LONE STAR
GROUNDWATER CONSERVATION DISTRICT

August 11, 2020

MINUTES OF PUBLIC HEARING ON PERMIT APPLICATIONS

The Board of Directors of the Lone Star Groundwater Conservation District ("District") met in regular session, open to the public but held via a publicly accessible webinar/telephone conference call, within the boundaries of the District on August 11, 2020.

CALL TO ORDER:

Vice President Traylor called to order the Public Hearing on Permit Applications at 6:00 PM announcing the meeting open to the public.

ROLL CALL:

The roll was called of the members of the Board of Directors, to wit:

Jon Paul Bouché
Harry Hardman
Jonathan Prykryl
Larry A. Rogers
Jim Spigener
Stuart Traylor

All members of the Board were present, with the exception of Director(s) Hardman, thus constituting a quorum of the Board of Directors. Also, in attendance at said meeting were Samantha Reiter, General Manager; Stacey V. Reese, District Counsel; District staff; and members of the public. *Copies of the public sign-in sheets and comment cards received are attached hereto as Exhibit "A" to the Regular Board of Directors Meeting minutes.*

PRAYER AND PLEDGES OF ALLEGIANCE:

Vice President Traylor called on Director Bouché for the opening prayer and Director Spigener to lead the Pledge of Allegiance and the Pledge of Allegiance to the state flag.

PUBLIC COMMENTS:

No comments were received.

Ms. Reiter briefed the Board on permit applications received for the month. Applications for consideration and recommended for possible approval included the below:

1. Time Interests, Inc.

Applicant is requesting registration of a new well and production authorization in the amount of 20,000 gallons for 2020 and 350,000 gallons for 2021 and annually thereafter. Based on technical review of the information supplied, it is the General Manager's recommendation to approve that which is requested.

2. Monarch Utilities, Inc. (Crystal Springs)

Applicant is requesting registration of a new well which will provide water to 90 single family residence. Based on technical review of the information supplied, it is the General Manager's recommendation to approve that which is requested.

3. Alsay Incorporated (Rig Supply MUD #144)

Applicant is requesting registration of a new well and production authorization in the amount of 10,000 gallons for 2020 and annually thereafter. Based on technical review of the information supplied, it is the General Manager's recommendation to approve that which is requested.

4. Weisinger Incorporated (City of Patton Village Supply well)

Applicant is requesting registration of a new well and production authorization in the amount of 1,000,000 gallons for 2020 **only**. Based on technical review of the information supplied, it is the General Manager's recommendation to approve that which is requested.

5. Gulf Coast Stabilized (Plant #20)

Applicant is requesting registration of a new well and production authorization in the amount of 1,000,000 gallons for 2020 and 5,000,000 gallons for 2021. Based on technical review of the information supplied, it is the General Manager's recommendation to approve that which is requested.

~~**6. Emerald Lakes POA**~~

~~Applicant request registration of a new well and production authorization in the amount of 500,000 gallons for 2020 and 1,000,000 gallons for 2021. Based on technical review of the information supplied, it is the General Manager's recommendation to approve that which is requested.~~

Ms. Reiter reported that there were six applications for this month but #6 needed to be stricken and added to next month's review. Following Ms. Reiter's report, Director Bouché motioned to approve items #1-5, as recommended by the General Manager. Director Rogers seconded. Motion approved.

Vice President Traylor adjourned the public hearing on permit applications at 6:04 PM.

PASSED, APPROVED, AND ADOPTED THIS 8th DAY OF SEPTEMBER 2020.

Larry A. Rogers, Board Secretary

LONE STAR
GROUNDWATER CONSERVATION DISTRICT

August 11, 2020

MINUTES OF PUBLIC HEARING ON RULEMAKING

The Board of Directors of the Lone Star Groundwater Conservation District ("District") met in regular session, open to the public, but held via a publicly accessible webinar/telephone conference call, within the boundaries of the District on August 11, 2020.

CALL TO ORDER:

Vice President Traylor called to order the Public Hearing on Rulemaking at 6:20 PM announcing the meeting open to the public.

ROLL CALL:

The roll was called of the members of the Board of Directors, to wit:

Jon Paul Bouché
Harry Hardman
Jonathan Prykryl
Larry A. Rogers
Jim Spigener
Stuart Traylor

All members of the Board were present, with the exception of Director(s) Hardman, thus constituting a quorum of the Board of Directors. Also, in attendance at said meeting were Samantha Reiter, General Manager; Stacey V. Reese, District Counsel; District staff; and members of the public. *Copies of the public sign-in sheets and comment cards received are attached hereto as Exhibit "A" to the Regular Board of Directors Meeting minutes.*

PRESENTATION AND DISCUSSION OF PROPOSED AMENDMENTS TO THE DISTRICT RULES AND DISTRICT REGULATORY PLAN ("DRP"):

Ms. Stacey Reese gave a slide presentation that provided an overview of the rulemaking process and discussed the list of the proposed amendments.

PUBLIC COMMENTS:

San Jacinto River Authority Deputy General Manager, Ron Kelling, Deputy, stated that SJRA own and operate 38 groundwater wells in Montgomery County permitted by Lone Star. He requested that the SJRA letter dated August 4 be entered into the official record of this official hearing. Overall, he is glad that the draft rules have provisions to limit groundwater pumping to achieve Desired Future Conditions. Mr. Kelling asked for a definition of "fair share" and a specification of the method Lone Star will use to quantify the "fair share". Further, he asked for clarification of the terms "Management Zones" and "proportional adjustments" in keeping of the DFCS. He discussed that Lone Star has a large task to keep the balance between all landowners' property rights and the negative impacts of subsidence caused by other landowners who want their fair share. *A copy of SJRA's letter of August 4, 2020 is hereto attached as Exhibit "B". A copy of SJRA public comments on August 11, 2020 is hereto attached as Exhibit "C".*

DISCUSSION, CONSIDERATION, AND POSSIBLE ACTION ADOPTING AMENDMENTS TO THE DISTRICT RULES AND/OR DRP AND/OR APPROVING ADDITIONAL REVISIONS FOR PUBLICATION:

Ms. Stacey Reese announced that the board could discuss public comments, ask questions, consider additional proposed revisions and take action to adopt the rules or approve additional revisions for publication. She explained that she had taken all the public input and worked together with the consultants and general manage to produce the red-lined copy of the Draft Rules that each director had before them. Using the PowerPoint presentation, she discussed each rule revision and then opened the floor for a Q & A session.

Director Bouché expressed the desire to schedule another hearing on the revised rules. He asked for the consultants' approach to the rules within the legislature's responsibility-preserving the aquifer while also protecting property rights.

Consultant James Beach responded to Director Bouché inquiries by stating that the underlying consideration is protecting private property rights.

Director Spigener asked Ms. Reese to review the rule changes with regard to impact on the GRPs. Ms. Reese explained that the District Regulatory Plan (DRP) would be repealed and with repeal Large Volume Users would not be required to join a GRP, and the District would resume all invoicing and permitting directly with the well owner.

Director Rogers asked for an explanation of District's plan of achieving the DFC. Ms. Reese discussed the 2010 DFC as 61,000-acre feet which was attached to the latest District's Management Plan so that it would be administratively complete with the Texas Water Development Board. However, the District did not agree that the 2010 DFC was the District's Management standard. The Texas Water Development Board has testified to the Texas legislature that this remains an open unresolved question in Chapter 36. Ms. Reese anticipate the legislature will take that up next session and clarify, though she noted that there is no concern that Lone Star would achieve the DFC.

James Beach explains that the MAG is the estimated volume that can be pumped to achieve the DFC within 60 years and reminded the board that the DFC is a long-term goal. Mr. Beach said that in a given year some wells may pump higher volume than the DFC allows but that DFCs are calculated over a 60-year span and that USGS monitoring wells are used for tracking this pumpage.

Director Traylor posed the question that if there are to be cutbacks, would the District be forced to choose winners and losers and asked for the criteria in making that determination.

Ms. Reese responded by saying that according to the proposed rules; if there was a problem in achieving the DFC in a particular aquifer then the District has opportunity to designate that area as a Management Zone and/or issue a proportional adjustment order. Any permit holder in the affected aquifer would receive a cutback pro rata. New permits can be issued even during a cutback time but would be subject to the same cutbacks.

ADJOURN:

President Hardman adjourned the public hearing on permit applications at 6:27 PM.

PASSED, APPROVED, AND ADOPTED THIS 8th DAY OF SEPTEMBER 2020.

Larry A. Rogers, Board Secretary

LONE STAR
GROUNDWATER CONSERVATION DISTRICT

August 11, 2020

MINUTES OF REGULAR MEETING

The Board of Directors of the Lone Star Groundwater Conservation District ("District") met in regular session, open to the public, held via a publicly accessible webinar/telephone conference call, within the boundaries of the District on August 11, 2020.

CALL TO ORDER:

Vice President Traylor presided and called to order the regular Board of Directors meeting at 6:00 PM, announcing that it was open to the public.

ROLL CALL:

The roll was called of the members of the Board of Directors, to wit:

Jon Paul Bouché
Harry Hardman
Jonathan Prykryl
Larry A. Rogers
Jim Spigener
Stuart Traylor

All members of the Board were present, with the exception of Director(s) Hardman, thus constituting a quorum of the Board of Directors. In attendance at said meeting were Samantha Reiter, General Manager; Stacey V. Reese, District Counsel; District staff; and members of the public. *Copies of the public sign-in sheets and comment cards received are attached hereto as Exhibit "A".*

PUBLIC COMMENTS:

Mr. John Yoars, resident of The Woodlands, joined the meeting via ZOOM and addressed the nine factors in establishing a DFC that Lone Star must consider in its Management Plan. His concerns are with the subsidence in the neighbourhoods around Rayford Road and the 3-5-foot elevation drop described in the latest INTERA report given at the GMA 14 meeting. He contended that the elevation drop would not allow for the Jasper aquifer to recharge. Mr. Yoars expressed concern about using the Run "D" model and the need to incorporate using surface water into the plan. He suggested to the board that the surface water be factored into the Management Plan. *A copy of the Yoars public comment is attached hereto as Exhibit "C".*

EXECUTIVE SESSION:

After a proper and legally sufficient announcement to the public by President Hardman, the Board of Directors recessed into a Closed Executive Session at 6:17 PM pursuant to Texas Government Code, Sections 551.071, to consult with the District's attorney regarding pending or contemplated litigation, settlement offers, personnel matters (§551.074), or on matters in which the duty of the attorney to the governmental body under the Texas Disciplinary Rules of Professional Conduct of the State Bar of Texas clearly conflicts with the Texas Open Meetings Act, Chapter 551, Government Code.

RECONVENE IN OPEN SESSION:

Following Executive Session, the Board reconvened in Open Session and President Hardman declared it open to the public at 7:15 PM.

APPROVAL OF THE MINUTES:

Vice President Traylor stated the Board would consider the meeting minutes as listed for approval on today's agenda. Without further discussion, upon a motion by Director Traylor seconded by Director Prykryl, the Board approved the meeting minutes as presented.

a) July 14, 2020, Public Stakeholders Meeting
b) July 14, 2020, Public Hearing on Permit Applications
c) July 14, 2020, Regular Board of Directors Meeting
d) August 4, 2020, Public Workshop for District Rules

REVIEW OF UNAUDITED FINANCIALS FOR THE MONTH OF JULY 2020;

Ms. Samantha Reiter reported that for the month of June 2020, income was $166,638 and expenses were $134,299 resulting in a net income of $32,339. Year-to-date net income is $446,615. Total cash was $1,331,151.

DISCUSS, CONSIDER AND POSSIBLE ACTION REGARDING APPROVAL OF RESOLUTION #20-004 ADOPTING AMENDED FY 2020 BUDGETS:

Ms. Reiter reviewed that the Budget Committee had met the previous week and as a result suggested amending the FY 2020 budget. The singular item was the addition of the Subsidence Study Phase II. After discussion, upon a motion by Director Spigener and seconded by Director Rogers the Board approved the amended FY 2020 budget. Motion passed. *A copy of Resolution 20-004 is attached hereto as Exhibit "D".*

DISCUSS, CONSIDER AND POSSIBLE ACTION REGARDING APPROVAL OF RESOLUTION #20-005 ADOPTING FY 2021 BUDGETS:

Ms. Reiter commented that the main item added was the Subsidence Study Phase II. Upon a motion by Director Spigener and seconded by Director Prykryl the Board approved the FY 2021 budget. Motion passed. *A copy of Resolution 20-005 is attached hereto as Exhibit "E".*

DISCUSS, CONSIDER AND POSSIBLE ACTION AS NECESSARY ON RESOLUTION #20-006 AUTHORIZING WATER USE FEE RATE SCHEDULE FOR 2021:

Ms Reiter explained that this is typical time of year to review the water use fee rate and determine for the upcoming year. She discussed the rates for pumping in all three aquifers and suggested that they remain the same as previous year. Upon a motion by Director Spigener and seconded by Director Prykryl the Board approved the resolution authorizing the water use fee rate for 2021. Motion passed. *A copy of Resolution 20-006 is attached hereto as Exhibit "F".*

RECEIVE INFORMATION FROM DISTRICT'S TECHNICAL CONSULTANTS REGARDING SUBSIDENCE STUDIES AND/OR DISCUSSION REGARDING THE SAME:

a) Discussion, consideration, and possible action regarding Subsidence Study Phase 1 Draft Report.

Mr. Mike Thornhill discussed the fact that Phase I is now in the final draft stage with public input deadline extended until July 31st. All public comments collected were considered in editing the report and producing the final draft. Public comments that received individual attention were addressed in Appendix "A" of the report. Upon a motion by Director Spigener and seconded by Director Prykryl, the Board approved the Subsidence Study Phase 1 Report. Motion passed. *A copy of the report is attached hereto as Exhibit "G".*

b) Discussion, consideration, and possible action to approve Subsidence Study Phase 2 Scope of Work.

Ms. Reiter concluded that based on previous board discussion the consensus was to table this item. Upon a motion by Director Rogers, seconded by Director Prykryl, Item (B) Discussion, consideration and possible action to approve Subsidence Study Phase 2 Scope of work would be considered at a later date. Motion passed.

GROUNDWATER MANAGEMENT AREA 14 - UPDATE THE BOARD ON THE ISSUES RELATED TO JOINT PLANNING ACTIVITIES AND DEVELOPMENT OF DESIRED FUTURE CONDITIONS IN GMA 14:

Ms. Reiter, General Manager, reported that the GMA 14 met on July 15th with a report to follow.

a) Discussion, consideration, and possible action on any items related to Lone Star GCD's proposal(s) to and/or participation in GMA 14

Ms. Reiter reported that the GMA 14 group met on July 15th and received a presentation from Wade Oliver, consultant with INTERA. The presentation discussed the nine factors to consider in setting a DFC. There was no action taken at this meeting. Ms. Reiter announced the next meeting is set for September 16th. According to the agenda discussions will center on the environmental and socioeconomic impact of the DFC.

GENERAL MANAGER'S REPORT:

Ms. Samantha Reiter reminded board members about the sign up for the Texas Alliance of Groundwater Districts Summit on September 1-3, 2020 which is now being held virtually. She also announced the upcoming board election including the seat representing Place 1- Montgomery County Precinct 1, the seat representing Place 6- City of Conroe, and Place 5- Montgomery County At-Large position. Anyone wishing to run for a board position must submit an application for a place on the ballot no later than Monday, August 17th at 5:00 pm. The drawing for place on the ballot will be Monday, August 24th at 9:00 am.

GENERAL COUNSEL'S REPORT:

Ms. Reese apprised the Board on one law case, the Fazzino and Brazos Valley GCD, currently at the trial court in Waco, Texas. The case is scheduled for a jury trial in February 2021. There was a motion filed to dismiss some of the claims but briefing needs to be completed.

NEW BUSINESS:

Director Rogers requested an update of the Educational Outreach Program. Ms. Reiter explained that Ms. Jennifer Thayer is currently examining using another company offering digital learning. It is hoped that the new company could provide less costly learning materials while still supplying the same quality curriculum and learing results as the current WaterWise Program. More information will be provided at the September board meeting.

ADJOURN:

There being no further business, Director Bouché motioned to adjourn the meeting and Director Spigener seconded. The meeting was adjourned at 7:27 PM.

PASSED, APPROVED, AND ADOPTED THIS 8th DAY OF SEPTEMBER 2020.

Larry A. Rogers, Board Secretary

Exhibit "A"

August 11, 2020 BOD Meeting

Panelist

Stacey Reese

Samantha Reiter

Jennifer Thayer

Jonathan Prykryl

Jim Spigener

Jon Bouche

Stuart Traylor

James Beach

Attendees

John Yoars

Matt Corley

Mike Keester

Michael Sullivan

Ron Kelling

Tina Felkai

Chris Meeks

Simon Sequeria

Laura Norton

Suellen Myers

Exhibit "B"

San Jacinto River Authority

ADMINISTRATIVE OFFICE
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August 4, 2020

Board of Directors and
Samantha Reiter, General Manager
Lone Star Groundwater Conservation District
655 Conroe Park North Drive
Conroe, Texas 77303

Re: Draft Rules of the Lone Star Groundwater Conservation District

Dear Ms. Reiter and Board Members:

The San Jacinto River Authority ("SJRA") appreciates the opportunity to review the Draft Rules of the Lone Star Groundwater Conservation District ("Lone Star") or ("District") and provide you with questions and comments to which we would appreciate Lone Star providing responses.

General Comments and Questions:

The SJRA is pleased to see that Lone Star's Draft Rules propose to continue the regulation of groundwater pumping in Montgomery County as necessary to achieve the Desired Future Conditions ("DFCs") established for the aquifers. However, while these Draft Rules *contemplate* the Board *potentially* adopting rules to regulate production in a way that achieves the DFCs, they do not provide any specifics or objective standards describing what those regulations are, what they will be based on, or how they will be implemented. Rather, the Draft Rules discuss "proportional adjustment" regulations as if they are something new when, in reality, the Draft Rules simply propose to delete the District's current proportional adjustment regulations (the District Regulatory Plan) and replace them with new proportional adjustment regulations, but without any guidance on the specific nature of the replacement regulations.

The Draft Rules make it entirely unclear as to how Lone Star will actually achieve the 2010 DFCs that are included in the current Management Plan that was recently adopted by the Lone Star Board and approved by the Texas Water Development Board. A serious concern is that the total volume of groundwater production in Montgomery County permitted by Lone Star is approximately 98,089 afpy, and the Modeled Available Groundwater ("MAG") associated with the currently-approved DFC is approximately 61,629 afpy as determined by the Texas Water Development Board ("TWDB"). The fact that the permitted groundwater production is over

36,000 afpy greater than the MAG raises serious concerns as to how Lone Star will actually achieve the current DFCs with these Draft Rules. Until Lone Star adopts its new proportional adjustment regulations, the Draft Rules will not achieve the established DFCs, protect water levels in wells, prevent land subsidence, or generally protect the groundwater and aquifers in Montgomery County.

The only new management strategy set forth in the Draft Rules presently is well spacing. Well spacing is a tool for managing interference between wells and their cones of depression. We are unaware of any permittee in Montgomery County that has expressed a problem with interference between wells or cones of depression. The problem is total production from the aquifer and the very real consequences that result from declining water levels. It is unclear how Lone Star intends to use spacing for managing total aquifer production to achieve a DFC when cones of depression in an unconfined aquifer typically extend distances much greater than the spacing restrictions provided in the Draft Rules. Moreover, because spacing rules apply only to new wells, and because the existing wells that are exempt from spacing rules are already pumping more groundwater than is available under the MAG, there is no possibility that well spacing rules will achieve the DFC.

The Draft Rules are unclear as to the basis that will be used to reissue Historic Use and Operating Permits. Will the permitted limits for Historic Use and Operating Permits effective December 31, 2015, be used as the basis?

Without clarity of specific rules, processes, procedures, and/or protocols that Lone Star will follow to develop defendable Annual Production Limitations, Management Zones, and Proportional Adjustments, it is difficult to see how Lone Star will achieve the approved DFCs of the Chicot, Evangeline, and Jasper aquifers of Montgomery County and achieve the "best practicable conservation and development practices for the groundwater resources of Montgomery County."

Specific Comments and Questions:

1. The Texas Water Development Board ("TWDB") recently approved Lone Star's Management Plan, which refers to the 2010 Desired Future Conditions ("DFCs") and acknowledges that Lone Star is working with other members of GMA 14 to propose appropriate DFCs by May 1, 2021, and adopt final DFCs by January 5, 2022. The referenced 2010 DFCs include limitations for average drawdowns of the Chicot, Evangeline, and Jasper aquifers in Montgomery County. The Modeled Available Groundwater ("MAG") associated with those 2010 DFCs is approximately 61,629 afpy as determined by the TWDB (GAM Run 10-038 MAG Report, November 18, 2011).

   During a presentation to the Lone Star Board of Directors on April 14, 2020, consultants stated that the total volume of groundwater production in Montgomery County permitted by Lone Star is approximately 98,089 afpy. Therefore the current amount of permitted groundwater withdrawals exceeds the MAG by over 36,000 afpy.

   How will the Draft Rules proposed by Lone Star achieve the currently adopted DFCs?

2. The Draft Rules provide for the issuance of permits (Draft Rule Section 2) to include Annual Production Limitations (Draft Rule 4.1) and potentially Management Zones (Draft Rule 6.2)

and Proportional Adjustment (Draft Rule 6.3), however the specific details are not provided as to how these parameters/restrictions will be quantified or implemented.

What specific rules, processes, procedures, and/or protocols will Lone Star follow to develop the Annual Production Limitations, Management Zones, and Proportional Adjustments to regulate groundwater pumping to meet the current 2010 DFCs for the reissuance of existing permits and the issuance of new permits?

What Best Available Data and Science will be used to determine and defend the Annual Production Limitations, Management Zones, and Proportional Adjustments?

3. Section 1, Rule 1.1, Definitions - The term "fair share" is referenced in numerous portions of the Draft Rules, however it is not defined. What is Lone Star's definition of "fair share?" What specific processes, procedures, and/or protocols will Lone Star follow to determine each Well Owner's "fair share" as Annual Production Limitations, Management Zones, and Proportional Adjustments are developed?

4. Section 1, Rule 1.1, Definitions – The definition of "Administratively Complete" does not conform to Section 36.113(c), Water Code. The definition should be revised to indicate that the term means that all information required by the rules has been fully and accurately provided.

5. Section 1, Rule 1.1, Definitions – In the definition of "Aquifer of the District," the Draft Rule considers the Chicot and Evangeline Aquifers as one aquifer for regulatory purposes. What is the purpose of combining these aquifers?

6. Section 1, Rule 1.1, Definitions – The definition of "deteriorated well" is not consistent with the statute, Sec 1901.255 Occupations Code, or the TDLR rules. Also, in the definition of "deteriorated well," it is indicated that the determination of whether the well is deteriorated is "...in the discretion of the District." We suggest that the determination of a deteriorated well should be conducted in coordination with the Well Owner. This gives the Well Owner the opportunity to address any potential issues with the well before it is determined to be deteriorated.

7. Section 1, Rule 1.1, Definitions – In the definition of "Existing Well," a well is considered existing if "...the Administratively Complete well registration or permit or permit amendment application was filled, before the Effective Date." While Rule 2.3(f) provides that a new exempt well must be drilled and completed within 120 days following issuance of a registration, there is no similar provision in the Draft Rules for non-exempt wells. Also, the Draft Rules are not clear regarding whether the registration expires after that period of time. Is there a length of time for which the registration, permit, or permit amendment for a non-exempt well expires before the construction of a well must actually commence? If so, what is that length of time? Are registrants and permit holders able to request an extension of time to complete construction? The language in the current rules addressing these questions appears to have been eliminated in these Draft Rules.

8. Section 1, Rule 1.1, Definitions – What is the basis of determining the "maximum, instantaneous pump rate" in the definition of "Maximum Allowable Pumping Rate"? For

existing Wells? For new Wells? What operating conditions are used to determine this rate? Is it the highest pumping rate indicated on the pump curve for the well pump?

9. Section 1, Rule 1.1, Definitions and Section 8, Rule 8.1(c) – The "Overproduction Disincentive Fee" is identified as $3.00 per each 1000 gallons of water overproduced. While the fee may have been sufficient at the time it was originally adopted by Lone Star, the proposed fee does not appear to be large enough now to impact permittee behavior to comply with Lone Star's Rules. As a comparison, the current disincentive fee assessed by the Harris-Galveston Subsidence District is $9.24 per 1000 gallons. What study/analysis was used by Lone Star as the basis of the proposed Overproduction Disincentive Fee of $3.00 per 1000 gallons as an effective amount that will encourage compliance with the Rules?

10. Section 1, Rule 1.1, Definitions – "Owner" is defined as "the owner or holder of the right to produce groundwater from a tract of land." What specific "right to produce groundwater from a tract of land" is required of public/governmental entities?

11. Section 1, Rule 1.1, Definitions – Definition of the term "Qualifying Minor Violation" is missing.

12. Section 1, Rule 1.12, Request for Reconsideration and Appeal – The Draft Rule states "a request for an appeal may be filed with the District within twenty (20) calendar days of the date of the decision" for an appeal by the General Manager. Since these decisions of the General Manager are not made in a noticed public meeting, this provision should be changed to "within twenty (20) calendar days of the date a person is provided *notice of the* decision."

13. Section 1, Rule 1.17, District Management Plan – The Draft Rule identifies the general steps and timeframe for which a District Management Plan will be developed. Based on the timeframe provided and the schedule for the development of DFCs by GMA 14, it could be 2024 before a new District Management Plan is developed. Lone Star recently adopted a District Management Plan which was approved by the Texas Water Development Board and which included DFCs previously adopted by GMA 14 and Lone Star. Specifically how will Lone Star monitor the aquifers and assure that these Draft Rules achieve the current DFCs until such time as a new District Management Plan that includes the new DFCs to be adopted in 2022 is developed and adopted in three or four years?

14. Section 2, Rule 2.4, Historic Use Permits and Rule 2.5, Operating Permits – The Draft Rule retains Historic Use Permits and Operating Permits, but they do not seem to be differentiated in any way. Will Historic Use Permits be handled differently than Operating Permits?

15. Section 2, Rule 2.5, Operating Permits – Will Lone Star continue to issue new Operating Permits even after Proportional Adjustment rules have been implemented? If so, what will be the basis for the authorized production amount in the new Operating Permit? As the Draft Rules are currently written, isn't it possible that a permit applicant could just apply for more production than they actually need to circumvent the Proportional Adjustment requirements since there are no objective standards in the Draft Rules for how much water an applicant is entitled to apply for?

16. Section 2, Rule 2.8(a)(3), Considerations for Granting or Denying an Operating Permit – The Draft Rules indicate that Lone Star will consider whether "the proposed use of water unreasonably affects existing groundwater and surface water resources or existing permit holders" as a factor. What is a potential "unreasonable effect" when considering "fair share" of the applicant and other existing Well Owners in the vicinity of the proposed Well? What is the timeframe for which Lone Star will consider the "unreasonable effect"? Short-term? Long-term?

17. Section 2, Rule 2.8(a)(4), Considerations for Granting or Denying an Operating Permit – The Draft Rule indicates that "the proposed use of water is dedicated to a beneficial use" will be a factor. What information will Lone Star require and/or verify to determine that the applicant requires the total quantity of water that is requested in the Operating Permit? What is the acceptable timeframe for which the water will need to be used? In other words, how far out into the future can the demand be used to justify a new Operating Permit since permits are now to be issued in perpetuity and no longer for a specific permit term?

18. Section 2, Rule 2.8(b)(1), Considerations for Granting or Denying an Operating Permit – The Draft Rule states that "the District shall manage total groundwater production on a long-term basis to achieve the applicable Desired Future Conditions and shall consider: (1) the Modeled Available Groundwater determined by the Executive Administrator of the TWDB." The current Lone Star-adopted and TWDB-approved District Management Plan includes the 2010 DFCs which are associated with a MAG of 61,629 afpy as determined by the TWDB. How will Lone Star consider this MAG in the reissuance of existing permits and the granting or denying of new Operating Permits once these Draft Rules are adopted?

19. Section 2, Rule 2.8(b), Considerations for Granting or Denying an Operating Permit – Is the language taken from Section 36.1132(b), Water Code, intended to serve as a basis for the Proportional Adjustments in Section 6? The Draft Rule states that "yearly precipitation and production patterns" shall be considered. How will yearly precipitation and production be considered in determining whether and when to reduce production under Operating Permits, particularly if abnormally hot, dry or cool, wet weather occurs before or during the time of the implementation of Proportional Adjustment rules?

20. Section 2, Rule 2.9(c)(10), New or Amended Operating Permits Issued by District – What are "other adjustments" that the District may state in a permit?

21. Section 2, Rule 2.10 – Aggregation of Withdrawal Among Multiple Wells – The Draft Rule includes only the aggregation of "multiple wells that are a part of a well system that are owned and operated by the same person and serve the same subdivision, facility or a certified service area…" Owners of smaller systems may find complying with Annual Production Limitations (Draft Rule 4.1) and Proportional Adjustments (Draft Rule 6.3) financially challenging. Will Lone Star consider revising the Draft Rules to allow more cost-effective regional approaches to groundwater management driven by the free market through the aggregation of multiple Well Systems with multiple Well Owners and including such flexibility in its Proportional Adjustment Orders?

22. Section 2, Rule 2.11(b) – Historic Use and Operating Permit Terms; Administrative Review – The Draft Rule states that "The District shall reissue existing Historic Use Permits and

Operating Permits … including without limitation a Maximum Allowable Pumping Rate and Annual Production Limitations for each Aquifer of the District, and are subject to proportional adjustments in accordance to Rule 6.3 and management zones in accordance with Rule 6.2." Those limitations are not specifically quantified in the Draft Rules, therefore how will Lone Star develop the initial Annual Production Limitations, Management Zones and Proportional Adjustments as existing Historic Use Permits and Operating Permits are reissued?

How will Lone Star take into consideration that some permittees who already "overconverted" by using more alternative water under the current Lone Star rules aggregated and adjusted their planned groundwater pumpage downward so that other permittees could increase their groundwater pumpage through the Declaration of Intent process initiated by Lone Star in 2019? Will Lone Star "undo" the DOI process of 2019 and restore all Historic Use Permits and Operating Permits to December 31, 2015, levels? How will Lone Star assure that all existing permittees reissued permit amounts reflect their "fair share" of available groundwater?

For example, the SJRA Woodlands permits on December 31, 2015, reflected the following:

SJRA Woodlands HUP	4,913,470,000 gallons
SJRA Woodlands Operating Permit	<u>1,601,821,000 gallons</u>
Total	6,515,191,000 gallons

Through the Declaration of Intent process conducted by Lone Star in 2019, the total projected groundwater usage for 2020 is as follows:

Aggregated Permit	3,013,641,000 gallons

In addition, what process, procedures and protocols will Lone Star utilize to allocate amounts in each existing permit into the different aquifers?

23. Section 2, Rule 2.12 – Operating Permit Amendments and Limited Authorized Amendments to Historic Use Permits and Rule 2.17 Transfer of Well Ownership – The Draft Rule allows "change in ownership of a well" to be a minor amendment that can be considered and granted "without public notice and hearing." Transfer of ownership of permitted wells may have an impact on existing contractual arrangements among various Well Owners, therefore will Lone Star consider requiring a "public notice" upon application for a "change in ownership of a well" for permitted wells?

24. Section 3, Spacing and Location of Wells – How will the criteria of spacing and location of wells included in the Draft Rules specifically help Lone Star meet the TWDB-approved Management Plan and accompanying DFCs in the confined aquifers that exist in Montgomery County? Well spacing is designed to prevent interference between Wells, not as a tool capable for regulating total production from an aquifer. This is especially true under these Draft Rules, since the existing wells can already produce a greater quantity of water than the amount that will achieve the DFCs, and they are exempt from these spacing rules.

What is the specific Best Available Data and Science used in the development of the criteria in Draft Rule 3.3(a)? How were these criteria derived? Were those well spacing criteria developed based on cones of depression for wells in the confined area of the Aquifers or in the outcrop area? It is our understanding that the cone of depression for a well in the confined area of an Aquifer extends much farther out than the criteria provided in the Draft Rules. Has Lone Star reviewed any previous studies it conducted on well spacing? How do the recommended spacing distances in those previous studies compare to those proposed in the Draft Rule 3.3(a)?

25. Section 3, Rule 3.2(a), Spacing Requirement for All New Wells – The Draft Rules state that a New Well "may not be drilled within 50 feet of the property line." Since a goal of Lone Star is to protect property rights, shouldn't the spacing limits included in Rule 3.3(a) be considered as applicable spacing from a property line so that larger wells require a greater distance from the neighboring property? Otherwise, won't this end up being a race between adjacent property owners to see who can be the first to drill a well? The first property owner to drill a well will be able to produce a greater amount of groundwater than the adjacent property owner who arrives a day later with a well registration application.

    The Draft Rules do not include a restriction on the number of Wells owned by a single Well Owner on a specific property. As long as the Owner maintains the spacing limits between wells provided, there are no other restrictions, correct? Can an Owner drill a Chicot or Evangeline well on the same tract as a Jasper well without the need to comply with well spacing requirements as between the two wells? Also, given the automatic exception and waiver to spacing requirements provided under Draft Rule 3.4(b) and (c), can an Owner just exempt his own wells from meeting the spacing rules from each other, thereby working around the purpose and implementation of the spacing limits in Draft Rule 3.3(a)?

26. Section 3, Spacing and Location of Wells – Are there restrictions for the number of Exempt wells that can be located on one property? The current rules address this issue, but the Draft Rules do not. It appears this could lead to the drilling of multiple exempt wells on one property to avoid permit limits.

27. Section 4, Annual Production Limitations and Rule 4.1 Annual Production Limits for Permits – The Draft Rules state the District will "protect property rights by affording an opportunity for a fair share to every owner, the District shall manage total groundwater production on a long-term basis to achieve the applicable Desired Future Conditions." Specifically how and when will Lone Star develop the initial Annual Production Limits to meet the current DFCs that are included in the Lone Star Board-adopted and the TWDB-approved Management Plan? What will be the basis of those Annual Production Limitations?

    Also, Draft Rule 4.1 states "The District shall designate the Annual Production Limitations for each Aquifer of the District under each permit issued by the District." What does this mean to designate the Annual Production Limitations for the entire Aquifer as part of a permit decision?

28. Section 4, Annual Production Limitations and Draft Rule 4.2, Temporary Drought Buffer – The Draft Rules imply that a temporary increase in production authorized could be for some period of time less than a year. Should the temporary increase be for an entire year since it is

a total annual production issue? The Draft Rules state that "The Board may by resolution adopt a temporary drought buffer temporarily increasing the Annual Production Limitations…' and that "A person with permits where the Annual Production Limitations have been temporarily increased shall pay the Water Use Fees associated with the increased authorization." Some Well Owners may not want to increase their production during a drought and should not be forced to pay the additional Water Use Fee associated with the blanket increased authorization. Also, should Lone Star consider only allowing such Temporary Drought Buffers during more severe droughts?

29. Section 6, Rule 6.2, Authority to Establish Management Zones – The Draft Rules state that Lone Star may "create specific Management Zones within the District…" and that these Management Zones may include "…a more restrictive Maximum Allowable Pumping Rate" and "authorize total production and make proportional adjustments to Annual Production Limitations…." Specifically how will Lone Star consider the impact to economic development in Montgomery County and the establishment of "winners" and "losers" that will result from the breakup of Montgomery County into separate geographically based Management Zones?

30. Section 6, Rule 6.3, Proportional Adjustment – The Draft Rule does not quantify the specific initial Proportional Adjustment that may be included with the issuance of the revised permits discussed in Rule 2.11 (b). How and when will Lone Star develop the Proportional Adjustments for the initial reissued permits to comply with the current DFCs that are included in the Management Plan adopted by the Lone Star Board and approved by the TWDB?

31. Section 6, Rule 6.3 (g), Proportional Adjustment – The Draft Rules state "All affected permits shall comply with any adjusted maximum allocation limits within 5 years of the date of the Proportional Adjustment Order." Will Well Owners who may receive a Proportional Adjustment during the initial reissuance of permits be given five years to comply from the date of the initial reissuance of permits by Lone Star without the need to utilize Early Conversion Credits that were obtained under the old rules?

32. Section 6, Rule 6.3(f), Proportional Adjustment – The Draft Rules state "In the event that the Board elects to issue a Proportional Adjustment Order, then the procedures in Rule 4.1 shall apply to set new Annual Production Limitations under each permit issued for that particular Aquifer of the District or Management Zone." However, there are no procedures in Rule 4.1 that address how Lone Star determines the Annual Production Limitations or how Lone Star will amend permits to change the authorized production limits in them. Will permit holders be given notice and an opportunity for a public hearing? This issue is complicated by the Draft Rule that permits will be issued in perpetuity.

33. Section 10, Rule 10.1(b), Metering – The Draft Rules state "A mechanically driven, totalizing water meter is the only type of meter that nay be installed on a well permitted by or registered with the District." We have found mechanical flow meters to be less reliable, and as they begin to fail, they under report the water flow. We have found electromagnetic flow meters to be more reliable. If they start to drift, they can be electronically re-configured rather than rebuilt or replaced as is the case with mechanical flow meters. Will Lone Star add "electromagnetic flow meters" as an acceptable type of flow meter in the Rule?

34. Section 13, Rule 13.5(b), Desired Future Conditions Hearings – The Draft Rules state "the District shall make available in its office a copy of the proposed Desired Future Conditions and any supporting materials...." Given the size of the proposed DFC file, will Lone Star consider adding that it will also provide a copy of the proposed Desired Future Conditions and any supporting materials on its website for download by the public?

We would appreciate Lone Star responding to these questions and comments and the opportunity to discuss these questions and comments with Lone Star's staff and consultants at your convenience during the month of August and prior to Lone Star Board's consideration of the Draft Rules.

Sincerely,

Ronald D. Kelling

Ronald Kelling, P.E.
Deputy General Manager
San Jacinto River Authority

cc: Jace Houston, General Manager, SJRA

Exhibit "C"

Public Comments from San Jacinto River Authority to
Lone Star Groundwater Conservation District
Public Hearing on Draft Rules
Tuesday, August 11, 2020

Good evening to the Board of Directors of the Lone Star Groundwater Conservation District ("Lone Star"), General Manager Samantha Reiter, consultants and other stakeholders.

My name is Ron Kelling. I am the Deputy General Manager of the San Jacinto River Authority ("SJRA"). The SJRA owns, operates and maintains 38 groundwater wells in Montgomery County that are permitted by Lone Star.

We provided the attached letter dated August 4, 2020 to the Lone Star Board and Ms. Reiter as a part of the Public Workshop regarding the Draft Rules that Lone Star conducted last week. We request that the nine page letter which contains 34 comments and questions be entered into the official record for this Public Hearing.

Overall, we are glad to see that the Draft Rules have provisions to limit groundwater pumping to achieve the Desired Future Conditions (DFCs). As you state in the Preamble, Lone Star's mission is to honor and protect private property rights by affording an opportunity for a "fair share" to every owner. However, the term "fair share" is not defined. In addition, the methodology that Lone Star intends to use to quantify "fair share" in the development of Annual Permit Limitations, Management Zones and/or Proportional Adjustments to achieve the DFCs is also not provided in the Draft Rules.

The Lone Star Board has an unenviable task to balance the property rights of all land owners, not just those who want to withdraw their "fair share" of groundwater from under their property.

How will Lone Star protect all land owners' private property rights against negative impacts to their land caused by subsidence resulting from the pumpage of groundwater by other land owners who want their "fair share"?

How will Lone Star protect all land owners' private property rights against negative impacts to their own groundwater pumps caused by pumpage of groundwater by other land owners who also want their "fair share"?

How will Lone Star define "fair share" to protect the property rights of ALL land owners whether they desire to pump groundwater or not?

As board members, you will have the task of balancing all these competing interests – balancing how much groundwater permittees can utilize against the serious consequences that occur from using too much. Others who are responsible for groundwater management in the state of Texas have successfully achieved this balance by utilizing the best data and science available. As you are aware, it will be absolutely critical to Lone Star's success that the best science and the top scientists available be utilized to develop, implement and defend your rules to assure all land owners' private property rights are protected while achieving the DFCs.

I appreciate the opportunity to provide these comments.

Thank you,

Ronald Kelling, P.E.
Deputy General Manager
San Jacinto River Authority

LONE STAR GROUNDWATER CONSERVATION DISTRICT

Resolution No. 20-004

A RESOLUTION OF THE BOARD OF DIRECTORS OF THE LONE STAR GROUNDWATER CONSERVATION DISTRICT ADOPTING THE AMENDED OPERATING AND CAPITAL OUTLAY BUDGET FOR 2020

WHEREAS, the Lone Star Groundwater Conservation District (the "District") was created by the Legislature of the State of Texas by the Act of May 17, 2001, 77th Leg., R.S., ch. 1321, 2001 Tex. Gen. Laws 3246, as amended (the "Enabling Act"), as a groundwater conservation district operating under Chapter 36, Texas Water Code, and the Enabling Act; and

WHEREAS, the District's Board of Directors and staff has worked diligently to identify all reasonably anticipated District revenues, expenses, and activities for the January 1 through December 31, 2020 budget cycle, and, after giving much consideration to these important factors, has developed an Amended 2020 budget for the Board's consideration and deliberation (the "2020FY Budget");

WHEREAS, the District Board of Directors (the "Board") has reviewed and considered the 2020 Operating and Capital Budget;

WHEREAS, pursuant to Section 36.154 of the Texas Water Code, the District has prepared a budget that contains a complete financial statement, including a statement of the outstanding obligations of the District, the amount of cash on hand to the credit of each fund of the District, the amount of money received by the District from all sources during the previous year, the amount of money available to the District from all sources during the ensuing year, the amount of the balances expected at the end of the year in which the budget is being prepared, the estimated amount of revenues and balances available to cover the proposal budget, and the estimated fee revenues that will be required;

WHEREAS, the Board finds that the adoption of the Amended 2020 Budget, attached hereto as Attachment A and incorporated herein by this reference for all purposes, is merited to support the District's activities and related expenses from January 1, 2020 through December 31, 2020 and that the attached budget will allow the District to carry out the District's objectives and responsibilities as prescribed by the Enabling Act and Chapter 36 of the Texas Water Code.

NOW, THEREFORE, BE IT RESOLVED BY THE BOARD OF DIRECTORS OF THE LONE STAR GROUNDWATER CONSERVATION DISTRICT THAT:

1. The above recitals are true and correct.

2. The Board of Directors of the Lone Star Groundwater Conservation District hereby adopts an operating and capital outlay budget for January 1, 2020 to December 31,

2020 as provided in the budget appended hereto as "Attachment A," which is incorporated herein by this reference and is hereby approved and adopted.

3. The Board of Directors, its officers, and the District employees are further authorized to take any and all actions necessary to implement this resolution.

AND IT IS SO ORDERED.

PASSED AND ADOPTED on this 11th day of August 2020.

