SOLUTIONS

Steven Young, PhD, PE, PG

INTERA Incorporated
1812 Centre Creek Drive
Suite 300
Austin, TX 78754
512-425-2000

Geoscientist Seal

Steven C. Young, P.G., P.E., Ph.D.

Dr. Young was the technical lead responsible for assembling, interpreting, and documenting the information in the explanatory report. He is also the principal writer of the report.

STATE OF TEXAS
STEVE C YOUNG
GEOLOGY
231
LICENSED
PROFESSIONAL GEOSCIENTIST

Steven C Young 6/18/2016

Signature Date

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACROYNMS AND ABBREVIATIONS

AFY	acre feet per year
ASCRD	Aquifer Storage & Recovery Conservation District
CGC GAM	Central Gulf Coast Aquifers GAM
DFC	Desired Future Condition
GAM	groundwater availability model
GMA	Groundwater Management Area
GW-SW	Groundwater-surface water
HB	House Bill
INTERA	INTERA Incorporated
LCRB	Lower Colorado River Basin
MAG	modeled available groundwater
RFP	request for proposal
RMSE	root mean square error
TERS	total estimated recoverable storage
TWDB	Texas Water Development Board
UWCD	Underground Water Conservation District

1.0 INTRODUCTION

1.1 GMA 15

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).

The responsibility for GMA delineation was delegated to the Texas Water Development Board (TWDB). (Section 35.004, Chapter 35, Title 2, Texas Water Code). The initial GMA delineations were adopted on December 15, 2002, and are modified as necessary according to agency rules. There are 16 GMAs in Texas. **Figure 1-1** shows the boundaries of these 16 GMAs, including GMA 15. **Figure 1-2** shows the location of the 14 Groundwater Conservation Districts (GCDs) that are contained wholly or in part within the boundary of GMA 15: These 14 GCDs are Aransas County GCD, Bee GCD, Calhoun County GCD, Coastal Bend GCD, Coastal Plains GCD, Colorado County GCD, Corpus Christi Aquifer Storage & Recovery Conservation District (ASRCD), Evergreen Underground Water Conservation District (UWCD), Fayette County GCD, Goliad County GCD, Pecan Valley GCD, Refugio GCD, Texana GCD, and Victoria County GCD.

In GMA 15, the TWDB recognizes two major aquifers and three minor aquifers. **Figure 1-3** shows the footprints of the two major aquifers, the Gulf Coast and the Carrizo-Wilcox aquifers. The Carrizo-Wilcox occurs only as a subcrop in the four most up-dip counties, DeWitt, Karnes, Lavaca, and Fayette counties. **Figure 1-4** shows the footprints of the minor aquifers, which are the Yegua-Jackson, the Sparta and the Queen City aquifers. These three minor aquifers only occur as subcrops in Fayette County. **Table 1-1** is a stratigraphic column showing relative age and placement of the aquifers.

Table 1-1 A simplified stratigraphic column for GMA 15 (modified from Young and others, 2010)

<table>
<tr><th>EPOCH</th><th colspan="2">Hydrogeologic Unit</th></tr>
<tr><td>Holocene</td><td rowspan="3">Chicot Aquifer</td><td rowspan="7">Gulf Coast Aquifer</td></tr>
<tr><td>Pleistocene</td></tr>
<tr><td>Pliocene</td></tr>
<tr><td rowspan="3">Miocene</td><td>Evangeline Aquifer</td></tr>
<tr><td>Burkeville Confining Unit</td></tr>
<tr><td rowspan="2">Jasper Aquifer</td></tr>
<tr><td rowspan="2">Oligocene</td></tr>
<tr><td colspan="2">aquitard</td></tr>
<tr><td rowspan="5">Eocene</td><td colspan="2">Yegua-Jackson Aquifer</td></tr>
<tr><td colspan="2">Sparta Aquifer</td></tr>
<tr><td colspan="2">Queen City Aquifer</td></tr>
<tr><td colspan="2">aquitard</td></tr>
<tr><td colspan="2" rowspan="2">Carrizo-Wilcox Aquifer</td></tr>
<tr><td>Paleocene</td></tr>
</table>

In this report, the Gulf Coast Aquifer will be divided into four major hydrogeologic units, which are shown in Table 1-1. These four units are, from youngest to oldest, the Chicot Aquifer, the Evangeline Aquifer, the Burkeville Confining Unit, and the Jasper Aquifer.

There are fourteen counties in GMA 15. **Table 1-2** lists the fourteen counties and their area and population projects. In 2010, the fourteen counties had a population of 369,500 people, and the county with the largest population was Victoria County, with 86,800 people. The population of the fourteen counties is expected to grow to 473,000 people in 2070, with Victoria expanding to a population of 116,500 people.

Table 1-2 Population projection from the 2017 State Water Plan by county and the area for the counties

County Name	Area (sq miles)[1]	2010[2]	2020	2030	2040	2050	2060	2070
Aransas	252	23,158	24,463	24,991	24,937	25,102	25,103	25,104
Bee	880	31,861	33,478	34,879	35,487	35,545	35,579	35,590
Calhoun	506	21,381	24,037	26,866	29,622	32,276	34,906	37,454
Colorado	960	20,874	21,884	22,836	23,544	24,582	25,449	26,293
DeWitt	909	20,097	20,855	21,555	21,900	22,216	22,425	22,572
Fayette	950	24,554	28,373	32,384	35,108	37,351	39,119	40,476
Goliad	852	7,210	8,427	9,519	10,239	10,545	10,759	10,884
Jackson	829	14,075	14,606	15,119	15,336	15,515	15,627	15,699
Karnes	747	14,824	15,456	15,938	15,968	15,968	15,968	15,968
Lavaca	970	19,263	19,263	19,263	19,263	19,263	19,263	19,263
Matagorda	1,100	36,702	39,166	41,226	42,548	43,570	44,296	44,815
Refugio	770	7,383	7,687	7,929	7,985	8,119	8,175	8,213
Victoria	882	86,793	93,857	100,260	105,298	109,785	113,470	116,522
Wharton	1,086	41,280	43,804	46,614	48,860	50,804	52,599	54,189
GMA 15 Total		**369,455**	**395,356**	**419,379**	**436,095**	**450,641**	**462,738**	**473,042**

[1] Source of county areas is http://www.indexmundi.com/facts/united-states/quick-facts/texas/land-area#table

[2] 2010 is based on the United States Census

1.2 Joint Planning Process

The joint-planning process was first adopted by the Texas Legislature with the passage of House Bill (HB) 1763 in 2005. One of the requirements of HB 1763 is that, where two or more districts are located within the same boundaries of GMA, the districts shall establish Desired Future Conditions (DFCs) for all relevant aquifers in the GMA by no later than September 1, 2010 and every five years thereafter.

DFCs are defined in Title 31, Part 10, §356.10 (6) of the Texas Administrative Code as "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."

The specified future time extends through at least the period that includes the current planning period for the development of regional water plans pursuant to §16.053, Texas Water Code, or in perpetuity, as defined by participating districts within a GMA as part of the joint planning process. DFCs have to be physically possible, individually and collectively, if different DFCs are stated for different geographic areas overlying an aquifer or subdivision of an aquifer.

The joint-planning process was expanded significantly by the passage of Senate Bill 660 in 2011. The more substantive elements of the expanded process include: (1) new requirements that an explanatory report be developed and submitted at the conclusion of the joint-planning process to document that certain required factors for consideration have been addressed; (2) a change from requirements involving estimates of managed available groundwater to modeled available groundwater (MAG) (including the process for addressing exempt use); (3) new requirements for individual districts to provide for a 90-day public comment period, during which the individual district is to a hold public hearing on proposed DFCs before final adoption by at least two thirds of the district representatives in the GMA; and (4) as soon as possible after final adoption of the DFCs by district representatives in the GMA, individual districts are finally then to adopt the DFCs. Solely applicable to the current round of joint-planning, the deadline for adopting proposed DFCs was extended to May 1, 2016, by the passage of Senate Bill 1282 by the Texas Legislature in 2013.

If a GMA includes more than one district, those districts must engage in a joint planning process, including at least an annual meeting. The districts must jointly determine the DFCs for the management area and, in doing so, are required to consider the nine following factors:

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, 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;
8. the feasibility of achieving the DFC; and
9. any other information relevant to the specific DFCs.

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 desired future condition.”

1.3 GMA 15 Joint Planning

The joint-planning process established by HB 1763 in 2005 and amended by Senate Bill 660 in 2011 is a public, transparent process, where all planning decisions are made in open, publicly noticed meetings in accordance with provisions contained in Texas Water Code Chapter 36. From 2012 to 2015, GMA 15 convened 18 times within the boundary of the GMA at the dates listed in **Table 1-3**. All of the meetings were open to the public. All meeting notices were posted at least 10 days in advance of the meeting and included an invite to submit comments, questions, and requests for additional information to Tim Andruss of the Victoria County GCD by mail at 2805 N. Navarro St. Suite 210, Victoria, TX 77901, by email at admin@vcgcd.org, or by phone at (361) 579-6883.

Table 1-3 lists the dates and the major discussion topics of the GMA 15 joint planning meetings from 2012 to 2015. **Appendix A** contains the meeting notices and the minutes for the meetings. In June 2013, GMA 15 selected INTERA Incorporated (INTERA) to be their technical consultant. INTERA performed the groundwater availability model (GAM) simulations for GMA 15, provided technical guidance, and supported the preparation of this explanatory report.

Table 1-3 List of meetings that were convened GMA 15 from 2012 to 2016

Meeting Date	Quorum Present	Major Discussion Topic
June 20, 2012	Yes	Discussed joint planning requirements, groundwater monitoring and DFC compliance, regional water planning
October 10, 2012	Yes	GCDs report on recent and on-going hydrogeology projects, methods for estimating groundwater usage, appointed officers, interlocal GCD agreements, discussion of GCD management plans
February 14, 2013	Yes	Aquifer use and measured groundwater levels, RFP for hiring a consultant, possible use of LCRB model as alternative groundwater model
April 11, 2013	Yes	Population estimates, GCD annual reports, responses from RFP for consultant
June 13, 2013	Yes	GCD Management Plans, population estimates, INTERA selected as consultant
October 10, 2013	Yes	Lavaca GCD dissolved, regional water planning, GCD management plans, officer election
January 9, 2014	Yes	Regional water planning, review of GCD management plans, PDFCs, anticipated future pumping scenarios for GAM runs
April 10, 2014	Yes	Pumping scenarios for GAM Runs, assessment of GCD management plans on DFCs, TWDB report on an updated GAM*
July 10, 2014	Yes	Assessment of GCD management plans on DFCs, baseline and high-production pumping scenarios
October 9, 2014	Yes	GCD management plans, regional water planning, submitted INTERA files on water budgets, TERS, historical pumping
January 8, 2015	Yes	Social economic impact of DFCs, aquifer sustainability
April 9, 2015	Yes	Regional water planning issues, future pumping scenarios, impacts of drought on DFCs
July 15, 2015	Yes	Feasibility of DFCs, INTERA presentation, considerations regarding subsidence, social economic, personal property
August 13, 2015	Yes	Review of INTERA DFC pumping runs
October 8, 2015	Yes	Review of DFC pumping runs, review DFC adoption steps
December 9, 2015	Yes	Review of nine factors to consider regarding DFCs
January 16, 2016	Yes	Proposed DFCs
April 29, 2016	Yes	District Summaries of Public Comment Period, Adoption of DFCs

During the GMA 15 meeting on January 14, 2016, GMA 15 designated the draft Groundwater Management Area 15 Desired Future Conditions language, with modification, as the Proposed Desired Future Conditions of Groundwater Management Area 15. As required by Texas Water Code Section

36.108(d-2), the proposed DFCs were subsequently distributed to the individual districts in GMA 15. A period of not less than 90 days was provided to allow for public comments on the proposed DFCs; during this comment period, each district held a public hearing on the proposed DFCs. **Table 1-4** lists the date that each district conducted a public hearing on the proposed DFCs.

Table 1-4 Public hearings conducted by the GCDs regarding the proposed DFCs

GCD	Public Hearing Date
Aransas County GCD	March 23, 2016
Bee GCD	March 23, 2016
Calhoun County GCD	April 18, 2016
Coastal Bend GCD	April 25, 2016
Coastal Plains GCD	April 25, 2016
Colorado County GCD	April 27, 2016
Corpus Christi ASRCD	February 4, 2016
Evergreen UWCD	April 22, 2016
Fayette County GCD	March 7, 2016
Goliad County GCD	April 18, 2016
Pecan Valley GCD	April 19, 2016
Refugio GCD	April 18, 2016
Texana GCD	April 14, 2016
Victoria County GCD	April 15, 2016

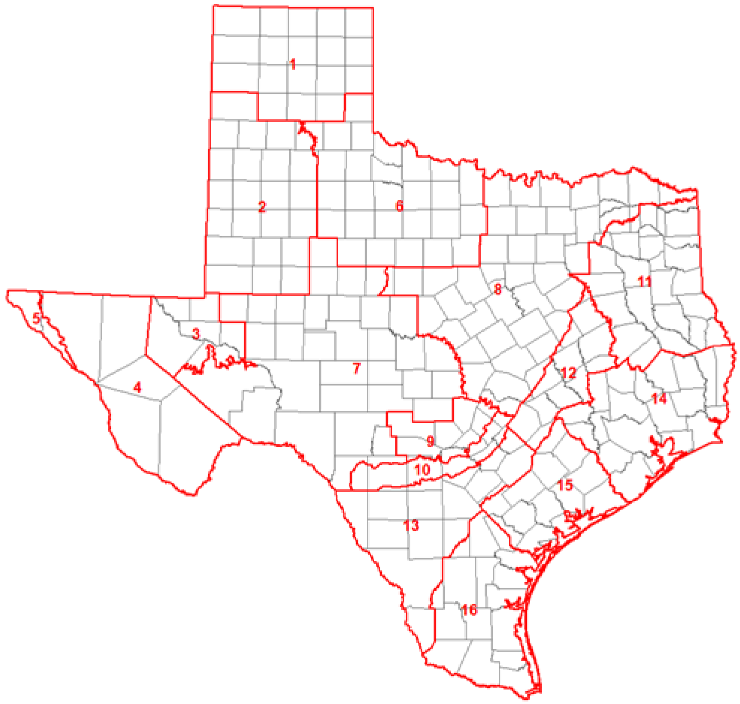


Figure 1-1 Delineation of 16 groundwater management zones in Texas (obtained from http://www.twdb.texas.gov/groundwater/management_areas/index.asp)

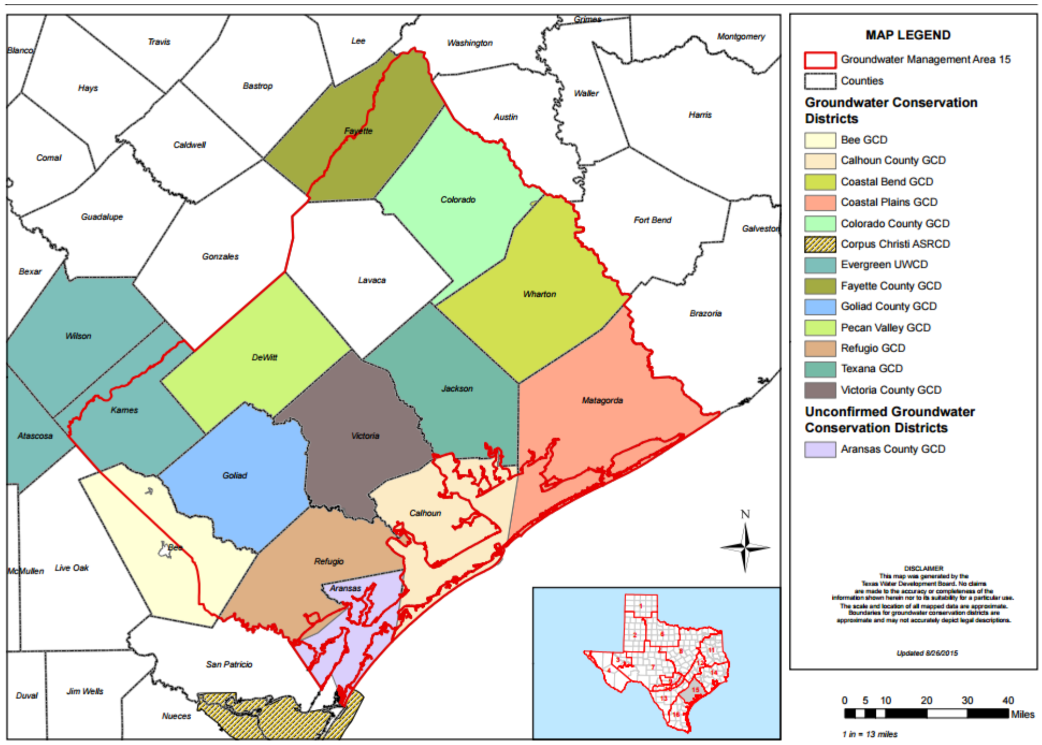


Figure 1-2 Delineation of GMA 15 showing locations of GCDs (obtained from http://www.twdb.texas.gov/groundwater/management_areas/gma15.asp)

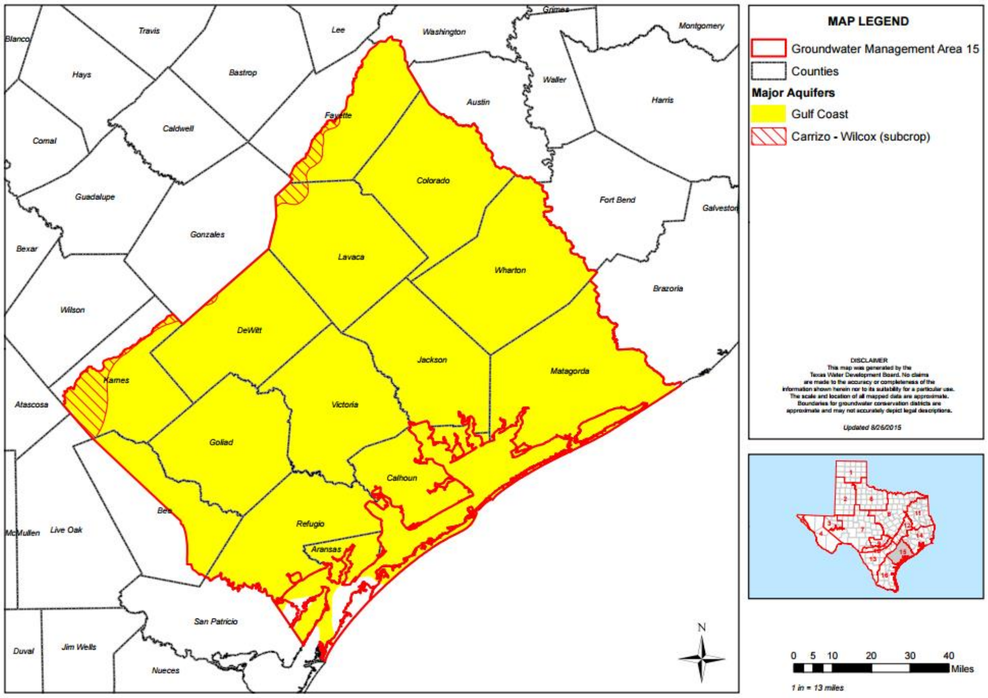


Figure 1-3 Map of GMA 15 major aquifer boundaries (obtained from http://www.twdb.texas.gov/groundwater/management_areas/gma15.asp)

