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Expert Report Evaluating Drawdown and Subsidence from Proposed Groundwater Production By Electro Purification

Prepared for:

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DECEMBER 2, 2013

TABLE OF AUTHORITIES[1]

1. Curriculum vitae for Dr. Steven C. Young

2. Thornhill Group, Inc, 2012. Phase 1 Hydrogeological Report – Non-Exempt Well Permit Application Bluebonnet Groundwater Conservation District Austin and Waller Counties Texas, prepared for Mr. Tim Throckmorton, Electro Purification, LLC,

3. Kasmarek, M. C, 2012. Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the North ern Part of the Gulf Coast Aquifer System Texas, 1891-2009. Scientific Report 201205154, Revised November 2012

4. Freese & Nichols and LBG Guyton, 2013. Effects of the Proposed Electro Purification Wellfield on Water Levels and Land Surface Subsidence,prepared for the Fort Bend Subsidence District

5. Wade, S.W., Ridgeway, C., and French, L., 2013. Analysis Paper: Review of the Houston Area Groundwater Model, Texas Water Development Board, Groundwater Resources Division, July 26, 2013

6. Kasmarek, M.C., and Robinson, 2004, Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System, Texas: United States Geological Society, Scientific Investigation Report 2004-5102.

7. Public Information Request, Letter from the Law Offices of Jackson, Sjobreg, McCarthy & Townsend dated June 28, 2013

8. Minutes from the Conference Call on August 16, 2013 between INTERA and the Fort Bend Subsidence District

9. Request for Subsidence Data to Satisfy our FOIA Request of June 28, 2013, Letter from Steve Young at INTERA dated September 19, 2013

10. Request for Additional Clay Thickness Data to Satisfy our FOIA Request as of June 28, 2013, Letter from Steve Young at INTERA dated September 23rd

[1] All authorities and exhibits to relied upon for this report are being made available for review pursuant to the Applicant's Disclsoures in this proceeding.

11. Request of Information under the Freedom on Information Act (FOIA) from the USGS Regarding the Development of the Northern Gulf Coast GAM and the Houston Area Groundwater Model, Letter from Steve Young at INTERA dated October 28, 2013

12. Request for Subsidence Data to Satisfy our FOIA Request of June 28, 2013

13. Espey, Huston & Associates, Inc., 1981. Harris Galveston Coastal Subsidence District Phase II Water Management Study

14. Young, S.C., and Kelley, V., eds., 2006, A site conceptual model to support the development of a detailed groundwater model for Colorado, Wharton, and Matagorda Counties: Prepared by the URS Corporation, Lower Colorado River Authority LSWP Report, Austin, TX.

15. Gabrysch, R,K.,. 1982. Ground-water Withdrawals and Land-surface subsidence in the Houston-Galveston Region, Texas, 1906-80. U.S. Geological Survey Open-File Report 82-571.

16. Young, S.C., Kelley, V., Baker, E., Budge, T., Hamlin, S., Galloway, B., Kalboss, R., and Deeds, N., 2010, Hydrostratigraphy of the Gulf Coast Aquifer from the Brazos to the Rio Grande: Unnumbered Report, prepared by URS for the Texas Water Development Board.

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

18. Letter from Mark Kasmarkey to Michael Turco, dated November 14, 2013, Subject: INTERA's November 8, 2013 letter to Mike Turco regarding FOIA requests for additional clay thickness data in correspondence dated September 23, 2013 and September 19, 2013.

1. INTRODUCTION

INTERA was retained to assess whether land subsidence could occur as a result of Electro Purification's (EP) applications to produce groundwater within the jurisdiction of the Blue Bonnet Groundwater Conservation District (BBGCD), and if so, to what degree. As part of this assessment INTERA has been engaged to review the hydrogeological and geotechnical data and groundwater models relevant and apply the best available science to predict the water level changes and resulting land subsidence in the area of the proposed well field.

Dr. Steven Young, a Principal Geoscientist at INTERA Inc. (INTERA), was asked to prepare this report and to provide prefiled testimony for the hearing on the merits involving the applications for groundwater production wells submitted to the BBGCD pending before the State Office of Adminstrative Hearing (SOAH), SOAH Docket No. 951-13-4182. INTERA is aware that EP has already provided the BBGCD with a Phase I Hydrogeological Report and a Phase I Supplement to that report. INTERA has reviewed these reports in preparation of making this report. However, none of INTERA staff, including Dr. Young, contributed nor assisted in the preparation the Phase I Hydrological Report , the Phase I Supplement, or the permit applications.

This report is current as of the December 2nd deadline established by the Adminstrative Law Judge. However, the analysis presented may be influenced by materials obtained throughout the discovery process and supplements will be provided to augment the findings of this report as necessary.

2. Qualification of Dr. Steven Young

Dr. Young is a Senior Geoscientist/Engineer at INTERA with over 30 years of experience in the fields of geology, hydrogeology, and numerical groundwater flow and transport modeling. He is a licensed professional geologist and a professional engineer in the state of Texas. Dr. Young received a Masters Degree in Civil Engineering from Stanford University and completed a Doctorate of Philosophy from University of Waterloo that focused on the design and analysis of aquifer pumping tests and using sedimentological concepts to characterize the hydraulic properties of aquifers. Dr. Young's academic career includes being awarded the Sigma-Gamma Epsilon Scholarship for the outstanding Geologist at the University of Virginia; being awarded the Wallace-Poole Prize for the Outstanding Environmental Science undergraduate at the University of Virginia; and being awarded the Pearson Medal for Best Dissertation in the Science Department at the University of Waterloo. Dr. Young has also taught graduate courses in hydrogeology and groundwater modeling at the University of Tennessee, Knoxville.

Since his arrival in Texas in 1998, Dr. Young has work extensively for the Texas Water Development Board, Groundwater Conservation Districts, and the Department of Defense.

During the last ten years, Dr. Young has performed considerable work in the Gulf Coast Aquifer System. In 2006, the Gulf Coast Society of Geological Associations awarded the Dr. Young's LSWP study second place in their annual Gordon I Atwater Best Poster Contest for work on defining the boundary between the Evangeline and Chicot Aquifers.

From 2009 to 2012, Dr. Young was funded by the TWDB to develop a revised lithology and stratigraphy of the Gulf Coast Aquifer System for the entire Texas Gulf Coast. From 2011 to 2013, Dr. Young managed a TWDB project to collect, review, and analyze measurements of geochemistry in the entire Texas Gulf Coast Aquifer System with the purpose of evaluating and improving, where appropriate, the conceptual groundwater flow model for the Gulf Coast Aquifer System and for the GAMs used by GMA 14, 15, and 16.

Dr. Young's Gulf Coast experience includes working for ten groundwater conservation districts, several municipalities, and private companies. This work includes applying groundwater models including the the Lower Colorado River Basin (LCRB) model to evaluate the potential impacts from well fields, to characterize fresh and brackish groundwater resources, to evaluate the potential for groundwater pumping to cause land subsidence, and to design groundwater monitoring network. A copy of Dr. Young's curriculum vitae is being simultaneously produced.

3.0 Summary of the Electro Purification Wellfield Application

On November 21, 2012, the Law Offices of Jackson, Sjoberg, McCarthy, and Townsend, LLP submitted an application package on behalf of Electro Purification, LLC (EP) to the BBGCD for purposes of developing an aggregated well field containing 10 wells to produce up to 22,500 acre-feet of groundwater from the Evangeline Aquifer. The wells are to be located in portions of Waller and Austin Counties. EP will be the owner and operator of the well field. The property where the proposed wells are to be located is owned by Cambco Interests, LP and Brazos Operations, LP. The property includes 3,200 acres that covers Waller (937 acres), Fort Bend (971 acres), and Austin (1,202 acres). The application package included the following applications for each of the ten wells: 1. Non-Exempt Water Well Drilling Registration Applications; 2) Well Operating Permit Applications; 3) Transportation Permit Applications; and 4) Well Aggregation Permit Applications. The application also included a preliminary Phase I Hydrogeological Report. At the request of the BBGCD, this Phase I Report was subsequently supplemented. The basic aquifer and well field information is described in preliminary Hydrogeological Report:

- The proposed well field consists of ten wells: seven wells within Waller County and three wells within Austin County.
- Each of the ten wells should be capable of pumping 1,500 to 2,000 gpm.

- The Evangeline is the targeted aquifer for groundwater production. The drilling registration applications for nine of the ten wells have a proposed casing depth of 700 feet and a proposed depth of 1500 feet.
- Based on geophysical log (API #47330982), there is over 275 feet of net sand thickness between 700 and 1,500 ft below ground surface.
- Using an estimated hydraulic conductivity of 200 gpd/ft^2 for the sands in the Evangeline Aquifer, the transmissivity of 55,000 gallons per day per foot (gpd/ft) is estimated for deposits between 700 and 1,500 feet
- Allowing for 100 feet of safety factor, there is at least 500 feet of available drawdown for sands below a depth of 700 feet below ground surface

By letter on March 20, 2013, the BBGCD requested that EP complete a supplemental Phase I report that considers a well field of one Chicot well, one Jasper well and eight Evangeline wells. On 15 April 2013, the Thornhill Group submitted a supplement to the Phase I Hydrogeologic Report. This supplement was filed as a result of discussions with the BBGCD that led to the modification of the EP well permits to consider not only the Evangeline aquifer but the Gulf Coast aquifer system as a whole so that pumping could occur in the Chicot and/or Jasper aquifers.

- The estimated net sand thickness and hydraulic conductivity for the Chicot Aquifer is 250 feet and 400 gpd/ft^2 , respectively
- The estimated net sand thickness and hydraulic conductivity for the Jasper Aquifer is 150 feet and 200 gpd/ft^2 , respectively

Prior to this expert report, EP has not yet tried to optimize the production among the EP well locations and the sand units in the Gulf Coast aquifer to reduce pumping impacts to potentially affected parties. This work is on-going and will be reported as results become available.

4.0 Summary of Findings

- The Houston Area Groundwater Model (HAGM) was developed to predict groundwater responses to pumping at a regional scale and therefore is not an appropriate tool for performing local-scale drawdown and land subsidence analyses at the EP wellfield.

- The HAGM model uses inappropriate hydraulic boundary conditions to simulate recharge into groundwater resulting from precipitation and from interaction with streams. These inappropriate boundary conditions produce physically unrealistic estimates of recharge and discharge in the historical water budgets for Fort Bend, Waller, and Austin counties. As a result of these in appropriate boundary conditions, the HAGM is not a reliable simulator of groundwater flow near the EP well field.

- The HAGM was calibrated with insufficient consideration of theoretical considerations and measured field aquifer properties that should be used to constrain the parameterization of aquifer properties. These properties include the occurrence of clay layers, occurrence of vertical hydraulic conductivity of clays, occurrence of preconsolidation heads, and occurrence of clay compressibility. These properties are important because they are used in the prediction of water level response and land subsidence.

- The report prepared by Freeze and Nichols and LBG Guyton for the Fort Bend Subsidence District (FBSD) over predicts the impacts from the EP Wellfield on the drawdown in Fort Bend County. Two of the reasons for this over predictions are: (1) the FBSD report relies on a well file used with the HAGM that incorrectly locates four of the EP wells inside of Fort Bend County; and (2) problems with the HAGM aquifer property files significantly underestimate the transmissivity of the Evangeline aquifer across the EP well field.

- In the vicinity of the EP well field, the LCRB model has a superior numerical representation of the conceptual groundwater flow in the Chicot and Evangeline aquifers than does the HAGM with respect to: recharge from precipitation; water exchange between aquifer and streams; the stratigraphy of the Chicot and Evangeline aquifers; the transmissivity of the Evangeline aquifer; the clay thicknesses in the Evangeline and Chicot aquifers; and historical water levels.

- In the vicinity of the EP Wellfield, the LCRB model can provide more realistic predictions of drawdown in the Evangeline aquifer associated with pumping of the EP wells than does the HAGM.

- The LCRB model predicts that prodcuction of 20 MGD from the EP wellfield from 2010 to 2070could result in a maximum drawdown of about 110 feet. The LCRB prediction is significantly more reliable and contains less sources of error than drawdown predictions from the HAGM, which has a maximum drawdown prediction of about 200 feet.

- The LCRB model predicts that production of 20 MGD from the EP wellfield from 2010 to 2070could result in a maximum land subsidence of about 1.0 ft. The LCRB prediction issignificantly more reliable than the land subsidence predictions from the HAGM shown, which as maximum land subsidence prediction of about 3.5 feet.

- Two major concerns with the prediction of land subsidence from the HAGM are: (1)drawdowns are over predicted because the transmissivity of the Evangeline aquifer is too low; and (2) because there is inadequate documentation of the clay thickness and aquifer parameters for the EP wellfield and for much of the model domain north and west of Fort Bend County.

- The Texas Water Development Board (TWDB) has not concluded that the HAGM is a reliable predictor of land subsidence at either the regional-scale or local-scale across GMA 14 predictor at the EP well field.

- Two of the recommendations to the developer of the HAGM have merit. These are that: 1) the MODFLOW recharge package and streamflow routing or river package be used in place of the general head boundary package for recharge and groundwater/surface water interaction and that 2) the HAGM update process include public stakeholder meetings with stakeholder review of the model report. By not implementing these two TWDB recommendations, the HAGM will become the only GAM used by the Groundwater Management Areas that does not meet these two minimal criteria.

- The field data and measurements of aquifer properties used by USGS personnel to develop geological surface and aquifer hydraulic parameters have not been released by the USGS despite a concentrated effort by Dr. Steve Young and Mr. Ed McCarthy. Multiple requests for information between June 2013 and October 2013 were made for such information pursuant to the Freedom of Information Act. The requests were submitted to the FBSD because it managed the development of the HAGM and the Press Model .

