TECHNICAL MEMORANDUM

Groundwater Model Update and Improvements
Harris Galveston Subsidence District, Fort Bend Subsidence District and
Lone Star Groundwater Conservation District

Prepared for

Freese & Nichols, Inc
And
Harris Galveston Subsidence District

Prepared by

LBG-Guyton Associates
Professional Groundwater and Engineering Services
Texas Registered Engineering Firm F-4432
11111 Katy Freeway, Suite 850
Houston, Texas 77079

May 2011

INTRODUCTION

The United States Geological Survey (USGS) utilized the Northern Gulf Coast Groundwater Availability Model (GAM) to perform a pumping simulation that added pumping for 2001 thru 2009 to the GAM pumping file. The GAM was previously used to simulate pumping and aquifer drawdown effects through 2000. The GAM was developed by the USGS for the Texas Water Development Board (TWDB) in 2004 and is referred to as the current conditions GAM in this memorandum. The GAM was developed to cover multiple counties from the Sabine River to the Colorado River and was developed as a macro scale model. At the time of its development there was limited hydraulic data available for the Jasper aquifer, which is a major aquifer in Montgomery County and in the past 10 years has become a significant groundwater resource in northern Harris County.

The model pumping file was updated through 2009 for use in the current conditions GAM simulation based on data provided by the HGSD, FBSD, LSGCD and TWDB. LBG-Guyton Associates (LBG-G) reviewed 1990 to 2009 pumping data and assigned pumping to the Chicot, Evangeline or Jasper aquifers, based on aquifer depths and well screen depths or well total depth. This type well and aquifer data evaluation was performed for large and small-capacity wells. The pumping file for 2001 thru 2009 was utilized by the USGS in the current conditions GAM model simulation of pumping through 2009. Additional pumping data for 2001 thru 2009 were obtained from the TWDB for counties surrounding Harris, Galveston, Fort Bend and Montgomery and provided to the USGS for use in the current conditions GAM simulation.

The USGS performed current condition GAM simulations utilizing the updated pumping data. Maps showing simulated water levels compared to field measured water levels were provided by the USGS as Figures 1 thru 6 and are included in the Appendix. The results (maps) were reviewed to assess if the GAM is accurately estimating the effects of groundwater pumping. The GAM is being improved and recalibrated by the USGS to provide a model that incorporates the additional aquifer and groundwater withdrawal data. Evaluation of the current conditions GAM simulations allows areas to be identified where model performance can be improved in a revised

Houston Area Groundwater Model (HAGM).

The HAGM will provide an improved and updated model to simulate the effects of groundwater withdrawals and estimates of future withdrawals. The HAGM can be used as the Harris Galveston Subsidence District (HGSD), Fort Bend Subsidence District (FBSD) and Lone Star Groundwater Conservation District (LSGCD) perform their groundwater planning, management and regulatory duties.

MODEL SIMULATIONS

Groundwater pumping by wells was assigned to either the Chicot, Evangeline or Jasper aquifer within the updated pumping file which distributes pumping by each one-mile square cell. The pumping was distributed within the model based on well location as latitude and longitude data were available for the wells. The total amount of pumping for one or more wells in a grid cell was assigned to that grid cell. In limited cases the pumping was distributed to nearby model grid cells within the same aquifer if the original amount of pumping per cell resulted in the model cell becoming dry during the model simulation. The USGS then performed the current conditions GAM simulation once the pumping was distributed within the model. The current conditions GAM simulated pumping from as early as 1891 thru 2009. GAM simulation water level head elevation maps for the Chicot, Evangeline and Jasper aquifers for the end of 2004 and the end of 2009 were compared to field measured water level elevations in the aquifers at the same times. The USGS provided maps by aquifer with simulated and measured water level elevations for the end of 2004 and 2009.

Chicot Aquifer Heads 2004

The 2004 current conditions GAM simulation predicts water levels that are too low in the Chicot aquifer in eastern parts of Harris County, south Liberty County, Chambers County and northern parts of Brazoria County. Figure 1 shows the 2004 simulated verses measured head in the Chicot aquifer and depicts measured head elevations of about -50 feet below sea level (bsl) and model calculated head elevations of about -100 feet bsl in the area along the boarder between Harris, Liberty and Chambers Counties. The model also calculates a water level elevation that is too low in parts of Brazoria County. Simulated and measured head comparisons are generally reasonable in other model areas.

Chicot Aquifer Heads 2009

The 2009 current conditions GAM simulation in general shows similar results to the 2004 current conditions GAM simulation. The GAM is predicting water levels that are too low in the east part of Harris County, south Liberty County, Chambers County and in the northern part of Brazoria County, as shown on Figure 1. In Brazoria County, the simulation is showing a water level elevation of -100 feet bsl while the measured water level elevation in the same area is -50 feet bsl. The simulated and measured head comparison generally are reasonable in other areas covered by the model.

Evangeline Aquifer Heads 2004

The 2004 current conditions GAM simulation shows reasonable simulated and measured head comparisons in the Evangeline aquifer generally in Harris and Fort Bend Counties, as shown on Figure 3. The model is underpredicting the water level elevations in central Harris County where the measured water level elevation is -200 feet bsl and the modeled water level elevation is -175 feet bsl. This is shown on Figure 3. The model also predicted the depth of heads too high in the west part of Fort Bend County compared to measured heads. In Brazoria County the model is showing water levels too low in the central part of the county compared to measured heads.

In Montgomery County, pumping from the Evangeline aquifer is concentrated along the I-45 corridor and it is difficult for the model to simulate the closely spaced contours of water level elevations. The issue should be at least partially addressed by updating the Evangeline aquifer pumping in the area. In Chambers County, the model is showing heads too deep and that should also be addressed with adjustments to model recharge, aquifer parameters or leakage values.

Evangeline Aquifer 2009

The model is reasonably representing heads in the east part of Harris County and in Fort Bend County, as shown on Figure 4. Simulated heads are too low by about 50 to 75 feet when compared to measured heads for 2009 for the Evangeline aquifer in Chambers County. In Brazoria County the model is showing water levels too low in the central part of the county compared to measured heads. The current conditions GAM is underestimating the depths of heads in parts of west central Harris County and west Montgomery County as the measured heads are deeper than the modeled heads. Again, the contours of heads are reasonably close together, which results in difficulties with the contouring programs when the model grid is one mile square. The Evangeline aquifer pumping file for Montgomery County and some model parameters should be revised to help with model calibration.

Jasper Aquifer Head 2004

The 2004 current conditions GAM simulation indicates the model predicts heads too low compared to measured heads for the Jasper aquifer in areas of north Harris County and southern and central Montgomery County, as shown on Figure 5. The measured water level elevations or heads are substantially higher than indicated by the model simulation. The deeper simulated heads in the areas are at least partially due to an underestimation of the Jasper aquifer transmissivity. A vast majority of the observation wells used to develop the measured head contours are located near or west of I-45. This limits data to support the contours in other areas while the model develops head contours in all direction from pumping areas.

Jasper Aquifer Heads 2009

Areas of north Harris County and southern and central Montgomery County show that the model is simulating heads at substantially deeper depths than they have been measured, as shown on Figure 6. The area encompassed by the cone of depression caused by Jasper aquifer pumping is expanding through the years and is evident from comparing the head contours on Figures 5 and 6. The overestimate of simulated head decline in north Harris County and Montgomery County is principally due to underestimated Jasper aquifer parameters.

MODEL ISSUES TO ADDRESS

The comparison of the current conditions GAM simulated heads and measured heads indicate areas with good correspondence between the two and areas where the model could be improved. The hydraulic properties of the Jasper aquifer in Montgomery and north Harris County require some adjustment. The current conditions GAM shows that for the Jasper aquifer in central and southern Montgomery County and in north Harris County, transmissivity values which show the aquifers ability to transmit water, appear to be lower than calculated transmissivity values based on well pumping tests. The pumping file data for Montgomery County also should be updated and improved in terms of the magnitude and areal distribution of the pumping.

Simulated heads were higher in the Evangeline aquifer along the I-45 corridor of Montgomery County than measured due to low historical pumping data, which can be updated to improve accuracy and areal distribution. Modifications of the hydraulic properties and pumping data will allow the model to simulate heads within each aquifer, improve calibration results and improve the model predictive capabilities for future pumping simulations.

STRATEGIES

The approach for improving the GAM model includes updating the model pumping file in certain areas with additional data and updating model hydraulic parameters in certain areas. Underestimates of pumping in the current conditions GAM in Montgomery County resulted in underestimates of head decline in Montgomery County for the Evangeline aquifer. Additional Montgomery County pumping data will be obtained from the TWDB, SJRA, LSGCD and LBG-G files. The additional pumping will be distributed by aquifer and areally within Montgomery County and will improve model calibration. The principal areas of emphasis will be along the I-45 corridor in central and southern Montgomery County. Additional pumping and water well data for the north part of Harris County for the Jasper aquifer will be collected and evaluated to improve the areal distribution of the pumping.

Additional hydrogeologic and aquifer parameter data will improve the groundwater model representation of aquifer hydraulic properties. Pumping test data for wells competed in the Evangeline and Jasper aquifers will provide site specific data to use in adjusting the model transmissivity values. The GAM utilizes the input parameters of aquifer thickness and aquifer hydraulic conductivity to calculate the model transmissivity. Well pumping test data would provide a field calculated estimate of transmissivity and well specific capacity. The model hydraulic conductivity can be updated based on the estimates of transmissivity and well specific capacity, which would improve the overall transmissivity representation in the model. Pumping tests from numerous wells located in Montgomery County and northern Harris County will be collected and assessed to develop transmissivity values for certain thicknesses of the Jasper and Evangeline aquifers.

The coefficients of storage utilized in the Chicot, Evangeline and Jasper aquifers within the model should be reviewed and modified if needed. The storage coefficient represents the aquifers ability to store and release water. Water comes out of aquifer storage with a decline in head. The storage coefficients in the current conditions GAM appear generally appropriate and may be modified near some of the aquifer outcrop areas.

In the Chambers County area recharge to the Chicot aquifer may be modified or the leakage or transmissivity values modified to improve modeling results. Groundwater pumping in the area is very limited and there is limited aquifer hydraulic data, as the water quality is not attractive for public supply or industrial uses and very few wells have been drilled in the area.

In Fort Bend County the Evangeline aquifer overall transmissivity may require some reduction or the leakage to the Evangeline may need to be lowered, as the model is underestimating the effects of pumping.

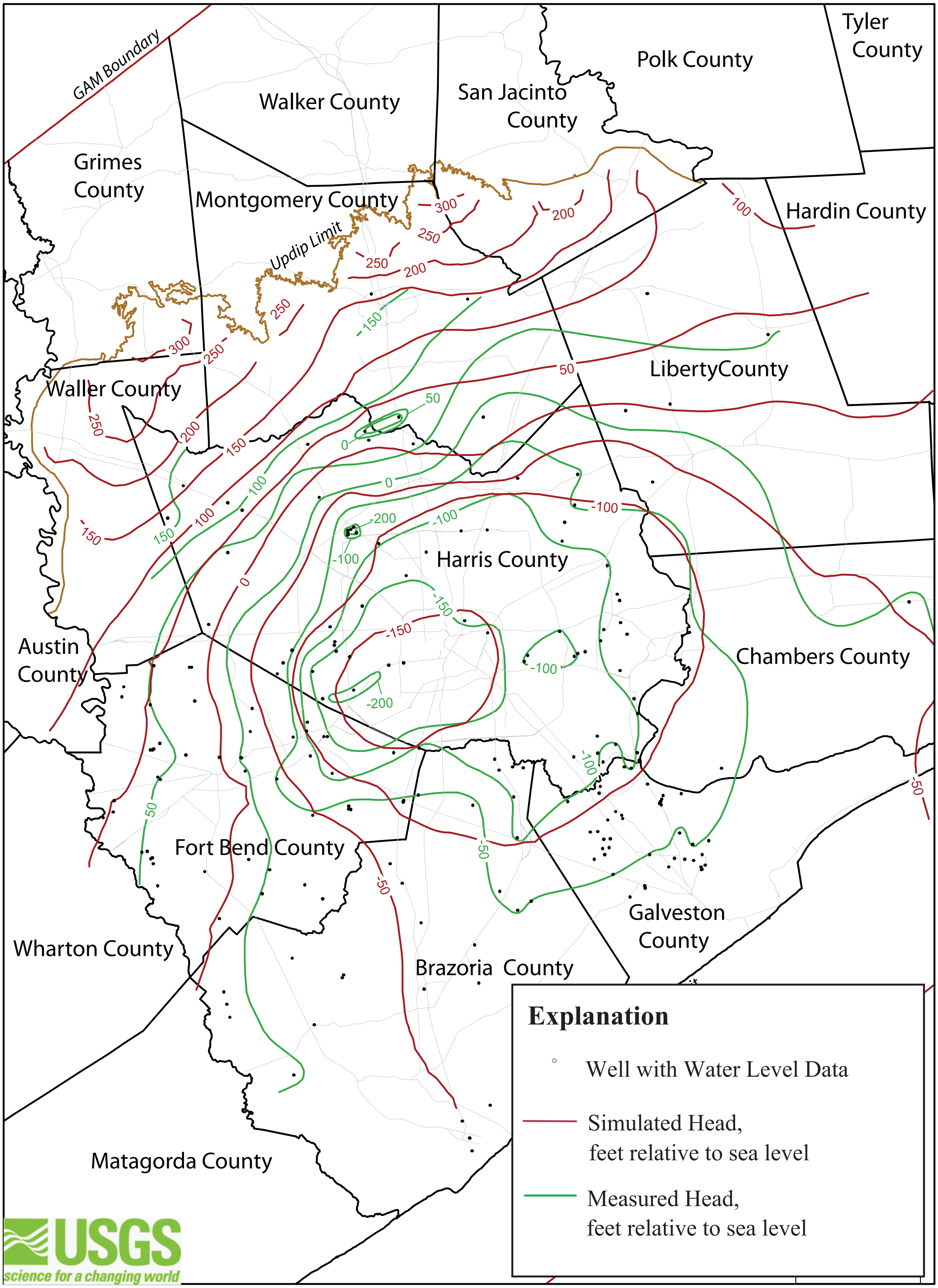
In summary, the current conditions GAM is providing simulation results that are within reasonable calibration in parts of the area. The simulation results also are showing that there is room for improvement so that simulated heads correspond to measured heads for all three aquifers over a larger modeled area. The model improvements and updating effort will continue probably until about the end of 2011. It is estimated that multiple model runs will be performed to check the model results after various changes are incorporated. At the conclusion of Work Order 3, a technical memorandum will be prepared detailing the results of the HAGM effort.

BIBLIOGRAPHY

Kasmarek, Mark C. and Robinson, James L., 2004, Hydrogeology and Simulation of Ground-Water Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System, Texas, U. S. Geological Survey Scientific Investigations Report 2004-5102, 103 pages.

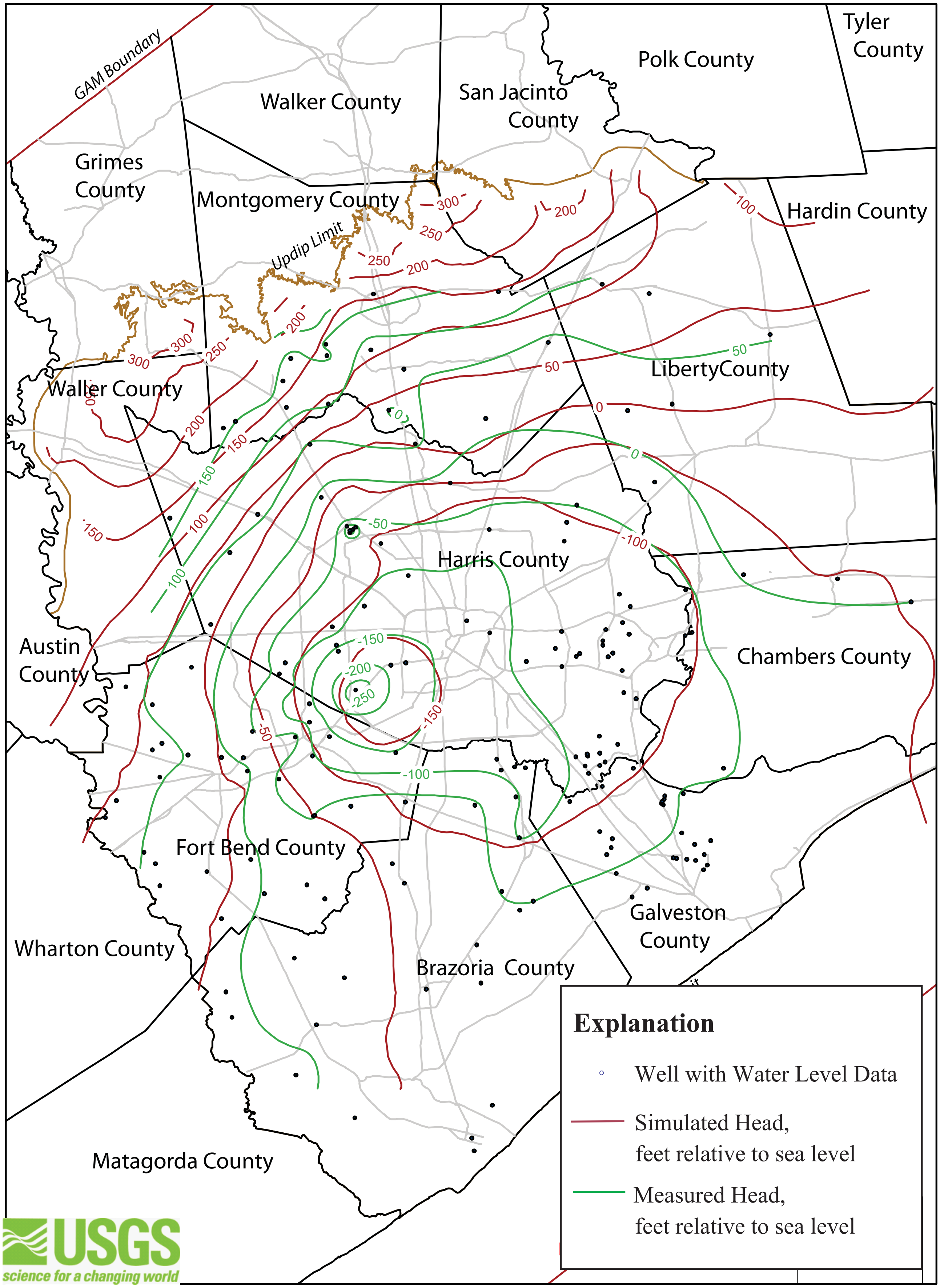
Kasmarek, Mark C., Reece, Brian D. and Houston, Natalie A., 2005, Evaluation of Ground-Water Flow and Land-Surface Subsidence Caused by Hypothetical Withdrawals in the Northern Part of the Gulf Coast Aquifer System, Texas, U. S. Geological Survey Scientific Investigations Report 2005-5024, 70 pages.

APPENDIX



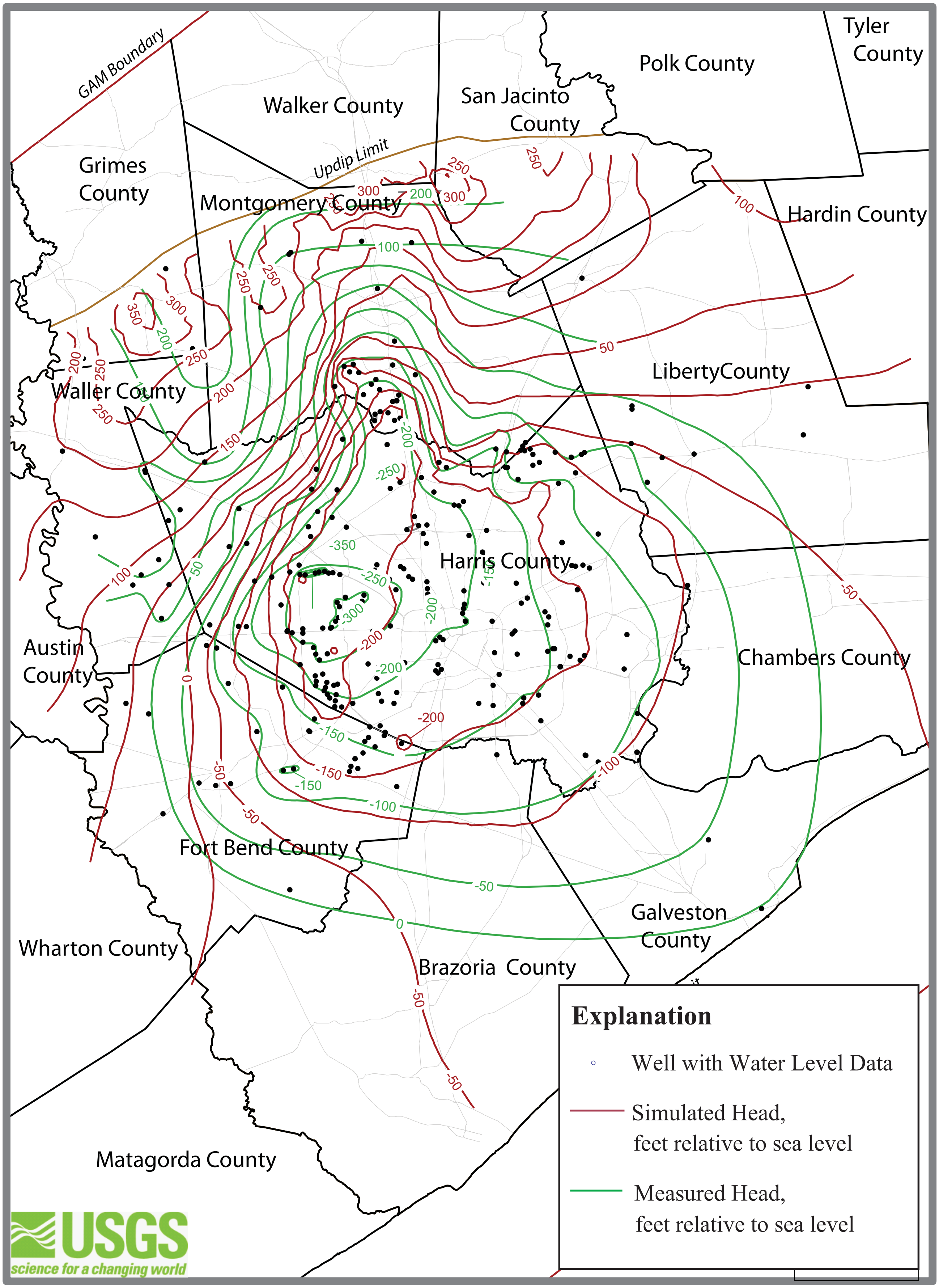
Simulated vs. Measured Head for the Chicot Aquifer, 2004

Figure 1



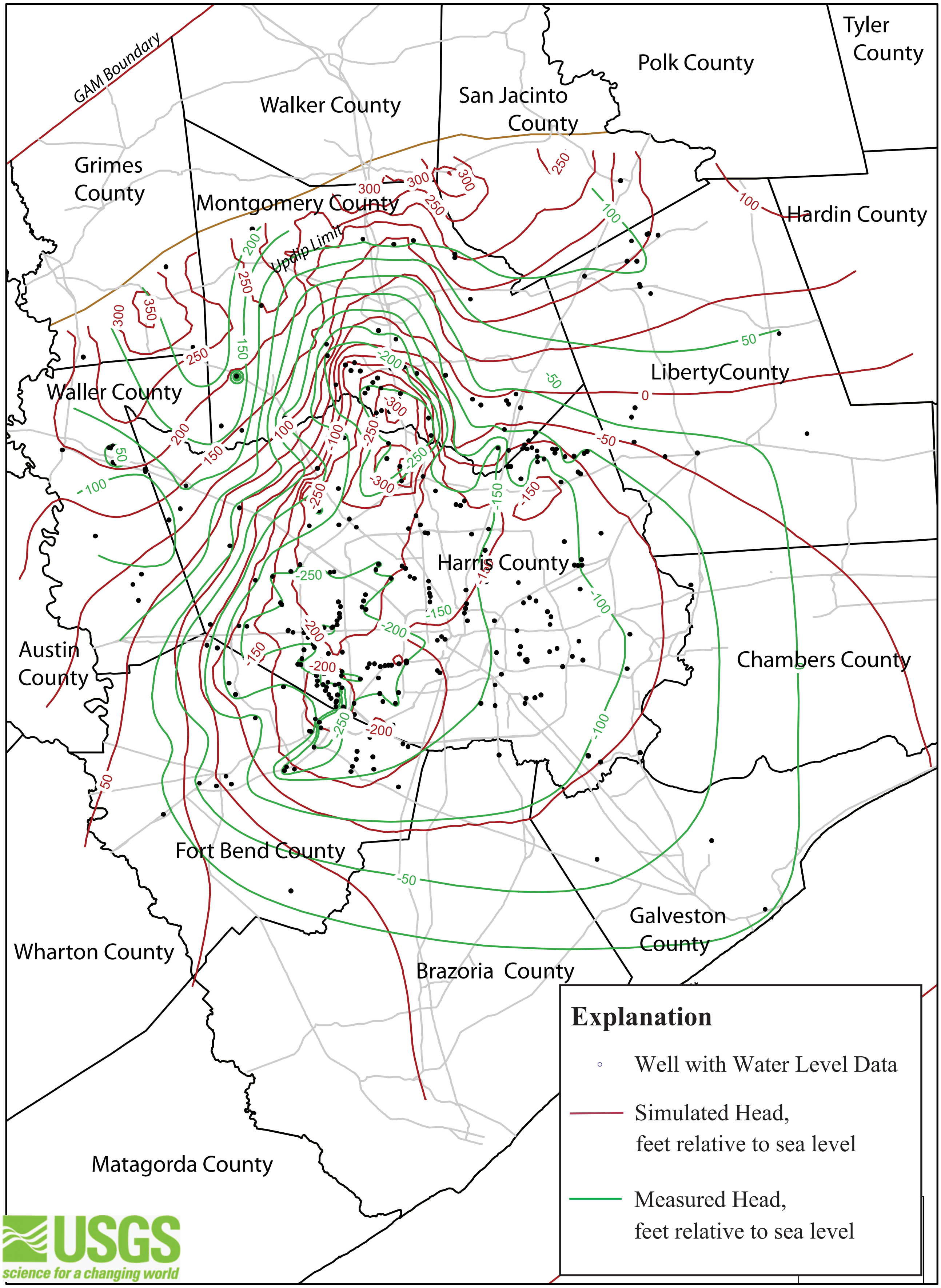
Simulated vs. Measured Head for the Chicot Aquifer, 2009

Figure 2



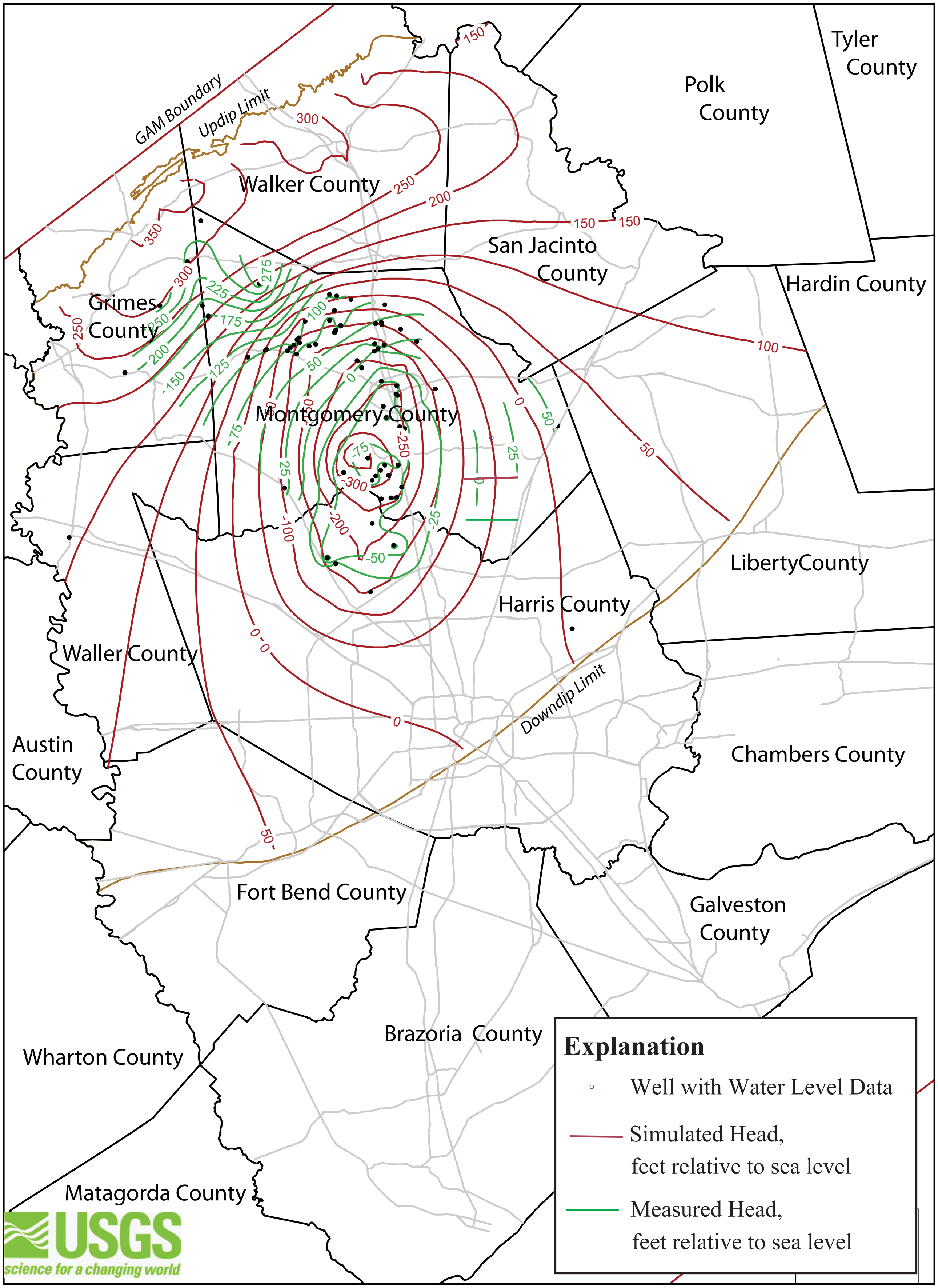
Simulated vs. Measured Head for the Evangeline Aquifer, 2004

Figure 3



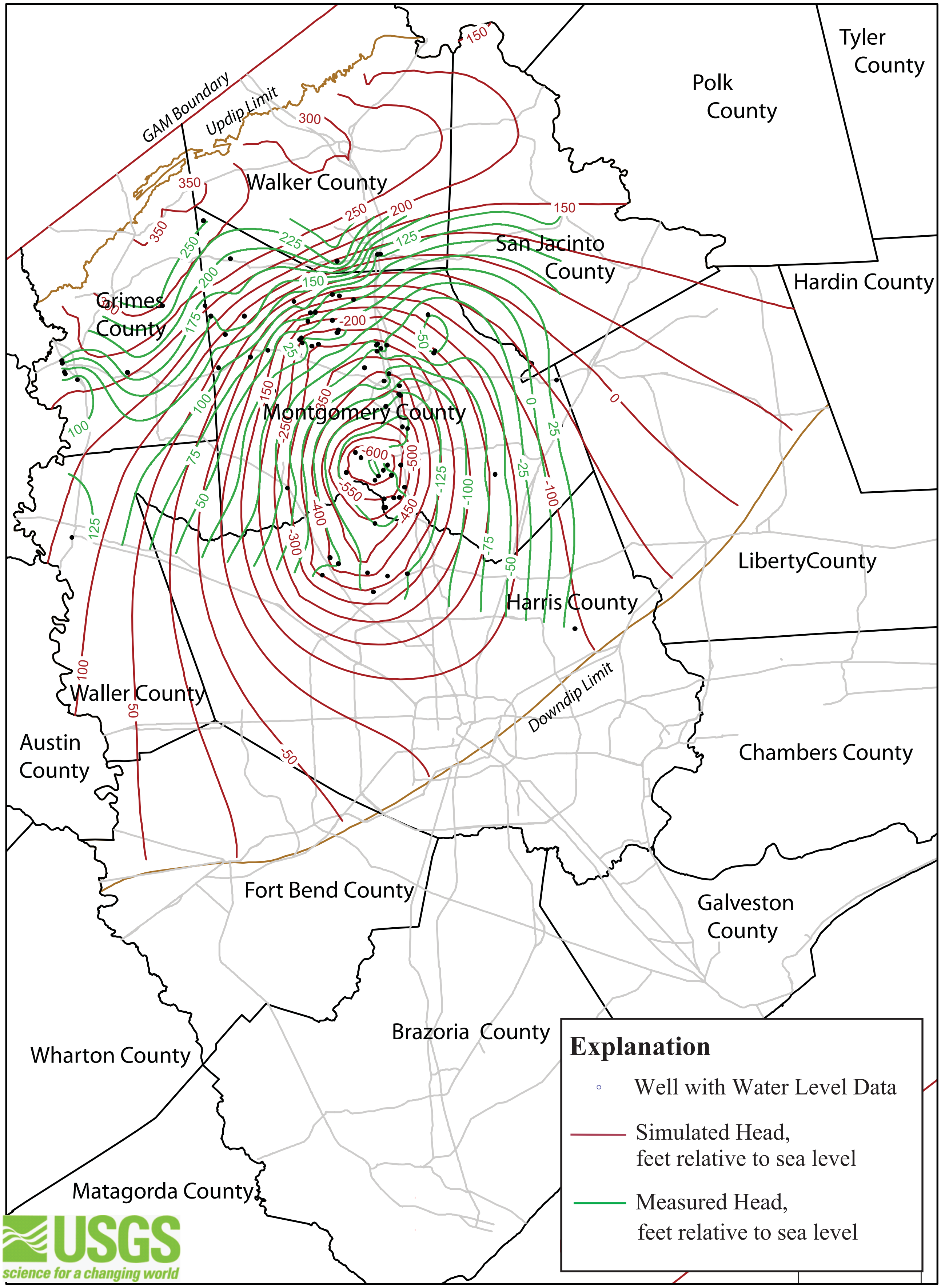
Simulated vs. Measured Head for the Evangeline Aquifer, 2009

Figure 4



Simulated vs. Measured Head for the Jasper Aquifer, 2004

Figure 5



Simulated vs. Measured Head for the Jasper Aquifer, 2009

Figure 6

TECHNICAL MEMORANDUM

Estimation of Exempt Groundwater Use from Registered Wells Within the Harris Galveston Subsidence District, Fort Bend Subsidence District and Lone Star Groundwater Conservation District

Prepared for

Freese & Nichols, Inc
And
Harris Galveston Subsidence District

Prepared by

LBG-Guyton Associates
Professional Groundwater and Engineering Services
Texas Registered Engineering Firm F-4432
11111 Katy Freeway, Suite 850
Houston, Texas 77079

May 2011

Estimation of Exempt Groundwater Use from Registered Wells Within the Harris Galveston Subsidence District, Fort Bend Subsidence District and Lone Star Groundwater Conservation District

INTRODUCTION

Groundwater is pumped within the Harris Galveston Subsidence District (HGSD), Fort Bend Subsidence District (FBSD) and Lone Star Groundwater Conservation District (LSGCD) from wells that are permitted and also from wells that are registered but unpermitted. Registered wells are those which are not required to obtain a permit for the use of the well to pump groundwater nor to report pumping on an annual basis. Registered well exempt pumping normally is from smaller diameter wells that pump a limited amount of groundwater and also wells that normally are not drilled to the depths of large-capacity public supply, industrial or irrigation wells. The objectives of this study task were to estimate the areal distribution and magnitude of the exempt pumping within the HGSD, FBSD and LSGCD and to estimate how the pumping could be incorporated in the Houston Area Groundwater Model that is being developed as part of the overall study by the U.S. Geological Survey (USGS).

The general methodology for estimating the amount of exempt pumping was to either estimate the number of registered wells within a county or to estimate the number of people within a county that were not provided water by a community water system. Data regarding the number of registered wells drilled within the study area were obtained from the Texas Water Development Board (TWDB), Texas Department of Licensing and Regulation (TDLR), HGSD, FBSD, LSGCD and local water well drilling contractors.

METHODS FOR ESTIMATING EXEMPT GROUNDWATER USE

Two approaches were utilized to estimate the amount of exempt groundwater use. Within the HGSD the number of exempt wells were estimated along with an estimated per capita use that ranged from 86 to 120 gallons per day per person (gpcd) and then an estimate of the number of people served per well. An average occupancy rate of 2.96 was used (Source: U.S.

Census Bureau 2005-2007 American Community Survey 3-Year Estimates, http://factfinder.census.gov/servlet/ADPTable?_bm=y&-geo_id=05000US48339&-qr_name=ACS_2007_3YR_G00_DP3YR2&-ds_name=ASC_2007_3YR_G00_&-_lang=en&-_sse=on). The estimate of the number of person served per well and the averaged gpcd was based on a study performed by the LSGCD for estimating exempt well pumping (Source: AECOM, 2009, Estimation of Exempt Use from Private Domestic Wells in Montgomery County: Lone Star Groundwater Conservation District) for the HGSD, the number of exempt wells included registered wells and small-capacity unpermitted wells that existed before the registration requirement began. The amount of water that might be pumped by exempt irrigation wells also was estimated for the HGSD. The number of small capacity irrigation wells was estimated based on the registered well database obtained from the HGSD.

The estimate of pumping for irrigation by registered wells also depended on data obtained from the City of Houston regarding the amount of water used for service connections during periods before and after a registered well was constructed. Those service connections were in the northeast part of Harris County, which encompassed the Kingwood and Forest Cove areas.

For the FBSD and the LSGCD data were available regarding the amount of the population that was served by community water systems. With that information the population not served by community water systems could be assumed to be served by registered well groundwater withdrawals. Utilizing a gpcd and a number of persons served per well, again estimated at 2.96, then an estimate of the exempt well groundwater pumping could be developed.

Exempt Pumping Estimate for HGSD

The exempt groundwater pumping estimate for HGSD included estimates of pumping from registered and pre-registration era domestic wells and also an estimate of pumping from registered small-capacity irrigation wells, such as those used for individual household landscape watering.

Domestic use is the primary category for registered and pre-registration era wells constructed in Harris and Galveston Counties. Over the past approximately 18 years for which records are available, there have been about 1,900 small irrigation wells constructed principally for individual household landscape watering. Of this number of small irrigation wells, approximately 950 of them have been constructed in the Kingwood/Forest Cove area.

For Harris and Galveston Counties there were approximately 6,243 registered domestic wells constructed from 2001 through 2010. This is based on well registration data provided by the HGSD. Assuming that the number of registered domestic wells constructed correlates with the change in population over that same period, which was an increase of about 733,000 people (3,650,768 in 2000 to 4,383,768 in 2010) an estimate of the total number of registered and pre-registration era domestic wells could be developed based on the total population in the HGSD. This method was selected to estimate the total number of registered size wells that could have been constructed through the past decades. For the 2001 through 2010 period, good records are available regarding the number of wells drilled and the population increase. During previous decades thousands of small-capacity wells were drilled as the population of the area increased both in areas served by community water systems and in areas provide water by individual privately owned wells. Assuming that the well to population ratio has been consistent in Harris and Galveston Counties through the decades then the total number of exempt domestic wells in the HGSD could be about 38,000 total, with about 33,000 estimated in Harris County and about 5,000 estimated in Galveston County using a 2010 population in HGSD of 4,383,768. Based on the available data from the HGSD, it is estimated that there could be an additional 2,000 household landscape irrigation wells located in the HGSD.

Water use data were collected from the City of Houston for 34 household irrigation wells located in the northeast part of Harris County. The data were collected for three years prior to the installation of an irrigation well and for three years following installation of the well and the average change in water use at the water service connection was compared to the three years prior to installation of the well. The average use decreased about 103,000 gallons per year per connection with the range in the change in use being from 12,000 to 235,000 gallons per year per service connection. With about 950 household irrigation wells registered in the sample area, the potential pumping from the wells was about 0.27 million gallons per day (mgd) or about 300 acre-feet per year (ac-ft/yr).

Included in the HGSD well database is a category of wells that are small to moderate use permitted well that are required to report pumping each year. In 2009 of the 3,763 wells in the category, pumping was reported for 3,019 wells or about 80 percent of the wells. Considering that a number of the estimated 38,000 registered and pre-registration era wells in the HGSD were drilled a few to several decades ago, it was assumed that 80 percent of the registered type wells were in use and 20 percent were not in use.

Utilizing this data and estimates of the number of registered and pre-registration era wells in HGSD, an estimate of exempt pumping within the area was developed. As provided in the following table.

Table 1. HGSD 2010 Estimated Exempt Well Groundwater Pumping

Estimated Number of Exempt Wells = 38,000	**Pumping**
Estimated Pumping @ 86 gpcd x 2.96 x 0.80 x 38,000	7.74 mgd 8,669 ac-ft/yr
Estimated Pumping @ 120 gpcd x 2.96 x 0.80 x 38,000	10.79 mgd 12,096 ac-ft/yr
Estimated exempt irrigation pumping 2,000 wells x 103,000 gpy	0.56 mgd 632 ac-ft/yr
Estimated Exempt Well Pumping	8.3 to 11.36 mgd 9,301 to 12,728 ac-ft/yr

Within Harris County there are an estimated about 33,000 domestic use wells and within Galveston County potentially up to about 5,000 domestic use wells. The western part of Galveston County has a higher concentration of registered (unpermitted) wells than in the east part of the county. It is estimated that approximately 1.08 to 1.49mgd (1,218 to 1,674 ac-ft/yr) of groundwater withdrawal could be occurring in Galveston County and about 6.96 to about 10.0 mgd (8,083 to about 11,054 ac-ft/yr) of groundwater withdrawal could be occurring in Harris County.

Aquifer Screened by Registered Wells

An illustration of the approximate distribution of registered wells within Harris County is shown as Figure 1 and for Galveston County as Figure 2. The information on Figure 1 shows that a larger percentage of the registered wells are located in the north and north central parts of the county. A large percentage of the registered wells are estimated to screen sands of the Chicot aquifer, as shown on Figure 1. In the northwest part of Harris County, based on well depth information, it is estimated that some of the wells screen sands of the Evangeline aquifer. As discussed previously, there are a significant number of small irrigation wells in the Kingwood/Forest Cove area and the density of the wells is represented on Figure 1. The registered wells shown on Figure 1 are those for which well location data were available. Review of well reports for the Kingwood/Forest Cover area show that the wells screen sands of the Chicot aquifer.

The information provided on Figure 2 shows a greater density of registered wells in the west and southwest parts of Galveston County. Much of the east and north parts of Galveston County are served by public water supply systems and are a more urban than rural environment. The registered wells principally screen sands of the Chicot aquifer with some probably screening limited sand strata within the Beaumont Clay Formation. The Evangeline aquifer principally does not contain fresh groundwater within Galveston County except in the very northwest part of the county, therefore it has a very limited attractiveness for construction of a domestic, irrigation or stock use water well.

Fort Bend County Exempt Pumping

In Fort Bend County, a substantial amount of the population lives in the area east and north of the Brazos River with the population of the county increasing by about 230,923 people in the period from 2000 to 2010, up to 585,375 people, based on the most recent census data. Utilizing the Fort Bend County Census Block information and known water service areas, it was calculated that about 59,000 of the county's total 2010 population lived outside a water service area. This represents about 10 percent of the overall county population. The population that lives outside a water service area is estimated to be principally in the area west of the Brazos River, north of Richmond/Rosenberg and in an area of Fresno in the very east part of the county. A map showing the distribution of registered wells is provided as Figure 3. Approximately 2,400 wells are shown on the illustration and approximately 3,200 wells are not shown as there were not locations provided for them at the time they were constructed. Data on the map shows a significant number of registered wells located south and southwest of the Cities of Richmond and Rosenberg, which is essentially a rural environment.

With an estimated population of about 59,000 people located outside community water service areas and assuming a gpcd from 86 to 120, it is estimated that the annual pumping from the registered wells ranges from 5.07 to 7.08 mgd (5,684 to 7,931 ac-ft/yr). The pumping of the groundwater is estimated to be distributed in the county somewhat in direct proportion to the areal distribution of the registered water wells. Well driller reports were collected for areas spread through the county to obtain well depth data to estimate the aquifers screened. The principal aquifer screened by many of the wells is the Chicot throughout a large part of the county. In the very east part of the county the water well drillers reports show that many of the wells screened shallow sands at a depth of less than 150 feet and thus those wells could screen thin sand strata of the Beaumont Clay.

Montgomery County Exempt Pumping

Montgomery County provides a setting with major population centers principally along the Interstate Highway 45 (I-45) corridor, along the Highway 59 corridor, in the area surrounding Lake Conroe and in the area around the towns of Magnolia and Montgomery. In other areas of the county there are thousands of domestic wells serving individual households. A study was performed by the LSGCD in 2009 regarding potential pumping from registered and pre-registration era wells. The results of that study showed that there were potentially about 54,300 people not serviced in the county by community water systems. Data collected for the study also showed that in areas that were provided water by 88 non large-volume groundwater user systems, the customers used an average of about 86 gallons per customer per day. An estimated

120 gpcd was utilized to bracket the potential amount of water that would be pumped by those in the county served by registered and pre-registration era wells.

With an estimated 54,300 people not served by community water systems and assuming a water demand that could vary from 86 to 120 gpcd the estimated amount of pumping from registered wells ranges from 4.64 to 6.52 mgd (5,200 to 7,300 ac-ft/yr). If it is assumed that the number of person served per well are 2.96 then the total number of registered wells for the estimated 54,300 people could be approximately 18,500 wells. It is likely that some of the wells are not in use and that some of the wells serve more than the estimated 2.96 people. Within the last nine years from 2002 through 2010, the LSGCD has registered 3,729 wells, which are unpermitted, meaning they are not required to be equipped with meters and report annual pumping.

As shown on Figure 4, which depicts registered wells that had location data provided at the time they were registered, the wells are spread through Montgomery County away from the areas served by the community water systems. Registered wells in the very northwest part of the county could obtain their supply from the Jasper aquifer while wells constructed in the central part of the county have a higher likelihood of obtaining water from the Evangeline aquifer and those in the southeast part of the county obtain water from the Chicot aquifer. This assessment is based on well driller reports field with the Texas Department of Licensing and Regulation and on the locations of the outcrops of the Jasper, Evangeline and Chicot aquifers.

The aquifers dip toward the coast and are located in the subsurface at adequate depths within the areas shown to provide water to the registered wells. The registered wells normally screen sands down to a maximum depth of 300 to 450 feet.

ESTIMATE OF FUTURE REGISTERED WELL PUMPING

Over the past decade the number of registered wells drilled within the HGSD, FBSD and LSGCD has been in the thousands, at least 12,000 based on data provided by the three entities. Data were provided by the three entities on a yearly basis of the number of registered wells drilled. This data along with an estimate of 2.96 people served per well and an average gpcd ranging from 86 to 120 gallons were used to estimate the rate at which pumping from registered wells might increase in the future. For the HGSD, an average of about 683 wells were constructed each year from 2008 through 2010. For the FBSD, the average number of registered wells constructed per year from 2008 to 2010 was 260 and for the LSGCD the average number of registered wells constructed per year over the same time period was 289. The estimate of the yearly increase in exempt pumping is provided in the following table.

Table 2. Estimated Future Increase in Exempt Pumping

Subsidence or Water Conservation District	2008-2010 Average New Registered Wells Constructed Per Year	Estimated Average Yearly Increase in Future Pumping
HGSD	683	0.13 to 0.24 mgd 144 to 271, ac-ft/yr
FBSD	260	0.06 to 0.09 mgd 74 to 104, ac-ft/yr
LSGCD	289	0.07 to 0.10 mgd 82 to 115, ac-ft/yr

The estimated increase in pumping is very small compared to the overall pumping from permitted wells within the two subsidence districts and one groundwater conservation district, but it does represent an increase that is reflective of the continued increase in population within the area. It is estimated that the total number of registered wells that are drilled in future years will be proportional to the magnitude of the increase in population within the HGSD, FBSD and LSGCD.

IMPACTS OF EXEMPT PUMPING ON HOUSTON AREA GROUNDWATER MODEL

The pumping from registered wells is distributed through the four counties and a majority of the wells screen sands of the Chicot aquifer, as shown on Figures 1 thru 4. This is because the Chicot aquifer occurs in the subsurface to a depth of at least 400 to 450 feet over much of the area and sands that occur above a depth of 400 to 450 feet are capable of supporting the limited quantities of water that normally are pumped from each of the registered wells. Also in

Galveston County the Chicot is the aquifer that contains water of better quality than the Evangeline aquifer which contains water with higher concentrations of total dissolved solids.

Based on the estimates of exempt pumping for 2010, the pumping would constitute 3 to 4 percent of the overall pumping within the HGSD, about 4 to 6 percent of the overall pumping within the FBSD and about 7 to possibly 10 percent of the overall pumping within the LSGCD. The groundwater flow model is being recalibrated and results to date show a reasonably good correspondence between modeled and measured water levels for the Chicot aquifer in Harris County. In some parts of Harris County the model will be revised to improve performance. It is probable that the volume of exempt pumping would have only a very small effect on the model recalibration.

For Fort Bend County, the amount of exempt pumping also would probably have a small effect on water levels as the model is showing a reasonable correspondence between modeled and measured results in the Chicot aquifer for pumping through 2004 and 2009. Adding the exempt pumping and simultaneously keeping model results consistent with measured water level changes could mean that some Chicot hydraulic properties would require increasing.

For Montgomery County part of the exempt pumping is estimated to occur in the Jasper, Evangeline and Chicot aquifers and could constitute about 7 to possibly 10 percent of the overall pumping recorded in 2010. There is a good correspondence between modeled and measured water level drawdowns in the Chicot aquifer for a simulation of pumping through 2009. The estimated amount of exempt pumping could be added to the well file and certain Chicot and Evangeline model parameters adjusted if needed, to maintain a good correspondence between modeled and measured water level drawdowns or changes.

For the HGSD, FBSD and LSGCD the exempt pumping could be added to the well file for the appropriate aquifers and with an appropriate areal distribution. Shape files for the exempt pumping distribution would be provided to the USGS. Those shape files would include a reduction in exempt pumping in previous decades as the number of registered wells was lower in previous decades, as was the population in the HGSD, FBSD and LSGCD. The reduction in exempt pumping is proposed to correlate with the reduction in population. It is proposed that pumping be based on a gpcd of 120 gallons, which is consistent with the exempt pumping study performed by the LSGCD in 2009.

Model calibration simulations could be performed and adjustments to principally recharge, leakage or formation parameters for the Chicot and Evangeline aquifers instituted to maintain simulated water level changes within modeling calibration targets.

CONCLUSIONS

Small capacity wells that are registered have been constructed in the HGSD, FBSD and LSGCD for decades and that trend will continue. The amount of exempt pumping from the wells was estimated for 2010 and is summarized in the following table. The pumping was based on estimates of the number of registered wells and pre-registration era wells in the HGSD and on the population not served by a community water system in the FBSD and LSGCD.

Table 3. Estimated 2010 Exempt Well Groundwater Estimated Pumping

Area	**Estimated Exempt Pumping, mgd**	**Estimated Exempt Pumping, ac-ft/yr**
HSGD	8.30 to 11.36	9,301 to 12,728
FBSD	5.07 to 7.08	5,684 to 7,931
LSGCD	4.64 to 6.51	5,200 to 7,300
Total	**18.01 to 24.95**	**20,185 to 27,959**

The results show that the exempt pumping is about 4.4 to 6.1 percent of the total estimated permitted pumping of about 404.95 mgd (453,600 ac-ft/yr) by the HGSD, FBSD and LGGCD for 2010. The estimated rate of growth of the exempt pumping based on the average number of registered wells drilled over the past three years and extrapolating that trend forward, is about 0.27 to 0.39 mgd (300 to 440 ac-ft/yr) in total for the HGSD, FBSD and LSGCD. The increase in exempt pumping would be attributed to the future drilling of about 1,200 new wells each year within the three groundwater management areas. The future impacts of the exempt pumping can be included in simulations with the Houston Area Groundwater Model to assess the effects of the pumping on model calibration. An estimate of overall exempt pumping of about

24.95 mgd is proposed to be distributed over applicable areas of the model for 2010 with the amounts of exempt pumping lowered in previous decades when the population in the area was less. Because the amount of the pumping is small compared to the overall amount of pumping in the area, the effects of the exempt pumping on model results are estimated to be limited.

FIGURES

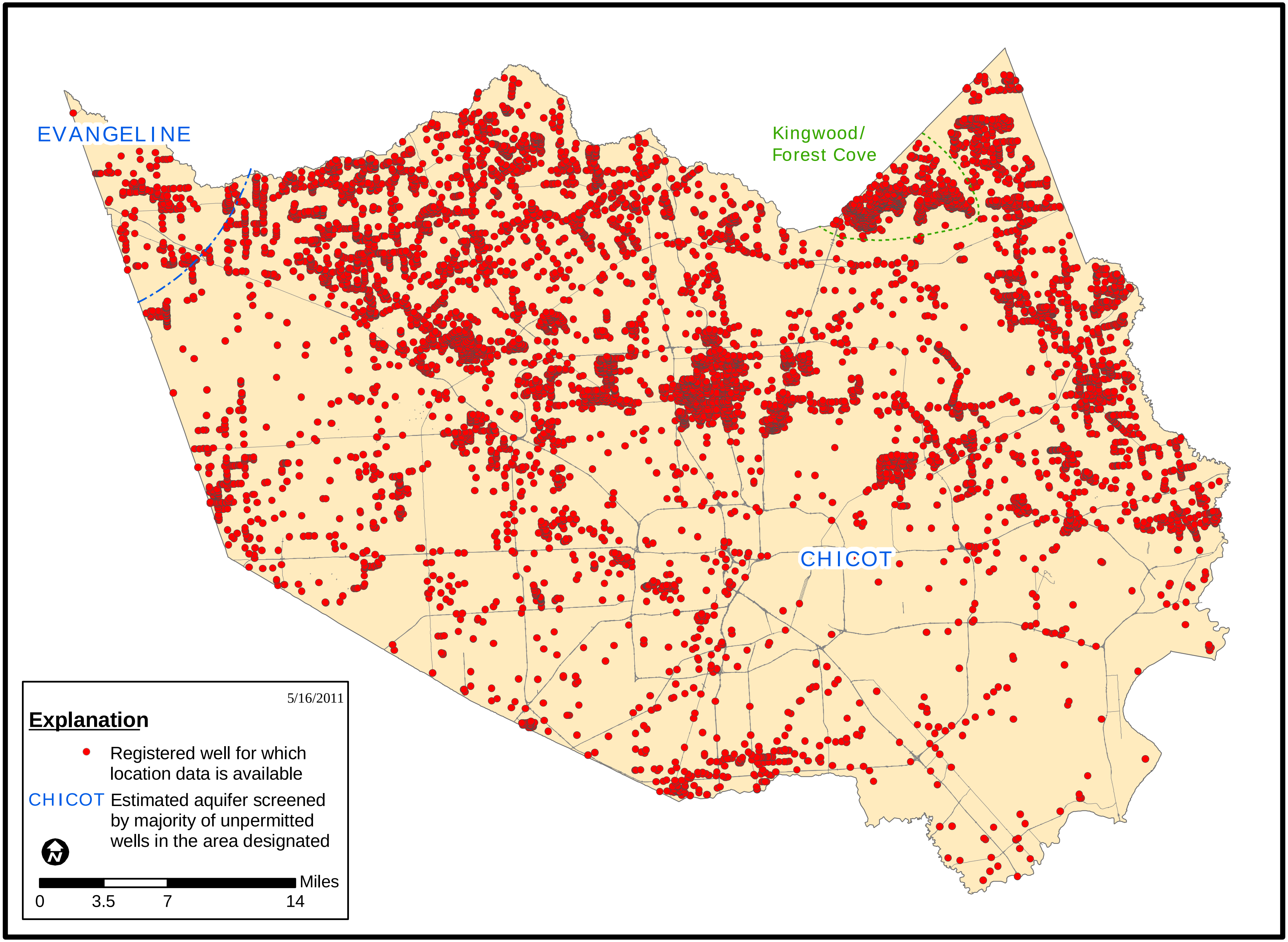


FIGURE 1. LOCATIONS OF REGISTERED WELLS IN HARRIS COUNTY

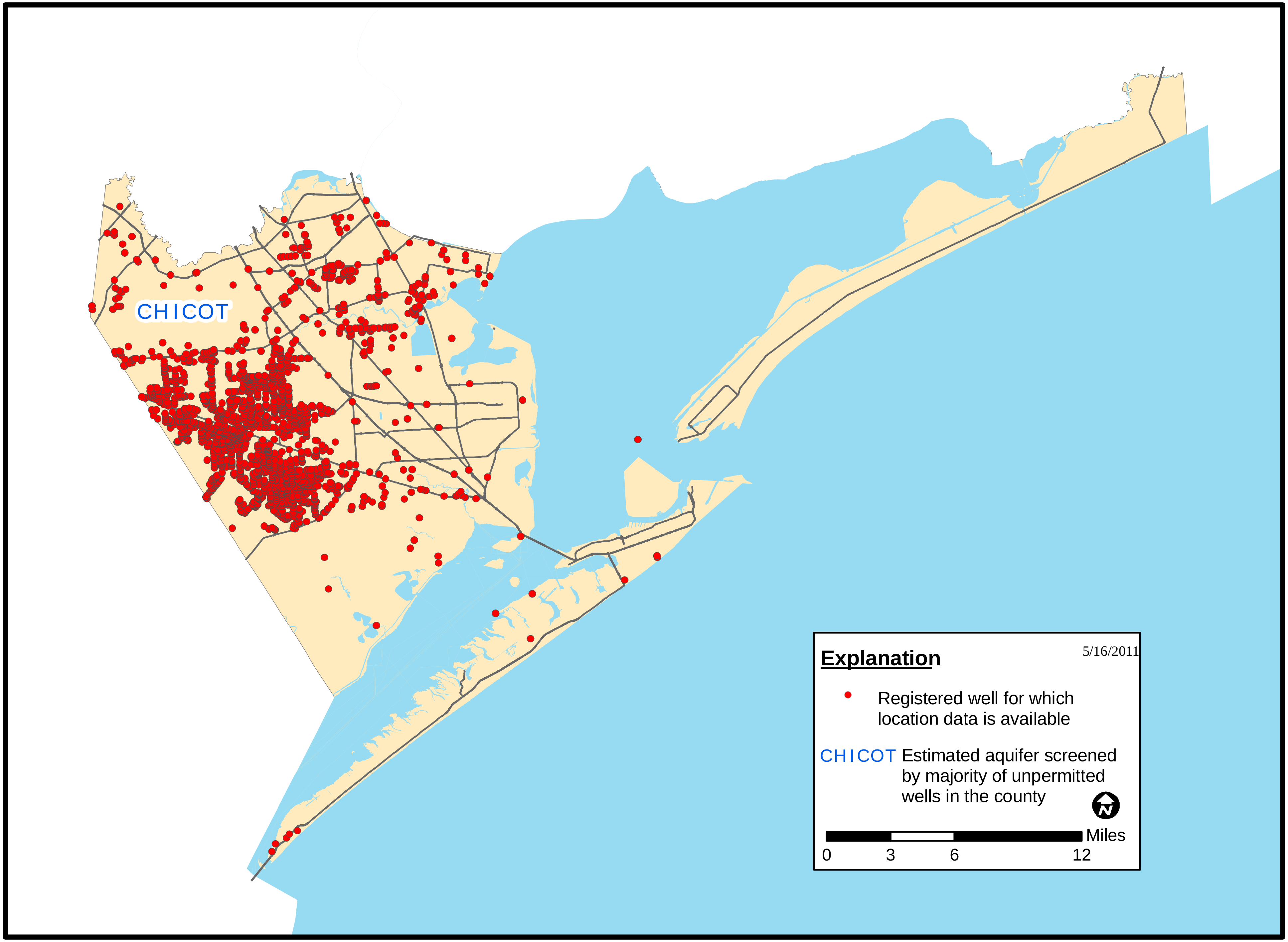


FIGURE 2. LOCATIONS OF REGISTERED WELLS IN GALVESTON COUNTY

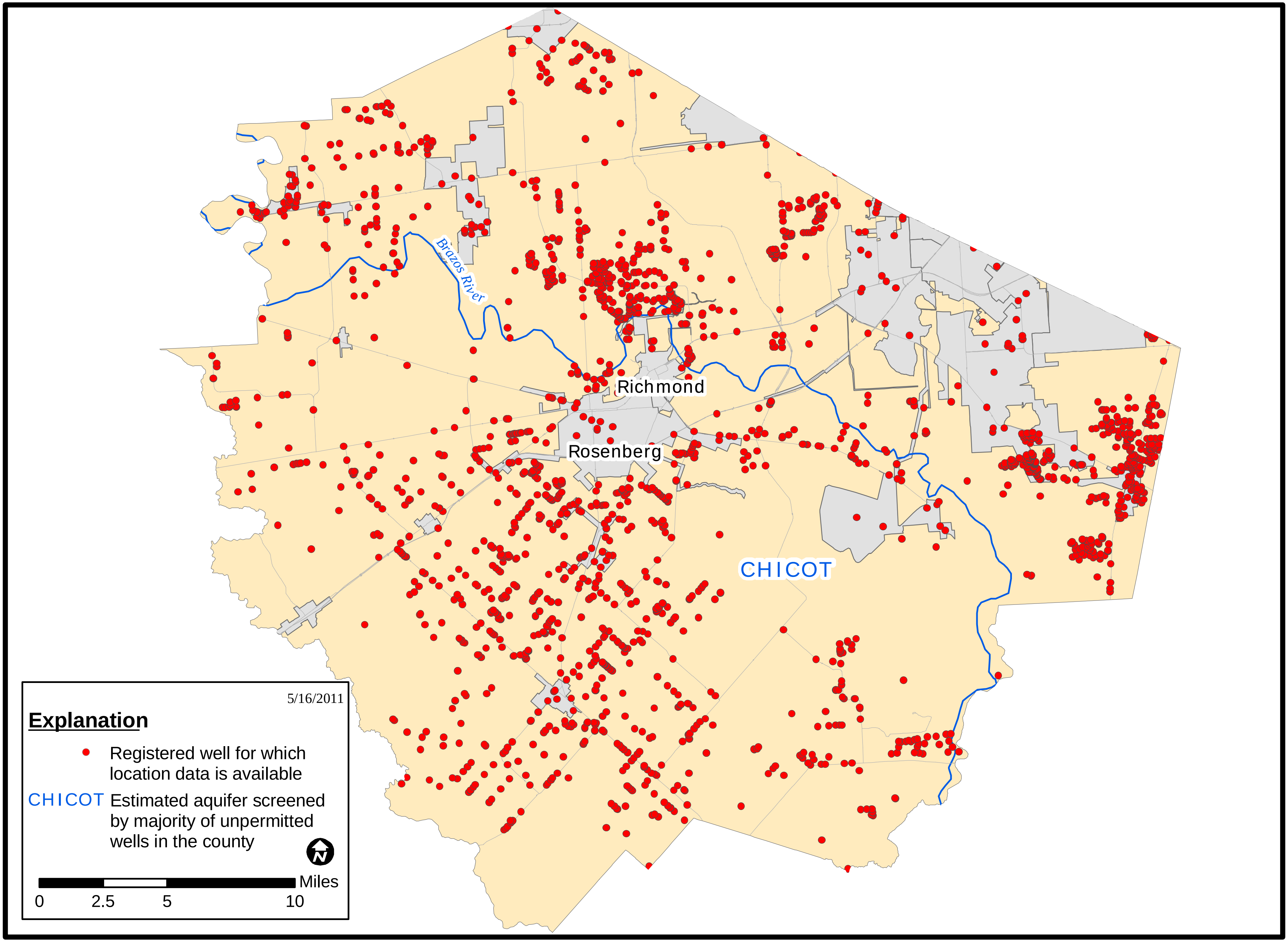


FIGURE 3. LOCATIONS OF REGISTERED WELLS IN FORT BEND COUNTY

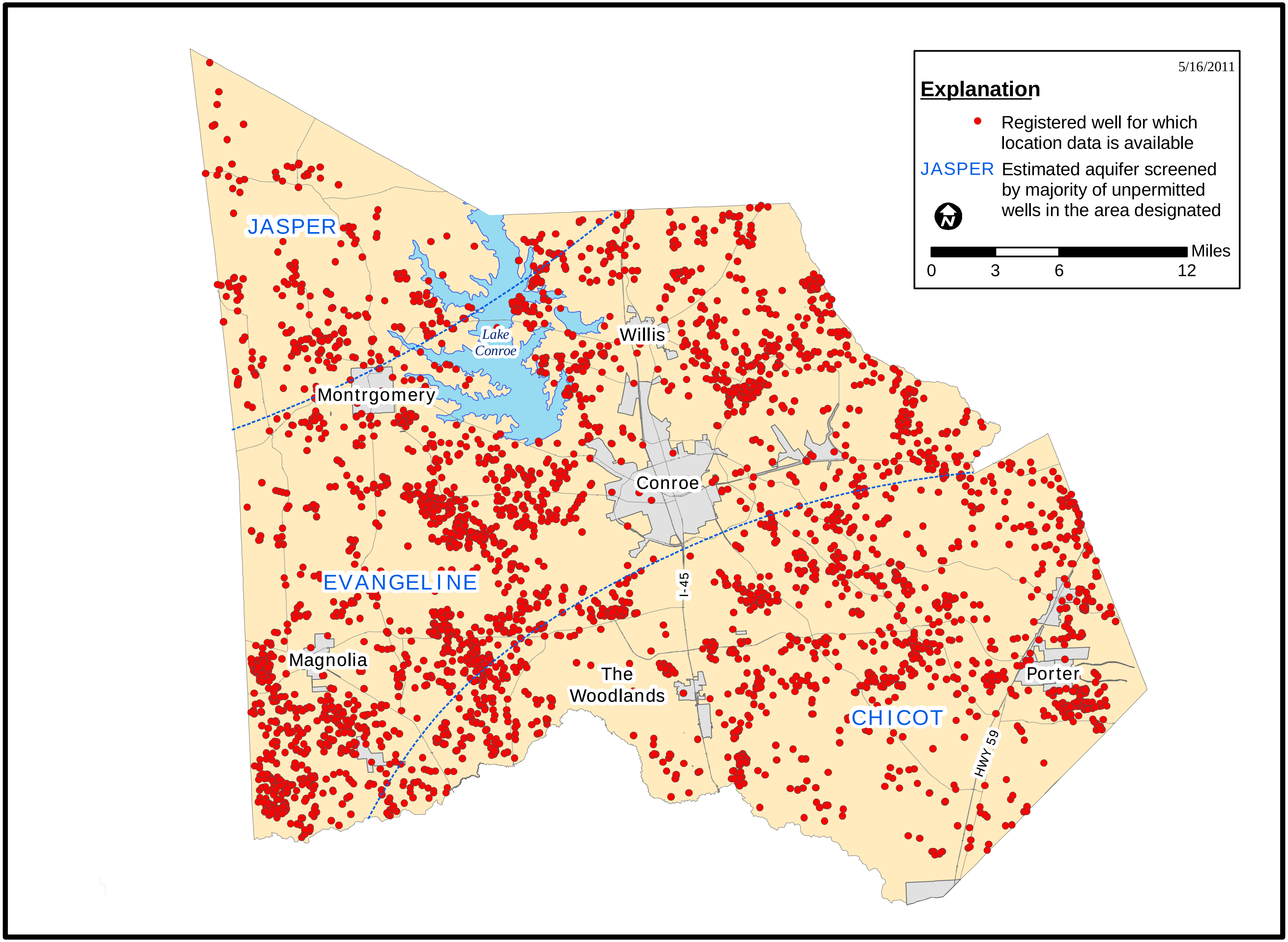
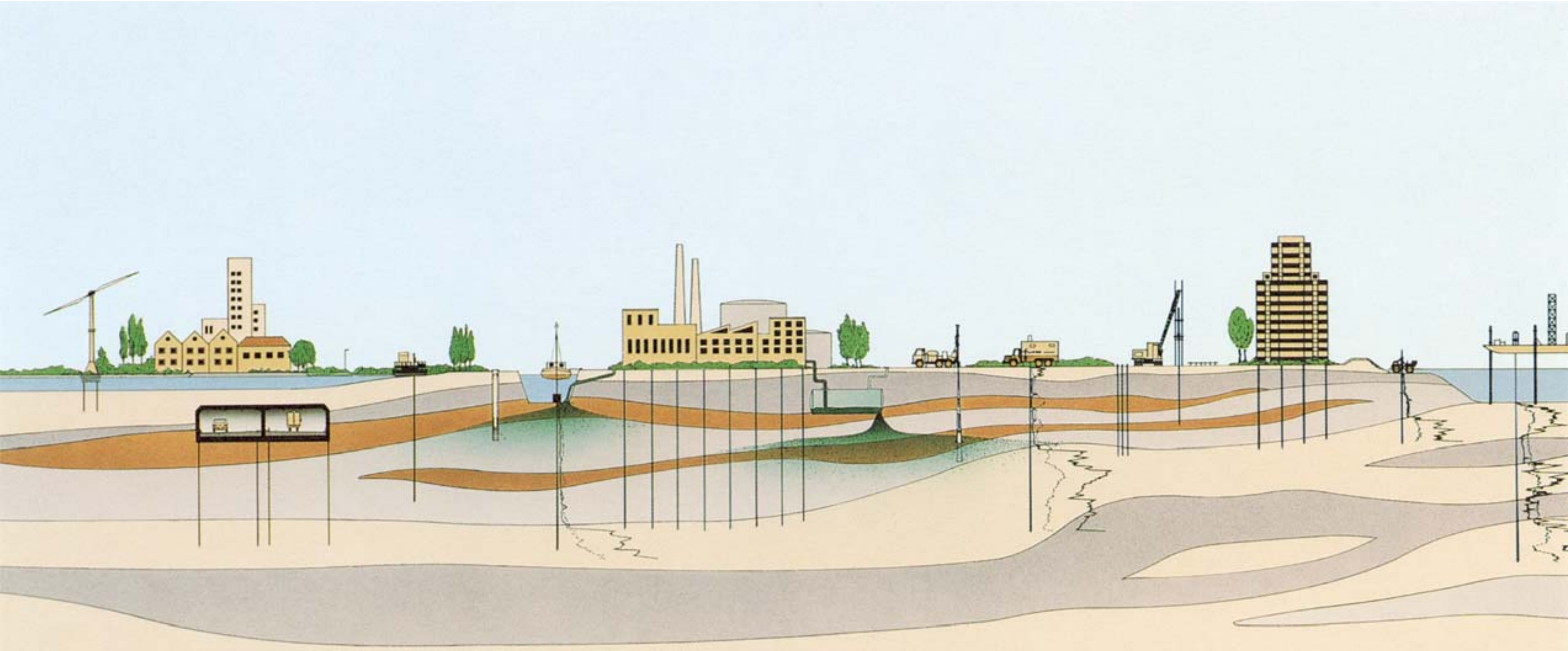


FIGURE 4. LOCATIONS OF REGISTERED WELLS IN MONTGOMERY COUNTY

FUGRO CONSULTANTS, INC.

GEOTECHNICAL SERVICES
WORK ORDER 2 – DATA PREPARATION
HARRIS-GALVESTON SUBSIDENCE DISTRICT
HARRIS, GALVESTON AND FORT BEND COUNTIES, TEXAS

FREESE AND NICHOLS, INC.
HOUSTON, TEXAS
MAY 2011



6100 Hillcroft (77081)
P.O. Box 740010
Houston, Texas 77274
Tel: (713) 369-5400
Fax: (713) 369-5518

Report No. 04.12100052 – Work Order 2
May 18, 2011

Freese and Nichols, Inc.
3100 Wilcrest, Suite 200
Houston, Texas 77042

Attention: Mr. Michael V. Reedy, P.E.
Water Resources Group Manager

Geotechnical Services
Work Order 2 – Data Preparation
Harris-Galveston Subsidence District
Harris, Galveston and Fort Bend Counties, Texas

Fugro Consultants, Inc. is pleased to submit this report of our geotechnical services related to Work Order 2 for the current effort to update the model used for predicting subsidence in Harris, Galveston and Fort Bend Counties. We have performed our services in general accordance with our Cost Estimate No. 0412-10-0052p2 dated October 19, 2010. Mr. Michael V. Reedy of Freese and Nichols, Inc. authorized our services through a Subconsultant Authorization dated November 11, 2010 under our Master Subconsultant Agreement.

We appreciate the opportunity to be of continued service to Freese and Nichols and the Harris-Galveston Subsidence District, and we look forward to providing additional services for Work Order 3 of this project. Please call us if you have any questions or comments concerning this report or when we may be of further assistance.

Sincerely,
FUGRO CONSULTANTS, INC.
TBPE Firm Registration No. F-299

Nathan E. Thompson, E.I.T.
Project Professional

Scott A. Marr, P.E, LEED AP
Project Manager

Copies Submitted: Addressee (4)
NET/SAM
R:\04120\2010 Projects\0001-0099\0412-10-0052\Reporting\04.12100052dr.docx

CONTENTS

ILLUSTRATIONS

APPENDICES

SUMMARY

The Harris-Galveston Subsidence District (HGSD) and Fort Bend Subsidence District (FBSD) use a computer program and numerical models of selected locations within their respective districts to predict subsidence caused by pumpage of groundwater. The program is called PRESS (Predictions Relating Effective Stress and Subsidence).

The 26 site models in Harris, Galveston, and Fort Bend counties used with the PRESS program to estimate future subsidence require recalibration using measured data approximately every 5 to 10 years. Since the last recalibration of the site models in 1997 and 1998, groundwater usage patterns and the resulting patterns of water level decline and subsidence have changed substantially. Fugro Consultants, Inc. (Fugro), LBG-Guyton, and Freese and Nichols, Inc. (FNI) are currently working with the HGSD, the FBSD, the Lone Star Groundwater Conservation District (Lone Star GCD), the United States Geological Survey (USGS) and the National Geodetic Survey (NGS) to recalibrate the PRESS site models.

Work Order 2 for the current PRESS model recalibration effort focuses on gathering and preparing available data for use in running and assessing the performance of the 26 PRESS site models. More specifically, Work Order 2 consists of development of a preliminary design hydrograph and compilation of existing subsidence data for each of the 26 PRESS sites.

Design hydrographs are based on measurements of groundwater levels in wells located within or nearby a PRESS site, as well as output from a groundwater model developed by the USGS and LBG-Guyton. Preliminary design hydrographs developed during Work Order 2 are presented in Appendices A through Z. We expect minor adjustments may be made to the preliminary design hydrographs in Work Order 3 during recalibration efforts. Final design hydrographs will be presented at the completion of Work Order 3.

Sources of subsidence data include benchmarks, borehole extensometers, continuously operating reference stations (CORS) and Global Positioning System (GPS) data obtained from Port-A-Measure (PAM) stations. PRESS model output from previous studies are also relevant to this recalibration effort. Compiled subsidence data is presented in Appendices A through Z.

The preliminary design hydrographs developed and the subsidence data compiled during Work Order 2 will be used to run the PRESS model for each of the 26 active PRESS sites as part of Work Order 3.

1.0 INTRODUCTION

1.1 Project Description

The Harris-Galveston Subsidence District (HGSD) and Fort Bend Subsidence District (FBSD) use a computer program and numerical models of selected locations within their respective districts to predict subsidence caused by pumpage of groundwater. The program is called PRESS (Predictions Relating Effective Stress and Subsidence).

The program was originally adapted for use by the HGSD, and the individual site models that the program uses were initially developed and calibrated in two steps from 1978 to 1982. First, Fugro (formerly McClelland Engineers, Inc.) modified an existing computer program and applied it to six HGSD sites (McClelland 1979). In the second step, Espey, Huston & Associates, Inc. (EH&A 1982) further refined the program. They also expanded the number of PRESS models to 21 and used a procedure to calibrate all of the site models through the 1978 benchmark releveling.

The HGSD PRESS models were recalibrated by Fugro in 1997 (Fugro 1997), and a supplement to that study (Fugro 2000) was issued in 2000 to address corrections made by LBG-Guyton Associates (LBG-Guyton) to an input error. Prior to 1997, the HGSD discontinued the use of one of the original sites, but two new sites were developed and calibrated in the 1997 study, leaving a total of 22 active HGSD PRESS sites. Fugro calculated predicted subsidence using the HGSD PRESS models with different groundwater usage scenarios in 1999 (Fugro 1999) and 2002 (Fugro 2002a, 2002c).

The PRESS model was first applied to four FBSD sites by Geo Associates in 1990. We understand that the four FBSD PRESS models were developed and calibrated in a manner similar to the development and calibration of PRESS models for the HGSD, based on known subsidence through 1987 and water levels through 1990. The four FBSD PRESS sites were recalibrated by Fugro in 1998 (Fugro 1998). Fugro calculated predicted subsidence using the FBSD PRESS models with a different groundwater usage scenario in 2002 (Fugro 2002b).

Since the last recalibration of the site models in 1997 and 1998, groundwater usage patterns and the resulting patterns of water level decline and subsidence have changed substantially. The 26 site models in Harris, Galveston and Fort Bend counties used with the PRESS program to estimate future subsidence require recalibration using measured data approximately every 5 to 10 years. Fugro, LBG-Guyton, and Freese and Nichols, Inc. (FNI) are currently working with the HGSD, the FBSD, the Lone Star GCD, the United States Geological Survey (USGS) and the National Geodetic Survey (NGS) to recalibrate the PRESS site models.

1.2 PRESS Model Overview

The PRESS model predicts subsidence using two forms of input. The first input includes the soil stratigraphy and geotechnical parameters associated with each compacting clay layer modeled for a given PRESS site. We are not modifying this input for any PRESS site model during Work

Order 2. The second input is a single design hydrograph representing the groundwater level in a given PRESS site at any time from the year 1906 to a selected future date. Development of the site design hydrograph is a primary focus of Work Order 2.

With these inputs, the PRESS program uses Terzaghi one-dimension consolidation theory to predict consolidation of clay layers. Sand layers are assumed to be incompressible. The Terzaghi theory is widely used by geotechnical engineers to predict the settlement of clays in response to the loads applied by structures. The program uses the theory to predict subsidence of the ground surface causes by increases in the inter-particle stresses (called effective stresses) within clay layers in response to reductions in the groundwater pressure caused by groundwater pumpage (Fugro 1997).

1.3 Purposes and Scope

Work Order 2 for the current PRESS model recalibration effort focuses on gathering and preparing available data for use in running and assessing the performance of the 26 PRESS site models. More specifically, the purposes of Work Order 2 were to: 1) develop a preliminary design hydrograph using historical data, well data, and Houston Area Groundwater Model (HAGM) output (prepared by others) for each of the 26 existing PRESS sites, and 2) compiling existing subsidence data from benchmarks, extensometers and PAM sites for future comparison to the PRESS output for each of the 26 sites. The following sections further describe the proposed scope of services for Work Order 2:

- Consult with Mr. Bill Elsbury and Mr. Mark Fuhriman, both of whom have worked on the PRESS models previously, for modeling suggestions, input, and information;
- Submit hydrographs for review to LBG-Guyton and FNI;
- Evaluate the current condition of water level data and subsidence data at each of the 26 sites and recommend PRESS sites (with input from FNI, LBG-Guyton, USGS and HGSD) on which to run PRESS model analyses;
- Prepare a discussion of results;
- Develop a scope and cost estimate for Work Order 3 of the project, including running the PRESS model on 26 sites; and
- Provide information for review, and comment on any presentations prepared for the HGSD.

Future Work Orders will potentially include the following activities:

- Run the PRESS model at each of the 26 sites;
- Recalibrate PRESS models for sites that indicate a need for recalibration, and re-run the PRESS model for those sites;
- Check USGS well data and NGS survey data for accuracy and potential modifications;
- Recalibrate/reprogram PRESS models based on evaluation;

- Compare PRESS results based on various HAGM data scenarios;
- Develop future PRESS sites;
- Assess and identify input parameters for the MODFLOW model and SUBS package being developed by the USGS;
- Compare PRESS model to SUBS package; and
- Develop recommendations for future uses of PRESS and SUBS models.

2.0 DEVELOPMENT OF PRELIMINARY DESIGN HYDROGRAPHS

Our activities related to development of a preliminary design hydrograph for each PRESS site model aquifer are discussed in this section. We have included discussion relating to collection, processing and review of a) data from USGS and private wells, b) HAGM groundwater model output, and c) historical site model hydrographs.

2.1 Introduction

A primary objective for Work Order 2 was to develop a preliminary design hydrograph for each PRESS site model aquifer. The design hydrographs are based on measurements of groundwater levels in wells located within or nearby a PRESS site, as well as output from a groundwater model developed by the USGS and LBG-Guyton. Data from USGS wells were used where available – after review of all USGS well data, gaps were identified and private well sources were reviewed in an attempt to fill in the gaps. Output from the groundwater model were provided by LBG-Guyton and referenced along with well data during development of preliminary design hydrographs for this study.

The following sections discuss in further detail the sources of data explored for Work Order 2 and the methods used for data collection and interpretation and development of a design hydrograph for each PRESS site model aquifer. We expect minor adjustments may be made to the preliminary design hydrographs in Work Order 3 during recalibration efforts. Final design hydrographs will be presented at the completion of Work Order 3.

2.2 Well Hydrographs

We compiled and plotted historical water level data, as represented by hydrographs of observation wells within the boundaries of and, in some cases, near the various PRESS sites. The compiled well hydrographs are presented in Appendices A through Z.

2.2.1 USGS Wells

Our primary source of historical water level data was the USGS. USGS water level data were obtained from the USGS National Water Information System (NWIS) Web Interface. The NWIS database includes well number, site name, well location, ground surface elevation, historical depth-to-water measurements, well depth, and status of the well at the time of each water level measurement. USGS wells are identified in the legend for each well hydrograph presented in Appendices A through Z by the last 7 digits of their USGS site name, e.g., “60-61-824.” Note that to provide consistency with labeling presented in the most recent recalibration studies (Fugro 1997, 1998) the full nine digit site name is not listed, *i.e.*, the two digit USGS county code is not included in the well identification. In addition to the well name, well screen depths and ground surface elevation are provided in the legends for each USGS well.

We first attempted to obtain updated water level readings for all wells presented in the most recent recalibration studies (Fugro 1997, 1998). Next, we performed an extensive search in the NWIS database for all wells located within or adjacent to the PRESS site boundaries. Wells discovered with this search that were not referenced in previous studies were evaluated to determine whether the data was sufficient to be referenced for development of a design hydrograph. Evaluation criteria included the spatial location of the well, the well screen depth, and quantity and quality of water level measurements. In addition to USGS annual well reports, we consulted Texas Department of Water Resources (TDWR) and Texas Water Development Board (TWDB) publications to obtain screen interval information. Wells added for this study are identified on the plates in Appendices A through Z.

Water level readings in the USGS NWIS database are provided as depths below ground surface at the well head. Since elevation varies across a PRESS site, we adjusted water level readings, *i.e.*, vertically translated, to correct for the difference between ground surface elevation at a given well head and the assumed ground surface elevation across the entire PRESS site model. Assumed ground surface elevations for each PRESS site model were kept consistent with the previous recalibration study (Fugro 1997, 1998).

While reviewing the USGS well data, we discovered discrepancies between ground surface elevations reported in the USGS NWIS database and those found in recent USGS annual well reports. We consulted with the USGS and were informed that ground surface elevations for wells in Harris County were updated based on Light Detection and Ranging (LiDAR) data obtained from a survey in 2001 following Hurricane Allison. As a result, there is a vertical shift in well data for Harris County wells at the year 2001 – this shift is evident by a break in the USGS well hydrographs presented in Appendices A through Z.

We also noted certain data “spikes” that seemed to deviate substantially from other wells within a PRESS site. We were advised by LBG-Guyton that these “spikes” were likely the result of water level measurements taken before and during well pumping operations. As mentioned previously, the USGS well records contain a “well status” at the time of a given water level measurement. The status field in a well record includes notes indicating if the site was flowing (i.e., under artesian conditions), plugged, recently pumped, pumping at the time of water level measurement, obstructed, *etc.*, when each water level reading was taken. After consultation with LBG-Guyton and FNI, we reviewed all USGS well records for the observed data “spikes” and, for the purposes of this study, removed water level readings taken during well pumping operations.

2.2.2 Private Well Data

After compiling and plotting all USGS well data within PRESS boundaries and, in some cases, immediately adjacent to the PRESS sites, we worked with LBG-Guyton and FNI to identify gaps in the well hydrograph data. LBG-Guyton reviewed their internal database of municipal utility district (MUD) well information and provided additional water level measurements for wells in five PRESS sites: Cypress Creek, FM 1960, Humble, Katy, and Langham Creek.

The raw well data provided by LBG-Guyton were processed similarly to the USGS well data. Only static water level readings were plotted. Depth adjustments, *i.e.*, vertical translations, were applied to the data based on the difference between ground surface elevation at the well head and the assumed ground surface elevation for the PRESS site model.

All private well data are presented on the hydrograph plots in Appendices A through Z. Private wells are distinguishable from USGS wells via the well identification or site name, i.e., the private wells are not identified by the USGS “xx-xx-xxx” name format.

2.3 Groundwater Model Output

LBG-Guyton provided output from the HAGM run performed for this study. The spatial coverage of the model encompasses all 26 PRESS sites. Output consists of water level elevations for both the Chicot and Evangeline aquifers from the year 1900 to 2010. One water level elevation was provided per year. LBG-Guyton converted the raw groundwater model output to depths below an assumed ground surface elevation for each PRESS site. We translated the assumed ground surface elevations from HAGM to match the PRESS site models and presented the groundwater model output accordingly. We generally used output provided from the Chicot aquifer for PRESS model upper aquifers and output from the Evangeline aquifer for PRESS model lower aquifers. For single aquifer PRESS site models, we were consistent with previous recalibration efforts (Fugro 1997, 1998) when selecting output from either the Chicot or Evangeline aquifer.

In many cases, two sets of groundwater model output were provided for a single PRESS site. This is a result of the grid spacing used to set up the USGS groundwater model. Obtaining multiple outputs for a single PRESS site is consistent with previous studies. However, in the previous recalibration efforts, the location of a specific set of groundwater model output was provided in terms of a specific cell in the HAGM model or a State Grid designation. The results of the HAGM run provided for this study identified the location of a set of model output by latitude and longitude. As the HAGM model has been changed since the previous recalibration effort, we did not choose a specific set of HAGM output based solely on consistency with model output reported in previous recalibration studies. We plotted all HAGM output alongside the respective well hydrographs, as presented in Appendices A through Z.

2.4 Historical Site Hydrographs

We utilized historical site hydrographs developed in previous studies from two time periods: January 1906 through January 1980, and January 1980 through January 1995. Historical site hydrographs from January 1906 through January 1980 were originally developed by EH&A for the Phase II study (EH&A 1982), and hydrographs from January 1980 through January 1995 were developed by Fugro in the latest recalibration studies (Fugro 1997, 1998). We kept the historical site hydrographs through 1995 consistent with those presented in the Fugro recalibration studies.

We developed a site hydrograph from January 1995 to January 2010 for each PRESS model aquifer by interpreting the well data and groundwater model output compiled and processed for this study. We reviewed the rationale behind the development of historical site hydrographs in the 1997 and 1998 Fugro recalibration studies and kept a consistent relationship between historical site hydrograph and well data whenever possible.

2.5 Projected Site Hydrographs

In order to run the PRESS models and predict subsidence in Harris, Galveston and Fort Bend Counties over the next 50 to 60 years, we must project the site hydrographs over the time period of interest and use this, along with the historical site hydrographs, as input to the PRESS model. In the past, this projection has been primarily based on the results of the USGS groundwater model (MODFLOW) for the time period of interest. To date, we have not been provided groundwater model output projections past the year 2010. We understand that the USGS will complete this groundwater model run in the near future and we will develop projected site hydrographs at that point in future work orders.

3.0 COMPILATION OF SUBSIDENCE DATA

Our activities related to compilation of subsidence data are discussed in this section. We have included discussion related to collection, processing and review of data from borehole extensometers, PAM sites, and benchmarks, as well as computed subsidence data from previous studies.

3.1 Introduction

The second objective of Work Order 2 was the compilation of subsidence data for future comparison to the PRESS model output from each of the 26 sites. In previous studies, the primary sources of subsidence data were benchmarks and borehole extensometers. As early as 1987, the HGSD with guidance from NGS began implementing GPS technology to obtain subsidence measurements. GPS technology is employed using a system of stable elevation reference points (CORS) and a number of local, ground-surface points of measurement similar to conventional benchmarks (PAM sites). CORS and PAM sites are being increasingly relied upon by the HGSD for subsidence measurements and will be incorporated in the upcoming assessments of PRESS model output and site correlation.

Consistent with previous recalibration studies (Fugro 1997, 1998), vertical shifts were applied to all relative measures of subsidence. These shifts enable comparison to a total record of subsidence in a given PRESS model site using sources of data with varying starting dates. The vertical shift applied to any data presented in previous recalibration studies – borehole extensometers and benchmarks – has been kept consistent. A vertical shift for any new sources of subsidence data added for this study was estimated based on the established data and the location of the new data source.

The following sections discuss in further detail the subsidence data compiled and processed for Work Order 2 in preparation for comparison to PRESS model output.

3.2 Borehole Extensometers

Borehole extensometers are deeply anchored benchmarks consisting of a pipe installed in a concrete plug in the bottom of a deep well and extending to above the ground surface. Slip joints are incorporated in the well casing during installation to ensure that the elevation of the concrete plug is not affected by compaction of soil around the well casing. Subsidence is measured by recording the differential movement between ground surface and the pipe.

The USGS installed 13 borehole extensometers in Harris and Galveston counties starting in the early 1960s. If the concrete plug at the bottom of the well is installed beneath all compacting clay layers surrounding the well, the extensometer measures total subsidence. Six of the 13 extensometers installed by the USGS are of this nature, referred to as “total” extensometers. The other seven USGS extensometers were installed with the concrete plug located within the compacting clay layers. These extensometers measure a portion of the total subsidence and are referred to as “partial” extensometers.

We have incorporated seven extensometers in the subsidence data presented in Appendices A through Z. Of the seven extensometers to be used in this study, five are total extensometers and two – both located in the NASA PRESS site – are partial extensometers. More details on the extensometers to be used for calibration of the PRESS model output are included in information for specific PRESS sites in Appendices A through Z.

3.3 CORS and PAM Sites

The HGSD is moving toward a heavier reliance on GPS technology for collection of subsidence data. To provide stable elevation points in the greater Houston area, GPS antennas are attached to deep borehole extensometers. The HGSD operates four permanent stations that continuously collect data and are known as GPS Continuously Operating Reference Stations, (CORS). GPS readings can also be taken from various locations at ground surface around the greater Houston area and referenced to the various CORS measurements to determine subsidence. The HGSD attains ground surface GPS readings using GPS Port-A-Measure devices, (PAMs). The PAMs consist of trailers instrumented with GPS receivers and associated equipment. Measurements are taken by setting the PAM trailer up at a given PAM station and taking continuous readings for one week at a time. The current HGSD plan for collection of PAM data includes measuring each PAM station once per month.

The HGSD currently operates 65 PAM stations in the greater Houston area. We have incorporated data from 18 PAM stations – eight of the PRESS sites do not have a PAM station within their boundaries. Many of the PAM stations have only been measured recently, for the past few years, but their information is included in this study and will be relied heavily upon for future subsidence assessments.

All GPS elevation measurements taken with the PAM devices are compared to the deep borehole CORS stations to obtain a subsidence measurement. The raw data provided by the HGSD includes three subsidence values for each reading – one reading per day during each week of measurement. Per the guidance of the NGS, we only used subsidence values obtained by comparison to the “LKHU” CORS site when processing the PAM data. We were advised by the NGS that this site is the most stable of the HGSD CORS sites and provides the most consistent source of data.

3.4 Benchmarks

The NGS provided data from benchmark releveling using GPS procedures from the years 1995, 2000, 2005 and 2007. All survey efforts were initiated by the HGSD, with technical guidance provided by the NGS. For the 2000 campaign, primarily a launching point for PAM station expansion, measurements were performed by a volunteer effort of local, city and county agencies as well as private survey companies. The 2005 survey focused on PAM stations and CORS, while the 2007 effort focused on updating benchmark elevations to be used in PRESS model calibration and preparing for another PAM station expansion. Similar to the procedure utilized in the recalibration studies (Fugro 1997, 1998), data were provided in the form of changes in elevation as opposed to adjusted benchmark heights.

In an effort to identify additional sources of benchmark data, we reviewed the data used for comparison to PRESS model output in previous recalibration efforts (Fugro 1997, 1998), a directory of benchmarks in the greater Houston area that participated in the 2000 releveling program, and publicly available NGS datasheets. We were advised by the NGS that the information in the publicly available datasheets was not up to date. To address this, we requested additional releveling information from the NGS for all identified benchmarks from which we had not yet received data. The NGS provided additional information from a portion of the requested benchmarks.

We reviewed the new benchmark data alongside other sources of subsidence data – extensometers, PAM stations, and historical benchmark data – along with FNI, the HGSD, the USGS and the NGS. Inconsistencies when compared to other available subsidence data were noted in a majority of the new benchmark data. To address these inconsistencies, the NGS performed an extensive review and reprocessed the raw benchmark data from 1995, 2000, 2005 and 2007. The reprocessed data were provided by the NGS and is presented in the subsidence plots in Appendices A through Z.

3.5 Computed Subsidence Output

We included computed subsidence output obtained from PRESS model runs in previous studies in the subsidence plates provided in Appendices A through Z. Output from groundwater pumpage scenario CSD 96 (Fugro 1997, 1998) is presented for all PRESS sites. For PRESS sites in Harris County, output is also presented for groundwater pumpage scenario CSD 99 (Fugro 1999). The CSD 96 scenario was based on the assumption that all increases in water consumption in the District after January 1, 1995 would be met by groundwater (Fugro 1997). The CSD 99 scenario represents a gradual shift towards surface water consumption from groundwater that was originally proposed in a draft of the 1999 District Regulatory Plan – more details are included in the report related to the PRESS model runs for this scenario (Fugro 1999).

4.0 SUMMARY

A brief summary of the information compiled for Work Order 2 is presented in this section. We have included general comments on the hydrograph data and groundwater model output used to develop preliminary design hydrographs, as well as the subsidence data collected for comparison to PRESS model runs to be completed as part of Work Order 3. A qualitative discussion related to expected and observed correlations between the well hydrograph and subsidence data is also included in this section. Finally, a review of how the information compiled for Work Order 2 will be utilized in upcoming Work Order 3 is presented.

4.1 Preliminary Design Hydrographs

The primary sources of information used for development of preliminary design hydrographs are well hydrographs, whether from the USGS or private sources. For most PRESS sites, we were able to collect substantial well data to develop a preliminary design hydrograph that we are confident that it represents the groundwater conditions of the area.

However, here are a few instances in which well hydrograph data applicable to a PRESS site model aquifer are not available: Crosby (Upper), Galveston County (Lower), and Langham Creek (Upper). Additionally, there is only one well available for the Hobby upper model aquifer, but this well is located approximately 3 miles east of the PRESS site boundary and the most recent reading is from 2007. A summary of the number of wells used in the previous calibration effort compared to the number of wells we have measurements for since the previous calibration effort is presented in the following table.

Table 4.1 – Summary of Wells Used in Previous and Current Studies

Site	*Model Aquifer*	*# Wells (1996 Study)*	*# Wells (Current Study)*
Baytown	Single	10	8
Bellaire	Lower	9	2
	Upper	3	3
Bellaire West	Lower	12	13
	Upper	4	3
Crosby	Lower	1 (+ Map Data)	3
	Upper	1 (+ Map Data)	0
Cypress Creek	Single	8	5
Downtown	Single	8	6
Eagle Point	Single	8	6
FM 1960	Single	8	8
Galena Park	Single	6	6
Galveston County	Lower	0	0
	Upper	8	8

Table 4.1 – Summary of Wells Used in Previous and Current Studies (*cont.*)

Site	***Model Aquifer***	***# Wells (1996 Study)***	***# Wells (Current Study)***
Genoa	Single	6	5
Harrisburg	Single	3	2
Hobby	Lower	3	2
	Upper	1	0
Humble	Lower	2	3
	Upper	5	2
Katy	Single	7	5
Langham Creek	Lower	2	5
	Upper	3	0
La Porte	Single	2	3[a]
Long Point	Lower	5	5
	Upper	2	1
NASA	Single	18	17
North Houston	Lower	9	6
	Upper	4	1[b]
Pasadena	Lower	4	5
	Upper	4	3
Sheldon	Single	11	11
Arcola	Lower	14	1
	Upper	1	1
Needville	Single	16	5[c]
Richmond-Rosenberg	Lower	5	4[d]
	Upper	23	3
Smithers Lake	Single	8	3[e]

[a] Recent readings (within 5 years) from only 2 wells.
[b] Most recent well reading in 2007.
[c] Two wells used for model hydrograph.
[d] Three of the four wells have most recent readings from 2005.
[e] One well has most recent reading in 2003.

A lack of well hydrograph data is most likely indicative of a lack of groundwater pumping at depths consistent with the model aquifer. As a result, changes may need to be made to the PRESS site model in Work Order 3 – the PRESS site may need to be modeled with a single model aquifer, as opposed to dual model aquifers. However, this determination should only be made after completing additional PRESS model runs and assessing the performance of the current model.

Without sufficient well hydrograph data, groundwater model output must increasingly be relied upon to develop design hydrographs. A review of the HAGM output provided for Work Order 2 and presented in Appendices A through Z shows many instances of significant variation between HAGM output and both well hydrograph data and model output presented in previous studies. We recommend that the USGS and LBG-Guyton further review the HAGM output to assess the confidence with which it may be used to develop PRESS site design hydrographs. This review should be completed prior to the upcoming performance of groundwater model runs by the USGS – these runs are intended to provide data for development of projected design hydrographs to be used as input for PRESS model runs in Work Order 3.

4.2 Subsidence Data

The primary sources of subsidence data were benchmarks and borehole extensometers in previous studies. However, no new benchmarks with a history of releveling information applicable for this study have been located. CORS and PAM sites are being increasingly relied upon by the HGSD for subsidence measurements have been included in this study and provide valuable information related to subsidence since the previous study. For the purposes of this study, we believe that most of the PRESS sites (with the exception of three sites) have adequate subsidence data to compare model output to in Work Order 3 for the purposes of calibrating the PRESS site models.

Gaps in the subsidence data collected for Work Order 2 are primarily related to sites in which benchmarks provide the only source of subsidence data available: Galena Park, Galveston County and Long Point. The Galena Park and Galveston County sites each contain three benchmarks with readings from the most recent NGS survey, completed in 2007. The most recent subsidence data available in the Long Point PRESS site is from the 2000 NGS survey, when three benchmarks within the boundaries of the Long Point PRESS site were surveyed. In the Sheldon site, we were provided no data after 1995 for the three benchmarks located within the PRESS site boundaries.

In order to perform adequate calibrations in future studies for the three PRESS sites with limited data since the previous study, we recommend that a) benchmarks located within the boundaries of these PRESS sites are included in future NGS surveys, and b) additional sources of subsidence data, *e.g.*, PAM or CORS sites, are established within the PRESS site boundaries.

Table 4.2 – Summary of Subsidence Data Sources Used in Previous and Current Studies

Site	***# Subsidence Data Sources***	
	1996 Study	***Current Study***
Baytown	6	4
Bellaire	4	3
Bellaire West	4	3
Crosby	5	3
Cypress Creek	3	3
Downtown	7	4
Eagle Point	4	4
FM 1960	4	4
Galena Park	5	3
Galveston County	4	4
Genoa	4	4
Harrisburg	5	3
Hobby	3	3
Humble	4	3
Katy	5	4
Langham Creek	5	4
La Porte	4	4
Long Point	5	3
NASA	5	7
North Houston	5	2
Pasadena	4	3
Sheldon	5	3
Arcola	3	3
Needville	4	4
Richmond-Rosenberg	6	5
Smithers Lake	4	5

4.3 Correlations

Some general assessment of the information compiled for Work Order 2 may be made based on the expected correlation between changes in groundwater level and subsidence since 1995. We generally expect that as groundwater levels decrease in an area, subsidence occurs. Conversely, if groundwater levels increase, we expect that subsidence will likely cease.

General trends since 1995 in the groundwater and subsidence data compiled for each PRESS site are presented in Table 4.1 on the following page. Trends are indicated by symbols – up and down arrows for cases in which changes have clearly occurred and a dash if changes are negligible. The arrows generally correspond to a trend of groundwater levels and, in the case of subsidence data, the ground surface. In other words, a down arrow in a water level column indicates a drop in groundwater level, while a down arrow in the subsidence column indicates subsidence is occurring. Based on the expected relationship outlined in the previous paragraph, the last column in Table 4.1 includes an indication of a “Questionable” or “Good” correlation. A “Questionable” correlation indicates a greater likelihood that minor recalibration efforts will be required after initial PRESS model runs in Work Order 3.

4.4 Future Work Orders

PRESS model runs for each of the 26 active PRESS sites are planned for Work Order 3. First, a confirmation run will be performed for each PRESS site with the design hydrographs developed during Work Order 2. Output from the PRESS model confirmation runs will be compared to subsidence data compiled during Work Order 2. The need for minor recalibration efforts related to soil stratigraphy, model aquifer parameters, geotechnical parameters for clay layers, etc., will be assessed based on this comparison.

Next, the design hydrograph for each PRESS site will be projected to a future date using updated groundwater model output to be provided by the USGS. The PRESS model will be run on each of the 26 active PRESS sites using the project design hydrographs to predict subsidence to the future date determined by the HGSD.

Table 4.3 – Correlation Between Post-1995 Groundwater and Subsidence Data

Press Site	*General Trends*			*Correlation*
	Water Levels		Subsidence	
	Chicot	Evangeline		
Arcola	↑	↓	↓	Questionable
Baytown	↑	↑	–	Good
Bellaire	↑	↑	↓	Questionable
Bellaire West	↑	↑	↓	Questionable
Crosby	↑	↑	–	Good
Cypress Creek	↑	↑	↓	Questionable
Downtown	↑	↑	↑	Good
Eagle Point	–	–	↓	Questionable
FM 1960	↑	↑	↓	Questionable
Galena Park	↑	↑	–	Good
Galveston County	↑	↓	↓	Questionable
Genoa	↑	↑	–	Good
Harrisburg	↑	↑	–	Good
Hobby	↑	↑	↓	Questionable
Humble	↑	↑	↓	Questionable
Katy	↓	↓	↓	Good
La Porte	↑	↑	–	Good
Langham Creek	–	↓	↓	Good
Long Point	↑	↑	↓	Questionable
NASA	↑	↑	–	Good
Needville	–	–	–	Good
North Houston	↑	↑	–	Good
Pasadena	↑	↑	↑	Good
Richmond-Rosenberg	–	↓	↓	Good
Sheldon	↑	↑	–	Good
Smithers Lake	↓	↓	↓	Good

5.0 REFERENCES

Espey, Huston & Associates, Inc. (1982), “Water Management Study – Phase II,” Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

Fugro-McClelland (Southwest), Inc. (1997), “Recalibration of PRESS Models and Development of Two New Models; Harris and Galveston Counties, Texas,” Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

Fugro-McClelland (Southwest), Inc. (1998), “Recalibration of PRESS Models; Fort Bend County, Texas,” Fort Bend Subsidence District, Friendswood, Texas.

Fugro South, Inc. (1999), “Subsidence Predictions, Scenarios CSD-97, CSD-98, and CSD-99, Harris-Galveston Coastal Subsidence District,” Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

Fugro South, Inc. (2000), “Subsidence Predictions, Scenarios FBSD-100 and FBSD-101, Fort Bend Subsidence District,” Fort Bend Subsidence District, Friendswood, Texas.

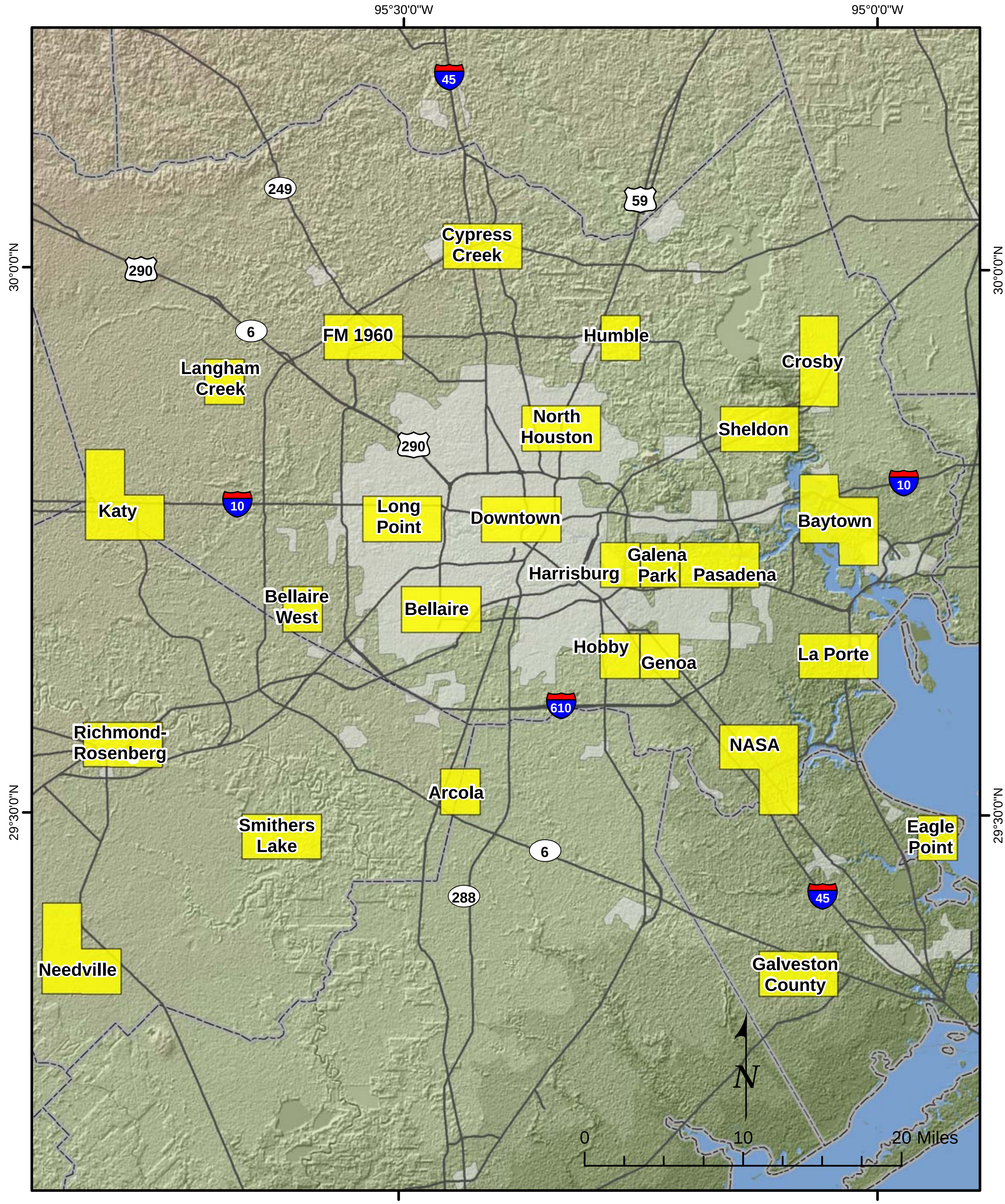
Fugro South, Inc. (2002a), “Subsidence Predictions, Scenario CSD-96Z, Harris-Galveston Coastal Subsidence District,” Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

Fugro South, Inc. (2002b), “Subsidence Predictions, Scenario FB-103, Fort Bend Subsidence District,” Fort Bend Subsidence District, Friendswood, Texas.

Fugro South, Inc. (2002c), “Subsidence Predictions, Scenario CSD-104, Harris-Galveston Coastal Subsidence District,” Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

McClelland Engineers, Inc. (1979), “Subsidence Cause and Effect,” Chapter IV, in Water Management Study – Phase I, by Espey, Huston & Associates, Inc., Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

ILLUSTRATIONS



PLAN OF PRESS MODEL SITES

PLATE 1

APPENDICES

A: ARCOLA SITE

A.1 Introduction

The Arcola site covers a 2.5-min sized area of the Almeda Topographic Quadrangle, made up of the eastern half of the 7th ninth and the western half of the 8th ninth on the Almeda quad sheet. The general site location is shown on Plate 1, and a detailed site map is presented on Plate A-1. The site boundaries are consistent with the previous recalibration study (Fugro 1998).

A.2 Aquifers

The model aquifer definitions, as revised during the recalibration study (Fugro 1998) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 400 to 580 ft
	Lower: 950 to 1,300 ft
Bottom of Compacting Interval:	1,800 ft
Bottom of Chicot Aquifer:	About 700 ft
Bottom of Evangeline Aquifer:	About 2,600 ft

A.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

A.3.1 Wells. We selected nine wells to use for development of the design hydrograph for the Arcola PRESS site. Locations of the wells are included in the detailed Arcola PRESS site map presented on Plate A-1. All nine of the wells selected for this study were used previously in the recalibration study (Fugro 1998). Six other wells used in the previous recalibration effort were not included in this study, as they did not contribute to development of site hydrographs and no additional data have been collected since the previous recalibration. We assumed a ground surface elevation of 66 ft when vertically translating the well data for this site.

Eight of the nine wells referenced for the Arcola site are screened in the Chicot aquifer. We used these wells, presented on Plate A-2, to develop the design hydrograph for the upper model aquifer. Five of the eight wells have only one data point, which was recorded at the time the well was drilled. Only one well, LJ-65-29-709, has data obtained after 1995.

One of the nine wells used for the Arcola site, LJ-65-29-706, is screened in the Evangeline aquifer. The hydrograph from this well was used to develop the design hydrograph for the model lower aquifer and is presented on Plate A-3.

A.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Arcola site. The outputs are referred to as “Arcola 1” and “Arcola 2” in the information provided by LBG-Guyton. “Arcola 1” is from a location of latitude 29°31’46.6”N and longitude 95°26’25.0”W. “Arcola 2” is from a location of latitude 29°30’45.7” and longitude 95°28’2.0”. We assumed a ground surface elevation of 84 feet when vertically translating this output.

A.3.3 Design Hydrographs. We used the upper and lower model aquifer site hydrographs presented in the previous recalibration effort (Fugro 1998) through the year 1995. To extend these hydrographs to 2010, we continued the trends established in the recalibration effort by using well LJ-65-29-709 for the upper model aquifer and well LJ-65-29-706 for the lower model aquifer. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

A.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

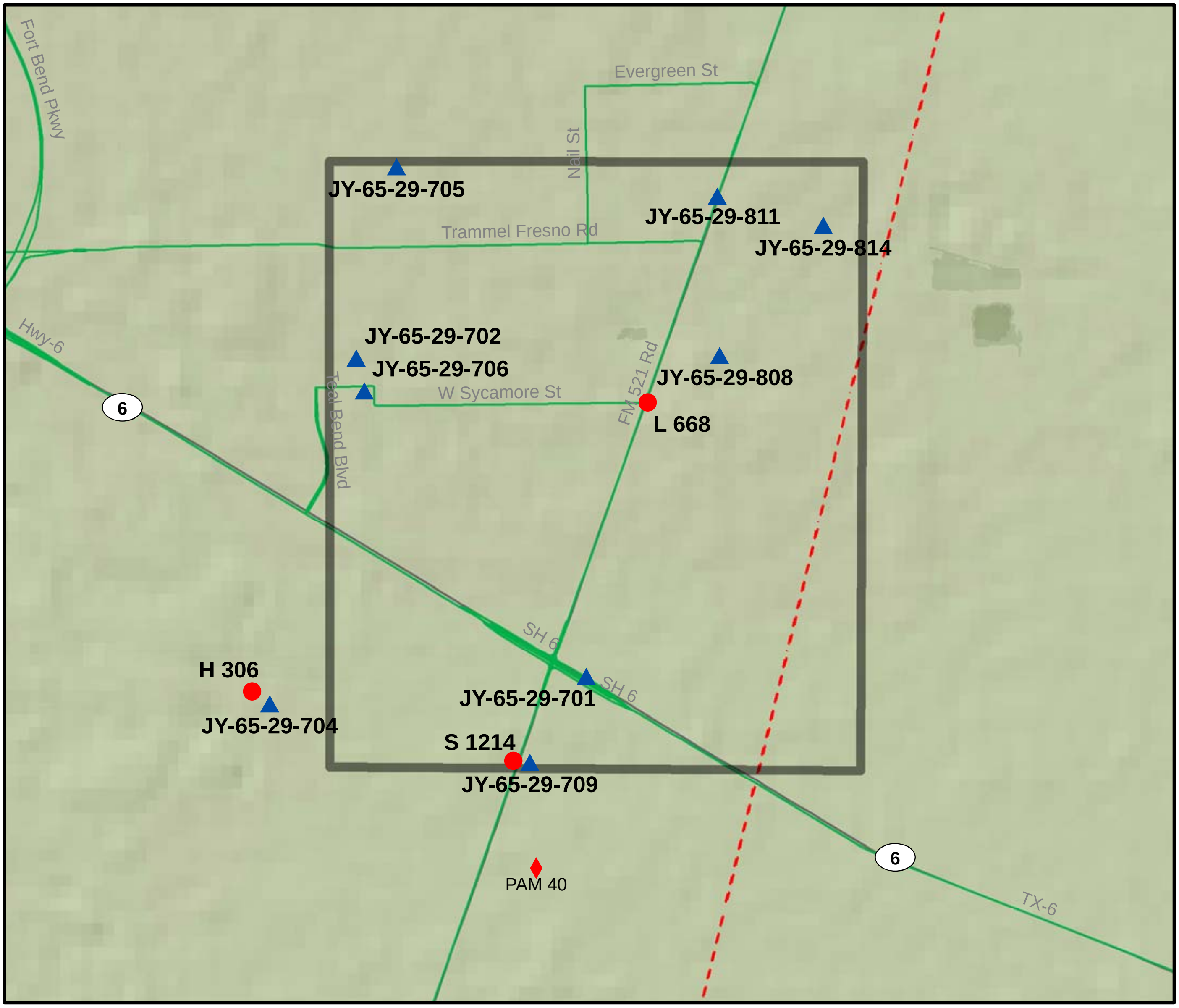
A.4.1 Benchmarks. Consistent with the previous recalibration effort, data from three benchmarks will be used in the current study:

- H 306;
- L 668; and
- S 1214.

The locations of these benchmarks are shown on Plate A-1, and subsidence data are presented on Plate A-4. All of these benchmarks were used in the original calibration as well as the first recalibration (Fugro 1998).

A.4.2 PAM Station. Data from PAM station 40, also presented on Plate A-4, will be used for recalibration efforts in future phases of this study. The location of PAM 40, just south of the PRESS site boundary, is presented on Plate A-1. Data from PAM 40 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on review of other subsidence data sources available, we applied a vertical offset of 2.7 ft to the PAM data.

A.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenario CSD 96 is presented on Plate A-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenario CSD 96 are included in *Section 3.5*.



Legend:

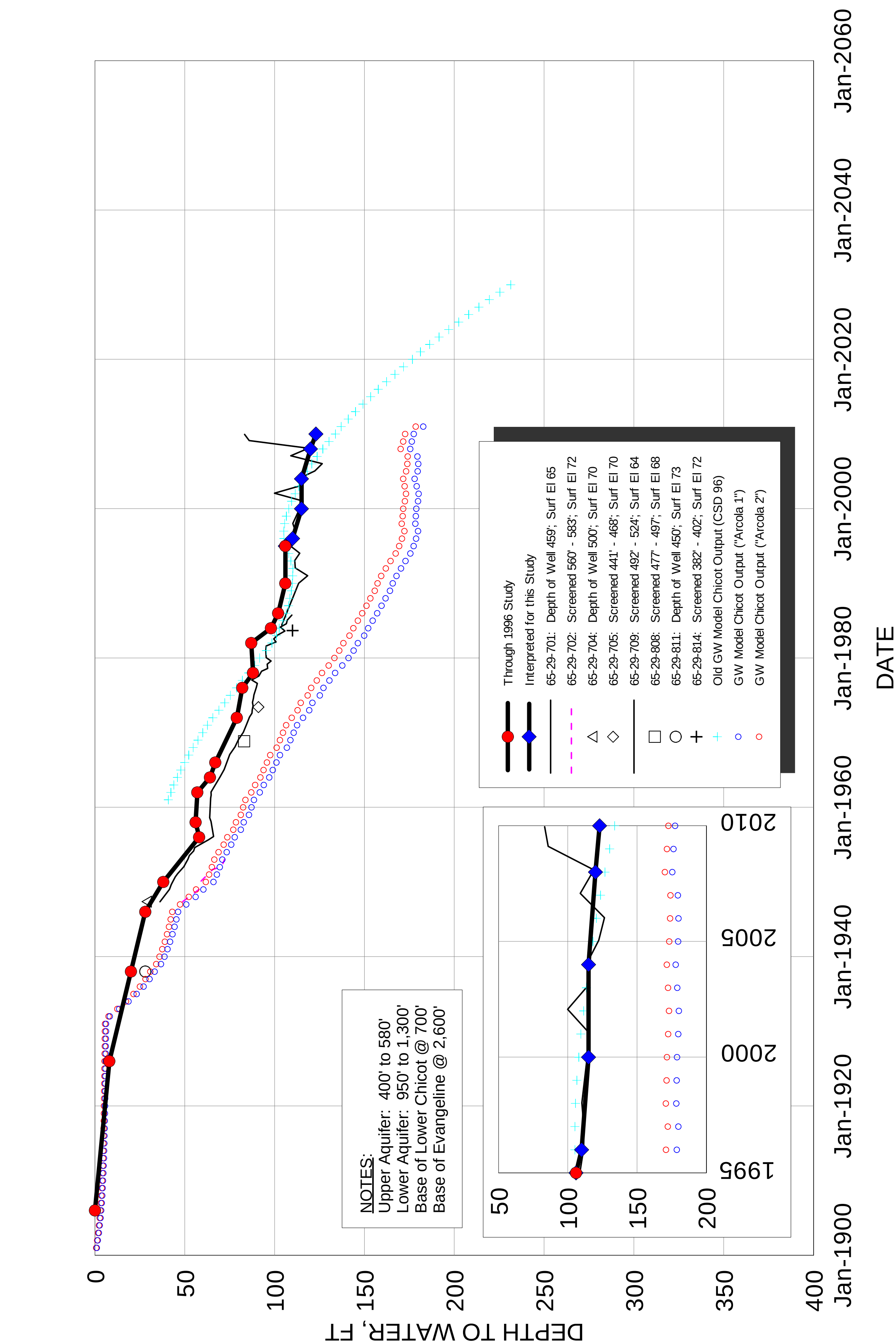
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

SITE MAP
ARCOLA PRESS SITE

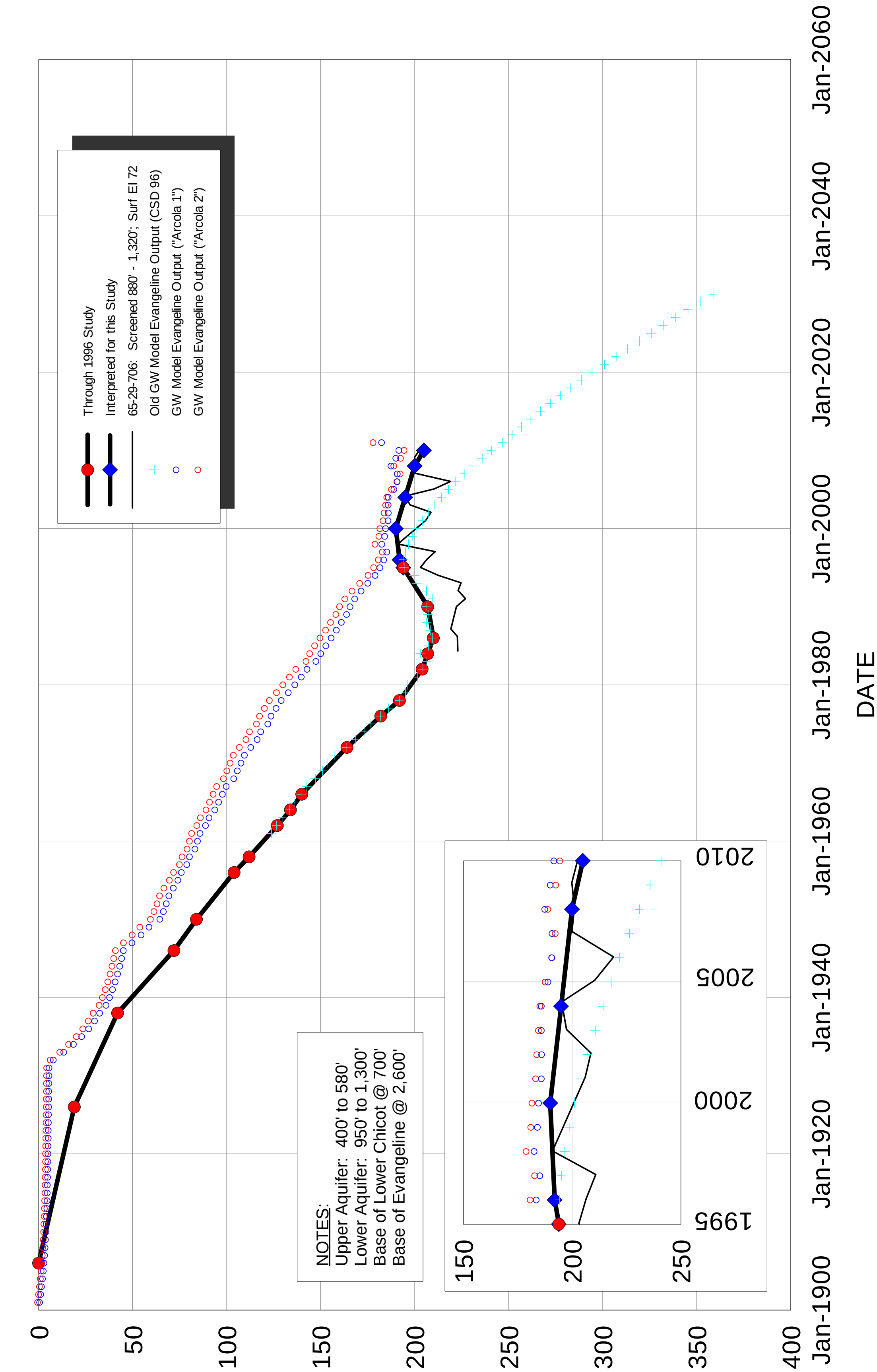
PLATE A-1



HYDROGRAPHS FOR ARCOLA SITE
MODEL UPPER AQUIFER

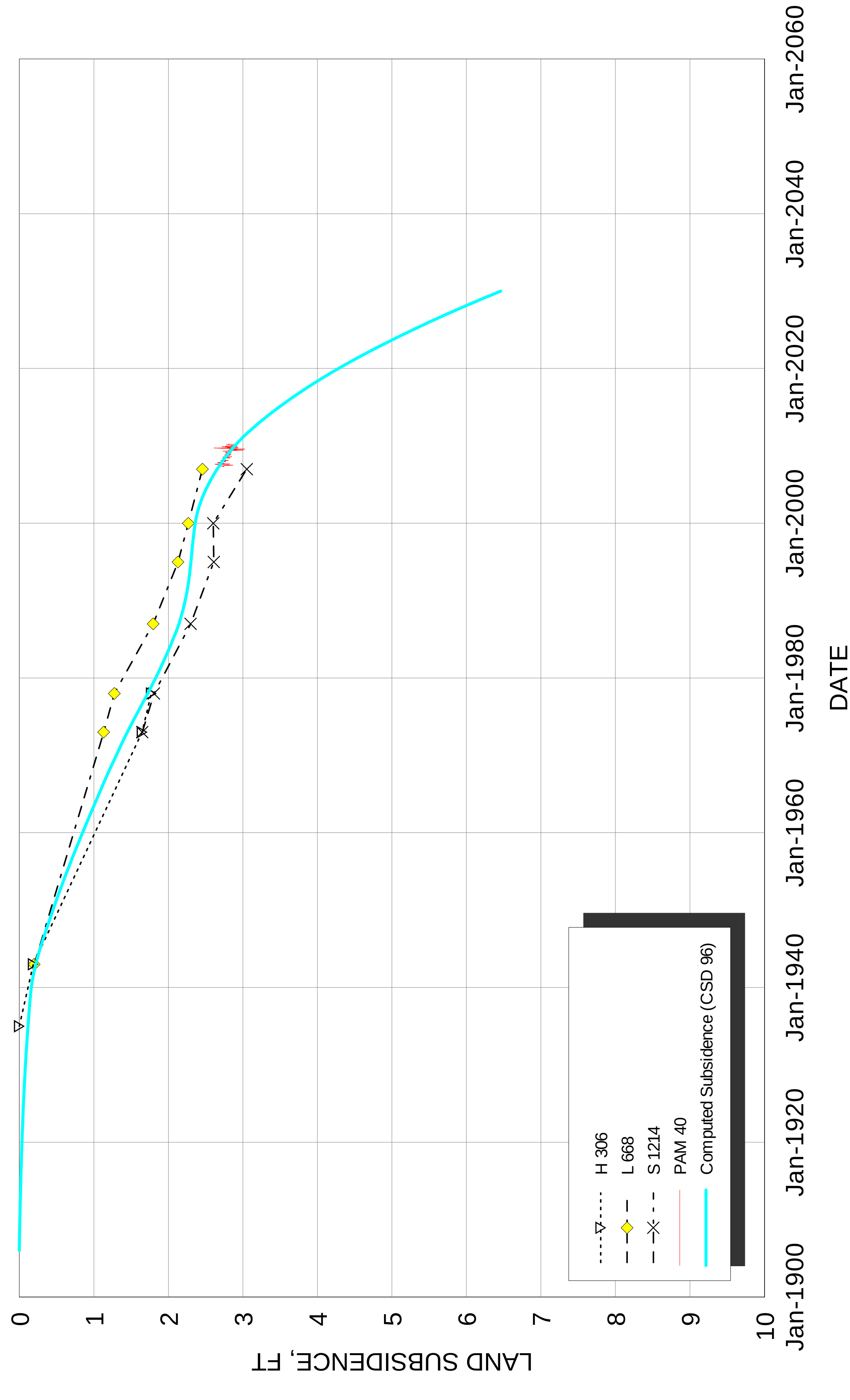
PLATE A-2

FUGRO



HYDROGRAPHS FOR ARCOLA SITE
MODEL LOWER AQUIFER

PLATE A-3



COMPUTED AND MEASURED SUBSIDENCE
ARCOLA SITE

PLATE A-4

B: BAYTOWN SITE

B.1 Introduction

The Baytown site covers two full ninths and one partial ninth in the south and central parts of the Highlands Topographic Quadrangle and one partial ninth in the northeast part of the La Porte Topographic Quadrangle in Harris County. The site is shown in general on Plate 1 and in greater detail on Plate B-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

B.2 Aquifer

The Baytown site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	400 to 1,363 ft
Bottom of Compacting Interval:	1,460 ft
Bottom of Chicot Aquifer:	About 500 to 600 ft
Bottom of Evangeline Aquifer:	About 2,500 to 3,000 ft

B.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

B.3.1 Wells. We selected 12 wells to use for development of a design hydrograph for the Baytown PRESS site. Locations of the wells are included in the detailed Baytown PRESS site map presented on Plate B-1. All of the wells used in the recalibration study (Fugro 1997), a total of 10 wells, are included in this study. After consultation with LBG-Guyton, we added two wells for this study, as identified on Plate B-2:

- LJ-65-16-904; and
- LJ-65-16-602.

We assumed a ground surface elevation of 28 ft when vertically translating all well data for this site.

Nine of the 12 wells used for development of the Baytown site design hydrograph are screened within the boundaries of the model aquifer depths. However, a review of data from the three wells not screened within the model aquifer boundaries – LJ-65-16-925, LJ-65-16-931 and LJ-65-16-932 – shows good agreement with other well data. Additionally, the site hydrograph used as input to the PRESS model in the previous recalibration study generally follows data from well LJ-65-16-931 (Fugro 1997). We have included output from the three wells in Plate B-2.