LONE STAR GROUNDWATER CONSERVATION DISTRICT

By: ______________________
Stuart Traylor, Vice-President

ATTEST:

____
Larry A. Rogers, Board Secretary

LONE STAR GROUNDWATER CONSERVATION DISTRICT
T E X A S
MONTGOMERY COUNTY, TEXAS

	2020 Amended Adopted Budget
INCOME	
ADMINISTRATIVE FEES	
Application Fees	
AWS Production Permit	$ 3,000
AWS Groundwater Test Wells	1,500
Transfer of Early Conversion Credits	-
Existing Well Application	1,500
Emergency Permit	
Operating Permit	22,000
Transfer of Permitted Authorization	1,500
GRP Amendment Application	
Application Fee- Other	4,950
Total Application Fees	34,450
Change in Ownership	4,000
Open Records Request	1,500
Publications Fees	5,000
Returned Check Fee / Other Admin fees	50
Well Re-inspection Fee	2,000
Total ADMINISTRATIVE FEES	47,000
INTEREST INCOME	5,000
LONE STAR GCD WATER USE FEES	
Early Conversion Credit Water Use Fee	44,060
Export Water Use Fee	600
Historical Use	1,157,000
Ag Permits	1,616
Operating Permit - 2020	814,000
AWS Production Fees -2020	167,378
Over Pumpage Fee	5,500
Penalty/Interest	5,000
Total LSGCD WATER USE FEES	2,195,154
Total Income	$ 2,247,154
EXPENSE	
ADVERTISING/PUBLIC NOTICES	$ 10,000
ATTORNEY FEES	
General Counsel Work	330,000
Additional Legal Work	10,000
Total ATTORNEY FEES	340,000
AUDIT FEES	8,750
BOARD EXPENSE	
Per Diem	50,000
Payroll Tax Liability	3,825
Board Meeting Expense	4,000
Meeting/Conference	3,000
Total BOARD EXPENSE	60,825

	2020 Amended Adopted Budget
BUILDING EXPENSE	
Building Maintenance	20,000
Utilities/Custodial/Phone/Cable	47,000
Upgrade phone service	-
Upgrade sound and recording system-board room	5,000
Total BUILDING EXPENSE	72,000
COMPUTER SUPPORT	
Hosting/Internet/Backup	17,000
Software	4,000
Computer Repair & Support	15,500
Total COMPUTER SUPPORT	36,500
EDUCATION/PUBLIC AWARENESS COORDINATION	
Educational Curriculum in Schools	50,000
ET Weather Station Network/PAM Unit	4,000
Communication/Public Awareness	4,500
Water Efficiency Network	750
Website Modification	2,500
Rainwater Collection Maintenance	500
Conservation products	3,500
Total EDUCATION/PUBLIC AWARENESS CORRDINATION	65,750
ELECTION EXPENSE	100,000
ENGINEERING CONSULTANT SERVICES	
District Engineer	5,000
Engineering Consultant Services	200,000
Well Permitting Database Management	5,000
GMA 14 Planning	150,000
Total ENG/CONSULTANT SERVICES	360,000
FIELD/TECHNICAL EXPENSE	
Field Supplies	3,000
Fuel Expense	3,000
Vechicle-capital expense	26,000
Vehicle/Mobile Lab Repair and Maintenance	2,500
Total FIELD/TECH EXPENSE	34,500
INSURANCE EXPENSE	
Bonds	438
Building Insurance	3,756
Errors & Omissions	2,601
Liability	1,178
Vehicle Insurance	3,115
Total INSURANCE EXPENSE	11,088
LITIGATION EXPENSE	
Legal - Lawsuit	15,000
Legal - DFC Appeal	-
Engineering Consultant Services	-

	2020 Amended Adopted Budget
Total LITIGATION EXPENSE	15,000
MANAGER	
Travel/Edu/Training	3,000
Vehicle Allowance	6,000
Total MANAGER	9,000
MEMBERSHIPS DUES/SUBSCRIPTIONS	4,500
MISCELLANEOUS	1,500
OFFICE	
Office Equipment	6,000
Supplies	3,500
Total OFFICE EXPENSES	9,500
PAYROLL EXPENSES (Employee)	
Salaries	475,000
Medical/Life	52,000
Payroll Tax Liability	35,000
Unemployment Tax	1,400
Retirement	29,000
Payroll Service Fees	1,000
Tuition Assistance	-
Temporary	-
Workman's Comp	1,884
Payroll Expenses-Other	-
Total PAYROLL EXPENSES	595,284
POSTAGE EXPENSE	
Postage Meter and Supplies	2,000
Postage/Shipping/Delivery Service	5,000
Total POSTAGE EXPENSE	7,000
PRINTING (Non-PR...Envelopes...)	4,500
PROGRAMS	
Additional Scientific Programs	25,000
Hydrogeological Modeling/Protection	1,000
Subsidence Study - Phase I	60,000
Subsidence Study - Phase II	50,000
The Woodlands CORS-Interlocal Agreement	5,000
USGS JOINT FUNDING AGREEMENT	
USGS - Technical Assistance	
USGS - Groundwater Level Data	15,350
USGS - Water Level change/subsidence	154,800
USGS - Water Quality Recon/Catahoula	-
Total PROGRAMS	311,150
REBATE WATER USE FEES	30,000
RESERVE FUNDS - Expense	-
TRAVEL/TRAINING STAFF	3,000
Total Expense	$ 2,089,847

	2020 Amended Adopted Budget
Other	
DEPRECIATION	50,000
NET INCOME	**$ 107,307**

LONE STAR GROUNDWATER CONSERVATION DISTRICT

Resolution No. 20-005

A RESOLUTION OF THE BOARD OF DIRECTORS OF THE LONE STAR GROUNDWATER CONSERVATION DISTRICT ADOPTING AN OPERATING AND CAPITAL OUTLAY BUDGET FOR 2021

WHEREAS, the Lone Star Groundwater Conservation District (the "District") was created by the Legislature of the State of Texas by the Act of May 17, 2001, 77th Leg., R.S., ch. 1321, 2001 Tex. Gen. Laws 3246, as amended (the "Enabling Act"), as a groundwater conservation district operating under Chapter 36, Texas Water Code, and the Enabling Act; and

WHEREAS, the District's Board of Directors and staff has worked diligently to identify all reasonably anticipated District revenues, expenses, and activities for the January 1 through December 31, 2021 budget cycle, and, after giving much consideration to these important factors, has developed a proposed 2021 budget for the Board's consideration and deliberation (the "2021FY Budget");

WHEREAS, the District Board of Directors (the "Board") has reviewed and considered the 2021 Operating and Capital Budget;

WHEREAS, pursuant to Section 36.154 of the Texas Water Code, the District has prepared a budget that contains a complete financial statement, including a statement of the outstanding obligations of the District, the amount of cash on hand to the credit of each fund of the District, the amount of money received by the District from all sources during the previous year, the amount of money available to the District from all sources during the ensuing year, the amount of the balances expected at the end of the year in which the budget is being prepared, the estimated amount of revenues and balances available to cover the proposal budget, and the estimated fee revenues that will be required;

WHEREAS, the Board finds that the adoption of the 2021 Budget, attached hereto as Attachment A and incorporated herein by this reference for all purposes, is merited to support the District's activities and related expenses from January 1, 2021 through December 31, 2021 and that the attached budget will allow the District to carry out the District's objectives and responsibilities as prescribed by the Enabling Act and Chapter 36 of the Texas Water Code.

NOW, THEREFORE, BE IT RESOLVED BY THE BOARD OF DIRECTORS OF THE LONE STAR GROUNDWATER CONSERVATION DISTRICT THAT:

1. The above recitals are true and correct.

2. The Board of Directors of the Lone Star Groundwater Conservation District hereby adopts an operating and capital outlay budget for January 1, 2021 to December 31,

2021 as provided in the budget appended hereto as "Attachment A," which is incorporated herein by this reference and is hereby approved and adopted.

3. The Board of Directors, its officers, and the District employees are further authorized to take any and all actions necessary to implement this resolution.

AND IT IS SO ORDERED.

PASSED AND ADOPTED on this 11th day of August 2020.

LONE STAR GROUNDWATER CONSERVATION DISTRICT

By: ______________________

Stuart Traylor, Vice-President

ATTEST:

____

Larry A Rogers, Board Secretary

LONE STAR GROUNDWATER CONSERVATION DISTRICT
MONTGOMERY COUNTY, TEXAS

	2021 Adopted Budget
INCOME	
ADMINISTRATIVE FEES	
Application Fees	
AWS Production Permit	$ 3,000
AWS Groundwater Test Wells	1,500
Transfer of Early Conversion Credits	
Existing Well Application	1,500
Emergency Permit	
Operating Permit	22,000
Transfer of Permitted Authorization	1,500
GRP Amendment Application	
Application Fee- Other	4,950
Total Application Fees	34,450
Change in Ownership	4,000
Open Records Request	1,500
Publications Fees	5,000
Returned Check Fee / Other Admin fees	50
Well Re-inspection Fee	2,000
Total ADMINISTRATIVE FEES	47,000
INTEREST INCOME	5,000
LONE STAR GCD WATER USE FEES	
Early Conversion Credit Water Use Fee	44,060
Export Water Use Fee	600
Historical Use	1,157,000
Ag Permits	1,616
Operating Permit - 2020	814,000
AWS Production Fees -2020	167,378
Over Pumpage Fee	5,500
Penalty/Interest	5,000
Total LSGCD WATER USE FEES	2,195,154
Total Income	$ 2,247,154
EXPENSE	
ADVERTISING/PUBLIC NOTICES	$ 10,000
ATTORNEY FEES	
General Counsel Work	360,000
Additional Legal Work	12,000
Total ATTORNEY FEES	372,000
AUDIT FEES	8,750
BOARD EXPENSE	
Per Diem	53,000
Payroll Tax Liability	4,820
Board Meeting Expense	4,000
Meeting/Conference	2,000
Total BOARD EXPENSE	63,820

	2021 Adopted Budget
BUILDING EXPENSE	
Building Maintenance	20,000
Utilities/Custodial/Phone/Cable	47,000
Upgrade phone service	-
Upgrade sound and recording system-board room	-
Total BUILDING EXPENSE	67,000
COMPUTER SUPPORT	
Hosting/Internet/Backup	15,000
Software	5,000
Computer Repair & Support	15,500
Total COMPUTER SUPPORT	35,500
EDUCATION/PUBLIC AWARENESS COORDINATION	
Educational Curriculum in Schools	50,000
ET Weather Station Network/PAM Unit	15,000
Communication/Public Awareness	8,500
Water Efficiency Network	750
Website Modification	2,500
Rainwater Collection Maintenance	750
Conservation products	3,500
Total EDUCATION/PUBLIC AWARENESS CORRDINATION	81,000
ELECTION EXPENSE	100,000
ENGINEERING CONSULTANT SERVICES	
District Engineer	5,000
Engineering Consultant Services	200,000
Well Permitting Database Management	5,000
GMA 14 Planning	100,000
Total ENG/CONSULTANT SERVICES	310,000
FIELD/TECHNICAL EXPENSE	
Field Supplies	3,000
Fuel Expense	3,000
Vechicle-capital expense	5,000
Vehicle/Mobile Lab Repair and Maintenance	2,500
Total FIELD/TECH EXPENSE	13,500
INSURANCE EXPENSE	
Bonds	438
Building Insurance	3,756
Errors & Omissions	2,601
Liability	1,178
Vehicle Insurance	3,115
Total INSURANCE EXPENSE	11,088
LITIGATION EXPENSE	
Legal - Lawsuit	-
Legal - DFC Appeal	50,000
Engineering Consultant Services	-

	2021 Adopted Budget
Total LITIGATION EXPENSE	50,000
MANAGER	
Travel/Edu/Training	6,000
Vehicle Allowance	7,200
Total MANAGER	13,200
MEMBERSHIPS DUES/SUBSCRIPTIONS	4,500
MISCELLANEOUS	1,500
OFFICE	
Office Equipment	6,000
Supplies	3,500
Total OFFICE EXPENSES	9,500
PAYROLL EXPENSES (Employee)	
Salaries	525,000
Medical/Life	52,000
Payroll Tax Liability	35,000
Unemployment Tax	1,400
Retirement	29,000
Payroll Service Fees	1,000
Tuition Assistance	
Temporary	
Workman's Comp	1,884
Payroll Expenses-Other	
Total PAYROLL EXPENSES	645,284
POSTAGE EXPENSE	
Postage Meter and Supplies	2,000
Postage/Shipping/Delivery Service	5,500
Total POSTAGE EXPENSE	7,500
PRINTING (Non-PR...Envelopes...)	7,000
PROGRAMS	
Additional Scientific Programs	25,000
Hydrogeological Modeling/Protection	1,000
Subsidence Study - Phase I	-
Subsidence Study - Phase II	125,000
The Woodlands CORS-Interlocal Agreement	
USGS JOINT FUNDING AGREEMENT	
USGS - Technical Assistance	
USGS - Groundwater Level Data	15,350
USGS - Water Level change/subsidence	154,800
USGS - Water Quality Recon/Catahoula	
Total PROGRAMS	321,150
REBATE WATER USE FEES	30,000
RESERVE FUNDS - Expense	
TRAVEL/TRAINING STAFF	3,000
Total Expense	**$ 2,165,292**

	2021 Adopted Budget
Other	
DEPRECIATION	50,000
NET INCOME	**$ 31,862**

RESOLUTION NO. #20-006

LONE STAR GROUNDWATER CONSERVATION DISTRICT

RESOLUTION ADOPTING 2021 WATER USE FEES FOR THE LONE STAR GROUNDWATER CONSERVATION DISTRICT PURSUANT TO THE RULES OF THE LONE STAR GROUNDWATER CONSERVATION DISTRICT

THE STATE OF TEXAS §

COUNTY OF MONTGOMERY §

WHEREAS, the Lone Star Groundwater Conservation District ("District") was created by the Legislature of the State of Texas in Acts 2001, 77th Leg., R.S., ch. 1321, p. 3246, § 1(a), as amended (the "Enabling Act"), as a groundwater conservation district operating under Chapter 36, Texas Water Code, and the Enabling Act; and

WHEREAS, pursuant to said Act, § 5(a), the District Board of Directors of the District (the "Board") has the permitting and general management powers granted under Chapter 36 of the Texas Water Code;

WHEREAS, § 36.101 of the Texas Water Code authorizes a groundwater conservation district to make and enforce rules to provide for conserving, preserving, protecting, and recharging of the groundwater or of a groundwater reservoir or its subdivisions in order to control subsidence or prevent waste of groundwater and to carry out the powers and duties provided by Chapter 36 of the Texas Water Code;

WHEREAS, §§ 36.205 and 36.122 of the Texas Water Code and the Act authorize the District to assess fees on the production of groundwater within its jurisdiction and for the transfer of such water for use outside of the District;

WHEREAS, the assessment of such fees serves a legitimate regulatory purpose;

WHEREAS, the rules of the District authorize the Board of Directors of the District to establish by resolution a regulatory water use fee to accomplish the purposes of the District;

WHEREAS, the rules of the District authorize the Board of Directors of the District to establish by resolution a groundwater transport fee for the transportation of groundwater out of the District;

WHEREAS, the District staff have worked diligently to forecast all reasonably anticipated revenues, expenses, and activities; and after giving much consideration to these important factors, the Board of Directors recommends a regulatory water use fee of $0.085 per 1,000 gallons for all groundwater permitted in the Chicot, Evangeline and Jasper Aquifers, other than agricultural use for the calendar year 2021;

NOW, THEREFORE, BE IT RESOLVED BY THE BOARD OF DIRECTORS OF THE LONE STAR GROUNDWATER CONSERVATION DISTRICT AS FOLLOWS:

1. The following fees are hereby adopted as the regulatory water use fees of the District for calendar year 2021.

   - A regulatory water use fee of $1 per acre-foot of groundwater permitted in any aquifer for "agricultural use" as that term is defined by § 36.001(20), TEX. WATER CODE ANN. (Vernon Supp. 2004);

   - a regulatory water use fee of $0.085 per 1,000 gallons for all uses, other than "agricultural use", of groundwater permitted in the Chicot, Evangeline and Jasper Aquifers; and

   - a regulatory water use fee of $0.06 per 1,000 gallons for all uses, other than "agricultural use", of groundwater permitted in the Catahoula Aquifer,

2. Notwithstanding subsection(1), in the event that the application of these adopted rates results in a total annual regulatory water use fee payment of less than ($10.00) for an individual permit issued by the District, the regulatory water use fee payment to be assessed to such a permit shall be the Minimum Regulatory Water Use Fee, which is hereby established as ($10.00) and so adopted.

3. The District shall impose a 50 percent export surcharge in addition to the District's regulatory water use fee for in-District use for transportation of groundwater for use outside of the District, subject to the Act and District Rules. Such fees set forth above shall be assessed as set forth in the Rules of the District for the time period of January 1, 2021, through December 31, 2021;

4. The regulatory water use and groundwater transport fees so adopted shall be effective January 1, 2021, and continue in effect until modified by the Board of Directors;

5. The regulatory water use and groundwater transport fees so adopted shall supersede any and all such fees previously adopted by Resolution or other action of the Board of Directors; and

6. The General Manager is further authorized to take any and all reasonable action necessary for the implementation of this resolution.

AND IT IS SO ORDERED.

PASSED AND ADOPTED this 11th day of August 2020.

LONE STAR GROUNDWATER CONSERVATION DISTRICT

By: ______________________

Stuart Traylor, Vice-President

ATTEST:

____

Larry A. Rogers, Board Secretary

LONE STAR GROUNDWATER CONSERVATION DISTRICT
T E X A S
MONTGOMERY COUNTY, TEXAS

Exhibit "G"

SUBSIDENCE INVESTIGATIONS – PHASE 1
ASSESSMENT OF PAST AND CURRENT INVESTIGATIONS

Prepared for:

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GEOSCIENTIST'S SEAL

This report was prepared by THORNHILL GROUP, INC., and LRE Water, licensed professional geoscientist firms in the State of Texas.

Mr. Thornhill was the Project Manager for this work. He was responsible for developing the overall conclusions for the Phase 1 work and for the final review and acceptance of this report. Mr. Thornhill also had primary responsibility for Sections 3.0, 5.0, and 6.0.

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SUBSIDENCE INVESTIGATIONS – PHASE 1
ASSESSMENT OF PAST AND CURRENT INVESTIGATIONS

1.0 INTRODUCTION

Numerous studies have been conducted and reports written over the last 50 years addressing land-surface subsidence and growth-fault movement in what has been historically called the “Houston-Galveston region of Texas” which, as associated with subsidence studies, has consistently included all of Harris County and “parts of” Brazoria, Chambers, Fort Bend, Galveston, Liberty, Montgomery and Waller counties. With rapid population growth and expansion outward from central Harris County, water demand and pumping distributions have changed relatively rapidly. Historically, Lone Star Groundwater Conservation District (LSGCD) has cooperated and participated with the United States Geological Survey (USGS), Harris-Galveston Subsidence District (HGSD) and Fort Bend Subsidence District (FBSD) in installing new global positioning system (GPS) monitoring sites, supporting programs to monitor aquifer water levels, and modeling efforts that include subsidence simulations. However, LSGCD had not conducted its own independent investigations to study subsidence. Therefore, LSGCD approved this Phase 1 scope of work for the subsidence study. This report provides a summary of the work conducted and descriptions of the data and information compiled.

1.1 Background

Subsidence has been a concern in the Gulf Coast Region for almost a century, particularly in the coastal areas and large portions of Harris and Galveston counties where relatively large amounts of land surface elevation changes have been documented and correlated to artesian pressure changes in the Chicot and Evangeline aquifers. Additionally, intensive historical pumping in Harris County for municipal water use and large irrigation pumping operations in the “Katy Area” (that is, Harris, Waller and Fort Bend counties) caused notable subsidence in neighboring counties, including the southern part of Montgomery County. As population has grown outward from Houston and subsidence district regulatory programs have been implemented, the distribution of pumping has changed and so has the reported occurrence of subsidence. Current Texas Water Development Board (TWDB) approved modeling results indicate that, while subsidence has been arrested in the areas where the most severe compaction occurred, some areas of Harris, Fort Bend, Montgomery, Waller, Austin and some neighboring counties will experience additional subsidence through 2070, even with previous LSGCD and current subsidence district regulatory programs in place. Therefore, the potential occurrence, extent and ramifications of subsidence are of significant interest to many stakeholders in Groundwater Management Area 14 (GMA 14) and LSGCD. As LSGCD has expressed its intent to fulfill the statutory mandate to “control subsidence,” and has recognized that effects of production respond across a “common reservoir” and are not restricted to county boundaries, the Phase 1 work is useful to LSGCD and other groundwater conservation districts (GCDs) in the Joint Planning efforts of GMA 14.

1.2 Purpose and Goals

The purposes of the LSGCD subsidence study generally are to:

- Address subsidence from Montgomery County's perspective;
- Investigate and evaluate specific concerns and claims including possible causes and distributions of historical and future subsidence in Montgomery County and neighboring counties, and the occurrence and potential causes of activation or movement of local growth faults;
- Develop a basis for understanding potential short-term and long-term impacts and ramifications associated with subsidence and the cost-benefit of pumping groundwater; and,
- Prepare for proper subsidence (and other) considerations regarding joint-planning processes with other districts and stakeholders in GMA 14.

The primary goals of Phase 1 are:

- Developing a working understanding of historical information and reporting, including modeling with the TWDB-approved Houston Area Groundwater Model (HAGM) to ensure that subsidence is properly considered by GMA 14 in deriving desired future conditions (DFCs) for the various common reservoirs;
- Estimating the amount and distribution of subsidence within the LSGCD boundaries from pre-development periods through 2000, immediately prior to the formation of the district;
- Correlating estimates of compaction and subsidence with spatial and temporal distributions of groundwater pumping and artesian pressure changes in each layer of the Gulf Coast Aquifer System – the Chicot, Evangeline, and Jasper aquifers; and,
- Predicting possible compaction with various projected future pumping distributions using the HAGM.

1.3 Work Conducted

Phase 1 of the LSGCD subsidence study was intended to comprehensively collect and compile information and data sets, to become better educated and develop a functional overview and "working knowledge" of subsidence information, to conduct preliminary modeling utilizing the approved groundwater availability model (GAM), known as the Houston Area Groundwater Model (HAGM), in order to be prepared for the on-going GMA 14 planning process, and to develop a detailed scope of services and costs for Phase 2 of the study. There are few conclusions in this report as Phase 1 was intended to develop a primer on subsidence information and a roadmap for moving forward with a more comprehensive study. Phase 2 will include detailed data processing and analysis, critiques and conclusions to fulfill the objectives and goals of the project. The work conducted for Phase 1 included:

Task 1.1 – Background Data Compilation and Workup – subsidence studies in the Houston area began as early as the 1940s, but detailed studies began in the mid-1970s and numerous reports of laboratory testing of core samples, monitoring results and additional studies have since been published. This task involved acquiring and compiling data from available previous studies and databases including the TWDB, USGS, HGSD, FBSD, LSGCD, University of Texas Bureau of Economic Geology (BEG), University of Houston (UH), Rice University (Rice), Texas A&M University (TAMU), other institutions, consultant reports, peer-reviewed journals and in-house libraries and files. Work products for Task 1.1 include:

- Datasets in *ArcGIS™* formats that can be utilized for sorting and analyzing data and for creating subsequent work products. Datasets include historical water level monitoring, subsidence monitoring, and groundwater pumping; and,
- Maps, cross sections, tabulations, charts, hydrographs and diagrams to illustrate the data and information, to describe the local hydrogeological and hydraulic conditions. Task 1 work provided the basis for subsequent tasks.

Task 1.2 – Synopsis of Past Studies and Information – the consultant team compiled a comprehensive digital library of subsidence studies and has provided herein key information from selected reports, including recently released reports specific to subsidence and growth fault concerns in Montgomery County (see References). Pertinent illustrations from previous reports have been incorporated into reporting for Phase 1, and some original maps and illustrations created from the acquired datasets, including illustrating through geologic maps and cross sections variations across LSGCD and the Houston area regarding depths, structure, sand thickness, aquifer productivity, clay layers, artesian pressures and other properties associated with compaction and subsidence. This task also included building and evaluating datasets and developing illustrations regarding sequential mapping in order to illustrate historical spatial and temporal distributions of groundwater pumping and artesian pressure changes in all layers of the Gulf Coast Aquifer System, and to correlate pumping and pressure changes to compaction in the various layers and cumulative subsidence.

Task 1.3 – HAGM Modeling – this task included utilizing the current TWDB-approved GAM known as the HAGM to assess the model predictions with respect to reported historical conditions and projected future conditions. Specifically, this task included estimating subsidence amounts and distributions in Montgomery County for time periods prior to the formation of LSGCD (and/or prior to land-surface elevation monitoring at Port-A-Measure (PAM) sites, etc.). Modeling efforts allowed for estimating total current compaction and corresponding subsidence in each layer of the Gulf Coast Aquifer System, and projecting future compaction in each layer and corresponding total subsidence based on various distributions of groundwater pumping.

Task 1.4 – Overview of Regulatory and Management Frameworks – this task included reviewing Chapter 36 of the Texas Water Code (TWC), the LSGCD's Management Plan, subsidence districts' regulatory plans, and historical and projected pumping schedules for Harris, Fort Bend and Galveston counties based on information presented by the subsidence districts. Historical reports by the USGS and TWDB show that groundwater owners in Harris and Fort Bend counties have in the past pumped more groundwater than other counties within GMA 14. Additionally, data show that large portions of artesian pressure declines and subsidence in counties neighboring Harris and Fort Bend counties were caused by pumping within the subsidence districts. Regulatory plans in subsidence districts have led to overall reductions in groundwater use and significant changes in the areal distributions of pumping. Predicting future pumping, artesian pressure changes, and land-surface subsidence depends on understanding the continued implementation of regulatory plans.

Task 1.5 – Meetings with Cooperators and Stakeholders – due to COVID-19, all meetings were postponed. The LSGCD General Manager, Samantha Reiter, is in the process of scheduling one (1) meeting with potential cooperators, stakeholders and the public. The meeting will include a presentation of Phase 1 work and discussions of the scope of services prepared for Phase 2 work.

Task 1.6 – Develop Scope of Work and Costs for Subsequent Phases – this task included developing a detailed scope of services, associated specific costs, and timeline with benchmarks for deliverables for each task of Phase 2 of the subsidence study.

Task 1.7 – Summary Report and Presentation to Board – this task included providing a presentation to the board prior to the final Phase 1 report being written. This task also included preparing a written report with illustrations and supporting documentation.

2.0 HYDROGEOLOGY AND SUBSIDENCE

The TWDB delineates the Gulf Coast Aquifer System (GCAS) as a band of relatively young geologic formations that parallel the Gulf of Mexico coastline from the southern Texas border with Mexico to the east Texas border with Louisiana (George and others, 2011). For groundwater production, the sand units of the GCAS are the targets for well completion. For subsidence considerations, the thickness and type of clay present within the aquifers is of interest because as wells draw water from the sand units the water in the clays may leak into the sand units causing the clays to compact. The following provides a brief description of the hydrogeologic conditions with an emphasis on the conditions that may affect land surface subsidence.

2.1 Hydrostratigraphy

The hydrostratigraphy of the aquifer refers to the subsurface delineations of the geology where groundwater primarily flows. The hydrostratigraphic units of an aquifer may not be the same as the lithostratigraphic units which are delineated by the type of rock or sediment that make up the geologic units. In this section we will focus on the hydrostratigraphy of the GCAS and how the lithology correlates to the hydrostratigraphic units.

2.1.1 Lithology

Commonly, the hydrostratigraphic units which make up the GCAS in and around Montgomery County are, from shallowest to deepest, the Chicot Aquifer, the Evangeline Aquifer, the Burkeville confining unit, and the Jasper Aquifer (Young and others, 2012). Underlying the Jasper, parts of the Catahoula Formation form the Catahoula Confining System (Young and others, 2012) though the sandstone units of the formation are important sources of groundwater to some users within the LSGCD (Seifert, Jr., 2015). Young and others (2012) subdivided the hydrostratigraphic units based on identifiable age markers in the geologic units that comprise the larger units. Table 1 summarizes the local hydrostratigraphic and geologic units within Montgomery County.

The lithologic characteristics of the geologic units are controlled by the depositional system for each unit. The Fleming Group comprises the basal geologic units of the GCAS and is characterized as a fluvial-deltaic depositional system. The lowermost Oakville Formation is generally sand-rich while the overlying Lagarto typically contains more clay (Young and others, 2012). Following the classification of Young and others (2012), the Lower Lagarto and the Oakville form the Jasper Aquifer, while the Middle Lagarto correlates to the Burkeville and can be identified as having a lower sand content than either the upper or lower sections of the formation.

The Goliad Formation along with the Upper Lagarto form the Evangeline Aquifer. The top of the dominant clays of the Middle Lagarto formation mark the base of the Evangeline. The Goliad Formation is a massive fluvial sandstone in the Montgomery County area (Young and others, 2012). Generally, the sandstones in the Lower Goliad are thicker and more conglomeritic than the sandstones of the Upper Goliad (Hoel, 1982; Morton and others, 1988; Young and others, 2012).

Formations above the Goliad comprise the Chicot Aquifer. Recent alluvial deposits are considered separate from the Chicot, though for practical purposes the shallow alluvial deposits may be considered part of the Chicot aquifer as they would typically be hydraulically connected to the older formations. In the study area, the Willis Formation was deposited in a nonmarine, fluvial depositional system and is typically characterized as having gravelly coarse sands. Glacial-interglacial cycles influenced the deposition of the Lissie Formation resulting in fine-grained sand and sandy clay layers. The uppermost Beaumont Formation is clay-rich with sandy fluvial and deltaic-distributary channels.

2.1.2 Aquifer and Clay Thickness

The geologic units of the GCAS dip toward the Gulf of Mexico. As the units dip, they typically also become thicker creating a wedge shape. The total thickness of the aquifer is more than 4,000 feet in southern Montgomery County (Young and others, 2012). However, 95 percent of registered wells have a depth of 520 feet or less and produce groundwater from the upper portions of the GCAS.

As previously mentioned, groundwater production wells will be completed in the sand units of the aquifers. As water is drawn from the sands, groundwater will move from the clay layers into the sands. In areas with higher clay thicknesses the potential for subsidence is higher than for areas with thinner clays. The following provides a brief description of the sand and clay thicknesses of the formations that make up the GCAS within Montgomery County.

The Beaumont Formation does not extend into Montgomery County (see Figure 1). However, the Lissie and Willis formations of the Chicot Aquifer are present. The Lissie and Willis formations are both up to 500 feet thick within Montgomery County and each averages about 250 feet thick. Typically, the units are about 60 percent sand. Within Montgomery County, the clay thickness of the Lissie and Willis formations is greatest in the southeast. The estimated clay thickness of the Lissie Formation is 250 feet near Porter, TX (see Figure 2) and the estimated clay thickness of the Willis Formation is about 250 feet near The Woodlands, TX (see Figure 3). In geologic terms, these formations are relatively young with the Lissie Formation being less than 1.8 million years and the Willis Formation forming during the Pliocene Epoch and being less than 5.3 million years.

For the Evangeline Aquifer, the Upper Goliad is generally not present within Montgomery County, but the Lower Goliad and the Upper Lagarto are present within most of the county (see Figure 4). The Lower Goliad is reportedly more the 1,000 feet thick within the county and the Upper Lagarto exceeds 700 feet thick. Both units are primarily sand, but Young and others (2012) report the Upper Lagarto has a higher sand content than the Lower Goliad. However, there are some areas with very high clay thicknesses within the Lower Goliad. For example, clay thickness of up to 500 feet is found near Porter, TX in the Lower Goliad (Figure 5). In the Upper Lagarto, the clay thickness is generally greatest in a band extending from Magnolia, TX through Conroe, TX where the clay thickness is greater than 150 feet (see Figure 6). Similar to the formations that comprise the Chicot Aquifer, the clays within the formations that comprise the Evangeline are relatively young at less than 16 million years.

The Middle Lagarto (equivalent to the Burkeville) averages about 450 feet thick in Montgomery County with a maximum thickness of nearly 800 feet. While the Middle Lagarto is generally considered to be clay rich, sand percentage estimates from Young and others (2012) indicate the sand content is comparable to the other formations making up the GCAS. While the datasets show a relatively high sand content, the size of the sand grains may be small compared to other formations of the GCAS, making it less capable of providing water to wells. The dataset from Young and others (2012) for the Middle Lagarto indicates some uncertainty in the clay thickness along a northeast trending band through Montgomery, TX. In the area updip (northwest) of the band, the clay thickness gradually increases to about 300 feet and then abruptly decreases to 200 feet or less through much of the rest of the county (see Figure 7). The uncertainty is likely associated with Young and others (2012) combining two or more datasets. The clay thickness contours to the southeast of the band are likely representative of the clay thickness in the Middle Lagarto as the estimates are based on analysis of geophysical logs in the area.

The Lower Lagarto and Oakville formations that comprise the Jasper Aquifer are found throughout nearly all of Montgomery County. These formations exceed 500 feet and 700 feet, respectively. The maximum sand percentage for these formations is slightly less than the maximum values for the other formations that comprise the GCAS. Clay thickness within the Lower Lagarto is generally more than 150 feet throughout most of the county with the clay thickness exceeding 350 feet northwest of Porter, TX (see Figure 8). The clay thickness of the Oakville Formation is typically more than the Lower Lagarto. In much of the county, the clay thickness of the Oakville exceeds 250 feet with a maximum thickness of more than 500 feet found in an area southeast of Conroe, TX (see Figure 9). The formations that make up the Jasper are the oldest of the GCAS.

2.2 Structure

As mentioned above, the formations of the GCAS dip and thicken toward the Gulf of Mexico creating a wedge-shaped aquifer. The top of the GCAS is at land surface throughout the District. However, due to the formations dipping at a rate of about 65 feet per mile, in most of Montgomery County the top of the units that make up the Evangeline and Jasper hydrostratigraphic units is encountered below land surface.

To illustrate the structure of the local geologic and hydrostratigraphic units, we prepared five cross-sections through Montgomery County (see Figure 10). Three of the cross-sections are along the dip of the geologic units and are essentially perpendicular to the Gulf Coast (see Figure 11, Figure 12 and Figure 13). Two cross-sections illustrate the configuration of the units along their strike and are essentially parallel to the coastline (see Figure 14 and Figure 15). Structural cross-sections are from the files developed by Young and others (2012). The total dissolved solids (TDS) isolines are from data sets developed by Young and others (2016).

The three cross-sections along the dip of the aquifer (see Figure 11, Figure 12 and Figure 13) illustrate how the rate of dip is relatively consistent across the District. However, the dip and structure south of Montgomery County does not appear to reflect the shallow salt dome mapped along cross-section B-B’ (see Figure 12; Figure 16). In addition, the cross-sections do not appear to reflect the major growth faults mapped in Montgomery County (see Figure 17). Nonetheless, the datasets presented do adequately reflect the complexity of the structure of the GCAS along with the estimated sand and clay thicknesses as they relate to potential subsidence.

2.3 General Subsidence Processes

As discussed by Furnans and others (2018), there are three primary variables that determine the magnitude, location, and timing of subsidence related to groundwater pumping, namely:

- The distribution, thickness, and compressibility of clay layers;
- The amount and timing of water-level changes; and,
- The lowest historical water level (that is, long-term water level declines).

Compaction of the aquifer materials, and associated land surface subsidence, occurs when there is an increase in the effective stress on the geologic formations. Terzaghi (1925) developed a relationship that allows for the calculation of the changes in effective stress within the aquifer given the changes in water level. According to Terzaghi's relation, the effective stress within an aquifer may be simplified into two components, namely, geostatic stress and hydrostatic stress (Leake and Galloway, 2007):

$$\sigma' = \sigma - u$$

where

$\sigma' = effective\ stress\ (psi)$
$\sigma = geostatic\ stress\ (psi)$
$u = hydrostatic\ stress\ (psi)$

The geostatic stress is relatively constant being related to the depth of burial, depth to moist sediments, and sediment characteristics. The hydrostatic stress changes easily and as water levels decline, the hydrostatic stress decreases which causes the effective stress to increase. As the effective stress increases the geologic units compress causing a decrease in the ratio of the open space in the formation to the solids making up the formation (that is, the void ratio) based on the compression and recompression indices of the units which are directly related to the elastic and inelastic storage coefficients for the aquifer units (Leake and Galloway, 2007). These aquifer properties control the amount of elastic and inelastic compaction that occurs with inelastic compaction due to water level declines being permanent and of much greater magnitude than elastic compaction or expansion.

The void ratio within clay sediments is generally much higher than in sand sediments and may exceed 50 percent. In addition, clay minerals typically have a flat, plate-like structure while sands tend to be rounded and more irregular. When deposited, the orientation of the clay minerals is random, but as the effective stress increases the clay mineral grains reorient perpendicular to the direction of the effective stress. Figure 18 illustrates how this reorientation of the minerals is manifested in compaction of the aquifer and land surface subsidence.

In Houston and the surrounding area, there are currently more than 200 subsidence monitoring locations. Most of these locations use GPS receivers to monitor the movement of land surface though there are a handful of extensometers that are able to directly measure compaction of specific aquifer intervals. Figure 19 illustrates the location of several sites maintained by UH and the HGSD with a land surface subsidence monitoring history of more than five years (HGSD, 2020) along with contours of the total subsidence from 1906 to 2017 as reported by the HGSD. As Figure 19 illustrates, the highest rates and amounts of subsidence are south of Montgomery County. Based on the available measurements, the rate of subsidence is one-half inch per year or less throughout LSGCD and is typically less than one-quarter inch per year.

3.0 EXISTING STUDIES AND DATA

Most historical subsidence studies for the "Houston-Galveston region" include all of Harris County and parts of Brazoria, Chambers, Fort Bend, Galveston, Liberty, Montgomery, and Waller counties. Subsidence has been recognized in the Houston-Galveston region of Texas for almost 100 years. One of the earliest reported occurrences of land-surface sinking is the 1926 relatively localized subsidence associated with the Goose Creek oil field.

Historical subsidence across the region is primarily associated with groundwater withdrawals from the Chicot and Evangeline aquifers in Harris County, with the earliest studies linking groundwater pumping to subsidence conducted in the 1940s and 1950s (Winslow and Doyel, 1954; Winslow and Wood, 1959; Gabrysch, 1967). There have been numerous subsidence studies conducted for the region, with some of the defining studies conducted in the 1970s and 1980s. Also, critical monitoring programs and continuations of previous studies are on-going. Additionally, new and expanded studies have begun or are being planned to add to the understanding of subsidence in the region.

3.1 Types of Studies and Data Available

This study focuses on a review of previous studies beginning in the 1970s that formed the critical background understanding of subsidence in the region and formed the basis for current and on-going monitoring programs performed by the USGS and HGSD. The following provides a general synopsis of the types of studies available, data and information collected and compiled, and overviews of key findings from previous work. Brief detailed summaries for selected reference studies are included in Section 3.2.

3.1.1 Topography and Re-Leveling

The USGS has used topographic maps (with one-foot contour intervals) from 1915 through 1917 leveling efforts as a basis to estimate land-surface subsidence in the Houston area during the last 100 years (Kasmarek and others, 2009). Initially, all land-surface subsurface subsidence determinations in the region were made by geodetic differential leveling. A detailed discussion of the history and methodologies of control leveling is beyond the scope of this study.

The U.S. Department of Commerce National Oceanic and Atmospheric Administration (NOAA) discusses the history, instrumentation and methods in its document titled ***Control Leveling*** (Whalen, 1978). Measuring land-surface changes via leveling involves comparing surveyed elevations of official benchmarks at determined locations at specific times. Elevations are determined and obtained by conventional, but precise, leveling methods. The USGS reports, "Most of the determinations were made by the National Geodetic Survey and their predecessor agency, the U.S. Coast and Geodetic Survey. Elevations determined by private and public entities other than the National Geodetic Survey (City of Houston; Texas Department of Highways and Public Transportation; U.S. Army Corps of Engineers; and others) also have been used" (Gabrysch, 1980).

Reportedly, there are up to 2,500 benchmarks in the leveling network, with some sites dating back to 1906 (Ratzlaff, 1982). Figure 20 shows locations of benchmarks and subsidence determined by leveling from 1906 to 1973, showing maximum subsidence in southeastern Montgomery County of one foot. Due to the regional nature of subsidence most of the benchmarks have moved. Therefore, re-leveling efforts were required (for example, 1978 and 1987) to maintain consistency in reported subsidence values. Each leveling effort is labor intensive and relatively expensive.

As other technologies have become available and accessible, land-surface elevation determinations from new methods can be correlated to the most recent leveling efforts. For example, data from remote sensing methods such as Light Detection and Radar (LiDAR) and Interferometric Synthetic Aperture Radar (InSAR) can be obtained and processed to more cost-effectively compare land-surface movement over time and over larger areas, allowing for determinations of subsidence and fault movement. As an example, the USGS estimated long-term subsidence by subtracting land-surface elevations determined from 2001 LiDAR imagery from the 1915-1917 topographic maps, and showed maximum subsidence between 1915/1917 and 2001 of slightly less than three (3) feet in southeastern Montgomery County (Kasmarek and others, 2009). Because leveling formed the initial basis of subsidence measurements and determinations, Phase 2 of the LSGCD subsidence study will include reviewing and understanding the evolution and accuracy of historical land-elevation measurements, particularly in Montgomery County.

3.1.2 Hydrogeology and Geotechnical

Subsidence and surficial expressions of hundreds of identified growth faults resulted in numerous studies beginning in the 1970s and 1980s, with most of the earlier studies focused in areas of greatest subsidence. In fact, the connections and relationships between land-surface subsidence, surficial movement along growth fault planes, and salt domes has been debated.

Subsidence

As discussed in Section 2.3, the three primary variables that determine the magnitude, location, and timing of subsidence related to groundwater pumping are: 1) the distribution, thickness and compressibility of clay layers; 2) the amount and timing of water-level changes (which are governed by pumping); and, 3) the lowest historical (long-term) water level (Furnans and others, 2018). The USGS and TWDB published between 1974 and 1976 several initial and defining reports pertaining to Houston-area subsidence based on field geologic and geotechnical studies at sites within areas that had experienced the most subsidence, including:

- The area of Burnett, Scott, and Crystal Bays near Baytown, Texas (Gabrysch and Bonnet, 1974);
- At Seabrook, Texas (Gabrysch and Bonnet, 1976); and,
- The area of Moses Lake near Texas City, Texas (Gabrysch and Bonnet, 1976).

The three studies listed above included the following: drilling and obtaining core samples of clays from test holes; geophysical logging to determine sand and clay thicknesses; obtaining laboratory analyses of geologic and geotechnical parameters including mineralogy, specific gravity, plasticity, porosity, consolidation coefficient, and compressibility with depth (or loading); understanding of the local and regional distribution of pumping in the Chicot and Evangeline aquifers; and, compiling water-level measurements to derive artesian pressure declines in each aquifer. Deepest clay samples at the Baytown site were collected from a depth of 1,216 feet which is within the approximate upper one-third of the Evangeline aquifer. For the Baytown study, a clay core sample was collected from a UH site, approximately 19 miles to the west of the Baytown site, from a depth of 1,647 feet which is slightly deeper than the upper half of the Evangeline. The deepest clay sample collected at the Moses Lake site was collected from a depth of 700 feet, and all the clay samples for the site were obtained from the Chicot Aquifer (Gabrysch and Bonnet, 1976). The deepest clay sample for the Seabrook study was collected from a depth of 1,340 feet below land surface, which is within approximately the upper 40 percent of the Evangeline Aquifer. The USGS determined from the laboratory and field data ranges in a unit measure of compressibility, which they termed specific compaction (Gabrysch, 1967). In later reports based on the 1970s studies the USGS concluded, “Records of compaction at different depth intervals obtained from extensometers, subsidence based on elevation data, and laboratory testing show that most of the subsidence is due to compaction of shallow material. It is suspected that compressibility of the material is related both to the age of sediments and the depth of burial” (Gabrysch, 1984). The first extensometers were installed at each of the three study sites which allowed for correlation of past compaction and resulting subsidence to the geologic, geotechnical, pumping and water-level data collected. Additionally, the three original extensometers and those added layers allow for ongoing direct measurements of compaction in the targeted completion intervals. Results of the field studies and correlating extensometer readings to leveling results for total subsidence were used to develop hydraulic and geotechnical parameters for modeling efforts including Predictions Relating Effective Stress to Subsidence (PRESS) models in Harris, Galveston, and Fort Bend Counties, the initial GAM and HAGM.

The geologic setting and pumping distribution in Montgomery County is and will be different than that found downdip (that is, Harris County). As illustrated in Section 2.0, the total thicknesses and clay thicknesses in the Chicot and Evangeline layers are generally thinner in Montgomery County than in Harris County. The clay layers in the Upper Jasper are similar on both sides of the county boundary between Montgomery and Harris counties (Kasmarek and Robinson, 2004). INTERA utilized the results determined for Chicot and Evangeline clay layers in Harris County and made adjustments for depth to derive estimates for clay properties for the Jasper Aquifer (Kelley and others, 2018). Gabrysch noted that relative compressibility of clay layers is related to both the geologic age and depth of materials. Based on information presented by Young and others (2012) and the University of Houston (Yu and others, 2014), Table 2 summarizes the geologic age and depositional systems associated with the layers of the GCAS.

Phase 2 of this subsidence study will provide critical and detailed assessments of thickness and distributions of sand and clay layers and associated hydraulic parameters for the GCAS layers in Montgomery County, and particularly with respect to the Burkeville and Jasper units.

Growth Faults

The BEG reported in 1977 that there were at least 150 miles of active faults with topographic escarpments in Harris and Galveston counties (Kreitler, 1977). While the 1977 BEG study did not include Montgomery County, long southwest-to-northeast trending fault traces in northern Harris County almost certainly cross the county line. Fault traces are commonly recognizable as lineations on aerial photographs, although vegetation and land use changes can mask surficial fault expressions. Kreitler concluded that there is fault control of subsidence, although he did reference others who suggested that faulting and subsidence were unrelated (McClelland Engineers, 1966; Van Siclen, 1967). Kreitler also suggested that faulting may “compartmentalize” groundwater flow and the resulting subsidence.

The UH reports that more than 300 active faults intersect land surface in the Houston area (Engelkemeir and Khan, 2013), and used LiDAR to map faults. The UH notes, “Most (80%) of the faults in the Houston area occur over salt domes.” The UH study noted that the Hockley-Conroe Fault System extends “well outside of Harris County”. The UH concludes that fault locations do not closely correlate to subsidence depressions, but instead appear to be more closely related to regional and salt-dome tectonics (Engelkemeir and Khan, 2013).

I2M Associates, LLC (I2M) and SWS Environmental Services (SWS) reported on growth faulting and subsidence (Campbell and others, 2018), noting Ground-Penetrating Radar (GPR) as an effective technology to characterize faults below roadways. I2M and SWS note that LiDAR will also help identify faults, but that surface mapping is also required. I2M and SWS point out that faulting is common atop and near salt domes, and that Mullican III (1988) concluded that 70 percent of 30 salt domes he evaluated experienced subsidence, collapse or both due to natural or anthropogenic causes (Campbell and others, 2018). I2M and SWS state that "…the hypothesis that soft-sedimentation/growth faulting is related to subsidence and fluid withdrawal from the subsurface in some areas was once soundly discounted. The relationship of faulting to subsidence (or vice versa): and the mechanisms for the observed faulting are still being debated" (Campbell and others, 2018). They note that faulting is likely caused to varying degrees at different places by subsidence, movement of salt domes and the deeper Louann salt bed, and load-induced crustal warping at depth.

Southern Methodist University (SMU) reported the use of InSAR to identify and monitor growth faults (Qu and others, 2019). The SMU study focused on the Hockley-Conroe Fault System, identifying specifically the "…Hockley fault [sic] System, the Big Barn fault [sic] System and the Conroe Fault System" (Qu and others, 2019). The SMU report notes that salt domes are a major cause of local faulting and maps show at least three salt domes along the trend of the Hockley-Conroe Fault System. The SMU study concludes that "…newly discovered fault activation appears to be related to the stress associated with fluid pressure reductions caused by excessive water extraction from Montgomery County aquifers" (Qu and others, 2019). Specifically, the study states that the cause of the faulting determined from the 2007 through 2011 InSAR imagery is related to "…excessive groundwater exploitation" and "…continuous mining of groundwater from the Jasper aquifer…" in Montgomery County (Qu and others, 2019). However, the only direct evidence provided correlating pumping to the faulting is general recitations of total groundwater pumping in Montgomery County in 1976, 2000 and 2010 (Qu and others, 2019) with a map showing "…the InSAR observed deformation rate from 2007 to 2011…" and contours illustrating groundwater elevation change in the Jasper Aquifer from 2000 to 2011.