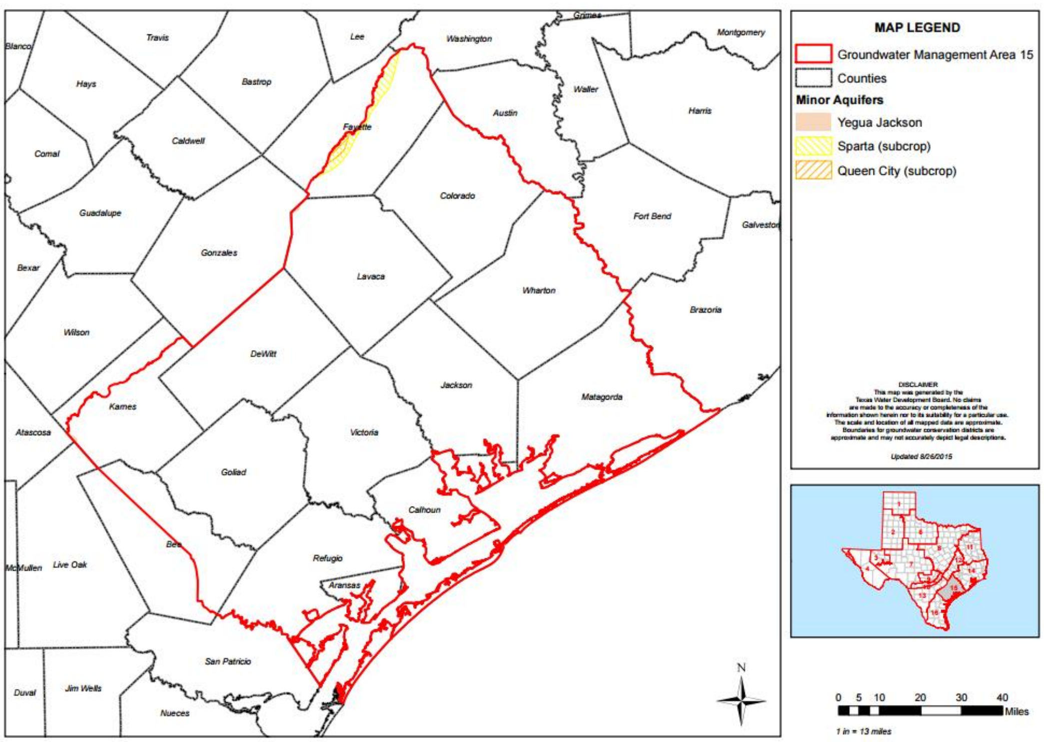


Figure 1-4 Map of GMA 15 minor aquifer boundaries (obtained from http://www.twdb.texas.gov/groundwater/management_areas/gma15.asp)

2.0 GMA 15 DESIRED FUTURE CONDITIONS

2.1 Gulf Coast Aquifers

The three Gulf Coast aquifers of interest are the Chicot Aquifer, the Evangeline Aquifer, and the Jasper Aquifer. As shown in Table 1-1, the Burkeville Confining Unit lies between and separates the Evangeline and the Jasper aquifers. For the purpose of establishing DFCs, GMA 15 has adopted the boundaries in the Central Gulf Coast GAM (CGC GAM) (Chowdhury and others, 2004) to define the areas and volumes associated with the Chicot Aquifer, Evangeline Aquifer, the Jasper Aquifer, and the Burkeville Confining Unit.

On April 29, 2016, GMA 15 Representatives approved resolution 2016-01 titled Resolution to Adopt the Desired Future Conditions for Groundwater Management Area 15. **Appendix B** contains the resolution. The adopted DFCs are based on acceptable levels of drawdown for each county and the entire groundwater management area from 2000 to 2070. Groundwater Management Area 15 adopts Desired Future Conditions (DFCs) as average drawdowns that occur between January 2000 and December 2069 for the following:

Gulf Coast Aquifer System – 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 Central Gulf Coast Aquifer GAM (Chowdhury and others, 2004).

Chicot and Evangeline Aquifers – represents an average drawdown for the Chicot Aquifer and the Evangeline Aquifer that is weighted by the area of each hydrogeological unit in the Central Gulf Coast Aquifer GAM (Chowdhury and others, 2004).

Jasper Aquifer- represents an average drawdown for the area of the Jasper Aquifer in the Central Gulf Coast Aquifer GAM (Chowdhury and others, 2004).

Groundwater Management Area 15 adopts Desired Future Conditions for each county within the groundwater management area (county-specific DFCs) and adopts a Desired Future Condition for the counties in the groundwater management area (GMA-specific DFC). The Desired Future Condition for the counties in the groundwater management area shall not exceed an average drawdown of 13 feet for the Gulf Coast Aquifer System at December 2069. Desired Future Conditions for each county within the groundwater management area (county-specific DFCs) shall not exceed the values specified in **Table A-1** at December 2069.

Table A-1 Desired Future Conditions for GMA 15 expressed as an Average Drawdown between January 2000 and December 2069.

Aransas County	0 feet of drawdown of the Gulf Coast Aquifer System
Bee County	7 feet of drawdown of the Gulf Coast Aquifer System;
Calhoun County	5 feet of drawdown of the Gulf Coast Aquifer System
Colorado County	17 feet of drawdown of the Chicot and Evangeline Aquifers and 23 feet of drawdown of the Jasper Aquifer
Dewitt County	17 feet of drawdown of the Gulf Coast Aquifer System
Fayette County	16 feet of drawdown of the Gulf Coast Aquifer System
Goliad County	10 feet of drawdown of the Gulf Coast Aquifer System
Jackson County	15 feet of drawdown of the Gulf Coast Aquifer System
Karnes County	22 feet of drawdown of the Gulf Coast Aquifer System
Lavaca County	18 feet of drawdown of the Gulf Coast Aquifer System
Matagorda County	11 feet of drawdown of the Chicot and Evangeline Aquifers
Refugio County	5 feet of drawdown of the Gulf Coast Aquifer System
Victoria County	5 feet of drawdown of the Gulf Coast Aquifer System
Wharton County	15 feet of drawdown of the Chicot and Evangeline Aquifers

2.2 Carrizo-Wilcox Aquifer

GMA 15 considers the portion of the Carrizo-Wilcox Aquifer within boundary of GMA 15 non-relevant for joint planning purposes. The portion of this aquifer system present within GMA 15 is small, downdip, and only present at great depths. Use and projected demands from the Carrizo-Wilcox Aquifer within GMA 15 is negligible to non-existent. The total estimated recoverable storage (TERS) for the Carrizo-Wilcox is 17,475,000 to 52,425,000 acre-feet for all of GMA 15. Approximately 85% of the TERS present within GMA 15 is within the boundaries of Evergreen UWCD and Fayette County GCD. Evergreen UWCD and Fayette County GCD manage their Carrizo-Wilcox resources as part of GMA 13 and GMA 12, respectively. Therefore, GMA 15 concludes that the desired future conditions in adjacent or hydraulically connected relevant aquifers will not be affected.

2.3 Yegua-Jackson, Sparta, and Queen-City aquifers

GMA 15 considers the portions of the Yegua-Jackson, Sparta, and Queen-City Aquifers within the boundary of GMA 15 non-relevant for joint planning purposes. The portions of these aquifers within GMA 15 are small. Use and projected demands from these aquifers within GMA 15 is negligible to non-existent. The TERS for the Queen City Aquifer is 160,000 to 480,000 acre-feet for all of GMA 15 and located only within Fayette County. The TERS for the Sparta Aquifer is 725,000 to 2,175,000 acre-feet for all of GMA 15 and located only within Fayette County. The Fayette County GCD has additional groundwater resources in both the Queen City and Sparta aquifers outside of GMA 15 and manages these resources as part of GMA 12. The TERS for the Yegua-Jackson Aquifer is 202,500 to 607,500 acre-feet for all of GMA 15 and located only within Karnes County and Lavaca County. The boundary of Evergreen UWCD includes Karnes County. Evergreen UWCD manages the Yegua-Jackson Aquifer resources as part of GMA 13. Estimated use from the Yegua-Jackson Aquifer within Lavaca County is less than 10 acre-feet/year. Lavaca County is not located within the boundary of an existing groundwater conservation district and the groundwater resources within are not managed. Therefore, GMA 15 concludes that the desired future conditions in adjacent or hydraulically connected relevant aquifers will not be affected.

3.0 POLICY JUSTIFICATION

The adoption of DFCs by districts, pursuant to the requirements and procedures set forth in Texas Water Code Chapter 36, is an important policy-making function. DFCs are planning goals that state a desired condition of the groundwater resources in the future in order to promote better long-term management of those resources. Districts are authorized to utilize different approaches in developing and adopting DFCs based on local conditions and the consideration of other statutory criteria as set forth in Texas Water Code Section 36.108.

GMA 15 and each of its member districts evaluated DFCs with regard to the nine factors required by Texas Water Code Section 36.108(d), as listed in Section 1.2. In addition to these nine factors, GMA 15 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.

In evaluating the DFCs, GMA 15 and the individual districts recognizes that: 1) the production capability of the aquifer varies significantly across GMA 15, 2) historical groundwater production is significantly different across GMA 15, and 3) the importance of groundwater production to the social-economic livelihood of an area is significantly varied among the districts. As a result of this recognition, a key GMA 15 policy decision was to allow districts to set different DFCs for portion of a specific aquifer within their boundaries, as long as the different DFCs could be shown to be physically possible. The allowance of different DFCs among the districts is justified for several reasons. One reason is that the Texas Water Code Section 36.108(d)(1) authorizes the adoption of different DFCs for different geographic areas over the same aquifer based on the boundaries of political subdivisions. The statute expressly and specifically directs districts "to consider uses or conditions of an aquifer within the management area, including conditions that differ substantially from one geographic area to another" when developing and adopting DFCs for:

1. each aquifer, subdivision of an aquifer, or geologic strata located in whole or in part within the boundaries of the management area; *or*
2. each geographic area overlying an aquifer in whole or in part or subdivision of an aquifer within the boundaries of the management area.

The Legislature's addition of the phrase "in whole or in part" makes it clear that districts may establish a "different" DFC for a geographic area that does not cover the entire aquifer but only part of that aquifer. Moreover, the plain meaning of the term "geographic area" in this context clearly includes an area defined by political boundaries, such as those of a district or a county.

Each district in GMA 15 submitted a summary of the public comment period and public hearing regarding the proposed DFCs inclusive of all relevant comments received during the 90-day public comment period regarding the proposed DFCs, any suggested revisions to the proposed DFCS, and the basis for the revisions. The summaries are provided in **Appendix C**. GMA 15 Representatives reviewed the summary submittals during a meeting held on April 29, 2016. The DFCs that were considered and proposed for final adoption specify acceptable drawdown levels in the Gulf Coast aquifers on a county-by-county basis and across the entire GMA 15.

4.0 TECHNICAL JUSTIFICATION

The adopted DFCs for the Gulf Coast Aquifer in Section 2.0 were partly developed from simulations of various future pumping scenarios using the CGC GAM (Chowdhury and others, 2004).

4.1 Overview of the Central Gulf Coast GAM (CGC GAM)

The development of the CGC GAM (Chowdhury and others, 2004) began with Waterstone Environmental Hydrology and Engineering, Inc. (Waterstone and Parsons, 2003), and was completed by the TWDB. **Figure 4-1** shows the model domain for the CGC GAM. The model boundary is defined by: (1) the limits of the outcrop area in the west, (2) the Gulf of Mexico, (3) groundwater divide to the north through the Colorado-Fort Bend-Brazoria counties, and (4) groundwater divide to the south through Jim Hogg, Brooks, and Kenedy counties. The model has four layers, which from top to bottom represent the Chicot Aquifer, the Evangeline Aquifer, the Burkeville confining Unit, and the Jasper Aquifer. **Figure 4-2** shows the layering of the model using both three-dimensional and two-dimensional surfaces.

The groundwater code used to model the groundwater flow is MODFLOW-96 (Harbaugh and McDonald, 1996). MODFLOW-96 is code that solves the groundwater flow equation for a finite-difference numerical grid. The numerical grid for the CGC GAM consists of grid cells with dimensions of one mile by one mile. The thickness of each grid cell equals the thickness of the model layer/geologic unit that it represents. The dimension of the grid cell is important because it limits the resolution at which the groundwater system can be described. Among the limitations placed on the model solution by the numerical grid are the following:

- the aquifer properties assigned to a grid cell are assumed to be uniform and constant;
- all the of wells located within the area of a grid cell are represented by a single well at the center of the grid cell;
- all of the wells that pump from a geologic unit are assumed be screened across the entire length of the geologic unit; and
- the water level for the entire grid cell volume is represented by a single value at the center of the grid cell.

The model approach described by the TWDB (Chowdhury and others, 2004) includes: (1) calibrating the model for steady-state conditions from 1910 to 1940 (based on assumptions of no water level change during pre-pumping conditions), and (2) calibrating the model for transient conditions from 1940 to 1999 (based on assumed yearly changes in pumping). The steady-state calibration was performed primarily to investigate the model sensitivity to changes in aquifer properties and boundary conditions. The transient calibration was performed to estimate the final aquifer parameters and boundary conditions for the final model.

The transient calibration by the TWDB primarily focused on adjusting hydraulic parameters to match measured water levels obtained from the TWDB groundwater well database. The vast majority of the water levels used to calibrate the model are from the Chicot and Evangeline aquifers. Only a few water level measurements were associated with the Burkeville Confining Unit and the Jasper aquifer. Both the TWDB and the Waterstone reports provide relatively little information regarding aquifer properties, recharge distributions, and hydraulic boundary conditions. As a result, a reader has little to no information with which to evaluate the reasonableness of many model parameters important to making predictions of pumping impacts.

4.2 Development of the CGC GAM

The primary criteria used by the TWDB to evaluate the model calibration results were comparison between simulated and measured water levels. A standard metric for assessing the goodness in matching historic water levels is the root-mean square error (RMSE). The RMSE is a measure of the average difference between the measured and simulated water levels. The acceptable value of RMSE is both model- and problem-dependent. For regional models that span hundreds of miles, an RMSE of about 10% of the range in head values is generally accepted as a minimum goal during model calibration.

Chowdhury and others (2004) use water levels from 1989 and 1999 to calibrate the CGC GAM. **Figure 4-3** compares the measured and simulated water levels for 1989 and 1999, respectively. The RMSE for the calibration is 46 feet for 1989 and 36 feet for 1999. The RMSE values for the 1989 calibration period and for the 1999 calibration period are about 5% of the total change in water levels across the model area shown in Figure 4-1.

In addition to water levels, Chowdhury and others (2004) show matches for baseflows in streams. **Figure 4-4** shows comparisons between measured and simulated base flows for three river gages in the model domain. The figures show that the simulated base flows are significantly lower than the measured values. Referring to the underestimated stream flows in Figure 4-4, Chowdhury and others (2004) state:

> "In regional groundwater flow models, it is always difficult to reproduce baseflow where the errors in the simulated heads in the aquifers could be potentially large and the state in the river are fixed. A global increase in stream conductance causes too much of a hydraulic interaction between the aquifers and the streams in the central Gulf Coast GAM (Waterstone and Parson, 2003) and would require unreasonable recharge to calibrate the model."

Among the concerns with the calibration of the CGC GAM is that Chowdhury and others (2004) and Waterstone and Parson (2003) provide relatively little documentation and data that can be used to check the reasonableness of the model parameters. With regard to hydraulic properties, Chowdhury and others (2004) do not present any results from specific aquifer tests, geophysical logs, or regional hydrogeological studies to justify their parameterization of the aquifer properties. Chowdhury and others (2004) use three hydraulic conductivity zones (**Figure 4-5**) to model the Evangeline Aquifer but they do not compare these zonation values and results from analysis of field data.

With regard to pumping rates, Chowdhury and others (2004) state that they recalibrated the Waterstone draft GAM based on TWDB estimates of pumpage distribution. However, Chowdhury and others (2004) do not discuss the procedure used to assign TWDB pumping rates to the grid cells among the aquifer layers and the potential sources of error and uncertainty.

Chowdhury and others (2004) present the following three water budgets for the CGC GAM: 1) steady-state for pre-development; 2) transient conditions for 1989; and, 3) transient conditions for 1999. Water budgets provide a breakdown of where the sources and discharges of water occur in the groundwater model. All three of these water budgets are reproduced and shown in **Table 4-1**.

The water budget for the pre-development conditions, which represents the time prior to pumping, is about 600,000 acre feet per year (AFY). The two primary sources of inflow are streams (69%) and recharge from precipitation (29%). The two primary sources of outflows are streams (84%) and the Gulf of Mexico (16%). The average water budget for the 1989 and the 1999 pumping conditions is about 1,000,000 AFY. The increase in the water budget is caused by groundwater pumping, which averages

Table 4-1 Water budgets from the CGC GAM (from Chowdhury and others, 2004)

Steady-state Conditions for Pre-Development				
Parameter	**Flow (in) (AFY)**	**Flow (out) (AFY)**	**Flow (in) (percent)**	**Flow (out) (percent)**
Drains	0	-4,075	0%	1%
Lake Leakage	9,319	0	2%	0%
Evapo-transpiration	0	0	0%	0%
Gulf of Mexico	0	-97,008	0%	16%
Recharge	180,796	0	29%	0%
Stream Leakage	426,578	-515,610	69%	84%
Total	**616,693**	**-616,693**	**100%**	**100%**
Transient Conditions for 1989				
Parameter	**Flow (in) (AFY)**	**Flow (out) (AFY)**	**Flow (in) (percent)**	**Flow (out) (percent)**
Storage	365,155	-237,054	32.53%	21.12%
Pumping	0	-386,932	0%	34%
Drains	0	-1,832	0%	0%
Lake Leakage	21,752	0	2%	0%
Evapo-transpiration	0	-37,920	0%	3%
Gulf of Mexico	2,579	-71,551	0%	6%
Recharge	265,448	0	24%	0%
Stream Leakage	467,671	-387,296	42%	35%
Total	**1,122,605**	**-1,122,585**	**100%**	**100%**
Transient Conditions for 1999				
Parameter	**Flow (in) (AFY)**	**Flow (out) (AFY)**	**Flow (in) (percent)**	**Flow (out) (percent)**
Storage	248,228	-22,549	25.53%	2.32%
Pumping	0	-425,020	0%	44%
Drains	0	-2,035	0%	0%
Lake Leakage	21,409	0	2%	0%
Evapo-transpiration	0	-20,958	0%	2%
Gulf of Mexico	1,299	-87,330	0%	9%
Recharge	182,909	0	19%	0%
Stream Leakage	518,498	-414,450	53%	43%
Total	**972,343**	**-972,342**	**100%**	**100%**

about 400,000 AFY. The three major sources of inflow are leakage from stream (47%), water release from aquifer storage (29%), and recharge (21%). The three major sources of discharge are groundwater flow to streams (39%), pumping from the aquifer (39%), and addition of water into storage (12%).

4.3 Application of CGC GAM

The CGC GAM was used to simulate the impact of pumping for a period from January 1, 2000 to December 31, 2071. The initial water level conditions for the predictive GAM runs from Chowdhury and others (2004) for December 1999 and are shown in **Figure 4-6**. To help establish appropriate benchmarks for districts to evaluate pumping impacts, **Appendix D** presents the water budgets for each county for 1999. These water budgets were presented to the GMA 15 by INTERA on April 10, 2014.