B.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Baytown site. The outputs are referred to as “Baytown 1” and “Baytown 2” in the information provided by LBG-Guyton. “Baytown 1” is from a location of latitude 29°46’14.6”N and longitude

95°2’43.8”W. “Baytown 2” is from a location of latitude 29°44’8.3” and longitude 95°1’4.7”. We assumed a ground surface elevation of 28 feet when vertically translating this output.

B.3.3 Design Hydrograph. We used the site hydrograph presented in the previous recalibration effort (Fugro 1997) for dates through 1995. To extend this hydrograph to 2010, we continued the trend established in the previous recalibration effort by generally following well LJ-65-16-931. This trend is in general agreement with other well data collected for the site. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

B.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

B.4.1 Benchmarks. Data from five benchmarks will be used in the current study:

- TORY HILL;
- DAVIS RM1;
- HGCSD 32;
- HGCSD 33; and
- Y 1249.

Locations of the benchmarks are shown on Plate B-1, and subsidence data are presented on Plate B-3. Four benchmarks were used in the previous recalibration study (Fugro 1997). Benchmark Y 1249 was added for this study and, after a review of the other subsidence data available at the site, a vertical offset of 6.6 ft was added to the data starting in 1995.

B.4.2 Extensometer. Data from one extensometer, LJ-65-16-931 or “Baytown Total”, will be used for comparison to the PRESS model output. The location of the “Baytown Total” extensometer is shown on Plate B-1, and data from the extensometer is presented on Plate B-3. In addition to this extensometer, data from LJ-65-16-930 (“Baytown Partial”) was used in the previous recalibration study. However, based on recommendations from the HGSD, this extensometer will not be referenced for the current study, as this “partial” extensometer may not accurately represent total subsidence in the area.

B.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate B-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.

Legend:

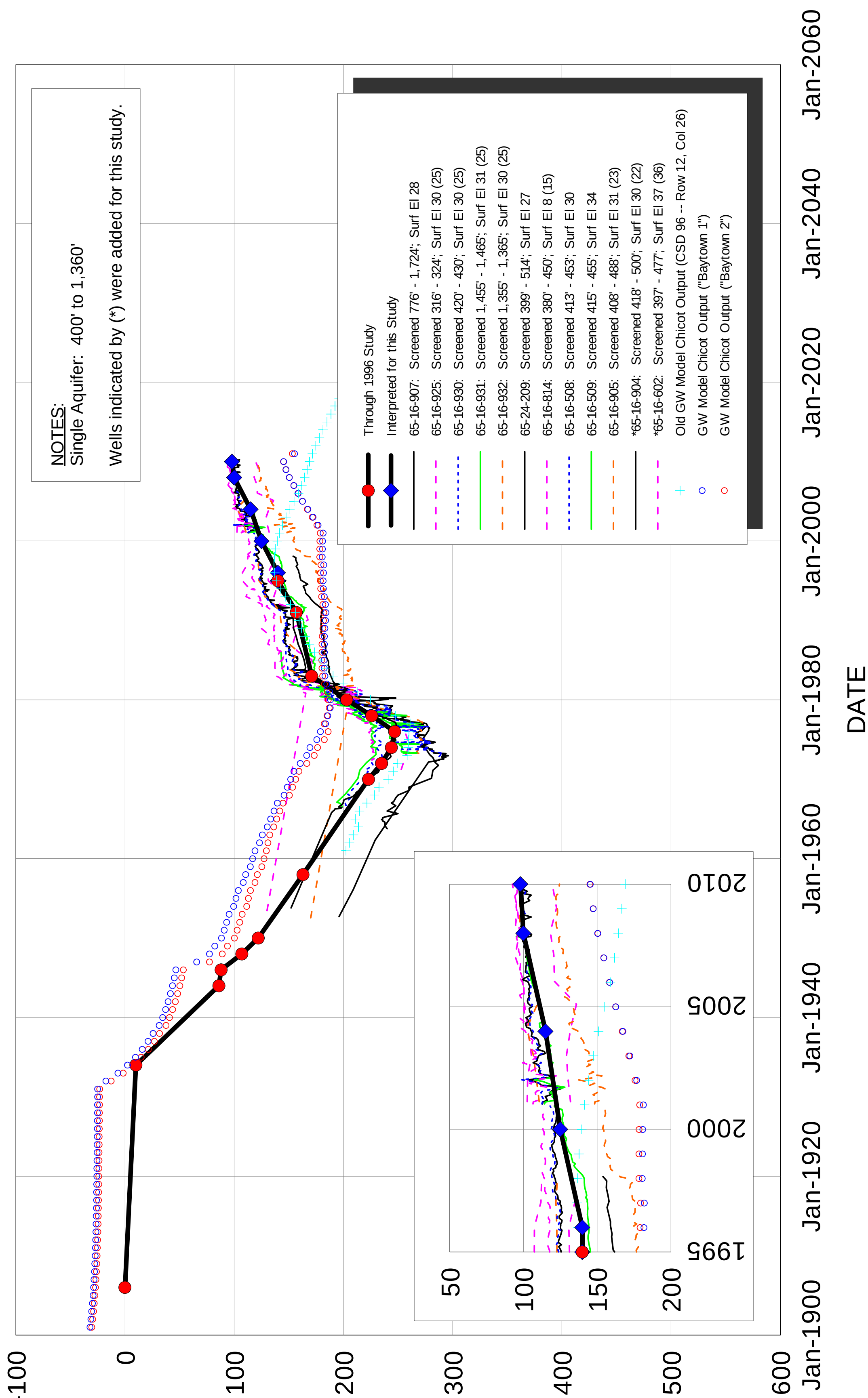
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▭ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 6,000 12,000 Feet

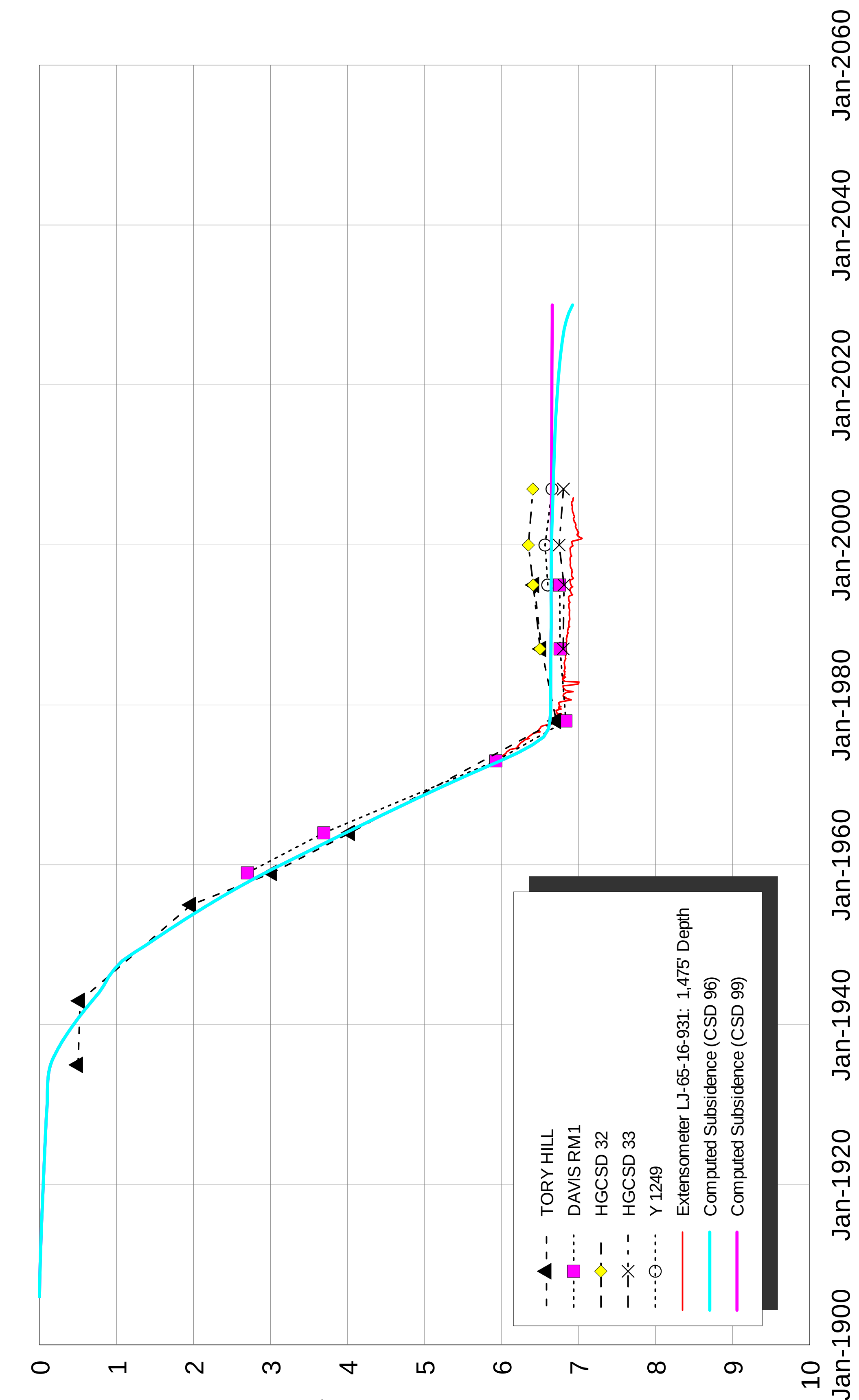
SITE MAP
BAYTOWN PRESS SITE

PLATE B-1



HYDROGRAPHS FOR BAYTOWN SITE
SINGLE MODEL AQUIFER

PLATE B-2



COMPUTED AND MEASURED SUBSIDENCE
BAYTOWN SITE

PLATE B-3

C: BELLAIRE SITE

C.1 Introduction

The Bellaire site covers two ninths in the west and central part of the Bellaire Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate C-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

C.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 550 to 800 ft
	Lower: 850 to 2,000 ft
Bottom of Compacting Interval:	1,960 ft
Bottom of Chicot Aquifer:	About 600 to 700 ft
Bottom of Evangeline Aquifer:	About 2,000 to 2,500 ft

C.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

C.3.1 Wells. The 12 wells referenced previously in the recalibration study (Fugro 1997) are all included in this study. In addition, we have added four wells not previously used for calibration:

- LJ-65-21-150 (model upper aquifer);
- LJ-65-21-229 (model upper aquifer);
- LJ-65-20-520 (model upper aquifer); and
- LJ-65-21-417 (model lower aquifer).

Locations of all wells are included in the detailed Bellaire PRESS site map presented on Plate C-1. We assumed a ground surface elevation of 60 ft when vertically translating all well data for this site.

Six of the wells are screened in the model upper aquifer and are presented on Plate C-2. Nine of the remaining 10 wells have confirmed screen depths located completely in the model lower aquifer. We were unable to confirm the bottom screen depth for well LJ-65-21-417, added for this study. However, a comparison of the data from this well agrees closely with the only other well from the model lower aquifer with readings after 1995 – LJ-65-20-619. As a result, we are confident that LJ-65-21-417 is screened in the model lower aquifer and have included data from this well in the model lower aquifer wells presented on Plate C-3.

C.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Bellaire site. The outputs are referred to as “Bellaire 1” and “Bellaire 2” in the information provided by LBG-Guyton. “Bellaire 1” is from a location of latitude 29°41’7.7”N and longitude 95°26’42.8”W. “Bellaire 2” is from a location of latitude 29°41’23.5” and longitude 95°28’5.4”. We assumed a ground surface elevation of 60 feet when vertically translating this output.

C.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997) for dates through 1995. There were no well observations available after 1995 for the two wells used primarily to develop the upper model aquifer site hydrograph in the previous recalibration effort (LJ-65-20-111 and LJ-65-20-118). To extend the upper model aquifer hydrograph to 2010, we generally followed trend present in the groundwater model output and in the two wells screened just below the upper model aquifer: LJ-65-20-412 and LJ-65-20-416. Consistent with the previous study, we generally chose a visual average of the available hydrograph data to extend the lower model aquifer design hydrograph to the year 2010. The old and new portions of the design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

C.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

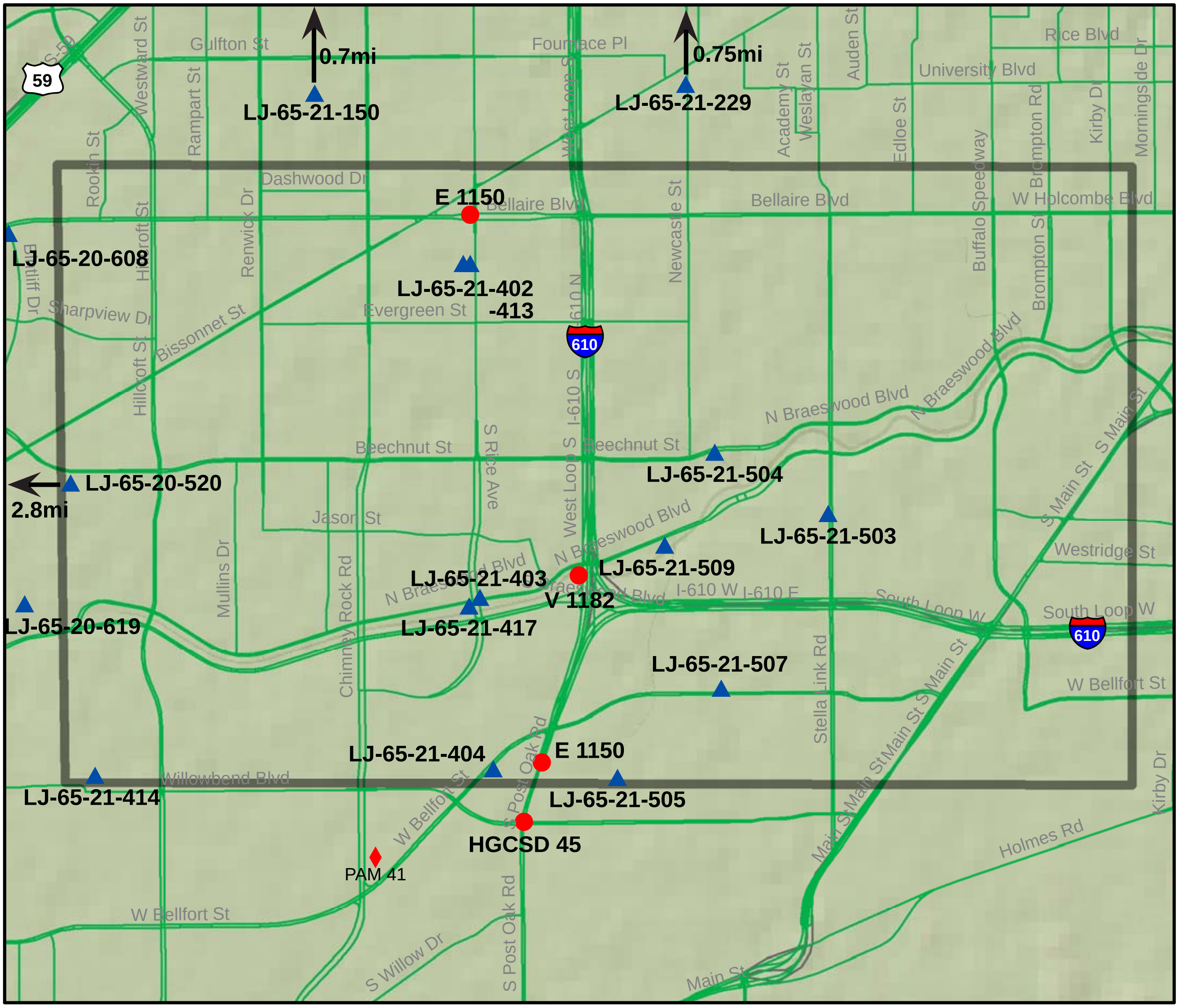
C.4.1 Benchmarks. Consistent with the previous recalibration effort, data from four benchmarks will be used in the current study:

- E 1150;
- F 1150;
- V 1182; and
- HGCSD 45.

Locations of these benchmarks are shown on Plate C-1, and subsidence data are presented on Plate C-4. Two benchmarks – E 1150 and F 1150 – were used in the original calibration, and all four were used for the first recalibration (Fugro 1997).

C.4.2 PAM Station. Data from PAM station 41, also presented on Plate C-4, will be used for recalibration efforts in future phases of this study. The location of PAM 41, just south of the PRESS site boundary, is presented on Plate C-1. Data from PAM 41 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on a review of other subsidence data sources available, we applied a vertical offset of 7.0 ft to the PAM data.

C.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate C-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

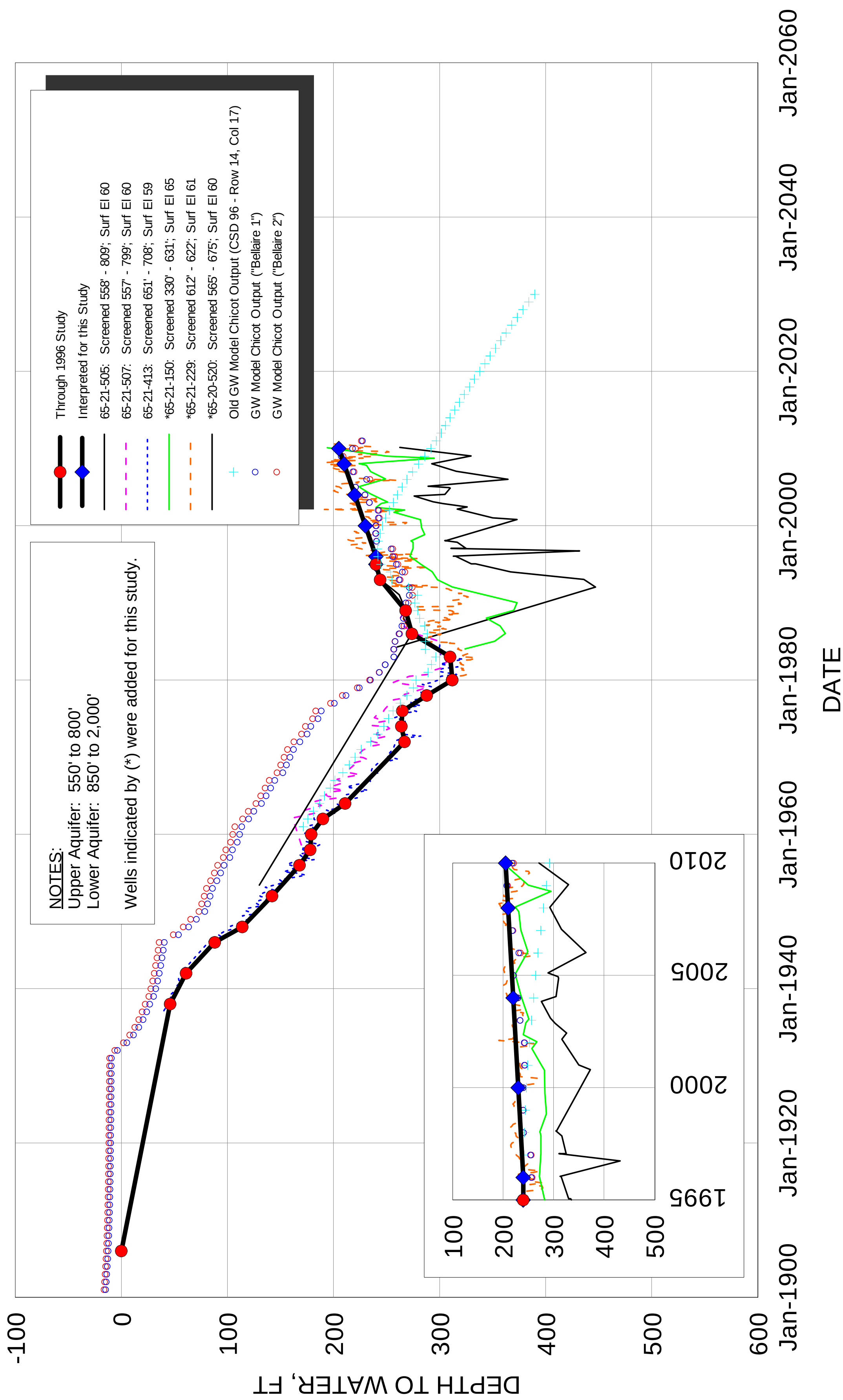
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ☐ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

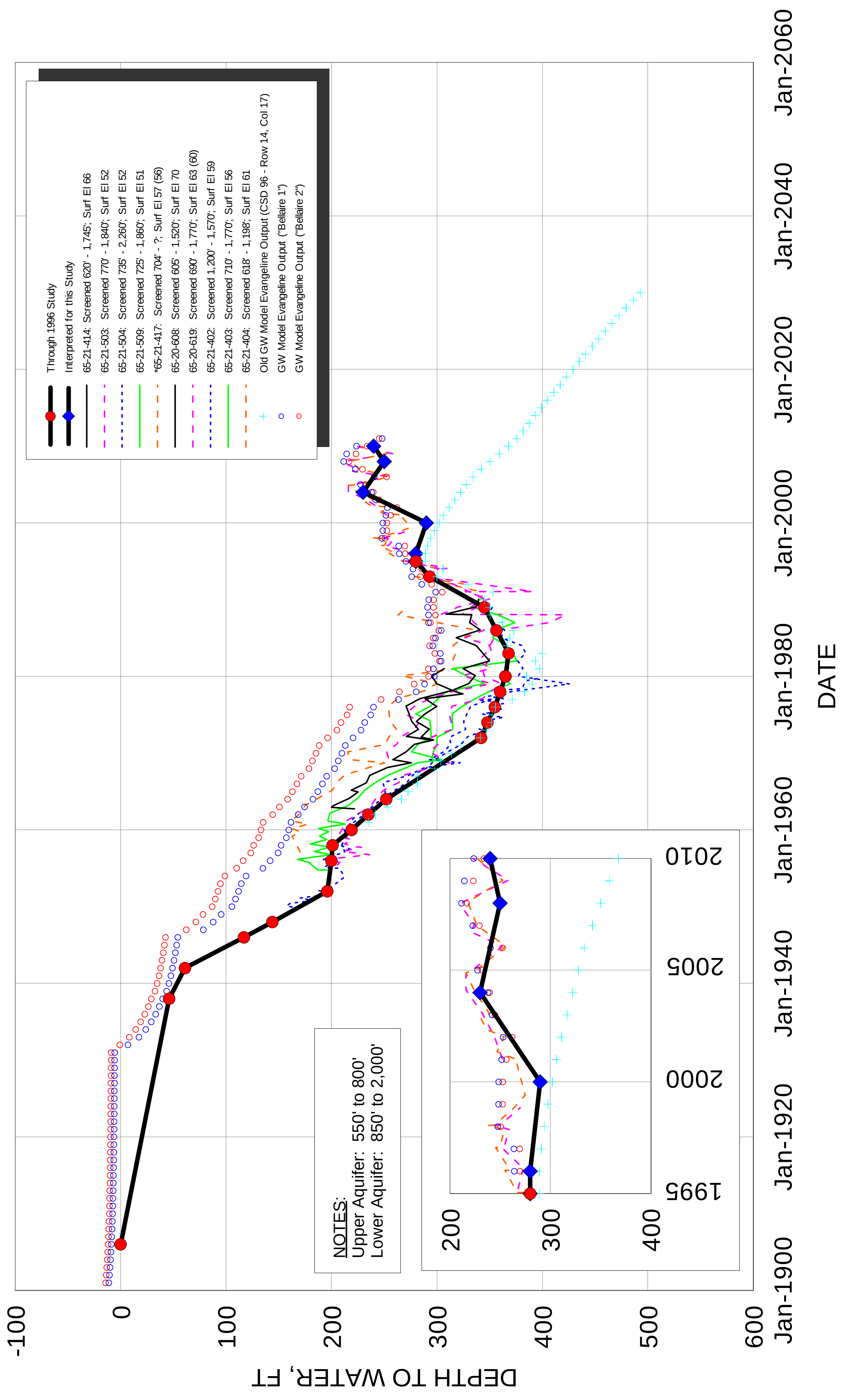
SITE MAP
BELLAIRE PRESS SITE

PLATE C-1



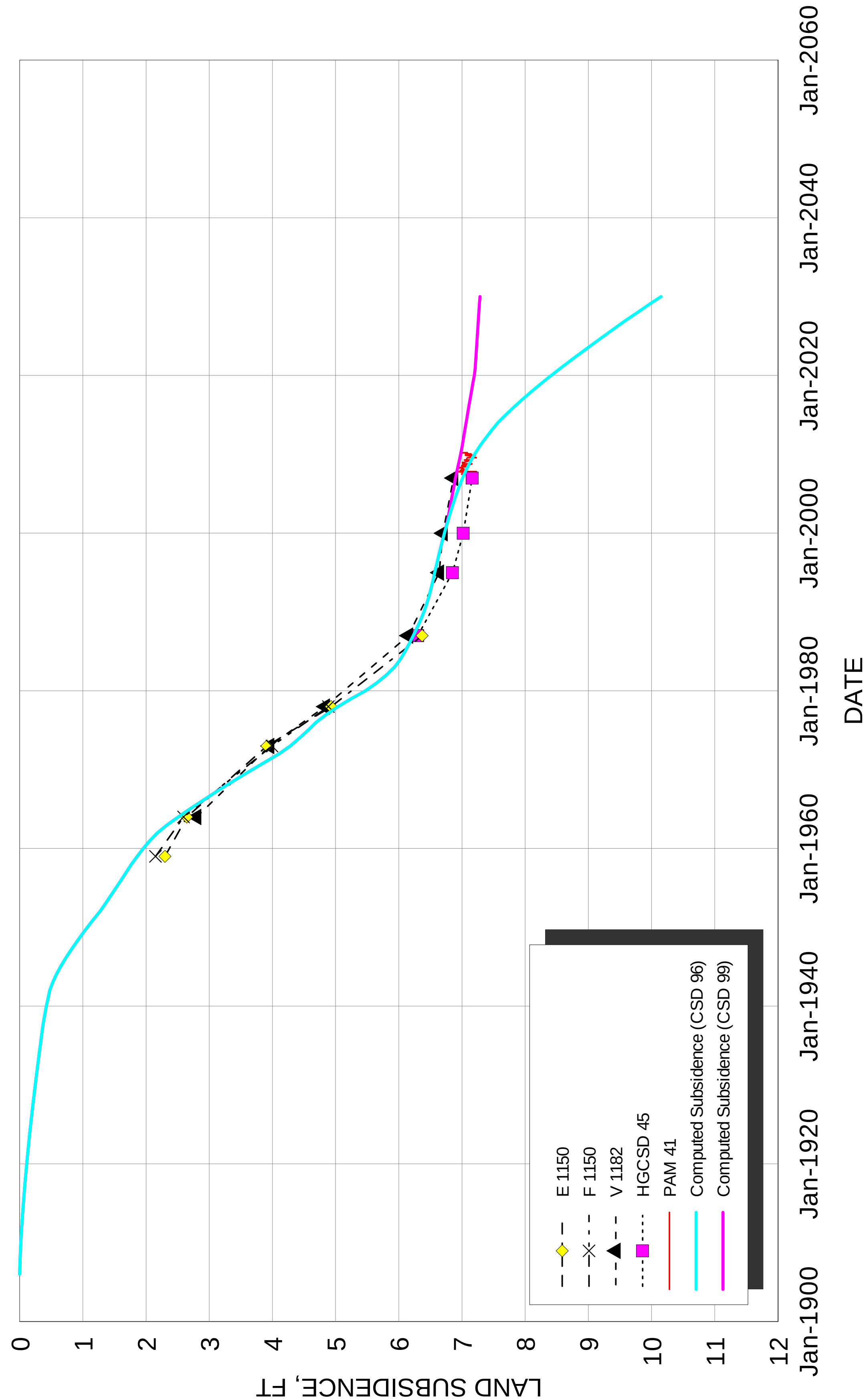
HYDROGRAPHS FOR BELLAIRE SITE
MODEL UPPER AQUIFER

PLATE C-2



HYDROGRAPHS FOR BELLAIRE SITE
MODEL LOWER AQUIFER

PLATE C-3



COMPUTED AND MEASURED SUBSIDENCE
BELLAIRE SITE

PLATE C-4

D: BELLAIRE WEST SITE

D.1 Introduction

The Bellaire West site covers one ninth in the west part of the Alief Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate D-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

D.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 450 to 500 ft
	Lower: 1,000 to 1,500 ft
Bottom of Compacting Interval:	1,780 ft
Bottom of Chicot Aquifer:	About 600 to 700 ft
Bottom of Evangeline Aquifer:	About 2,000 to 2,500 ft

D.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

D.3.1 Wells. The 16 wells referenced previously in the recalibration study (Fugro 1997) are all included in this study. In addition, we have added two wells not previously used for calibration:

- LJ-65-20-408 (model lower aquifer); and
- LJ-65-20-421 (model lower aquifer).

Locations of all wells are included in the detailed Bellaire West PRESS site map presented on Plate D-1. We assumed a ground surface elevation of 84 ft when vertically translating all well data for this site.

Four wells – two screened solely in the Chicot and two screened in both the Chicot and Evangeline aquifers – are presented on Plate D-2 for the upper model aquifer. The remaining 12 wells are screened in the model lower aquifer and are presented on Plate D-3.

D.3.2 Groundwater Model Output. We were only provided one set of groundwater model output for the Bellaire West site. The output, referred to as “Bellaire West 1” in the information provided by LBG-Guyton, is from a location of latitude 29°41’22.3”N and longitude 95°36’39.9”W. We assumed a ground surface elevation of 84 feet when processing and plotting this output.

D.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997).

There were no well observations available after 1995 for the three upper aquifer wells used in developing the site hydrographs in the previous recalibration effort. To extend the upper model aquifer hydrograph to 2010, we generally followed trends present in two of the wells added for this study: LJ-65-21-229 and LJ-65-21-150.

Wells LJ-65-21-504 and LJ-65-24-503 were primarily followed for development of the site hydrograph for the lower model aquifer in the previous recalibration study. There were no well observations available for these two wells after 1995. We generally followed trends shown in the data for wells LJ-65-21-417 and LJ-65-20-619 to extend the lower model aquifer design hydrograph to 2010.

The old and new portions of the design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

D.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

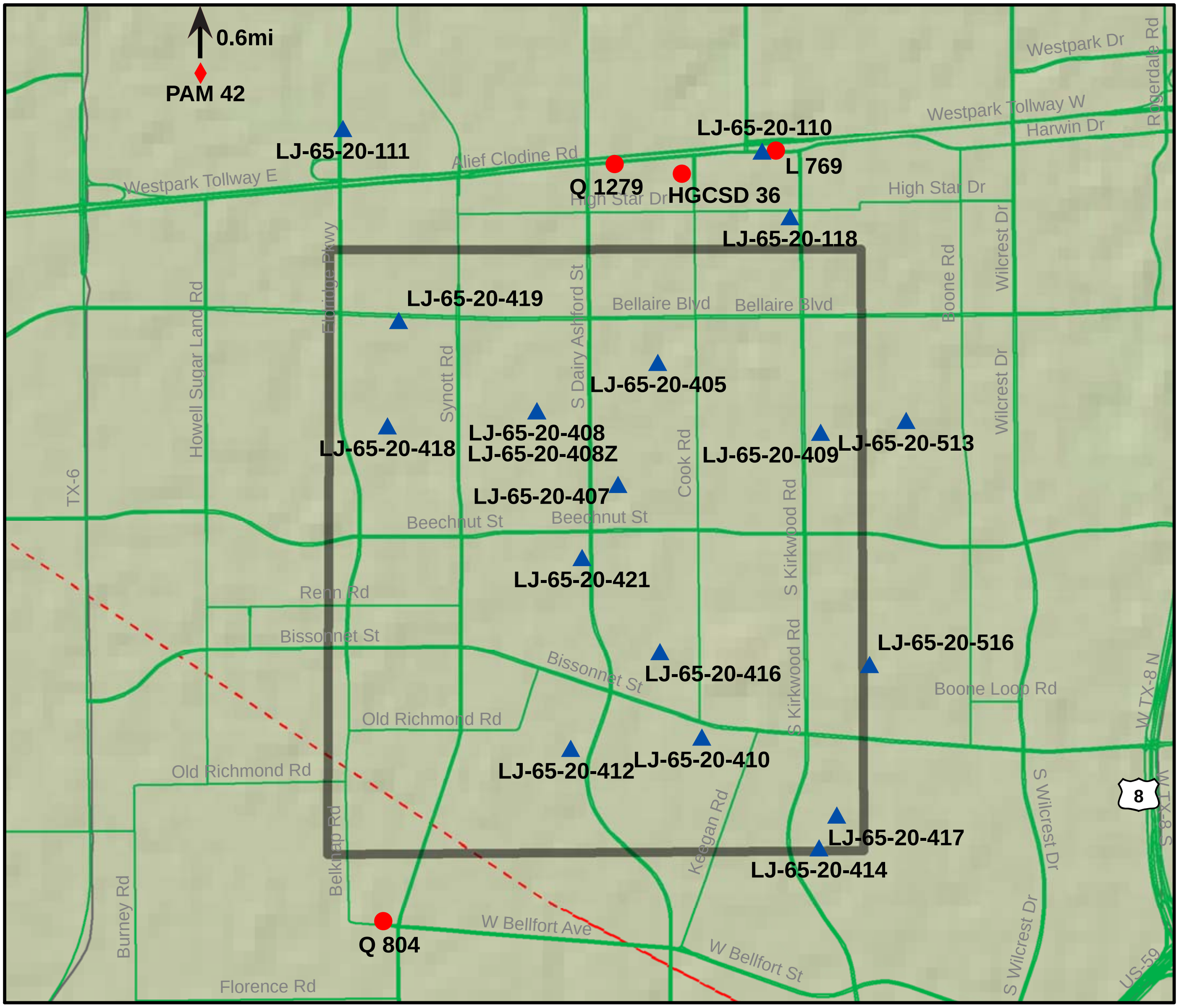
D.4.1 Benchmarks. Consistent with the previous recalibration effort, data from four benchmarks will be used in the current study:

- L 769;
- Q 804;
- Q 1279; and
- HGCSD 36.

The locations of these benchmarks are shown on Plate D-1, and subsidence data are presented on Plate D-4.

D.4.2 PAM Station. Data from PAM station 42, also presented on Plate D-4, will be used for recalibration efforts in future phases of this study. The location of PAM 42, approximately 0.6mi north / northeast of the PRESS site boundaries, is presented on Plate D-1. Data from PAM 42 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on our review of other subsidence data sources available, we applied a vertical offset of 6.0 ft to the PAM data.

D.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate D-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

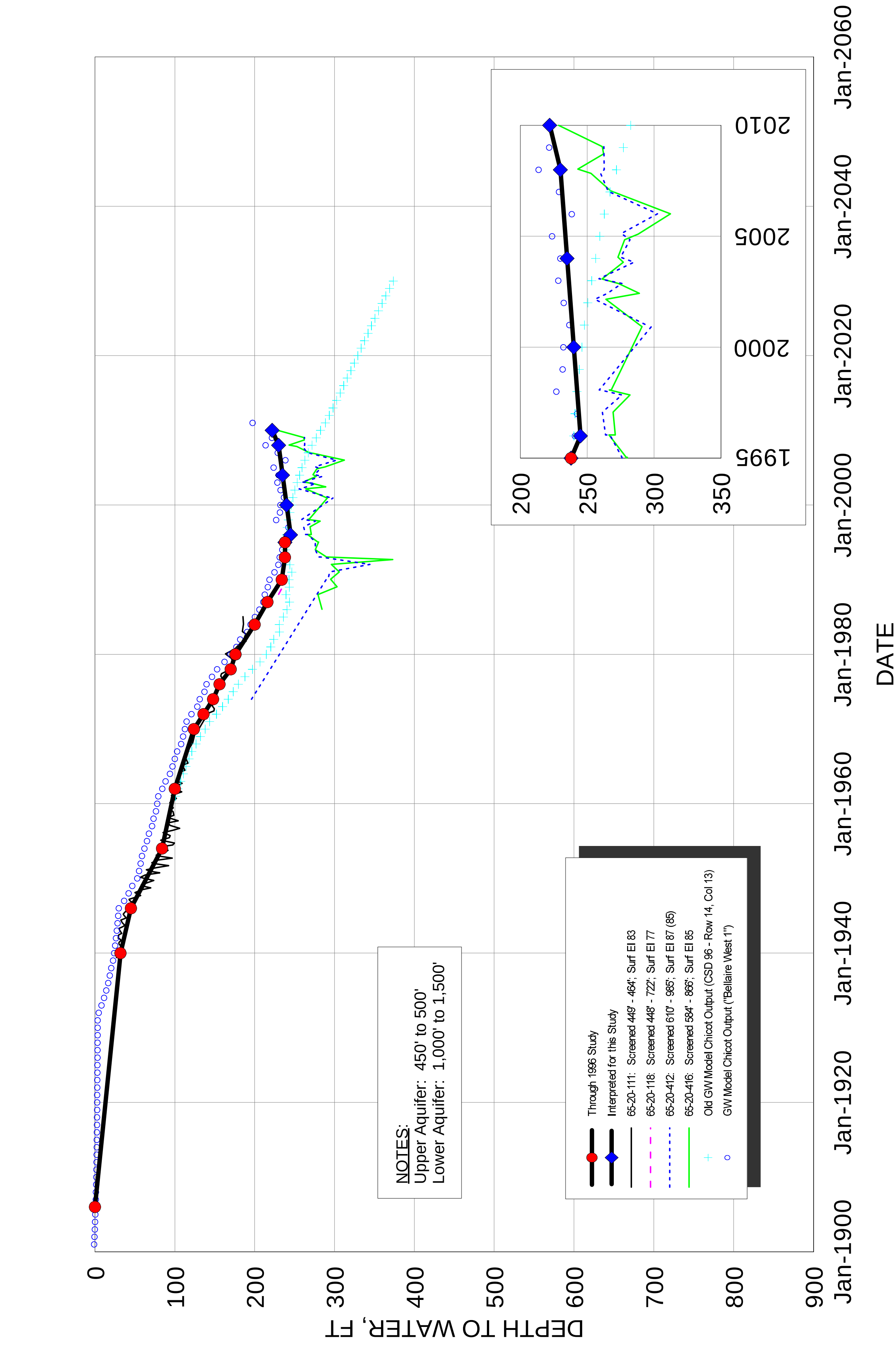
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

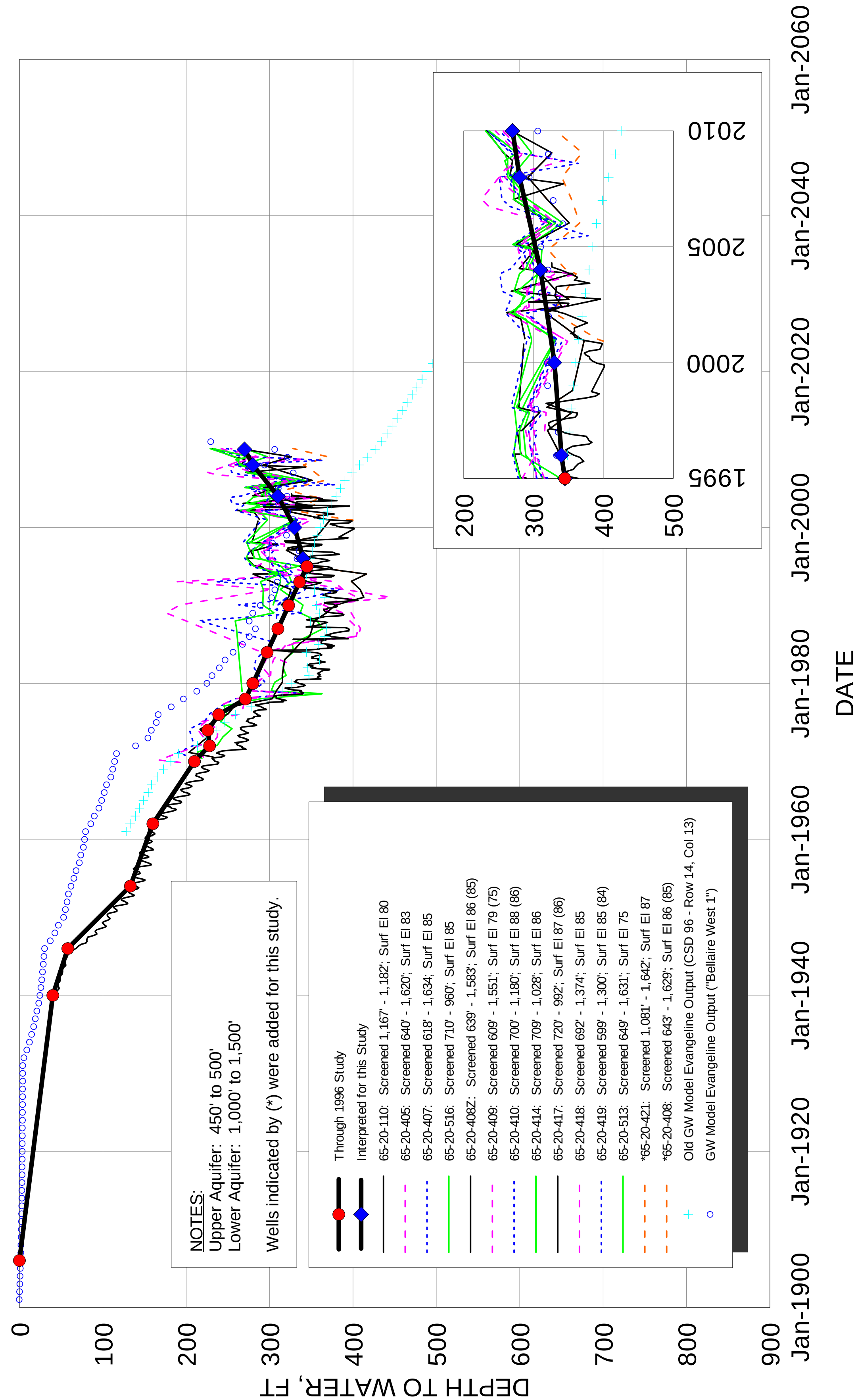
SITE MAP
BELLAIRE WEST PRESS SITE

PLATE D-1



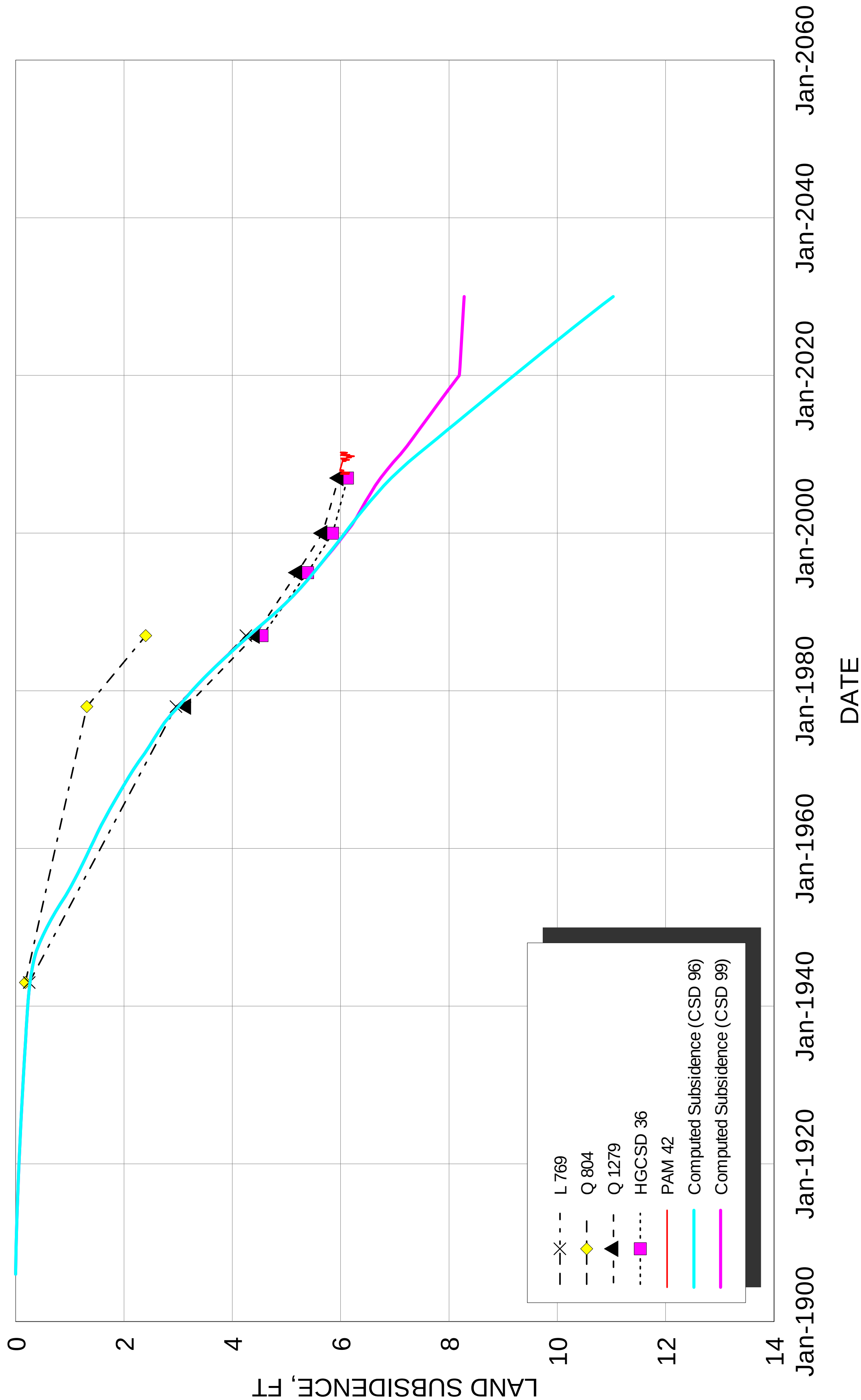
HYDROGRAPHS FOR BELLAIRE WEST SITE
MODEL UPPER AQUIFER

PLATE D-2



HYDROGRAPHS FOR BELLAIRE WEST SITE
MODEL LOWER AQUIFER

PLATE D-3



COMPUTED AND MEASURED SUBSIDENCE
BELLAIRE WEST SITE

PLATE D-4

E: CROSBY SITE

E.1 Introduction

The Crosby site covers two ninths in the central part of the Crosby Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate E-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

E.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 200 to 300 ft
	Lower: 700 to 1,500 ft
Bottom of Compacting Interval:	1,500 ft
Bottom of Chicot Aquifer:	About 450 to 550 ft
Bottom of Evangeline Aquifer:	About 1,800 to 2,300 ft

E.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

E.3.1 Wells. In addition to the two wells referenced in the previous recalibration study, we have added two additional wells not previously used for calibration:

- LJ-65-07-907 (model lower aquifer); and
- LJ-65-08-708 (model lower aquifer).

Locations of all wells are included in the detailed Crosby PRESS site map presented on Plate E-1. We assumed a ground surface elevation of 46 ft when vertically translating all well data for this site.

Consistent with the previous study, data from one well and published maps up to the year 1995 are presented on Plate E-2 for the upper model aquifer. No data from after 1995 were available for well LJ-65-08-809, and published maps were not reviewed as part of this study. No additional wells were identified in the area that could be used for the model upper aquifer. The remaining three wells used for the Crosby site are screened in or nearer the model lower aquifer and are presented on Plate E-3.

E.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Crosby site. The outputs are referred to as "Crosby 1" and "Crosby 2" in the information provided by LBG-Guyton. "Crosby 1" is from a location of latitude 29°56'25.6"N and longitude 95°3'33.8"W. "Crosby 2" is from a location of latitude 29°53'58.4" and longitude 95°4'3.6". We assumed a ground surface elevation of 46 feet when vertically translating this output.

E.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997).

There were no well observations available after 1995 for well LJ-65-08-809, used primarily to develop the design hydrograph in the previous recalibration effort. To extend the upper model aquifer hydrograph to 2010, we generally followed trends present in the groundwater model output.

To extend the design hydrograph for the lower model aquifer to 2010, we selected a general visual average of the hydrograph data available. This average also generally follows the trend present in the groundwater model output.

The old and new portions of the upper and lower model aquifer design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

E.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

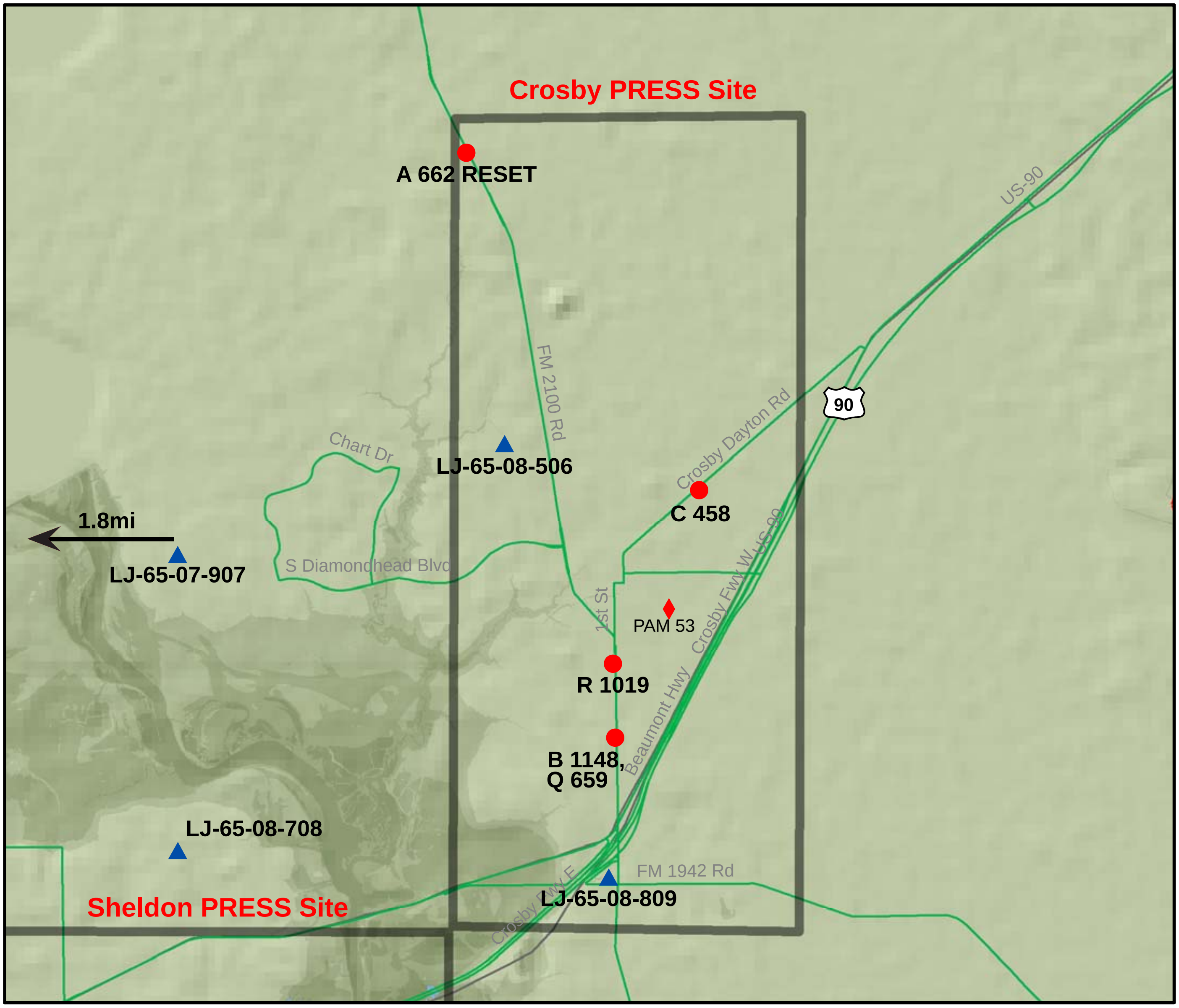
E.4.1 Benchmarks. Consistent with the previous recalibration study, data from five benchmarks will be used in the current study:

- Q 659;
- R 1019;
- B 1148;
- A 662 RESET; and
- C 458.

Locations of the benchmarks are shown on Plate E-1 and subsidence data are presented on Plate E-4.

E.4.2 PAM Station. Data from PAM station 53, also presented on Plate E-4, will be used for recalibration efforts in future phases of this study. The location of PAM 53 is presented on Plate E-1. Data from PAM 53 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on review of other subsidence data sources available, we applied a vertical offset of 4.0 ft to the PAM data.

E.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate E-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

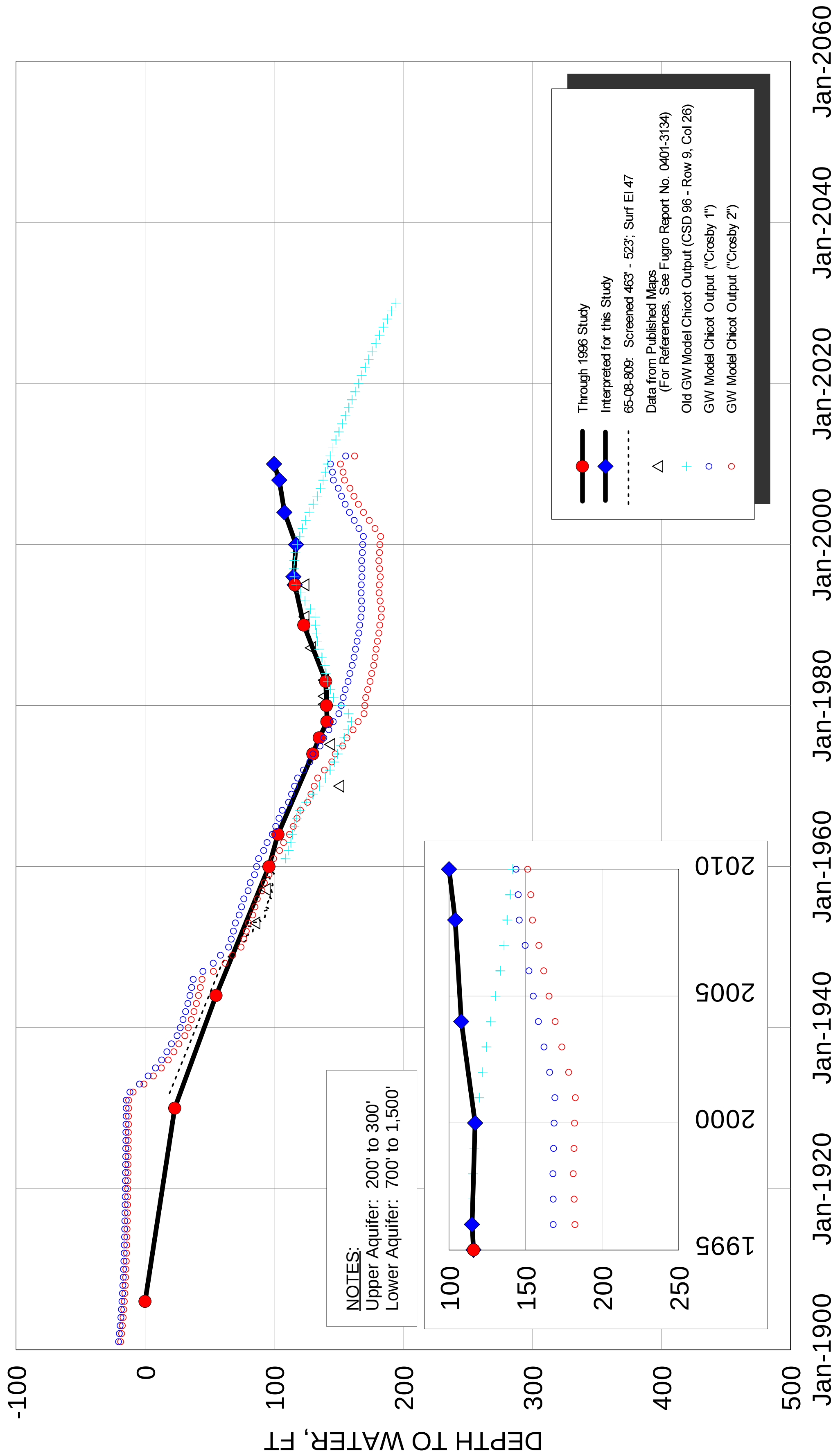
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▭ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 6,000 12,000 Feet

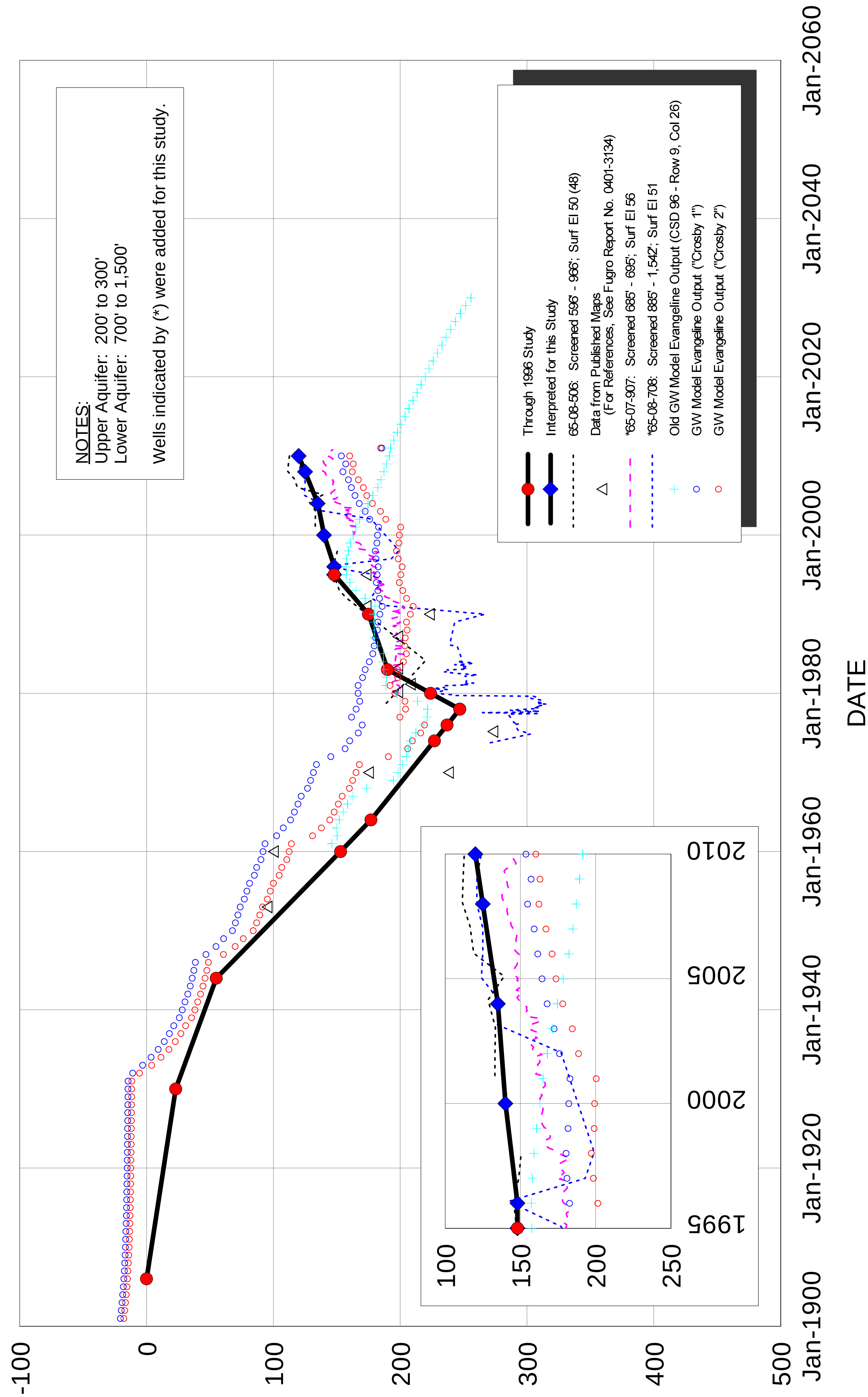
SITE MAP
CROSBY PRESS SITE

PLATE E-1



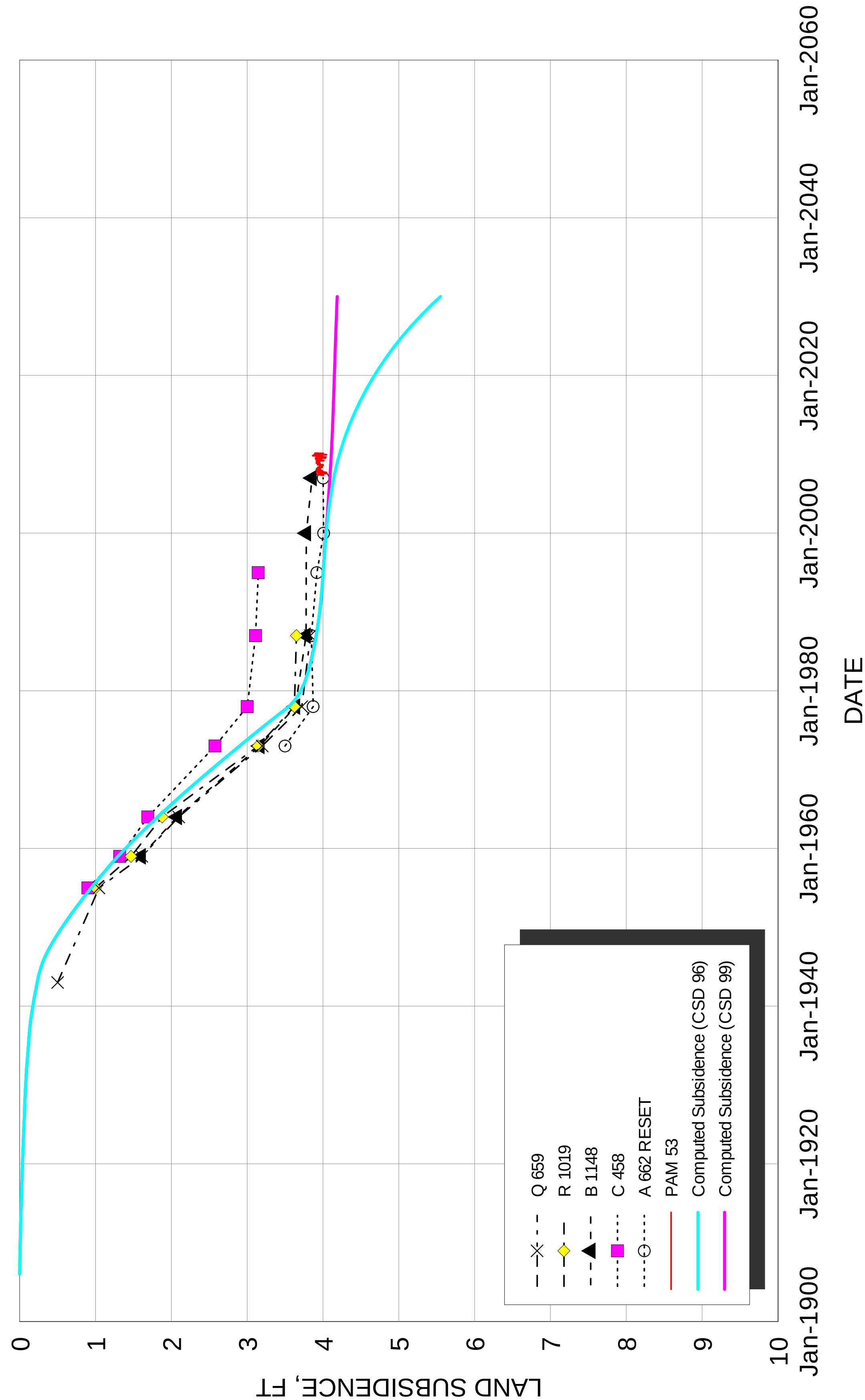
HYDROGRAPHS FOR CROSBY SITE
MODEL UPPER AQUIFER

PLATE E-2



HYDROGRAPHS FOR CROSBY SITE
MODEL LOWER AQUIFER

PLATE E-3



COMPUTED AND MEASURED SUBSIDENCE
CROSBY SITE

PLATE E-4

F: CYPRESS CREEK SITE

F.1 Introduction

The Cypress Creek site covers two ninths in the Spring Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate F-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

F.2 Aquifer

The Cypress Creek site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	660 to 1,300 ft
Bottom of Compacting Interval:	1,300 ft
Bottom of Chicot Aquifer:	About 400 to 500 ft
Bottom of Evangeline Aquifer:	About 1,000 to 1,500 ft

F.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

F.3.1 Wells. We selected 12 wells to use in this study for the Cypress Creek PRESS site. Locations of the wells are included in the detailed Cypress Creek PRESS site map presented on Plate F-1. The eight wells used in the recalibration study (Fugro 1997) are included in this study. In addition, we added four wells for this study, as identified on Plate F-2:

- Ponderosa Forest U.D. Well 3;
- North Forest M.U.D. Well 1;
- Timber Lane U.D. Well 2; and
- Harris County WCID Well 2.

Data for the four wells added for this study are from a private source and were provided by LBG-Guyton. We assumed a ground surface elevation of 105 ft when vertically translating all well data for this site.

Ten of the 12 wells presented on Plate F-2 are screened within the boundaries of the model aquifer depths. A review of data from the two wells not screened within the model aquifer boundaries, LJ-60-61-905 and Timber Lane U.D. Well 2, shows good agreement with other well data.

F.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Cypress Creek site. The outputs are referred to as “Cypress Creek 1” and “Cypress Creek 2” in the information provided by LBG-Guyton. “Cypress Creek 1” is from a location of latitude 30°0’55.8”N and longitude 95°25’41.7”W. “Cypress Creek 2” is from a location of latitude 30°1’6.75” and longitude 95°23’26.8”. We assumed a ground surface elevation of 105 feet when vertically translating this output.

F.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1997). To extend this hydrograph to 2010, we continued the trend established in the recalibration effort by generally following well LJ-60-61-914. This trend is in general agreement with other well data collected for the site as well as the groundwater model output. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

F.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

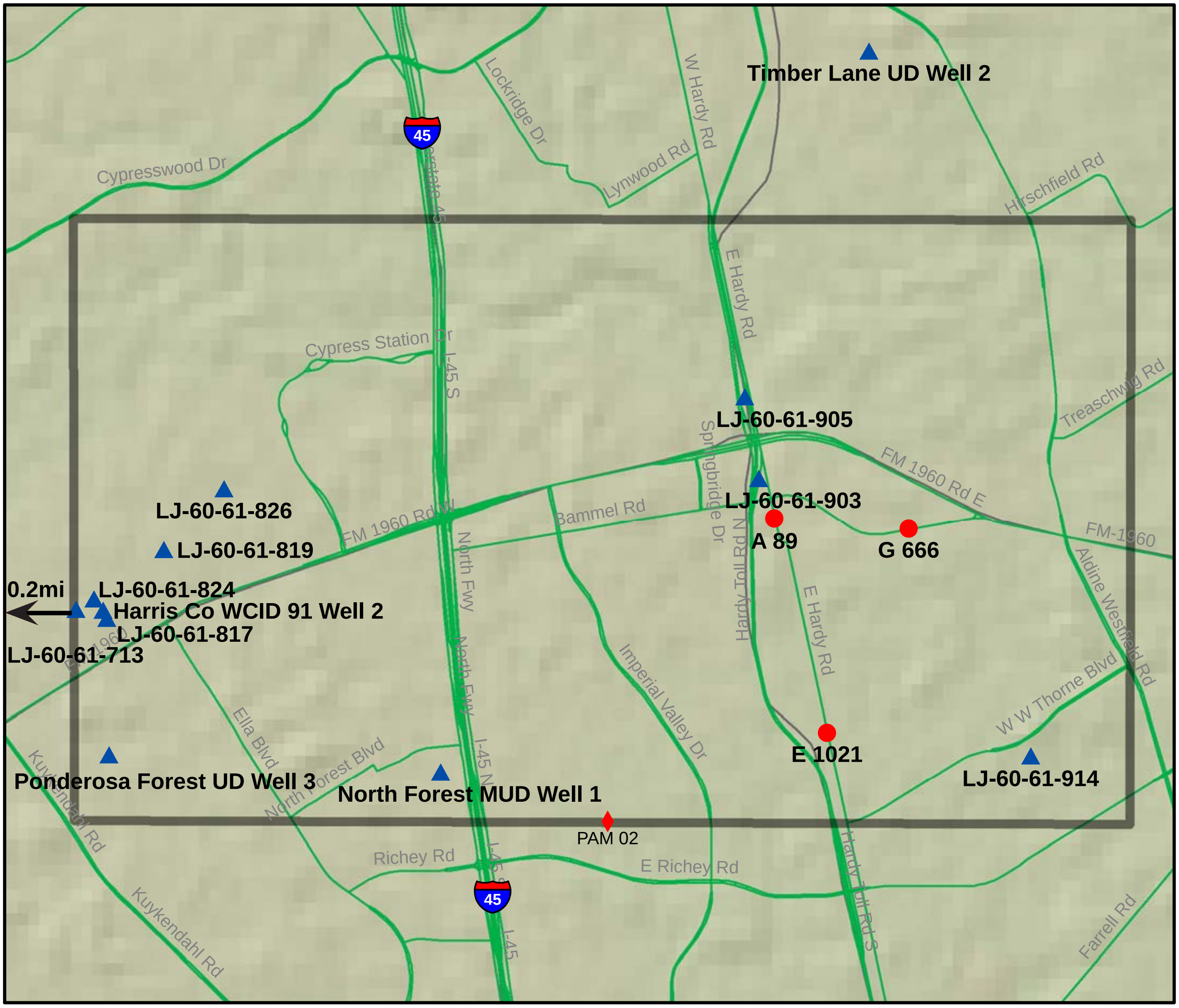
F.4.1 Benchmarks. Data from four benchmarks will be used in the current study:

- A 89;
- E 1021;
- G 666; and
- PAM 02 ARP.

Locations of the benchmarks are shown on Plate F-1 and subsidence data are presented on Plate F-3. Three benchmarks were used in the previous recalibration study (Fugro 1997). Benchmark PAM 02 ARP was added for this study and, with an applied vertical offset of 2.4 ft, agrees well with other subsidence data.

F.4.2 PAM Station. Data from PAM station 02, also presented on Plate F-4, will also be used for recalibration efforts in this study. The location of PAM 02 is presented on Plate F-1. PAM 02 was installed fairly early in comparison to most other PAM stations in Harris, Galveston and Fort Bend counties – PAM 02 data extend back to 1996. Based on review of other subsidence data sources available, we applied a vertical offset of 2.4 ft to the PAM data.

F.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate F-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

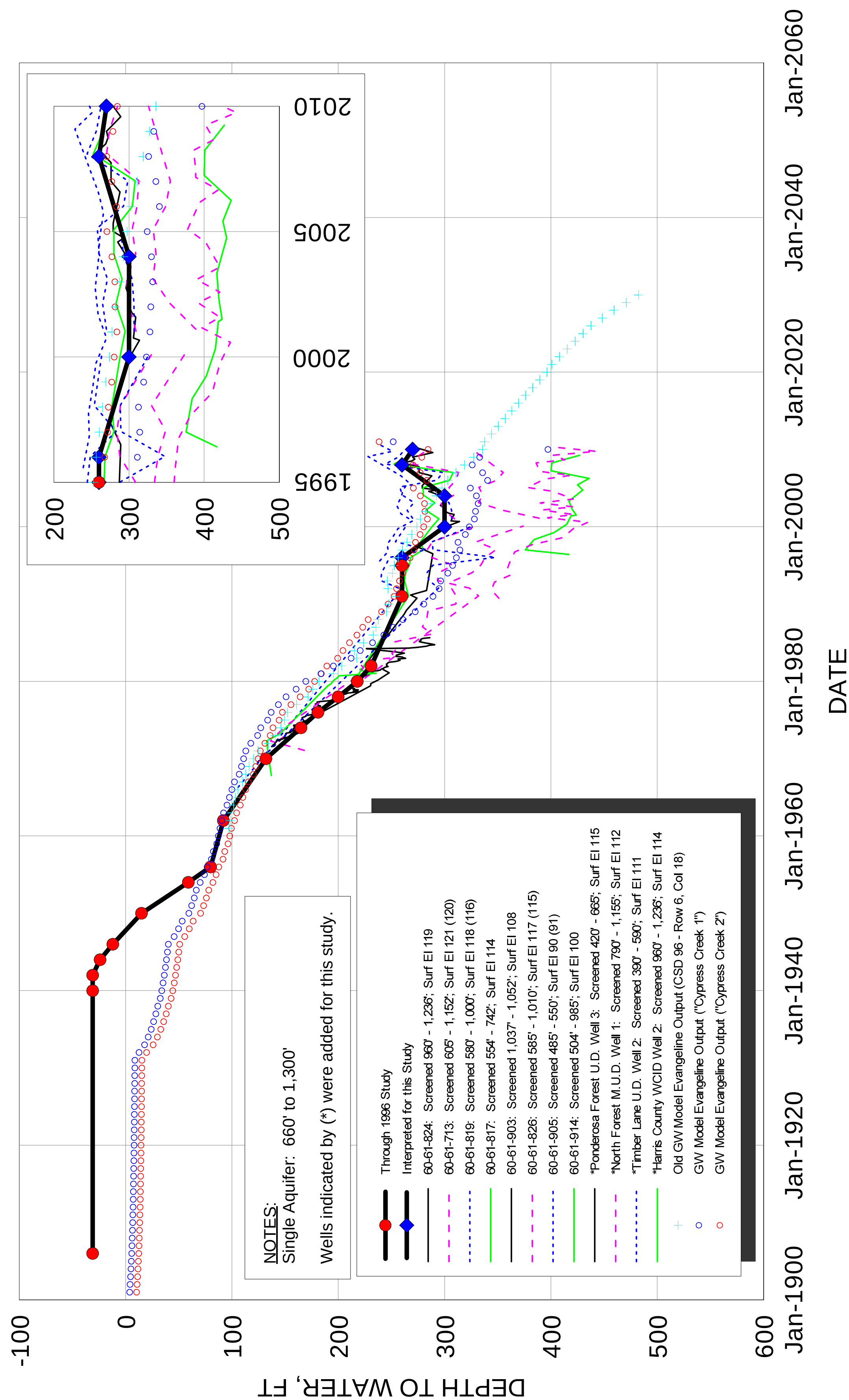
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▭ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

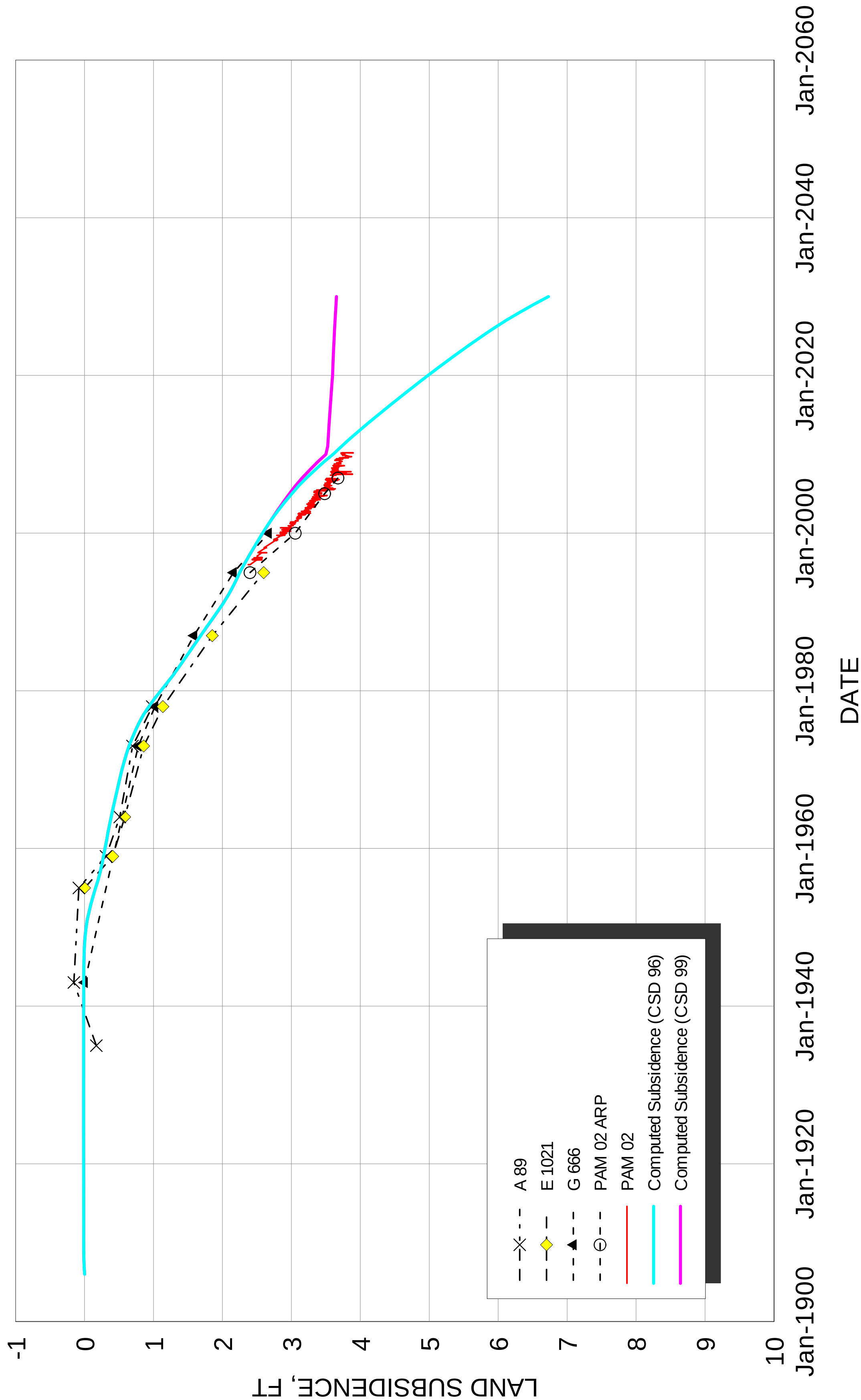
SITE MAP
CYPRESS CREEK PRESS SITE

PLATE F-1



HYDROGRAPHS FOR CYPRESS CREEK SITE
SINGLE MODEL AQUIFER

PLATE F-2



COMPUTED AND MEASURED SUBSIDENCE
CYPRESS CREEK SITE

PLATE F-3

G: DOWNTOWN SITE

G.1 Introduction

The Downtown site covers one ninth in the southeast corner of the Houston Heights Topographic Quadrangle and one ninth in the southwest corner of the Settegast Quadrangle, as shown in general on Plate 1 and in greater detail on Plate G-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

G.2 Aquifer

The Downtown site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	875 to 1,600 ft
Bottom of Compacting Interval:	2,150 ft
Bottom of Chicot Aquifer:	About 600 to 700 ft
Bottom of Evangeline Aquifer:	About 1,700 to 2,200 ft

G.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

G.3.1 Wells. We selected nine wells to use in this study for the Downtown PRESS site. Locations of the wells are included in the detailed Downtown PRESS site map presented on Plate G-1. The eight wells used in the recalibration study (Fugro 1997) are included in this study. The one well added for this study, LJ-65-14-746, is identified on Plate G-2. We assumed a ground surface elevation of 48 ft when vertically translating all well data for this site.

Eight of the nine wells presented on Plate G-2 are screened within the boundaries of the model aquifer depths. The well added for this study, LJ-65-14-746, is screened just below the model aquifer depths. However, a review of data from this well shows good agreement with other well data.

G.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Downtown site. The outputs are referred to as “Downtown 1” and “Downtown 2” in the information provided by LBG-Guyton. “Downtown 1” is from a location of latitude 29°46’39.1”N and longitude 95°21’23.3”W. “Downtown 2” is from a location of latitude 29°46’18.1” and longitude 95°23’34.0”. We assumed a ground surface elevation of 48 feet when vertically translating this output.

G.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1997). To extend this hydrograph to 2010, we continued the trend established in the recalibration effort by generally following wells LJ-65-13-904 and LJ-65-14 and LJ-65-14-735. This trend is in general agreement with other well data collected for the site as well as the groundwater model output. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

G.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

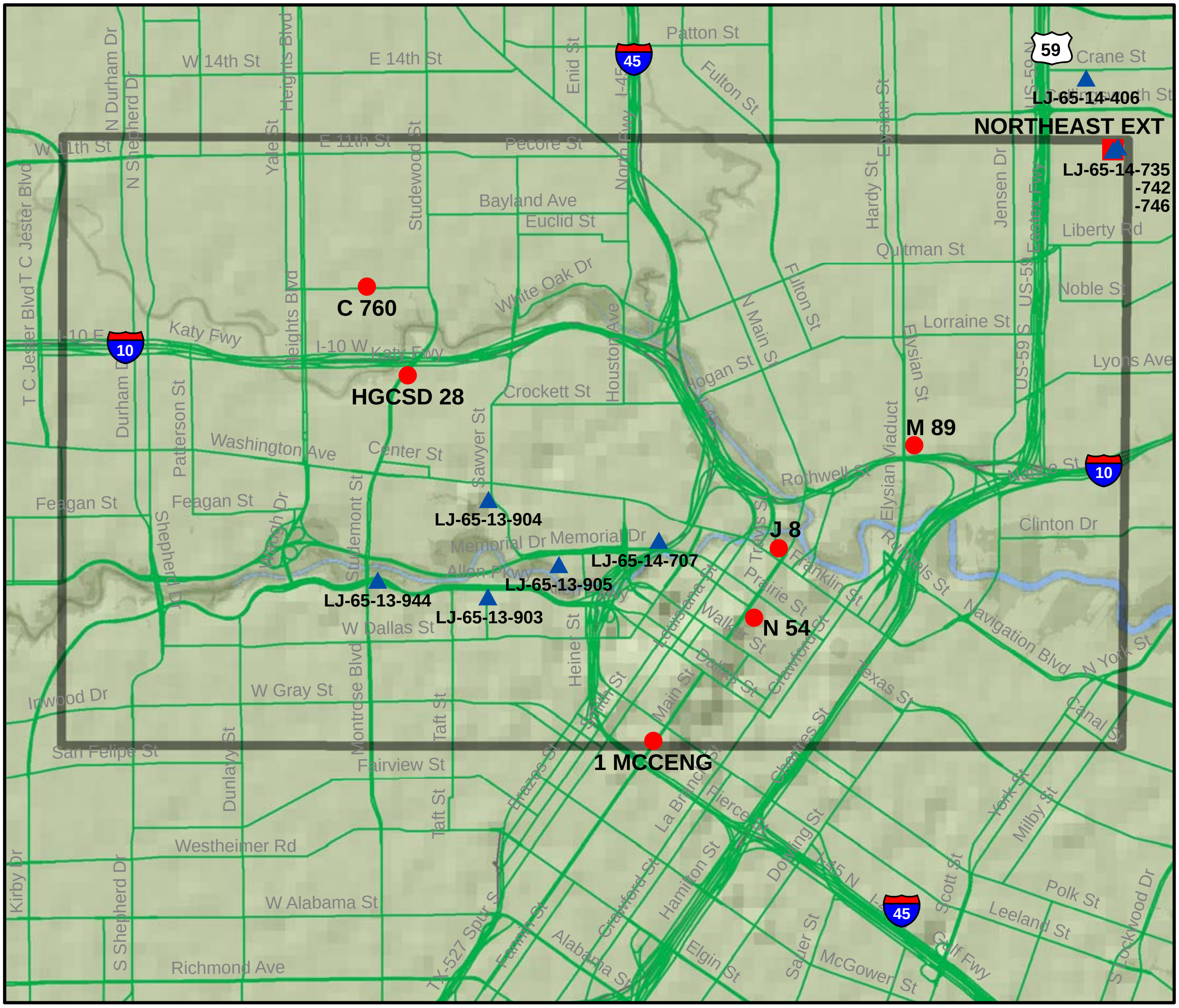
G.4.1 Benchmarks. Consistent with the previous recalibration study, data from six benchmarks will be used in the current study:

- C 760;
- 1 MCCENG;
- N 54;
- J 8;
- M 89; and
- HGCSD 28.

Locations of the benchmarks are shown on Plate G-1 and subsidence data are presented on Plate G-3.

G.4.2 Extensometer. Data from one extensometer, LJ-65-14-746 or “Northeast”, will be used for comparison to the PRESS model output. The location of the “Northeast” extensometer is shown on Plate G-1, and data from the extensometer are presented on Plate G-3.

G.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate G-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

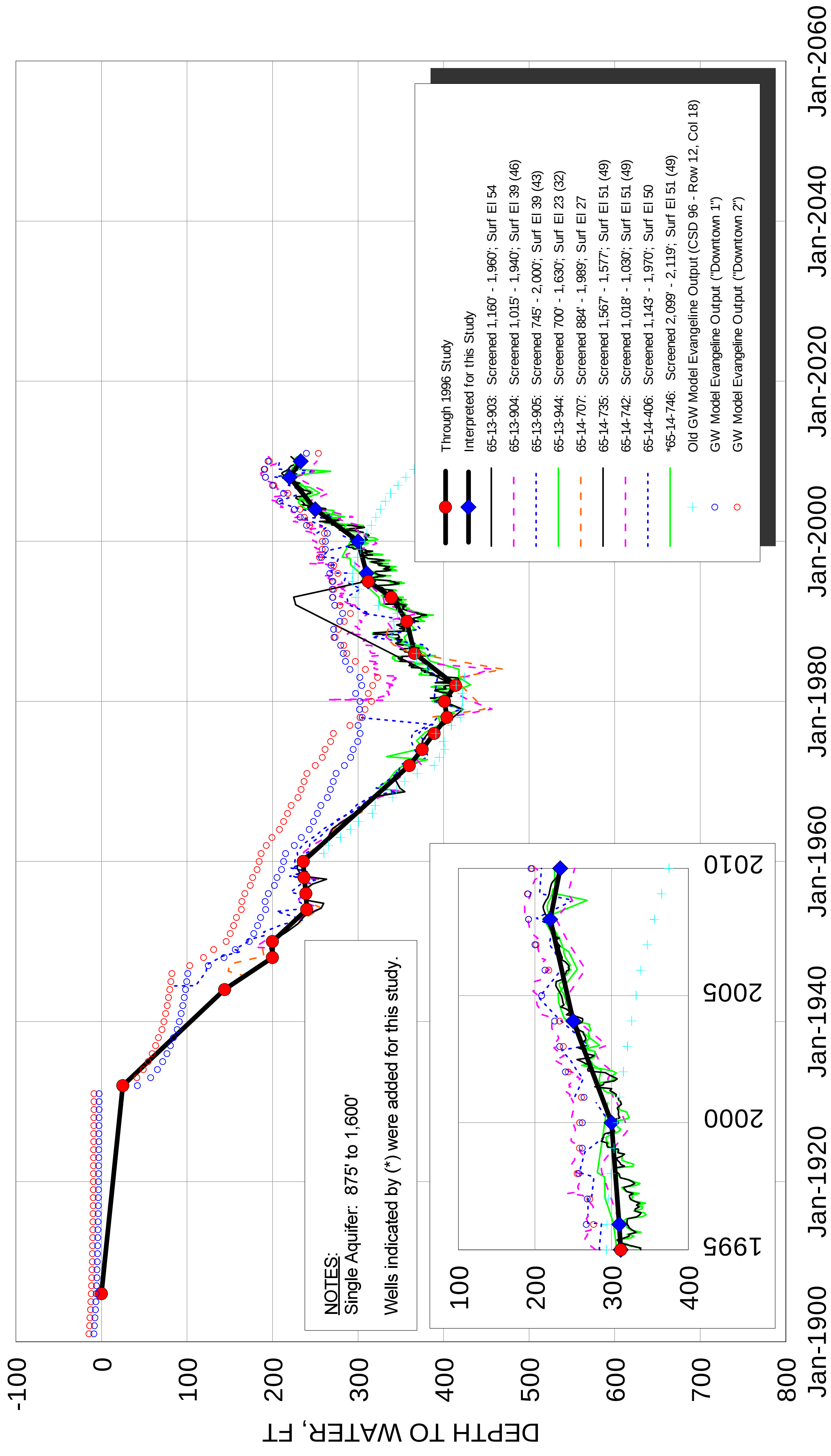
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▭ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

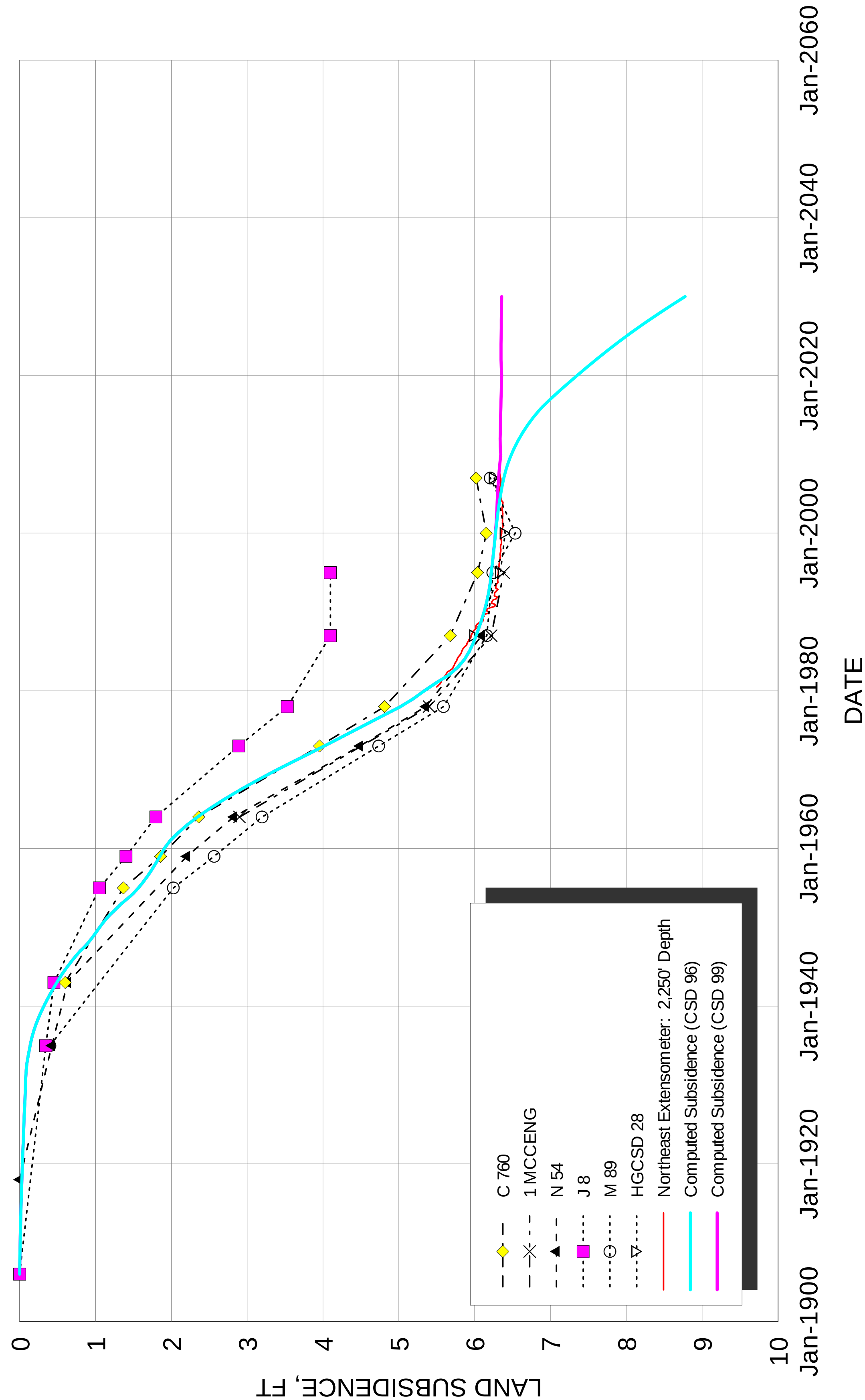
SITE MAP
DOWNTOWN PRESS SITE

PLATE G-1



HYDROGRAPHS FOR DOWNTOWN SITE
SINGLE MODEL AQUIFER

PLATE G-2



COMPUTED AND MEASURED SUBSIDENCE
DOWNTOWN SITE

PLATE G-3

H: EAGLE POINT SITE

H.1 Introduction

The Eagle Point site covers one ninth in the Texas City Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate H-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

H.2 Aquifer

The Eagle Point site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	570 to 660 ft
Bottom of Compacting Interval:	2,125 ft
Bottom of Chicot Aquifer:	About 800 to 900 ft
Bottom of Evangeline Aquifer:	About 4,500 to 5,000 ft

H.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

H.3.1 Wells. We selected 11 wells to use in this study for the Eagle Point PRESS site. Locations of the wells are included in the detailed Eagle Point PRESS site map presented on Plate H-1. The eight wells and published map data used in the recalibration study (Fugro 1997) are included in this study. The three wells added for this study are identified on Plate H-2. We assumed a ground surface elevation of 12 ft when vertically translating all well data for this site.

Ten of the 11 wells presented on Plate H-2 are screened within the boundaries of the model aquifer depths. Well LJ-64-33-303 was completed approximately 275 ft above the upper boundary of the model aquifer. Wells LJ-64-33-203, -207, -208 and -301 were discontinued as monitoring wells even before the previous recalibration study (Fugro 1997). All of these wells are included in Plate H-2 for reference to previous studies.

H.3.2 Groundwater Model Output. We were only provided one set of groundwater model output for the Eagle Point site. The output, referred to as “Eagle Point 1” in the information provided by LBG-Guyton, is from a location of latitude 29°29’4.3”N and longitude 94°56’9.7”W. We assumed a ground surface elevation of 12 feet when processing and plotting this output.

H.3.3 Design Hydrograph. We used the site hydrograph presented in the previous recalibration effort (Fugro 1997) for years through 1995. The site hydrograph developed in the previous recalibration effort was developed primarily based on data from published maps and groundwater model output. We did not reference published map data for this study, and the updated groundwater model output described in *Section H.3.2* differs significantly from that used in the previous study. As a result, we chose a general visual average of the well data available to extend the design hydrograph to 2010. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

H.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

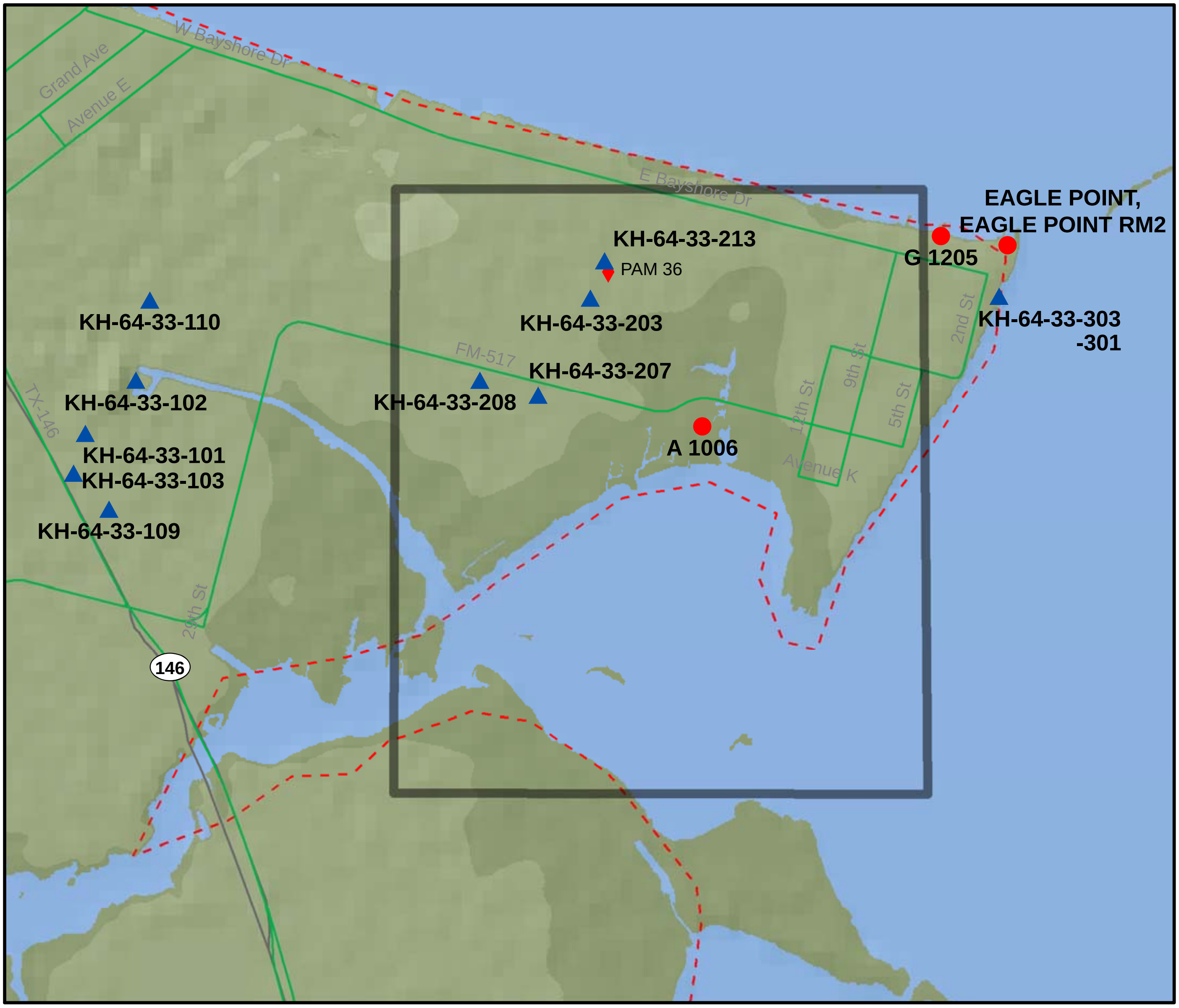
H.4.1 Benchmarks. Consistent with the previous recalibration study, data from four benchmarks will be used in the current study:

- EAGLE POINT;
- EAGLE POINT RM2;
- A 1006; and
- G 1205.

Locations of the benchmarks are shown on Plate H-1 and subsidence data are presented on Plate H-3.

H.4.2 PAM Station. Data from PAM station 36, also presented on Plate H-3, will be used for recalibration efforts in this study. The location of PAM 36 is presented on Plate H-1. Data from PAM 36 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on review of other subsidence data sources available, we applied a vertical offset of 2.2 ft to the PAM data.

H.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate H-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

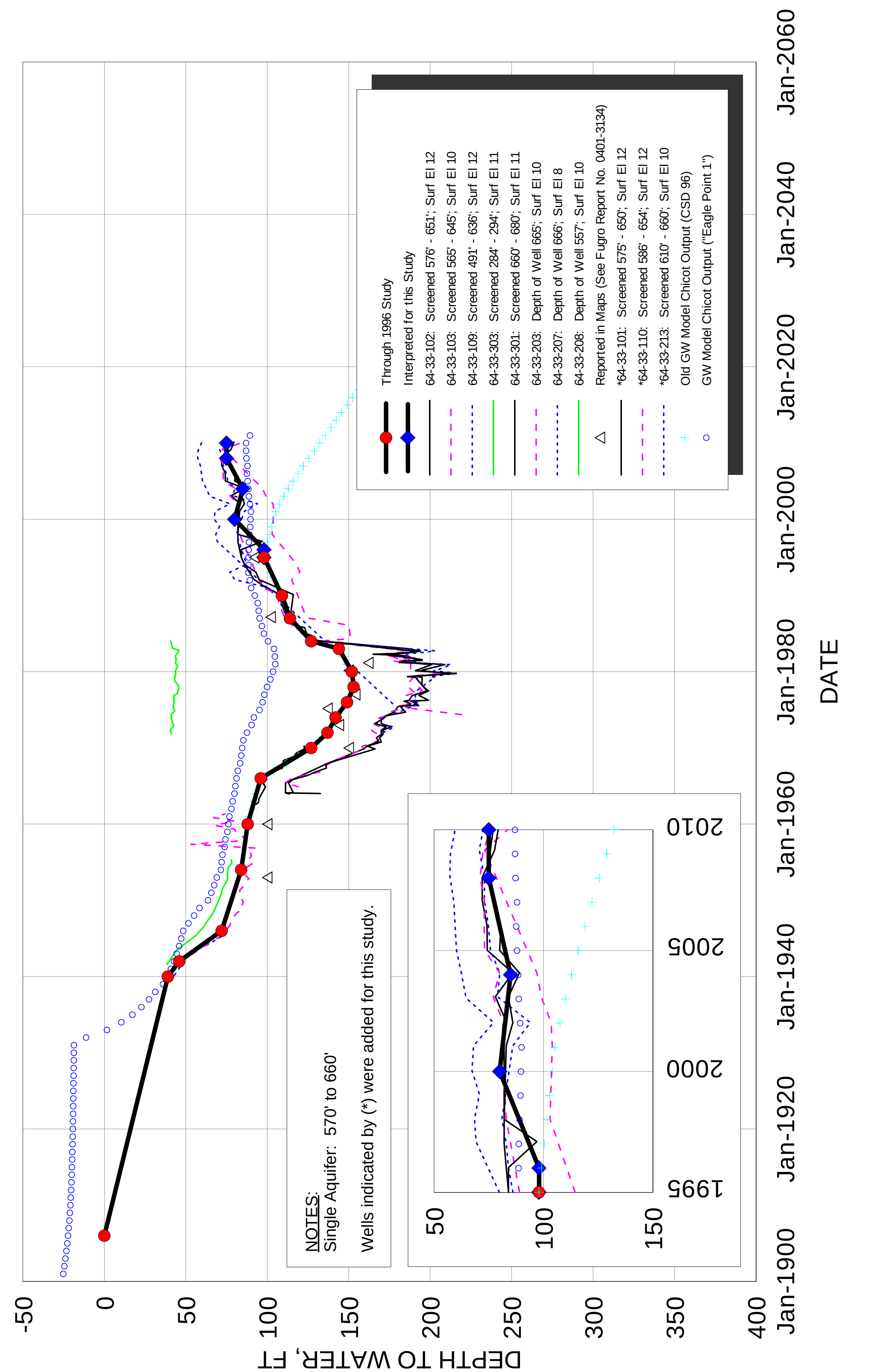
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

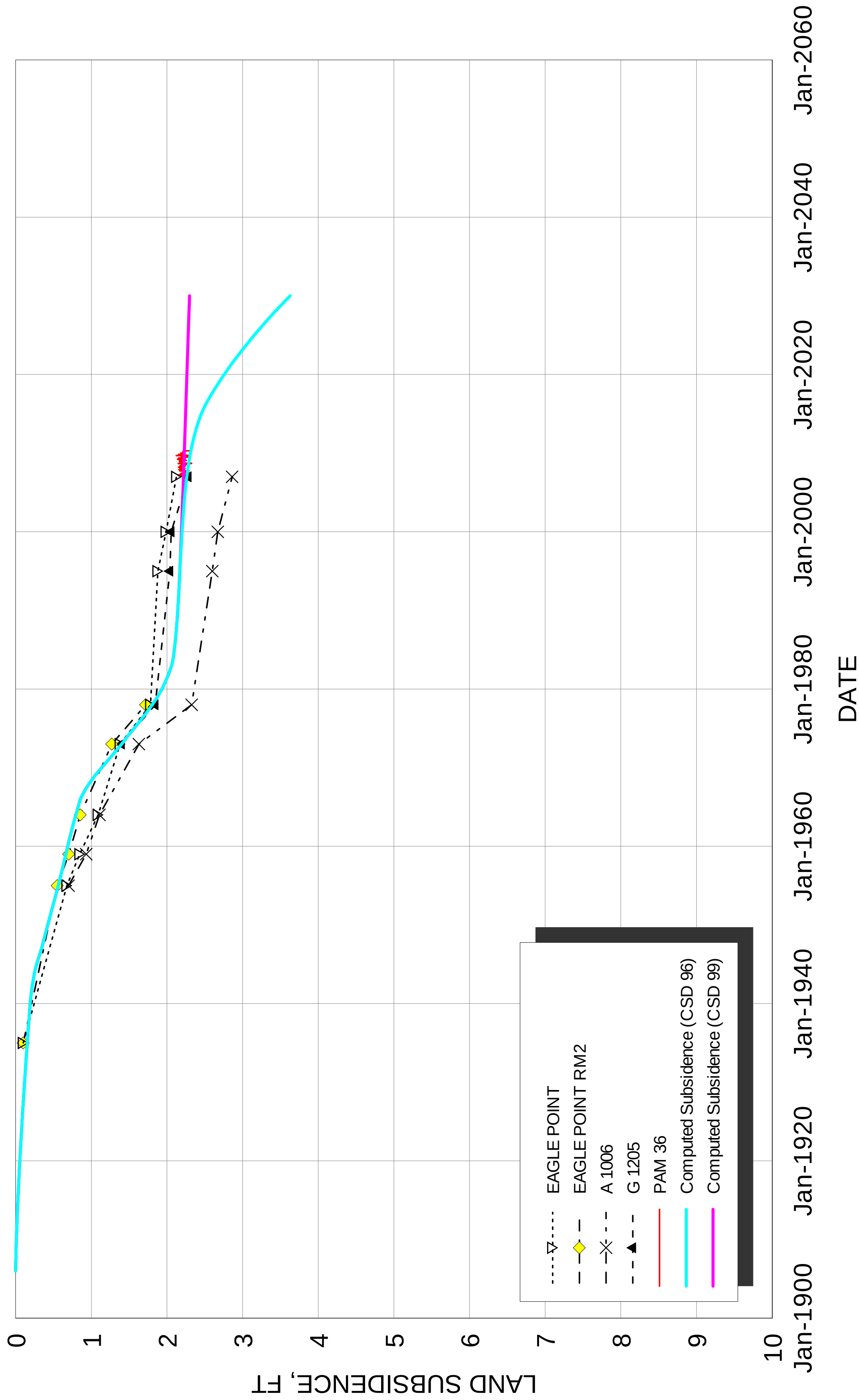
SITE MAP
EAGLE POINT PRESS SITE

PLATE H-1



HYDROGRAPHS FOR EAGLE POINT SITE
SINGLE MODEL AQUIFER

PLATE H-2



COMPUTED AND MEASURED SUBSIDENCE
EAGLE POINT SITE

PLATE H-3

I: FM 1960 SITE

I.1 Introduction

The FM 1960 site covers two ninths of the Satsuma Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate I-1. The site boundaries are consistent with the previous recalibration study (Fugro 1997).

I.2 Aquifer

The FM 1960 site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	540 to 1,400 ft
Bottom of Compacting Interval:	1,326 ft
Bottom of Chicot Aquifer:	About 500 to 600 ft
Bottom of Evangeline Aquifer:	About 1,000 to 1,500 ft

I.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

I.3.1 Wells. We selected 20 wells to use in this study for the FM 1960 PRESS site. Locations of the wells are included in the detailed FM 1960 PRESS site map presented on Plate I-1. The eight wells used in the recalibration study (Fugro 1997) are included in this study, and 12 new wells have been added. These 12 wells are identified on Plate I-2. Seven of the 12 new wells were obtained from the USGS NWIS, while the other five are from private sources and were provided by LBG-Guyton. We assumed a ground surface elevation of 95 ft when vertically translating all well data for this site.

Of the 20 wells presented on Plate I-2, 19 are screened within the boundaries of the model aquifer depths. Well LJ-65-04-507 was completed above the upper boundary of the model aquifer, but was included in the previous recalibration study and is included in Plate I-2 for reference. Six of the eight wells used in the previous recalibration study were discontinued as monitoring wells prior to this study.

I.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the FM 1960 site. The outputs are referred to as “1960 1” and “1960 2” in the information provided by LBG-Guyton. “1960 1” is from a location of latitude 29°56’0.6”N and longitude 95°33’54.8”W. “1960 2” is from a location of latitude 29°56’13.7” and longitude 95°31’40.5”. We assumed a ground surface elevation of 95 feet when vertically translating this output.

I.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1997). To extend the site hydrograph to 2010, we chose a general visual average of the well data collected for this study. The trend seen in this average generally agrees with the groundwater model output provided for the FM 1960 site. Nearly all of the well data collected for this study show a rebound after the year 2000 – the exception is Mills Road M.U.D. Well 1, which generally flattens out after 2000 but does not show a significant rebound. This rebound is reflected in our site hydrograph and is in general agreement with the groundwater model output. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

I.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

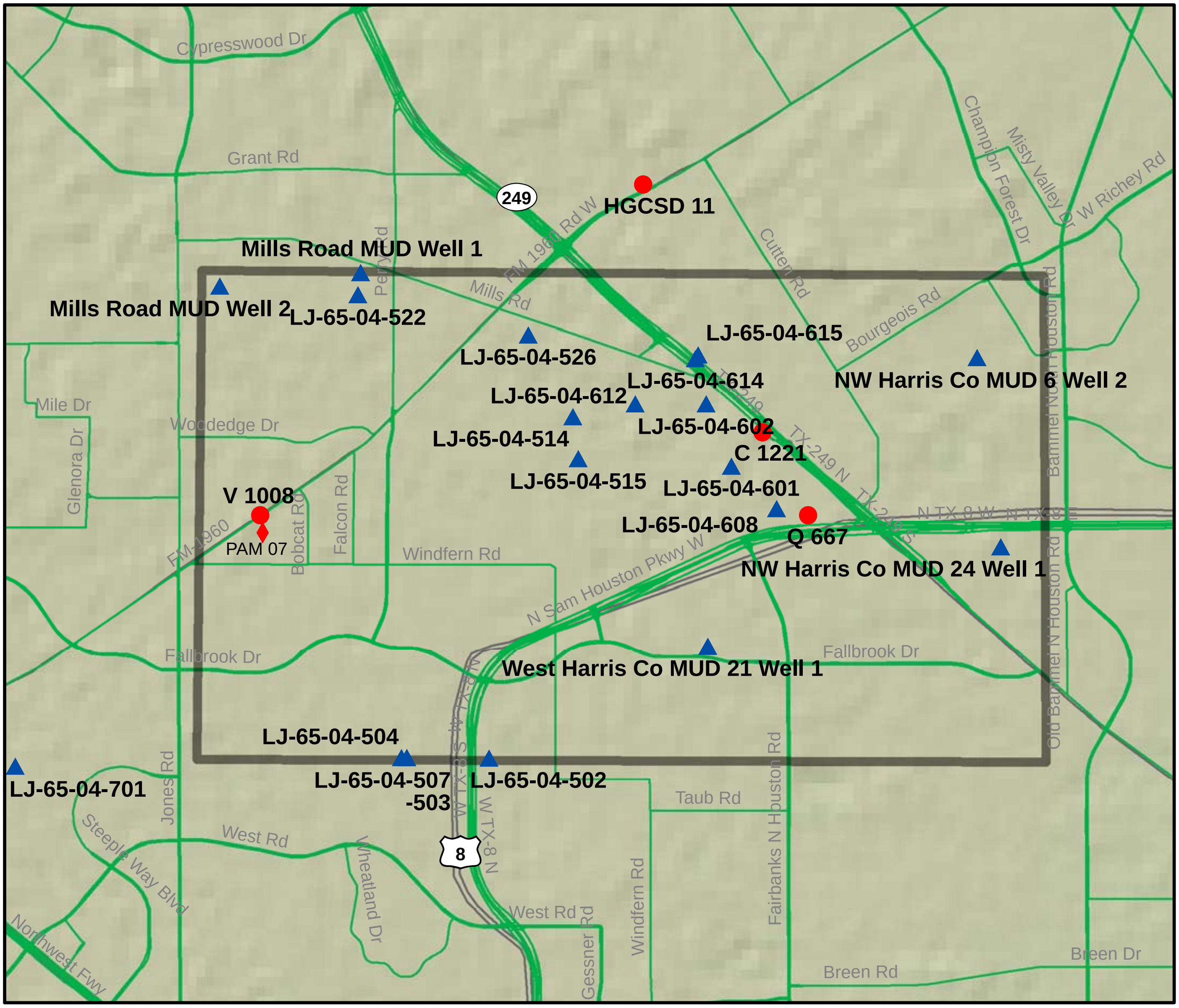
I.4.1 Benchmarks. Data from five benchmarks will be used in the current study:

- V 1008;
- Q 667;
- C 1221;
- HGCSD 11; and
- PAM 07 ARP.

The locations of the benchmarks are shown on Plate I-1 and subsidence data are presented on Plate I-3. Four benchmarks were used in the previous recalibration study (Fugro 1997). Benchmark PAM 07 ARP was added for this study and, based on a review of the other subsidence data available through the year 2000, a vertical offset of 5.3 ft was applied.

I.4.2 PAM Station. Data from PAM station 07, also presented on Plate I-3, will be used for recalibration efforts in this study. The location of PAM 07 is presented on Plate I-1. PAM station 07 was one of the earlier installed PAM sites in Harris County – data are available from the year 1999. After a review of the other available subsidence data, we applied a vertical offset of 5.0 ft to the PAM data.

I.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate I-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

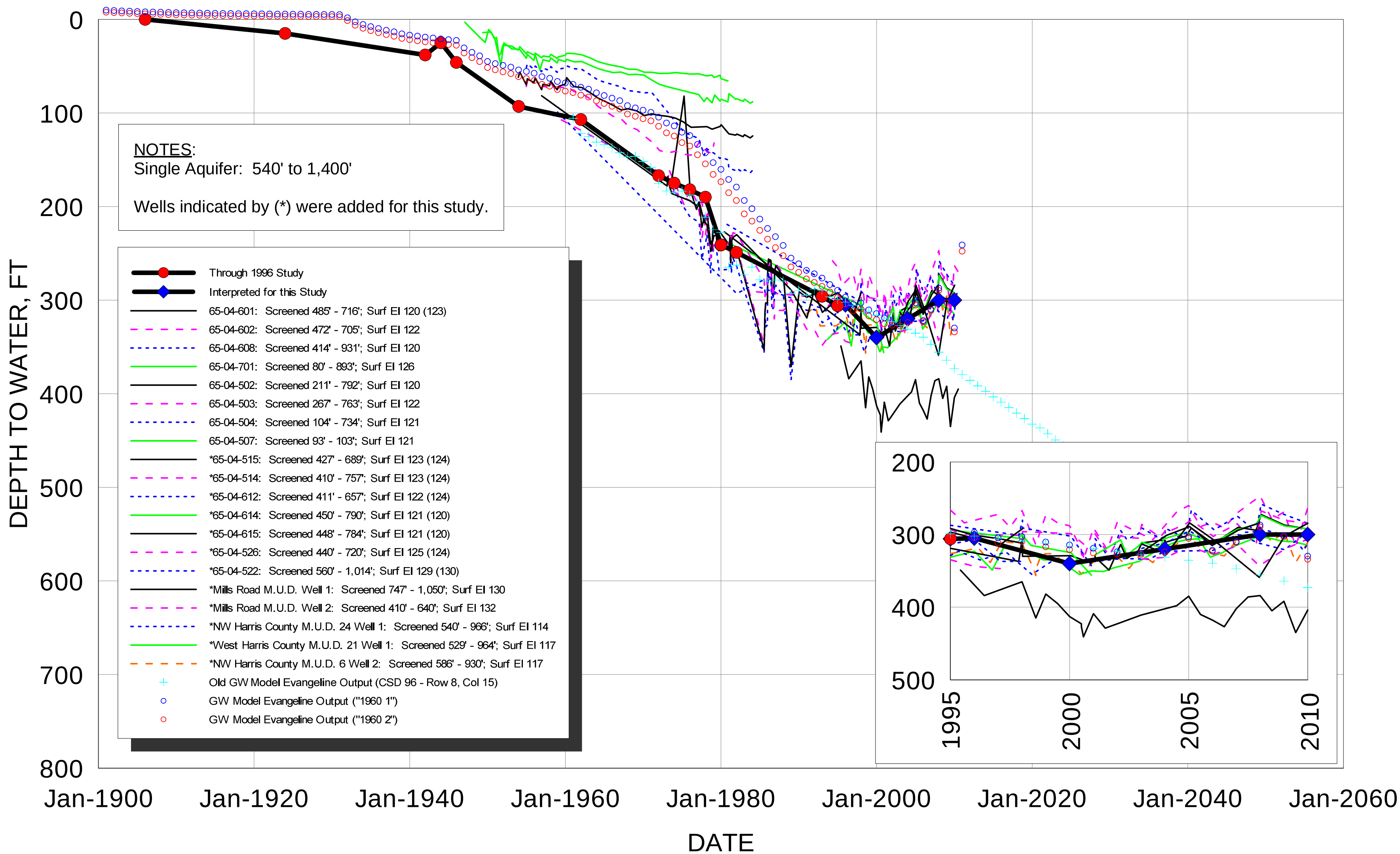
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 5,000 10,000 Feet

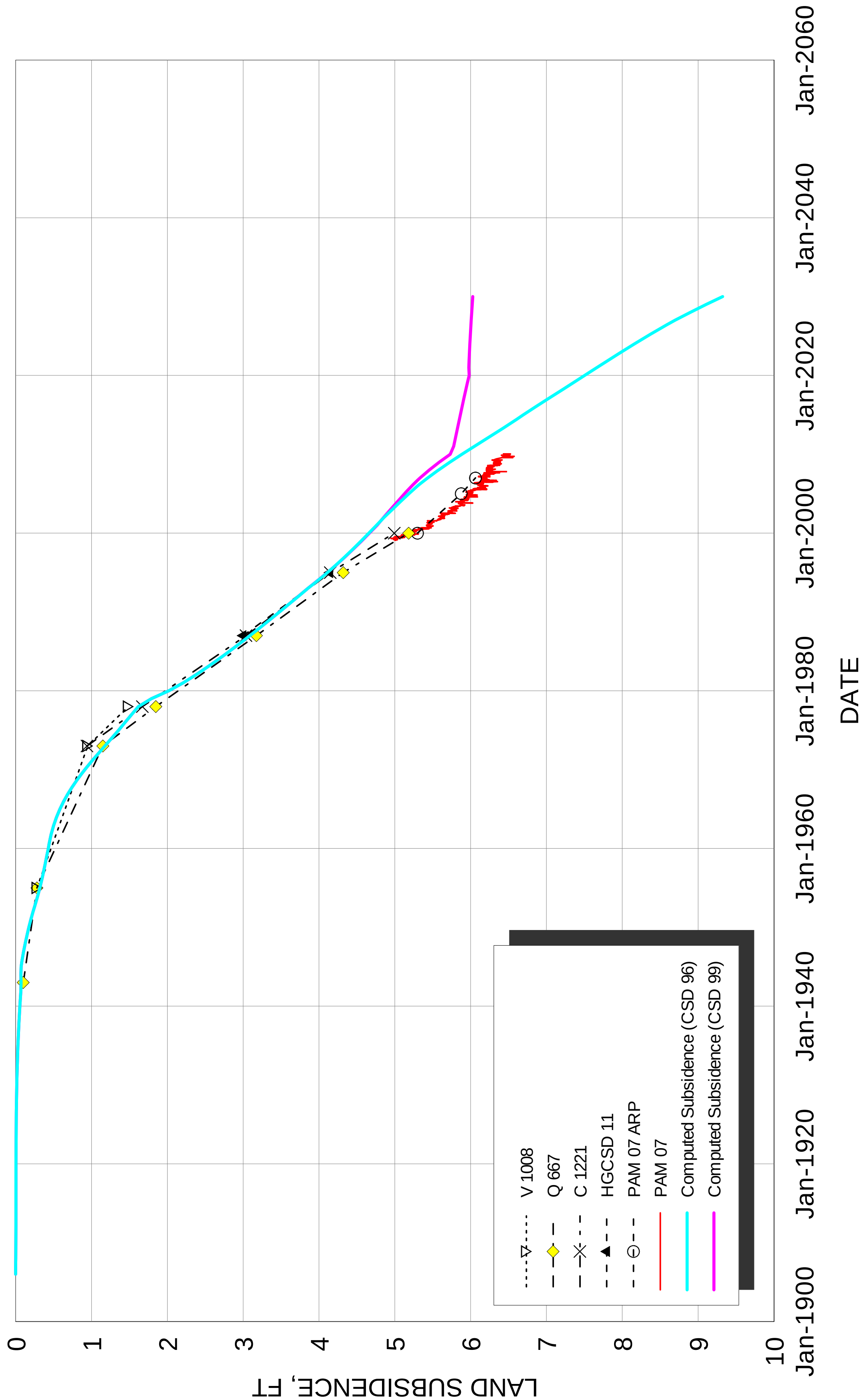
SITE MAP
FM 1960 PRESS SITE

PLATE I-1



HYDROGRAPHS FOR FM 1960 SITE
SINGLE MODEL AQUIFER

PLATE I-2



COMPUTED AND MEASURED SUBSIDENCE
FM 1960 SITE

PLATE I-3

J: GALENA PARK SITE

J.1 Introduction

The Galena Park site covers one ninth of the Pasadena Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate J-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

J.2 Aquifer

The Galena Park site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	600 to 1,300 ft
Bottom of Compacting Interval:	2,354 ft
Bottom of Chicot Aquifer:	About 600 to 700 ft
Bottom of Evangeline Aquifer:	About 2,300 to 2,700 ft

J.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

J.3.1 Wells. Consistent with the previous recalibration study, we selected six wells to use for the Galena Park PRESS site. Locations of the wells are included in the detailed Galena Park PRESS site map presented on Plate J-1. We assumed a ground surface elevation of 33 ft when vertically translating all well data for this site.

All of the six wells presented on Plate J-2 are screened within the boundaries of the model aquifer depths. Well LJ-65-23-102 was discontinued as a monitoring well prior to this study but is included in Plate J-2 for reference.

J.3.2 Groundwater Model Output. We were only provided one set of groundwater model output for the Galena Park site. The output, referred to as “Galena 1” in the information provided by LBG-Guyton, is from a location of latitude 29°43’36.9”N and longitude 95°14’0.4”W. We assumed a ground surface elevation of 33 feet when processing and plotting this output.

J.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1997). To extend the site hydrograph to 2010, we continued the methodology used previously and chose a general visual average of the well data collected for this study. The trend seen in this average generally agrees with the groundwater model output provided for the Galena Park site. Old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

J.4 Subsidence Data

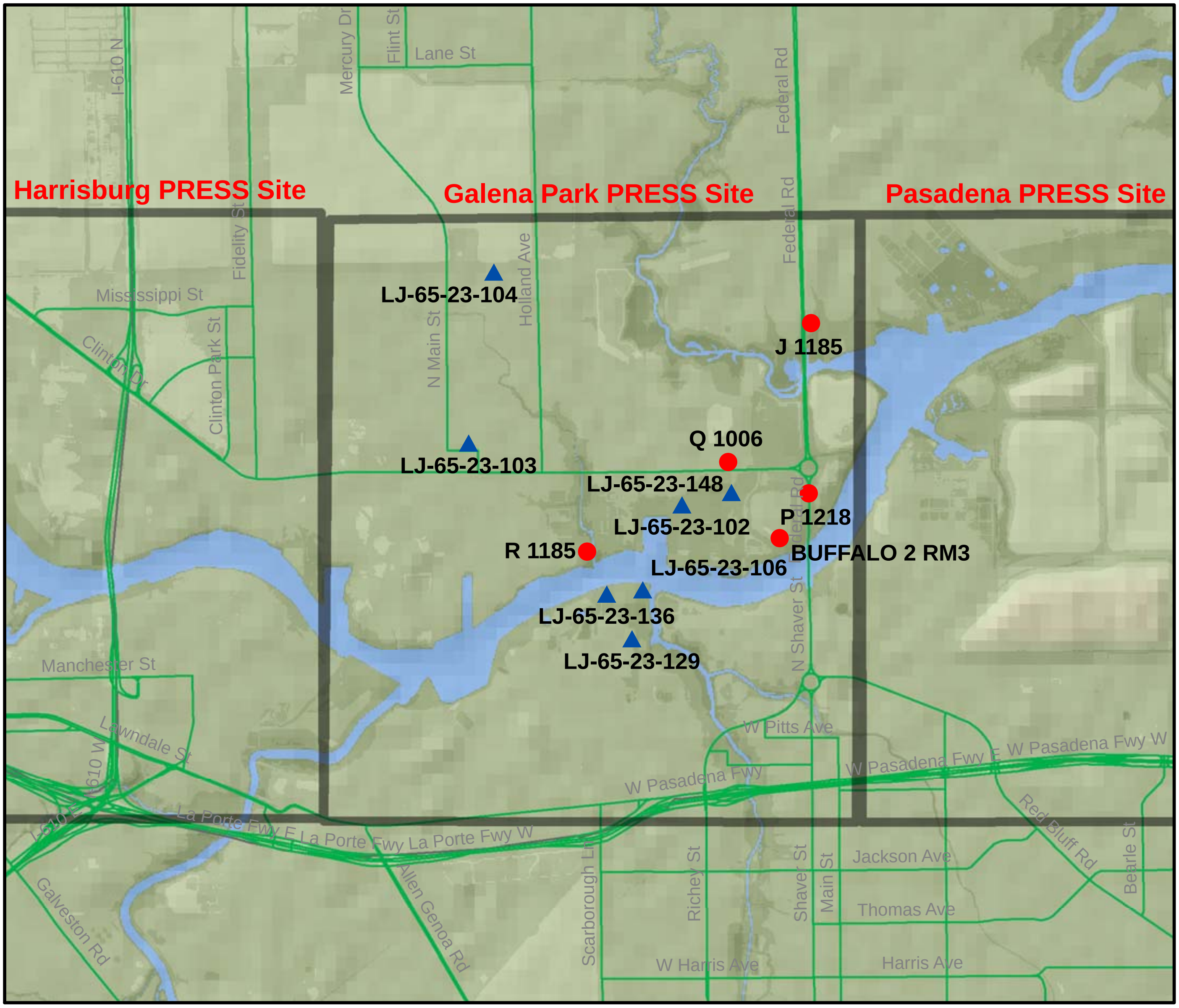
Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

J.4.1 Benchmarks. Consistent with the previous recalibration study, data from five benchmarks will be used in the current study:

- Q 1006;
- BUFFALO 2 RM3;
- J 1185;
- P 1218; and
- R 1185.

The locations of the benchmarks are shown on Plate J-1 and subsidence data are presented on Plate J-3.