Damage to structures located atop faults that have recently moved has been identified by residents in The Woodlands and at the Conroe Aquatics Center. The San Jacinto River Authority (SJRA) installed safety measures and monitoring benchmarks along portions of its pipeline that cross the Big Barn and Egypt faults. The SJRA engaged consulting geologist Carl E. Norman, Ph.D., PG, to conduct a series of 10 measurements between 2016 and 2020 to monitor fault movement. Dr. Norman concluded that the slight movements at some of the measured benchmarks are too small to indicate fault activation or movement. Some area residents disagree with that finding. Data from the Continuous Operated Reference Stations (CORS) are available along the Hockley Fault System (near Woodlands High School) as part of HOUSTONNET.

Phase 2 will include collecting more fault documentation including additional reports, evaluating benchmark data, and processing available remote sensing imagery. The work will also involve conducting correlations during specific time periods as related to pumping and water-level changes in and near Montgomery County.

3.1.3 Extensometers

Borehole extensometers provide the only means of direct measurement of compaction within a particular geologic interval. Extensometers are expensive to install and are only applicable for a specific site;

however, they provide a continuous and precise record of compaction. Combined with collecting geologic and geotechnical data, water-level measurements, and vertical and lateral pumping distributions, extensometer data allow for determining critical parameters for understanding and predicting subsidence. Extensometer data are quite helpful as they allow for correlation with other methods including leveling, GPS methods, and remote sensing technologies.

There are currently 12 sites with 14 borehole extensometers in Harris, Galveston, and Fort Bend counties, with paired (that is, shallow and deep) extensometers at two sites. Where extensometers are co-located, they can be used to delineate between compaction in shallow versus deep zones. Extensometer readings also illustrate the variation in compaction based on depth, character, and thickness of the clay layers. There are no extensometers in Montgomery County, and the closest extensometer is the Lake Houston site. Extensometer information is important regarding LSGCD's subsidence study because the extensometer data were used to develop key correlations and modeling parameters used in the PRESS modeling and in the development of the GAM and HAGM.

3.1.4 Global Positioning System Network

Beginning in the late 1980s permanent sites were installed and land surface measured repetitively via GPS technologies. Prior to 2000, 15 permanent sites were installed and currently there are more than 200 sites maintained and monitored by the HGSD and UH. There are two types of sites; CORS and PAM sites. These sites allow for collecting relatively continuous data with good areal coverage in a cost-effective manner. The collected data requires post-processing to account for satellite orbit, clock information, atmospheric conditions, and other potential interferences. Reported "daily ambiguity" is six (6) to eight (8) millimeters vertically and less horizontally. Due to the small scale of reported subsidence (that is, millimeters or centimeters), it is critical that any problems associated with a CORS or PAM site or abnormalities in the processed data be carefully checked and corrected. For example, a professional engineer representing the Lake Conroe Citizens Network (LCCN) provided public comments to LSGCD (and others) questioning the accuracy and validity of reported data and results for CORS-TXCN near the City of Conroe (Massey, 2015). Phase 2 of this study will include evaluations of the raw data and data-processing technology.

UH reports the average subsidence rate based on GPS data for the period from 2005 to 2014 to be between 17 and 19 millimeters per year (mm/yr), or 0.67 to 0.75 inches per year (in/yr), and only mentions pumping from the Chicot and Evangeline aquifers (Wang and others, 2015). Figure 21 is a map generated and presented by the HGSD showing the highest rates of subsidence during the period from 2015 to 2019 occurred in southwest Harris County, near Jersey Village, and in northwest Harris County near Tomball, with reported subsidence rates greater than 2 centimeters per year (cm/yr), or greater than 0.79 inches per year (in/yr). HGSD reports that the highest measured rates of subsidence in Montgomery County is between 1.0 and 1.4 cm/yr (0.4 and 0.6 in/yr) near the Woodlands and just to the north of Tomball. HGSD provides charts and comments that subsidence at one site, PAM Site 13 (PA13), has reduced from about 2 cm/yr to less than 0.5 cm/yr coinciding with implementation of alternative water sources in Montgomery County (see Figure 22).

There are 15 GPS sites within Montgomery County. Such sites are the only means by which to timely and efficiently determine essentially real-time movement of land surface at sites in Montgomery County, and other counties. The sites only allow for determining the overall movement of land surface, and do not independently allow for determining the magnitude of compaction in any one layer of the GCAS.

Therefore, the GPS data must be carefully and accurately processed, compared, and correlated to historical pumping and water-level data to assess in which formations compaction is primarily occurring.

3.1.5 LiDAR and InSAR (Remote Sensing)

Remote sensing techniques, particularly LiDAR and InSAR have been utilized to quantify land-surface movement over time with respect to both subsidence and movement along growth faults. Processing of imagery can provide high resolution and refined scale interpretations to identify even small amounts of land movement. It was previously mentioned in this report that the USGS utilized LiDAR to compare with historical topography to estimate long-term regional subsidence. Also, InSAR was discussed relative to studies to identify surface expressions of growth faults, and how subsequent dates of imagery can be used to quantify movement over time. LiDAR is typically utilized over smaller areas while InSAR may provide more expansive coverage and may be a cost-effective technology for studying fault movement and bolstering subsidence measurements. Comparing remote sensing data with GPS and extensometer measurements provides opportunities for correlation of multiple data types and enhances reliability.

UH reported, “Contrary to previous studies in which the locations of subsidence appeared to be expanding toward the northwest, current results show that the area of subsidence is shrinking and migrating toward the northeast” (Khan and others, 2014). UH concluded that “(t)he digital elevation model (DEM) derived from LiDAR documented elevation changes within the salt domes relative to their surroundings” presumably for the period from 1994 to 2011 (Khan and others, 2014). The same study notes that sediment compaction due to groundwater withdrawal cannot account for all of the subsidence and uplift delineated, and states that more study of salt diapirism in the subsurface may be warranted.

The USGS conducted investigations utilizing GPS data and InSAR imagery to assess land-surface subsidence from 1993 to 2000. The USGS notes potential error considerations in processing and utilizing LiDAR including interference that may be introduced due to dense vegetation, atmospheric moisture, high humidity, and topography. While southern Montgomery County and areas south are relatively flat topographically, central and northern parts of the county exhibit significant topographic relief (Bawden and others, 2012). Figure 23 provides a map from the USGS that shows the rate of subsidence at PAM Site 13 near The Woodlands to be as much as 20 mm/yr, while the subsidence rate in northwest Harris County is at least double that rate – the dates for the map are unclear. Figure 24 provides a map that shows Evangeline aquifer water level changes from 1990 to 2003.

Effectively utilizing remote sensing imagery and deriving reliable and accurate results and conclusions requires proper correlation of the imagery intervals (that is, time) to known data such as pumping distribution (vertically and laterally) and water-level or pressure changes. Phase 2 of this subsidence study will look into acquiring and processing imagery and making detailed correlations and comparisons to aquifer data for all layers of the aquifer. Additionally, we understand that HGSD is undertaking expanded InSAR studies within the region. LSGCD should monitor progress of those studies and/or may wish to inquire as to participating in the studies as possible. Phase 2 of this subsidence study will better determine the level of participation by LSGCD.

Some studies have used remote sensing techniques to assess flood plains before, during and after flooding events. Phase 1 of this subsidence study focused on previous works in which subsidence and fault movements were detected and/or measured, not on studies addressing potential flooding resulting from such movement.

3.1.6 Analytical and Numeric Models

Due to population growth and regulation resulting in relatively rapid changes in pumping locations and distributions away from where subsidence has historically been greatest and has been measured for many years, modeling has become necessary to be able to predict potential compaction and resulting subsidence over larger areas and with varying parameter estimates. Electric analog modeling of the Houston area aquifers was first conducted in 1965, and a second electric analog model was constructed in 1975 that allowed for inter-aquifer leakage (Carr and others, 1985). The USGS developed the first digital groundwater-flow model that also allowed for simulating and predicting compaction in the Chicot and Evangeline clay layers in 1985. Analytical modeling of subsidence was introduced in the early 1980s. The USGS developed the initial TWDB-approved GAM for the Northern Gulf Coast Aquifer in 2004, and the Northern Gulf Coast Aquifer GAM was updated to the HAGM in 2012 (modified in 2013). The HAGM is the first groundwater flow model that expressly simulates compaction in all of the clay layers of the designated GCAS in GMA 14, including the Burkeville confining layer and the underlying Jasper Aquifer.

Analytical PRESS Model

The USGS reports that the first model to simulate land-surface subsidence is known as the Predictions Relating Effective Stress to Subsidence (PRESS) model (Espey, Huston, and Associates, Inc., 1982), which is essentially a site-by-site analytical model (Kasmarek, 2013). PRESS does not simulate water-level or artesian head changes. Fugro-McClelland, Inc. used the PRESS model to simulate subsidence in 1997, and simulated water-level declines from an LBG-Guyton Associates model (1997) were used as input data for PRESS model runs at more than 20 sites in the Houston area (Kasmarek, 2013). PRESS model runs were conducted for 26 sites in Harris, Galveston and Fort Bend counties utilizing water levels from HAGM simulations as inputs; the subsidence simulated by the HAGM compared favorably with PRESS runs utilizing HAGM water-levels (Kasmarek, 2013). Figure 25 provides a map from the USGS showing the comparison of PRESS subsidence calculations as compared to results from the HAGM and actual measured values (Kasmarek, 2013). INTERA notes that PRESS model results are representative of a defined area over which the modeled parameters are considered representative (Kelley and others, 2018). PRESS models have been created for six (6) extensometer sites (Kelley and others, 2018). Therefore, it is apparent that the parameters for PRESS models are derived at least in part by calibrating the compaction/subsidence to actual measured values. PRESS can simulate one or two layers, but if two layers are modeled, head values must be specified independently for each zone (Kelley and others, 2018).

Original GAM and the HAGM (Numeric Groundwater Flow Models)

The USGS reports that nine (9) groundwater flow models prior to the HAGM were developed covering at least parts of the HAGM study area (Kasmarek and Robinson, 2004). Kasmarek and Strom (2002) developed a groundwater flow model that simulated groundwater flow and compaction/subsidence in the area. Subsequently, Kasmarek and Robinson (2004) developed the original Northern Gulf Coast Aquifer Groundwater Availability Model (NGC GAM) which was conducted "…in cooperation with the Texas Water Development Board and the Harris-Galveston Coastal Subsidence District" and is reported in USGS Scientific Investigations Report (SIR) 2004-5102. While clay thickness maps were provided in the 2004 report, the USGS states, "*Compaction of clays in the Jasper aquifer and the Burkeville confining unit were not simulated because the sediments of those units are geologically older, more deeply buried, and therefore more consolidated relative to the sediments of the Chicot and Evangeline aquifers. Additionally, substantial potentiometric-surface declines such as have occurred in the Chicot and Evangeline aquifers in* *the greater Houston area have not occurred in the Jasper aquifer, and probably not in the Burkeville confining unit*" (Kasmarek and Robinson, 2004). The USGS subsequently utilized the NGC GAM to simulate various hypothetical withdrawal scenarios and reported the projected water-level changes and subsidence in report SIR 2005-5024. Subsidence predictions documented in the 2005 report showed large subsidence amounts in Montgomery County by the year 2000 with none of the subsidence represented by Jasper pumping (which was limited to less than 50 million gallons per day or less than 56,000 acre-feet per year throughout the GMA 14 model area). The USGS reported that the model runs (showing excessive drawdown and subsidence) using the hypothetical withdrawal scenarios "…indicated the need for modifications to the NGC GAM model input data…" (Kasmarek and others, 2005). The USGS made input changes and re-calibrated the model.

The USGS developed the HAGM in 2012 and revised the report in 2013 (Kasmarek, 2013) "…in cooperation with the Harris-Galveston Subsidence District, the Fort Bend Subsidence District, and the Lone Star Groundwater Conservation District". Per the USGS, the HAGM was updated and recalibrated to better reflect current (and future) groundwater withdrawals, and to be able to simulate compaction in the Chicot, Evangeline, Burkeville and Jasper layers of the GCAS (Kasmarek, 2013). The USGS states, "Local and regional water managers can use the HAGM as a tool to simulate aquifer response (changes in water levels and clay compaction) to future estimated water demands" (Kasmarek, 2013). The USGS notes, "Because a large area of land-surface subsidence has been documented in Harris County and parts of Galveston, Fort Bend, Montgomery, Brazoria, Waller, Liberty, and Chambers counties, only these areas of the HAGM can be considered calibrated for elastic- and inelastic-storativity", noting values for all layers of the GCAS (Kasmarek, 2013). Additionally, the USGS noted that "…good correlation exists between the PRESS and HAGM simulated values" for the PRESS model sites located within HGSD and FBSD (Kasmarek, 2013). The point of this information is not that the HAGM is perfect or "correct" as, in fact, there are several problematic issues with the HAGM including the lack of documentation, general head boundary conditions simulating recharge, the lack of the model's ability to convert from artesian to water-table conditions, and possible calibration concerns. However, the HAGM is currently the best available science based on its acceptance by the TWDB and is based on numerous and repetitive efforts to calibrate a model that includes representative compaction parameters for all layers of the GCAS.

Based on the reported model parameters and on numerous model runs conducted for GMA 14 purposes, the HAGM shows that the Burkeville confining layer and the Jasper Aquifer are much less susceptible to compaction and resulting subsidence than the overlying Chicot and Evangeline aquifers. Figure 26 illustrates the inelastic-clay storativity parameter in the HAGM for the Jasper Aquifer. Section 4.0 of this report includes discussions and illustrations of specific model runs utilizing the HAGM.

Brackish Jasper Aquifer Subsidence Model (INTERA)

On behalf of the Harris-Galveston and Fort Bend subsidence districts, INTERA created a model to simulate compaction and resulting subsidence due to artesian-head reductions in the Jasper Aquifer (Kelley and others, 2018). We have only reviewed the published report for the Jasper model, and do not yet have the model files. Figure 27 shows that the "Study Area" as delineated in the published report extends into the northern half of Montgomery County and Figure 28 illustrates that the model grid covers the entirety of Montgomery County in addition to other counties. A review of the report shows that INTERA populated the entire model grid domain with hydraulic parameters; however, Figure 29 shows and the report states that the extent of the Jasper compaction model domain coincides with the brackish groundwater delineation from the brackish water delineation study reported in 2016 for the TWDB (Young and others, 2016; Kelley and others, 2018). Detailed reviews of the actual model files, model simulations and report are needed. However, based on our preliminary review, the INTERA Brackish Jasper model is generally based on the following:

- Utilizing laboratory geotechnical values from core samples collected from the Chicot and upper half of the Evangeline during the 1970s at the Seabrook, Moses Lake and Baytown study sites and adjusting the values for parameters including porosity, compressibility, specific storage, and vertical hydraulic conductivity values based on depths of burial; and,
- Simulating 500 feet of pressure decline in the Jasper Aquifer centered for each nine-by-nine-mile cell.

The INTERA report assesses "…the relative risk of subsidence from brackish groundwater development in the Jasper Aquifer" (Kelley and others, 2018). The report concludes, "The literature, available data and calibrated models confirm that the Jasper will compact." However, in the previous sentence INTERA states that there "…is a general lack of data regarding subsidence potential for the Jasper Aquifer." The INTERA Jasper report also states, "It is our opinion that the general relative risk to subsidence from pumping in the Jasper Aquifer is supported by available data under the assumptions employed. However, *the absolute amount of compaction that may be predicted to occur is considered uncertain*. For these reasons, *the risk assessment was performed in a manner to report relative risk of subsidence* so that the underlying trends in risk are presented *without presenting actual compaction or subsidence amounts*" (emphasis added). Therefore, contrary to some public statements, the INTERA Jasper model clearly does not definitively predict any certain amount of compaction (also note that all compaction does not translate to surface expressions of subsidence). Figure 30 illustrates potential compaction amounts from INTERA's Jasper model with a range from low to high. Figure 31 provides a map included in the INTERA report illustrating the relative or "total normalized risk scope" for the Jasper Aquifer. Phase 2 of the LSGCD subsidence study will include a detailed review of INTERA's Jasper model files and report.

3.1.7 Water-Level and Pumping Records

To assess pumping within Montgomery County we obtained reported pumping and permitted well data from the District. For wells that had not been assigned an aquifer within the District database, we used completion information along with the formation depths developed by Young and others (2012) to identify the likely aquifer from which the well was producing. For some wells, the production interval could not be identified and was simply assigned as producing from an indeterminate aquifer.

In the early 1980s, total pumping in Montgomery County was less than 27,000 acre-feet per year and did not increase significantly until the early 1990s (Seifert, Jr., 2015). Reported production since 2009 peaked in 2011 at about 94,000 acre-feet. Since 2011, overall pumping has generally decreased with the largest declines in pumping occurring in the Evangeline and Jasper. Evangeline pumping decreased from more than 42,000 acre-feet in 2011 to about 28,000 acre-feet in 2018 while Jasper pumping declined from about 38,000 acre-feet to 18,000 acre-feet during the same period. Figure 32 illustrates the total reported pumping in Montgomery County.

As would be expected with the pumping pattern illustrated in Figure 32 measured water levels tend to be deepest around 2011 followed by a general recovery. The largest changes in water levels have occurred in the deeper wells in southern Montgomery County. Figure 33 provides several hydrographs illustrating the reported changes in water levels. The location of each well associated with a hydrograph is shown on Figure 34.

Using the water level data from the TWDB Groundwater Database (TWDB, 2020), we also developed contours of the water level over the last 30 years. As we observed in the hydrographs for wells completed in the Chicot Aquifer, water levels have generally declined but at a relatively slow rate in that aquifer. Figure 35 illustrates the changes in water levels in the Chicot aquifer at 10-year intervals beginning in the winter 1988-89. Comparison of Figure 35(A) and Figure 35(D) reveals that the 50-foot contour has moved northwesterly on the map indicating deeper water levels in the Chicot Aquifer in the southern part of District.

Over the last 10 years, annual pumping volumes from the Chicot are less than 10,000 acre-feet and are generally less than 7,500 acre-feet. While these water level declines are in part due to pumping in LSGCD, the water level declines are also due to production in neighboring counties. Figure 35 illustrates the distribution of reported pumping from the Chicot Aquifer in Montgomery County that influences the water levels in the aquifer. As the series of maps in Figure 36 illustrate, the highest pumping rates from the Chicot are generally in south-central Montgomery County, east of Interstate 45.

The water level declines in the Evangeline are more evident than those in the Chicot. In Figure 37, we observe water levels decline from about -100 feet mean sea level (MSL) to -250 feet MSL between map (A) and map (C). In map (D) we observe some rise in the Evangeline water levels in southern Montgomery County. As previously stated, pumping in the Evangeline has decreased recently which has resulted in the water level rise. As illustrated in the series of maps in Figure 38 much of the decrease in pumping also occurred in southern Montgomery County as indicated by the transition from warm colors to cool colors.

Most of the wells with recent Jasper water-level measurements are in southern Montgomery County (see Figure 39). While there are few early measurements, the available data on map (A) indicate relatively shallow water levels. More recent measurements shown on map (D) indicate water levels have declined by about 200 feet.

The recent distribution of pumping in the Jasper is illustrated in the map series in Figure 40. The water level declines observed in the Jasper in southern Montgomery County are primarily due to the pumping in that area. The map series on Figure 40 also shows the decrease in Jasper pumping that occurred in 2016. With the decrease in pumping, we would anticipate water levels to rise.

3.2 Summaries of Selected References

The following provides brief detailed summaries of information presented in selected references related to subsidence.

3.2.1 Identification of the Vulnerability of the Major and Minor Aquifers of Texas to Subsidence with Regard to Groundwater Pumping

The objective of this project was to assess the subsidence risk due to groundwater pumping for every major and minor aquifer in Texas to assist Groundwater Conservation Districts in meeting their subsidence control and joint planning requirements. Subsidence is a process that is difficult to measure because it usually happens very slowly and can take decades to accumulate tens of feet of land surface decline. As it typically takes a long time to manifest, prediction of future subsidence due to groundwater pumping based on information available today is an important part of subsidence risk evaluation. Furnans and others (2018) synthesized water level decline predictions and aquifer characteristics using subsidence prediction tools and summarized these data for each of the major and minor aquifers in Texas.

In order to conduct the assessment, Furnans and others (2018) analyzed data from thousands of well logs and driller's reports. They also incorporated available subsidence observations, pumping records, and results from groundwater availability models to quantitatively assess subsidence potential. Using the data and calculation, they developed tools and techniques to evaluate the potential for subsidence based on clay thickness, clay type, aquifer lithology, pre-consolidation level, and future water level changes. Project deliverables included geodatabases of subsidence risk evaluations for each aquifer, a written report detailing the results of work associated with the project, and an Excel-based subsidence prediction tool.

The prediction tool developed was designed as a screening level assessment of the risk for subsidence based on clay thickness, clay type, and predicted water level changes at a well site. While it utilizes the equations for predicting subsidence, it was not designed to be used in place of numerical models which assess differential subsidence in a more robust manner. One key limitation of the tool is that it does not account for the delay between water level decline and compaction; rather, the tool applies the equations to calculate the total compaction relative to a change in water level.

3.2.2 Subsidence Risk Assessment and Regulatory Considerations for the Brackish Jasper Aquifer

The HGSD and FBSD commissioned Kelley and others (2018) for two purposes. In particular, the purposes of the project were to: 1) develop a relative risk assessment of subsidence related to brackish groundwater pumping in the Jasper Aquifer and 2) recommend a permitting and data collection process through which the brackish portion of the Jasper Aquifer could be developed while providing additional scientific data to aid management of the aquifer. Results from the study (see Figure 31) are limited to the geographic area south of Montgomery County, and suggest relatively high subsidence risk where the Jasper Aquifer is shallowest.

The report details methodologies for computing subsidence over time, and provides a detailed description of the mathematical basis for computing subsidence as included in both the PRESS model (Espey, Huston, and Associates, Inc., 1982) and MODFLOW-SUB (Hoffman and others, 2003). The authors utilized the MODFLOW-SUB package in conjunction with the HAGM (Kasmarek, 2013) rather than the PRESS model in assessing subsidence risk because such model results would be available over the entire study area domain (rather than at only selected PRESS model sites across the domain). The report also details a relative risk assessment methodology similar to that from Furnans and others (2018), yet applicable only to the Jasper Aquifer within Harris, Fort Bend, Galveston, and Brazoria Counties. The authors recognize the lack of available hydrogeologic data from the brackish portion of the Jasper Aquifer results in uncertainty in the computed subsidence values yet consider the uncertainty sufficiently uniform across the study area to allow for relative subsidence risk assessment.

3.2.3 Land Surface Subsidence in the Houston-Galveston Region, Texas

This report was completed in 1975 by the USGS under a cooperative agreement with the TWDB and the cities of Houston and Galveston. A second report with the same title (yet focused on the period 1906-1980) was also completed and published in 1984. All material summarized in this section stems from these reports, referenced as: (Gabrysch and Bonnet, 1975) and (Gabrysch, 1984).

These reports present further data quantifying groundwater withdrawals in Harris and Galveston county, corresponding water level changes, and resulting rates of aquifer compaction and land subsidence. They demonstrate that subsidence rates were diminished after 1948 when Houston began utilizing more surface water to meet its water needs. This diminished subsidence rate continued until the 1970s when groundwater usage rates increased to levels exceeding those from the period before extensive surface water usage.

The authors demonstrate how subsidence may be lessened with decreased pumping of groundwater and how water levels can recover as a result. They used extensometers to measure compaction resulting from pumping in the Chicot and Evangeline aquifers, and concluded that most of the compaction was occurring within the shallower portion of the Chicot Aquifer. They also concluded that 80 to 85 percent of the subsidence that would occur as a result of groundwater pumping prior to 1973 had likely already occurred as of 1975. All combined, the reports provide evidence supporting the notion that limiting further groundwater usage in the Houston-Galveston region would limit any further subsidence. The authors also developed a basic method for predicting future subsidence based on clay compressibility, clay layer thickness, calculated water level declines, and specific-unit compaction quantities.

3.2.4 Land Surface Subsidence in the Texas Coastal Region

This report was completed in 1982 by the USGS under a cooperative agreement with the Texas Department of Water Resources. All material summarized in this section stems from the report, referenced as: (Ratzlaff, 1982). The purposes of the project were to: 1) quantify amounts of subsidence within the Gulf Coast Aquifer along the entire Texas Gulf Coast, and 2) qualitatively determine the cause for the subsidence. Potential causes were: 1) groundwater extraction, 2) oil and gas extraction, and 3) sulfur mining. Subsidence was quantified by comparing surveyed benchmarks as established by the National Geodetic Survey over the period from 1906 to 1973.

Counties of interest to LSGCD in this report were included within “Subregion 2” as defined in the USGS study. However, analysis was limited to the areas between (and including) Harris County to the Gulf of Mexico. Montgomery County was excluded from the analysis by Ratzlaff. As shown on Figure 20, analyses demonstrated that the majority of Subregion 2 experienced at least 0.5 feet of subsidence between 1906 and 1973 as a result of groundwater withdrawals. Portions of the Pasadena-Houston Ship Channel and surrounding area subsided by up to 9 feet over this same time period due to groundwater withdrawals. Subsidence due to oil and gas withdrawals was considered as a “local” occurrence and was reported as difficult to quantify due to a lack of accurate withdrawal information.

3.2.5 Investigation of Land Subsidence in the Houston-Galveston Region of Texas by using the Global Positioning System and Interferometric Synthetic Aperture Radar, 1993-2000

This report was undertaken by the USGS and was completed in 2012. All material summarized in this section stems from the report, referenced as: (Bawden and others, 2012). The report documents the use of InSAR along with long-term GPS measurements from CORS to quantify subsidence within the Greater Houston area. The analysis was focused largely on Harris County with minimal analysis and description provided for adjacent counties. For the study, InSAR data were available from July 25, 1992 to December 19, 2000.

Analyses indicated good agreement between subsidence determined from relative GPS measurements and determined from InSAR data. Results suggest that the area of maximum historical subsidence (near Pasadena and the Houston Ship Channel) has stabilized, with subsidence largely decreasing or with the land surface elevation rebounding (increasing) slightly. The InSAR analysis also shows that most of the recent subsidence in the region is to the northwest of downtown Houston, including portions of southern Montgomery County. Subsidence rates in southern Montgomery County were calculated as 20 mm/yr (approximately 0.75 in/yr).

Based on information reported by Bawden and others (2012), it appears that InSAR data are available for the majority of counties adjacent to Harris County, including the entire extent of Montgomery County. However, the analysis and results presented in the report largely focused on Harris County and the downtown Houston area, due to the availability of CORS GPS stations in these areas. It is possible that analysis of the InSAR data covering Montgomery County (not presented in this report) would provide additional insight into subsidence and land movement within the LSGCD.

4.0 PRELIMINARY MODELING

The HAGM is the TWDB adopted representation of the best available science for the GCAS. The HAGM was developed to simulate groundwater flow and compaction of the four hydrostratigraphic layers of the GCAS. Currently, the HGSD is working with the USGS to replace the HAGM with the Gulf Coast Land Subsidence and Groundwater-Flow Model (GULF 2023). The USGS anticipates the draft of this new model will be complete by summer 2021.

The HAGM was published in 2013 (Kasmarek, 2013) and has been used for joint planning by GMA 14 during the current and previous cycles. However, like the ongoing GULF 2023 model being developed, the HAGM was primarily developed as part of a regulatory plan update by HGSD and its primary purpose was to assess the potential effects of management decisions by that entity. With a focus on the HGSD regulatory area, some modeling assumptions were applied that may be insignificant to the HGSD regulatory area but add uncertainty to the modeling results in Montgomery County. Examples of these limitations include (Keester, 2019):

- How it simulates recharge, evapotranspiration, and surface water interaction using a general head boundary;
- Grid discretization of one square mile; and,
- Constant transmissivity and storage properties.

While the HAGM has limitations with regard to its representation of the GCAS, groundwater flows, and subsidence predictions, it is nonetheless considered the best tool for planning and evaluation of groundwater management strategies by the TWDB. Results from modeling simply must be interpreted within the model limitations. For this report, we reviewed several previously conducted model simulations to assess the potential impacts of various pumping scenarios. Table 3 summarizes the various scenarios reviewed and Table 4 provides the simulated pumping in each scenario at the end of the predictive period in Montgomery County.

As shown on Table 4, there is a wide range in the simulated pumping rates for the GCAS. In the simulations reviewed, pumping at the end of the predictive period ranges from about 64,000 to nearly 150,000 acre-feet per year. Figure 41 illustrates the range in the simulated pumping for each of the aquifers of the GCAS in Montgomery County. As observed on the box-and-whisker plot, the greatest range in simulated pumping is from the Jasper Aquifer with comparatively small ranges in the Chicot and Evangeline (Figure 42 illustrates the parts of the box-and-whisker plot presented in Figure 41).

As we observe during GMA 14 joint planning meetings, there are many ways to present the results from the HAGM. Examples of the various presentations include average drawdown, average subsidence, change in storage, or percent remaining available drawdown, along with many others (INTERA, 2019; Keester and others, 2020; LSGCD, 2020). These presentations of the results are simply ways to summarize the model output which is limited to water levels, aquifer compaction, and volumetric flow for each one square mile of the simulated hydrostratigraphic unit. Using these model outputs along with other data we are able to better understand and correlate model results to real-world measurements and measurement locations.

For our review and consideration of the results from the various scenarios, we focused on the evaluation of model results at active monitoring well locations. As recently presented to GMA 14 (Keester and others, 2020; LSGCD, 2020), rather than using results from the thousands of active model cells, we used the results at locations identified as monitoring wells in the TWDB groundwater database (TWDB, 2020). This method limits the evaluation to locations which historically also provide a real-world measurement. Figure 43 illustrates the location of monitoring wells utilized within the District to evaluate the model results. Table 5 and Table 6 provide the results at the end of the predictive period for the reviewed simulations for the average change in water levels and compaction of the aquifer sediments, respectively.

Like the distribution of pumping, the range in the average water-level decline (that is, drawdown) in the Jasper Aquifer is much larger than the Chicot or Evangeline. As shown on Figure 44, the average drawdown in the Jasper ranges from nearly zero to almost 700 feet under the various scenarios. However, there is a very small range in average drawdown of just 23 to 42 feet in the Chicot and typically an increase in the water levels (that is, negative average drawdown) in the Evangeline.

Unlike the average drawdown, the simulation results shown the greatest range in maximum compaction associated with predicted water-level declines occurs in the Chicot. As shown on Figure 45, the average maximum compaction simulated from the scenarios is about 1.75 feet associated with the small range in average drawdown. Comparison of Figure 44 and Figure 45 suggests that there is a relationship between the compaction of the aquifer and the average drawdown.

To investigate the relationship between the average drawdown and the simulated maximum compaction of the aquifer materials, we prepared cross-plots comparing the results for the Chicot (See Figure 46), Evangeline (see Figure 47), and Jasper (see Figure 48). The linear relationship between water level decline and aquifer compaction is clear in each of the aquifers. However, the slope of the trendline through the data points suggests the impact per foot of water-level decline on compaction is nearly 1,000 times greater in the Chicot compared to the Jasper and about 100 times greater compared to the Evangeline. Importantly, these results are based on the parameters used in the HAGM and are likely to change with the updated model.

With regard to the Chicot, the model results show the impact of water level declines on compaction with the relatively small amount of pumping in Montgomery County. We therefore investigated the impact of pumping outside of the county on aquifer compaction and land-surface subsidence. We performed a simulation where all pumping in the subsidence districts was turned off beginning on January 1, 2010 and a simulation where all pumping in Montgomery County was turned off beginning on January 1, 2010. We then compared the results from these simulations with the simulation of all predicted pumping to assess the difference in predicted subsidence under different pumping assumptions and the associated changes in water level. Figure 49 illustrates contours of the predicted additional subsidence under the Run D pumping scenario (Seifert, Jr., 2017); Figure 50 illustrates contours of the predicted additional subsidence under the Run D pumping scenario with pumping turned off in the subsidence districts beginning on January 1, 2010; and, Figure 51 illustrates contours of the predicted additional subsidence under the Run D pumping scenario with pumping turned off in Montgomery County beginning on January 1, 2010.

Comparison of the contours shows there is little predicted additional subsidence when the pumping within the subsidence districts is turned off (Figure 51). This reduction in predicted additional subsidence from the baseline simulation (Figure 50) is due to recovery of the predicted water level in the region. With predicted pumping in Montgomery County turned off, predicted subsidence is also reduce but to a lesser extent (Figure 51). While the total amount of predicted additional subsidence is relatively small, the HAGM parameterizes compaction of the Chicot Aquifer due to water-level declines as the primary factor contributing to land surface subsidence. Future model updates (such as the GULF 2023 model) may modify the parameterization of compaction variables resulting in a change in the predicted subsidence due to regional water-level declines.

5.0 REGULATORY AND MANAGEMENT OVERVIEW

LSGCD is a groundwater conservation district subject to the statues in Chapter 36 of the Texas Water Code (TWC). GCDs must adopt a management plan to address eight (8) specified management goals. TWC §36.1071(a)(3) mandates that one of the management goals that a district's management plan shall address is "controlling and preventing subsidence". A GCD's management plan must "identify the performance standards and management objectives under which the district will operate to achieve the management goals identified…" (TWC §36.1071(e)(1)). Section 10.3 of the LSGCD's Management Plan provides the management objectives and performance standard for **Controlling and Preventing Subsidence:**

Management Objectives

1) The District shall, in cooperation with the Harris-Galveston Subsidence District, monitor in real-time and maintain a network of 8 subsidence monitor stations to continually measure subsidence. To date, minor subsidence of less than 1 foot has been measured at monitoring stations located in the southern portion of the District.
2) Each year, the District shall participate in a joint conference with the neighboring groundwater conservation districts or subsidence districts focused on sharing information regarding subsidence and the control and prevention of subsidence through the regulation of groundwater production.
3) Controlling and preventing subsidence will be addressed during the review and processing of permits as authorized in Chapter 36 and District Rules, and in setting desired future conditions for the common reservoirs.

Performance Standards

1) Each year, a summary of the joint conference on subsidence issues will be included in the Annual Report submitted by the General Manager to the Board of Directors of the District (2020 Management Plan Page 15 Revised April 14, 2020).
2) Results from the subsidence monitoring stations will be noted in the summary of the joint conference on subsidence and included in an annual report to the District Board of Directors.
3) The District will continue its subsidence study and provide updates on the results of the study in the Annual Report of the District provided to the Board of Directors.

TWC §36.1071(f) states, "The district shall adopt rules necessary to implement the management plan." TWC §36.101(a) states, "A district may make and enforce rules, including rules limiting groundwater production based on tract size or the spacing of wells, to provide for conserving, preserving, protecting and recharging of the groundwater or of a groundwater reservoir or its subdivisions in order to control subsidence…" (emphasis added). According to TWC, "'Subsidence' means the lowering in elevation of the land surface caused by withdrawal of groundwater" (TWC §36.001(10)).

Because subsidence is typically a regional issue, the joint planning process through GMA 14 is where "the rubber meets the road" with respect to controlling subsidence. Each of the layers of the GCAS is hydraulically connected across multiple county lines; therefore, pumping in one county affects water levels in other counties and can affect subsidence, depending in large part on the amount of pumping and aquifer geometry. Under TWC §36.108(d)(4) "the impact on subsidence" is one of nine (9) factors that GMAs must consider in setting DFCs.

Subsidence districts are not Chapter 36 GCDs and do not have the same requirements for management plans, rulemaking or setting DFCs as part of a GMA (although they are important stakeholders in the GMA process). The HGSD and the FBSD regulate groundwater production in essentially the same way and in accordance with a district regulatory plan. The amount of groundwater pumping allowed is based, not directly on an aquifer condition, but on a percentage of the total water demand within the subsidence district.

Each subsidence district is divided into regulatory areas with pumping in the regulatory areas having large subsidence amounts curtailed first. Over time, the pumping in each area becomes a smaller and smaller percentage of total water demand. The management plan for HGSD has already led to a drastic reduction in pumping in central and eastern parts of Harris County and all of Galveston County. Areas to the north and west in Harris County will experience substantial reductions in the percentage of groundwater allowed by 2025 with additional curtailments in 2035. Figure 52 shows the regulatory areas in the HGSD and FBSD. Figure 53 shows projected total pumping in both HGSD and FBSD through 2070. Figure 54 shows total pumping in each of the regulatory areas of the HGSD. Note that Area 3 has undergone a slight total reduction in pumping, while Area 1 and Area 2 have been curtailed drastically. While the total pumping amount is very important, a more precise aerial and vertical distribution of pumping is needed to assess the potential for continued and on-going subsidence in Area 3 of HGSD and Area A of FBSD. Phase 2 of this subsidence study will include a detailed look at pumping distributions in Montgomery County and adjacent areas that can affect water levels and subsidence in Montgomery County.

6.0 NEXT PHASE OF STUDY

The objective of Phase 2 work is to build upon summaries and data collection efforts in Phase 1 to focus on the potential for future land-surface deformation within Montgomery County and adjacent areas, specific potential impacts of subsidence within Montgomery County, and monitoring of subsidence within Montgomery County. Specific goals of Phase 2 are to:

- Build upon Phase 1 summaries with detailed evaluations, assessments, and critiques of previous data and studies;
- Address past and potential future land-surface deformation associated with subsidence and fault movement within Montgomery County;
- Develop both a high-level and locally-specific assessment of possible drainage and flooding concerns as related to potential future subsidence, land development, and other factors;
- Develop recommendations, conceptual plans, and budgetary cost estimates for field studies and monitoring programs, such as:
    - Collecting core samples for geologic and geotechnical analyses;
    - Processing InSAR for topographic changes and fault detection; and/or,
    - Installing an extensometer anchored in the formations making up the Jasper Aquifer;
- Prepare deliverables and a project report describing and illustrating the work conducted with key findings and conclusions. Additionally, the work will include preparing one or more presentations to the Board and stakeholders to communicate the work performed and results.

The following proposed Phase 2 tasks are designed to meet the project goals outlined above.

Task 1 –Technical Evaluations of Existing Data and Recent Studies

This task will involve detailed technical analyses of available data and information that builds upon the summaries discussed in Section 3.0. The evaluations to be conducted utilizing data and information collected are presented as individual sub-tasks below.

Task 1.1 – Topographic and Re-Leveling Efforts

As discussed in Section 3.1.1, all land-surface subsidence determinations in the region were initially made by geodetic differential leveling. It is important to understand the initial basis and accuracy of historical subsidence measurements and estimates within Montgomery County. Work during this effort will include collection and review of benchmark data from the National Geodetic Survey and consideration of the uncertainty associated with survey measurements.

Task 1.2 – Hydrogeology, Geology, and Geotechnical Studies

As discussed in Section 2.3, the three primary variables that determine the magnitude, location, and timing of subsidence related to groundwater pumping are: 1) the distribution, thickness and compressibility of clay layers; 2) the amount and timing of water-level changes; and, 3) the lowest historical water level (Furnans and others, 2018). Several studies from the 1970s and 1980s formed the basis for understanding the correlation of the distribution and timing of pumping with water-level declines and associated occurrence of land-surface subsidence and/or fault movement (see Section 3.0). Additionally, geologic studies including geophysical log analysis and geotechnical studies by the USGS provide the only available direct data for the clay characteristics for the Chicot and Evangeline layers of the GCAS. While these studies are for the upper portions of the aquifer system, data from these studies have formed the basis for parameters in recent models that estimate clay compaction in deeper formations of the aquifer. This task will include critical evaluations of the thickness and distributions of sand and clay layers, hydraulic parameters, physical properties, overburden depths, and other geologic formation related factors associated with subsidence within Montgomery County.

Task 1.3 – GPS Monitoring Data and Interpretations

As discussed in Section 3.1.3, beginning in the late 1980s permanent sites were installed and land surface locations were measured repetitively via GPS technologies. Now there are more than 200 sites maintained and monitored by the USGS and UH. Such sites are the only means by which to timely and efficiently determine movement of the land surface at sites in Montgomery County. The sites only allow for determining the overall movement of land surface and do not independently allow for determining the magnitude of compaction in any one layer of the GCAS. To better understand within which formation(s) compaction is occurring, the GPS data must be carefully compared and correlated to historical pumping at well sites, completion intervals of the wells, and changes in water-level within the wells. This task will involve evaluation of data from the GPS monitoring sites and performing the correlations with pumping and water level data.

Task 1.4 – Remote Sensing

LiDAR data collected over multiple years can be compared to assess land surface deformation (see Section 3.1.5). In particular, the LiDAR data from recent years can be compared with historical benchmark elevations from the National Geodetic Survey to assess subsidence that may have occurred in the past. Similarly, researchers have assessed relatively recent land surface deformation due to subsidence or fault movement using InSAR. This task will include reviewing existing research, particularly related to recent studies applying InSAR data, and correlating findings to historical distributions of pumping, water-level changes, and land surface deformation measurements collected at GPS sites.

Task 1.5 – Drainage and Flooding

While consideration of surface water resources is not part of LSGCD's primary mission, the District understands the concerns of its constituents with regard to the potential changes in surface water drainage that may occur due to land surface subsidence. However, there is some uncertainty with regard to existing research on how differential land surface subsidence may affect drainage patterns within Montgomery County. For this sub-task, we propose obtaining available surface water models from the SanJac Drainage Study (https://sanjacstudy.org/), or other available sources, and evaluating the models, assumptions, and documentation to assess the potential for using these models to assess subsidence effects on Montgomery County drainage and flooding.

Task 2 –Subsidence Modeling

Many of the groundwater flow models covering the study area have explicitly included simulation of aquifer compaction associated with potentiometric surface declines. These models apply various implementations of the equations used to estimate compaction of geologic materials associated with aquifer depressurization. This task will focus on how compaction is simulated in existing models and in the model package under development for MODFLOW 6.

The equations for estimating subsidence are fairly straightforward (see Section 2.3). However, the assumptions included in the parameters used to perform the calculations can significantly affect the results. Understanding the implementation of the equations and the assumptions included in the input parameters is important to understanding the model predictions along with the uncertainty in the prediction results.

Task 2.1 – PRESS Model (Espey, Huston, and Associates, Inc., 1982)

The PRESS model is used extensively in Harris County to predict subsidence due to changes in water levels. Review of the model and parameterization of the factors controlling subsidence will include a review of extensometer data, how it correlates to changes in water levels, and how the data are used to calibrate the PRESS model sites. As these PRESS sites were used to help develop and calibrate the HAGM, understanding the parameterization included in these models directly relates to how subsidence is simulated in Montogomery County.

Task 2.2 – Houston Area Jasper Model (Kelley and others, 2018)

The existing model of potential future subsidence due to production and water level changes in the Jasper Aquifer (Kelley and others, 2018) adopts assumptions for the clay properties in the deeper formations based on data from shallower zones. This sub-task will evaluate the assumptions applied in the model and the level of uncertainty in the results associated with these assumptions. Work will also include obtaining a copy of the model files and performing a comparison of the parameters in this model that affect subisidence calculations with the parameters used in the HAGM. We also anticipate parameters from this model will inform the input parameters in future models and will compare the parameters to those in the GULF 2023 model (see Task 2.3) when it becomes available.

Task 2.3 – Gulf Coast Land Subsidence and Groundwater-Flow Model (GULF 2023)

The GULF 2023 model is currently under development by the USGS. While the complete model is not available, the USGS has reported that the MODFLOW 6 package for simulating aquifer compaction is complete and available for download and analysis via GitHub. During the HGSD Joint Regulatory Plan Review meeting on May 20, 2020, the USGS stated that the new package will allow simulation of inelastic and elastic compaction of both the clay and sand units in the aquifer. Since this new MODFLOW 6 package will likely build upon previous MODFLOW packages, we will perform a review of the previous subsidence equation implementations (in existing MODFLOW packages) as well as analyze the implementation of the equations within the newer MODFLOW 6 package. We will assess how the new implementation algorithms (within MODFLOW 6) may affect predictions of land surface subsidence within Montgomery County. While this task does not include work related to Stakeholder participation in the model development, evaluating and understanding the techniques and methods applied within this new MODFLOW 6 package will aid significantly in performing a future review of the GULF 2023 model and how it simulates subsidence in Montgomery County.

Task 2.4 – Subsidence Visualization

Understanding the spatial and temporal occurrence of subsidence will aid in the communication of past and predicted impacts of pumping on land deformation. Using the data and models gathered/developed in previous tasks and during this study, we will develop visualization tools that can be easily incorporated into the District's web-based database hosted by Halff. Specifically, we anticipate creating time series datasets that Halff can incorporate into the database with a slider that will allow users to view on an annual basis the pumping amount and locations, water levels, and subsidence. Specific work to be conducted under this sub-task includes:

1) Using benchmarks from the National Geodetic Survey and recent topographic data (such as LiDAR) to estimate subsidence amounts and distributions in Montgomery County for time periods prior to the formation of LSGCD (and/or prior to land-surface elevation monitoring at PAM sites).
2) Estimating total current compaction and corresponding subsidence in each layer of the GCAS since pre-development in Montgomery County.
3) Creating spatial and temporal datasets of pumping, water level, and subsidence.
4) Coordinating with Halff on incorporating the data and visualizations into the LSGCD web-based database.