Two scenarios of pumping rates and locations were generated by the GMA 15 for the time period from 2000 to 2070 to represent alternative future pumping scenarios. Each pumping scenario is contained in a single computer file that can be read and used by the CGC GAM. The two scenarios are called “Baseline” and “High-Production.” The “Baseline” scenario represented a district’s current MAG, with updates to account for anticipated district growth and/or permits recently awarded. There was no consensus among the districts for a definition of “High-Production.” The “High-Production” scenario was developed to allow several districts to evaluate the impact of increased pumping on drawdowns.

In order to help represent spatial and temporal trends of interest to the districts adequately, the pumping scenarios were generated using a template that allowed yearly changes in pumping in any grid cell or group of cells in the GAM, so that the districts could represent future pumping rates at the temporal and spatial resolution they deemed appropriate for the joint planning process. Several versions of the Baseline and the High-Production pumping files were generated and run with the CGC GAM in 2014. The final set of pumping files used to help establish the adopted DFCs include the designation “Option 1.” **Table 4-2** presents the pumping by county and by aquifer in 2070 for the Baseline Option 1 pumping scenario. **Table 4-3** presents the pumping by county and by aquifer in 2070 for the High-Production Option 1 pumping scenario. **Figure 4-7** shows the annual variation of total pumping by county for the Baseline Option 1 pumping scenario. **Figure 4-8** shows the annual variation of total pumping by county for the High-Production Option 1 pumping scenario.

Table 4-2 2070 pumping rates associated with the Baseline Pumping Scenario

County	Chicot Aquifer	Evangeline Aquifer	Burkeville Confining Unit	Jasper Aquifer	Total
Aransas	1,863	0	0	0	**1,863**
Austin	3,180	4,006	5	22	**7,214**
Bee	3,707	5,505	17	289	**9,518**
Brazoria	8,901	289	0	0	**9,189**
Calhoun	7,950	68	0	0	**8,018**
Colorado	31,602	40,066	0	919	**72,587**
Dewitt	1,019	7,818	166	6,408	**15,411**
Fayette	0	264	405	1,878	**2,546**
Fort Bend	6,248	5,381	0	0	**11,629**
Goliad	714	10,702	306	102	**11,824**
Jackson	66,147	24,529	0	0	**90,676**
Karnes	0	105	627	3,262	**3,993**
Lavaca	3,095	12,647	151	4,692	**20,585**
Matagorda	33,898	7,121	0	0	**41,020**
Refugio	3,383	2,636	0	0	**6,019**
Victoria	32,170	27,873	0	0	**60,043**
Wharton	114,878	66,575	0	0	**181,452**
Total	**318,755**	**215,584**	**1,676**	**17,572**	**553,587**

Table 4-3 2070 pumping rates associated with the High-Production Pumping Scenario

County	Chicot Aquifer	Evangeline Aquifer	Burkeville Confining Unit	Jasper Aquifer	Total
Aransas	1,863	0	0	0	**1,863**
Austin	3,180	4,006	5	22	**7,214**
Bee	3,707	5,505	17	289	**9,518**
Brazoria	8,901	289	0	0	**9,189**
Calhoun	12,456	10,070	0	0	**22,526**
Colorado	48,419	62,874	0	919	**112,211**
Dewitt	1,019	7,813	165	19,178	**28,176**
Fayette	0	914	1,380	6,664	**8,958**
Fort Bend	6,286	5,381	0	0	**11,667**
Goliad	724	12,288	311	286	**13,609**
Jackson	92,308	85,452	0	0	**177,760**
Karnes	0	105	737	4,485	**5,327**
Lavaca	3,095	12,647	151	4,692	**20,585**
Matagorda	42,732	9,063	0	0	**51,795**
Refugio	6,379	37,951	0	0	**44,331**
Victoria	104,670	70,373	0	50,000	**225,043**
Wharton	135,864	78,713	0	0	**214,577**
Total	**471,604**	**403,442**	**2,766**	**86,536**	**964,348**

The CGC GAM was used to simulate future groundwater conditions using the same average conditions for recharge and stream water levels used by the TWDB to generate MAGs from the 2010 DFCs (Hill and Oliver, 2011). The average drawdowns for each county by aquifer are presented in **Table 4-4** for the Baseline Option 1 simulation and in **Table 4-5** for the High-Production Option 1 simulation. To evaluate the sensitivity of predicted drawdown to recharge, the Baseline Option 1 future pumping scenario was also run with 50% of the average recharge rate. Simulated average drawdown results for the "50% recharge" simulation are provided in **Table 4-6**. Prior to considering the results in Tables 4-4, 4-5, and 4-6 for proposing DFCs, GMA 15 had the TWDB verify the values in Table 4-4 by recalculating the average drawdowns using the codes developed by the TWDB.

Table 4-4 Average drawdowns (feet) from 2000 to 2070 for the Baseline Option 1 Pumping Scenario

County	Chicot	Evangeline	Chicot+ Evangeline	Burkeville	Jasper	Gulf Coast Aquifer System	Overall (without Burkeville)
Aransas	-0.1	5.8	0.0	NA	NA	0.0	**0.0**
Bee	1.3	8.7	6.2	7.7	5.6	6.5	**6.0**
Calhoun	-0.6	10.7	2.6	2.8	NA	2.6	**2.6**
Colorado	12.8	26.0	20.1	22.6	24.8	22.0	**21.8**
Dewitt	1.2	6.1	5.4	17.0	26.1	17.3	**17.4**
Fayette	NA	5.6	5.6	17.7	18.1	16.1	**15.5**
Goliad	-3.4	0.7	-0.1	7.2	10.5	5.2	**4.2**
Jackson	15.2	20.2	17.7	14.4	22.0	17.5	**18.5**
Karnes	NA	0.3	0.3	18.2	24.0	20.4	**21.0**
Lavaca	7.2	6.8	6.9	16.1	31.1	17.6	**18.2**
Matagorda	4.0	17.2	8.0	16.7	NA	8.8	**8.0**
Refugio	-0.4	7.3	3.2	2.8	NA	3.1	**3.2**
Victoria	-4.4	6.0	1.0	5.0	9.5	3.5	**3.0**
Wharton	14.6	12.4	13.5	25.5	28.4	20.0	**18.1**
Average	**5.5**	**11.4**	**8.5**	**15.1**	**22.0**	**13.2**	**12.6**

NA – not applicable because model does include this unit in this county

Table 4-5 Average drawdowns (feet) from 2000 to 2070 for the High-Production Option 1 Pumping Scenario

County	Chicot	Evangeline	Chicot+ Evangeline	Burkeville	Jasper	Gulf Coast Aquifer System	Overall (without Burkeville)
Aransas	0.0	46.0	1.1	NA	NA	1.1	**1.1**
Bee	3.8	15.4	11.5	11.1	6.5	10.1	**9.7**
Calhoun	4.5	108.4	34.1	7.9	NA	33.9	**34.1**
Colorado	30.4	54.3	43.6	36.7	36.6	40.0	**41.1**
Dewitt	4.0	9.5	8.7	27.0	53.3	32.4	**34.5**
Fayette	NA	15.0	15.0	40.5	50.4	42.6	**43.2**
Goliad	4.5	13.1	11.3	12.9	19.6	14.2	**14.7**
Jackson	65.4	143.6	104.4	52.8	42.0	82.2	**92.0**
Karnes	NA	1.6	1.6	21.3	32.8	27.2	**28.7**
Lavaca	25.0	19.1	20.9	21.2	35.6	25.9	**27.7**
Matagorda	8.2	65.2	25.5	27.3	NA	25.7	**25.5**
Refugio	1.6	67.7	32.0	20.0	NA	30.2	**32.0**
Victoria	27.0	81.3	55.1	68.3	180.1	79.5	**83.8**
Wharton	38.4	60.7	49.6	43.6	38.3	45.5	**46.1**
Average	**20.7**	**56.2**	**38.7**	**34.9**	**46.7**	**39.6**	**41.1**

Table 4-6 Average drawdowns (feet) from 2000 to 2070 for the Baseline Option 1 Pumping Scenario with 50% pumping

County	Chicot	Evangeline	Chicot+ Evangeline	Burkeville	Jasper	Gulf Coast Aquifer System	Overall (without Burkeville)
Aransas	-0.1	7.0	0.1	NA	NA	0.1	**0.1**
Bee	14.7	19.8	18.0	13.4	9.6	14.4	**14.9**
Calhoun	-0.4	12.2	3.2	2.9	NA	3.2	**3.2**
Colorado	27.4	38.8	33.7	29.8	30.0	31.7	**32.4**
Dewitt	9.6	8.9	9.0	19.7	28.1	20.1	**20.2**
Fayette	NA	12.6	12.6	21.7	20.8	19.9	**19.1**
Goliad	3.0	5.0	4.6	9.9	12.7	8.5	**7.9**
Jackson	23.8	27.4	25.6	17.2	23.8	23.2	**25.2**
Karnes	NA	12.2	12.2	22.6	25.6	23.6	**23.9**
Lavaca	24.0	13.4	16.6	19.4	33.4	23.0	**24.4**
Matagorda	4.5	19.4	9.0	17.3	NA	9.8	**9.0**
Refugio	0.6	9.9	4.9	4.2	NA	4.8	**4.9**
Victoria	-0.3	9.4	4.8	7.0	11.7	6.5	**6.4**
Wharton	21.4	19.2	20.3	28.4	30.4	24.7	**23.4**
Average	**10.4**	**17.6**	**14.1**	**18.8**	**24.7**	**17.6**	**17.2**

4.4 Evidence and Sources of Predictive Uncertainty in CGC GAM Simulations of Pumping Scenarios

During the July 2015 GMA 15 meeting, INTERA discussed sources of error and uncertainty in the predicted water levels in Tables 4-4,4-5, 4-6. A list of these sources is presented in **Figure 4-9**. **Appendix E** contains the slide presentation that INTERA presented to GMA 15 regarding predictive uncertainty associated with the CGC GAM. Several of the documented sources of uncertainty include flaws in the conceptual groundwater flow model, insufficient field data, inaccurate aquifer properties, oversimplified aquifer dynamics, improper aquifer boundaries and stratigraphy, and inadequate numerical spatial resolution. Among the references discussed to illustrate examples of the documented sources of uncertainty and error in the CGC GAM are Chowdhury and others (2004), TWDB (2014), Young (2012; 2014), Young and Kelley (2006), and Young and others (2010; 2012; 2013). A key message in the July discussion was the TWDB statement regarding the CGC GAM simulations by Hill and Oliver (2011):

> "The groundwater model used in developing estimates of modeled available groundwater is the best available scientific tool that can be used to estimate the pumping that will achieve the desired future conditions. Although the groundwater model used in this analysis is the best available scientific tool for this purpose, it, like all models, has limitations. In reviewing the use of models in environmental regulatory decision-making, the National Research Council (2007) noted:
>
> 'Models will always be constrained by computational limitations, assumptions, and knowledge gaps. They can best be viewed as tools to help inform decisions rather than as machines to generate truth or make decisions. Scientific advances will never make it

possible to build a perfect model that accounts for every aspect of reality or to prove that a given model is correct in all respects for a particular regulatory application. These characteristics make evaluation of a regulatory model more complex than solely a comparison of measurement data with model results.'

Given these limitations, users of this information are cautioned that the modeled available groundwater numbers should not be considered a definitive, permanent description of the amount of groundwater that can be pumped to meet the adopted desired future condition. Because the application of the groundwater model was designed to address regional scale questions, the results are most effective on a regional scale. The TWDB makes no warranties or representations relating to the actual conditions of any aquifer at a particular location or at a particular time."

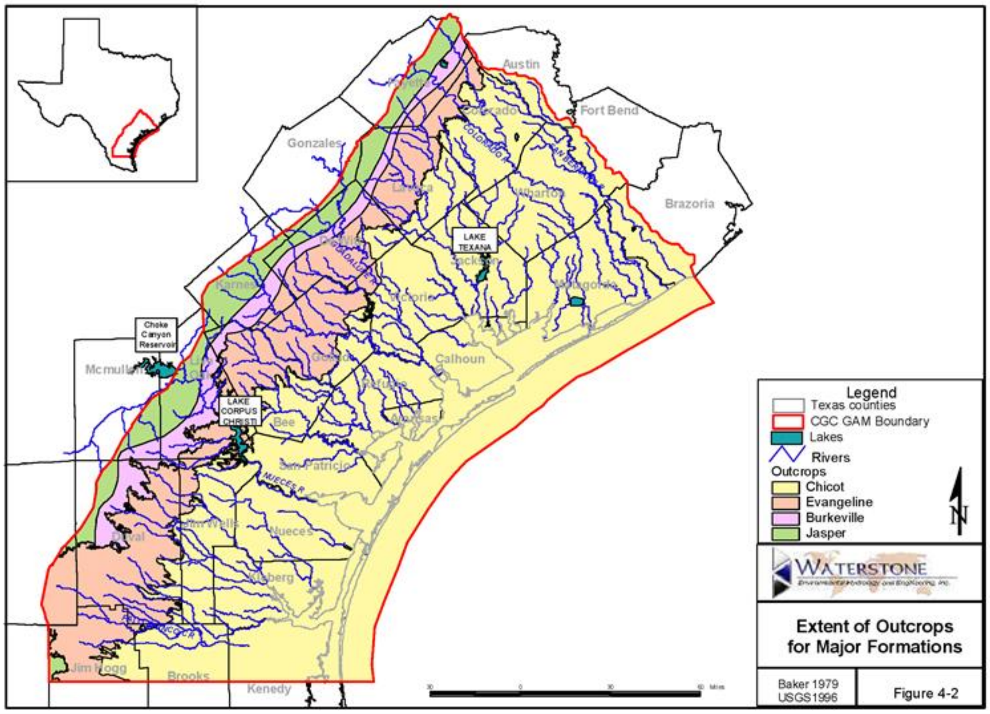


Figure 4-1 Model domain for the Central Gulf Coast GAM (Waterstone and Parson, 2003)

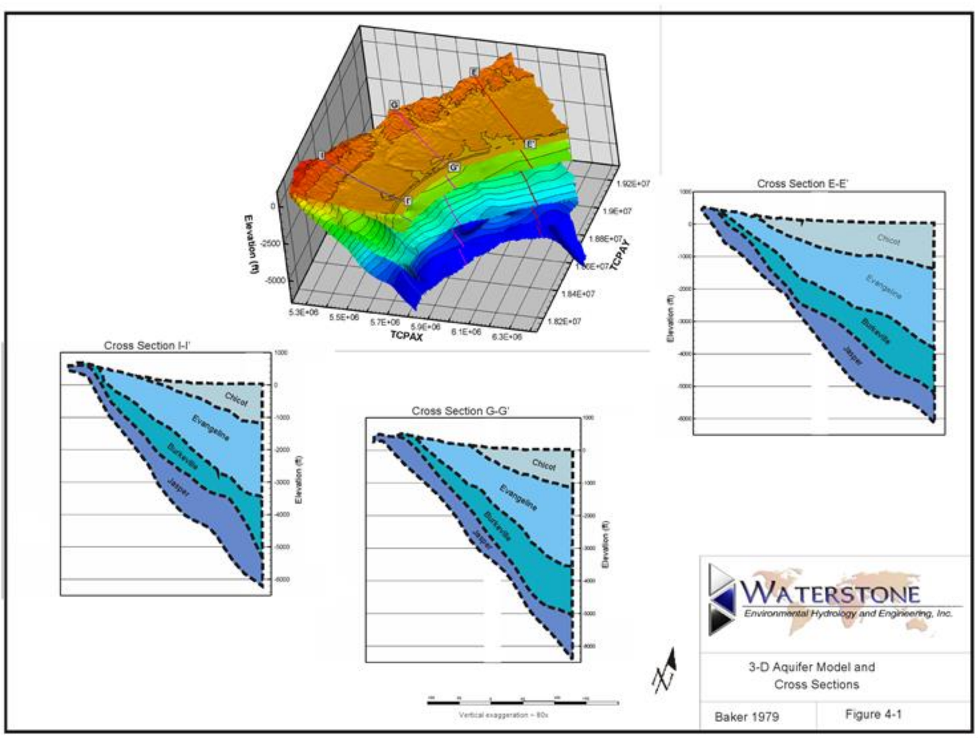


Figure 4-2 Three-dimensional surfaces and two-dimensional cross-sections showing the model layers for the Central Gulf Coast GAM (Waterstone and Parson, 2003)

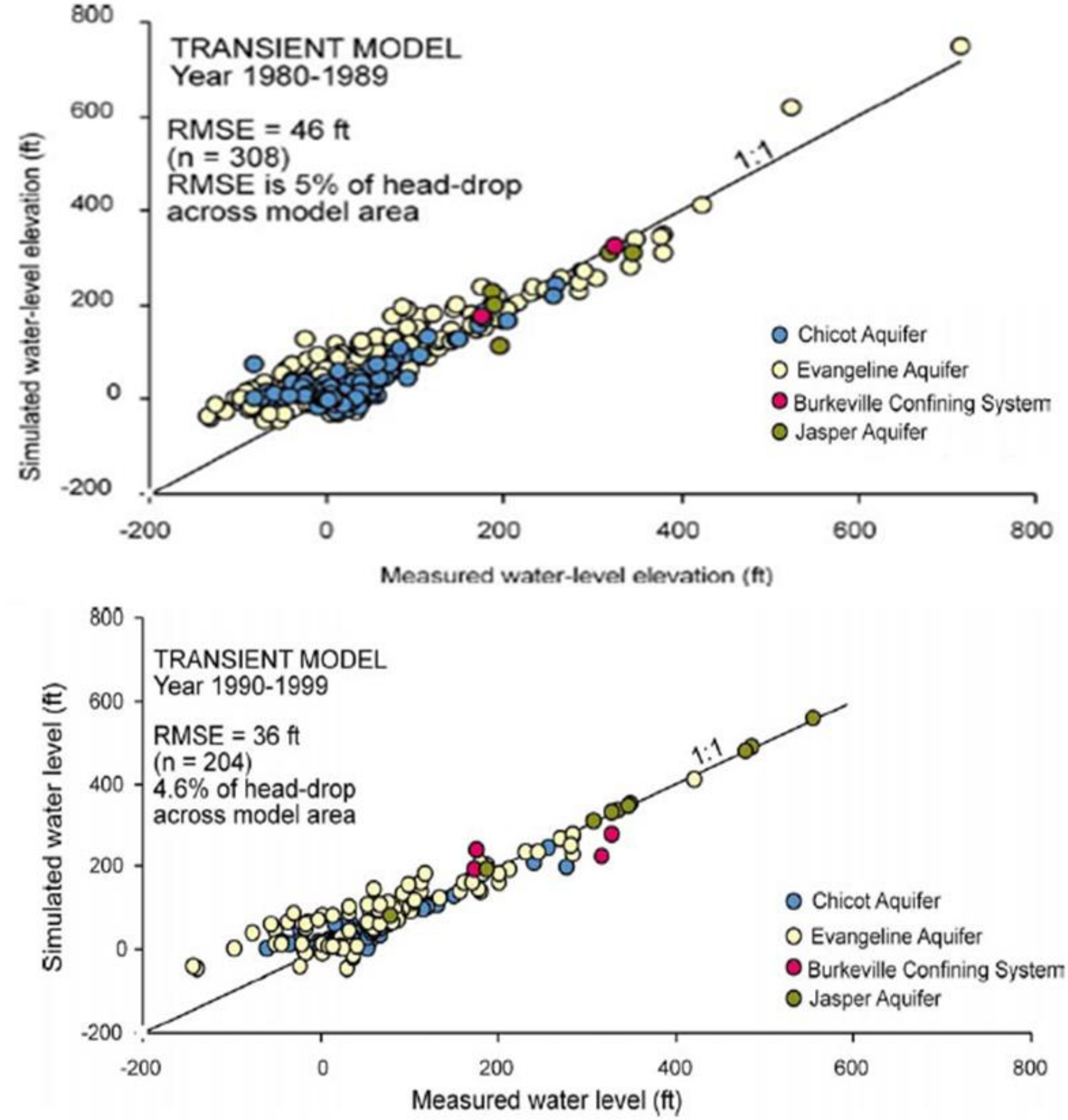


Figure 4-3 Comparison of measured and simulated water levels presented by Chowdhury and others (2004) for the CGC GAM for 1989 (top plot) and 1999 (bottom plot)