5.0 Projected Aquifer Drawdown

Figure 1 shows a predicted drawdown in 2070 for the Evangeline Aquifer caused by pumping the EP well field 20 MGD from 2020 to 2070 based on the application of the HAGM and included in the FBSD Report. Figure 2 shows the results produced by INTERA using the HAGM model files provided by FBSD. Slight differences in the contours in Figures 1 and 2 are attributed to the difference in the software used to generate and plot the contours. An important difference between the two figuresis the location of the proposed EP wells. Figure 1 depicts the locations of the EP wells as submitted to the BBGCD,but the supporting model files to the FBSD Report show that these locations were not actually used in the FBSD HAGM simulation. Thus the results depicted in Figure 1 (and in the FBSD Report) are misleading. Figure 2 shows the locations of the wells as modeled in the FBSD HAGM run. Because the HAGM uses grid cells that are one square mile and the HAGM requires that pumping occurs at the center of a grid cell, the EP well locations cannot be accurately represented by the HAGM. Figure 3 shows the actual EP well locations and those locations used by the HAGM run described in the FBSD report.

Figure 4 shows predicted drawdown in 2070 for the Evangeline Aquifer that INTERA produced using the LCRB model. Like the FBSD Report, the EP wellfield was assumed to pump 20 MGD from 2020 to 2070. The LCRB simulation shows drawdowns that are about 50% less than those predicted by the FBSD HAGM 20 MGD run. Figure 5 shows predicted drawdown in 2070 for the Evangeline Aquifer that INTERA produced using the LCRB model with less than 20 MGD pumping at the EP wellfield. The model run reflected in Figure 5 also assumed phased production at the EP wellfield, pumping5 MGD from 2013 until 2025, at which time the EP well field pumps 10 MGD until 2070. The drawdowns for this pumping scenario are about 75% less than those predicted by the FBSD HAGM 20 MGD run.

For the 20 MGD pumping scenario, the HAGM simulations produce significantly greater drawdown than does the LCRB model simulations. One of the reasons for the higher drawdown is that the HAGM inputs significantly lower hydraulic conductivity values in the Evangeline aquifer than the LCRB model. In general, with all other aquifer parameters being equal, the predicted drawdown will be inversely proportional to the value of hydraulic conductivity. Thus, an aquifer with a higher average hydraulic conductivity will have a lower drawdown than a similar constructed aquifer with a lower average hydraulic conductivity.

Figure 6 shows the hydraulic conductivity in the Evangeline Aquifer in the HAGM which represents the Evangeline aquifer using a single model layer. Near the EP wellfield, the HAGM hydraulic conductivity is between 1 and 2 ft/day. In contrast, Figure 7 and Figure 8 show the hydraulic conductivity in the Evangeline aquifer in the LCRB model, which represents the portion of the Evangeline aquifer below the Chicot aquifer using two model layers. Near the EP wellfield, the LCRB hydraulic conductivity averages about 12 ft/day and 4 ft/day in the upper and lower portions of the Evangeline aquifer, respectively. Thus, in the vicinity of the EP wellfield, the LCRB model has significantly higher hydraulic conductivity values than does the HAGM model. Analysis of estimated hydraulic conductivity values calculated for the Evangeline based on pumping tests and a specific capacity test in the LCRB site conceptual model report indicates that the HAGM values of hydraulic conductivity in the vicinity of the EP site are too low. This conclusion is also supported by the Phase I Hydrogeologic Report by the Thornhill Group, which provides information that supports an average hydraulic conductivity of about 9 ft/day in the Evangeline aquifer near the EP wellfield.

Besides the difference in magnitudes, the hydraulic conductivity fields for the Evangeline aquifer are significantly different in their spatial distribution. Whereas the pattern in the HAGM has a noticeable "crater" or halo of high hydraulic conductivity in the area of Harris County, the pattern in the LCRB model has a noticeable trend of higher values up dip (northeast) and lower values toward the ocean (southwest). The trend in the LCRB model is derived from depositional facies and sand maps that were used to constrain the aquifer hydraulic properties during the model calibration process using an advanced parameter estimation technique. The trend in the HAGM is attributed to a trial-and-error manual calibration technique that had the objective of matching water levels at the expense, and without proper regard, of properly conditioning hydraulic properties of aquifers in models to sand maps, results of pump tests, and maps of depositional facies.

Sand maps are useful in constraining hydraulic conductivity because the average hydraulic conductivity of an aquifer increases as the percentage of sand increases (coarse grain deposits). Thus, maps of high sand percentages should correlate with higher hydraulic conductivity values in an aquifer. Figure 9 and Figure 10 show the percent sand coverage in the Goliad formations that comprise the Evangeline aquifer. The general location of these areas of high sand percentages are significantly better correlated with the areas of high hydraulic conductivity values in the LCRB model than the HAGM.

In conclusion:

- The FBSD Report over predicts the drawdown in Fort Bend County from the EP well field.
- For the scenario of pumping 20 MGD for the EP wells from 2010 to 2070, the predictions of drawdown from the LCRB model shown in Figure 4 are more reliable and contains less sources of error than predictions from the HAGM shown in Figures 1 and 2.
- The HAGM was calibrated with insufficient consideration to sand maps, depositional facies, and pumping test results constraint the hydraulic conductivity values used to represent the Evangeline Aquifer in the vicinity of the EP well field.

6.0 Projected Land Subsidence

Figure 11 shows the FBSD Report's prediction of land subsidence from pumping the EP well field at 20 MGD from 2020 to 2070. Figure 11 is based on the application of the HAGM and reported by the FBSD. Figure 12 shows the results produced by INTERA using the HAGM model files provided by FBSD. Slight differences in the contours in Figures 11 and 12 are attributed to the difference in the software used to generate and plot the contours. The maximum land subsidence in both plots is about 3.5 feet. Both sets of results indicate land subsidence greater than 3.0 feet in Fort Bend County, greater than 2.0 feet within the footprint of the proposed Allen Creek Reservoir in Austin County, and approximately a 10 mile reach of the Brazos River will experience land subsidence greater than 1 foot.

Figure 13 shows predicted land subsidence from pumping the EP wellfield 20 MGD from 2020 to 2070 based on the application of the LCRB model. The predicted land subsidence is significantly less than the amounts shown in Figures 11 and 12. Results from the LCRB model indicate that the maximum land subsidence is about 1 foot in Fort Bend County, that the maximum land subsidence is Iess than 0.25 feet within the footprint of the proposed Allen Creek Reservoir in Austin County, and that no portion of the Brazos River will experience land subsidence greater than 1 foot. Figure 14 shows predicted land subsidence in 2070 using the LCRB model based on the EP wellfield pumping 5 MGD from 2013 until 2025, at which time the EP wellfield pumps 10 MGD until 2070. The predicted land subsidence is approximately 30% and approximately 10% of the total land subsidence predicted by the LCRB model and the HAGM, respectively, for pumping the EP well field at 20 MGD from 2020 to 2070.

The LCRB model predictions are considered to more reliable for than HAGM predictions. This is, in part, because the HAGM significantly over predicts drawdown (see discussions in Section 5). There is no evidence that the aquifer properties utilized in the HAGM are based on a site specific measurements of clay thickness in the vicinity of the EP wellfield. Land subsidence in Gulf Coast Aquifer system is largely controlled by the dewatering of clays. Thus, with other aquifer conditions being equal, greater land subsidence will occur where the clay thicknesses are greatest.

Figure 15 shows the total clay thickness map assigned to the Evangeline aquifer that was used in to develop the hydraulic and subsidence properties of the aquifer for the HAGM and the GMA 15 GAM. The figure shows localized thickness highs near the EP well site and localized thickness lows and anomalously low clay thicknesses in Matagorda County and southern Wharton County. Based on page 4 of the HAGM report, the map clay values are based on Figure 16 to this report, which is copied from a 1982 report by Mr Gabrysch. A major concern with the 1982 Gabrysch report is that contours of clay thicknesses do not extend to the EP wellfield and in fact do not provide any coverage for many of the counties included in the HAGM. In addition, the 1982 Gabrysch report does not provide the amount or location of data used to generate these contours. The entire discussion of the clay thickness data provided by Mr. Gabrysch is as follows:

> "The base of the compacting interval within the Evangeline aquifer is not known. Measurements of water levels are sufficient to conclude that the entire thickness of the aquifer has been affected by loading. Therefore, the total clay thickness of the Evangeline was determined from electrical logs and is shown in figure 36.
>
> The increase in clay thickness from about 500 feet (152 m) in the northern part of the region to about 2,500 feet (760 m) along the Gulf of Mexico reflects both an increase in thickness of the aquifer and an increased percentage of clay in the system. Only a very small amount of the clay in the southern part of the region is compacting. Most of the subsidence is due to compaction of clay in the Chicot aquifer.
>
> A map of clay thickness for the Chicot aquifer is shown in figure 37. The Chicot aquifer does not thicken toward the coast as rapidly as the Evangeline. Regionally, the clay thickness increases from less than 100 feet (30 m) in the northwest part of the region to about 600 feet (183 m) in the southern part. Locally in the southern part, however, the clay thickness may be as much as 700 feet (213 m)."

Based on the very limited data in the HAGM report and Gabrysch 1982 report, there is insufficient data for anyone to know the reliability of the clay thickness values. What we do know is that the Evangeline clay thickness values in west, north and west of Fort Bend are not consistent with the sand and clay maps developed as part of the LCRB model, the TWBD reports on the Gulf Coast Aquifer system. Figure 17 shows the location of the geophysical logs used in the TWDB report on the geology of the Northern Gulf Coast to generate sand and clay thickness maps of the Evangeline aquifer. Figure 18 shows the type of detailed analysis provided by the

TWDB data delivered as part of the project. The logs in Figure 18 are located close to the PRESS model sites for Katy, Langham Creek, and Richmond and Rosenberg.

Because of the importance of aquifer hydraulic properties to properly characterize and model groundwater flow in aquifers, Dr. Steve Young and Mr. Edward McCarthy submitted multiple written requests to the FBSD for release of the \clay thickness data and other hydraulic and geotechnical properties of the aquifer. As of the writing of this report, none of the files containing clay thickness values or measured aquifer hydraulic and geotechnical properties have been provided. In addition, the USGS in a letter dated November 14 has implied that no information is available because:

> " it is thought that these [clay] records along with many other documents were destroyed when flood water from Tropical Storm Allison in June 2001 inundated the USGS office located at the time in downtown Houston."

As part of this project, efforts will continue to obtain key documentation and data from the USGS and the FBSD, and to determine the impact on the lack of field measurements of clay thickness data and other aquifer properties since 2001 on the development of GMA 14 GAM and the HAGM.

Among the major concerns that INTERA has with the field measurements of clay thickness and the properties of clays affecting subsidence is the lack of field measurements data used to justify the wide range of values in preconsolidated heads, virgin compressibility, and elastic compressibility used by the USGS and the FBSD in developing and applying the PRESS model and the HAGM.

Despite lack of substantial information and data from the USGS and FBSD to justify their model parameterization, INTERA has built a PRESS model for the Katy Site based on our evaluation of model parameters used by the HAGM and PRESS models, the clay thickness data available from the TWDB Gulf Coast projects and from drawdown predicted from the LCRB model. Figure 19 shows the comparison among the measured land subsidence values, the predictions from the FBSD PRESS model, and the INTERA PRESS model. In Figure 19 the water levels are assumed to remain the same from 2011 to 2030 to help evaluate potential difference with the two predicted PRESS models. The results indicate that the INTERA model fits the measured data slightly better than does the FBSD model and that the INTERA model requires significantly less time for the pressures to equilibrate between the sand and clays than does the FBSD model. If additional information can be obtained, INTERA will examine the assumptions and data associated with PRESS models already developed by INTERA.

In conclusion,

- For the scenario of pumping 20 MGD for the EP wells from 2010 to 2070, the predictions of land subsidence from the LCRB model, which predicts a maximum land subsidence of about 1.0 foot, are significantly more reliable than the land subsidence predictions from the HAGM shown, which predicts a maximum land subsidence of about 3.5 ft

- Two major concerns with the prediction of land subsidence from the HAGM are that drawdowns are over predicted because of the transmissivity of the Evanageline aquifer is too low and because there is inadequate documentation of the clay thickness and aquifer parameters for the EP wellfield and for much of the model domain north and west of Fort Bend County.
- The HAGM was developed and continues to be maintained without availability to the field data and measurements of aquifer properties used by USGS personnel to develop geological surface and aquifer hydraulic parameters. This data has not be released despite multiple requests pursuant to the Freedom of Information Act.
- A PRESS model for the EP site is being developed for INTERA. However, the development of the PRESS model is hampered by INTERA's lack of success with securing the measurements of clay thicknesses and aquifer hydraulic properties from the FBSD and the USGS.

7.0 Inadequacy of the HAGM

The USGS has been developing models of the Northern Gulf Coast Aquifer System for decades. The latest version of these models is the HAGM which is intended to supersede its predecessor--the GMA 14 GAM. According to the HAGM report, the need for updating the GMA 14 by water managers in the greater Houston area occurred because areal distribution of groundwater withdrawals has changed in the study area (and subsequently, areas undergoing land-surface subsidence as a result) since 2000, which was the end of the calibration period for the GMA 14 GAM. With each progression of the USGS groundwater flow model, the model results and model parameters become more reasonable as a result of substantial resource being spent to improve the model. However, despite these efforts, the HAGM has several significant problems associated with its current state which prevents it from being a reliable predictor of impacts of pumping on water levels and land subsidence over a 50-year planning period for site specific well field such as the EP wellfield. Several of the significant problems will be discussed henceforth.