Task 3 – Potential Impacts to Drainage and Flooding

This task would not be conducted without approval from LSGCD after review of the evaluation conducted in Task 1.5. If the information available from the existing information available from the SanJac Study and if LSGCD decides to move forward with modeling of subsidence effects on drainage patterns within Montgomery County, we would modify the existing models (identified in Task 1.5) to reflect changes in land use and/or topography due to subsidence. Steps to model the potential impacts include:

1) Modeling land use changes and runoff effects with HEC-HMS
    a. Simulate future land use and compute storm-runoff for 100-yr Atlas-14 storms
    b. Consider varying land use and impervious cover scenarios
2) Model differential subsidence across all of Montgomery County
    a. Based on specific modeled pumping and specific locations
    b. Likely use HAGM predictions of subsidence to calculate changes in topography
3) Adjust existing HEC-RAS models of Montgomery County drainages based on the modeled differential land surface elevation change due to subsidence
4) Run HEC-RAS models to generate new floodplains and compare to existing floodplains

Task 4 – Conceptual Plans and Budgetary Cost Estimates for Data Collection and Monitoring

Data collection is the only way to know for certain what is occurring with regard to subsidence. This task will involve developing recommendations, conceptual plans, and budgetary cost estimates for field studies and monitoring programs. Based on the information gathered during this study, examples of projects include:

1) Collecting core samples for geologic and geotechnical analyses. These analyses will provide direct measurement of the compressibility coefficients that are a key parameter in the prediction of subsidence due to depressurization.
2) Processing InSAR for topographic changes and fault detection. InSAR analyses are a relatively new process that can detect very small changes in land surface elevation. For high subsidence risk areas, Furnans and others (2018) recommended automation of InSAR data processing as a long-term low cost means of assessing subsidence.
3) Installing an extensometer anchored in the formations making up the Jasper Aquifer. There are currently no extensometers that measure compaction of the clay layers in the formations that

make up the Jasper Aquifer. With the importance of the Jasper to District constituents, it would be important to measure the compaction of the Jasper due to depressurization.

4) Expansion of automated water level and land surface deformation monitoring.

Task 5 – Reporting and Presentations

This final task will involve providing a written report to the LSGCD Board of Directors. We will also present the final report to the LSGCD Board and Public at a regular board meeting. The final report will document the key findings and conclusions related to the investigations conducted to meet the project goals.

7.0 CONCLUSIONS

This Phase 1 study has resulted in the following: a successful and effective effort to acquire a comprehensive library of information; compiling a working database that will be effective in developing applicable and accurate correlations related to temporal and spatial changes in aquifer conditions and land surface; conducting preliminary modeling (applicable to GMA 14 work) that illustrated the need to manage the entire common reservoir particularly with respect to water uses, aquifer conditions, subsidence and property rights. Based on Phase 1 work, we provide the following observations and conclusions:

- Subsidence has been recognized in Harris County since at least the 1920s;
- Studies and monitoring have built upon critical work conducted during the 1970s which addressed land surface movement due to subsidence and numerous growth faults;
- Montgomery County had experienced subsidence in decades when pumping within the county was less than half the current levels;
- Causes of the occurrence and activation (that is, new movement) of growth faults can include any one or a combination of factors including subsidence due to fluid production (shallow or deep), salt dome movement or deeper salt diapirism, and/or deep-seated fault movement associated with the massive fault system along the Gulf Coastal Plain;
- The susceptibility of formations to compaction or subsidence varies with the geologic age, depth, character, thickness, and lithology of clay layers;
- Regulation, population growth and migration and the associated shift in groundwater pumping locations have resulted in subsidence essentially ceasing in some areas and increasing in other areas;
- Previous and on-going studies along with monitoring have provided critical understanding of subsidence and growth faults within the region; however, there are many questions and specific considerations for Montgomery County that must be directly assessed in order to derive conclusive answers; and,
- Detailed correlations of land-surface movement over time with aquifer changes (particularly, pumping and water-levels) are needed to better assign cause-and-effect relationships regarding subsidence in Montgomery County.

Phase 1 work involved effectively compiling comprehensive background data and developing a working understanding and knowledge of land-surface movement to be able to conduct the needed subsequent detailed data analyses, technical evaluations, critiques, modeling, and assessments of implications relative to Montgomery County. This work was successfully completed, and the next phase of the investigations can begin. As detailed in the Phase 2 plan, the next phase of investigation will focus efforts on deriving the conclusive answers to several specific questions and issues as they relate to Montgomery County and the management of groundwater resources by Lone Star Groundwater Conservation District.

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Draft Report
Comments and Responses

The following provides a summary of the written and verbal comments received by LSGCD during the comment period on the Phase 1 draft report. Where possible we provided the verbatim comment. In many cases, we summarized our understanding of the comment as it applied to the Phase 1 report. We then provide a brief response (in *italics*) to the comment. Comments regarding LSGCD policies are not included.

General Comments

Several public comments were received requesting additional time for review of the draft report. Generally, the commenters stated the amount of time between posting of the draft report and the stakeholder meeting was insufficient for a detailed review.

In response to the requests for additional time, LSGCD extended the public comment period to July 31, 2020.

Several public comments were received requesting there be additional time for review and stakeholder meetings as part of the next phase of the subsidence investigations.

Interim draft deliverables will be submitted for each task of additional phases. There will be 60 to 90 days between the draft deliverable and the final task report to allow time for at least one stakeholder meeting and public comment.

Jonathon Smith, Porter SUD

Mr. Smith provided several editorial comments and suggestions to the draft report and draft executive summary.

We appreciate the suggestions provided and have incorporated many of Mr. Smith's proposed revisions into the final report.

Additionally, Mr. Smith provided written comments on behalf of Porter SUD in a letter dated July 31, 2020, which are addressed in the following:

Mr. Smith provided comments in support of LSGCD's Management Plan approved on May 15, 2020

No response required.

Mr. Smith provided a comment supporting Mr. Ron Kelling's statements.

See response to Mr. Kelling's statements.

Mr. Smith provided a comment supporting Mr. Michael J. Turco's statements.

See response to Mr. Turco's statements

Mr. Smith also requested that LSGCD implement a more transparent and stakeholder-inclusive process as it continues to develop the science, including (at a minimum) providing regular progress reports to stakeholders and longer review and comment periods. *Phase 2 study plans include provision for regular updates and workshops to include stakeholders, and for longer review and comment periods.*

<u>Michael J. Turco, General Manager, Harris-Galveston Subsidence District</u>

“In section 2.1.2 and 2.3 the authors present data developed by other researchers related to the hydrostratigraphy and lithologic properties of the Gulf Coast Aquifer System and discuss the importance of these characteristics in the context of subsidence mechanics. It is mentioned that the primary considerations for subsidence are: 1) The amount of clay in the aquifer material; 2) Aquifer water-level changes: and 3) the lowest historical water level. Please be advised that the historical minimum is not as important as the duration and magnitude of the depressurization (water-level decline).”

We agree and understood the difference in the discussion. Clarifying language added to the sections to indicate we were not considering the instantaneous minimum water level, but were considering the long-term aquifer water level.

“Drought is not mentioned at all in the phase one report, but it is an important consideration since those are the times when water demand increases significantly. Recent droughts in the region resulted in large water-level declines and annual rates of subsidence.”

Drought is an important consideration when considering potential groundwater production to meet demand. However, assessing predicted demands, associated groundwater production to meet those demands, and corresponding water-level declines in relation to changes in climatic conditions was beyond the scope of this Phase 1 Subsidence Study. The next phase of the report will include specific correlations that will include consideration of drought periods and associated pumping changes, water-level responses, and land-surface movement.

“Mr. Thornhill and Mr. Keester suggested in their presentation to the Board in June that the susceptibility of the Jasper was 1,000 times less than the Chicot aquifer according to the HAGM. Although the HAGM model is the model of record, HGSD/FBSD/USGS/TWDB are cooperating to update and revise the model to address known limitations which include the simulation of compaction in the Jasper aquifer. It is important that Lone Star recognize that the current state of the science is that the Jasper can compact ….”

We understand that the formations comprising the Jasper can compact and that the current “state-of-the-science” indicates that Jasper compaction can range from negligible to a few feet, depending on model parameter assumptions. The results presented are within the context of input parameters and results from the HAGM as reported by the USGS and evidenced in various model runs. As stated in Section 4.0 of the report, “While the HAGM has limitations with regard to its representation of the GCAS, groundwater flows, and subsidence predictions, it is nonetheless considered the best tool for planning and evaluation of groundwater management strategies. Results from modeling simply must be interpreted within the model limitations.”

“…Figure 50 misrepresents the impact of groundwater withdrawal in Harris County on subsidence in Montgomery County.”

Figure 50 presents the calculated difference in predicted additional subsidence from two model simulations. The figure and text have been revised to state the model results more clearly.

Ronald Kelling, P.E., Deputy General Manager, San Jacinto River Authority

"We understand that Phase 1 was intended primarily to be a literature review, however it appears that the report also includes conclusions made by Lone Star's consultants regarding the information that was obtained."

Correct. Specifically, within Section 7.0 we provided "observations and conclusions" related to Phase 1 work.

"Mr. Thornhill and Mr. Keester appear to dispel any correlation of subsidence to compaction in the Jasper aquifer caused by removal of groundwater that is presented in research by others. Yet even though they dismiss correlations drawn by others, Mr. Thornhill and Mr. Keester appear to attempt to justify a substantial lowering of the water levels of the Jasper aquifer by specifically quantifying a small amount of potential compaction and resulting subsidence. In other words, they dismiss reports connecting water-level declines in the Jasper to subsidence, and then they claim to know with confidence that only 0.35 feet of subsidence will occur from massive drawdowns in the Jasper."

Mr. Kelling provides bulleted references to specific items in the report following the comment. In the next to last bullet point, Mr. Kelling references two points from the conclusions section that highlight the questions and additional research needed to understand the causal relationships between pumping, water levels, and subsidence in Montgomery County. His last bullet point references information from Section 4.0 Preliminary Modeling.

The points from the report conclusions section are based on the overall Phase 1 work. The information presented in the modeling section is a reporting of a comparison of many model simulations from work conducted by us, the GMA 14 consultant, and as part of the LSGCD Strategic Planning Study. We did not provide any opinion or justification in the report regarding the modeled water-level decline, rather the focus in the modeling section was on the results from the HAGM. We do not dismiss the potential for compaction in the Jasper nor do we have confidence in the HAGM results. In the modeling section of the report we clearly state some of the limitation of the HAGM and that "[r]esults from modeling simply must be interpreted within the model limitations."

"How can Mr. Thornhill and Mr. Keester try to correlate removal of groundwater from the Jasper aquifer to such low amounts of additional long-term compaction with such specificity, when they devote time in their report attempting to disregard the correlation or at least raise concerns about the validity of such correlation? These messages appear to be contradictory."

See previous response. There is no contradiction in the reporting of modeling results, available data, and existing research.

The referenced correlation and specificity is in reporting of HAGM results. A model provides specificity though it may still be inaccurate. We recognize the limitations of the HAGM and that the results from the are to be interpreted within those limitations. We also are aware that questions remain regarding the correlation of pumping, water level changes, and compaction within the formations of the Gulf Coast Aquifer System.

Mr. Kelling states that the authors "…appear to attempt to cast doubt on the findings of the research reported by NASA and the Schuler-Foscue Endowment at SMU…" related to reported "recent" activation of growth faulting being related to pumping from the Jasper aquifer in Montgomery County. Mr. Kelling asks whether the authors consulted with the SMU researchers for Phase 1 and whether there will be such consultation during Phase 2.

The authors certainly never intended to cast any doubt as to the quality or accuracy of the work presented and, in fact, assumed for our Phase 1 assessments that the imagery processing and resulting presentations are correct and accurate. However, it is our opinion that the sparse information regarding the timing and distribution of pumping is not adequate to draw definitive conclusions regarding fault movement resulting from only pumping from the Jasper. Certainly, we recognize that pumping from the Jasper and the associated drawdown may be a cause or the cause of the reported fault movement. However, we feel that additional analysis is needed and we intend to conduct such evaluations in the next phase of the study. The LSGCD consulting team has outlined Phase 2 work tasks that include more detailed evaluations and assessments of the InSAR technology. We agree with Mr. Kelling's suggestion and we will communicate with SMU and other stakeholders as we conduct more detailed assessments.

Mr. Kelling notes within a bullet-point list addressing his concern that the authors "…appear to dispel any correlation of subsidence to compaction in the Jasper aquifer caused by removal of groundwater…" by noting on Page 17 of the report that we selected specific sentences to conclude "the INTERA Jasper model clearly does not definitively predict any certain amount of compaction (also note that all compaction does not translate to surface expressions of subsidence)".

Our conclusion is substantiated by the following quote from the INTERA model report which is included on Page 17 of the LSGCD Phase 1 report: "However, the absolute amount of compaction that may be predicted to occur is considered uncertain" (Kelley and others, 2018, p. 64). The authors also provide quotes on Page 17 stating that INTERA concludes that the literature, data and models confirm that the Jasper will compact, and we provide quotes in which INTERA acknowledges that there is a lack of data regarding subsidence associated with the Jasper (Kelley and others, 2018, p. 61). The Phase 1 report acknowledges that more analyses must be conducted and more data must be collected to better understand and quantify potential compaction and subsidence due to Jasper Aquifer pumping. Phase 2 of the study recommends such detailed study and planning of data collection programs.

<u>John Yoars, resident of Grogan's Mill Village in The Woodlands</u>

Mr. Yoars provided comments related to modeling and considerations associated with the joint planning efforts between LSGCD and other members of Groundwater Management Area 14.

In Section 5.0 of the report we provide a brief regulatory and management overview. However, our focus was on the current Texas Water Code requirements for LSGCD and a comparison with the requirements for a subsidence district.

"…Phase 2 of your study needs to focus more on current aquifer response habits…"

Part of Phase 2 of the study is to investigate the correlation between pumping, water level changes, and compaction of the formations making up the Gulf Coast Aquifer System.

<u>Neil Gaynor, resident of The Woodlands</u>

Mr. Gaynor provided written and oral comments during the July 10, 2020 LSGCD Phase 1 Workshop, and then subsequently provided additional written comments to the District during the extended comment period.

Mr. Gaynor stated, based on his review of "…several subsidence maps covering Harris and Montgomery Counties, including Figures 19, 20 and 25 in the draft report..." in relation to mapped subsidence where I-45 crosses Spring Creek, "[a] conclusion that considerable subsidence occurred in Montgomery County during earlier decades is not convincing."

The conclusion drawn by LSGCD consultants in the Phase 1 report is supported by data from parts of the county that have historically experienced the maximum subsidence. However, Phase 2 of the subsidence study will include refining the estimated and/or measured timing, magnitude and distribution of subsidence across Montgomery County and neighboring areas.

During the Stakeholder meeting Mr. Gaynor commented on the potential for increased flood risk due to subsidence and asked that it be considered in Phase 2 of the study.

Phase 2 includes a task to review available data and research related to changes in flood risk in Montgomery County due to land surface subsidence. Phase 2 also includes an optional task to utilize existing surface water models developed for watersheds in Montgomery County to assess how flood risk maps could change due to predicted subsidence.

"Developing a working understanding [of historical information and reporting] is a laudable goal, but it needs to be clearly stated that LSGCD is a recipient of the information generated and therefore will be better informed to consider subsidence due to aquifer depressurization in achieving its mandate."

LSGCD funded and is the recipient of the data and reports gathered as well as the final Phase 1 report.

"[Estimating the amount and distribution of subsidence within the LSGCD boundaries from pre-development periods through 2000, immediately prior to the formation of the district] is an important goal in that insight into model calibration is a key consideration. In other words, what modifications to model parameters are needed to achieve a history match for all historical data?"

Specific measurements of the compaction properties of the aquifer materials have never been obtained in Montgomery County. During Phase 2 of the study, we will work specifically to infer these values using available measurements of the changes in land surface, water level, and pumping.

"Partitioning inelastic compaction due to depressurization in each aquifer and the Burkeville confining unit is a key consideration to achieve this goal through HAGM or more advanced models, when available. In addition, documentation of needed adjustments to modeling parameters should be part of this goal or ensured in the Phase 2 study."

During Phase 2 of the study, we will work specifically to infer these values using available measurements of the changes in land surface, water level, and pumping. We will also be working *withing the Stakeholder process for the new model to share information derived regarding the compaction parameters.*

"Achieving this goal [predicting possible compaction with various projected future pumping distributions using the HAGM] is central to decision-making on the volume of groundwater pumping and aquifer depressurization in LSGCD. Subsidence may have significant impacts on streamflow characteristics when runoff from high-rainfall events exceed the capacity of such streams to maintain flow within their banks. It is, of course, recognized that this will be addressed in Phase 2."

Phase 2 includes a task to review available data and research related to changes in flood risk in Montgomery County due to predicted land surface subsidence. The HAGM is one tool used for making predictions of subsidence due to changes in water level. The GULF 2023 model is under development by the USGS and will replace the HAGM when it is approved by the TWDB. Subsidence predictions from the GULF 2023 model will likely be different than those from the HAGM.

"An overall observation is that the Phase 1 study goals should have been recapitulated in the conclusions section to demonstrate that these goals had indeed been met, associating the goals to specific and quantifiable answers.'

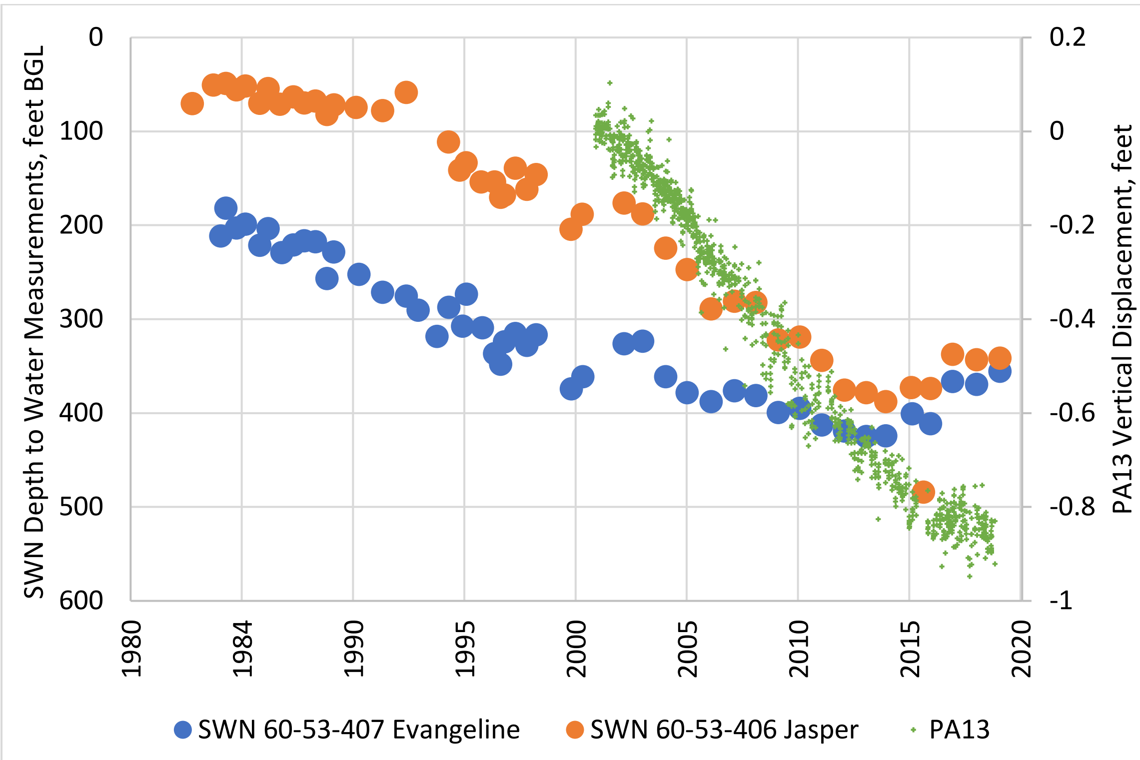
No response required.

Mr. Gaynor provided several questions and thoughts regarding the simulation of compaction in the Jasper. In particular, he inquired about the parameters used in the HAGM to simulate compaction and related his inquiry to statements made by Mr. Wade Oliver and to a Jasper model developed by INTERA for the HGSD. Mr. Gaynor closes his comments with two questions: "What changes to the modeling parameters are needed to provide more realistic compaction behavior under conditions of anticipated pumping from this aquifer? Would it be advisable to conduct a test model run using these more realistic parameters?"

We agree with Mr. Oliver that the conceptual model is that the Jasper can compact. It has always been understood that the Jasper can compact and that conceptual model is not new. As demonstrated by INTERA in their Jasper model, there is a great deal of uncertainty in the amount of compaction that can occur due to depressurization of the formations in the Jasper. To the last questions, the parameters included in the HAGM may be "realistic" values or they may need to be adjusted. The modeling conducted used the current model of record that was developed by the USGS and reflected their understanding of realistic compaction parameters for the Jasper. The USGS is currently developing the GULF 2023 model and may recalibrate the Jasper compaction parameters. During Phase 2 of the study, we will work specifically to infer these compaction parameter values using available measurements of the changes in land surface, water level, and pumping. We will also be working withing the Stakeholder process for the GULF 2023 model to share information derived regarding the compaction parameters.

Mr. Gaynor provided comments regarding the correlation of water-level decline to the vertical displacement recorded at PA13. Some of the comments referenced a presentation to GMA 14 that illustrated the change in water levels at an Evangeline well and a Jasper well to the vertical displacement at PA13. Mr. Gaynor concludes with a question: "Can the PA13 data be employed in an empirical approach for estimating a range of compressibility parameters by using water level change, cumulative fine-grained layer thickness and surface subsidence?"

> *There is no disputing the data showing the vertical displacement recorded at PA13. However, it is important to note that vertical displacement does respond to long-term water-level declines. The hydrographs shown by Mr. Oliver are for wells located approximately 1.5 miles apart. At the same location as the Jasper well (60-53-406) for which Mr. Oliver shows water levels, there is also an Evangeline well (60-53-407). The figure below illustrates the long-term water level changes at these wells that are at the same location along with the PA13 vertical displacement:*



> *As the figure shows, and as Mr. Gaynor pointed out, there have been water-level declines and recovery in both aquifers. During Phase 2 of the study, we will work specifically to assess compaction parameter values for the formations of the Gulf Coast Aquifer System in Montgomery County using available measurements of the changes in land surface, water level, and pumping.*

Mr. Gaynor provided comments regarding the modeling scenarios and results presentation. He provided some questions regarding the calculation of average subsidence and the use of average subsidence in planning. There is also a request to provide maps of total subsidence by decade.

> *We appreciate the comment and believe some of these questions are better suited for the GMA 14 planning group. Average subsidence is a modeling calculation and will not be a part of the subsidence study results. Phase 2 proposed work includes developing maps of total subsidence and potentially an interactive means for visualizing past subsidence.*

"Figure 7: This map shows an abrupt clay thickness change in Middle Lagarto Formation (equivalent to Burkeville confining unit as described in the report, Table 1) in northern Montgomery County and adjacent areas in Grimes and San Jacinto counties. This abrupt change follows an approximately northeast to southwest trend. On page 6 of the report, the abrupt change is attributed to other authors "combining two or more datasets." This attribution suggests a non-geological reason for the anomalous thickness change. It is incumbent on the LSGCD consultants to provide an alternative methodology to map the thickness of this important confining unit in a geologically plausible manner."

We will investigate the work by Young and others (2012) during Phase 2 of the study to address the apparent inconsistency in the formation mapping. LSGCD will provide in Phase 2 geologic maps in accordance with the best available data and methodologies.

"Figure 14: This stratigraphically and structural strike section shows a very large variation in thickness of Middle Lagarto Formation (Burkeville confining unit, Table 1) with a maximum thickness in Montgomery County, becoming zero thickness in eastern Waller and westernmost Harris Counties, and a similar decrease to zero thickness in San Jacinto County. The implication is that the missing Middle Lagarto Formation (Burkeville confining unit) may allow hydraulic communication between the Evangeline and Jasper aquifers. What evidence is available to test the potential for communication between the two aquifers? In this diagram, two wells in Montgomery County (wells 6037716 and 6037807) appear to penetrate the thickest part of the Middle Lagarto. Are these wells simply stratigraphic test wells? Are these wells completed in the Middle Lagarto or in the Upper Goliad Formations? Given the thickness of the Middle Lagarto (Burkeville confining unit) would more inelastic compaction be expected if it depressurizes?"

The cross section presents unaltered datasets from Young and others (2012). We will investigate the potential hydraulic connection between the hydrostratigraphic units during Phase 2 of the study. Thickness is one factor in compaction; clay mineral composition, geologic age and depth of burial are also factors.

"Figure 22: This plot of vertical movement of the PA13 test site in The Woodlands shows a dramatic decline in subsidence rate immediately following the implementation of the SJRA project to supply Lake Conroe surface water to The Woodlands and other entities in Montgomery County. The consultants should explain the phrase "No alternative water required." It would seem that to minimize subsidence, alternative water would have been required since 2001."

Figure 22 is presented unaltered from HGSD (Turco, 2019). The annotations on the chart are from the HGSD and were unaltered by LSGCD.

"Figure 26: This map shows the inelastic storativity in the Jasper aquifer. A search in the report for an explanation or reference to the term inelastic storativity was not included in the report. The initial impression of this map is one of a big blob centered on Montgomery County. Can the authors provide the basis from a depositional systems perspective for the distribution of this aquifer property?"

The map is reproduced without alteration from Kasmarek (2013). The derivation and distribution of model parameters are discussed in more detail in that report.

"Figures 28, 29 and 31: These figures show firstly, the HAGM modeling grid (layer 4), the compaction model domain (layer 2) and the total subsidence normalized risk score for the Jasper aquifer. Please confirm that layer 4 corresponds the Jasper aquifer and layer 2 corresponds to the Evangeline aquifer. Is the HAGM model based on a one-mile grid increment? Figure 31 shows an increasing risk for compaction in the Jasper towards the north of the model domain. Unfortunately, the compaction model domain only includes the easternmost part of Montgomery County. It would seem that the trend should of be concern, which presumably will be addressed in Phase 2."

These figures are reproduced from Kelley and others (2018). The model domain shown and model layer is not the same as the HAGM. We refer readers to the Kelley and others (2018) report for further details beyond the summary provided in this Phase 1 report. During Phase 2 of the study, we will work specifically to assess compaction parameter values for the formations of the Gulf Coast Aquifer System in Montgomery County using available measurements of the changes in land surface, water level, and pumping.

"Figures 38 & 40: Reported LSGCD pumping rate maps for the Evangeline (Fig. 38) and Jasper aquifers (Fig. 39), respectively, show substantial decreases in The Woodlands area after 2015. This observation is noted in the text on page 18. It seems that the decrease in pumping rates is localized to The Woodlands area in southern Montgomery County. To what factors do the authors attribute this reduction in pumping rates in the Evangeline and Jasper aquifers?"

The reduction in pumping correlates with the transition to utilizing surface water resources.

"Figures 31 & 41: Are these maps identical? In the text (page 19), the authors indicate, in discussing Figure 41, that given the limitation of the modeled geographic area to be south of Montgomery County, a relatively high subsidence risk may be where the Jasper aquifer is shallowest. Are the authors suggesting that there is higher subsidence risk related to Jasper depressurization in Montgomery County? The Jasper in Montgomery County is certainly shallower than in Harris County."

These are the same figure. The report has been corrected to only include the figure one time (references revised in Final Report to Figure 31). The information is a summary or the results from the work by Kelley and others (2018). The statement is an observation of the information shown on the map. During Phase 2 of the study, we will work specifically to assess compaction parameter values for the formations of the Gulf Coast Aquifer System in Montgomery County using available measurements of the changes in land surface, water level, and pumping.

"Figure 48 (Final Report Figure 47): What is the explanation for apparent decompaction in the Evangeline aquifer for zero and -10 feet of drawdown?"

We are uncertain as to why the results from the HAGM had a negative compaction result. We are aware of many uncertainties in the HAGM. The results provided illustrate the trend of the correlation of the model results.

"Figure 49 (Final Report Figure 48): From which areal part of the Jasper layer in the HAGM model are these numbers extracted? The maximum simulated compaction is a constant 0.15 feet for a range in drawdown of 400 feet. Is this realistic? What does maximum compaction in the Burkeville layer look like for a range in drawdown of 400 feet?"

The average drawdown represents a calculation using all active model cells for the Jasper in Montgomery County. The maximum compaction location can vary within Montgomery County depending upon which model cell shows the largest amount of compaction. The results presented *are from the HAGM and must interpreted within the model's limitations. We did not look at changes in the Burkeville as no pumping is occurring in that layer of the model in Montgomery County.*

"Figure 50: The map is suggested to represent subsidence due to aquifer pumping in HGSD and FBSD. Does this map represent additional subsidence to that has already taken place? What does total subsidence look like? Isn't the whole point of doing a study of subsidence to determine the impact of pumping in Montgomery County? It would be more meaningful to show subsidence due to all districts' pumping including LSGCD."

This map and text have been revised.

Simon Seguiera, Quadvest

Provided comment regarding the Brazos Valley Groundwater Conservation District versus Fazzino court case.

No response required for the Phase 1 report.

Webb Melder, Montgomery County citizen

Mr. Melder provided a comment that subsidence does not recognize county lines. He then shared his additional comments as four questions. These questions are summarized as follows: (1) What subsidence studies were conducted previously by LSGCD; (2) What subsidence studies have been conducted by SJRA and were they provided to LSGCD; (3) Did SJRA suggest installing extensometers in The Woodlands; and, (4) What are the plans to reduce subsidence due to pumping outside of Montgomery County.

Data collected during the Phase 1 work illustrates the regional subsidence. We attempted to review and incorporate as much data and existing research as possible in the Phase 1 report. If additional information, data sources, or reports are available, we welcome the information and will include it in Phase 2 of the study.

Table 1. Hydrostratigraphic and geologic units of the Gulf Coast Aquifer System within and near Montgomery County (Popkin, 1971; Young and others, 2012).

<table>
<tr><th>Epoch</th><th>Hydrostratigraphic Unit</th><th colspan="3">Geologic Unit</th><th>Characteristics</th><th>Thickness*</th><th>Percent Sand*</th></tr>
<tr><td>Holocene</td><td colspan="4">Alluvium</td><td>Clay, sand, and gravel</td><td></td><td></td></tr>
<tr><td rowspan="2">Pleistocene</td><td rowspan="3">Chicot</td><td colspan="3">Beaumont</td><td>Clay rich with sandy lenses</td><td></td><td></td></tr>
<tr><td colspan="3">Lissie</td><td>Fine-grained sands and sandy clays</td><td>25-537 (252)</td><td>38-74 (60)</td></tr>
<tr><td>Pliocene</td><td colspan="3">Willis</td><td>Gravelly coarse sands</td><td>25-538 (230)</td><td>26-79 (59)</td></tr>
<tr><td rowspan="6">Miocene</td><td rowspan="3">Evangeline Aquifer</td><td colspan="2" rowspan="2">Goliad</td><td>Upper</td><td>Thinner, less conglomeritic sands</td><td></td><td>45-62 (53)</td></tr>
<tr><td>Lower</td><td>Thicker, more conglomeritic sands</td><td>50-1,034 (326)</td><td>36-71 (54)</td></tr>
<tr><td rowspan="4">Fleming Group</td><td rowspan="3">Lagarto</td><td>Upper</td><td>Clayey sand</td><td>150-707 (367)</td><td>40-86 (60)</td></tr>
<tr><td>Burkeville Confining Unit</td><td>Middle</td><td>Clay rich</td><td>150-792 (453)</td><td>36-86 (58)</td></tr>
<tr><td rowspan="2">Jasper Aquifer</td><td>Lower</td><td>Clayey sand</td><td>150-566 (339)</td><td>45-62 (53)</td></tr>
<tr><td colspan="2">Oakville</td><td>Sand rich</td><td>67-711 (485)</td><td>17-67 (50)</td></tr>
<tr><td>Oligocene</td><td>Catahoula</td><td></td><td colspan="2">Catahoula</td><td></td><td></td><td></td></tr>
</table>

Figure 1. Clay thickness of the Beaumont Formation. Clay thickness calculated by subtracting the sand thickness from the total thickness as provided in the data set by Young and others (2012).

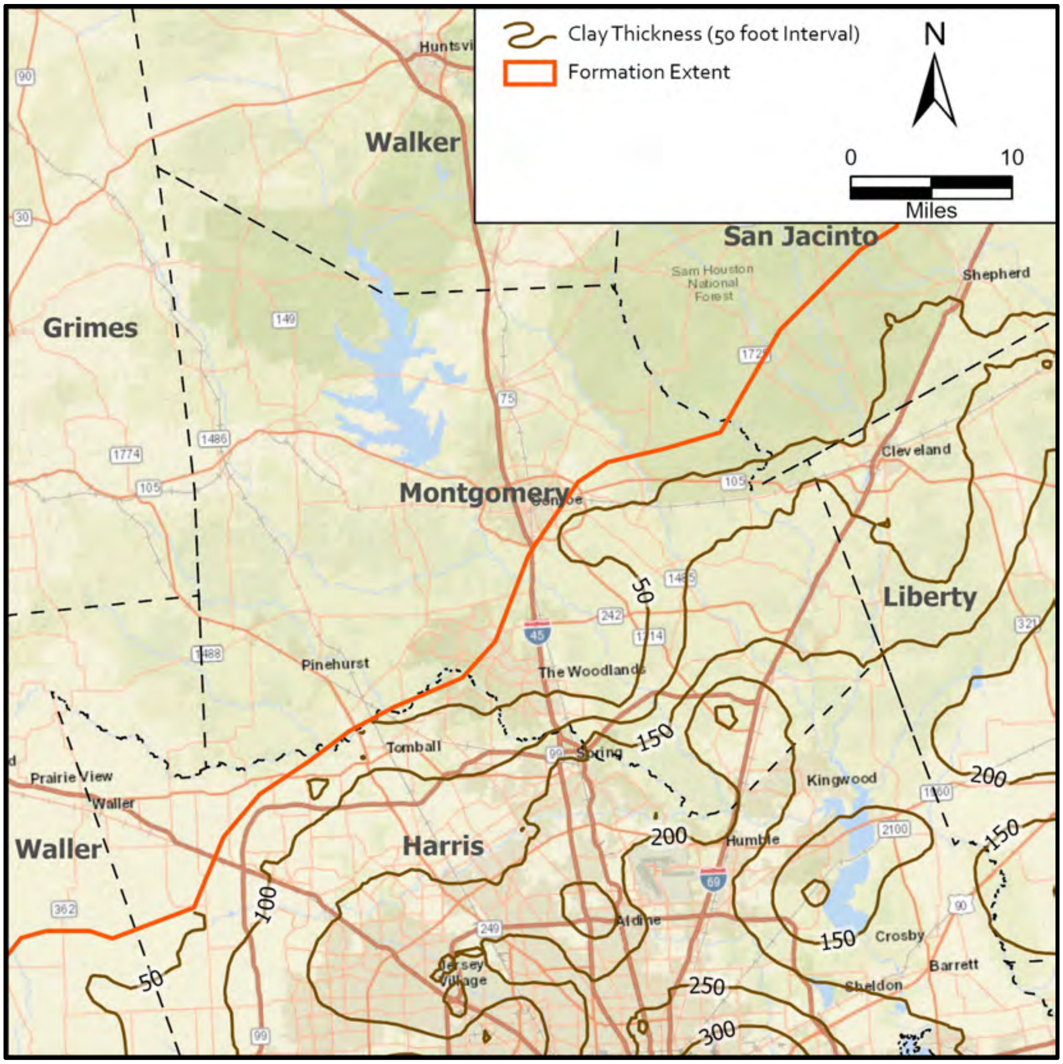


Figure 2. Clay thickness of the Lissie Formation. Clay thickness calculated by subtracting the sand thickness from the total thickness as provided in the data set by Young and others (2012).

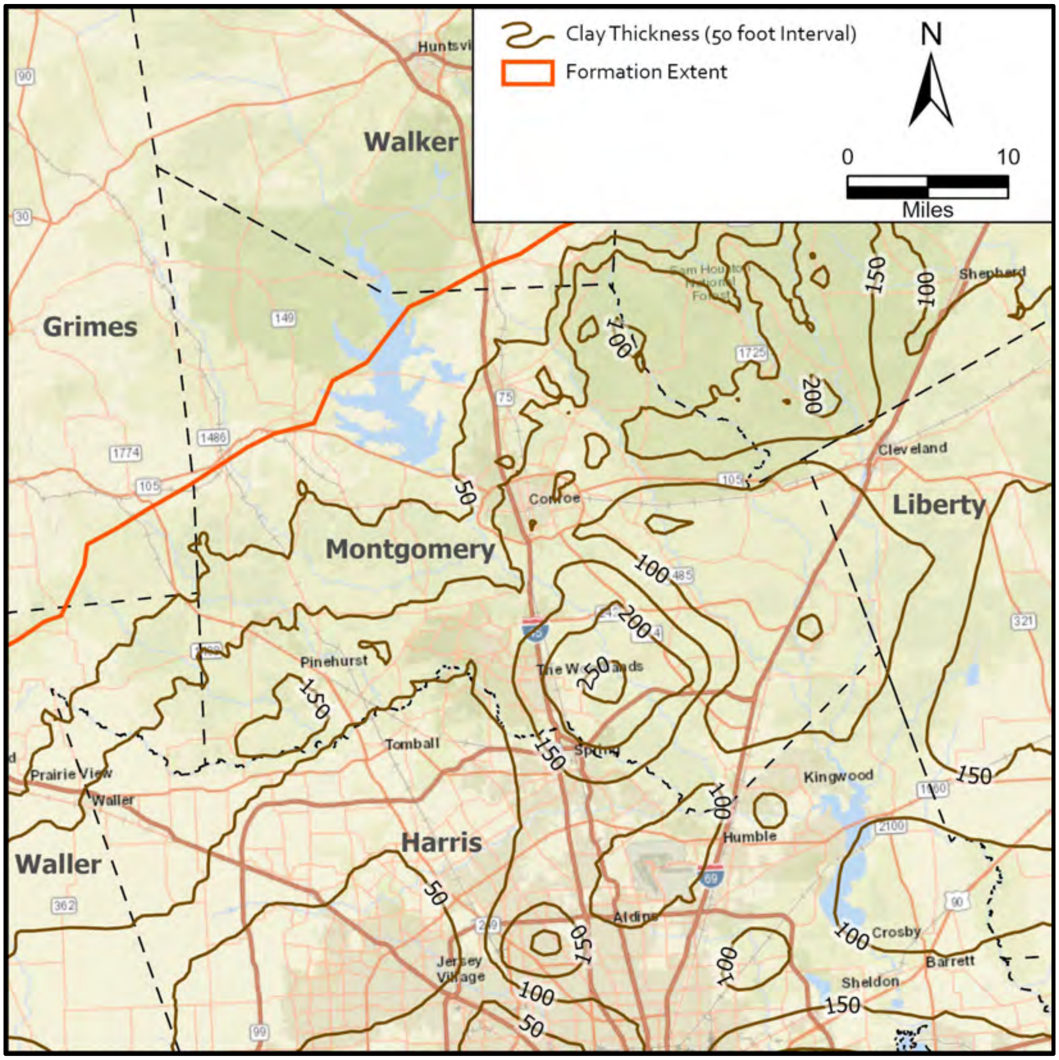


Figure 3. Clay thickness of the Willis Formation. Clay thickness calculated by subtracting the sand thickness from the total thickness as provided in the data set by Young and others (2012).

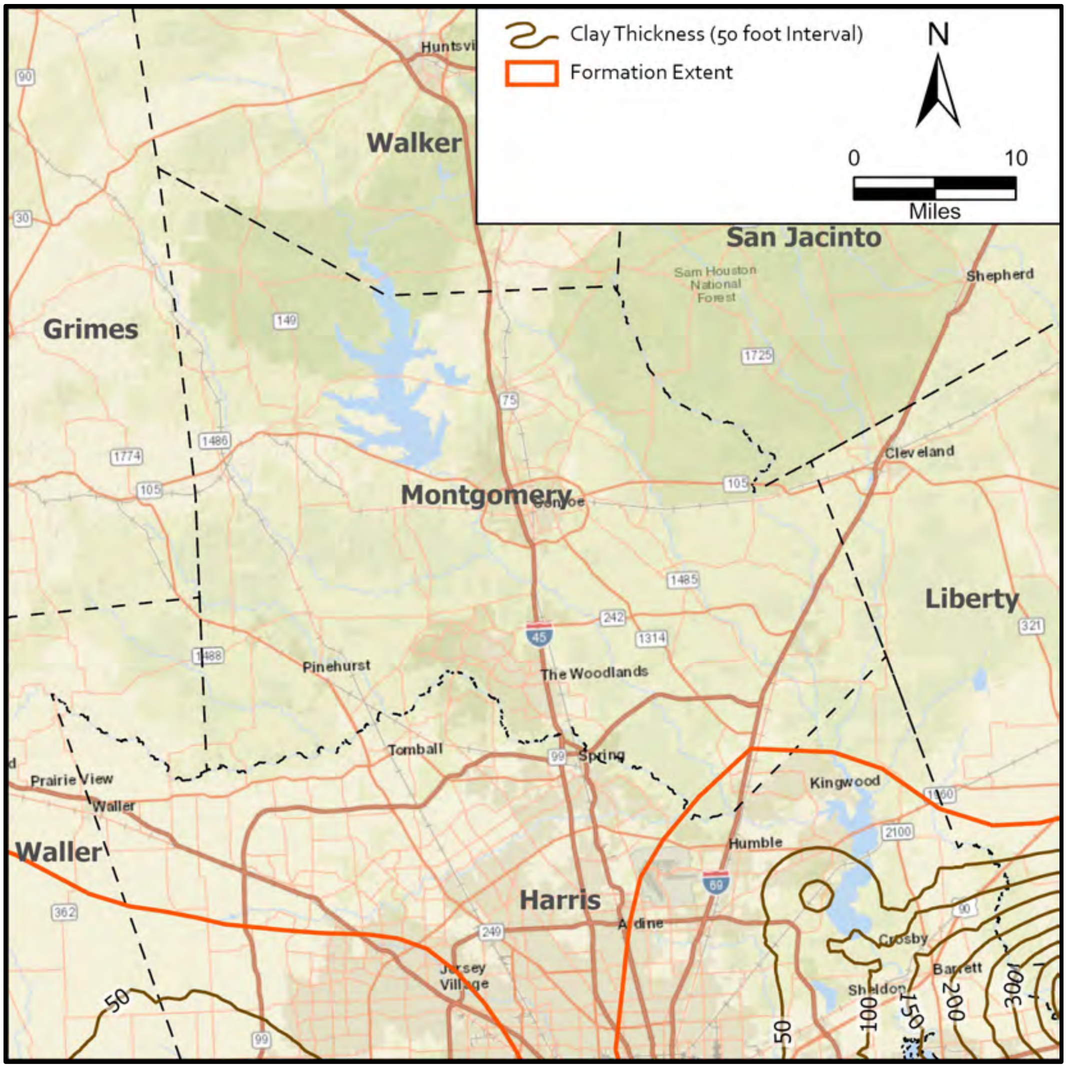


Figure 4. Clay thickness of the Upper Goliad Formation. Clay thickness calculated by subtracting the sand thickness from the total thickness as provided in the data set by Young and others (2012).

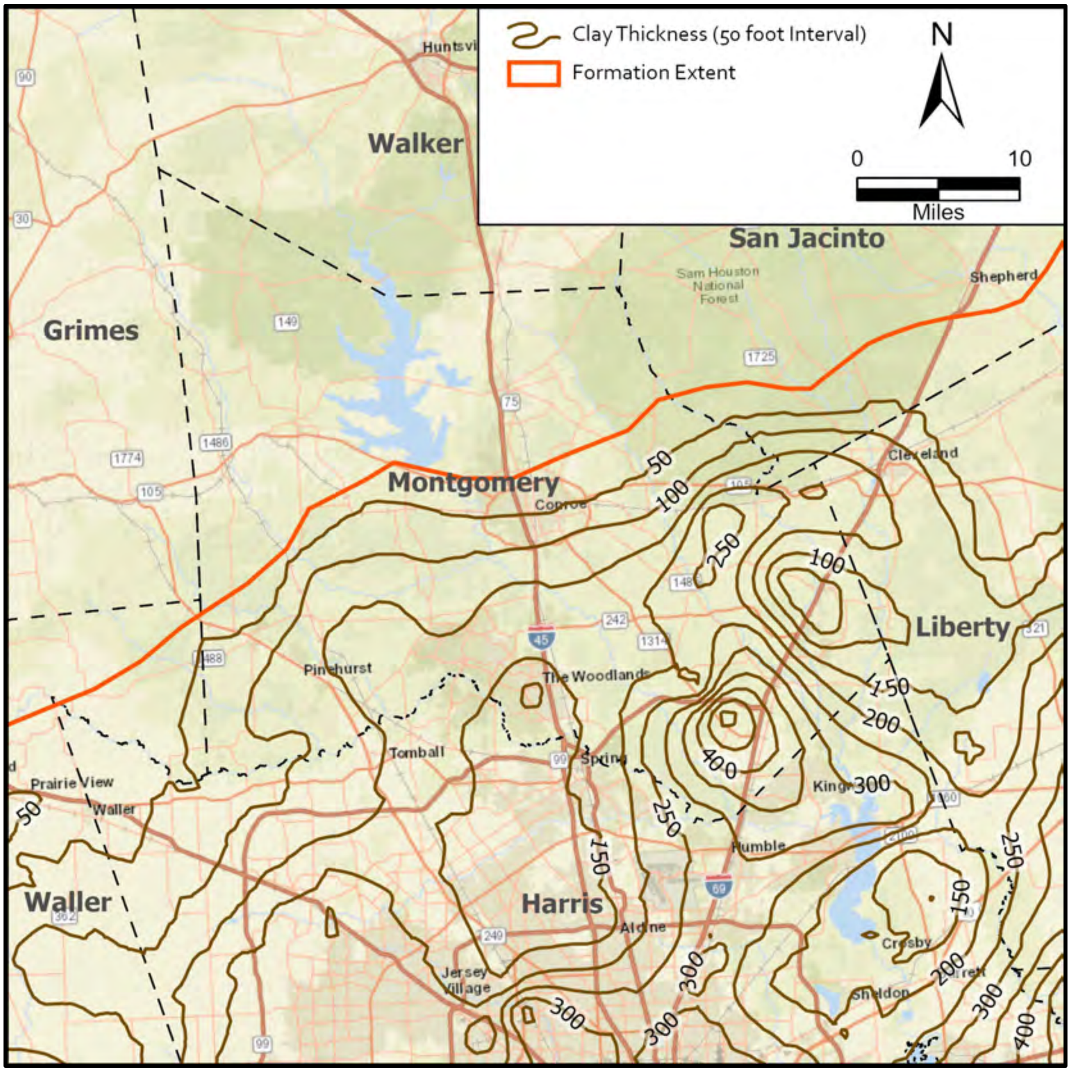


Figure 5. Clay thickness of the Lower Goliad Formation. Clay thickness calculated by subtracting the sand thickness from the total thickness as provided in the data set by Young and others (2012).