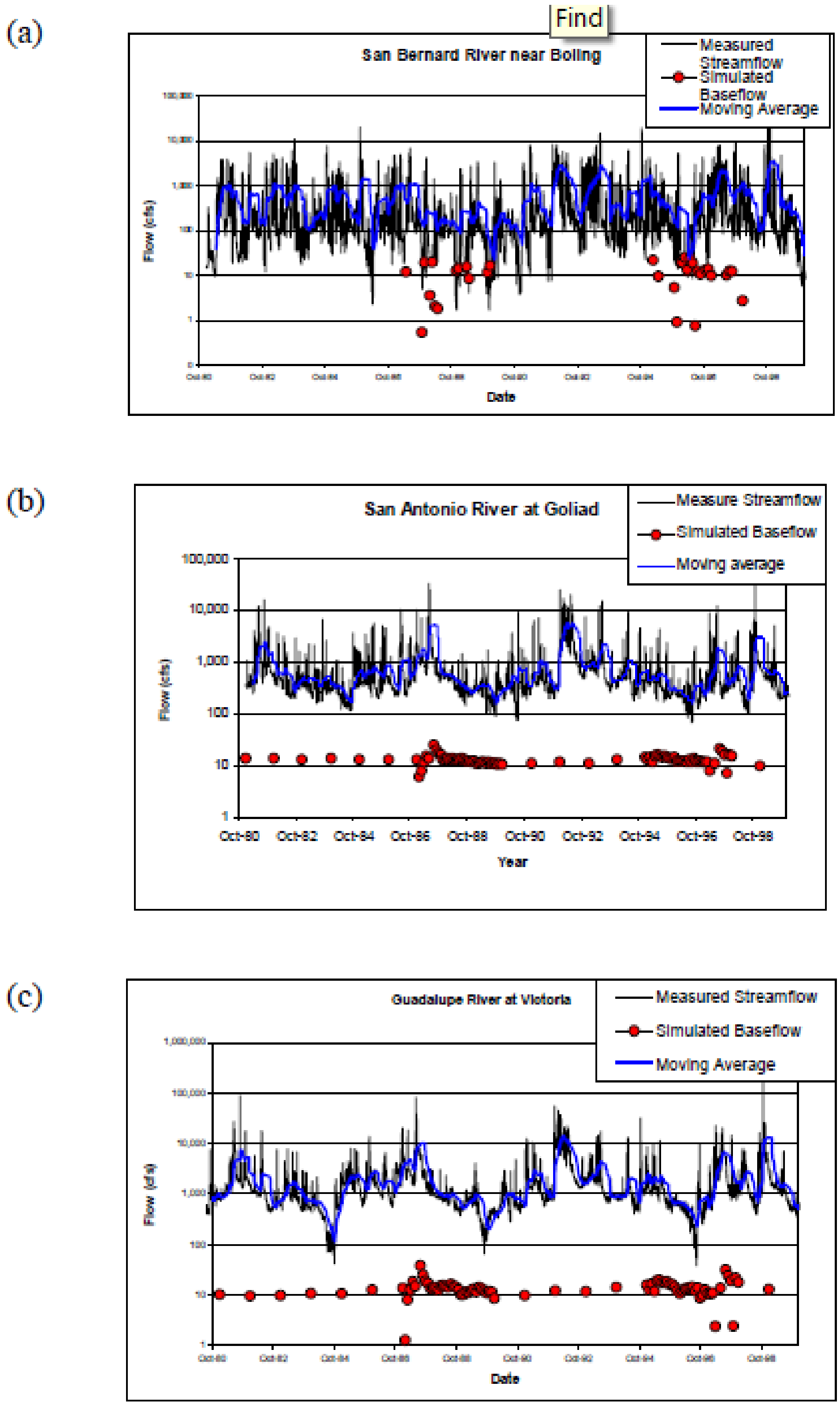


Figure 4-4 Comparison of streamflow hydrographs with simulated baseflow for the (a) San Bernard River near Boling, (b) San Antonio River at Goliad, and (c) Guadalupe River at Victoria (Chowdhury and others, 2004)

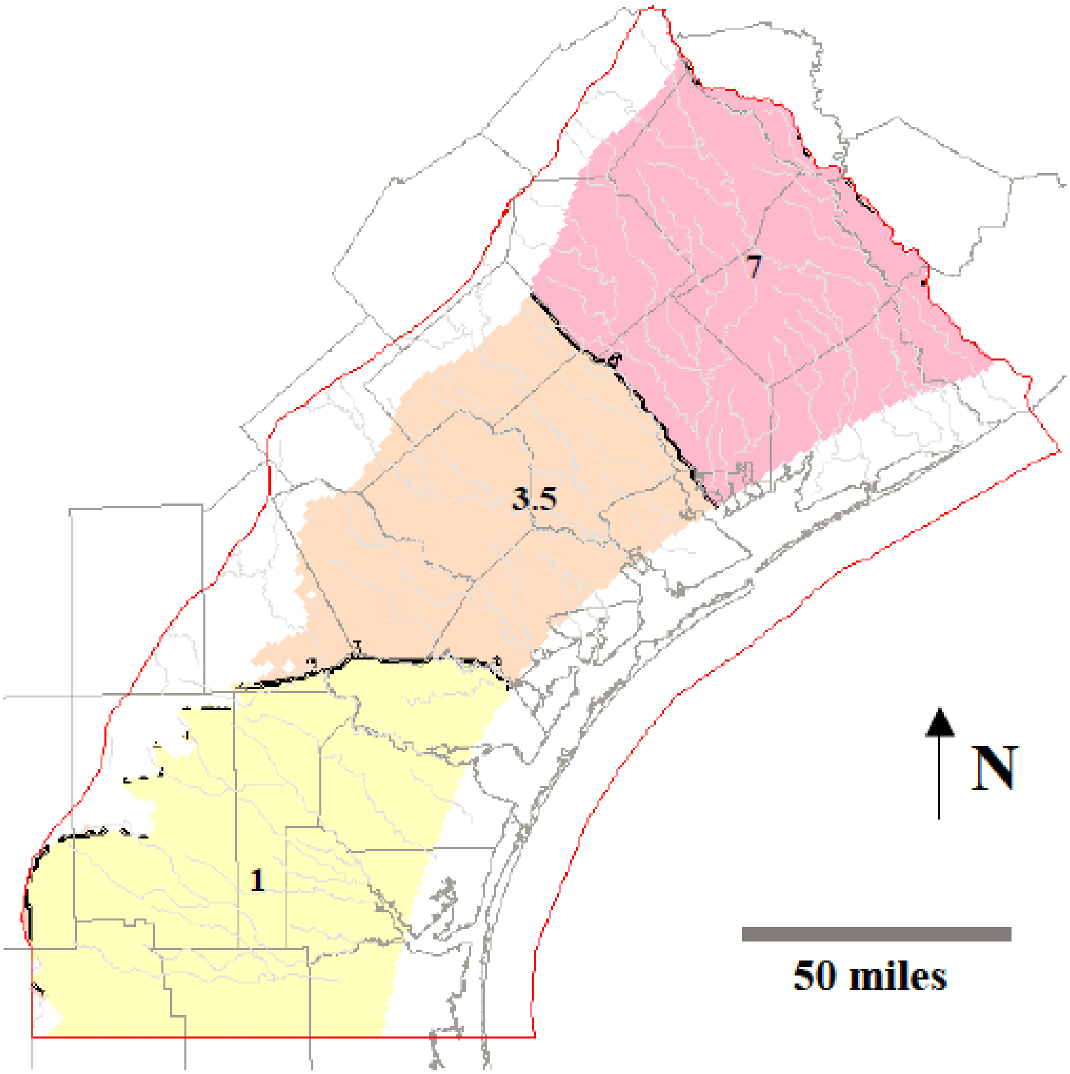


Figure 4-5 Hydraulic conductivity zones in the Evangeline Aquifer used from the calibrated CGC GAM. Hydraulic conductivity values labeled for each zone are in ft/day (from Waterstone and Parsons, 2003)

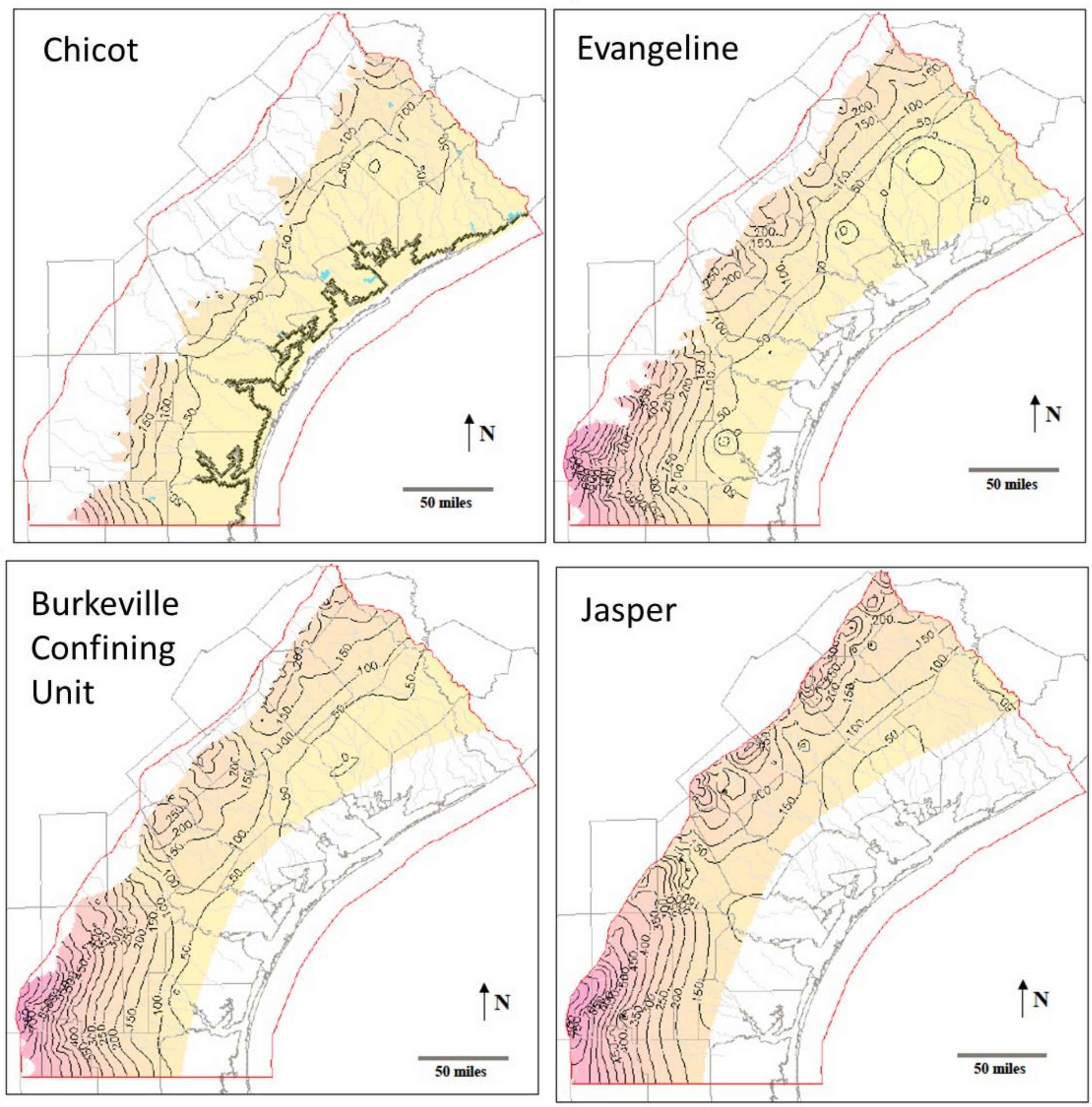


Figure 4-6 1999 Water levels simulated for the Chicot Aquifer, Evangeline Aquifer, the Burkeville Confining Unit, and the Jasper Aquifer by the Central Gulf Coast GAM (Chowdhury and others, 2004).

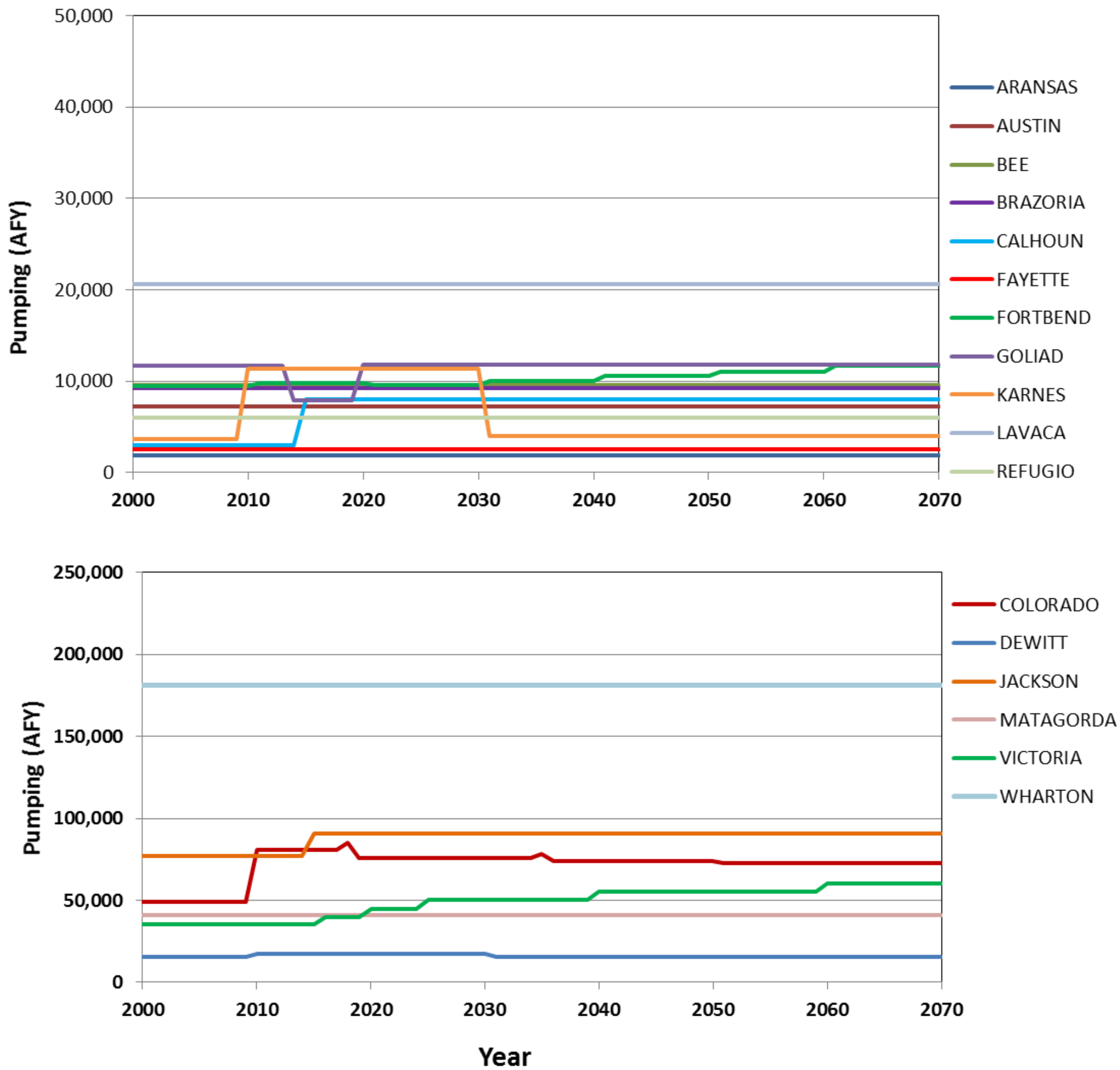


Figure 4-7 Annual changes in pumping by county for the Baseline Future Pumping Scenario

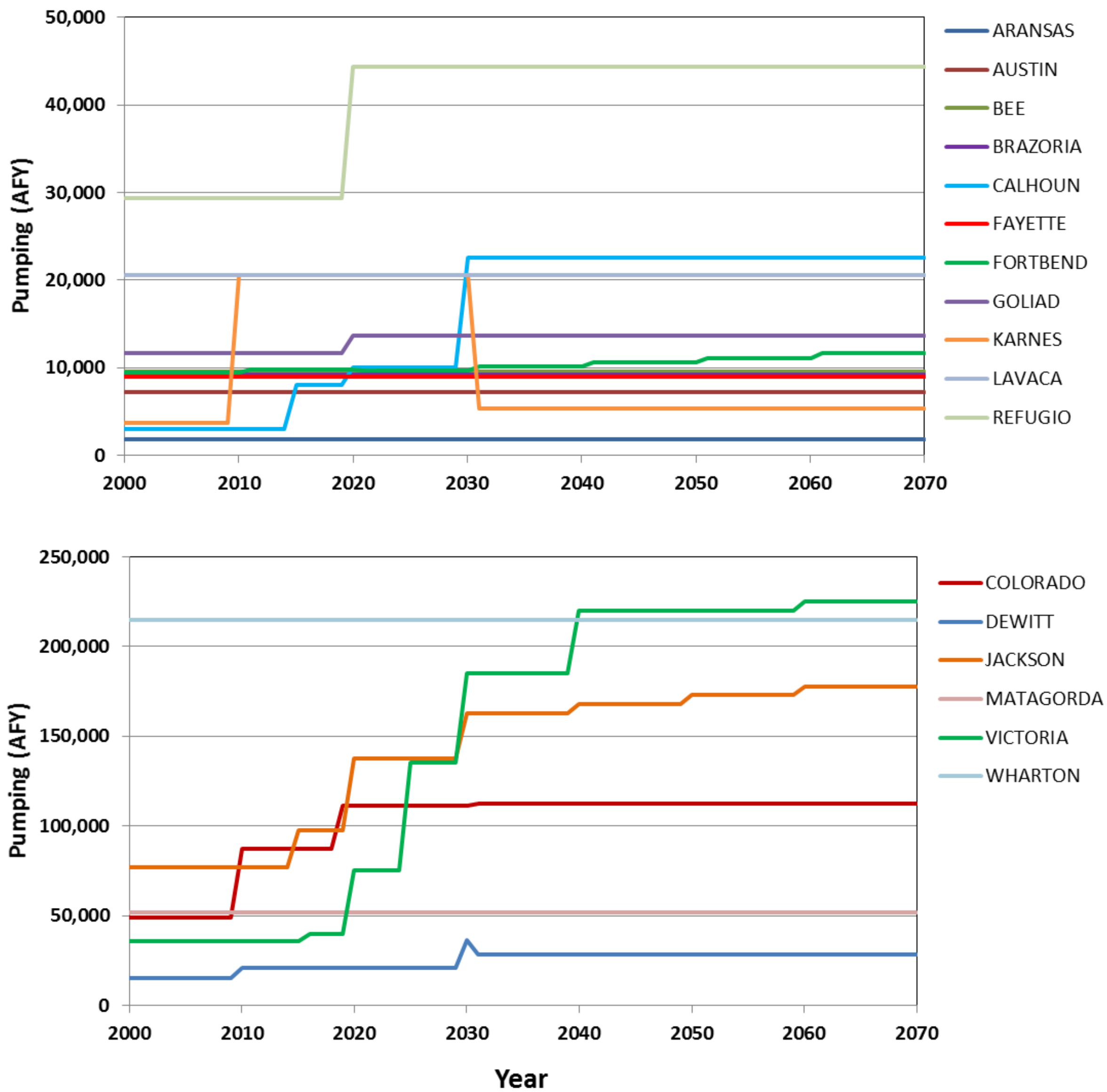


Figure 4-8 Annual changes in pumping by county for the High-Production Future Pumping Scenario