<u>Lack of a Credible Approach for Simulating Recharge and Groundwater-Surface Water Interactions</u>

The HAGM uses MODFLOW General-Head Boundary (GHB) package to simulate recharge from precipitation and the interaction and exchange of water between groundwater and surface water systems. This package allows the water table of an aquifer system to function as a head dependent flux. As a result, the recharge that enters the aquifer is not dependent on precipitation, land use, climatic variations, or the location and water levels in streams. Rather, this (GHB) package allows a modeler to implicitly direct the model to establish spatial distribution for "recharge" to the aquifer and "discharge" from the aquifer based largely on the topographic elevation of the grid cell. In order to demonstrate the problems with using GHBs, the spatial distribution of the net flux across the water table and the contributors to this net flux are mapped and tabulated in the LCRB model and the HAGM for predevelopment conditions. Predevelopment conditions represent the steady-state condition that exist prior to any pumping and where the water levels are not changing because total inflows equal total outflows.

In Figure 20, the net flux in inches per year are plotted across the uppermost layer for the LCRB model. This values are scaled between values of >10inches/yr and < 10 inches/yr and represent the average flux across the surface area of the grid cell. As shown, the majority of the land area in the LCRB model is covered with a net flux entering the groundwater system at a rate between about 2 and 4 inches/year in the brownish area with major discharges occurring in the areas where stream reaches exists in the black and bluish area. In Figure 21, the net flux in inches per year are plotted across the uppermost layer for the HAGM in the same manner as done for the LCRB model in Figure 20. The pattern and magnitudes are significantly different. The vast majority of the recharge is limited to the outcrop in the up dip area (north west area) where higher elevations exist and where with very low recharge rates (< 0.01 inches/yr) or discharges are occurring across the vast majority of the coastal plains (areas of low elevation by the coast). Whereas the net fluxes and pattern of recharge values associated with the LCRB model are consistent with the estimates values and spatial variation of recharge determined a recharge study for the Gulf Coast Aquifer System (see Figure 22) and conceptual flow model of the central and northern Gulf Coast aquifer, the net fluxes and pattern of recharge values associated with the HAGM are not.

Because of the problems associated with the inability of GHBs to properly model recharge and groundwater-surface water interactions, the TWDB requires their contractors who develop GAMs using primarily TWDB funding to not use GHBs as the HAGM does to simulate recharge and groundwater-surface water interactions. At the onset of the development of the HAGM, TWDB staff recommended that the MODFLOW recharge package and streamflow routing or river package be used in place of the general head boundary package for recharge and groundwater/surface water interaction. However, based on TWDB review of the current HAGM this change was not made because of time and budget constraints.

<u>A Manual-Method of Model Calibration that Overemphasizes Matching Model Output Targets at the Expense of Underemphasizing Matching Targets for Aquifer Hydraulic Properties</u>

As stated on page 17 of the HAGM report, the HAGM was calibrated by an iterative trial-and-error adjustment of selected model input data (the aquifer properties that control water flow, recharge, discharge, and storage) in a series of transient simulations until the model output (simulated heads and land-surface subsidence and selected water-budget components) reasonably reproduced field measured (or estimated) aquifer responses and specified model calibration criteria. The specificied model calibration criteria consistent of eight elements. Seven of the eight elements were focused on improving the match between simulated and measured values of either water levels and land subsidence. The remaining criteria was a quantitative comparison of simulated water-budget components primarily recharge and withdrawal rates. As explained above because the model does not explicitly define recharge from precipitation the criteria for determining the how recharge rates are reasonable are questioned by INTERA especially since the recharge pattern and magnitudes are very different between Figures 21 and 22.

A significant comparison that is lacking in criteria to evaluate the reasonableness and acceptability of the calibrated HAGM is whether the hydraulic aquifer parameters are reasonable. As a result,the HAGM report fails to present a thorough and meaningful discussion of field measurements, targets , or theoretical consideration for aquifer hydraulic properties. As a consequence there is the possibility for unrepresentative for unrealistic aquifer properties to become a part of the HAGM. In constract to the HAGM report the LCRB report and project provides a discussion of the data and methodology used to condition aquifer parameters . Figure 23 shows an example that illustrates how field can be and was used to constrain the hydraulic conductivity values in the LCRB model.

Based on our current knowledge of the hydraulic conductivity field geology of the Evangeline aquifer, the HAGM hydraulic conductivity field for the Evangeline Aquifer appears to be more a result of manually adjusting model properties at a very fine scale without regard to geology information , sand maps, or results from pumping with a goal of improving matches to historical water level measurements than of developing model properties that represent the geological variability in the aquifer system so that reliable predictions pumping impacts can be simulated. Similarly, the spatial distribution in the Evangeline Aquifer of preconsolidated heads in Figure 24 and inelastic specific storage values in Figure 25 do not appear to justified based presumed geological heterogeinty but rather the goal of matching either water levels or land subsidence measurements.

Preconsolidation head is important predicting subsidence because for changes in hydraulic head in which head remains above preconsolidation head, an elastic response is computed. For changes in head in which head declines below preconsolidation head, an inelastic response is computed, permanent clay compaction is calculated, and the preconsolidation head is reset to the new head value. The HAGM report states that an initial value of preconsolidation head of about 70 ft below the starting head was used and that a preconsolidation head of about 70 ft was used by previous USGS models. However, as shown by in Figure 24, the preconsolidation head value in the HAGM spans from about 20 ft to 140 feet in the central portion of the HAGM. Moreover, the preconsolidation head values used in the PRESS models for the PRESS sites often have a range of values between 0 and 150 feet that vary with depth in the Evangeline. As a result, without additional discussion and justification of the preconsolidation values in Figure 24, there is reason to question whether or not the spatial distribution of preconsolidation head is based on geological heterogeniety or is an artifact of the calibration process.

Similarly, the HAGM states that the initial values of elastic- and inelastic-clay storativity were coincident with the values in the GMA 14 GAM. But the the HAGM report provides no more discussion or justification of how the final distribution of inelastic values sin Figure 25 agree with measurement values, with values with from the PRESS models, or with the final values in the GMA 14 GAM. As shown in Figure 25,there is are locations where significant differences exist between the inelastic storage values in the PRESS model and HAGM in the Evangeline

Aquifer. Moreover, the large changes that occur in the inelastic storage values at the scale of a few files are not explain the HAGM report.

Based on an evaluation of the spatial distribution of hydraulic conductivity, preconsolidation head, and inelastic storativity there appears and the eight criteria cited in the HAGM report used to guide model calibration, there is overwhelming lines of evidence that:

- too much emphasis was placed on manually adjusting aquifer parameters without proper regard to geological information or field data to achieve improved matches between simulated and measured historical water level and land subsidence values, and,
- too little emphasis instead of developing aquifer properties based on a proper balance between improving the match between simulated and measured historical water level and the match between aquifer parameters and field data and geological consideration so that the model can provide reliable prediction of drawdowns and land subsidence to pumping.

<u>The grid size and model layering scheme that are too large to capture important details about the shallow flow system, aquifer heterogeneity, and groundwater pumping</u>

In the vicinity of the EP well field, the HAGM has grid cells that with areas of one square mile and uses two model layers to represent the Chicot and Evangeline Aquifers. Whereas for this same area, the LCRB model has grid cells with areas of 0.25 or 0.125 square miles and uses six model layers to represent the Chicot and the Evangeline Aquifers. Thus, the LCRB model as a significantly better vertical and areal resolution to model ocal –scale impacts than does the the HAGM.

With regard to its limitation to address local scale conditions, the HAGM report is clear in its message. On page 52, the HAGM report states:

> “Several factors limit, or detract from, the ability of the HAGM to reliably predict aquifer responses to future conditions. The HAGM, like any nonlinear numeric model, is a simplification of the actual, complex aquifer system it simulates. Additionally, the HAGM is a regional-scale model, and as such, it is intended for regional-scale rather than local-scale analyses. Discretization of the HAGM study area into 1-square-mile grid blocks in which aquifer properties and conditions are assumed to be averages over the area of each grid block precludes site-specific analyses”

On page 50, the HAGM report states:

> “The HAGM is a regional-scale model, and as such, it is intended for regional-scale rather than local-scale analyses.”

In conclusion,

- The Houston Area Groundwater Model (HAGM) was developed to predict groundwater responses to pumping at a regional scale and therefore is not an appropriate tool for performing local-scale drawdown and land subsidence analyses at the EP wellfield
- The HAGM model uses an inappropriate hydraulic boundary conditions to simulate recharge into groundwater resulting from precipitation and from interaction with streams. These inappropriate boundary conditions produce physically unrealistic estimates of recharge and discharge in the historical water budgets for Fort Bend, Waller, and Austin counties. As a result of these in appropriate boundary conditions, the HAGM is not a reliable simulator of groundwater flow near the EP well field.
- The HAGM was calibrated with insufficient consideration of theoretical considerations and measured field aquifer properties that should be used to constrain the parameterization of aquifer properties. These properties are important because they are used in the prediction of water level response and land subsidence and include the parameterization at the EP well field site of the following: the occurrence of clay layers, of vertical hydraulic conductivity of clays, of preconsolidation heads, and of clay compressibility.
- The TWDB conclusion that the HAGM is a better model than the existing North Gulf Coast GAM for joint planning in Groundwater Management Area 14 is correct. However, the TWDB's conclusion is not evidence that the HAGM is a reliable predictor of land subsidence at either the regional-scale or local-scale across GMA 14 predictor at the EP well field.
- The USGS and FDSD decision not the follow the two of the TWDB recommendations in adversely affected the predictive reliability and utilty of the HAGM. The two TWDB recommendations were: 1) use the MODFLOW recharge package and streamflow routing or river package be used in place of the general head boundary package for recharge and groundwater/surface water interaction and that 2) include public stakeholder meetings with stakeholder review as part of the model development process.

8.0 Strategy for Developing Acceptable Impacts to BBGCD

Based on preliminary LCRB model simulations not discussed in this report, there appears considerable opportunity for reducing the drawdown and land subsidence impacts associated with pumping the Evangeline Aquifer at 20 MGD from 2020 to 2070 at the location of the EP well fields. These analysis show that because the Chicot Aquifer is more transmissive than the Evangeline, the shifting of some pumping from the Evangeline to the Chicot can be performed with in a manner where the overall drawdown impacts on nearby wells can be reduced while as reducing the land subsidence impacts at areas of concern. Areas of concern include the portions of the 100-year flood plain where subsidence could lead to undesired flooding risks to investments or where it could adversely impact the design and operation of the proposed Allen Creek Reservoir.

Preliminary analysis using the predicted land subsidence values from the LCRB model for the worst case scenario of pumping 20 MGD indicates that the land subsidence shown in Figure 13 is already manageable with regard to the Brazos 100-yr flood plain. These analysis indicate that in only a few ares will the floodplain expand to maximum additional width of about 400 feet. For a vast majority of the impacted area, the floodplain along the Brazos River will expand less than a few hundred feet in width. A encouraging result in Figure 13 and Figure 14 is that the unoptimized pumping scheme already has a preference for generate the greatest land subsidence in areas that are away from the proposed Allen Creek Reservoir which is shown in Figure 1. Moreover the reduction of the pumping by about 50% shown in Figure 14 leads to approximate reduction of land subsidence by 65%.

In conclusion,

- These presented and preliminary results predicted by the LCRB model suggest that the use of Chicot aquifer, staged pumping over time, and redistribution of pumping among wells will generate multiple pumping scenarios that should provide acceptable impacts associated with both drawdown and land subsidence

9.0 Conclusions

The EP team with INTERA is well versed in the development and application of the LCRB model, the HAGM, and the PRESS model and their potential strengths and weaknesses for determining the drawdown and land subsidence that can be attributed to pumping at the EP well field. This report represents an interim assessment of the type and magnitude of the impacts that may occur for two pumping scenarios at the EP well field. The EP team will continue with their assessment of the HAGM, with evaluation and possible improvements to the LCRB model if appropriate, and the development of a PRESS model for the EP wellfield if appropriate. Based on the data presented, the HAGM is considered to be an inappropriate model for predicting impacts at the local scale at the EP well field for several reasons including its large grid cell size and model layers, its underrepresentation of the Evangeline transmissivity a the EP well site, inadequate representation of recharge and groundwater surface interactions , and significant concerns with the lack of documentation and rationale for spatial distribution of important aquifer properties that affect predicted drawdown and subsidence at the EP wellfield. Nevertheless, the HAGM will be continued to be used because its benefits as a regional planning tool for GMA 14. Until such time that the USGS provides the EP team or others with the field measurements and related data that is the backbone to the development of the HAGM model, the EP team will consider the best set of field data including clay and sand thicknesses for the EP wellfield are those developed by the LCRA-SAWS Water Project. The EP team will be supplementing the findings of this interim report in late February 2014.