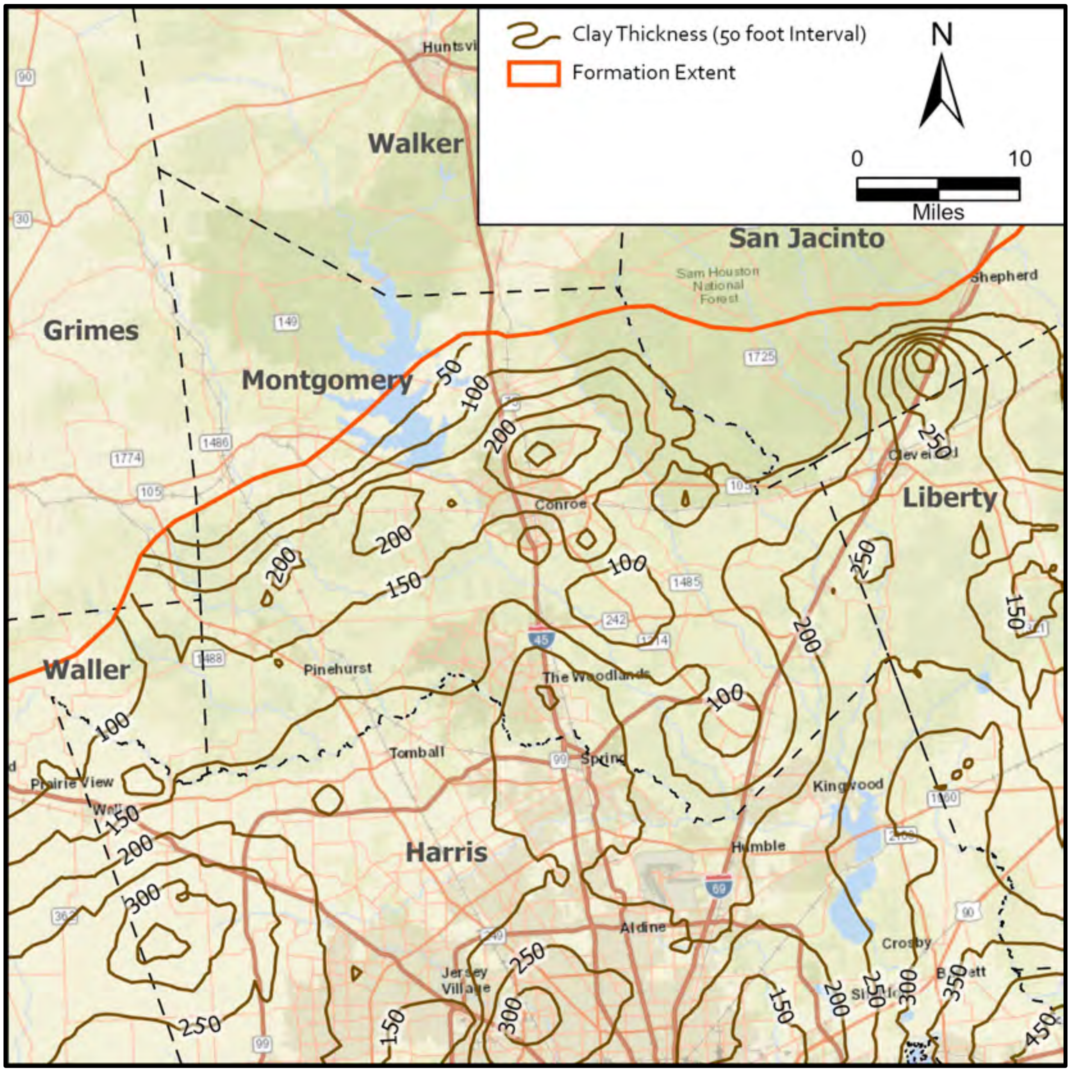


Figure 6. Clay thickness of the Upper Lagarto Formation. Clay thickness calculated by subtracting the sand thickness from the total thickness as provided in the data set by Young and others (2012).

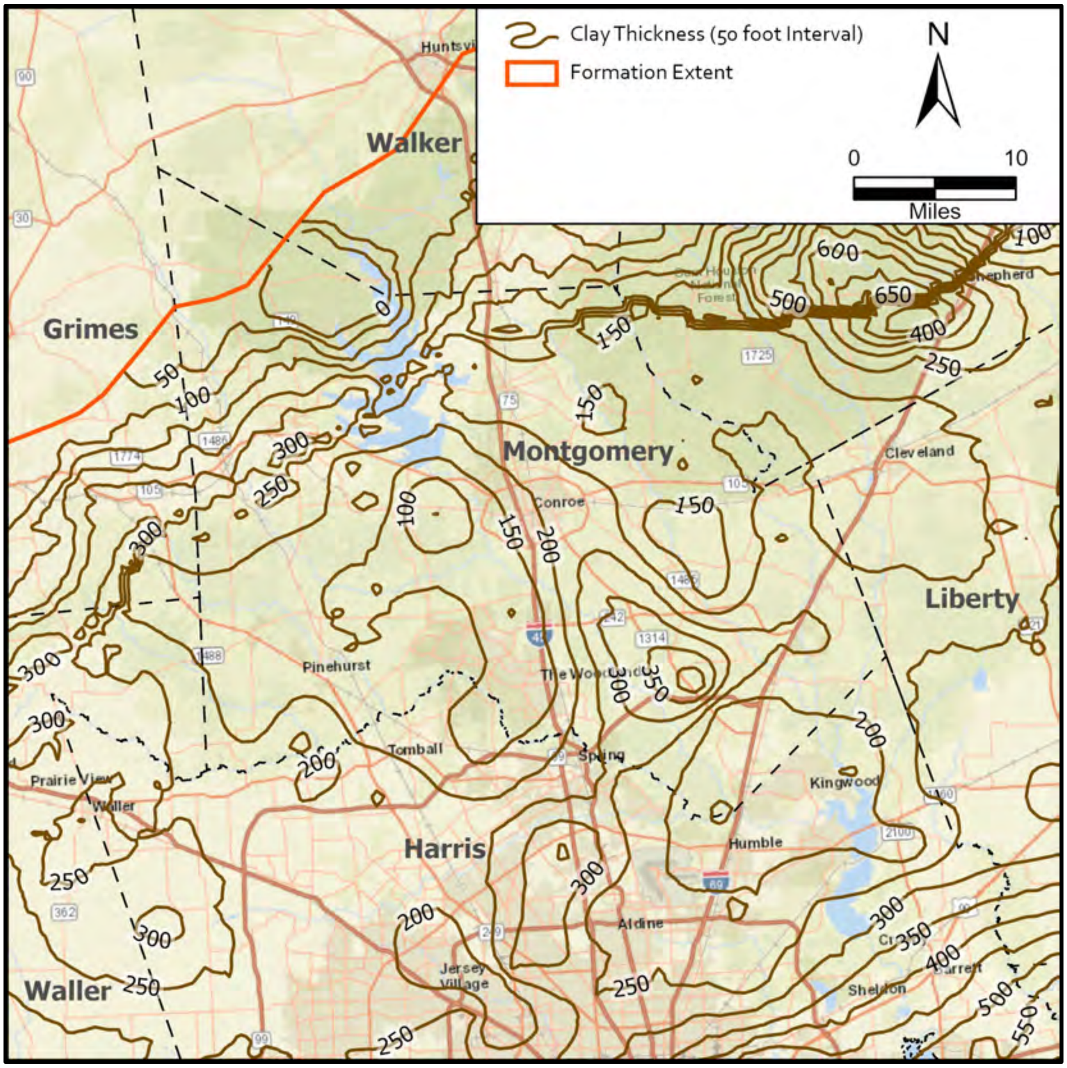


Figure 7. Clay thickness of the Middle Lagarto Formation. Clay thickness calculated by subtracting the sand thickness from the total thickness as provided in the data set by Young and others (2012).

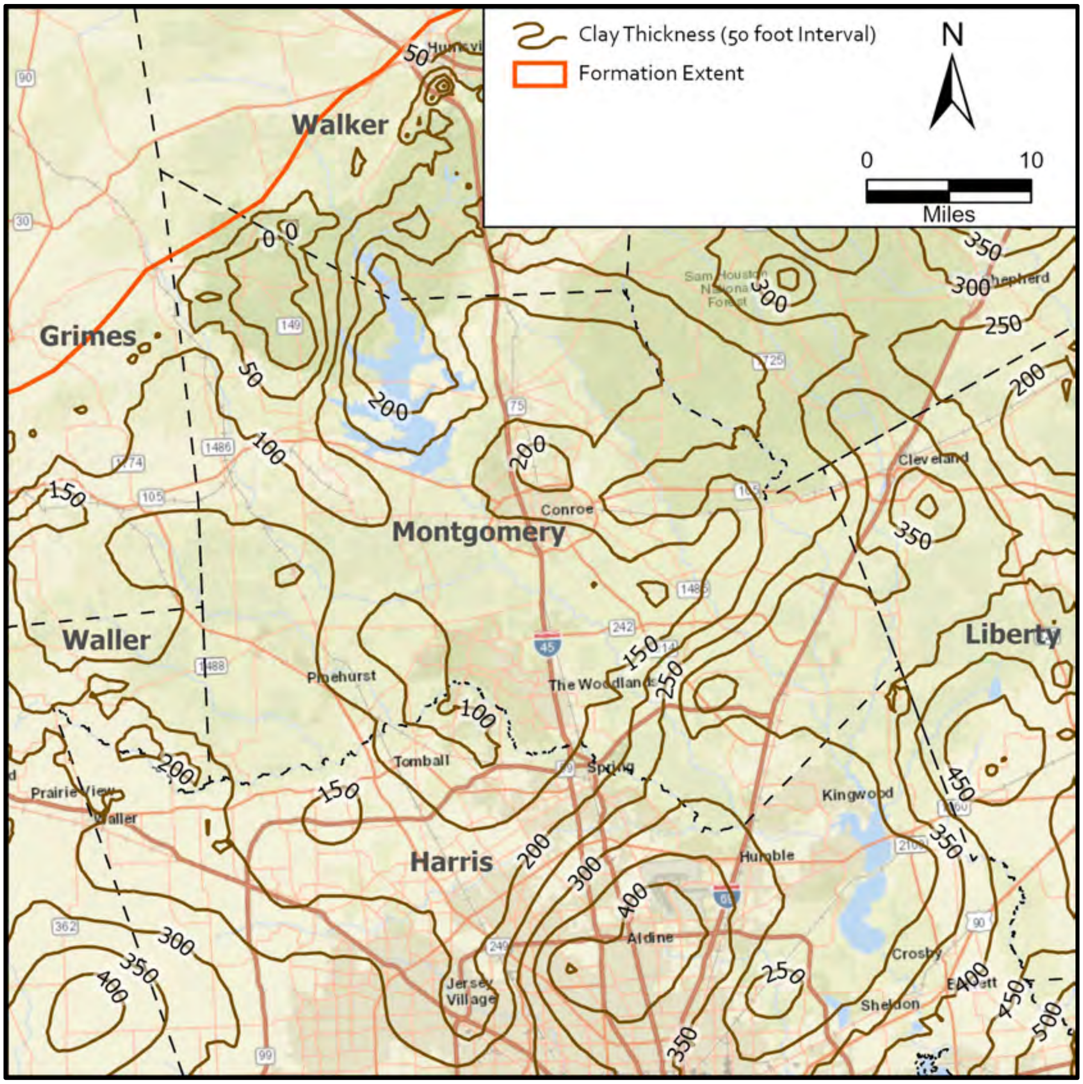


Figure 8. Clay thickness of the Lower Lagarto Formation. Clay thickness calculated by subtracting the sand thickness from the total thickness as provided in the data set by Young and others (2012).

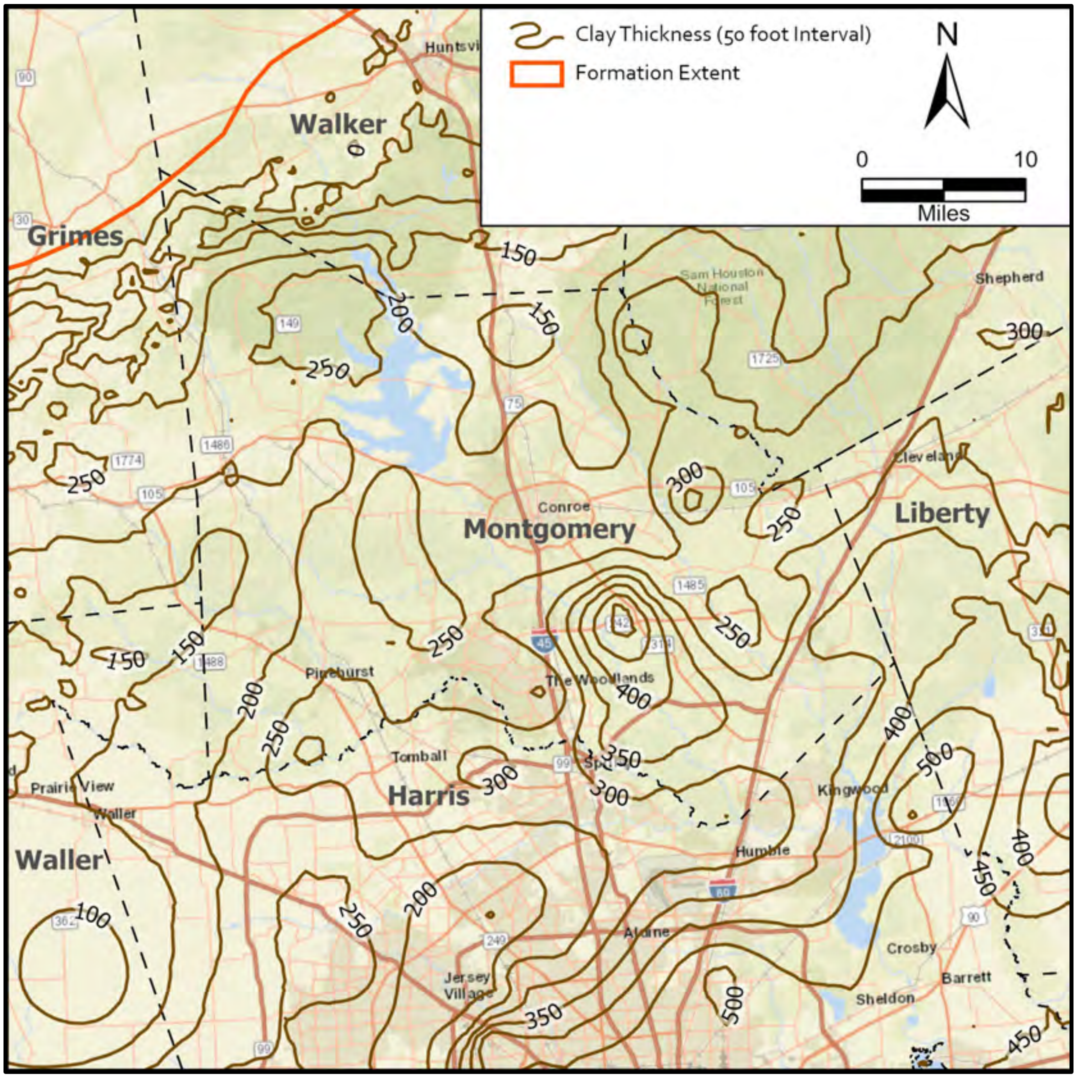


Figure 9. Clay thickness of the Oakville Formation. Clay thickness calculated by subtracting the sand thickness from the total thickness as provided in the data set by Young and others (2012).

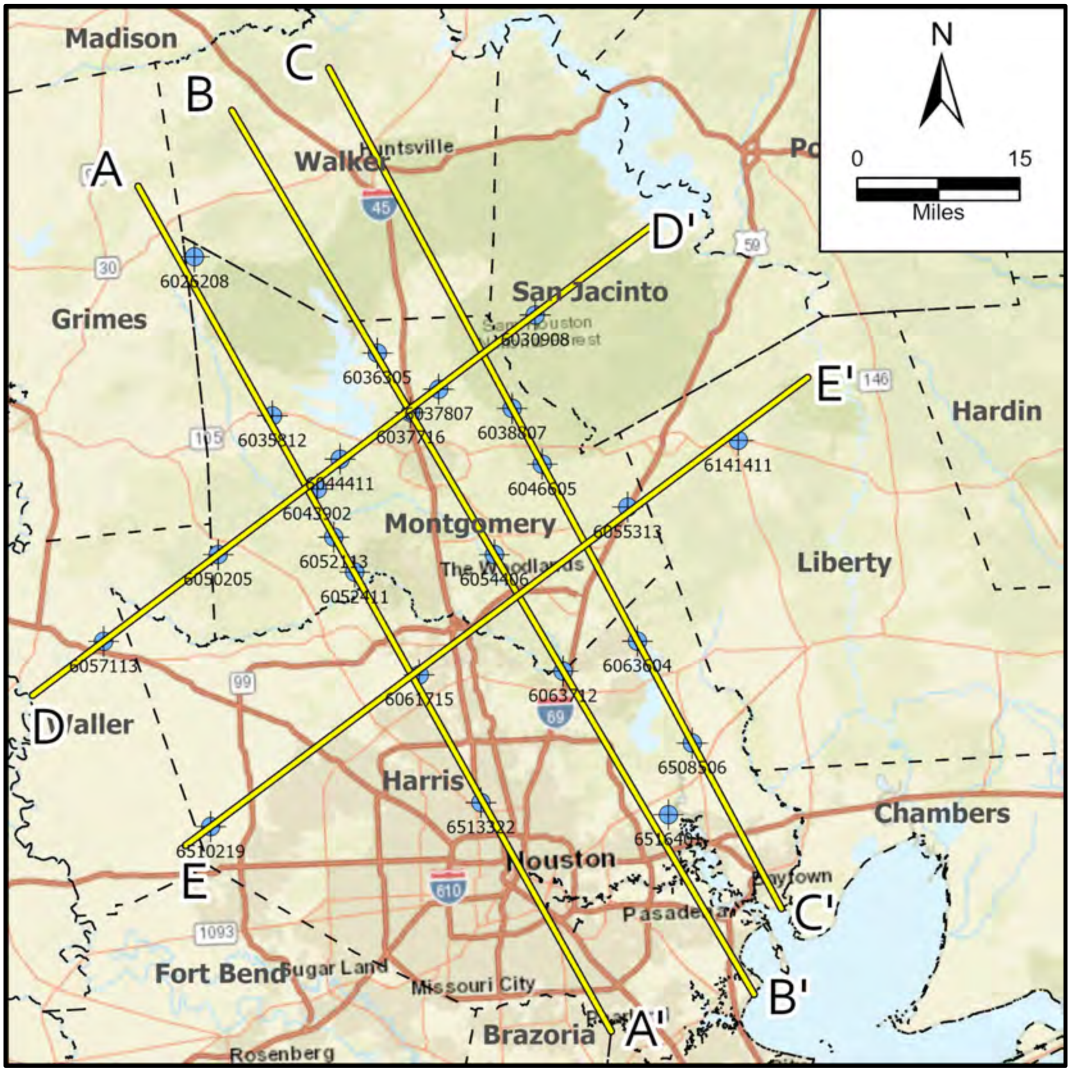


Figure 10. Location of cross-sections.

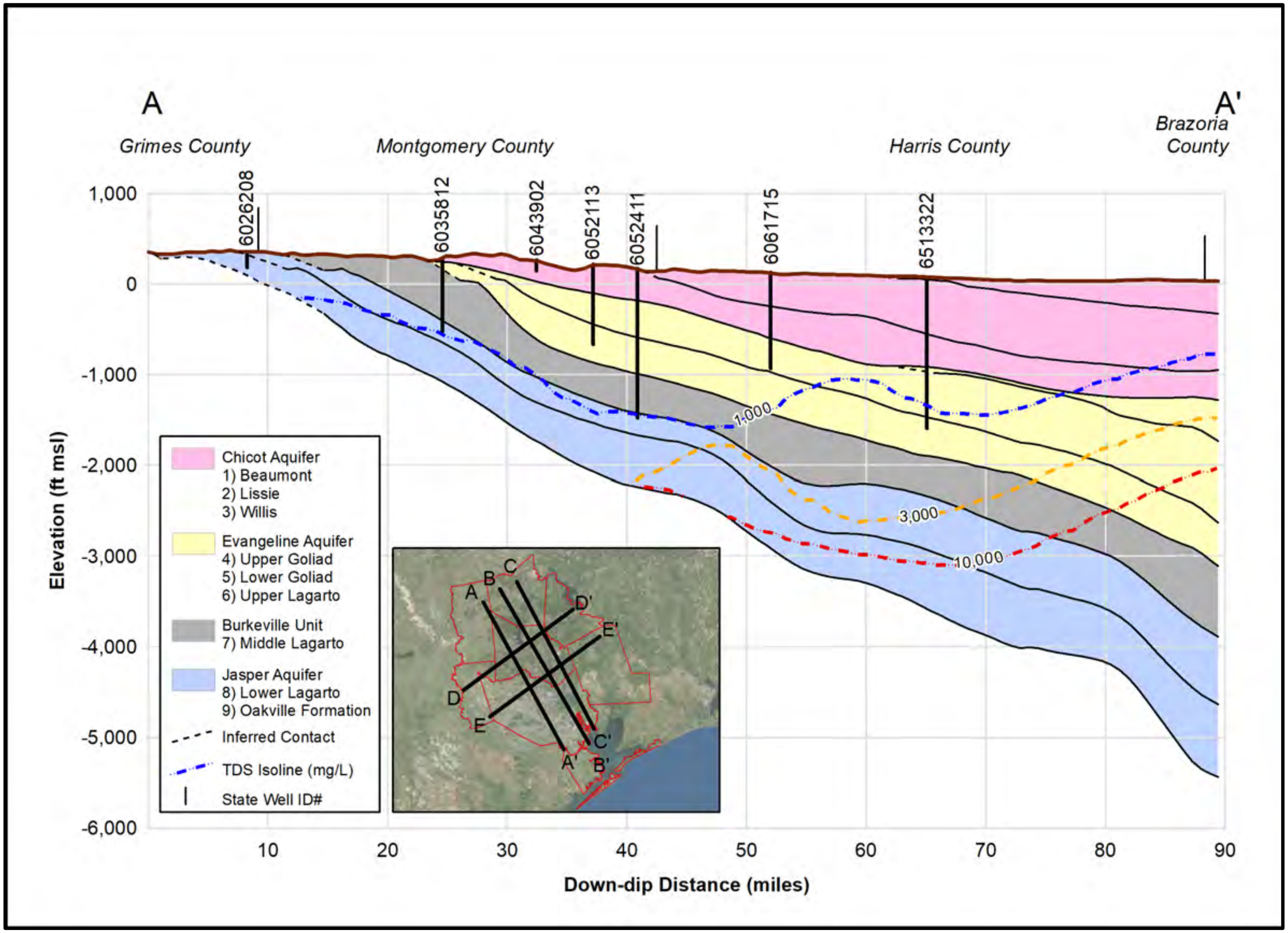


Figure 11. A-A' dip cross-section. Formation elevations from Young and others (2012). TDS isolines from Young and others (2016).

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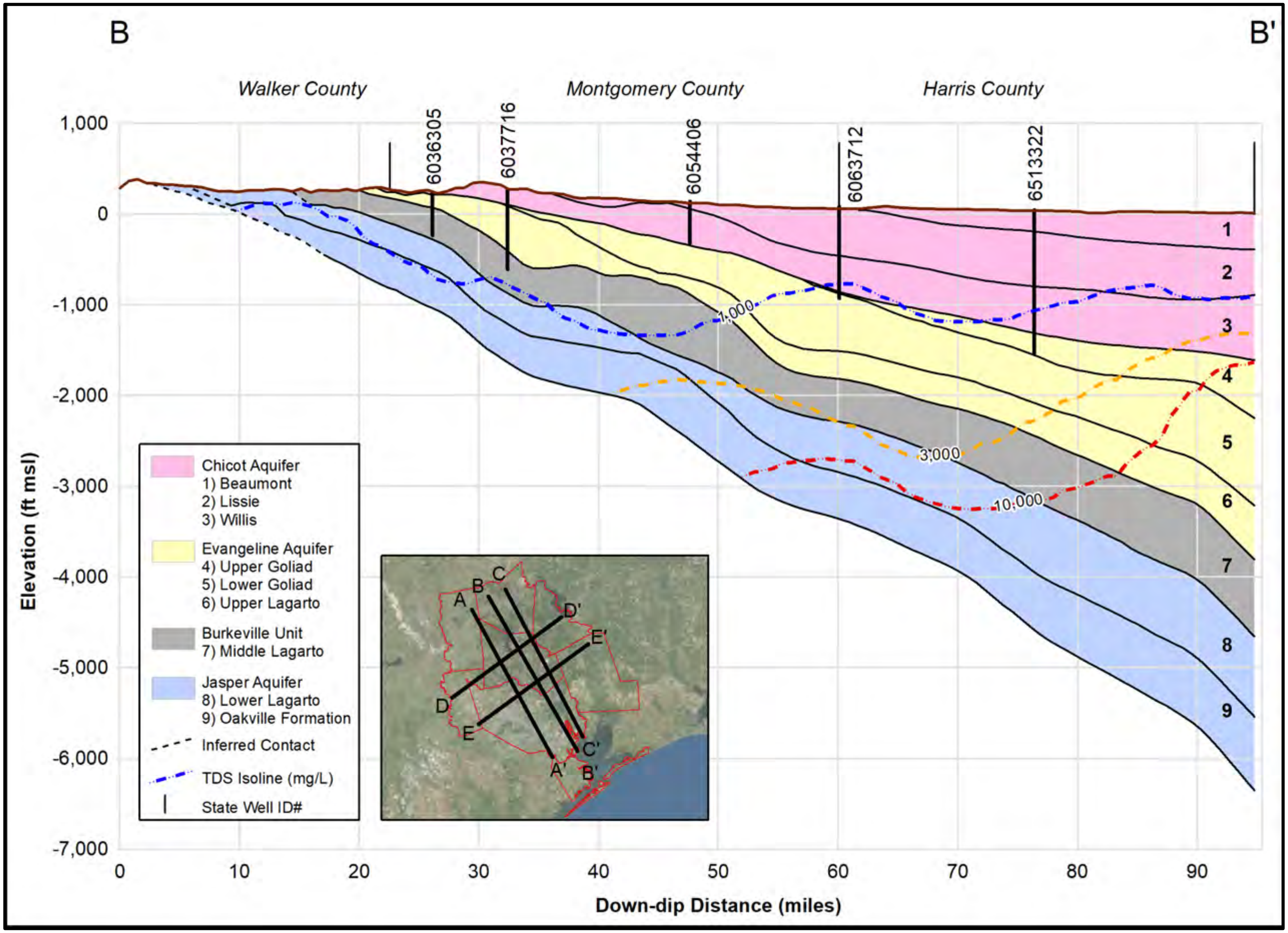

Figure 12. B-B' dip cross-section. Formation elevations from Young and others (2012). TDS isolines from Young and others (2016).

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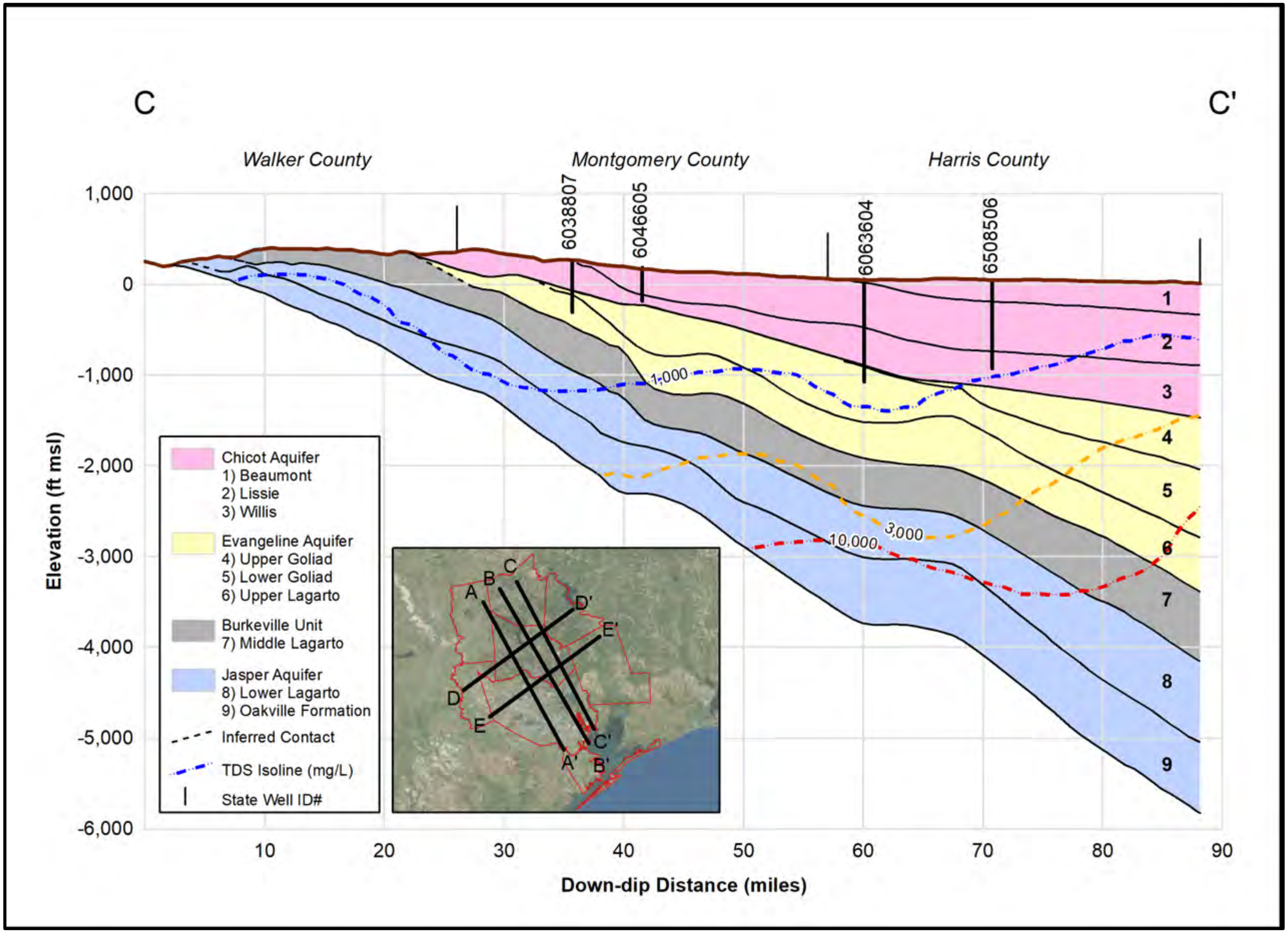

Figure 13. C-C' dip cross-section. Formation elevations from Young and others (2012). TDS isolines from Young and others (2016).

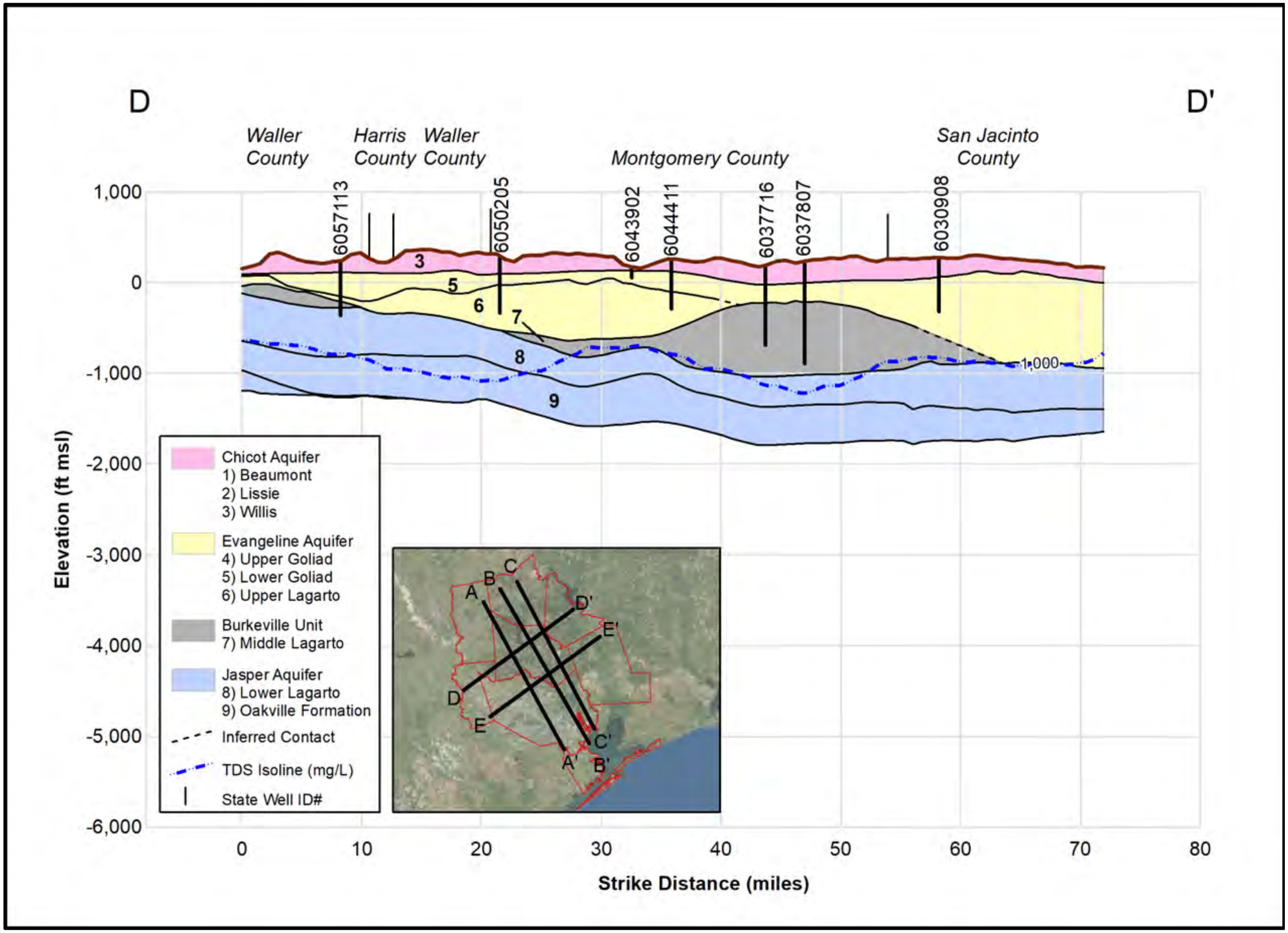

Figure 14. D-D' strike cross-section. Formation elevations from Young and others (2012). TDS isolines from Young and others (2016).

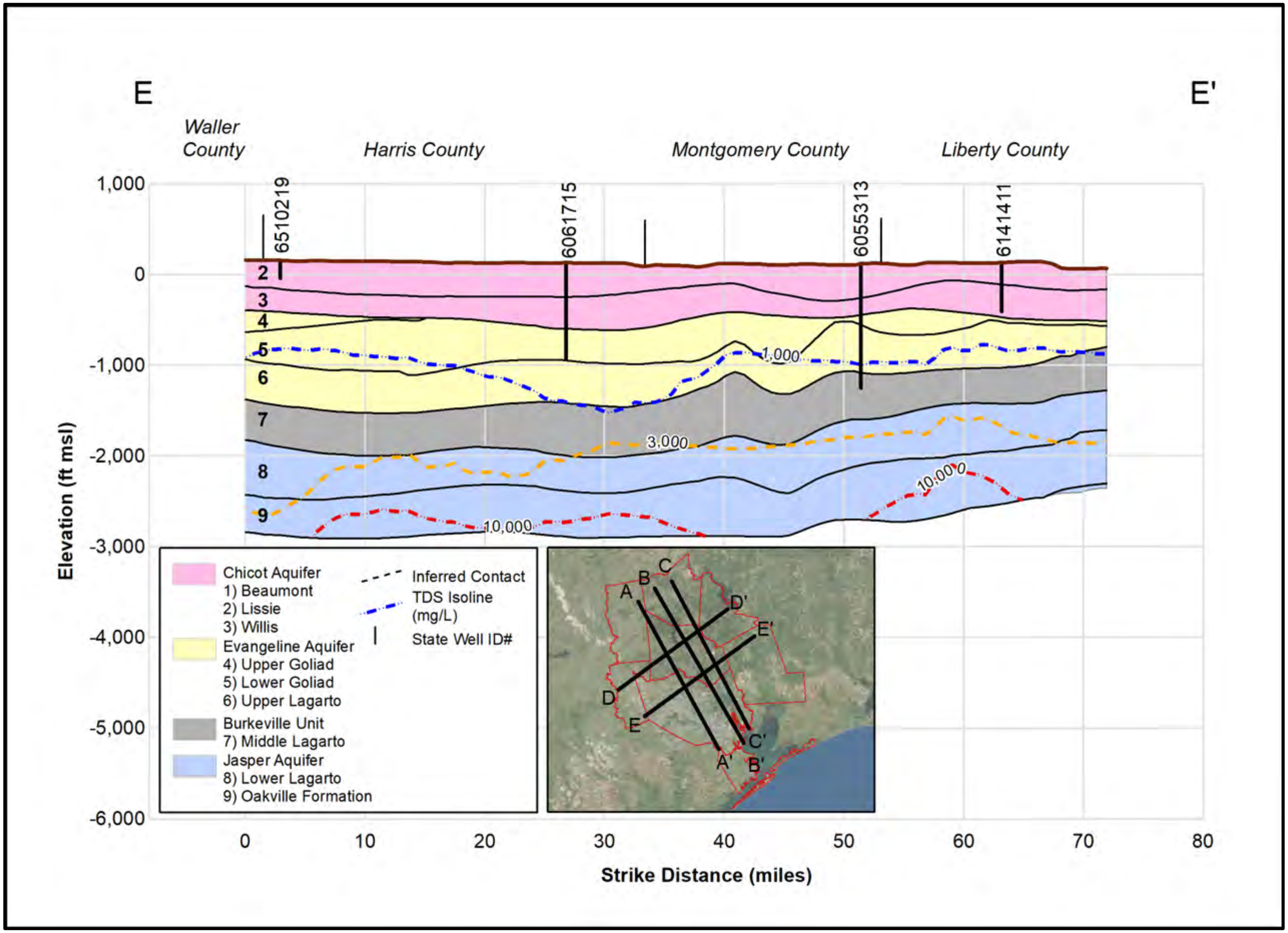

Figure 15. E-E' strike cross-section. Formation elevations from Young and others (2012). TDS isolines from Young and others (2016).

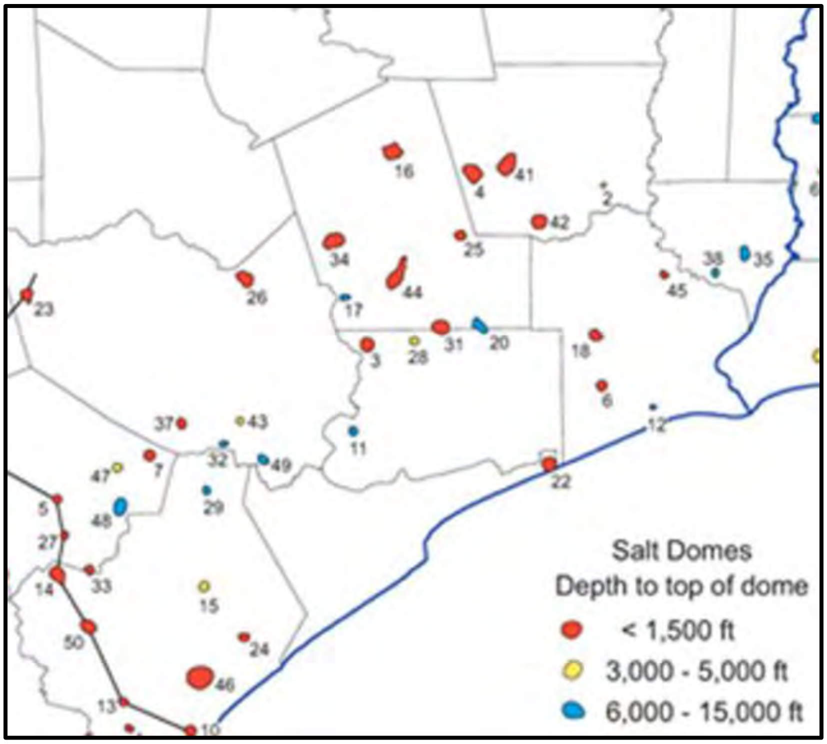

Figure 16. Salt domes in the Gulf Coast area. Reproduced from Young and others (2012).

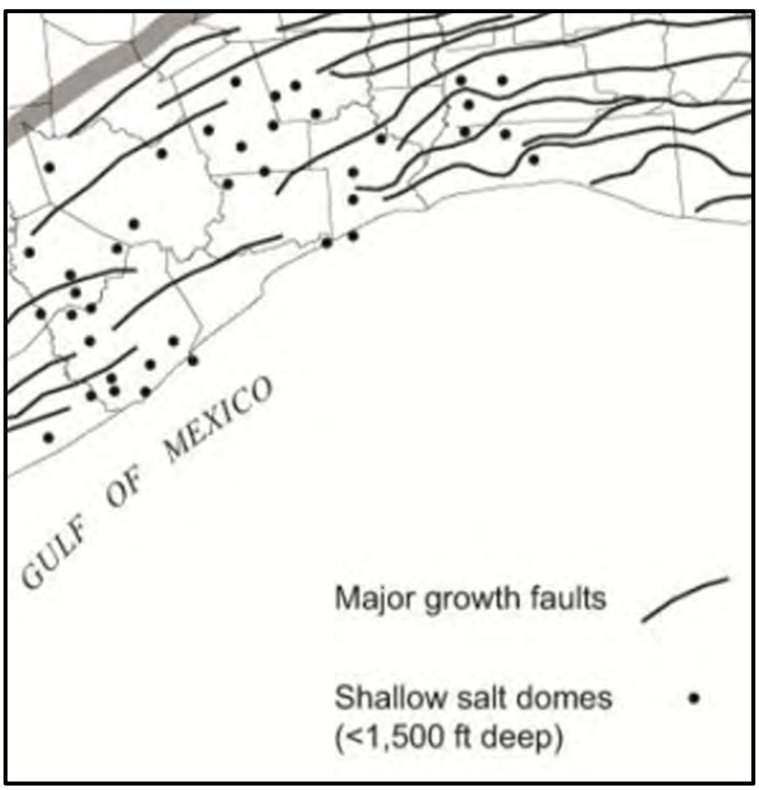

Figure 17. Illustration of major growth faults in the Gulf Coast area. Reproduced from Young and others (2012).

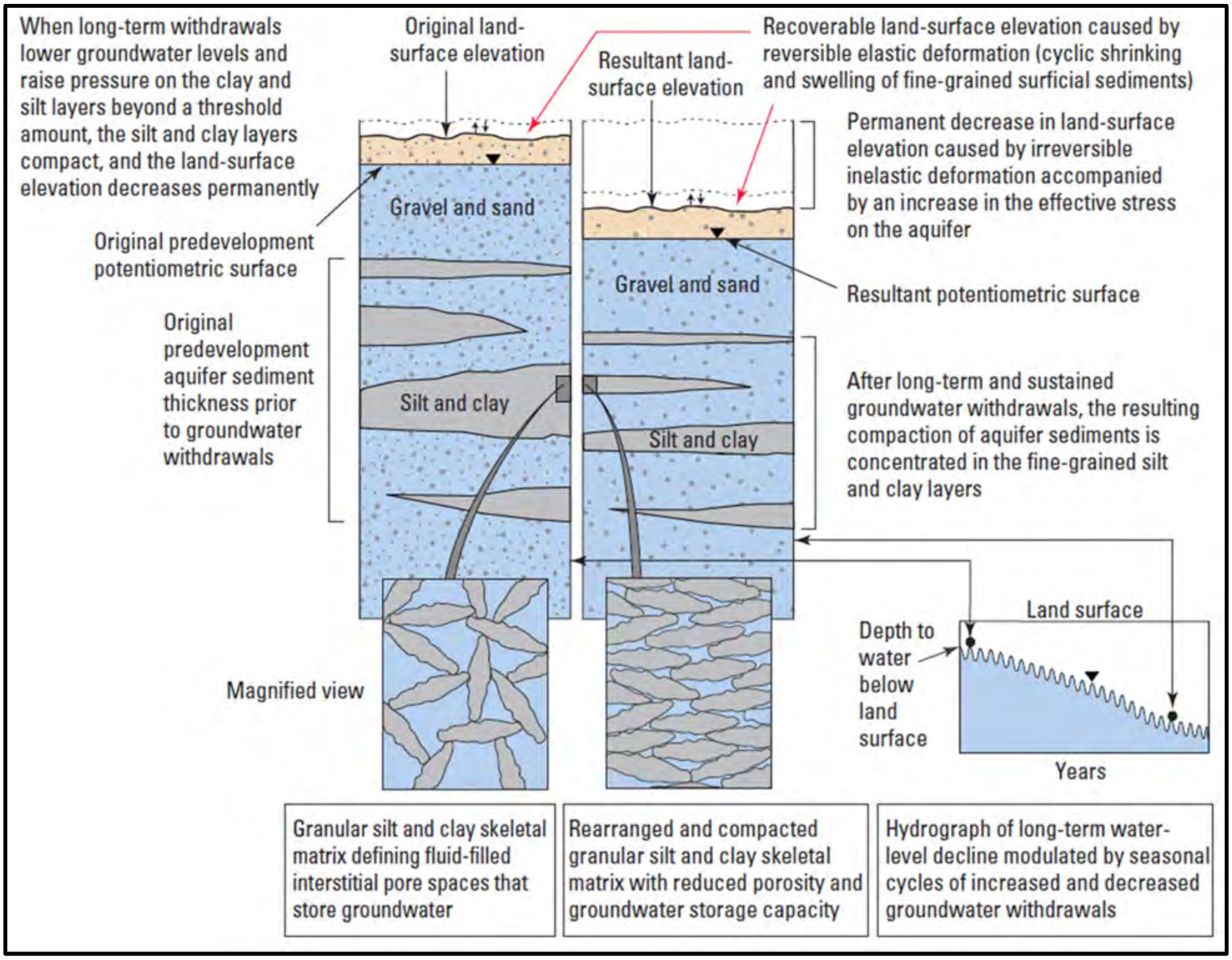

Figure 18. Illustration of subsidence due to reorientation of fine-grained aquifer sediments. Reproduced from Kasmarek and Ramage (2017).