J.4.2 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate J-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

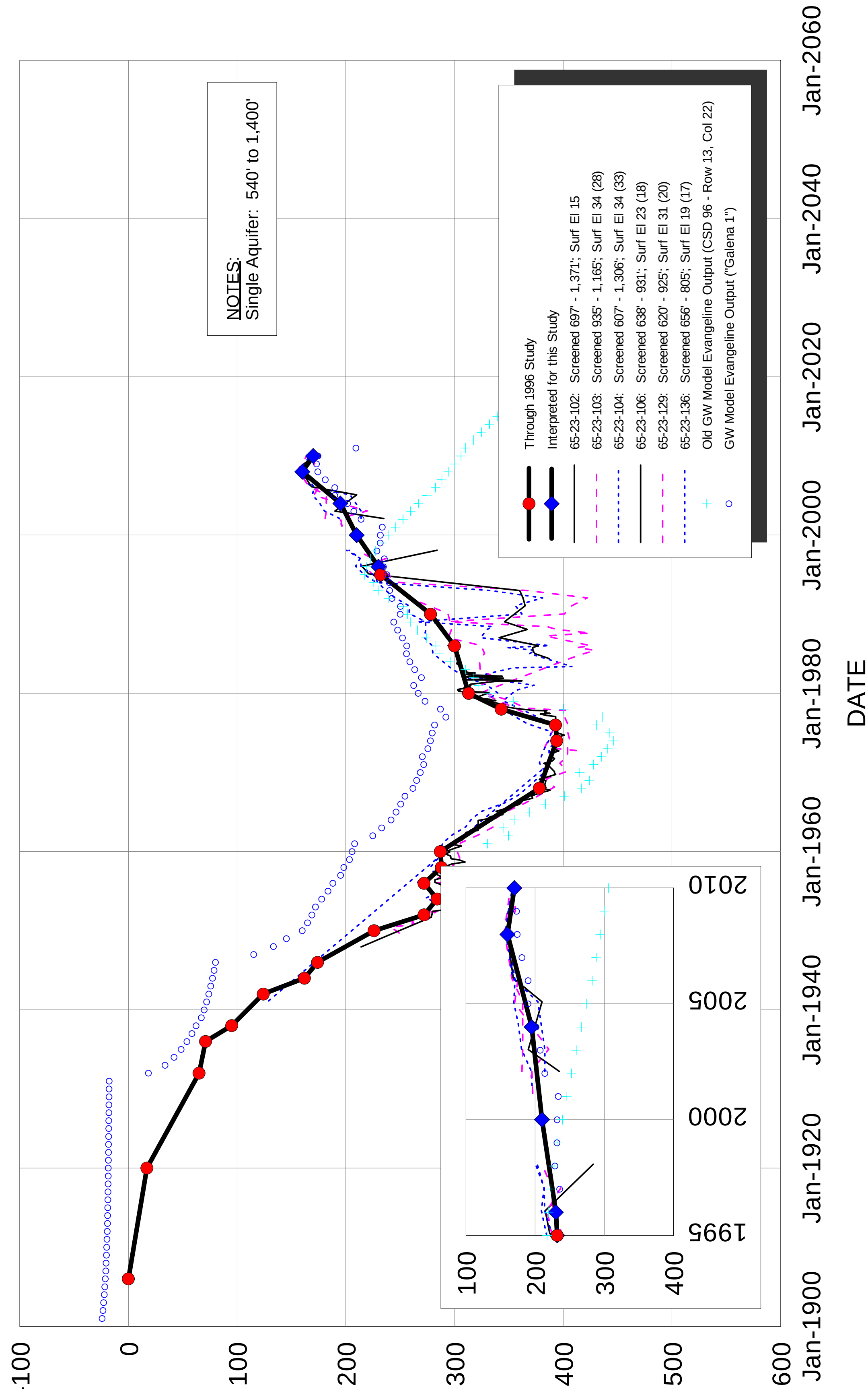
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▢ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

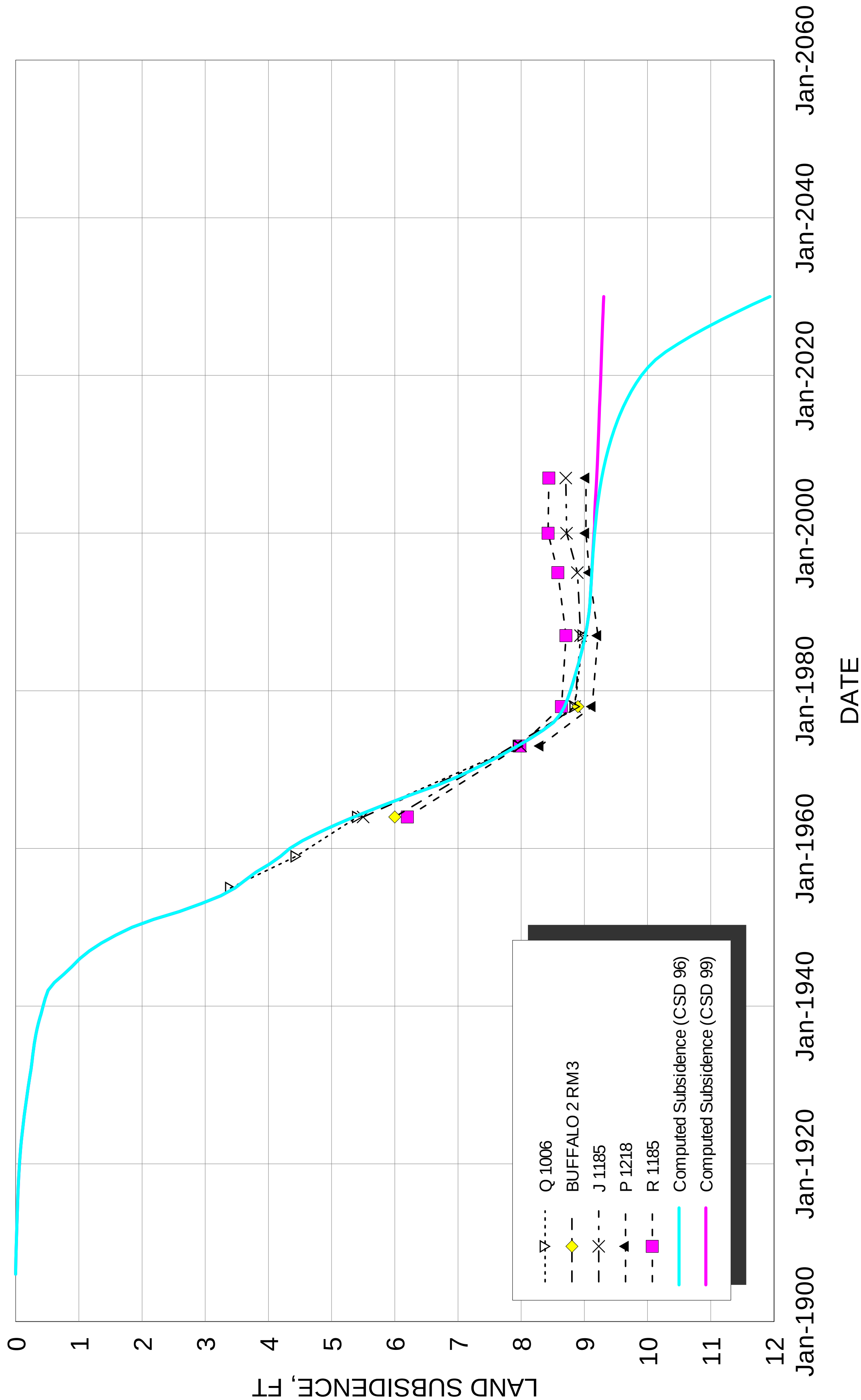
SITE MAP
GALENA PARK PRESS SITE

PLATE J-1



HYDROGRAPHS FOR GALENA PARK SITE
SINGLE MODEL AQUIFER

PLATE J-2



COMPUTED AND MEASURED SUBSIDENCE
GALENA PARK SITE

PLATE J-3

K: GALVESTON COUNTY SITE

K.1 Introduction

The Galveston County site covers two ninths of the Hitchcock Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate K-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

K.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 500 to 950 ft
	Lower: 1,200 to 3,300 ft
Bottom of Compacting Interval:	3,300 ft
Bottom of Chicot Aquifer:	About 800 to 1,000 ft
Bottom of Evangeline Aquifer:	About 4,000 to 4,500 ft

K.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

K.3.1 Wells. In addition to the eight wells referenced in the previous recalibration study, we have added four additional wells not previously used for calibration:

- LJ-65-48-202 (model upper aquifer);
- LJ-65-48-207 (model upper aquifer);
- LJ-65-48-209 (model upper aquifer); and
- LJ-65-48-213 (model upper aquifer).

Locations of all wells are included in the detailed Galveston County PRESS site map presented on Plate K-1. We assumed a ground surface elevation of 20 ft when vertically translating all well data for this site.

All wells used for this study are screened in the model upper aquifer, as shown on Plate K-2. Well LJ-65-48-302 was discontinued as a monitoring well prior to this study but is included on Plate K-2 for reference. As was the case with the previous recalibration study, there are no well data available for the model lower aquifer – this is reflected in Plate K-3. Data from published maps were not reviewed as part of this study.

K.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Galveston County site. The outputs are referred to as “Galveston 1” and “Galveston 2” in the information provided by LBG-Guyton. “Galveston 1” is from a location of latitude 29°21’21.6”N and longitude 95°3’27.2”W. “Galveston 2” is from a location of latitude 29°21’10.2” and longitude 95°2'2.9". We assumed a ground surface elevation of 20 feet when vertically translating this output.

K.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997).

For the previous recalibration study, the design hydrograph for the model upper aquifer was developed primarily based on the water level measurements from wells LJ-65-48-201, -204 and -208. To extend the upper model aquifer hydrograph to 2010, we generally followed this methodology, choosing a visual average of the data from these three wells along with well LJ-65-48-502. Well LJ-65-48-502 was added because, unlike wells LJ-65-48-201 and -208, we have data for -502 through 2010.

As in the previous study, there are no well data from which to base a design hydrograph for the lower model aquifer. The groundwater model output was used as a basis for the site hydrograph developed in the previous recalibration. To extend the site hydrograph for the model lower aquifer to 2010, we continued the trend established in the previous study and generally followed the updated groundwater model output.

The old and new portions of the upper and lower model aquifer design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

K.4 Subsidence Data

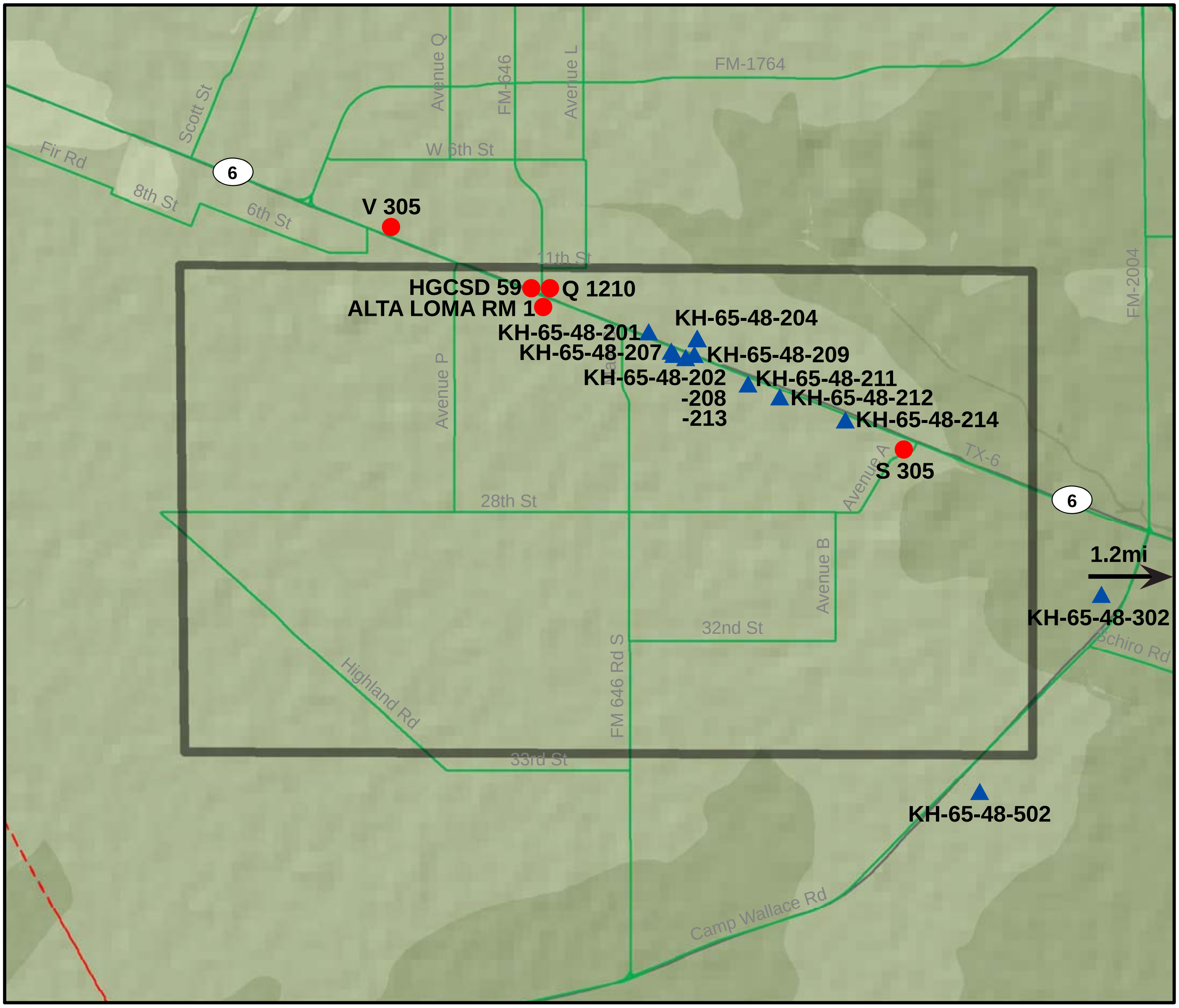
Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

K.4.1 Benchmarks. Data from five benchmarks will be used in the current study:

- S 305;
- ALTA LOMA RM1;
- V 305;
- HGCSD 59; and
- Q 1210.

Locations of the benchmarks are shown on Plate K-1 and subsidence data are presented on Plate K-4. Four benchmarks were used in the previous recalibration study (Fugro 1997). Benchmark Q 1210 was added for this study and, with a vertical offset of 2.4 ft applied to data starting in the year 1995, agrees well with other subsidence data.

K.4.2 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate K-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

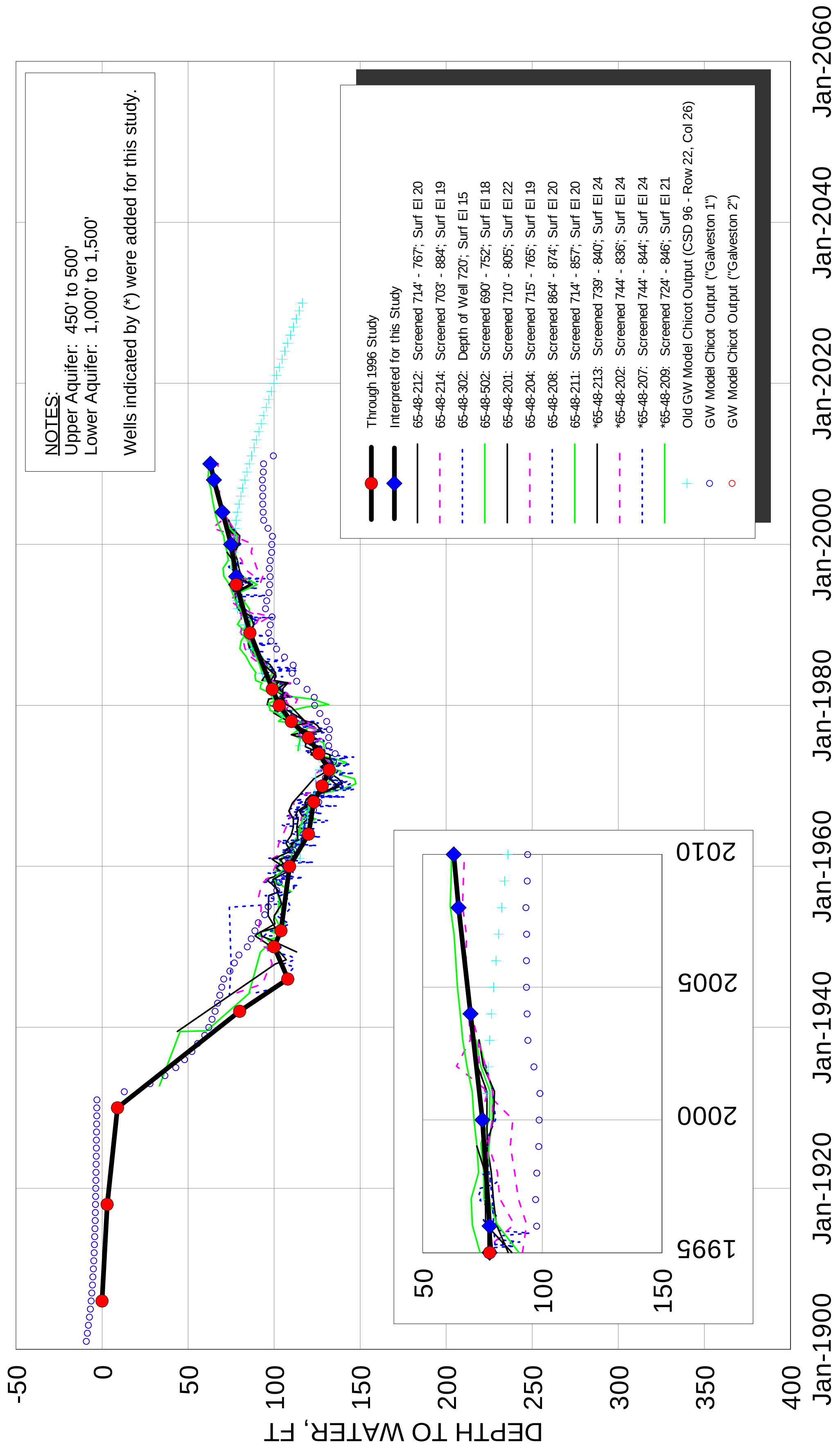
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- □ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 5,000 10,000 Feet

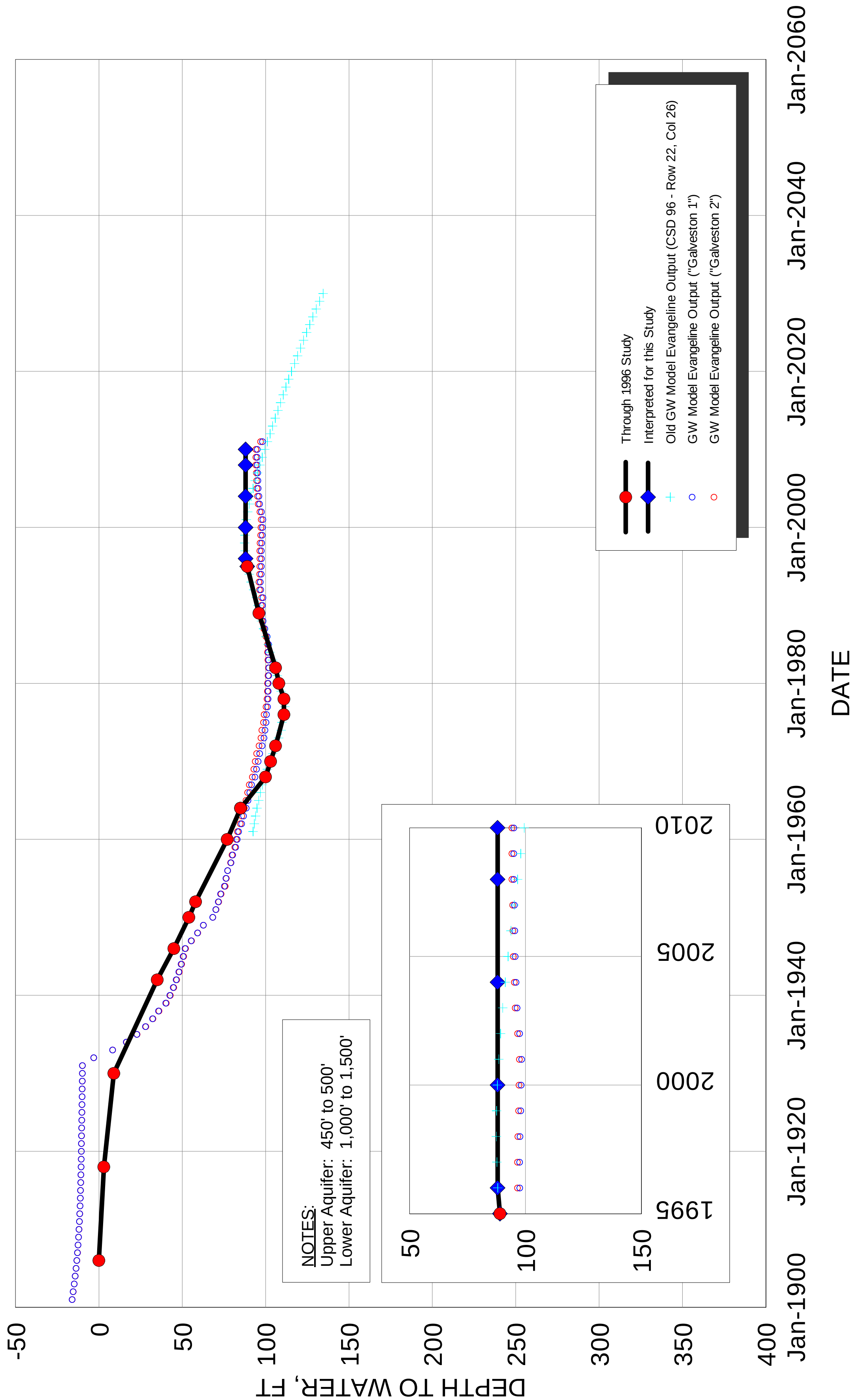
SITE MAP
GALVESTON COUNTY PRESS SITE

PLATE K-1



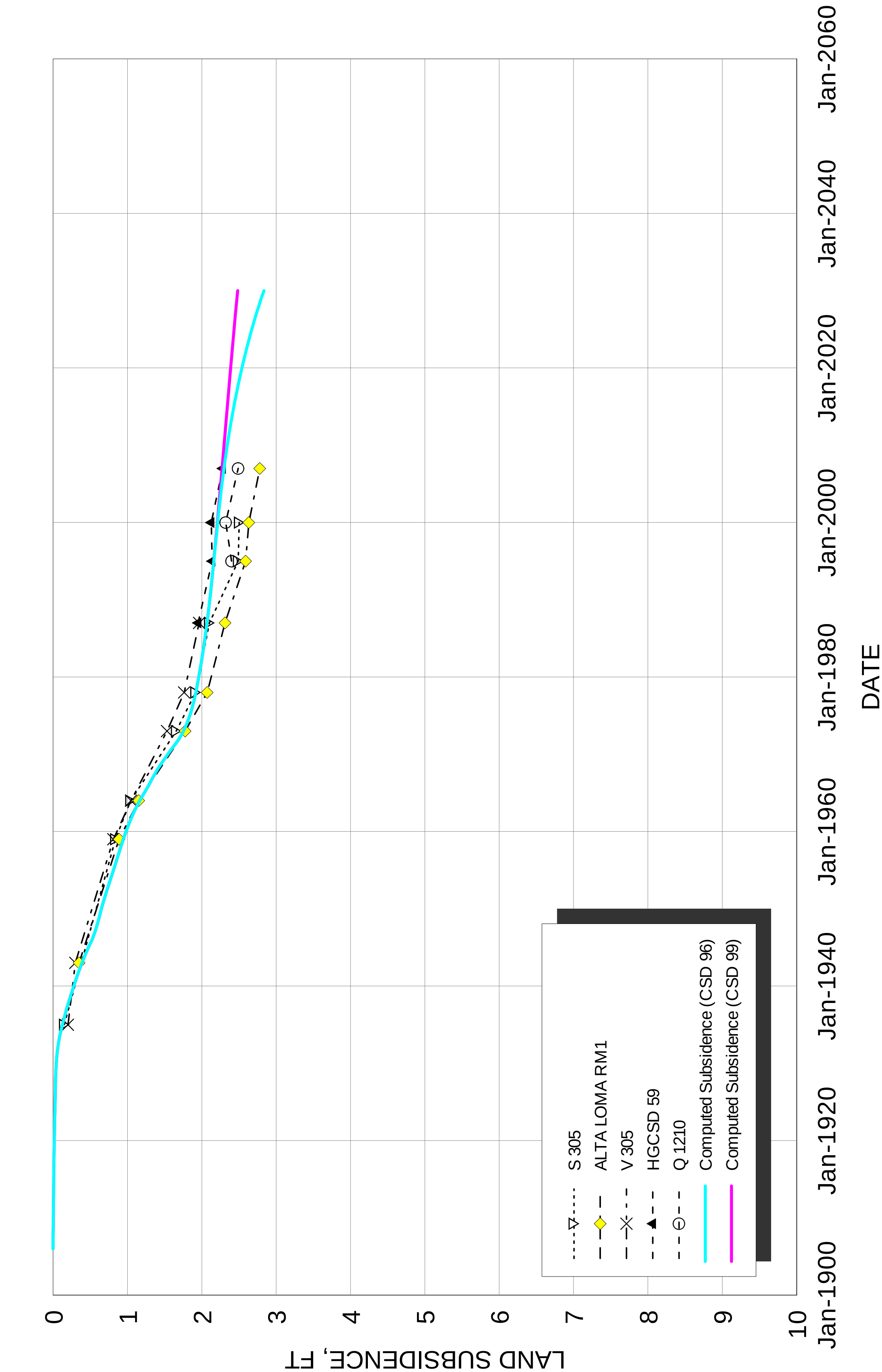
HYDROGRAPHS FOR GALVESTON COUNTY SITE
MODEL UPPER AQUIFER

PLATE K-2



HYDROGRAPHS FOR GALVESTON COUNTY SITE
MODEL LOWER AQUIFER

PLATE K-3



COMPUTED AND MEASURED SUBSIDENCE
GALVESTON COUNTY SITE

PLATE K-4

L: GENOA SITE

L.1 Introduction

The Genoa site covers one ninth of the Pasadena Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate L-1. The site boundaries are consistent with the previous recalibration study (Fugro 1997).

L.2 Aquifer

The Genoa site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	500 to 1,900 ft
Bottom of Compacting Interval:	2,500 ft
Bottom of Chicot Aquifer:	About 500 to 600 ft
Bottom of Evangeline Aquifer:	About 2,500 to 3,000 ft

L.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

L.3.1 Wells. We selected nine wells to use for the Genoa PRESS site. Locations of the wells are included in the detailed Genoa PRESS site map presented on Plate L-1. The six wells included in the previous recalibration study are shown on Plate L-2. Four of the six were discontinued as monitoring wells prior to this study. Wells LJ-65-23-809 and LJ-65-31-211 were used in the previous study and have updated information after 1995. In addition to those two wells, we added three new wells, not previously referenced, for this study:

- LJ-65-23-727;
- LJ-65-23-709; and
- LJ-65-23-732.

We assumed a ground surface elevation of 47 ft when vertically translating all well data for this site.

L.3.2 Groundwater Model Output. We were only provided one set of groundwater model output for the Genoa PRESS site. The output, referred to as “Genoa 1” in the information provided by LBG-Guyton, is from a location of latitude 29°38’34.8”N and longitude 95°13’34.6”W. We assumed a ground surface elevation of 47 feet when processing and plotting this output.

L.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1997). Previously, well LJ-65-23-809 was primarily used to develop the site hydrograph. The data from this well after 1995 roughly agree with a general visual average of the other well data collected for the Genoa site. To extend the site hydrograph to 2010, we continued the methodology used previously and generally followed well LJ-65-23-809. The trend seen in this well and the other well data also agrees with the groundwater model output provided for the Genoa site. Old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

L.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

L.4.1 Benchmarks. Consistent with the previous recalibration study, data from four benchmarks will be used in the current study:

- V 1144;
- A 640 RESET 1962;
- Z 639 RESET 1965; and
- HGCSD 48.

Locations of the benchmarks are shown on Plate L-1 and subsidence data are presented on Plate L-3.

I.4.2 PAM Station. Data from PAM station 38, also presented on Plate L-3, will be used for recalibration efforts in this study. The location of PAM 38 is presented on Plate L-1. Data from PAM 38 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on our review of other subsidence data sources available, we applied a vertical offset of 7.5 ft to the PAM data.

L.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate L-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.

Legend:

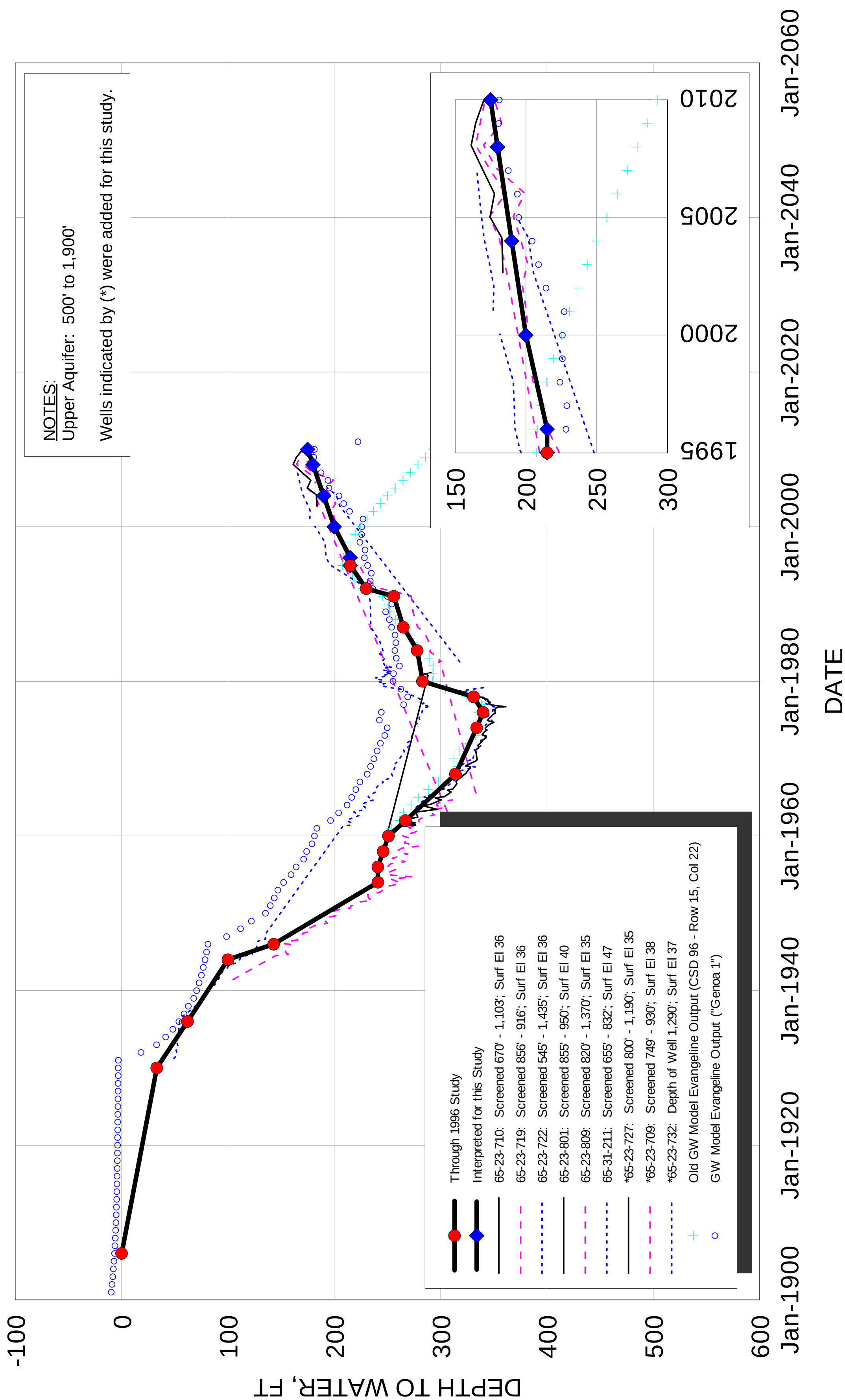
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

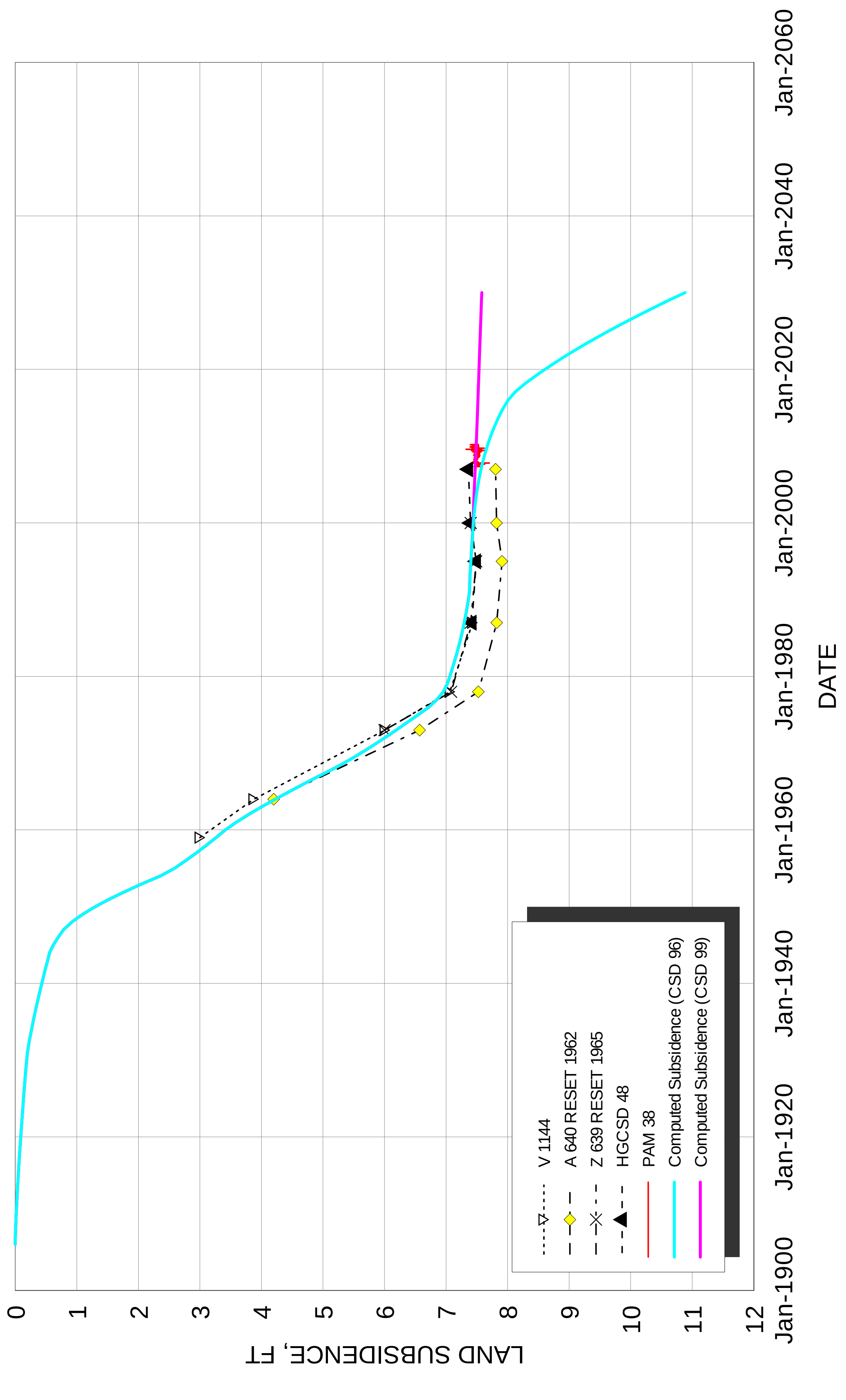
SITE MAP
GENOA PRESS SITE

PLATE L-1



HYDROGRAPHS FOR GENOA SITE
SINGLE MODEL AQUIFER

PLATE L-2



COMPUTED AND MEASURED SUBSIDENCE

GENOA SITE

PLATE L-3

M: HARRISBURG SITE

M.1 Introduction

The Harrisburg site covers one ninth of the Park Place Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate M-1. The site boundaries are consistent with the previous recalibration study (Fugro 1997).

M.2 Aquifer

The Harrisburg site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	600 to 1,300 ft
Bottom of Compacting Interval:	2,354 ft
Bottom of Chicot Aquifer:	About 600 to 700 ft
Bottom of Evangeline Aquifer:	About 2,000 to 2,500 ft

M.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

M.3.1 Wells. Consistent with the previous recalibration study, we are referencing data from three wells for the Harrisburg PRESS site. Locations of the wells are included in the detailed Harrisburg PRESS site map presented on Plate M-1, and well hydrographs are shown on Plate M-2. We assumed a ground surface elevation of 21 ft when vertically translating all well data for this site.

M.3.2 Groundwater Model Output. We were only provided one set of groundwater model output for the Genoa PRESS site. The output, referred to as “Harrisburg 1” in the information provided by LBG-Guyton, is from a location of latitude 29°43’20.9”N and longitude 95°16’12.7”W. We assumed a ground surface elevation of 21 feet when processing and plotting this output.

M.3.3 Design Hydrograph. We used the site hydrograph presented in the previous recalibration effort (Fugro 1997) for dates through 1995. Previously, well LJ-65-22-317 was primarily used to construct the site hydrograph. To extend the site hydrograph to 2010, we generally used a visual average of the data from wells LJ-65-22-317 and -622. The trend seen in the data from these wells also agrees with the groundwater model output provided for the Harrisburg site. Old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

M.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

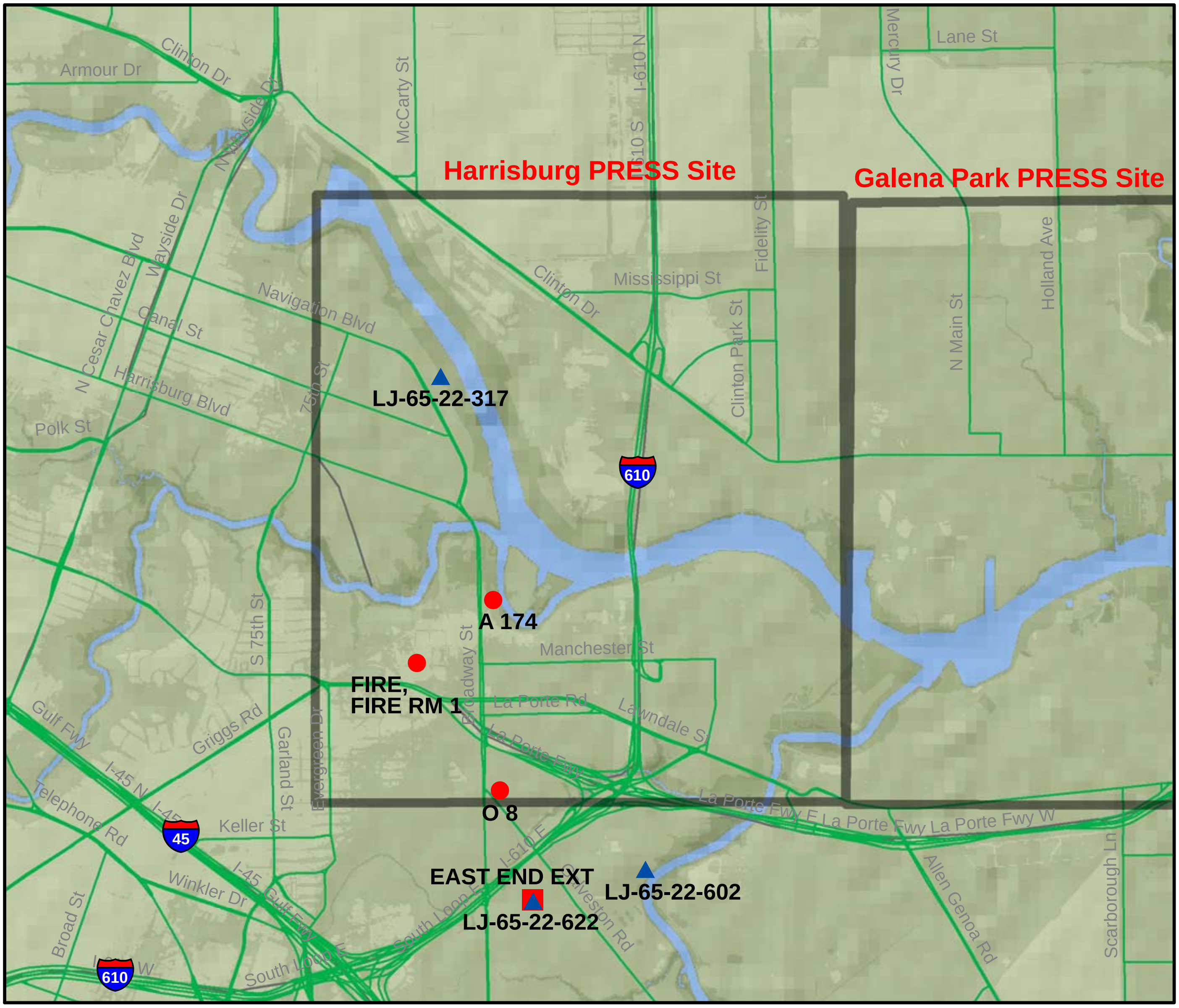
M.4.1 Benchmarks. Consistent with the previous recalibration study, data from four benchmarks will be used in the current study:

- FIRE;
- O 8;
- FIRE RM 1; and
- A 174.

Locations of the benchmarks are shown on Plate M-1 and subsidence data are presented on Plate M-3.

M.4.2 Extensometer. Data from one extensometer, LJ-65-22-622 or “East End”, will be used for comparison to the PRESS model output. The location of the “East End” extensometer is shown on Plate M-1, and data from the extensometer are presented on Plate M-3.

M.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate M-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

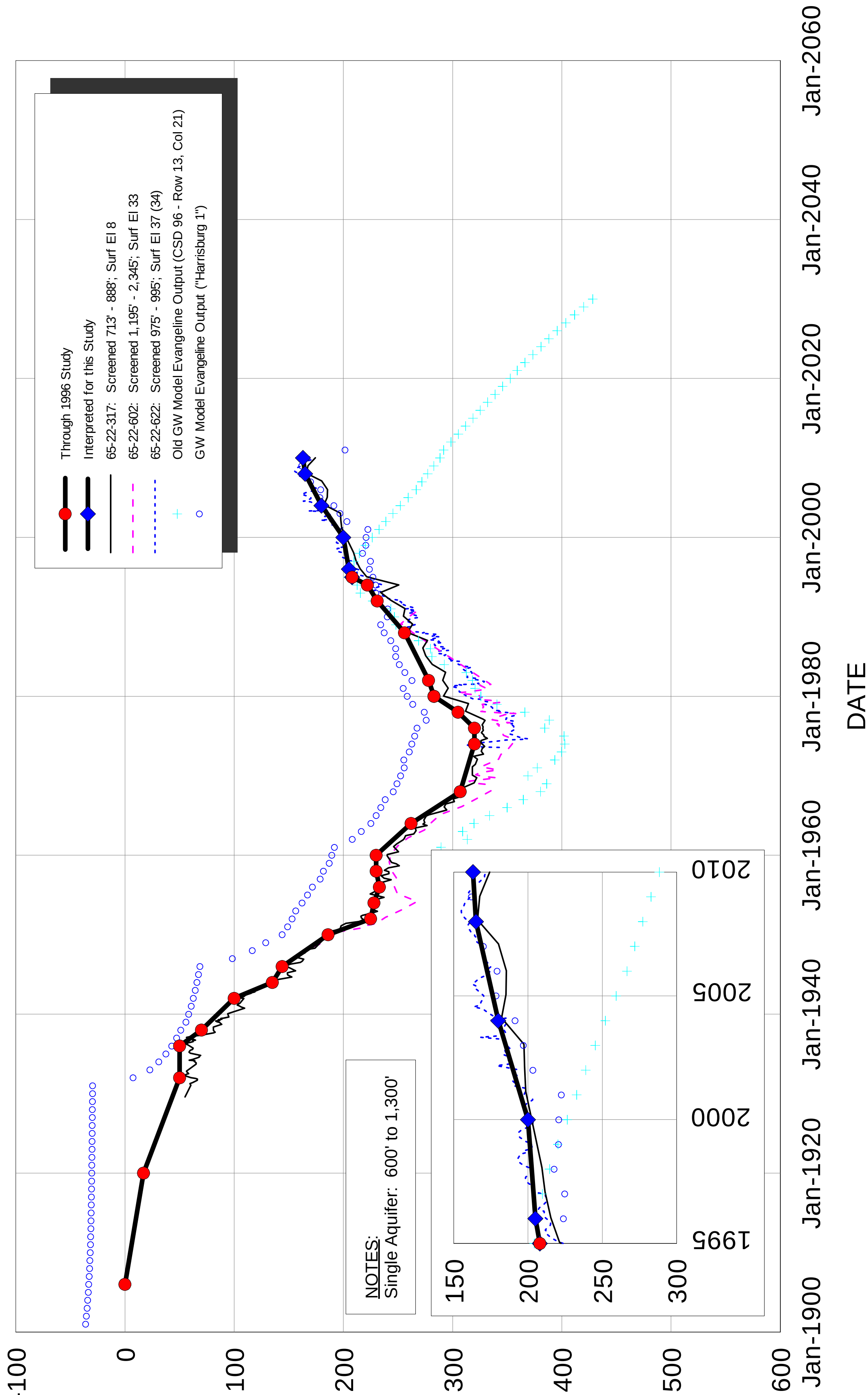
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▭ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

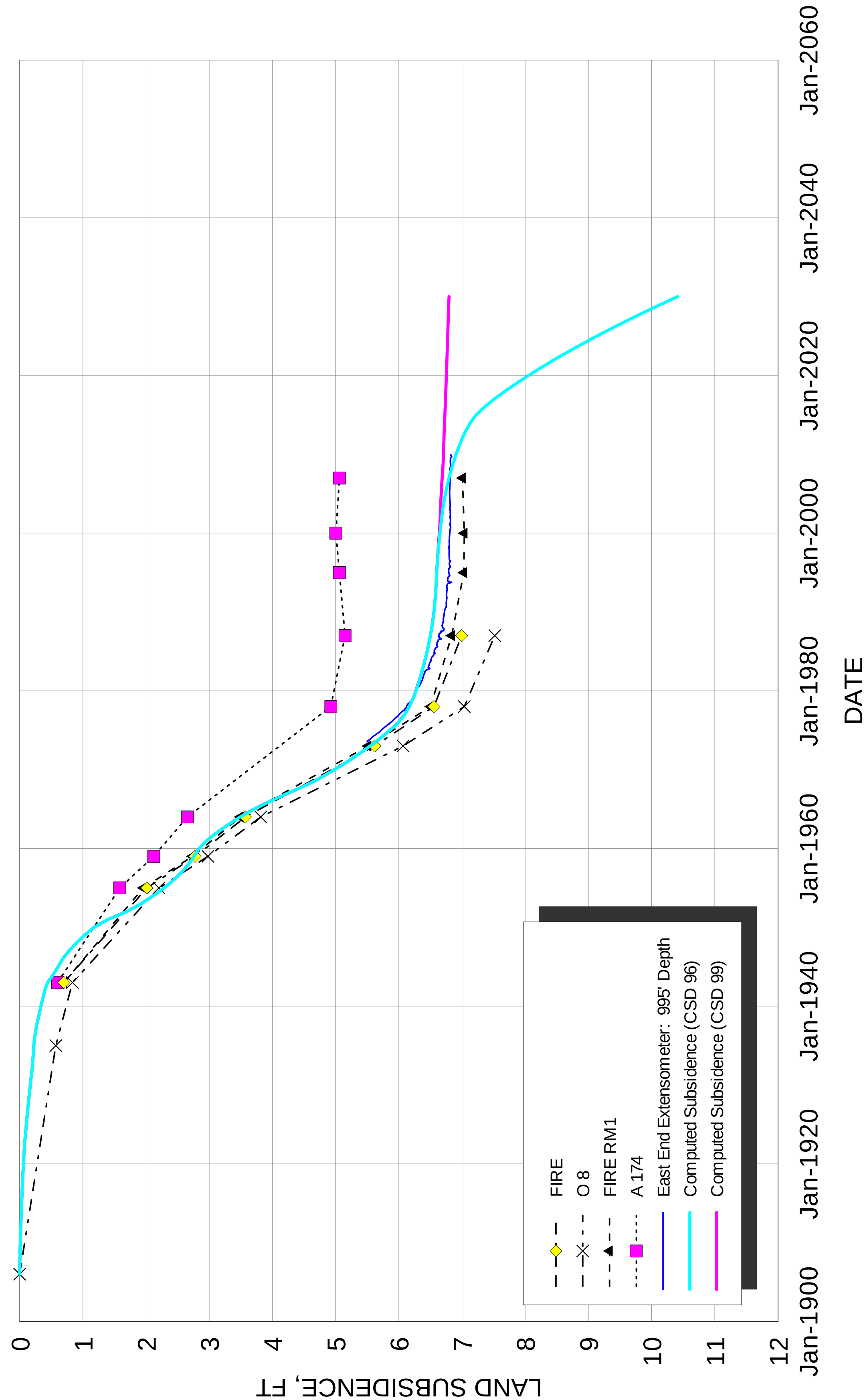
SITE MAP
HARRISBURG PRESS SITE

PLATE M-1



HYDROGRAPHS FOR HARRISBURG SITE
SINGLE MODEL AQUIFER

PLATE M-2



COMPUTED AND MEASURED SUBSIDENCE
HARRISBURG SITE

PLATE M-3

N: HOBBY SITE

N.1 Introduction

The Hobby site covers one ninth in the Park Place Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate N-1. The site boundaries are consistent with the previous recalibration study (Fugro 1997).

N.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 550 to 650 ft Lower: 900 to 1,850 ft
Bottom of Compacting Interval:	2,500 ft
Bottom of Chicot Aquifer:	About 600 to 700 ft
Bottom of Evangeline Aquifer:	About 2,700 to 3,200 ft

N.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

N.3.1 Wells. We have chosen five wells to use for the Hobby site in this study. In addition to the four wells used in the previous recalibration study, and after consultation with LBG-Guyton, we have chosen to use well LJ-65-31-211, located just outside the southeast corner of the adjacent Genoa PRESS site. Locations of all wells are included in the detailed Hobby PRESS site map presented on Plate N-1. We assumed a ground surface elevation of 47 ft when vertically translating all well data for this site.

Two of the five wells used for the Hobby PRESS site are screened in the model upper aquifer, as shown on Plate N-2. Of these two, only LJ-65-31-211, added for this study, has data available after 1995. Well LJ-65-22-803 was discontinued as monitoring well prior to 1995. The other three wells in the Hobby PRESS site are screened in the model lower aquifer, as shown on Plate N-3. Well LJ-65-22-801 was discontinued as a monitoring well prior to this study but is included on Plate N-3 for reference.

N.3.2 Groundwater Model Output. We were only provided one set of groundwater model output for the Hobby PRESS site. The output, referred to as “Hobby 1” in the information provided by LBG-Guyton, is from a location of latitude 29°38’58.9”N and longitude 95°16’27.3”W. We assumed a ground surface elevation of 47 feet when processing and plotting this output.

N.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997). We continued trends established in the previous study when extending the design hydrographs for the model upper and lower aquifers to the year 2010. For the model upper aquifer, we generally followed well LJ-65-31-211. We followed wells LJ-65-22-802 and -901 to extend the site hydrograph for the model lower aquifer to 2010. The old and new portions of the upper and lower model aquifer design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

N.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

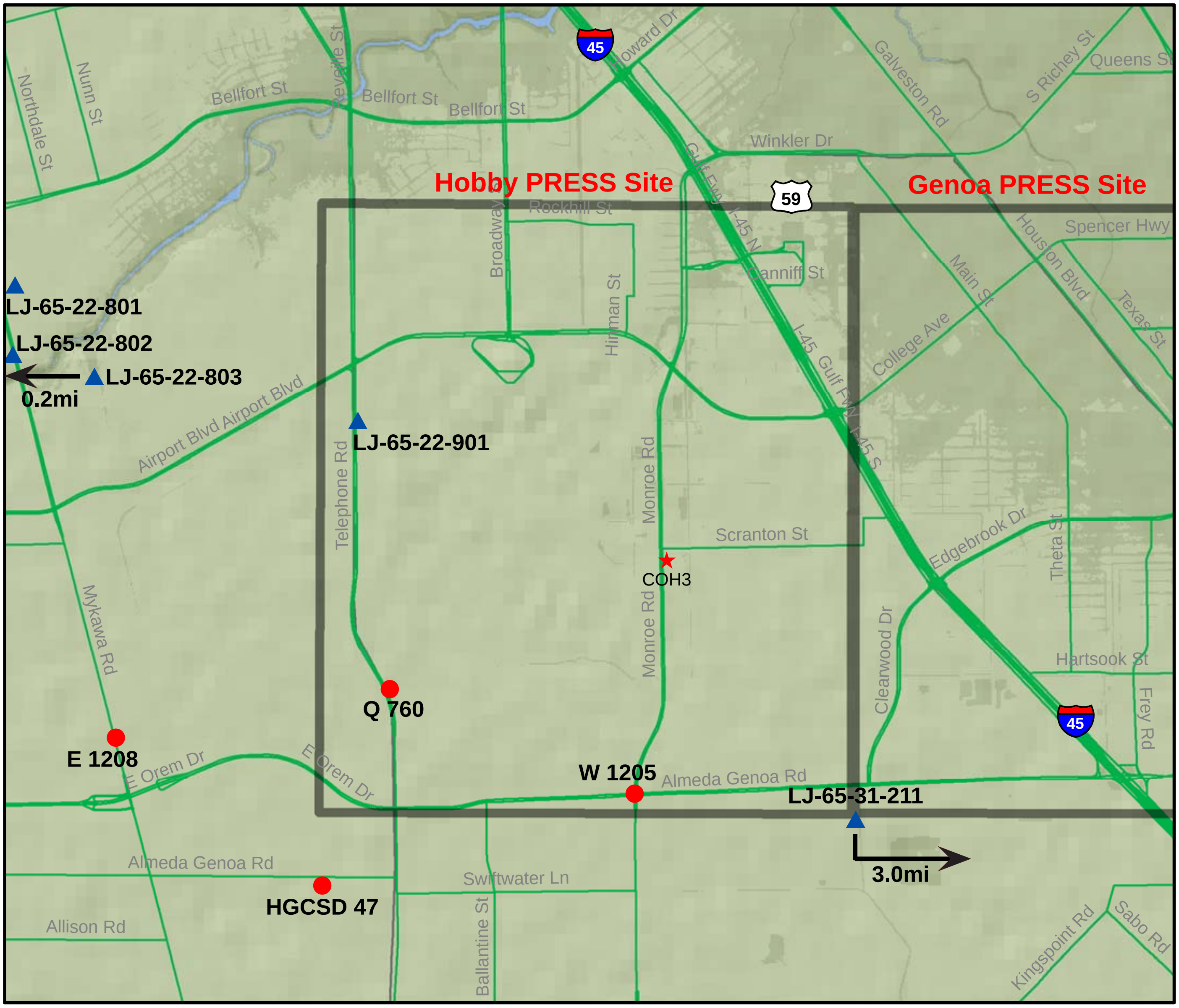
N.4.1 Benchmarks. Data from four benchmarks will be used in the current study:

- Q 760;
- W 1205;
- E 1208; and
- HGCSD 47.

Locations of the benchmarks are shown on Plate N-1 and subsidence data are presented on Plate N-4. Three benchmarks were used in the previous recalibration study (Fugro 1997). Benchmark HGCSD 47 was added for this study and, with a vertical offset of 6.9 ft applied to data starting in the year 1995 (the same as the offset applied to benchmark E 1208), agrees well with other subsidence data for the Hobby PRESS site.

N.4.2 CORS Site. Data from a CORS site operated by the City of Houston, referred to as "COH3" in subsidence information provided by the HGSD, will be used in this study. The location of COH3 is provided in Plate N-1 and subsidence data is shown in Plate N-4. The data is fairly recent, as collection started in 2007. Based on our review of the other subsidence data available in the Hobby PRESS site, we applied a vertical offset of 7.0 ft to the COH3 data starting in 2007.

N.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate N-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

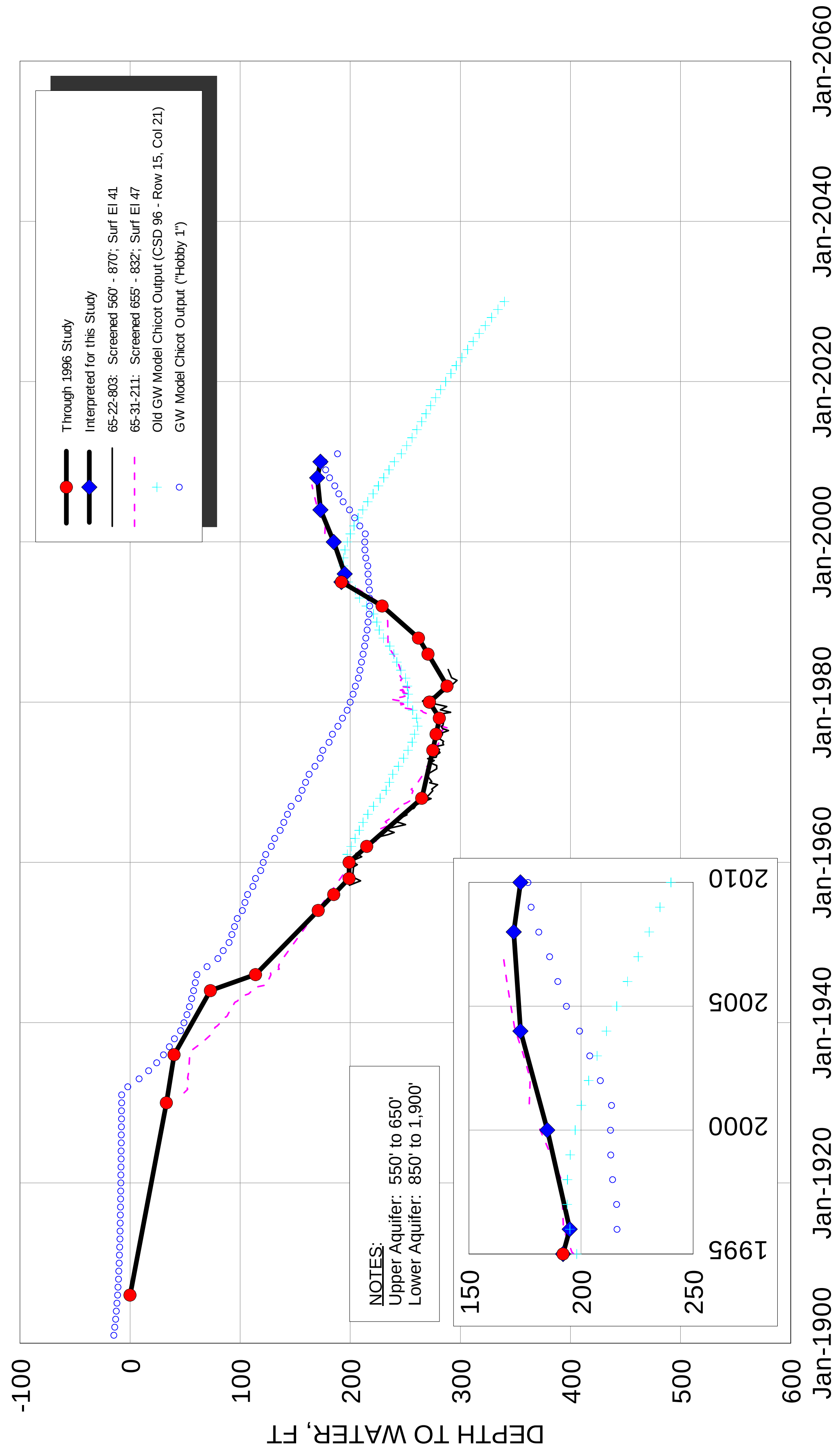
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▢ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

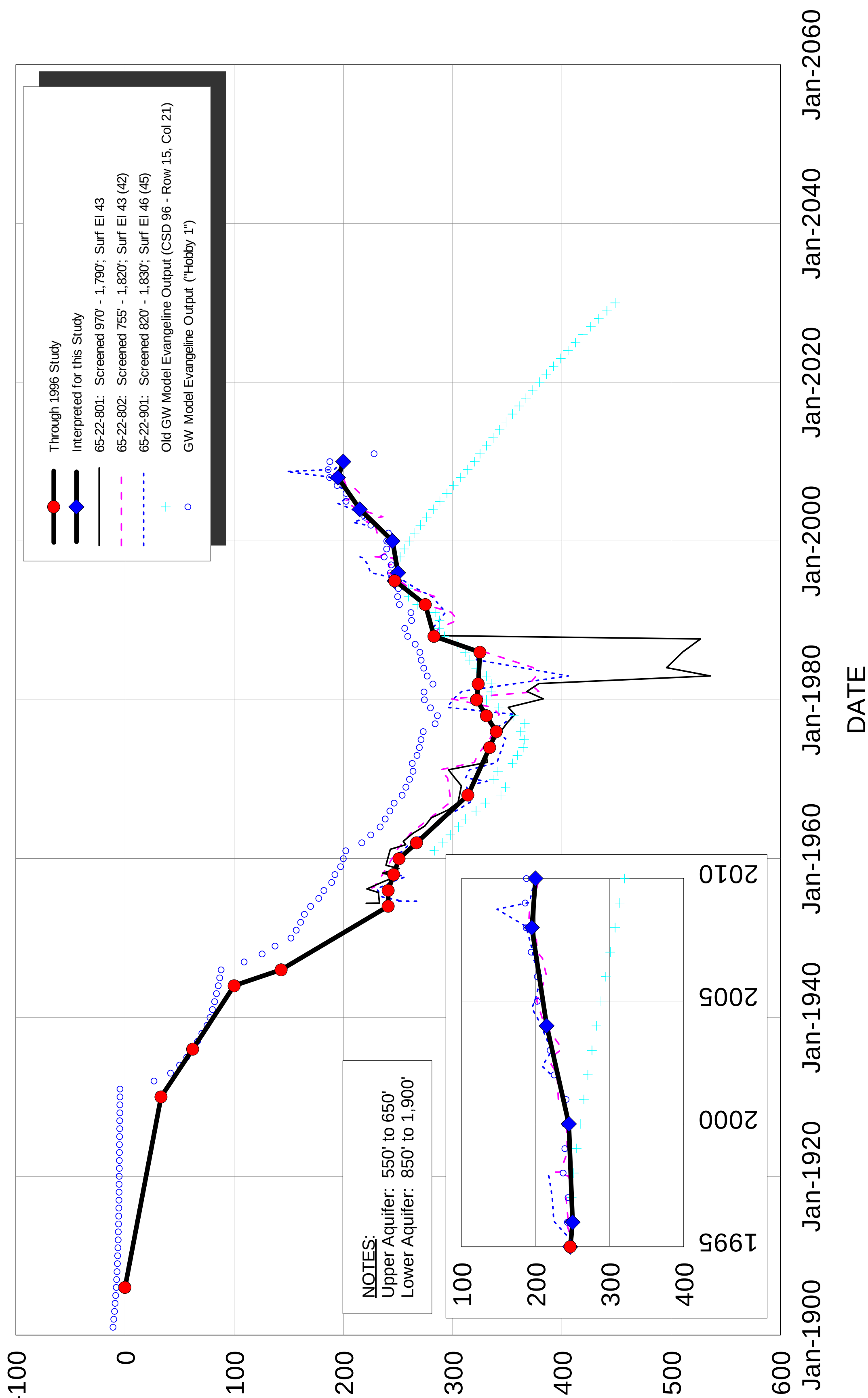
SITE MAP
HOBBY PRESS SITE

PLATE N-1



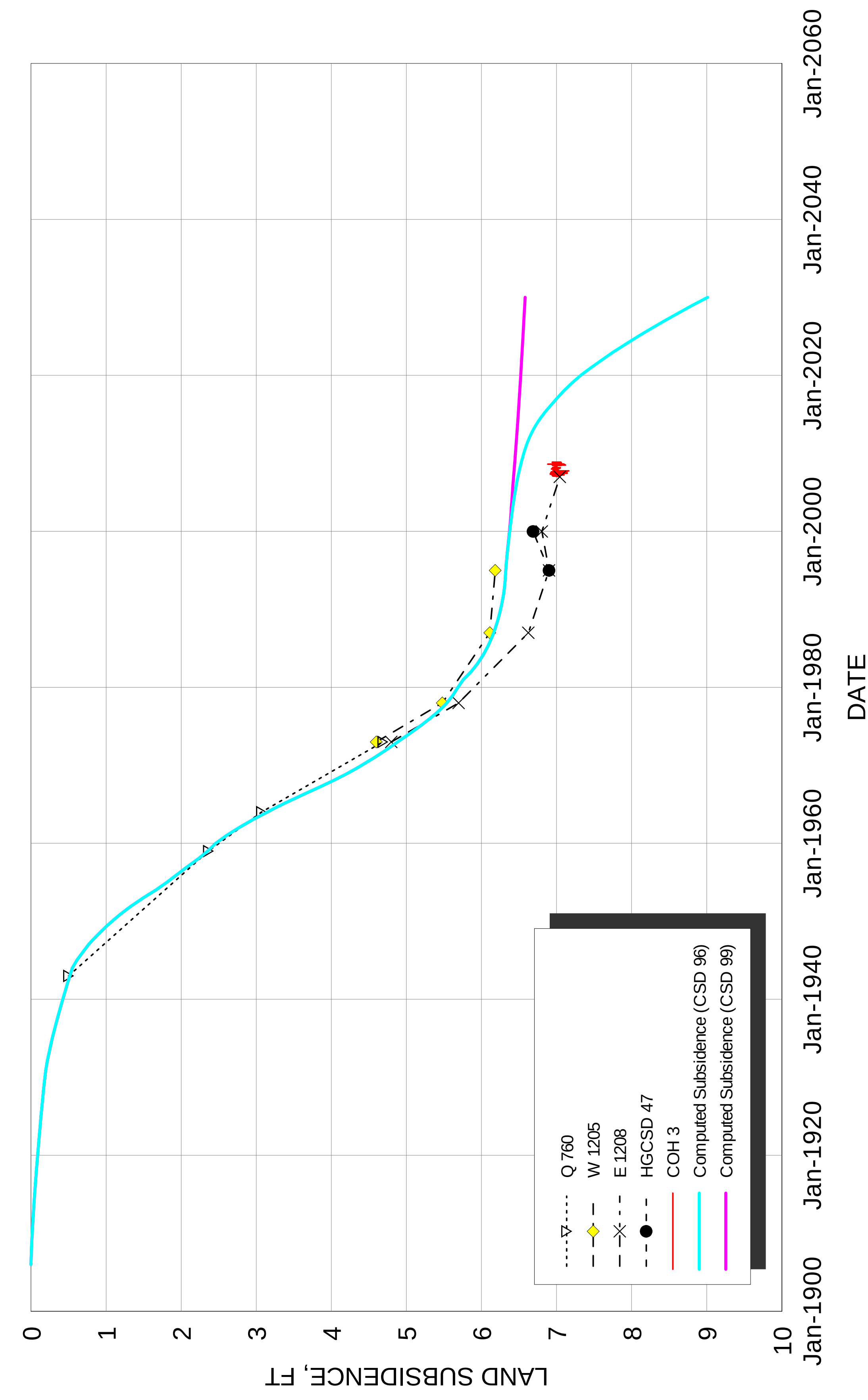
HYDROGRAPHS FOR HOBBY SITE
UPPER MODEL AQUIFER

PLATE N-2



HYDROGRAPHS FOR HOBBY SITE
LOWER MODEL AQUIFER

PLATE N-3



COMPUTED AND MEASURED SUBSIDENCE
HOBBY SITE

PLATE N-4

O: HUMBLE SITE

O.1 Introduction

The Humble site covers one ninth in the Humble Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate O-1. The Humble PRESS site was created as part of the previous recalibration study (1997). The site boundaries shown on Plate O-1 are consistent with those developed previously.

O.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 365 to 650 ft
	Lower: 900 to 1,150 ft
Bottom of Compacting Interval:	1,390 ft
Bottom of Chicot Aquifer:	650 ft
Bottom of Evangeline Aquifer:	1,760 ft

O.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

O.3.1 Wells. We have chosen 10 wells to use for the Humble site in this study. In addition to the seven wells used in the previous recalibration study, and after consultation with LBG-Guyton, we have added the following three wells not previously used for calibration:

- El Dorado M.U.D. Well 2 (model lower aquifer);
- LJ-65-06-528 (model upper aquifer); and
- LJ-65-06-804 (model upper aquifer).

Locations of all wells are included in the detailed Humble PRESS site map presented on Plate O-1. Data from El Dorado M.U.D. Well 2 are from a private source and were provided by LBG-Guyton. We assumed a ground surface elevation of 72 ft when vertically translating all well data for this site.

The same five wells used for the previous recalibration study that are screened in the model upper aquifer will be used for this study – these wells are shown on Plate O-2. Only two of the five wells have data available after 1995 – LJ -65-06-601 and -612. The remaining five wells in the Humble PRESS site are screened in the model lower aquifer, as shown on Plate O-3. Well LJ-65-06-604 was discontinued as a monitoring well prior to this study but is included on Plate O-3 for reference.

O.3.2 Groundwater Model Output. We were only provided one set of groundwater model output for the Humble PRESS site. The output, referred to as “Humble 1” in the information provided by LBG-Guyton, is from a location of latitude 29°55’52.4”N and longitude 95°16’37.2”W. We assumed a ground surface elevation of 72 feet when processing and plotting this output.

O.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997). We continued trends established in the previous study when extending the design hydrographs for the model upper and lower aquifers to the year 2010. For the model upper aquifer, we generally followed wells LJ-65-06-601 and -612. We generally followed well LJ-65-06-616 to extend the site hydrograph for the model lower aquifer to 2010. This well shows good general agreement with the other wells added for this study as well as the groundwater model output provided for the Humble site. The old and new portions of the upper and lower model aquifer design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

O.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

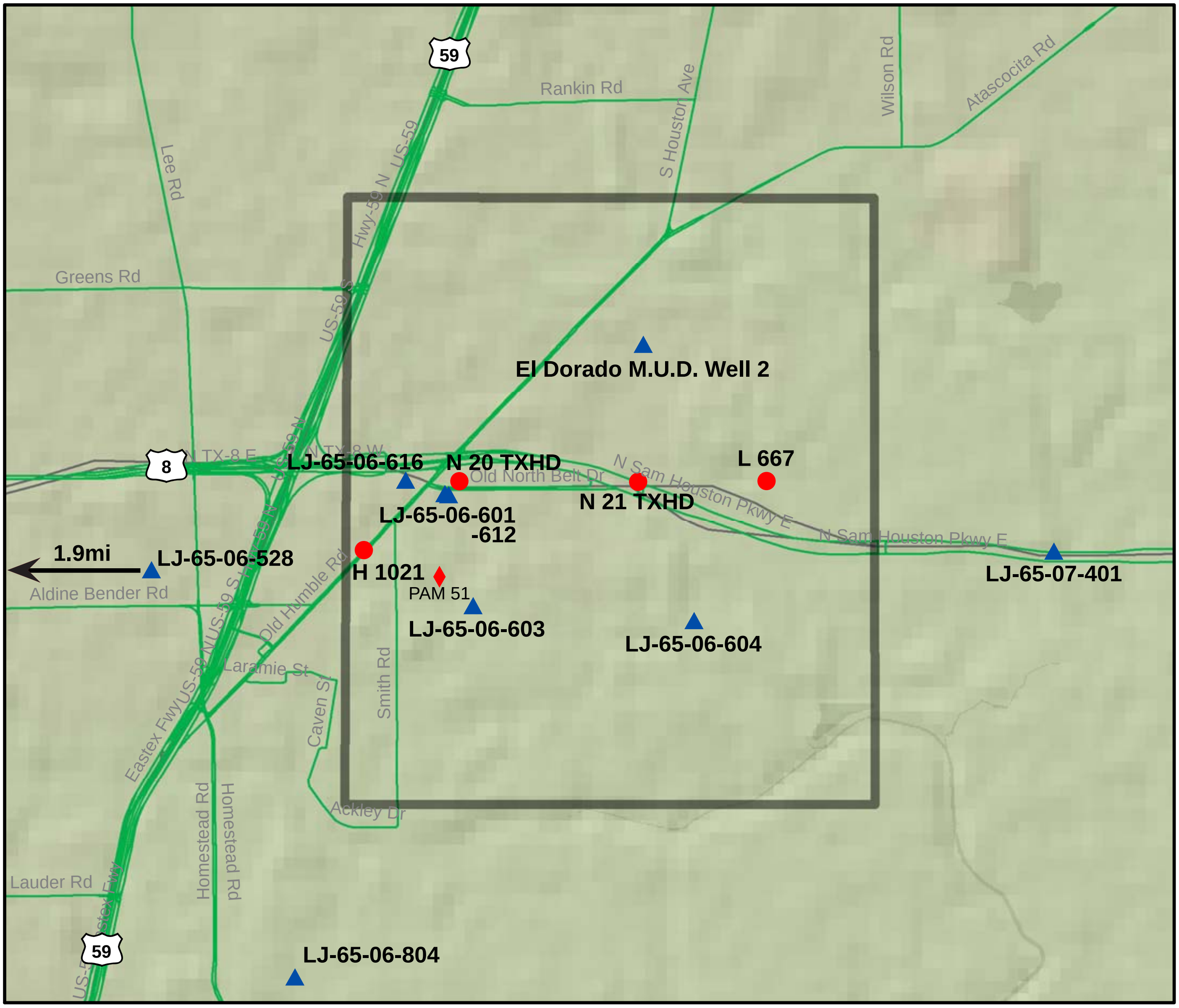
O.4.1 Benchmarks. Consistent with the previous recalibration study, data from four benchmarks will be used in the current study:

- L 667;
- H 1021;
- N20 TXHD; and
- N21 TXHD.

Locations of the benchmarks are shown on Plate O-1 and subsidence data are presented on Plate O-4.

O.4.2 PAM Station. Data from PAM station 51, also presented on Plate O-4, will be used for recalibration efforts in this study. The location of PAM 51 is presented on Plate O-1. Data from PAM 51 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on review of other subsidence data sources available, we applied a vertical offset of 4.6 ft to the PAM data.

O.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate O-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

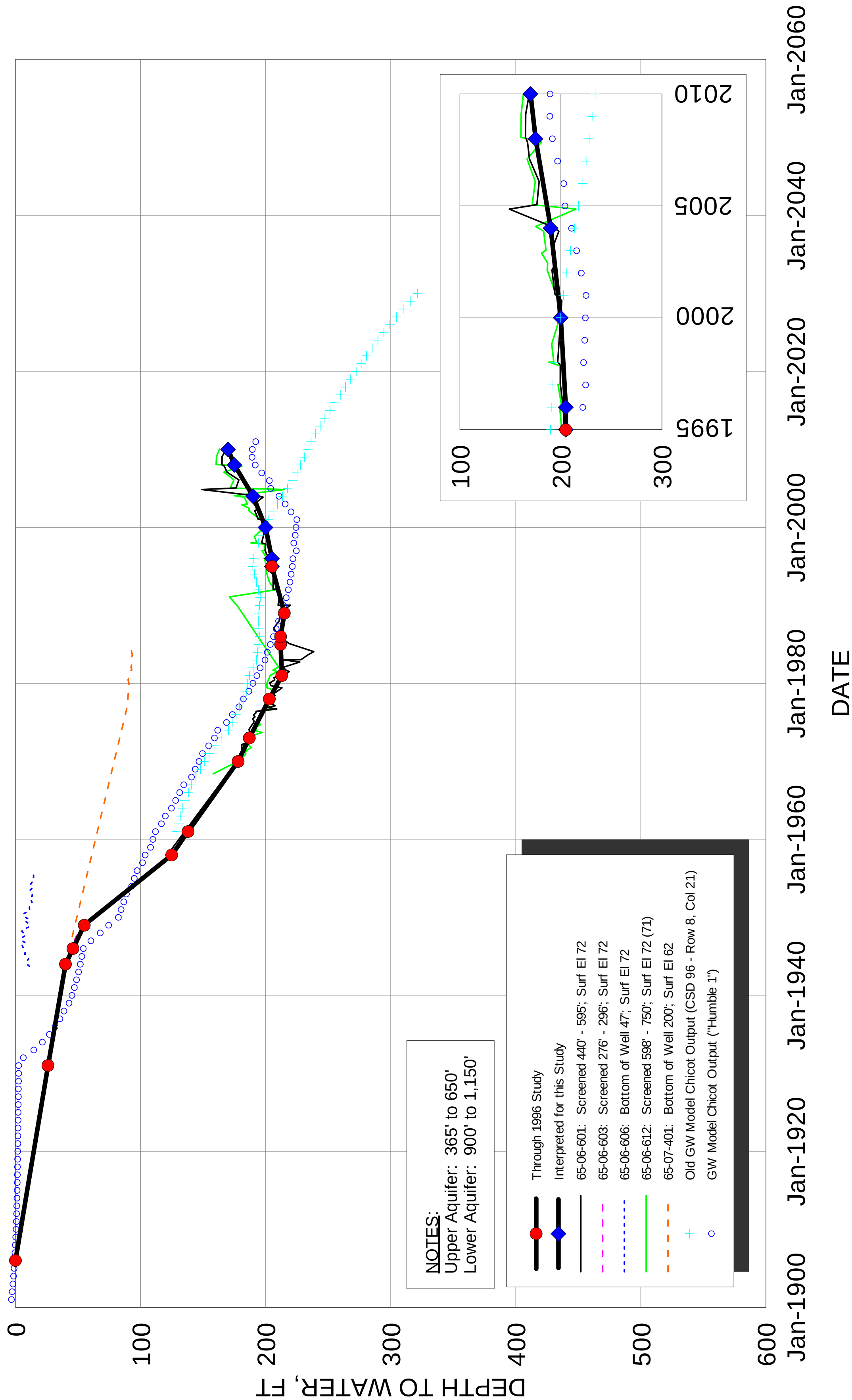
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

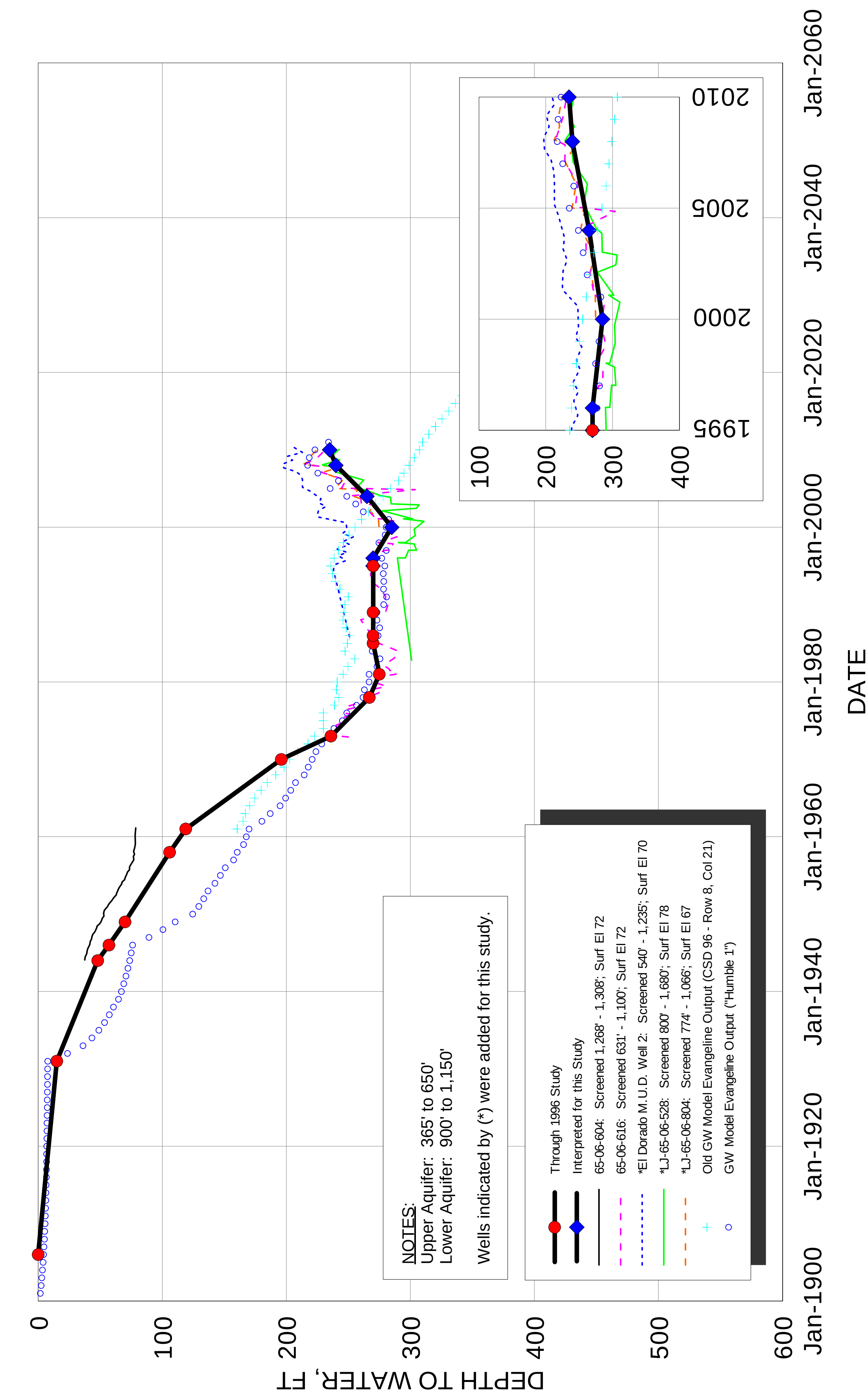
SITE MAP
HUMBLE PRESS SITE

PLATE O-1



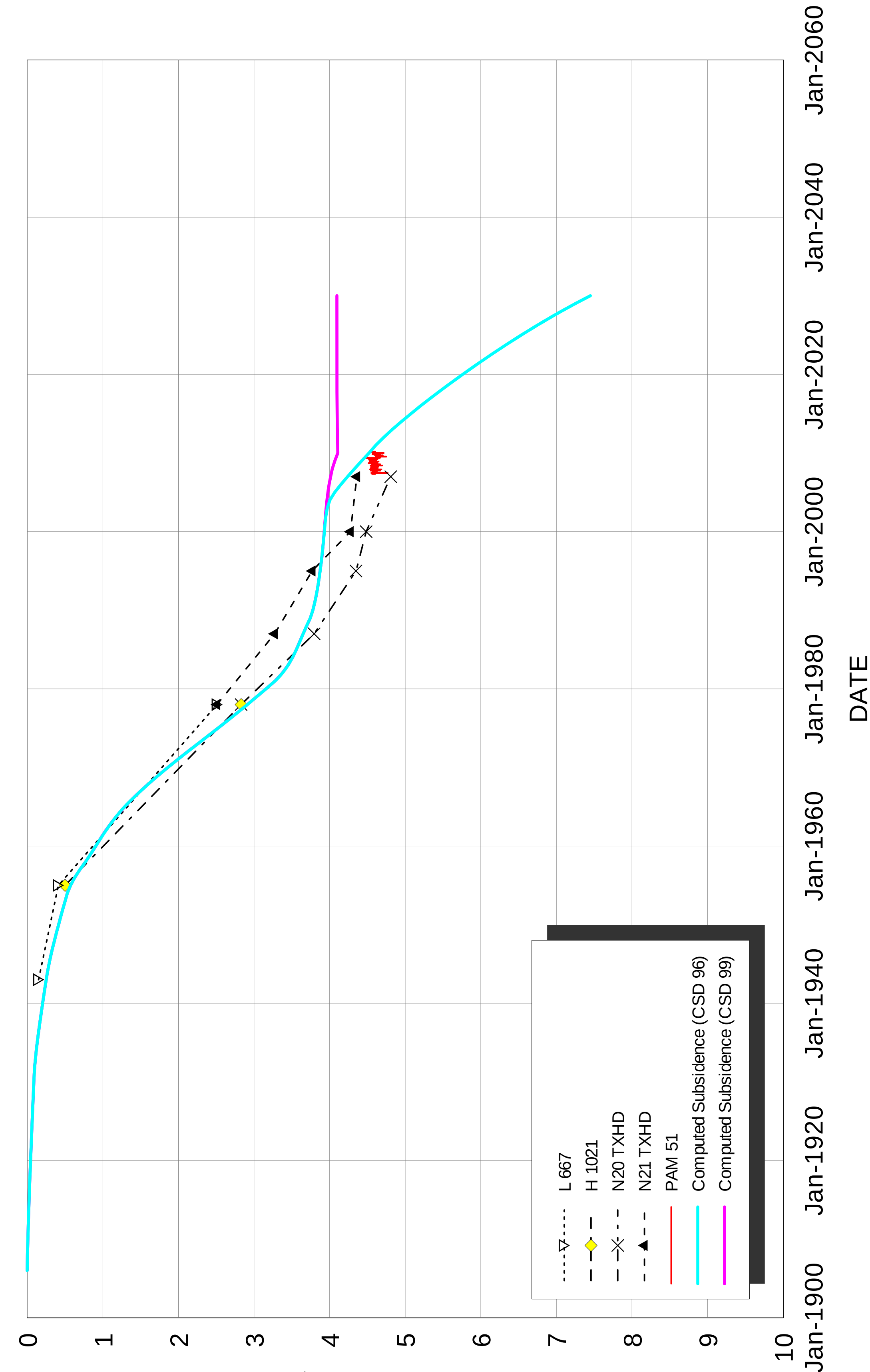
HYDROGRAPHS FOR HUMBLE SITE
UPPER MODEL AQUIFER

PLATE O-2



HYDROGRAPHS FOR HUMBLE SITE
LOWER MODEL AQUIFER

PLATE O-3



COMPUTED AND MEASURED SUBSIDENCE
HUMBLE SITE

PLATE O-4

P: KATY SITE

P.1 Introduction

The Katy site covers three ninths of the Katy Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate P-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

P.2 Aquifer

The Katy site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	400 to 1,000 ft
Bottom of Compacting Interval:	1,360 ft
Bottom of Chicot Aquifer:	About 300 to 400 ft
Bottom of Evangeline Aquifer:	About 1,500 to 2,000 ft

P.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

P.3.1 Wells. We have chosen 15 wells to use for the Katy site in this study. In addition to the seven wells used in the previous recalibration study, and after consultation with LBG-Guyton, we have added the following eight wells not previously used for calibration:

- LJ-65-10-611, -811 and -812;
- Cimarron M.U.D. Well 1;
- Fort Bend County M.U.D. 37 Well 1;
- West Memorial M.U.D. Well 1;
- Interstate M.U.D. Well 1; and
- Harris-Fort Bend County M.U.D. 5 Well 1.

Locations of all wells are included in the detailed Katy PRESS site map presented on Plate P-1. Wells LJ-65-10-611, -811 and -812 are from the USGS NWIS, while data from the other five wells added for this study are from private sources and were provided by LBG-Guyton. The wells added for this study were screened within the model aquifer but are generally screened to deeper depths than wells used in previous calibrations. We assumed a ground surface elevation of 131 ft when vertically translating all well data for this site.

Five wells used in the previous study were discontinued as monitoring wells prior to 1995: LJ-65-10-501, -901, -904, -906 and -911. These wells are included on Plate P-2 for reference.

P.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Katy site. The outputs are referred to as “Katy 1” and “Katy 2” in the information provided by LBG-Guyton. “Katy 1” is from a location of latitude 29°48’47.0”N and longitude

95°48’51.8”W. “Katy 2” is from a location of latitude 29°46’12.1” and longitude 95°47’57.4”. We assumed a ground surface elevation of 131 feet when vertically translating this output.

P.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1997). Previously, wells LJ-65-10-501, -902 and -904, along with the groundwater model output, were primarily used to construct the site hydrograph. As mentioned previously, these wells were discontinued as monitoring wells prior to 1995. After consultation with LBG-Guyton, we determined that we should not drastically shift the design hydrograph deeper to move closer to deeper screened wells added for this study. To extend the site hydrograph to 2010, we generally followed the trends established through 1995 and seen in the updated groundwater model output. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

P.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

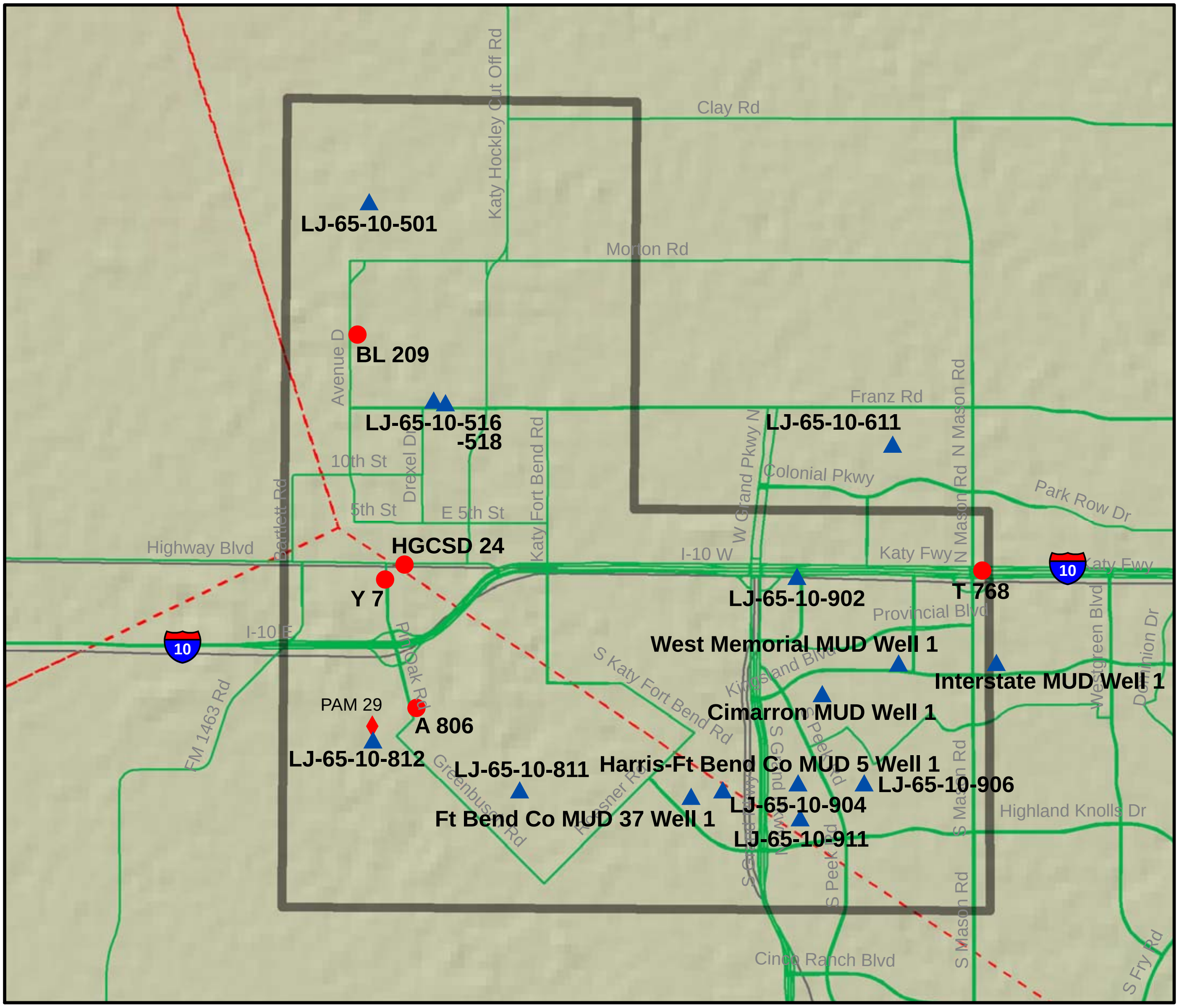
P.4.1 Benchmarks. Consistent with the previous recalibration study, data from five benchmarks will be used in the current study:

- Y 7;
- A 806;
- BL 209;
- T 768; and
- HGCSD 24.

Locations of the benchmarks are shown on Plate P-1 and subsidence data are presented on Plate P-3.

P.4.2 PAM Station. Data from PAM station 29, also presented on Plate P-3, will be used for recalibration efforts in this study. The location of PAM 29 is presented on Plate P-1. Data from PAM 29 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on review of other subsidence data sources available, we applied a vertical offset of 1.7 ft to the PAM data.

P.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate P-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

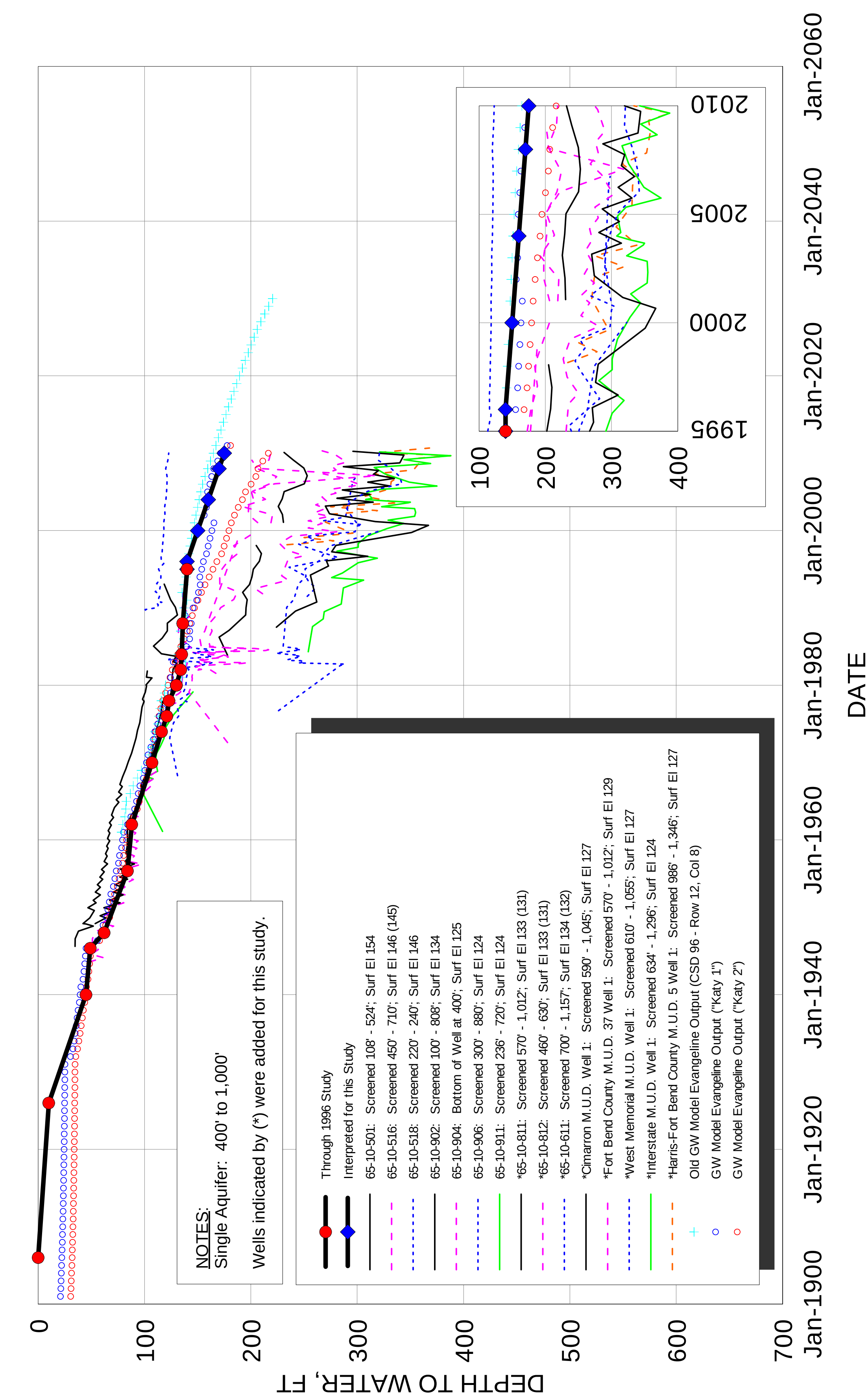
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 6,000 12,000 Feet

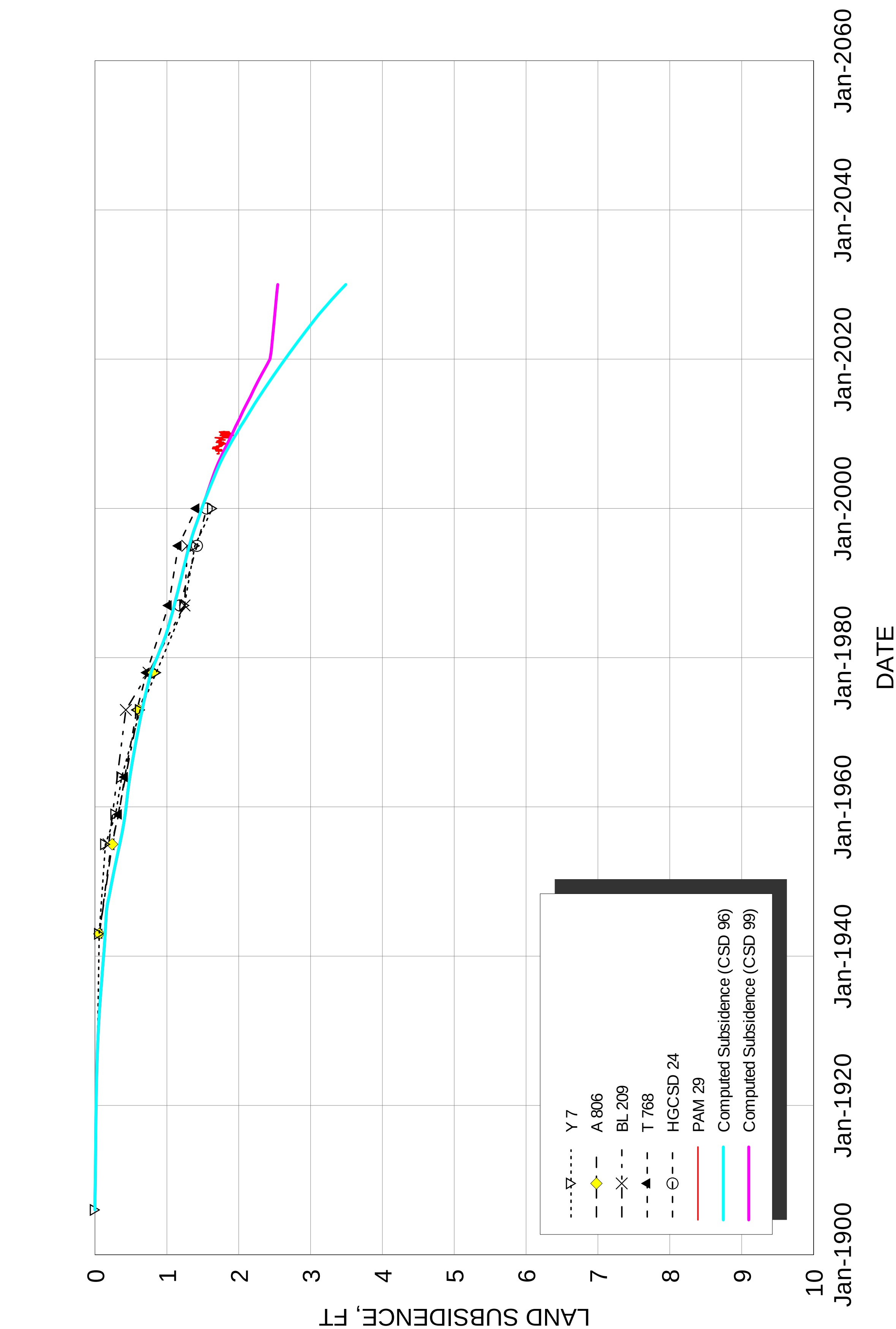
SITE MAP
KATY PRESS SITE

PLATE P-1



HYDROGRAPHS FOR KATY SITE
SINGLE MODEL AQUIFER

PLATE P-2



COMPUTED AND MEASURED SUBSIDENCE
KATY SITE

PLATE P-3

Q: LA PORTE SITE

Q.1 Introduction

The La Porte site covers two ninths of the La Porte Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate Q-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

Q.2 Aquifer

The La Porte site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	400 to 1,600 ft
Bottom of Compacting Interval:	2,000 ft
Bottom of Chicot Aquifer:	About 600 ft
Bottom of Evangeline Aquifer:	About 3,300 to 3,800 ft

Q.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

Q.3.1 Wells. For this study, we have selected four wells to use for the La Porte site. In addition to the two wells used in the previous recalibration study, and after consultation with LBG-Guyton, we have added the following two wells not previously used for calibration:

- LJ-65-24-811; and
- LJ-65-24-920.

Locations of all wells are included in the detailed La Porte PRESS site map presented on Plate Q-1. Well LJ-65-24-804 was discontinued prior to 1995 but is included on Plate Q-2 for reference. We assumed a ground surface elevation of 20 ft when vertically translating all well data for this site.

Q.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the La Porte site. The outputs are referred to as “La Port 1” and “La Port 2” in the information provided by LBG-Guyton. “La Port 1” is from a location of latitude 29°38’37.4”N and longitude 95°1’25.5”W. “La Port 2” is from a location of latitude 29°39’3.2” and longitude 95°4’12.6”. We assumed a ground surface elevation of 20 feet when vertically translating this output.

Q.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1997). To extend the site hydrograph to 2010, we generally followed a visual average of the data available for wells LJ-65-24-902, -811 and -920. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

Q.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

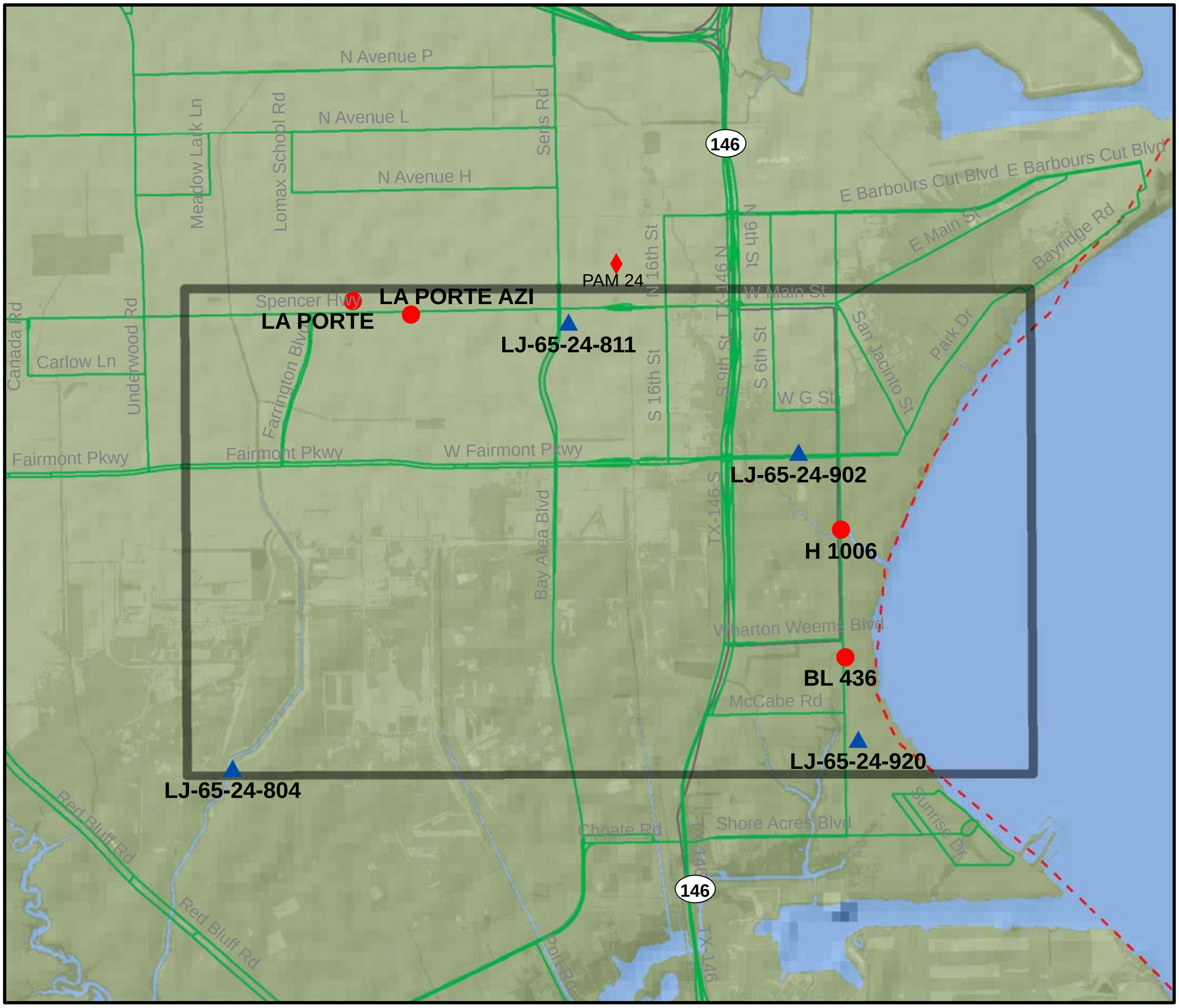
Q.4.1 Benchmarks. Data from five benchmarks will be used in the current study:

- LA PORTE;
- LA PORTE ZAI;
- H 1006;
- BL 436; and
- PAM 24 ARP.

Locations of the benchmarks are shown on Plate Q-1 and subsidence data are presented on Plate Q-3. Four benchmarks were used in the previous recalibration study (Fugro 1997). A limited amount of data from benchmark PAM 24 ARP – two points from 2005 and 2007, respectively – was added for this study. There is a significant gap of approximately 1.5 ft in the data from benchmarks LA PORTE and H 1006, so we applied a vertical shift to the PAM 24 ARP data of 7.3 feet, an approximate average of the other available subsidence data.

Q.4.2 PAM Station. Data from PAM station 24, also presented on Plate Q-3, will be used for recalibration efforts in this study. The location of PAM 24 is presented on Plate Q-1. Data from PAM 24 start in the year 2002. After the review of other subsidence data described in *Section Q.4.1* as related to benchmark PAM 24 ARP, we applied a vertical offset of 7.3 ft to the PAM data.

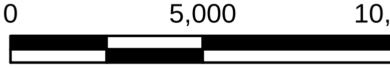
Q.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate Q-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

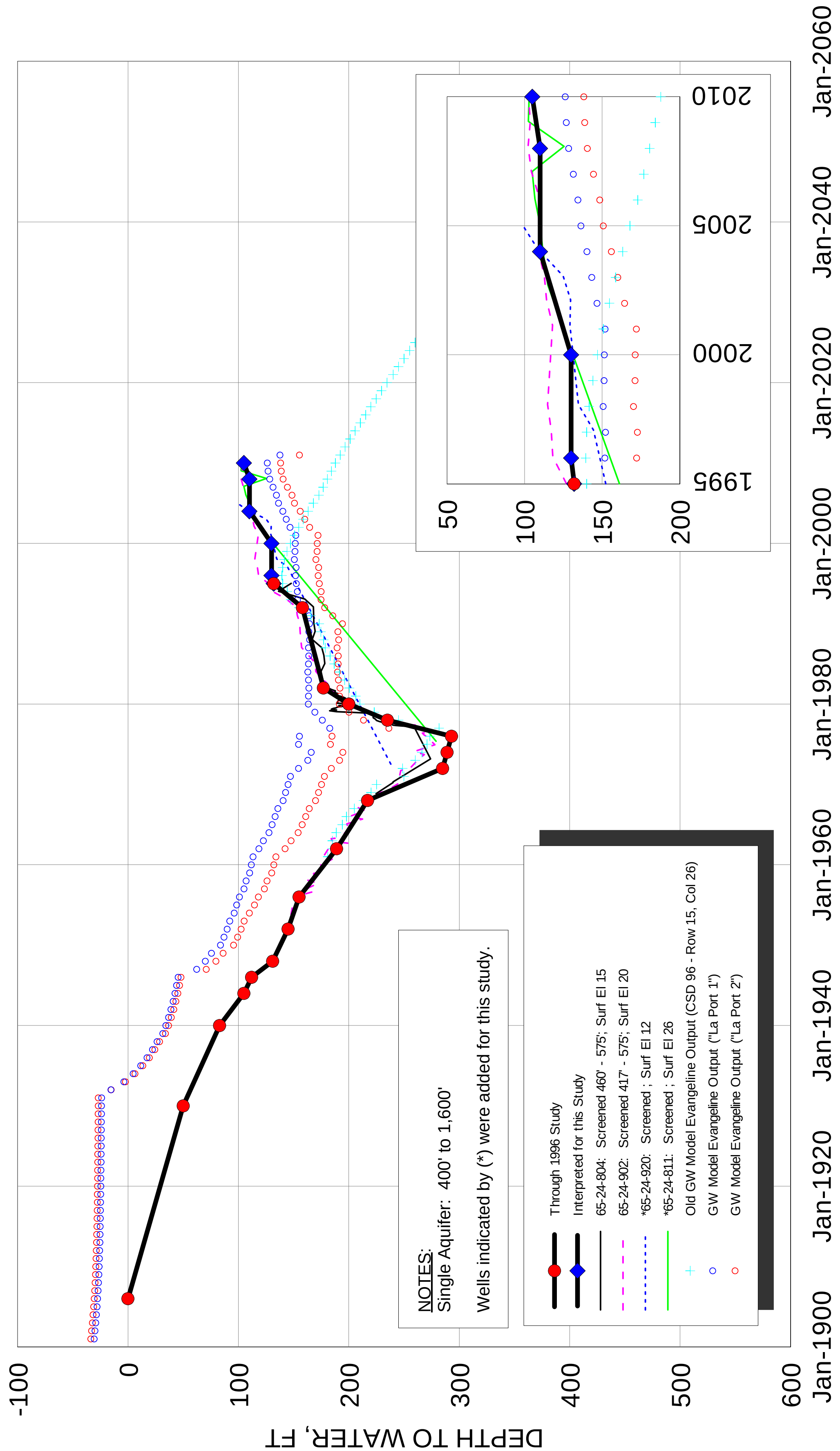
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ☐ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.



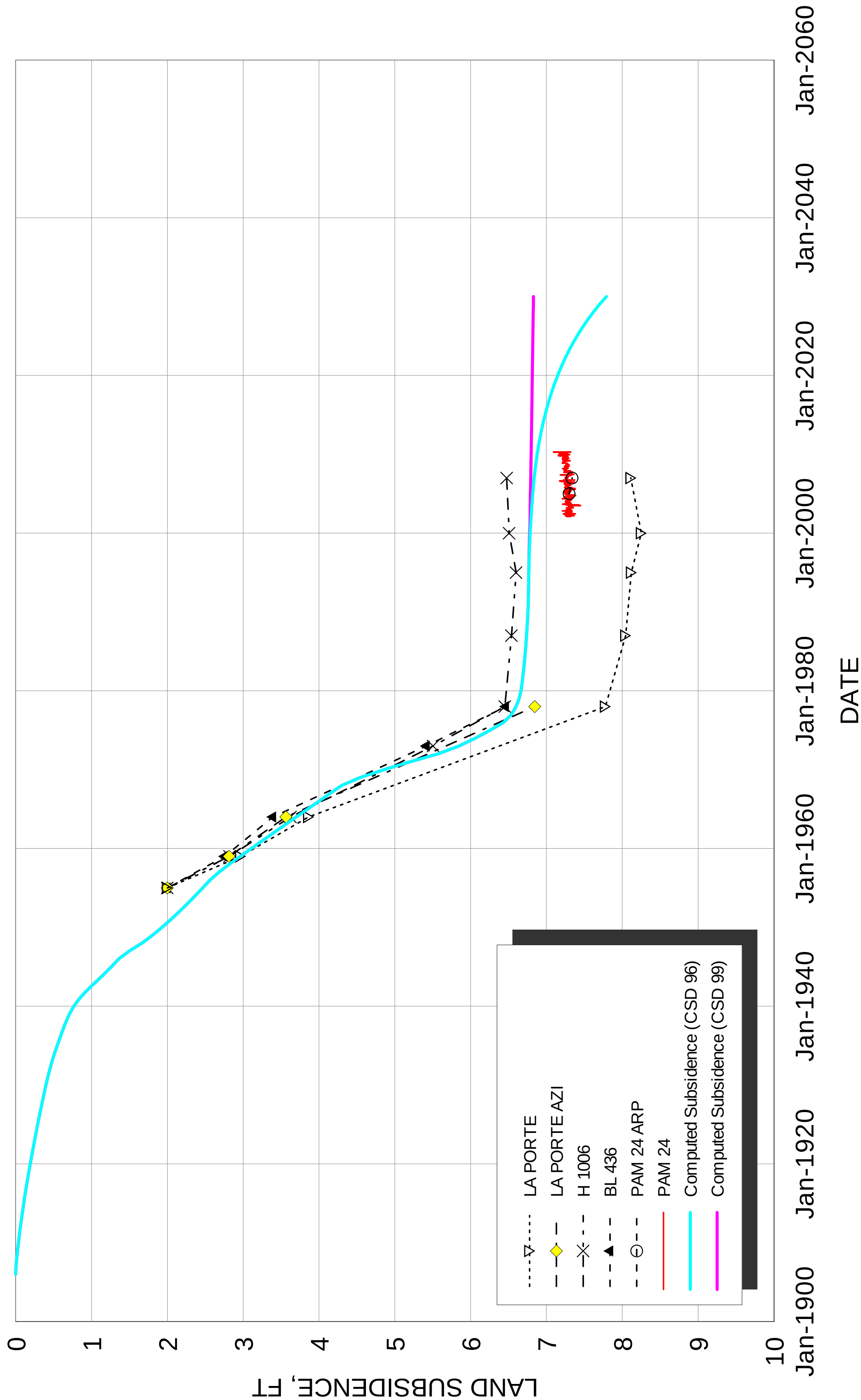
SITE MAP
LA PORTE PRESS SITE

PLATE Q-1



HYDROGRAPHS FOR LA PORTE SITE
SINGLE MODEL AQUIFER

PLATE Q-2



COMPUTED AND MEASURED SUBSIDENCE
LA PORTE SITE

PLATE Q-3

R: LANGHAM CREEK SITE

R.1 Introduction

The Langham Creek site covers one ninth in the Cypress Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate R-1. The Langham Creek PRESS site was created as part of the previous recalibration study (Fugro 1997). The site boundaries shown on Plate R-1 are consistent with those developed previously.

R.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 250 to 348 ft
	Lower: 550 to 1,034 ft
Bottom of Compacting Interval:	1,192 ft
Bottom of Chicot Aquifer:	640 ft
Bottom of Evangeline Aquifer:	1,630 ft

R.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

R.3.1 Wells. We have chosen nine wells to use for the Langham Creek site in this study. In addition to the five wells used in the previous recalibration study, and after consultation with LBG-Guyton, we have added the following four wells not previously used for calibration:

- M.U.D. 264 Well #1 (model lower aquifer);
- M.U.D. 264 Well #2 (model upper aquifer);
- M.U.D. 70 Well #2 and
- M.U.D. 165 Well #1 (model upper aquifer).

Locations of all wells are included in the detailed Langham Creek PRESS site map presented on Plate R-1. Data from the four wells added for this study are from private sources and were provided by LBG-Guyton. We assumed a ground surface elevation of 134 ft when vertically translating all well data for this site.

As was the case in the previous recalibration study, there are no well data available for the model upper aquifer. The three wells shown on Plate R-2 – LJ-65-03-606, LJ-65-11-203 and -204 – have no data available after 1970. They are provided for reference. The remaining six wells are screened in the model lower aquifer, as shown on Plate R-3.

R.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Langham Creek site. The outputs are referred to as “Langham Creek 1” and “Langham Creek 2” in the information provided by LBG-Guyton. “Langham Creek 1” is from a location of latitude 29°53’19.2”N and longitude 95°41’35.0”W. “Langham Creek 2” is from a location of latitude 29°51’25.7” and longitude 95°41’12.3”. We assumed a ground surface elevation of 134 feet when vertically translating this output.

R.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997). We continued trends established in the previous study when extending the design hydrographs for the model upper and lower aquifers to the year 2010. For the model upper aquifer, we generally followed the provided groundwater model output. Recorded groundwater levels are highly dependent on screen depth in the area of the Langham Creek PRESS site. After consultation with LBG-Guyton, we followed well LJ-65-03-810 to extend the site hydrograph for the model lower aquifer to 2010. The old and new portions of the upper and lower model aquifer design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

R.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

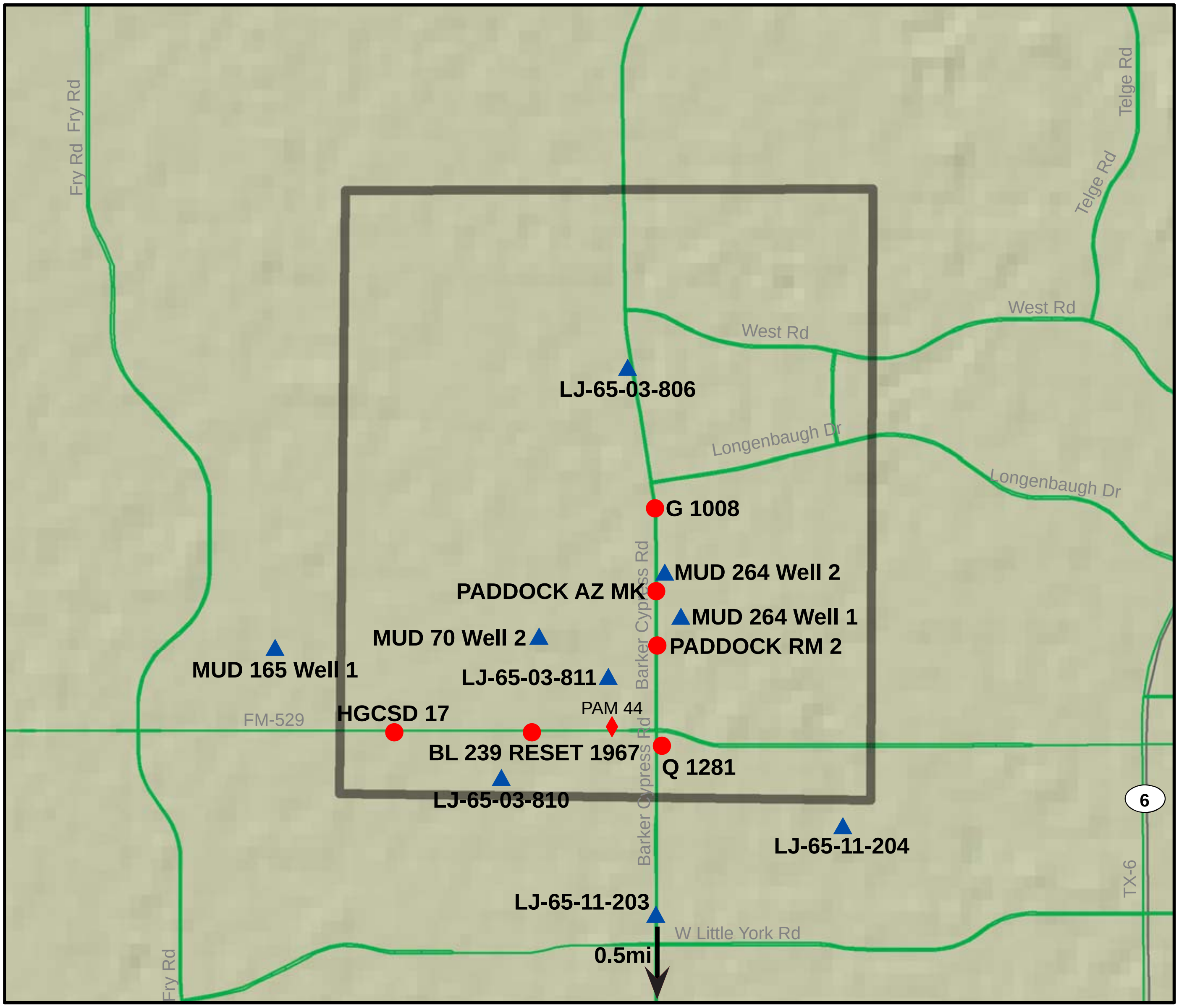
R.4.1 Benchmarks. Data from six benchmarks will be used in the current study:

- G 1008;
- PADDOCK AZ MK;
- PADDOCK RM2;
- Q 1281;
- BL 239 RESET 1967; and
- HGCSD 17.

Locations of the benchmarks are shown on Plate R-1 and subsidence data are presented on Plate R-3. Five benchmarks were used in the previous recalibration study (Fugro 1997). A limited amount of data from benchmark HGCSD – two points from 1995 and 2000, respectively – was added for this study. Based on a review of the other subsidence data available at the site, we applied a vertical shift of 2.6 ft to the data for HGCSD 17 in the year 1995.

R.4.2 PAM Station. Data from PAM station 44, also presented on Plate R-4, will be used for recalibration efforts in this study. The location of PAM 44 is presented on Plate R-1. Data from PAM 44 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on review of other subsidence data sources available, we applied a vertical offset of 4.1 ft to the PAM data.

R.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate R-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

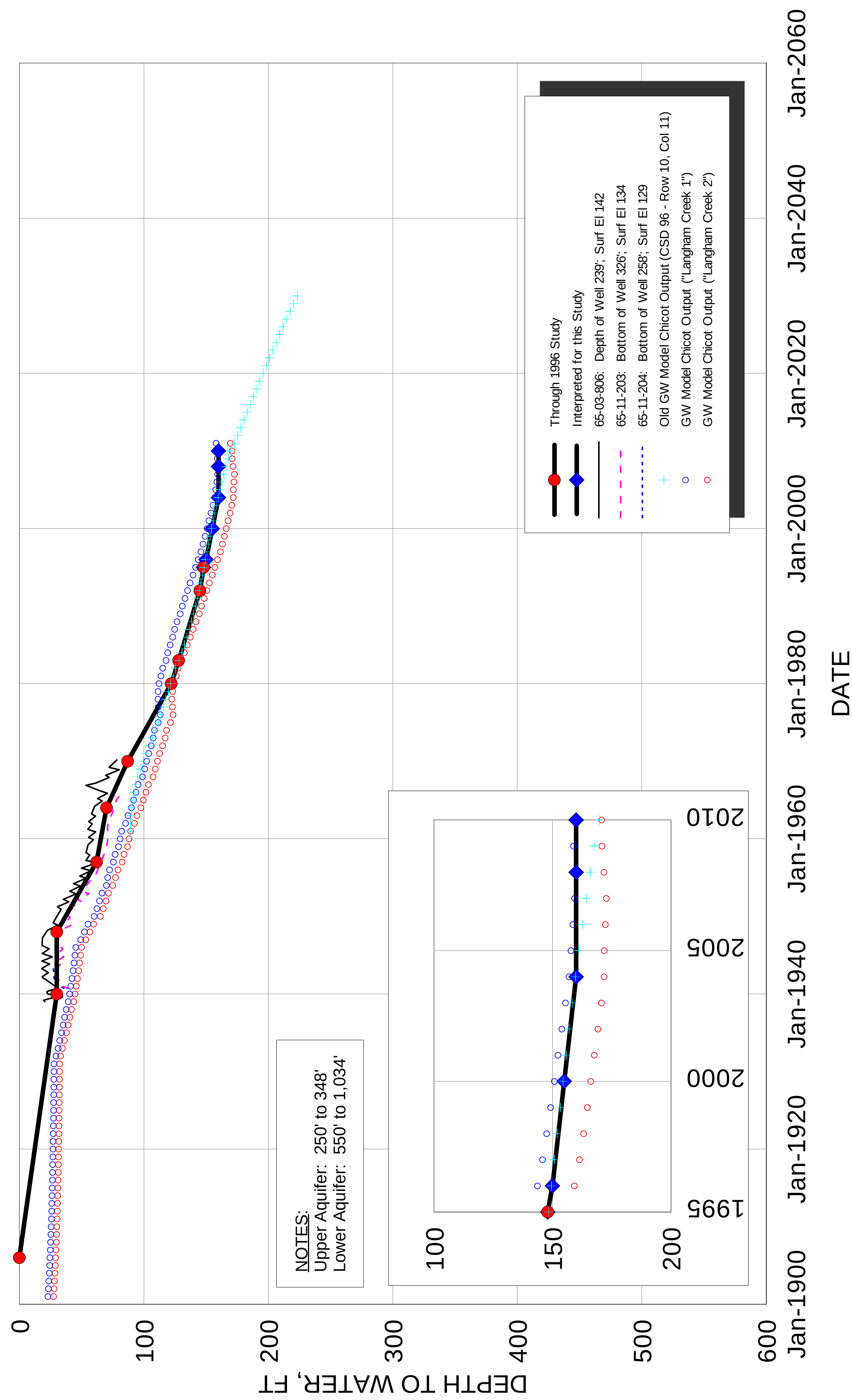
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 4,000 8,000 Feet

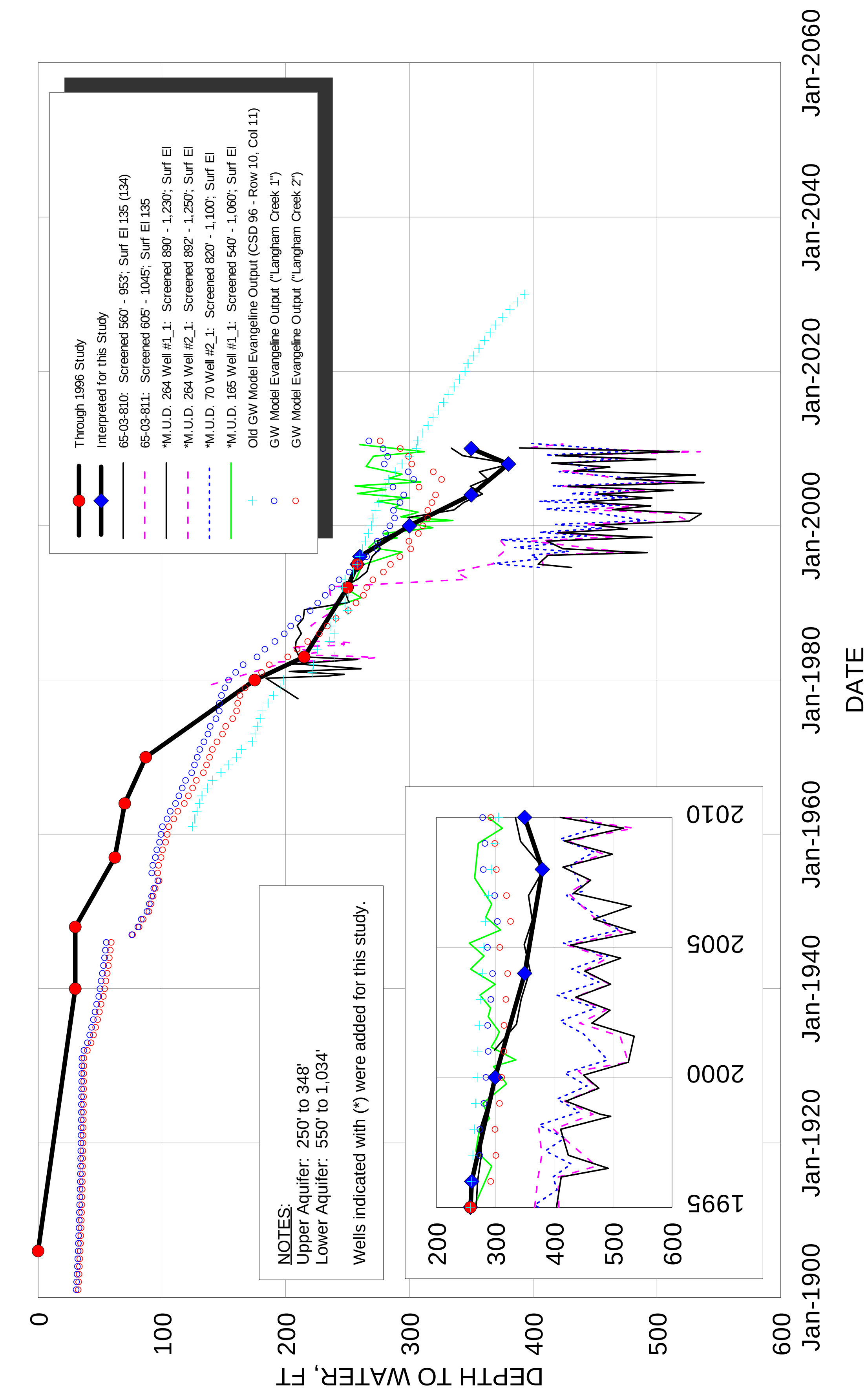
SITE MAP
LANGHAM CREEK PRESS SITE

PLATE R-1



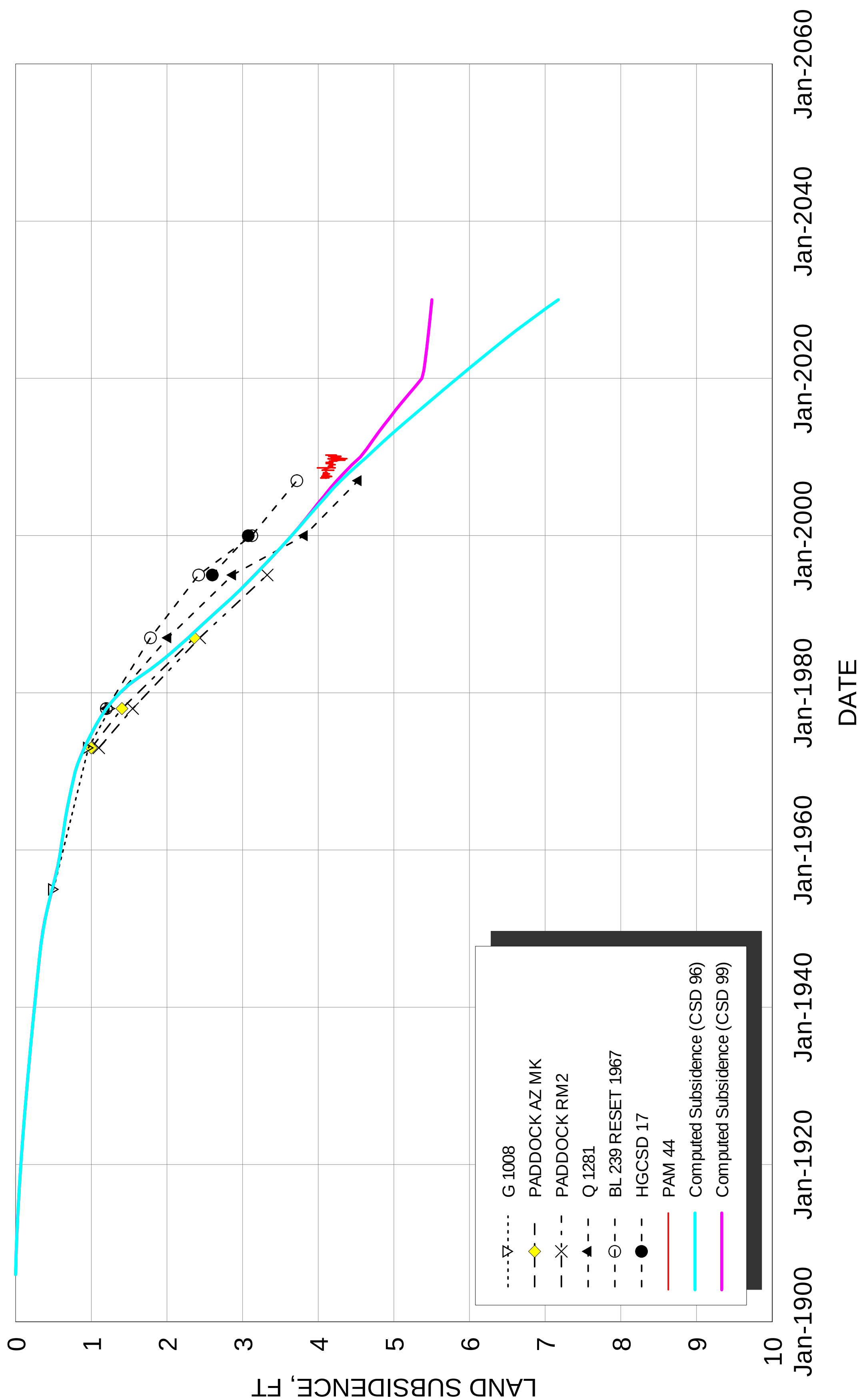
HYDROGRAPHS FOR LANGHAM CREEK SITE
MODEL UPPER AQUIFER

PLATE R-2



HYDROGRAPHS FOR LANGHAM CREEK SITE
MODEL LOWER AQUIFER

PLATE R-3



COMPUTED AND MEASURED SUBSIDENCE
LANGHAM CREEK SITE

PLATE R-4

S: LONG POINT SITE

S.1 Introduction

The Long Point site covers one ninth of the Hedwig Village and one ninth of the Houston Heights Topographic Quadrangles, as shown in general on Plate 1 and in greater detail on Plate S-1. The site boundaries are consistent with the previous recalibration study (Fugro 1997).