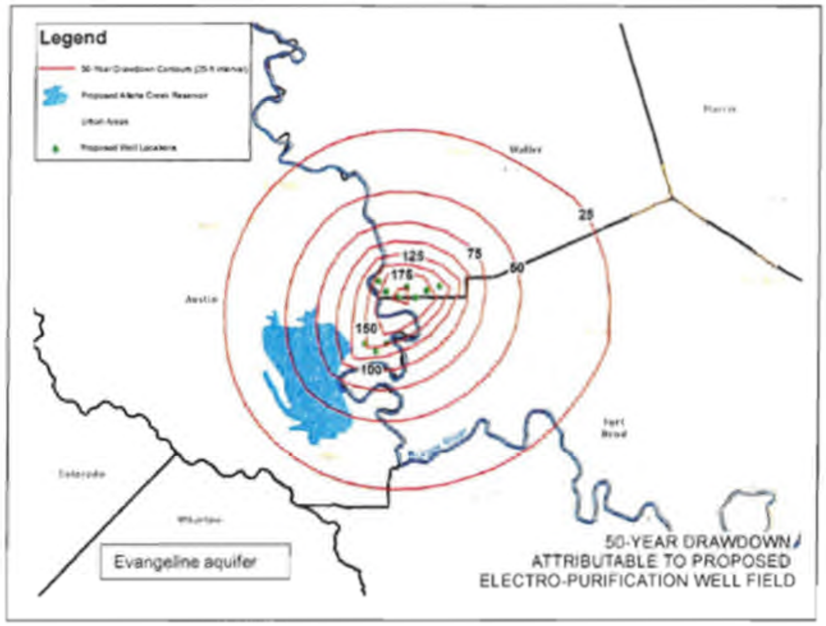

Figure 3.5. 50-Year (2020-2070) drawdown in the Evangeline aquifer attributable to the EP wellfield

Figure 1. 50-yr (2020-2070) drawdown in the Evangeline aquifer attributable to the EP wellfield for the scenario of pumping 20 MGD from 2020 to 2070

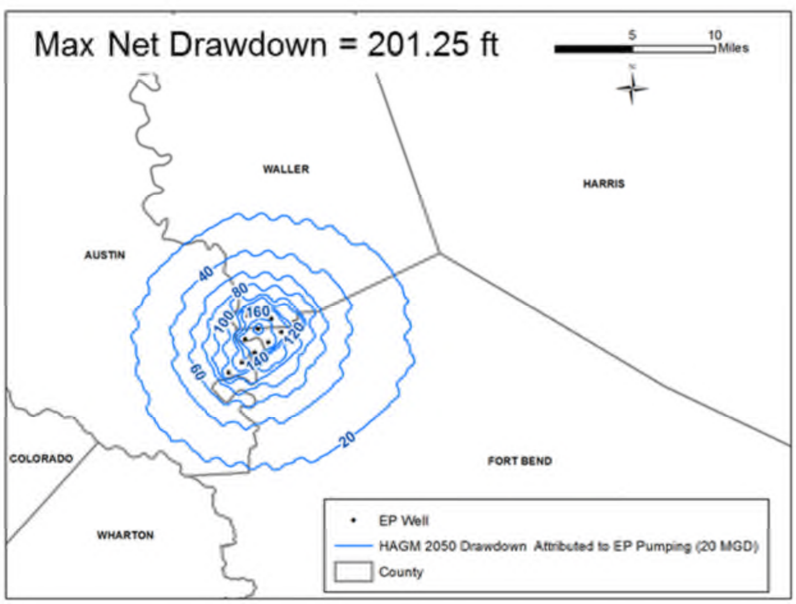

Figure 2. Results produced by INTERA for 50-yr (2020-2070) drawdown in the Evangeline aquifer attributable to the EP wellfield for pumping 20 MGD from 2020 to 2070 based on HAGM model files provided by Freese and Nichols

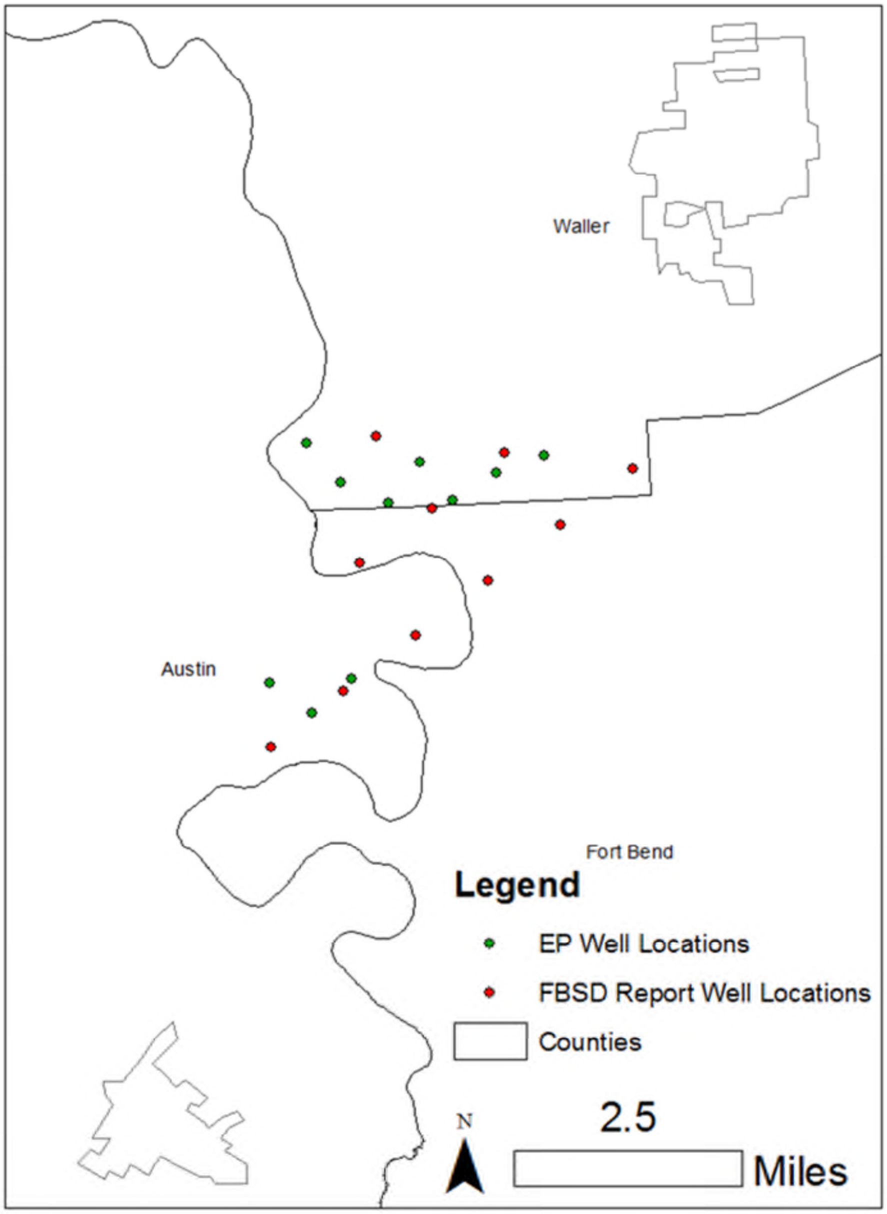

Figure 3. Comparison of EP well locations submitted as part of the BBGCD permit and the well locations used by the FBSD HAGM runs to represent the EP well locations

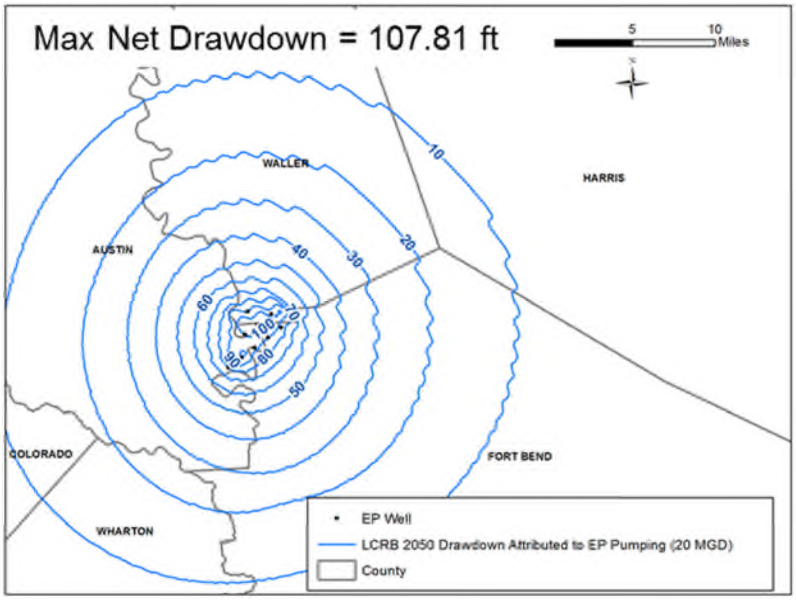

Figure 4. Results produced by INTERA using the LCRB model for 50-yr (2020-2070) drawdown in the Evangeline aquifer attributable to the EP wellfield for the scenario of pumping 20 MGD from 2020 to 2070

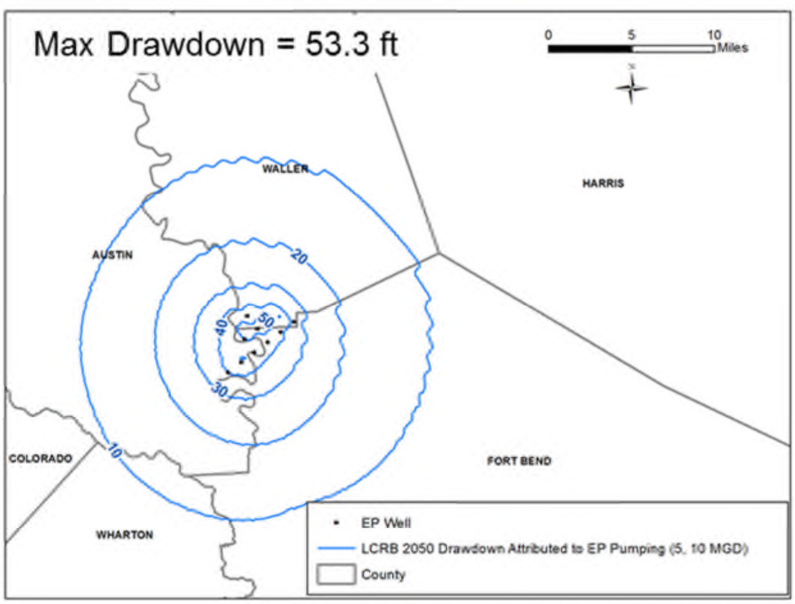

Figure 5. Results produced by INTERA using the LCRB model for drawdown in the Evangeline aquifer attributable to the EP wellfield for the scenario of pumping of 5 MGD starting in 2013 and increasing to 10 MGD in 2025.

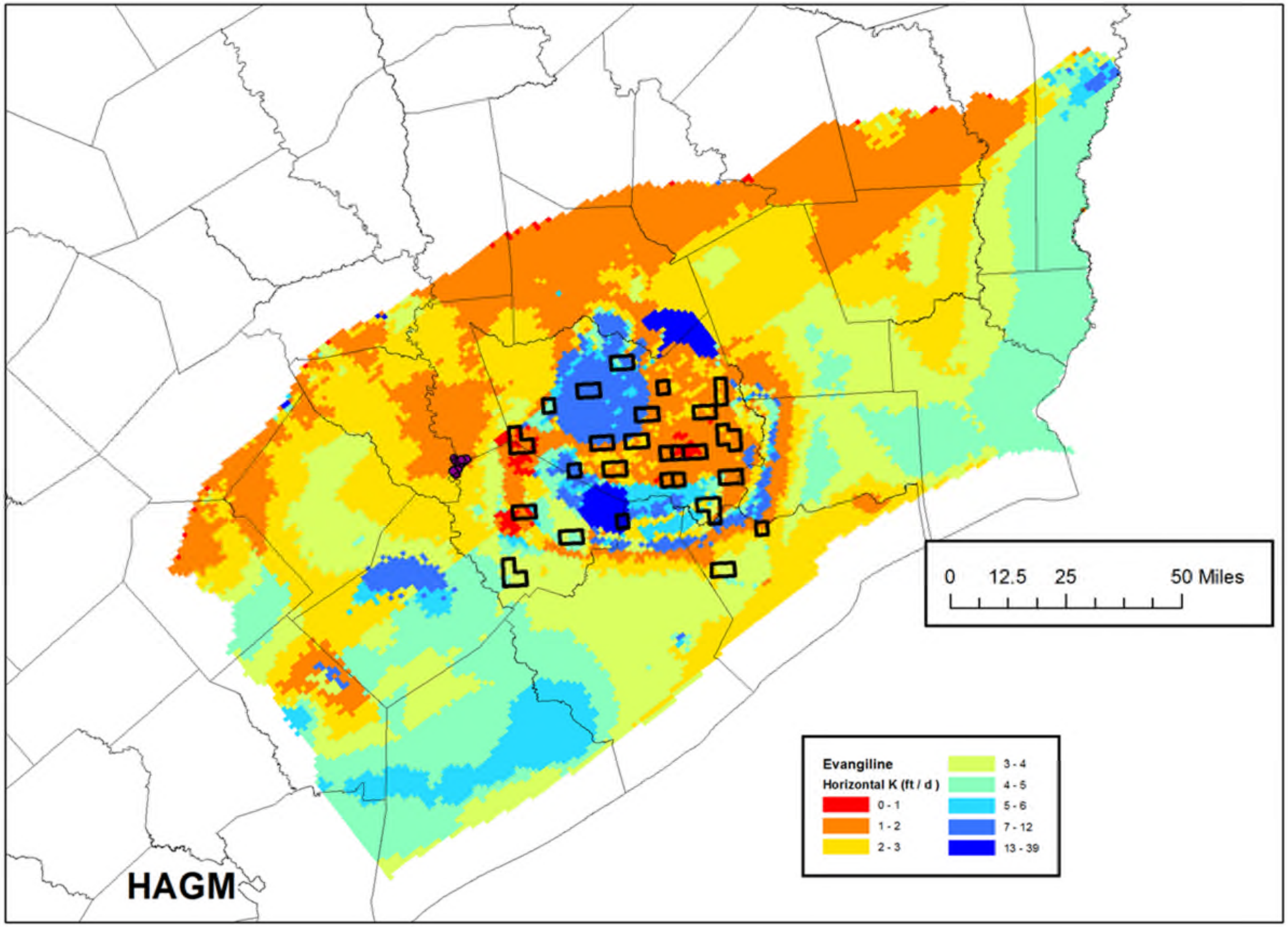

Figure 6. Spatial distribution of horizontal hydraulic conductivity of the Evangeline Aquifer used by the HAGM. Black polygons represent sites modeled by the PRESS model and the purple circles represent the location of the EP wells.