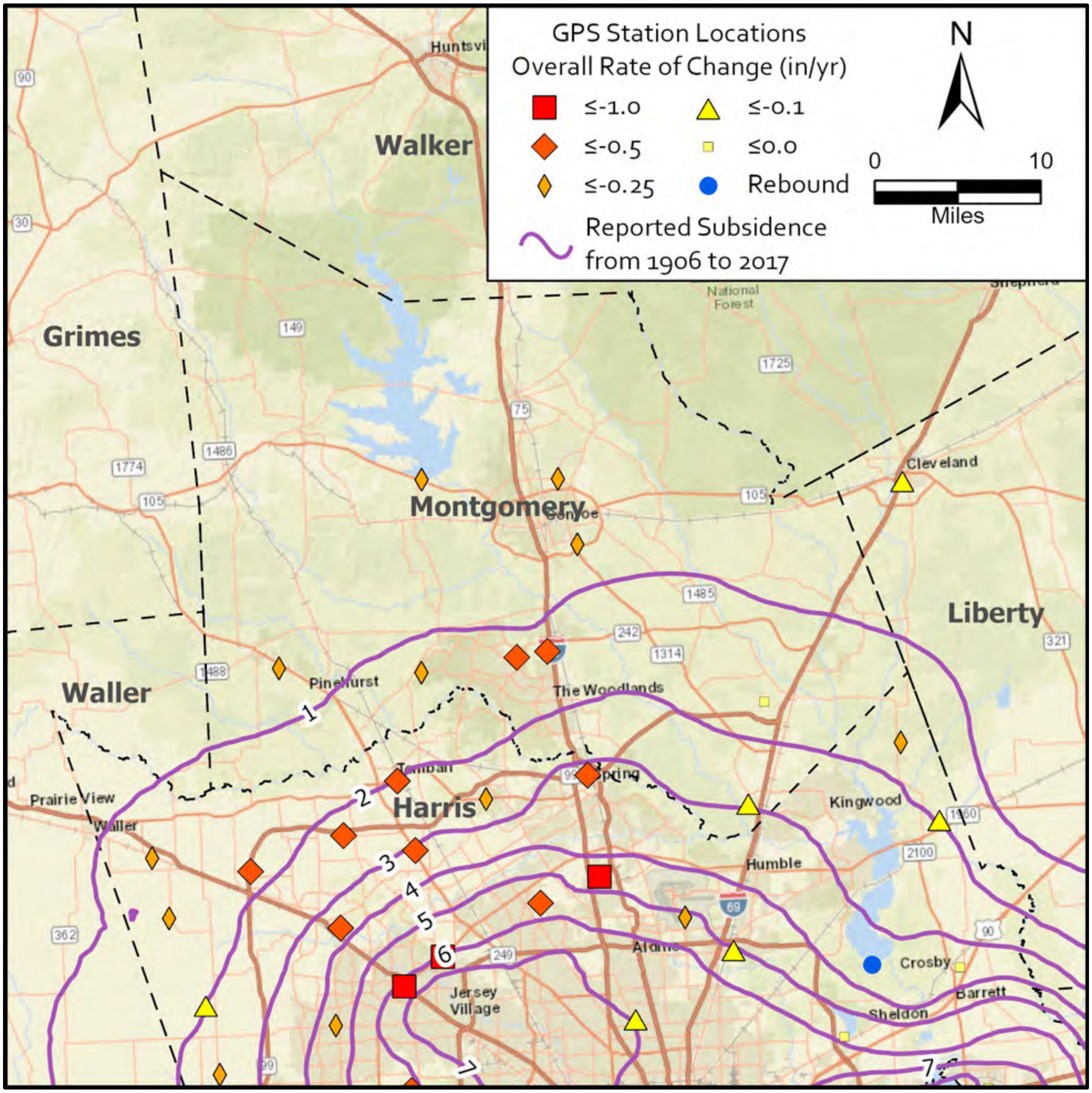

Figure 19. Subsidence rate at monitoring locations with a minimum of 5 year measurement history and reported land surface subsidence from 1906 through 2017.

Table 2. Geologic age and depositional systems associated with the layers of the Gulf Coast Aquifer System.

Hydrostatigraphic Unit	Geologic Age (Million Years)	Depositional System
Chicot Aquifer	Pliestocene/Pliocene (≤5.3)	Fluvial/Meanderbelt
Evangeline Aquifer	Pliocene/Miocene	Lower Coastal Plain Fluvial/Coastal
Burkeville Confining Layer	Miocene	Lower Coastal Plain Fluvial/ Coastal/Bay Fill/Lagoonal
Jasper Aquifer	Miocene (≤23.7)	Wave Dominated Delta Facies

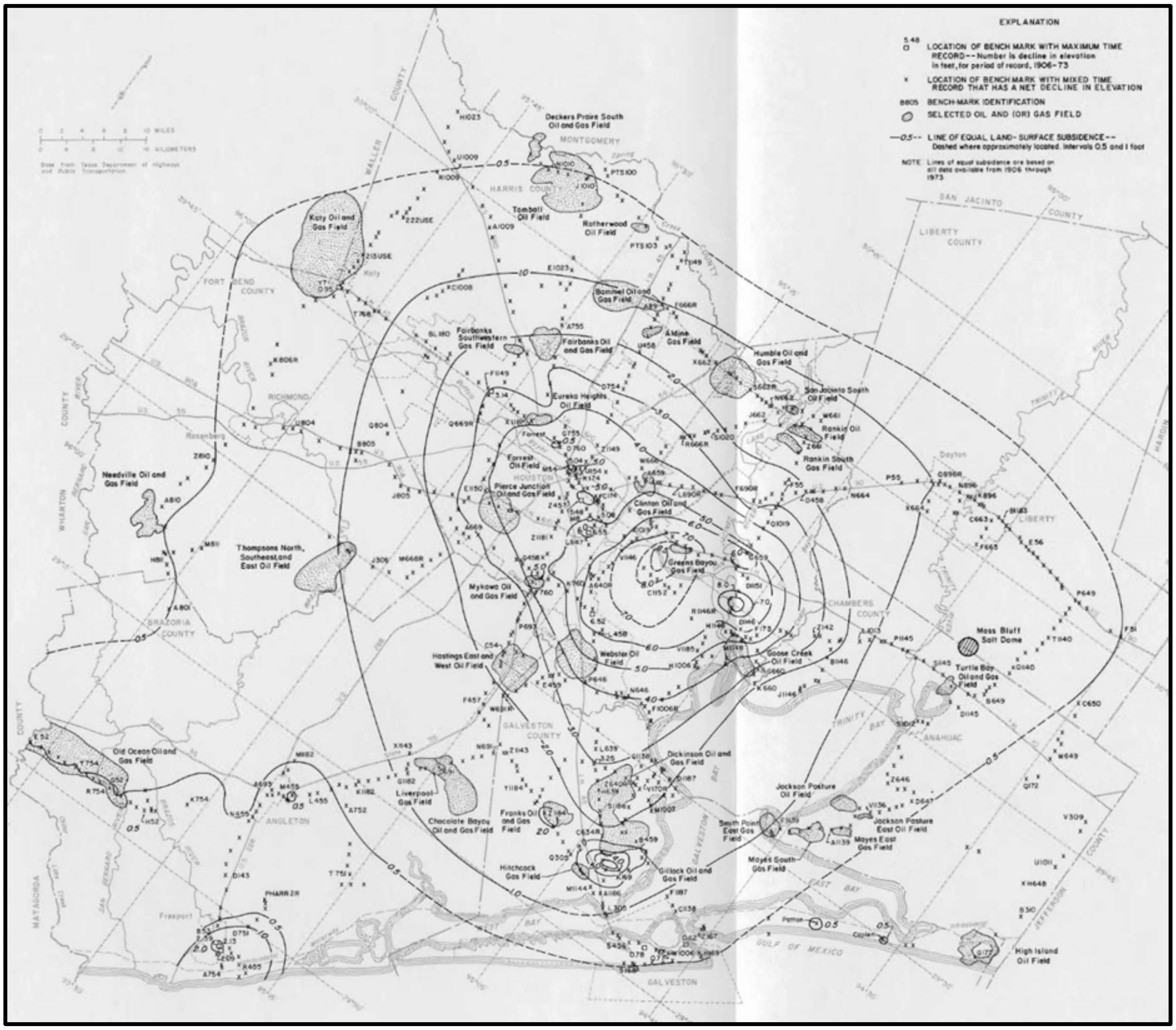

Figure 20. Land-surface subsidence in Subregion 2, 1906-1973, as calculated by Ratzlaff (1982). Reproduced without alteration from Figure 5 of Ratzlaff (1982).

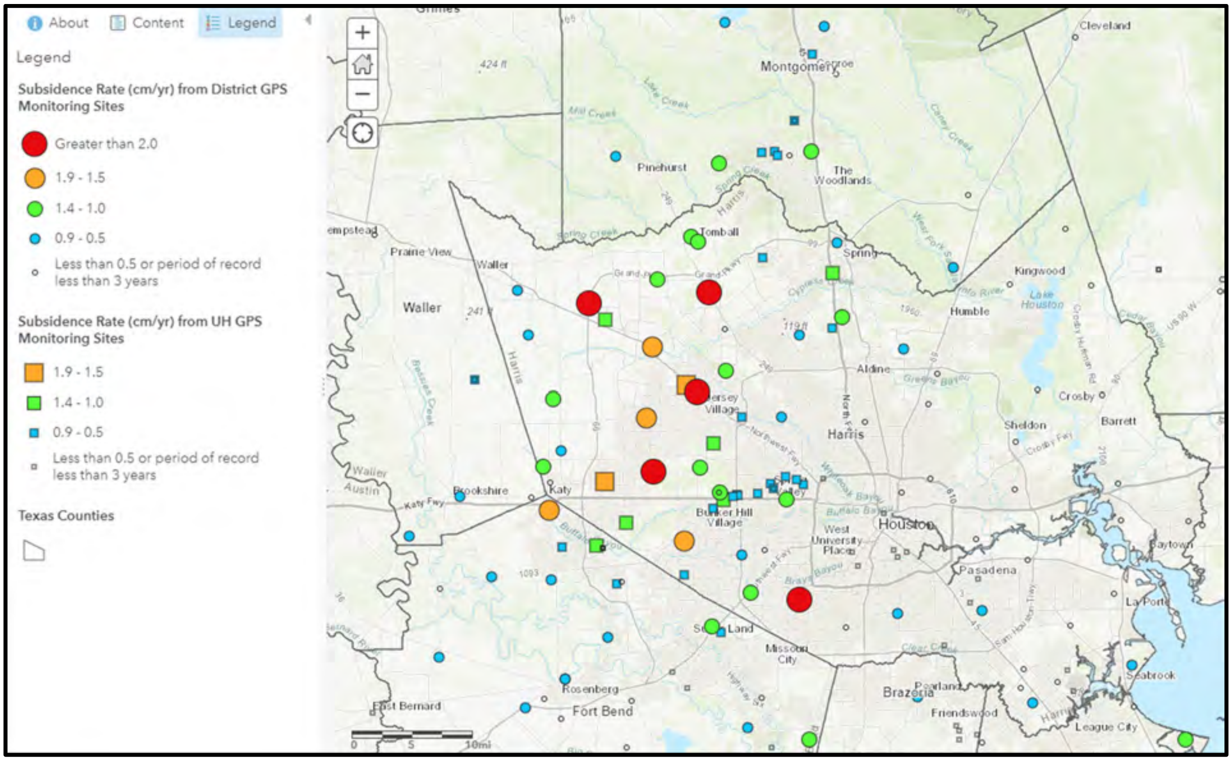

Figure 21. Rate of subsidence in the Houston area. Larger, warm color circles indicate a higher rate of subsidence (https://www.arcgis.com/home/webmap/viewer.html?webmap=a3e7214071f6421fb745d9866e2d3985).

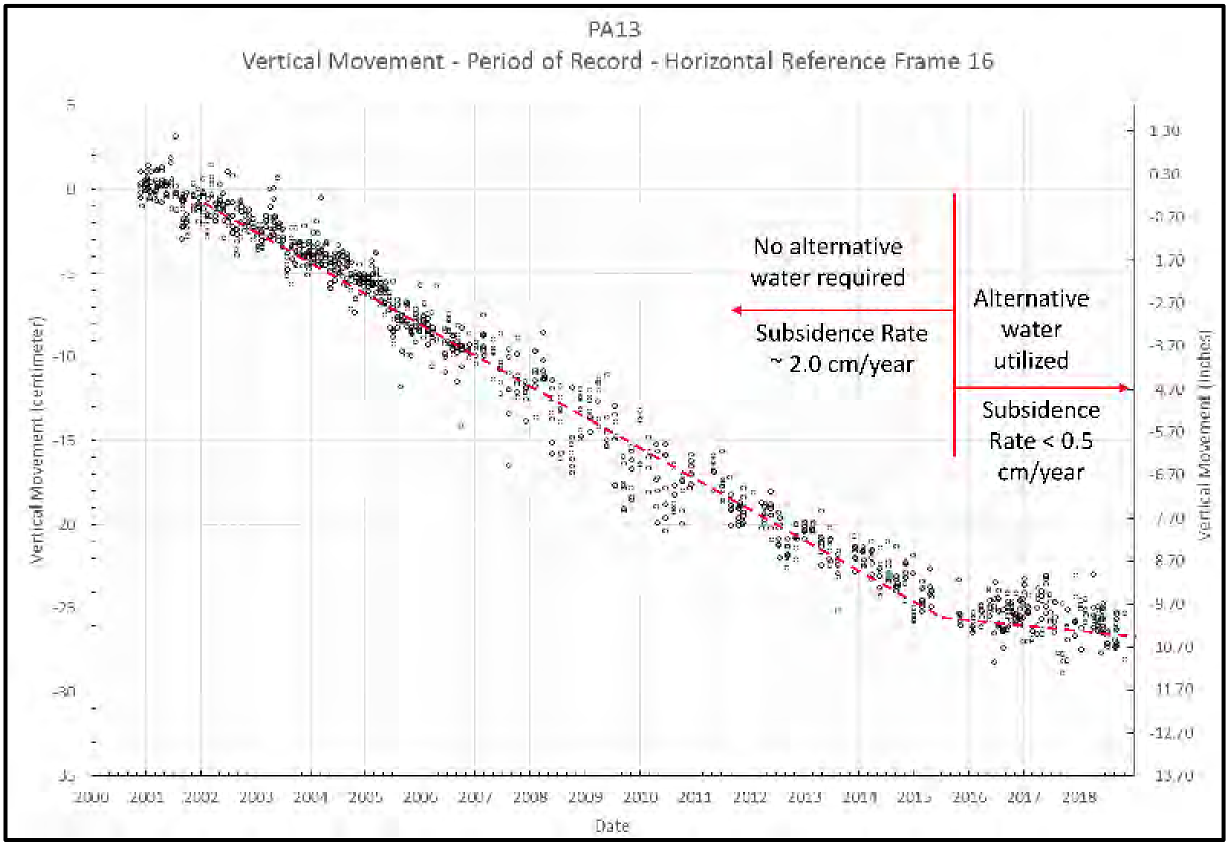

Figure 22. GPS measurements of the vertical change in land surface at PA13 site near The Woodlands (HGSD Annual Groundwater Report, PowerPoint Presentation by Michael Turco to GMA 14, 6/26/19).

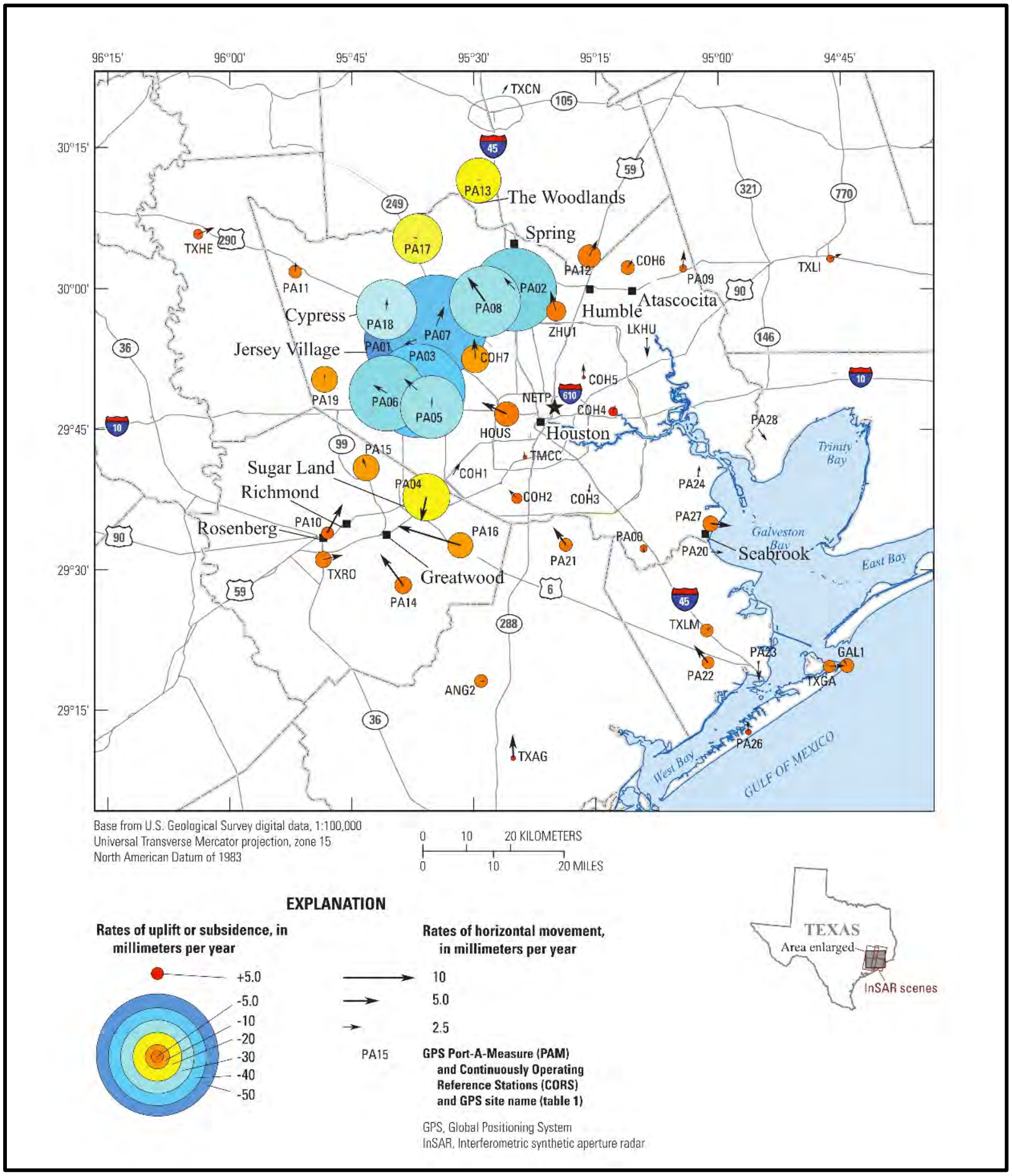

Figure 23. Map illustrating rates of subsidence from GPS readings (from Bawden, Johnson, Kasmarek, Brandt, and Middleton, 2012).

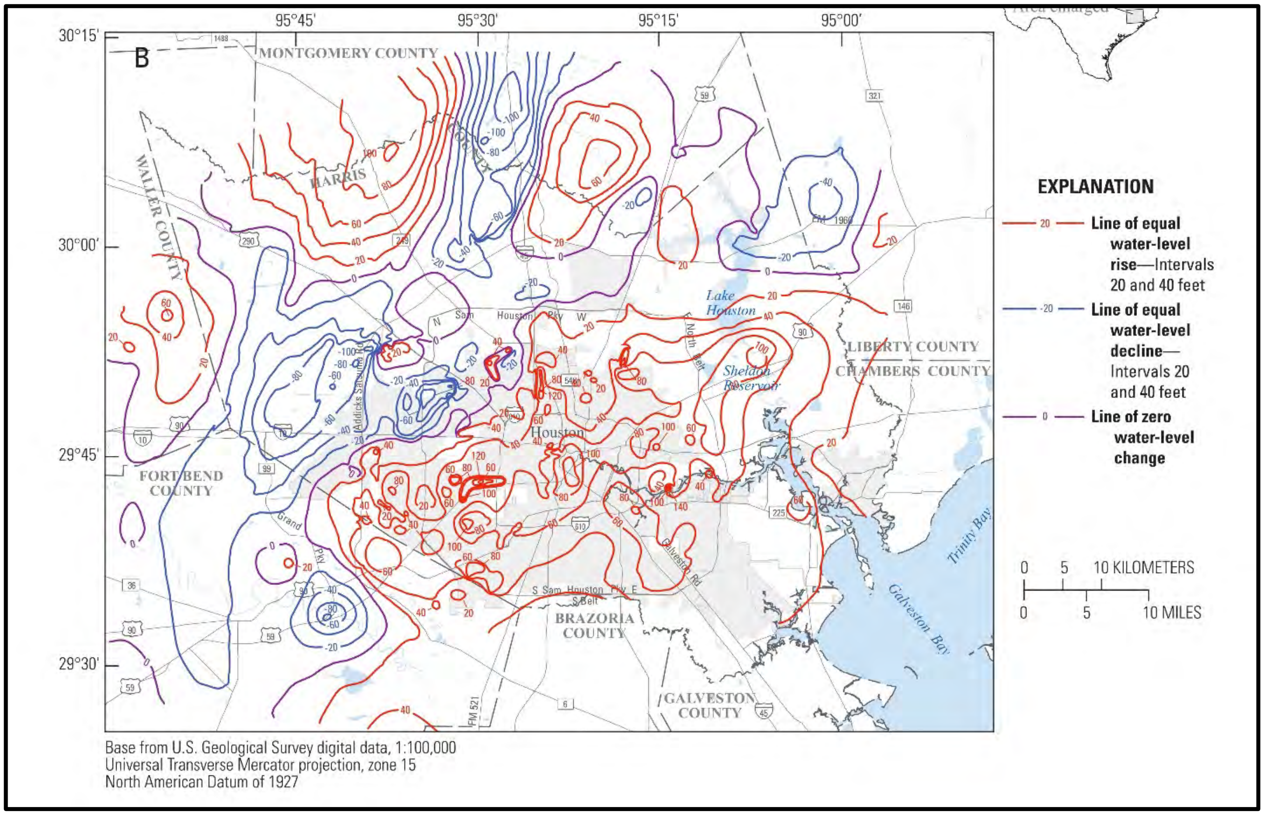

Figure 24. Map illustrating changes in water levels in the Evangeline aquifer between 1990 and 2003 (from Bawden, Johnson, Kasmarek, Brandt, and Middleton, 2012).

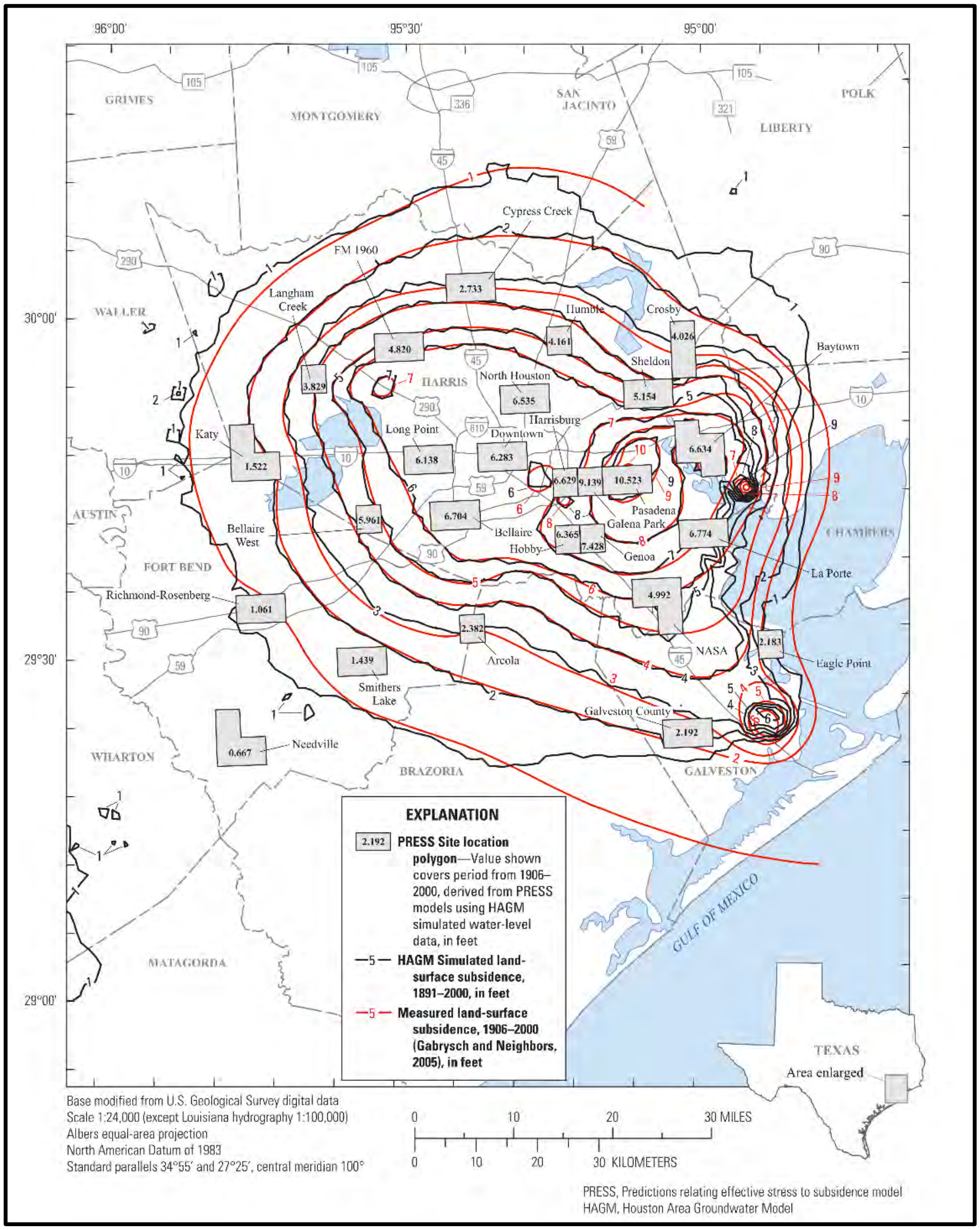

Figure 25. Map showing long-term subsidence values from PRESS models, HAGM simulations, and measurements (from Kasmarek, 2013).

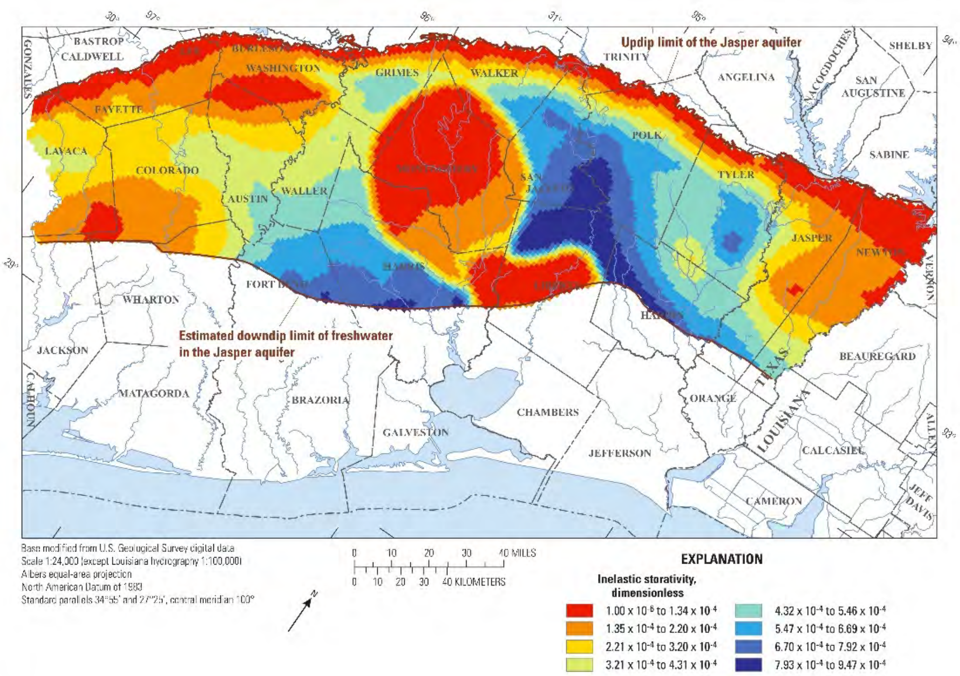

Figure 18. Simulated inelastic-clay storativity of the Jasper aquifer in the Houston Area Groundwater Model study area.

Simulation of Groundwater Flow and Land-Surface Subsidence 31

Figure 26. Map showing HAGM values for inelastic-clay storativity in the Jasper aquifer (from Kasmarek, 2013)

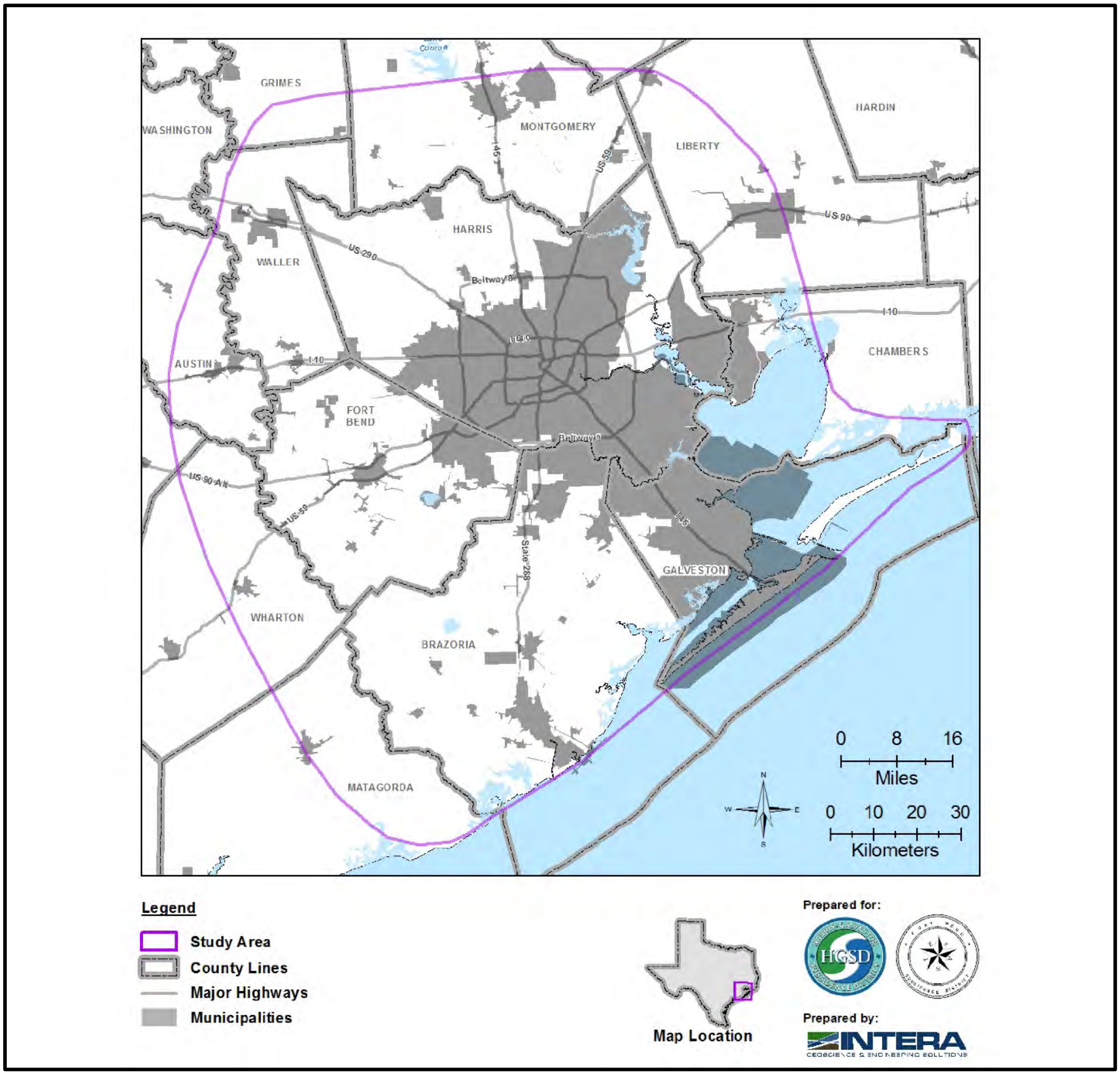

Figure 27. Map showing the study area for INTERA's brackish Jasper aquifer subsidence risk assessment (from Kelley, Deeds, Young and Pinkard, 2018).

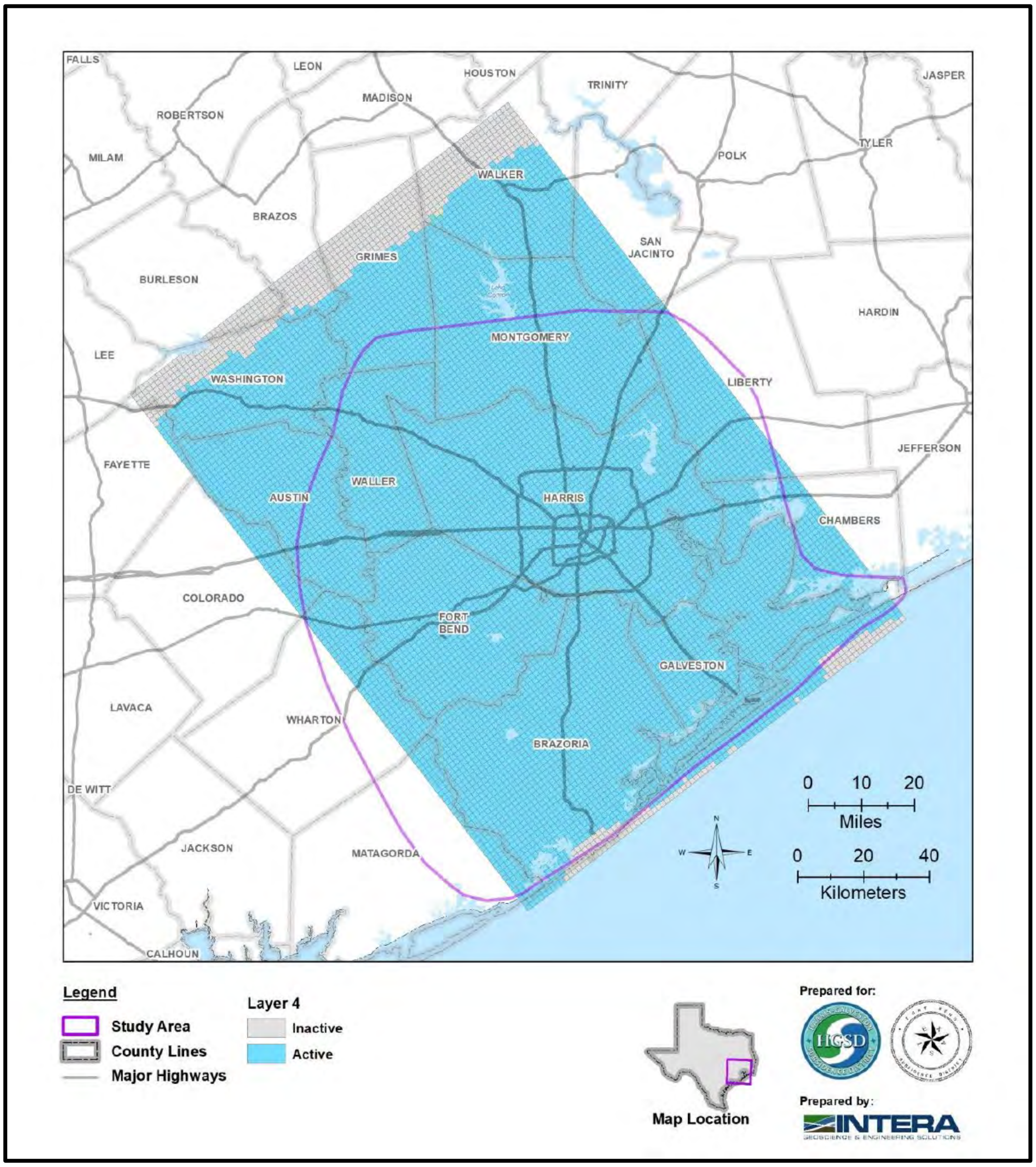

Figure 28. Map showing INTERA's model grid for its brackish Jasper aquifer subsidence risk assessment (from Kelley, Deeds, Young, and Pinkard, 2018).

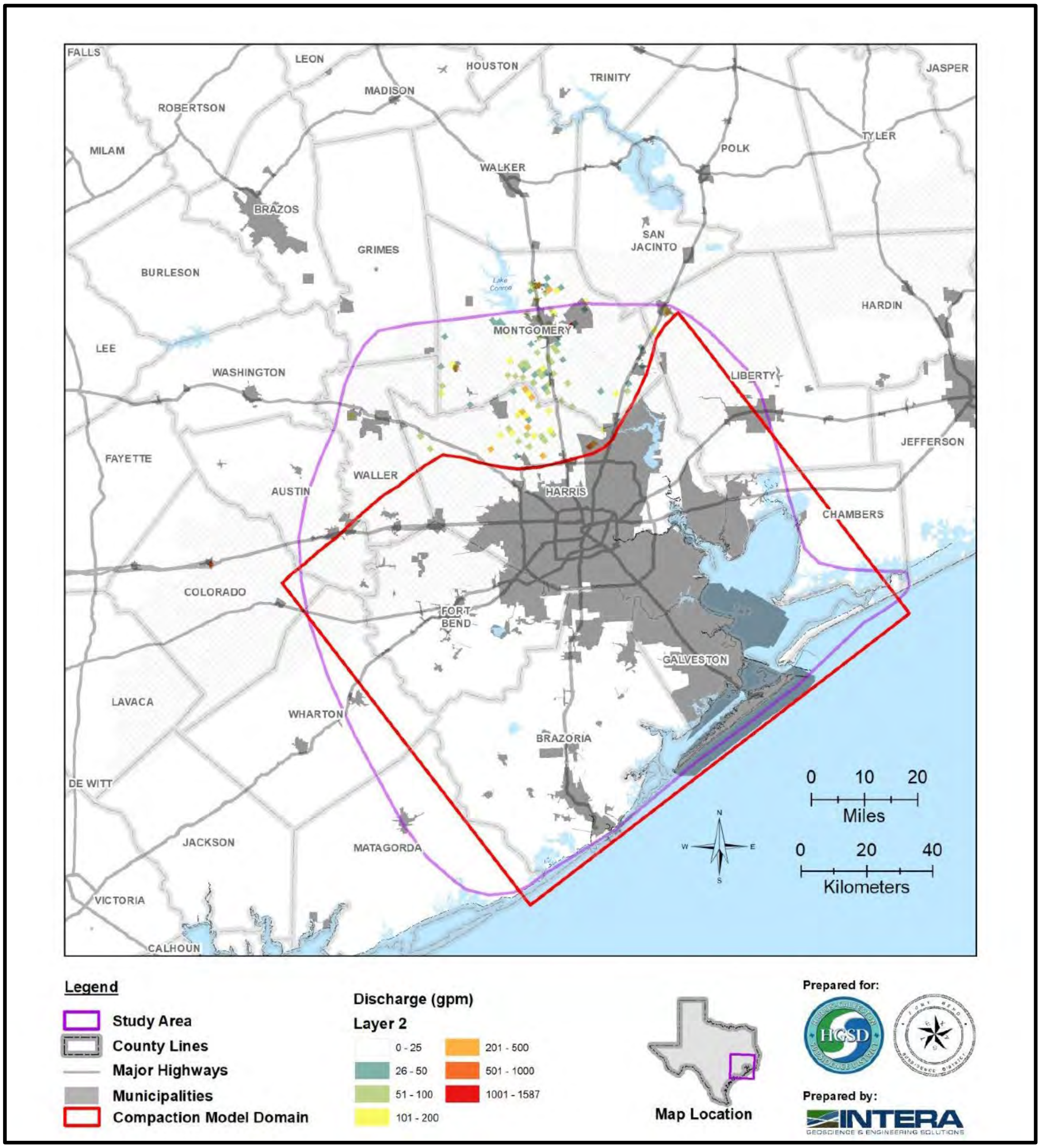

Figure 29. Map showing INTER's extent of Jasper compaction modeling domain (from Kelley, Deeds, young, and Pinkard, 2018)

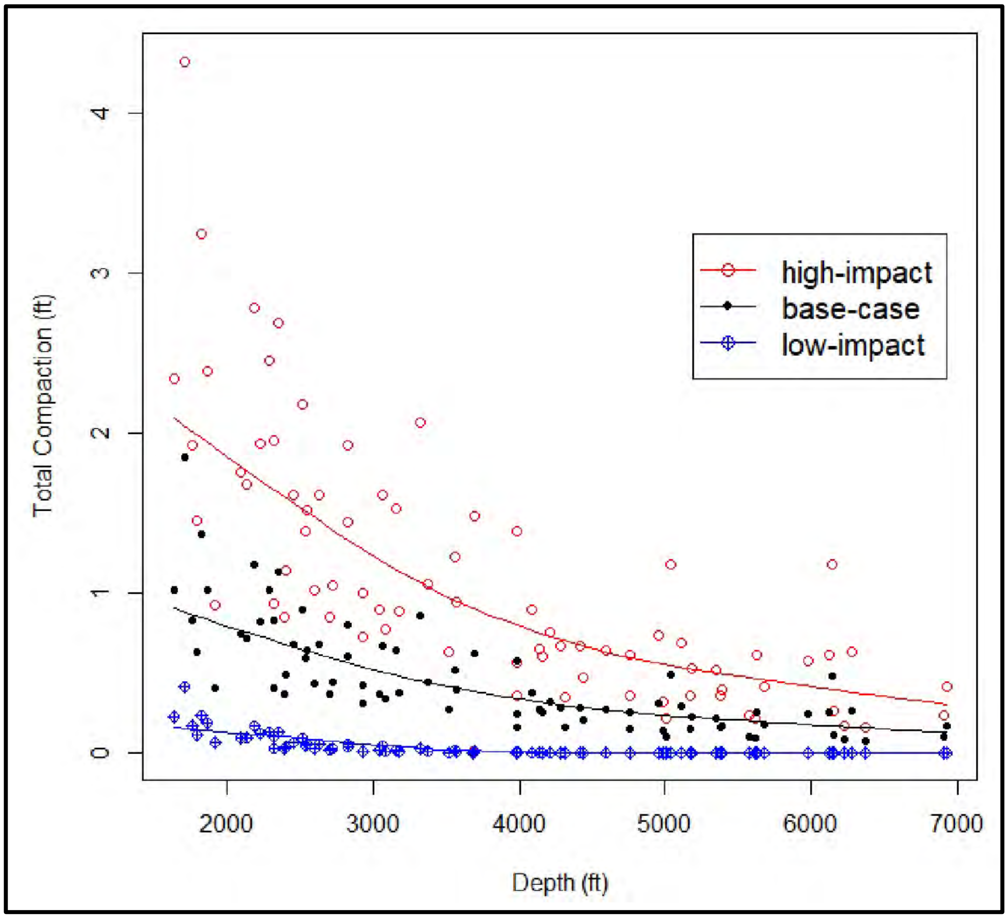

Figure 30. Chart showing INTERA's simulated variation of 10-year compaction with depth for three sensitivity cases – Jasper aquifer (from Kelley, Deeds, young, and Pinkard, 2018)

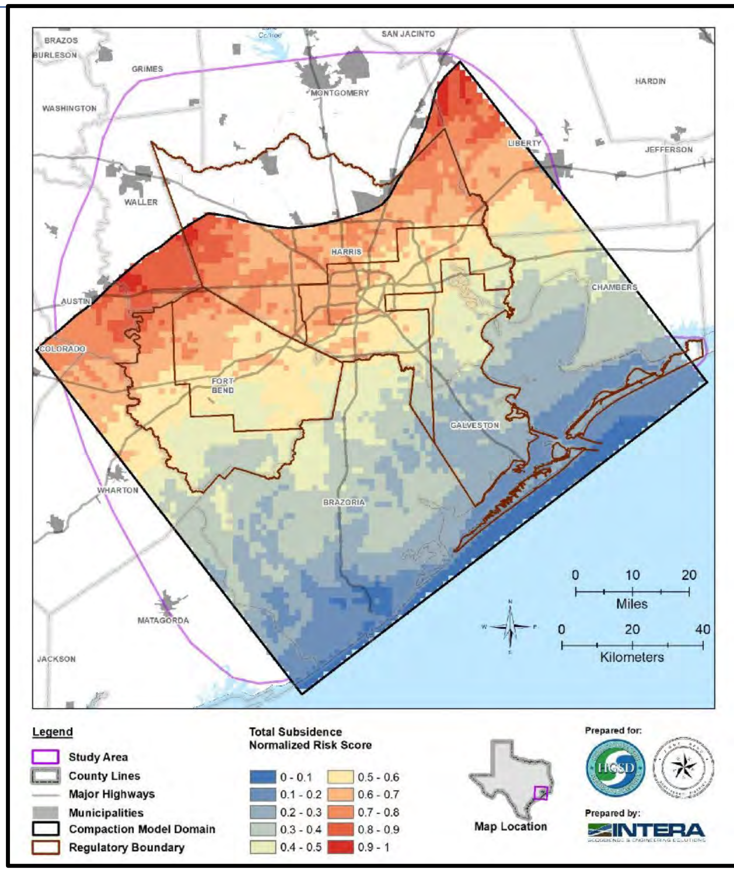

Figure 31. Map showing INTERA's Jasper aquifer total subsidence normalized risk score (from Kelley, Deeds, Young, and Pinkard, 2018)

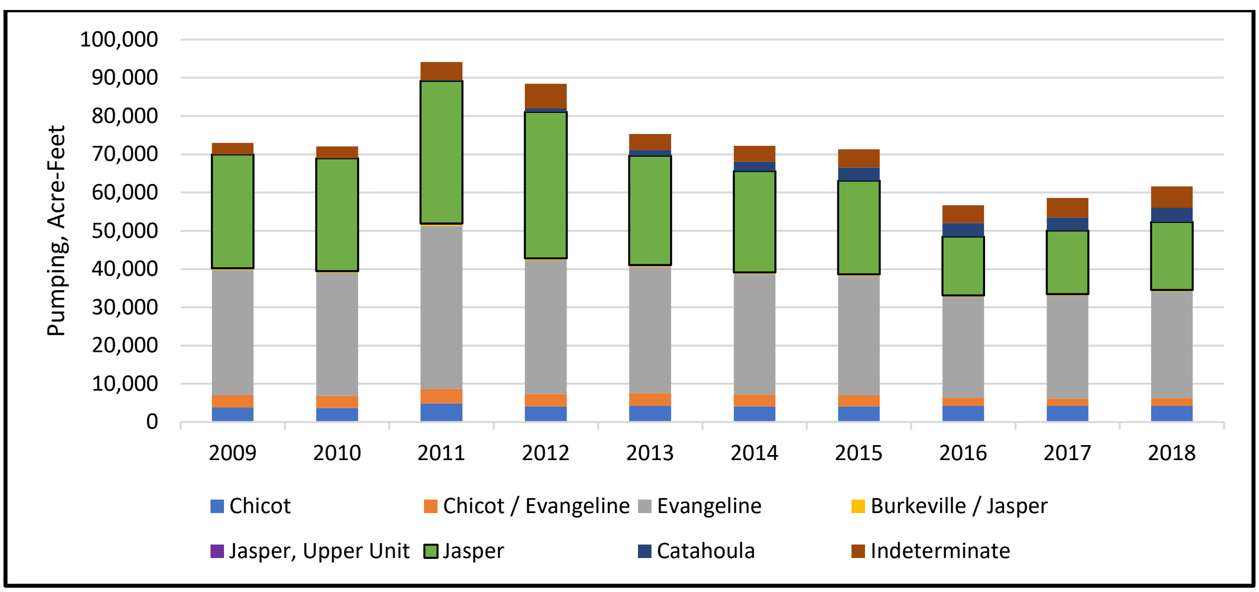

Figure 32. LSGCD reported pumping associated with permits by assigned aquifer.