S.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 390 to 650 ft
	Lower: 680 to 1,800 ft
Bottom of Compacting Interval:	1,650 ft
Bottom of Chicot Aquifer:	About 600 to 700 ft
Bottom of Evangeline Aquifer:	About 1,800 to 2,300 ft

S.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

S.3.1 Wells. We have chosen eight wells to use for the Long Point site in this study. In addition to the seven wells used in the previous recalibration study, and after consultation with LBG-Guyton, we have added well LJ-65-12-801 to this study for reference in the model upper aquifer. Locations of all wells are included in the detailed Long Point PRESS site map presented on Plate S-1. We assumed a ground surface elevation of 74 ft when vertically translating all well data for this site.

Three of the eight wells used for the Long Point PRESS site are screened in the model upper aquifer, as shown on Plate S-2. Of these three, only LJ-65-12-801, added for this study, has data available after 1995. Wells LJ-65-12-502 and -917 were discontinued as monitoring wells prior to 1995. The other five wells in the Long Point PRESS site are screened in the model lower aquifer, as shown on Plate S-3.

S.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Long Point site. The outputs are referred to as “Long Point 1” and “Long Point 2” in the information provided by LBG-Guyton. “Long Point 1” is from a location of latitude 29°46’25.7”N and longitude 95°28’35.6”W. “Long Point 2” is from a location of latitude 29°46’6.3” and longitude 95°30’48.0”. We assumed a ground surface elevation of 74 feet when vertically translating this output.

S.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997). The site hydrograph for the model upper aquifer was previously developed based primarily on water levels obtained from well LJ-65-12-502. As mentioned previously, this well was discontinued as a monitoring well prior to 1995. To extend the design hydrograph for the model upper aquifer to 2010, we generally follow the trends shown in well LJ-65-12-801, added for this study, as well as the updated groundwater model output provided for the Long Point site.

We continued the trend established in the previous study to extend the model lower aquifer design hydrograph to the year 2010. We generally followed well LJ-65-12-701 through 2007, after which there are no readings for -701. The updated groundwater model output generally follows LJ-65-12-701 after 1995, so we followed the groundwater model output to complete the model lower aquifer design hydrograph.

The old and new portions of the upper and lower model aquifer design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

S.4 Subsidence Data

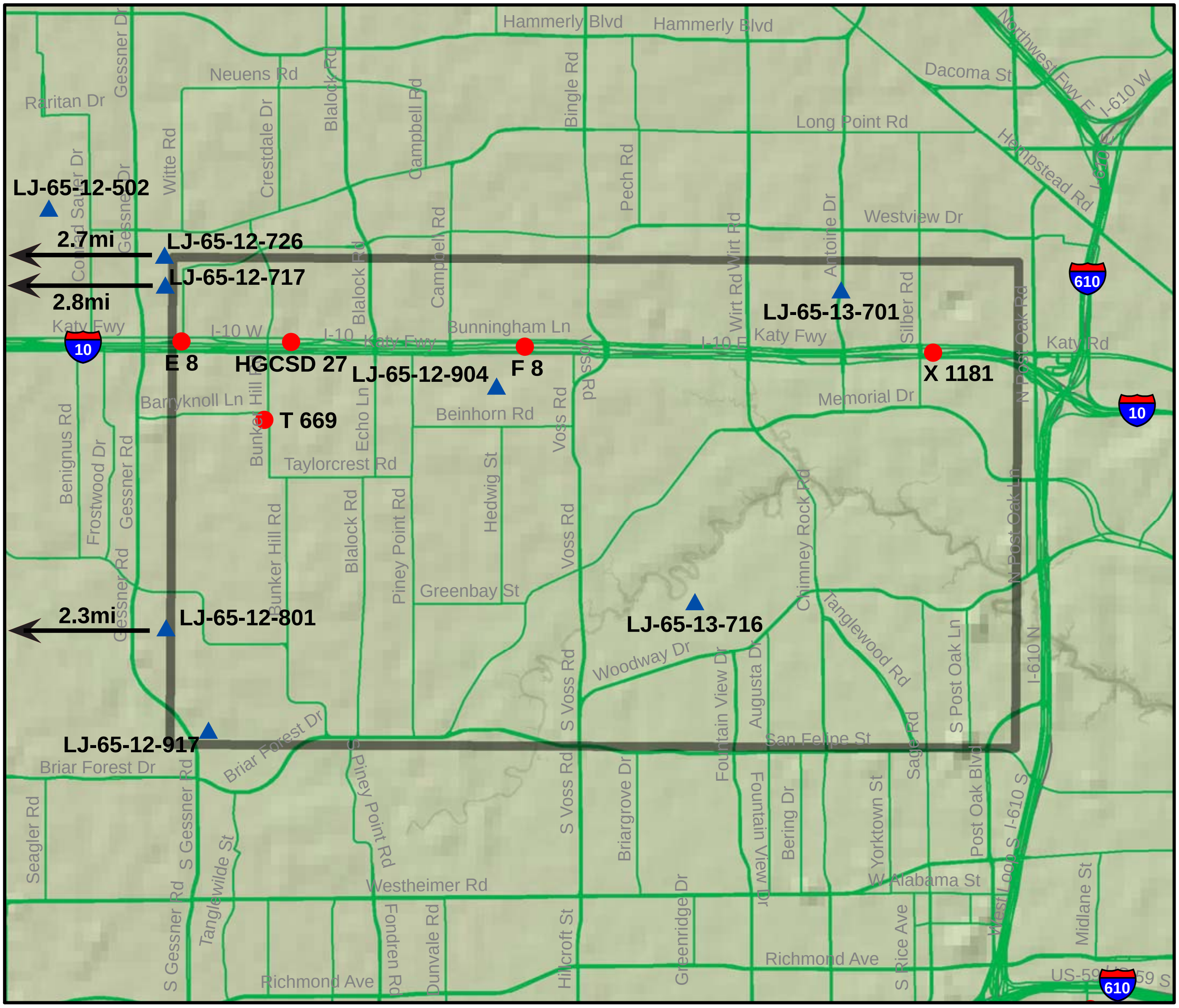
Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

S.4.1 Benchmarks. Data from five benchmarks will be used in the current study:

- E 8;
- T 669;
- F 8;
- X 1181; and
- HGCSD 27.

Locations of the benchmarks are shown on Plate S-1 and subsidence data are presented on Plate S-4. Four benchmarks were used in the previous recalibration study (Fugro 1997). Benchmark HGCSD 27 was added for this study and, with a vertical offset of 5.0 ft applied to data in the year 1987, agrees well with other subsidence data for the Long Point PRESS site.

S.4.2 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate S-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

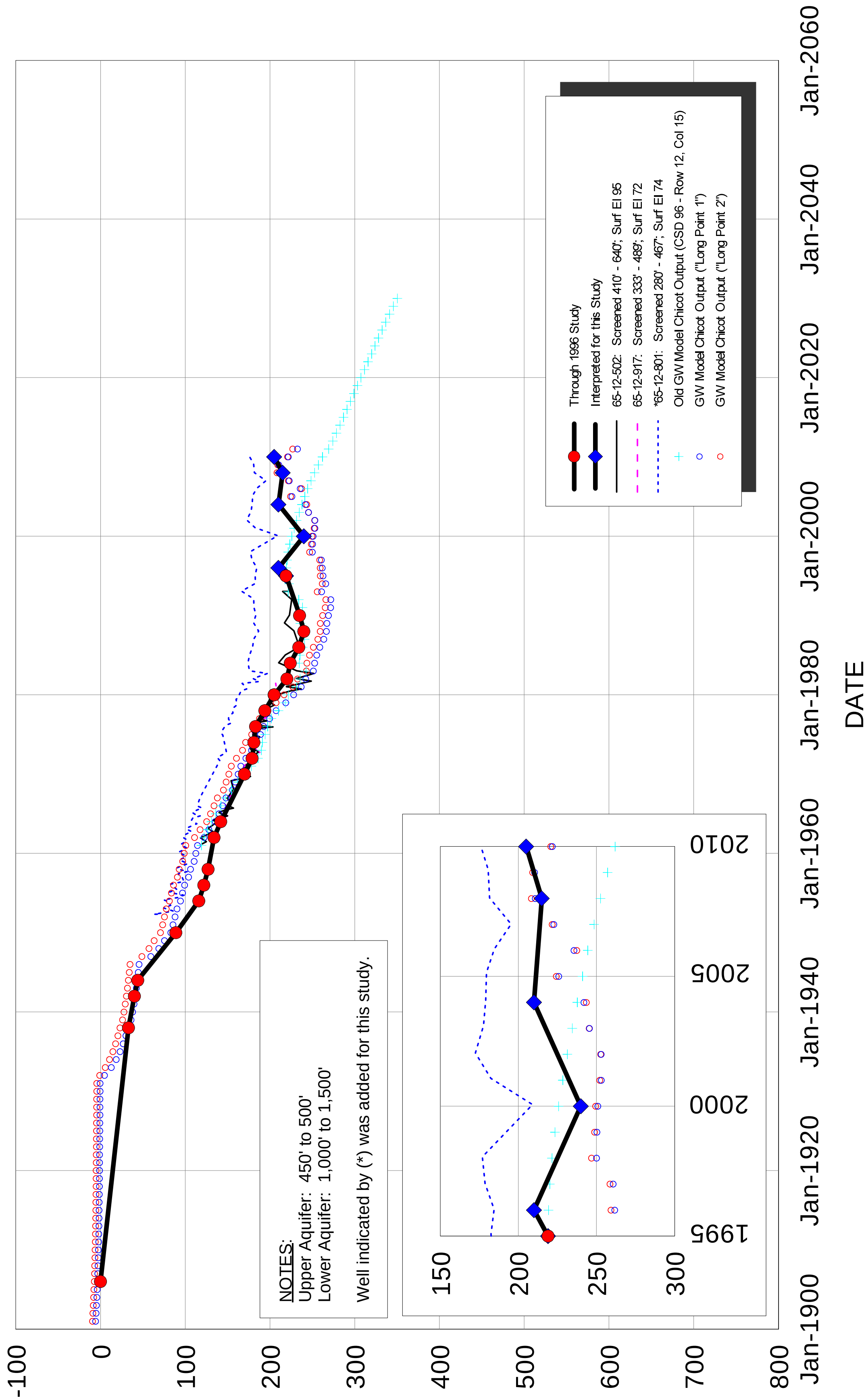
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▭ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 5,000 10,000 Feet

SITE MAP
LONG POINT PRESS SITE

PLATE S-1



HYDROGRAPHS FOR LONG POINT SITE
MODEL UPPER AQUIFER

PLATE S-2

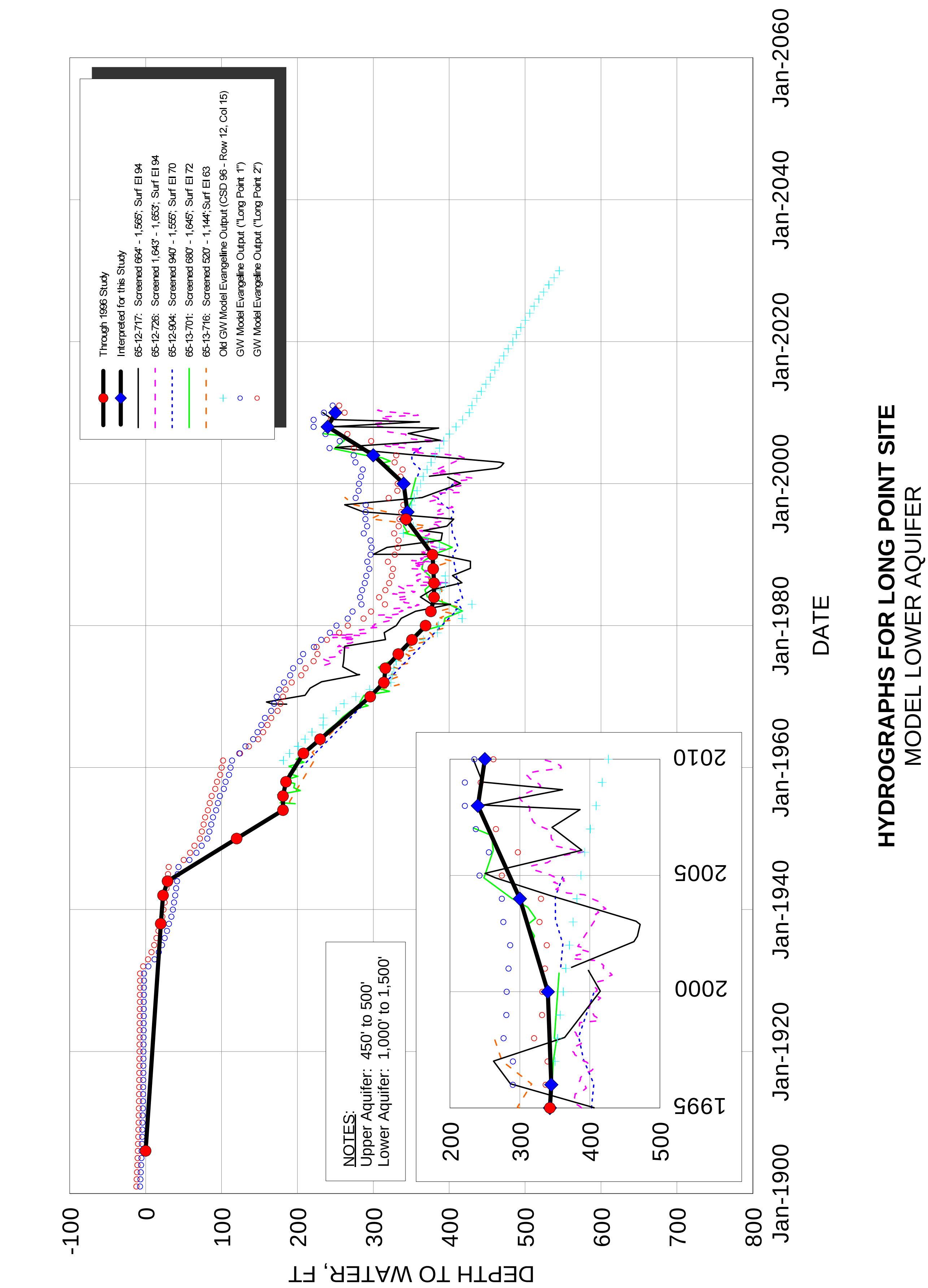
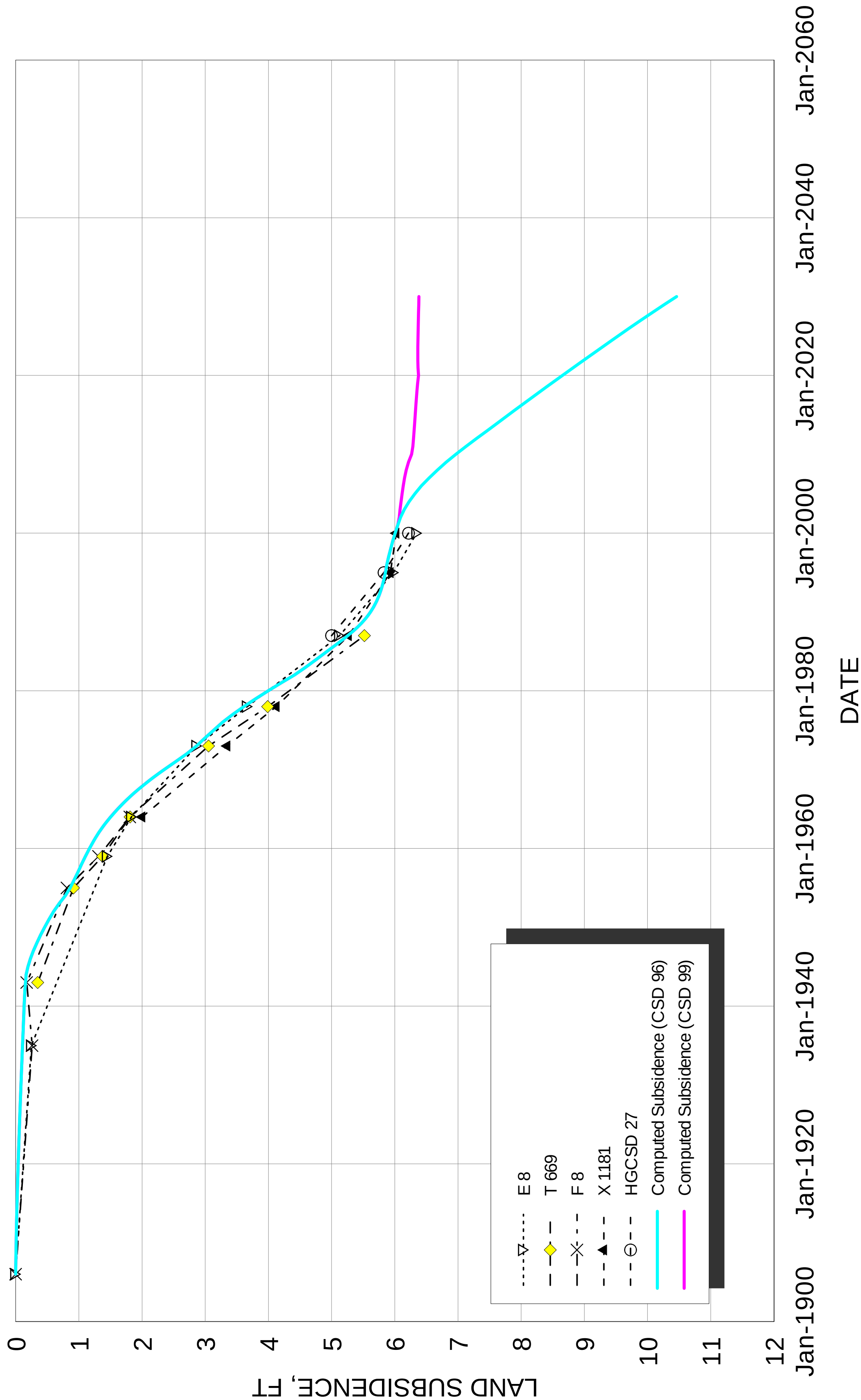

HYDROGRAPHS FOR LONG POINT SITE
MODEL LOWER AQUIFER
DEPTH TO WATER, FT
DATE
-100
0
100
200
300
400
500
600
700
800
Jan-1900
Jan-1920
Jan-1940
Jan-1960
Jan-1980
Jan-2000
Jan-2020
Jan-2040
Jan-2060
Through 1996 Study
Interpreted for this Study
65-12-717: Screened 664' - 1,565'; Surf El 94
65-12-726: Screened 1,643' - 1,653'; Surf El 94
65-12-904: Screened 940' - 1,555'; Surf El 70
65-13-701: Screened 680' - 1,645'; Surf El 72
65-13-716: Screened 520' - 1,144'; Surf El 63
Old GW Model Evangeline Output (CSD 96 - Row 12, Col 15)
GW Model Evangeline Output ("Long Point 1")
GW Model Evangeline Output ("Long Point 2")
NOTES:
Upper Aquifer: 450' to 500'
Lower Aquifer: 1,000' to 1,500'
200
300
400
500
1995
2000
2005
2010

PLATE S-3



COMPUTED AND MEASURED SUBSIDENCE
LONG POINT SITE

PLATE S-4

T: NASA SITE

T.1 Introduction

The NASA site includes one ninth of the Friendswood Topographic Quadrangle and two ninths of the League City Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate T-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

T.2 Aquifer

The NASA site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	465 to 1,500 ft
Bottom of Compacting Interval:	2,000 ft
Bottom of Chicot Aquifer:	About 600 ft
Bottom of Evangeline Aquifer:	About 3,500 to 4,000 ft

T.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

T.3.1 Wells. For this study, we have selected 23 wells to use for the NASA site. In addition to the 18 wells used in the previous recalibration study, and after consultation with LBG-Guyton, we have added the following five wells not previously used for calibration:

- LJ-65-32-405;
- LJ-65-32-425;
- LJ-65-32-427;
- LJ-65-32-430; and
- LJ-65-32-701.

Locations of all wells are included in the detailed NASA PRESS site map presented on Plate T-1. Four wells – LJ-65-32-404, -415, -714 and -716 – were discontinued as monitoring wells prior to 1995 but are included on Plate T-2 for reference. We assumed a ground surface elevation of 25 ft when vertically translating all well data for this site.

T.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the NASA site. The outputs are referred to as “NASA 1” and “NASA 2” in the information provided by LBG-Guyton. “NASA 1” is from a location of latitude 29°33’54.9”N and longitude 95°7’24.0”W. “NASA 2” is from a location of latitude 29°31’13.4” and longitude 95°6’31.2”. We assumed a ground surface elevation of 25 feet when vertically translating this output.

T.3.3 Design Hydrograph. We used the site hydrograph presented in the previous recalibration effort (Fugro 1997) for dates through 1995. To extend the site hydrograph to 2010, we generally followed a visual average of the data available for active wells and the updated groundwater model output provided for the NASA site. Consistent with the previous study, we essentially ignored the hydrograph for well LJ-65-32-702 in making our interpretations due to questions on the precision of readings for this well. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

T.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

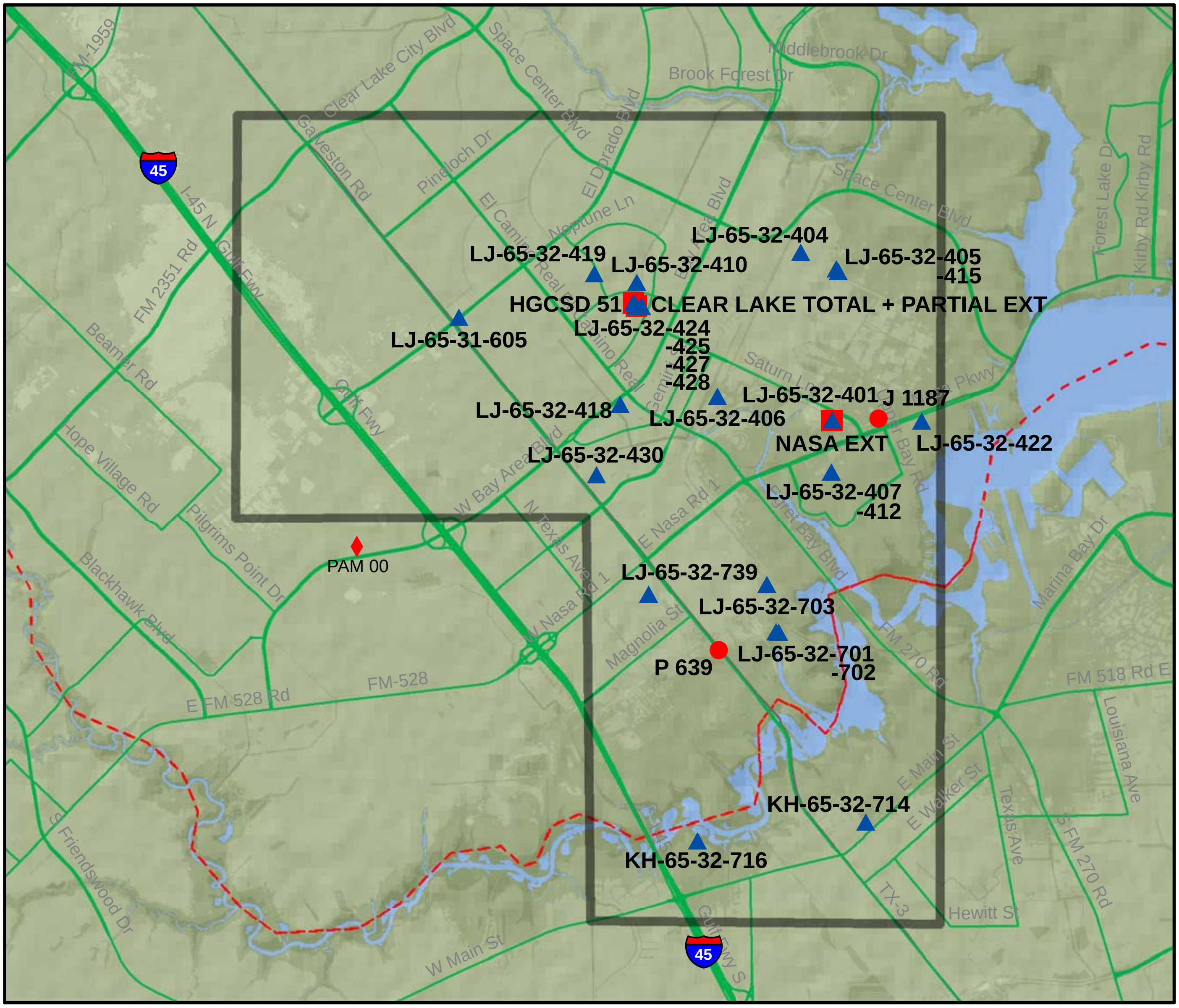
T.4.1 Benchmarks. Data from four benchmarks will be used in the current study:

- P 639;
- J 1187;
- HGCSD 51; and
- PAM 00 ARP.

Locations of the benchmarks are shown on Plate T-1 and subsidence data are presented on Plate T-3. Three benchmarks were used in the previous recalibration study (Fugro 1997). Benchmark PAM 00 ARP was added for this study and, based on a review of other subsidence data available for the NASA site, a vertical offset of 5.1 ft was applied to data starting in the year 1995.

T.4.2 Extensometers. Data from three extensometers – LJ-65-32-401 or “Clear Lake Partial”, LJ-65-32-428 or “Clear Lake Total”, and “NASA Partial” – will be used for comparison to the PRESS model output. The Clear Lake extensometers were presented and referenced for the previous recalibration effort, but the NASA Partial extensometer has been added for this study. After a review of the other subsidence data available, a vertical offset of 4.05 ft was applied to the NASA Partial extensometer data, which starts in the year 1973. The locations of all extensometers are shown on Plate T-1, and data from the extensometers are presented on Plate T-3.

T.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate T-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

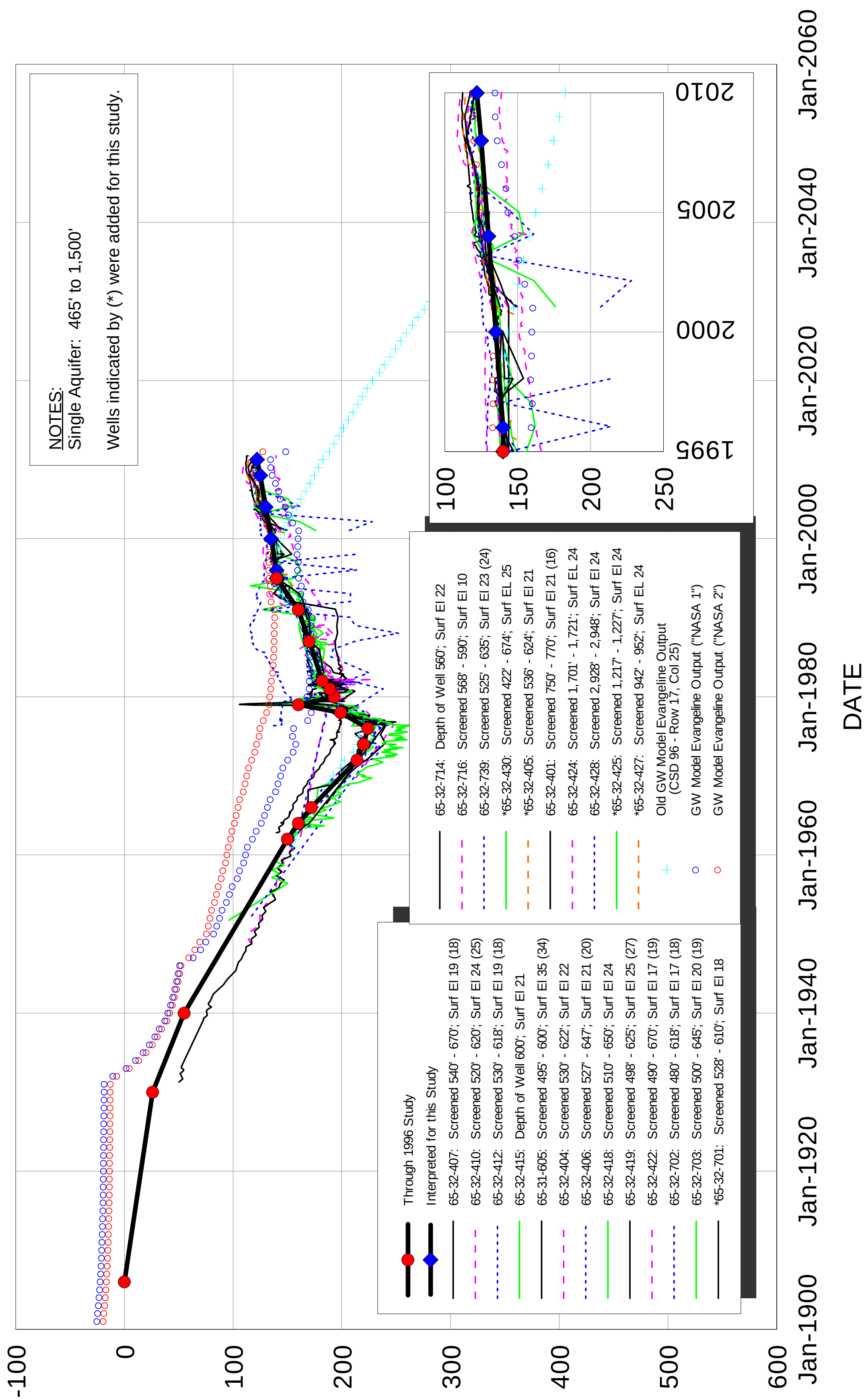
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

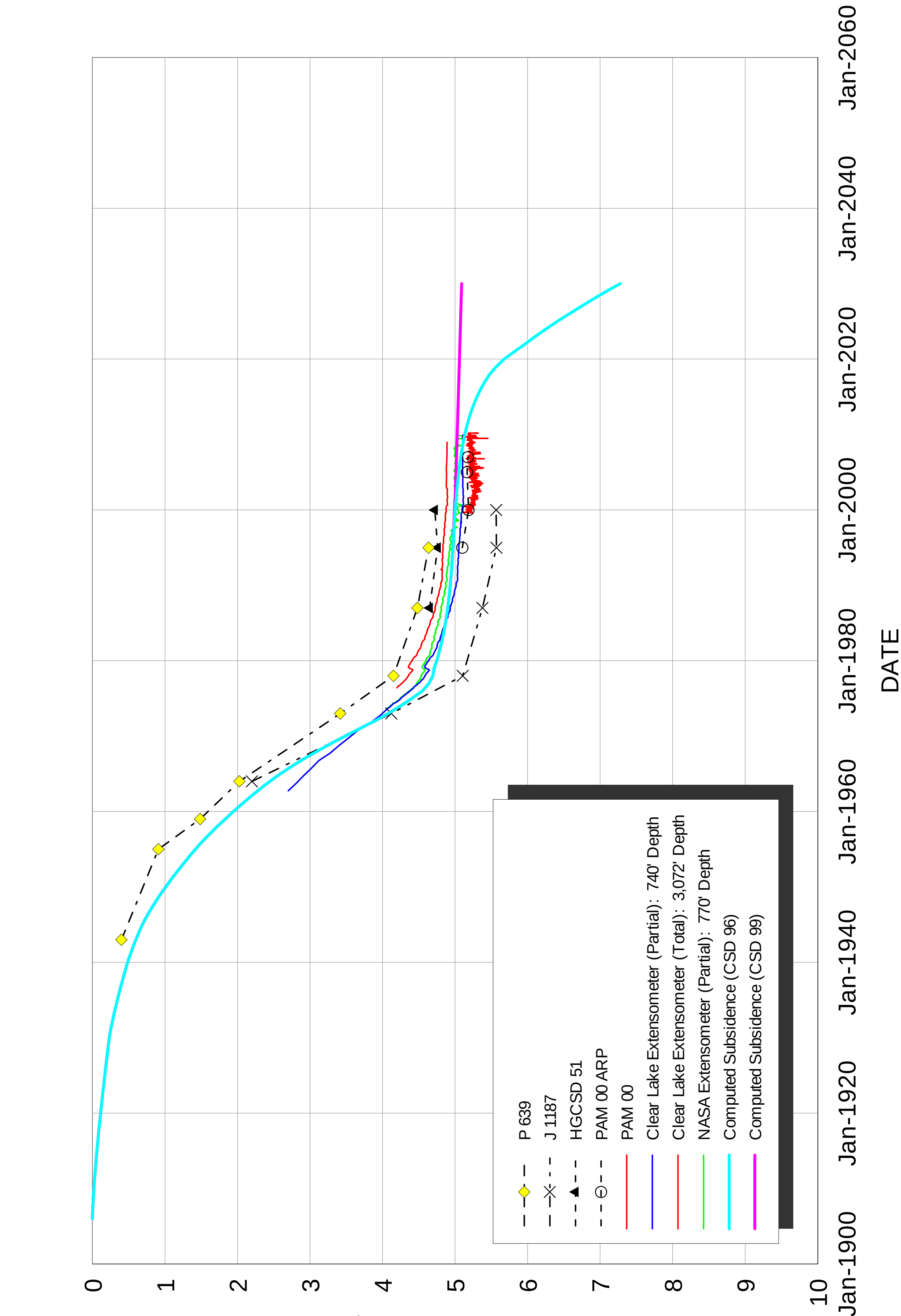
0 6,000 12,000 Feet

SITE MAP
NASA PRESS SITE

PLATE T-1



HYDROGRAPHS FOR NASA SITE
SINGLE MODEL AQUIFER



COMPUTED AND MEASURED SUBSIDENCE
NASA SITE

PLATE T-3

U: NEEDVILLE SITE

U.1 Introduction

The Needville site includes one ninth in the southwest corner of the Needville Topographic Quadrangle and two ninths in the northwest area of the Guy Topographic Quadrangle. A general site location is shown on Plate 1 and detail site map is presented on Plate U-1. The site boundaries are consistent with the previous recalibration study (Fugro 1998).

U.2 Aquifer

The Needville site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	80 to 410 ft
Bottom of Compacting Interval:	1,800 ft
Bottom of Chicot Aquifer:	About 700 ft
Bottom of Evangeline Aquifer:	About 2,500 ft

U.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

U.3.1 Wells. For this study, we have selected 19 wells to use for the Needville site. In addition to the 16 wells used in the previous recalibration study, and after consultation with LBG-Guyton, we have added the following three wells not previously used for calibration:

- LJ-65-42-501;
- LJ-65-33-801; and
- LJ-65-33-803.

Locations of all wells are included in the detailed Needville PRESS site map presented on Plate U-1. Of the 16 wells referenced in the previous study, only two have water level readings after 1995 – LJ-65-34-701 and -702. The other 14 wells were discontinued as monitoring wells prior to 1995 but are included on Plate U-2 for reference. We assumed a ground surface elevation of 85 ft when vertically translating all well data for this site.

U.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Needville site. The outputs are referred to as “Needville-1” and “Needville-2” in the information provided by LBG-Guyton. “Needville-1” is from a location of latitude 29°22’54.4”N and longitude 95°51’3.7”W. “NASA 2” is from a location of latitude 29°20’45.2” and longitude 95°49’15.0”. We assumed a ground surface elevation of 85 feet when vertically translating this output.

U.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1997). To extend the site hydrograph to 2010, we followed the trend established in previous studies and used well LJ-65-34-701 as a primary basis for our design hydrograph. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

U.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

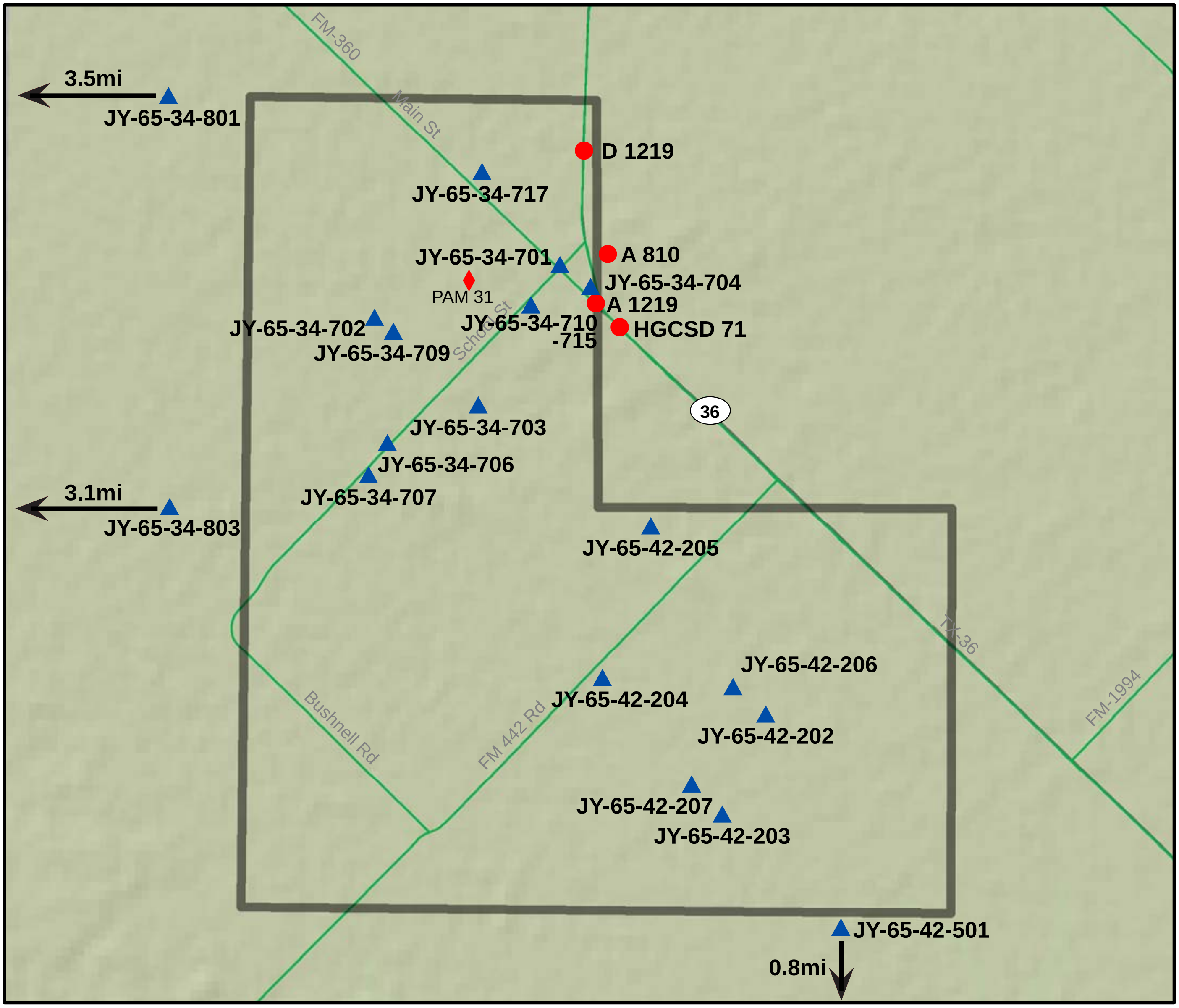
U.4.1 Benchmarks. Consistent with the previous recalibration study, data from four benchmarks will be used in the current study:

- A 810;
- A 1219;
- D 1219; and
- HGCSD 71.

Locations of the benchmarks are shown on Plate U-1 and subsidence data are presented on Plate U-3.

U.4.2 PAM Station. Data from PAM station 31, also presented on Plate U-3, will be used for recalibration efforts in this study. The location of PAM 31 is presented on Plate U-1. Data from PAM 31 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on review of other subsidence data sources available, we applied a vertical offset of 0.85 ft to the PAM data.

U.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenario CSD 96 is presented on Plate U-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenario CSD 96 are included in *Section 3.5*.



Legend:

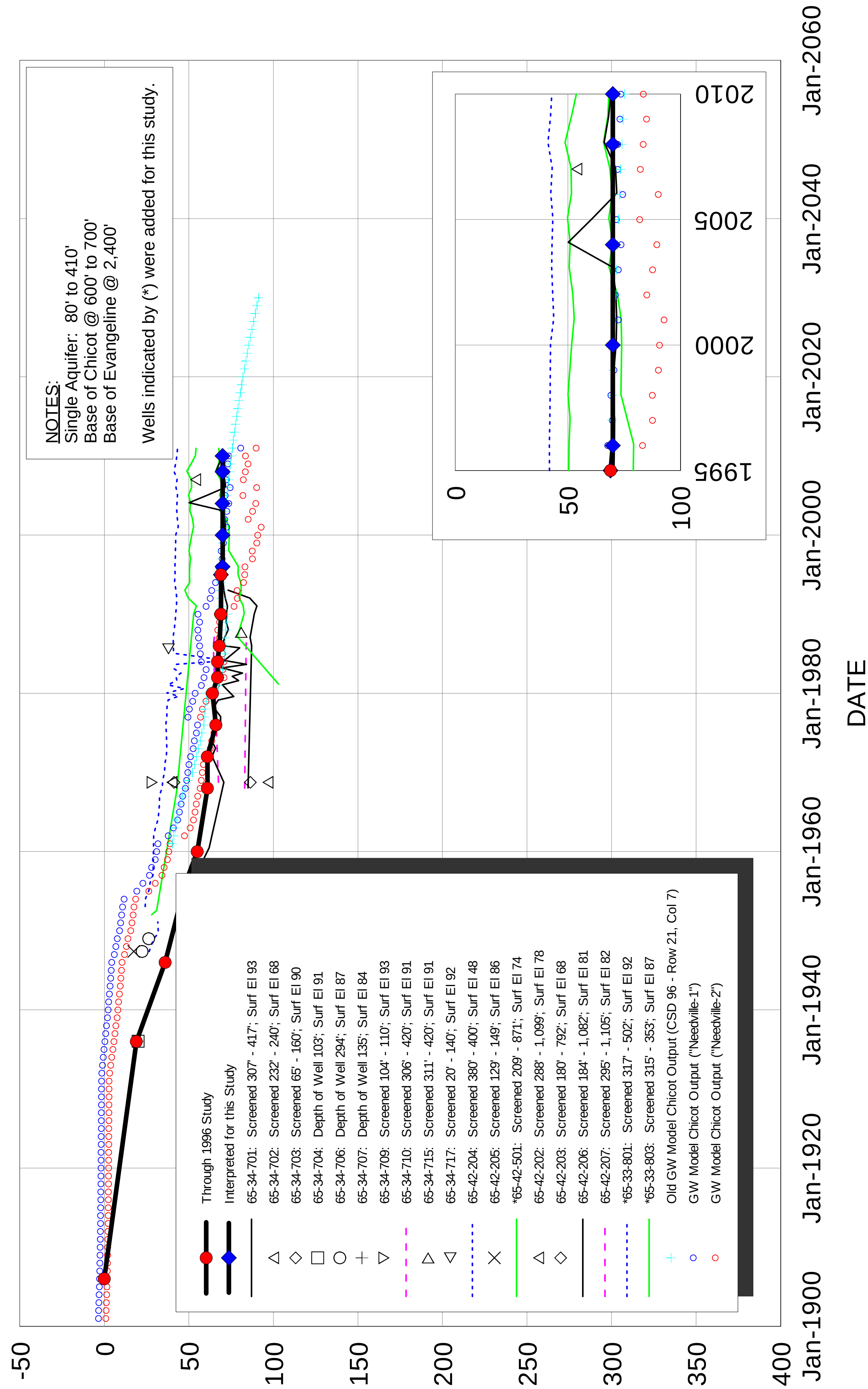
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 6,000 12,000 Feet

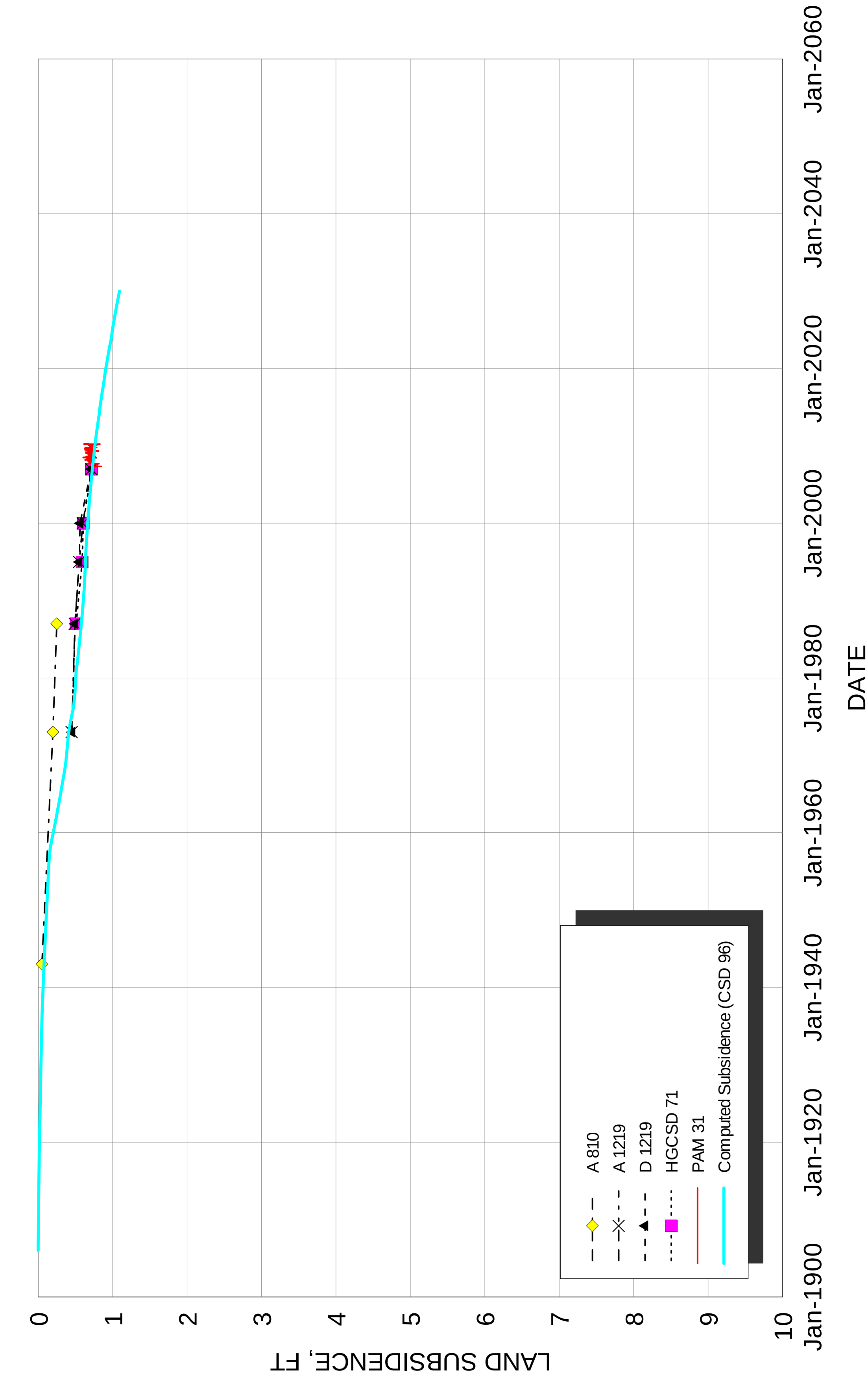
SITE MAP
NEEDVILLE PRESS SITE

PLATE U-1



HYDROGRAPHS FOR NEEDVILLE SITE
SINGLE MODEL AQUIFER

PLATE U-2



COMPUTED AND MEASURED SUBSIDENCE
NEEDVILLE SITE

PLATE U-3

V: NORTH HOUSTON SITE

V.1 Introduction

The North Houston site covers two ninths of the Settegast Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate V-1. The site boundaries are consistent with the previous recalibration study (Fugro 1997).

V.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 400 to 500 ft
	Lower: 950 to 2,000 ft
Bottom of Compacting Interval:	2,000 ft
Bottom of Chicot Aquifer:	About 500 to 600 ft
Bottom of Evangeline Aquifer:	About 1,800 to 2,300 ft

V.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

V.3.1 Wells. Consistent with the previous recalibration effort, we have chosen 13 wells to use for the North Houston site in this study. Locations of all wells are included in the detailed North Houston PRESS site map presented on Plate V-1. We assumed a ground surface elevation of 68 ft when vertically translating all well data for this site.

Three of the eight wells used for the Long Point PRESS site are screened in the model upper aquifer, as shown on Plate S-2. Of these three, only LJ-65-12-801, added for this study, has data available after 1995. Wells LJ-65-12-502 and -917 were discontinued as monitoring wells prior to 1995. The other five wells in the Long Point PRESS site are screened in the model lower aquifer, as shown on Plate S-3.

V.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the North Houston site. The outputs are referred to as “North Houston 1” and “North Houston 2” in the information provided by LBG-Guyton. “North Houston 1” is from a location of latitude 29°50’59.5”N and longitude 95°21’11.4”W. “North Houston 2” is from a location of latitude 29°51’15.7” and longitude 95°19’0.7”. We assumed a ground surface elevation of 68 feet when vertically translating this output.

V.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997). We continued the trend established in previous studies for the model upper aquifer and extended the design hydrograph to 2010 by generally following well LJ-65-14-203. Similarly, we generally selected a visual average of the well data available for the model lower aquifer, primarily focusing on wells LJ-65-14-101, -103, -403 and -404. The old and new portions of the upper and lower model aquifer design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

V.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

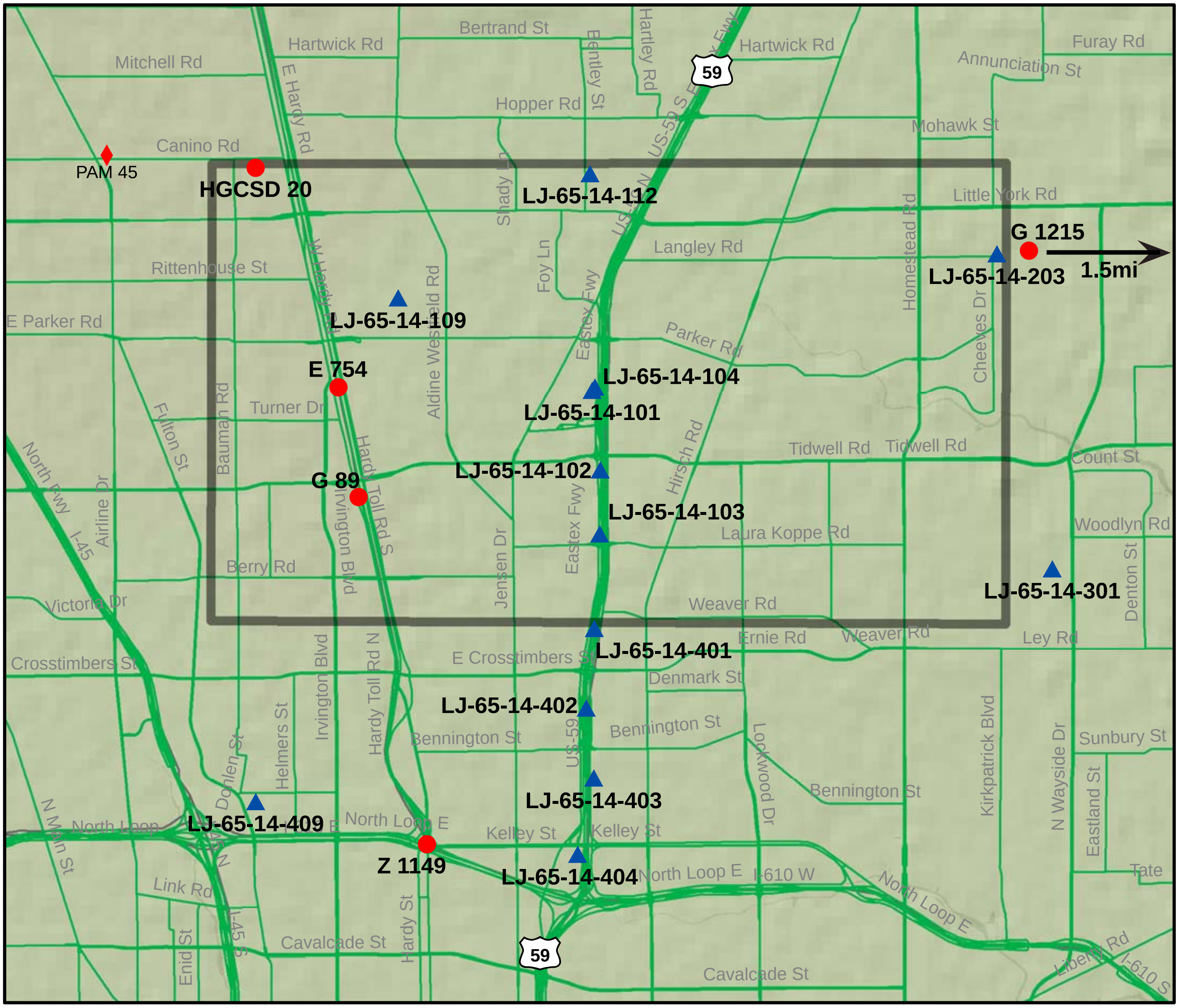
V.4.1 Benchmarks. Consistent with the previous recalibration study, data from five benchmarks will be used in the current study:

- G 89;
- E 754;
- Z 1149;
- G 1215; and
- HGCSD 20.

Locations of the benchmarks are shown on Plate V-1 and subsidence data are presented on Plate V-4.

V.4.2 PAM Station. Data from PAM station 45, also presented on Plate V-4, will be used for recalibration efforts in this study. The location of PAM 45 is presented on Plate V-1. Data from PAM 45 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on a review of other subsidence data sources available, we applied a vertical offset of 6.6 ft to the PAM data.

V.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate V-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*



Legend:

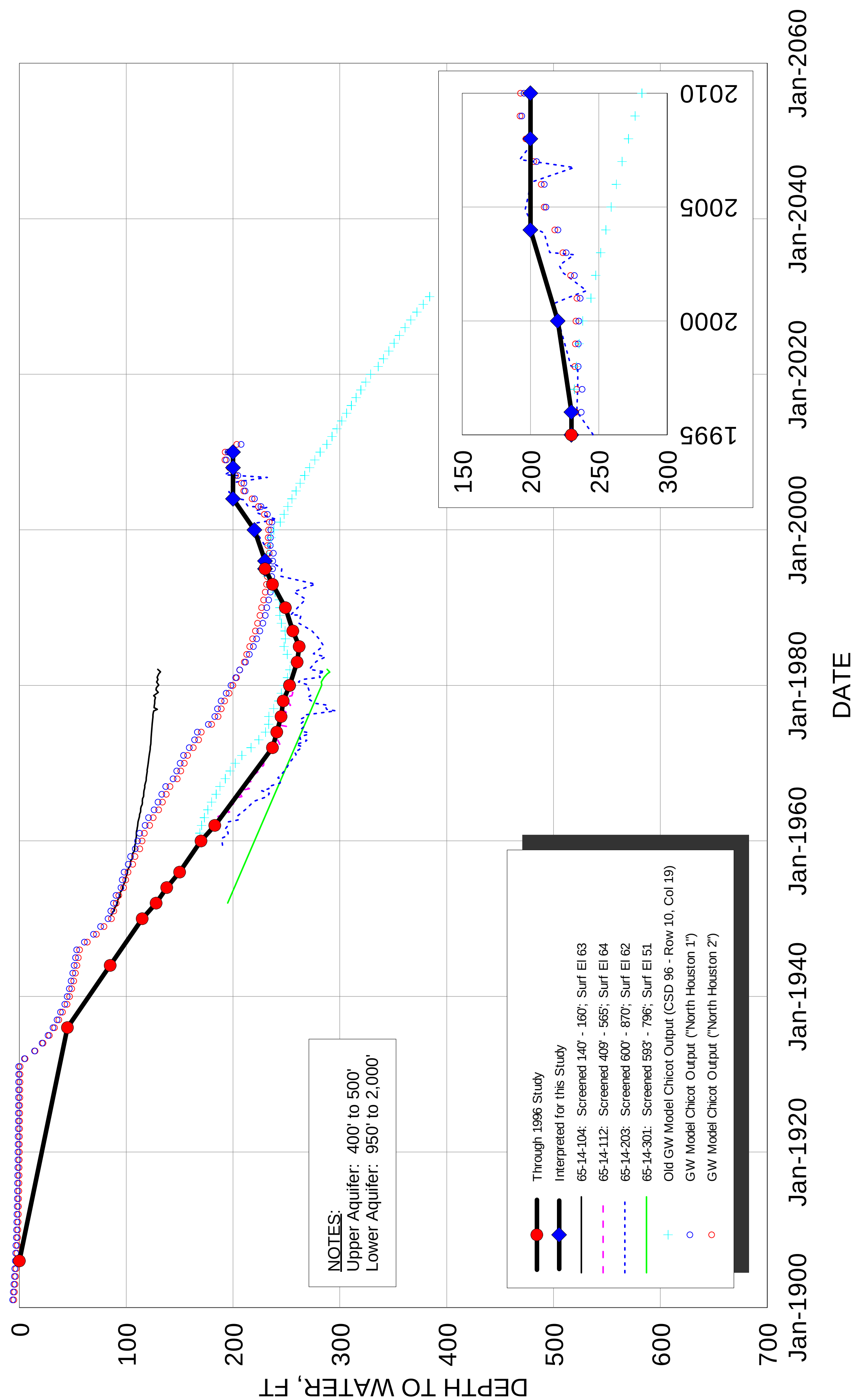
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 5,400 10,800 Feet

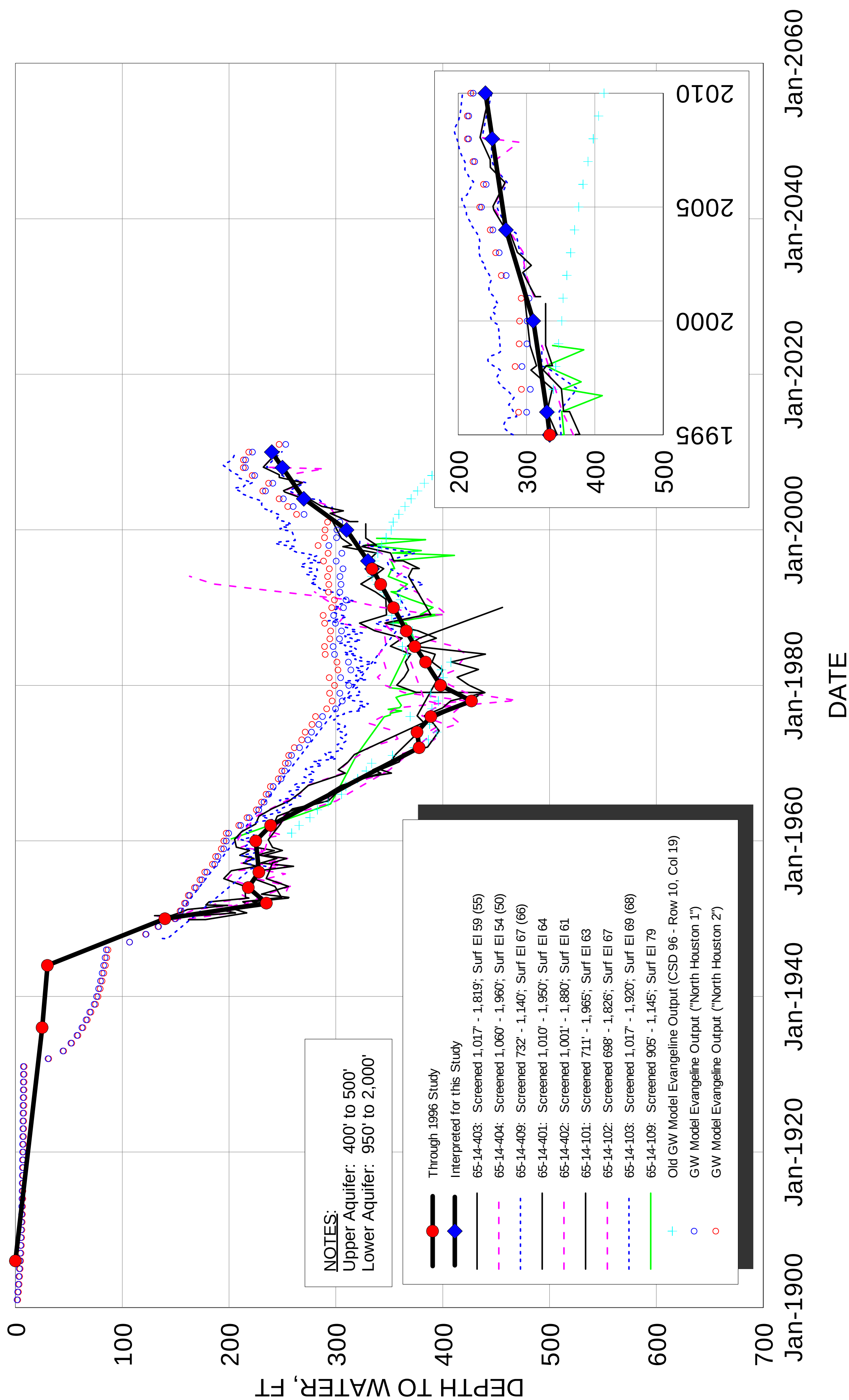
SITE MAP
NORTH HOUSTON PRESS SITE

PLATE V-1



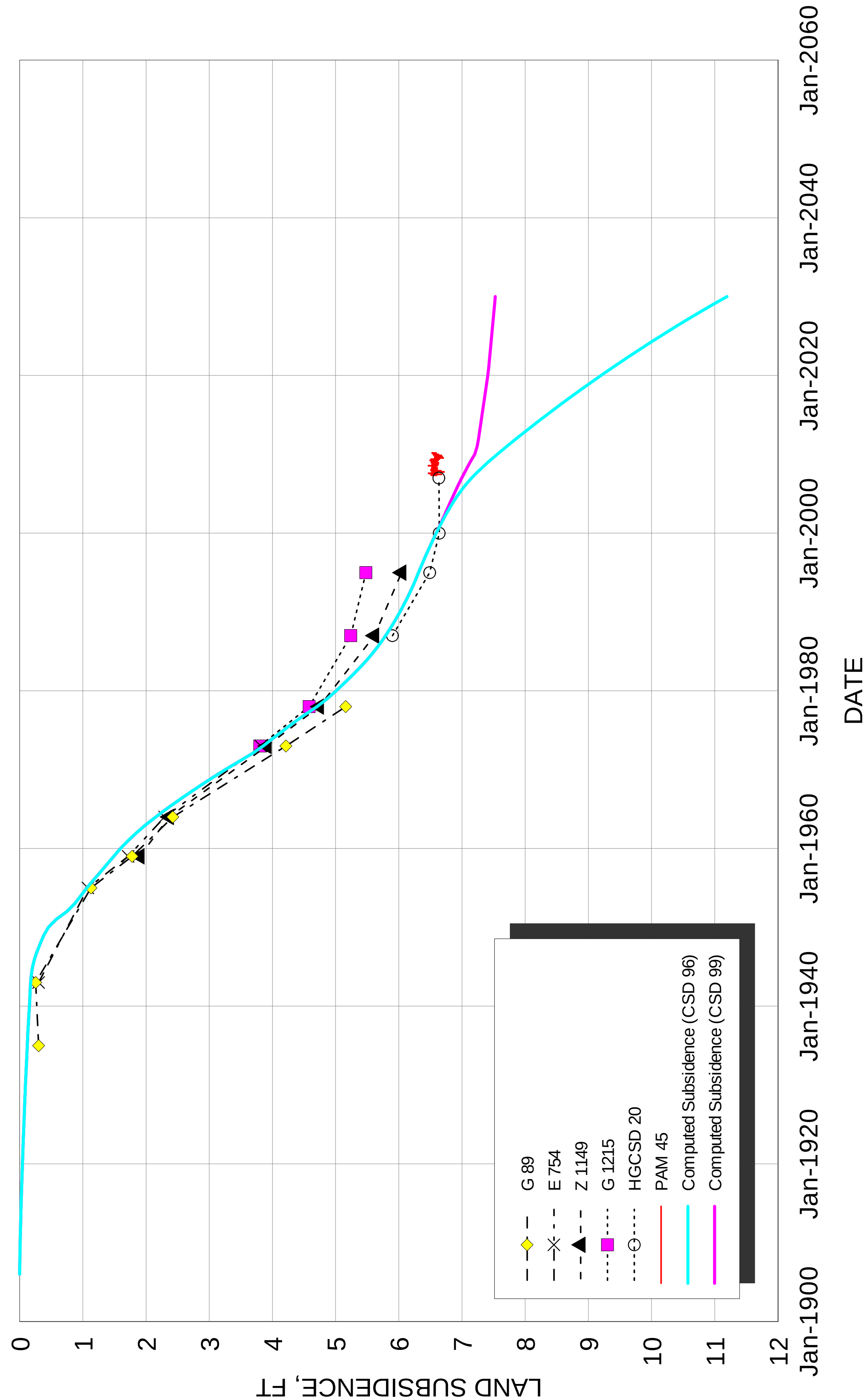
HYDROGRAPHS FOR NORTH HOUSTON SITE
UPPER MODEL AQUIFER

PLATE V-2



HYDROGRAPHS FOR NORTH HOUSTON SITE
LOWER MODEL AQUIFER

PLATE V-3



COMPUTED AND MEASURED SUBSIDENCE
NORTH HOUSTON SITE

PLATE V-4

W: PASADENA SITE

W.1 Introduction

The Pasadena site covers two ninths of the Pasadena Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate W-1. Site boundaries are consistent with the previous recalibration study (Fugro 1997).

W.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1997) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 325 to 375 ft
	Lower: 650 to 1,330 ft
Bottom of Compacting Interval:	2,594 ft
Bottom of Chicot Aquifer:	About 500 to 700 ft
Bottom of Evangeline Aquifer:	About 2,500 to 3,000 ft

W.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

W.3.1 Wells. We have selected 12 USGS wells to use for the Pasadena site in this study. In addition to the eight wells used in the previous recalibration study, we have added the following four wells to use for the current recalibration effort:

- LJ-65-23-323 (model lower aquifer);
- LJ-65-23-324 (model lower aquifer);
- LJ-65-23-326 (model lower aquifer); and
- LJ-65-23-215 (model lower aquifer).

Locations of all wells are included in the detailed Pasadena PRESS site map presented on Plate W-1. We assumed a ground surface elevation of 22 ft when vertically translating all well data for this site.

Four of the 12 wells used for the Pasadena PRESS site are screened in the model upper aquifer, as shown on Plate W-2. Well LJ-65-23-220 was discontinued as a monitoring well prior to 1995 but is included on Plate W-2 for reference. The other eight wells in the Pasadena PRESS site, including the four wells added for this study, are screened in the model lower aquifer, as shown on Plate W-3. Wells LJ-65-23-221 and -307 were also discontinued as monitoring wells prior to 1995.

W.3.2 Groundwater Model Output. We were provided one set of groundwater model output for the Pasadena site. The output is referred to as “Pasadena 1” in the information provided by LBG-Guyton. “Pasadena 1” is from a location of latitude 29°43’27.3”N and longitude 95°9’4.6”W. We assumed a ground surface elevation of 22 feet when vertically translating this output.

W.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1997). The design hydrograph for the model upper aquifer was primarily based on well LJ-65-23-220 in previous studies. As mentioned previously, this well was discontinued prior to 1995. However, the other three wells screened in the model upper aquifer show very similar water level data after 1995, which appears to be a continuation of the trend seen in -220 prior to 1995. We extended the design hydrograph for the model upper aquifer by following a general visual average of the data for wells LJ-65-23-302 and -320 and LJ-65-24-111.

We continued the trend established in previous studies for the model lower aquifer and extended the design hydrograph to 2010 by generally following a visual average of the well data available. With the exception of well LJ-65-23-215, all of the wells show very similar water level data. We essentially ignored well LJ-65-23-215 in our interpretation of the design hydrograph.

The old and new portions of the upper and lower model aquifer design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

W.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

W.4.1 Benchmarks. Consistent with the previous recalibration study, data from three benchmarks will be used in the current study:

- B 1147;
- 33.529; and
- HGCSD 41.

Locations of the benchmarks are shown on Plate W-1 and subsidence data are presented on Plate W-4.

W.4.2 Extensometer. Data from one extensometer, LJ-65-23-322 or “Pasadena”, will be used for comparison to the Pasadena PRESS model output. The location of the “Pasadena” extensometer is shown on Plate W-1, and data from the extensometer are presented on Plate W-3.

W.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate W-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.

Legend:

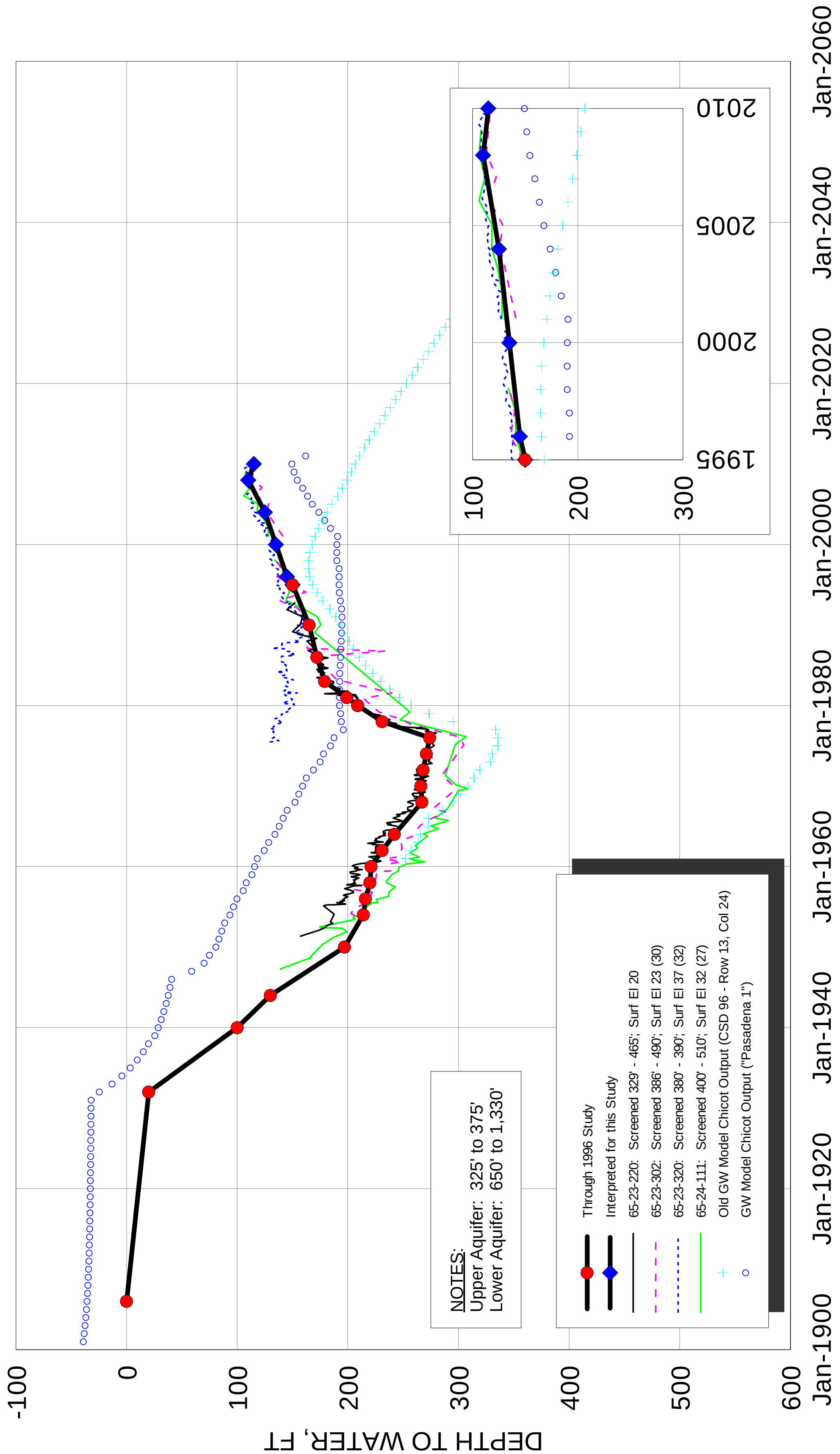
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▭ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 5,000 10,000 Feet

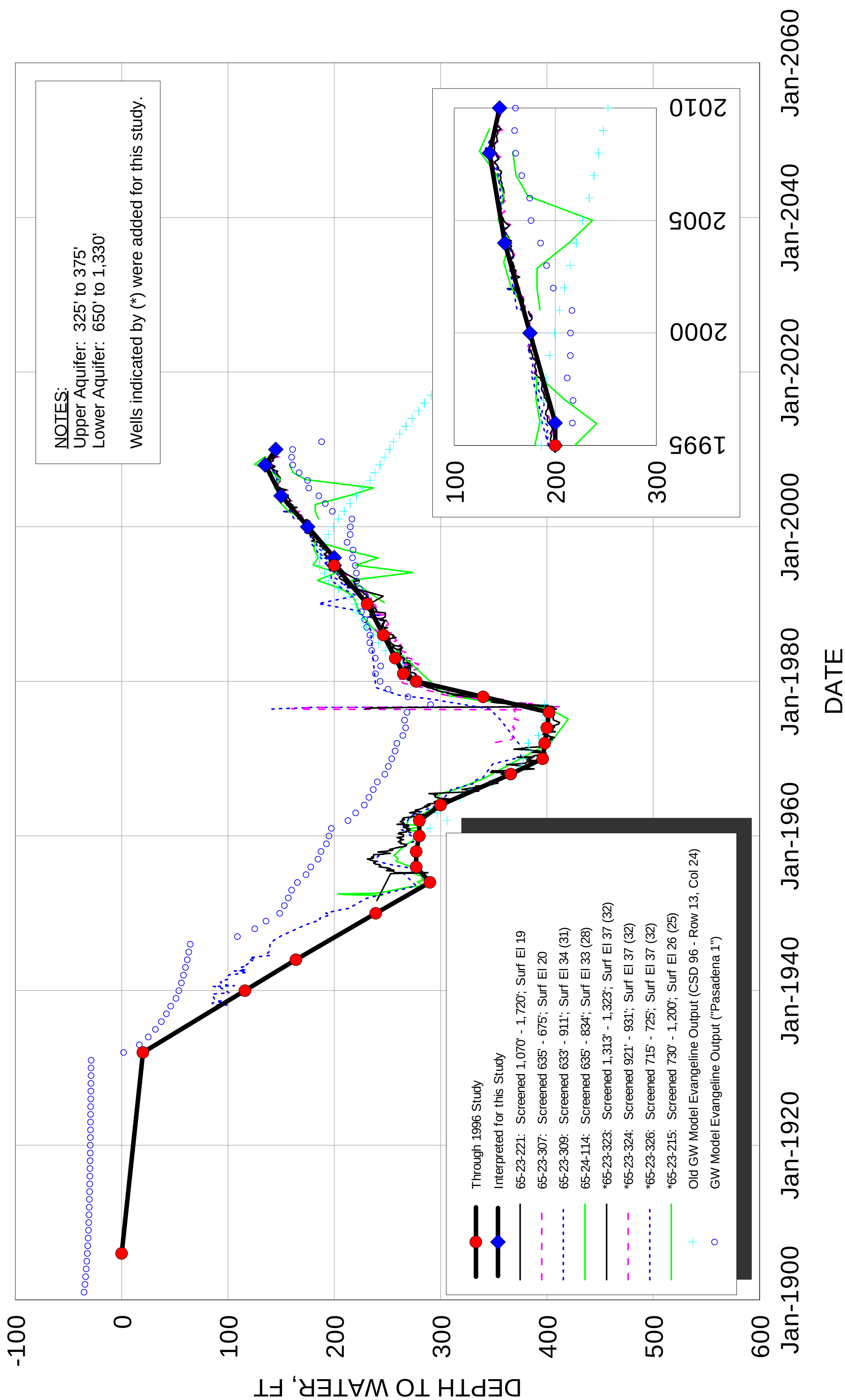
SITE MAP
PASADENA PRESS SITE

PLATE W-1

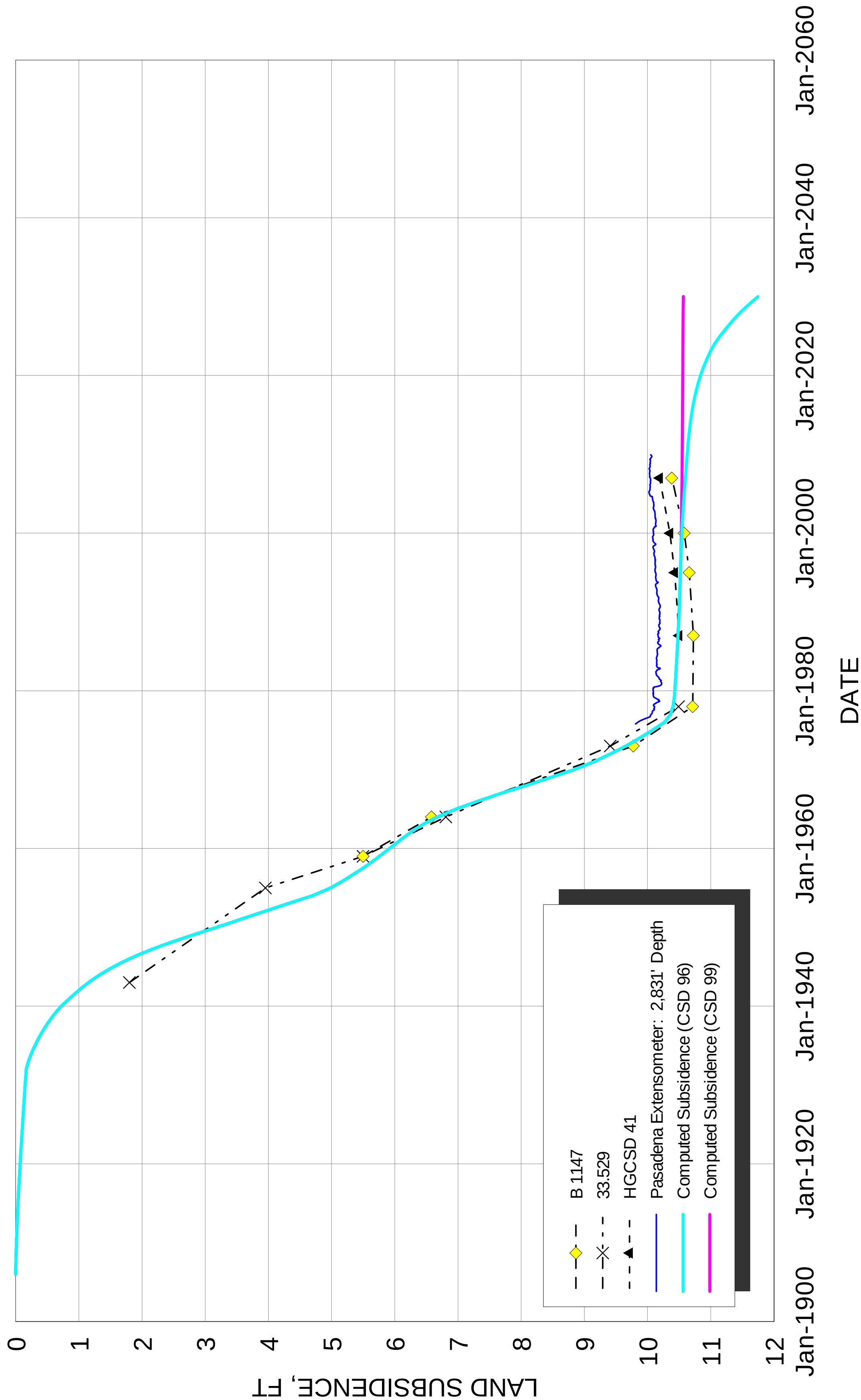


HYDROGRAPHS FOR PASADENA SITE
UPPER MODEL AQUIFER

PLATE W-2



HYDROGRAPHS FOR PASADENA SITE
LOWER MODEL AQUIFER



COMPUTED AND MEASURED SUBSIDENCE
PASADENA SITE

PLATE W-4

X: RICHMOND-ROSENBERG SITE

X.1 Introduction

The Richmond-Rosenberg site covers two ninths of the east-central part of the Ricmond Topographic Quadrangle, as shown in general on Plate 1 and in greater detail on Plate X-1. Site boundaries are consistent with the previous recalibration study (Fugro 1998).

X.2 Aquifers

The model aquifer definitions, consistent with the previous recalibration study (Fugro 1998) are as follows:

Aquifer Modeled as:	Dual Aquifer
Model Aquifer Depths:	Upper: 70 to 475 ft
	Lower: 650 to 1,590 ft
Bottom of Compacting Interval:	2,280 ft
Bottom of Chicot Aquifer:	About 600 to 700 ft
Bottom of Evangeline Aquifer:	About 2,400 ft

X.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

X.3.1 Wells. We have selected 29 USGS wells to use for the Richmond-Rosenberg site in this study. In addition to the 28 wells used in the previous recalibration study, we have added the following well to use for the current recalibration effort:

- LJ-65-26-520 (model lower aquifer).

Locations of all wells are included in the detailed Richmond-Rosenberg PRESS site map presented on Plate X-1. We assumed a ground surface elevation of 97 ft when vertically translating all well data for this site.

Of the 29 total wells used for the Richmond-Rosenberg PRESS site, 23 are screened in the model upper aquifer, as shown on Plate X-2. Only three of the 23 have data points after 1995: LJ-65-26-603, -605 and -613. The other 20 wells screened in the model upper aquifer were discontinued as monitoring wells prior to 1995 but are included on Plate X-2 for reference. The remaining six wells in the Richmond-Rosenberg PRESS site, including the well added for this study, are screened in the model lower aquifer, as shown on Plate X-3. Wells LJ-65-26-503 and -614 were also discontinued as monitoring wells prior to 1995.

X.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Richmond-Rosenberg site. The outputs are referred to as “Richmond-Rosenberg 1” and “Richmond-Rosenberg 2” in the information provided by LBG-Guyton. “Richmond-Rosenberg 1” is from a location of latitude 29°33’25.6”N and longitude 95°46’10.4”W. “Richmond-Rosenberg

2” is from a location of latitude 29°33’48.9” and longitude 95°48’57.6”. We assumed a ground surface elevation of 97 feet when vertically translating this output.

X.3.3 Design Hydrographs. We used the site hydrographs for the upper and lower model aquifers presented in the previous recalibration effort (Fugro 1998). We continued the trend established previously and primarily relied on well LJ-65-26-613 to extend the design hydrograph for the model upper aquifer to 2010. For the lower model aquifer, we followed a general visual average of the well data and groundwater model output available to extend the design hydrograph to 2010. The old and new portions of the upper and lower model aquifer design hydrographs are represented with a bold line connecting red and blue circular dots, respectively.

X.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

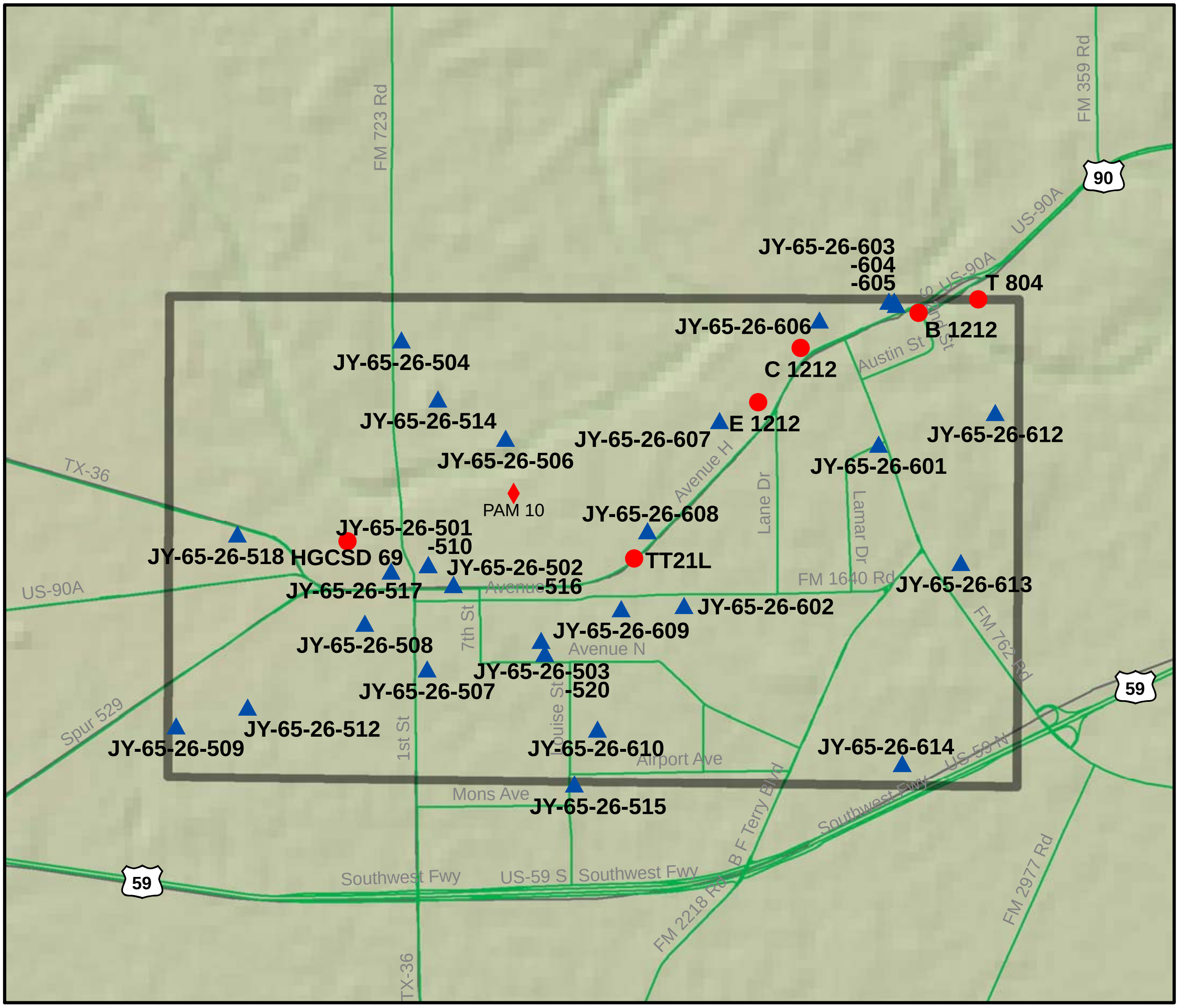
X.4.1 Benchmarks. Data from seven benchmarks will be used in the current study:

- B 1212;
- C 1212;
- E 1212;
- T 804;
- TT21L;
- HGCSD 69; and
- PAM 10 ARP.

Locations of the benchmarks are shown on Plate X-1 and subsidence data are presented on Plate X-4. Six benchmarks were used in the previous recalibration study (Fugro 1998). Benchmark PAM 10 ARP was added for this study and, based on a review of the other subsidence data available through the year 2000, a vertical offset of 0.6 ft was applied to the first data point in the year 2000.

X.4.2 PAM Station. Data from PAM station 10, also presented on Plate X-4, will be used for recalibration efforts in this study. The location of PAM 10 is presented on Plate X-1. PAM station 10 was one of the earlier installed PAM sites in Fort Bend County – data are available from the year 1999. After a review of the other available subsidence data, we applied a vertical offset of 0.6 ft to the PAM data.

X.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenario CSD 96 is presented on Plate X-4 for comparison of previous subsidence predictions with current data. More details on pumpage scenario CSD 96 are included in *Section 3.5*.



Legend:

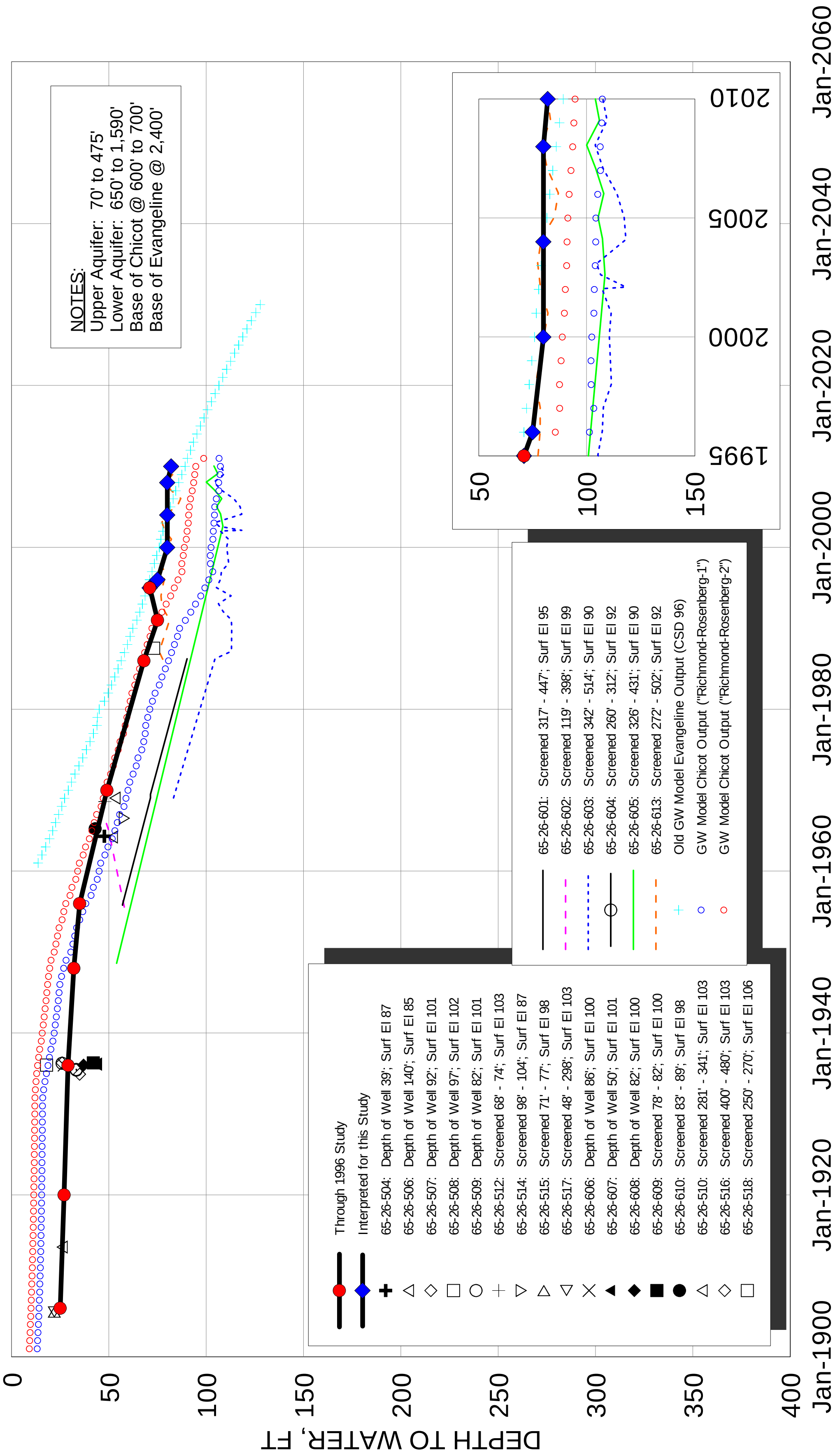
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▭ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 5,000 10,000 Feet

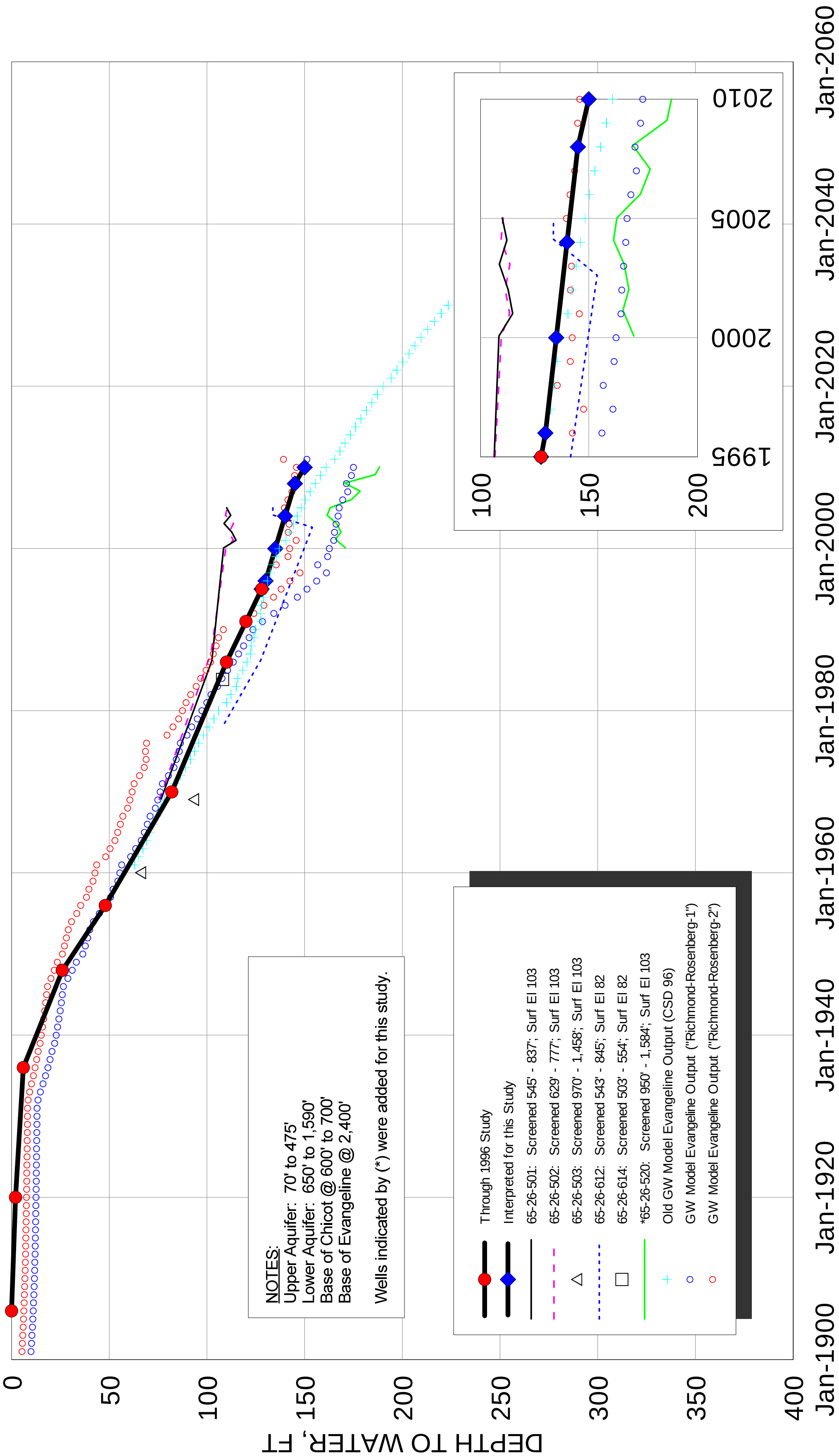
SITE MAP
RICHMOND-ROSENBERG PRESS SITE

PLATE X-1



HYDROGRAPHS FOR RICHMOND-ROSENBERG SITE
UPPER MODEL AQUIFER

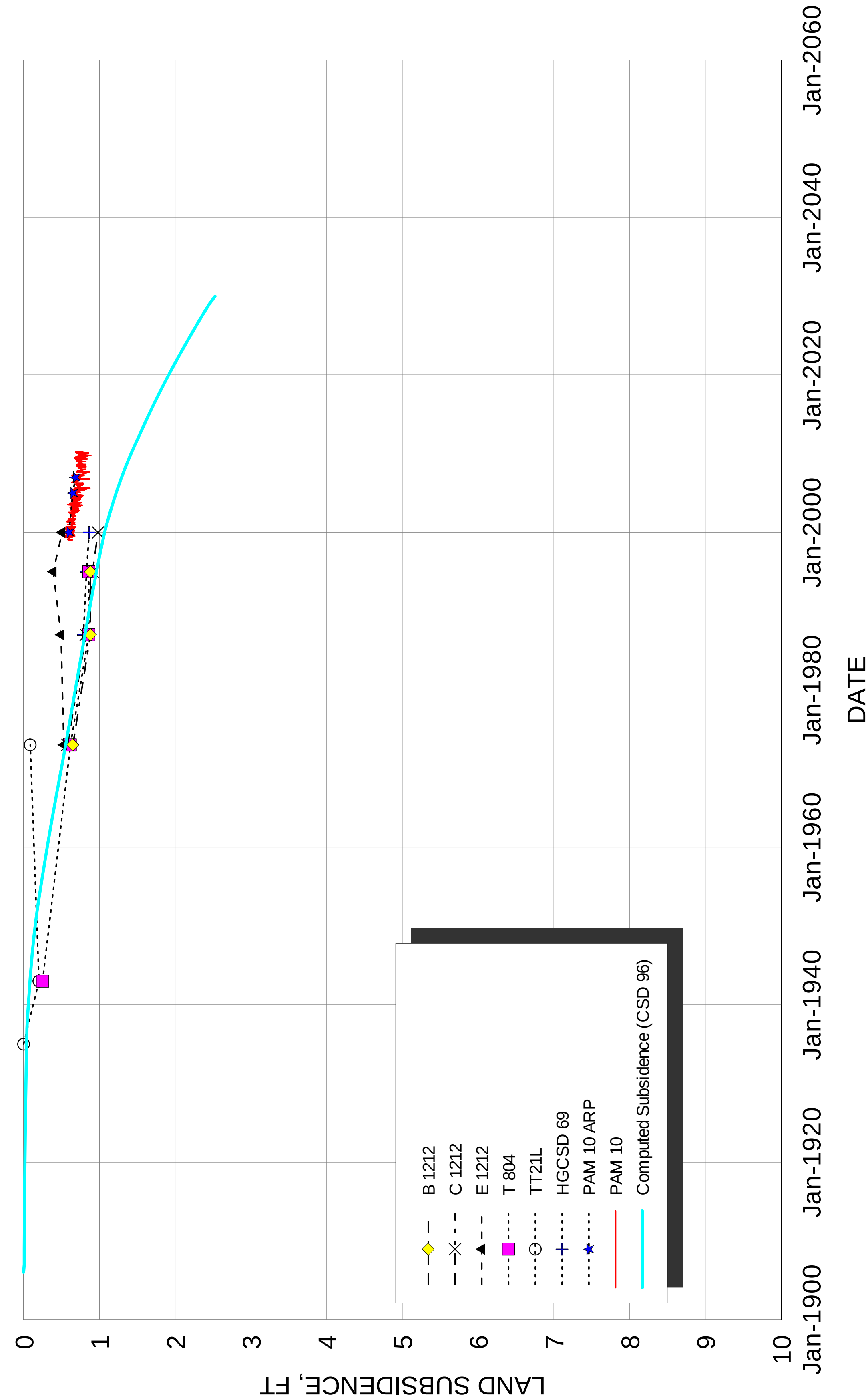
PLATE X-2



HYDROGRAPHS FOR RICHMOND-ROSENBERG SITE

LOWER MODEL AQUIFER

PLATE X-3



COMPUTED AND MEASURED SUBSIDENCE
RICHMOND-ROSENBERG SITE

PLATE X-4

Y: SHELDON SITE

Y.1 Introduction

The Sheldon site includes one ninth of the Jacinto City and one ninth of the Highlands Topographic Quadrangles. A general site location is shown on Plate 1 and a detailed site map is presented on Plate Y-1. The site boundaries are consistent with the previous recalibration study (Fugro 1997).

Y.2 Aquifer

The Needville site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	700 to 1,600 ft
Bottom of Compacting Interval:	1,640 ft
Bottom of Chicot Aquifer:	About 500 to 600 ft
Bottom of Evangeline Aquifer:	About 2,000 to 2,500 ft

Y.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

Y.3.1 Wells. Consistent with the previous recalibration study (Fugro 1997), we have selected 10 wells to use for the Sheldon site. Locations of all wells are included in the detailed Sheldon PRESS site map presented on Plate Y-1. We assumed a ground surface elevation of 45 ft when vertically translating all well data for this site.

Y.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Sheldon site. The outputs are referred to as “Sheldon 1” and “Sheldon 2” in the information provided by LBG-Guyton. “Sheldon 1” is from a location of latitude 29°51’14.0”N and longitude 95°6’49.8”W. “Sheldon 2” is from a location of latitude 29°50’58.0” and longitude 95°8’58.5”. We assumed a ground surface elevation of 45 feet when vertically translating this output.

Y.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1997). To extend the site hydrograph to 2010, we followed the trend established in previous studies and used a general visual average of the well data and groundwater model output available. The downward spike present in the data for well LJ-65-16-114 is not identified as a result of groundwater pumping in the USGS database, but appears to be anomalous in comparison to all other well data in the Sheldon site. We essentially ignored this spike in our interpretation. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

Y.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

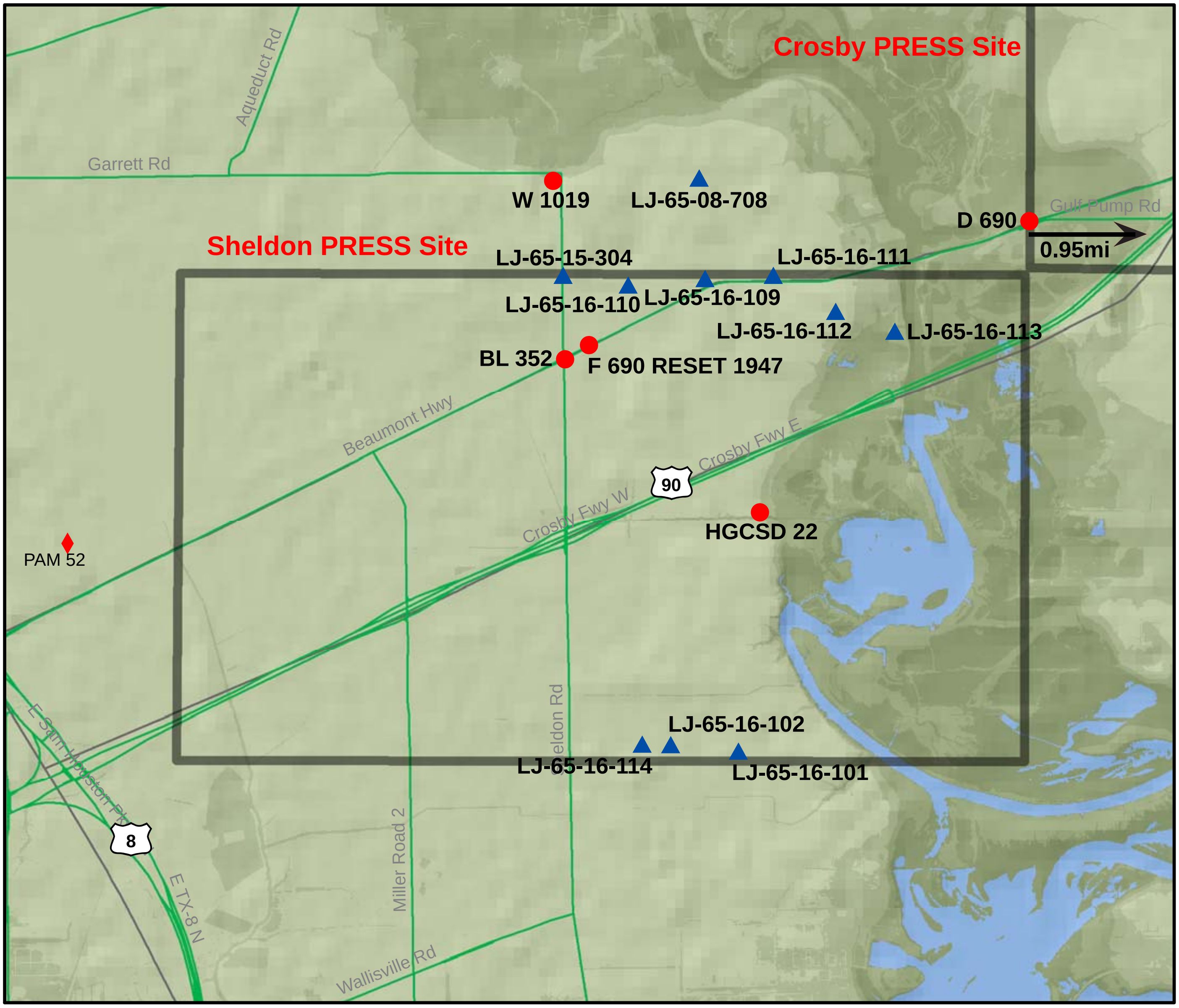
Y.4.1 Benchmarks. Consistent with the previous recalibration study, data from five benchmarks will be used in the current study:

- BL 352;
- F 690 RESET 1947;
- W 1019;
- D 690; and
- HGCSD 22.

Locations of the benchmarks are shown on Plate Y-1 and subsidence data are presented on Plate Y-3.

Y.4.2 PAM Station. Data from PAM station 52, also presented on Plate Y-3, will be used for recalibration efforts in this study. The location of PAM 52 is presented on Plate Y-1. Data from PAM 52 are fairly recent, starting in 2007, but will continue to be referenced in future subsidence studies. Based on review of other subsidence data sources available, we applied a vertical offset of 3.0 ft to the PAM data.

Y.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenarios CSD 96 and CSD 99 are presented on Plate Y-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenarios CSD 96 and CSD 99 are included in *Section 3.5*.



Legend:

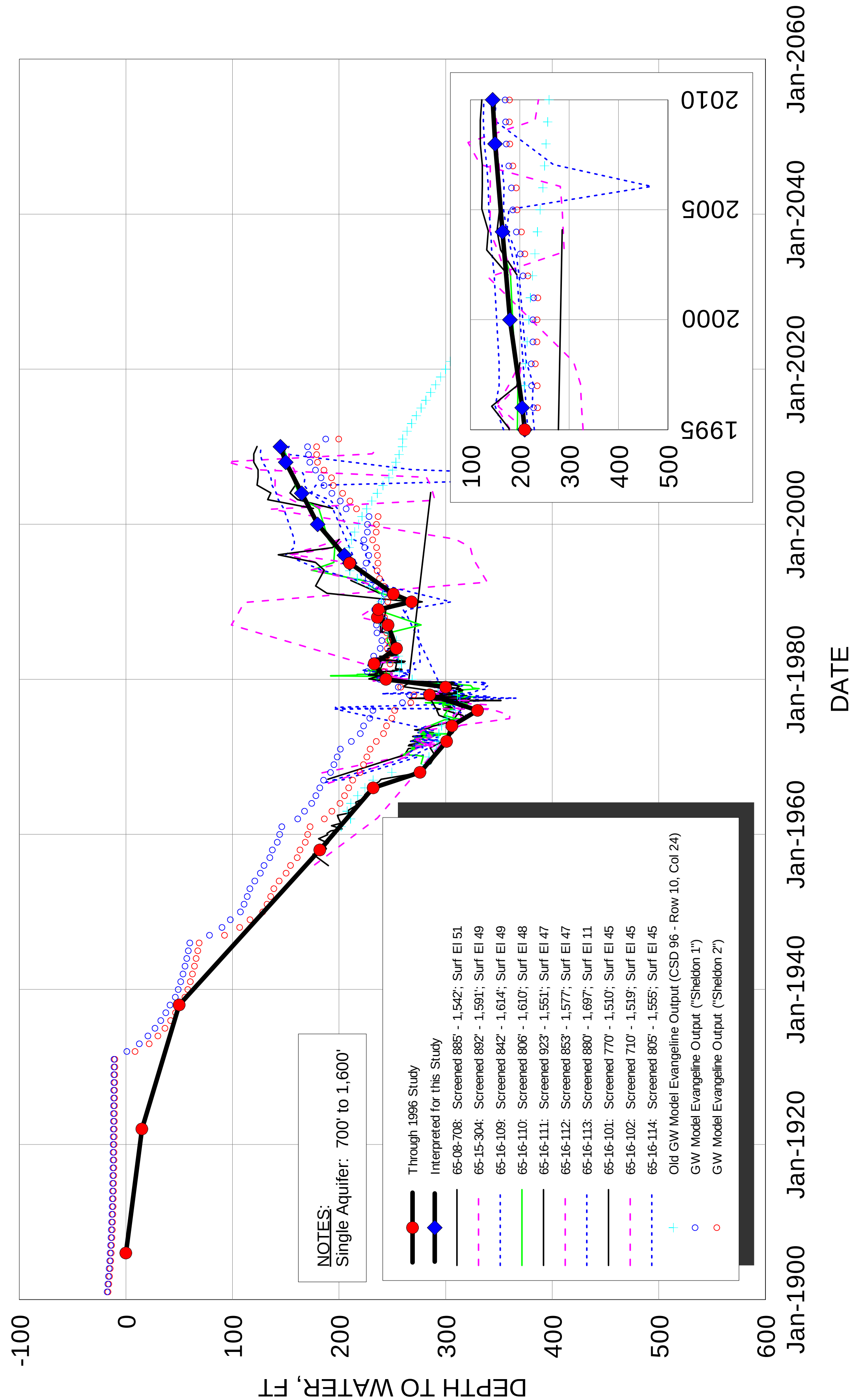
- ▲ Observation Well
- ♦ PAM Station
- ★ CORS
- ● Benchmark
- ■ Borehole Extensometer
- ▭ PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 5,000 10,000 Feet

SITE MAP
SHELDON PRESS SITE

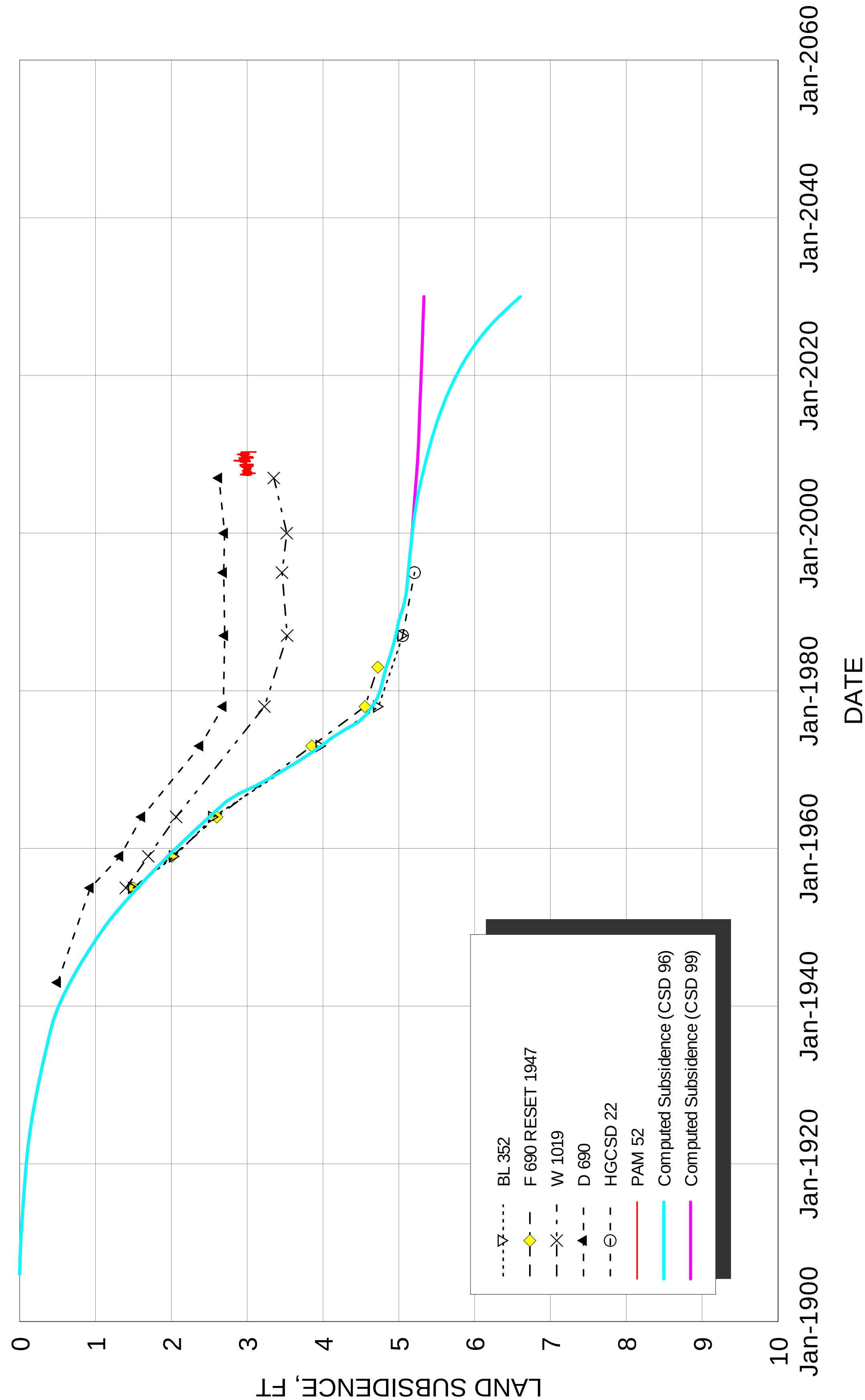
PLATE Y-1



HYDROGRAPHS FOR SHELDON SITE

SINGLE MODEL AQUIFER

PLATE Y-2



COMPUTED AND MEASURED SUBSIDENCE
SHELDON SITE

PLATE Y-3

Z: SMITHERS LAKE SITE

Z.1 Introduction

The Smithers Lake site covers one ninth of the northeast corner of the Smithers Lake Topographic Quadrangle and one ninth of the northwest corner of the Thompsons Topographic Quadrangles. A general site location is shown on Plate 1 and a detailed site map is presented on Plate Z-1. Site boundaries are consistent with the previous recalibration study (Fugro 1998).

Z.2 Aquifer

The Needville site is modeled as a single model aquifer as defined below:

Aquifer Modeled as:	Single Aquifer
Model Aquifer Depths:	420 to 730 ft
Bottom of Compacting Interval:	1,200 ft
Bottom of Chicot Aquifer:	About 700 ft
Bottom of Evangeline Aquifer:	About 2,600 ft

Z.3 Wells and Groundwater Data

Information on the wells and groundwater data used to develop the design hydrograph for this PRESS site model is presented below.

Z.3.1 Wells. Consistent with the previous recalibration study (Fugro 1997), we have selected eight wells to use for the Smithers Lake site. Locations of all wells are included in the detailed Smithers Lake PRESS site map presented on Plate Z-1. Five of the eight wells – LJ-65-35-301, LJ-65-36-101, -102, -103, and -104 – were discontinued as monitoring wells prior to 1995. We assumed a ground surface elevation of 67 ft when vertically translating all well data for this site.

Z.3.2 Groundwater Model Output. We were provided two sets of groundwater model output for the Smithers Lake site. The outputs are referred to as “Smithers Lake 1” and “Smithers Lake 2” in the information provided by LBG-Guyton. “Smithers Lake 1” is from a location of latitude 29°28’52.7”N and longitude 95°36’18.6”W. “Smithers Lake 2” is from a location of latitude 29°28’33.0” and longitude 95°38’28.8”. We assumed a ground surface elevation of 67 feet when vertically translating this output.

Z.3.3 Design Hydrograph. For dates up until 1995, we used the site hydrograph presented in the previous recalibration effort (Fugro 1998). To extend the site hydrograph to 2010, we followed the trend established in previous studies and used a general visual average of the well data and groundwater model output available. The old and new portions of the design hydrograph are represented with a bold line connecting red and blue circular dots, respectively.

Z.4 Subsidence Data

Information on the subsidence data collected and processed for comparison to output from future PRESS model runs is presented below.

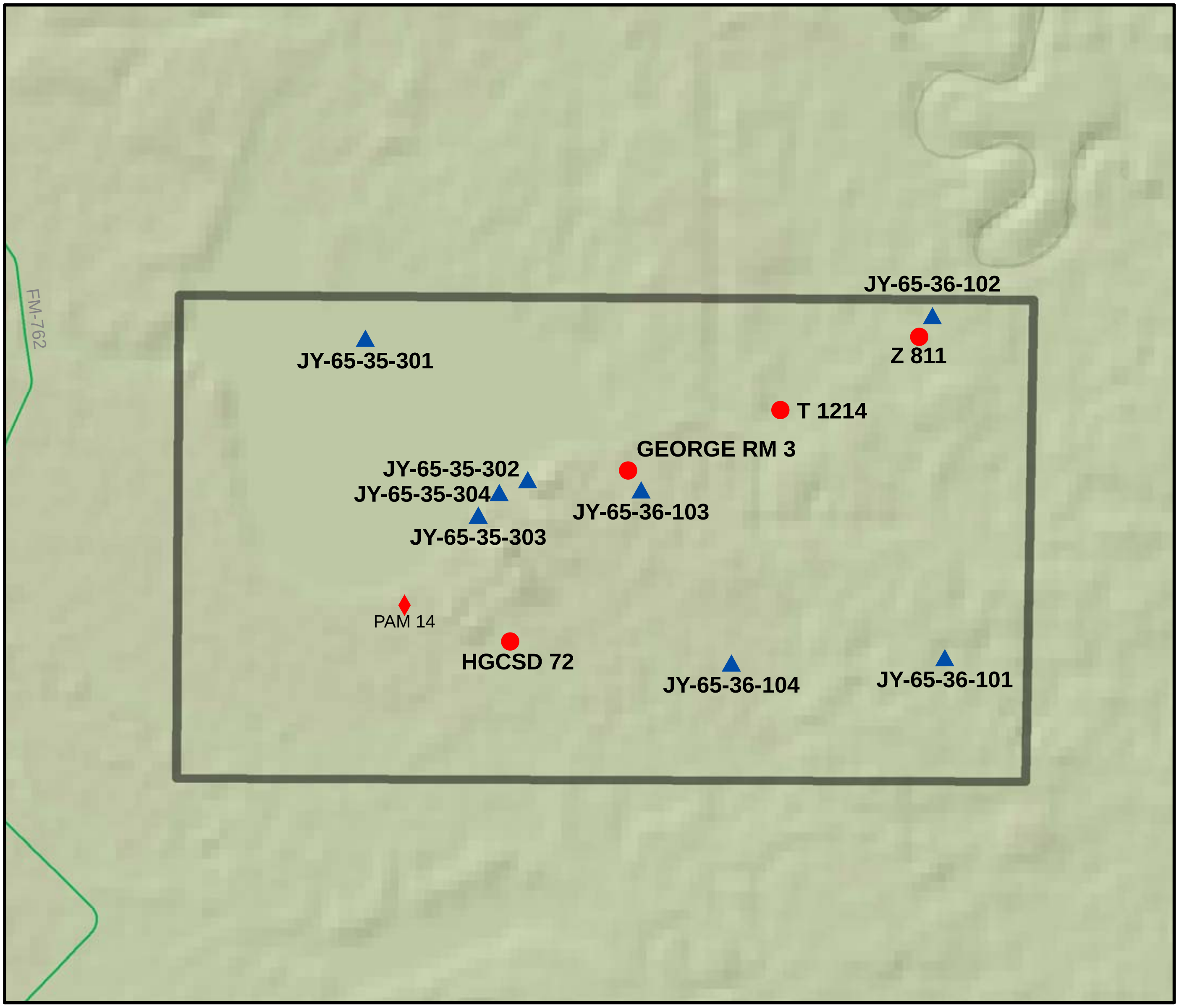
Z.4.1 Benchmarks. Data from six benchmarks will be used in the current study:

- GEORGE RM3;
- GEORGE;
- T 1214;
- Z 811;
- HGCSD 72; and
- PAM 14 ARP.

Locations of the benchmarks are shown on Plate Z-1 and subsidence data are presented on Plate Z-3. Four benchmarks were used in the previous recalibration study (Fugro 1998). The validity of the 1995 data point for benchmark GEORGE RM3 was questioned in the previous study and was not used for recalibration efforts. During this study, we raised the same question about the validity of GEORGE RM3 data points provided from 1995 and 2000 to the NGS. The NGS reprocessed the data and performed a field visit to the benchmark, and determined that the data points provided for GEORGE RM3 in 1995 and 2000 were actually from the GEORGE benchmark. As a result, we have included two data points from GEORGE in this study, with a vertical offset of 1.25 ft applied in 1995. Benchmark PAM 14 ARP was also added for this study and, based on a review of the other subsidence data available through the year 2000, a vertical offset of 1.15 ft was applied to the first data point in the year 2000.

Z.4.2 PAM Station. Data from PAM station 14, also presented on Plate Z-3, will be used for recalibration efforts in this study. The location of PAM 14 is presented on Plate Z-1. Based on review of other subsidence data sources available, we applied a vertical offset of 1.15 ft to the PAM data.

Z.4.3 Computed Subsidence Output. PRESS model output from groundwater pumpage scenario CSD 96 is presented on Plate Z-3 for comparison of previous subsidence predictions with current data. More details on pumpage scenario CSD 96 are included in *Section 3.5*.



Legend:

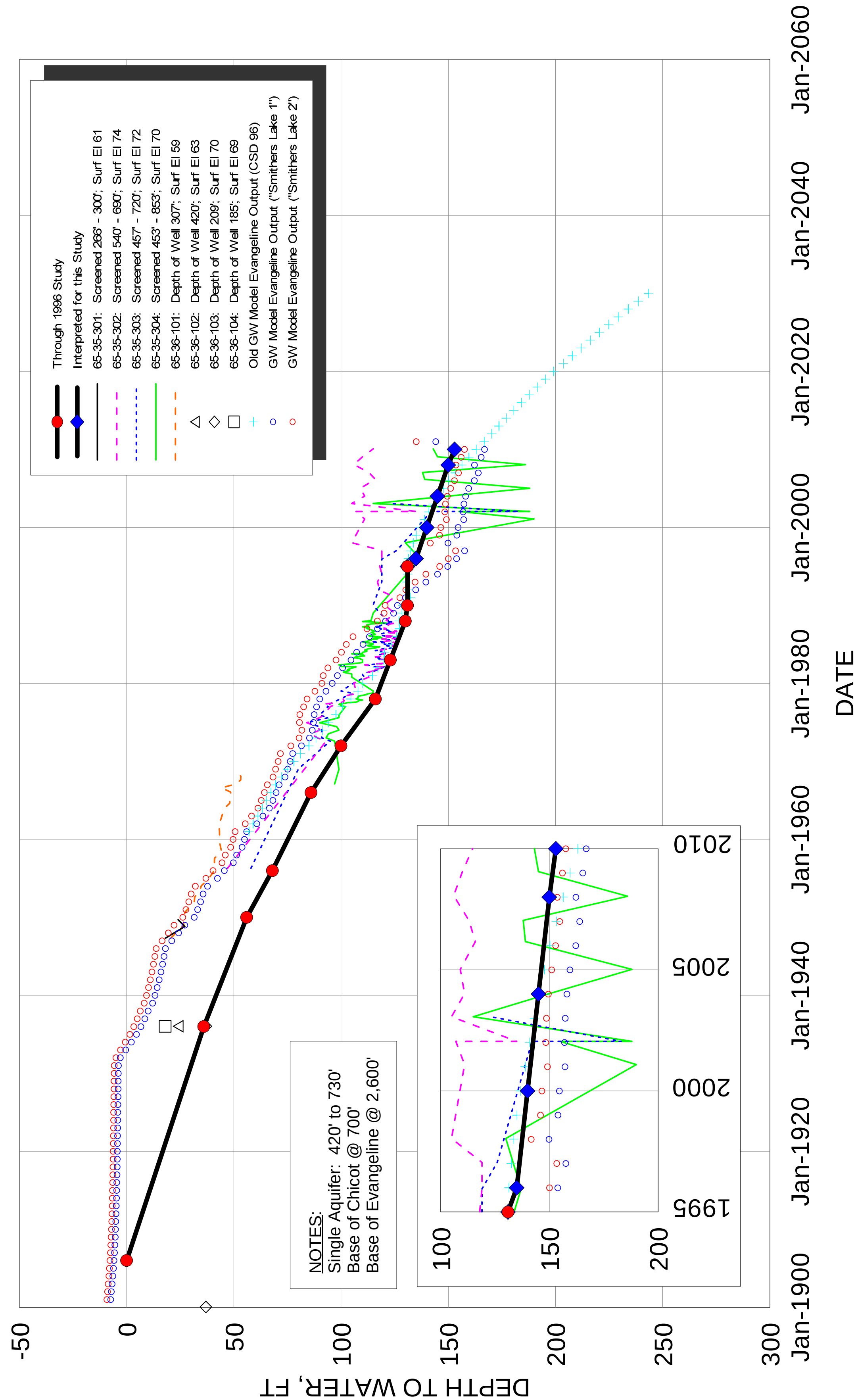
- Observation Well
- PAM Station
- CORS
- Benchmark
- Borehole Extensometer
- PRESS Site Boundary

Note: Base map obtained from ESRI national imagery.