1. Central Gulf Coast GAM Report (2004)
   - **a. Calibration statistics between measured and model values**
   - **b. Plots of residuals for different aquifers**

2. LCRA-SAWS Water Project (LSWP) Reports (2005 to 2009)
   - **a. Spatial placement of pumping**
   - **b. Vertical placement of pumping**
   - **c. Temporal and Spatial distribution of recharge**
   - **d. Numerical discretization around streams**
   - **e. Aquifer boundaries**
   - **f. Spatial variability in aquifers**
   - **g. Addition of land subsidence (aquifer storage)**

3. DFC Presentation to GMA 15 on Behalf of CCGCD, CBGCD, CPGCD (2010)
   - **a. Volume-weighted versus area-weighted drawdown averages**
   - **b. Difference in pumping by aquifer between GMA model and reported by district**
   - **c. Incomplete spatial coverage of aquifers by active model grid cells**

4. PVGCD Report Regarding the Impacts of Large-scale Pumping (2012)
   - **a. Catahoula is an important Gulf Coast Geologic Unit**
   - **b. Burkeville is not a low permeability unit for most of DeWitt County**
   - **c. Jasper and Burkeville transmissivity is too low. Non-uniqueness of Central GAM calibration – can be recalibrated with much high recharge and transmissivity values**

5. VCGCD Report discussing Science Development Program (2012)
   - **a. Aquifer boundaries and hydraulic properties – Burkeville K too low and K distribution for Chicot and Evangeline not consistent with field data**
   - **b. Recharge and GW-SW exchange**

6. VCGCD Report discussing Transmissivity values from Aquifer Tests (2014)/ TWDB Regional ASR & OCS Plan for Golden Crescent Region of Texas (2014)
   - **a. Evangeline modeled transmissivity values are too low in Victoria County**
   - **b. Notable differenced between measured and modeled transmissivity in Jackson County**

7. TWDB Report Evaluation of Hydrogeochemical Data regarding Implication to Developing Gulf Coast GAMs (2013)
   - **a. Implications to Conceptual Model**
   - **b. Considerations for Implementing Recharge and GW-SW Interaction**

8. On-going studies by CBGCD, CPGCD, VCGCD, TGCD, RGCD, EUWCD, and PVGCD to Support Development of GAM 15 & 16 (2015)
   - **a. Groundwater-surface water interaction**
   - **b. Aquifer Hydraulic Properties are spatially variable**
   - **c. Considerable uncertainty in recharge estimates**
   - **d. Land-Subsidence has appear to occurred**

Figure 4-9 Eight different studies that document source of predictive error and uncertainty in the CGC GAM simulations

5.0 FACTORS CONSIDERED FOR THE DESIRED FUTURE CONDITIONS

Section 36.108(d)(1-8) of the Texas Water Code requires districts of a GMA document the consideration of the nine listed factors (provided in Section 1.2) prior to proposing a DFC. This section of the explanatory report summarizes information considered by GMA 15 regarding the factors.

5.1 Aquifer Uses and Conditions

Texas Water Code Section 36.108(d)(1) directs districts to consider, during the joint-planning process, "aquifer uses or conditions within the management area, including conditions that differ substantially from one geographic area to another." Information on aquifer uses and conditions that was discussed in the GMA 15 includes, but is not limited, to the following:

- The TWDB water use surveys
- The TWDB historical groundwater pumping database
- The TWDB groundwater well database
- Documentation of the CGC GAM including Chowdhury and others (2004) and Waterstone and Parson (2003)
- Documentation of the Lower Colorado River Basin Model Report (Young and Kelley, 2006; Young and others, 2009)
- Reponses from the districts regarding GMA 15 Questionnaire #2

As summarized in the GMA 15 December 2015 meeting minutes:

> "The aquifer uses and conditions differ substantially across Groundwater Management Area 15. Groundwater production is generally greater in the northeastern portions of GMA 15 in Colorado, Wharton, Matagorda, and Jackson counties. Groundwater in the northeastern portion of GMA 15 is predominately used for irrigation purposes. Groundwater production in the central portion of GMA 15 in Victoria County is predominately used for irrigation, municipal, and industrial uses. Groundwater production in the north central portion of GMA 15 in DeWitt County and Karnes County is predominately used for domestic and livestock purposes as well as supporting oil and gas production in the Eagle Ford Shale. Groundwater production in the southwestern portions of GMA 15 is predominately used for domestic, livestock, and agricultural uses. The condition of the Gulf Coast Aquifer differs significantly geographically. Generally, the capacity of the Gulf Coast Aquifer to produce groundwater increases to the northeast and decreases to the southwest as well as increase down dip relative to up dip portions of the Gulf Coast Aquifer."

The differences in the groundwater pumped by the counties were discussed in the April 2014 meeting. A planning sheet, provided in **Appendix F**, was distributed to each district that contained the following information for each county:

- TWDB pumping estimates from 2000 to 2011
- Decadal values for current MAGs
- Decadal summary of the 2012 State Water Plan for groundwater supplies, water demands and groundwater supply strategies
- Decadal summary of the 2017 State Water Plan Water Demands

- Total Estimated Recoverable Storage

Table 5-1 summarizes the average and median groundwater pumping from 2000 to 2011 based on the TWDB groundwater database. The average county pumping in the Gulf Coast Aquifer ranges from a low of 483 AFY in Aransas County to a high of 127,475 AFY in Wharton County. Over 80% of the pumping in the 14 counties occurs in four northeast counties: Wharton, Matagorda, Colorado, and Jackson counties. Pumping in these four counties is dominated by irrigation.

Table 5-1 Average groundwater pumping (AFY) from 2000 to 2011 for counties in GMA 15 based on TWDB historical groundwater pumping

County	Aquifer	Average	Median	Minimum	Maximum
Aransas	Gulf Coast Aquifer	483	483	425	589
	Other Aquifer	18	11	1	55
	Unknown	4	3	0	10
	Subtotal	**505**	**497**	**426**	**655**
Bee	Edwards-BFZ Aquifer	105	91	78	178
	Gulf Coast Aquifer	6,568	5,988	5,545	8,916
	Other Aquifer	279	263	157	491
	Unknown	206	205	195	218
	Subtotal	**7,159**	**6,547**	**5,975**	**9,803**
Calhoun	Gulf Coast Aquifer	1,000	618	489	1,854
	Other Aquifer	21	14	0	54
	Unknown	13	14	2	23
	Subtotal	**1,034**	**646**	**491**	**1,932**
Colorado	Gulf Coast Aquifer	30,476	26,925	20,397	54,843
	Other Aquifer	742	742	168	1,315
	Trinity Aquifer*	468	0	0	3,311
	Unknown	196	0	0	725
	Subtotal	**31,882**	**27,667**	**20,565**	**60,194**
DeWitt	Gulf Coast Aquifer	4,821	4,776	3,889	6,188
	Other Aquifer	42	42	4	97
	Unknown	595	265	43	1,808
	Subtotal	**5,458**	**5,083**	**3,936**	**8,093**
Fayette	Carrizo-Wilcox Aquifer	19	14	2	44
	Gulf Coast Aquifer	3,082	3,306	1,493	3,911
	Other Aquifer	196	117	77	573
	Queen City Aquifer	5	1	0	14
	Sparta Aquifer	220	138	94	758
	Unknown	34	29	20	57
	Yegua-Jackson Aquifer	236	111	61	1150
	Subtotal	**3,792**	**3,715**	**1,747**	**6,506**

County	Aquifer	Average	Median	Minimum	Maximum
Goliad	Gulf Coast Aquifer	3,395	3,878	1,093	5,272
	Unknown	40	42	30	46
	Subtotal	**3,435**	**3,920**	**1,123**	**5,318**
Jackson	Gulf Coast Aquifer	46,373	44,056	36,064	90,186
	Other Aquifer	624	682	6	1,184
	Unknown	40	43	31	43
	Subtotal	**47,037**	**44,781**	**36,101**	**9,1413**
Karnes	Carrizo-Wilcox Aquifer	167	153	98	276
	Gulf Coast Aquifer	3,457	3,405	2,638	4,408
	Unknown	690	218	0	2,326
	Yegua-Jackson Aquifer	267	326	48	487
	Subtotal	**4,581**	**4,101**	**2,785**	**7,497**
Lavaca	Gulf Coast Aquifer	9,219	8,573	6,993	13,683
	Other Aquifer	999	999	676	1,322
	Unknown	74	54	54	133
	Yegua-Jackson Aquifer	7	7	6	8
	Subtotal	**10,298**	**9,633**	**7,729**	**15,146**
Matagorda	Gulf Coast Aquifer	34,945	32,418	21,060	55,044
	Other Aquifer	380	25	14	2,171
	Unknown	45	43	38	55
	Subtotal	**35,369**	**32,486**	**21,112**	**57,270**
Refugio	Gulf Coast Aquifer	2,269	2,077	1,625	3,930
	Unknown	47	48	30	62
	Subtotal	**2,316**	**2,124**	**1,655**	**3,992**
Victoria	Gulf Coast Aquifer	13,900	11,253	6,430	32,864
	Unknown	40	42	32	45
	Subtotal	**13,941**	**11,295**	**6,462**	**32,909**
Wharton	Gulf Coast Aquifer	127,475	13,0978	87,380	185,772
	Other Aquifer	1,976	1,976	1,909	2,042
	Unknown	51	55	38	56
	Subtotal	**129,501**	**133,008**	**89,327**	**187,871**

*Note: there no pumping from the Trinity Aquifer in Colorado. There values are incorrectly stated in the TWDB historical pumping database

The spatial distribution of the pumping across the counties and among the Chicot Aquifer, Evangeline Aquifer, Burkeville Confining Unit, and Jasper aquifer is provided in **Appendix G**. **Appendix H** illustrates the spatial distribution of pumping by county used to establish the DFC and MAG during the 2010 joint planning. The figures in Appendices G and H show the total pumping across a grid cell. Each grid cell covers one square mile. To help facilitate comparison of pumping among counties and among the four hydrogeological units, the pumping rate per grid cell is color-coded using the same scale for all figures. The scale consists of the following seven intervals:

1. no pumping;
2. < 10 AFY;
3. 10 to 30 AFY;
4. 30 to 100 AFY;
5. 100 to 300 AFY;
6. 300 to 1,000 AFY; and
7. > 1,000 AFY.

The information in Appendices G and H was first presented in the April 2014 GMA 15 meeting and discussed during several later GMA 15 meetings. Based on considerations of information in Section 5.1, GMA 15 anticipates that the adoption of the DFCs will not impact the aquifer use and conditions within GMA 15 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.

5.2 Water Supply Needs and Water Management Strategies

Texas Water Code Section 36.108 (d)(2) directs districts to consider, during the joint-planning process, the water supply needs and water management strategies included in the state water plan. GMA 15 comprises an area spanning Regional Water Planning Areas K, L, N, and P. District representatives from GMA 15 attended the planning meetings for Regions K, L, N, and P. During the planning period, the representatives provided reports to the GMA 15 regarding the activities of the planning groups. In addition to considering the regional planning reports, the district representatives considered water supply needs and recommended water management strategies included in 2012 State Water Plan and the 2017 State Water Planned Water Demands, which are contained in Appendix F.

The overall water needs for a region, as defined within the Texas State Water Plan, are the demands (based on water demand projections developed during the water planning process for six major water use sectors) that cannot be met with existing supplies. These existing supplies may be inadequate to satisfy demands due to natural conditions (e.g., instance, sustainable supply of an aquifer or firm yield of a reservoir) or infrastructure limitations (e.g., inadequate diversion, treatment, or transmission capacity). A review of the future water management strategies within a region gives some insight into the potential future supply for meeting an identified need. Therefore, future groundwater management strategies identified in the 2012 Texas State Water Plan indicate the potential future demand for groundwater in addition to currently utilized supplies. **Table 5-2** provides 2012 State Water Planning Values for 2060 for GMA 15 Counties. The summation of Gulf Coast groundwater strategies for the 14 counties is 142,654 AFY. Over 90% of these strategies are associated with Wharton, Matagorda, Jackson, and Colorado counties. These large numbers indicate a potential future demand for groundwater in these four counties, in addition to currently utilized supplies.

Based on a review of the a summary of the water supply needs and water management strategies of the 2012 Texas State Water Plan, GMA 15 determined that the proposed DFCs are not anticipated to have a significant impact on the water supplies, water supply needs, or water management strategies of the 2012 Texas State Water Plan 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.

Table 5-2 2012 State Water Planning values for 2060 for GMA 15 counties in addition to 2010 MAG values

County	MAG	2012 State Water Plan Amounts for 2060 (AFY)			
		Groundwater Supplies	Water* Demands	Water* Supply Need (-) Surplus (+)	Gulf Coast Strategy
Aransas	1,862	579	4,335	-1,579	200
Bee (GMA 15)	10,660	7,121	11,578	-890	11,016
Calhoun	2,995	2,345	86,370	8,206	0
Colorado	48,953	38,508	188,786	-7,357	15,519
Dewitt	14,616	10,335	4,907	6,394	0
Fayette	18,917	11,742	79,542	-25,054	632
Goliad	11,699	4,566	19,224	6,728	0
Jackson	76,386	57,728	63,531	-3,971	5,053
Karnes (GMA 15)	3,116	5,269	6,167	536	161
Lavaca	20,373	14,445	13,550	895	0
Matagorda	45,896	36,302	319,162	-137,320	29,566
Refugio	29,328	2,952	2,002	1,262	0
Victoria	35,694	30,941	126,617	-65,275	0
Wharton	178,493	171,310	297,503	-60,550	80,507
Total	**498,988**	**394,143**	**122,3274**	**-277,975**	**142,654**

*water demands and water supply includes both groundwater and surfwater demands and supplies

5.3 Hydrological Conditions

Texas Water Code Section 36.108 (d)(3) requires that all GCDs, during the joint-planning process, consider hydrological conditions, including for each aquifer in the management area the total estimated recoverable storage (TERS) as provided by the TWDB executive administrator, and the average annual recharge, inflows, and discharge. As part of the joint-planning process, district representatives in GMA 15 reviewed and considered estimates of TERS, inflows, outflows, recharge, and discharge for all relevant aquifers based on results from the most recently adopted GAMs and technical assessments from the TWDB.

5.3.1 Total Estimated Recoverable Storage (TERS)

The Texas Administrative Code Rule §356.10 (Texas Administrative Code, 2011) defines the TERS as the estimated amount of groundwater within an aquifer that accounts for recovery scenarios that range between 25 percent and 75 percent of the porosity-adjusted aquifer volume. TERS values may include a mixture of water quality types, including fresh, brackish, and saline groundwater, because the available data and the existing groundwater availability models do not differentiate between different water quality types.

Wade and Anaya (2014) calculate TERS for the portion of the aquifers within GMA 15 that lies within the official lateral aquifer boundaries as delineated by George and others (2011). **Appendix I** presents the report by Wade and Anaya (2014) in its entirety. **Table 5-3** and **Figure 5-1** present the TERS values calculated for portions Gulf Coast Aquifer in 14 counties of interest. The TERS values do not take into account the effects of land surface subsidence, degradation of water quality, or any changes to surface water-groundwater interaction that may occur as the result of extracting groundwater from the aquifer.

Table 5-3 Total Estimated Recoverable Storage by County for the Gulf Coast Aquifer Provided by Wade and Anaya (2014).

County	25% of Total Storage	75% of Total Storage
Aransas	1,375,000	4,125,000
Bee	3,000,000	9,000,000
Calhoun	4,250,000	12,750,000
Colorado	7,000,000	21,000,000
DeWitt	5,550,000	16,650,000
Fayette	5,860,000	17,580,000
Goliad	6,500,000	19,500,000
Jackson	11,250,000	33,750,000
Karnes	12,397,500	37,192,500
Lavaca	8,080,000	24,240,000
Matagorda	12,000,000	36,000,000
Refugio	5,750,000	17,250,000
Victoria	9,750,000	29,250,000
Wharton	18,000,000	54,000,000

During the GMA 15 April 2015 meeting, INTERA provided a summary of the TERS values per county in the Groundwater Planning Datasheets (Appendix I) and explained the assumptions and methods used to calculate TERS. Several example calculations were demonstrated for the district members. **Appendix J** provides the INTERA entire presentation as provided in April 2015.

5.3.2 Groundwater Water Budgets and Issues of Pumping Sustainability

During the GMA 15 April 2015 meeting, INTERA presented historical water budgets by county for the years 1981, 1990, and 1999 (see Appendix J). The important concepts of aquifer dynamics and their role in determining groundwater availability were explained. In addition, the inflow and outflow water budget were discussed in terms of factors important to establishing sustainable groundwater pumping rates. A modeling example from GMA 15 was presented to illustrate that a major consideration when estimating sustainable pumping rates is how accurately the GAM predicts/represents the processes responsible for captured groundwater flow by pumping. Among the important points regarding the groundwater water budgets and sustainability is tracking the shape of the curve showing average-drawdown changes over time and the curve of storage depletion over time.

The key water budget concepts discussed the April 2015 GMA 15 meeting were reiterated at several other meetings and at all meetings where water budget results were discussed. **Figure 5-2** provides example water budgets for Matagorda and Refugio counties that are in Appendix J and associated with Baseline Option 1. The water budgets have been developed with sufficient detail to understand the exchange of groundwater flow between counties, between aquifers, and between surface water and groundwater. **Figure 5-3** shows plots of average drawdown over time from 2000 to 2070 for Matagorda and Refugio counties that are in Appendix J and are associated with Baseline Option 1. The drawdown curves have sufficient resolution so that annual changes can be visually tracked and evaluated to determine whether or not the pumping rate is sustainable. **Figure 5-4** is a plot of water levels in the Chicot Aquifer in 2070 predicted by the Baseline Option 1 pumping scenario and is included in Appendix J. The contours of the water levels are in sufficient detail so that the general groundwater flow direction can be deduced within and between counties.

5.3.3 Overall Assessment

Based on a review of the TERS and simulated water budgets associated with the Baseline (Option 1) model run, the adoption of the DFCs of GMA 15 are not anticipated to impact the hydrological conditions within GMA 15 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.