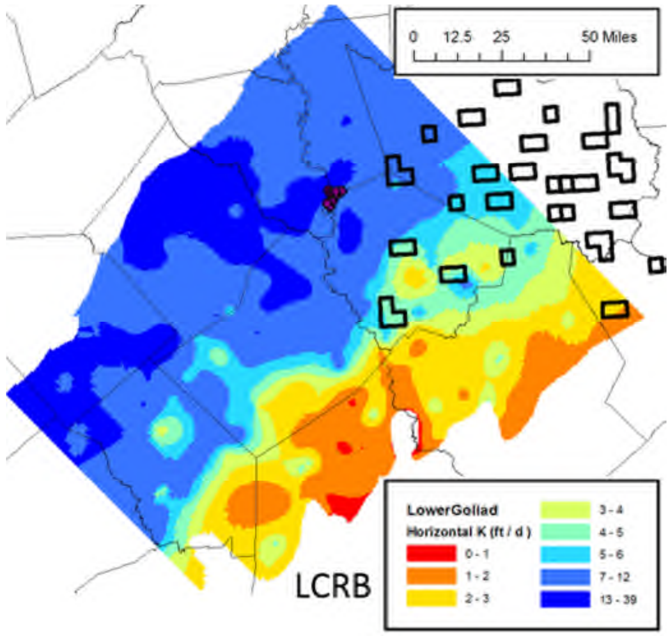

Figure 7. LCRB Model Hydraulic Conductivity for the Upper Evangeline Aquifer. Black polygons represent sites modeled by the PRESS model and the purple circles represent the location of the EP wells.

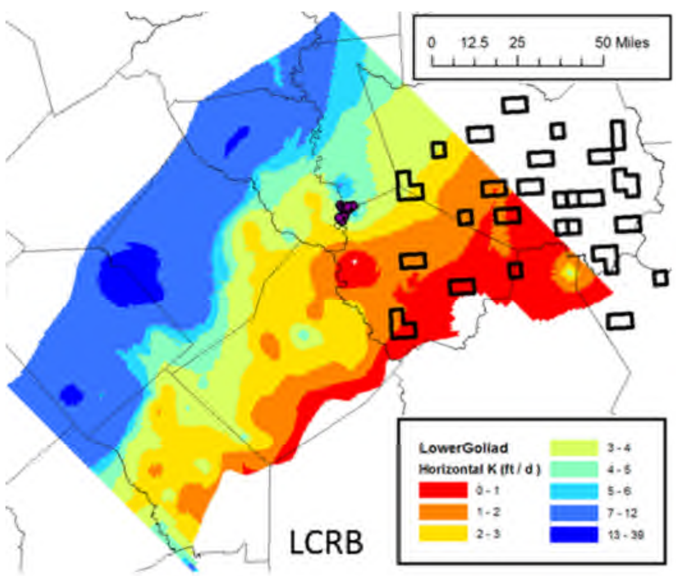

Figure 8. LCRB Model Hydraulic Conductivity for the Lower Evangeline Aquifer. Black polygons represent sites modeled by the PRESS model and the purple circles represent the location of the EP wells.

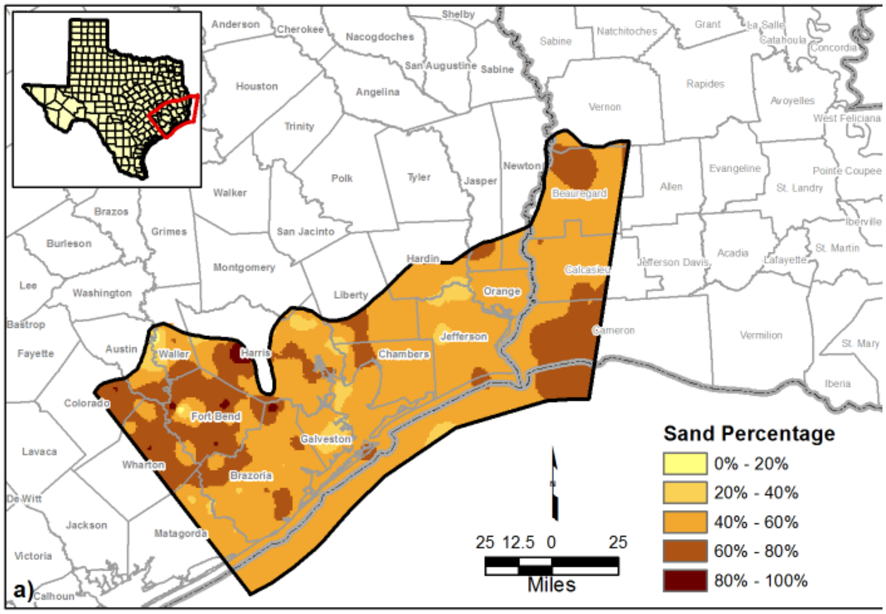

Figure 9. The percent sand coverage in the upper Goliad geologic unit that comprises the uppermost region of the Evangeline aquifer as defined by TWDB most recent characterization of the Gulf Coast aquifer (from Figure 8-9 of Young and others, 2012).

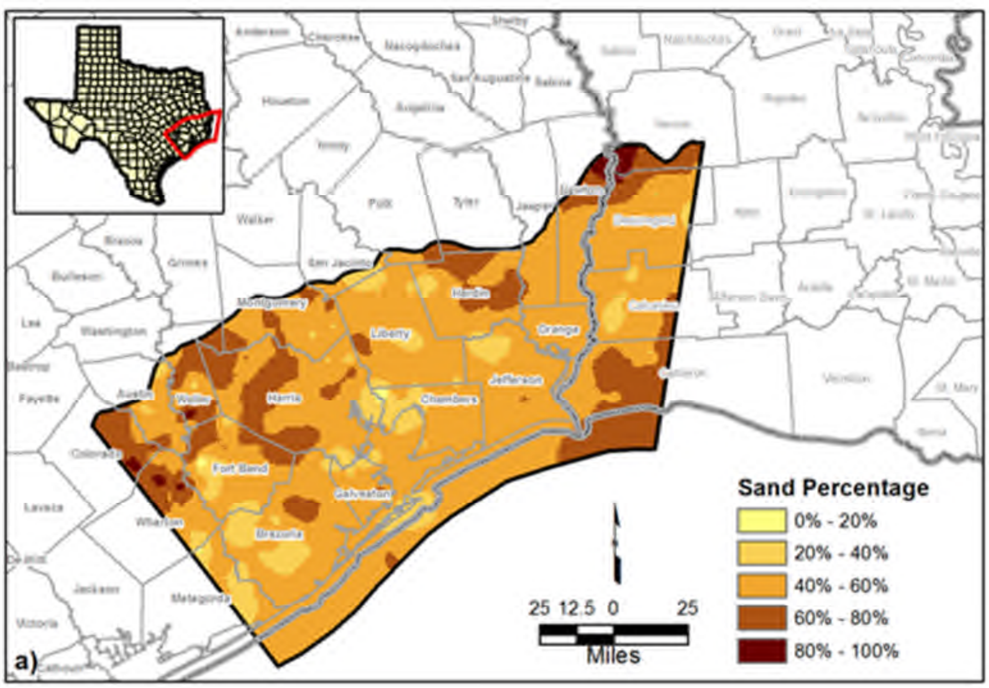

Figure 10. The percent sand coverage in the lower Goliad geologic unit that comprises the middle region of the Evangeline aquifer as defined by TWDB most recent characterization of the Gulf Coast aquifer (from Figure 8-13 of Young and others, 2012).

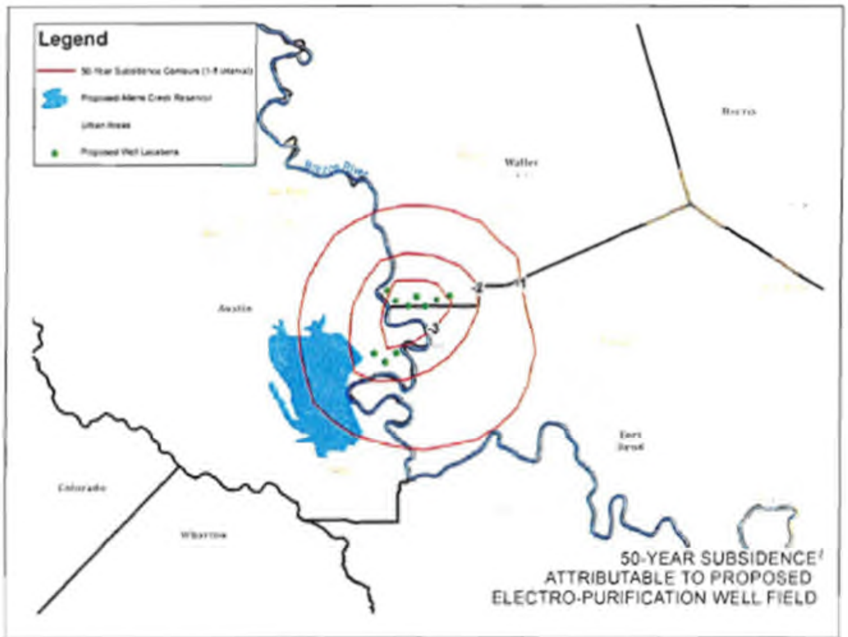

Figure 11. 50-yr (2020-2070) land subsidence attributable to the EP wellfield for the scenario of pumping 20 MGD from 2020 to 2070

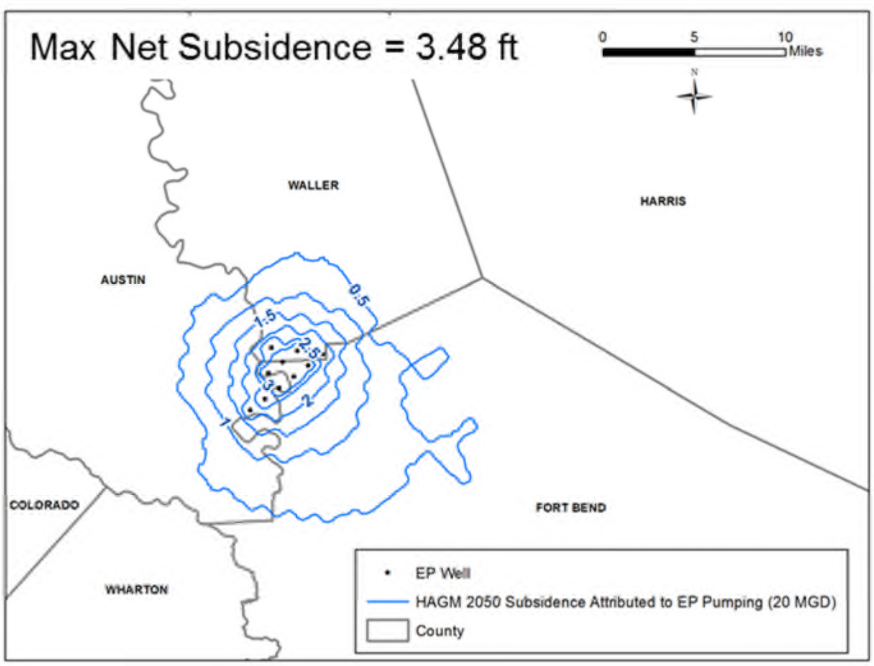

Figure 12. Results produced by INTERA for 50-yr (2020-2070) of land subsidence attributable to the EP wellfield for pumping 20 MGD from 2020 to 2070 based on HAGM model files provided by Freese and Nichols

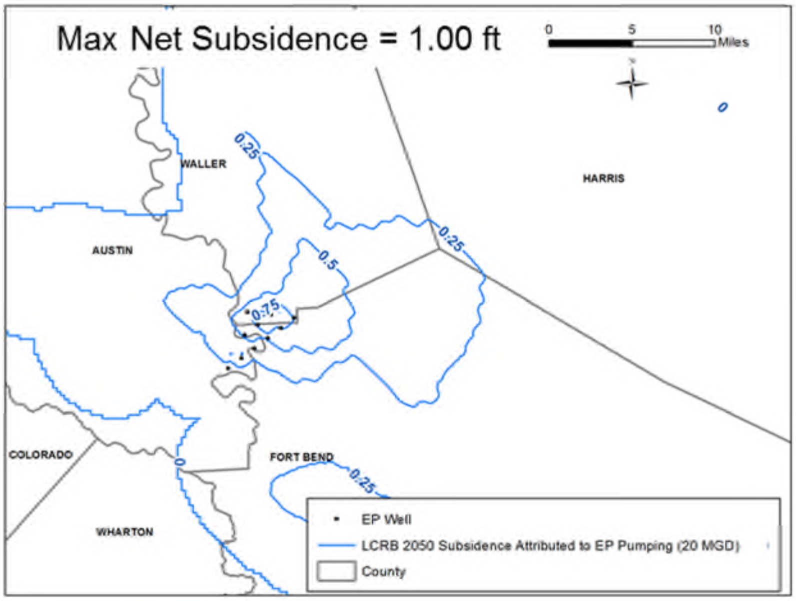

Figure 13. Results produced by INTERA using the LCRB model for 50-yr (2020-2070) of land subsidence attributable to the EP wellfield for pumping 20 MGD from 2020 to 2070

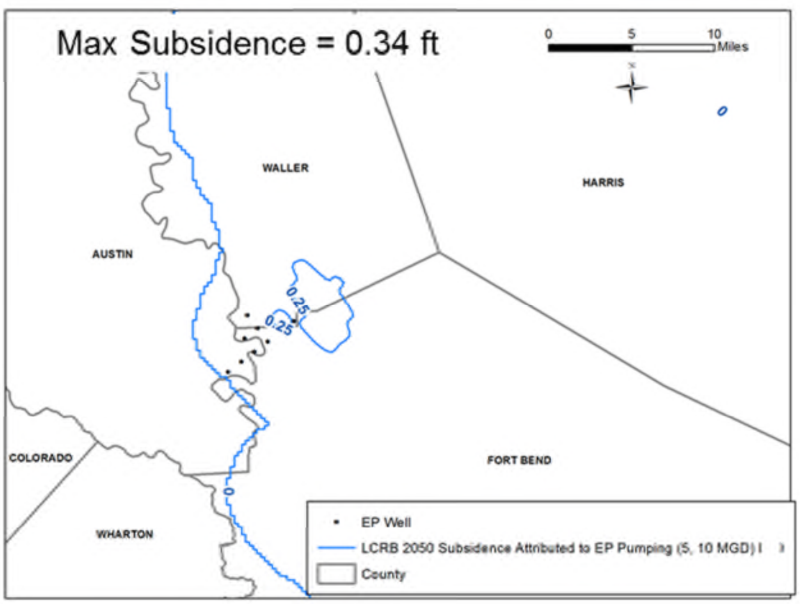

Figure 14. Results produced by INTERA using the LCRB model for land subsidence from 2013 to 2070 attributable to the EP wellfield from pumping of 5 MGD starting in 2013 and increasing to 10 MGD in 2025.