0 5,000 10,000 Feet

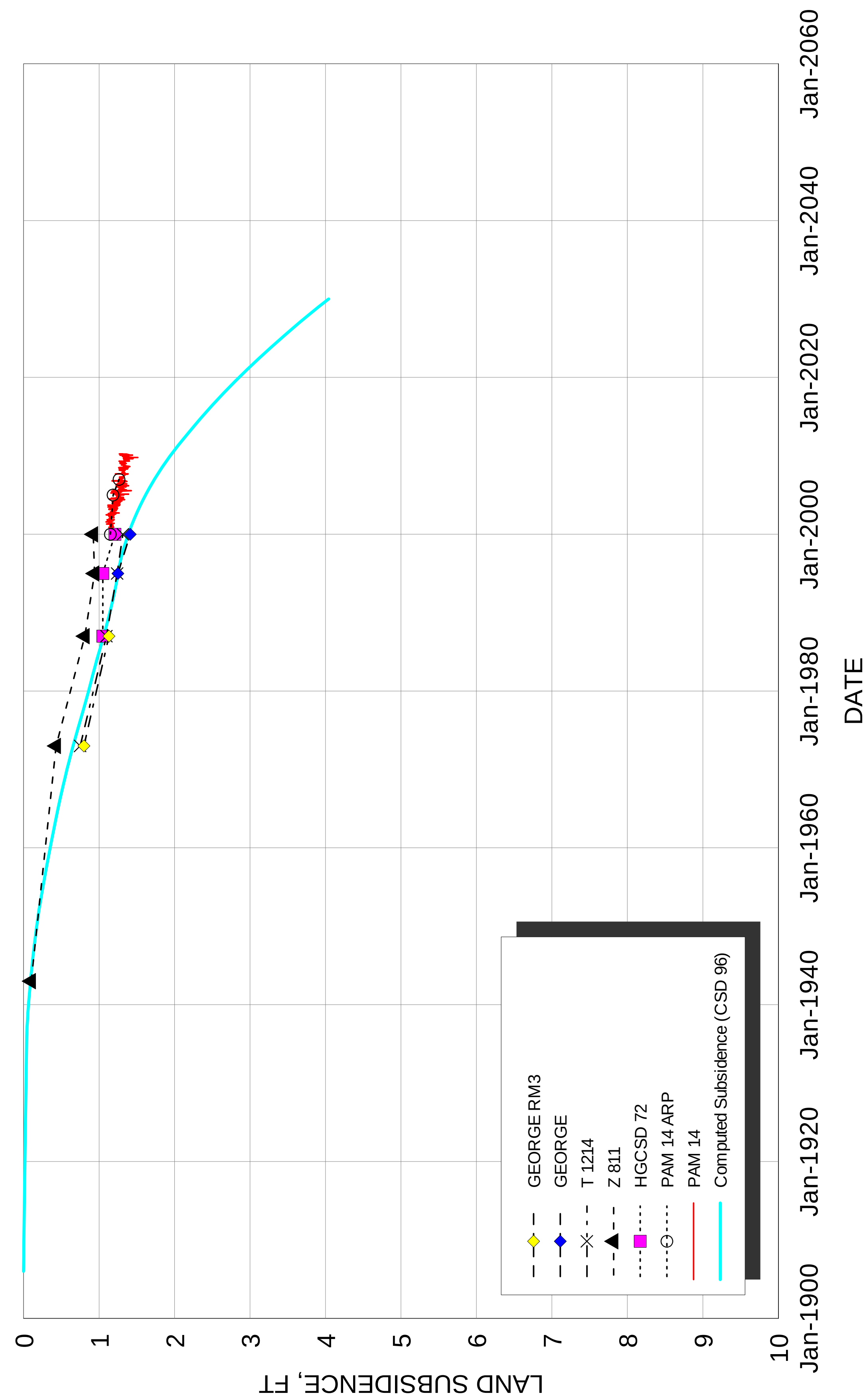
SITE MAP
SMITHERS LAKE PRESS SITE

PLATE Z-1



HYDROGRAPHS FOR SMITHERS LAKE SITE
SINGLE MODEL AQUIFER

PLATE Z-2



COMPUTED AND MEASURED SUBSIDENCE
SMITHERS LAKE SITE

PLATE Z-3

MEMORANDUM

FREESE AND NICHOLS
Innovative approaches
Practical results
Outstanding service
3100 Wilcrest Drive, Suite 200 • Houston, Texas 77042 • 713-600-6800 • fax 713-600-6801 www.freese.com

TO: Ron Neighbors

CC: Tom Michel, Kathy Turner Jones

FROM: Bill Thaman

SUBJECT: HGSD Regional Groundwater Update Project: Work Order 2 Population Projection Methodology Summary

DATE: March 22, 2011

Attachments:

- Minutes from meetings with population forecast providers
- Metrostudy methodology
- Description of the UHHCPP Sam-Houston model

Introduction

The purpose of this memorandum is to summarize the population projection methodology selected as a result of Work Order 2 Task G "Evaluate Alternative Population Projection Methodologies". The activities under this task are as follows:

a. Meet with University of Houston Hobby Center for Public Policy (UHHCPP: Dr. Steven Craig, et al, http://www.uh.edu/hcpp) to discuss data and information available, methodology used to develop, timing, and cost.
b. Meet with Municipal Information Services (MIS, http://mudhatter.com) to discuss products and services. MIS offers the "MIS MUD Database" every January and uses it, as well as Census and other information, to perform demographic analyses and projections.
c. Meet with Harris-Galveston Area Council (H-GAC: http://www.h-gac.com) to discuss population projections and parcel-based land use data. H-GAC performs population projections on 1 square mile grids; they also create annual land use datasets, by county, based on land parcels, with 2008 being the most recent. Determine when their 2009 land use dataset will be available.
d. Meet with American Metro to discuss products and services.
e. Determine if there are other organizations that perform sub-county population projections and conduct meetings as necessary. Maximum two (2) additional organizations.
f. Develop an approach for population projections based on input from Project Sponsors and Regional Stakeholders. Discuss with Project Sponsors and obtain approval in the second workshop called for in Task A(f).
g. Prepare a written document summarizing the Population Projection methodology developed and approved by the Project Sponsors as a result of this task.

Meetings With Population Projection Providers

Meetings with various population projection providers were conducted in November and December 2010. An overview of the meetings is in Table 1. The meeting minutes are attached to this memo.

Table 1. Overview of Population Projection Providers Interviewed

Entity	Meeting Date	Overview
University of Houston Hobby Center for Public Policy – Dr. Steven Craig	11/30/2010	Strength is long-term projections that are driven by regional economics and projections of jobs. Projections are performed on the Census Tract level. Provided projections for the 1999 HGSD Regulatory Plan
Harris-Galveston Area Council – Dmitry Messen	12/6/2010	Regional projections done using cohort survival techniques. Macro projections are distributed to the land parcel level. Projections are tied to the Regional Transportation Plan
Metrostudy – Brad Colliander	12/14/2010	Distribution of population based primarily on single-family housing activity. Quarterly housing survey in proprietary database with 35 years of history. Short-term accuracy (5-10 yrs). Provided projections for the 1999 HGSD Regulatory Plan
Municipal Information Services (MIS) – Dr. Ronald Welch	12/14/2010	Deals exclusively with MUD data; collects on the ground data himself. Short-term accuracy using knowledge of buildout rates (5 yrs). Longer term projections are statistically based.
Population and Survey Analysts (PASA) – Dr. Pat Gusman	12/16/2010	Very similar to Metrostudy techniques, but only performs on the ground surveys as needs dictate.

Recommended Methodology

The FNI team met with the project partners 1/11/2011 and made a recommendation to use Metrostudy and the Dr. Craig from the University of Houston Hobby Center for Public Policy (UHHCP); it was proposed that Metrostudy would perform short-term projections (2010-2020) and UHHCP would perform long-term projections (2010-2070). The project partners agreed that the project will move forward with this approach, and this approach was included as part of Work Order 4 that was authorized by the HGSD Board of Directors in their March 9, 2011 meeting.

Methodology Overview

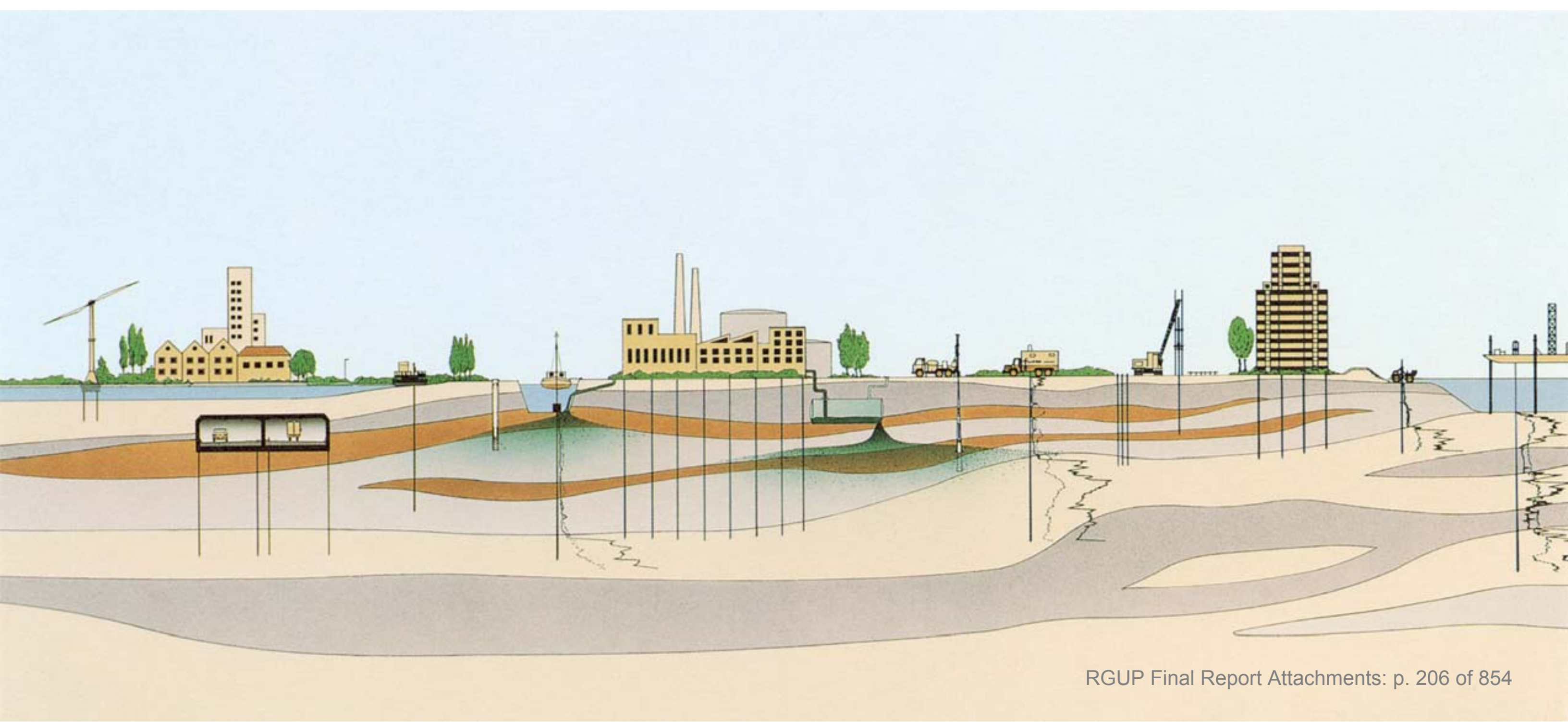
Since the next regulatory conversion step will likely occur within the next 10-15 years, it's important that the projections of population are as accurate as possible during that period. Metrostudy's strength is in short-term projections that are guided by past and current performance in housing starts, along with their knowledge of future housing supplies gained from their relationships with area land developers, engineers, and planning/zoning office representatives; for that reason they were recommended for supplying projections through 2020 and providing guidance to the FNI team as to the pattern of growth through 2030. The Metrostudy methodology is attached to this memo.

Since the approach used by Metrostudy is not accurate beyond 10 years, another approach is required for the long-term projections out to 2070. The UHHCPP provides projections that are a result of modeling long-term trends in the regional economy. The premise is that all population must be supported by employment. UHHCPP uses the Small Area Model- Houston (SAM-Houston) model to allocate population and employment to United State Census Tracts. The model's statistical module determines how population and employment allocation has changed over the last three decades and uses urban economic theory to estimate a model of future allocation. The land use module uses H-GAC parcel-based land use data and evaluates an areas developable capacity to adjust forecasts to be consistent with that capacity. A detailed description of the Sam-Houston model is attached to this memo.

FUGRO CONSULTANTS, INC.

GEOTECHNICAL SERVICES
WORK ORDER 3 – PRESS MODEL ANALYSES
HARRIS-GALVESTON SUBSIDENCE DISTRICT
HARRIS, GALVESTON AND FORT BEND COUNTIES, TEXAS

FREESE AND NICHOLS, INC.
HOUSTON, TEXAS
NOVEMBER 2011



6100 Hillcroft (77081)
P.O. Box 740010
Houston, Texas 77274
Tel: (713) 369-5400
Fax: (713) 369-5518

Report No. 04.12100052 – Work Order 3
November 17, 2011

Freese and Nichols, Inc.
3100 Wilcrest, Suite 200
Houston, Texas 77042

Attention: Mr. Michael V. Reedy, P.E.
Water Resources Group Manager

Geotechnical Services
Work Order 3 – PRESS Model Analyses
Harris-Galveston Subsidence District
Harris, Galveston and Fort Bend Counties, Texas

Fugro Consultants, Inc. is pleased to submit this report of our geotechnical services related to Work Order 3 for the current effort to update the model used for predicting subsidence in Harris, Galveston and Fort Bend Counties. We have performed our services in general accordance with our Cost Estimate No. 0412-10-0052p3-Revision No. 1 dated February 22, 2011. Mr. Michael V. Reedy of Freese and Nichols, Inc. (FNI) authorized our services through a Subconsultant Authorization dated March 2, 2011 under our Master Subconsultant Agreement.

We appreciate the opportunity to be of continued service to Freese and Nichols and the Harris-Galveston Subsidence District, and we look forward to providing additional services for future phases of this project. Please call us if you have any questions or comments concerning this report or when we may be of further assistance.

Sincerely,
FUGRO CONSULTANTS, INC.
TBPE Firm Registration No. F-299

Nathan E. Thompson, E.I.T.
Project Professional

Scott A. Marr, P.E, LEED AP
Project Manager

Copies Submitted: Addressee (4)
NET/SAM
R:\04120\2010 Projects\0001-0099\0412-10-0052\Reporting\Work Order 3\04.12100052 WO3 Final Report.docxx

CONTENTS

Page

ILLUSTRATIONS

APPENDICES

SUMMARY

The Harris-Galveston Subsidence District (HGSD) and Fort Bend Subsidence District (FBSD) use a computer program and numerical models of selected locations within their respective districts to predict subsidence caused by pumpage of groundwater. The program is called PRESS (Predictions Relating Effective Stress and Subsidence). A total of 26 PRESS model locations have been established.

The 26 site models in Harris, Galveston, and Fort Bend counties used with the PRESS program to estimate future subsidence require recalibration using measured data approximately every five to ten years. Since the last recalibration of the site models in 1997 and 1998, groundwater usage patterns and the resulting patterns of water level decline and subsidence have changed substantially. Fugro Consultants, Inc. (Fugro), LBG-Guyton, and Freese and Nichols, Inc. (FNI) are currently working with the HGSD, the FBSD, the Lone Star Groundwater Conservation District (Lone Star GCD), the United States Geological Survey (USGS) and the National Geodetic Survey (NGS) to recalibrate the PRESS site models.

In Work Order 2, our efforts focused on gathering and preparing available data for use in running and assessing the performance of the 26 PRESS site models. More specifically, Work Order 2 consisted of the development of a preliminary design hydrograph and compilation of existing subsidence data for each of the 26 PRESS sites.

In this work order, we focused on running and assessing the performance of the 26 PRESS site models. More specifically, we performed PRESS model runs for each of the 26 existing PRESS sites. We compared PRESS-computed subsidence to existing subsidence data for each of the 26 sites. After the project team made independent evaluations, we made minor changes to design hydrographs where appropriate and re-ran PRESS. We prepared a discussion of the results and identified any sites that may require further recalibration of the existing models.

Based on the PRESS models' ability to predict the current rate of subsidence, we believe that 25 of the 26 existing PRESS site models are suitable for prediction of future subsidence. The FM 1960 model currently under predicts subsidence since 2000. An in-depth recalibration, possibly including changes to the model aquifer definitions, should be performed before the FM 1960 model is considered reliable for prediction of future subsidence.

1.0 INTRODUCTION

1.1 Project Description

The Harris-Galveston Subsidence District (HGSD) and Fort Bend Subsidence District (FBSD) use a computer program and numerical models of selected locations within their respective districts to predict subsidence caused by pumpage of groundwater. The program is called PRESS (Predictions Relating Effective Stress and Subsidence).

The program was originally adapted for use by the HGSD, and the individual site models that the program uses were initially developed and calibrated in two steps from 1978 to 1982. First, Fugro (formerly McClelland Engineers, Inc.) modified an existing computer program and applied it to six HGSD sites (McClelland 1979). In the second step, Espey, Huston & Associates, Inc. (EH&A 1982) further refined the program. EH&A also expanded the number of PRESS models to 21 and used a procedure to calibrate all of the site models through the 1978 benchmark releveling.

The HGSD PRESS models were recalibrated by Fugro in 1997 (Fugro 1997), and a supplement to that study (Fugro 2000) was issued in 2000 to address corrections made by LBG-Guyton Associates (LBG-Guyton). Prior to 1997, the HGSD discontinued the use of one of the original sites, but two new sites were developed and calibrated in the 1997 study, leaving a total of 22 active HGSD PRESS sites. Fugro calculated predicted subsidence using the HGSD PRESS models with different groundwater usage scenarios in 1999 (Fugro 1999) and 2002 (Fugro 2002a, 2002c).

The PRESS model was first applied to four FBSD sites by Geo Associates in 1990. We understand that the four FBSD PRESS models were developed and calibrated in a manner similar to the development and calibration of PRESS models for the HGSD, based on known subsidence through 1987 and water levels through 1990. The four FBSD PRESS sites were recalibrated by Fugro in 1998 (Fugro 1998). Fugro calculated predicted subsidence using the FBSD PRESS models with a different groundwater usage scenario in 2002 (Fugro 2002b).

Since the last recalibration of the site models in 1997 and 1998, groundwater usage patterns and the resulting patterns of water level decline and subsidence have changed substantially. The 26 site models in Harris, Galveston and Fort Bend counties used with the PRESS program to estimate future subsidence require recalibration using measured data approximately every five to ten years. Fugro, LBG-Guyton, and FNI are currently working with the HGSD, the FBSD, the Lone Star Groundwater Conservation District, the United States Geological Survey (USGS) and the National Geodetic Survey (NGS) to recalibrate the PRESS site models.

1.2 PRESS Model Overview

The PRESS model calculates subsidence using two forms of input. The first input includes the soil stratigraphy and geotechnical parameters associated with each compacting clay layer modeled for a given PRESS site. We did not modify the soil strata or geotechnical parameters for any PRESS site model during Work Order 3. The second input is a single design hydrograph representing the groundwater level in a given PRESS site at any time from the year 1906 to a selected future date. Development of preliminary design hydrographs was a primary objective of Work Order 2.

With these inputs, the PRESS program uses Terzaghi one-dimension consolidation theory to calculate consolidation of clay layers. Sand layers are assumed to be incompressible. The Terzaghi theory is widely used by geotechnical engineers to calculate the settlement of clays in response to the loads applied by structures. The program uses the theory to calculate subsidence of the ground surface causes by increases in the inter-particle stresses (called effective stresses) within clay layers in response to reductions in the groundwater pressure caused by groundwater pumpage (Fugro 1997).

1.3 Work Order 2

Work Order 2 for the current PRESS model recalibration effort focused on gathering and preparing available data for use in running and assessing the performance of the 26 PRESS site models. More specifically, Work Order 2 consisted of development of a preliminary design hydrograph and compilation of existing subsidence data for each of the 26 PRESS sites since the last recalibration effort in 1998-99.

Design hydrographs are based on measurements of groundwater levels in wells located within or nearby a PRESS site, as well as output from a groundwater model developed by the USGS and LBG-Guyton. Sources of subsidence data include benchmarks, borehole extensometers, continuously operating reference stations (CORS) and Global Positioning System (GPS) data obtained from Port-A-Measure (PAM) stations. PRESS model output from previous studies are used in the current recalibration effort.

The preliminary design hydrographs developed and the subsidence data compiled during Work Order 2 are presented in Fugro Report No. 04.12100052 – Work Order 2, dated May 18, 2011.

1.4 Purposes and Scope

Work Order 3 for the current PRESS model recalibration effort focused on running and assessing the performance of the 26 PRESS site models. More specifically, the purposes of Work Order 3 were to: 1) run PRESS for each of the 26 existing PRESS sites, 2) compare PRESS-computed subsidence to existing subsidence data for each of the 26 sites, 3) make minor changes to design hydrographs where appropriate, with concurrence from the project team, and re-run PRESS, and 4) prepare discussion of results and identify sites that may require recalibration of the existing model. The following sections further describe the proposed scope of services for Work Order 3:

- Consult with Mr. Bill Elsbury and Mr. Mark Fuhriman, both of whom have worked on the PRESS models previously, for modeling suggestions, input, and information;
- Compile input files for PRESS using design hydrographs developed in Work Order 2 for 26 existing PRESS sites;
- Run PRESS for 26 existing sites;

- Compare PRESS output to existing subsidence data compiled in Work Order 2;
- Make minor changes to design hydrographs for PRESS sites where identified as appropriate by the project team, and re-run PRESS for these sites;
- Prepare discussion of results and identify sites that may require recalibration of existing model;
- Develop cost estimates for future work orders, including recalibrating the PRESS models; and
- Provide information for review, and comment on any presentations prepared for the HGSD.

Future Work Orders may include the following activities:

- Predict future subsidence based on groundwater pumpage scenarios provided by the HGSD;
- Recalibrate PRESS models for sites that indicate a need for recalibration, and re-run the PRESS model for those sites;
- Compare PRESS results based on various Houston Area Groundwater Model (HAGM) data scenarios;
- Develop future PRESS sites;
- Assess and identify input parameters for the MODFLOW model and SUB package being developed by the USGS;
- Compare PRESS model to SUB package; and
- Develop recommendations for future uses of PRESS and SUB models.

2.0 PRESS MODEL RUNS

Our activities related to completion of the PRESS model runs are discussed in this section. We completed initial PRESS model runs for each of the 26 existing PRESS sites and reviewed the results in comparison to existing subsidence data. After review, we made minor revisions to design hydrographs where appropriate, with concurrence from the project team, and identified a site which may benefit from more extensive recalibration. We ran the PRESS model once again for sites where design hydrograph revisions were made. Additional discussion on each of these steps is included in the following paragraphs.

2.1 Initial PRESS Model Runs

After a thorough review of the PRESS program used for the most recent recalibration efforts (Fugro 1997, 1998), we did not identify a need for any changes to the source code. We executed the PRESS program, using batch files to control program execution, successfully on our current computing platform and operating system.

We created input files for the PRESS model at each of the 26 existing PRESS sites. We made no changes to the soil strata or geotechnical parameters assigned during the most recent calibration efforts (Fugro 1997, 1998). We used the preliminary design hydrographs developed during Work Order 2 to model generalized groundwater levels over time. We ran the PRESS program for each model representing the 26 existing PRESS sites and processed the output to allow for comparison to existing subsidence data.

2.2 Evaluation of Site Models

Computed subsidence, i.e., PRESS model output, was plotted with existing subsidence data compiled during Work Order 2 to allow for evaluation of model calibration. The PRESS output and subsidence data were reviewed by Fugro, FNI, LBG-Guyton, and the HGSD to determine which sites could benefit from changes to the preliminary design hydrographs, and which sites might require more in-depth recalibration to be reliable for future subsidence predictions. Based on this review, the team concluded that changes to the design hydrograph should be made for five PRESS models – Arcola (model lower aquifer), Cypress Creek, Eagle Point, Humble (model upper aquifer), and Langham Creek (model lower aquifer) – and in-depth recalibration should be considered in the future for the FM 1960 PRESS model.

2.3 Revised Design Hydrographs

Design hydrographs for the five sites identified in the preceding paragraph were revised based on input from LBG-Guyton, FNI, and the HGSD. The final design hydrographs are presented in Appendix A on Plates A-1 through A-26.

To maintain consistency with previous recalibration efforts (Fugro 1997, 1998), we did not make any changes to design hydrographs prior to the year 1996. The following paragraphs provide details on revisions made to the preliminary design hydrographs developed during Work Order 2.

2.3.1 Arcola

In refining the design hydrograph to represent the Arcola model lower aquifer, we continue the trend established in the most recent recalibration effort by following well LJ-65-29-706. However, we follow a more general water level trend in the data rather than following water depth data "spikes" in well LJ-65-29-706.

2.3.2 Cypress Creek

For the Cypress Creek PRESS model, we established the final design hydrograph by generally leveling out (no increase or decrease in water level) the hydrograph after the year 2004. This is generally consistent with the well data collected as a whole, and follows the trend seen in the groundwater model output. This differs from the approach taken in previous recalibration efforts by following the pattern of several wells rather than solely following well LJ-60-61-914 after the year 2004.

2.3.3 Eagle Point

Revisions to the preliminary design hydrograph for the Eagle Point PRESS model include a slight decline in water level in the years 2008 and 2010. The project team agrees that this more closely represents the collected well data and groundwater model output.

2.3.4 Humble

Based on input from the project team, we revised the final design hydrograph for the Humble model upper aquifer by generally shifting the overall magnitude of the water level to follow the groundwater model output after the year 1995 rather than from wells LJ-65-601 and -612. The trends of both wells and the groundwater model are similar and both show increasing water levels since 2000.

2.3.5 Langham Creek

We revised the design hydrograph for the Langham Creek model lower aquifer based on input from the project team. To define the final design hydrograph, we increased water levels after the year 2000 to more closely follow trends in the groundwater model output and data from M.U.D. 165 Well No. 1.

2.4 Updated PRESS Model Runs

We created revised input files based on the final design hydrographs, and updated PRESS model runs were completed. Input files used for the updated PRESS model runs are presented in Appendix B on Plates B-1 through B-26. Computed subsidence from the updated PRESS model runs are presented for review compared to measured subsidence data in Appendix C on Plates C-1 through C-26.

2.5 Historical Site Hydrographs

A historical site hydrograph was developed for each of the 26 PRESS site models. We utilized historical site hydrographs developed in previous studies for the time period from January 1906 through January 1995. Historical site hydrographs from January 1906 through January 1980 were originally developed by EH&A for the Phase II study (EH&A 1982), and hydrographs from January 1980 through January 1995 were developed by Fugro in the latest recalibration studies (Fugro 1997, 1998). We kept the historical site hydrographs through 1995 consistent with those presented in the Fugro recalibration studies.

We developed the portion of the historical hydrograph from January 1995 to January 2010 for each PRESS model aquifer by interpreting the well data and groundwater model output compiled and processed for this study. We reviewed the rationale behind the development of historical site hydrographs in the 1997 and 1998 Fugro recalibration studies and kept a consistent relationship between historical site hydrograph and well data whenever possible.

2.6 Discussion of Results

We assessed the quality of current model calibrations by comparing computed subsidence to collected subsidence data. Plate 2 presents the average measured subsidence at each PRESS site from 2000 to 2010. We compared this measured subsidence to the calculated subsidence values computed using the PRESS models. This comparison is shown for each existing PRESS site in Appendix C on Plates C-1 through C-26 and is summarized in the table on the following page.

For our review, we primarily focused on years following 2000. In some cases, the vertical shift applied to measured subsidence data starting after the year 1995 (not tied back to 1906) during Work Order 2 was adjusted for this report for presentation purposes. This allows for better comparison of the rate of subsidence over the time period of the measured data. We consider the ability of the PRESS model to calculate the current rate of subsidence more important than its calculation of the magnitude of total subsidence since 1906.

Based on the PRESS models' ability to predict the current rate of subsidence, we believe that 25 of the 26 existing PRESS site models are suitable for prediction of future subsidence. The FM 1960 model currently under predicts subsidence since 2000. An in-depth recalibration, possibly including changes to the model aquifer definitions, should be performed before the FM 1960 model is considered reliable for prediction of future subsidence.

2.1 – Summary of Measured Subsidence Comparison to PRESS Calculated Subsidence

Site	*Water Level Trend*		*Subsidence (2000-2010), ft*		*Correlation*
	Chicot	*Evangeline*	*Measured*	*Calculated (PRESS)*	
Arcola	↓	↓	0.4	0.30	Good
Baytown	↑	↑	0.05	0.01	Good
Bellaire	↑	↑	0.15	0.18	Good
Bellaire West	↑	↑	0.3	0.38	Good
Crosby	↑	↑	0	0.04	Good
Cypress Creek	↑	↑	0.85	0.86	Good
Downtown	↑	↑	-0.2	0.01	Good
Eagle Point	–	–	0.15	0.03	Good
FM 1960	↑	↑	1.4	0.70	Marginal
Galena Park	↑	↑	0	0.04	Good
Galveston County	↑	↓	0.15	0.11	Good
Genoa	↑	↑	0	0.03	Good
Harrisburg	↑	↑	0	0.05	Good
Hobby	↑	↑	0.1	0.05	Good
Humble	↑	↑	0.2	0.18	Good
Katy	↓	↓	0.7*	0.70	Good
La Porte	↑	↑	0	0	Good
Langham Creek	–	↓	0.75	1.05	Good
Long Point	↑	↑	N/A	0.33	N/A
NASA	↑	↑	0	0.03	Good
Needville	–	–	0.1	0.04	Good
North Houston	↑	↑	0	0.29	Good
Pasadena	↑	↑	-0.1	0	Good
Richmond-Rosenberg	–	↓	0.15	0.26	Good
Sheldon	↑	↑	0	0.04	Good
Smithers Lake	↓	↓	0.2	0.44	Good

Notes:
1. * - Katy subsidence interpolated using measurements prior to 2000 and since 2007.
2. No measured subsidence available since 2000 for the Long Point site.

3.0 SUMMARY AND FUTURE REVIEW AND WORK ORDERS

3.1 Summary

In general, we believe the calibration of PRESS models is good (with the exception of FM 1960) and the models are suitable predictive tools. However, any predictions of future subsidence are empirical, and we believe the individual site models need to be reviewed and recalibrated at intervals of five to ten years.

To retain the capability to review the model calibrations and to create new models if desired, we recommend that the HGSD continue to obtain data on groundwater conditions and subsidence. We recommend that groundwater data be collected annually. We recommend continued collection of subsidence data from existing extensometers, benchmarks, continuously operating reference stations (CORS) and Global Positioning System (GPS) data obtained from Port-A-Measure (PAM) stations.

Data from 12 of the 18 PAM stations utilized for this recalibration effort are available only within the past five years. We recommend performing a releveling of benchmarks in the next five to ten years or prior to the next assessment, whichever is sooner, in PRESS sites with recently installed PAM stations and no extensometer data available, i.e., the Arcola, Bellaire, Bellaire West, Crosby, Eagle Point, Genoa, Humble, Katy, Langham Creek, Needville, North Houston and Sheldon PRESS sites. In addition to providing an additional source of reliable subsidence data, releveling will serve as a check on the accuracy of PAM site readings, which may then be more confidently relied upon for future subsidence measurements.

We recommend that a PAM station be established within the boundaries of the Galena Park, Galveston County and Long Point PRESS sites. Benchmarks are the only sources of subsidence data currently available at each of these sites, and there has been no subsidence data collected at the Long Point site since the year 2000.

Several sites would benefit from an expansion of the groundwater well network. We recommend additional sources of groundwater measurements in the following PRESS sites (for dual aquifer model sites, the relevant aquifer is identified in parentheses): Arcola, Crosby (upper), Galveston County (lower), Hobby (upper), Langham Creek (upper), Long Point (upper) and North Houston (upper).

3.2 Future Work Orders

We recommend an in-depth recalibration, possibly including changes to the model aquifer definitions, should be performed before the FM 1960 model is considered reliable for prediction of future subsidence. We expect that LBG-Guyton and the USGS will develop future groundwater model scenarios. This will create hydrographs for each PRESS site will be projected to a future date using updated groundwater model output to be provided by the USGS. The PRESS model will be run on each of the 26 active PRESS sites using the project design hydrographs to predict subsidence to the future date determined by the HGSD.

4.0 REFERENCES

Espey, Huston & Associates, Inc. (1982), "Water Management Study – Phase II," Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

Fugro-McClelland (Southwest), Inc. (1997), "Recalibration of PRESS Models and Development of Two New Models; Harris and Galveston Counties, Texas," Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

Fugro-McClelland (Southwest), Inc. (1998), "Recalibration of PRESS Models; Fort Bend County, Texas," Fort Bend Subsidence District, Friendswood, Texas.

Fugro South, Inc. (1999), "Subsidence Predictions, Scenarios CSD-97, CSD-98, and CSD-99, Harris-Galveston Coastal Subsidence District," Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

Fugro South, Inc. (2000), "Subsidence Predictions, Scenarios FBSD-100 and FBSD-101, Fort Bend Subsidence District," Fort Bend Subsidence District, Friendswood, Texas.

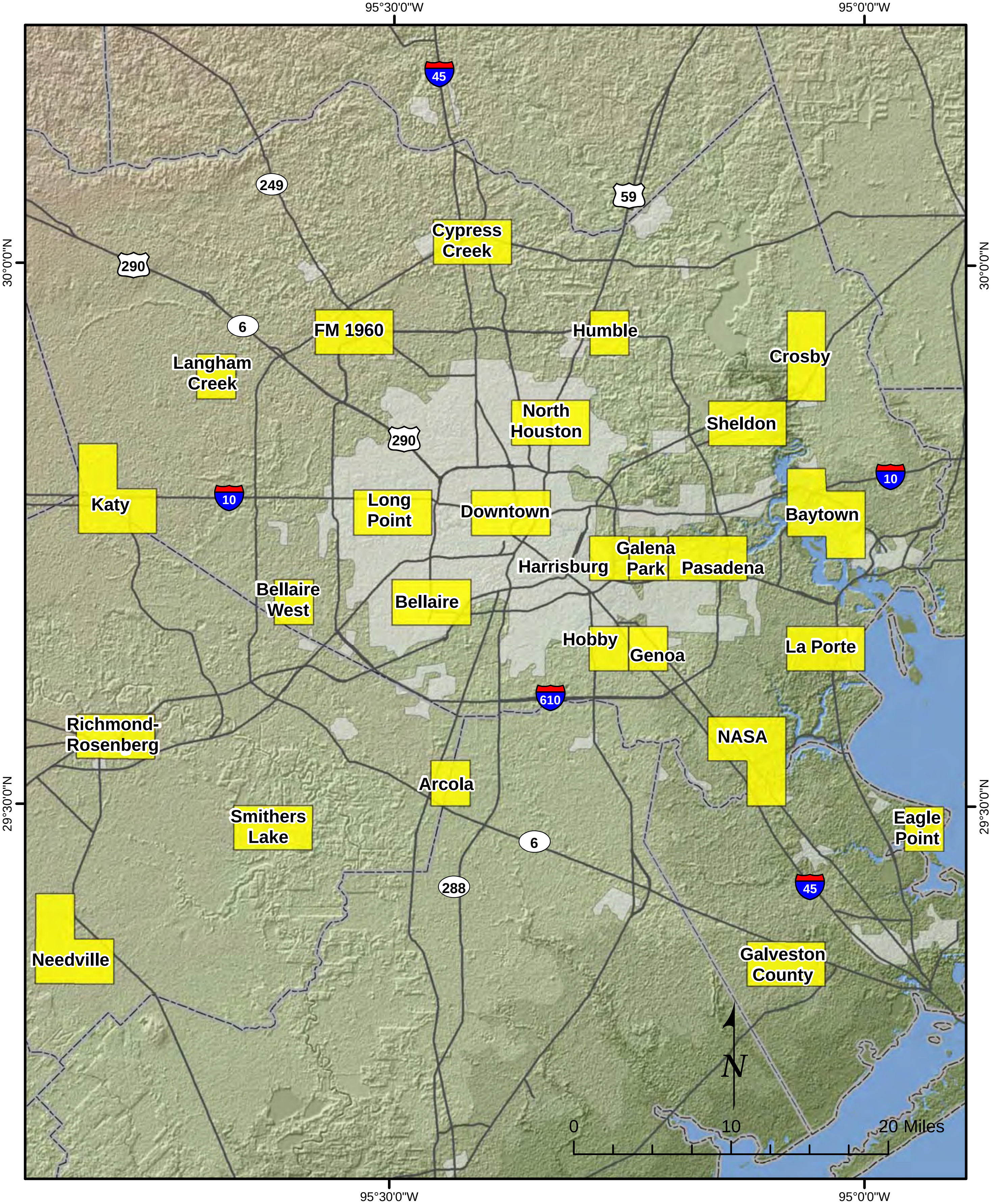
Fugro South, Inc. (2002a), "Subsidence Predictions, Scenario CSD-96Z, Harris-Galveston Coastal Subsidence District," Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

Fugro South, Inc. (2002b), "Subsidence Predictions, Scenario FB-103, Fort Bend Subsidence District," Fort Bend Subsidence District, Friendswood, Texas.

Fugro South, Inc. (2002c), "Subsidence Predictions, Scenario CSD-104, Harris-Galveston Coastal Subsidence District," Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

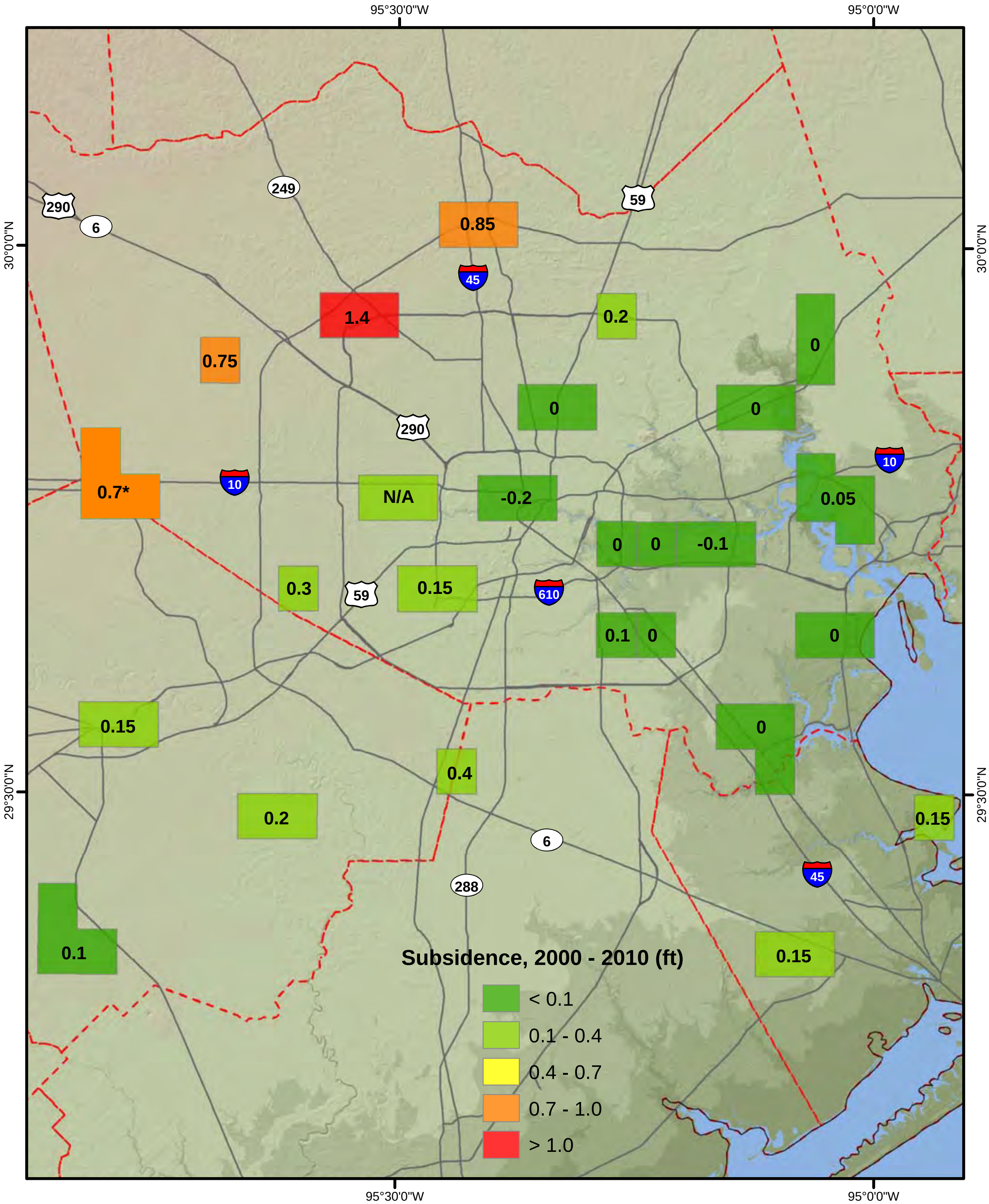
McClelland Engineers, Inc. (1979), "Subsidence Cause and Effect," Chapter IV, in Water Management Study – Phase I, by Espey, Huston & Associates, Inc., Harris-Galveston Coastal Subsidence District, Friendswood, Texas.

ILLUSTRATIONS



PLAN OF PRESS MODEL SITES

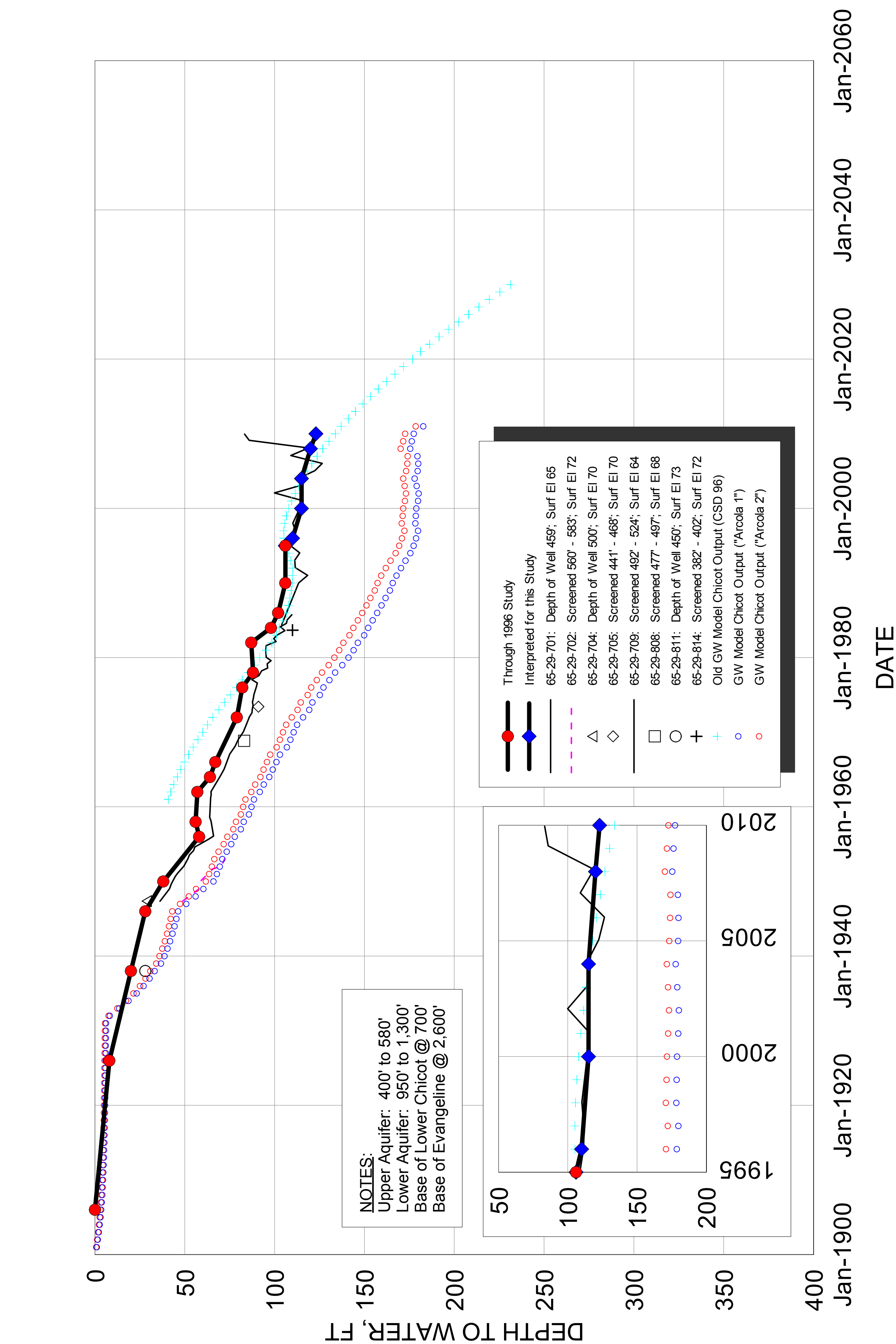
PLATE 1



AVERAGE MEASURED SUBSIDENCE, 2000 - 2010

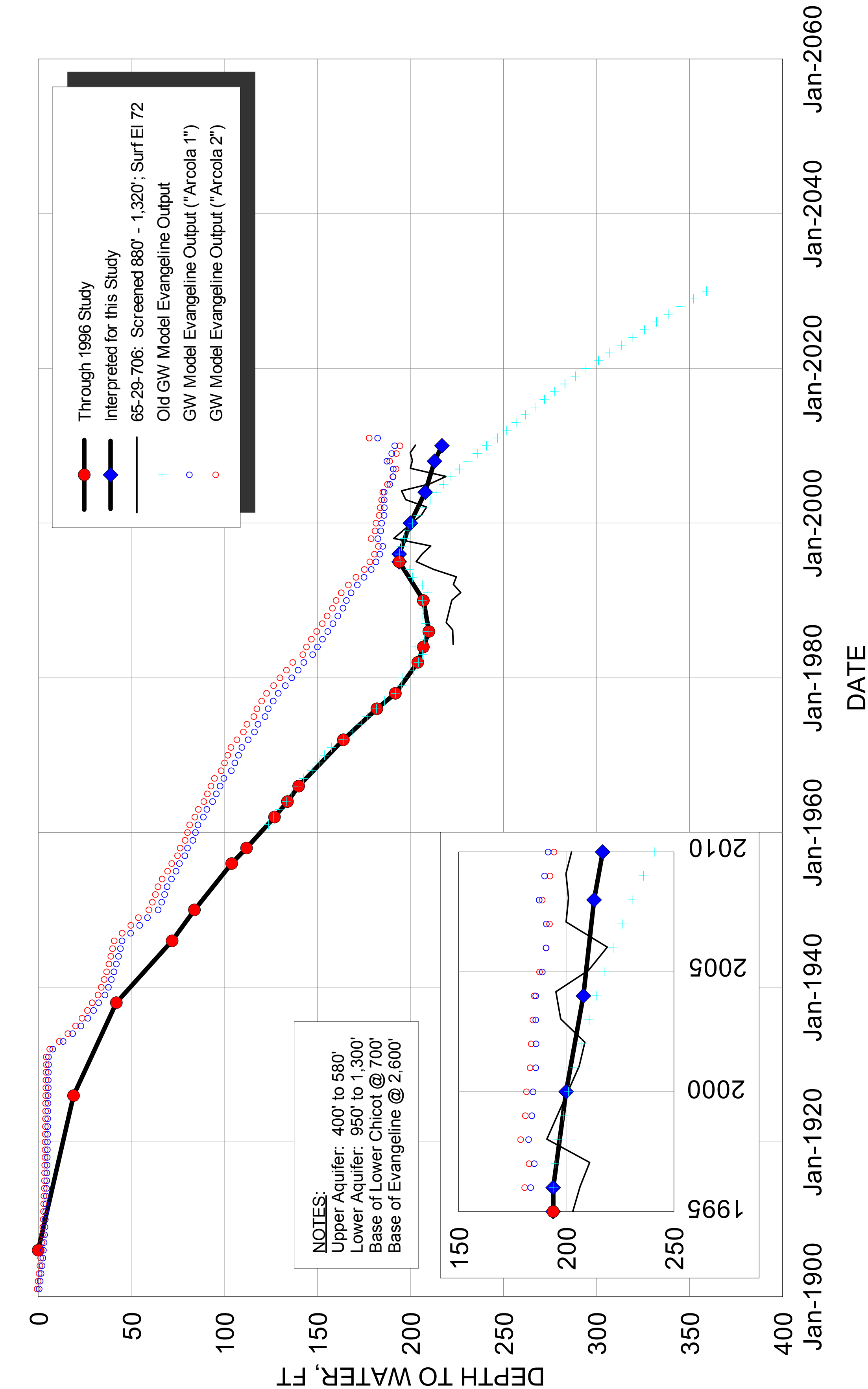
PLATE 2

APPENDIX A – DESIGN HYDROGRAPHS



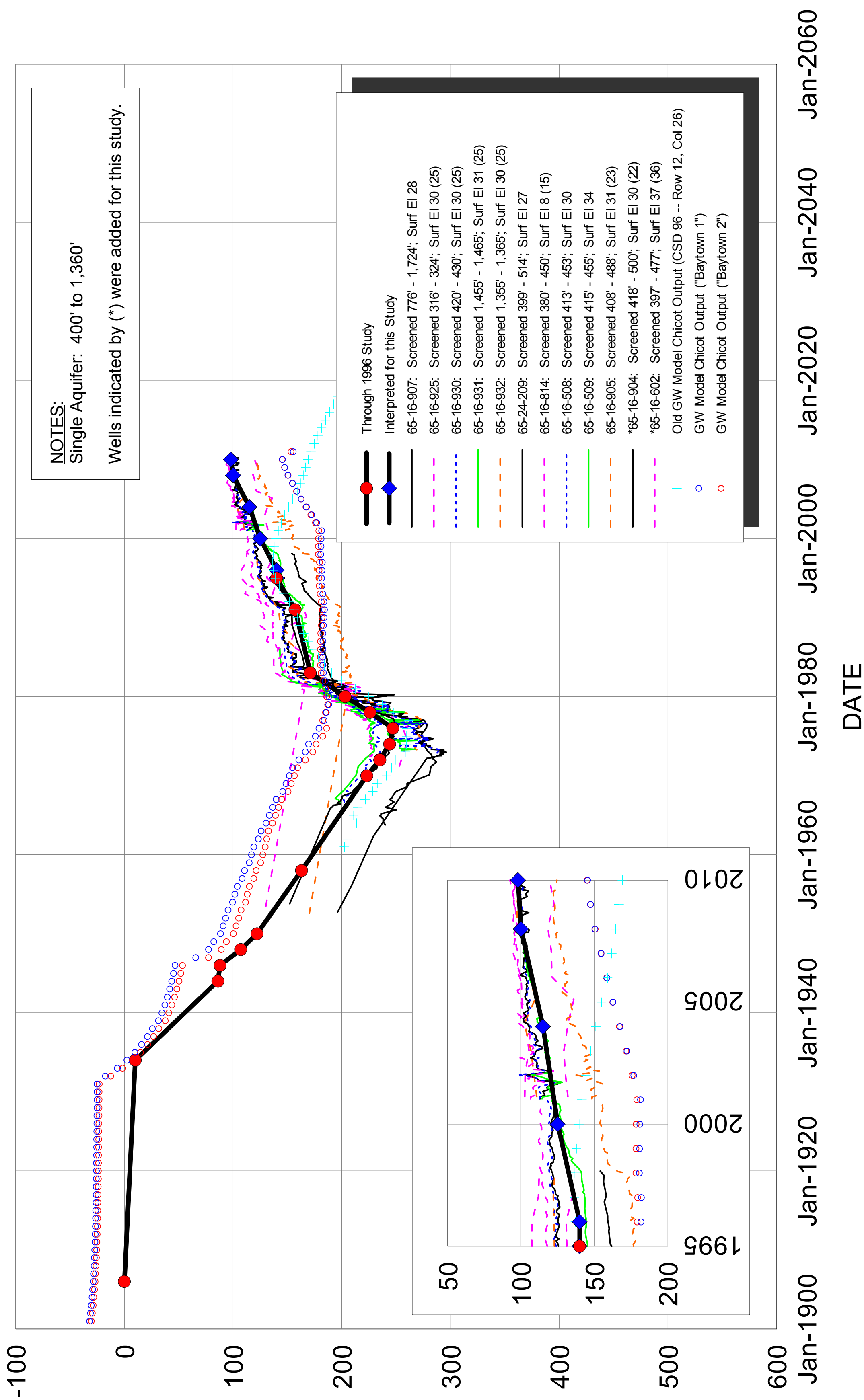
HYDROGRAPHS FOR ARCOLA SITE
MODEL UPPER AQUIFER

PLATE A-1



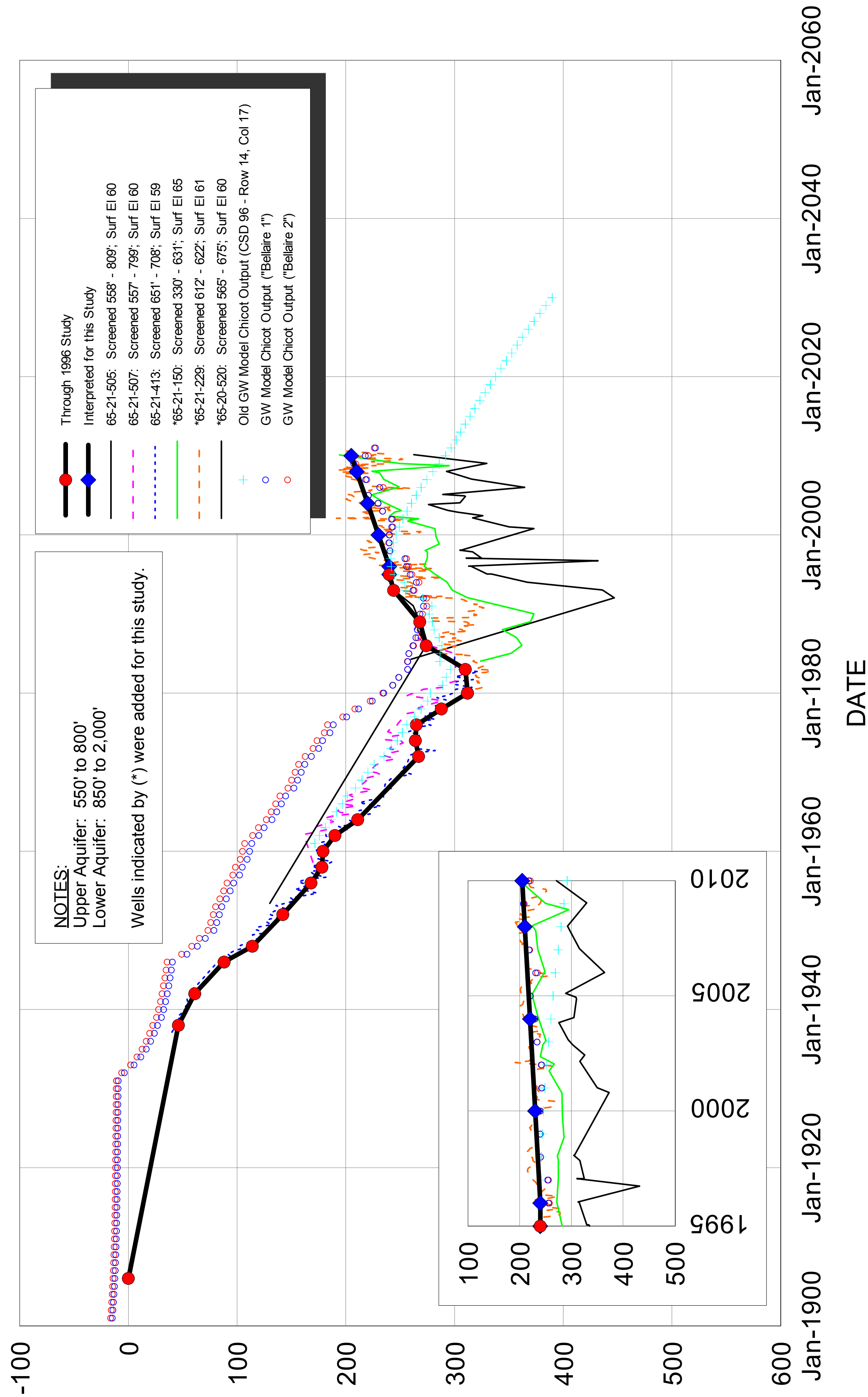
HYDROGRAPHS FOR ARCOLA SITE
MODEL LOWER AQUIFER

PLATE A-2



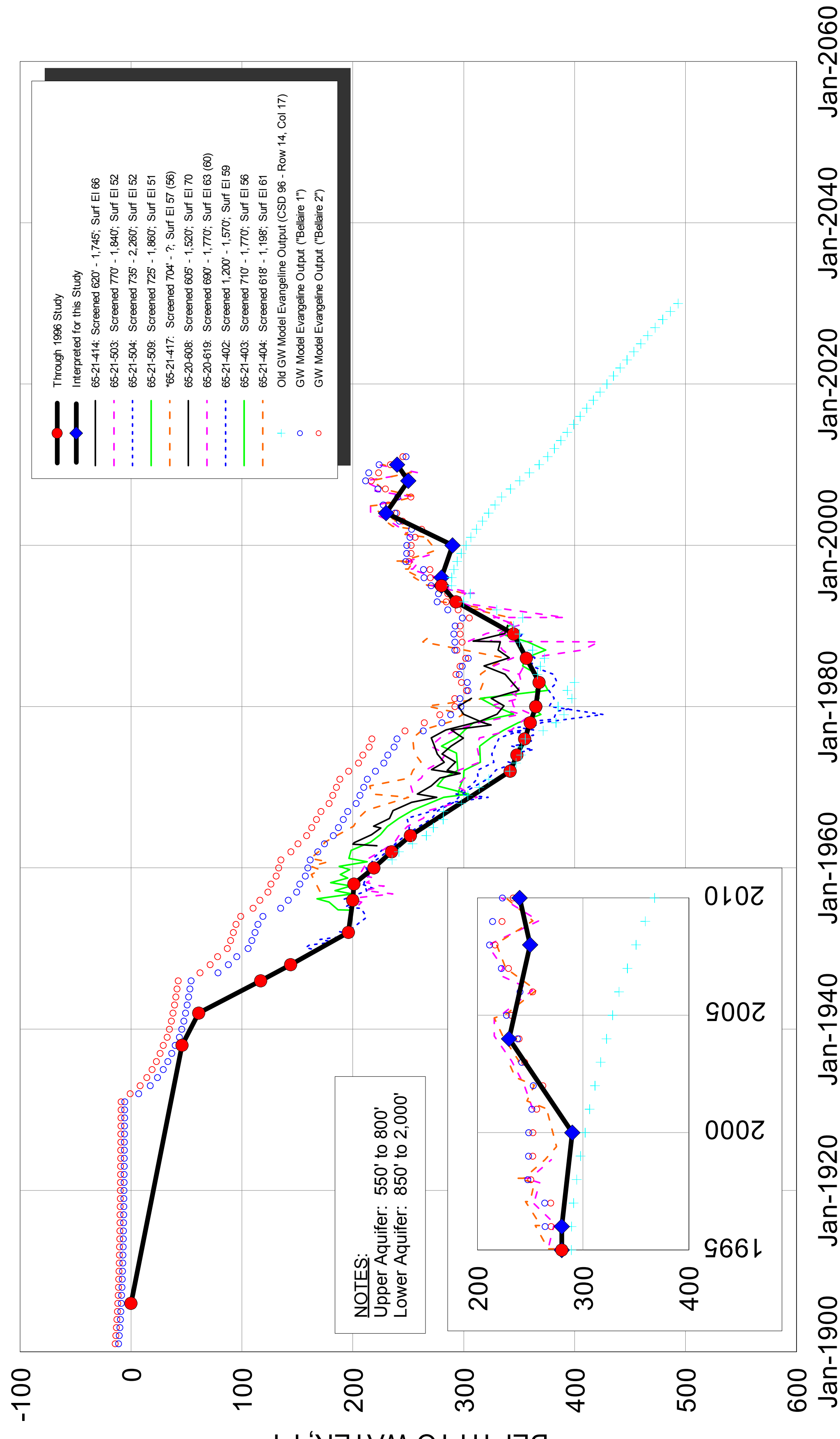
HYDROGRAPHS FOR BAYTOWN SITE
SINGLE MODEL AQUIFER

PLATE A-3



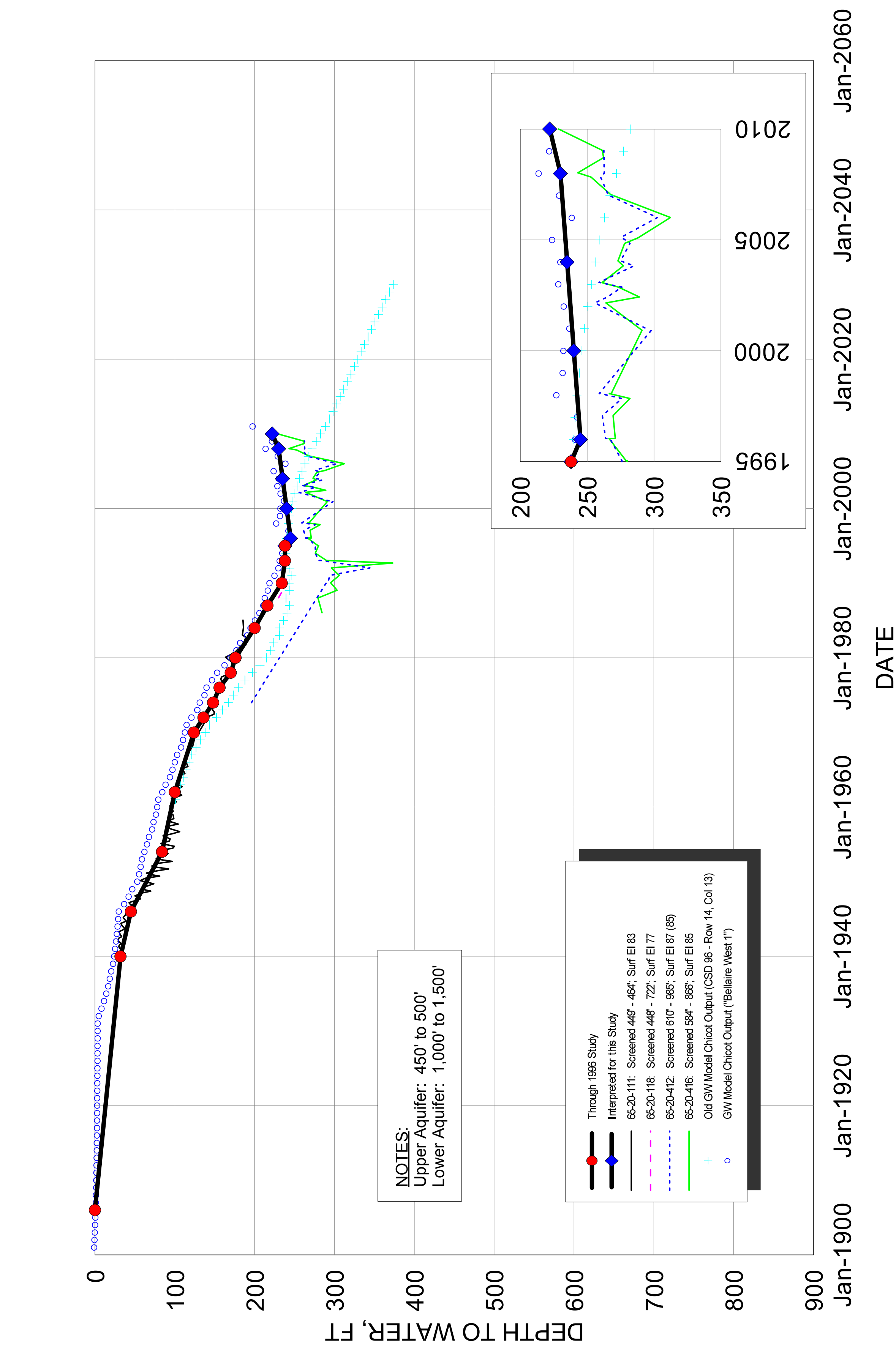
HYDROGRAPHS FOR BELLAIRE SITE
MODEL UPPER AQUIFER

PLATE A-4



HYDROGRAPHS FOR BELLAIRE SITE
MODEL LOWER AQUIFER

PLATE A-5



HYDROGRAPHS FOR BELLAIRE WEST SITE
MODEL UPPER AQUIFER

PLATE A-6

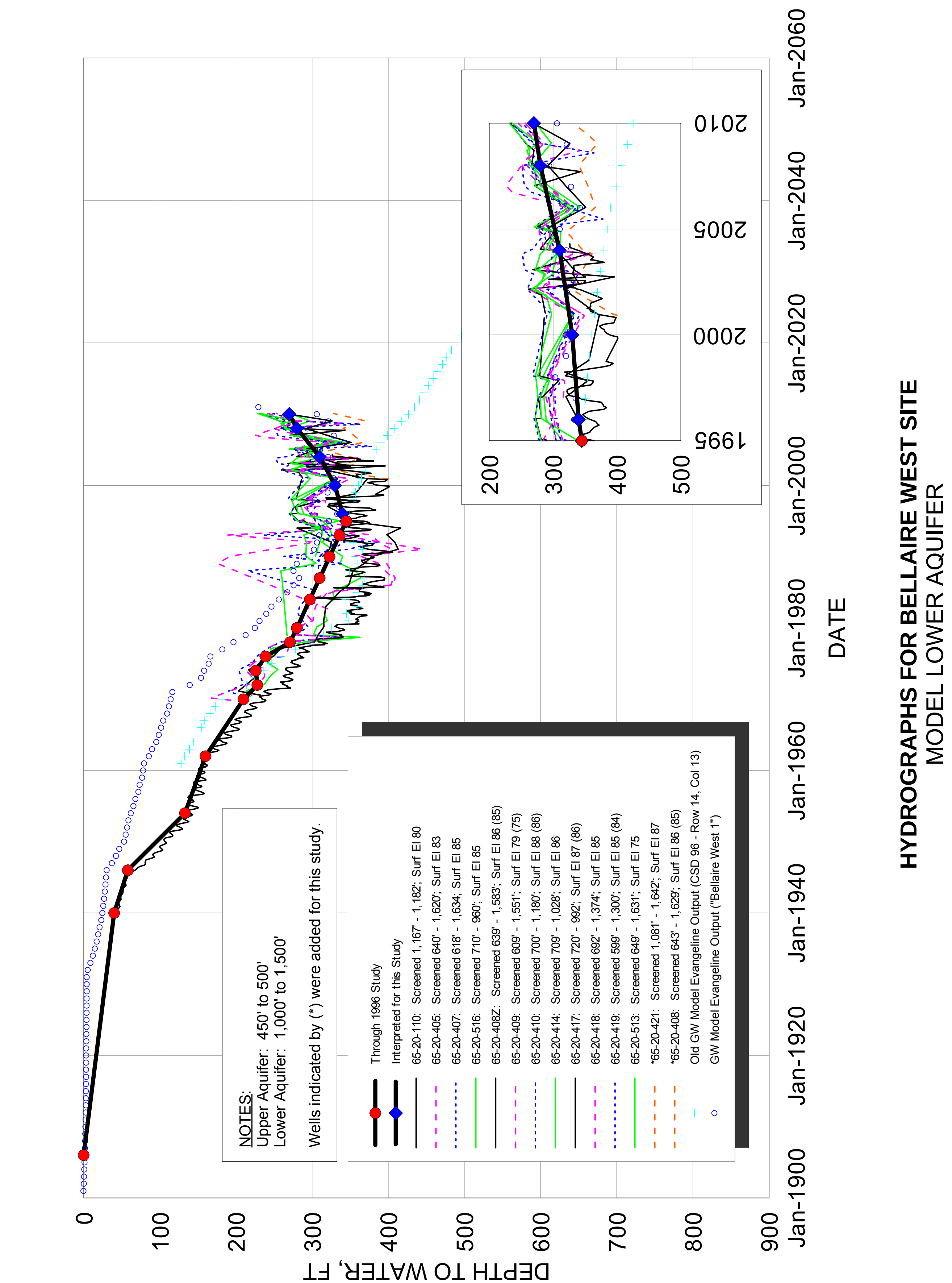
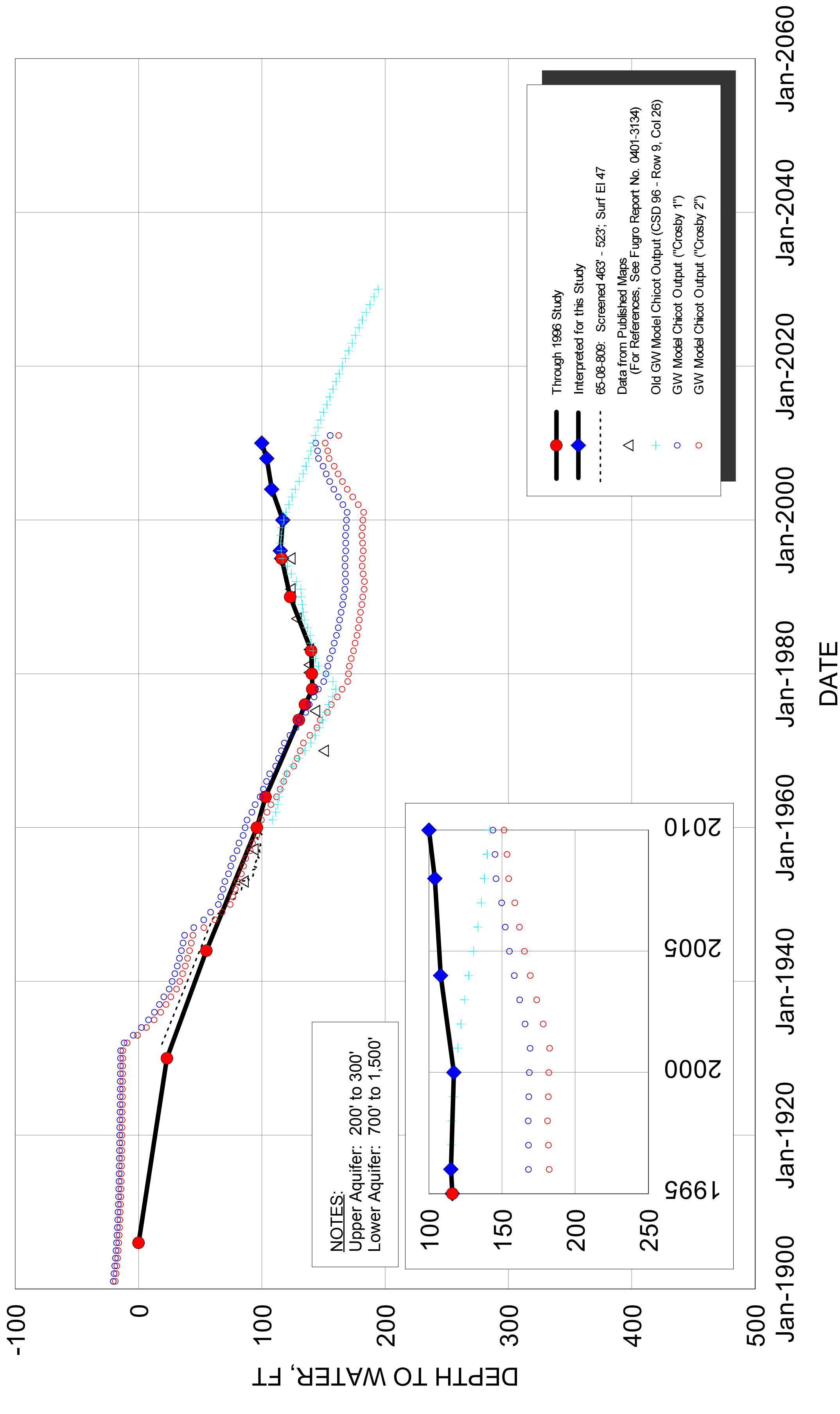
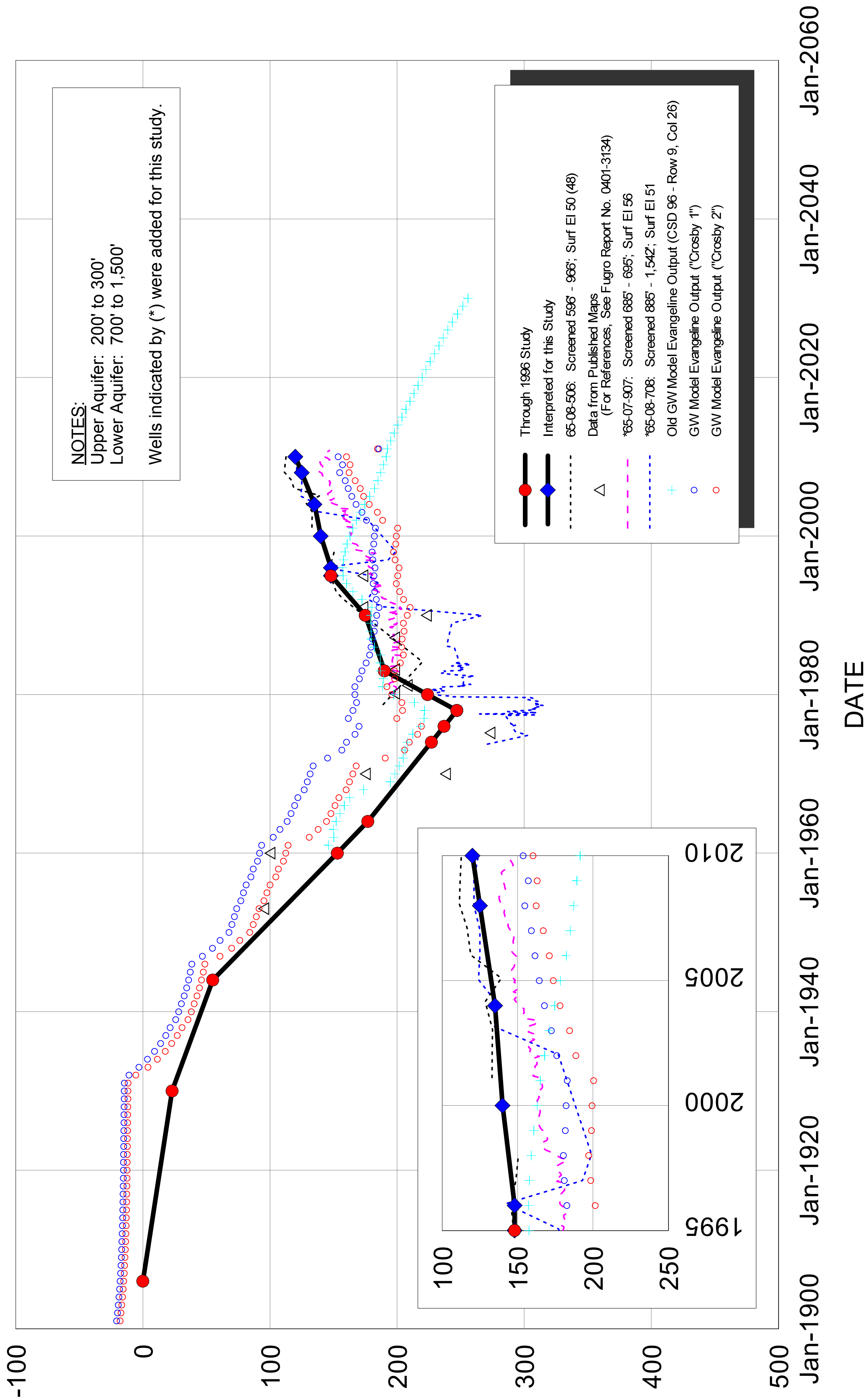

HYDROGRAPHS FOR BELLAIRE WEST SITE
MODEL LOWER AQUIFER
DEPTH TO WATER, FT
DATE
0
100
200
300
400
500
600
700
800
900
Jan-1900
Jan-1920
Jan-1940
Jan-1960
Jan-1980
Jan-2000
Jan-2020
Jan-2040
Jan-2060
NOTES:
Upper Aquifer: 450' to 500'
Lower Aquifer: 1,000' to 1,500'
Wells indicated by (*) were added for this study.
Through 1996 Study
Interpreted for this Study
65-20-110: Screened 1,167' - 1,182'; Surf El 80
65-20-405: Screened 640' - 1,620'; Surf El 83
65-20-407: Screened 618' - 1,634'; Surf El 85
65-20-516: Screened 710' - 960'; Surf El 85
65-20-408Z: Screened 639' - 1,583'; Surf El 86 (85)
65-20-409: Screened 609' - 1,551'; Surf El 79 (75)
65-20-410: Screened 700' - 1,180'; Surf El 88 (86)
65-20-414: Screened 709' - 1,028'; Surf El 86
65-20-417: Screened 720' - 992'; Surf El 87 (86)
65-20-418: Screened 692' - 1,374'; Surf El 85
65-20-419: Screened 599' - 1,300'; Surf El 85 (84)
65-20-513: Screened 649' - 1,631'; Surf El 75
*65-20-421: Screened 1,081' - 1,642'; Surf El 87
*65-20-408: Screened 643' - 1,629'; Surf El 86 (85)
Old GW Model Evangeline Output (CSD 96 - Row 14, Col 13)
GW Model Evangeline Output ("Bellaire West 1")
200
300
400
500
1995
2000
2005
2010

PLATE A-7



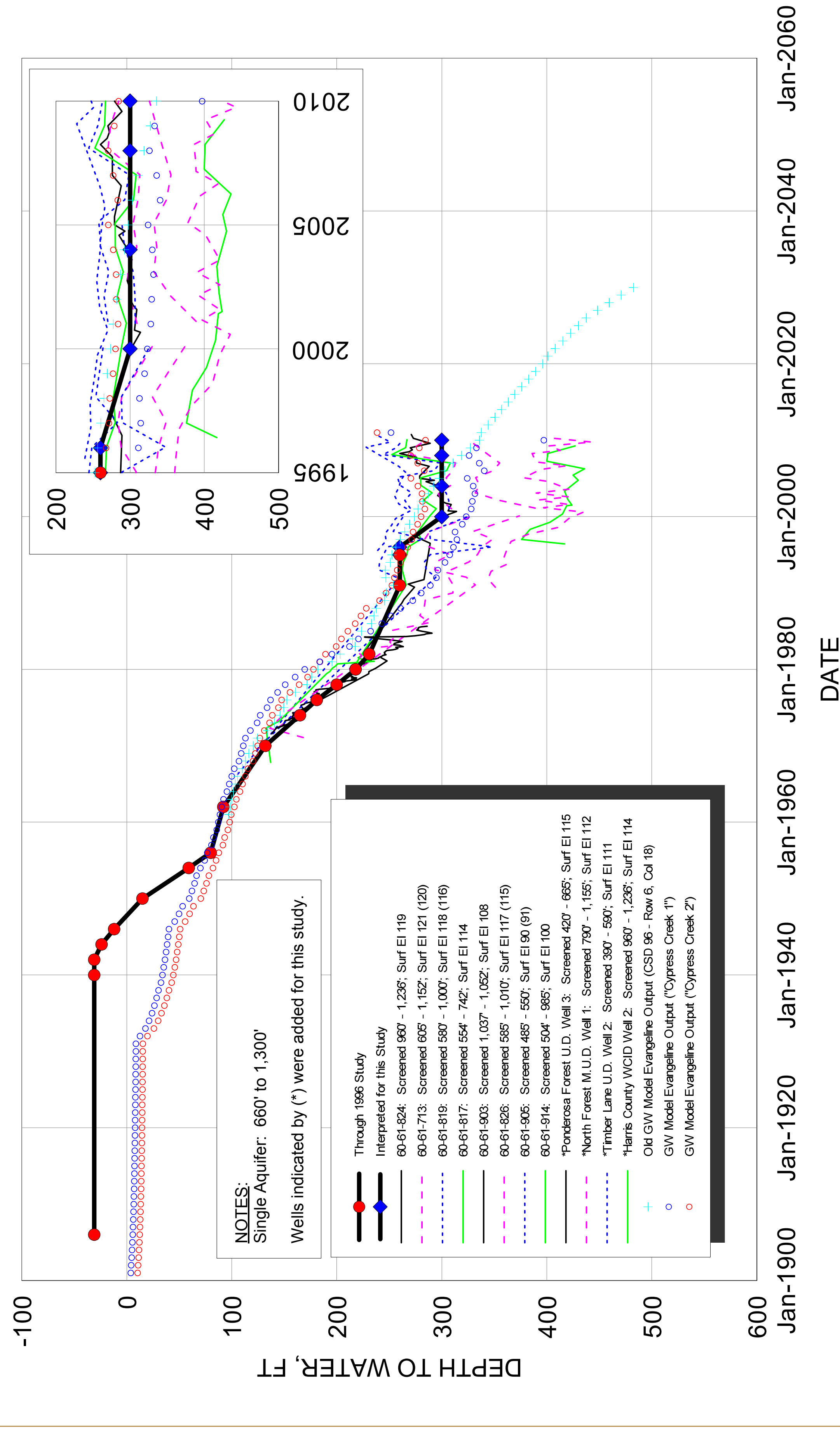
HYDROGRAPHS FOR CROSBY SITE
MODEL UPPER AQUIFER

PLATE A-8



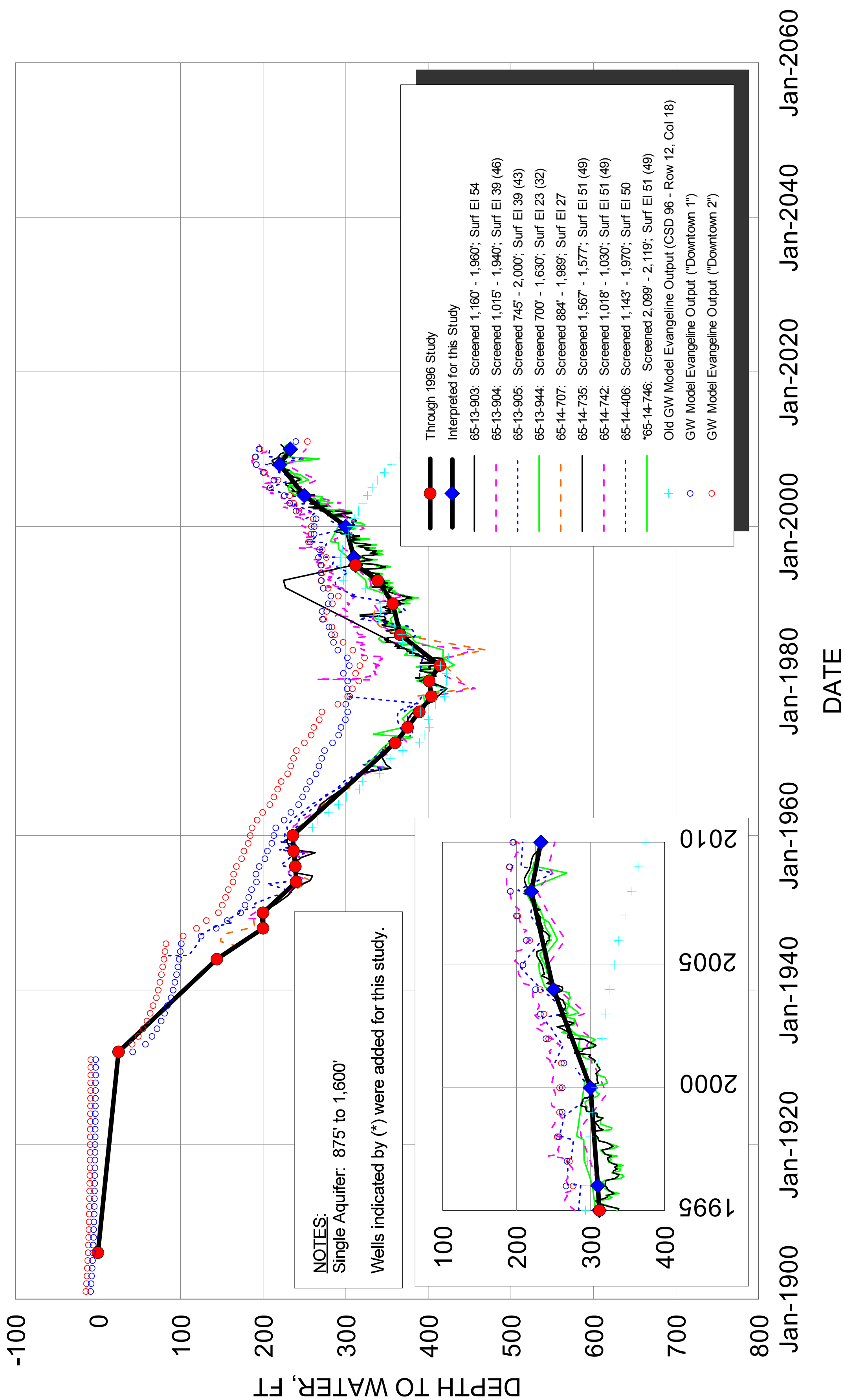
HYDROGRAPHS FOR CROSBY SITE
MODEL LOWER AQUIFER

PLATE A-9



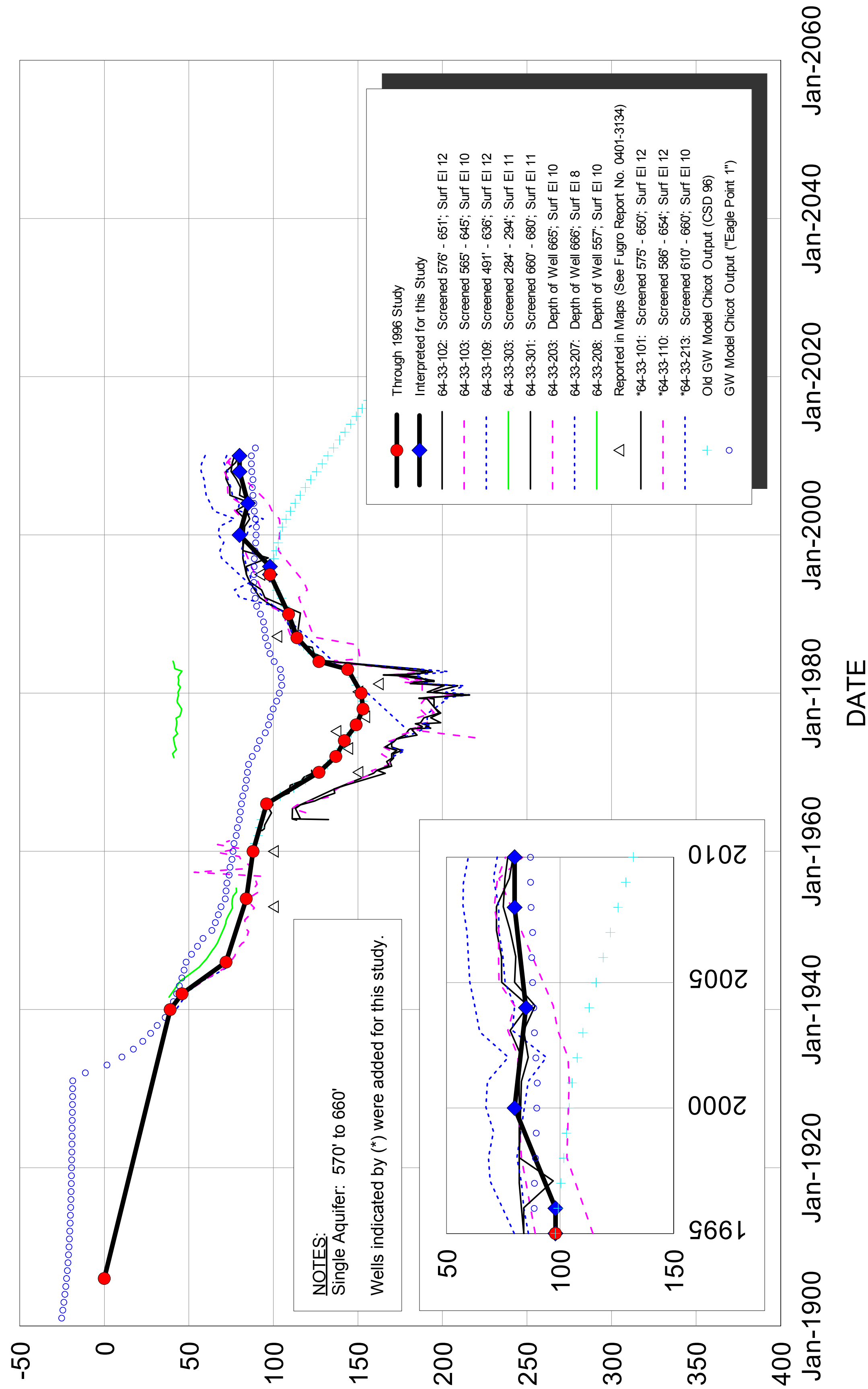
HYDROGRAPHS FOR CYPRESS CREEK SITE
SINGLE MODEL AQUIFER

PLATE A-10



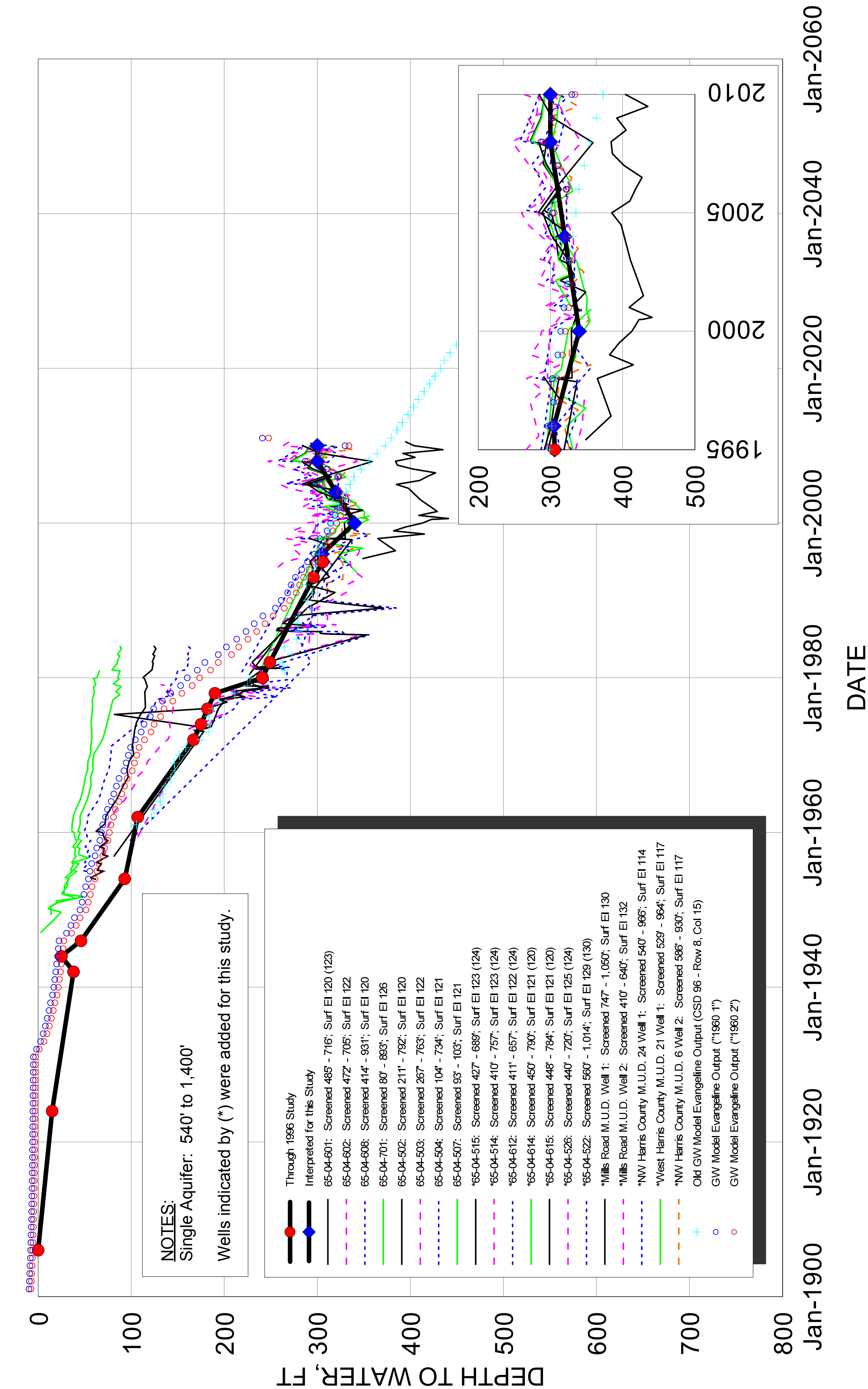
HYDROGRAPHS FOR DOWNTOWN SITE
SINGLE MODEL AQUIFER

PLATE A-11



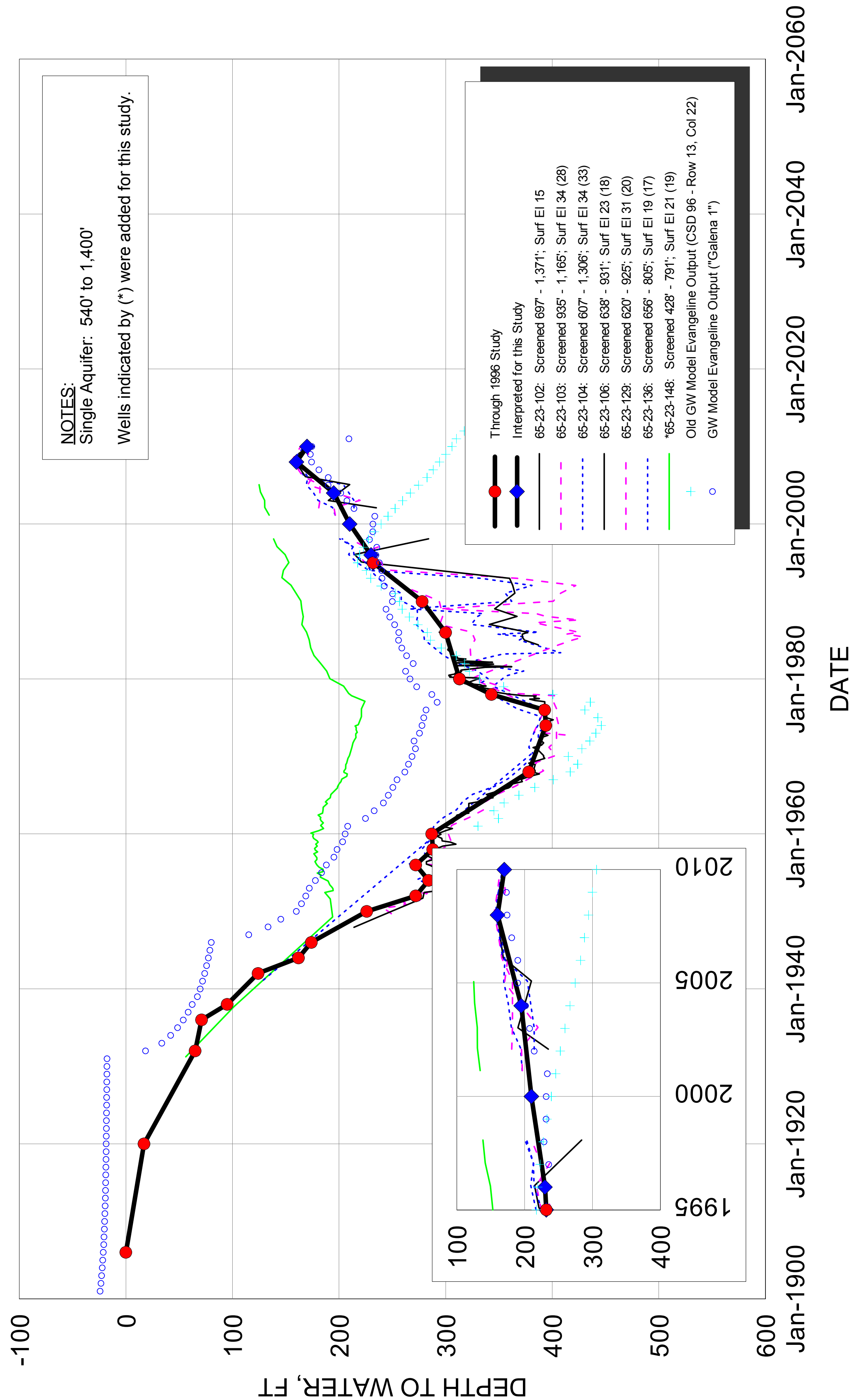
HYDROGRAPHS FOR EAGLE POINT SITE
SINGLE MODEL AQUIFER

PLATE A-12



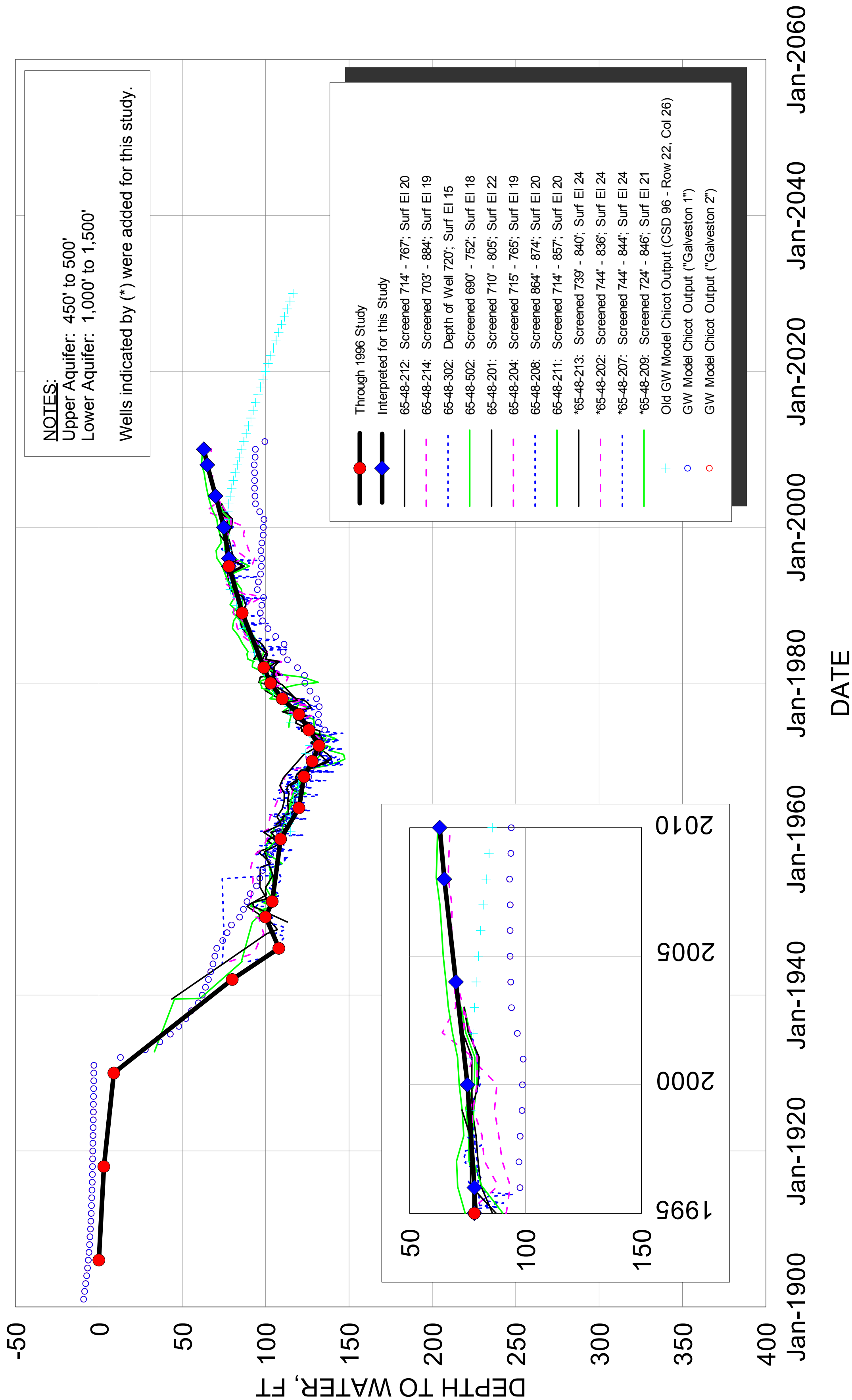
HYDROGRAPHS FOR FM 1960 SITE
SINGLE MODEL AQUIFER

PLATE A-13



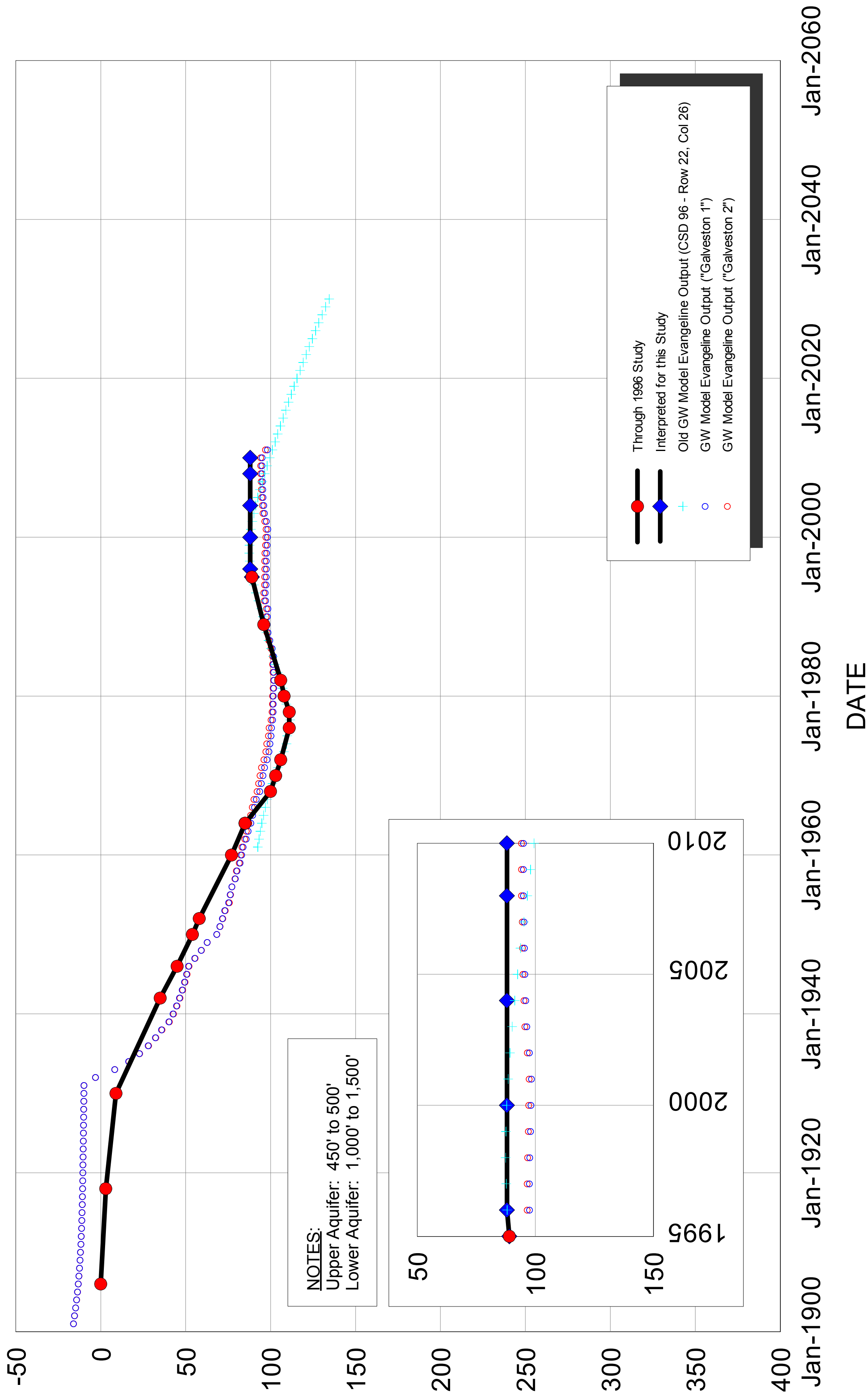
HYDROGRAPHS FOR GALENA PARK SITE
SINGLE MODEL AQUIFER

PLATE A-14



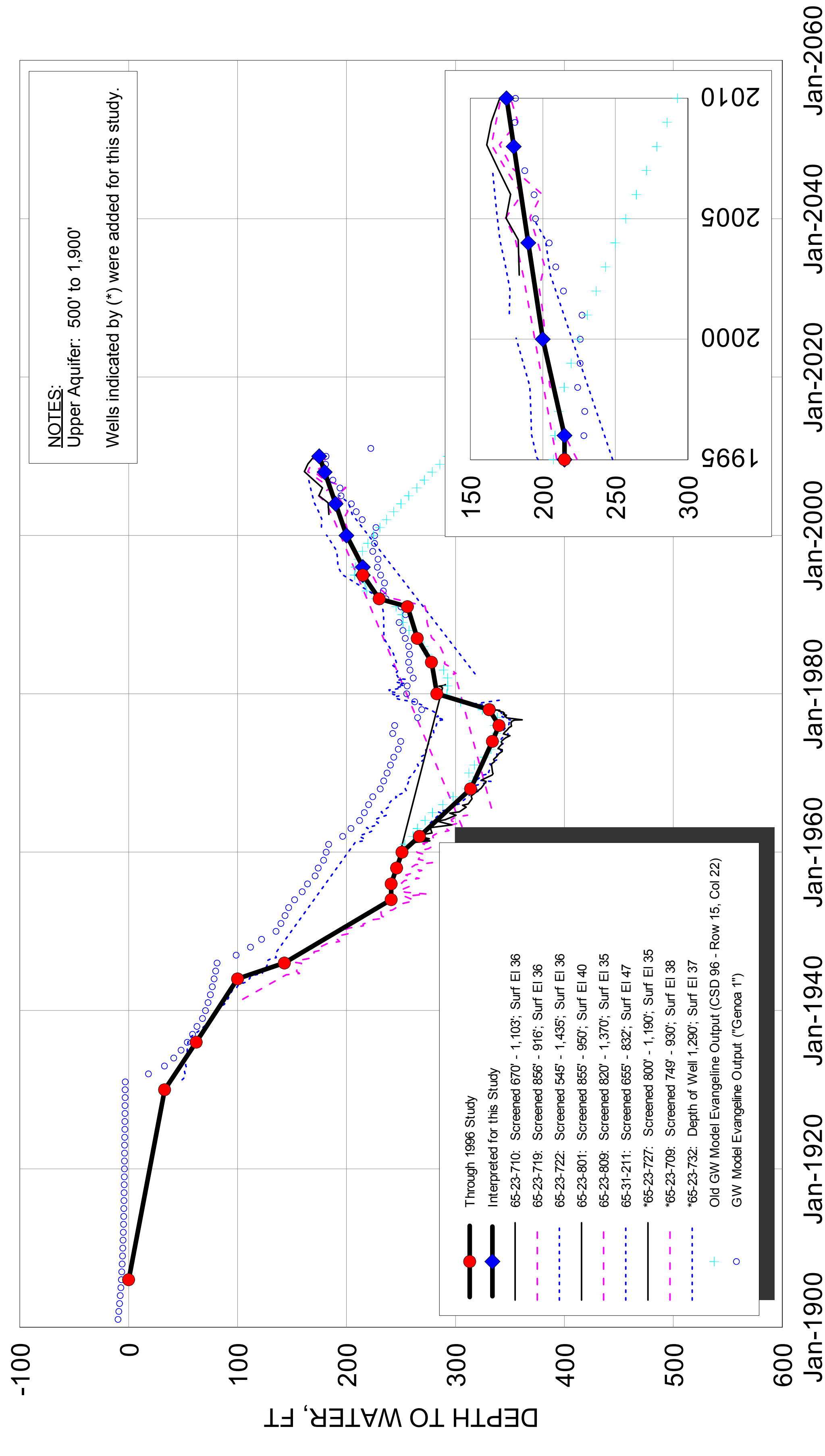
HYDROGRAPHS FOR GALVESTON COUNTY SITE
MODEL UPPER AQUIFER

PLATE A-15



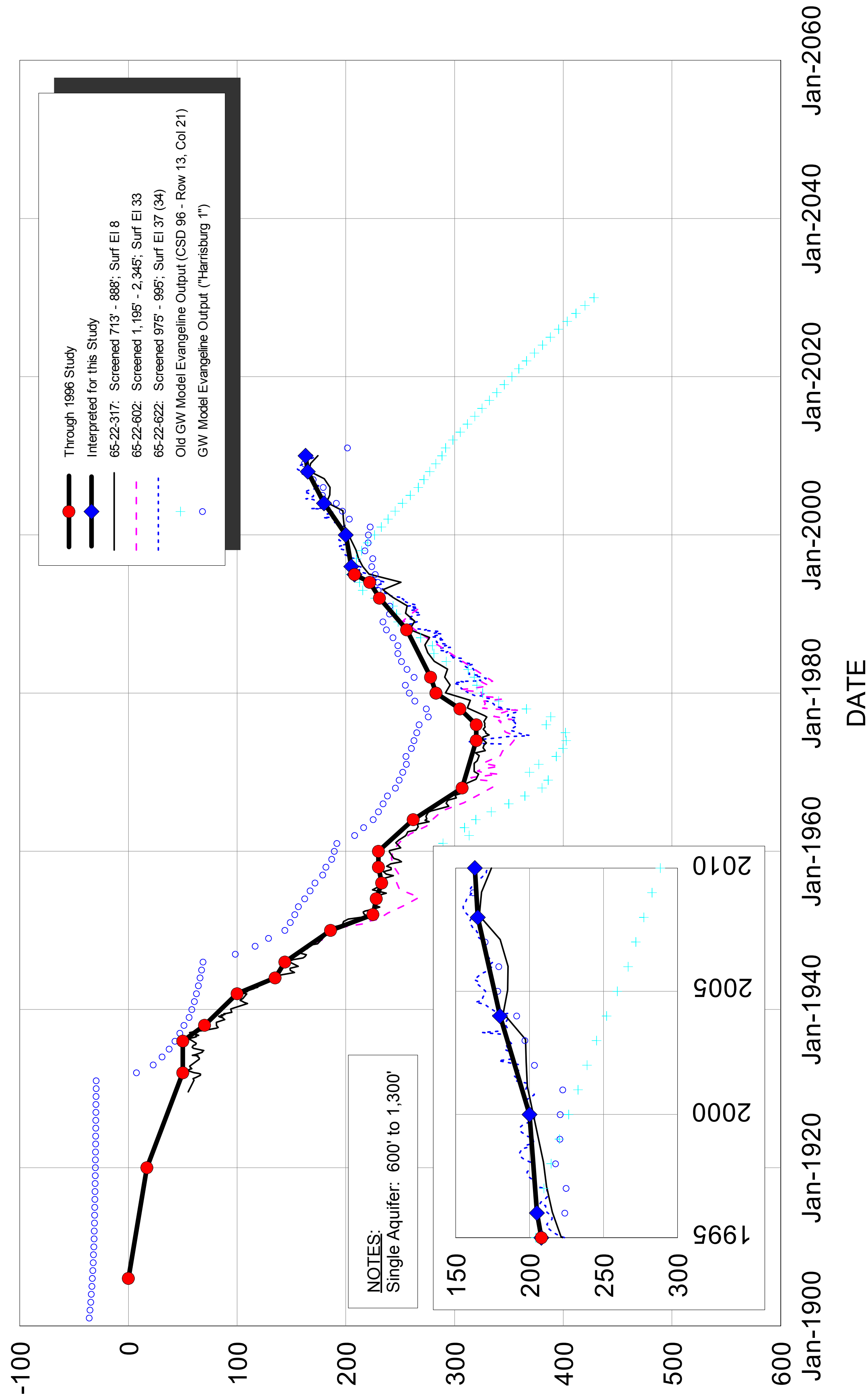
HYDROGRAPHS FOR GALVESTON COUNTY SITE
MODEL LOWER AQUIFER

PLATE A-16



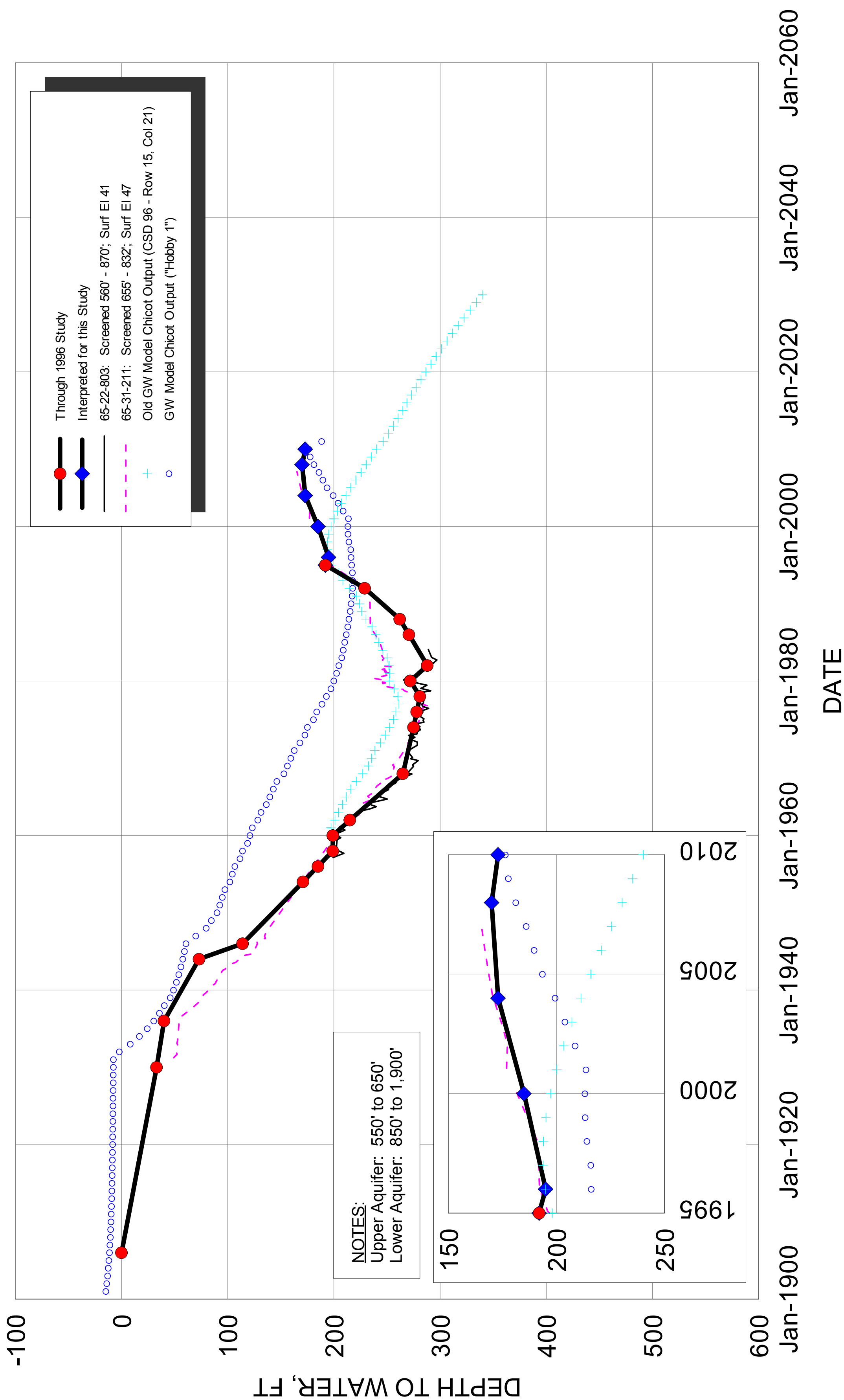
HYDROGRAPHS FOR GENOA SITE
SINGLE MODEL AQUIFER

PLATE A-17

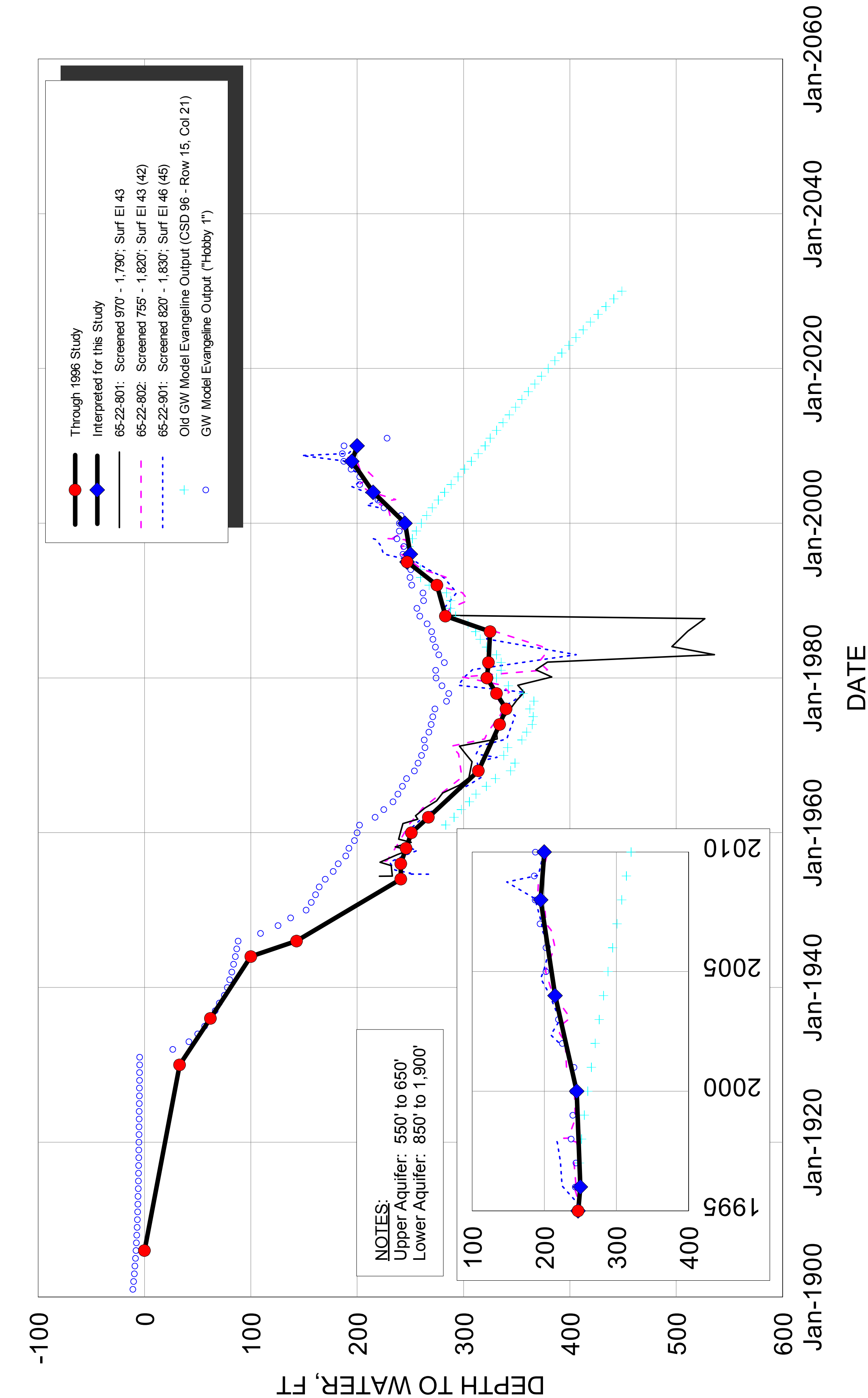


HYDROGRAPHS FOR HARRISBURG SITE
SINGLE MODEL AQUIFER

PLATE A-18

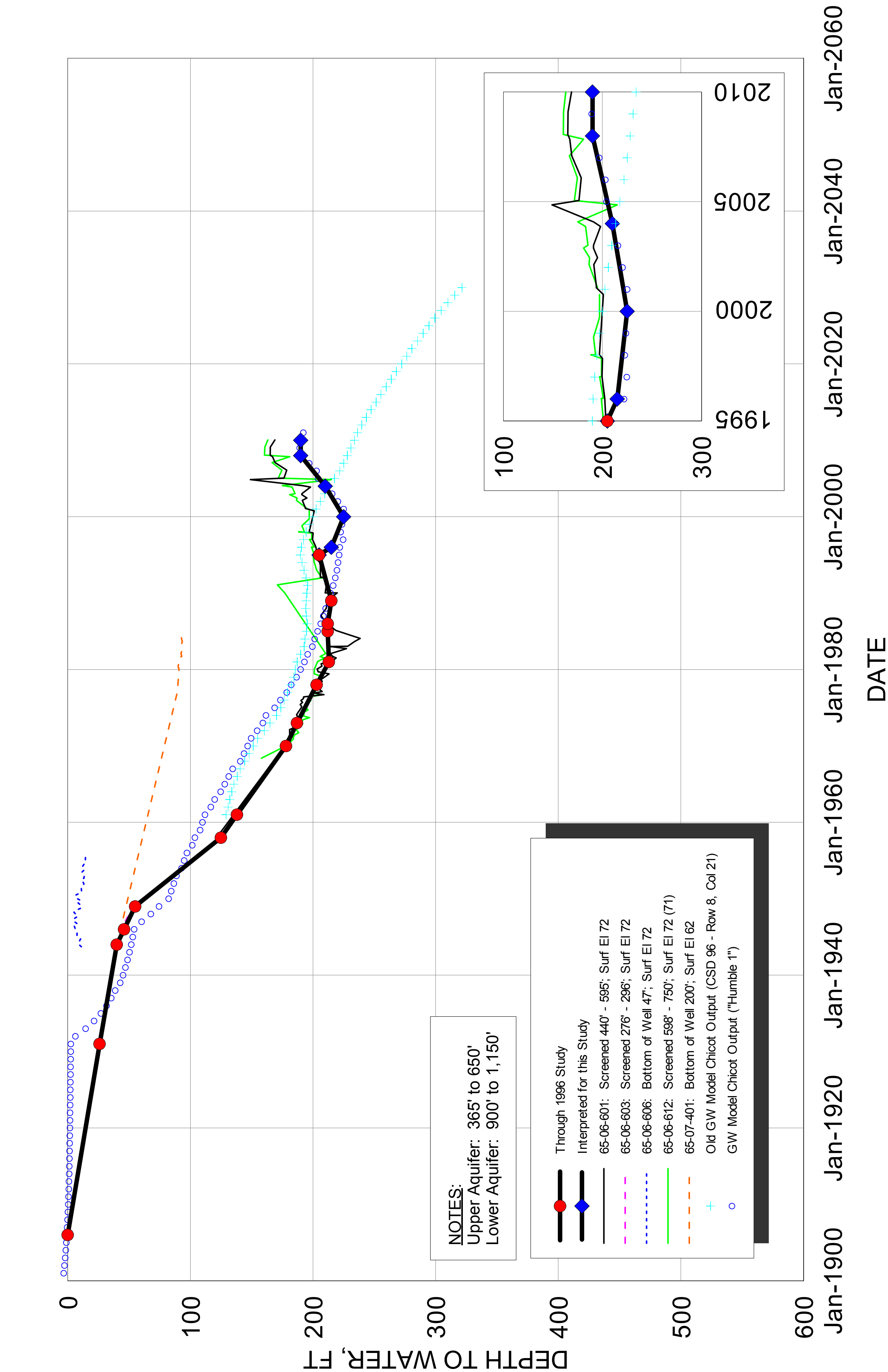


HYDROGRAPHS FOR HOBBY SITE
UPPER MODEL AQUIFER



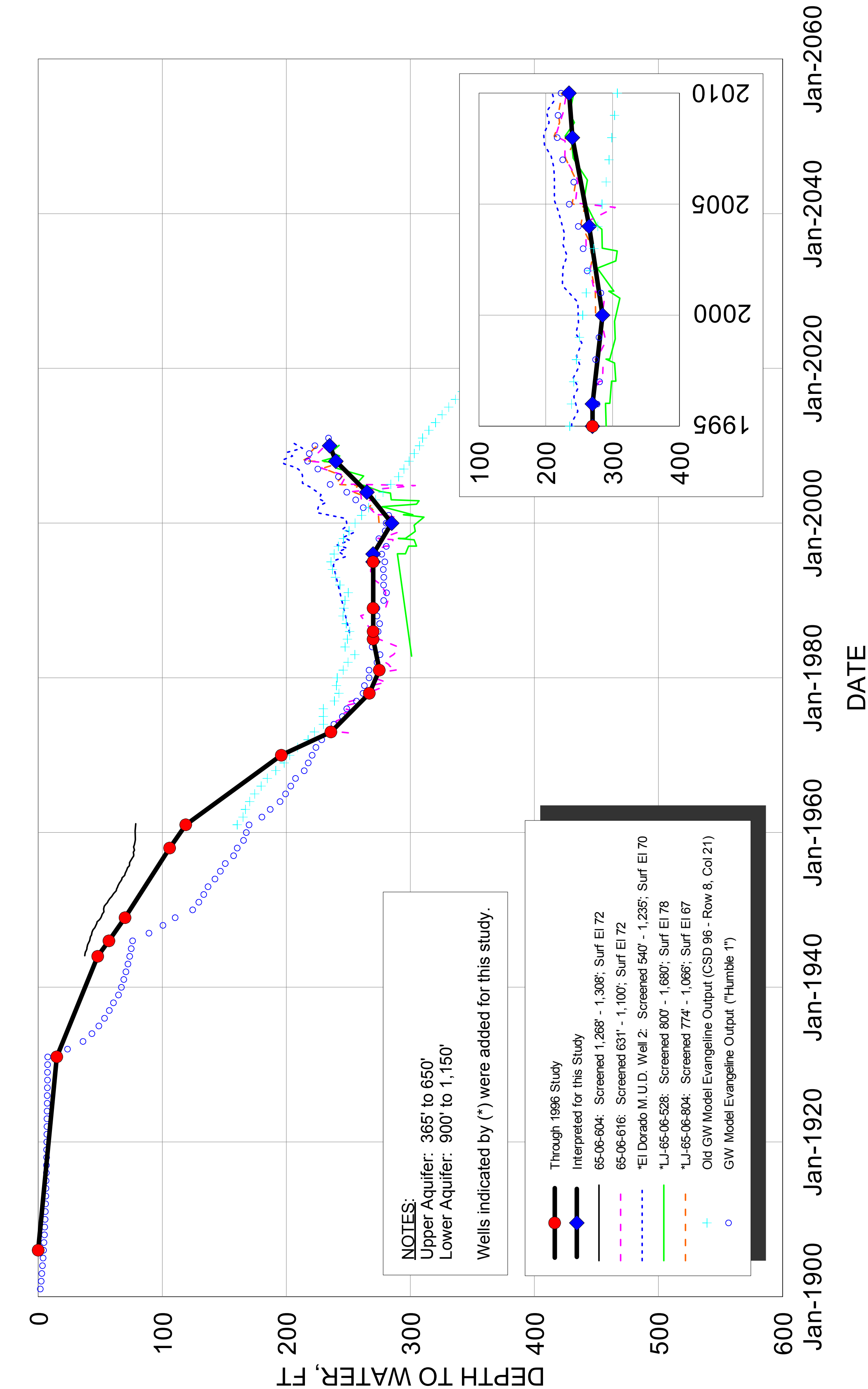
HYDROGRAPHS FOR HOBBY SITE
LOWER MODEL AQUIFER