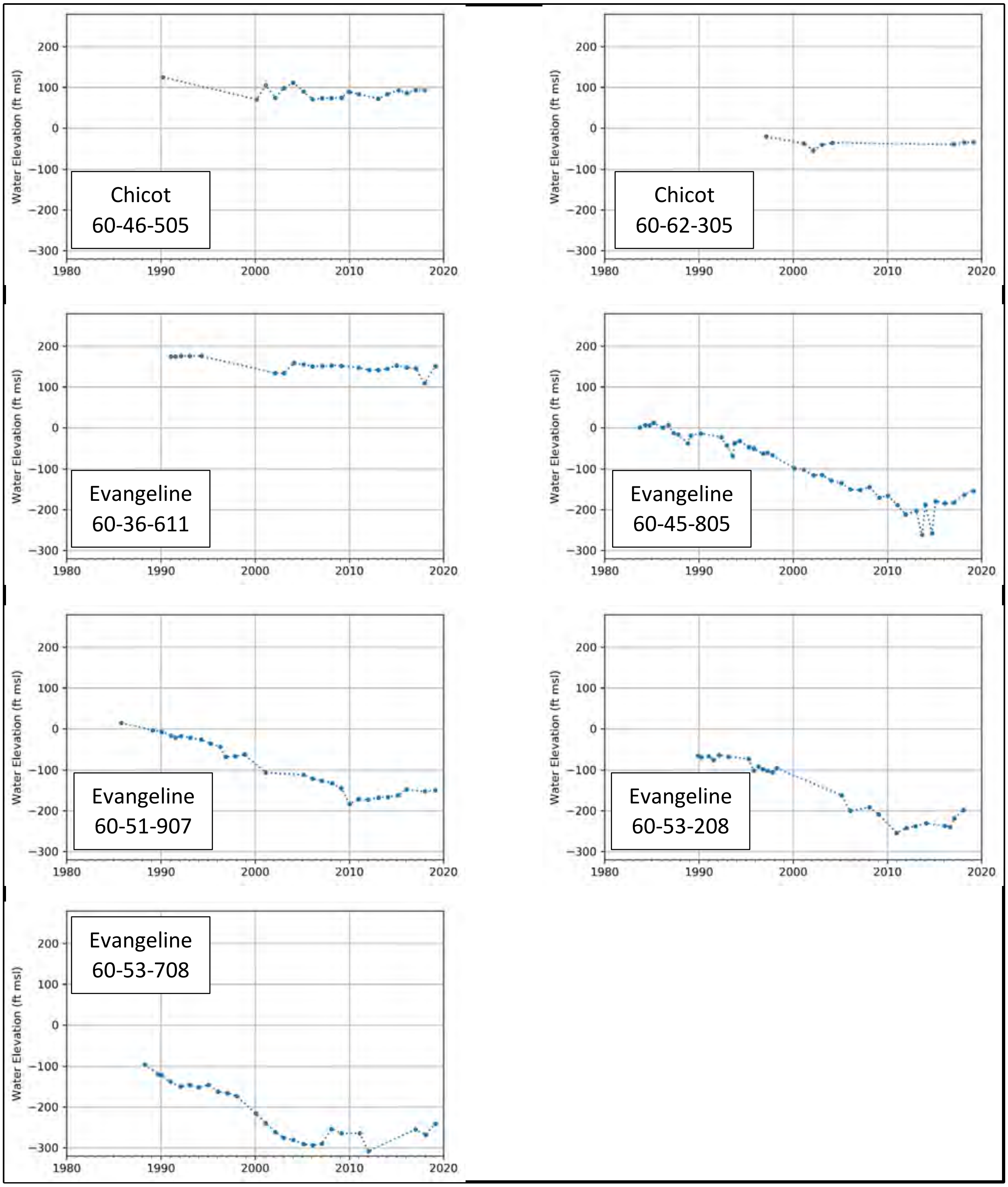

Figure 33. Reported water levels from the TWDB Groundwater Database (TWDB, 2020).

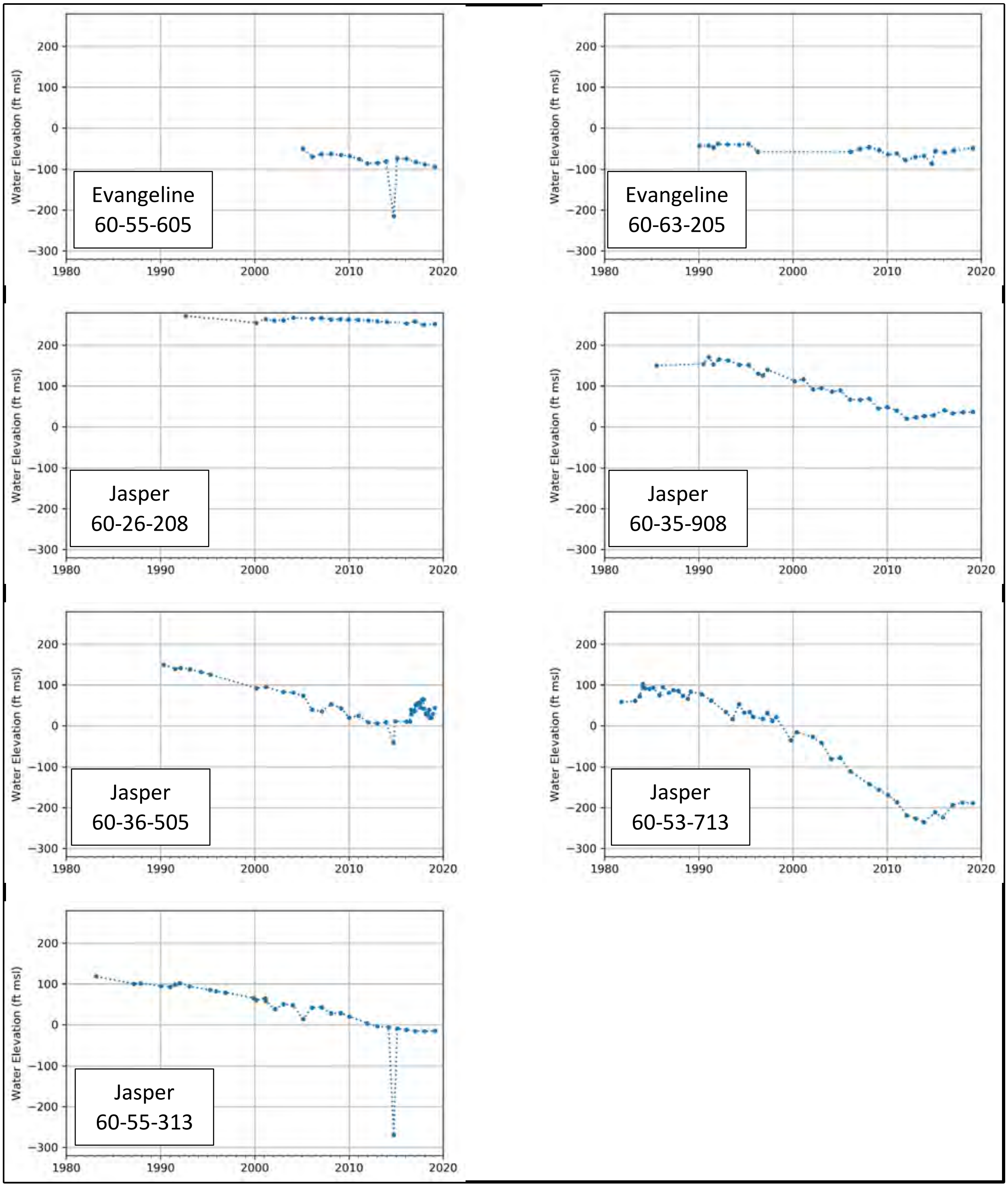

Figure 33. (continued) Reported water levels from the TWDB Groundwater Database (TWDB, 2020).

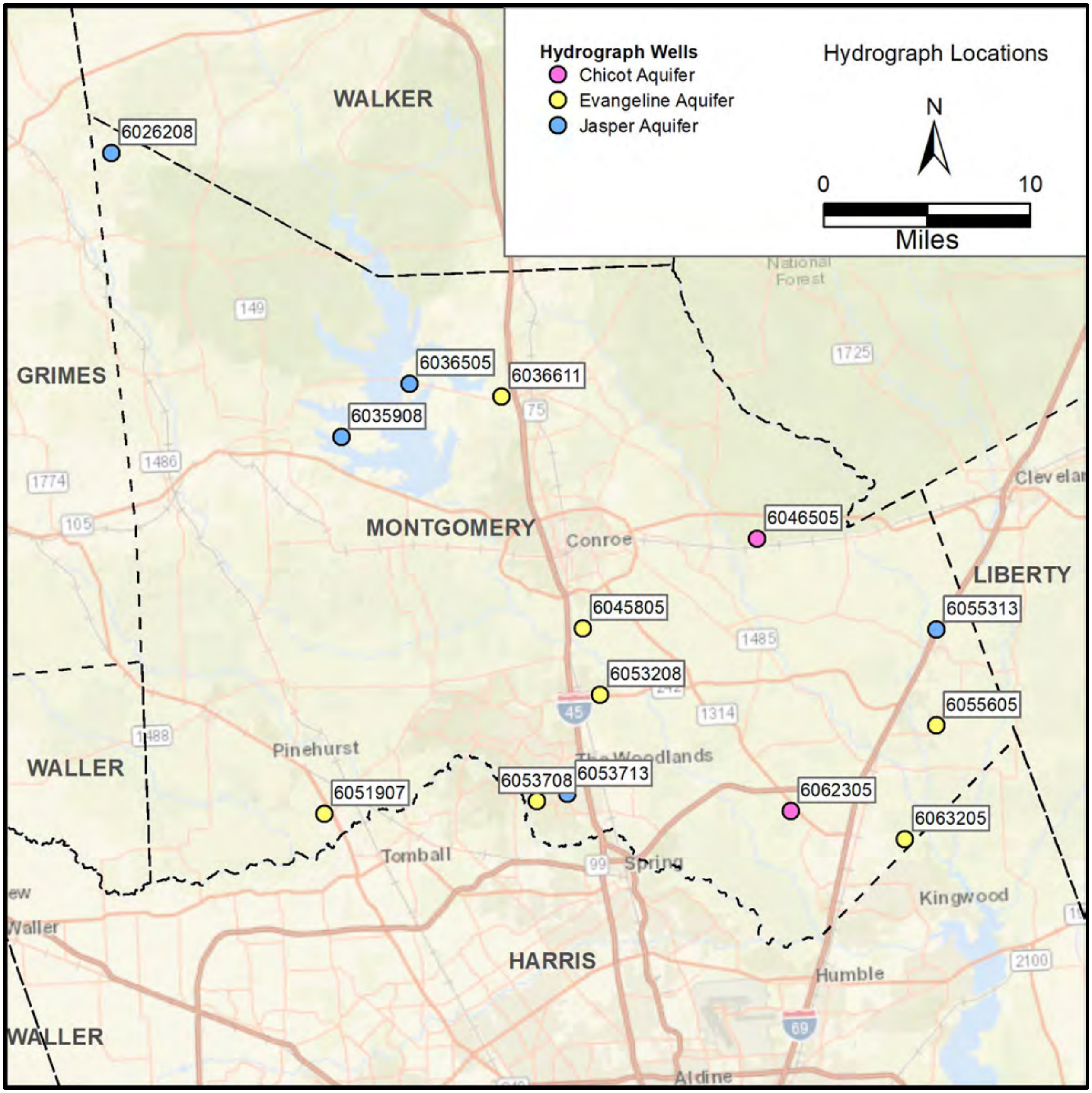

Figure 34. Map illustrating the location of the reported water levels from the TWDB Groundwater Database (TWDB, 2020).

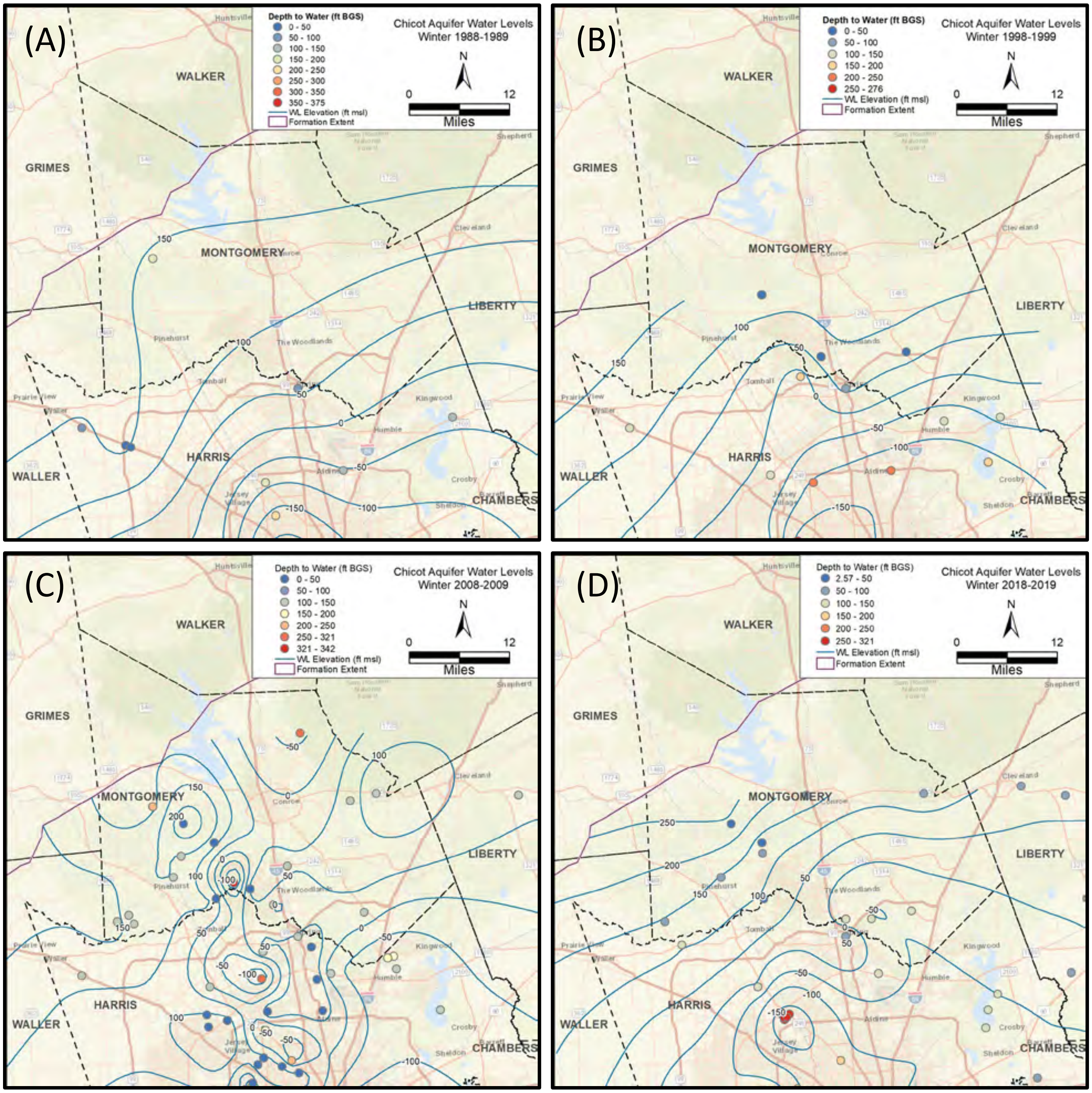

Figure 35. Estimated water levels in the Chicot Aquifer. Well locations, aquifer designation, and measured water level from the TWDB Groundwater Database (TWDB, 2020).

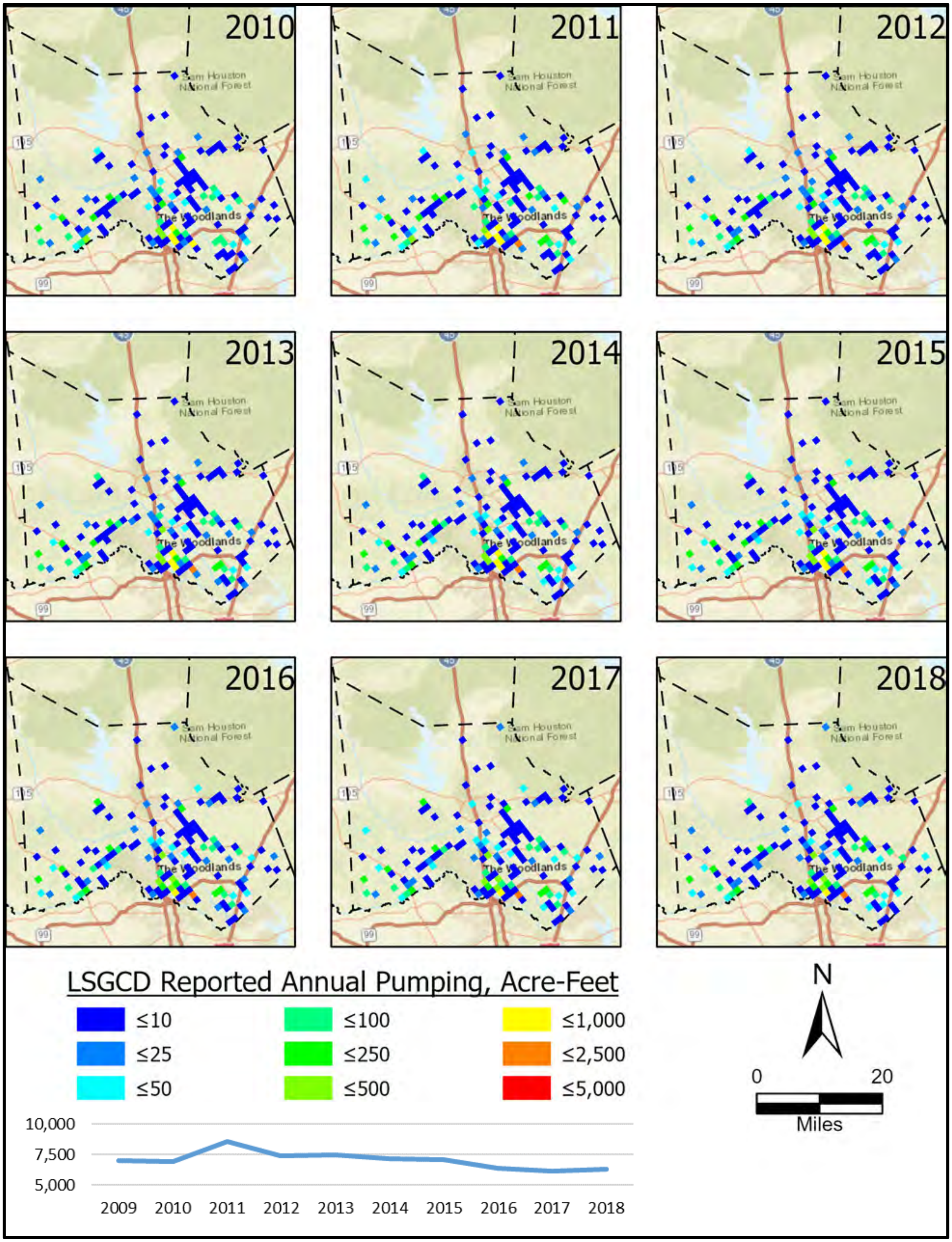

Figure 36. LSGCD reported pumping from permitted wells completed in the Chicot Aquifer.

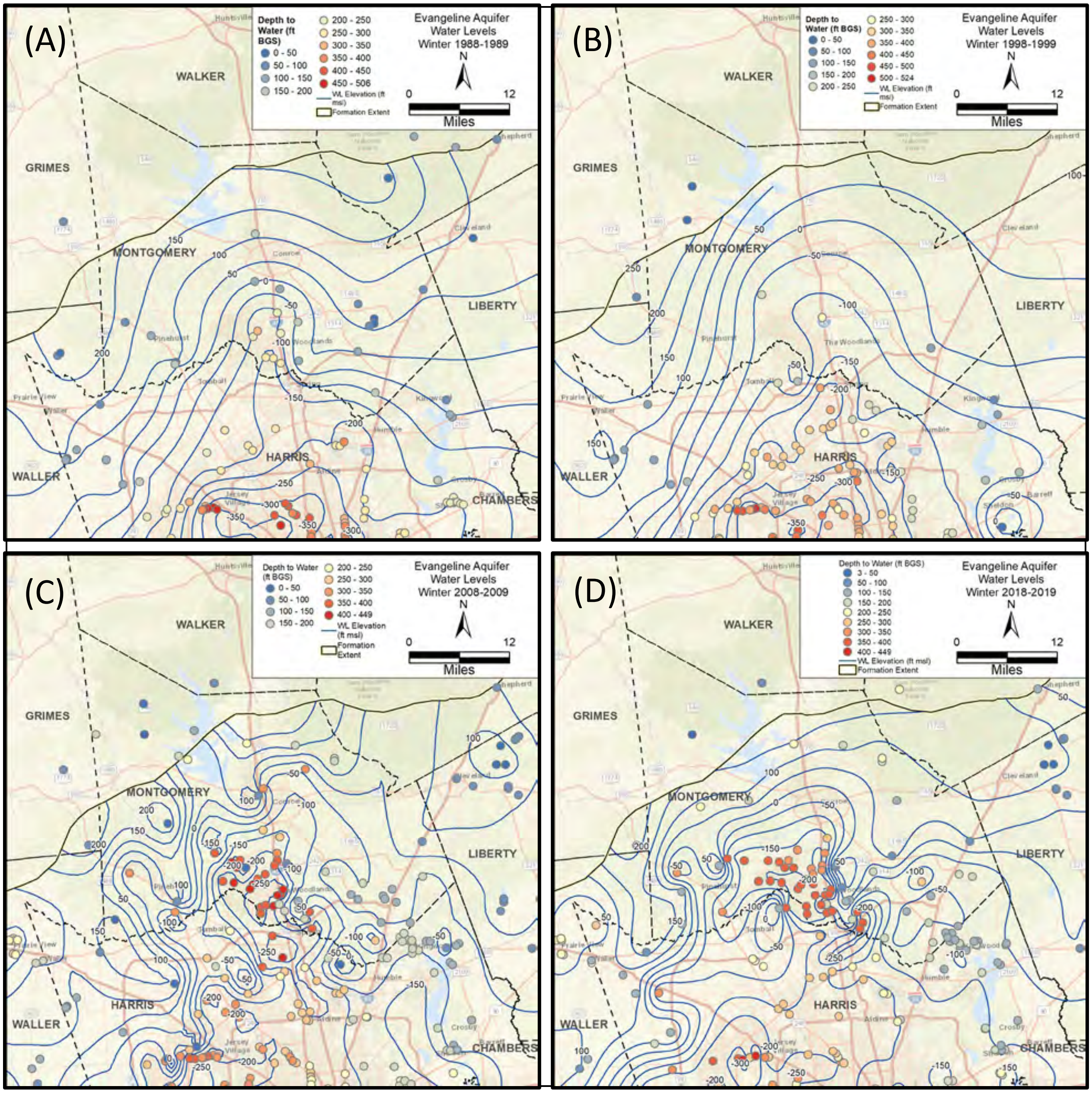

Figure 37. Estimated water levels in the Evangeline Aquifer. Well locations, aquifer designation, and measured water level from the TWDB Groundwater Database (TWDB, 2020).

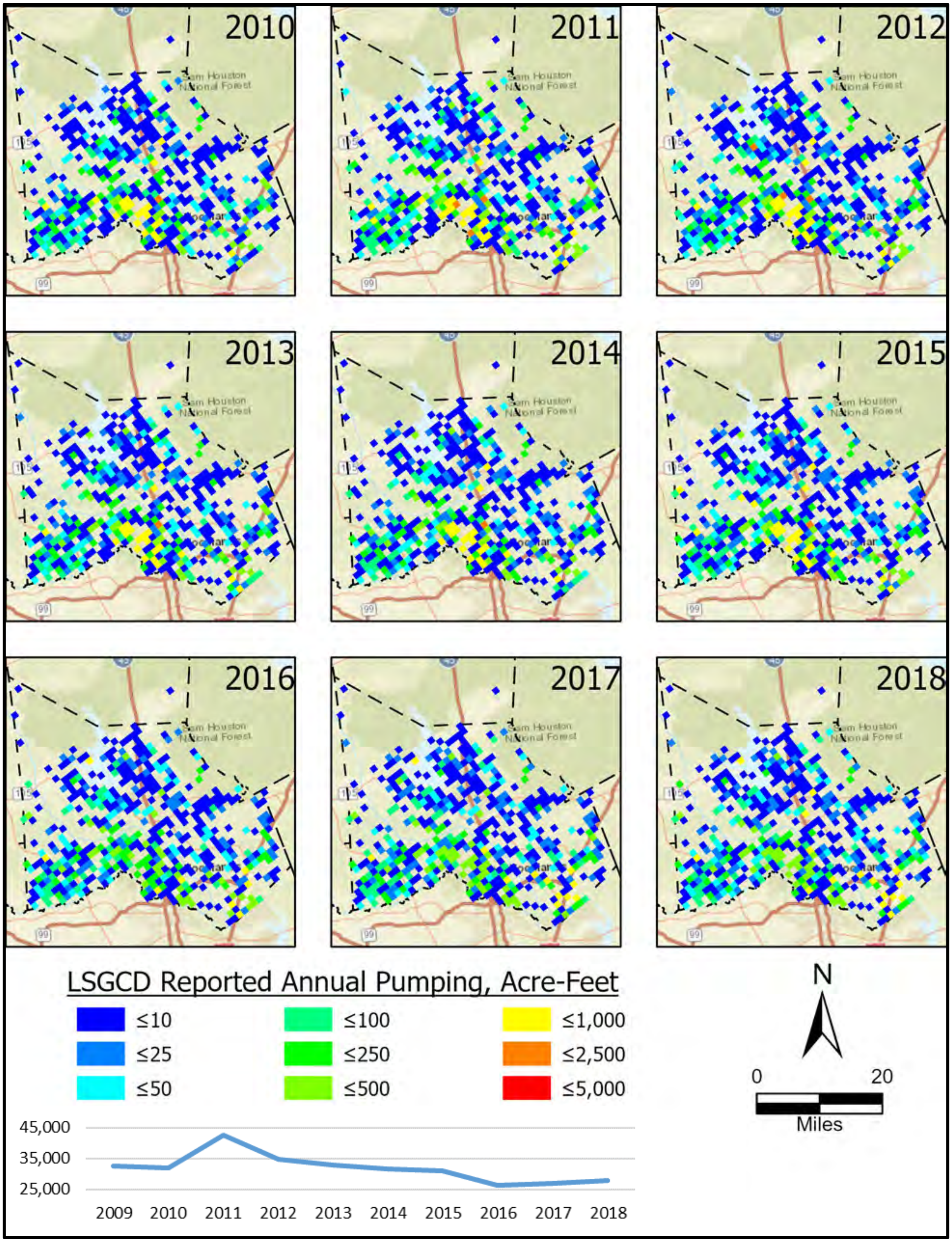

Figure 38. LSGCD reported pumping from permitted wells completed in the Evangeline Aquifer.

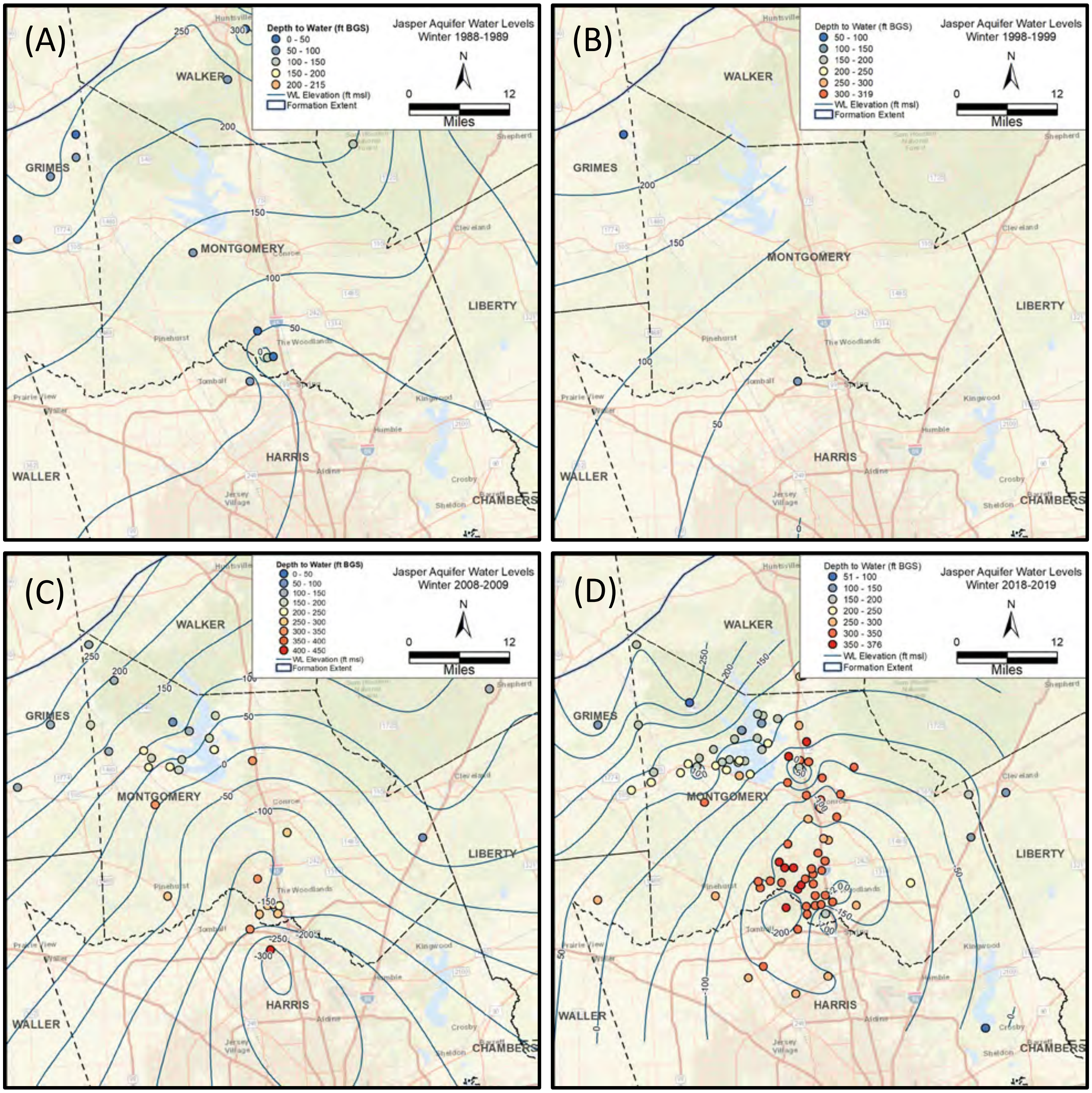

Figure 39. Estimated water levels in the Jasper Aquifer. Well locations, aquifer designation, and measured water level from the TWDB Groundwater Database (TWDB, 2020).

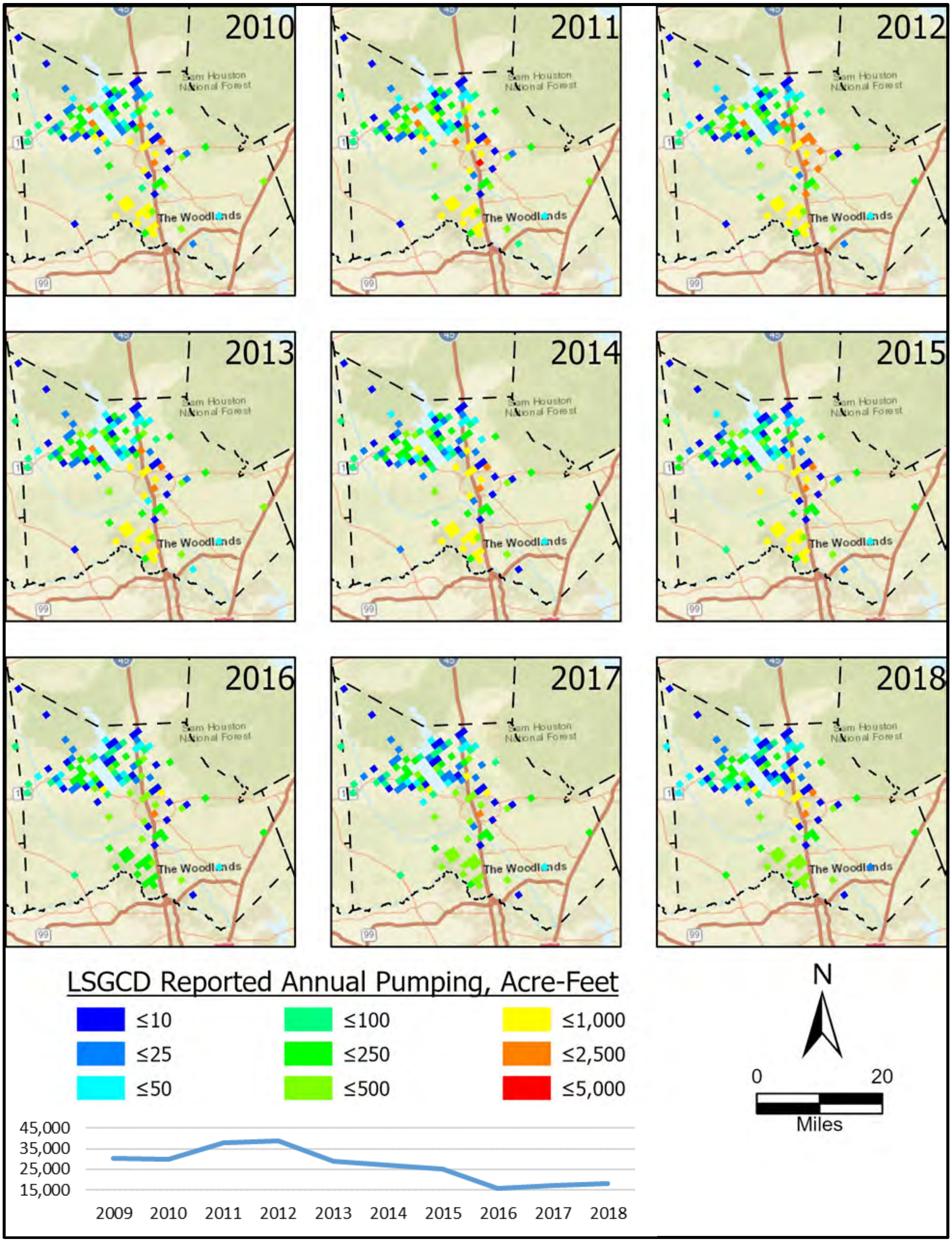

Figure 40. LSGCD reported pumping from permitted wells completed in the Jasper Aquifer.

Table 3. Modeling scenarios reviewed for evaluation of potential effects of groundwater production in Montgomery County.

Scenario ID	Description	Source
2010 MAG	GMA 14 modeled available groundwater simulation	Hassan (2011)
2016 MAG	GMA 14 modeled available groundwater simulation	Wade (2016)
2016 MAG with 2010 LSGCD	2016 MAG with 2010 MAG for Montgomery County	Hassan (2011); Wade (2016)
Run D (LSGCD Option 3)	2016 MAG with additional pumping in Montgomery County	Seifert, Jr. (2017)
75 Pct	Median of water level above the bottom of existing wells equal to 75 percent	INTERA (2019)
Alt WMS 1	2016 MAG with added pumping across GMA 14 for WMS	Keester and others (2020)
Alt WMS 2	2016 MAG with added pumping across GMA 14 for WMS except “County-Other” entities	Keester and others (2020)
Alt WMS 3	2016 MAG with added pumping across GMA 14 for WMS identified as PWS entities	Keester and others (2020)
Alt WMS 4	2010 MAG with added pumping across GMA 14 for WMS	Keester and others (2020)
Alt WMS 5	2016 MAG with 2010 LSGCD with added pumping across GMA 14 for WMS	Keester and others (2020)
Alt WMS 6	75 Pct with added pumping across GMA 14 for WMS	Keester and others (2020)
Alt WMS 7	2016 MAG with added pumping for the City of Conroe and The Woodlands WMS	TGI & LRE (2020)
Alt WMS 8	2016 MAG with added pumping for the City of Conroe WMS	TGI & LRE (2020)
LSGCD Option 1	Run D with less remaining available drawdown in the GCAS	LSGCD (2020)
LSGCD Option 2	Run D with less remaining available drawdown in the Jasper	LSGCD (2020)

Table 4. Simulated pumping in acre-feet per year at the end of the predictive period for each of the modeling scenarios reviewed for evaluation of potential effects of groundwater production in Montgomery County.

Scenario ID	Chicot	Evangeline	Jasper	GCAS
2010 MAG	1,722	40,707	21,615	64,043
2016 MAG	14,175	26,529	23,301	64,004
2016 MAG with 2010 LSGCD	1,722	40,707	21,615	64,043
Run D (LSGCD Option 3)	11,250	43,917	44,330	99,497
75 Pct	16,229	32,014	29,010	77,253
Alt WMS 1	14,175	27,306	91,689	133,169
Alt WMS 2	14,175	27,107	68,849	110,130
Alt WMS 3	14,175	27,107	67,562	108,843
Alt WMS 4	1,722	41,484	90,003	133,208
Alt WMS 5	1,722	41,484	90,003	133,208
Alt WMS 6	16,229	32,791	97,398	146,418
Alt WMS 7	14,175	26,529	50,796	91,499
Alt WMS 8	14,175	26,529	39,729	80,432
LSGCD Option 1	17,975	44,902	53,160	116,037
LSGCD Option 2	11,883	52,058	47,504	111,445

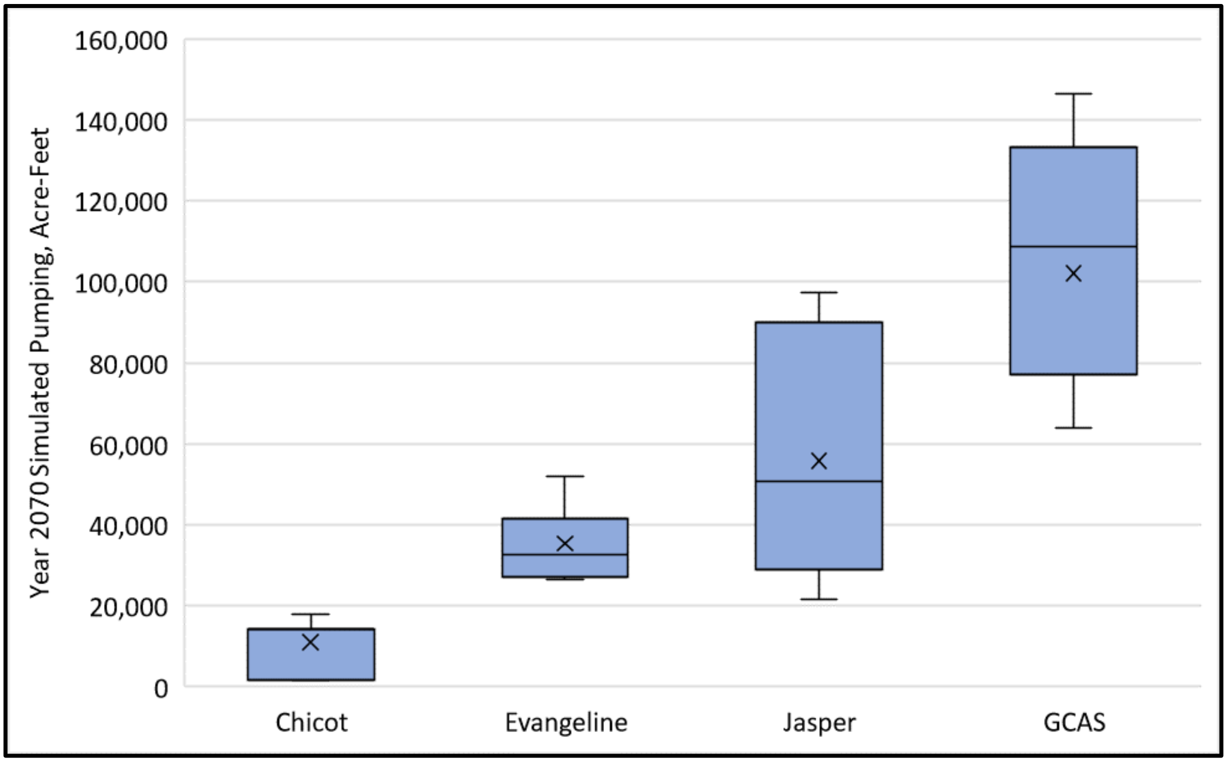

Figure 41. Box-and-whisker plot illustrating the distribution of simulated pumping within Montgomery County in each of the scenarios.