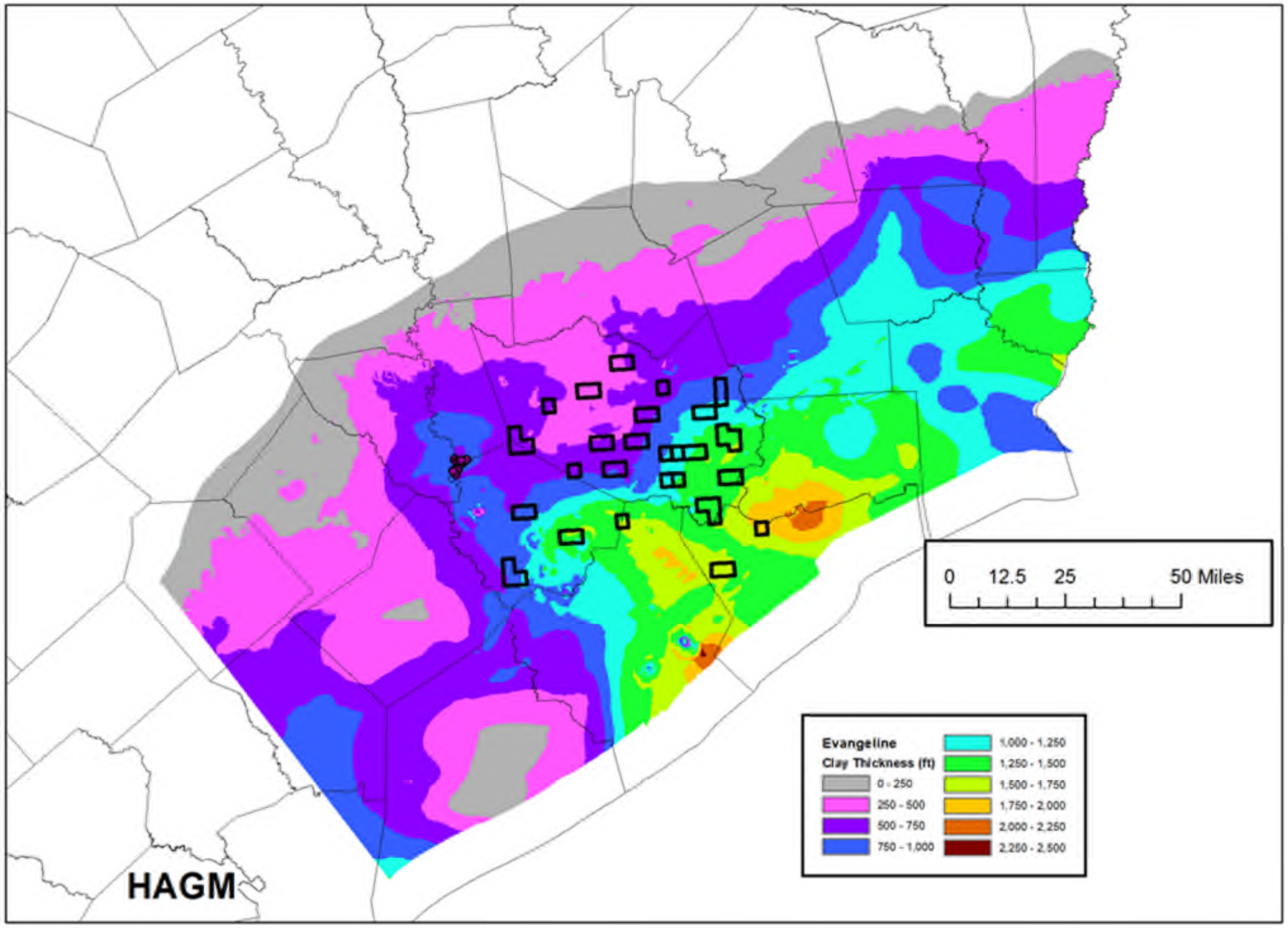

Figure 15. Clay thickness map for the Evangeline aquifer that is used for the development of HGAM and the GMA 14 GAM (based on data shown in Figure 17 of the GMA 14 GAM report)

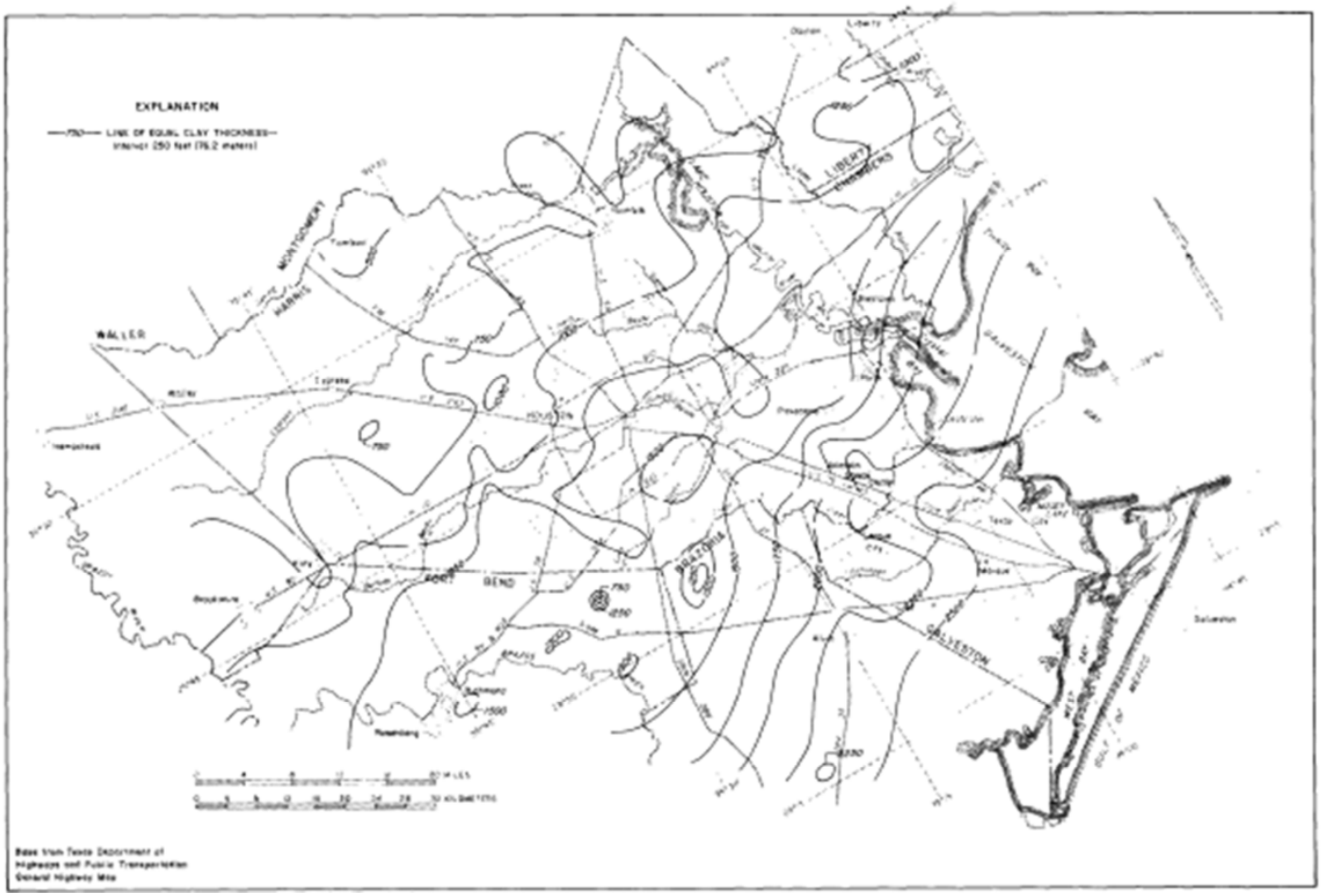

Figure 16. Contour to cumulative clay thickness in the Evanageline Aquifer provided in Figure ?? of the 1982 Gabrysch Report.

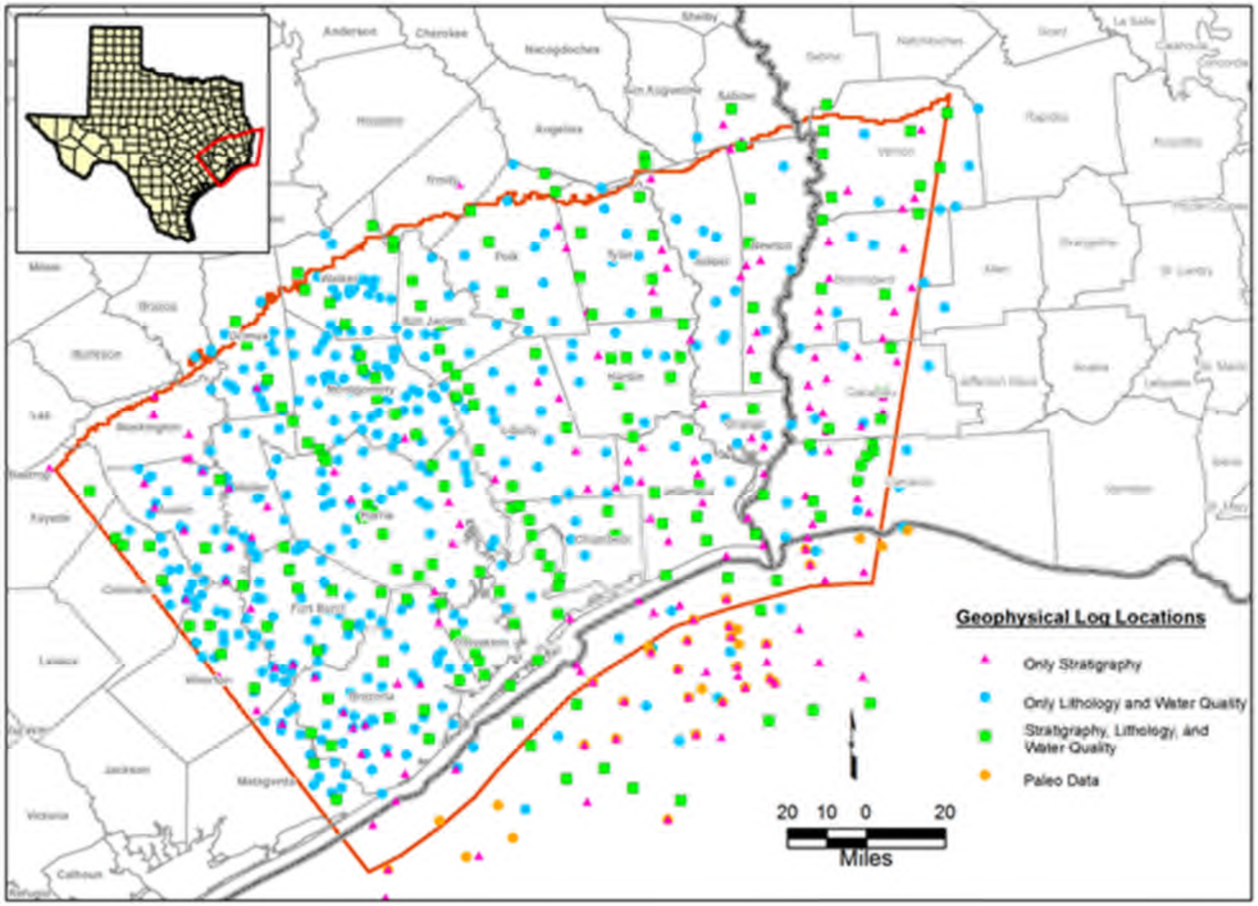

Figure 17. Location of the approximately 800 logs used to characterize the stratigraphy and lithology of the northern portion of the Gulf Coast Aquifer System.