PLATE A-20



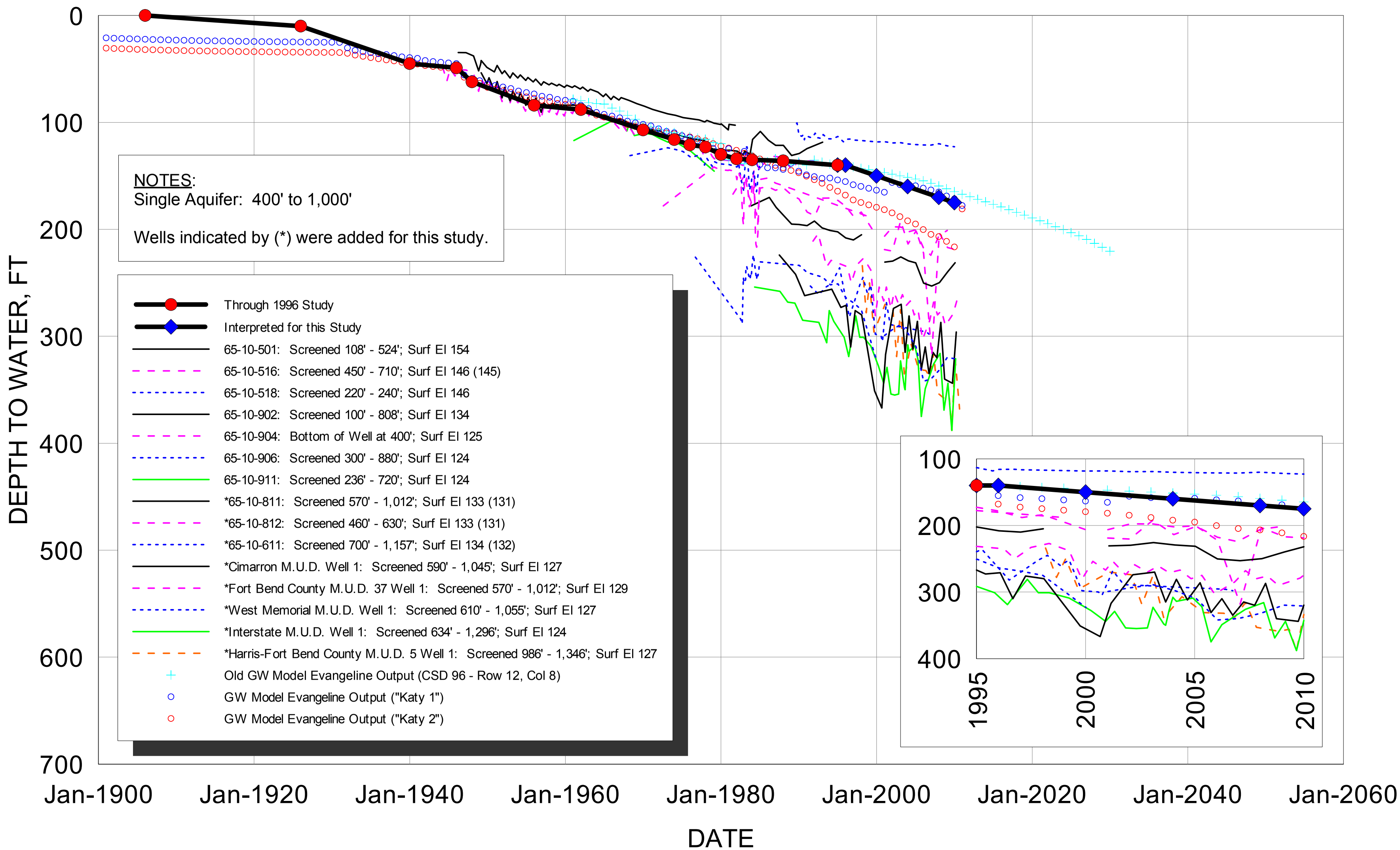
HYDROGRAPHS FOR HUMBLE SITE
UPPER MODEL AQUIFER

PLATE A-21



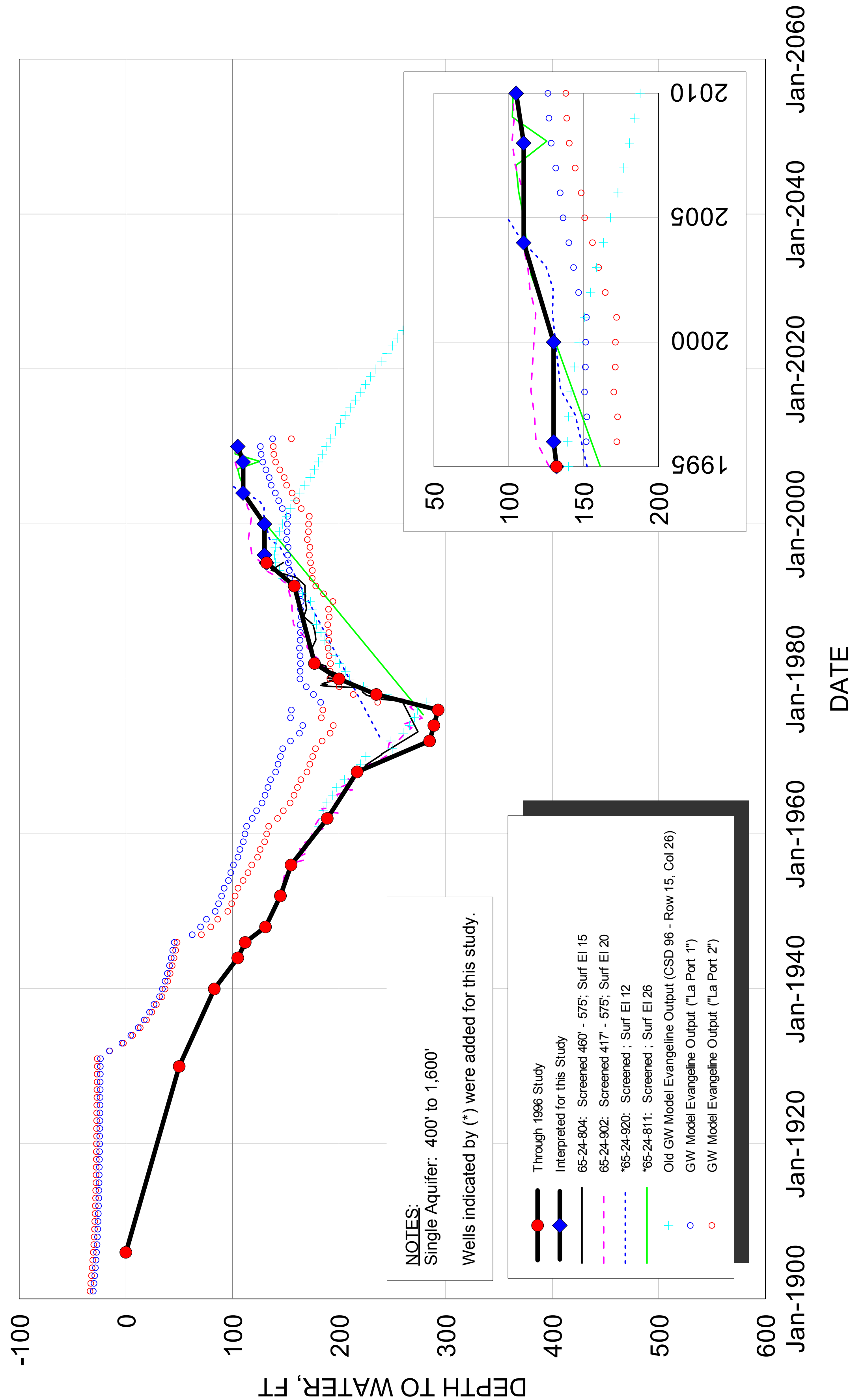
HYDROGRAPHS FOR HUMBLE SITE
LOWER MODEL AQUIFER

PLATE A-22



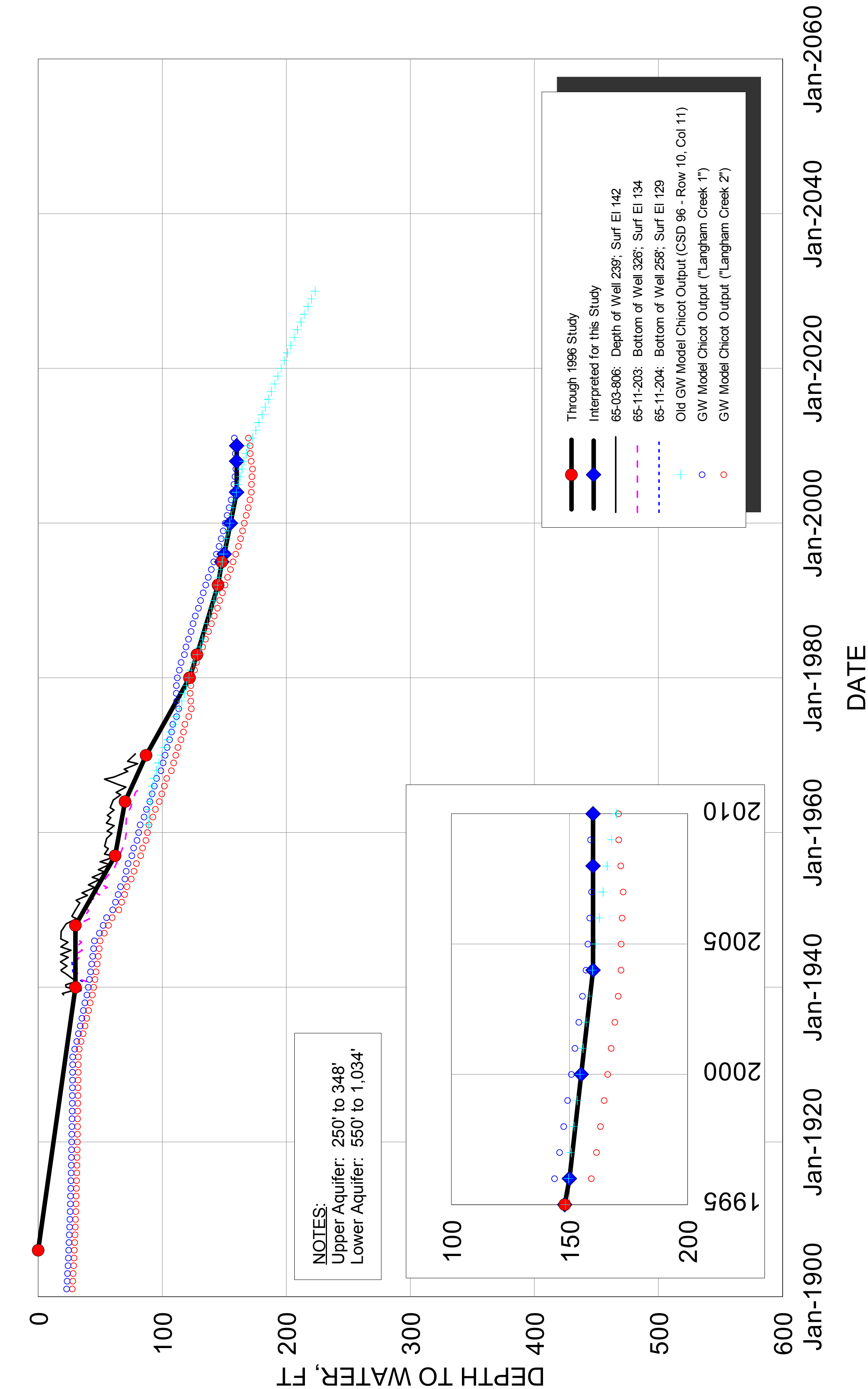
HYDROGRAPHS FOR KATY SITE
SINGLE MODEL AQUIFER

PLATE A-23

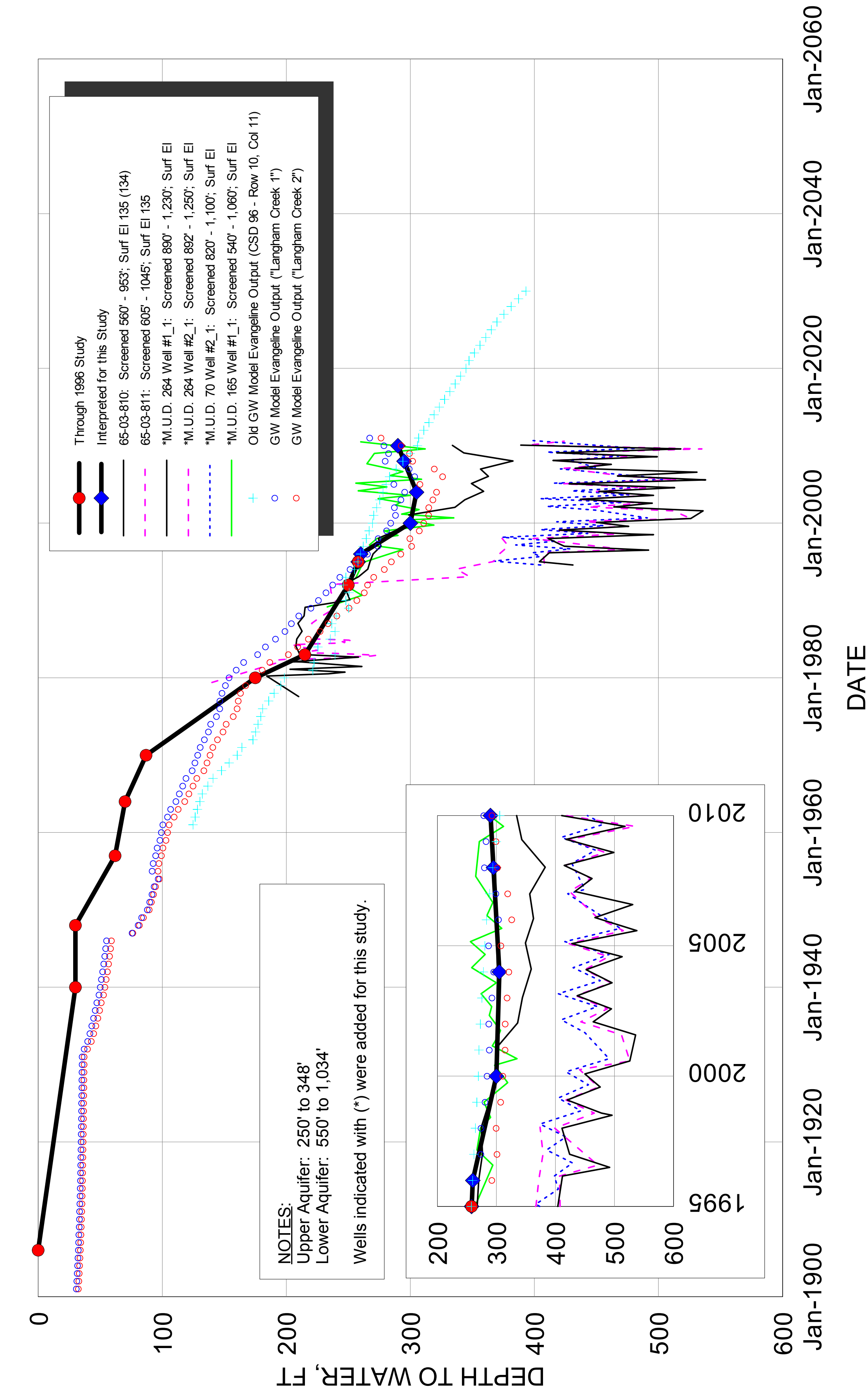


HYDROGRAPHS FOR LA PORTE SITE
SINGLE MODEL AQUIFER

PLATE A-24



HYDROGRAPHS FOR LANGHAM CREEK SITE
MODEL UPPER AQUIFER



HYDROGRAPHS FOR LANGHAM CREEK SITE
MODEL LOWER AQUIFER

PLATE A-26

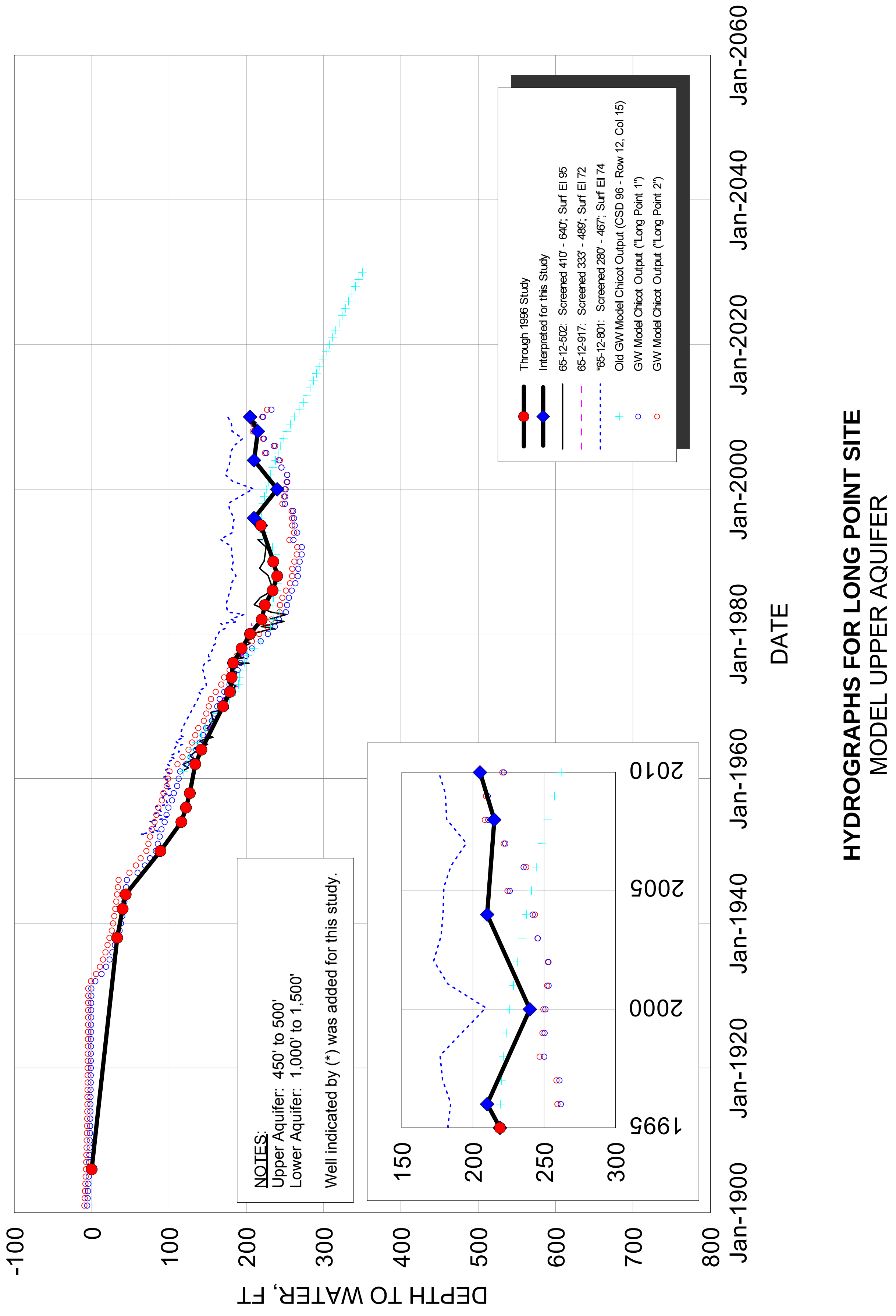
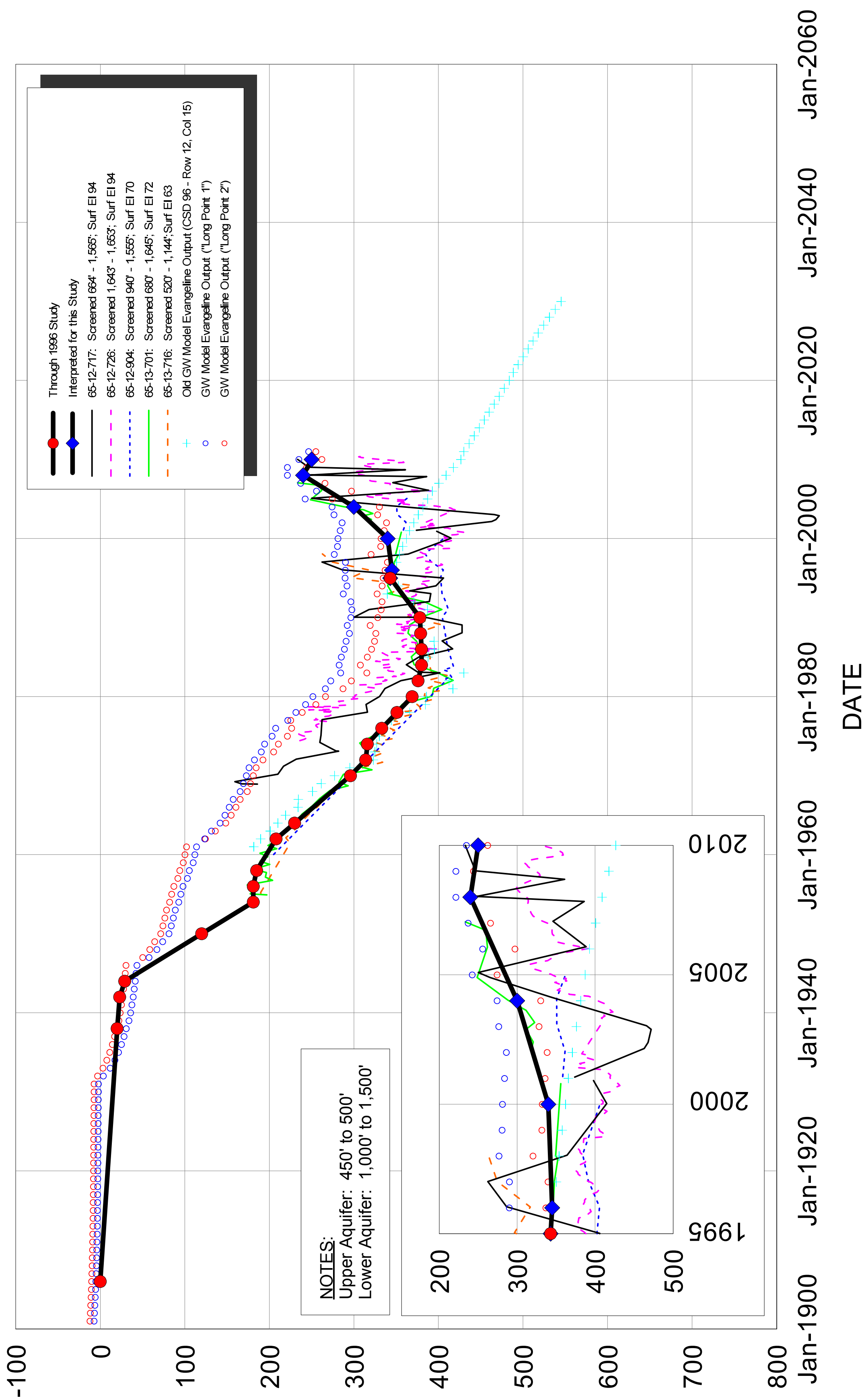
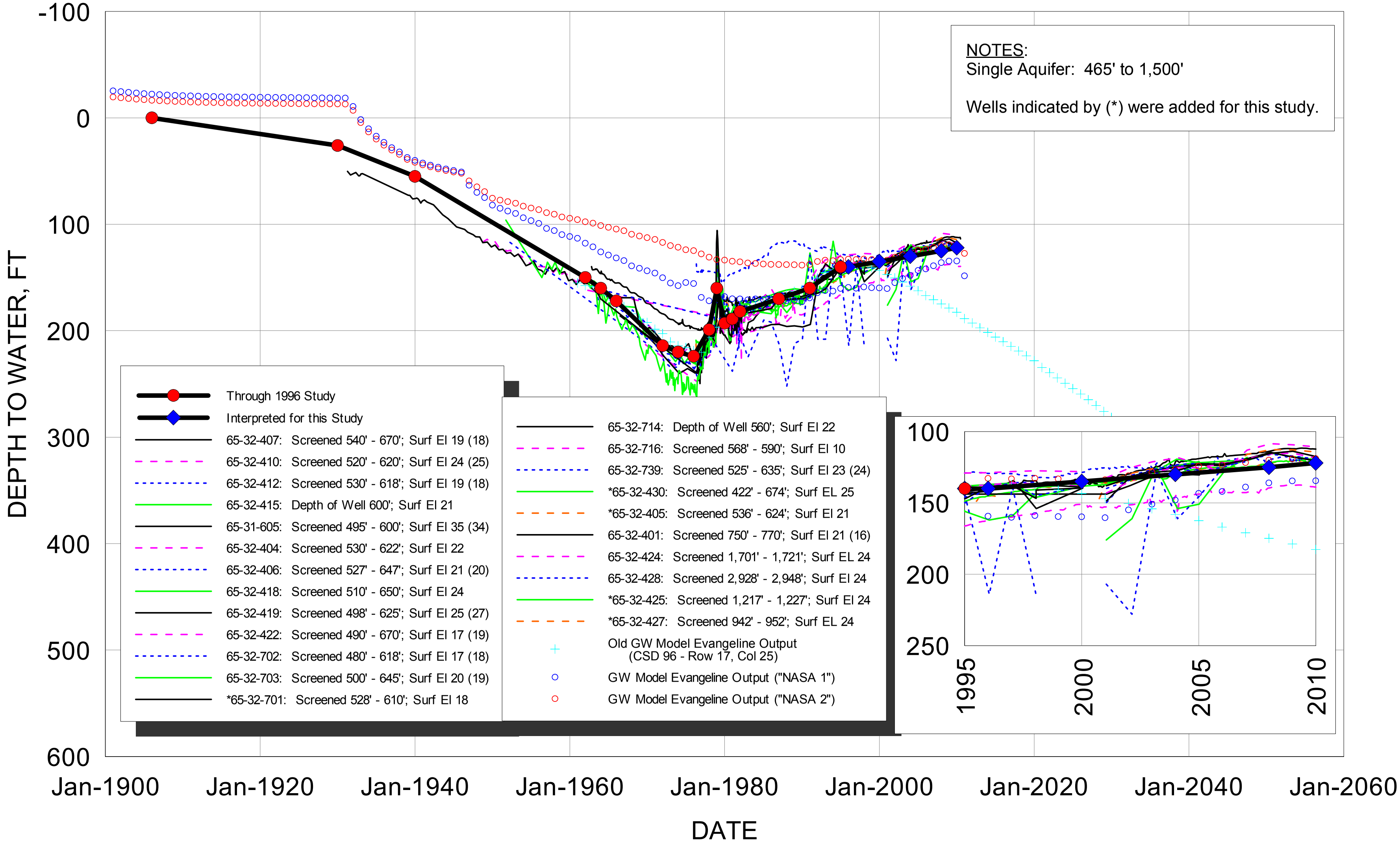

HYDROGRAPHS FOR LONG POINT SITE
MODEL UPPER AQUIFER
DEPTH TO WATER, FT
DATE
-100
0
100
200
300
400
500
600
700
800
Jan-1900
Jan-1920
Jan-1940
Jan-1960
Jan-1980
Jan-2000
Jan-2020
Jan-2040
Jan-2060
NOTES:
Upper Aquifer: 450' to 500'
Lower Aquifer: 1,000' to 1,500'
Well indicated by (*) was added for this study.
150
200
250
300
1995
2000
2005
2010
Through 1996 Study
Interpreted for this Study
65-12-502: Screened 410' - 640'; Surf El 95
65-12-917: Screened 333' - 489'; Surf El 72
*65-12-801: Screened 280' - 467'; Surf El 74
Old GW Model Chicot Output (CSD 96 - Row 12, Col 15)
GW Model Chicot Output ("Long Point 1")
GW Model Chicot Output ("Long Point 2")

PLATE A-27



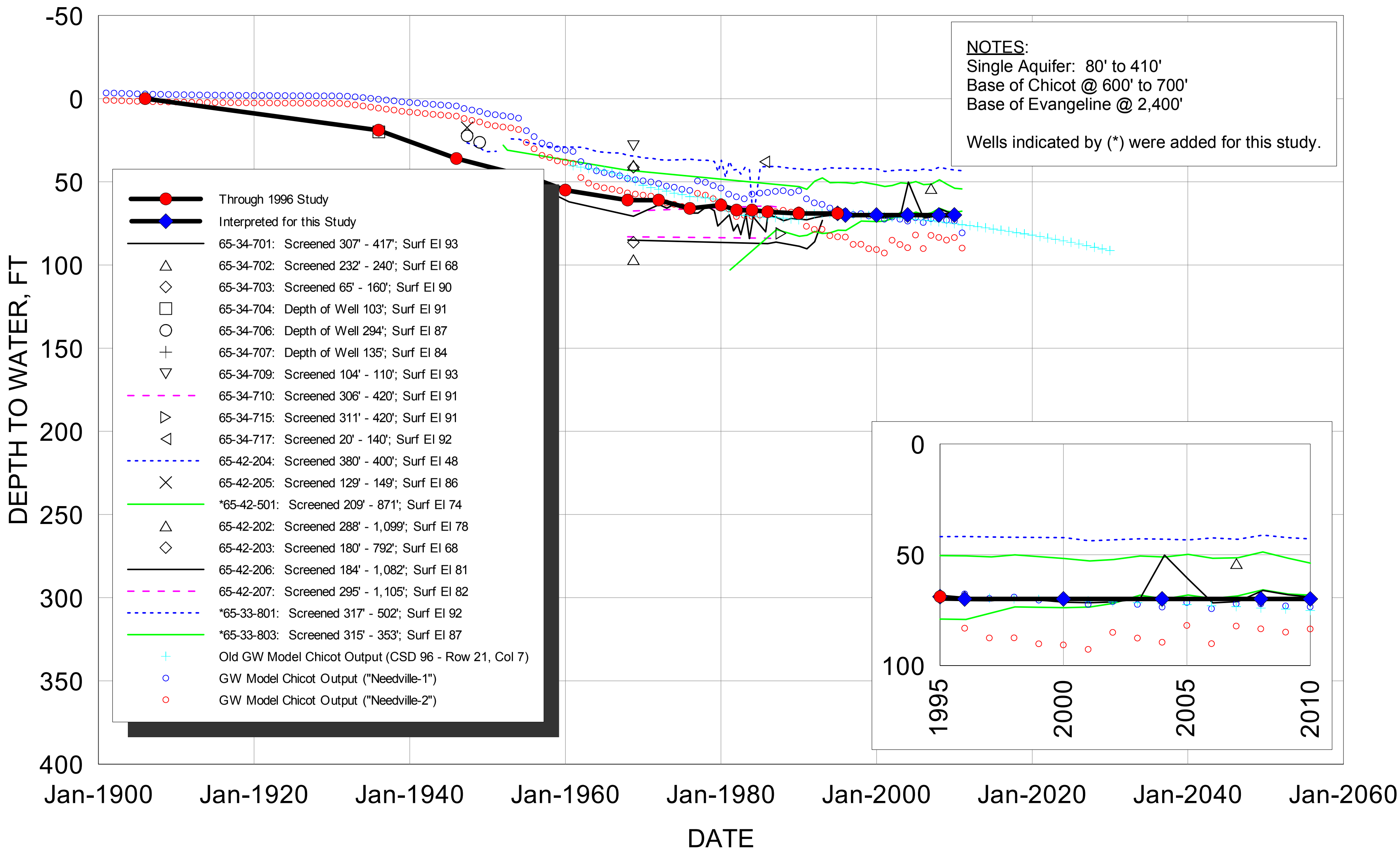
HYDROGRAPHS FOR LONG POINT SITE
MODEL LOWER AQUIFER

PLATE A-28



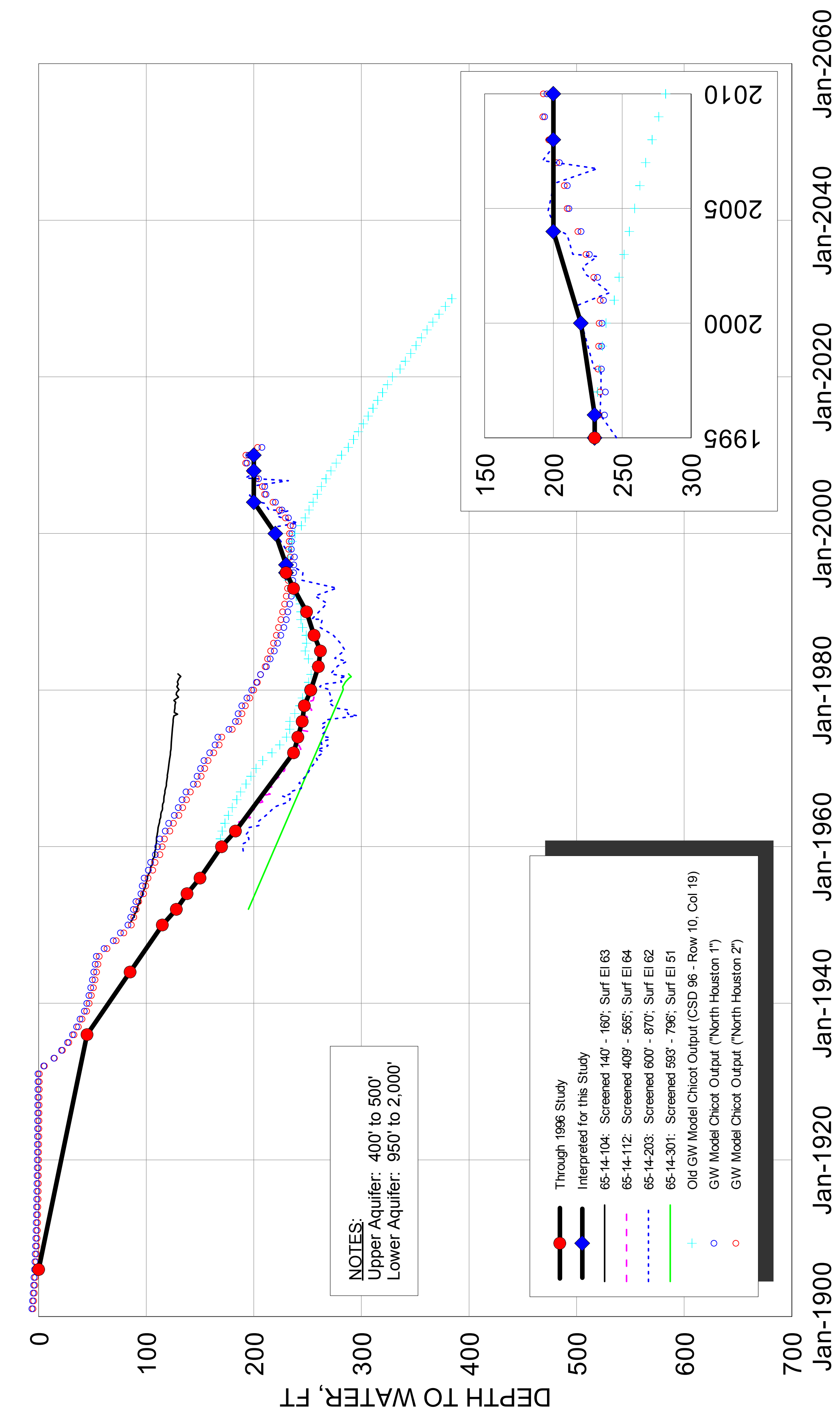
HYDROGRAPHS FOR NASA SITE
SINGLE MODEL AQUIFER

PLATE A-29



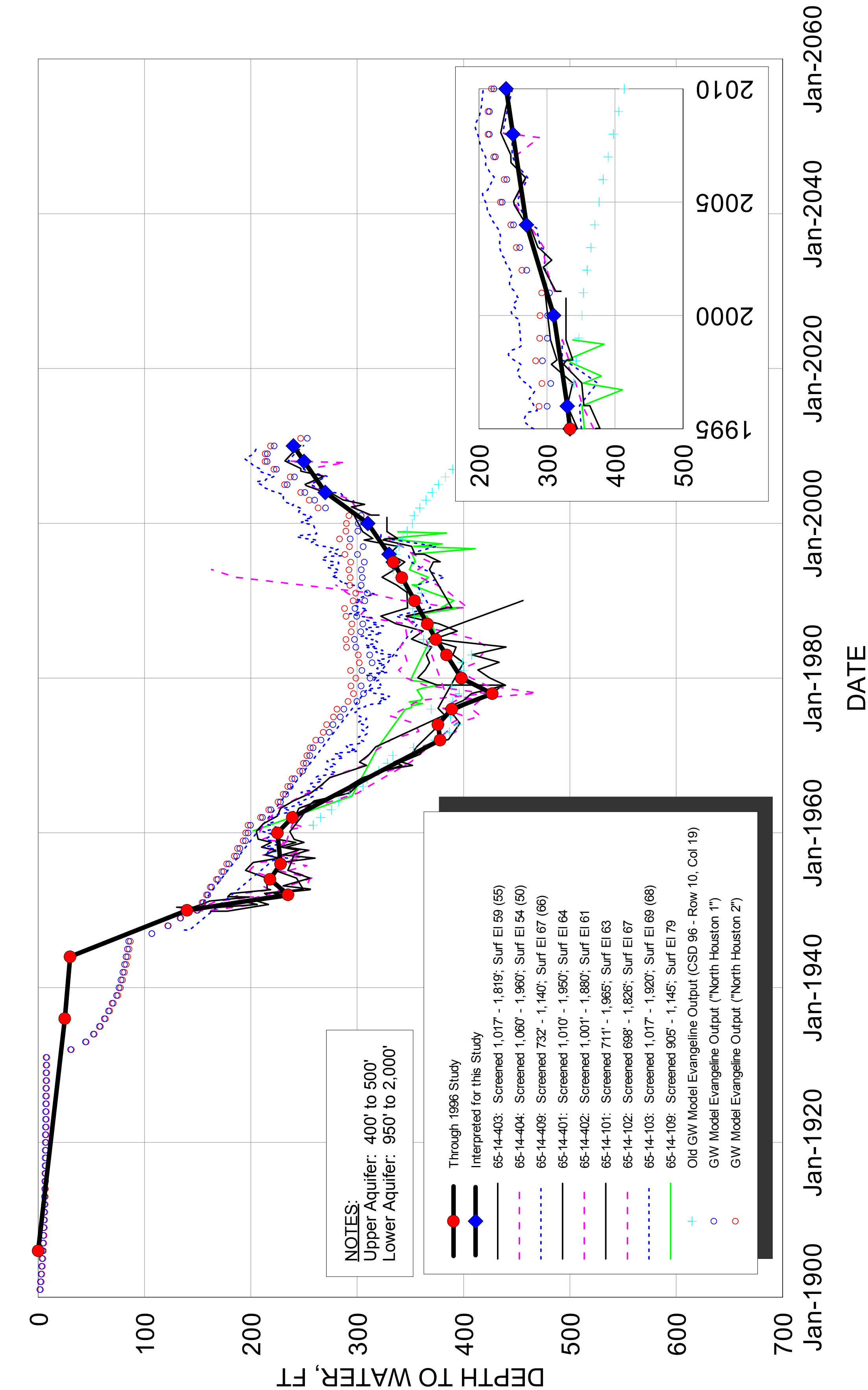
HYDROGRAPHS FOR NEEDVILLE SITE
SINGLE MODEL AQUIFER

PLATE A-30



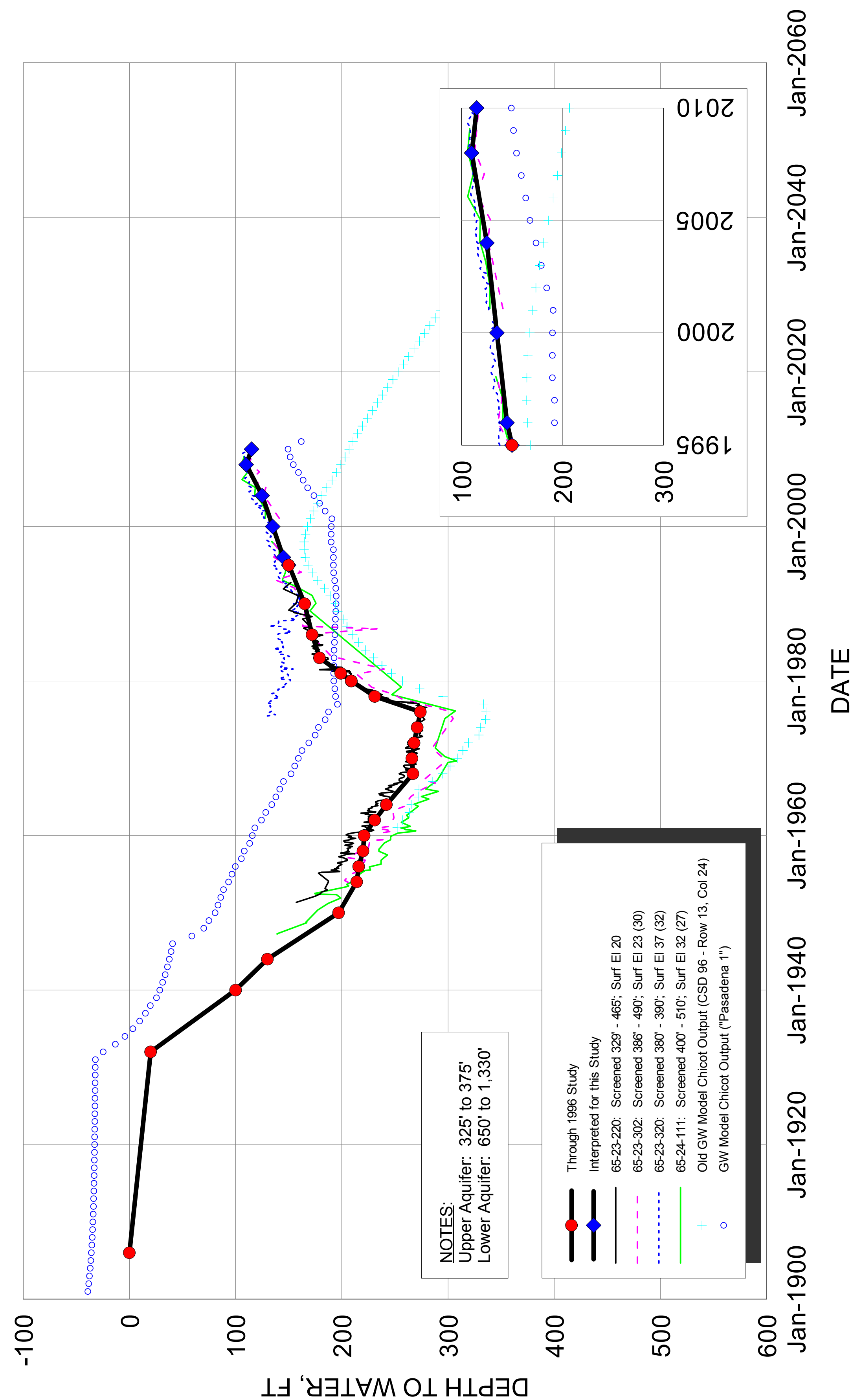
HYDROGRAPHS FOR NORTH HOUSTON SITE
UPPER MODEL AQUIFER

PLATE A-31



HYDROGRAPHS FOR NORTH HOUSTON SITE
LOWER MODEL AQUIFER

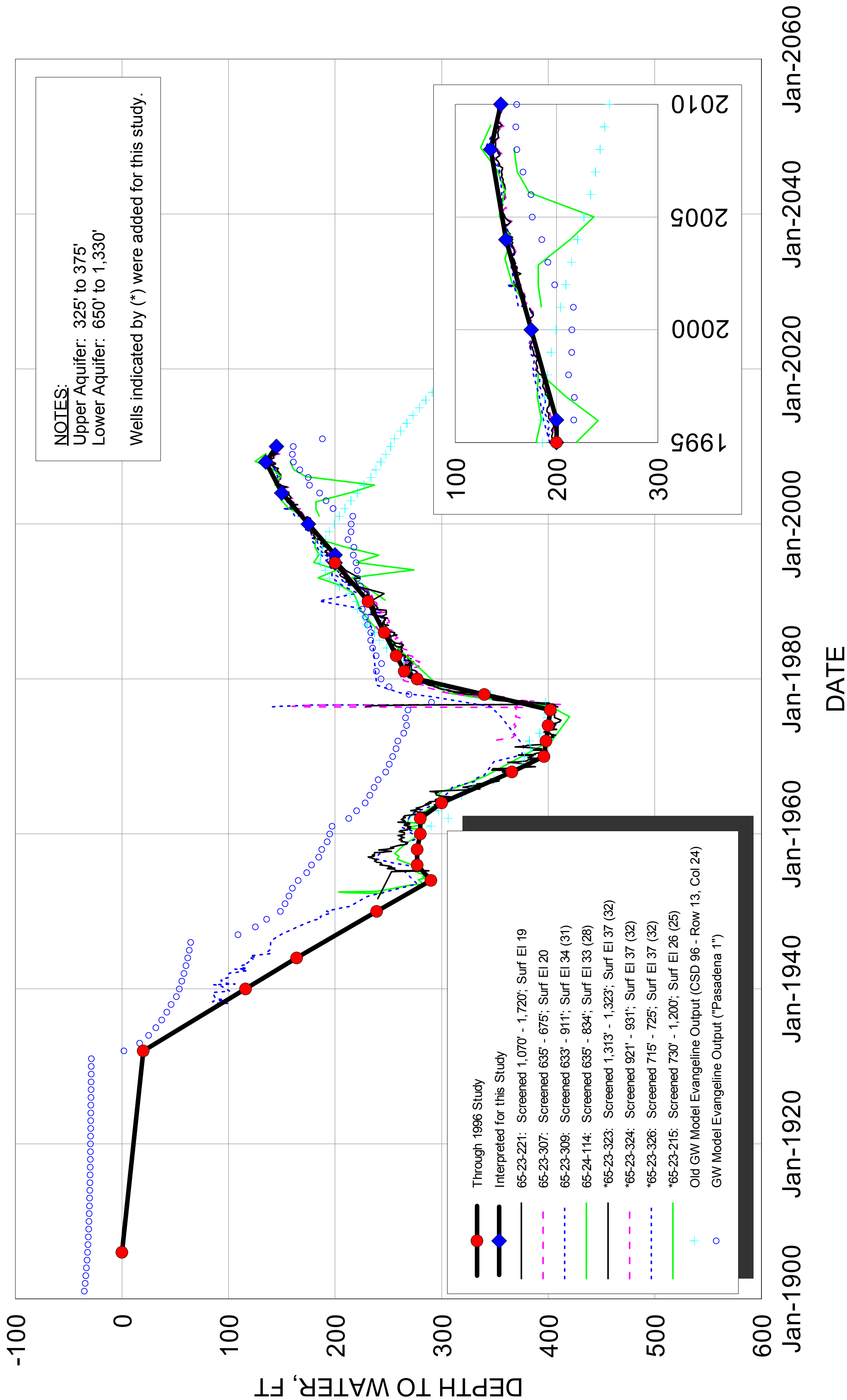
PLATE A-32



HYDROGRAPHS FOR PASADENA SITE
UPPER MODEL AQUIFER

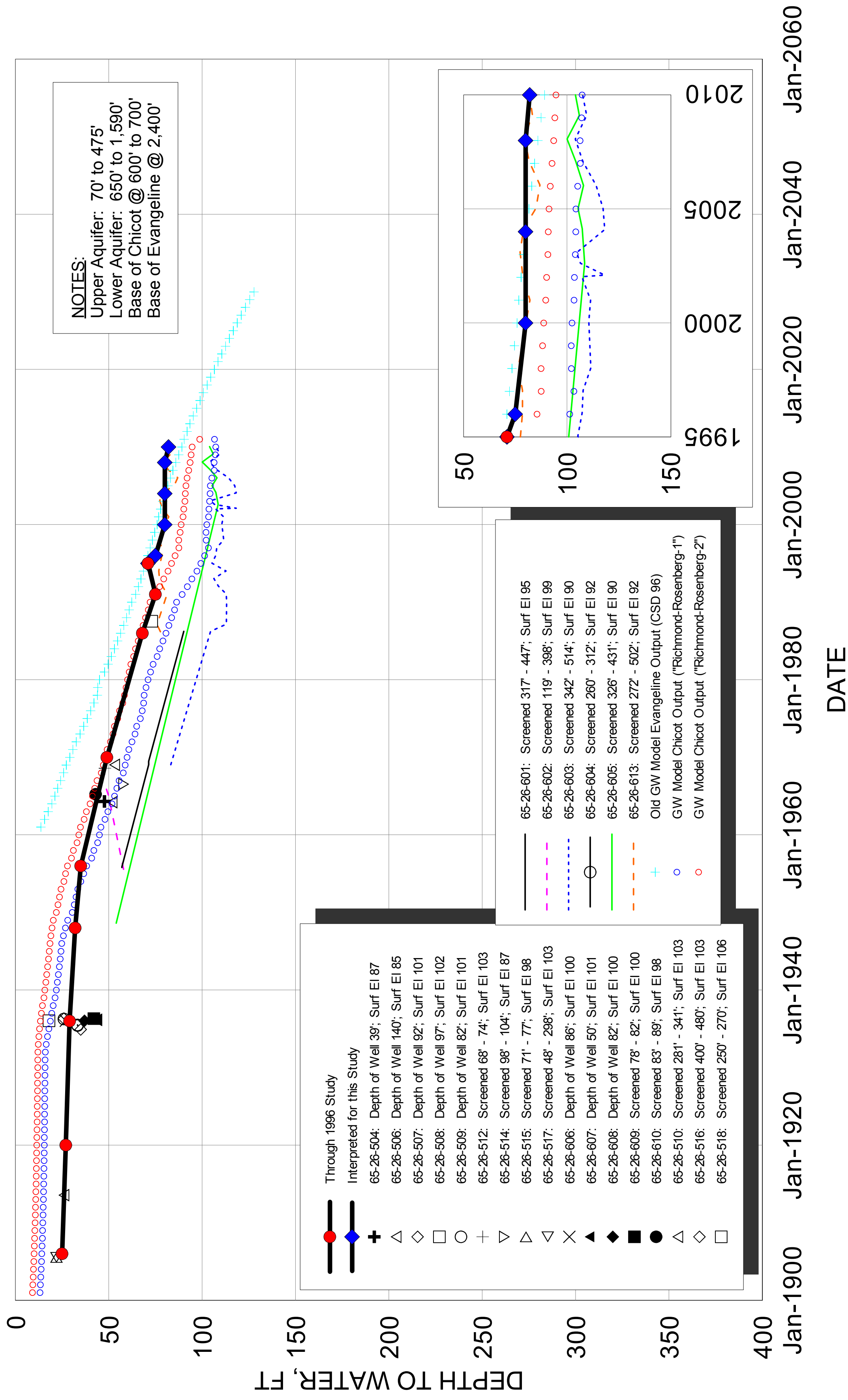
PLATE A-33

FUGRO

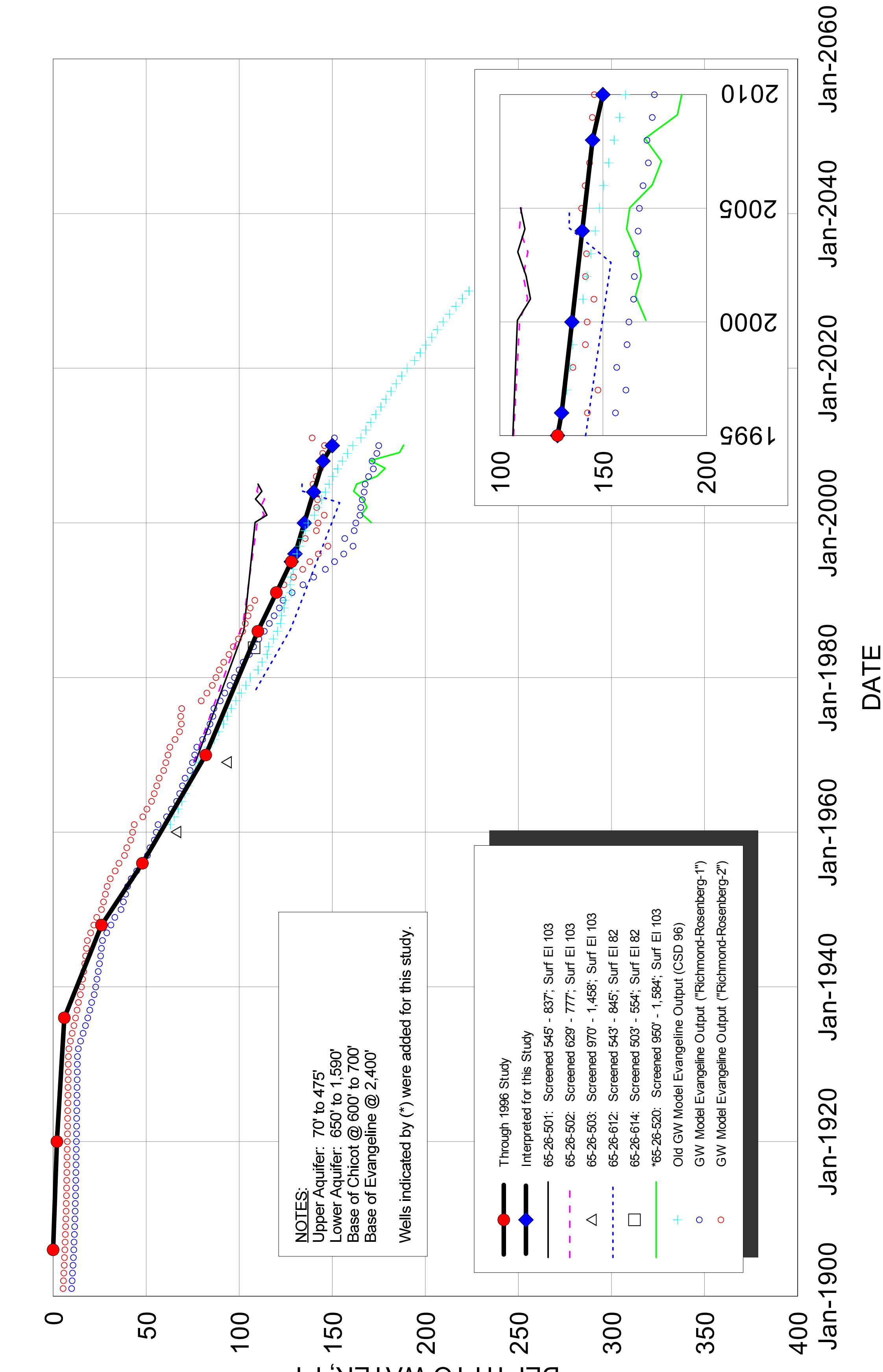


HYDROGRAPHS FOR PASADENA SITE
LOWER MODEL AQUIFER

PLATE A-34



HYDROGRAPHS FOR RICHMOND-ROSENBERG SITE
UPPER MODEL AQUIFER



HYDROGRAPHS FOR RICHMOND-ROSENBERG SITE
LOWER MODEL AQUIFER

PLATE A-36

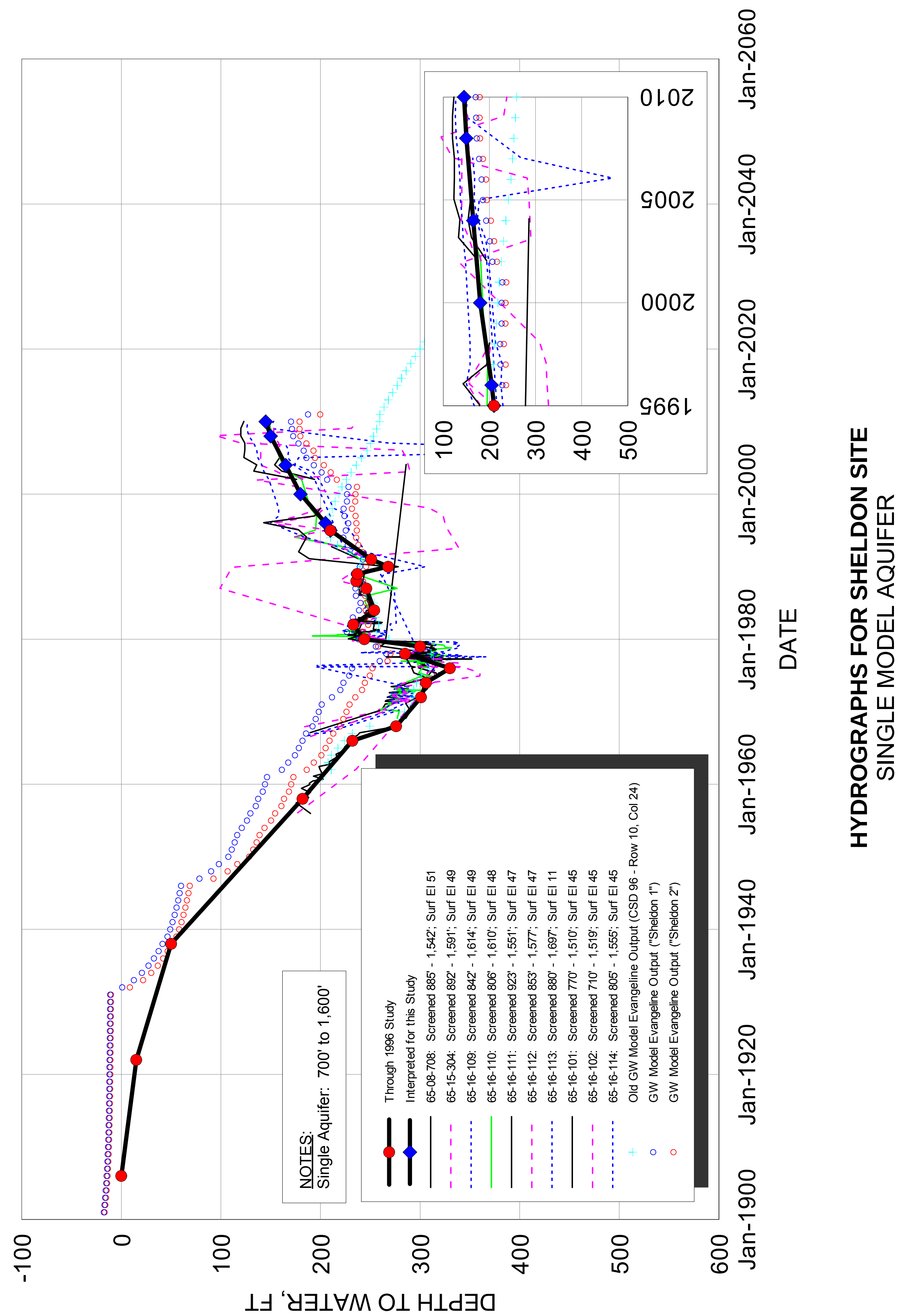
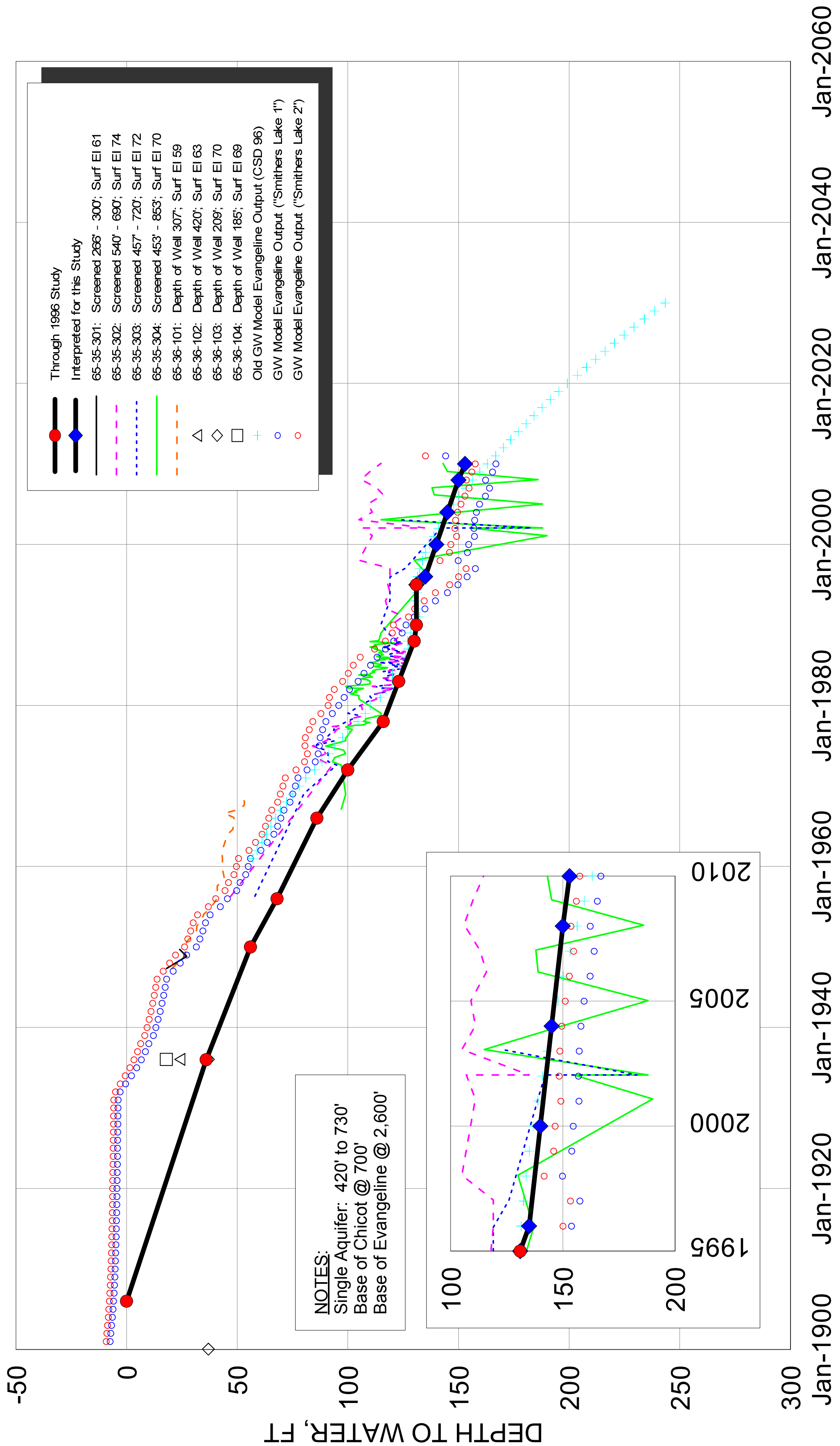

HYDROGRAPHS FOR SHELDON SITE
SINGLE MODEL AQUIFER
DEPTH TO WATER, FT
DATE
NOTES:
Single Aquifer: 700' to 1,600'
Through 1996 Study
Interpreted for this Study
65-08-708: Screened 885' - 1,542'; Surf El 51
65-15-304: Screened 892' - 1,591'; Surf El 49
65-16-109: Screened 842' - 1,614'; Surf El 49
65-16-110: Screened 806' - 1,610'; Surf El 48
65-16-111: Screened 923' - 1,551'; Surf El 47
65-16-112: Screened 853' - 1,577'; Surf El 47
65-16-113: Screened 880' - 1,697'; Surf El 11
65-16-101: Screened 770' - 1,510'; Surf El 45
65-16-102: Screened 710' - 1,519'; Surf El 45
65-16-114: Screened 805' - 1,555'; Surf El 45
Old GW Model Evangeline Output (CSD 96 - Row 10, Col 24)
GW Model Evangeline Output ("Sheldon 1")
GW Model Evangeline Output ("Sheldon 2")

PLATE A-37



HYDROGRAPHS FOR SMITHERS LAKE SITE
SINGLE MODEL AQUIFER

PLATE A-38

APPENDIX B – PRESS INPUT FILES

ARCOLA SITE APR 2011

2 360 16 23 1
400 580 950 1300 1800
300
570
683
738
790
875
985
1153
1355
1503
1640
1768
2010
2335
2518
2675

1	0	0	0
7201	8	19	0
11521	20	42	0
14401	28	72	0
15841	38	84	0
18001	58	104	0
18721	56	112	0
20161	57	127	0
20881	64	134	0
21601	67	140	0
23761	79	164	0
25201	82	182	0
25921	88	192	0
27361	87	204	0
28081	98	207	0
28801	102	210	0
30241	106	207	0
32041	106	194	0
32401	110	194	0
33841	115	200	0
35281	115	208	0
36721	120	213	0
37441	123	217	0

COMPACTING INTERVAL NO. 1: 125-475 FT DEPTH

200 50 0.5 100 100
1.7E-3 1.7E-3
1.5E-4 1.5E-4
1.5E-6 1.5E-6
0 252 36 1 50

COMPACTING INTERVAL NO. 2: 475-655 FT DEPTH

120 40 0.5 100 100
8.4E-4 8.4E-4
1.2E-4 1.2E-4
1.2E-6 1.2E-6

0 490 36 1 50
COMPACTING INTERVAL NO. 3: 655-700 FT DEPTH
35 35 0.5 100 150
6.3E-4 6.3E-4
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 588 36 1 50
COMPACTING INTERVAL NO.4: 700-775 FT DEPTH
10 10 0.5 100 150
5.5E-4 5.5E-4
1.0E-4 1.0E-4
1.0E-6 1.0E-6
0 634 36 1 50
COMPACTING INTERVAL NO. 5: 775-805 FT DEPTH
30 30 0.2 100 150
4.9E-4 4.9E-4
9.8E-5 9.8E-5
9.8E-7 9.8E-7
0 677 36 1 50
COMPACTING INTERVAL NO. 6: 805-945 FT DEPTH
20 10 0.5 100 50
3.9E-4 3.9E-4
9.1E-5 9.1E-5
9.1E-7 9.1E-7
0 746 36 1 50
COMPACTING INTERVAL NO. 7: 945-1025 FT DEPTH
60 30 0.25 100 50
3.0E-4 3.0E-4
8.2E-5 8.2E-5
8.2E-7 8.2E-7
0 836 36 1 50
COMPACTING INTERVAL NO. 8: 1025-1280 FT DEPTH
40 10 0.5 100 50
2.0E-4 2.0E-4
7.1E-5 7.1E-5
7.1E-7 7.1E-7
0 972 36 1 50
COMPACTING INTERVAL NO. 9: 1280-1430 FT DEPTH
75 15 0.5 100 0
1.2E-4 1.2E-4
5.9E-5 5.9E-5
5.9E-7 5.9E-7
0 1135 36 1 50
COMPACTING INTERVAL NO. 10: 1430-1575 FT DEPTH
130 130 0.52 100 0
8.2E-5 8.2E-5
5.2E-5 5.2E-5
5.2E-7 5.2E-7
0 1264 36 1 50
COMPACTING INTERVAL NO. 11: 1575-1705 FT DEPTH
35 35 0.5 100 0
5.8E-5 5.8E-5
4.6E-5 4.6E-5
4.6E-7 4.6E-7

0 1382 36 1 50
 COMPACTING INTERVAL NO. 12: 1705-1830 FT DEPTH
94 47 0.5 100 0
4.2E-5 4.2E-5
4.1E-5 4.1E-5
4.1E-7 4.1E-7
0 1489 36 1 50
 COMPACTING INTERVAL NO. 13: 1830-2190 FT DEPTH
140 20 0.5 100 0
2.3E-5 2.3E-5
3.3E-5 3.3E-5
3.3E-7 3.3E-7
0 1693 36 1 50
 COMPACTING INTERVAL NO. 14: 2190-2480 FT DEPTH
90 30 0.5 100 0
1.0E-5 1.0E-5
2.4E-5 2.4E-5
2.4E-7 2.4E-7
0 1959 36 1 50
 COMPACTING INTERVAL NO. 15: 2480-2555 FT DEPTH
75 75 0.5 100 0
6.5E-6 6.5E-6
2.1E-5 2.1E-5
2.1E-7 2.1E-7
0 2110 36 1 50
 COMPACTING INTERVAL NO. 16: 2555-2795 FT DEPTH
140 35 0.5 100 0
4.4E-6 4.4E-6
1.8E-5 1.8E-5
1.8E-7 1.8E-7
0 2248 36 1 50
EOF

BAYTOWN SITE Apr 2011
1 360 11 21 1
400 1363 1460
100
227
345
379
583
730
802
924
1140
1215
1362
1 0 0
10081 10 32
13681 86 86
14401 88 88
15121 107 107
15841 122 122
18721 163 163
23041 223 0
23761 235 0
24481 244 0
25201 247 0
25921 226 0
26641 203 0
27721 171 0
30601 157 0
32041 140 0
32401 140 0
33841 125 0
35281 115 0
36721 100 0
37441 98 0
INTERVAL NO. 1: 50 - 150 FT
56 28 0.5 56 60
6.31E-2 6.31E-2
5.02E-4 5.02E-4
5.02E-6 5.02E-6
0.0 100 36 1 50
INTERVAL NO. 2: 176 - 278 FT
42 10.5 0.25 126 60
2.38E-2 2.38E-2
3.29E-4 3.29E-4
3.29E-6 3.29E-6
0.0 220 36 1 50
INTERVAL NO. 3: 328 - 362 FT
34 34 0.5 192 100
1.03E-3 1.03E-3
1.2E-4 1.2E-4
1.2E-6 1.2E-6
0.0 331 36 1 50

INTERVAL NO. 4: 366 - 392 FT
23 23 0.5 210 100
1.03E-3 1.03E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0.0 362 36 1 50
INTERVAL NO. 5: 499 - 666 FT
114 19 0.5 222 150
8.2E-4 8.2E-4
9.4E-5 9.4E-5
9.4E-7 9.4E-7
0.0 565 36 1 50
INTERVAL NO. 6: 672 - 787 FT
40 10 0.25 222 120
5.6E-4 5.6E-4
8.2E-5 8.2E-5
8.2E-7 8.2E-7
0.0 713 36 1 50
INTERVAL NO. 7: 787-817 FT
30 10 0.5 222 120
4.4E-4 4.4E-4
7.6E-5 7.6E-5
7.6E-7 7.6E-7
0.0 782 36 1 50
INTERVAL NO. 8: 817-1030 FT
96 16 0.4 222 0
3.4E-4 3.4E-4
6.9E-5 6.9E-5
6.9E-7 6.9E-7
0.0 924 36 1 50
INTERVAL NO. 9: 1112-1168 FT
50 25 0.5 222 0
2.0E-4 2.0E-4
5.7E-5 5.7E-5
5.7E-7 5.7E-7
0.0 1196 36 1 50
INTERVAL NO. 10: 1190-1240 FT
50 50 0.5 222 0
1.6E-4 1.6E-4
5.2E-5 5.2E-5
5.2E-7 5.2E-7
0.0 1298 36 1 50
INTERVAL NO. 11: 1264-1460 FT
81.2 11.6 0.2 222 0
1.1E-4 1.1E-4
4.6E-5 4.6E-5
4.6E-7 4.6E-7
0.0 1500 36 1 50
EOF

```
BELLAIRE SITE  Apr 2011
2 360 8 26 1.0
550 800 850 2000 2001
113
190
315
450
680
980
1370
1750
1 0 0 0
11521 46 46 46
12961 61 61 61
14401 88 117 117
15121 114 144 144
16561 142 196 196
18001 168 200 200
18721 178 201 201
19441   179     219     0
20161   190     235     0
20881   211     252     0
23761   267     342     0
24481   264     348     0
25201   265     355     0
25921   288     360     0
26641   312     365     0
27721   310     368     0
28801   274     357     0
29881   268     345     0
31321   244     293     0
32041   240     280     0
32401   240     280     0
33841   230     290     0
35281   220     230     0
36721   210     250     0
37441   205     240     0
 COMPACTING INTERVAL NO. 1, 80-145 FT
60 30 0.2 100 60
2.7E-3 2.7E-3
3.4E-4 3.4E-4
3.4E-6 3.4E-6
0 113 36 1 50
 COMPACTING INTERVAL NO. 2, 180-195 FT
15 15 0.25 100 60
2.2E-3 2.2E-3
2.3E-4 2.3E-4
2.3E-6 2.3E-6
0 186 36 1 50
 COMPACTING INTERVAL NO. 3, 270-325 FT
55 55 0.5 100 100
1.6E-3 1.6E-3
1.3E-4 1.3E-4
```

```
1.3E-6 1.3E-6
0 303 36 1 50
 COMPACTING INTERVAL NO. 4, 390-565 FT
64 16 0.2 100 150
1.1E-3 1.1E-3
1.0E-4 1.0E-4
1.0E-6 1.0E-6
0 429 36 1 50
 COMPACTING INTERVAL NO. 5, 640-720 FT
60 20 0.2 100 150
6.4E-4 6.4E-4
8.5E-5 8.5E-5
8.5E-7 8.5E-7
0 664 36 1 50
 COMPACTING INTERVAL NO. 6, 800-1165 FT
180 45 0.5 100 0
3.0E-4 3.0E-4
6.6E-5 6.6E-5
6.6E-7 6.6E-7
0 976 36 1 50
 COMPACTING INTERVAL NO. 7, 1285-1460 FT
120 60 0.5 100 0
1.1E-4 1.1E-4
4.6E-5 4.6E-5
4.6E-7 4.6E-7
0 1510 36 1 50
 COMPACTING INTERVAL NO. 8, 1530-1960 FT
180 30 0.2 100 0
4.3E-5 4.3E-5
3.3E-5 3.3E-5
3.3E-7 3.3E-7
0 2030 36 1 50
EOF
```

BELLAIRE WEST SITE Apr 2011
2 360 10 21 1.0
450 500 1000 1500 3000
155
260
400
545
765
1000
1170
1410
1550
1700
1 0 0 0
12241 32 40 40
14401 45 58 58
17281 84 133 133

20161	100	160	0
23041	124	210	0
23761	136	228	0
24481	148	226	0
25201	156	239	0
25921	170	271	0
26641	176	280	0
28081	200	297	0
29161	216	310	0
30241	234	323	0
31321	238	336	0
32041	238	345	0
32401	245	340	0
33841	240	330	0
35281	235	310	0
36721	230	280	0
37441	222	270	0

COMPACTING INTERVAL NO. 1, 120-190 FT
34 17 0.25 100 60
2.4E-3 2.4E-3
2.8E-4 2.8E-4
2.8E-6 2.8E-6
0 155 36 1 50
COMPACTING INTERVAL NO. 2, 210-310 FT
100 100 0.5 100 100
1.8E-3 1.8E-3
1.7E-4 1.7E-4
1.7E-6 1.7E-6
0 251 36 1 50
COMPACTING INTERVAL NO. 3, 345-460 FT
60 30 0.2 100 150
1.3E-3 1.3E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 382 36 1 50
COMPACTING INTERVAL NO.4, 525-565 FT

50 25 0.25 100 40
9.0E-4 9.0E-4
9.6E-5 9.6E-5
9.6E-7 9.6E-7
0 526 36 1 50
COMPACTING INTERVAL NO. 5, 620-910 FT
90 30 0.2 100 40
5.2E-4 5.2E-4
8.0E-5 8.0E-5
8.0E-7 8.0E-7
0 747 36 1 50
COMPACTING INTERVAL NO. 6, 940-1065 FT
125 125 0.5 100 0
2.8E-4 2.8E-4
6.4E-5 6.4E-5
6.4E-7 6.4E-7
0 1004 36 1 50
COMPACTING INTERVAL NO. 7, 1110-1225 FT
70 35 0.25 100 0
1.8E-4 1.8E-4
5.5E-5 5.5E-5
5.5E-7 5.5E-7
0 1237 36 1 50
COMPACTING INTERVAL NO. 8, 1345-1485 FT
130 130 0.5 100 0
1.0E-4 1.0E-4
4.4E-5 4.4E-5
4.4E-7 4.4E-7
0 1565 36 1 50
COMPACTING INTERVAL NO. 9, 1505-1600 FT
66 22 0.2 100 0
7.1E-5 7.1E-5
3.9E-5 3.9E-5
3.9E-7 3.9E-7
0 1757 36 1 50
COMPACTING INTERVAL NO. 10, 1620-1780 FT
160 160 0.8 100 0
4.9E-5 4.9E-5
3.5E-5 3.5E-5
3.5E-7 3.5E-7
0 1963 36 1 50
EOF

CROSBY SITE Apr 2011
2 360 10 17 1.0
200 300 700 1500 2500
130
285
420
530
715
890
1105
1235
1370
1470
1 0 0 0
8641 23 23 0
13681 55 55 0
19441 96 153 0
20881 103 177 0
24481 130 227 0
25201 135 237 0
25921 141 247 0
26641 141 224 0
27721 140 190 0
30241 123 175 0
32041 116 148 0
32401 115 148 0
33841 112 140 0
35281 108 135 0
36721 104 125 0
37441 100 120 0
COMPACTING INTERVAL NO. 1, 90-170 FT
80 80 0.5 100 60
2.5E-3 2.5E-3
1.9E-4 1.9E-4
1.9E-6 1.9E-6
0 130 36 1 50
COMPACTING INTERVAL NO. 2, 240-330 FT
54 18 0.2 100 60
1.7E-3 1.7E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 275 36 1 50
COMPACTING INTERVAL NO. 3, 380-460 FT
80 80 0.5 100 120
1.2E-3 1.2E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 400 36 1 50
COMPACTING INTERVAL NO. 4, 490-575 FT
30 15 0.25 100 120
9.4E-4 9.4E-4
9.7E-5 9.7E-5
9.7E-7 9.7E-7

0 510 36 1 50
COMPACTING INTERVAL NO. 5, 630-800 FT
90 45 0.5 100 40
5.8E-4 5.8E-4
8.3E-5 8.3E-5
8.3E-7 8.3E-7
0 698 36 1 50
COMPACTING INTERVAL NO. 6, 820-960 FT
60 20 0.2 100 40
3.7E-4 3.7E-4
7.0E-5 7.0E-5
7.0E-7 7.0E-7
0 867 36 1 50
COMPACTING INTERVAL NO. 7, 1040-1170 FT
130 130 0.65 100 0
2.2E-4 2.2E-4
5.9E-5 5.9E-5
5.9E-7 5.9E-7
0 1148 36 1 50
COMPACTING INTERVAL NO. 8, 1195-1275 FT
80 80 0.5 100 0
1.6E-4 1.6E-4
5.2E-5 5.2E-5
5.2E-7 5.2E-7
0 1380 36 1 50
COMPACTING INTERVAL NO. 9, 1335-1410 FT
40 20 0.2 100 0
1.1E-4 1.1E-4
4.6E-5 4.6E-5
4.6E-7 4.6E-7
0 1510 36 1 50
COMPACTING INTERVAL NO. 10, 1440-1500 FT
50 50 0.5 100 0
8.6E-5 8.6E-5
4.2E-5 4.2E-5
4.2E-7 4.2E-7
0 1648 36 1 50
EOF

CYPRESS CREEK SITE Apr 2011
1 360 10 22 1.0
660 1300 1301
170
230
340
410
540
670
840
980
1100
1250
1 -31 0 0
12241 -31 0
12961 -31 0
13681 -24 0
14401 -12 0
15841 15 0
17281 59 0
18001 80 0
20161   92   0
23041   132   0
24481   165   0
25201   181   0
25921   200   0
26641   218   0
27361   231   0
30601   260   0
32041   260   0
32401   260   0
33841   300   0
35281   300   0
36721   300   0
37441   300   0
COMPACTING INTERVAL NO. 1, 150-180 FT
30 30 0.2 100 60
2.3E-3 2.3E-3
2.6E-4 2.6E-4
2.6E-6 2.6E-6
0 167 36 1 50
COMPACTING INTERVAL NO. 2, 190-260 FT
60 60 0.5 100 60
2.0E-3 2.0E-3
1.9E-4 1.9E-4
1.9E-6 1.9E-6
0 223 36 1 50
COMPACTING INTERVAL NO. 3, 320-350 FT
30 30 0.2 100 100
1.5E-3 1.5E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 326 36 1 50

COMPACTING INTERVAL NO. 4, 380-440 FT
60 60 0.5 100 150
1.2E-3 1.2E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 391 36 1 50
COMPACTING INTERVAL NO. 5, 515-590 FT
65 65 0.5 100 150
9.0E-4 9.0E-4
9.6E-5 9.6E-5
9.6E-7 9.6E-7
0 521 36 1 50
COMPACTING INTERVAL NO. 6, 640-710 FT
60 60 0.5 100 150
6.6E-4 6.6E-4
8.5E-5 8.5E-5
8.5E-7 8.5E-7
0 655 36 1 50
COMPACTING INTERVAL NO. 7, 740-940 FT
170 170 0.85 100 150
4.3E-4 4.3E-4
7.4E-5 7.4E-5
7.4E-7 7.4E-7
0 819 36 1 50
COMPACTING INTERVAL NO. 8, 950-1015 FT
65 65 0.5 100 0
3.0E-4 3.0E-4
6.6E-5 6.6E-5
6.6E-7 6.6E-7
0 976 36 1 50
COMPACTING INTERVAL NO. 9, 1030-1160 FT
60 60 0.5 100 0
2.2E-4 2.2E-4
5.9E-5 5.9E-5
5.9E-7 5.9E-7
0 1140 36 1 50
COMPACTING INTERVAL NO. 10, 1200-1300 FT
45 15 0.25 100 0
1.5E-4 1.5E-4
5.2E-5 5.2E-5
5.2E-7 5.2E-7
0 1346 36 1 50
EOF

DOWNTOWN SITE Apr 2011
1 360 12 24 1
875 1600 1991
96
199
384
548
694
1068
1350
1453
1607
1724
1815
1990
1 0 0
9361 25 18
13681 144 109
15121 200 165
15841 200 165
17281 240 205
18001 239 204
18721 237 202
19441 236 201
23761 360 0
24481 375 0
25201 389 0
25921 404 0
26641 401 0
27361 414 0
28801 366 0
30241 357 0
31321 339 0
32041 312 0
32401 310 0
33841 300 0
35281 250 0
36721 220 0
37441 235 0
INTERVAL NO. 1: 30 - 161 FT
80 40 0.5 30 60
3.0E-3 3.0E-3
6.0E-4 6.0E-4
6.0E-6 6.0E-6
0.0 96 36 1 50
INTERVAL NO. 2: 161 - 237 FT
54 27 0.9 98 60
2.2E-3 2.2E-3
2.3E-4 2.3E-4
2.3E-6 2.3E-6
0.0 194 36 1 50
INTERVAL NO. 3: 237 - 531 FT
132 44 0.25 189 100

1.4E-3 1.4E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0.0 367 36 1 50
INTERVAL NO. 4: 531 - 565 FT
21 21 0.5 269 150
9.0E-4 9.0E-4
9.6E-5 9.6E-5
9.6E-7 9.6E-7
0.0 529 36 1 50
INTERVAL NO. 5: 565 - 822 FT
84 28 0.25 341 150
6.2E-4 6.2E-4
8.4E-5 8.4E-5
8.4E-7 8.4E-7
0.0 678 36 1 50
INTERVAL NO. 6: 822 - 1314 FT
140 35 0.25 404 70
2.4E-4 2.4E-4
6.0E-5 6.0E-5
6.0E-7 6.0E-7
0.0 1097 36 1 50
INTERVAL NO. 7: 1314 - 1386 FT
15 15 0.75 404 0
1.2E-4 1.2E-4
4.7E-5 4.7E-5
4.7E-7 4.7E-7
0.0 1483 36 1 50
INTERVAL NO. 8: 1386 - 1520 FT
42 42 0.375 404 0
8.2E-5 8.2E-5
4.1E-5 4.1E-5
4.1E-7 4.1E-7
0.0 1624 36 1 50
INTERVAL NO. 9: 1535 - 1678 FT
60 20 0.50 404 0
6.0E-5 6.0E-5
3.7E-5 3.7E-5
3.7E-7 3.7E-7
0.0 1835 36 1 50
INTERVAL NO. 10: 1678 - 1770 FT
72 36 0.5 404 0
4.8E-5 4.8E-5
3.4E-5 3.4E-5
3.4E-7 3.4E-7
0.0 1996 36 1 50
INTERVAL NO. 11: 1800 - 1830 FT
30 30 0.5 404 0
3.9E-5 3.9E-5
3.2E-5 3.2E-5
3.2E-7 3.2E-7
0.0 2120 36 1 50
INTERVAL NO. 12: 1830 - 2150 FT
90 45 0.5 369 0

2.2E-5 2.2E-5
2.6E-5 2.6E-5
2.6E-7 2.6E-7
0.0 2360 36 1 50
EOF

EAGLE POINT SITE Apr 2011
1 360 13 23 1.0
500 900 2125
85
160
320
448
535
700
890
1055
1180
1290
1430
1625
2040
1 0 0
12241 39 0
12961 46 0
14401 72 0
17281 84 0
19441 88 0
21601   96   0
23041   127   0
23761   137   0
24481   142   0
25201   149   0
25921   153   0
26641   152   0
27721   144   0
28081   127   0
29161   114   0
30241   109   0
32041   98   0
32401   98   0
33841   80   0
35281   85   0
36721   80   0
37441   80   0
COMPACTING INTERVAL NO. 1, 70-100 FT DEPTH
30 30 0.2 100 20
2.8E-3 2.8E-3
3.8E-4 3.8E-4
3.8E-6 3.8E-6
0 90 36 1 50
COMPACTING INTERVAL NO. 2, 100-220 FT DEPTH
100 100 0.5 100 40
2.4E-3 2.4E-3
2.7E-4 2.7E-4
2.7E-6 2.7E-6
0 158 36 1 50
COMPACTING INTERVAL NO. 3, 250-390 FT DEPTH
90 45 0.5 100 40

1.6E-3 1.6E-3
1.2E-4 1.2E-4
1.2E-6 1.2E-6
0 312 36 1 50
COMPACTING INTERVAL NO. 4, 425-470 FT DEPTH
40 40 0.5 100 60
1.1E-3 1.1E-3
1.0E-4 1.0E-4
1.0E-6 1.0E-6
0 428 36 1 50
COMPACTING INTERVAL NO. 5, 480-590 FT DEPTH
60 60 0.5 100 70
9.1E-4 9.1E-4
9.6E-5 9.6E-5
9.6E-7 9.6E-7
0 521 36 1 50
COMPACTING INTERVAL NO. 6, 630-770 FT DEPTH
110 110 0.5 100 80
6.1E-4 6.1E-4
8.4E-5 8.4E-5
8.4E-7 8.4E-7
0 684 36 1 50
COMPACTING INTERVAL NO. 7, 800-980 FT DEPTH
180 180 0.9 100 0
3.8E-4 3.8E-4
7.1E-5 7.1E-5
7.1E-7 7.1E-7
0 867 36 1 50
COMPACTING INTERVAL NO. 8, 1020-1090 FT DEPTH
70 70 0.5 100 0
2.5E-4 2.5E-4
6.1E-5 6.1E-5
6.1E-7 6.1E-7
0 1072 36 1 50
COMPACTING INTERVAL NO. 9, 1175-1185 FT DEPTH
8 8 0.2 100 0
1.8E-4 1.8E-4
5.5E-5 5.5E-5
5.5E-7 5.5E-7
0 1250 36 1 50
COMPACTING INTERVAL NO. 10, 1232-1348 FT DEPTH
56 56 0.5 100 0
1.4E-4 1.4E-4
5.0E-5 5.0E-5
5.0E-7 5.0E-7
0 1402 36 1 50
COMPACTING INTERVAL NO. 11, 1350-1510 FT DEPTH
51 17 0.25 100 0
9.6E-5 9.6E-5
4.4E-5 4.4E-5
4.4E-7 4.4E-7
0 1593 36 1 50
COMPACTING INTERVAL NO. 12, 1580-1670 FT DEPTH
72 36 0.5 100 0

5.9E-5 5.9E-5
3.7E-5 3.7E-5
3.7E-7 3.7E-7
0 1860 36 1 50
COMPACTING INTERVAL NO. 13, 1955-2125 FT DEPTH
170 34 0.5 100 0
2.0E-5 2.0E-5
2.5E-5 2.5E-5
2.5E-7 2.5E-7
0 2429 36 1 50
EOF

FM 1960 SITE Apr 2011
1 360 7 20 1.0
540 1400 1401
110
300
615
840
940
1110
1300
1 0 0
6481 15 15
12961 38 38
13681 25 25
14401 46 46
17281 93 93

20161	107	0
23761	167	0
24481	175	0
25201	182	0
25921	190	0
26641	241	0
27361	249	0
31321	296	0
32041	306	0
32401	305	0
33841	340	0
35281	320	0
36721	300	0
37441	300	0

COMPACTING INTERVAL NO. 1, 50-170 FT
120 120 0.5 100 60
2.6E-3 2.6E-3
3.3E-4 3.3E-4
3.3E-6 3.3E-6
0 110 36 1 50
COMPACTING INTERVAL NO. 2, 200-390 FT
80 40 0.5 100 80
1.7E-3 1.7E-3
1.4E-4 1.4E-4
1.4E-6 1.4E-6
0 289 36 1 50
COMPACTING INTERVAL NO. 3, 450-780 FT
92 23 0.25 100 120
7.5E-4 7.5E-4
9.0E-5 9.0E-5
9.0E-7 9.0E-7
0 598 36 1 50
COMPACTING INTERVAL NO. 4, 790-890 FT
90 90 0.5 100 40
4.3E-4 4.3E-4
7.4E-5 7.4E-5
7.4E-7 7.4E-7

```
0 819 36 1 50
  COMPACTING INTERVAL NO. 5, 904-974 FT
64 64 0.5 100 20
3.3E-4 3.3E-4
6.8E-5 6.8E-5
6.8E-7 6.8E-7
0 922 36 1 50
  COMPACTING INTERVAL NO. 6, 984-1234 FT
148 74 0.5 100 20
2.1E-4 2.1E-4
5.8E-5 5.8E-5
5.8E-7 5.8E-7
0 1154 36 1 50
  COMPACTING INTERVAL NO. 7, 1278-1326 FT
34 17 0.25 100 20
1.3E-4 1.3E-4
4.9E-5 4.9E-5
4.9E-7 4.9E-7
0 1415 36 1 50
EOF
```

GALENA PARK SITE Apr 2011
1 360 12 27 1.0
600 1300 3500
185
330
380
470
595
950
1435
1670
1780
1845
2055
2287
1 0 0
5041 17 0
9361 65 0
10801 71 0
11521 95 0
12961 124 0
13681 162 0
14401 174 0
15841 226 0
16561 272 0
17281 284 0
18001 272 0
18721 288 0
19441 287 0
22321   378   0
24481   394   0
25201   393   0
25921   343   0
26641   313   0
28801   300   0
30241   278   0
32041   232   0
32401   230   0
33841   210   0
35281   195   0
36721   160   0
37441   170   0
  COMPACTING INTERVAL NO. 1, 100-270 FT
165 55 0.5 100 60
2.2E-3 2.2E-3
2.4E-4 2.4E-4
2.4E-6 2.4E-6
0 181 36 1 50
  COMPACTING INTERVAL NO. 2, 295-365 FT
70 70 0.5 100 100
1.5E-3 1.5E-3
1.2E-4 1.2E-4
1.2E-6 1.2E-6

0 317 36 1 50
COMPACTING INTERVAL NO. 3, 370-388 FT
18 18 0.2 100 100
1.4E-3 1.4E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 363 36 1 50
COMPACTING INTERVAL NO. 4, 425-515 FT
70 35 0.25 100 150
1.1E-3 1.1E-3
1.0E-4 1.0E-4
1.0E-6 1.0E-6
0 448 36 1 50
COMPACTING INTERVAL NO. 5, 560-630 FT
60 60 0.5 100 150
8.0E-4 8.0E-4
9.1E-5 9.1E-5
9.1E-7 9.1E-7
0 578 36 1 50
COMPACTING INTERVAL NO. 6, 700-1200 FT
150 15 0.25 100 120
3.2E-4 3.2E-4
6.7E-5 6.7E-5
6.7E-7 6.7E-7
0 935 36 1 50
COMPACTING INTERVAL NO. 7, 1310-1560 FT
210 70 0.5 100 0
9.4E-5 9.4E-5
4.3E-5 4.3E-5
4.3E-7 4.3E-7
0 1600 36 1 50
COMPACTING INTERVAL NO. 8, 1580-1765 FT
96 32 0.2 100 0
5.2E-5 5.2E-5
3.5E-5 3.5E-5
3.5E-7 3.5E-7
0 1920 36 1 50
COMPACTING INTERVAL NO. 9, 1770-1790 FT
20 20 0.2 100 0
4.0E-5 4.0E-5
3.2E-5 3.2E-5
3.2E-7 3.2E-7
0 2070 36 1 50
COMPACTING INTERVAL NO. 10, 1790-1880 FT
85 17 0.25 100 0
3.7E-5 3.7E-5
3.1E-5 3.1E-5
3.1E-7 3.1E-7
0 1934 36 1 50
COMPACTING INTERVAL NO. 11, 1900-2210 FT
237 79 .5 100 0
2.2E-5 2.2E-5
2.6E-5 2.6E-5
2.6E-7 2.6E-7

0 2059 36 1 50
  COMPACTING INTERVAL NO. 12, 2220-2354 FT
108 36 .2 100 0
1.1E-5 1.1E-5
2.0E-5 2.0E-5
2.0E-7 2.0E-7
0 2492 36 1 50
EOF

GALVESTON COUNTY SITE Apr 2011
2 360 15 24 1.0
500 950 1200 3300 3500
150
235
325
405
495
660
1080
1360
1520
1840
2205
2435
2755
2970
3180
1 0 0 0
4321 3 3 0
8641 9 9 0
12961 80 35 0
14401 108 45 0
15841 100 54 0
16561 104 58 0
19441 109 77 0
20881 120 85 0
22321 123 85 0
23041 128 100 0
23761 132 103 0
24481 126 106 0
25201 120 111 0
25921 110 111 0
26641 103 108 0
27361 99 106 0
29881 86 96 0
32041 78 89 0
32401 78 88 0
33841 75 88 0
35281 70 91 0
36721 65 97 0
37441 63 100 0
COMPACTING INTERVAL NO. 1, 120-180 FT
60 60 0.5 100 60
2.41E-3 2.41E-3
2.85E-4 2.85E-4
2.85E-6 2.85E-6
0 148 36 1 50
COMPACTING INTERVAL NO. 2, 200-270 FT
60 30 0.2 100 80
1.95E-3 1.95E-3
1.88E-4 1.88E-4
1.88E-6 1.88E-6

0 228 36 1 50
 COMPACTING INTERVAL NO. 3, 280-370 FT
90 90 0.5 100 80
1.55E-3 1.55E-3
1.21E-4 1.21E-4
1.21E-6 1.21E-6
0 312 36 1 50
 COMPACTING INTERVAL NO. 4, 390-420 FT
30 30 0.2 100 80
1.27E-3 1.27E-3
1.11E-4 1.11E-4
1.11E-6 1.11E-6
0 387 36 1 50
 COMPACTING INTERVAL NO. 5, 460-530 FT
60 20 0.2 100 150
1.02E-3 1.02E-3
1.03E-4 1.03E-4
1.03E-6 1.03E-6
0 471 36 1 50
 COMPACTING INTERVAL NO. 6, 610-710 FT
100 100 0.5 100 115
6.72E-3 6.72E-3
8.86E-4 8.86E-4
8.86E-6 8.86E-6
0 625 36 1 50
 COMPACTING INTERVAL NO. 7, 930-1230 FT
200 100 0.5 100 15
2.35E-4 2.35E-4
6.08E-4 6.08E-4
6.08E-6 6.08E-6
0 1113 36 1 50
 COMPACTING INTERVAL NO. 8, 1300-1420 FT
80 40 0.5 100 0
1.17E-4 1.17E-4
4.73E-5 4.73E-5
4.73E-7 4.73E-7
0 1497 36 1 50
 COMPACTING INTERVAL NO. 9, 1470-1570 FT
70 35 0.5 100 0
7.83E-5 7.83E-5
4.10E-5 4.10E-5
4.10E-7 4.10E-7
0 1716 36 1 50
 COMPACTING INTERVAL NO. 10, 1650-2030 FT
220 110 0.5 100 0
3.52E-5 3.52E-5
3.08E-5 3.08E-5
3.08E-7 3.08E-7
0 2154 36 1 50
 COMPACTING INTERVAL NO. 11, 2110-2300 FT
60 30 0.2 100 0
1.41E-5 1.41E-5
2.22E-5 2.22E-5
2.22E-7 2.22E-7

```
0 2655 36 1 50
 COMPACTING INTERVAL NO. 12, 2370-2500 FT
90 30 0.2 100 0
7.95E-6 7.95E-6
1.81E-5 1.81E-5
1.81E-7 1.81E-7
0 2970 36 1 50
 COMPACTING INTERVAL NO. 13, 2650-2860 FT
210 210 1.0 100 0
3.57E-6 3.57E-6
1.36E-5 1.36E-5
1.36E-7 1.36E-7
0 3408 36 1 50
 COMPACTING INTERVAL NO. 14, 2910-3030 FT
60 30 0.5 100 0
2.09E-6 2.09E-6
1.12E-5 1.12E-5
1.12E-7 1.12E-7
0 3700 36 1 50
 COMPACTING INTERVAL NO. 15, 3060-3300 FT
180 90 0.9 100 0
1.23E-6 1.23E-6
9.26E-6 9.26E-6
9.26E-8 9.26E-8
0 3990 36 1 50
EOF
```

```
GENOA SITE  Apr 2011
1 360 13 25 1.0
500 1900 2600
175
325
560
870
1035
1180
1340
1530
1770
1960
2130
2300
2460
1 0 0
8641    33 2
10801    62 4
13681    100 10
14401     143 15
17281     241 40
18001     241 50
18721     246 60
19441     251 70
20161   267     0
22321   314     0
24481   334     0
25201   340     0
25921   331     0
26641   283     0
28081   278     0
29161   265     0
30601   256     0
30961   230     0
32041   215     0
32401   215     0
33841   200     0
35281   190     0
36721   180     0
37441   175     0
 COMPACTING INTERVAL NO. 1, 110-240 FT
50 25 0.5 100 60
2.3E-3 2.3E-3
2.5E-4 2.5E-4
2.5E-6 2.5E-6
0 166 36 1 50
 COMPACTING INTERVAL NO. 2, 300-350 FT
50 25 0.5 100 100
1.6E-3 1.6E-3
1.2E-4 1.2E-4
1.2E-6 1.2E-6
0 308 36 1 50
```

COMPACTING INTERVAL NO. 3, 400-720 FT
220 55 0.5 100 150
8.6E-4 8.6E-4
9.5E-5 9.5E-5
9.5E-7 9.5E-7
0 531 36 1 50
COMPACTING INTERVAL NO. 4, 740-960 FT
75 15 0.25 100 150
4.0E-4 4.0E-4
7.2E-5 7.2E-5
7.2E-7 7.2E-7
0 842 36 1 50
COMPACTING INTERVAL NO. 5, 970-1070 FT
90 45 0.5 100 0
2.6E-4 2.6E-4
6.2E-5 6.2E-5
6.2E-7 6.2E-7
0 1051 36 1 50
COMPACTING INTERVAL NO. 6, 1170-1190 FT
20 20 0.5 100 0
1.8E-4 1.8E-4
5.5E-5 5.5E-5
5.5E-7 5.5E-7
0 1237 36 1 50
COMPACTING INTERVAL NO. 7, 1300-1400 FT
32 8 0.2 100 0
1.2E-4 1.2E-4
4.7E-5 4.7E-5
4.7E-7 4.7E-7
0 1419 36 1 50
COMPACTING INTERVAL NO. 8, 1470-1600 FT
80 80 0.5 100 0
7.5E-5 7.5E-5
4.0E-5 4.0E-5
4.0E-7 4.0E-7
0 1634 36 1 50
COMPACTING INTERVAL NO. 9, 1650-1890 FT
110 110 0.5 100 0
4.5E-5 4.5E-5
3.3E-5 3.3E-5
3.3E-7 3.3E-7
0 1940 36 1 50
COMPACTING INTERVAL NO. 10, 1900-2030 FT
110 110 0.5 100 0
2.5E-5 2.5E-5
2.7E-5 2.7E-5
2.7E-7 2.7E-7
0 2121 36 1 50
COMPACTING INTERVAL NO. 11, 2060-2200 FT
90 45 0.5 100 0
1.6E-5 1.6E-5
2.4E-5 2.4E-5
2.4E-7 2.4E-7
0 2314 36 1 50

COMPACTING INTERVAL NO. 12, 2230-2350 FT
90 45 0.5 100 0
1.1E-5 1.1E-5
2.0E-5 2.0E-5
2.0E-7 2.0E-7
0 2506 36 1 50
COMPACTING INTERVAL NO. 13, 2430-2500 FT
40 20 0.5 100 0
7.1E-6 7.1E-6
1.7E-5 1.7E-5
1.7E-7 1.7E-7
0 2688 36 1 50
EOF

HARRISBURG SITE Apr 2011
1 360 12 30 1.0
600 1300 3500
185
330
380
470
595
950
1435
1670
1780
1845
2055
2287
1 0 0
5041 17 0
9361 50 0
10801 50 0
11521 70 0
12961 100 0
13681 135 0
14401 144 0
15841 186 0
16561 225 0
17281 228 0
18001 233 0
18721 230 0
19441 230 0
20881   262   0
22321   307   0
24481   320   0
25201   320   0
25921   305   0
26641   283   0
27361   278   0
29521   256   0
30961   231   0
31681   222   0
32041   208   0
32401   205   0
33841   200   0
35281   180   0
36721   165   0
37441   163   0
COMPACTING INTERVAL NO. 1, 100-270 FT
165 55 0.5 100 60
2.2E-3 2.2E-3
2.4E-4 2.4E-4
2.4E-6 2.4E-6
0 181 36 1 50
COMPACTING INTERVAL NO. 2, 295-365 FT
70 70 0.5 100 100

1.5E-3 1.5E-3
1.2E-4 1.2E-4
1.2E-6 1.2E-6
0 317 36 1 50
COMPACTING INTERVAL NO. 3, 370-388 FT
18 18 0.2 100 100
1.4E-3 1.4E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 363 36 1 50
COMPACTING INTERVAL NO. 4, 425-515 FT
70 35 0.25 100 150
1.1E-3 1.1E-3
1.0E-4 1.0E-4
1.0E-6 1.0E-6
0 448 36 1 50
COMPACTING INTERVAL NO. 5, 560-630 FT
60 60 0.5 100 150
8.0E-4 8.0E-4
9.1E-5 9.1E-5
9.1E-7 9.1E-7
0 578 36 1 50
COMPACTING INTERVAL NO. 6, 700-1200 FT
150 15 0.25 100 120
3.2E-4 3.2E-4
6.7E-5 6.7E-5
6.7E-7 6.7E-7
0 935 36 1 50
COMPACTING INTERVAL NO. 7, 1310-1560 FT
210 70 0.5 100 0
9.4E-5 9.4E-5
4.3E-5 4.3E-5
4.3E-7 4.3E-7
0 1600 36 1 50
COMPACTING INTERVAL NO. 8, 1580-1765 FT
96 32 0.2 100 0
5.2E-5 5.2E-5
3.5E-5 3.5E-5
3.5E-7 3.5E-7
0 1920 36 1 50
COMPACTING INTERVAL NO. 9, 1770-1790 FT
20 20 0.2 100 0
4.0E-5 4.0E-5
3.2E-5 3.2E-5
3.2E-7 3.2E-7
0 2070 36 1 50
COMPACTING INTERVAL NO.10, 1790-1880 FT
85 17 0.25 100 0
3.7E-5 3.7E-5
3.1E-5 3.1E-5
3.1E-7 3.1E-7
0 1934 36 1 50
COMPACTING INTERVAL NO.11, 1900-2210 FT
237 79 .5 100 0

2.2E-5 2.2E-5
2.6E-5 2.6E-5
2.6E-7 2.6E-7
0 2059 36 1 50
COMPACTING INTERVAL NO.12, 2220-2354 FT
108 36 .2 100 0
1.1E-5 1.1E-5
2.0E-5 2.0E-5
2.0E-7 2.0E-7
0 2492 36 1 50
EOF

```
HOBBY AIRPORT SITE  Apr 2011
2 360 13 25 1.0
550 650 850 1900 2600
175
325
560
870
1035
1180
1340
1530
1770
1960
2130
2300
2460
1 0 0 0
8641 33 33 2
10801 40 62 4
13681 73 100 10
14401 114 143 15
17281 171 241 40
18001 185 241 50
18721 199 246 60
19441 199 251 70
20161   215    267    0
22321   265    314    0
24481   275    334    0
25201   278    340    0
25921   281    331    0
26641   272    322    0
27361   288    324    0
28801   271    325    0
29521   262    283    0
30961   229    275    0
32041   192    247    0
32401   195    250    0
33841   185    245    0
35281   173    215    0
36721   170    195    0
37441   173    200    0
 COMPACTING INTERVAL NO. 1, 110-240 FT
50 25 0.5 100 60
2.3E-3 2.3E-3
2.5E-4 2.5E-4
2.5E-6 2.5E-6
0 166 36 1 50
 COMPACTING INTERVAL NO. 2, 300-350 FT
50 25 0.5 100 100
1.6E-3 1.6E-3
1.2E-4 1.2E-4
1.2E-6 1.2E-6
0 308 36 1 50
```

COMPACTING INTERVAL NO. 3, 400-720 FT
220 55 0.5 100 150
8.6E-4 8.6E-4
9.5E-5 9.5E-5
9.5E-7 9.5E-7
0 531 36 1 50
COMPACTING INTERVAL NO. 4, 740-960 FT
75 15 0.25 100 150
4.0E-4 4.0E-4
7.2E-5 7.2E-5
7.2E-7 7.2E-7
0 842 36 1 50
COMPACTING INTERVAL NO. 5, 970-1070 FT
90 45 0.5 100 0
2.6E-4 2.6E-4
6.2E-5 6.2E-5
6.2E-7 6.2E-7
0 1051 36 1 50
COMPACTING INTERVAL NO. 6, 1170-1190 FT
20 20 0.5 100 0
1.8E-4 1.8E-4
5.5E-5 5.5E-5
5.5E-7 5.5E-7
0 1237 36 1 50
COMPACTING INTERVAL NO. 7, 1300-1400 FT
32 8 0.2 100 0
1.2E-4 1.2E-4
4.7E-5 4.7E-5
4.7E-7 4.7E-7
0 1419 36 1 50
COMPACTING INTERVAL NO. 8, 1470-1600 FT
80 80 0.5 100 0
7.5E-5 7.5E-5
4.0E-5 4.0E-5
4.0E-7 4.0E-7
0 1634 36 1 50
COMPACTING INTERVAL NO. 9, 1650-1890 FT
110 110 0.5 100 0
4.5E-5 4.5E-5
3.3E-5 3.3E-5
3.3E-7 3.3E-7
0 1940 36 1 50
COMPACTING INTERVAL NO. 10, 1900-2030 FT
110 110 0.5 100 0
2.5E-5 2.5E-5
2.7E-5 2.7E-5
2.7E-7 2.7E-7
0 2121 36 1 50
COMPACTING INTERVAL NO. 11, 2060-2200 FT
90 45 0.5 100 0
1.6E-5 1.6E-5
2.4E-5 2.4E-5
2.4E-7 2.4E-7
0 2314 36 1 50

COMPACTING INTERVAL NO. 12, 2230-2350 FT
90 45 0.5 100 0
1.1E-5 1.1E-5
2.0E-5 2.0E-5
2.0E-7 2.0E-7
0 2506 36 1 50
COMPACTING INTERVAL NO. 13, 2430-2500 FT
40 20 0.5 100 0
7.1E-6 7.1E-6
1.7E-5 1.7E-5
1.7E-7 1.7E-7
0 2688 36 1 50
EOF

HUMBLE SITE Apr 2011
2 360 10 20 1.0
365 650 900 1150 1410
49
119
232
345
430
546
696
782
958
1275
1 0 0 0
9001 26 15 15
13681 40 48 48
14401 46 57 57
15481 55 70 70
18721 125 106 106
19801   138   119   0
23041   178   196   0
24121   187   236   0
25921   203   267   0
27001   213   275   0
28441   212   270   0
28801   212   270   0
29881   215   270   0
32041   205   270   0
32401   215   270   0
33841   225   285   0
35281   210   265   0
36721   190   240   0
37441   190   235   0
COMPACTING INTERVAL NO. 1, 28-70 FT
36 18 0.3 100 60
3.10E-3 3.10E-3
4.62E-4 4.62E-4
4.62E-6 4.62E-6
0 48 36 1 50
COMPACTING INTERVAL NO. 2, 78-160 FT
72 36 0.5 100 60
2.60E-3 2.60E-3
3.28E-4 3.28E-4
3.28E-6 3.28E-6
0 112 36 1 50
COMPACTING INTERVAL NO. 3, 190-274 FT
57 19 0.3 100 60
1.96E-3 1.96E-3
1.89E-4 1.89E-4
1.89E-6 1.89E-6
0 220 36 1 50
COMPACTING INTERVAL NO. 4, 324-365 FT
41 41 0.3 100 100

1.48E-3 1.48E-3
1.13E-4 1.13E-4
1.13E-6 1.13E-6
0 333 36 1 50
 COMPACTING INTERVAL NO. 5, 420-440 FT
20 20 0.3 100 130
1.19E-3 1.19E-3
1.05E-4 1.05E-4
1.05E-6 1.05E-6
0 422 36 1 50
 COMPACTING INTERVAL NO. 6, 495-596 FT
69 23 0.3 100 150
8.95E-4 8.95E-4
9.48E-5 9.48E-5
9.48E-7 9.48E-7
0 546 36 1 50
 COMPACTING INTERVAL NO. 7, 682-710 FT
28 28 0.3 100 150
6.14E-4 6.14E-4
8.32E-5 8.32E-5
8.32E-7 8.32E-7
0 717 36 1 50
 COMPACTING INTERVAL NO. 8, 754-810 FT
75 75 0.5 100 150
4.95E-4 4.95E-4
7.73E-5 7.73E-5
7.73E-7 7.73E-7
0 818 36 1 50
 COMPACTING INTERVAL NO. 9, 850-1065 FT
48 12 0.2 100 00
3.20E-4 3.20E-4
6.64E-5 6.64E-5
6.64E-7 6.64E-7
0 1035 36 1 50
 COMPACTING INTERVAL NO. 10, 1160-1390 FT
124 31 0.5 100 00
1.44E-4 1.44E-4
5.05E-5 5.05E-5
5.05E-7 5.05E-7
0 1457 36 1 50
EOF

KATY SITE Apr 2011
1 360 8 21 1.0
400 1000 1360
173
438
570
698
768
887
1082
1278
1 0 0
7201 10 7
12241 45 29
14401 49 32
15121 62 40
18001 84 55
20161   88   0
23041   107   0
24481   116   0
25201   121   0
25921   123   0
26641   130   0
27361   134   0
28081   135   0
29521   136   0
32041   140   0
32401   140   0
33841   150   0
35281   160   0
36721   170   0
37441   175   0
INTERVAL NO. 1: 40 - 305 FT
45 15 .25 53 60
1.8E-3 1.8E-3
2.6E-4 2.6E-4
2.6E-6 2.6E-6
0.0 170 36 1 50
INTERVAL NO. 2: 398 - 477 FT
70 70 0.7 122 120
1.2E-3 1.2E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0.0 418 36 1 50
INTERVAL NO. 3: 494 - 645 FT
90 30 0.2 122 120
8.5E-4 8.5E-4
9.4E-5 9.4E-5
9.4E-7 9.4E-7
0.0 550 36 1 50
INTERVAL NO. 4: 671 - 724 FT
24 6 0.2 122 120
6.1E-4 6.1E-4

8.4E-5 8.4E-5
8.4E-7 8.4E-7
0.0 682 36 1 50
INTERVAL NO. 5: 740 - 796 FT
55 55 0.5 122 50
5.1E-4 5.1E-4
7.9E-5 7.9E-5
7.9E-7 7.9E-7
0.0 749 36 1 50
INTERVAL NO. 6: 809 - 964 FT
90 45 0.5 122 50
3.8E-4 3.8E-4
7.1E-5 7.1E-5
7.1E-7 7.1E-7
0.0 865 36 1 50
INTERVAL NO. 7: 976 - 1188 FT
110 55 0.5 109 0
2.3E-4 2.3E-4
5.9E-5 5.9E-5
5.9E-7 5.9E-7
0.0 1116 36 1 50
INTERVAL NO. 8: 1195 -1360 FT
92 46 0.5 79 0
1.4E-4 1.4E-4
5.0E-5 5.0E-5
5.0E-7 5.0E-7
0.0 1385 36 1 50
EOF

LANGHAM CREEK SITE Apr 2011
2 360 14 15 1.0
250 348 550 1034 1621
45
108
312
381
440
574
663
713
781
857
958
1108
1281
1488
1 0 0 0
12241 30 30 30
15121 30 30 61
18361 62 62 62
20881 70 70 0
23041 87 87 0
26641 122 175 0
27721 128 215 0
30961 145 250 0
32041 148 258 0
32401 150 260 0
33841 155 300 0
35281 160 305 0
36721 160 295 0
37441 160 290 0
COMPACTING INTERVAL NO. 1, 40-50 FT
10 10 0.2 100 60
3.13E-3 3.13E-3
4.72E-4 4.72E-4
4.72E-6 4.72E-6
0 26 36 1 50
COMPACTING INTERVAL NO. 2, 100-115 FT
15 15 0.25 100 60
2.68E-3 2.68E-3
3.47E-4 3.47E-4
3.47E-6 3.47E-6
0 98 36 1 50
COMPACTING INTERVAL NO. 3, 298-325 FT
27 27 0.5 100 120
1.61E-3 1.61E-3
1.28E-4 1.28E-4
1.28E-6 1.28E-6
0 325 36 1 50
COMPACTING INTERVAL NO. 4, 336-425 FT
89 89 0.5 100 120
1.35E-3 1.35E-3

1.09E-4 1.09E-4
1.09E-6 1.09E-6
0 398 36 1 50
COMPACTING INTERVAL NO. 5, 433-446 FT
13 13 0.25 100 150
1.17E-3 1.17E-3
1.04E-4 1.04E-4
6.82E-6 6.82E-6
0 459 36 1 50
COMPACTING INTERVAL NO. 6, 563-584 FT
21 21 0.5 100 150
8.34E-4 8.34E-4
9.26E-5 9.26E-5
9.26E-7 9.26E-7
0 592 36 1 50
COMPACTING INTERVAL NO. 7, 647-678 FT
31 31 0.5 100 150
6.68E-4 6.68E-4
8.57E-5 8.57E-5
8.57E-7 8.57E-7
0 677 36 1 50
COMPACTING INTERVAL NO. 8, 692-733 FT
41 41 0.5 100 150
5.89E-4 5.89E-4
8.21E-5 8.21E-5
8.21E-7 8.21E-7
0 723 36 1 50
COMPACTING INTERVAL NO. 9, 758-803 FT
45 45 0.5 100 40
4.97E-4 4.97E-4
7.74E-5 7.74E-5
7.74E-7 7.74E-7
0 784 36 1 50
COMPACTING INTERVAL NO. 10, 846-868 FT
22 22 0.5 100 0
4.11E-4 4.11E-4
7.24E-5 7.24E-5
7.24E-7 7.24E-7
0 850 36 1 50
COMPACTING INTERVAL NO. 11, 920-995 FT
75 75 0.5 100 0
3.20E-4 3.20E-4
6.64E-5 6.64E-5
6.64E-7 6.64E-7
0 934 36 1 50
COMPACTING INTERVAL NO. 12, 1034-1182 FT
141 47 0.5 100 0
2.19E-4 2.19E-4
5.83E-5 5.83E-5
5.83E-7 5.83E-7
0 1052 36 1 50
COMPACTING INTERVAL NO. 13, 1034-1182 FT
88 88 0.5 100 0
1.42E-4 1.42E-4

5.02E-5 5.02E-5
5.02E-7 5.02E-7
0 1176 36 1 50
COMPACTING INTERVAL NO. 14, 1384-1592 FT
108 36 0.5 100 0
8.48E-5 8.48E-5
4.20E-5 4.20E-5
4.20E-7 4.20E-7
0 1309 36 1 50
EOF

LA PORTE SITE Apr 2011
1 360 11 23 1.0
400 1600 3500
125
310
470
675
779
890
960
1060
1128
1326
1740
1 0 0
8641 50 0
12241 83 0
13681 105 0
14401 112 0
15121 131 0
16561 145 0
18001 155 0
20161 189 0
22321 217 0
23761 285 0
24481 289 0
25201 293 0
25921 235 0
26641 200 0
27361 177 0
30961 158 0
32041 132 0
32401 130 0
33841 130 0
35281 110 0
36721 110 0
37441 105 0
COMPACTING INTERVAL NO. 1 : 70-180 FT
110 110 .5 100 60
2.6E-3 2.6E-3
3.2E-4 3.2E-4
3.2E-6 3.2E-6
0 125 36 1 50
COMPACTING INTERVAL NO. 2 : 220-400 FT
120 60 .5 100 60
1.6E-3 1.6E-3
1.3E-4 1.3E-4
1.3E-6 1.3E-6
0 298 36 1 50
COMPACTING INTERVAL NO. 3 : 430-500 FT
30 10 .2 100 80
1.1E-3 1.1E-3
1.0E-4 1.0E-4

1.0E-6 1.0E-6
0 448 36 1 50
COMPACTING INTERVAL NO. 4: 650-700 FT
30 10 0.2 100 80
6.4E-4 6.4E-4
8.5E-5 8.5E-5
8.5E-7 8.5E-7
0 660 36 1 50
COMPACTING INTERVAL NO. 5: 770-788 FT
18 18 0.2 100 60
5.1E-4 5.1E-4
7.9E-5 7.9E-5
7.9E-7 7.9E-7
0 761 36 1 50
COMPACTING INTERVAL NO. 6: 870-910 FT
40 40 0.5 100 60
3.8E-4 3.8E-4
7.0E-5 7.0E-5
7.0E-7 7.0E-7
0 867 36 1 50
COMPACTING INTERVAL NO. 7: 940-975 FT
25 25 0.25 100 60
3.2E-4 3.2E-4
6.8E-5 6.8E-5
6.8E-7 6.8E-7
0 949 36 1 50
COMPACTING INTERVAL NO. 8: 1010-1100 FT
30 6 0.2 100 0
2.4E-4 2.4E-4
6.1E-5 6.1E-5
6.1E-7 6.1E-7
0 1086 36 1 50
COMPACTING INTERVAL NO. 9: 1056-1200 FT
51 17 0.25 100 0
2.1E-4 2.1E-4
1.16E-4 1.16E-4
1.16E-6 1.16E-6
0.0 1179 36 1 50
COMPACTING INTERVAL NO. 10: 1250-1400 FT
72 36 0.5 100 0
1.2E-4 1.26E-4
4.9E-5 4.9E-5
4.9E-7 4.9E-7
0.0 1450 36 1 50
COMPACTING INTERVAL NO. 11: 1480-2000 FT
170 34 0.5 100 0
4.3E-5 4.3E-5
3.3E-5 3.3E-5
3.3E-7 3.3E-7
0 2018 36 1 50
EOF

LONG POINT SITE Apr 2011
2 360 7 27 1.0
390 650 680 1800 2500
150
300
525
750
890
1040
1400
1 0 0 0
11521 33 20 0
12961 40 23 0
13681 44 29 0
15841 89 120 20
17281 116 181 50
18001 122 181 60
18721 127 185 70

20161	134	208	0
20881	142	230	0
23041	170	296	0
23761	179	314	0
24481	181	316	0
25201	183	333	0
25921	194	351	0
26641	205	369	0
27361	220	376	0
28081	224	380	0
28801	234	380	0
29521	240	379	0
30241	235	378	0
32041	219	343	0
32401	210	350	0
33841	240	400	0
35281	210	360	0
36721	215	320	0
37441	205	300	0

COMPACTING INTERVAL NO. 1, 90-220 FT
90 30 0.2 100 60
2.4E-3 2.4E-3
2.8E-4 2.8E-4
2.8E-6 2.8E-6
0 149 36 1 50
COMPACTING INTERVAL NO. 2, 230-370 FT
60 20 0.2 100 100
1.7E-3 1.7E-3
1.4E-4 1.4E-4
1.4E-6 1.4E-6
0 289 36 1 50
COMPACTING INTERVAL NO. 3, 400-650 FT
90 30 0.2 100 150
9.4E-4 9.4E-4
9.7E-5 9.7E-5

9.7E-7 9.7E-7
0 505 36 1 50
COMPACTING INTERVAL NO. 4, 700-800 FT
60 30 0.2 100 150
5.3E-4 5.3E-4
8.0E-5 8.0E-5
8.0E-7 8.0E-7
0 732 36 1 50
COMPACTING INTERVAL NO. 5, 850-940 FT
70 35 0.25 100 0
3.7E-4 3.7E-4
7.1E-5 7.1E-5
7.1E-7 7.1E-7
0 897 36 1 50
COMPACTING INTERVAL NO. 6, 1010-1070 FT
36 18 0.2 100 0
2.6E-4 2.6E-4
6.2E-5 6.2E-5
6.2E-7 6.2E-7
0 1059 36 1 50
COMPACTING INTERVAL NO. 7, 1150-1650 FT
180 90 0.5 100 0
1.0E-4 1.0E-4
4.5E-5 4.5E-5
4.5E-7 4.5E-7
0 1552 36 1 50
EOF

NASA SITE Apr 2011
1 360 23 22 1.0
465 1500 2001
12
30
48
95
134
169
193
237
295
340
382
440
457
515
686
703
733
813
880
992
1128
1326
1740
1 0 0
8641 26 6
12241 55 13

20161	150	0
20881	160	0
21601	172	0
23761	214	0
24481	220	0
25201	224	0
25921	199	0
26281	160	0
26641	193	0
27001	189	0
27361	182	0
29161	170	0
30601	160	0
32041	140	0
32401	140	0
33841	135	0
35281	130	0
36721	125	0
37441	122	0

INTERVAL NO. 1: 0-23 FT
23 23 0.5 5 60
3.40E-3 3.40E-3
5.61E-4 5.61E-4
5.61E-6 5.61E-6

0.0 12 36 1 50
INTERVAL NO. 2: 23-38 FT
15 15 0.375 13 60
3.24E-3 3.24E-3
5.12E-4 5.12E-4
5.12E-6 5.12E-6
0.0 30 36 1 50
INTERVAL NO. 3: 38-56 FT
15 15 0.375 20 60
3.11E-3 3.11E-3
4.72E-4 4.72E-4
4.72E-6 4.72E-6
0.0 48 36 1 50
INTERVAL NO. 4: 87-102 FT
15 15 0.375 39 60
2.76E-3 2.76E-3
3.74E-4 3.74E-4
3.74E-6 3.74E-6
0.0 95 36 1 50
INTERVAL NO. 5: 116-152 FT
30 30 0.6 56 60
2.50E-3 2.50E-3
3.08E-4 3.08E-4
3.08E-6 3.08E-6
0.0 135 36 1 50
INTERVAL NO. 6: 154-184 FT
30 30 0.6 70 60
2.29E-3 2.29E-3
2.60E-4 2.60E-4
2.60E-6 2.60E-6
0.0 166 36 1 50
INTERVAL NO. 7: 188-197 FT
9 9 0.5 80 60
2.16E-3 2.16E-3
2.31E-4 2.31E-4
2.31E-6 2.31E-6
0.0 189 36 1 50
INTERVAL NO. 8: 201-272 FT
70 70 0.7 98 40
1.94E-3 1.94E-3
1.86E-4 1.86E-4
1.86E-6 1.86E-6
0.0 230 36 1 50
INTERVAL N0. 9: 272-317 FT
45 45 0.9 122 40
1.68E-3 1.68E-3
1.40E-4 1.40E-4
1.40E-6 1.40E-6
0.0 284 36 1 50
INTERVAL NO. 10: 317-362 FT
45 45 0.9 141 60
1.50E-3 1.50E-3
1.13E-4 1.13E-4
1.13E-6 1.13E-6

0.0 326 36 1 50
INTERVAL NO. 11: 369- 95 FT
30 30 0.6 159 60
1.35E-3 1.35E-3
1.14E-4 1.14E-4
1.14E-6 1.14E-6
0.0 365 36 1 50
INTERVAL NO. 12: 429-450 FT
20 20 0.4 182 120
1.17E-3 1.17E-3
1.08E-4 1.08E-4
1.08E-6 1.08E-6
0.0 419 36 1 50
INTERVAL NO. 13: 454-460 FT
3 3 0.3 190 120
1.12E-3 1.12E-3
1.06E-4 1.06E-4
1.06E-6 1.06E-6
0.0 435 36 1 50
INTERVAL NO. 14: 508-522 FT
15 15 0.3 193 120
9.66E-4 9.66E-4
1.01E-4 1.01E-4
1.01E-6 1.01E-6
0.0 495 36 1 50
INTERVAL N0. 15: 674-698 FT
20 20 0.4 193 120
6.30E-4 6.30E-4
8.65E-5 8.65E-5
8.65E-7 8.65E-7
0.0 670 36 1 50
INTERVAL NO. 16: 701-704 FT
3 3 0.3 193 0
6.04E-4 6.04E-4
8.53E-5 8.53E-5
8.53E-7 8.53E-7
0.0 687 36 1 50
INTERVAL NO. 17: 725-740 FT
15 15 0.375 193 0
5.61E-4 5.61E-4
8.30E-5 8.30E-5
8.30E-7 8.30E-7
0.0 716 36 1 50
INTERVAL NO. 18: 780-845 FT
30 30 0.5 193 0
4.59E-4 4.59E-4
7.73E-5 7.73E-5
7.73E-7 7.73E-7
0.0 793 36 1 50
INTERVAL NO. 19: 875-885 FT
8 8 0.2 193 0
3.88E-4 3.88E-4
7.27E-5 7.27E-5
7.27E-7 7.27E-7

0.0 858 36 1 50
INTERVAL NO. 20: 934-1050 FT
56 56 0.7 193 0
2.93E-4 2.93E-4
6.58E-5 6.58E-5
6.58E-7 6.58E-7
0.0 993 36 1 50
INTERVAL NO. 21: 1056-1200 FT
51 17 0.25 194 0
2.09E-4 2.09E-4
5.82E-5 5.82E-5
5.82E-7 5.82E-7
0.0 1179 36 1 50
INTERVAL NO. 22: 1250-1400 FT
72 36 0.5 195 0
1.27E-4 1.27E-4
4.88E-5 4.88E-5
4.88E-7 4.88E-7
0.0 1450 36 1 50
INTERVAL NO. 23: 1480-2000 FT
170 34 0.5 198 0
4.52E-5 4.52E-5
3.37E-5 3.37E-5
3.37E-7 3.37E-7
0.0 2018 36 1 50
EOF

NEEDVILLE SITE Apr 2011

```
1 360  6  19 1
80  410  1800
265
1245
1555
1750
1965
2375
1       0       0
10801   19      0
14401   36      0
18001   48      0
19441   55      0
22321   61      0
23761   61      0
25201   66      0
26641   64      0
27361   67      0
28081   67      0
28801   68      0
30241   69      0
32041   69      0
32401   70      0
33841   70      0
35281   70      0
36721   70      0
37441   68      0
 COMPACTING INTERVAL NO. 1: 100-530 FT DEPTH
100 20  0.5 100 50
1.8E-3 1.8E-3
1.7E-4 1.7E-4
1.7E-6 1.7E-6
0 256 36 1 50
 COMPACTING INTERVAL NO. 2: 960-1530 FT DEPTH
245 35  0.5  100 0
1.6E-4 1.6E-4
6.5E-5 6.5E-5
6.5E-7 6.5E-7
0 992 36 1 50
 COMPACTING INTERVAL NO. 3: 1530-1580 FT DEPTH
50 50 0.2 100  0
7.2E-5 7.2E-5
4.9E-5 4.9E-5
4.9E-7 4.9E-7
0 1252 36 1 50
 COMPACTING INTERVAL NO.4: 1700-1800 FT DEPTH
100 100 0.5 100 0
4.4E-5 4.4E-5
4.1E-5 4.1E-5
4.1E-7 4.1E-7
0 1412 36 1 50
 COMPACTING INTERVAL NO. 5: 1900-2030 FT DEPTH
```

130 130 0.5 100 0
2.6E-5 2.6E-5
3.4E-5 3.4E-5
3.4E-7 3.4E-7
0 1594 36 1 50
COMPACTING INTERVAL NO. 6: 2030-2720 FT DEPTH
510 51 .5 100 0
9.2E-6 9.2E-6
2.4E-5 2.4E-5
2.4E-7 2.4E-7
0 1958 36 1 50
EOF