5.4 Environmental Factors

Texas Water Code §36.108 (d)(4) requires that districts, during the joint-planning process, consider environmental impacts, including impacts on spring flow and other interactions between groundwater and surface water. The primary environmental factor of interest in GMA 15 is whether or not groundwater pumping has an adverse impact on baseflows in rivers and streams. During the first, as well as this joint planning session, GMA 15 members have been concerned that the CGC GAM provides inaccurate estimates of groundwater-surface water exchange. These concerns are based on comparison with simulations of GW-SW interactions simulated by the Lower Colorado River Basin (LCRB) model (Young and others, 2010) and the inability of the CGC GAM to reasonably predict river baseflow (Chowdhury and others, 2004). A consensus among GMA 15 members is that the CGC GAM underestimates the contribution of groundwater to stream baseflow during pre-development conditions and overestimates the capture of stream baseflow for pumping conditions. The poor performance of the CGC GAM (see **Figure 4-4**) is believed to be caused by improper and excessively large numerical grid cells around the rivers and near the ground surface, which prevents a proper numerical representation of a shallow groundwater system.

The inability of the CGC GAM to predict GW-SW interactions adequately was discussed in several meetings and include discussions of the following topics: 1) the possible use of the LCRB model in conjunction with the CGC GAM; 2) the update of the CGC GAM by the TWDB; 3) uncertainty and error associated with the CGC GAM predictions; and 4) the concerns expressed by the Goliad County GCD dated August 19, 2015 to Dr. Steve Young (**Appendix L**). With regard to the problems with the CGC GAM with accurately predicting GW-SW interaction, the Goliad County GCD states in their August 19, 2015 letter to Dr. Young:

> "GCGCD has expressed a great interest in working with TWDB in developing the updated model of the Gulf Coast Aquifer for the Central Gulf Coast. In addition to the question of recharge, GCGCD is concerned that the modeled water budget shows a significant inflow

> of streams to the Evangeline and Chicot Aquifers. The USGS gain-loss studies of the Lower San Antonio River Basin and the Coleto Creek Watershed shows in both studies a surface water gain from the Aquifer. This discrepancy needs extensive further evaluation."

In addition, during the joint planning process, GCGCD included the following response to one of the survey questions:

> "Spring flow has declined in Goliad County for many years and continued drawdown of the aquifer will result in a further decline in spring flow."

The general consensus of GMA 15 is that the CGC GAM may not be a reliable predictor of GW-SW interaction for some pumping scenarios. As a result, the flow rates associated with GW-SW interactions in the calculated water budgets in Appendices C & K are considered by some GMA 15 districts as unreliable. In assessing the potential environmental impacts of pumping on GW-SW interaction, each district reviewed other information besides the results predicted by the CGC GAM. Such information included gain-loss studies performed on streams and results from other groundwater models and surface water models. Based on the collective analyses of the districts regarding GW-SW interaction, GMA 15 anticipates that the pumping rates associated with the Baseline (Option 1) 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

Texas Water Code Section 36.108 (d)(5) requires that districts, during the joint-planning process, consider the impacts of proposed DFCs on subsidence. Along the Texas Gulf Coast Aquifer, land subsidence is a potentially important issue associated with the management of groundwater. In Harris County, the pumping of groundwater has caused the land surface to subside more than three feet across most of the county and more than nine feet across the southeast part of the county. To help prevent land subsidence in the Gulf Coast, the Houston-Galveston Subsidence District was created in 1975, and the Fort Bend Subsidence District was created in 1989. Groundwater level decline, subsidence, and faulting are inter-related in the Gulf Coast Aquifer system, all having the potential for an adverse economic impact (Campbell and others, 2013). Jones and Larson (1975) estimated the cost associated with land subsidence in an approximately 900 square mile area, including the small portion of Harris County and some shoreline in Galveston County, to be about $32 million (about $150 million in 2015 terms) annually.

Land subsidence was discussed at several GMA 15 meetings, including April 10, 2015; July 15, 2015; December 9, 2015; and April 29, 2016. In July 15, 2015 (**Appendix M**) INTERA presented results from an ongoing study on land subsidence in GMA 15 funded by districts in GMA 15. **Figure 5-5** (from Appendix M) was discussed to demonstrate that land subsidence has occurred in GMA 15 and will likely continue occurring in the near future. During the discussion, four districts were identified as being interested in setting a DFC for land subsidence. Among the obstacles for setting a DFC for land subsidence is demonstrating compliance because of the inability of the districts to measure subsidence.

On April 29, 2016, INTERA provided a summary of an investigation into modeling and measuring land subsidence in the Texas central Gulf Coast. The presentation is provided in **Appendix N**. During the discussion, INTERA presented a paragraph of the study's Executive Summary that concisely summarizes the estimated historical land subsidence in GMA 15. This paragraph from Young (2016) is reproduced below:

> "The report presents ground surface elevation data from National Geodectic Survey (NGS) benchmarks called Permanent Identifiers (PIDs), old topographic maps, and LIght and raDAR (LIDAR) data from seven counties in GMA 15. The PID data provide ground surface elevations at 1,700 point locations prior to 1950. The topographic maps cover approximately 2,150 square miles and were constructed between 1950 and 1960. To extract point location data from the topographic maps, the maps were digitized and converted to Geographic Information System (GIS) files. The LIDAR data cover approximately 2,500 square miles and were collected after 2006. The joint analysis of these three data sets support the following conclusions:
>
> - The LIDAR and PID data indicate that DeWitt, Jackson, Matagorda, Refugio, Victoria, and Wharton counties have experienced at least 2 ft of land subsidence, and Calhoun County has experienced at least 1.5 ft of land subsidence.
> - The LIDAR and topographic map data indicate that Calhoun, DeWitt, Jackson, Matagorda, Refugio, Victoria, and Wharton counties have experienced at least 2 ft of land subsidence since 1950.
> - An analysis of the PID data, topographic map data, and LIDAR data indicates that more than two feet of average subsidence has occurred across about 100 square miles covering southwest Wharton, southeast Jackson, and northwest Matagorda counties."

During the GMA 15 discussion on April 29, 2016 INTERA presented an approach for performing scoping calculations of land subsidence based on simulated drawdowns from a groundwater model. The approach was demonstrated for the 14 locations shown in **Figure 5-6**. **Table 5-4** presents the calculated land subsidence at the 14 locations based on water levels predicted by the CGC GAM in 1999 and by the DFC GAM Run based on the Baseline Option 1 pumping file. Over the 70-year period, the anticipated increase in land subsidence at the 14 locations ranges between 0.1 and 1.2 feet. INTERA emphasizes that the values in **Table 5-4** have several major assumptions that should to be investigated and vetted fully prior to acting on any predicted land subsidence.

For this joint-planning session, no district proposed a DFC for land subsidence, but several districts are interested in establishing monitoring systems to measure land subsidence and for continuing further research into improving GMA 15's ability to predict land subsidence. As information becomes available, several GCDs may adjust their management plans and groundwater rules to prevent land subsidence, until which time the conditions are appropriate to propose DFCs for land subsidence.

Table 5-4 Prediction of land subsidence at fourteen sites in GMA 15 for the years 2000 and 2070 using drawdown simulated by the Central Gulf Coast GAM (Chowdhury and others, 2004) and clay thickness data from Young and others (2010; 2012)

ID	County	Drawdown (ft)								Clay Thickness (ft)				Land Subsidence (ft)	
		Chicot		Evangeline		Burkeville		Jasper		Chicot	Evangeline	Burkeville	Jasper	1940-2000	1940-2070
		1940-2000	1940-2070	1940-2000	1940-2070	1940-2000	1940-2070	1940-2000	1940-2070						
1	Calhoun	7.4	3.4	12.4	18.9	-	-	-	-	226	1299	418	925	0.4	0.5
2	Calhoun	-0.8	2.2	22.9	40.6	-	-	-	-	369	1442	407	1377	0.7	1.2
3	Dewitt	-	-	0.8	1.0	3.4	9.8	7.9	24.1	-	349	318	516	0.1	0.3
4	Dewitt	-	-	9.5	15.6	51.7	73.0	142.3	185.2	-	116	331	537	1.9	2.5
5	Jackson	18.7	55.7	64.7	88.1	39.2	56.3	22.0	45.4	139	683	224	618	1.4	2.2
6	Jackson	12.1	32.4	55.9	78.4	33.0	52.6	-	-	360	1096	339	966	1.5	2.3
7	Matagorda	-1.7	1.2	39.4	57.4	-	-	-	-	482	1569	652	1220	1.2	1.8
8	Matagorda	2.1	0.8	37.9	49.0	13.1	27.0	-	-	203	1264	415	1400	1.1	1.5
9	Refugio	5.2	1.8	3.4	10.1	-0.1	3.9	-	-	128	835	270	722	0.1	0.2
10	Refugio	0.3	1.2	4.1	15.5	-	-	-	-	264	1141	264	726	0.1	0.4
11	Victoria	5.0	8.0	13.2	40.1	1.7	6.4	-	-	207	757	225	550	0.2	0.7
12	Victoria	27.0	34.9	45.3	52.5	38.0	43.9	26.2	33.0	108	605	190	785	1.2	1.4
13	Wharton	75.4	94.1	156.7	149.8	61.9	90.2	27.9	59.9	84	780	266	610	3.2	3.7
14	Wharton	8.7	27.5	57.4	91.0	44.5	80.9	38.2	72.2	78	599	287	842	1.6	2.8

5.6 Socioeconomics

Texas Water Code Section 36.108 (d)(6) requires that GCDs consider socioeconomic impacts reasonably expected to occur as a result of the proposed DFCs for relevant aquifers as part of the joint-planning process. There is a lack of information available to GCDs regarding socioeconomic impacts that would be considered relevant to the joint-planning process. However, Texas statute requires that regional water plans include a quantitative description of the socioeconomic impacts of not meeting the identified water needs. Historically, this analysis has been performed for regional water planning groups by the TWDB. As a result, this section will rely heavily on the TWDB analyses for planning regions within GMA 15. In addition, GMA 15 Representatives participated in a questionnaire that covered several topics, including potential socioeconomic impacts of the proposed DFC. In addition to a short review of the TWDB regional planning socioeconomic impact analysis, this section will end with a qualitative discussion of socioeconomic impacts of the proposed DFCs based upon the questionnaire and discussion in public meetings held by GMA 15.

5.6.1 Regional Planning Assessment of Socioeconomic Impact

Consideration of socioeconomic impacts as part of water planning in Texas has been a fundamental element of the planning process dating back to the 1990s. Texas Water Code Section 16.051 (a) states that the TWDB "shall prepare, develop, formulate, and adopt a comprehensive state water plan that...

shall provide for... further economic development." Title 31 of the Texas Administrative Code, Section 357.7 (4)(A) states, "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." The socioeconomic analysis provided by the TWDB to support planning groups provides the only available consistent analysis of socioeconomic impacts of unmet water needs available for the state and as such is a valuable analysis for joint planning.

Socioeconomic analysis of unmet water needs is performed by the TWDB at the request of the individual regional water planning groups and is based on water supply needs from the regional water plans. A general description of the methodology and approach is reproduced below from "Socioeconomic Impacts of Projected Water Shortages for the Region P Regional Water Planning Group" (Ellis, Cho and Kluge, 2015a).

> "The analysis was performed using an economic modeling software package, IMPLAN (Impact for Planning Analysis), as well as other economic analysis techniques, and represents a snapshot of socioeconomic impacts that may occur during a single year during a drought of record within each of the planning decades. For each water use category, the evaluation focused on estimating income losses and job losses. The income losses represent an approximation of gross domestic product (GDP) that would be foregone if water needs are not met.
>
> The analysis also provides estimates of financial transfer impacts, which include tax losses (state, local, and utility tax collections); water trucking costs; and utility revenue losses. In addition, social impacts were estimated, encompassing lost consumer surplus (a welfare economics measure of consumer wellbeing); as well as population and school enrollment losses."

At the beginning of this round of joint-planning, GMA 15 Representatives only had access to the 2011 Regional Water Plan socioeconomic analyses (Norvell and Shaw, 2010a, 2010b, 2010c and 2010d). INTERA sent these technical reports to GMA 15 for circulation among district representatives on October 13, 2015. Since that time, the 2016 Regional Water Plans have been approved with updated socioeconomic analyses (Ellis, Cho and Kluge, 2015a, 2015b, 2015c and 2015d). Results presented in this section are taken from the 2016 Regional Water Plans, and all impact estimates are in 2013 dollars.

The socioeconomic impact analysis provided by the TWDB to Region K, Region L, Region N and Region P regional water planning groups for the 2016 regional water plans informed the district representatives' considerations of socioeconomic impacts reasonably expected to occur as a result of the proposed DFCs for relevant aquifers in GMA 15. These technical memoranda are included in their entirety as **Appendix O**, **Appendix P, Appendix Q** and **Appendix R**, respectively. To illustrate the impacts of not meeting water supply needs, examples for specific water user groups for each of the four regional water planning areas (K, L, N and O) along with regional summaries for Region L were presented to GMA 15 Representatives. These details are provided in **Appendix S**, which provides INTERA's presentation made to the GMA 15 Representatives on April 29, 2016.

A consistent method of evaluating losses across regions is to review regional social impacts calculated by the TWDB in their analysis. **Table 5-5** provides a summary of the consumer surplus losses, population losses and school enrollment losses from not meeting water supply needs for Region L in GMA 15. Region

L is presented because impacts to Region L are most significant. One can review all sector impacts as well as social impacts for all regions through review of **Appendices O through R**.

Table 5-5 Region-wide Social Impacts of Water Shortages in Region L (from Ellis, Cho and Kluge, 2015b).

Impact Measures	2020	2030	2040	2050	2060	2070
Consumer surplus losses ($ millions)	$29	$58	$108	$171	$264	$403
Population losses	3,356	3,821	4,324	4,693	5,591	9,199
School enrollment losses	621	707	800	868	1,034	1,702

* Year 2013 dollars, rounded. Entries denoted by a dash (-) indicate no economic impact. Entries denoted by a zero ($0) indicate income losses less than $500,000

The total economic impacts are significant, with Region L experiencing $1.99 billion in income losses and almost 18,300 job losses in 2020 if no water management strategies are implemented to meet projected shortages. Region K could suffer income losses of $1.557 billion in 2020 and a loss of 9,877 jobs. Region P income losses could be $9 million in 2020, with job losses estimated at 279. In Region N, income losses could be $4.49 billion in 2020, with job losses estimated at 24,000.

5.6.2 Other Considerations of Socioeconomic Impacts

While the information on socioeconomic impacts of not meeting water supply needs as quantified in the adopted 2016 regional water plans is useful for GMA 15 Representatives to consider, the factor to consider in joint-planning is what socioeconomic impacts result from the DFCs.

The challenge in joint-planning relative to regional planning is that no standardized local or regional socioeconomics analytical tool has been developed to support joint-planning. Also, the nature of socioeconomic impacts from proposed DFCs is unique from one GCD to another within a common GMA in that two or more GCDs may share a common DFC, but the method adopted by the individual GCD to achieve the DFC through local regulatory plans will inevitably result in differences in socioeconomic impacts.

Instead, GMA 15 - Representatives, through public meetings and through a questionnaire process, had discussions of qualitative socioeconomic impacts that may result from proposed DFCs. These impacts were both positive and negative, depending on the timing of the consideration. A summary of the results of the GMA 15 discussion and the results from the questionnaire can be found in INTERA’s July 15, 2015 GMA 15 presentation provided in **Appendix M** of this report.

Among the concerns expressed by the GCD is the economic impact of water level drawdown. Lower water levels in a well can cause types of costs: deeper well cost and pumping cost. In GMA 15, Goliad County GCD performed a preliminary cost impact analysis, which is provided in **Appendix T**. When an existing water source is no longer productive a replacement well is required or in the case of a new location, the well will need to be drilled deeper. In Goliad County, the depth between productive sands varies from 50-100 feet in most areas. A budget price for a new well, drilled well only, is $6500. Adding 75 feet to the depth adds $1500 to the cost. Goliad County GCD estimates that for each drop of 10 feet of water level to wells that pump a cumulative total of 7000 acre feet per year, the additional annual pumping cost is approximately $1,000,000.

Based on a review of the TWDB socioeconomic impact analysis for Region K, L, N, and P and related factors, GMA 15 members do not anticipate that the adoption of the DFCs of GMA 15 will adversely impact the socioeconomics in GMA 15 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.

5.7 Private Property Rights

Texas Water Code Section 36.108(d)(7) requires that district representatives consider the impact of proposed DFCs on the interests and rights in private property, including ownership and the rights of management area landowners and their lessees and assigns in groundwater, as recognized under Texas Water Code Section 36.002. GMA 15 recognizes that the primary vehicle in which private property rights are protected in GMA 15 is through each GCD's management plan and groundwater rules. Because the local hydrogeological conditions, environmental, and socioeconomic factors vary across GMA 15, the manner in which GCDs protect private property rights may vary among the GCDs.

GMA 15 members considered property rights when it reviewed other district groundwater management plan, participated in the GMA's survey questions regarding property rights, and it discussed recent court cases involving groundwater. The GMA 15 survey questions asked each GCD to describe the consequences related to private property rights, especially negative impacts, that may occur if the adopted DFCs did not achieve 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. During the July 2015 meeting, GMA 15 members discussed the potential consequences of too lax or too restrictive DFCs on personal property rights. In short, there are undesirable consequences that affect individual landowners if the DFCs are too lax or too restrictive. Some of the issues addressed by the district representatives are documented in INTERA's presentation (**Appendix M**) that provides GCD responses to the survey's questions regarding personal property rights. To assist GCDs with responding to public comments on the proposed DFCs, INTERA presented the information in **Appendix U** at the GMA 15 meeting on April 29, 2016. A keystone to all discussions regarding personal property rights is the Texas Water Code Section 36.002, which reads as follows:

> "Sec 36.002 Ownership of Groundwater.
> (a) The legislature recognizes that a landowner owns the groundwater below the surface of the landowner's land as real property.
> (b) The groundwater ownership and rights described by this section:
>
> 1) entitle the landowner, including a landowner's lessees, heirs, or assigns, to drill for and produce the groundwater below the surface of real property, subject to Subsection (d), without causing waste or malicious drainage of other property or negligently causing subsidence, but does not entitle a landowner, including a landowner's lessees, heirs, or assigns, to the right to capture a specific amount of groundwater below the surface of that landowner's land; and
> 2) do not affect the existence of common law defenses or other defenses to liability under the rule of capture.
>
> (c)Nothing in this code shall be construed as granting the authority to deprive or divest a landowner, including a landowner's lessees, heirs, or assigns, of the groundwater

ownership and rights described by this section.
(d)This section does not:

1) prohibit a district from limiting or prohibiting the drilling of a well by a landowner for failure or inability to comply with minimum well spacing or tract size requirements adopted by the district;
2) affect the ability of a district to regulate groundwater production as authorized under Section 36.113, 36.116, or 36.122 or otherwise under this chapter or a special law governing a district; or
3) require that a rule adopted by a district allocate to each landowner a proportionate share of available groundwater for production from the aquifer based on the number of acres owned by the landowner.

(e)This section does not affect the ability to regulate groundwater in any manner authorized under:

1) Chapter 626, Acts of the 73rd Legislature, Regular Session, 1993, for the Edwards Aquifer Authority;
2) Chapter 8801, Special District Local Laws Code, for the Harris-Galveston Subsidence District; and
3) Chapter 8834, Special District Local Laws Code, for the Fort Bend Subsidence District."