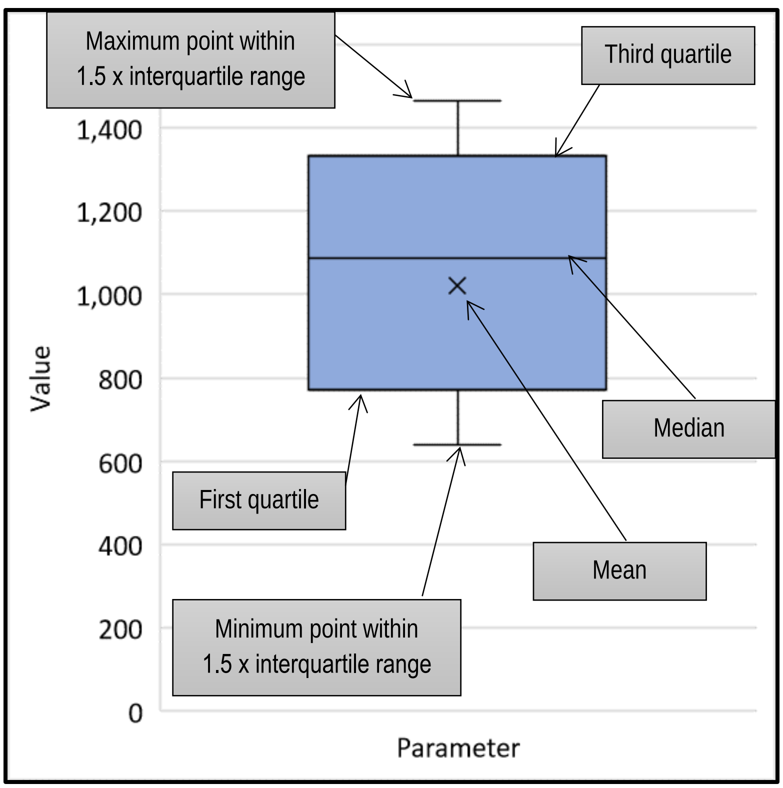

Figure 42. Legend illustrating the parts of the box and whisker plot. Interquartile range is the difference between the third and first quartile. Outliers beyond the minimum and maximum extents are not shown.

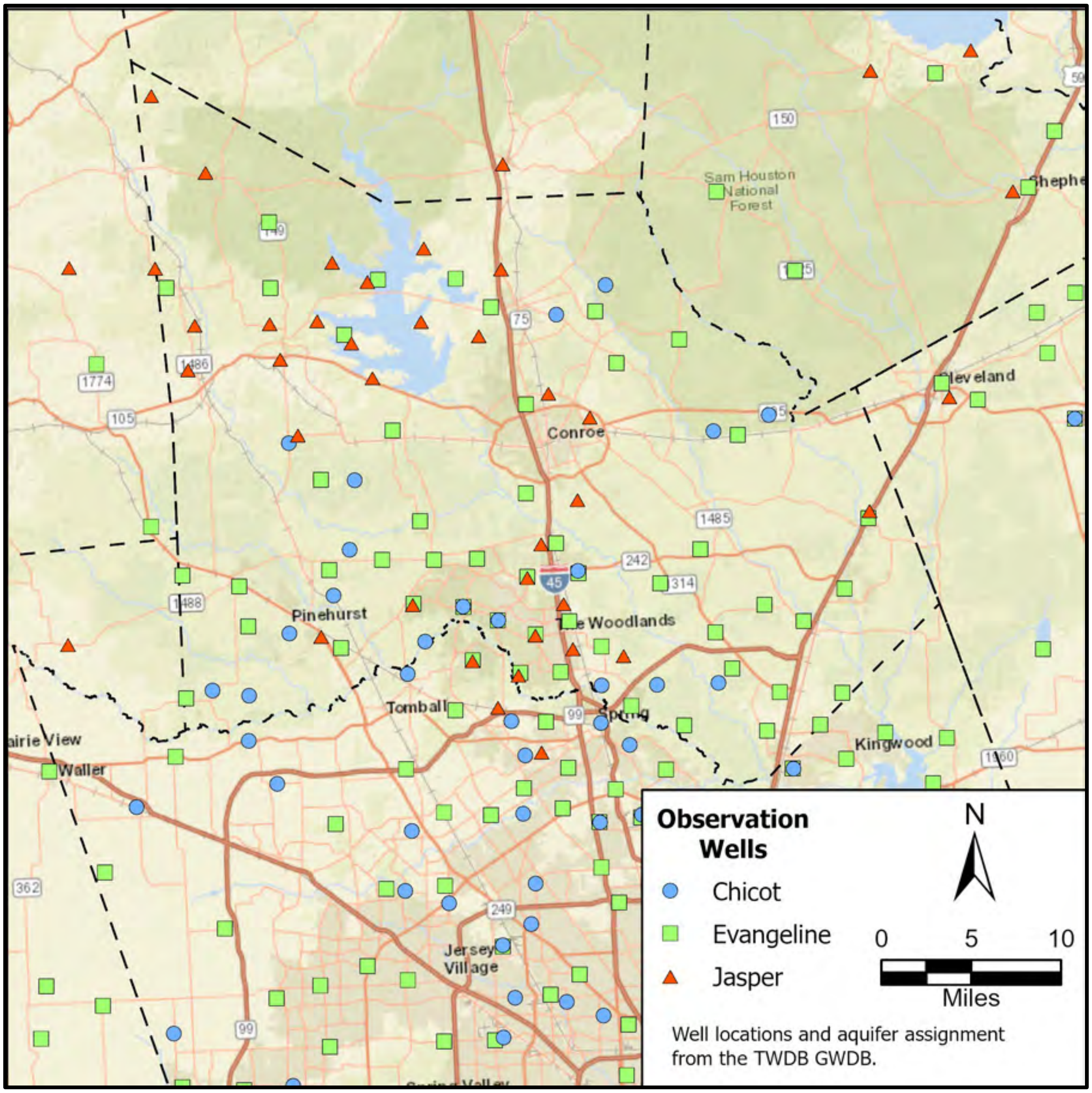

Figure 43. Location of monitoring wells used for analysis of model results within Montgomery County. Modified from Keester (2020).

Table 5. Average predicted change in water level in feet from January 1, 2010 to December 31, 2070 at identified monitoring well locations in Montgomery County under each scenario.

Scenario ID	Chicot	Evangeline	Jasper	GCAS
2010 MAG	23	-9	54	14
2016 MAG	31	-76	9	-37
2016 MAG with 2010 LSGCD	31	-19	18	-2
Run D (LSGCD Option 3)	36	-8	220	66
75 Pct	39	-65	146	12
Alt WMS 1	34	-68	531	126
Alt WMS 2	31	-71	317	59
Alt WMS 3	32	-73	294	51
Alt WMS 4	26	-1	547	168
Alt WMS 5	34	-11	541	161
Alt WMS 6	42	-57	669	175
Alt WMS 7	33	-74	250	37
Alt WMS 8	31	-76	129	0
LSGCD Option 1*	42	16	328	118
LSGCD Option 2*	40	12	350	123

*values are for predictive period ending 12/31/2080

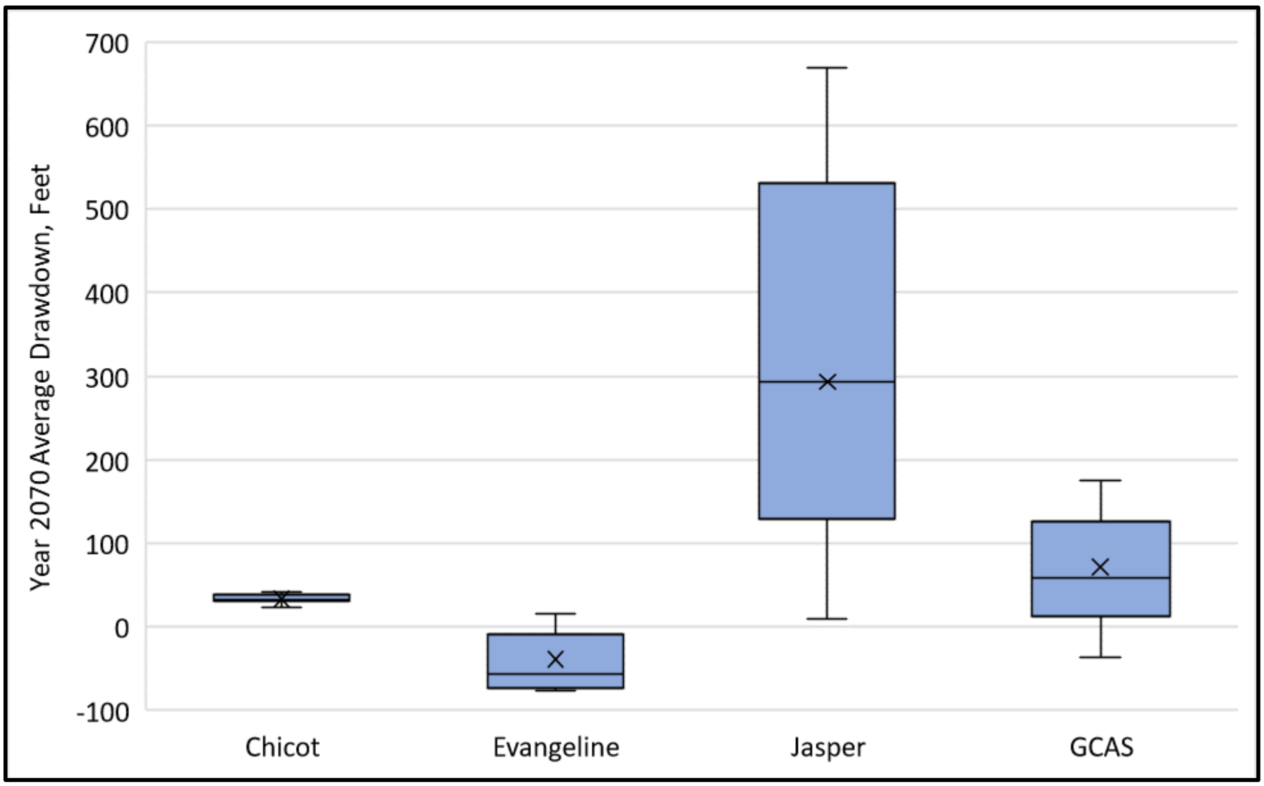

Figure 44. Box-and-whisker plot illustrating the distribution of average drawdown within Montgomery County in each of the scenarios. See Figure 2 for an explanation of the box-and-whisker plot.

Table 6. Maximum predicted compaction in feet from January 1, 2010 to December 31, 2070 at identified monitoring well locations in Montgomery County under each scenario. Compaction of the GCAS represents the predicted land surface subsidence.

Scenario ID	Chicot	Evangeline	Jasper	GCAS
2010 MAG	0.5	-0.6	0.05	-0.3
2016 MAG	1.6	0.2	0.05	1
2016 MAG with 2010 LSGCD	1.4	0.4	0.05	0.7
Run D (LSGCD Option 3)	1.9	0.7	0.15	1.6
75 Pct	2.2	0.3	0.15	1.8
Alt WMS 1	1.9	0.2	0.25	1.5
Alt WMS 2	1.6	0.2	0.15	1.1
Alt WMS 3	1.6	0.2	0.15	1.1
Alt WMS 4	1.1	-0.6	0.15	0.6
Alt WMS 5	1.8	0.4	0.25	1.5
Alt WMS 6	2.8	0.3	0.35	2.6
Alt WMS 7	1.6	0.2	0.15	1.1
Alt WMS 8	1.6	0.2	0.05	1
LSGCD Option 1*	3	0.7	0.15	2.9
LSGCD Option 2*	2.1	0.7	0.15	1.9

*values are for predictive period ending 12/31/2080

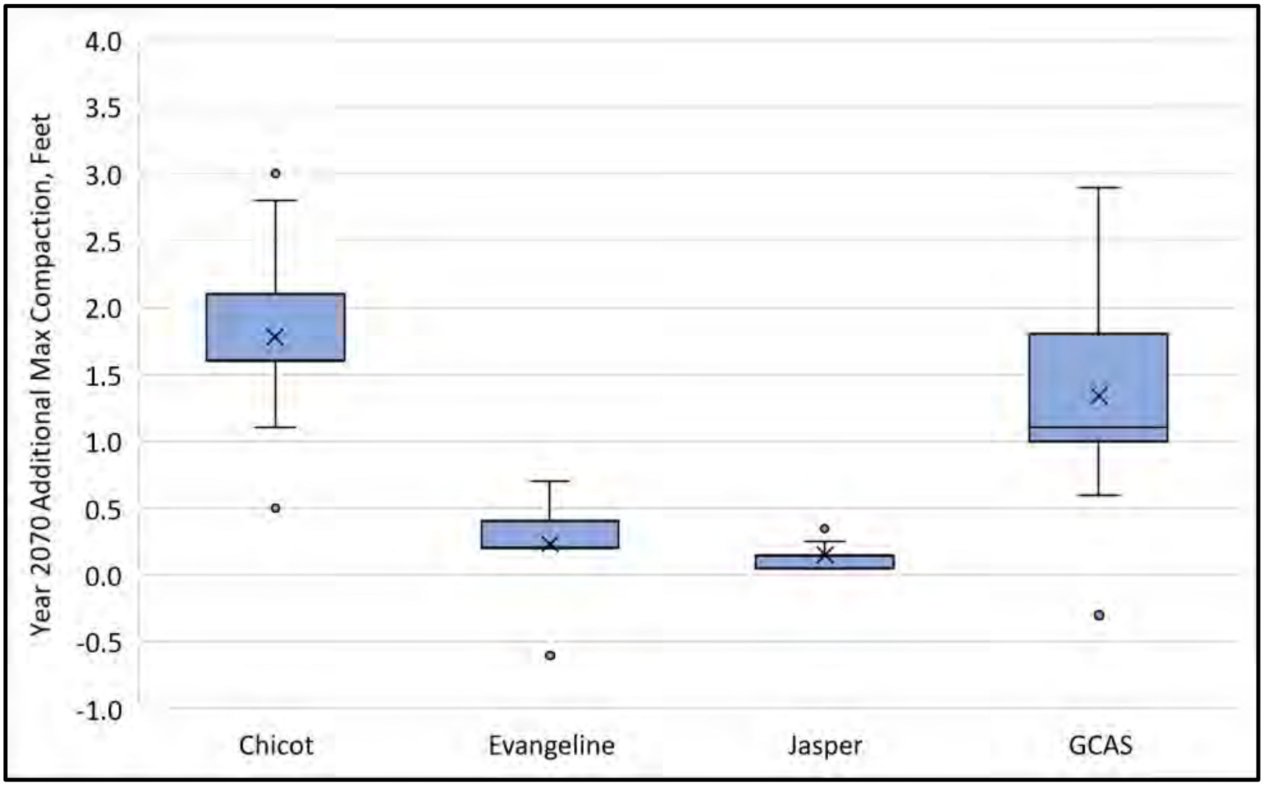

Figure 45. Box-and-whisker plot illustrating the distribution of maximum compaction within Montgomery County in each of the scenarios. The maximum compaction range for the GCAS represents land-surface subsidence.

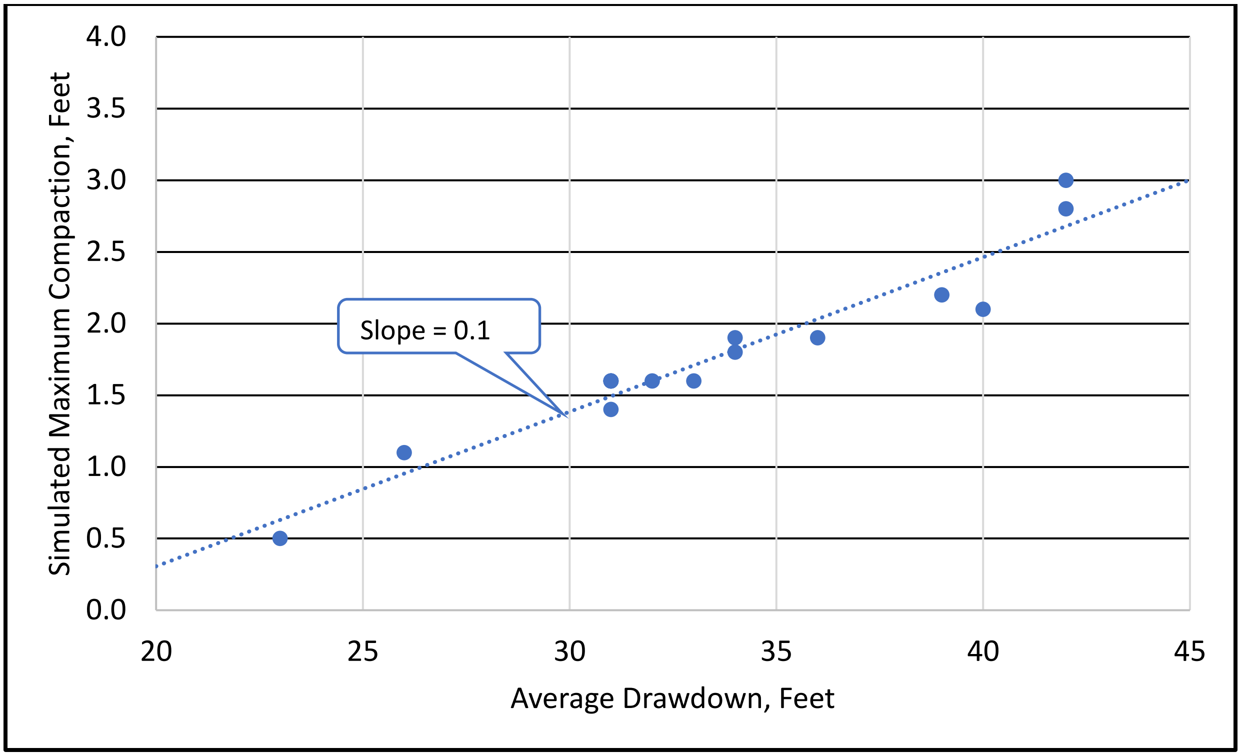

Figure 46. Comparison of simulation results for the Chicot Aquifer showing the relationship between average drawdown and maximum compaction.

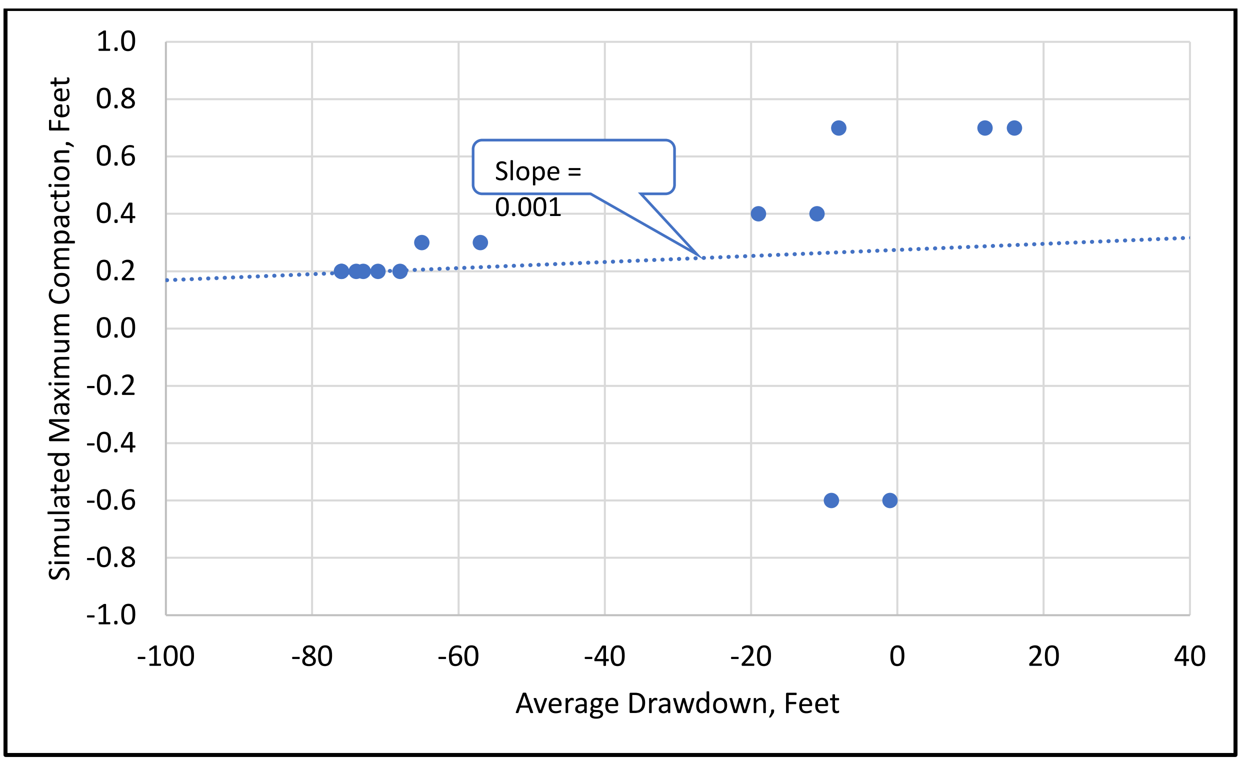

Figure 47. Comparison of simulation results for the Evangeline Aquifer showing the relationship between average drawdown and maximum compaction.

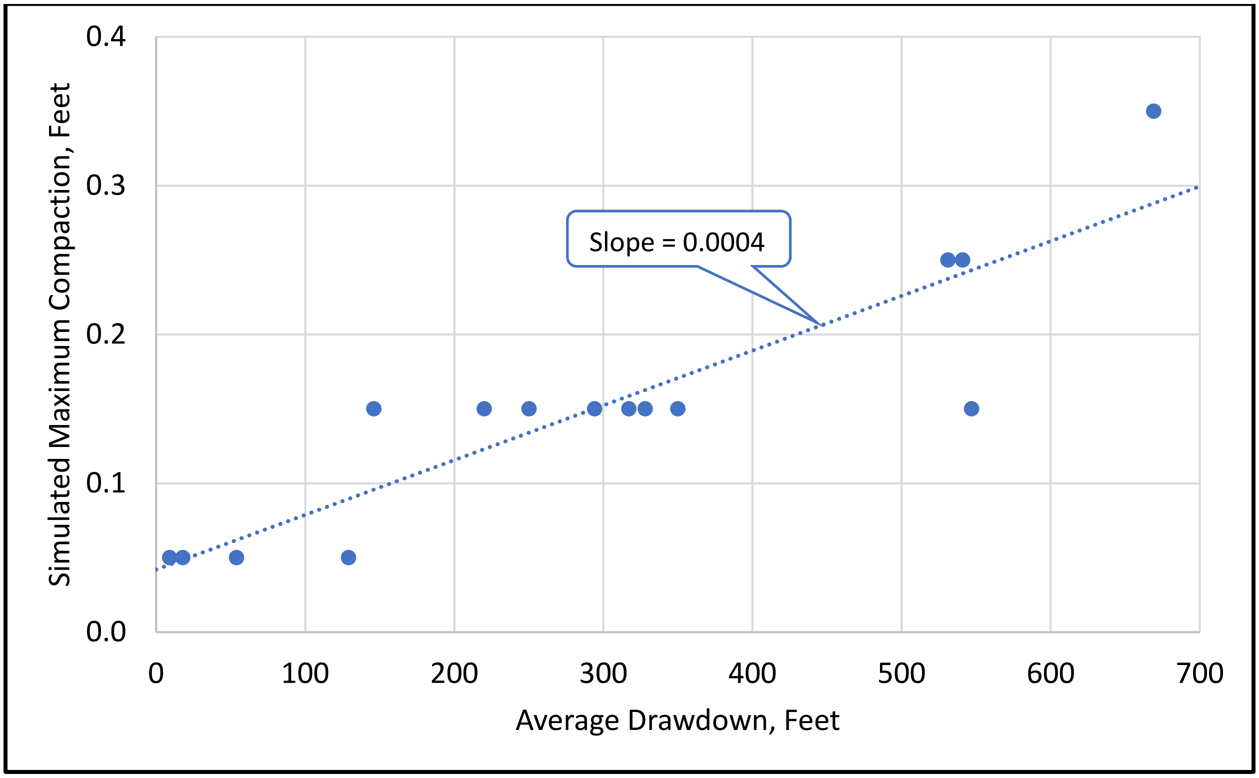

Figure 48. Comparison of simulation results for the Jasper Aquifer showing the relationship between average drawdown and maximum compaction.

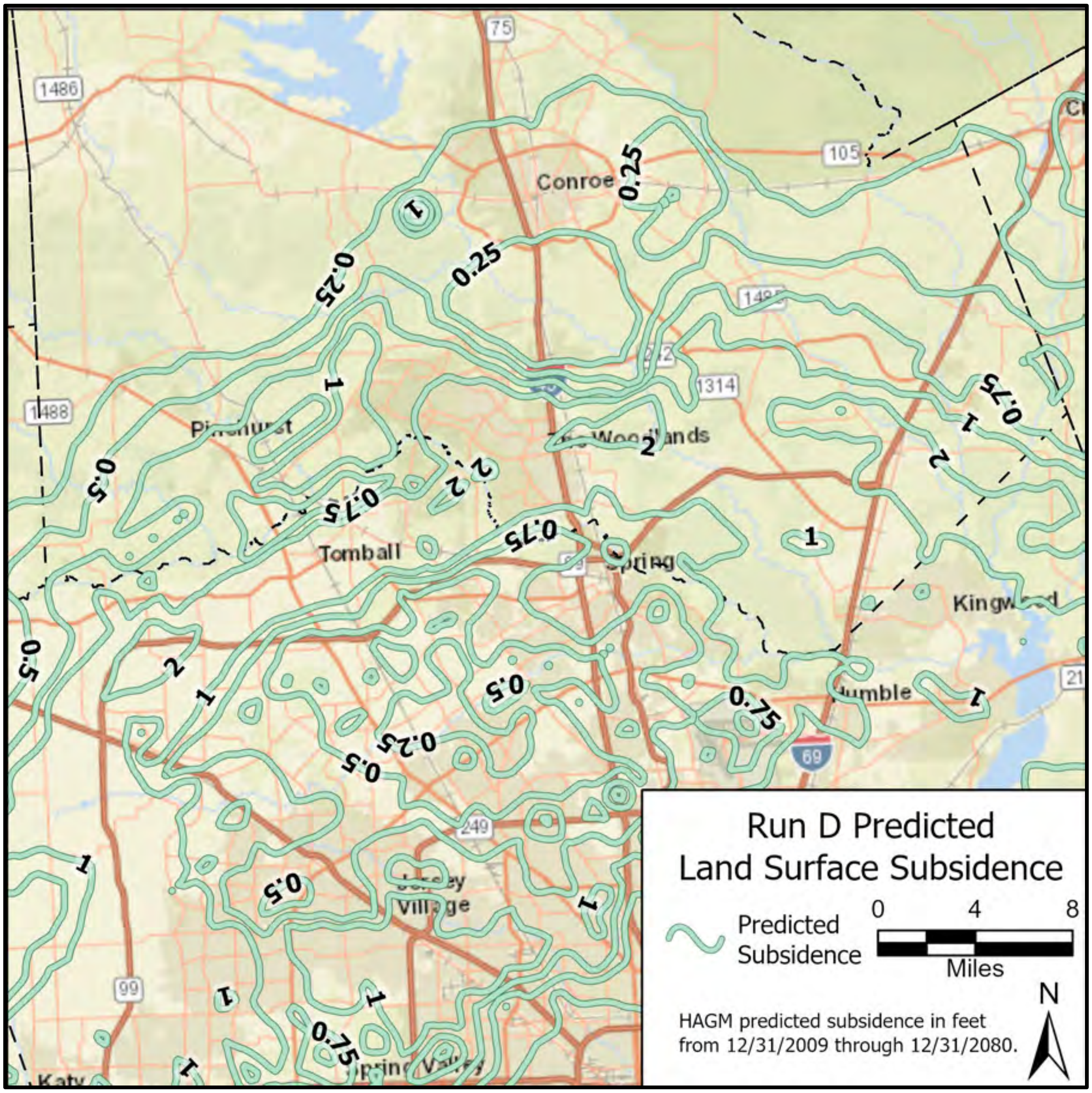

Figure 49. Predicted additional subsidence due to Run D simulated pumping.

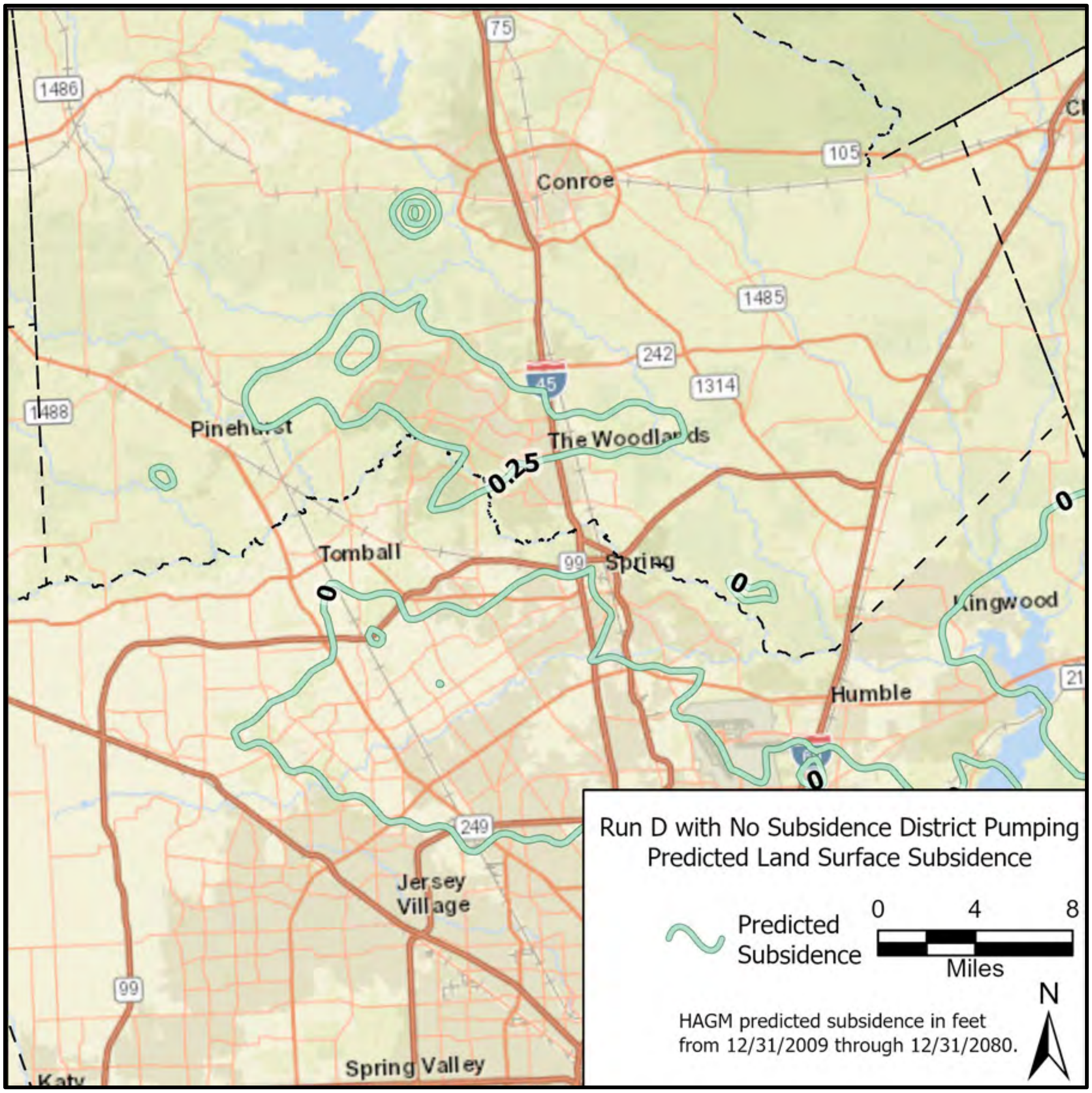

Figure 50. Predicted additional subsidence due to Run D simulated pumping with pumping in the subsidence districts set to zero at the beginning of the predictive period (1/1/2010).

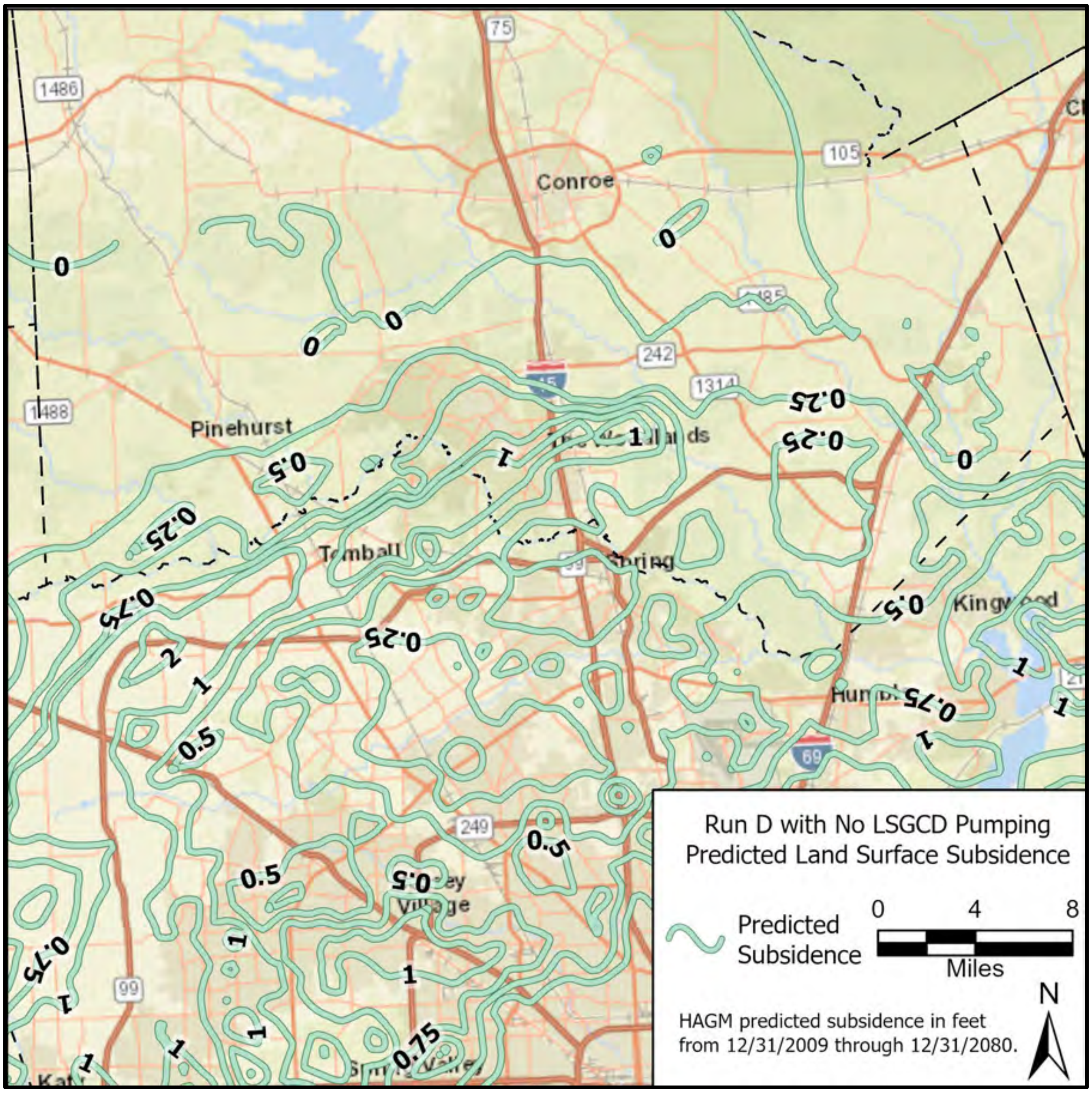

Figure 51. Predicted additional subsidence due to Run D simulated pumping with pumping in Montgomery County set to zero at the beginning of the predictive period (1/1/2010).

5.0 Regulatory and Management Overview

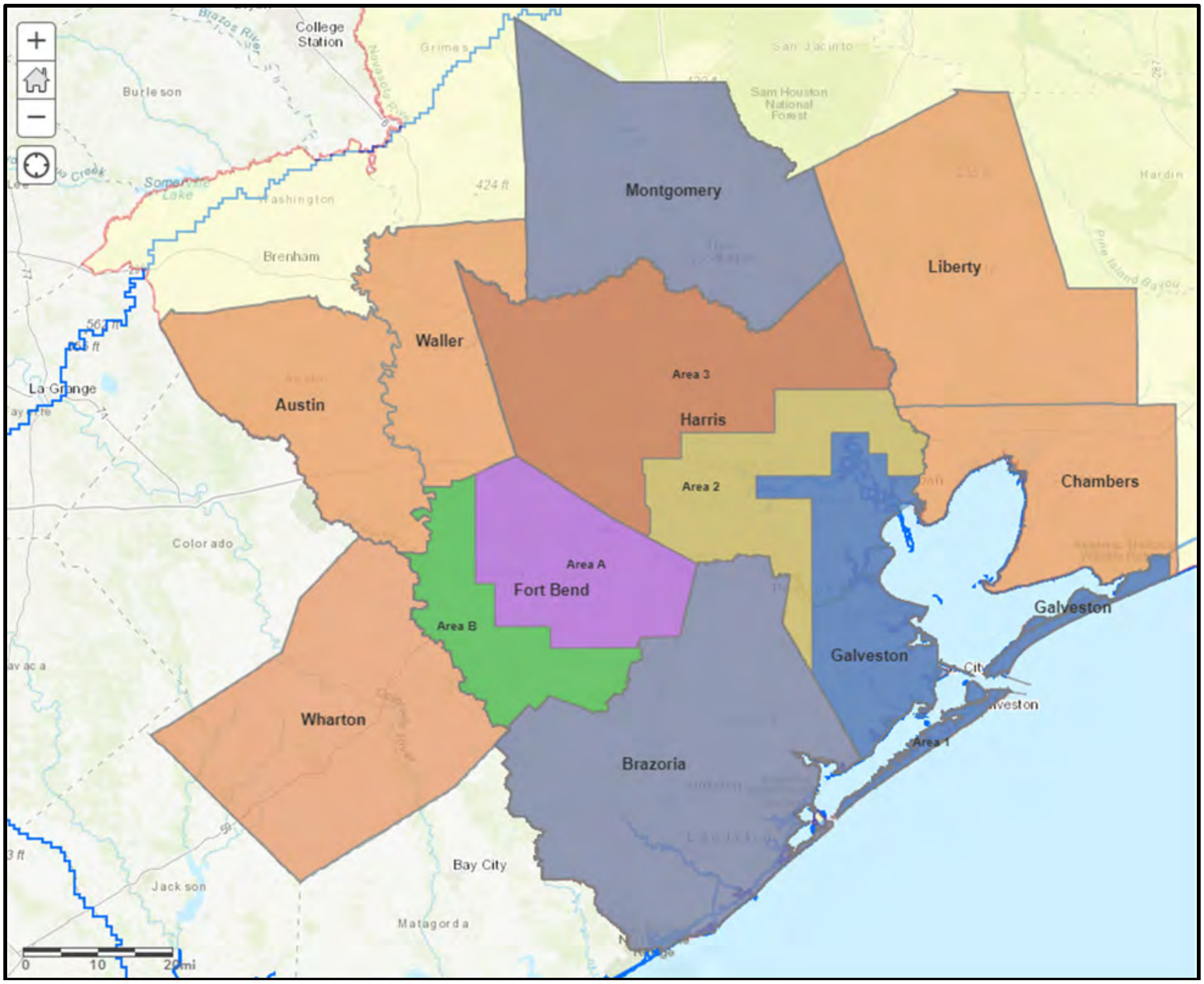

Figure 52. Regulatory areas in the HGSD and FBSD. Image from the HGSD Regulatory Plan Review web map accessed June 16, 2020 (https://www.arcgis.com/home/item.html?id=5c534d3137d34c04b5460dee0813984f).

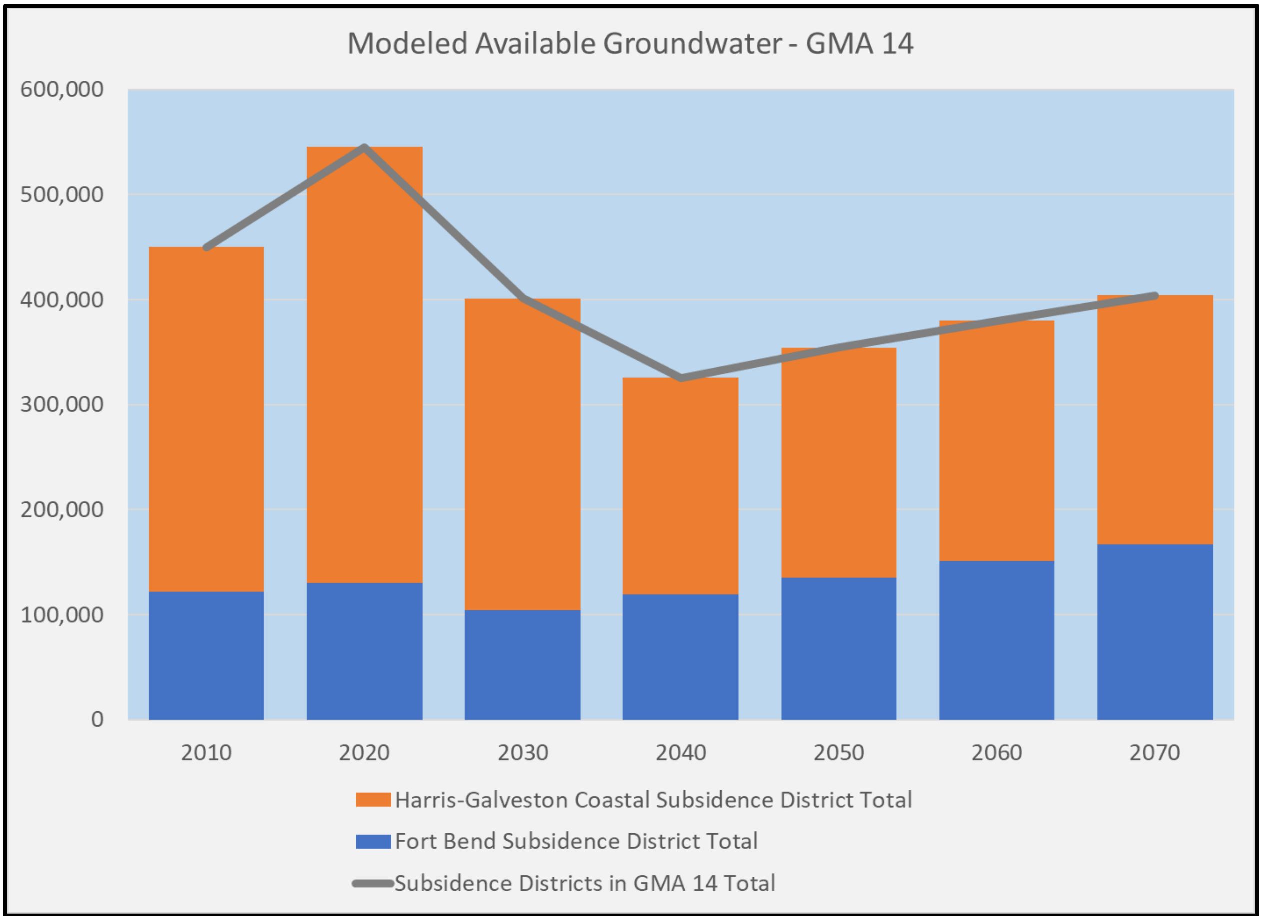

Figure 53. Projected total pumping in HGSD and FBSD through 2070 (Wade, 2016).

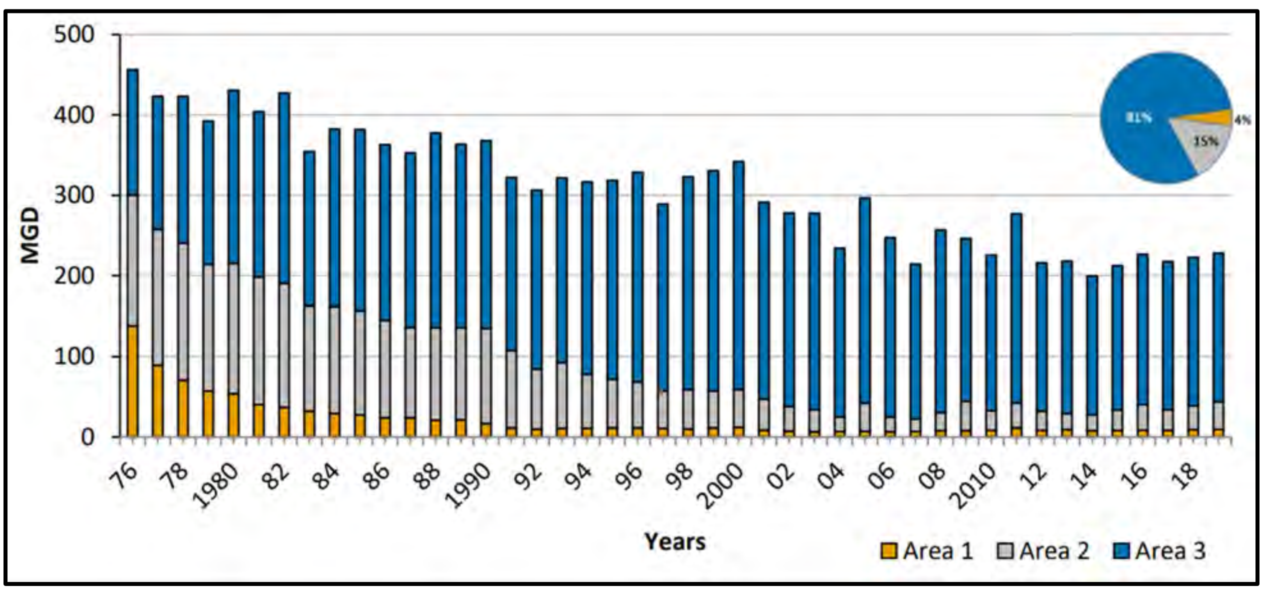

Figure 54. Historical pumping in HGSD (Petersen and others, 2020).