NORTH HOUSTON SITE Apr 2011
2 360 10 25 1.0
400 500 950 2000 2001
90
230
350
460
570
650
870
1210
1540
1825
1 0 0 0
10801 45 25 25
13681 85 30 30
15841 115 140 140
16561 128 235 235
17281 138 218 218
18001 150 228 228
19441 170 225 225
20161   183   239   0
23761   237   378   0
24481   241   376   0
25201   245   389   0
25921   247   427   0
26641   253   398   0
27721   260   384   0
28441   262   374   0
29161   256   366   0
30241   249   354   0
31321   237   342   0
32041   230   334   0
32401   230   330   0
33841   220   310   0
35281   200   270   0
36721   200   250   0
37441   200   240   0
COMPACTING INTERVAL NO. 1, 70-130 FT
60 60 0.5 100 60
2.8E-3 2.8E-3
3.8E-4 3.8E-4
3.8E-6 3.8E-6
0 90 36 1 50
COMPACTING INTERVAL NO. 2, 170-290 FT
120 120 0.5 100 60
2.0E-3 2.0E-3
1.9E-4 1.9E-4
1.9E-6 1.9E-6
0 195 36 1 50
COMPACTING INTERVAL NO. 3, 300-400 FT
70 70 0.5 100 100
1.5E-3 1.5E-3

1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 335 36 1 50
 COMPACTING INTERVAL NO. 4, 420-500 FT
30 10 0.2 100 150
1.1E-3 1.1E-3
1.0E-4 1.0E-4
1.0E-6 1.0E-6
0 440 36 1 50
 COMPACTING INTERVAL NO. 5, 520-600 FT
35 35 0.5 100 150
8.4E-4 8.4E-4
9.4E-5 9.4E-5
9.4E-7 9.4E-7
0 552 36 1 50
 COMPACTING INTERVAL NO. 6, 630-700 FT
60 60 0.5 100 150
6.9E-4 6.9E-4
8.7E-5 8.7E-5
8.7E-7 8.7E-7
0 713 36 1 50
 COMPACTING INTERVAL NO. 7, 750-950 FT
180 90 0.5 100 120
4.2E-4 4.2E-4
7.4E-5 7.4E-5
7.4E-7 7.4E-7
0 848 36 1 50
 COMPACTING INTERVAL NO. 8, 990-1440 FT
150 50 0.5 100 0
1.7E-4 1.7E-4
5.4E-5 5.4E-5
5.4E-7 5.4E-7
0 1291 36 1 50
 COMPACTING INTERVAL NO. 9, 1475-1600 FT
125 125 0.5 100 0
7.3E-5 7.3E-5
4.0E-5 4.0E-5
4.0E-7 4.0E-7
0 1744 36 1 50
 COMPACTING INTERVAL NO. 10, 1650-2000 FT
200 40 0.5 100 0
3.5E-5 3.5E-5
3.1E-5 3.1E-5
3.1E-7 3.1E-7
0 2134 36 1 50
EOF

PASADENA SITE   Apr 2011
2 360 15 28 1.0
325. 375. 650. 1330. 2520.
128.
259.
462.
570.
660.
871.
1147.
1421.
1575.
1660.
1795.
2059.
2287.
2398.
2520.
1 0 0 0
9361 20 20 1
12241 100 116 7
13681 130 164 32
15841 197 239 71
17281 214 290 93
18001 216 277 92
18721 220 277 92
19441 221 280 93
20161   231   280   0
20881   242   300   0
22321   267   366   0
23041   266   396   0
23761   268   398   0
24481   271   400   0
25201   274   402   0
25921   231   340   0
26641   209   277   0
27001   199   265   0
27721   179   257   0
28801   172   246   0
30241   165   231   0
32041   150   200   0
32401   145   200   0
33841   135   175   0
35281   125   150   0
36721   110   135   0
37441   115   145   0
INTERVAL NO.1: 62-194 FT
102.0 34.0 0.25 90.9 60.
2.6E-3 2.6E-3
3.2E-4 3.2E-4
3.2E-6 3.2E-6
0.0 128.0 36. 1 50
INTERVAL NO.2: 194-324 FT

94.0 47.0 0.5 183.9 100.0
1.8E-3 1.8E-3
1.7E-4 1.7E-4
1.7E-6 1.7E-6
0.0 252.0 36. 1 50
INTERVAL NO.3: 375-548 FT
50.0 25.0 0.25 254.1 150.0
1.1E-3 1.1E-3
1.0E-4 1.0E-4
1.0E-6 1.0E-6
0.0 440.0 36. 1 50
INTERVAL NO.4: 548-592 FT
44.0 44.0 0.5 284.0 150.0
8.5E-4 8.5E-4
9.4E-5 9.4E-5
9.4E-7 9.4E-7
0.0 540.0 36. 1 50
INTERVAL NO.5: 628-692 FT
38.0 19.0 0.5 308.9 150.0
6.7E-4 6.7E-4
8.7E-5 8.7E-5
8.7E-7 8.7E-7
0.0 645.0 36. 1 50
INTERVAL NO.6: 752-991 FT
66.0 11.0 0.25 320.0 100.0
3.9E-4 3.9E-4
7.2E-5 7.2E-5
7.2E-7 7.2E-7
0.0 850.0 36. 1 50
INTERVAL NO.7: 998-1296 FT
108.0 18.0 0.375 320.0 0.0
2.0E-4 2.0E-4
5.6E-5 5.6E-5
5.6E-7 5.6E-7
0.0 1200.0 36. 1 50
INTERVAL NO.8: 1331-1512 FT
72.0 36.0 0.18 308.4 0.0
9.2E-5 9.2E-5
4.4E-5 4.4E-5
4.4E-7 4.4E-7
0.0 1512.0 36. 1 50
INTERVAL NO.9: 1532-1618 FT
90 30 0.5 289 0
6.6E-5 6.6E-5
3.8E-5 3.8E-5
3.8E-7 3.8E-7
0.0 1685.0 36. 1 50
INTERVAL NO.10: 1618-1702 FT
72.0 36.0 0.5 278.4 0.0
5.3E-5 5.3E-5
3.5E-5 3.5E-5
3.5E-7 3.5E-7
0.0 1781.0 36. 1 50
INTERVAL NO.11: 1702-1888 FT

85.0 17.0 0.25 261.4 0.0
3.7E-5 3.7E-5
3.1E-5 3.1E-5
3.1E-7 3.1E-7
0.0 1934.0 36. 1 50
INTERVAL NO.12: 1908-2210 FT
237.0 79.0 0.5 234.6 0.0
2.2E-5 2.2E-5
2.6E-5 2.6E-5
2.6E-7 2.6E-7
0.0 2059.0 36. 1 50
INTERVAL NO.13: 2220-2354 FT
108.0 36.0 0.35 199.4 0.0
1.1E-5 1.1E-5
2.0E-5 2.0E-5
2.0E-7 2.0E-7
0.0 2492.0 36. 1 50
INTERVAL NO.14: 2367-2430 FT
63.0 63.0 0.9 185.3 0.0
8.0E-6 8.0E-6
1.9E-5 1.9E-5
1.9E-7 1.9E-7
0.0 2619.0 36. 1 50
INTERVAL NO.15: 2448-2594 FT
54.0 13.5 0.25 170.0 0.0
5.8E-6 5.8E-6
1.7E-5 1.7E-5
1.7E-7 1.7E-7
0.0 2757.0 36. 1 50
EOF

RICHMOND-ROSENBERG SITE Apr 2011
2 360 14 14 1
250 475 650 1590 2280
200
540
880
1025
1195
1420
1598
1705
1755
1805
1930
1990
2050
2215

1	25	0	0
5041	27	2	0
10801	29	6	0
15121	32	26	0
18001	35	48	0
23041	49	82	0
28801	68	110	0
30601	75	120	0
32041	71	128	0
32401	75	130	0
33841	80	135	0
35281	80	140	0
36721	80	145	0
37441	82	150	0

COMPACTING INTERVAL NO. 1: 0-250 FT DEPTH
90 30 .5 100 100
2.6E-3 2.6E-3
3.3E-4 3.3E-4
3.3E-6 3.3E-6
0 103 36 1 50
COMPACTING INTERVAL NO. 2: 400-680 FT DEPTH
45 15 0.5 100 100
9.1E-4 9.1E-4
1.2E-4 1.2E-4
1.2E-6 1.2E-6
0 434 36 1 50
COMPACTING INTERVAL NO. 3: 830-930 FT DEPTH
90 45 .5 100 130
3.9E-4 3.9E-4
9.1E-5 9.1E-5
9.1E-7 9.1E-7
0 705 36 1 50
COMPACTING INTERVAL NO.4: 930-1120 FT DEPTH
40 40 .5 100 130
2.7E-4 2.7E-4
8.0E-5 8.0E-5

8.0E-7 8.0E-7
0 823 36 1 50
COMPACTING INTERVAL NO. 5: 1120-1270 FT DEPTH
150 150 .6 100 0
1.8E-4 1.8E-4
6.8E-5 6.8E-5
6.8E-7 6.8E-7
0 963 36 1 50
COMPACTING INTERVAL NO. 6: 1270-1570 FT DEPTH
75 15 0.5 100 0
1.0E-4 1.0E-4
5.6E-5 5.6E-5
5.6E-7 5.6E-7
0 1157 36 1 50
COMPACTING INTERVAL NO. 7: 1570-1625 FT DEPTH
40 40 0.25 100 0
6.4E-5 6.4E-5
4.7E-5 4.7E-5
4.7E-7 4.7E-7
0 1301 36 1 50
COMPACTING INTERVAL NO. 8: 1675-1735 FT DEPTH
60 60 0.5 100 0
4.9E-5 4.9E-5
4.3E-5 4.3E-5
4.3E-7 4.3E-7
0 1391 36 1 50
COMPACTING INTERVAL NO. 9: 1735-1775 FT DEPTH
15 15 0.2 100 0
4.4E-5 4.4E-5
4.1E-5 4.1E-5
4.1E-7 4.1E-7
0 1435 36 1 50
COMPACTING INTERVAL NO. 10: 1775-1835 FT DEPTH
60 60 0.8 100 0
3.8E-5 3.8E-5
3.9E-5 3.9E-5
3.9E-7 3.9E-7
0 1479 36 1 50
COMPACTING INTERVAL NO. 11: 1895-1965 FT DEPTH
15 15 .5 100 0
3.3E-5 3.3E-5
3.7E-5 3.7E-5
3.7E-7 3.7E-7
0 1530 36 1 50
COMPACTION INTERVAL NO. 12: 1965-2015 FT DEPTH
70 70 .5 100 0
2.8E-5 2.8E-5
3.5E-5 3.5E-5
3.5E-7 3.5E-7
0 1587 36 1 50
COMPACTION INTERVAL NO. 13: 2015-2085 FT DEPTH
70 70 .5 100 0
2.1E-5 2.1E-5
3.2E-5 3.2E-5

3.2E-7 3.2E-7
0 1689 36 1 50
  COMPACTION INTERVAL NO. 14: 2085-2345 FT DEPTH
90 30 .5 100 0
1.4E-5 1.4E-5
2.7E-5 2.7E-5
2.7E-7 2.7E-7
0 1796 36 1 50
EOF

SHELDON SITE Apr 2011
1 360 9 25 1.0
700 1600 1601
125
235
315
425
668
853
1050
1255
1540
1 0 0
5761 15 15
11521 50 50
18721 182 182

21601	232	0
22321	276	0
23761	301	0
24481	306	0
25201	330	0
25921	285	0
26281	300	0
26641	244	0
27361	233	0
28081	254	0
29161	246	0
29521	236	0
29881	237	0
30241	268	0
30601	251	0
32041	210	0
32401	205	0
33841	180	0
35281	165	0
36721	150	0
37441	145	0

COMPACTING INTERVAL NO. 1, 90-160 FT
70 70 0.5 100 60
2.6E-3 2.6E-3
3.3E-4 3.3E-4
3.3E-6 3.3E-6
0 125 36 1 50
COMPACTING INTERVAL NO. 2, 230-242 FT
12 12 0.2 100 60
1.9E-3 1.9E-3
1.9E-4 1.9E-4
1.9E-6 1.9E-6
0 228 36 1 50
COMPACTING INTERVAL NO. 3, 290-340 FT
50 50 0.5 100 100
1.6E-3 1.6E-3
1.3E-4 1.3E-4

1.3E-6 1.3E-6
0 303 36 1 50
 COMPACTING INTERVAL NO. 4, 350-500 FT
150 150 0.75 100 150
1.2E-3 1.2E-3
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 405 36 1 50
 COMPACTING INTERVAL NO. 5, 600-735 FT
34 17 0.25 100 120
6.5E-4 6.5E-4
8.6E-5 8.6E-5
8.6E-7 8.6E-7
0 653 36 1 50
 COMPACTING INTERVAL NO. 6, 785-920 FT
124 62 0.5 100 0
4.1E-4 4.1E-4
7.3E-5 7.3E-5
7.3E-7 7.3E-7
0 831 36 1 50
 COMPACTING INTERVAL NO. 7, 925-1175 FT
112 28 0.2 100 0
2.5E-4 2.5E-4
6.2E-5 6.2E-5
6.2E-7 6.2E-7
0 1072 36 1 50
 COMPACTING INTERVAL NO. 8, 1220-1290 FT
70 70 0.5 100 0
1.4E-4 1.4E-4
5.0E-5 5.0E-5
5.0E-7 5.0E-7
0 1353 36 1 50
 COMPACTING INTERVAL NO. 9, 1440-1640 FT
80 20 0.2 100 0
7.3E-5 7.3E-5
4.0E-5 4.0E-5
4.0E-7 4.0E-7
0 1744 36 1 50
EOF

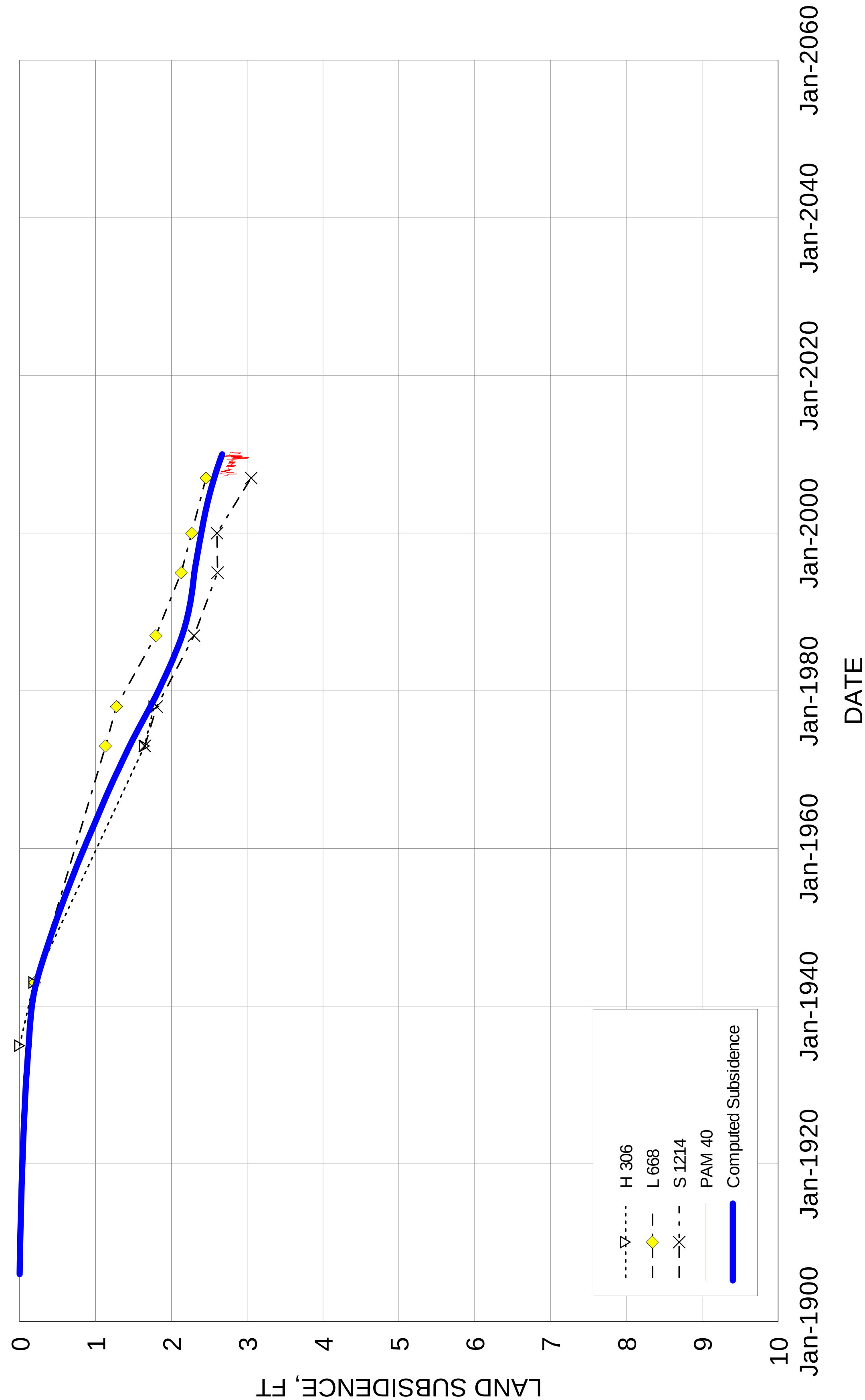
SMITHERS LAKE SITE Apr 2011
1 360 6 16 1
420 730 1200
175
380
635
890
988
1143

1	0	0
10801	36	0
15841	56	0
18001	68	0
21601	86	0
23761	100	0
25921	116	0
27721	123	0
29521	130	0
30241	131	0
32041	131	0
32401	135	0
33841	140	0
35281	145	0
36721	150	0
37441	153	0

COMPACTING INTERVAL NO. 1: 0-350 FT DEPTH
135 45 .5 100 15
2.3E-3 2.3E-3
2.6E-4 2.6E-4
2.6E-6 2.6E-6
0 141 36 1 50
COMPACTING INTERVAL NO. 2: 350-410 FT DEPTH
55 55   .5 100 110
1.4E-3 1.4E-3
1.4E-4 1.4E-4
1.4E-6 1.4E-6
0 309 36 1 50
COMPACTING INTERVAL NO. 3: 410-860 FT DEPTH
100 20 .5 100 130
7.2E-4 7.2E-4
1.1E-4 1.1E-4
1.1E-6 1.1E-6
0 518 36 1 50
COMPACTING INTERVAL NO. 4: 860-920 FT DEPTH
40 20 .5 100 80
3.8E-4 3.8E-4
9.0E-5 9.0E-5
9.0E-7 9.0E-7
0 727 36 1 50
COMPACTING INTERVAL NO. 5: 920-1055 FT DEPTH
20 10 .2 100 0
3.0E-4 3.0E-4
8.2E-5 8.2E-5

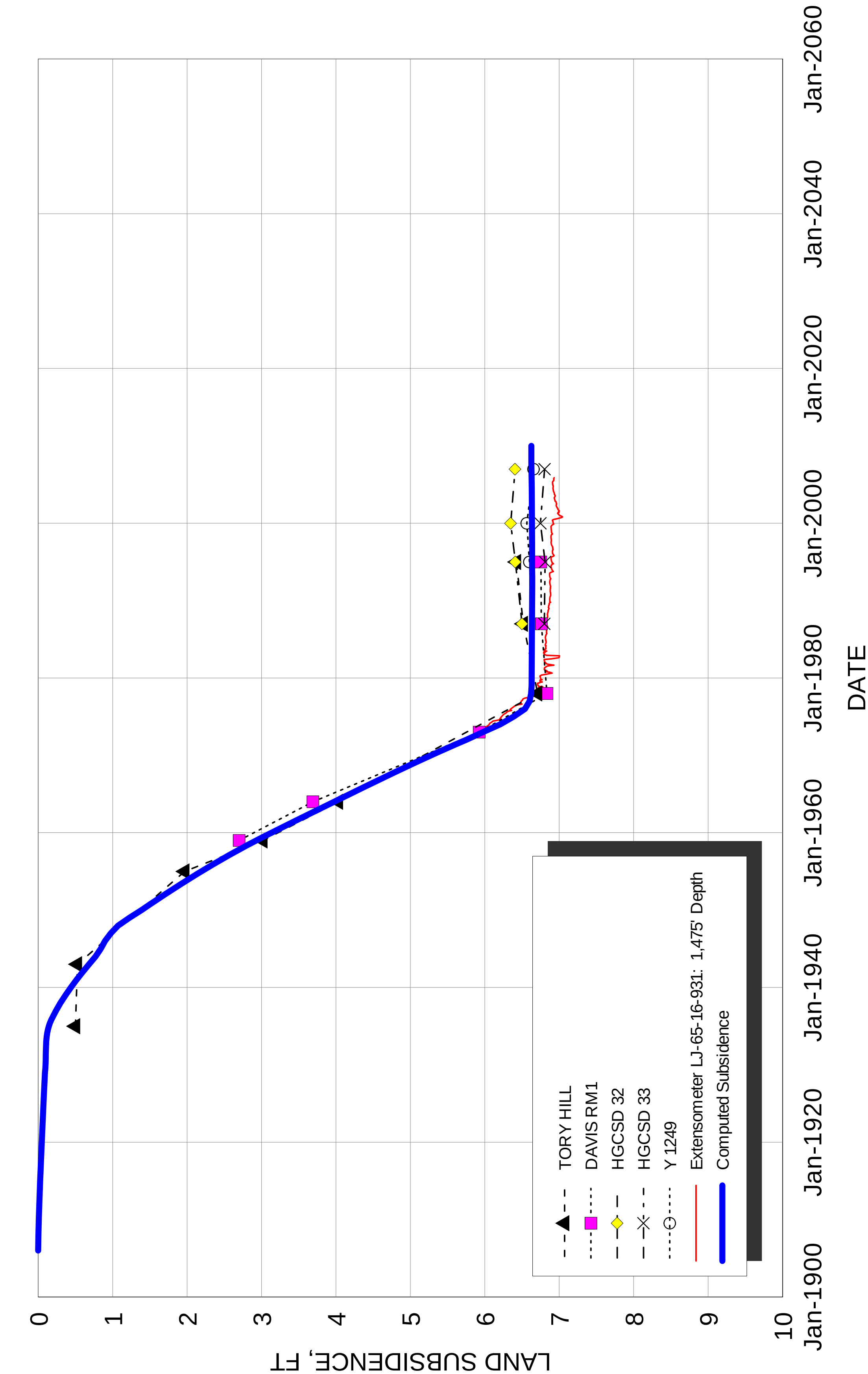
8.2E-7 8.2E-7
0 807 36 1 50
COMPACTING INTERVAL NO. 6: 1055-1230 FT DEPTH
30 30 0.5 100 0
2.0E-4 2.0E-4
7.1E-5 7.1E-5
7.1E-7 7.1E-7
0 929 36 1 50
EOF

APPENDIX C – PRESS MODEL OUTPUT AND SUBSIDENCE DATA



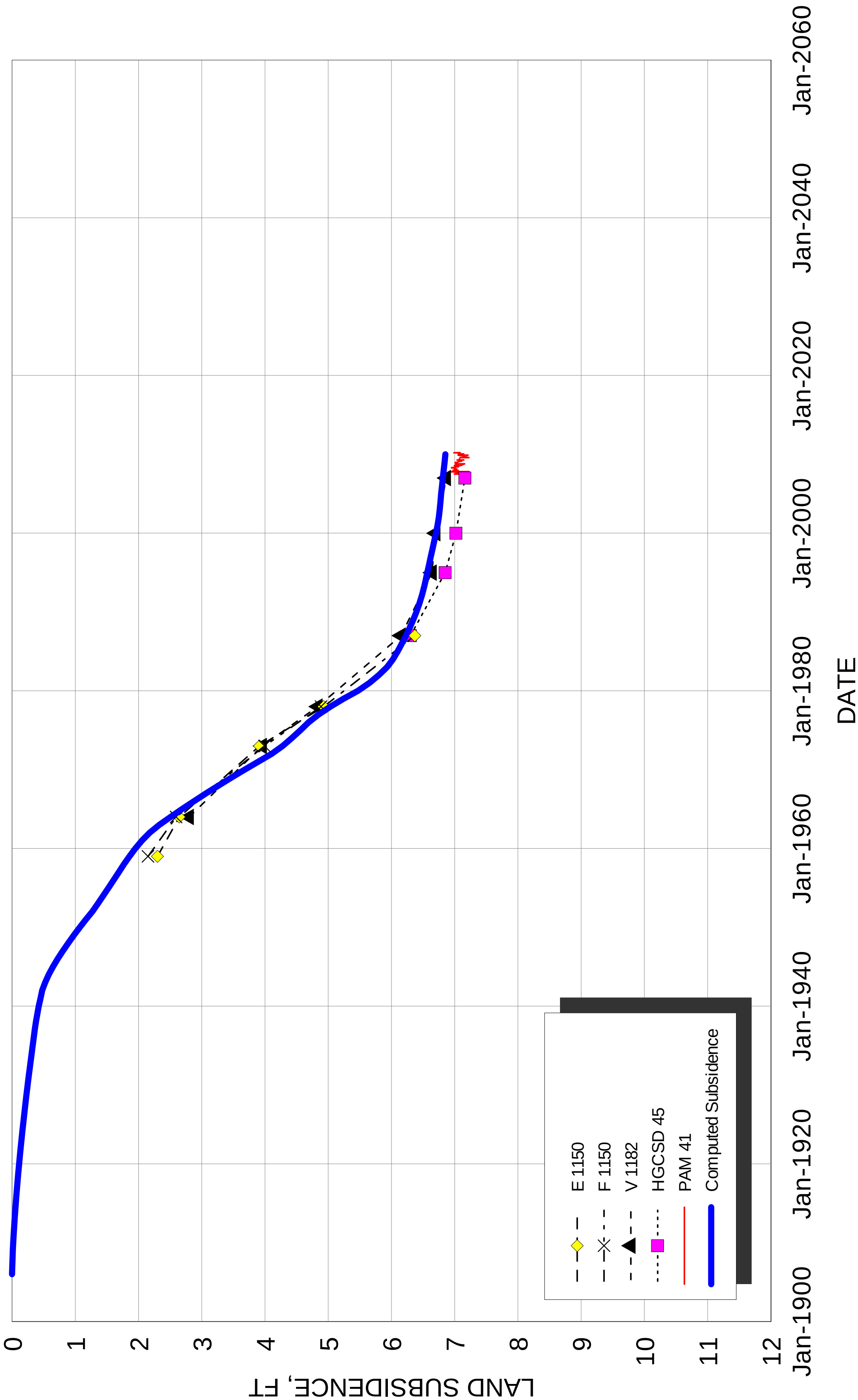
COMPUTED AND MEASURED SUBSIDENCE
ARCOLA SITE

PLATE C-1



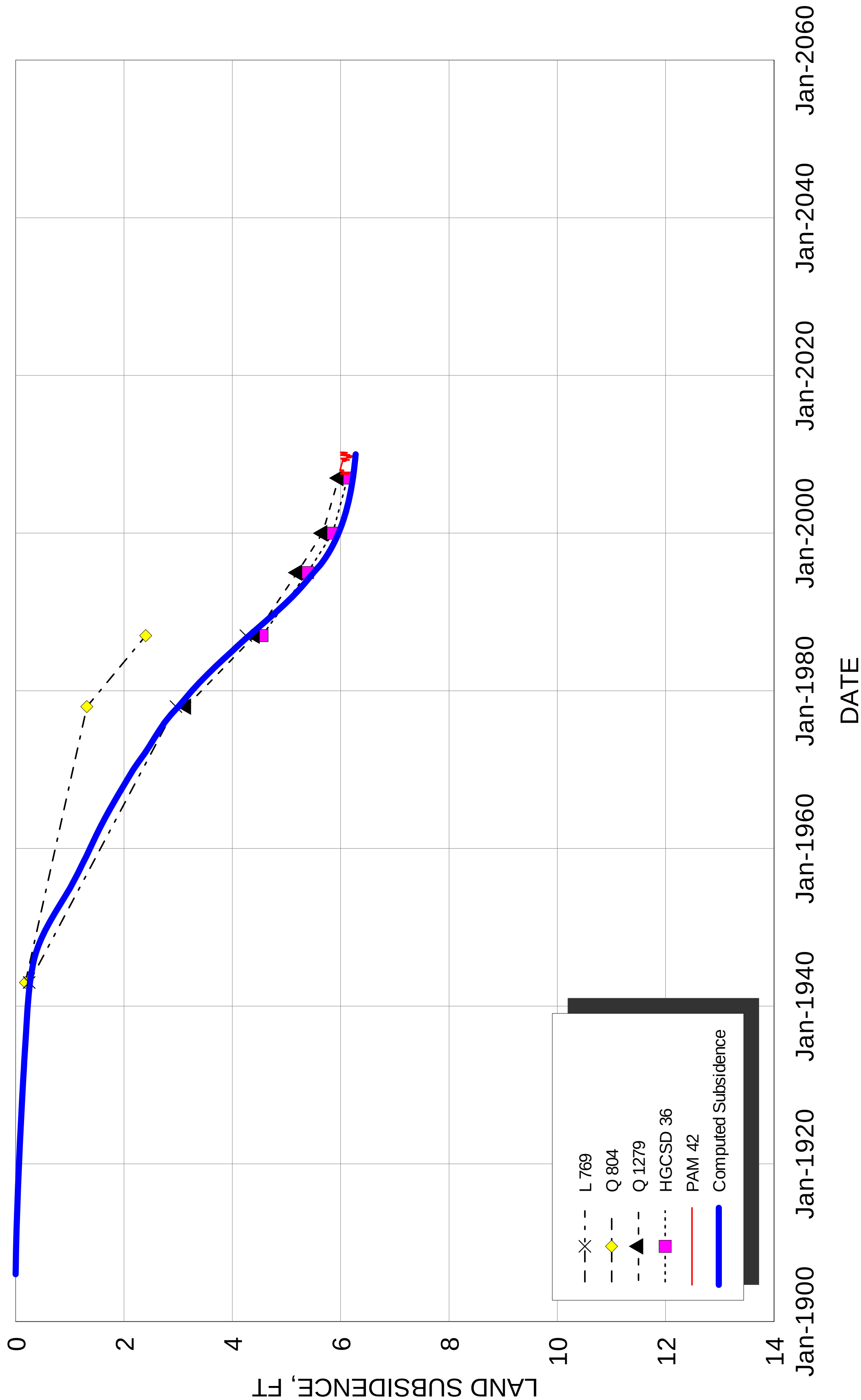
COMPUTED AND MEASURED SUBSIDENCE
BAYTOWN SITE

PLATE C-2



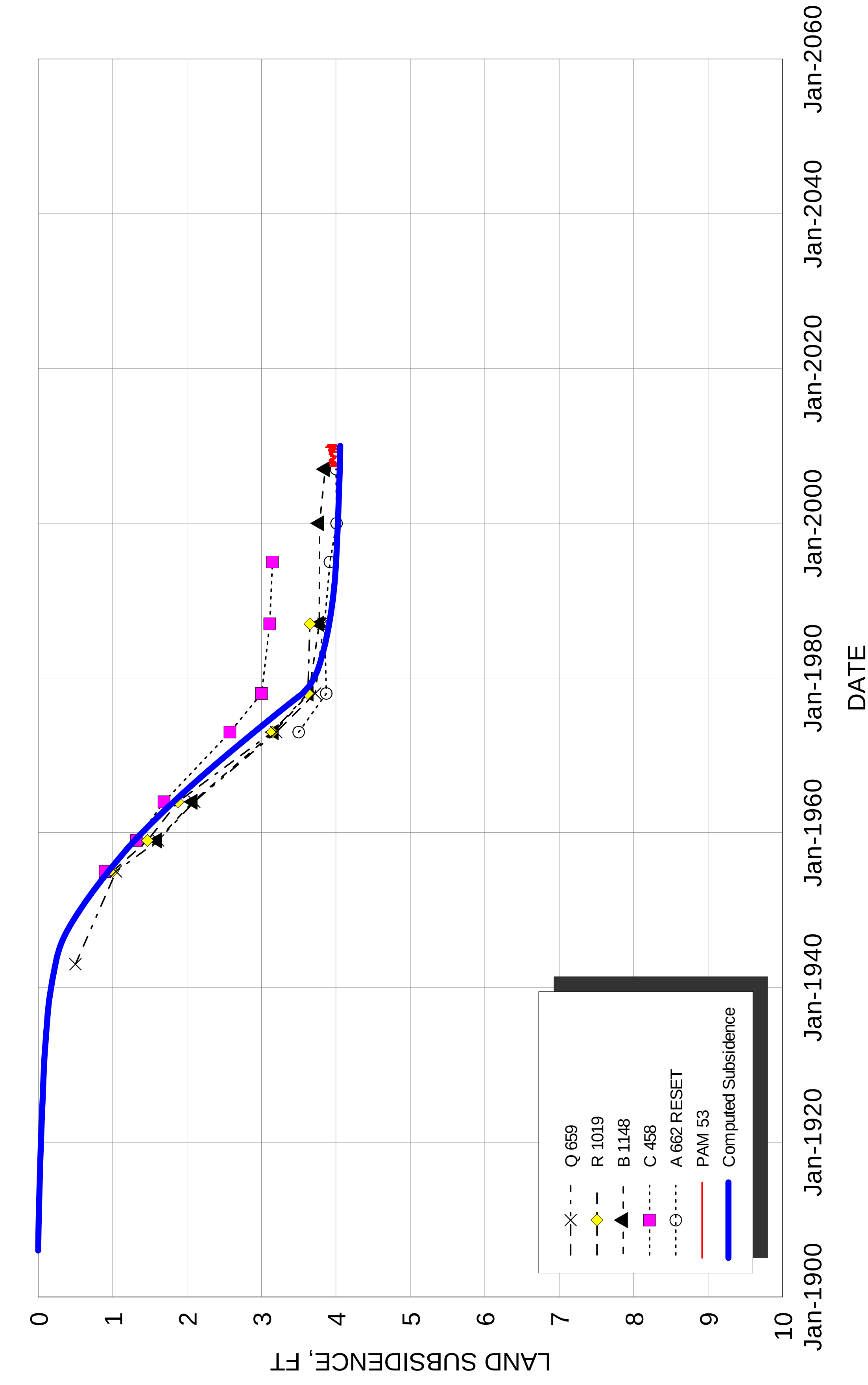
COMPUTED AND MEASURED SUBSIDENCE
BELLAIRE SITE

PLATE C-3



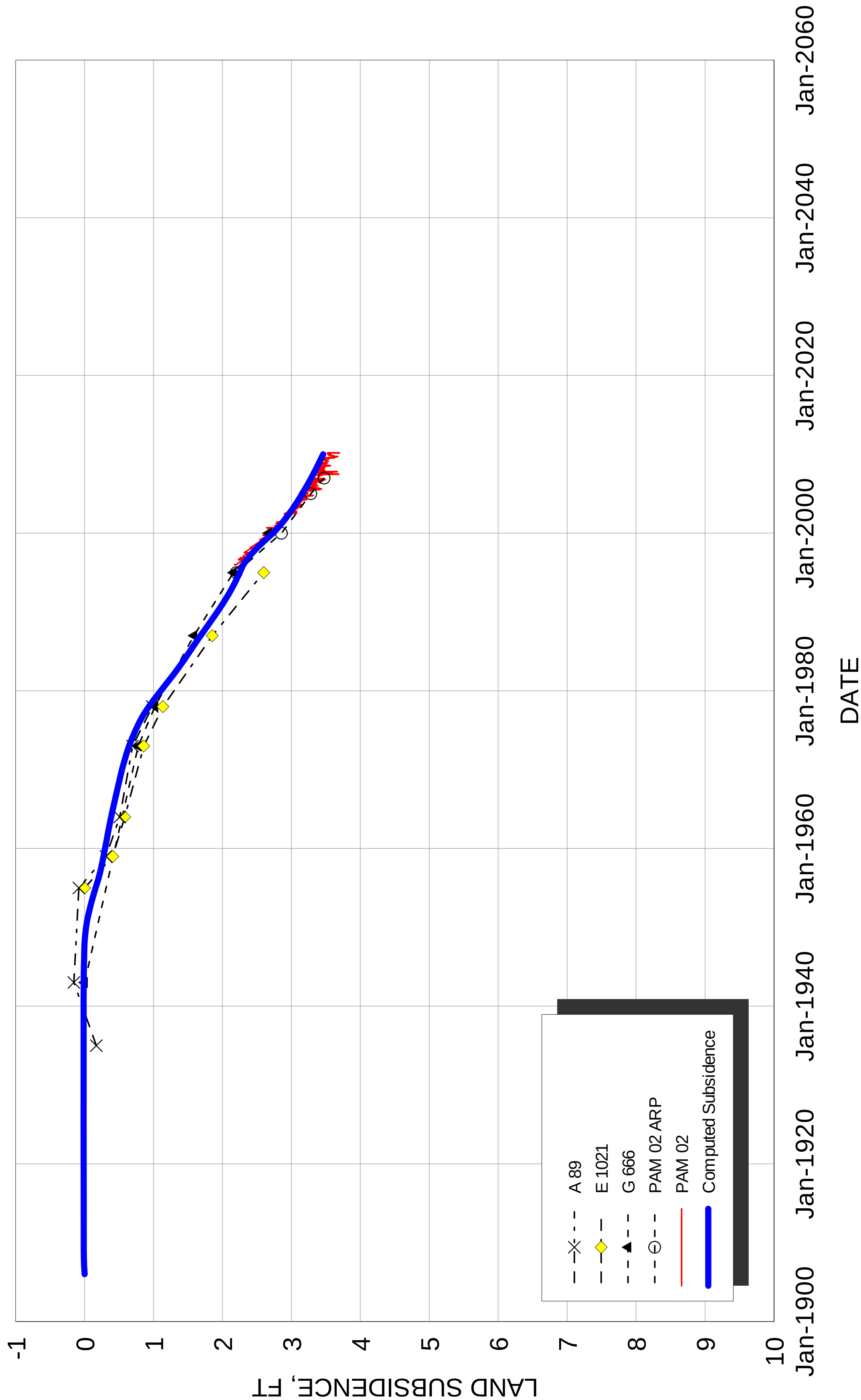
COMPUTED AND MEASURED SUBSIDENCE
BELLAIRE WEST SITE

PLATE C-4



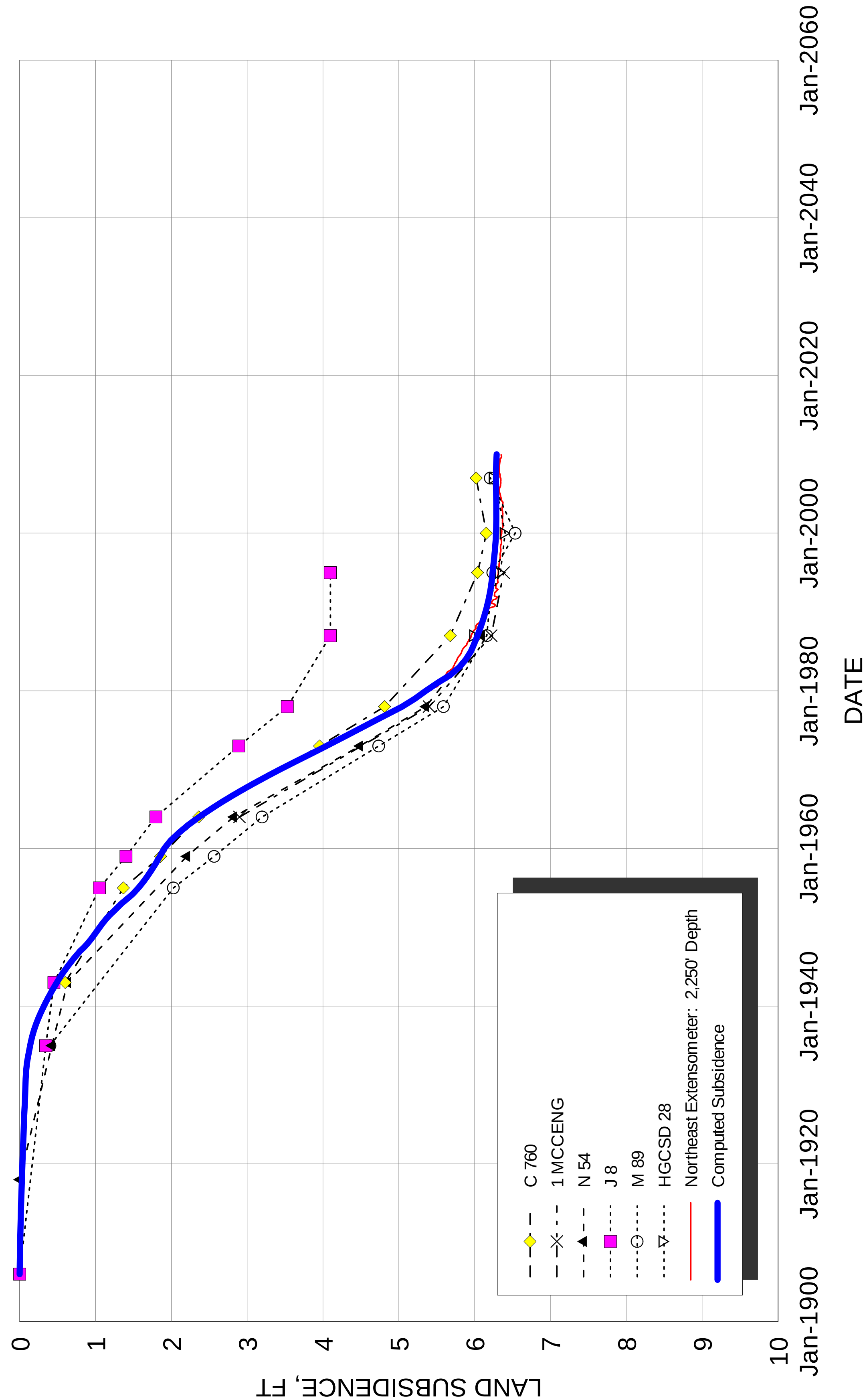
COMPUTED AND MEASURED SUBSIDENCE
CROSBY SITE

PLATE C-5



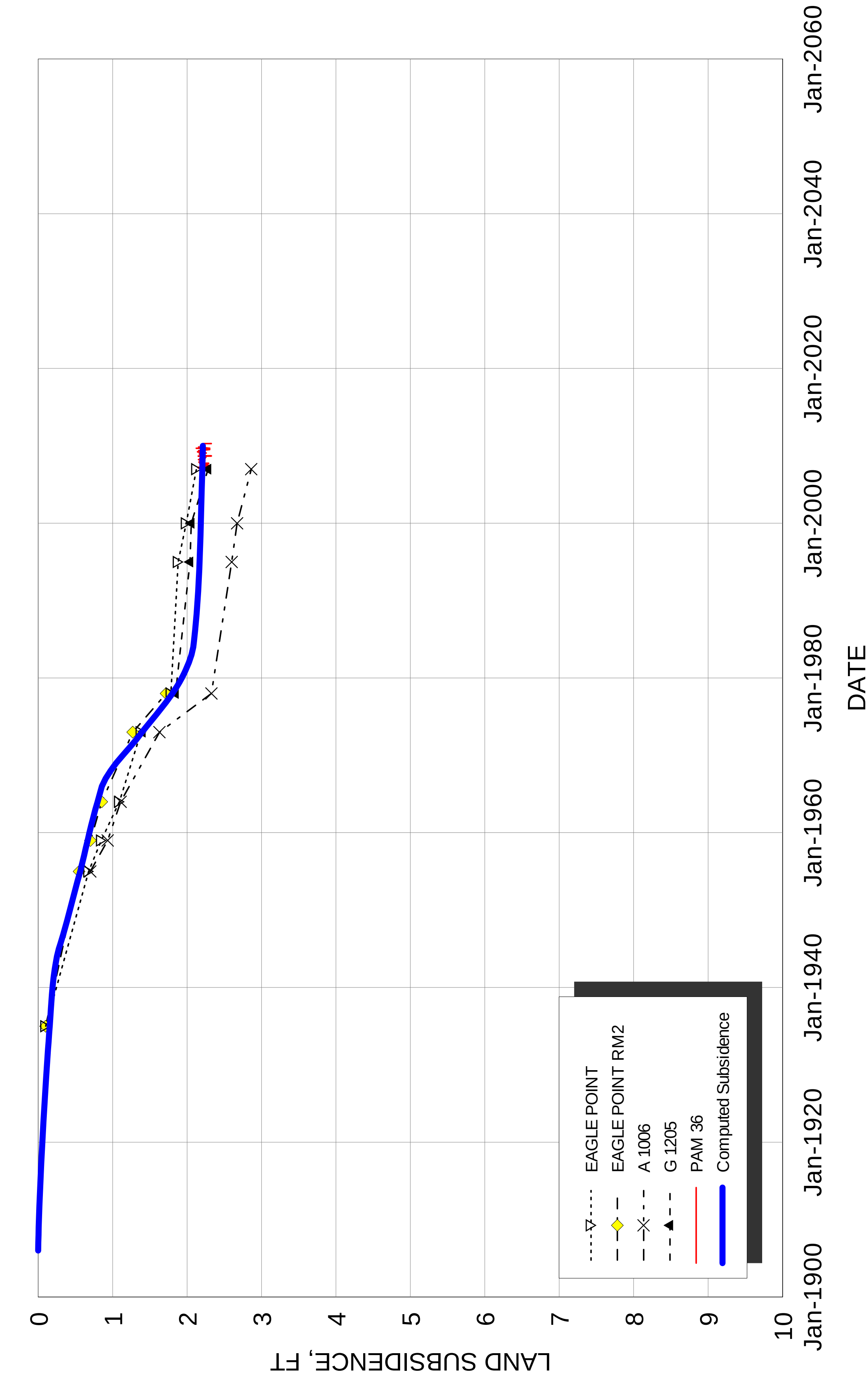
COMPUTED AND MEASURED SUBSIDENCE
CYPRESS CREEK SITE

PLATE C-6



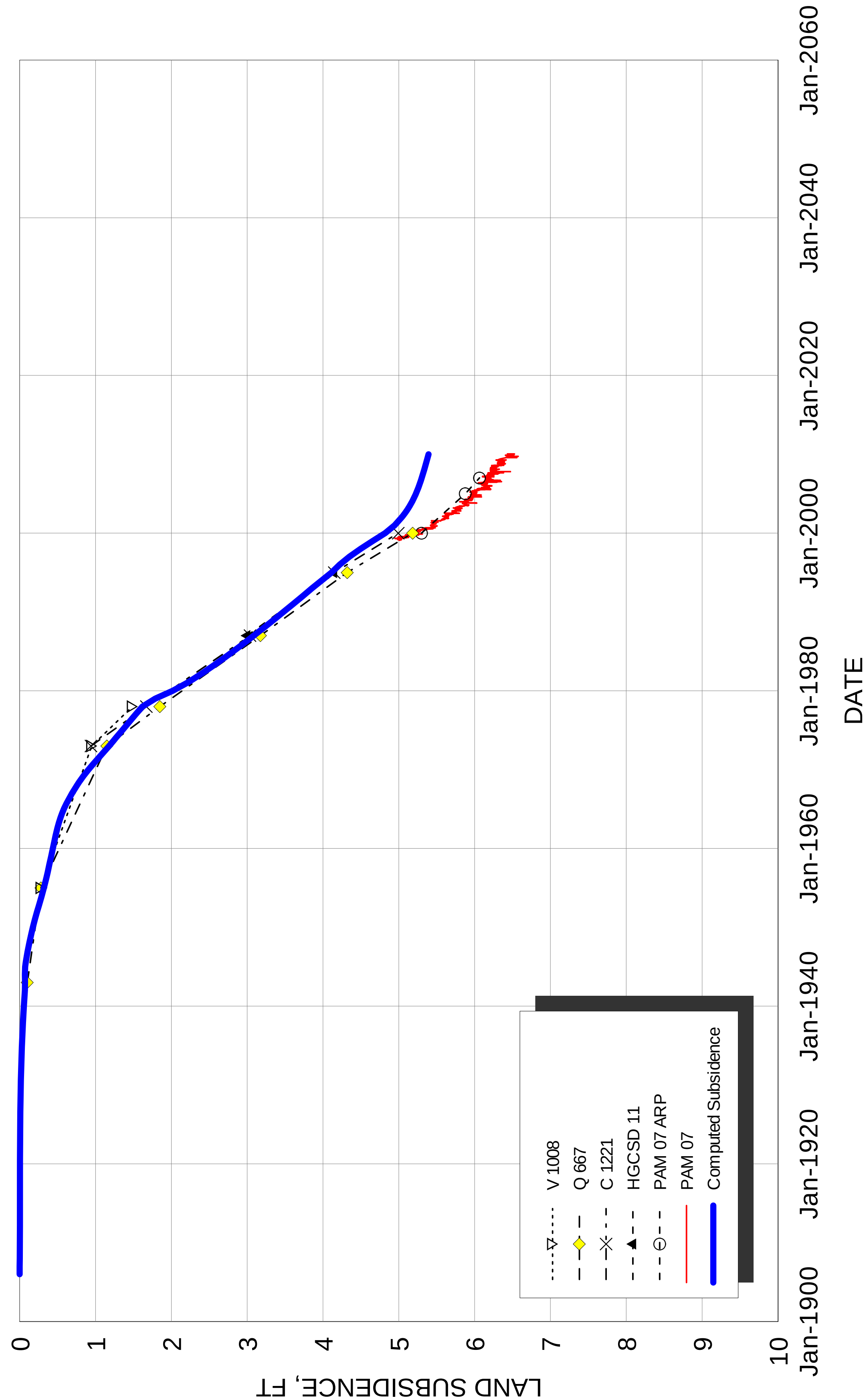
COMPUTED AND MEASURED SUBSIDENCE
DOWNTOWN SITE

PLATE C-7



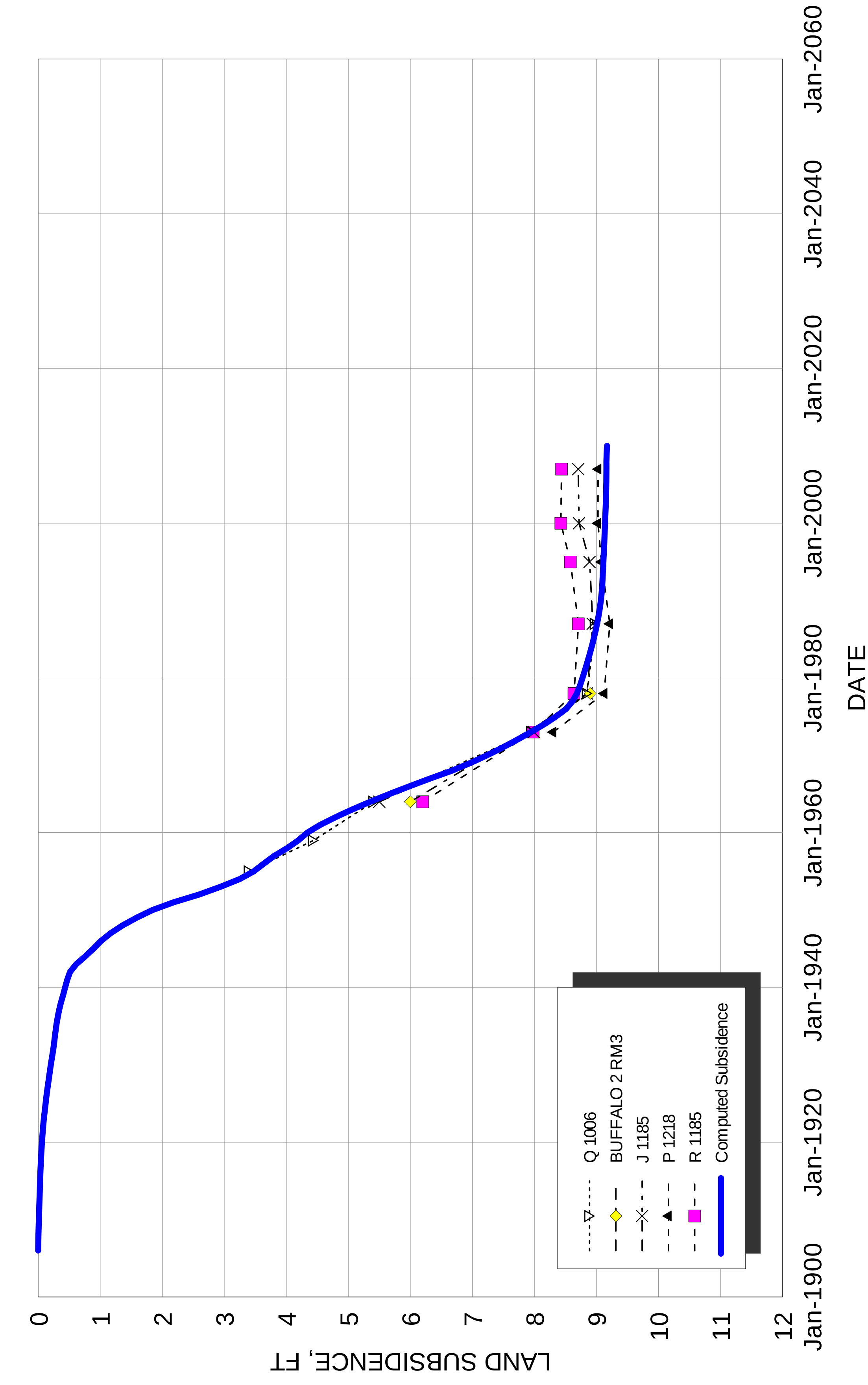
COMPUTED AND MEASURED SUBSIDENCE
EAGLE POINT SITE

PLATE C-8



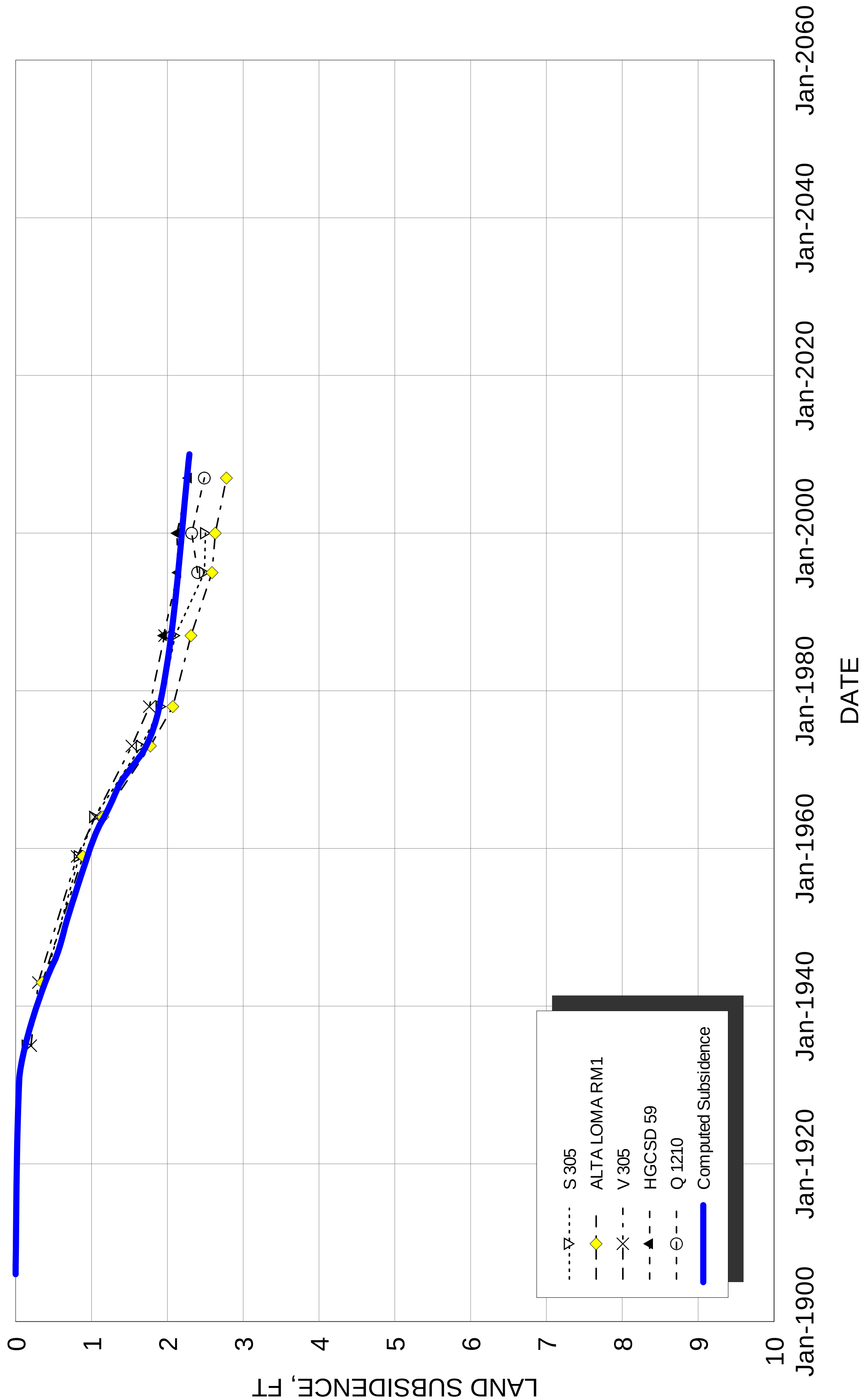
COMPUTED AND MEASURED SUBSIDENCE
FM 1960 SITE

PLATE C-9



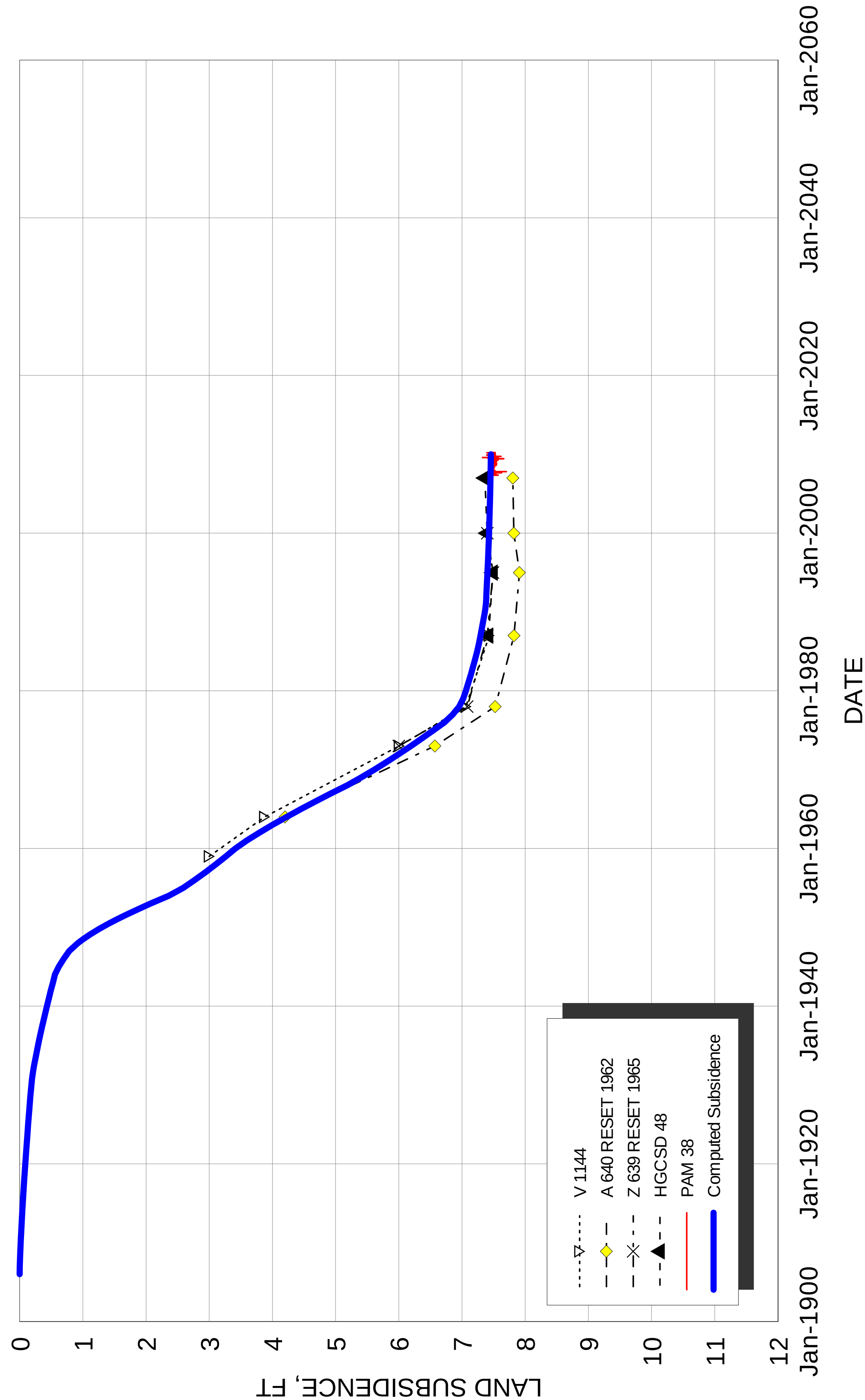
COMPUTED AND MEASURED SUBSIDENCE
GALENA PARK SITE

PLATE C-10



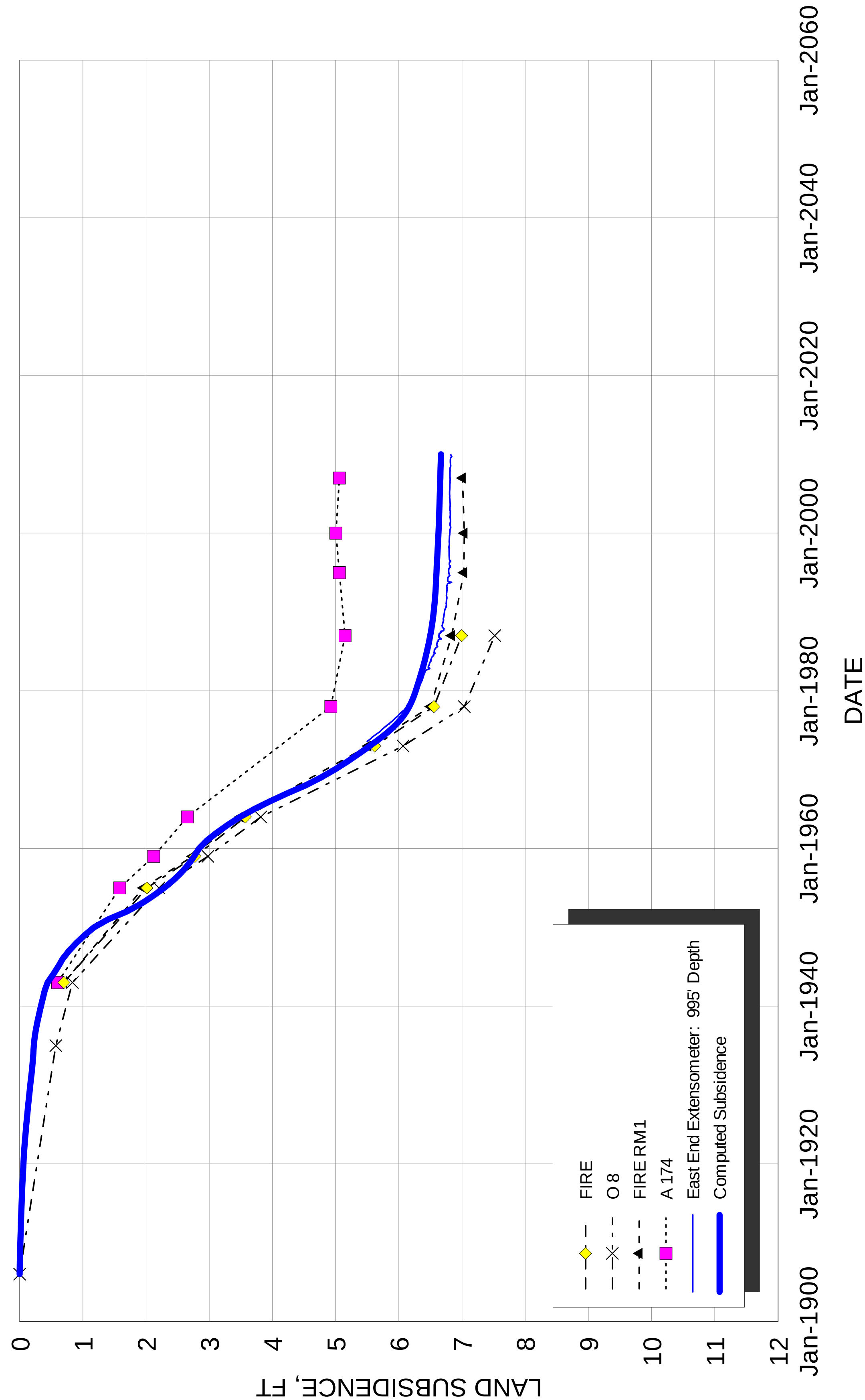
COMPUTED AND MEASURED SUBSIDENCE
GALVESTON COUNTY SITE

PLATE C-11



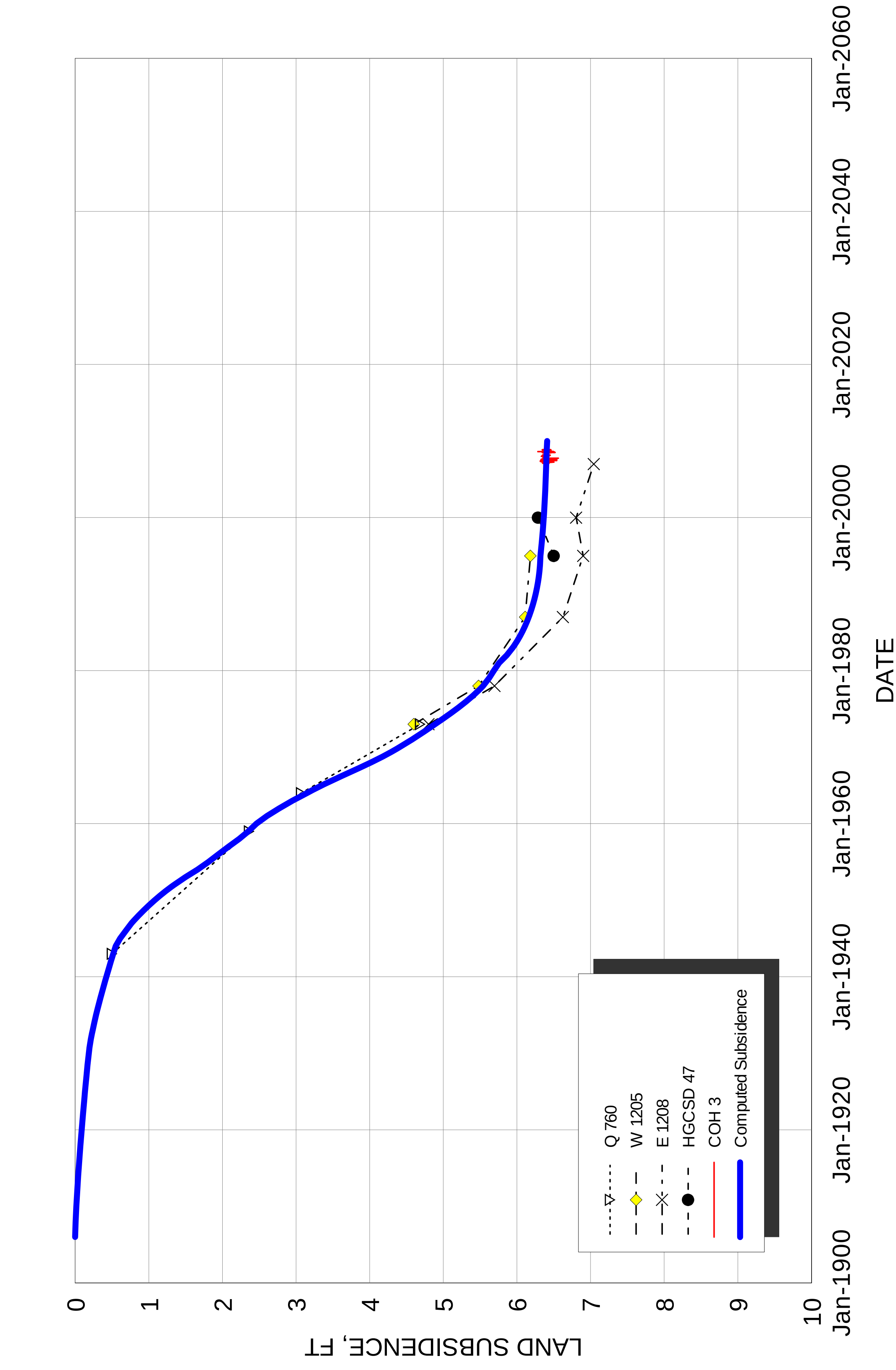
COMPUTED AND MEASURED SUBSIDENCE
GENOA SITE

PLATE C-12



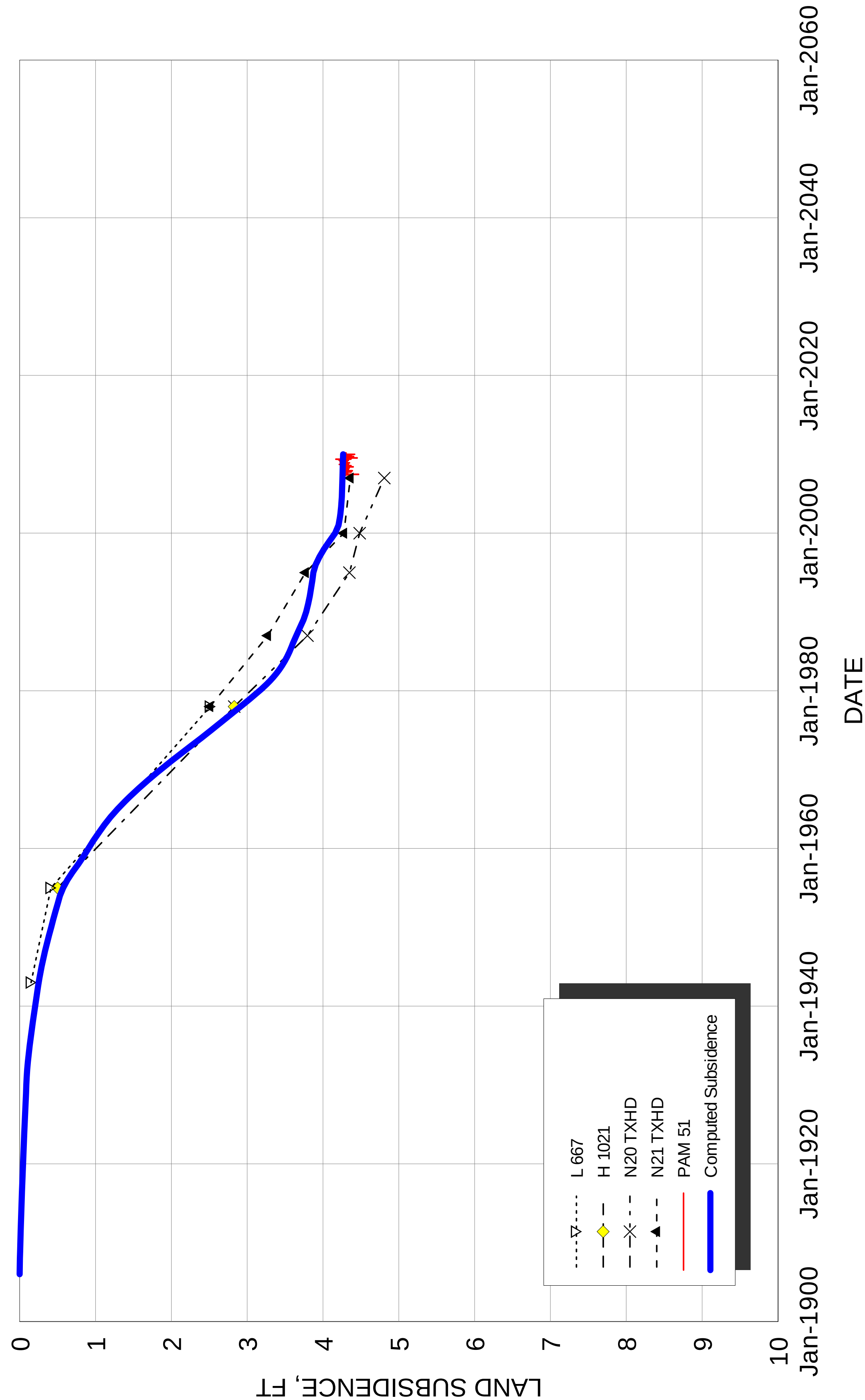
COMPUTED AND MEASURED SUBSIDENCE
HARRISBURG SITE

PLATE C-13

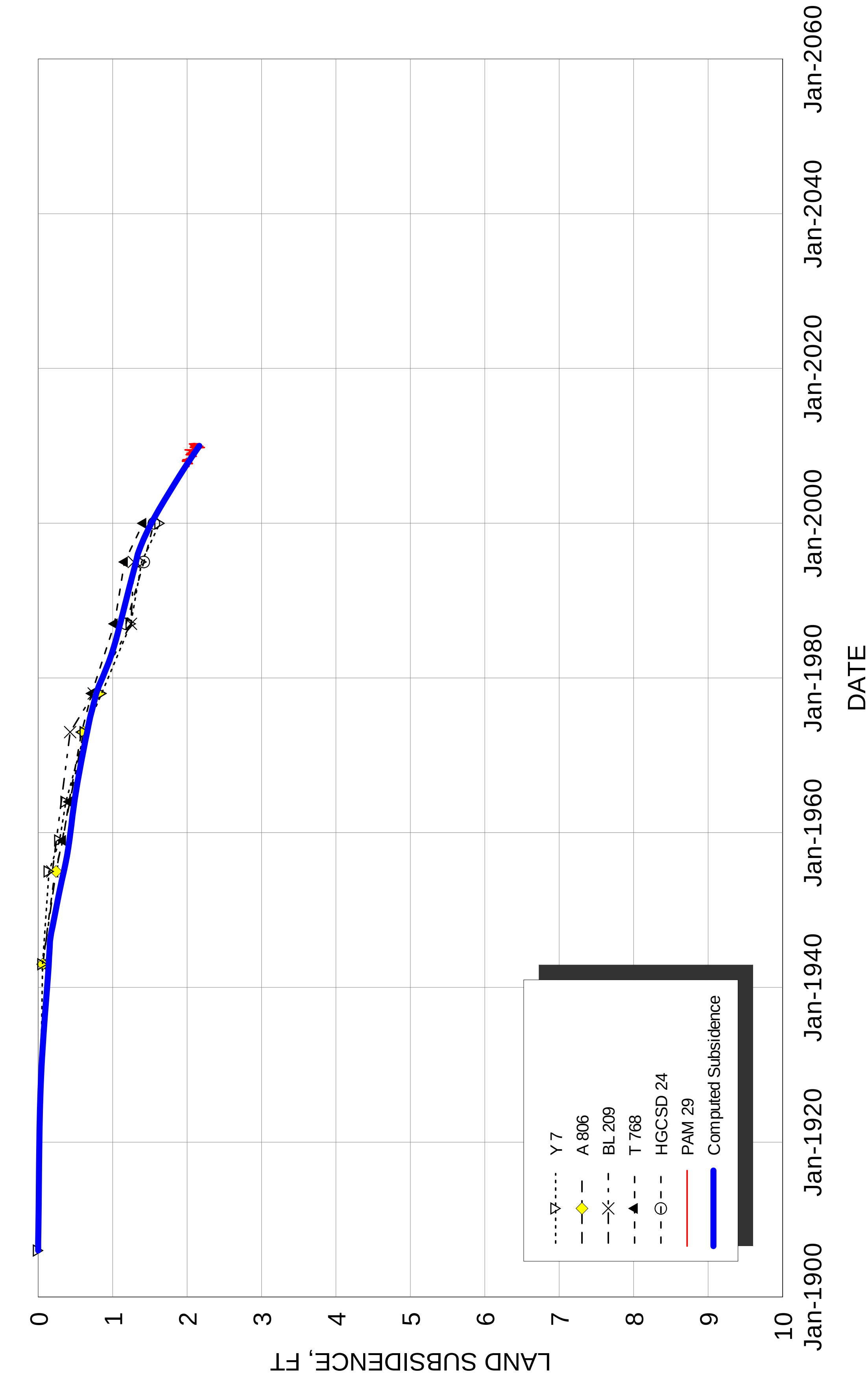


COMPUTED AND MEASURED SUBSIDENCE
HOBBY SITE

PLATE C-14



COMPUTED AND MEASURED SUBSIDENCE
HUMBLE SITE



COMPUTED AND MEASURED SUBSIDENCE
KATY SITE

PLATE C-16

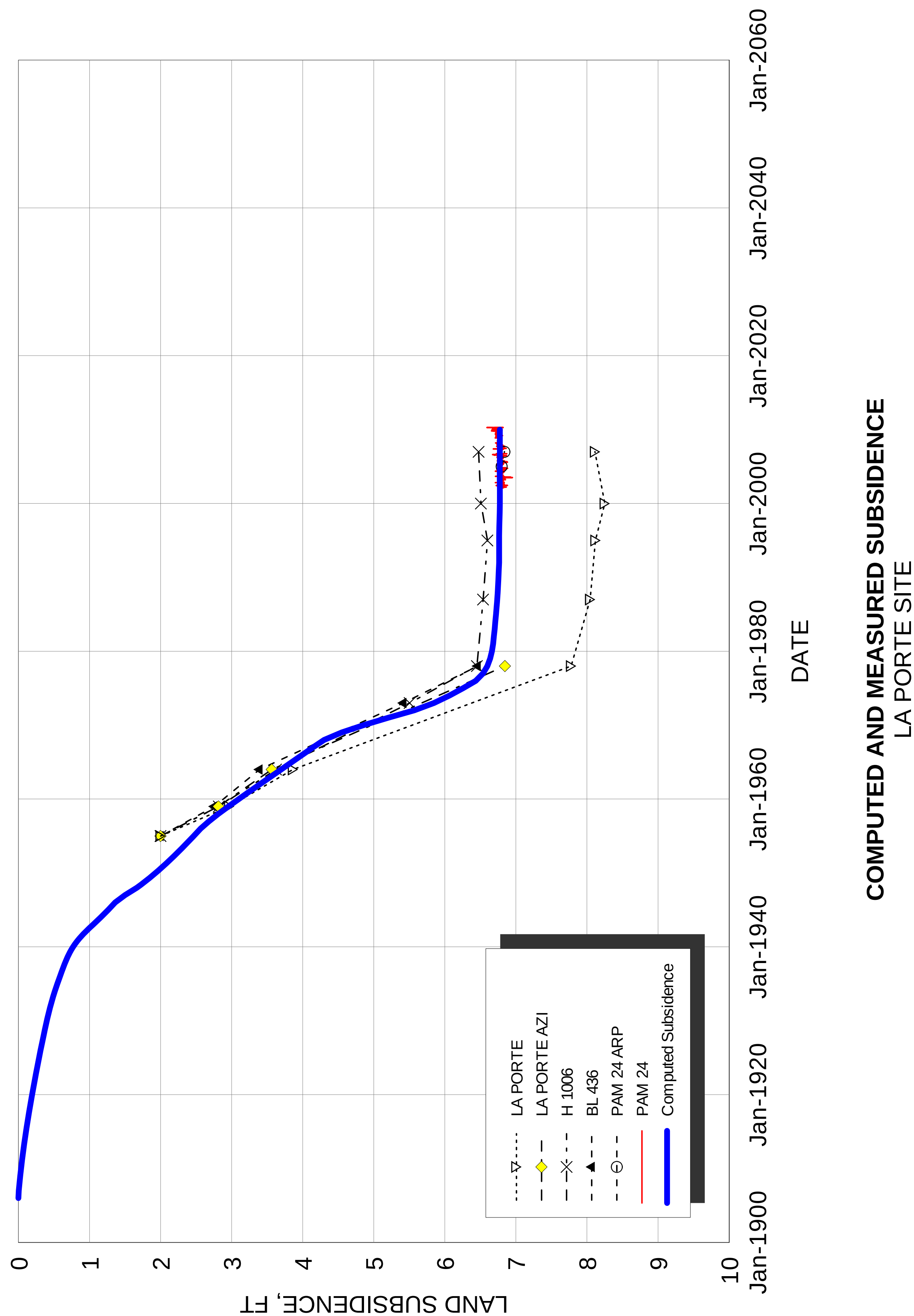
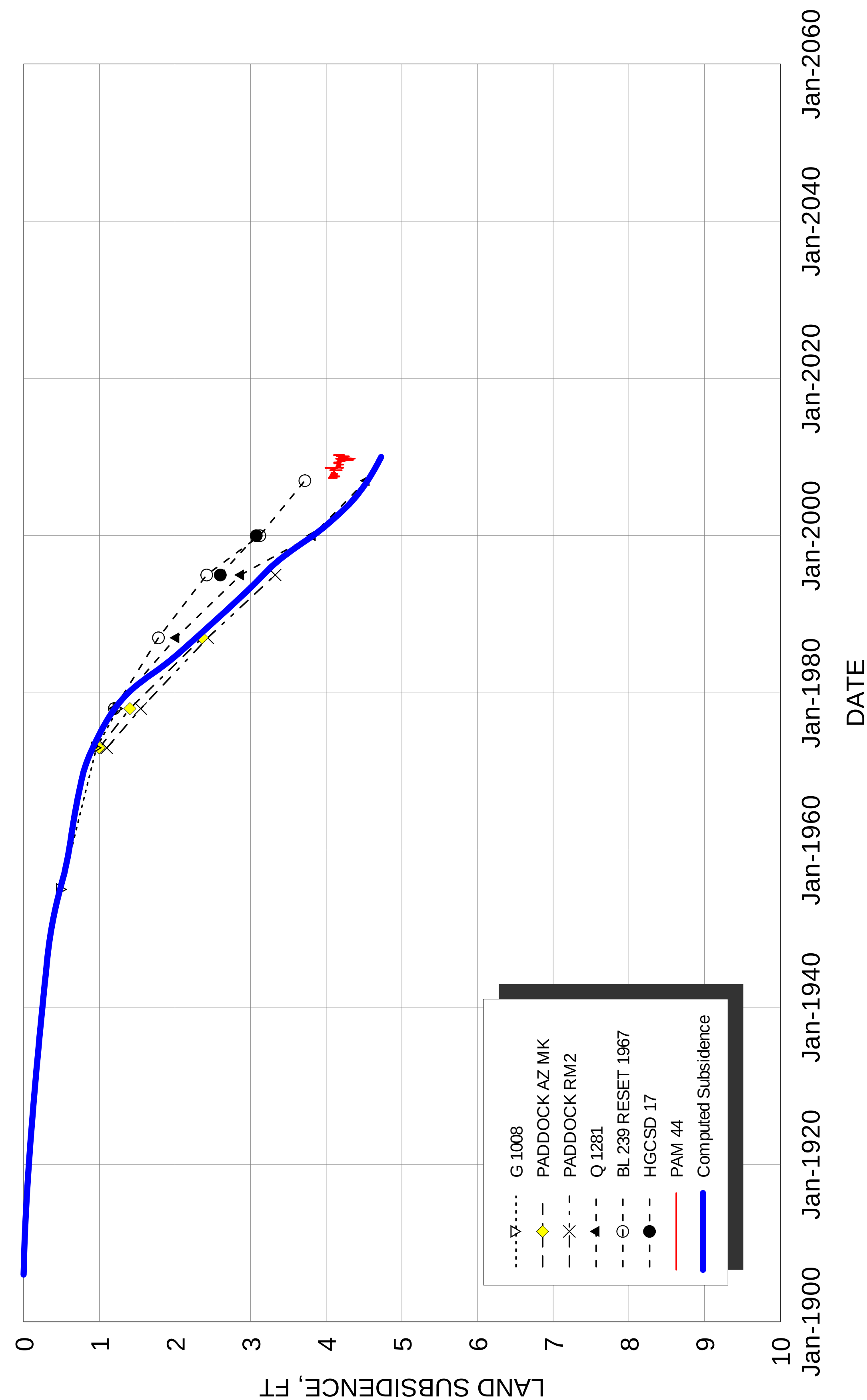
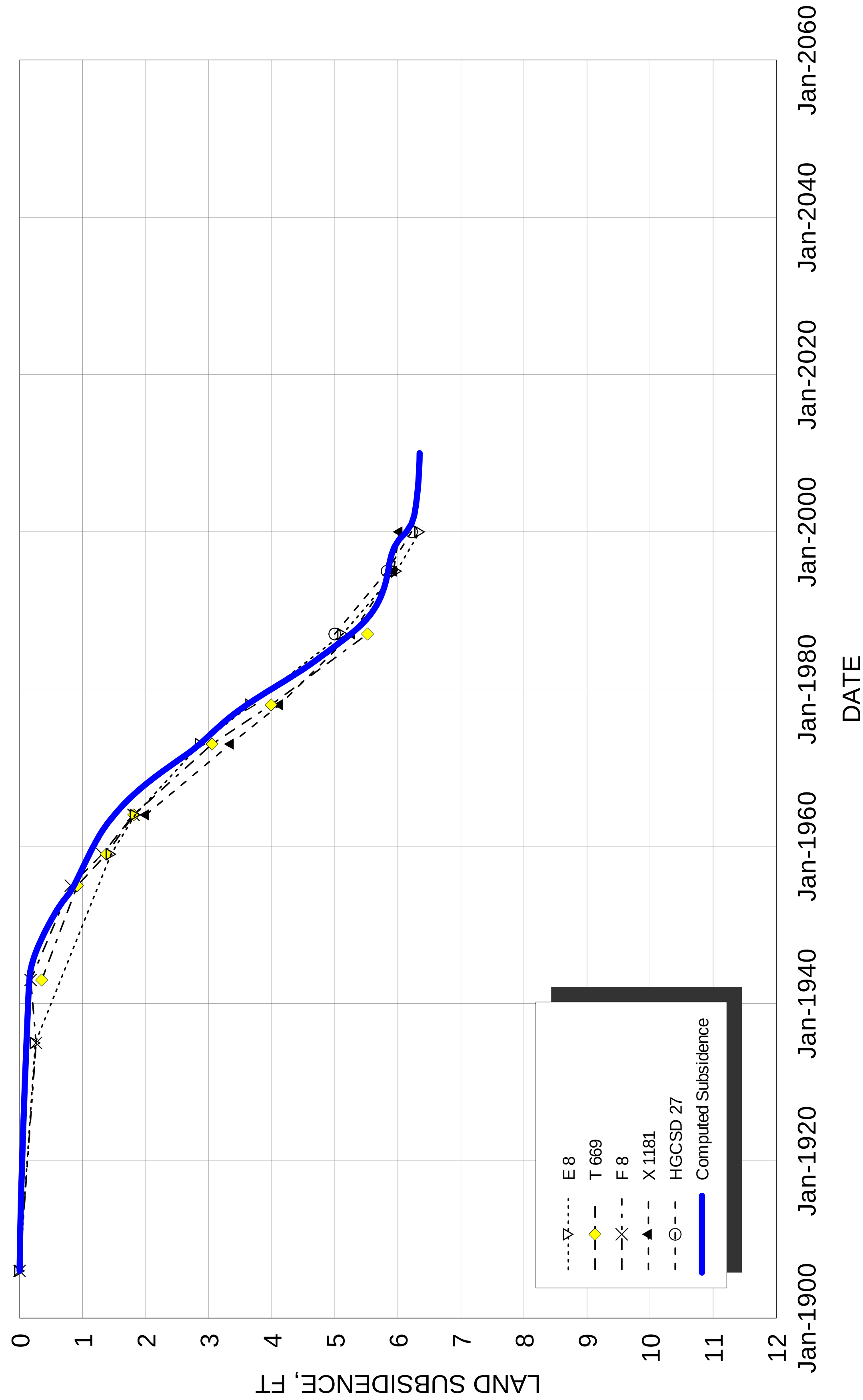

LA PORTE
LA PORTE AZI
H 1006
BL 436
PAM 24 ARP
PAM 24
Computed Subsidence
LAND SUBSIDENCE, FT
0
1
2
3
4
5
6
7
8
9
10
Jan-1900
Jan-1920
Jan-1940
Jan-1960
Jan-1980
Jan-2000
Jan-2020
Jan-2040
Jan-2060
DATE
COMPUTED AND MEASURED SUBSIDENCE
LA PORTE SITE

PLATE C-17



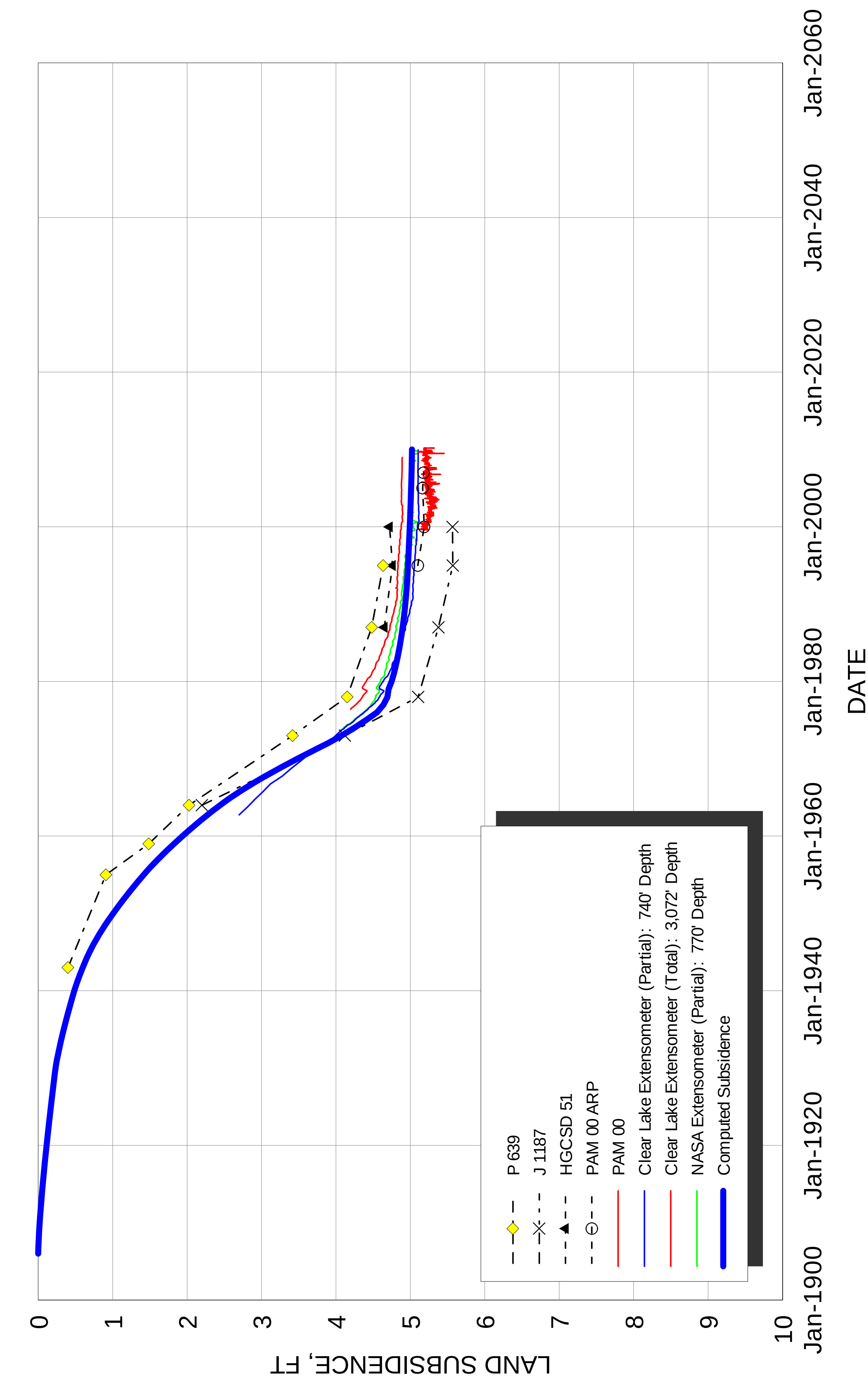
COMPUTED AND MEASURED SUBSIDENCE
LANGHAM CREEK SITE

PLATE C-18



COMPUTED AND MEASURED SUBSIDENCE
LONG POINT SITE

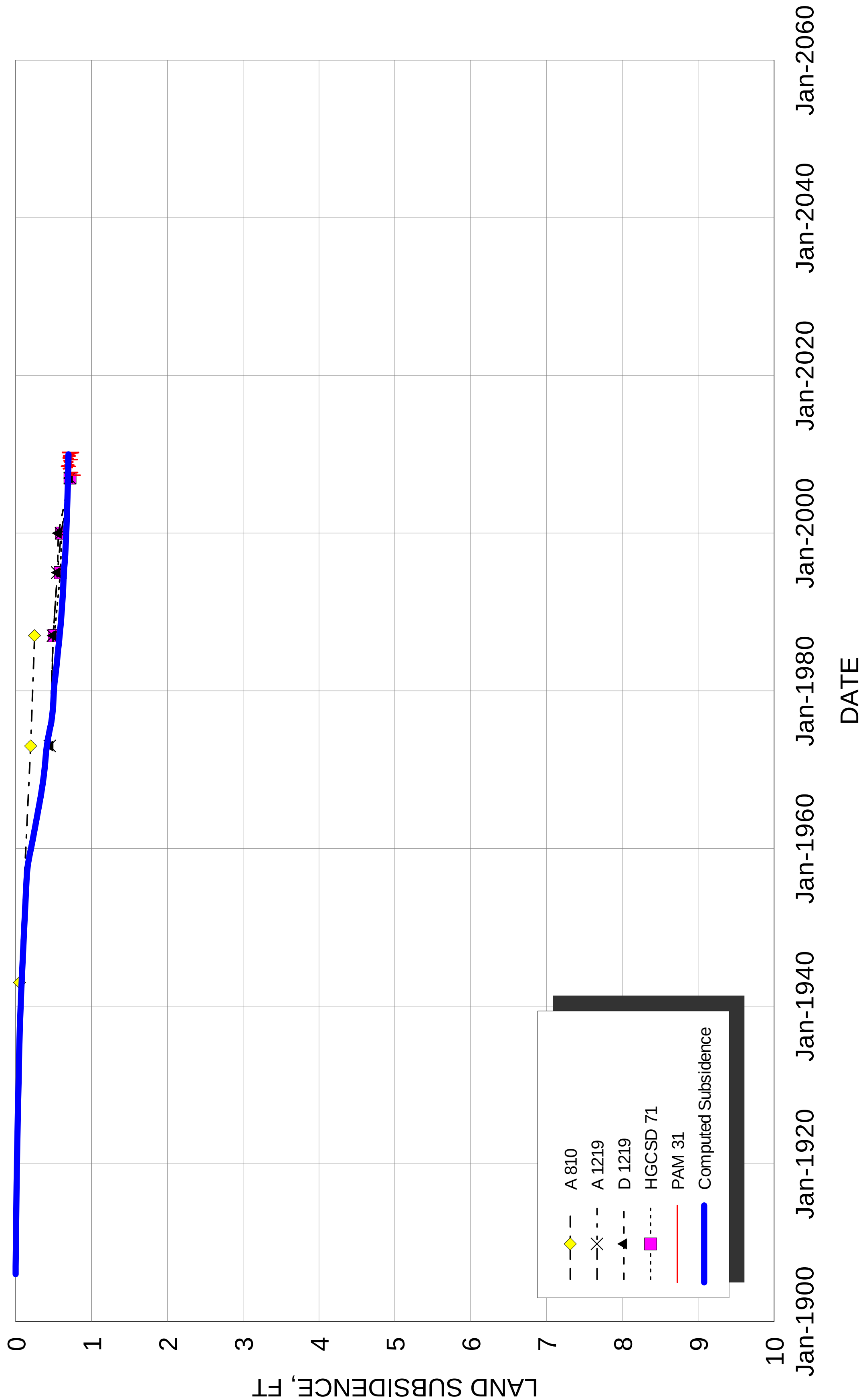
PLATE C-19



COMPUTED AND MEASURED SUBSIDENCE

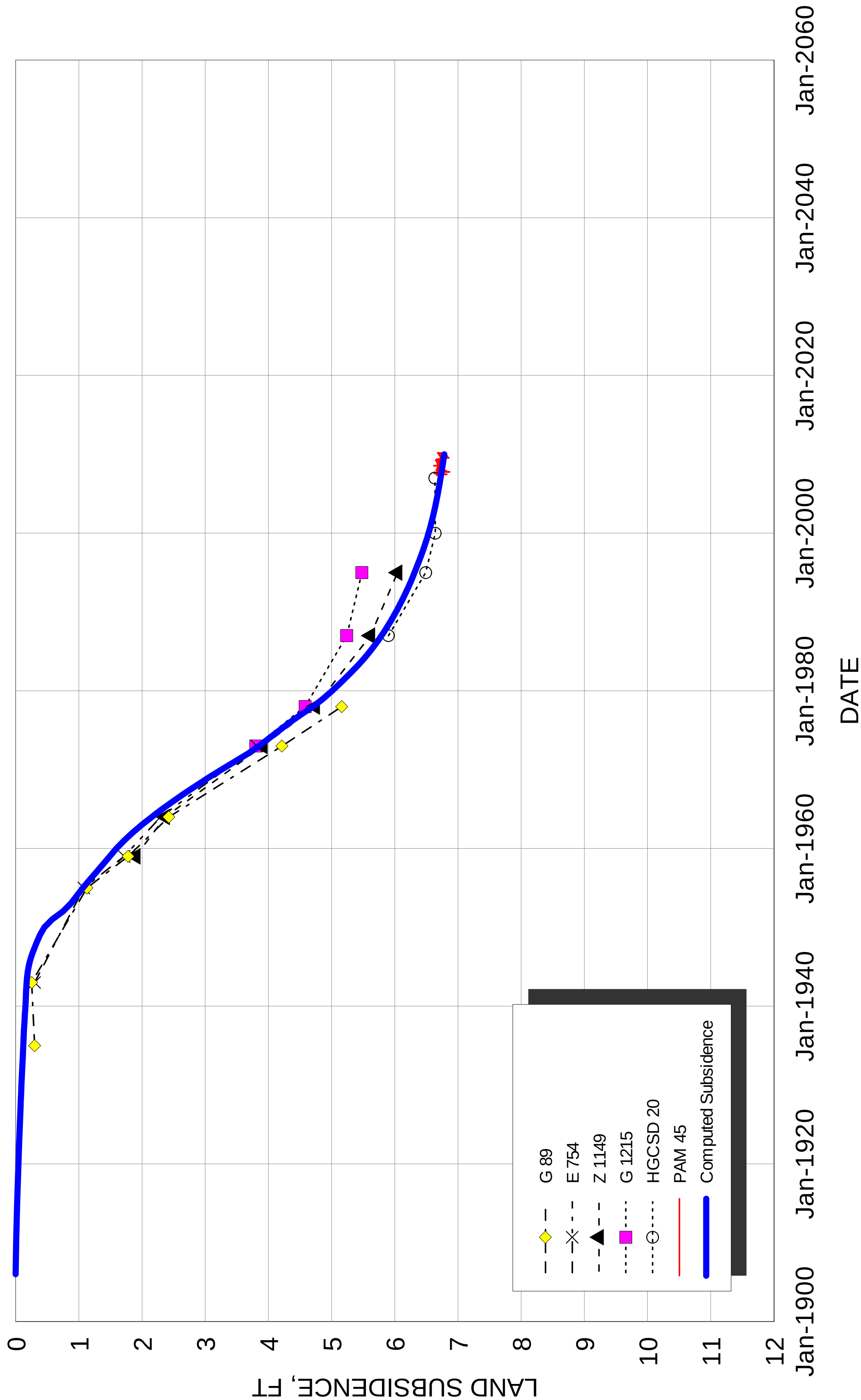
NASA SITE

PLATE C-20



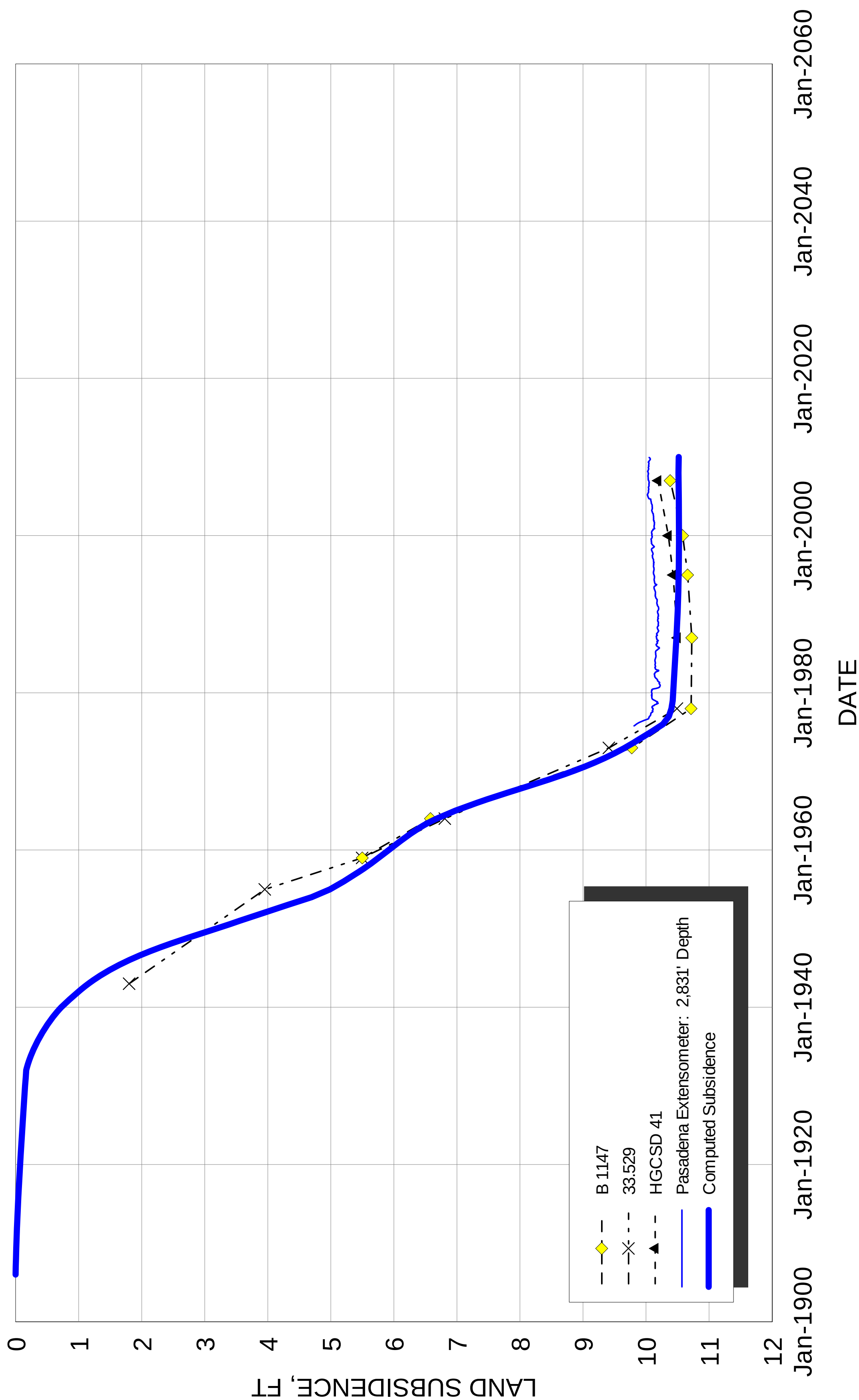
COMPUTED AND MEASURED SUBSIDENCE
NEEDVILLE SITE

PLATE C-21



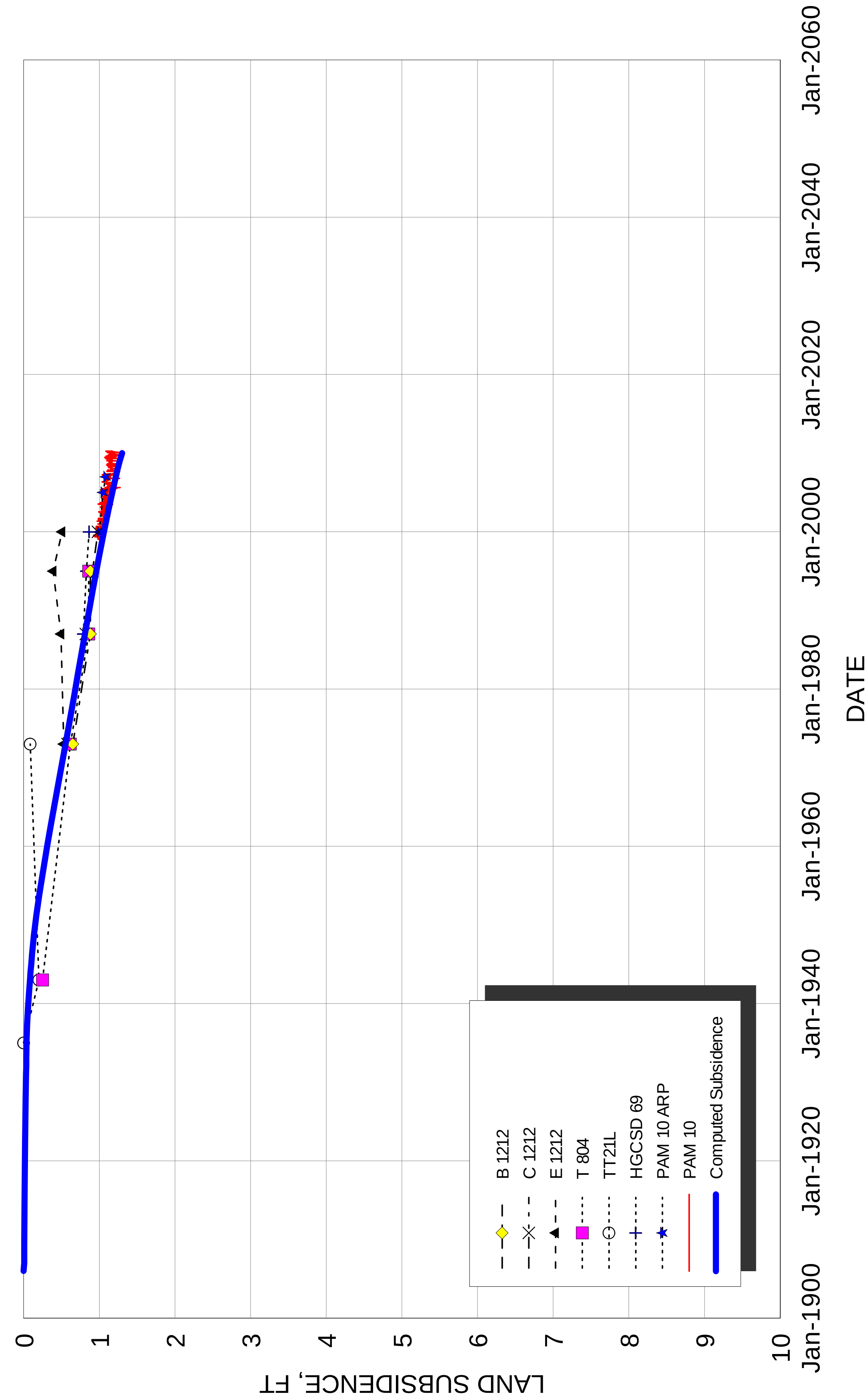
COMPUTED AND MEASURED SUBSIDENCE
NORTH HOUSTON SITE

PLATE C-22



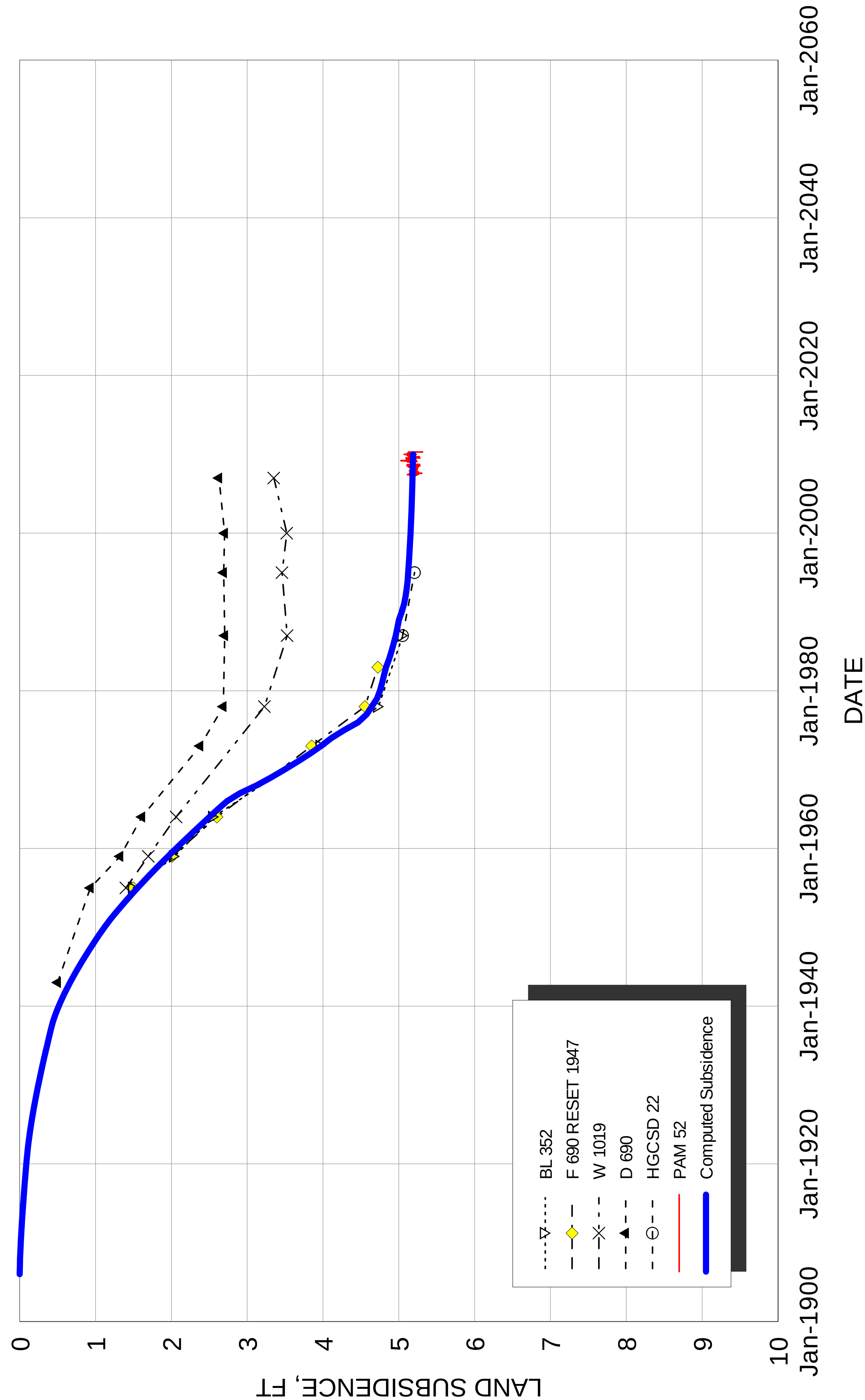
COMPUTED AND MEASURED SUBSIDENCE
PASADENA SITE

PLATE C-23



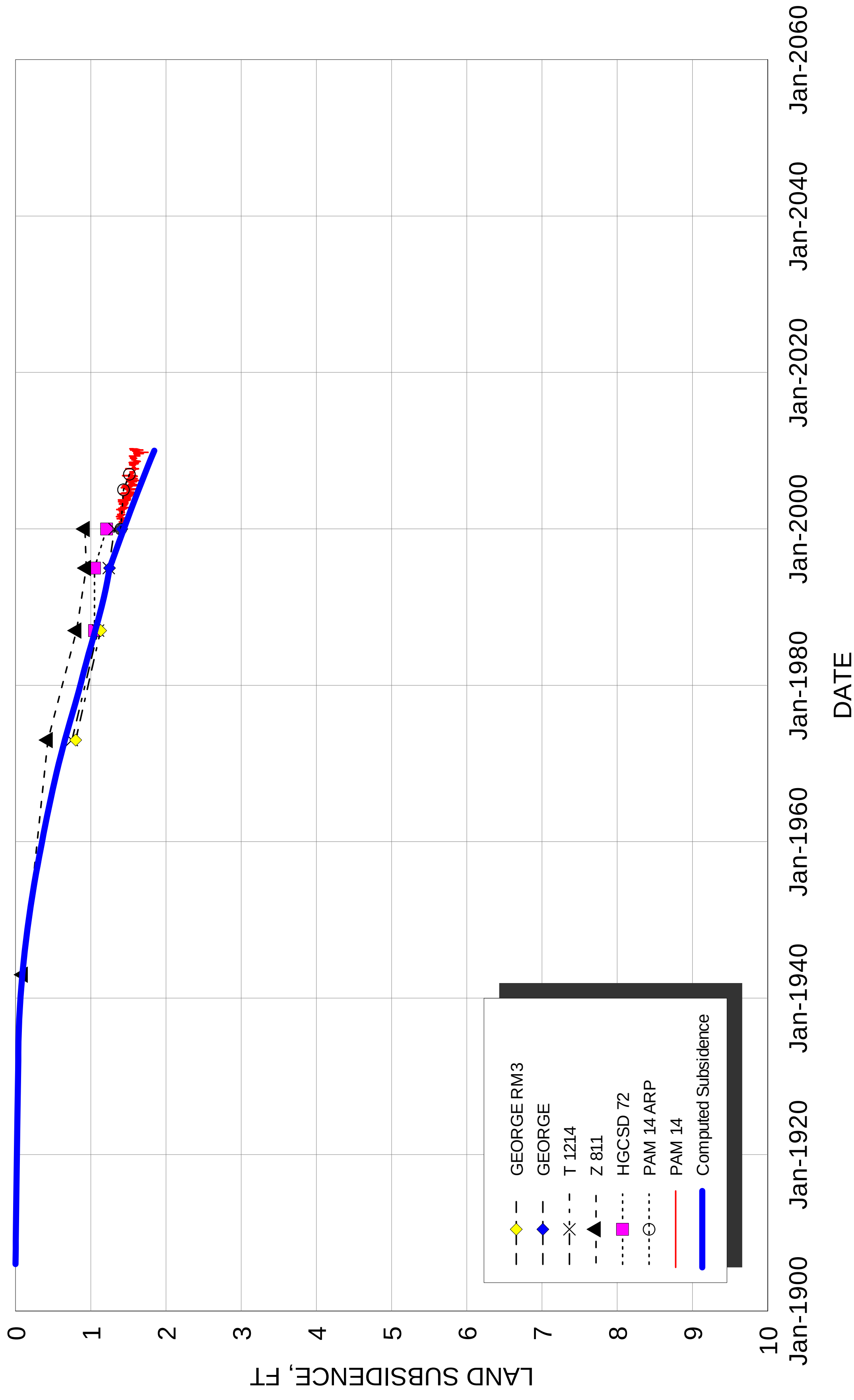
COMPUTED AND MEASURED SUBSIDENCE
RICHMOND-ROSENBERG SITE

PLATE C-24



COMPUTED AND MEASURED SUBSIDENCE
SHELDON SITE

PLATE C-25



COMPUTED AND MEASURED SUBSIDENCE
SMITHERS LAKE SITE

PLATE C-26

MEMORANDUM

FREESE AND NICHOLS

Innovative approaches
Practical results
Outstanding service

3100 Wilcrest Drive, Suite 200 • Houston, Texas 77042 • 713-600-6800 • fax 713-600-6801 www.freese.com

TO: Regional Groundwater Update Project Partners

CC:

FROM: William J. Thaman, P.E.

SUBJECT: Methodology for Developing Baseline Per Capita Daily Water Demand

DATE: December 22, 2011

Per capita daily water demands, usually referred to as "GPCD" (Gallons Per Capita Daily) are used to calculate total municipal water demand for municipalities (e.g. cities) and water utility districts (e.g. MUDs, WCIDs).

For the purposes of this project, GPCD is calculated as:

$$GPCD = \frac{Annual\ Municipal\ Water\ Demand\ \left(\frac{gallons}{year}\right)}{Population\ x\ (365\frac{days}{year})}$$

In this case GPCD represents the average amount of water used, per person, on a daily basis, throughout the year. Annual GPCDs can fluctuate to a large degree due to variable climatic conditions from year to year. Also, GPCDs can decline over time due to the implementation of water conservation practices.

"Baseline" GPCDs will be used in the Regional Groundwater Update Project (RGUP) to calculate water demand for the year 2010 (current conditions). Beyond 2010, GPCDs for currently developed areas will be adjusted on an annual basis due to the assumed effects of conservation, and GPCDs will be established for newly developing areas based on the assumed type of development (e.g. small lot master planned community, estate lot rural subdivision, multi-family etc.) and future conservation standards. The discussion herein is only concerned with the development of baseline GPCDs, i.e. the GPCDs used for current conditions.

Methodology: Climatic Assumptions

The baseline GPCDs are GPCDs that represent approximately "average" climatic conditions. For the RGUP, it was decided that the GPCDs should represent a period of time that included a mix of years that were, according to the Palmer Drought Index (PDI), wetter than normal, drier than normal, and approximately normal, and where data was available for the entire period.

The period selected is 2000-2008; this period averages out to be neither drought conditions nor moist conditions. The PDIs for this period, in the Houston area, are shown in Table 1.

Table 1. PDIs for Gage 414307 (Houston FAA Airport)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC_	AVG
2000	-3.59	-4.04	-4.58	-4.03	-3.43	-3.83	-4.16	-4.38	-4.15	-3.52	-0.74	-0.46	-3.41
2001	0.55	-0.79	1.35	-0.07	-0.68	2.17	1.73	3.17	3.75	3.76	3.83	4.44	1.93
2002	3.26	2.00	2.11	2.51	2.14	1.31	2.77	3.38	2.68	3.52	3.11	3.28	2.67
2003	2.30	1.87	0.85	-0.22	-1.99	-1.85	-1.14	-0.64	0.90	0.81	0.49	0.35	0.14
2004	0.47	1.11	-0.60	-0.54	0.31	0.78	0.68	0.76	-0.47	-0.91	1.13	0.11	0.24
2005	-0.84	-0.56	0.41	-0.75	-0.77	-1.45	1.57	0.83	-0.95	-1.44	-1.75	-2.17	-0.66
2006	-2.87	-3.18	-3.70	-3.93	-3.46	-2.03	0.06	0.00	-0.55	2.84	1.39	1.47	-1.16
2007	2.71	1.44	3.24	3.30	3.86	3.35	4.40	4.68	4.53	3.14	2.93	1.63	3.27
2008	3.07	2.86	2.51	1.39	-0.77	-0.62	-0.79	0.45	-0.67	-0.99	-0.86	-1.56	0.34
AVG	0.56	0.08	0.18	-0.26	-0.53	-0.24	0.57	0.92	0.56	0.80	1.06	0.79	0.37

The period contains, according to National Climatic Data Center (NCDC) classifications, one "severe drought" year (2000), one "very moist" year (2007), one "moderately moist" year (2002), and six years classified as having "mid-range" conditions. Overall, the average PDI is 0.37, which is well within the "mid-range" class (PDI between -1.99 and +1.99).

Methodology: Data

Data sources include:

- Individual water system engineers/managers;
- Regional Water Authority (RWA) engineers/managers;
- Texas Water Development Board (TWDB) Water Use Survey;
- Harris Galveston Subsidence District (HGSD), Fort Bend Subsidence District (FBSD), and Lone Star Groundwater Conservation District (LSGCD) reported pumpage.

The preferred source, when available, is always individual water systems and RWAs. Due to the large number of systems represented, and the inability to contact each system directly, data from these sources is scant. The data source used for the vast majority of systems is the TWDB Water Use Survey. Each municipality and water district in the State reports their surface water and groundwater intake, purchased water, sold water, and population to the TWDB on an annual basis. The TWDB data is preferred over data from HGSD/FBSD/ LSGCD because it includes all use, not just groundwater use, accounts for sold water, and reports annual population. Where TWDB data is not available, use data is supplemented by the subsidence districts and LSGCD, or the GPCD from a neighboring system is assumed.

Municipal use data typically contains commercial use and irrigation use for parks, medians, and landscaping. Ideally these uses would be broken out, but due to the difficulty and cost of doing this, most water system managers keep these uses as part of municipal use. One type of use that may or may not be included in reported municipal use, but that usually isn't, is water used for refilling amenity ponds. Typically refill water is supplied by wells that are operated by Homeowners and Property Owners Associations (HOAs and POAs). The pumpage data associated with this use is available from HGSD, FBSD, and LSGCD, but is not included in the GPCD calculations. Pond refilling will be treated as a separate type of groundwater use, much like industrial, agricultural, livestock, and mining use.

Results

Results are shown in Table 2. The systems are identified as to their Texas Commission on Environmental Quality (TCEQ) Public Water System (PWS) Name.