Based on a review of the districts management plans and related factors, the majority of the GMA 15 members do not anticipate that the adoption of the DFCs of GMA 15 will impact the hydrological conditions within GMA 15 significantly affect personal property rights associated with groundwater 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. Among the GCDs that did not embrace this position was Goliad County GCD. Goliad County GCD's position is that the adoption of the DFC could significantly impact interests and rights in private property within Goliad County.

5.8 Feasibility of Achieving the Proposed Desired Future Condition

Texas Water Code Section 36.108 (d)(8) requires that GCDs, during the joint-planning process, consider the feasibility of achieving the proposed DFC(s). This requirement was added to the joint-planning process with the passage of Senate Bill 660 by the 82nd Texas Legislature in 2011. However, this review concept actually dates back to the rules adopted by the TWDB in 2007 to provide guidance as to what the TWDB would consider during a petition process regarding the reasonableness of an adopted DFC. In these rules, the TWDB required that an adopted DFC must be physically possible from a hydrological perspective.

During the TWDB's review of multiple petitions regarding the reasonableness of adopted DFCs in GMAs from 2010 to 2011, the evaluation of whether or not an adopted DFC was physically possible was based on whether or not the DFC(s) could be reasonably simulated using the TWDB's adopted GAM for the aquifer(s) in question. This was a valid approach because if an adopted DFC was not physically possible, then, under the physical laws of hydrology as incorporated in the mathematical calculations executed during model simulations, the model would not execute the prescribed simulation successfully.

GMA 15 considers a valid evaluation of the feasibility of DFCs as whether or not the proposed DFCs are consistent with the DFCs predicted by the CGC GAM, using appropriate and reasonable environmental conditions and within the confidence limits of the CGC GAM. GMA 15 recognizes the GAMs as representing the best science for understanding the groundwater flow systems in GAM 15, while at the same time recognizing that the GAMs have been demonstrated to contain error and uncertainty. As such, GMA 15 will presume that DFCs are feasible if they can be generated by a GAM within a reasonable tolerance. GMA 15 spent several meetings discussing the potential limitations of the CGC GAM, and what reasonable tolerance limits are for CGC predictions of average drawdown values (see **Appendix M**). Among these reasons for using tolerance criteria for evaluating the feasibility of a DFC are:

- GAM Predictive Uncertainty/Error
- Unknown Errors in Stargin 1999 Water Level Conditions
- Uncertainty in Future Environmental Conditions (for instance recharge and rivers levels)
- Uncertainty in Future Pumping Rates & Locations
- Error/Uncertainty in Measurement of DFCs to Demonstrate Compliance
- Non-uniqueness of model calibration

In light of the issues above and other known limitations and possible errors in the CGC GAM, GMA 15 members agreed that DFCs would be considerable feasible, compatible and physically possible if the difference between the proposed DFCs and the DFC predicted by the CGC GAM are within 3.5 feet, except in the case of Goliad County. For this comparison, the DFCs of interest are average drawdown values from 2000 to 2070 for an aquifer in a county. Factors considered for a determining tolerance criterion of 3.5 feet include:

- Residuals and RMSE between the measured and simulated values for historical water levels produced by the CGC GAM;
- Sensitivity of the simulated drawdown to the recharge rate used in the predictive simulation and estimates of uncertainty in the magnitude and distribution of historical and predicted recharge rates;
- Sensitivity of the simulated drawdown to the hydraulic properties of the aquifer properties in the predicted simulation and observed differences between measured hydraulic aquifer properties and modeled aquifer hydraulic properties in the CGC GAM;
- Uncertainty in the temporal and spatial distribution of historical and future pumping in the GMA 15 counties; and
- The list of evidence and sources of GAM predictive uncertainty in **Appendix M**.

GMA 15 considers the proposed Goliad County DFCs to be compatible and physically possible if the difference between the proposed and predicted DFCs are within 5.0 feet. Factors considered by GMA 15 for determining the tolerance criterion of 5.0 feet have been documented by Goliad County GCD (see **Appendix L** and **Appendix V**) and include:

- an evaluation of water level change in 60 Evangeline Aquifer wells from 2003 to 2015, which indicates that the GAM underpredicts drawdown in the Evangeline Aquifer underlying Goliad County;

- an evaluation of water level change in 15 Chicot Aquifer wells from 2003 to 2015, which indicates that the GAM underpredicts drawdown in the Chicot Aquifer underlying Goliad County;
- an evaluation of gain-loss studies performed by the United States Geological Survey that indicates that the GAM overpredicts leakage from the streams in areas of pumping; and
- evidence suggesting that the GAM's average recharge rate for Goliad County is too high.

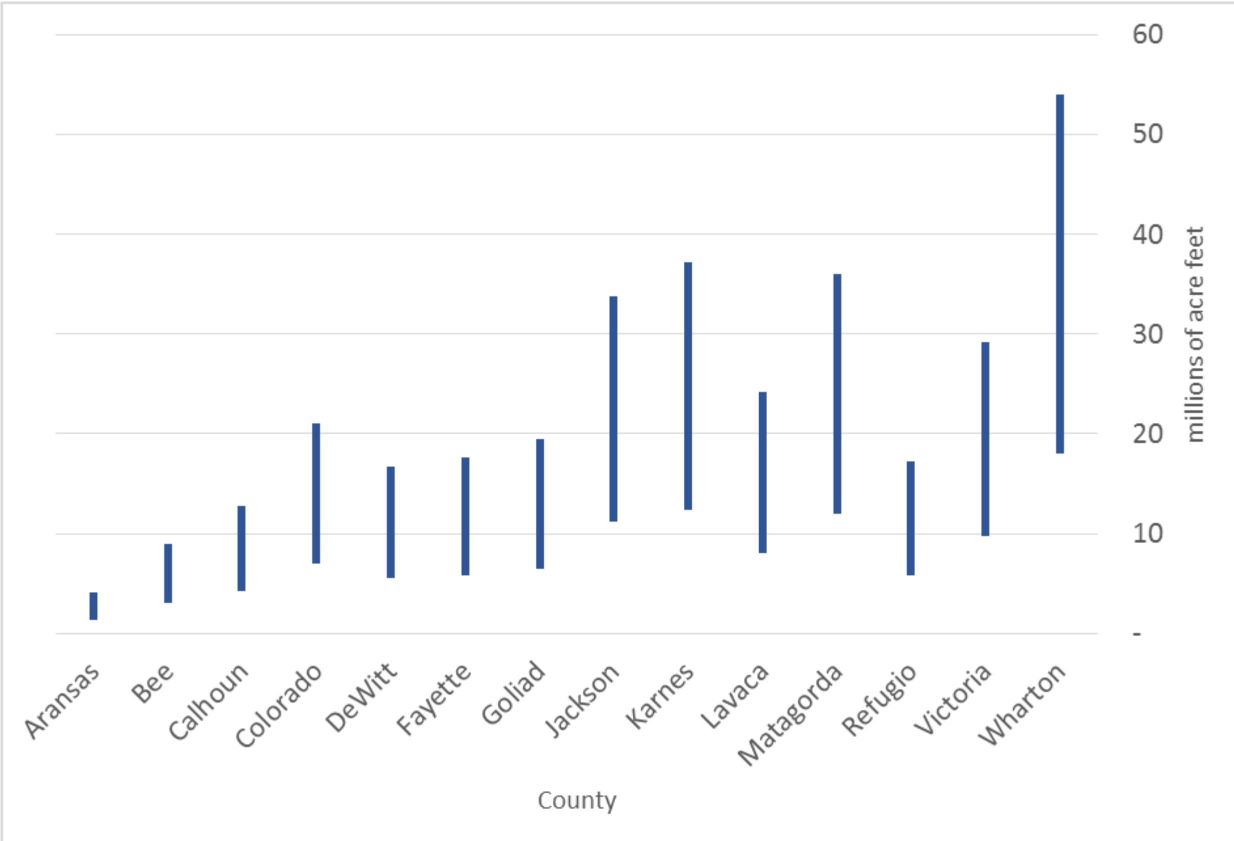
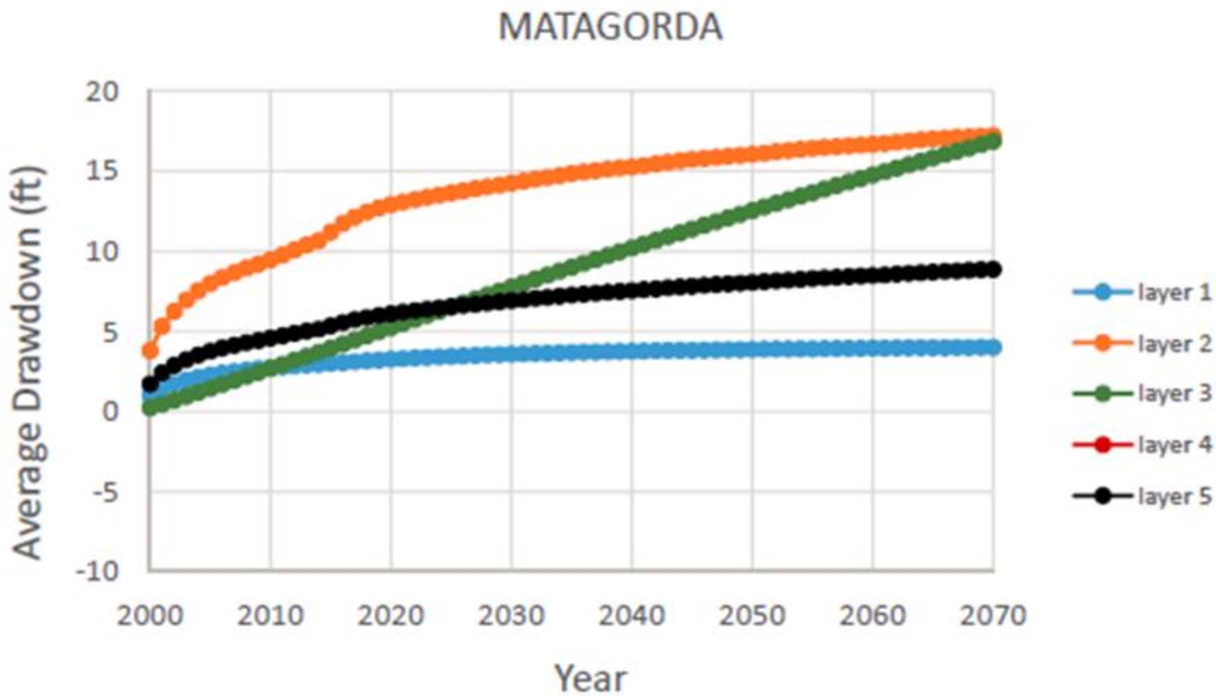


Figure 5-1 Total Estimated Recoverable Storage by County for the Gulf Coast Aquifer Provided by Wade and Anaya (2014).

Matagorda	2030				2050				2070			
	Chicot	Evangeline	Burkeville	Jasper	Chicot	Evangeline	Burkeville	Jasper	Chicot	Evangeline	Burkeville	Jasper
Inflow												
River Leakage	792	0	0	-	792	0	0	-	792	0	0	-
Recharge	22,372	0	0	-	22,372	0	0	-	22,372	0	0	-
Net Stream Leakage	32,163	0	0	-	33,575	0	0	-	34,247	0	0	-
Net Vertical Leakage Upper	-	9,009	-	-	-	9,306	-	-	-	9,533	-	-
Net Vertical Leakage Lower	-	318	0	-	-	291	0	-	-	262	0	-
Net Lateral Flow From Brazoria	-	1,218	-	-	-	1,212	-	-	-	1,180	-	-
Net Lateral Flow From Wharton	2,288	-	3	-	1,731	-	2	-	1,466	-	-	-
Total Inflow	*57,615*	*10,545*	*3*	-	*58,470*	*10,809*	*2*	-	*58,877*	*10,975*	-	-
Outflow												
Wells	31,733	7,121	0	-	31,733	7,121	0	-	31,733	7,121	0	-
Drains	243	0	0	-	241	0	0	-	240	0	0	-
Et	3,023	0	0	-	3,011	0	0	-	3,005	0	0	-
Net Head Dep Bounds	5,277	0	0	-	5,118	0	0	-	5,053	0	0	-
Net Vertical Leakage Upper	-	-	318	-	-	-	291	-	-	-	262	-
Net Vertical Leakage Lower	9,009	-	-	-	9,306	-	-	-	9,533	-	-	-
Net Lateral Flow To Brazoria	2,791	-	6	-	2,807	-	6	-	2,819	-	6	-
Net Lateral Flow To Calhoun	57	-	-	-	56	-	-	-	56	-	-	-
Net Lateral Flow To Jackson	346	595	-	-	579	610	-	-	682	620	-	-
Net Lateral Flow To Wharton	-	2,914	-	-	-	3,122	-	-	-	3,267	-	-
Net Lateral Outflow To Other Areas	6,176	-	-	-	6,014	-	-	-	5,948	-	-	-
Total Outflow	*58,655*	*10,630*	*324*	-	*58,865*	*10,853*	*297*	-	*59,069*	*11,008*	*268*	-
Inflow - Outflow	-1,040	-85	-321	-	-395	-44	-295	-	-192	-33	-268	-
Storage Change	-1,045	-70	-321	-	-395	-38	-295	-	-191	-24	-267	-
Model Error	5	-15	0	-	0	-6	0	-	-1	-9	-1	-
Model Error (percent)	0.01%	0.14%	0.00%	-	0.00%	0.06%	0.00%	-	0.00%	0.08%	0.37%	-

Refugio	2030				2050				2070			
	Chicot	Evangeline	Burkeville	Jasper	Chicot	Evangeline	Burkeville	Jasper	Chicot	Evangeline	Burkeville	Jasper
Inflow												
Recharge	14,562	0	0	-	14,562	0	0	-	14,562	0	0	-
Net Vertical Leakage Lower	397	98	0	-	305	92	0	-	250	85	0	-
Net Lateral Flow From Bee	5,130	2,573	16	-	5,077	2,549	15	-	4,944	2,530	15	-
Net Lateral Flow From Goliad	3,118	2,809	12	-	3,101	2,806	12	-	3,098	2,807	12	-
Net Lateral Flow From Victoria	223	-	-	-	166	-	-	-	163	-	-	-
Total Inflow	*23,430*	*5,480*	*28*	-	*23,211*	*5,447*	*27*	-	*23,017*	*5,422*	*27*	-
Outflow												
Wells	3,226	2,624	0	-	3,226	2,624	0	-	3,226	2,624	0	-
Drains	111	0	0	-	110	0	0	-	110	0	0	-
Et	1,846	0	0	-	1,843	0	0	-	1,842	0	0	-
Head Dep Bounds	4,905	0	0	-	4,888	0	0	-	4,882	0	0	-
Net Stream Leakage	4,419	0	0	-	3,985	0	0	-	3,707	0	0	-
Net Vertical Leakage Upper	-	397	98	-	-	305	92	-	-	250	85	-
Net Lateral Flow To Aransas	2,195	34	-	-	2,193	33	-	-	2,193	33	-	-
Net Lateral Flow To Calhoun	489	108	-	-	494	115	-	-	497	122	-	-
Net Lateral Flow To San Patricio	2,883	789	3	-	3,026	809	3	-	3,108	820	4	-
Net Lateral Flow To Victoria	-	1,520	-	-	-	1,540	-	-	-	1,551	-	-
Net Lateral Outflow To Other Areas	3,477	24	-	-	3,473	25	-	-	3,472	24	-	-
Total Outflow	*23,551*	*5,496*	*101*	-	*23,238*	*5,451*	*95*	-	*23,037*	*5,424*	*89*	-
Inflow - Outflow	-121	-16	-73	-	-27	-4	-68	-	-20	-2	-62	-
Storage Change	-123	-20	-73	-	-30	-4	-68	-	-21	-4	-62	-
Model Error	2	4	0	-	3	0	0	-	1	2	0	-
Model Error (percent)	0.01%	0.07%	0.00%	-	0.01%	0.00%	0.00%	-	0.00%	0.04%	0.00%	-

Figure 5-2 Water budgets calculated for Matagorda and Refugio counties from GMA 15 Baseline Option 1 DFC model simulation



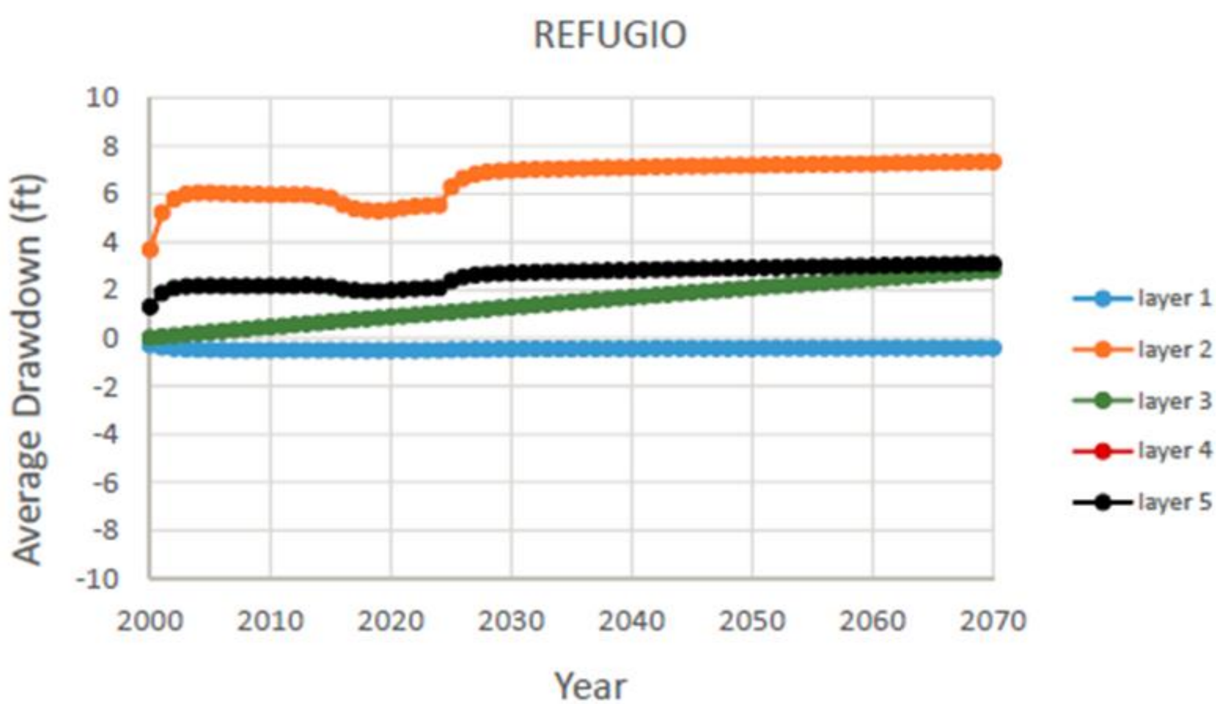


Figure 5-3 Average drawdown curves from 2000 to 2070 calculated for Matagorda and Refugio counties from GMA 15 Baseline Option 1 DFC model simulation (model layer 1 represents the Chicot Aquifer, layer 2 the Evangeline Aquifer, layer 3 the Burkeville confining unit, and layer 4 the Jasper Aquifer)