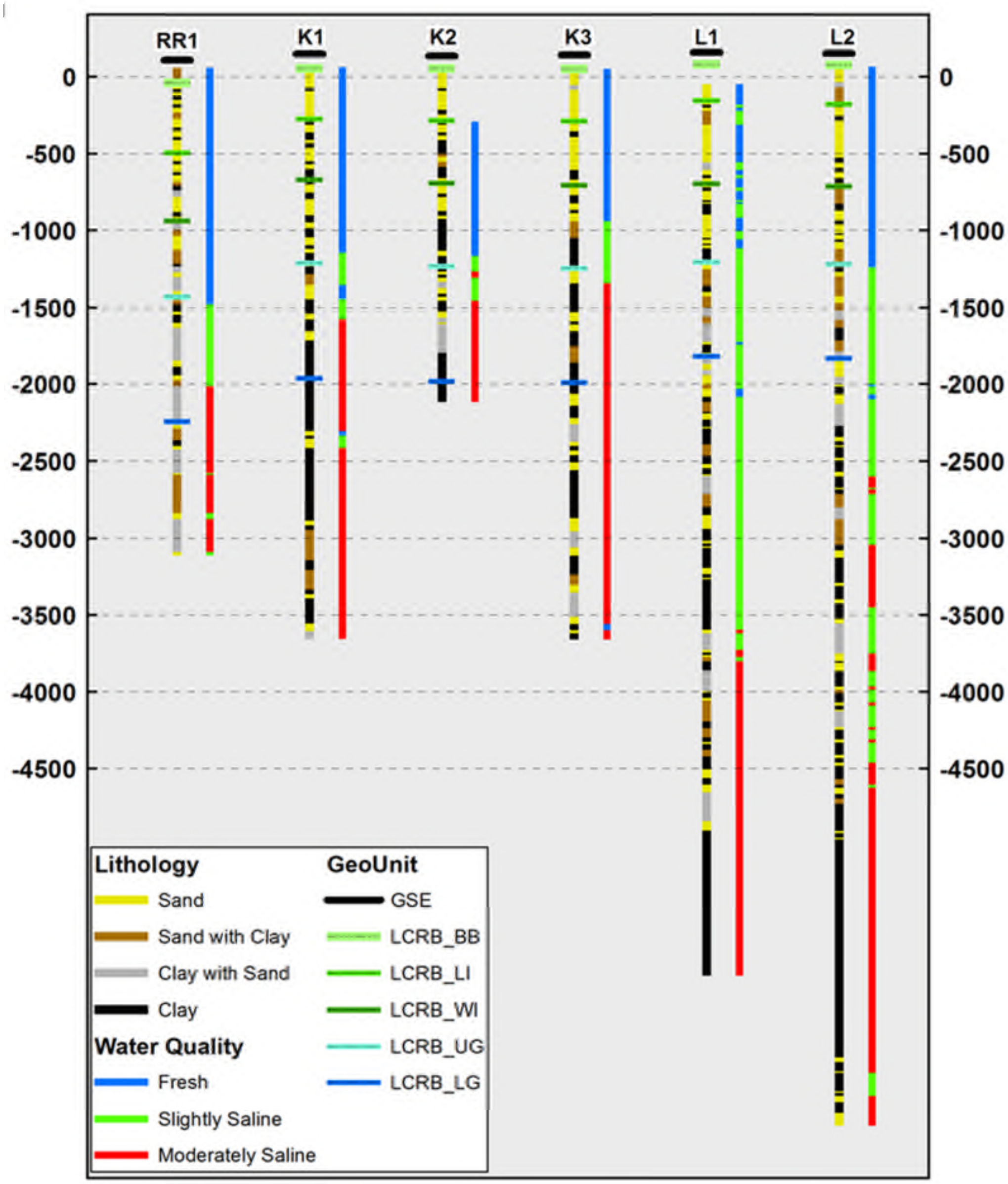

Figure 18. Vertical profile of lithology and water quality generated from the analysis of geophysical logs near the PRESS sites for Richmond and Rosenberg (RR1), for Katy (K1, K2, K3), and for Langham Creek (L1 and L2) as part of the TWDB project to better define the stratigraphy and better characterize the lithology and water quality of the Gulf Coast Aquifer System.

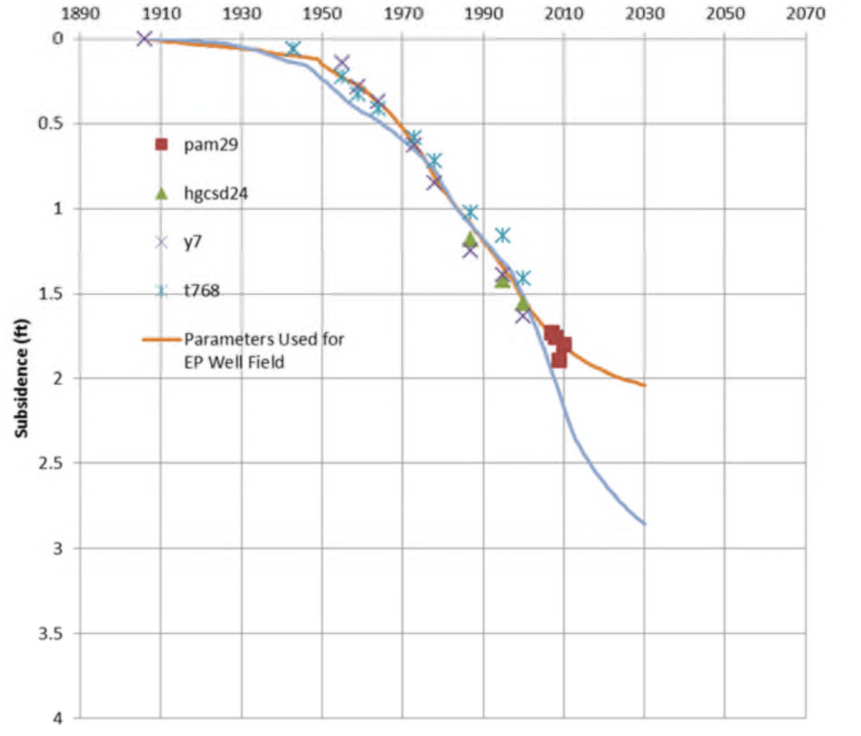

Figure 19. Measured land subsidence at the Katy Press site over time and simulated results from a PRESS model developed by Freese and Nichols for Scenario 5 (blue line) and by INTERA as part of a preliminary results using the clay thickness data in Figure 18 for K1 (orange line).

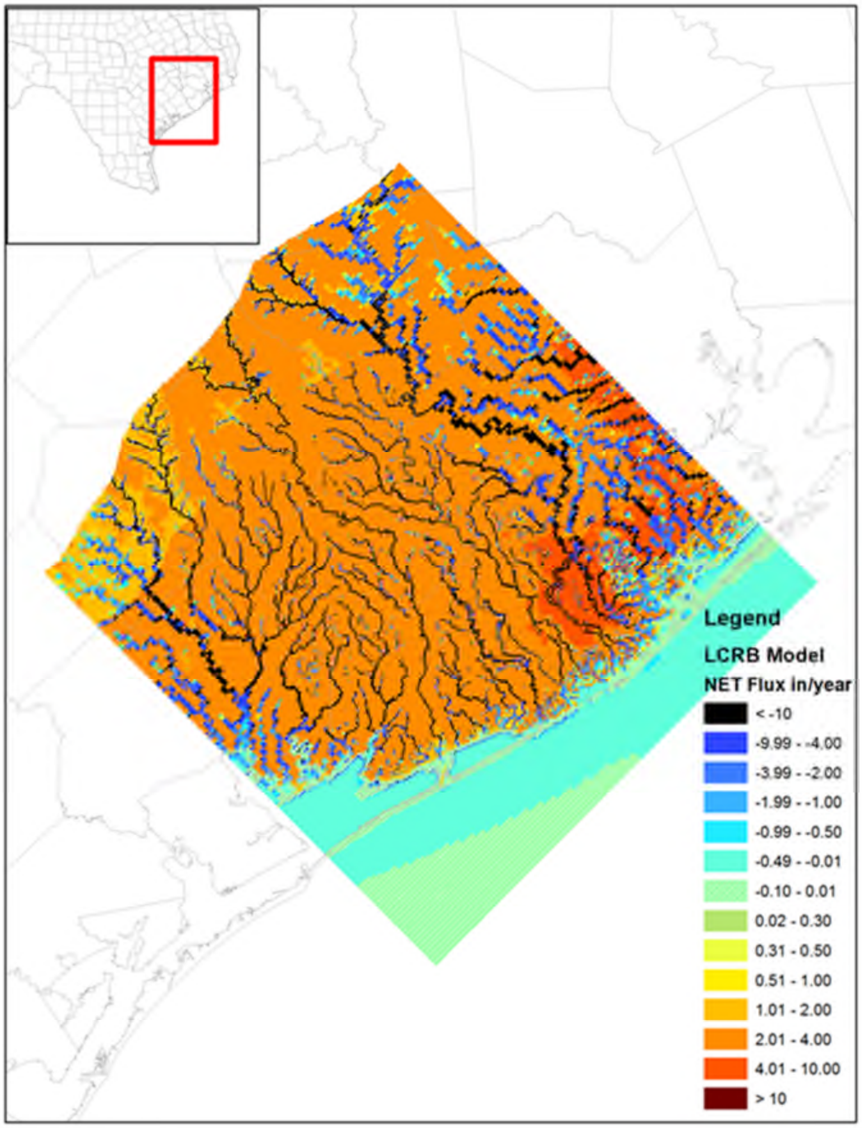

Figure 20. Calculated net fluxes across the water table for each active grid cell in the LCRB model for steady-state predevelopment conditions (no pumping).

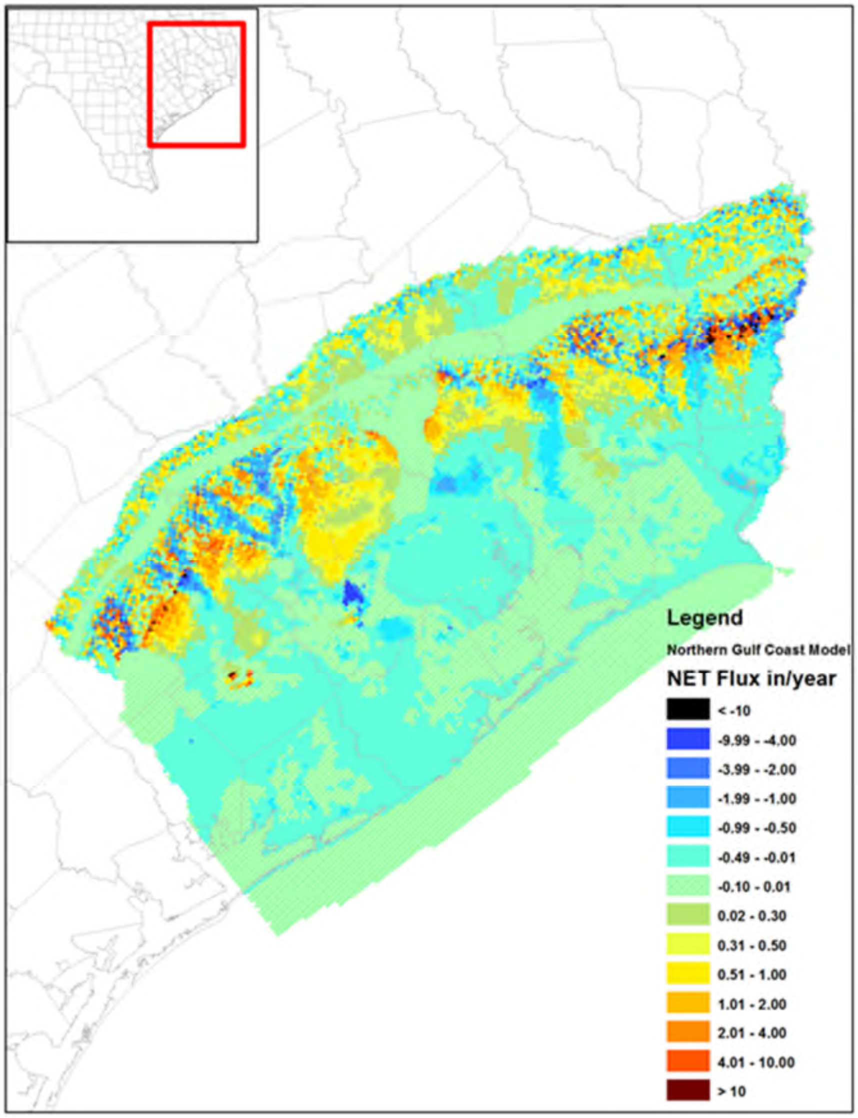

Figure 21. Calculated net fluxes across the water table for each active grid cell in the GMA 14 GAM for steady-state predevelopment conditions(no pumping)

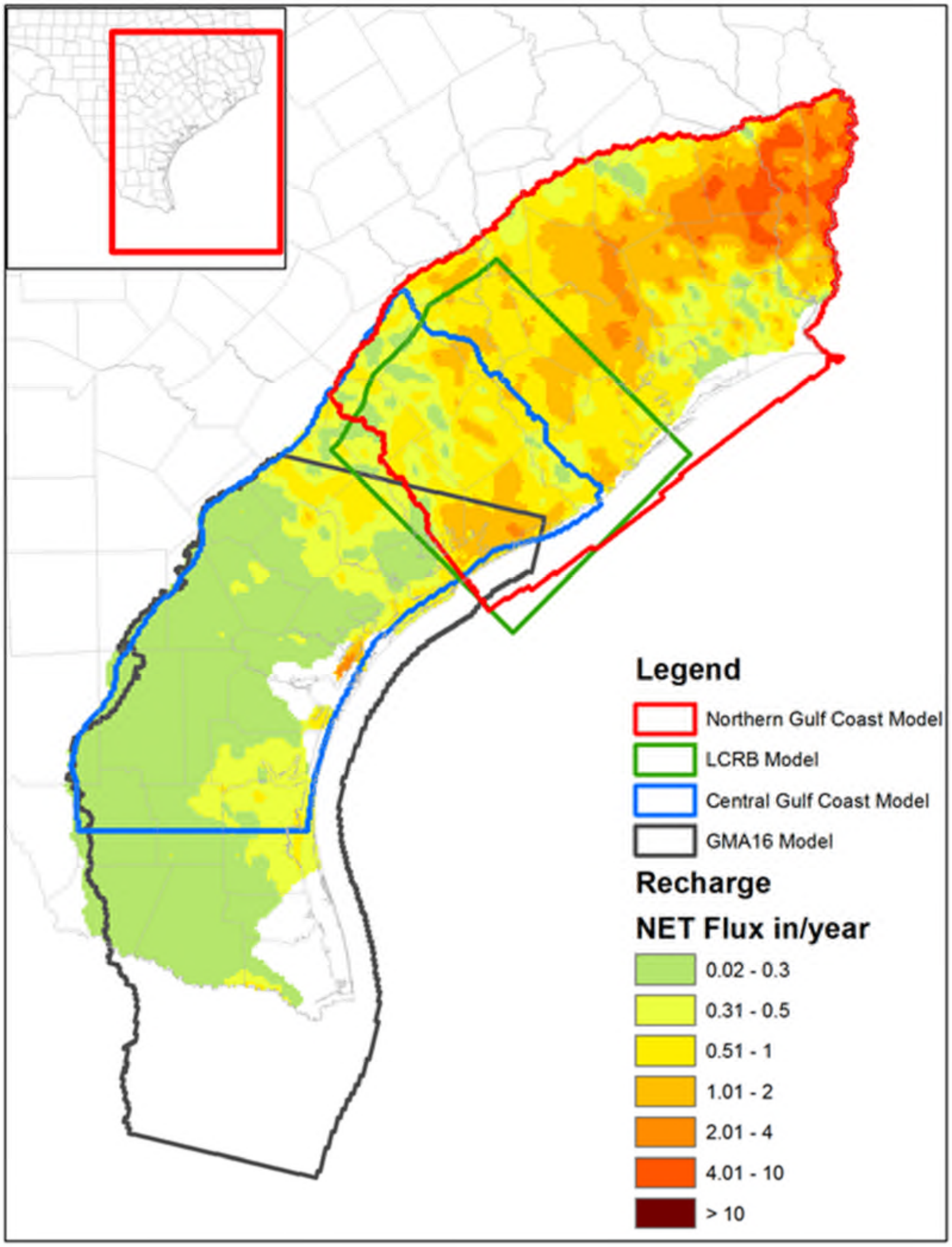

Figure 22. Distribution of recharge rates replotted to show a different symbology for the recharge rate and to show the location of four groundwater flow models. Note that the model domain for the Northern Gulf Coast Model and the HAGM are identical.