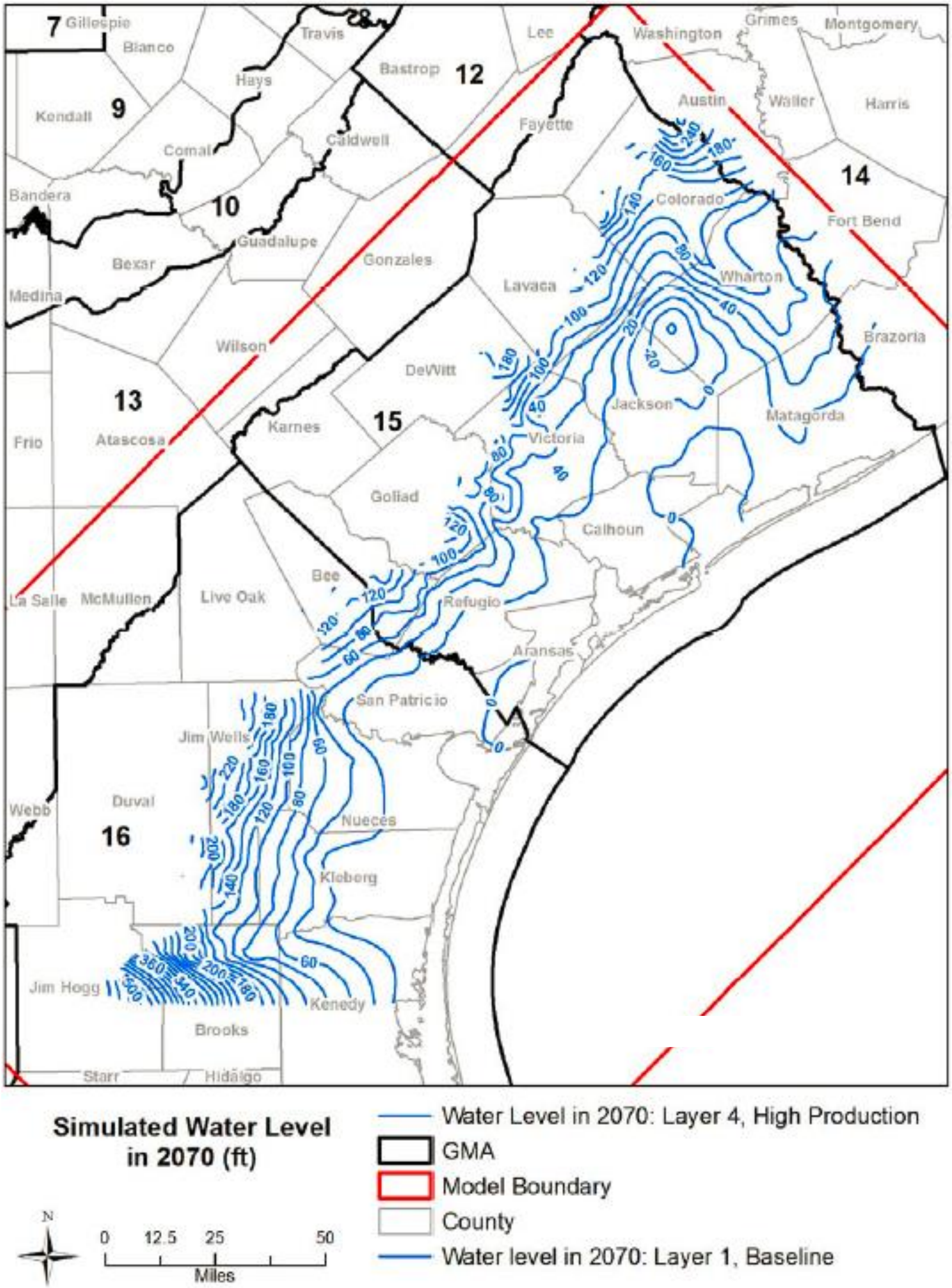


Figure 5-4 Contours of 2070 water levels for the Chicot Aquifer for from GMA 15 Baseline Option 1 DFC model simulation

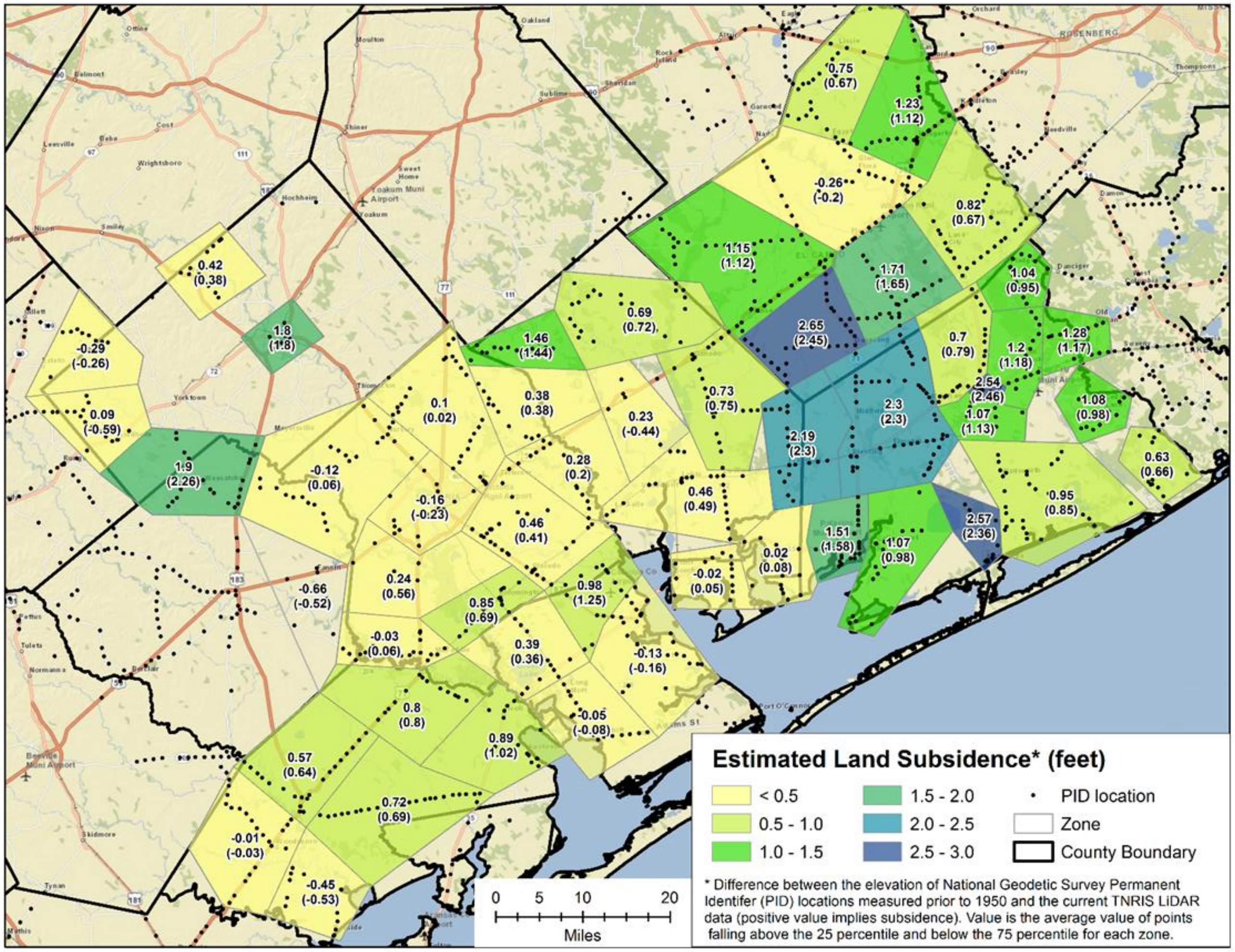


Figure 5-5 Estimated average land subsidence from before 1950 to after 2003 for specific polygons as determined by the difference between ground surface elevation from PIDs surveyed prior to 1950 and from LIDAR surveys after 2006 at the locations of the PIDs. Land Subsidence values are expressed as averages and medians (in parenthesis) of the differences calculated at PIDS located inside the polygons. Positive values indicate lower ground surface elevation at later time. Negative values indicate higher ground surface elevation at later time.

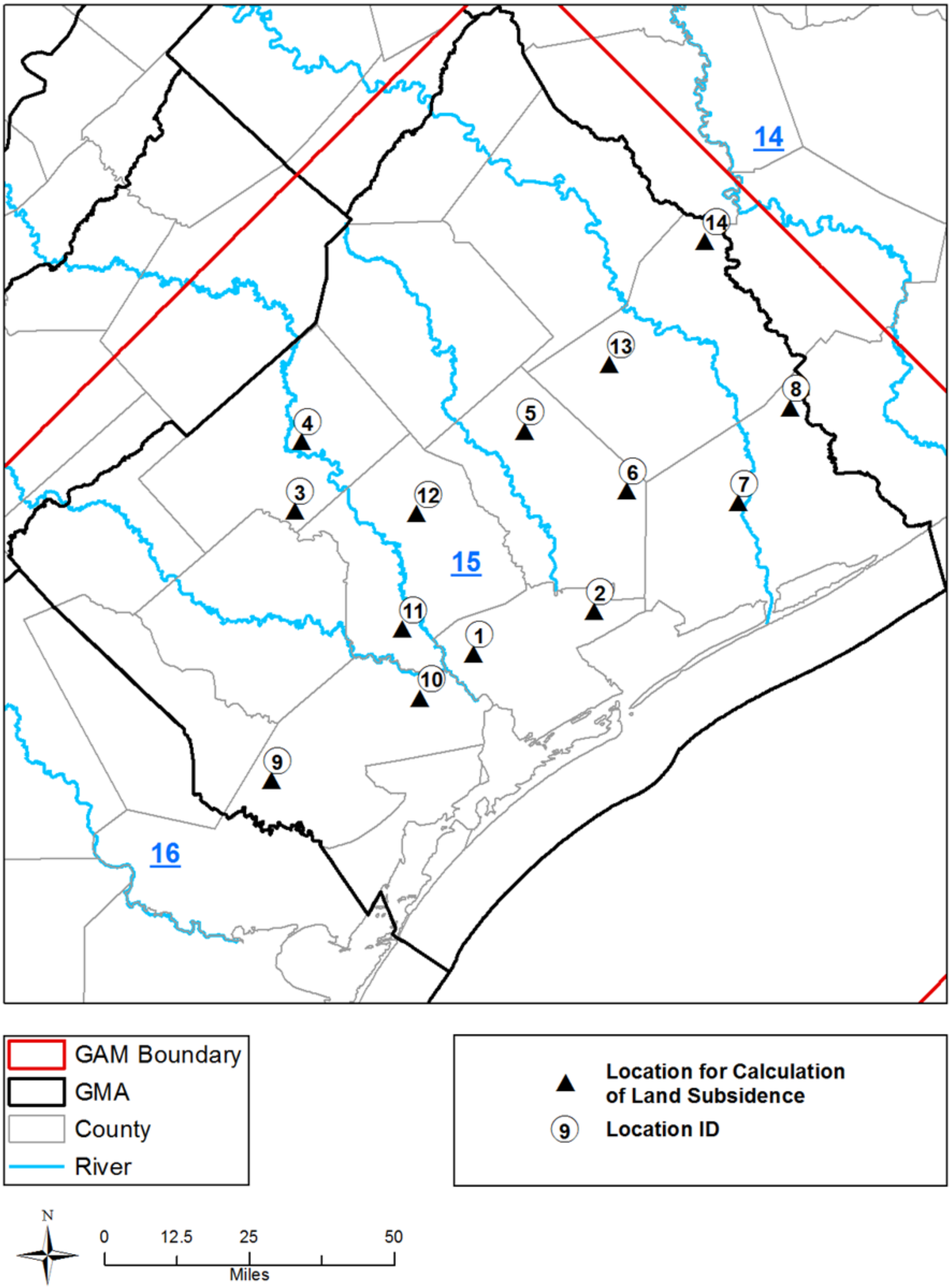


Figure 5-6 Locations in GMA 15 where land subsidence is calculated in Table 5-6.

6.0 REFERENCES

Campbell, M. D., H.M. Wise, and R.C. Bost. 2014. Growth faulting and subsidence in the Houston, Texas Area: Guide to the origins, relationships, hazards, potential impacts and methods of investigation: Published for the Graduates and Members of The Institute of Environmental Technology, Houston, Texas, The Houston Geological Society, and, The American Institute of Professional Geologists, 102 p.

Chowdhury, A., S. Wade, R.E. Mace, and C. Ridgeway. 2004. Groundwater Availability of the Central Gulf Coast Aquifer System: Numerical Simulations through 1999: Texas Water Development Board, unpublished report. Harbaugh and McDonald, 1996.

Ellis, J., Y. Cho, and K. Kluge. 2015(a). Socioeconomic Impacts of Projected Water Shortages for the Region K Regional Water Planning Area, prepared by the Texas Water Development Board, September 2015.

Ellis, J., Y. Cho, and K. Kluge. 2015(b). Socioeconomic Impacts of Projected Water Shortages for the Region L Regional Water Planning Area, prepared by the Texas Water Development Board, September 2015.

Ellis, J., Y. Cho, and K. Kluge. 2015(c). Socioeconomic Impacts of Projected Water Shortages for the Region N Regional Water Planning Area, prepared by the Texas Water Development Board, September 2015.

Ellis, J., Y. Cho, and K. Kluge. 2015(d). Socioeconomic Impacts of Projected Water Shortages for the Region P Regional Water Planning Area, prepared by the Texas Water Development Board, August 2015.

George and others (2011).

Harbaugh, A.W. and M.G. McDonald. 1996. User's Documentation for MODFLOW-96, an update to the U.S. Geological Survey Modular Finite-Difference Ground-Water Flow Model: U.S. Geological Survey Open-File Report 96-485.

Hill, M. E. and W. Oliver. 2011. GAM Run 10-28 MAG. Texas Water Development Report, Austin, TX.

Jones, L. L. and J. Larson. 1975. Economic effects of land subsidence due to excessive groundwater withdrawal in the Texas Gulf Coast area: Texas Water Resources Institute, Texas A & M University, Technical Report No. 67, 33 p.

National Research Council, 2007, Models in Environmental Regulatory Decision Making Committee on Models in the Regulatory Decision Process, National Academies Press, Washington D.C., 287 p.

Norvell, S.E. and D.S. Shaw. 2010(a). Socioeconomic Impacts of Projected Water Shortages for the Coastal Bend Regional Water Planning Area, prepared by the Texas Water Development Board, February 2010.

Norvell, S.E. and D.S. Shaw. 2010(b). Socioeconomic Impacts of Projected Water Shortages for the Lower Colorado Regional Water Planning Area (Region K), prepared by the Texas Water Development Board, May 2010.

Norvell, S.E. and D.S. Shaw. 2010 (c). Socioeconomic Impacts of Projected Water Shortages for the Lavaca (Region P) Regional Water Planning Area, prepared by the Texas Water Development Board, May 2010.

Norvell, S.E. and D.S. Shaw. 2010(d). Socioeconomic Impacts of Projected Water Shortages for the South Central Texas Regional Water Planning Area (Region L), prepared by the Texas Water Development Board, June 2010.

Texas Water Code, 2011

TWDB, 2014

Wade, S. and R. Anaya. 2014. Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 15, Texas Water Development Board Report, Prepared for GMA 15, January 15, 2014.

Waterstone Engineering, Inc., and Parsons, Inc., 2003, Groundwater availability of the central Gulf Coast aquifer: Numerical simulations to 2050, Central Gulf Coast, Texas: Contract draft report submitted to Texas Water Development Board, variously paginated.

Young, S.C. 2016. “Estimates of Land Subsidence in GMA 15 Based on Ground Surface Elevation Data and Model Results,” Prepared for Calhoun County GCD, Coastal Bend GCD, Coast Plains GCD, Pecan Valley GCD, Refugio GCD, Texana GCD, and Victoria GCD. Prepared by INTERA Inc., Austin TX.

Young, S.C. 2014. “Groundwater Science Development Program: Evaluation of Pumping Tests Data from Public Water Supply Wells in Victoria County,” Prepared for Victoria GCD. Prepared by INTERA Inc., Austin TX.

Young. S.C., T. Yan, and D. Lupton. 2012. Large-Scale Pumping and Hydraulic Fracturing on the Gulf Coast Aquifer System in DeWitt County: Pecan Valley Groundwater Conservation District.

Young and others (2013)

Young, S.C., V. Kelley, eds., N. Deeds, P. Knox, T. Budge, and E. Baker. 2006. A Site Conceptual Model to Support the Development of a Detailed Groundwater Model for Colorado, Wharton, and Matagorda Counties: Lower Colorado River Authority, Austin, Texas.

Young, S.C., V. Kelley, T. Budge, and N. Deeds. 2009. Development of the LSWP Groundwater Flow Model for the Chicot and Evangeline Aquifers in Colorado, Wharton, and Matagorda Counties: Lower Colorado River Authority, Austin, Texas.

Young, S.C., P.R. Knox, E. Baker, T. Budge, S. Hamlin, B. Galloway, R. Kalbouss, and N. Deeds. 2010. Hydrostratigraphic of the Gulf Coast Aquifer from the Brazos River to the Rio Grande: Texas Water Development Board Report, 203 p.

Young, S.C., T. Ewing, S. Hamlin, E. Baker, and D. Lupton. 2012. Updating the Hydrogeologic Framework for the Northern Portion of the Gulf Coast Aquifer, Unnumbered Report: Texas Water Development Board.

Appendix A

Copies of Agenda and Minutes for GMA 15 2012 – Present

Appendix B

GMA 15 Resolution for Proposed DFCs Dated January 15, 2015

Appendix C

GCD Summary Reports of Public Hearings on DFCs

Appendix D

Water Budgets Predicted by the Central Gulf Coast GAM for 1999 by County

Appendix E

INTERA July 10, 2015 Presentation Discussing Evidence and Sources of GAM Predictive Uncertainty

Appendix F

Groundwater Planning Datasheets for Counties in GMA 15 Managed by GCDs

Appendix G

Spatial Distribution of Pumping by County and Geological Unit for 1999 in the CGC GAM (Chowdhury and others, 2014)

Appendix H

Spatial Distribution of Pumping by County and Geological Unit for 2000 to 2060 in the CGC GAM for establishing the MAG (Hill and Oliver, 2014)

Appendix I

GAM Task 13-038: Total Estimated Recoverable Storage for Aquifers in Groundwater Management Area 15 (Wade and Anaya, 2014)

Appendix J

INTERA's Presentation to GMA 15 on April 10, 2014

Appendix K

Letter from INTERA to Tim Andruss Dated December 2, 2015 Providing GAM Modelling Results from the Baseline Option 1 and the High-Production Option 1 Pumping Files

Appendix L

Letter from Goliad County to Steve Young, INTERA, dated August 19, 2015

Appendix M

INTERA's Presentation to GMA 15 on July 15, 2015

Appendix N

INTERA Presenation to GMA 15 on Land Subsidence on April 29, 2016

Appendix O

TWDB Socioeconomic Impact Assessment for Region K Planning

Appendix P

TWDB Socioeconomic Impact Assessment for Region L Planning

Appendix Q

TWDB Socioeconomic Impact Assessment for Region N Planning

Appendix R

TWDB Socioeconomic Impact Assessment for Region P Planning

Appendix S

INTERA Presentation to GMA 15 on Socioecomonics on April 29, 2016

Appendix T

Goliad County Economic Impact Assessment on Lower Water Levels

Appendix U

INTERA Presentation to GMA 15 on Property Rights on April 29, 2016

Appendix V

Goliad County Supporting Information to Appendix M