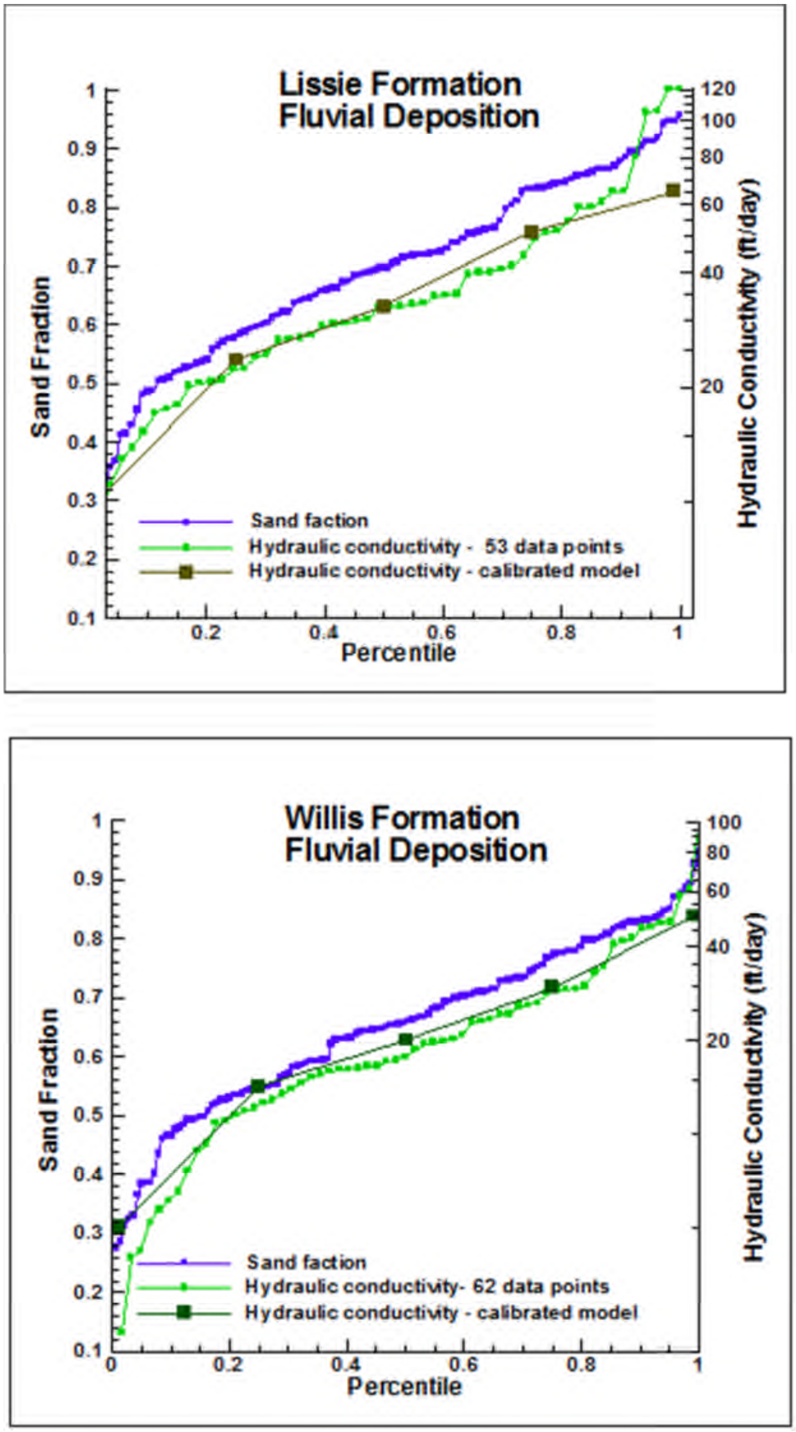

Figure 23. Cumulative Distribution Functions for the Alluvial Depositional Regions in the Lissie and Willis Formations for the Sand Percentages Calculated from Geophysical Logs, the Hydraulic Conductivity Measurements from Pumping Tests, and the Hydraulic Conductivity Values from the Numerical Model Grid Cells.

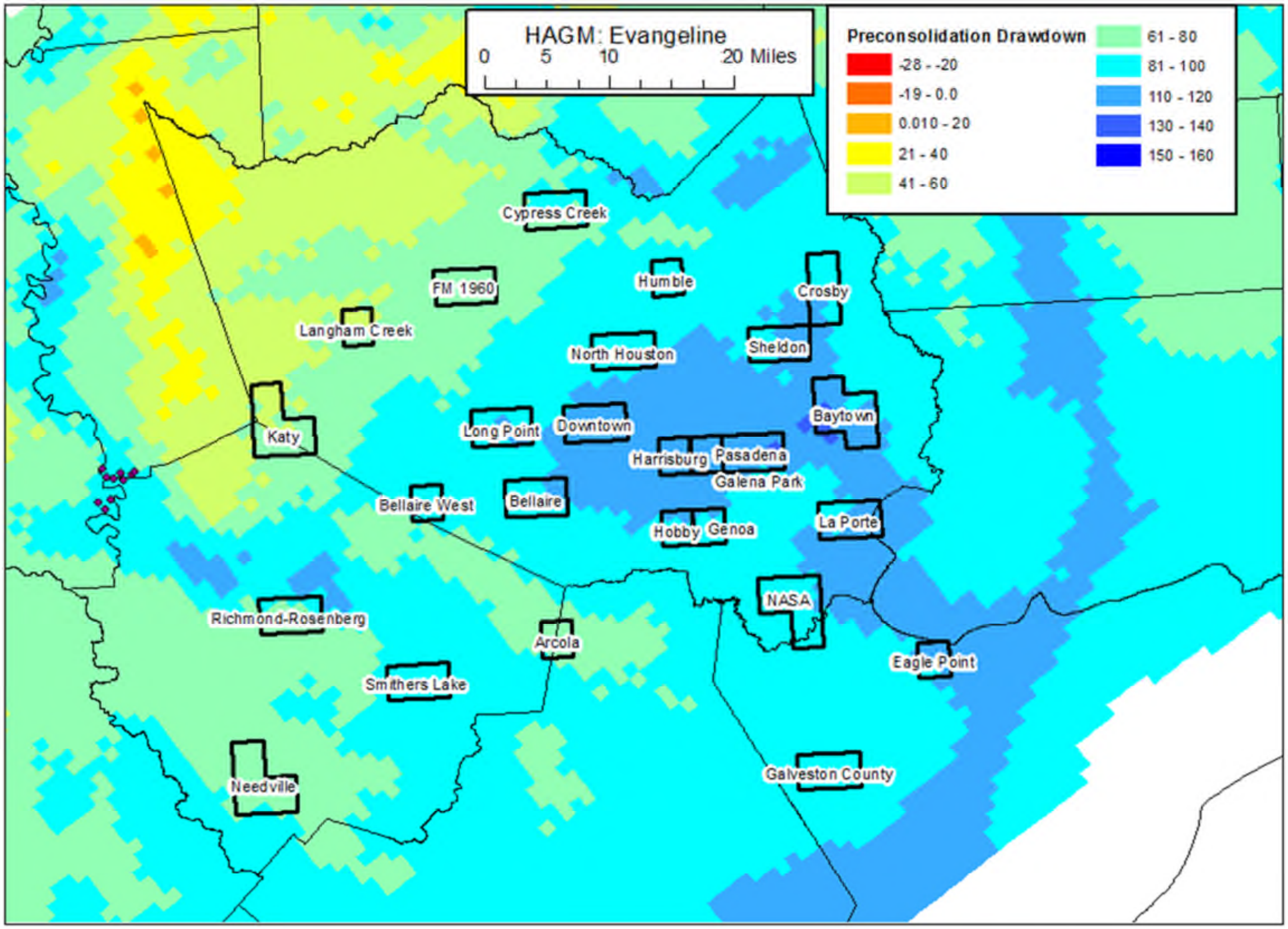

Figure 24. Spatial distribution of preconsolidation head (or drawdown)for the Evangeline Aquifer in the HAGM . Location of the PRESS model sites are designated by black polygons with labels.

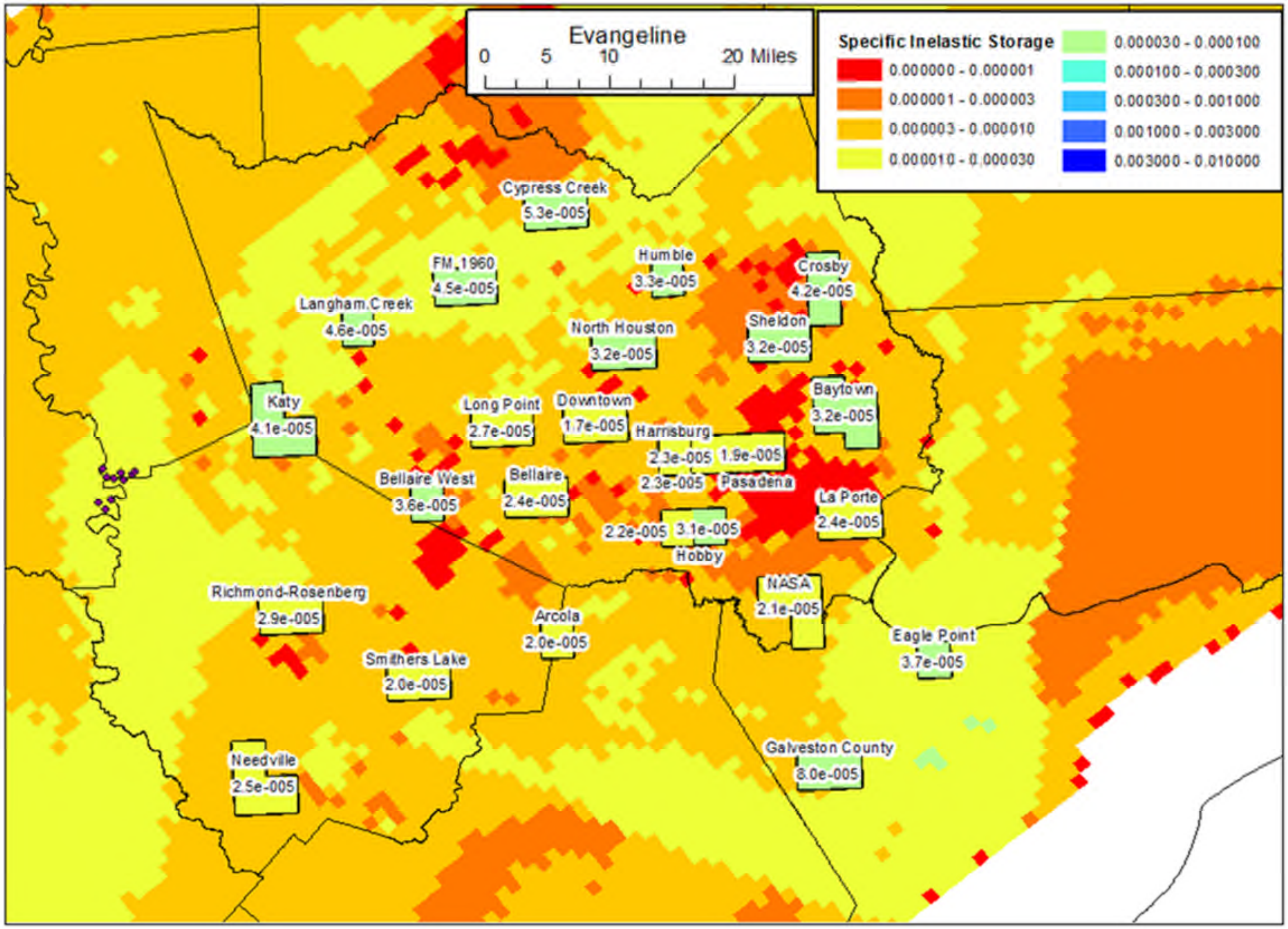

Figure 25. Spatial distribution of inelastic specific for the Evangeline Aquifer in the HAGM. Location of the PRESS model sites are designated by black polygons with labels.