Table 2. Baseline GPCDs by County and Public Water System

COUNTY	PWS NAME	GPCD	METHOD
BRAZORIA	ANCHOR ROAD MOBILE HOME PARK	98	CITY OF ANGLETON
BRAZORIA	ANGLECREST SUBDIVISION	84	TWDB WATER USE SURVEY
BRAZORIA	BATEMAN WATER WORKS	159	TWDB WATER USE SURVEY
BRAZORIA	BAYOU SHADOWS WATER SYSTEM	37	TWDB WATER USE SURVEY
BRAZORIA	BEECHWOOD SUBDIVISION	108	TWDB WATER USE SURVEY
BRAZORIA	BERNARD ACRES	59	TWDB WATER USE SURVEY
BRAZORIA	BERNARD OAKS SUBDIVISION	69	TWDB WATER USE SURVEY
BRAZORIA	BERNARD RIVER OAKS	67	TWDB WATER USE SURVEY
BRAZORIA	BRAZORIA COUNTY FWSD 1 DAMON	99	TWDB WATER USE SURVEY
BRAZORIA	BRAZORIA COUNTY MUD 2	225	TWDB WATER USE SURVEY
BRAZORIA	BRAZORIA COUNTY MUD 21	79	TWDB WATER USE SURVEY
BRAZORIA	BRAZORIA COUNTY MUD 25	90	TWDB WATER USE SURVEY
BRAZORIA	BRAZORIA COUNTY MUD 29	74	TWDB WATER USE SURVEY
BRAZORIA	BRAZORIA COUNTY MUD 3	225	BRAZORIA COUNTY MUD 2
BRAZORIA	BRAZORIA COUNTY MUD 31	399	TWDB WATER USE SURVEY
BRAZORIA	BRAZORIA COUNTY MUD 4	134	TWDB WATER USE SURVEY
BRAZORIA	BRAZORIA COUNTY MUD 6	179	TWDB WATER USE SURVEY
BRAZORIA	BRAZOS RIVER CLUB	80	TWDB WATER USE SURVEY
BRAZORIA	BRIAR MEADOWS	100	HEIGHTS COUNTRY SUBD
BRAZORIA	BRYAN BEACH WSC	120	TWDB WATER USE SURVEY
BRAZORIA	CALICO FARMS SUBDIVISION	74	TWDB WATER USE SURVEY
BRAZORIA	CENTENNIAL PLACE	111	TWDB WATER USE SURVEY
BRAZORIA	CHOCTAW SUBDIVISION	86	TWDB WATER USE SURVEY
BRAZORIA	CITY OF ALVIN	104	TWDB WATER USE SURVEY
BRAZORIA	CITY OF ANGLETON	98	TWDB WATER USE SURVEY
BRAZORIA	CITY OF BRAZORIA	98	TWDB WATER USE SURVEY
BRAZORIA	CITY OF CLUTE	114	TWDB WATER USE SURVEY
BRAZORIA	CITY OF DANBURY	103	TWDB WATER USE SURVEY
BRAZORIA	CITY OF FREEPORT	109	TWDB WATER USE SURVEY
BRAZORIA	CITY OF FREEPORT SLAUGHTER ROAD	100	HEIGHTS COUNTRY SUBD
BRAZORIA	CITY OF HILLCREST VILLAGE	137	TWDB WATER USE SURVEY
BRAZORIA	CITY OF LAKE JACKSON	119	TWDB WATER USE SURVEY
BRAZORIA	CITY OF LIVERPOOL	57	TWDB WATER USE SURVEY
BRAZORIA	CITY OF MANVEL	239	TWDB WATER USE SURVEY
BRAZORIA	CITY OF OYSTER CREEK	111	TWDB WATER USE SURVEY
BRAZORIA	CITY OF PEARLAND	118	TWDB WATER USE SURVEY
BRAZORIA	CITY OF PEARLAND MUD 1	118	CITY OF PEARLAND

COUNTY	PWS NAME	GPCD	METHOD
BRAZORIA	CITY OF RICHWOOD	80	TWDB WATER USE SURVEY
BRAZORIA	CITY OF SWEENY	122	TWDB WATER USE SURVEY
BRAZORIA	CITY OF WEST COLUMBIA	115	TWDB WATER USE SURVEY
BRAZORIA	COLONY TRAILS SUBDIVISION	100	HEIGHTS COUNTRY SUBD
BRAZORIA	COMMODORE COVE IMPROVEMENT DISTRICT	100	TWDB WATER USE SURVEY
BRAZORIA	COUNTRY MEADOWS	73	TWDB WATER USE SURVEY
BRAZORIA	DEMI JOHN I S WATER SYSTEM	100	HEIGHTS COUNTRY SUBD
BRAZORIA	DEMI JOHN PLACE WATER SYSTEM	100	HEIGHTS COUNTRY SUBD
BRAZORIA	GRASSLANDS	74	TWDB WATER USE SURVEY
BRAZORIA	HASTINGS HOMEOWNERS WATER SYSTEM	130	TWDB WATER USE SURVEY
BRAZORIA	HEIGHTS COUNTRY SUBDIVISION	100	TWDB WATER USE SURVEY
BRAZORIA	HOLIDAY SHORES	95	TWDB WATER USE SURVEY
BRAZORIA	HOMELAND SUBDIVISION	68	TWDB WATER USE SURVEY
BRAZORIA	JONES CREEK TERRACE	77	TWDB WATER USE SURVEY
BRAZORIA	JONES CREEKWOOD	79	TWDB WATER USE SURVEY
BRAZORIA	KEY LARGO UTILITIES	129	TWDB WATER USE SURVEY
BRAZORIA	LAS PLAYAS	100	HEIGHTS COUNTRY SUBD
BRAZORIA	LEE RIDGE SUBDIVISION	100	HEIGHTS COUNTRY SUBD
BRAZORIA	LINCECUM WATER POWERS ADDITION	100	HEIGHTS COUNTRY SUBD
BRAZORIA	MALLARD LAKE CLUB	100	HEIGHTS COUNTRY SUBD
BRAZORIA	MARIA ELENA'S MOBILE HOMES	104	CITY OF ALVIN
BRAZORIA	MARK V ESTATES	69	TWDB WATER USE SURVEY
BRAZORIA	MARLIN MARINA WATER SYSTEM	100	HEIGHTS COUNTRY SUBD
BRAZORIA	MEADOWLAND SUBDIVISION	72	TWDB WATER USE SURVEY
BRAZORIA	MEADOWLARK SUBDIVISION	88	TWDB WATER USE SURVEY
BRAZORIA	MEADOWVIEW SUBDIVISION	75	TWDB WATER USE SURVEY
BRAZORIA	MOORELAND SUBDIVISION WATER SYSTEM	73	TWDB WATER USE SURVEY
BRAZORIA	OAK BEND ESTATES	84	TWDB WATER USE SURVEY
BRAZORIA	OAK CREST OF MANVEL	100	HEIGHTS COUNTRY SUBD
BRAZORIA	OAK MANOR MUD	110	TWDB WATER USE SURVEY
BRAZORIA	OYSTER CREEK ESTATES	100	HEIGHTS COUNTRY SUBD
BRAZORIA	PALM CREST	100	HEIGHTS COUNTRY SUBD
BRAZORIA	PALMETTO SUBDIVISION	92	TWDB WATER USE SURVEY
BRAZORIA	PALOMA ACRES SUBDIVISION	100	HEIGHTS COUNTRY SUBD
BRAZORIA	PLEASANT MEADOWS SUBDIVISION	97	TWDB WATER USE SURVEY
BRAZORIA	RIVER OAKS	75	TWDB WATER USE SURVEY
BRAZORIA	RIVER RUN WATER SYSTEM	96	SAN BERNARD RIVER ESTATES
BRAZORIA	RIVERSIDE ESTATES	100	HEIGHTS COUNTRY SUBD
BRAZORIA	ROBIN COVE WATER SUBDIVISION	91	TWDB WATER USE SURVEY
BRAZORIA	ROSHARON TOWNSHIP	100	HEIGHTS COUNTRY SUBD
BRAZORIA	ROYAL RIDGE	79	TWDB WATER USE SURVEY
BRAZORIA	RYAN LONG SUBDIVISION 2 WATER SYSTEM	88	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
BRAZORIA	SAN BERNARD RIVER ESTATES	96	TWDB WATER USE SURVEY
BRAZORIA	SAVANNAH PLANTATION SUBDIVISION	100	HEIGHTS COUNTRY SUBD
BRAZORIA	SHADY CREEK SECTION 3 WATER SYSTEM	100	HEIGHTS COUNTRY SUBD
BRAZORIA	SOUTH MEADOWS WEST	100	HEIGHTS COUNTRY SUBD
BRAZORIA	STERLING ESTATES	115	TWDB WATER USE SURVEY
BRAZORIA	STONERIDGE LAKE SUBDIVISION	100	HEIGHTS COUNTRY SUBD
BRAZORIA	SUNCREEK ESTATES SECTION 1	299	TWDB WATER USE SURVEY
BRAZORIA	SUNCREEK RANCH SECTION 2	72	TWDB WATER USE SURVEY
BRAZORIA	TOWN OF HOLIDAY LAKES	89	TWDB WATER USE SURVEY
BRAZORIA	TOWN OF QUINTANA	100	HEIGHTS COUNTRY SUBD
BRAZORIA	TREASURE ISLAND MUD	72	TWDB WATER USE SURVEY
BRAZORIA	TURTLE COVE LOT OWNERS ASSOC	165	TWDB WATER USE SURVEY
BRAZORIA	TWIN LAKES CLUB	100	HEIGHTS COUNTRY SUBD
BRAZORIA	VARNER CREEK UTILITY DISTRICT	133	TWDB WATER USE SURVEY
BRAZORIA	VILLAGE OF SURFSIDE BEACH	71	TWDB WATER USE SURVEY
BRAZORIA	VILLAGE TRACE WATER SYSTEM	82	TWDB WATER USE SURVEY
BRAZORIA	WAGON WHEEL ESTATES WATER SYSTEM	117	TWDB WATER USE SURVEY
BRAZORIA	WELLBORN ACRES	171	TWDB WATER USE SURVEY
BRAZORIA	WESTWOOD SUBDIVISION	87	TWDB WATER USE SURVEY
BRAZORIA	WEYBRIDGE SUBDIVISION WATER SYSTEM	96	TWDB WATER USE SURVEY
BRAZORIA	WILCO WATER CO	75	TWDB WATER USE SURVEY
BRAZORIA	WINDSONG SUBDIVISION	74	TWDB WATER USE SURVEY
BRAZORIA	WOLF GLEN WATER SYSTEM	100	HEIGHTS COUNTRY SUBD
BRAZORIA	WOLFE AIR PARK	100	HEIGHTS COUNTRY SUBD
BRAZORIA	WOOD OAKS WATER WORKS	100	HEIGHTS COUNTRY SUBD
FORT BEND	5TH STREET WATER SYSTEM	103	MEADOWCREEK MUD
FORT BEND	723 UTILITY	131	CITY OF RICHMOND
FORT BEND	BAY RIDGE CHRISTIAN COLLEGE AND APARTMEN	211	CITY OF KENDLETON
FORT BEND	BELLFORT PUD	109	FB COUNTYMUD 41
FORT BEND	BIG OAKS MUD	125	NFBWA
FORT BEND	BLUE RIDGE WEST MUD	123	TWDB WATER USE SURVEY
FORT BEND	BRAZOS LAKES WATER SUPPLY	103	TWDB WATER USE SURVEY
FORT BEND	BRIDLEWOOD ESTATES WATER SYSTEM	184	TWDB WATER USE SURVEY
FORT BEND	CINCO MUD 1	291	NFBWA
FORT BEND	CINCO MUD 10	205	NFBWA
FORT BEND	CINCO MUD 12	275	NFBWA
FORT BEND	CINCO MUD 14	174	NFBWA
FORT BEND	CINCO MUD 2	195	NFBWA
FORT BEND	CINCO MUD 3	137	NFBWA
FORT BEND	CINCO MUD 5	208	NFBWA
FORT BEND	CINCO MUD 6	161	NFBWA
FORT BEND	CINCO MUD 7	177	NFBWA

COUNTY	PWS NAME	GPCD	METHOD
FORT BEND	CINCO MUD 8	120	TWDB WATER USE SURVEY
FORT BEND	CINCO MUD 9	154	NFBWA
FORT BEND	CINCO SOUTHWEST MUD 1	246	NFBWA
FORT BEND	CINCO SOUTHWEST MUD 2	246	NFBWA
FORT BEND	CINCO SOUTHWEST MUD 3	246	NFBWA
FORT BEND	CINCO SOUTHWEST MUD 4	246	NFBWA
FORT BEND	CITY OF BEASLEY	113	TWDB WATER USE SURVEY
FORT BEND	CITY OF FULSHEAR	202	NFBWA
FORT BEND	CITY OF KENDLETON	211	TWDB WATER USE SURVEY
FORT BEND	CITY OF MEADOWS PLACE	141	TWDB WATER USE SURVEY
FORT BEND	CITY OF MISSOURI CITY MUSTANG BAYOU WATE	128	MISSOURI CITY JOINT GRP (2008)
FORT BEND	CITY OF NEEDVILLE	107	TWDB WATER USE SURVEY
FORT BEND	CITY OF ORCHARD	136	TWDB WATER USE SURVEY
FORT BEND	CITY OF RICHMOND	131	TWDB WATER USE SURVEY
FORT BEND	CITY OF ROSENBERG	108	TWDB WATER USE SURVEY
FORT BEND	CITY OF SUGAR LAND	185	TWDB WATER USE SURVEY
FORT BEND	CITY OF SUGAR LAND RIVER PARK	185	CITY OF SUGARLAND
FORT BEND	FIRST COLONY MUD 9	138	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY FWSD 1	62	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY FWSD 2	90	NFBWA
FORT BEND	FORT BEND COUNTY MUD 106	276	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 108	174	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 109	125	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 111	208	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 112	227	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 115 RIVERSTONE	238	MISSOURI CITY JOINT GRP (2008)
FORT BEND	FORT BEND COUNTY MUD 116 CANYON GATE	130	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 117	126	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 118	156	NFBWA
FORT BEND	FORT BEND COUNTY MUD 119	160	NFBWA
FORT BEND	FORT BEND COUNTY MUD 121	131	CITY OF RICHMOND
FORT BEND	FORT BEND COUNTY MUD 122	135	NFBWA
FORT BEND	FORT BEND COUNTY MUD 123	127	NFBWA
FORT BEND	FORT BEND COUNTY MUD 124	173	NFBWA
FORT BEND	FORT BEND COUNTY MUD 128	207	FBC MUD 129
FORT BEND	FORT BEND COUNTY MUD 129	207	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 130	304	NFBWA
FORT BEND	FORT BEND COUNTY MUD 131	158	SIENNA PLANTATION MUDS
FORT BEND	FORT BEND COUNTY MUD 132	167	FBC MUD 133
FORT BEND	FORT BEND COUNTY MUD 133	167	NFBWA
FORT BEND	FORT BEND COUNTY MUD 134A	324	NFBWA
FORT BEND	FORT BEND COUNTY MUD 134B	324	NFBWA

COUNTY	PWS NAME	GPCD	METHOD
FORT BEND	FORT BEND COUNTY MUD 134C	324	NFBWA
FORT BEND	FORT BEND COUNTY MUD 140 RIVERS EDGE	131	CITY OF RICHMOND
FORT BEND	FORT BEND COUNTY MUD 141	158	SIENNA PLANTATION MUDS
FORT BEND	FORT BEND COUNTY MUD 142	158	NFBWA
FORT BEND	FORT BEND COUNTY MUD 143 WATER VIEW ESTA	151	NFBWA
FORT BEND	FORT BEND COUNTY MUD 145 RIO VISTA	28	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 146	233	NFBWA
FORT BEND	FORT BEND COUNTY MUD 149	154	MISSOURI CITY JOINT GRP (2008)
FORT BEND	FORT BEND COUNTY MUD 151	203	NFBWA
FORT BEND	FORT BEND COUNTY MUD 152	129	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 155	107	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 158	125	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 162	89	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 165	156	NFBWA
FORT BEND	FORT BEND COUNTY MUD 182	203	FBC MUD 151
FORT BEND	FORT BEND COUNTY MUD 185	113	NFBWA
FORT BEND	FORT BEND COUNTY MUD 187	108	CITY OF ROSENBERG
FORT BEND	FORT BEND COUNTY MUD 188	203	FBC MUD 151
FORT BEND	FORT BEND COUNTY MUD 189	158	SIENNA PLANTATION MUDS
FORT BEND	FORT BEND COUNTY MUD 19	63	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 190	161	GRAND MISSION MUD 1
FORT BEND	FORT BEND COUNTY MUD 194	161	GRAND MISSION MUD 1
FORT BEND	FORT BEND COUNTY MUD 195	203	FBC MUD 151
FORT BEND	FORT BEND COUNTY MUD 198	203	FBC MUD 151
FORT BEND	FORT BEND COUNTY MUD 2	105	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 23	91	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 24	79	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 25	111	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 26 QUAIL GREEN WEST	95	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 30	102	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 34	232	NFBWA
FORT BEND	FORT BEND COUNTY MUD 35	223	NFBWA
FORT BEND	FORT BEND COUNTY MUD 37	253	NFBWA
FORT BEND	FORT BEND COUNTY MUD 41	109	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 42	147	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 46	209	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 47	122	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 48	103	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 49	138	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 5	108	CITY OF ROSENBERG
FORT BEND	FORT BEND COUNTY MUD 50	194	NFBWA
FORT BEND	FORT BEND COUNTY MUD 51	111	FB COUNTY MUD 25

COUNTY	PWS NAME	GPCD	METHOD
FORT BEND	FORT BEND COUNTY MUD 52	111	FB COUNTY MUD 25
FORT BEND	FORT BEND COUNTY MUD 53	253	FBC MUD 37
FORT BEND	FORT BEND COUNTY MUD 57	179	NFBWA
FORT BEND	FORT BEND COUNTY MUD 58	134	NFBWA
FORT BEND	FORT BEND COUNTY MUD 65	108	CITY OF ROSENBERG
FORT BEND	FORT BEND COUNTY MUD 66	94	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 67	181	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 68	133	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 69	199	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY MUD 81 WESTON LAKES	359	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY WCID 2	261	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY WCID 3	355	TWDB WATER USE SURVEY
FORT BEND	FORT BEND COUNTY WCID 8	355	FBC WCID 3
FORT BEND	FULBROOK SUBDIVISION WATER PLANT	202	CITY OF FULSHEAR
FORT BEND	GRAND LAKES MUD 1	200	NFBWA
FORT BEND	GRAND LAKES MUD 2	336	NFBWA
FORT BEND	GRAND LAKES MUD 4	181	NFBWA
FORT BEND	GRAND MISSION MUD 1	161	NFBWA
FORT BEND	GRAND MISSION MUD 2	281	NFBWA
FORT BEND	HARRIS FORT BEND COUNTIES MUD 5	195	NFBWA
FORT BEND	HARRIS-FORT BEND COUNTIES MUD 1	109	NFBWA
FORT BEND	KINGDOM HEIGHTS WATER SYSTEM	131	CITY OF RICHMOND
FORT BEND	KINGSBRIDGE MUD	117	NFBWA
FORT BEND	LAKES OF MISSION GROVE	233	FBC MUD 146
FORT BEND	MEADOWCREEK MUD	103	TWDB WATER USE SURVEY
FORT BEND	NIAGRA PUBLIC WATER SUPPLY	62	FBC FWSD 1
FORT BEND	NORTH MISSION GLEN MUD	87	TWDB WATER USE SURVEY
FORT BEND	PALMER PLANTATION MUD 1	245	TWDB WATER USE SURVEY
FORT BEND	PALMER PLANTATION MUD 2	198	TWDB WATER USE SURVEY
FORT BEND	PARK PLACE SOUTHWEST	108	CITY OF ROSENBERG
FORT BEND	PECAN GROVE MUD	173	TWDB WATER USE SURVEY
FORT BEND	PLANTATION MUD	118	TWDB WATER USE SURVEY
FORT BEND	QUAIL VALLEY UTILITY DISTRICT	122	TWDB WATER USE SURVEY
FORT BEND	RIVERWOOD FOREST	202	CITY OF FULSHEAR
FORT BEND	ROSEMEADOWS III	107	CITY OF NEEDVILLE
FORT BEND	ROYAL LAKES ESTATES	184	BRIDLEWOOD EST
FORT BEND	SHADOW GROVE ESTATES	131	CITY OF RICHMOND
FORT BEND	SIENNA PLANTATION MANAGEMENT DISTRICT	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION MUD 1	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION MUD 10	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION MUD 12	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION MUD 13	158	MISSOURI CITY JOINT GRP (2008)

COUNTY	PWS NAME	GPCD	METHOD
FORT BEND	SIENNA PLANTATION MUD 2	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION MUD 3	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION MUD 4	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION MUD 5	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION MUD 6	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION MUD 7	158	MISSOURI CITY JOINT GRP (2008)
FORT BEND	SIENNA PLANTATION THE WOODS	294	TWDB WATER USE SURVEY
FORT BEND	SOUTHWEST ENVIRONMENTAL RESOURCES	108	CITY OF ROSENBERG
FORT BEND	SUN RANCH WATER SYSTEM	103	BRAZOS LAKES WS
FORT BEND	TELEVIEW TERRACE SUBDIVISION	109	TWDB WATER USE SURVEY
FORT BEND	THUNDERBIRD UTILITY DISTRICT 1	170	TWDB WATER USE SURVEY
FORT BEND	THUNDERBIRD UTILITY DISTRICT SYSTEM 2	115	TWDB WATER USE SURVEY
FORT BEND	TURNER WATER SERVICE	62	FBC FWSD 1
GALVESTON	BACLIFF MUD	71	TWDB WATER USE SURVEY
GALVESTON	BAYVIEW MUD	63	TWDB WATER USE SURVEY
GALVESTON	BOLIVAR PENINSULA SUD	69	TWDB WATER USE SURVEY
GALVESTON	CITY OF FRIENDSWOOD	124	TWDB WATER USE SURVEY
GALVESTON	CITY OF GALVESTON	243	TWDB WATER USE SURVEY
GALVESTON	CITY OF HITCHCOCK	122	TWDB WATER USE SURVEY
GALVESTON	CITY OF JAMAICA BEACH	141	TWDB WATER USE SURVEY
GALVESTON	CITY OF LA MARQUE	126	TWDB WATER USE SURVEY
GALVESTON	CITY OF LEAGUE CITY	120	TWDB WATER USE SURVEY
GALVESTON	CITY OF TEXAS CITY	121	TWDB WATER USE SURVEY
GALVESTON	GALVESTON COUNTY FWSD 6 TIKI ISLAND	152	TWDB WATER USE SURVEY
GALVESTON	GALVESTON COUNTY MUD 12	94	TWDB WATER USE SURVEY
GALVESTON	GALVESTON COUNTY MUD 29	243	CITY OF GALVESTON
GALVESTON	GALVESTON COUNTY WCID 1	99	TWDB WATER USE SURVEY
GALVESTON	GALVESTON COUNTY WCID 12	170	TWDB WATER USE SURVEY
GALVESTON	GALVESTON COUNTY WCID 19	111	TWDB WATER USE SURVEY
GALVESTON	GALVESTON COUNTY WCID 8	99	TWDB WATER USE SURVEY
GALVESTON	HIGHLAND BAYOU ESTATES WSC	122	CITY OF HITCHCOCK
GALVESTON	K & B WATERWORKS	99	TWDB WATER USE SURVEY
GALVESTON	LONE PINE SUBDIVISION	121	CITY OF TEXAS CITY
GALVESTON	SAN LEON MUD	108	TWDB WATER USE SURVEY
GALVESTON	TIFFANY WATER CO	108	TWDB WATER USE SURVEY
HARRIS	ADDICKS UTILITY DISTRICT	106	TWDB WATER USE SURVEY
HARRIS	ALBURY MANOR UTILITY COMPANY	185	TWDB WATER USE SURVEY
HARRIS	ALDINE FOREST SUBDIVISION	153	TWDB WATER USE SURVEY
HARRIS	ALDINE MEADOWS	102	TWDB WATER USE SURVEY
HARRIS	ALDINE VILLAGE SUBDIVISION	183	TWDB WATER USE SURVEY
HARRIS	ALICE ACRES MOBILE HOME SUBDIVISION	80	TWDB WATER USE SURVEY
HARRIS	ALTON THEISS SUBDIVISION	80	POSTWOOD MUD

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	AMBERWOOD SUBDIVISION	98	TWDB WATER USE SURVEY
HARRIS	BAKER ROAD MUD	158	TWDB WATER USE SURVEY
HARRIS	BALABAN APARTMENTS 1	57	FOREST CREEK APTS
HARRIS	BALABAN APARTMENTS 2	57	FOREST CREEK APTS
HARRIS	BAMMEL FOREST UTILITY COMPANY	146	TWDB WATER USE SURVEY
HARRIS	BAMMEL OAKS ESTATES 1	57	TWDB WATER USE SURVEY
HARRIS	BAMMEL OAKS ESTATES 2	82	TWDB WATER USE SURVEY
HARRIS	BAMMEL UTILITY DISTRICT	161	TWDB WATER USE SURVEY
HARRIS	BARKER CYPRESS MUD	112	TWDB WATER USE SURVEY
HARRIS	BAYBROOK MUD 1	961	TWDB WATER USE SURVEY
HARRIS	BAYER WATER SYSTEM	275	HC MUD 249
HARRIS	BEAUMONT PLACE	64	TWDB WATER USE SURVEY
HARRIS	BEECHNUT MUD	299	TWDB WATER USE SURVEY
HARRIS	BENDER CREEK APARTMENTS	57	FOREST CREEK APTS
HARRIS	BERGVILLE ADDITION	72	TWDB WATER USE SURVEY
HARRIS	BERRY HILL ESTATES	85	TWDB WATER USE SURVEY
HARRIS	BILMA PUD	183	TWDB WATER USE SURVEY
HARRIS	BINFORD PLACE SUBDIVISION	108	TWDB WATER USE SURVEY
HARRIS	BISSONNET MUD	120	TWDB WATER USE SURVEY
HARRIS	BLUE BELL MANOR SUBDIVISION	220	TWDB WATER USE SURVEY
HARRIS	BOUDREAUX GARDENS	100	TWDB WATER USE SURVEY
HARRIS	BRIDGESTONE MUD	109	TWDB WATER USE SURVEY
HARRIS	BRITTMOORE UTILITY	261	TWDB WATER USE SURVEY
HARRIS	CANAL TERRACE SUBDIVISION	78	LAKE MUD
HARRIS	CANDLELIGHT HILLS SUBDIVISION	199	TWDB WATER USE SURVEY
HARRIS	CASTLEWOOD MUD	123	TWDB WATER USE SURVEY
HARRIS	CASTLEWOOD SUBDIVISION	74	TWDB WATER USE SURVEY
HARRIS	CEDAR BAYOU ESTATES	87	TWDB WATER USE SURVEY
HARRIS	CEDAR BAYOU PARK	124	TWDB WATER USE SURVEY
HARRIS	CHAMPION LAKES ESTATES WATER PLANT	114	EST FROM HGSD DATA
HARRIS	CHARTERWOOD MUD	143	TWDB WATER USE SURVEY
HARRIS	CHELFORD CITY MUD	116	TWDB WATER USE SURVEY
HARRIS	CHELFORD ONE MUD	144	TWDB WATER USE SURVEY
HARRIS	CHIMNEY HILL MUD	93	TWDB WATER USE SURVEY
HARRIS	CIMARRON MUD	132	TWDB WATER USE SURVEY
HARRIS	CITY OF BAYTOWN	137	TWDB WATER USE SURVEY
HARRIS	CITY OF BELLAIRE	186	TWDB WATER USE SURVEY
HARRIS	CITY OF BUNKER HILL VILLAGE	282	TWDB WATER USE SURVEY
HARRIS	CITY OF DEER PARK	130	TWDB WATER USE SURVEY
HARRIS	CITY OF GALENA PARK	81	TWDB WATER USE SURVEY
HARRIS	CITY OF HILSHIRE VILLAGE	193	TWDB WATER USE SURVEY
HARRIS	CITY OF HOUSTON	143	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	CITY OF HOUSTON BELLEAU WOODS	119	KINGWOOD
HARRIS	CITY OF HOUSTON DISTRICT 73	121	EST FROM HGSD DATA
HARRIS	CITY OF HOUSTON DISTRICT 82	121	EST FROM HGSD DATA
HARRIS	CITY OF HOUSTON HARRIS COUNTY MUD 159	143	CITY OF HOUSTON
HARRIS	CITY OF HOUSTON HUNTERWOOD	143	CITY OF HOUSTON
HARRIS	CITY OF HOUSTON SPANISH COVE SUBDIVISION	143	CITY OF HOUSTON
HARRIS	CITY OF HOUSTON UTILITY DISTRICT 5 KINGW	119	EST FROM HGSD DATA
HARRIS	CITY OF HOUSTON WILLOW CHASE	132	HC MUD 230
HARRIS	CITY OF HUMBLE	194	TWDB WATER USE SURVEY
HARRIS	CITY OF JACINTO CITY	95	TWDB WATER USE SURVEY
HARRIS	CITY OF JERSEY VILLAGE	151	TWDB WATER USE SURVEY
HARRIS	CITY OF KATY	166	TWDB WATER USE SURVEY
HARRIS	CITY OF LA PORTE	116	TWDB WATER USE SURVEY
HARRIS	CITY OF MORGANS POINT	239	TWDB WATER USE SURVEY
HARRIS	CITY OF NASSAU BAY	207	TWDB WATER USE SURVEY
HARRIS	CITY OF PASADENA	97	TWDB WATER USE SURVEY
HARRIS	CITY OF SEABROOK	161	TWDB WATER USE SURVEY
HARRIS	CITY OF SHOREACRES	110	TWDB WATER USE SURVEY
HARRIS	CITY OF SOUTH HOUSTON	106	TWDB WATER USE SURVEY
HARRIS	CITY OF SOUTHSIDE PLACE	197	TWDB WATER USE SURVEY
HARRIS	CITY OF SPRING VALLEY VILLAGE	178	TWDB WATER USE SURVEY
HARRIS	CITY OF TOMBALL	184	TWDB WATER USE SURVEY
HARRIS	CITY OF WEBSTER	159	TWDB WATER USE SURVEY
HARRIS	CITY OF WEST UNIVERSITY PLACE	163	TWDB WATER USE SURVEY
HARRIS	CLAY ROAD MUD	84	TWDB WATER USE SURVEY
HARRIS	CLEAR BROOK CITY MUD	85	TWDB WATER USE SURVEY
HARRIS	CLEAR LAKE CITY WATER AUTHORITY	198	TWDB WATER USE SURVEY
HARRIS	CNP UTILITY DISTRICT	87	TWDB WATER USE SURVEY
HARRIS	COE INDUSTRIAL PARK	131	TWDB WATER USE SURVEY
HARRIS	COLONIAL HILLS	128	TWDB WATER USE SURVEY
HARRIS	CORBELLO WATER SYSTEM	124	K LAKE TERRACE
HARRIS	CORNERSTONE MUD	156	NFBWA
HARRIS	COTTAGE GARDENS	185	ALBURY MANOR UTIL CO
HARRIS	COUNTRY CLUB GREEN	184	CITY OF TOMBALL
HARRIS	COUNTRY LIVING APARTMENTS	57	FOREST CREEK APTS
HARRIS	COUNTRY TERRACE SUBDIVISION	134	TWDB WATER USE SURVEY
HARRIS	CREEKSIDE ESTATES SOUTH	189	TWDB WATER USE SURVEY
HARRIS	CROSBY MUD	167	TWDB WATER USE SURVEY
HARRIS	CY CHAMP PUD	313	TWDB WATER USE SURVEY
HARRIS	CYPRESS BEND SUBDIVISION	97	TWDB WATER USE SURVEY
HARRIS	CYPRESS CREEK RANCH	201	HC MUD 389
HARRIS	CYPRESS CREEK UTILITY DISTRICT	196	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	CYPRESS CROSSING	92	TWDB WATER USE SURVEY
HARRIS	CYPRESS FIELDS SUBDIVISION	99	TWDB WATER USE SURVEY
HARRIS	CYPRESS FOREST PUD	247	TWDB WATER USE SURVEY
HARRIS	CYPRESS FOREST WATER SYSTEM	132	HC MUD 230
HARRIS	CYPRESS HILL MUD 1	114	TWDB WATER USE SURVEY
HARRIS	CYPRESS HILL SUBDIVISION	133	TWDB WATER USE SURVEY
HARRIS	CYPRESS KLEIN UTILITY DISTRICT WIMBLETON	250	TWDB WATER USE SURVEY
HARRIS	CYPRESS PASS ESTATES	150	TWDB WATER USE SURVEY
HARRIS	CYPRESS PLACE	152	TWDB WATER USE SURVEY
HARRIS	CYPRESSWOOD UTILITY DISTRICT	129	TWDB WATER USE SURVEY
HARRIS	DELYNN WATER SYSTEM	132	TWDB WATER USE SURVEY
HARRIS	DOGWOOD TREE WATER SYSTEM	72	TWDB WATER USE SURVEY
HARRIS	DORSET T PLACE	80	TWDB WATER USE SURVEY
HARRIS	DOWDELL PUD	94	TWDB WATER USE SURVEY
HARRIS	EL DORADO UTILITY DISTRICT	125	TWDB WATER USE SURVEY
HARRIS	EMERALD FOREST UTILITY DISTRICT	141	TWDB WATER USE SURVEY
HARRIS	EN CANTO REAL UTILITY DISTRICT	95	TWDB WATER USE SURVEY
HARRIS	ENCHANTED VALLEY ESTATES WSC	198	TWDB WATER USE SURVEY
HARRIS	ESTATES OF HOLLY LAKES	247	TWDB WATER USE SURVEY
HARRIS	ESTATES OF WILLOW CREEK	184	CITY OF TOMBALL
HARRIS	ESTATES WATER CORP	167	CROSBY MUD
HARRIS	FAIRWAY CROSSING	131	LUCE BAYOU PUD
HARRIS	FALLBROOK UTILITY DISTRICT	102	TWDB WATER USE SURVEY
HARRIS	FAULKEY GULLY MUD	190	TWDB WATER USE SURVEY
HARRIS	FOREST CREEK APARTMENTS	57	TWDB WATER USE SURVEY
HARRIS	FOREST HILLS MUD	101	TWDB WATER USE SURVEY
HARRIS	FOREST MANOR SUBDIVISION	116	TWDB WATER USE SURVEY
HARRIS	FOUNTAINHEAD MUD	164	TWDB WATER USE SURVEY
HARRIS	FOUNTAINVIEW SUBDIVISION	130	TWDB WATER USE SURVEY
HARRIS	FRY ROAD MUD	216	TWDB WATER USE SURVEY
HARRIS	GRANT ROAD ESTATES MOBILE HOME SUB	67	TWDB WATER USE SURVEY
HARRIS	GRANT ROAD PUD	168	TWDB WATER USE SURVEY
HARRIS	GRANTWOOD SUBDIVISION	197	TWDB WATER USE SURVEY
HARRIS	GREEN TRAILS MUD	280	TWDB WATER USE SURVEY
HARRIS	GREENGATE ACRES SUBDIVISION	128	TWDB WATER USE SURVEY
HARRIS	GREENLAND SQUARE SUBDIVISION WS	114	EST FROM HGSD DATA
HARRIS	GREENWOOD PLACE CIVIC CLUB	153	ALDINE FOREST
HARRIS	GREENWOOD UTILITY DISTRICT	113	TWDB WATER USE SURVEY
HARRIS	GREENWOOD VILLAGE	106	TWDB WATER USE SURVEY
HARRIS	H O E WSC	91	TWDB WATER USE SURVEY
HARRIS	H2O TECH INC WATER SYSTEM	165	POP WEIGHTED GPCD AVERAGES
HARRIS	HAMILTON ESTATES WATER SYSTEM	183	VILLAGE OF NEW KENTUCKY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	HARRIS COUNTY FWSD 1A	107	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY FWSD 1B	104	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY FWSD 27	82	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY FWSD 45	117	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY FWSD 47	85	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY FWSD 51	116	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY FWSD 52	252	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY FWSD 58	150	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY FWSD 6	181	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY FWSD 61	155	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY LEADERSHIP ACADEMY	165	POP WEIGHTED GPCD
HARRIS	HARRIS COUNTY MUD 1	128	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 102	159	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 104	131	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 105	87	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 106	115	HC MUD 152
HARRIS	HARRIS COUNTY MUD 109	112	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 11	109	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 118	114	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 119	103	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 120	157	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 122	82	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 127	117	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 130	334	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 132	232	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 136	178	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 144	90	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 147	96	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 148 KINGSLAKE	105	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 149	123	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 150	131	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 151	146	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 152	115	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 153	179	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 154	115	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 155	185	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 156	139	HC MUD 173
HARRIS	HARRIS COUNTY MUD 157	97	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 158	106	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 16	108	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 162	170	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 163	152	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	HARRIS COUNTY MUD 165	87	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 166	85	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 167	140	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 168	235	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 172	176	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 173	139	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 179	75	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 18 HEATHERWOOD HUNTERS	157	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 180	96	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 183	106	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 185	68	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 186	232	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 188	80	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 189	129	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 191	267	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 196	242	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 200 CRANBROOK	83	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 202	121	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 205	83	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 208	138	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 211	370	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 215	72	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 216	201	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 217	90	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 220	62	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 221	175	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 222	209	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 23	97	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 230	132	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 233	891	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 238	128	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 239	86	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 24	145	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 248	136	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 249	275	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 25 BROOK HOLLOW WEST S	1,020	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 250	133	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 255	216	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 257	232	HC MUD 186
HARRIS	HARRIS COUNTY MUD 26	89	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 261	149	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 264	185	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	HARRIS COUNTY MUD 275	129	CYPRESSWOOD UD
HARRIS	HARRIS COUNTY MUD 276	159	HC MUD 102
HARRIS	HARRIS COUNTY MUD 278	110	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 280	119	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 281	119	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 282	157	NW HARRIS COUNTY MUD 5
HARRIS	HARRIS COUNTY MUD 284	99	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 285	124	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 286	733	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 287	87	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 290	103	TRAIL OF THE LAKES MUD
HARRIS	HARRIS COUNTY MUD 304	172	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 316	179	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 322 FAIRFIELD VILLAGE	185	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 33	117	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 341	174	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 342	142	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 344	237	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 345	205	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 354	157	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 36	273	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 360	173	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 361	66	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 364	135	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 365	180	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 367	272	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 368	93	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 370	155	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 371	166	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 372	395	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 374 CYPRESS CREEK LAKE	166	HC MUD 371
HARRIS	HARRIS COUNTY MUD 374 CYPRESS CREEK LAKE	166	HC MUD 371
HARRIS	HARRIS COUNTY MUD 383	219	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 389	201	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 391	109	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 396	157	HC MUD 354
HARRIS	HARRIS COUNTY MUD 397	157	HC MUD 354
HARRIS	HARRIS COUNTY MUD 399	89	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 400 - WEST	162	EST FROM HGSD DATA
HARRIS	HARRIS COUNTY MUD 405	218	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 412	107	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 419	166	HC MUD 371

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	HARRIS COUNTY MUD 420	100	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 421	143	CITY OF HOUSTON
HARRIS	HARRIS COUNTY MUD 43	89	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 432	159	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 44	194	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 46	129	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 468	555	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 48	139	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 480	143	CITY OF HOUSTON
HARRIS	HARRIS COUNTY MUD 49	106	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 5	138	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 50	124	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 500	176	HC MUD 172
HARRIS	HARRIS COUNTY MUD 53	89	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 55 HERITAGE PARK	110	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 58	193	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 6 CARRIAGE LANE	117	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 61	286	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 62	286	HC MUD 61
HARRIS	HARRIS COUNTY MUD 64	134	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 65	144	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 69 BONAIRE MEISTERWOOD	122	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 70	134	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 71	138	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 8	277	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 81	129	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 82	92	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 86	190	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY MUD 96	80	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY UTILITY DISTRICT 14	102	NORTHWEST PARK MUD
HARRIS	HARRIS COUNTY UTILITY DISTRICT 15	96	HC MUD 180
HARRIS	HARRIS COUNTY UTILITY DISTRICT 16	95	EST FROM HGSD DATA
HARRIS	HARRIS COUNTY UTILITY DISTRICT 6	142	EST FROM HGSD DATA
HARRIS	HARRIS COUNTY WCID 1	117	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 109	278	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 110	227	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 113 ENCHANTED VILLAGE	138	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 114	182	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 116	352	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 119	115	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 132	244	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 133	104	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	HARRIS COUNTY WCID 136	107	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 156	159	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 21	130	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 36	55	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 50 EL LAGO	193	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 70	99	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 74	132	SUNBELT FWSD
HARRIS	HARRIS COUNTY WCID 84	202	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 89	73	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 91	174	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 92	127	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 96	199	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID 99	194	TWDB WATER USE SURVEY
HARRIS	HARRIS COUNTY WCID FONDREN ROAD	93	TWDB WATER USE SURVEY
HARRIS	HARRIS MONTGOMERY COUNTIES MUD 386	204	TWDB WATER USE SURVEY
HARRIS	HARRIS-FORT BEND COUNTIES MUD 3	112	TWDB WATER USE SURVEY
HARRIS	HEATHER GLEN SUBDIVISION	143	CITY OF HOUSTON
HARRIS	HEATHERGATE PUBLIC UTILITY	74	TWDB WATER USE SURVEY
HARRIS	HEATHERLOCH MUD	104	TWDB WATER USE SURVEY
HARRIS	HERON LAKES ESTATES	143	COH
HARRIS	HIDDEN VALLEY SUBDIVISION	143	HEATHER GLEN SUBD
HARRIS	HIGHLAND RIDGE SUBDIVISION	79	TWDB WATER USE SURVEY
HARRIS	HORSEPEN BAYOU MUD	127	TWDB WATER USE SURVEY
HARRIS	HOUSE CORRAL STREET WATER SYSTEM	105	TWDB WATER USE SURVEY
HARRIS	HUFFMAN HOLLOW APARTMENTS	57	FOREST CREEK APTS
HARRIS	HUNTERS GLEN MUD	94	TWDB WATER USE SURVEY
HARRIS	HUNTERS VILLAGE SUBDIVISION	137	CITY OF BAYTOWN
HARRIS	HYDIES CROSSING	108	OAKWOOD VILLAGE MH SUBD
HARRIS	IMPERIAL VALLEY MHC	115	HC MUD 154
HARRIS	INTERSTATE MUD	203	TWDB WATER USE SURVEY
HARRIS	INVERNESS FOREST IMPROVEMENT DISTRICT	129	EST FROM HGSD DATA
HARRIS	J & L TERRY LANE	124	CEDAR BAYOU PARK
HARRIS	JACKRABBIT ROAD PUD	142	TWDB WATER USE SURVEY
HARRIS	K ESTATES WATER SYSTEM	95	TWDB WATER USE SURVEY
HARRIS	K LAKE TERRACE	124	TWDB WATER USE SURVEY
HARRIS	KENWOOD SUBDIVISION WATER SYSTEM	117	TWDB WATER USE SURVEY
HARRIS	KICKAPOO FARMS SUBDIVISION	87	TWDB WATER USE SURVEY
HARRIS	KINGS MANOR MUD	202	TWDB WATER USE SURVEY
HARRIS	KINGSLAND ESTATES WSC	201	HC MUD 216
HARRIS	KIRKMONT MUD	91	TWDB WATER USE SURVEY
HARRIS	KITZWOOD SUBDIVISION	82	TWDB WATER USE SURVEY
HARRIS	KLEIN PUD	210	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	KLEINWOOD MUD	374	TWDB WATER USE SURVEY
HARRIS	LA CASITA HOMES II	137	TWDB WATER USE SURVEY
HARRIS	LAKE FOREST UTILITY DISTRICT	224	TWDB WATER USE SURVEY
HARRIS	LAKE MUD	78	TWDB WATER USE SURVEY
HARRIS	LAKES OF FAIRHAVEN	157	HC MUD 354
HARRIS	LAKES OF ROSEHILL WATER SYSTEM	99	CYPRESS FIELDS SUBD
HARRIS	LANGHAM CREEK UTILITY DISTRICT	107	TWDB WATER USE SURVEY
HARRIS	LIM APARTMENTS	57	FOREST CREEK APTS
HARRIS	LONGHORN TOWN UTILITY DISTRICT	198	TWDB WATER USE SURVEY
HARRIS	LOUETTA NORTH PUD	112	TWDB WATER USE SURVEY
HARRIS	LOUETTA ROAD UTILITY DISTRICT	204	TWDB WATER USE SURVEY
HARRIS	LUCE BAYOU PUD	131	TWDB WATER USE SURVEY
HARRIS	MADING LANE WATER SYSTEM	164	TWDB WATER USE SURVEY
HARRIS	MALCOMSON ROAD UTILITY DISTRICT	232	TWDB WATER USE SURVEY
HARRIS	MAREK ROAD WATER SYSTEM	220	BLUE BELL MANOR
HARRIS	MARKS GLEN SUBDIVISION	120	TWDB WATER USE SURVEY
HARRIS	MARY FRANCIS SUBDIVISION	103	TWDB WATER USE SURVEY
HARRIS	MASON CREEK UTILITY DISTRICT	185	TWDB WATER USE SURVEY
HARRIS	MAYDE CREEK MUD	168	TWDB WATER USE SURVEY
HARRIS	MCFARLAND VILLAGE APARTMENTS	57	FOREST CREEK APTS
HARRIS	MCGEE PLACE	124	CEDAR BAYOU PARK
HARRIS	MEADOWHILL REGIONAL MUD	113	TWDB WATER USE SURVEY
HARRIS	MEADOWLAKE ESTATES	85	PARKWAY UD
HARRIS	MEMORIAL HILLS UTILITY DISTRICT	229	TWDB WATER USE SURVEY
HARRIS	MEMORIAL MUD	110	TWDB WATER USE SURVEY
HARRIS	MEMORIAL VILLAGES WATER AUTHORITY	438	TWDB WATER USE SURVEY
HARRIS	MESQUITE MHP	86	TIMBERWILDE MH SUBD
HARRIS	MILLS ROAD MUD	108	TWDB WATER USE SURVEY
HARRIS	MISSION BEND MUD 1	141	TWDB WATER USE SURVEY
HARRIS	MISSION BEND MUD 2	156	TWDB WATER USE SURVEY
HARRIS	MOBILE HOME ESTATES	86	TIMBERWILDE MH SUBD
HARRIS	MORTON ROAD MUD	127	TWDB WATER USE SURVEY
HARRIS	MOUNT HOUSTON ROAD MUD	98	TWDB WATER USE SURVEY
HARRIS	NEWPORT MUD	49	TWDB WATER USE SURVEY
HARRIS	NITSCH & SON UTILITY	143	CITY OF HOUSTON
HARRIS	NORTH BELT FOREST SUBDIVISION WATER SYST	162	HC MUD 400 WEST
HARRIS	NORTH BELT UTILITY DISTRICT	139	TWDB WATER USE SURVEY
HARRIS	NORTH FOREST MUD	138	TWDB WATER USE SURVEY
HARRIS	NORTH GREEN MUD	94	TWDB WATER USE SURVEY
HARRIS	NORTH PARK PUD	82	TWDB WATER USE SURVEY
HARRIS	NORTH WOODS ESTATES	99	TWDB WATER USE SURVEY
HARRIS	NORTHAMPTON MUD	215	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	NORTHEAST HARRIS COUNTY MUD 1 EDGEWOOD VILLAGE	124	HC MUD 285
HARRIS	NORTHEAST HARRIS COUNTY MUD 1 SHELDON RIDGE	124	K LAKE TERRACE
HARRIS	NORTHGATE CROSSING MUD 1	151	TWDB WATER USE SURVEY
HARRIS	NORTHGATE CROSSING MUD 2	151	TWDB WATER USE SURVEY
HARRIS	NORTHLINE TERRACE SUBDIVISION	143	CITY OF HOUSTON
HARRIS	NORTHWEST FREEWAY MUD	83	EST FROM HGSD DATA
HARRIS	NORTHWEST HARRIS COUNTY MUD 10	144	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 12	92	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 15	110	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 16	113	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 19	162	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 20	114	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 21	255	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 22	107	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 23	95	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 24	106	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 28	115	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 29	287	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 30	199	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 32	158	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 36	350	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 5	157	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 6	125	TWDB WATER USE SURVEY
HARRIS	NORTHWEST HARRIS COUNTY MUD 9	296	TWDB WATER USE SURVEY
HARRIS	NORTHWEST PARK MUD	102	TWDB WATER USE SURVEY
HARRIS	NORTHWOOD MUD 1	180	TWDB WATER USE SURVEY
HARRIS	NOTTINGHAM COUNTRY MUD	182	TWDB WATER USE SURVEY
HARRIS	OAK MANOR	119	COH UD 5 KINGWOOD
HARRIS	OAKMONT PUD	125	TWDB WATER USE SURVEY
HARRIS	OAKS OF ROSEHILL THE	247	ESTATES OF HOLLY LAKES
HARRIS	OAKWOOD VILLAGE MOBILE HOME SUBDIVISION	108	TWDB WATER USE SURVEY
HARRIS	ORANGE GROVE WATER SUPPLY	132	SUNBELT FWSD
HARRIS	PARK FOREST WATER SYSTEM	135	HC MUD 364
HARRIS	PARKLAND ESTATES	126	TWDB WATER USE SURVEY
HARRIS	PARKWAY UTILITY DISTRICT	85	TWDB WATER USE SURVEY
HARRIS	PASADENA EL CARY ESTATES	198	CLEAR LAKE CITY WA
HARRIS	PINE OAK FOREST WATER	230	WESTADOR MUD
HARRIS	PINE TRAILS UTILITY	111	TWDB WATER USE SURVEY
HARRIS	PINE VILLAGE PUD	122	TWDB WATER USE SURVEY
HARRIS	PITCAIRN WSC	117	TWDB WATER USE SURVEY
HARRIS	PLAZA 290	183	VILLAGE OF NEW KENTUCKY
HARRIS	PONDEROSA FOREST UTILITY DISTRICT	126	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	POSTWOOD MUD	80	TWDB WATER USE SURVEY
HARRIS	POWDER MILL ESTATES	73	SPRING CREEK VALLEY EST
HARRIS	PRESTONWOOD FOREST UTILITY DISTRICT	285	TWDB WATER USE SURVEY
HARRIS	PROVENCE WATER SYSTEM	55	TWDB WATER USE SURVEY
HARRIS	QUAIL OAK SUBDIVISION	95	QUAILWOOD WS
HARRIS	QUAILWOOD WATER SYSTEM	95	TWDB WATER USE SURVEY
HARRIS	RALSTON ACRES WATER SUPPLY CORPORATION	143	CITY OF HOUSTON
HARRIS	RAMBLEWOOD UTILITY & WSC	150	TWDB WATER USE SURVEY
HARRIS	RANKIN ROAD WEST MUD	111	TWDB WATER USE SURVEY
HARRIS	RED OAK TERRACE	109	TWDB WATER USE SURVEY
HARRIS	REID ROAD MUD 1	162	TWDB WATER USE SURVEY
HARRIS	REID ROAD MUD 2	151	TWDB WATER USE SURVEY
HARRIS	REMINGTON MUD 1	100	TWDB WATER USE SURVEY
HARRIS	RENN ROAD MUD	94	TWDB WATER USE SURVEY
HARRIS	RESERVOIR ACRES SUBDIVISION	59	TWDB WATER USE SURVEY
HARRIS	RICEWOOD MUD	162	TWDB WATER USE SURVEY
HARRIS	RICHEY ROAD MUD	248	TWDB WATER USE SURVEY
HARRIS	ROLAN HEIGHTS SUBDIVISION	50	TWDB WATER USE SURVEY
HARRIS	ROLLING CREEK UTILITY DISTRICT	143	TWDB WATER USE SURVEY
HARRIS	ROLLING FORK PUD	124	TWDB WATER USE SURVEY
HARRIS	ROLLING OAKS	100	TWDB WATER USE SURVEY
HARRIS	ROYALWOOD MUD	124	TWDB WATER USE SURVEY
HARRIS	SAGEMEADOW UTILITY DISTRICT	90	TWDB WATER USE SURVEY
HARRIS	SAN JACINTO BEND ESTATES	117	HC WCID 1
HARRIS	SEQUOIA IMPROVEMENT DISTRICT	114	TWDB WATER USE SURVEY
HARRIS	SHASLA PUD	113	TWDB WATER USE SURVEY
HARRIS	SHELDON RIDGE	124	K LAKE TERRACE
HARRIS	SHELDON ROAD MUD	78	TWDB WATER USE SURVEY
HARRIS	SILVERWOODS SUBDIVISION	126	PONDEROSA FOREST UD
HARRIS	SOUTH TAYLOR LAKE VILLAGE WSC	99	TWDB WATER USE SURVEY
HARRIS	SOUTHWEST HARRIS COUNTY MUD 1	94	TWDB WATER USE SURVEY
HARRIS	SPANISH COVE PUD	225	TWDB WATER USE SURVEY
HARRIS	SPENCER ROAD PUD	182	TWDB WATER USE SURVEY
HARRIS	SPRING CREEK FOREST	101	TWDB WATER USE SURVEY
HARRIS	SPRING CREEK FOREST PUD	169	TWDB WATER USE SURVEY
HARRIS	SPRING CREEK TRAILS	92	TWDB WATER USE SURVEY
HARRIS	SPRING CREEK VALLEY ESTATES	73	TWDB WATER USE SURVEY
HARRIS	SPRING MEADOWS MUD	60	TWDB WATER USE SURVEY
HARRIS	SPRING WEST MUD	120	TWDB WATER USE SURVEY
HARRIS	SPRINGMONT SUBDIVISION	162	TWDB WATER USE SURVEY
HARRIS	STABLE GATES	157	NW HC MUD 5
HARRIS	STETNER ADDITION	120	SUNBELT FWSD

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	SUMMER LAKE RANCH	142	HC MUD 342
HARRIS	SUNBELT FWSD HIGH MEADOWS SUBDIVISON	132	TWDB WATER USE SURVEY
HARRIS	SUNBELT FWSD OAKGLEN SUBDIVISION	84	TWDB WATER USE SURVEY
HARRIS	SUNBELT FWSD OAKWILDE SUBDIVISION	120	TWDB WATER USE SURVEY
HARRIS	SWEA GARDENS ESTATES	81	TWDB WATER USE SURVEY
HARRIS	TALL PINES UTILITY	123	TWDB WATER USE SURVEY
HARRIS	TASFIELD	68	TWDB WATER USE SURVEY
HARRIS	TATTOR ROAD MUD	117	TWDB WATER USE SURVEY
HARRIS	TERRANOVA WEST MUD	174	TWDB WATER USE SURVEY
HARRIS	THE COMMONS WATER SUPPLY INC	121	COH DIST 82
HARRIS	TIMBER CREEK ESTATES	127	HC WCID 92
HARRIS	TIMBERLAKE IMPROVEMENT DISTRICT	155	HC FWSD 61
HARRIS	TIMBERLANE UTILITY DISTRICT	97	TWDB WATER USE SURVEY
HARRIS	TIMBERWILDE MH SUBDIVISION	86	TWDB WATER USE SURVEY
HARRIS	TOWER OAK BEND WSC	178	TWDB WATER USE SURVEY
HARRIS	TRAIL OF THE LAKES MUD	103	TWDB WATER USE SURVEY
HARRIS	TRAILWOOD SUBDIVISION	110	TWDB WATER USE SURVEY
HARRIS	TREICHEL WOODS ESTATES	89	TWDB WATER USE SURVEY
HARRIS	URBAN ACRES SUBDIVISION	100	TWDB WATER USE SURVEY
HARRIS	VILLA UTILITIES	42	TWDB WATER USE SURVEY
HARRIS	VILLAGE OF NEW KENTUCKY	183	TWDB WATER USE SURVEY
HARRIS	WALRAVEN SUBDIVISION	121	COH DIST 73
HARRIS	WAYNEWOOD PLACE CIVIC ASSOCIATION	210	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 1	300	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 10	121	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 11	143	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 14	113	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 15	243	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 17	168	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 2 CHASE	93	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 4	168	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 5	87	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 6	273	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 7	64	TWDB WATER USE SURVEY
HARRIS	WEST HARRIS COUNTY MUD 9	264	TWDB WATER USE SURVEY
HARRIS	WEST MEMORIAL MUD	160	TWDB WATER USE SURVEY
HARRIS	WEST MONTGOMERY UTILITY	114	TWDB WATER USE SURVEY
HARRIS	WEST PARK MUD	162	TWDB WATER USE SURVEY
HARRIS	WESTADOR MUD	230	TWDB WATER USE SURVEY
HARRIS	WESTERN HOMES SUBDIVISION	140	TWDB WATER USE SURVEY
HARRIS	WESTERN TRAILS SUBDIVISION	84	TWDB WATER USE SURVEY
HARRIS	WESTGATE SUBDIVISION	68	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
HARRIS	WESTLAKE MUD 1	102	TWDB WATER USE SURVEY
HARRIS	WESTON MUD	193	TWDB WATER USE SURVEY
HARRIS	WHITE OAK BEND MUD	179	TWDB WATER USE SURVEY
HARRIS	WINDFERN FOREST UTILITY DISTRICT	195	TWDB WATER USE SURVEY
HARRIS	WINDWOOD WATER SYSTEM	305	TWDB WATER USE SURVEY
HARRIS	WINTERHAVEN SUBDIVISION	232	MALCOMSON ROAD UD
HARRIS	WOODCREEK MUD	149	TWDB WATER USE SURVEY
HARRIS	WOODLAND OAKS SUBDIVISION	143	CITY OF HOUSTON
MONTGOMERY	1485 LIMITED CRYSTAL SPRINGS WATER CO	86	DEER GLEN WS
MONTGOMERY	AFTON PARK WATER SYSTEM	102	TWDB WATER USE SURVEY
MONTGOMERY	AIRPORT HEIGHTS	102	TWDB WATER USE SURVEY
MONTGOMERY	ALLENDALE WATER SYSTEM	69	BENNETT WOODS
MONTGOMERY	ALLENWOOD SUBDIVISION	135	TWDB WATER USE SURVEY
MONTGOMERY	ARROWHEAD LAKE & FRONTIER LAKE	91	TWDB WATER USE SURVEY
MONTGOMERY	AUTUMN ACRES WATER SYSTEM	62	TWDB WATER USE SURVEY
MONTGOMERY	BEAU VIEW UTILITIES	51	LSGCD DATABASE
MONTGOMERY	BENDERS LANDING WATER PLANT 1 & 2	185	TWDB WATER USE SURVEY
MONTGOMERY	BENNETT WOODS	69	TWDB WATER USE SURVEY
MONTGOMERY	BIG OAKS RANCHETT SUBDIVISION	97	DOBBIN-PLANTERSVILLE
MONTGOMERY	BRIDGEPOINT SUBDIVISION	188	POINT AQUARIUS MUD
MONTGOMERY	BRUSHY CREEK UTILITY	106	TWDB WATER USE SURVEY
MONTGOMERY	CANEY CREEK UTILITY	106	TWDB WATER USE SURVEY
MONTGOMERY	CAPE MALIBU WSC	127	TWDB WATER USE SURVEY
MONTGOMERY	CARRIAGE HILLS	154	TWDB WATER USE SURVEY
MONTGOMERY	CHAPARRAL PLACE WATER SYSTEM	152	TWDB WATER USE SURVEY
MONTGOMERY	CHATEAU WOODS MUD	92	TWDB WATER USE SURVEY
MONTGOMERY	CIMARRON COUNTRY	128	TWDB WATER USE SURVEY
MONTGOMERY	CITY OF CONROE	152	TWDB WATER USE SURVEY
MONTGOMERY	CITY OF CUT AND SHOOT	154	TWDB WATER USE SURVEY
MONTGOMERY	CITY OF MAGNOLIA	303	TWDB WATER USE SURVEY
MONTGOMERY	CITY OF MONTGOMERY	192	TWDB WATER USE SURVEY
MONTGOMERY	CITY OF OAK RIDGE NORTH	145	TWDB WATER USE SURVEY
MONTGOMERY	CITY OF PANORAMA VILLAGE	204	TWDB WATER USE SURVEY
MONTGOMERY	CITY OF SHENANDOAH	321	TWDB WATER USE SURVEY
MONTGOMERY	CITY OF SPLENDORA	101	LSGCD DATABASE
MONTGOMERY	CITY OF WILLIS	125	TWDB WATER USE SURVEY
MONTGOMERY	CITY OF WOOD BRANCH VILLAGE	117	TWDB WATER USE SURVEY
MONTGOMERY	CLEAR CREEK FOREST SECTION 12	84	LSGCD DATABASE
MONTGOMERY	CLEAR WATER COVE INC	107	LSGCD DATABASE
MONTGOMERY	CLOVER CREEK MUD	106	TWDB WATER USE SURVEY
MONTGOMERY	COE COUNTRY	97	TWDB WATER USE SURVEY
MONTGOMERY	CONROE BAY WATER SEWER SUPPLY	220	PARADISE COVE WS

COUNTY	PWS NAME	GPCD	METHOD
MONTGOMERY	CONROE RESORT	233	MC MUD 9
MONTGOMERY	CORINTHIAN POINT MUD 2	188	TWDB WATER USE SURVEY
MONTGOMERY	CREEKSIDE ACRES WATER SYSTEM	48	LSGCD DATABASE
MONTGOMERY	CREEKSIDE VILLAGE	94	TWDB WATER USE SURVEY
MONTGOMERY	CRIGHTON RIDGE SUBDIVISION	135	EAST PLANTATION UD
MONTGOMERY	CRIGHTON WOODS SUBDIVISION	135	EAST PLANTATION UD
MONTGOMERY	CROWN RANCH SUBDIVISION	97	DOBBIN-PLANTERSVILLE
MONTGOMERY	CRYSTAL FOREST SUBDIVISION	77	TWDB WATER USE SURVEY
MONTGOMERY	CRYSTAL SPRINGS SUBDIVISION	86	TWDB WATER USE SURVEY
MONTGOMERY	CRYSTAL SPRINGS WATER COMPANY CHASEWOOD	67	WOODHAVEN EST
MONTGOMERY	DECKER HILLS	72	TWDB WATER USE SURVEY
MONTGOMERY	DECKER OAKS	83	PINEHURST DECKER PRAIRIE WSC
MONTGOMERY	DECKER WOODS SUBDIVISION	86	TWDB WATER USE SURVEY
MONTGOMERY	DEER GLEN WATER SYSTEM	86	TWDB WATER USE SURVEY
MONTGOMERY	DEER RUN	88	LSGCD DATABASE
MONTGOMERY	DEERWOOD SUBDIVISION	84	TWDB WATER USE SURVEY
MONTGOMERY	DEL LAGO ESTATES UTILITY COMPANY	255	HARBORSIDE
MONTGOMERY	DIAMOND HEAD WSC	155	TWDB WATER USE SURVEY
MONTGOMERY	DOBBIN PLANTERSVILLE WSC 1	97	TWDB WATER USE SURVEY
MONTGOMERY	DOGWOOD HILLS	101	TWDB WATER USE SURVEY
MONTGOMERY	DOMESTIC WATER COMPANY ROYAL FOREST SUBD	70	LSGCD DATABASE
MONTGOMERY	EAST MONTGOMERY COUNTY MUD 1	82	TWDB WATER USE SURVEY
MONTGOMERY	EAST PLANTATION UTILITY DISTRICT	134	LSGCD DATABASE
MONTGOMERY	ENCHANTED COVE WATER SYSTEM	82	LSGCD DATABASE
MONTGOMERY	ENCHANTED FOREST	124	TWDB WATER USE SURVEY
MONTGOMERY	ESTATES OF LEGENDS RANCH	103	RAYFORD ROAD MUD
MONTGOMERY	EVERETT SQUARE WINDCREST ESTATES	96	WESTWOOD NORTH
MONTGOMERY	FAR HILLS UTILITY DISTRICT	205	TWDB WATER USE SURVEY
MONTGOMERY	FLAMINGO LAKES LOT OWNERS ASSOCIATION IN	79	TWDB WATER USE SURVEY
MONTGOMERY	FOREST WOODS SUBDIVISION	97	DOBBIN-PLANTERSVILLE
MONTGOMERY	GRAND HARBOR WATER SYSTEM	281	MC MUD 18
MONTGOMERY	GRAND OAKS MUD	303	CITY OF MAGNOLIA
MONTGOMERY	GREENFIELD FOREST	96	WESTWOOD NORTH WSC
MONTGOMERY	HARBORSIDE	255	LSGCD DATABASE
MONTGOMERY	HARRIS MONTGOMERY COUNTIES MUD 386 MAY VALLEY	204	TWDB WATER USE SURVEY
MONTGOMERY	HAVENSHIRE WATER SYSTEM	129	LSGCD DATABASE
MONTGOMERY	HAZY HOLLOW EAST ESTATES	66	TWDB WATER USE SURVEY
MONTGOMERY	HERITAGE OAKS SUBDIVISION	57	TWDB WATER USE SURVEY
MONTGOMERY	HIDDEN FOREST ESTATES	70	TWDB WATER USE SURVEY
MONTGOMERY	HIDDEN SPRINGS RANCH SUBDIVISION	91	ARROWHEAD LAKE
MONTGOMERY	HIGH MEADOWS RANCH WATER SUPPLY	135	INDIGO LAKES WS
MONTGOMERY	HIGHLINE OAKS WATER UTILITY	84	DEERWOOD SUBD

COUNTY	PWS NAME	GPCD	METHOD
MONTGOMERY	HILLGREEN SUBDIVISION WATER CO	154	CUT AND SHOOT
MONTGOMERY	HULON LAKES SUBDIVISION	88	TWDB WATER USE SURVEY
MONTGOMERY	INDIGO LAKES WATER SYSTEM	135	TWDB WATER USE SURVEY
MONTGOMERY	INDIGO RANCH	160	LSGCD DATABASE
MONTGOMERY	JOY VILLAGE	117	TWDB WATER USE SURVEY
MONTGOMERY	KEENAN WSC	97	DOBBIN-PLANTERSVILLE
MONTGOMERY	KIPLING OAKS 1	76	LSGCD DATABASE
MONTGOMERY	KIPLING OAKS AND TIMBERGREEN	76	KIPLING OAKS 1
MONTGOMERY	LAIRD ESTATES	117	WOOD BRANCH VILLAGE
MONTGOMERY	LAKE BONANZA WSC	85	TWDB WATER USE SURVEY
MONTGOMERY	LAKE CONROE FOREST SUBDIVISION	85	LAKE BONANZA WSC
MONTGOMERY	LAKE CONROE HILLS MUD	139	TWDB WATER USE SURVEY
MONTGOMERY	LAKE CONROE VILLAGE	57	TWDB WATER USE SURVEY
MONTGOMERY	LAKE CONROE WEST	101	TWDB WATER USE SURVEY
MONTGOMERY	LAKE CREEK FALLS	82	LSGCD DATABASE
MONTGOMERY	LAKE CREEK FOREST	110	TWDB WATER USE SURVEY
MONTGOMERY	LAKE FOREST FALLS SUBDIVISION	93	TWDB WATER USE SURVEY
MONTGOMERY	LAKE FOREST LODGE SUBDIVISION	129	TWDB WATER USE SURVEY
MONTGOMERY	LAKE LORRAINE WS	173	LSGCD DATABASE
MONTGOMERY	LAKE LOUISE SUBDIVISION	78	TWDB WATER USE SURVEY
MONTGOMERY	LAKE SOUTH WSC	85	LAKE BONANZA WSC
MONTGOMERY	LAKE WINDCREST WATER SYSTEM	159	TWDB WATER USE SURVEY
MONTGOMERY	LAKELAND WATER SYSTEM	146	TWDB WATER USE SURVEY
MONTGOMERY	LAKEVIEW POINTE APARTMENTS	85	LAKE BONANZA WSC
MONTGOMERY	LAKEWOOD COLONY	86	TWDB WATER USE SURVEY
MONTGOMERY	LAKEWOOD ON LAKE CONROE	188	POINT AQUARIUS MUD
MONTGOMERY	LAZY RIVER IMPROVEMENT DISTRICT	152	TWDB WATER USE SURVEY
MONTGOMERY	LIVE OAK ESTATES	109	TWDB WATER USE SURVEY
MONTGOMERY	LOCH NESS COVE SUBDIVISION WATER SYSTEM	103	TWDB WATER USE SURVEY
MONTGOMERY	LONE STAR PUBLIC WATER SYSTEM	66	TWDB WATER USE SURVEY
MONTGOMERY	MEACHEN MEADOWS SUBDIVISION WATER SYSTEM	87	TWDB WATER USE SURVEY
MONTGOMERY	MILLERS CROSSING	134	LSGCD DATABASE
MONTGOMERY	MINK BRANCH VALLEY	78	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY FWSD 6	100	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 112	305	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 115	140	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 15	149	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 16 WHITE OAK PLANT	139	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 18	281	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 19	128	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 24 COUNTRY COLONY	111	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 36	209	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
MONTGOMERY	MONTGOMERY COUNTY MUD 39	134	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 40	179	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 42	143	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 46	270	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 47	143	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 56	159	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 6	146	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 60	213	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 67	200	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 7	127	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 8	228	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 83	273	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 84	130	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 89	103	RAYFORD RD MUD
MONTGOMERY	MONTGOMERY COUNTY MUD 9	233	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 94	123	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 98	114	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY MUD 99	152	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY UD 2	193	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY UD 3	164	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY UD 4	224	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY COUNTY WCID 1	105	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY PLACE WATER SYSTEM	87	TWDB WATER USE SURVEY
MONTGOMERY	MONTGOMERY TRACE WATER SYSTEM	129	LAKE FOREST LODGE SUBD
MONTGOMERY	MOSTYN MANOR	152	TWDB WATER USE SURVEY
MONTGOMERY	MOUNT PLEASANT VILLAGE WATER SYSTEM	152	TWDB WATER USE SURVEY
MONTGOMERY	MOUNTAIN MAN	75	RODGERS ROAD
MONTGOMERY	NEW CANEY MUD	97	TWDB WATER USE SURVEY
MONTGOMERY	NORTHCREST RANCH WATER SYSTEM	81	TWDB WATER USE SURVEY
MONTGOMERY	NORTHWOOD WSC	101	CITY OF SPLENDORA
MONTGOMERY	OAK TREE SUBDIVISION	100	WOODRIDGE EST WS
MONTGOMERY	OLD MILL LAKE	305	LSGCD DATABASE
MONTGOMERY	OLD TAMINA WSC	81	TWDB WATER USE SURVEY
MONTGOMERY	PARADISE COVE WATER SYSTEM	220	LSGCD DATABASE
MONTGOMERY	PATTON LAKE CLUB	117	TWDB WATER USE SURVEY
MONTGOMERY	PATTON VILLAGE EAST WATER SYSTEM	75	LSGCD DATABASE
MONTGOMERY	PATTON VILLAGE WEST WATER SYSTEM	78	LSGCD DATABASE
MONTGOMERY	PEACH CREEK COLONY	117	WOOD BRANCH VILLAGE
MONTGOMERY	PEACH CREEK DAM & LAKE CLUB	69	TWDB WATER USE SURVEY
MONTGOMERY	PEACH CREEK OAKS SUBDIVISION	81	TWDB WATER USE SURVEY
MONTGOMERY	PINE LAKE SUBDIVISION NORTH WSC	173	LAKE LORRAINE WS
MONTGOMERY	PINEHURST DECKER PRAIRIE WSC	83	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
MONTGOMERY	PINEY POINT SUBDIVISION	83	TWDB WATER USE SURVEY
MONTGOMERY	PIONEER TRAILS SUBDIVISION	85	TWDB WATER USE SURVEY
MONTGOMERY	PLEASANT FOREST SUBDIVISION	81	TWDB WATER USE SURVEY
MONTGOMERY	POINT AQUARIUS MUD	188	TWDB WATER USE SURVEY
MONTGOMERY	PORTER SUD	117	TWDB WATER USE SURVEY
MONTGOMERY	PORTER TERRACE	83	TWDB WATER USE SURVEY
MONTGOMERY	RANCH CREST SUBDIVISION	161	WOODLAND LAKE EST
MONTGOMERY	RAYFORD ROAD MUD	103	TWDB WATER USE SURVEY
MONTGOMERY	RED OAK RANCH WATER SYSTEM	153	TWDB WATER USE SURVEY
MONTGOMERY	RIMWICK FOREST	107	TWDB WATER USE SURVEY
MONTGOMERY	RIVER CLUB WATER CO	273	MC MUD 83
MONTGOMERY	RIVER PLANTATION MUD	165	TWDB WATER USE SURVEY
MONTGOMERY	RIVERWALK SUBDIVISION	117	PORTER SUD
MONTGOMERY	ROGERS ROAD WATER SYSTEM	75	TWDB WATER USE SURVEY
MONTGOMERY	ROLLING FOREST SUBDIVISION	97	DOBBIN-PLANTERSVILLE
MONTGOMERY	ROLLING HILLS OAKS SUBDIVISION	126	TWDB WATER USE SURVEY
MONTGOMERY	ROMAN FOREST CONSOLIDATED MUD	120	TWDB WATER USE SURVEY
MONTGOMERY	ROMAN FOREST PUD 3	121	TWDB WATER USE SURVEY
MONTGOMERY	ROMAN FOREST PUD 4	223	TWDB WATER USE SURVEY
MONTGOMERY	RUSTIC OAKS SUBDIVISION	165	TWDB WATER USE SURVEY
MONTGOMERY	SADDLE & SURREY ACRES WSC	194	TWDB WATER USE SURVEY
MONTGOMERY	SAN JO UTILITIES	96	LSGCD DATABASE
MONTGOMERY	SENDERA LAKE ESTATES	165	TWDB WATER USE SURVEY
MONTGOMERY	SENDERA RANCH	138	TWDB WATER USE SURVEY
MONTGOMERY	SHADY ACRES	66	TWDB WATER USE SURVEY
MONTGOMERY	SHADY BROOK ACRES	70	TWDB WATER USE SURVEY
MONTGOMERY	SHADY OAKS ESTATES	97	DOBBIN-PLANTERSVILLE
MONTGOMERY	SONOMA RIDGE-MCCALL SOUND	91	WALNUT SPRINGS
MONTGOMERY	SOUTHERN MONTGOMERY COUNTY MUD	291	TWDB WATER USE SURVEY
MONTGOMERY	SPRING CREEK UTILITY DISTRICT	57	LSGCD DATABASE
MONTGOMERY	SPRING FOREST SUBDIVISION	58	TWDB WATER USE SURVEY
MONTGOMERY	STANLEY LAKE MUD	155	TWDB WATER USE SURVEY
MONTGOMERY	STILLWATER ESTATES	97	DOBBIN-PLANTERSVILLE
MONTGOMERY	STONECREST RANCH	161	TWDB WATER USE SURVEY
MONTGOMERY	STONEHEDGE ESTATES	154	CUT AND SHOOT
MONTGOMERY	SUNRISE RANCH	73	LSGCD DATABASE
MONTGOMERY	TEXABA SUBDIVISION	88	DEER RUN
MONTGOMERY	TEXAS LANDING UTILITIES GOODE CITY	70	LSGCD DATABASE
MONTGOMERY	TEXAS NATIONAL MUD	694	TWDB WATER USE SURVEY
MONTGOMERY	THE OAKS	424	TWDB WATER USE SURVEY
MONTGOMERY	THE WOODLANDS METRO CENTER MUD	321	CITY OF SHENANDOAH
MONTGOMERY	THE WOODLANDS MUD 2	297	TWDB WATER USE SURVEY

COUNTY	PWS NAME	GPCD	METHOD
MONTGOMERY	THOUSAND OAKS	204	LSGCD DATABASE
MONTGOMERY	TIMBER LINE ESTATES	90	LSGCD DATABASE
MONTGOMERY	TIMBER OAKS CROSSING	67	WOODHAVEN EST
MONTGOMERY	TIMBERLAND ESTATES	60	TWDB WATER USE SURVEY
MONTGOMERY	TIMBERLOCH ESTATES	78	LSGCD DATABASE
MONTGOMERY	TOWERING OAKS AND ROSEWOOD HILLS SUBDIVI	91	WALNUT SPRINGS
MONTGOMERY	TOWN OF WOODLOCH	108	TWDB WATER USE SURVEY
MONTGOMERY	VALLEY RANCH MUD 1	117	PORTER SUD
MONTGOMERY	VISTA VERDE WATER SYSTEMS	173	LAKE LORRAINE WS
MONTGOMERY	WALNUT SPRINGS	91	TWDB WATER USE SURVEY
MONTGOMERY	WASHINGTON COUNTY RAILROAD	72	LSGCD DATABASE
MONTGOMERY	WESTWOOD I & II	72	TWDB WATER USE SURVEY
MONTGOMERY	WESTWOOD NORTH WSC	96	TWDB WATER USE SURVEY
MONTGOMERY	WHISPERING PINES	78	LSGCD DATABASE
MONTGOMERY	WHITE OAK ESTATES WSC	92	CHATEAU WOODS
MONTGOMERY	WHITE OAK HILLS	71	TWDB WATER USE SURVEY
MONTGOMERY	WHITE OAK RANCH SECTION ONE	152	CITY OF CONROE
MONTGOMERY	WHITE OAK VALLEY ESTATES	63	TWDB WATER USE SURVEY
MONTGOMERY	WINCHESTER PLACE	68	TWDB WATER USE SURVEY
MONTGOMERY	WOODHAVEN ESTATES	66	LSGCD DATABASE
MONTGOMERY	WOODLAND LAKES ESTATES WSC	161	TWDB WATER USE SURVEY
MONTGOMERY	WOODLAND OAKS SUBDIVISION	72	WESTWOOD I & II
MONTGOMERY	WOODLAND RANCH	92	LSGCD DATABASE
MONTGOMERY	WOODRIDGE ESTATES WATER SYSTEM	100	TWDB WATER USE SURVEY
MONTGOMERY	YESTERDAYS CROSSING	132	LSGCD DATABASE

TO: Regional Groundwater Update Project Partners

CC:

FROM: William J. Thaman, P.E.

SUBJECT: Methodology for Developing 2010 Population and Water Demand

DATE: December 22, 2011

This memo describes the development of, and documents the results for, the 2010 population and water demand for the five principal counties in the Regional Groundwater Update Project (RGUP). The five principal counties are Brazoria, Fort Bend, Galveston, Harris, and Montgomery Counties.

The 2010 U.S. Census populations were distributed to all municipalities (cities, towns, villages, etc.) and water districts (MUDs, UDs, WCIDs, etc.) where a water system boundary was available. The water system boundaries were assembled from the following sources:

- Regional stakeholders;
- Texas Water Development Board Texas Water System Map (TWSM);
- Houston-Galveston Area Council (H-GAC)

The preponderance of system boundaries came from the TWSM; the TWSM was published by TWDB in May, 2011 entitled "*Texas Water System Map: The Compilation of a Statewide Geodataset and Digital Maps of Water Service Area Boundaries*". The resultant GIS geodataset represents a compilation of Certificate of Convenience and Necessity (CCN) facility boundaries, CCN facility lines, and water district boundaries into a comprehensive set of water system boundaries (polygons) for the entire State of Texas. This dataset represents the most complete single collection of water system boundaries for the Houston region.

The water system populations were developed by distributing the 2010 U.S. Census Block populations. The smallest geographical area that the Census reports population is Census Block. Census Blocks make up Block Groups; Block Groups make up Census Tracts; and Census Tracts make up Counties. Census Blocks vary in size; generally, the higher the population density, the smaller the block.

Other datasets used to develop water system populations are the H-GAC parcel-based land use GIS datasets, by county. Each land parcel is tagged with a land use code; e.g. Single-Family Residential, Multi-Family Residential, Commercial, Farm, Vacant, etc. These datasets were used to guide the distribution of population to the water systems.

Water demands were developed by multiplying the water system populations by each system's per capita demand. Each system's demand is met by either groundwater, surface water, or a combination of each. The objective is to define each system's groundwater demand in 2010, and assign that demand to one or more wells. In a later work order, these groundwater demands will be assigned to groundwater model grid cells.

Population Methodology

Population for each water system boundary was determined by intersecting the three geographic datasets mentioned above: water system boundaries, census blocks, and land parcels. Each water system boundary is intersected by one or more census blocks, and each census block is intersected by one or more land parcels. The distribution of population within each census block is determined by the locations of intersecting land parcels, and the population within each water system is determined by the combined intersection of census blocks and land parcels.

The intersections were made on a county by county basis by using ArcGIS 9.3 software. After the intersections were made, the populations were determined by a series of data queries performed in Microsoft Access. The GIS datasets, Access databases, and data queries used to develop the water system populations have been or will be delivered to the RGUP project partners electronically.

Water Demand Methodology

The 2010 water demands were developed by multiplying each water system's population by their per-capita daily water demand (GPCD). The development of GPCDs is discussed in a separate document. The resultant water demands represent the total demand on each water system. These demands may be met by groundwater supplies, surface water supplies, or both. There may be other demands within the boundary of each system that are not captured by the product of water system population and GPCD; e.g. industrial demands, agricultural demands, Homeowner Association irrigation demands, private well demands, or any other demand that is not supplied by the individual water system. These non-system demands will be accounted for in assigning groundwater withdrawal to the Houston Area Groundwater Model (HAGM), but are not part of this discussion.

Each water system is identified by the Texas Commission on Environmental Quality (TCEQ) as a Public Water System (PWS); as such, each has a PWS Name, and a PWS ID. Each PWS has one or more supply sources; each supply source may be a groundwater well, a surface water intake point, or a purchased source from another PWS. Each PWS has one or more of these supply source types that make up its overall supply. For example the City of Pearland gets part of its supply from the City of Houston (purchased surface water supply), and the rest of its supply from groundwater wells that it owns (groundwater well supply).

To determine the levels of groundwater withdrawal, there is an accounting of how groundwater is used within and among each PWS. For example, a PWS may have groundwater wells, and those wells may produce water for the owning PWS, but also for one or more PWSs that the owning PWS supplies water. Other PWSs do not have any physical source locations; all of their supply comes from another PWS through a system interconnect. Where this happens, that system's demand needs to be assigned to the PWS selling them water. Each situation must be accounted for, and from a groundwater demand perspective, all demand is assigned to the known PWS groundwater wells.

Results

Results are shown in Table 1. The columns are defined as:

(1) TCEQ County designation for the PWS;
(2) TCEQ PWS identifier;
(3) TCEQ PWS name;
(4) The number of currently active wells capable of supplying the PWS;

(5) The 2010 population for the PWS: calculated by intersecting the 2010 Census Blocks with the PWS service area boundary, and the H-GAC parcel based land use polygons;

(6) Baseline Gallons Per-Capita Daily (GPCD) value for the PWS;

(7) Total water demand for the PWS, defined as Population x GPCD;

(8) The total groundwater demand on the system. The groundwater demand on the system may be:

    a. < Total Water Demand (column 7), if all or a portion of the demand is met through a system interconnect;

    b. > Total Water Demand (column 7), if the PWS is supplying other systems through system interconnects.

(9) Column (7) – Column (8), except where demand is met through a groundwater interconnect.

The amounts in Column (8) are divided equally by the number of supply wells in Column (4). These values will be input in the groundwater model in a subsequent phase of the project.

Table 1. Population and Water Demand by Public Water System

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
BRAZORIA	0200251	ANCHOR ROAD MOBILE HOME PARK	1	27	98	2,646	2,646	-
BRAZORIA	0200361	ANGLECREST SUBDIVISION	1	209	84	17,556	17,556	-
BRAZORIA	0200563	BATEMAN WATER WORKS	1	26	159	4,134	4,134	-
BRAZORIA	0200570	BAYOU SHADOWS WATER SYSTEM	1	76	37	2,812	2,812	-
BRAZORIA	0200245	BEECHWOOD SUBDIVISION	2	200	108	21,600	21,600	-
BRAZORIA	0200065	BERNARD ACRES	2	31	59	1,829	1,829	-
BRAZORIA	0200338	BERNARD OAKS SUBDIVISION	2	123	69	8,487	8,487	-
BRAZORIA	0200043	BERNARD RIVER OAKS	1	26	67	1,742	1,742	-
BRAZORIA	0200025	BRAZORIA COUNTY FWSD 1 DAMON	2	612	99	60,588	60,588	-
BRAZORIA	0200386	BRAZORIA COUNTY MUD 2	5	3,390	225	762,750	3,448,226	-
BRAZORIA	0200610	BRAZORIA COUNTY MUD 21	2	3,036	79	239,844	239,844	-
BRAZORIA	0200615	BRAZORIA COUNTY MUD 25	1	1,668	90	150,120	150,120	-
BRAZORIA	0200612	BRAZORIA COUNTY MUD 29	3	1,476	74	109,224	109,224	-
BRAZORIA	0200560	BRAZORIA COUNTY MUD 3	0	4,107	225	924,075	-	-
BRAZORIA	0200645	BRAZORIA COUNTY MUD 31	2	251	399	100,149	100,149	-
BRAZORIA	0200327	BRAZORIA COUNTY MUD 4	1	2,534	134	339,556	339,556	-
BRAZORIA	0200578	BRAZORIA COUNTY MUD 6	0	6,176	179	1,105,504	-	-
BRAZORIA	0200278	BRAZOS RIVER CLUB	1	14	80	1,120	1,120	-
BRAZORIA	0200410	BRIAR MEADOWS	1	309	100	30,900	30,900	-
BRAZORIA	0200393	BRYAN BEACH WSC	1	56	120	6,720	6,720	-
BRAZORIA	0200152	CALICO FARMS SUBDIVISION	1	31	74	2,294	2,294	-
BRAZORIA	0200190	CENTENNIAL PLACE	1	36	111	3,996	3,996	-
BRAZORIA	0200128	CHOCTAW SUBDIVISION	1	28	86	2,408	2,408	-
BRAZORIA	0200001	CITY OF ALVIN	5	15,021	104	1,562,184	1,562,184	-
BRAZORIA	0200002	CITY OF ANGLETON	6	18,514	98	1,814,372	1,814,372	-
BRAZORIA	0200003	CITY OF BRAZORIA	2	2,941	98	288,218	-	288,218

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
BRAZORIA	0200004	CITY OF CLUTE	3	10,856	114	1,237,584	1,237,584	-
BRAZORIA	0200011	CITY OF DANBURY	2	1,712	103	176,336	176,336	-
BRAZORIA	0200005	CITY OF FREEPORT	2	11,592	109	1,263,528	-	1,263,528
BRAZORIA	0200125	CITY OF FREEPORT SLAUGHTER ROAD	1	57	100	5,700	5,700	-
BRAZORIA	0200028	CITY OF HILLCREST VILLAGE	2	730	137	100,010	100,010	-
BRAZORIA	0200006	CITY OF LAKE JACKSON	11	26,203	119	3,118,157	3,118,157	-
BRAZORIA	0200555	CITY OF LIVERPOOL	2	456	57	25,992	25,992	-
BRAZORIA	0200407	CITY OF MANVEL	4	795	239	190,005	190,005	-
BRAZORIA	0200230	CITY OF OYSTER CREEK	2	1,134	111	125,874	125,874	-
BRAZORIA	0200008	CITY OF PEARLAND	11	89,543	118	10,566,074	10,566,074	-
BRAZORIA	0200008	CITY OF PEARLAND	11	89,543	118	10,566,074	10,566,074	-
BRAZORIA	0200411	CITY OF PEARLAND MUD 1	0	5,541	118	653,838	-	-
BRAZORIA	0200035	CITY OF RICHWOOD	3	3,503	80	280,240	280,240	-
BRAZORIA	0200009	CITY OF SWEENY	4	3,043	122	371,246	371,246	-
BRAZORIA	0200010	CITY OF WEST COLUMBIA	3	3,850	115	442,750	442,750	-
BRAZORIA	0200604	COLONY TRAILS SUBDIVISION	1	257	100	25,700	25,700	-
BRAZORIA	0200033	COMMODORE COVE IMPROVEMENT DISTRICT	2	188	100	18,800	18,800	-
BRAZORIA	0200273	COUNTRY MEADOWS	2	125	73	9,125	9,125	-
BRAZORIA	0200234	DEMI JOHN I S WATER SYSTEM	2	97	100	9,700	9,700	-
BRAZORIA	0200185	DEMI JOHN PLACE WATER SYSTEM	2	40	100	4,000	4,000	-
BRAZORIA	0200360	GRASSLANDS	2	450	74	33,300	33,300	-
BRAZORIA	0200218	HASTINGS HOMEOWNERS WATER SYSTEM	1	215	130	27,950	27,950	-
BRAZORIA	0200349	HEIGHTS COUNTRY SUBDIVISION	2	113	100	11,300	11,300	-
BRAZORIA	0200029	HOLIDAY SHORES	2	225	95	21,375	21,375	-
BRAZORIA	0200040	HOMELAND SUBDIVISION	1	24	68	1,632	1,632	-
BRAZORIA	0200041	JONES CREEK TERRACE	4	868	77	66,836	66,836	-
BRAZORIA	0200042	JONES CREEKWOOD	1	40	79	3,160	3,160	-
BRAZORIA	0200401	KEY LARGO UTILITIES	1	1	129	129	129	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
BRAZORIA	0200067	LAS PLAYAS	1	52	100	5,200	5,200	-
BRAZORIA	0200506	LEE RIDGE SUBDIVISION	1	163	100	16,300	16,300	-
BRAZORIA	0200159	LINCECUM WATER POWERS ADDITION	1	67	100	6,700	6,700	-
BRAZORIA	0200277	MALLARD LAKE CLUB	1	31	100	3,100	3,100	-
BRAZORIA	0200670	MARIA ELENA'S MOBILE HOMES	1	-	104	-	-	-
BRAZORIA	0200432	MARK V ESTATES	3	144	69	9,936	9,936	-
BRAZORIA	0200461	MARLIN MARINA WATER SYSTEM	1	63	100	6,300	6,300	-
BRAZORIA	0200347	MEADOWLAND SUBDIVISION	1	141	72	10,152	10,152	-
BRAZORIA	0200271	MEADOWLARK SUBDIVISION	2	23	88	2,024	2,024	-
BRAZORIA	0200189	MEADOWVIEW SUBDIVISION	2	73	75	5,475	5,475	-
BRAZORIA	0200094	MOORELAND SUBDIVISION WATER SYSTEM	2	94	73	6,862	6,862	-
BRAZORIA	0200146	OAK BEND ESTATES	1	120	84	10,080	10,080	-
BRAZORIA	0200586	OAK CREST OF MANVEL	1	373	100	37,300	37,300	-
BRAZORIA	0200032	OAK MANOR MUD	2	566	110	62,260	62,260	-
BRAZORIA	0200607	OYSTER CREEK ESTATES	3	23	100	2,300	2,300	-
BRAZORIA	0200617	PALM CREST	1	83	100	8,300	8,300	-
BRAZORIA	0200242	PALMETTO SUBDIVISION	2	246	92	22,632	22,632	-
BRAZORIA	0200597	PALOMA ACRES SUBDIVISION	1	176	100	17,600	17,600	-
BRAZORIA	0200223	PLEASANT MEADOWS SUBDIVISION	1	30	97	2,910	2,910	-
BRAZORIA	0200139	RIVER OAKS	2	43	75	3,225	3,225	-
BRAZORIA	0200575	RIVER RUN WATER SYSTEM	1	53	96	5,088	5,088	-
BRAZORIA	0200058	RIVERSIDE ESTATES	1	27	100	2,700	2,700	-
BRAZORIA	0200541	ROBIN COVE WATER SUBDIVISION	1	44	91	4,004	4,004	-
BRAZORIA	0200036	ROSHARON TOWNSHIP	2	157	100	15,700	15,700	-
BRAZORIA	0200127	ROYAL RIDGE	1	89	79	7,031	7,031	-
BRAZORIA	0200108	RYAN LONG SUBDIVISION 2 WATER SYSTEM	1	73	88	6,424	6,424	-
BRAZORIA	0200460	SAN BERNARD RIVER ESTATES	2	128	96	12,288	12,288	-
BRAZORIA	0200599	SAVANNAH PLANTATION SUBDIVISION	1	153	100	15,300	15,300	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
BRAZORIA	0200148	SHADY CREEK SECTION 3 WATER SYSTEM	1	74	100	7,400	7,400	-
BRAZORIA	0200413	SOUTH MEADOWS WEST	1	404	100	40,400	40,400	-
BRAZORIA	0200363	STERLING ESTATES	2	80	115	9,200	9,200	-
BRAZORIA	0200624	STONERIDGE LAKE SUBDIVISION	1	105	100	10,500	10,500	-
BRAZORIA	0200640	SUNCREEK ESTATES SECTION 1	1	159	299	47,541	47,541	-
BRAZORIA	0200616	SUNCREEK RANCH SECTION 2	1	156	72	11,232	11,232	-
BRAZORIA	0200018	TOWN OF HOLIDAY LAKES	2	1,144	89	101,816	101,816	-
BRAZORIA	0200510	TOWN OF QUINTANA	2	31	100	3,100	3,100	-
BRAZORIA	0200038	TREASURE ISLAND MUD	0	16	72	1,152	-	1,152
BRAZORIA	0200062	TURTLE COVE LOT OWNERS ASSOC	2	64	165	10,560	10,560	-
BRAZORIA	0200488	TWIN LAKES CLUB	1	227	100	22,700	22,700	-
BRAZORIA	0200070	VARNER CREEK UTILITY DISTRICT	2	1,400	133	186,200	186,200	-
BRAZORIA	0200037	VILLAGE OF SURFSIDE BEACH	7	459	71	32,589	32,589	-
BRAZORIA	0200341	VILLAGE TRACE WATER SYSTEM	1	269	82	22,058	22,058	-
BRAZORIA	0200024	WAGON WHEEL ESTATES WATER SYSTEM	2	562	117	65,754	65,754	-
BRAZORIA	0200211	WELLBORN ACRES	1	13	171	2,223	2,223	-
BRAZORIA	0200254	WESTWOOD SUBDIVISION	1	23	87	2,001	2,001	-
BRAZORIA	0200019	WEYBRIDGE SUBDIVISION WATER SYSTEM	2	108	96	10,368	10,368	-
BRAZORIA	0200083	WILCO WATER CO	3	97	75	7,275	7,275	-
BRAZORIA	0200229	WINDSONG SUBDIVISION	2	42	74	3,108	3,108	-
BRAZORIA	0200370	WOLF GLEN WATER SYSTEM	2	94	100	9,400	9,400	-
BRAZORIA	0200409	WOLFE AIR PARK	1	48	100	4,800	4,800	-
BRAZORIA	0200444	WOOD OAKS WATER WORKS	1	18	100	1,800	1,800	-
FORT BEND	0790309	5TH STREET WATER SYSTEM	0	1,488	103	153,264	-	-
FORT BEND	0790425	723 UTILITY	2	100	131	13,100	13,100	-
FORT BEND	0790077	BAY RIDGE CHRISTIAN COLLEGE AND APARTMEN	1	166	211	35,026	35,026	-
FORT BEND	0790332	BIG OAKS MUD	2	6,878	125	859,750	859,750	-
FORT BEND	0790051	BLUE RIDGE WEST MUD	2	6,810	123	834,225	834,225	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
FORT BEND	0790363	BRAZOS LAKES WATER SUPPLY	1	279	103	28,807	28,807	-
FORT BEND	0790350	BRIDLEWOOD ESTATES WATER SYSTEM	3	1,361	184	249,841	249,841	-
FORT BEND	0790274	CINCO MUD 1	12	942	291	274,122	5,807,425	-
FORT BEND	0790386	CINCO MUD 10	0	2,719	205	557,395	-	-
FORT BEND	0790344	CINCO MUD 12	0	2,065	275	567,875	-	-
FORT BEND	0790422	CINCO MUD 14	0	5,076	174	883,224	-	-
FORT BEND	0790306	CINCO MUD 2	0	3,841	195	748,995	-	-
FORT BEND	0790292	CINCO MUD 3	0	2,530	137	346,610	-	-
FORT BEND	0790291	CINCO MUD 5	0	2,515	208	523,120	-	-
FORT BEND	0790316	CINCO MUD 6	0	2,187	161	352,107	-	-
FORT BEND	0790343	CINCO MUD 7	0	3,156	177	558,612	-	-
FORT BEND	0790324	CINCO MUD 8	0	3,267	120	391,223	-	-
FORT BEND	0790307	CINCO MUD 9	0	3,923	154	604,142	-	-
FORT BEND	0790438	CINCO SOUTHWEST MUD 1	4	696	246	171,216	1,464,930	-
FORT BEND	0790481	CINCO SOUTHWEST MUD 2	0	4,416	246	1,086,336	-	-
FORT BEND	0790521	CINCO SOUTHWEST MUD 3	0	87	246	21,402	-	-
FORT BEND	0790522	CINCO SOUTHWEST MUD 4	0	756	246	185,976	-	-
FORT BEND	0790014	CITY OF BEASLEY	2	639	113	72,101	72,101	-
FORT BEND	0790133	CITY OF FULSHEAR	2	1,125	202	227,250	227,250	-
FORT BEND	0790018	CITY OF KENDLETON	2	220	211	46,332	46,332	-
FORT BEND	0790025	CITY OF MEADOWS PLACE	3	4,585	141	645,976	645,976	-
FORT BEND	0790207	CITY OF MISSOURI CITY MUSTANG BAYOU WATE	1	2,708	128	346,624	346,624	-
FORT BEND	0790001	CITY OF NEEDVILLE	2	2,745	107	293,715	293,715	-
FORT BEND	0790037	CITY OF ORCHARD	2	328	136	44,572	44,572	-
FORT BEND	0790023	CITY OF RICHMOND	5	10,505	131	1,380,824	1,962,177	-
FORT BEND	0790003	CITY OF ROSENBERG	8	29,818	108	3,227,799	3,458,739	-
FORT BEND	0790005	CITY OF SUGAR LAND	14	72,885	185	13,459,430	13,523,807	-
FORT BEND	0790354	CITY OF SUGAR LAND RIVER PARK	2	4,272	185	790,320	790,320	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
FORT BEND	0790230	FIRST COLONY MUD 9	1	7,242	138	1,002,112	1,002,112	-
FORT BEND	0790474	FORT BEND COUNTY FWSD 1	1	146	62	9,052	9,052	-
FORT BEND	0790440	FORT BEND COUNTY FWSD 2	1	671	90	60,390	60,390	-
FORT BEND	0790296	FORT BEND COUNTY MUD 106	3	3,225	276	890,100	2,147,604	-
FORT BEND	0790297	FORT BEND COUNTY MUD 108	0	2,291	174	398,252	-	-
FORT BEND	0790298	FORT BEND COUNTY MUD 109	0	2,966	125	370,750	-	-
FORT BEND	0790317	FORT BEND COUNTY MUD 111	0	3,640	208	756,513	-	-
FORT BEND	0790253	FORT BEND COUNTY MUD 112	3	3,614	227	819,655	2,978,623	-
FORT BEND	0790403	FORT BEND COUNTY MUD 115 RIVERSTONE	1	1,563	238	371,994	973,536	-
FORT BEND	0790367	FORT BEND COUNTY MUD 116 CANYON GATE	2	2,723	130	353,990	353,990	-
FORT BEND	0790375	FORT BEND COUNTY MUD 117	0	3,877	126	488,502	-	-
FORT BEND	0790366	FORT BEND COUNTY MUD 118	3	3,887	156	606,372	606,372	-
FORT BEND	0790382	FORT BEND COUNTY MUD 119	1	5,636	160	901,760	901,760	-
FORT BEND	0790393	FORT BEND COUNTY MUD 121	0	2,886	131	378,066	-	-
FORT BEND	0790416	FORT BEND COUNTY MUD 122	1	3,300	135	445,500	774,049	-
FORT BEND	0790446	FORT BEND COUNTY MUD 123	0	2,587	127	328,549	-	-
FORT BEND	0790412	FORT BEND COUNTY MUD 124	2	2,452	173	424,196	424,196	-
FORT BEND	0790498	FORT BEND COUNTY MUD 128	0	311	207	64,377	-	-
FORT BEND	0790437	FORT BEND COUNTY MUD 129	0	2,906	207	601,542	-	-
FORT BEND	0790371	FORT BEND COUNTY MUD 130	3	2,175	304	661,200	661,200	-
FORT BEND	0790450	FORT BEND COUNTY MUD 131	2	658	158	103,964	103,964	-
FORT BEND	0790444	FORT BEND COUNTY MUD 133	1	674	167	112,558	112,558	-
FORT BEND	0790477	FORT BEND COUNTY MUD 134A	1	-	324	-	109,512	-
FORT BEND	0790533	FORT BEND COUNTY MUD 134C	0	338	324	109,512	-	-
FORT BEND	0790445	FORT BEND COUNTY MUD 140 RIVERS EDGE	0	1,222	131	160,082	-	-
FORT BEND	0790451	FORT BEND COUNTY MUD 141	2	10	158	1,580	1,580	-
FORT BEND	0790429	FORT BEND COUNTY MUD 142	2	4,606	158	727,748	727,748	-
FORT BEND	0790472	FORT BEND COUNTY MUD 143 WATER VIEW ESTA	0	1,287	151	194,337	-	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
FORT BEND	0790502	FORT BEND COUNTY MUD 145 RIO VISTA	0	351	28	9,828	-	-
FORT BEND	0790435	FORT BEND COUNTY MUD 146	2	2,248	233	523,784	523,784	-
FORT BEND	0790517	FORT BEND COUNTY MUD 149	1	5	154	770	770	-
FORT BEND	0790443	FORT BEND COUNTY MUD 151	2	2,857	203	579,971	579,971	-
FORT BEND	0790487	FORT BEND COUNTY MUD 152	0	378	129	48,762	-	-
FORT BEND	0790488	FORT BEND COUNTY MUD 155	0	671	107	71,797	-	-
FORT BEND	0790466	FORT BEND COUNTY MUD 158	0	505	125	63,125	-	-
FORT BEND	0790459	FORT BEND COUNTY MUD 162	2	1,225	89	109,025	109,025	-
FORT BEND	0790470	FORT BEND COUNTY MUD 165	0	1,121	156	174,876	-	-
FORT BEND	0790478	FORT BEND COUNTY MUD 185	1	239	113	27,007	27,007	-
FORT BEND	0790535	FORT BEND COUNTY MUD 187	0	166	108	17,928	-	-
FORT BEND	0790155	FORT BEND COUNTY MUD 19	0	527	63	33,377	-	-
FORT BEND	0790038	FORT BEND COUNTY MUD 2	2	6,906	105	726,117	726,117	-
FORT BEND	0790237	FORT BEND COUNTY MUD 23	4	11,226	91	1,019,695	1,067,490	-
FORT BEND	0790468	FORT BEND COUNTY MUD 24	0	605	79	47,795	-	-
FORT BEND	0790130	FORT BEND COUNTY MUD 25	4	11,339	111	1,255,794	1,255,794	-
FORT BEND	0790137	FORT BEND COUNTY MUD 26 QUAIL GREEN WEST	2	4,364	95	413,333	413,333	-
FORT BEND	0790146	FORT BEND COUNTY MUD 30	2	9,952	102	1,018,836	1,018,836	-
FORT BEND	0790200	FORT BEND COUNTY MUD 34	2	3,012	232	698,784	2,022,066	-
FORT BEND	0790433	FORT BEND COUNTY MUD 35	0	5,934	223	1,323,282	-	-
FORT BEND	0790189	FORT BEND COUNTY MUD 37	1	1,249	253	315,997	315,997	-
FORT BEND	0790229	FORT BEND COUNTY MUD 41	1	3,213	109	350,619	350,619	-
FORT BEND	0790254	FORT BEND COUNTY MUD 42	1	3,983	147	587,208	587,208	-
FORT BEND	0790315	FORT BEND COUNTY MUD 46	1	1,987	209	414,886	414,886	-
FORT BEND	0790220	FORT BEND COUNTY MUD 47	0	1,220	122	148,230	-	-
FORT BEND	0790267	FORT BEND COUNTY MUD 48	0	1,691	103	174,173	-	-
FORT BEND	0790256	FORT BEND COUNTY MUD 49	0	683	138	94,254	-	-
FORT BEND	0790482	FORT BEND COUNTY MUD 5	1	167	108	18,036	18,036	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
FORT BEND	0790277	FORT BEND COUNTY MUD 50	1	3,213	194	623,322	623,322	-
FORT BEND	0790455	FORT BEND COUNTY MUD 57	1	894	179	160,026	160,026	-
FORT BEND	0790458	FORT BEND COUNTY MUD 58	1	1,016	134	136,144	136,144	-
FORT BEND	0790486	FORT BEND COUNTY MUD 66	0	312	94	29,328	-	-
FORT BEND	0790252	FORT BEND COUNTY MUD 67	0	3,269	181	592,779	-	-
FORT BEND	0790262	FORT BEND COUNTY MUD 68	0	3,605	133	480,066	-	-
FORT BEND	0790325	FORT BEND COUNTY MUD 69	0	1,658	199	329,610	-	-
FORT BEND	0790268	FORT BEND COUNTY MUD 81 WESTON LAKES	2	1,574	359	564,436	564,436	-
FORT BEND	0790004	FORT BEND COUNTY WCID 2	7	28,770	261	7,508,970	7,662,234	-
FORT BEND	0790368	FORT BEND COUNTY WCID 3	2	596	355	211,580	211,580	-
FORT BEND	0790479	FORT BEND COUNTY WCID 8	1	52	355	18,460	18,460	-
FORT BEND	0790385	FULBROOK SUBDIVISION WATER PLANT	1	419	202	84,638	84,638	-
FORT BEND	0790410	GRAND LAKES MUD 1	0	3,544	200	708,800	-	-
FORT BEND	0790387	GRAND LAKES MUD 2	0	2,065	336	693,840	-	-
FORT BEND	0790356	GRAND LAKES MUD 4	3	1,283	181	232,223	1,634,863	-
FORT BEND	0790430	GRAND MISSION MUD 1	2	4,492	161	723,212	1,409,393	-
FORT BEND	0790449	GRAND MISSION MUD 2	0	1,128	281	316,968	-	-
FORT BEND	0790347	HARRIS FORT BEND COUNTIES MUD 5	2	2,407	195	469,365	679,081	-
FORT BEND	0790347	HARRIS FORT BEND COUNTIES MUD 5	2	2,407	195	469,365	679,081	-
FORT BEND	0790216	HARRIS-FORT BEND COUNTIES MUD 1	0	1,924	109	209,716	-	-
FORT BEND	0790462	KINGDOM HEIGHTS WATER SYSTEM	2	461	131	60,391	60,391	-
FORT BEND	0790158	KINGSBRIDGE MUD	2	9,371	117	1,096,407	1,096,407	-
FORT BEND	0790423	LAKES OF MISSION GROVE	1	168	233	29,400	29,400	-
FORT BEND	0790049	MEADOWCREEK MUD	1	1,833	103	189,257	189,257	-
FORT BEND	0790261	NIAGRA PUBLIC WATER SUPPLY	1	182	62	11,284	11,284	-
FORT BEND	0790174	NORTH MISSION GLEN MUD	2	10,041	87	875,001	875,001	-
FORT BEND	0790199	PALMER PLANTATION MUD 1	1	1,557	245	381,243	381,243	-
FORT BEND	0790323	PALMER PLANTATION MUD 2	1	2,477	198	489,208	583,462	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
FORT BEND	0790331	PARK PLACE SOUTHWEST	1	157	108	16,956	16,956	-
FORT BEND	0790132	PECAN GROVE MUD	5	12,718	173	2,202,758	2,202,758	-
FORT BEND	0790112	PLANTATION MUD	2	4,102	118	484,036	484,036	-
FORT BEND	0790028	QUAIL VALLEY UTILITY DISTRICT	4	8,658	122	1,058,441	1,058,441	-
FORT BEND	0790405	RIVERWOOD FOREST	1	660	202	133,320	133,320	-
FORT BEND	0790396	ROSEMEADOWS III	1	413	107	44,191	44,191	-
FORT BEND	0790364	ROYAL LAKES ESTATES	2	675	184	123,525	123,525	-
FORT BEND	0790389	SHADOW GROVE ESTATES	1	161	131	21,091	21,091	-
FORT BEND	0790493	SIENNA PLANTATION MANAGEMENT DISTRICT	0	110	158	17,380	-	-
FORT BEND	0790373	SIENNA PLANTATION MUD 1	5	-	158	-	2,623,304	-
FORT BEND	0790452	SIENNA PLANTATION MUD 10	0	2,947	158	465,626	-	-
FORT BEND	0790494	SIENNA PLANTATION MUD 12	0	766	158	121,028	-	-
FORT BEND	0790345	SIENNA PLANTATION MUD 2	0	5,204	158	822,232	-	-
FORT BEND	0790376	SIENNA PLANTATION MUD 3	0	6,147	158	971,226	-	-
FORT BEND	0790489	SIENNA PLANTATION MUD 4	0	8	158	1,264	-	-
FORT BEND	0790490	SIENNA PLANTATION MUD 5	0	800	158	126,400	-	-
FORT BEND	0790491	SIENNA PLANTATION MUD 6	0	3	158	474	-	-
FORT BEND	0790492	SIENNA PLANTATION MUD 7	0	6	158	948	-	-
FORT BEND	0790495	SIENNA PLANTATION THE WOODS	0	329	294	96,726	-	-
FORT BEND	0790144	SOUTHWEST ENVIRONMENTAL RESOURCES	3	415	108	44,820	44,820	-
FORT BEND	0790428	SUN RANCH WATER SYSTEM	1	32	103	3,296	3,296	-
FORT BEND	0790013	TELEVIEW TERRACE SUBDIVISION	2	496	109	53,993	53,993	-
FORT BEND	0790033	THUNDERBIRD UTILITY DISTRICT 1	2	3,010	170	511,700	511,700	-
FORT BEND	0790050	THUNDERBIRD UTILITY DISTRICT SYSTEM 2	1	728	115	83,356	83,356	-
FORT BEND	0790190	TURNER WATER SERVICE	1	12	62	744	744	-
GALVESTON	0840011	BACLIFF MUD	1	6,952	71	493,592	49,359	444,233
GALVESTON	0840010	BAYVIEW MUD	1	1,389	63	87,507	8,751	78,756
GALVESTON	0840044	BOLIVAR PENINSULA SUD	2	2,338	69	161,322	16,132	145,190

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
GALVESTON	0840002	CITY OF FRIENDSWOOD	6	34,396	124	4,265,104	426,510	3,838,594
GALVESTON	0840003	CITY OF GALVESTON	6	44,662	243	10,852,866	1,085,287	9,767,579
GALVESTON	0840004	CITY OF HITCHCOCK	3	6,894	122	841,068	84,107	756,961
GALVESTON	0840030	CITY OF JAMAICA BEACH	0	984	141	138,744	-	138,744
GALVESTON	0840006	CITY OF LA MARQUE	3	13,968	126	1,759,968	175,997	1,583,971
GALVESTON	0840007	CITY OF LEAGUE CITY	3	82,131	120	9,855,720	985,572	8,870,148
GALVESTON	0840008	CITY OF TEXAS CITY	10	43,725	121	5,290,725	529,073	4,761,653
GALVESTON	0840036	GALVESTON COUNTY FWSD 6 TIKI ISLAND	0	966	152	146,832	-	146,832
GALVESTON	0840021	GALVESTON COUNTY MUD 12	1	1,510	94	141,940	14,194	127,746
GALVESTON	0840214	GALVESTON COUNTY MUD 29	0	216	243	52,488	-	52,488
GALVESTON	0840001	GALVESTON COUNTY WCID 1	4	20,852	99	2,064,348	206,435	1,857,913
GALVESTON	0840031	GALVESTON COUNTY WCID 12	2	2,315	170	393,550	39,355	354,195
GALVESTON	0840028	GALVESTON COUNTY WCID 19	1	360	111	39,960	3,996	35,964
GALVESTON	0840009	GALVESTON COUNTY WCID 8	1	3,586	99	355,014	35,501	319,513
GALVESTON	0840080	HIGHLAND BAYOU ESTATES WSC	1	20	122	2,440	244	2,196
GALVESTON	0840187	K & B WATERWORKS	1	98	99	9,702	970	8,732
GALVESTON	0840229	LONE PINE SUBDIVISION	1	78	121	9,438	944	8,494
GALVESTON	0840063	SAN LEON MUD	1	5,012	108	541,296	54,130	487,166
GALVESTON	0840057	TIFFANY WATER CO	0	20	108	2,160	-	2,160
HARRIS	1011019	ADDICKS UTILITY DISTRICT	1	4,353	106	461,418	129,840	331,578
HARRIS	1012052	ALBURY MANOR UTILITY COMPANY	0	133	185	24,605	-	-
HARRIS	1010410	ALDINE FOREST SUBDIVISION	1	143	153	21,879	21,879	-
HARRIS	1010092	ALDINE MEADOWS	1	145	102	14,790	14,790	-
HARRIS	1010931	ALDINE VILLAGE SUBDIVISION	2	860	183	157,380	157,380	-
HARRIS	1011236	ALICE ACRES MOBILE HOME SUBDIVISION	2	234	80	18,720	18,720	-
HARRIS	1012806	ALTON THEISS SUBDIVISION	1	23	80	1,840	1,840	-
HARRIS	1011920	AMBERWOOD SUBDIVISION	1	526	98	51,548	51,548	-
HARRIS	1012962	BAKER ROAD MUD	0	791	158	124,978	-	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010689	BALABAN APARTMENTS 1	1	13	60	780	780	-
HARRIS	1011028	BALABAN APARTMENTS 2	1	21	60	1,260	1,260	-
HARRIS	1010096	BAMMEL FOREST UTILITY COMPANY	0	1,298	146	189,508	-	135,403
HARRIS	1010809	BAMMEL OAKS ESTATES 1	0	743	57	42,351	-	-
HARRIS	1010810	BAMMEL OAKS ESTATES 2	2	157	82	12,874	55,225	-
HARRIS	1010365	BAMMEL UTILITY DISTRICT	1	2,180	161	350,980	100,205	250,775
HARRIS	1011613	BARKER CYPRESS MUD	1	4,932	112	552,384	-	552,384
HARRIS	1012698	BAYBROOK MUD 1	0	501	961	481,461	-	481,461
HARRIS	1010212	BAYER WATER SYSTEM	3	1,227	275	337,425	337,425	-
HARRIS	1010098	BEAUMONT PLACE	2	2,173	64	139,072	27,814	111,258
HARRIS	1012082	BEECHNUT MUD	1	1,678	299	501,722	501,722	-
HARRIS	1010180	BENDER CREEK APARTMENTS	2	243	60	14,580	14,580	-
HARRIS	1010099	BERGVILLE ADDITION	1	32	72	2,304	2,304	-
HARRIS	1011860	BERRY HILL ESTATES	1	315	85	26,775	26,775	-
HARRIS	1011872	BILMA PUD	2	3,927	183	718,641	205,172	513,469
HARRIS	1011551	BINFORD PLACE SUBDIVISION	1	114	108	12,312	12,312	-
HARRIS	1010883	BISSONNET MUD	2	8,592	120	1,031,040	1,031,040	-
HARRIS	1010647	BLUE BELL MANOR SUBDIVISION	3	3,200	220	704,000	704,000	-
HARRIS	1011084	BOUDREAUX GARDENS	2	117	100	11,700	11,700	-
HARRIS	1011550	BRIDGESTONE MUD	4	14,120	109	1,539,080	439,407	1,099,673
HARRIS	1011014	BRITTMOORE UTILITY	2	3,487	261	910,107	910,107	-
HARRIS	1010639	CANAL TERRACE SUBDIVISION	2	385	78	30,030	6,006	24,024
HARRIS	1010532	CANDLELIGHT HILLS SUBDIVISION	2	1,590	199	316,410	90,335	226,075
HARRIS	1011833	CASTLEWOOD MUD	1	2,228	123	274,044	274,044	-
HARRIS	1010111	CASTLEWOOD SUBDIVISION	1	1,242	74	91,908	91,908	-
HARRIS	1012174	CEDAR BAYOU ESTATES	1	64	87	5,568	1,114	4,454
HARRIS	1010112	CEDAR BAYOU PARK	0	843	124	104,532	-	104,532
HARRIS	1013146	CHAMPION LAKES ESTATES WATER PLANT	2	316	114	36,024	36,024	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010632	CHARTERWOOD MUD	2	4,228	143	604,604	247,246	431,990
HARRIS	1010782	CHELFORD CITY MUD	2	9,164	116	1,063,024	1,063,024	-
HARRIS	1010767	CHELFORD ONE MUD	1	4,769	144	686,736	686,736	-
HARRIS	1010910	CHIMNEY HILL MUD	1	6,088	93	566,184	566,184	-
HARRIS	1011410	CIMARRON MUD	3	4,830	132	637,560	637,560	-
HARRIS	1010003	CITY OF BAYTOWN	5	66,257	137	9,077,209	1,815,442	7,261,767
HARRIS	1010004	CITY OF BELLAIRE	4	16,836	186	3,131,496	626,299	2,505,197
HARRIS	1010106	CITY OF BUNKER HILL VILLAGE	4	3,667	282	1,034,094	206,819	827,275
HARRIS	1010007	CITY OF DEER PARK	3	36,775	130	4,780,750	478,075	4,302,675
HARRIS	1010009	CITY OF GALENA PARK	3	10,835	81	877,635	87,764	789,872
HARRIS	1012987	CITY OF HILSHIRE VILLAGE	0	746	193	143,978	-	-
HARRIS	1010013	CITY OF HOUSTON	127	1,855,828	143	265,383,404	29,342,593	238,845,064
HARRIS	1011594	CITY OF HOUSTON BELLEAU WOODS	1	29	119	3,451	3,451	-
HARRIS	1011585	CITY OF HOUSTON DISTRICT 73	2	3,326	121	402,446	402,446	-
HARRIS	1011593	CITY OF HOUSTON DISTRICT 82	4	543	121	65,703	65,703	-
HARRIS	1011782	CITY OF HOUSTON HARRIS COUNTY MUD 159	3	6,709	143	959,387	959,387	-
HARRIS	1011715	CITY OF HOUSTON HUNTERWOOD	0	2,573	143	367,939	-	294,351
HARRIS	1011590	CITY OF HOUSTON SPANISH COVE SUBDIVISION	0	725	143	103,675	-	-
HARRIS	1010348	CITY OF HOUSTON UTILITY DISTRICT 5 KINGW	17	57,610	119	6,855,590	6,855,590	-
HARRIS	1011902	CITY OF HOUSTON WILLOW CHASE	2	243	132	32,076	32,076	-
HARRIS	1010014	CITY OF HUMBLE	5	14,689	194	2,849,666	2,901,116	-
HARRIS	1010015	CITY OF JACINTO CITY	2	10,549	95	1,002,155	200,431	801,724
HARRIS	1010016	CITY OF JERSEY VILLAGE	3	7,801	151	1,177,951	1,177,951	-
HARRIS	1010017	CITY OF KATY	6	12,783	166	2,121,978	2,121,978	-
HARRIS	1010018	CITY OF LA PORTE	7	27,777	116	3,222,132	322,213	2,899,919
HARRIS	1010087	CITY OF MORGANS POINT	1	256	239	61,184	6,118	55,066
HARRIS	1010152	CITY OF NASSAU BAY	2	3,977	207	823,239	82,324	740,915
HARRIS	1010293	CITY OF PASADENA	7	135,670	97	13,159,990	2,631,998	10,527,992

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010062	CITY OF SEABROOK	3	11,607	161	1,868,727	186,873	1,681,854
HARRIS	1010207	CITY OF SHOREACRES	3	1,493	110	164,230	16,423	147,807
HARRIS	1010294	CITY OF SOUTH HOUSTON	5	17,104	106	1,813,024	362,605	1,450,419
HARRIS	1010023	CITY OF SOUTHSIDE PLACE	1	1,715	197	337,855	67,571	270,284
HARRIS	1010214	CITY OF SPRING VALLEY VILLAGE	1	3,715	178	661,270	661,270	-
HARRIS	1010026	CITY OF TOMBALL	6	10,174	184	1,872,016	1,872,016	-
HARRIS	1010226	CITY OF WEBSTER	2	4,917	159	781,803	78,180	703,623
HARRIS	1010027	CITY OF WEST UNIVERSITY PLACE	2	14,832	163	2,417,616	483,523	1,934,093
HARRIS	1011681	CLAY ROAD MUD	1	4,728	84	397,152	77,985	319,167
HARRIS	1010418	CLEAR BROOK CITY MUD	4	18,332	85	1,558,220	311,644	1,246,576
HARRIS	1010056	CLEAR LAKE CITY WATER AUTHORITY	6	60,921	198	12,062,358	1,206,236	10,856,122
HARRIS	1010429	CNP UTILITY DISTRICT	4	6,701	87	582,987	166,443	416,544
HARRIS	1011845	COE INDUSTRIAL PARK	1	5	131	655	655	-
HARRIS	1010116	COLONIAL HILLS	2	695	128	88,960	88,960	-
HARRIS	1010077	CORBELLO WATER SYSTEM	2	131	124	16,244	3,249	12,995
HARRIS	1011692	CORNERSTONE MUD	1	4,556	156	710,736	710,736	-
HARRIS	1013271	COTTAGE GARDENS	2	1,138	185	210,530	210,530	-
HARRIS	1013189	COUNTRY CLUB GREEN	1	108	184	19,872	19,872	-
HARRIS	1011501	COUNTRY LIVING APARTMENTS	2	113	60	6,780	6,780	-
HARRIS	1011260	COUNTRY TERRACE SUBDIVISION	3	1,163	134	155,842	31,168	124,674
HARRIS	1011647	CREEKSIDE ESTATES SOUTH	1	520	189	98,280	98,280	-
HARRIS	1010118	CROSBY MUD	2	2,522	167	421,174	84,235	336,939
HARRIS	1011522	CY CHAMP PUD	2	4,193	313	1,312,409	374,693	937,716
HARRIS	1010119	CYPRESS BEND SUBDIVISION	2	874	97	84,778	84,778	-
HARRIS	1013296	CYPRESS CREEK RANCH	0	13	201	2,613	-	-
HARRIS	1010430	CYPRESS CREEK UTILITY DISTRICT	3	2,444	196	479,024	479,024	-
HARRIS	1010629	CYPRESS CROSSING	2	159	92	14,628	14,628	-
HARRIS	1011651	CYPRESS FIELDS SUBDIVISION	2	1,620	99	160,380	160,380	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010919	CYPRESS FOREST PUD	2	4,896	247	1,209,312	345,259	864,053
HARRIS	1010120	CYPRESS FOREST WATER SYSTEM	4	683	132	90,156	90,156	-
HARRIS	1012378	CYPRESS HILL MUD 1	3	6,094	114	694,716	694,716	-
HARRIS	1011792	CYPRESS HILL SUBDIVISION	1	7	133	931	931	-
HARRIS	1010431	CYPRESS KLEIN UTILITY DISTRICT WIMBLETON	2	2,990	250	747,500	255,521	534,089
HARRIS	1011552	CYPRESS PASS ESTATES	1	105	150	15,750	15,750	-
HARRIS	1010254	CYPRESS PLACE	1	108	152	16,416	16,416	-
HARRIS	1010432	CYPRESSWOOD UTILITY DISTRICT	2	3,790	129	488,910	139,584	349,326
HARRIS	1010469	DELYNN WATER SYSTEM	2	41	132	5,412	1,082	4,330
HARRIS	1010927	DOGWOOD TREE WATER SYSTEM	1	25	72	1,800	1,800	-
HARRIS	1010122	DORSET T PLACE	1	58	80	4,640	4,640	-
HARRIS	1010592	DOWDELL PUD	2	3,921	94	368,574	368,574	-
HARRIS	1010471	EL DORADO UTILITY DISTRICT	2	2,910	125	363,750	363,750	-
HARRIS	1010541	EMERALD FOREST UTILITY DISTRICT	2	5,489	141	773,949	773,949	-
HARRIS	1010687	EN CANTO REAL UTILITY DISTRICT	1	1,103	95	104,785	104,785	-
HARRIS	1010978	ENCHANTED VALLEY ESTATES WSC	2	294	198	58,212	58,212	-
HARRIS	1012794	ESTATES OF HOLLY LAKES	2	63	247	15,561	15,561	-
HARRIS	1013262	ESTATES OF WILLOW CREEK	1	121	184	22,264	22,264	-
HARRIS	1010675	ESTATES WATER CORP	1	79	167	13,193	13,193	-
HARRIS	1013127	FAIRWAY CROSSING	1	451	131	59,081	59,081	-
HARRIS	1010340	FALLBROOK UTILITY DISTRICT	2	7,300	102	744,600	744,600	-
HARRIS	1011602	FAULKEY GULLY MUD	3	5,552	190	1,054,880	301,168	753,712
HARRIS	1011252	FOREST HILLS MUD	1	2,480	101	250,480	250,480	-
HARRIS	1010264	FOREST MANOR SUBDIVISION	1	246	116	28,536	28,536	-
HARRIS	1010435	FOUNTAINHEAD MUD	2	5,651	164	926,764	264,591	662,173
HARRIS	1010127	FOUNTAINVIEW SUBDIVISION	2	2,172	130	282,360	282,360	-
HARRIS	1011679	FRY ROAD MUD	1	2,286	216	493,776	493,776	-
HARRIS	1011996	GRANT ROAD ESTATES MOBILE HOME SUB	2	86	67	5,762	5,762	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1011991	GRANT ROAD PUD	1	1,606	168	269,808	77,030	192,778
HARRIS	1010130	GRANTWOOD SUBDIVISION	3	148	197	29,156	29,156	-
HARRIS	1011839	GREEN TRAILS MUD	1	2,146	280	600,880	725,858	-
HARRIS	1010132	GREENGATE ACRES SUBDIVISION	2	580	128	74,240	74,240	-
HARRIS	1013055	GREENLAND SQUARE SUBDIVISION WS	1	268	114	30,552	30,552	-
HARRIS	1010710	GREENWOOD PLACE CIVIC CLUB	1	28	153	4,284	4,284	-
HARRIS	1010554	GREENWOOD UTILITY DISTRICT	1	4,126	113	466,238	93,248	372,990
HARRIS	1010011	GREENWOOD VILLAGE	2	3,276	106	347,256	347,256	-
HARRIS	1011101	H O E WSC	1	446	91	40,586	40,586	-
HARRIS	1013011	H2O TECH INC WATER SYSTEM	1	79	165	13,035	1,304	11,732
HARRIS	1012916	HAMILTON ESTATES WATER SYSTEM	1	38	183	6,954	6,954	-
HARRIS	1010082	HARRIS COUNTY FWSD 1A	1	500	107	53,500	10,700	42,800
HARRIS	1010590	HARRIS COUNTY FWSD 1B	0	418	104	43,472	-	43,472
HARRIS	1010261	HARRIS COUNTY FWSD 27	0	1,759	82	144,238	-	144,238
HARRIS	1010545	HARRIS COUNTY FWSD 45	2	434	117	50,778	50,778	-
HARRIS	1010260	HARRIS COUNTY FWSD 47	1	1,673	85	142,205	-	142,205
HARRIS	1010238	HARRIS COUNTY FWSD 51	3	15,184	116	1,761,344	-	1,761,344
HARRIS	1010233	HARRIS COUNTY FWSD 52	3	2,878	252	725,256	207,061	518,195
HARRIS	1010209	HARRIS COUNTY FWSD 58	3	1,015	150	152,250	152,250	-
HARRIS	1010768	HARRIS COUNTY FWSD 6	2	1,671	181	302,451	30,245	272,206
HARRIS	1010237	HARRIS COUNTY FWSD 61	6	12,914	155	2,001,670	2,337,862	-
HARRIS	1010539	HARRIS COUNTY MUD 1	1	3,616	128	462,848	462,848	-
HARRIS	1010503	HARRIS COUNTY MUD 102	3	8,723	159	1,386,957	597,483	789,474
HARRIS	1011534	HARRIS COUNTY MUD 104	1	3,038	131	397,978	397,978	-
HARRIS	1011227	HARRIS COUNTY MUD 105	2	6,508	87	566,196	566,196	-
HARRIS	1013160	HARRIS COUNTY MUD 106	2	3,515	115	404,225	820,036	-
HARRIS	1010620	HARRIS COUNTY MUD 109	2	7,650	112	856,800	856,800	-
HARRIS	1010426	HARRIS COUNTY MUD 11	2	2,864	109	312,176	312,176	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010897	HARRIS COUNTY MUD 118	2	4,716	114	537,624	537,624	-
HARRIS	1010626	HARRIS COUNTY MUD 119	2	6,046	103	622,738	622,738	-
HARRIS	1010774	HARRIS COUNTY MUD 120	2	11,026	157	1,731,082	1,731,082	-
HARRIS	1012391	HARRIS COUNTY MUD 122	0	1,170	82	95,940	-	95,940
HARRIS	1012229	HARRIS COUNTY MUD 127	1	4,390	117	513,630	94,981	418,649
HARRIS	1012097	HARRIS COUNTY MUD 130	3	2,579	334	861,386	549,901	311,485
HARRIS	1010616	HARRIS COUNTY MUD 132	2	4,990	232	1,157,680	1,157,680	-
HARRIS	1010599	HARRIS COUNTY MUD 136	2	2,648	178	471,344	37,023	434,321
HARRIS	1010923	HARRIS COUNTY MUD 144	1	2,507	90	225,630	5,011	220,619
HARRIS	1011243	HARRIS COUNTY MUD 147	1	2,427	96	232,992	232,992	-
HARRIS	1010938	HARRIS COUNTY MUD 148 KINGSLAKE	2	3,556	105	373,380	74,676	298,704
HARRIS	1011296	HARRIS COUNTY MUD 149	2	3,727	123	458,421	83,226	375,195
HARRIS	1011250	HARRIS COUNTY MUD 150	2	9,160	131	1,199,960	682,968	516,992
HARRIS	1010905	HARRIS COUNTY MUD 151	2	6,050	146	883,300	883,300	-
HARRIS	1010902	HARRIS COUNTY MUD 152	2	7,472	115	859,280	859,280	-
HARRIS	1012133	HARRIS COUNTY MUD 153	1	6,951	179	1,244,229	1,244,229	-
HARRIS	1011642	HARRIS COUNTY MUD 154	2	6,445	115	741,175	741,175	-
HARRIS	1012351	HARRIS COUNTY MUD 155	1	2,400	185	444,000	39,836	404,164
HARRIS	1013327	HARRIS COUNTY MUD 156	0	1,487	139	206,693	-	-
HARRIS	1011430	HARRIS COUNTY MUD 157	4	12,824	97	1,243,928	1,243,928	-
HARRIS	1012297	HARRIS COUNTY MUD 158	0	7,332	106	777,192	-	-
HARRIS	1011705	HARRIS COUNTY MUD 16	1	1,745	108	188,460	53,805	134,655
HARRIS	1011612	HARRIS COUNTY MUD 162	1	2,504	170	425,680	114,661	311,019
HARRIS	1012213	HARRIS COUNTY MUD 163	1	4,671	152	709,992	299,458	410,534
HARRIS	1012187	HARRIS COUNTY MUD 165	2	12,839	87	1,116,993	1,116,993	-
HARRIS	1013181	HARRIS COUNTY MUD 166	0	3,020	85	256,700	-	-
HARRIS	1012842	HARRIS COUNTY MUD 167	2	6,681	140	935,340	935,340	-
HARRIS	1011783	HARRIS COUNTY MUD 168	2	9,236	235	2,170,460	2,170,460	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1012970	HARRIS COUNTY MUD 172	1	2,228	176	392,128	206,693	392,128
HARRIS	1012971	HARRIS COUNTY MUD 173	1	3,411	139	474,129	25,502	448,627
HARRIS	1011848	HARRIS COUNTY MUD 179	1	3,168	75	237,600	-	237,600
HARRIS	1010512	HARRIS COUNTY MUD 18 HEATHERWOOD HUNTERS	2	3,403	157	534,271	152,534	381,737
HARRIS	1011799	HARRIS COUNTY MUD 180	1	4,868	96	467,328	467,328	-
HARRIS	1011824	HARRIS COUNTY MUD 183	2	3,854	106	408,524	50,754	357,770
HARRIS	1011914	HARRIS COUNTY MUD 185	1	3,400	68	231,200	112,137	119,063
HARRIS	1012214	HARRIS COUNTY MUD 186	2	2,740	232	635,680	144,190	491,490
HARRIS	1011982	HARRIS COUNTY MUD 188	1	4,897	80	391,760	-	391,760
HARRIS	1011809	HARRIS COUNTY MUD 189	2	2,621	129	338,109	338,109	-
HARRIS	1012362	HARRIS COUNTY MUD 191	1	2,395	267	639,465	182,567	456,898
HARRIS	1013002	HARRIS COUNTY MUD 196	2	5,020	242	1,214,840	1,214,840	-
HARRIS	1012007	HARRIS COUNTY MUD 200 CRANBROOK	3	9,238	83	766,754	418,954	730,014
HARRIS	1012356	HARRIS COUNTY MUD 202	1	2,114	121	255,794	73,029	182,765
HARRIS	1012704	HARRIS COUNTY MUD 205	0	1,072	83	88,976	-	-
HARRIS	1012419	HARRIS COUNTY MUD 208	2	3,463	138	477,894	253,812	224,082
HARRIS	1012145	HARRIS COUNTY MUD 211	0	491	370	181,670	-	129,803
HARRIS	1012812	HARRIS COUNTY MUD 215	1	946	72	68,112	68,112	-
HARRIS	1012577	HARRIS COUNTY MUD 216	1	399	201	80,199	80,199	-
HARRIS	1011983	HARRIS COUNTY MUD 217	1	2,388	90	214,920	51,460	163,460
HARRIS	1013321	HARRIS COUNTY MUD 220	0	870	62	53,940	-	-
HARRIS	1012972	HARRIS COUNTY MUD 221	1	3,862	175	675,850	675,850	-
HARRIS	1013054	HARRIS COUNTY MUD 222	1	4,631	209	967,879	967,879	-
HARRIS	1010649	HARRIS COUNTY MUD 23	2	2,849	97	276,353	330,293	-
HARRIS	1012740	HARRIS COUNTY MUD 230	1	3,436	132	453,552	453,552	-
HARRIS	1012498	HARRIS COUNTY MUD 233	1	348	891	310,068	88,524	221,544
HARRIS	1012361	HARRIS COUNTY MUD 238	2	7,190	128	920,320	508,008	412,312
HARRIS	1012392	HARRIS COUNTY MUD 239	1	3,063	86	263,418	263,418	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010572	HARRIS COUNTY MUD 24	3	7,771	145	1,126,795	321,700	805,095
HARRIS	1013306	HARRIS COUNTY MUD 248	0	2,472	136	336,192	-	-
HARRIS	1013135	HARRIS COUNTY MUD 249	1	1,961	275	539,275	539,275	-
HARRIS	1010422	HARRIS COUNTY MUD 25 BROOK HOLLOW WEST S	1	-	1,020	-	463,500	-
HARRIS	1012350	HARRIS COUNTY MUD 250	1	784	133	104,272	30,056	74,216
HARRIS	1012766	HARRIS COUNTY MUD 255	0	1,109	216	239,544	-	-
HARRIS	1010715	HARRIS COUNTY MUD 26	3	10,391	89	924,799	924,799	-
HARRIS	1012866	HARRIS COUNTY MUD 261	0	1,091	149	162,559	-	-
HARRIS	1012330	HARRIS COUNTY MUD 264	2	3,613	185	668,405	159,649	508,756
HARRIS	1012496	HARRIS COUNTY MUD 275	1	1,000	129	129,000	129,000	-
HARRIS	1012942	HARRIS COUNTY MUD 276	1	3,396	159	539,964	256,700	539,964
HARRIS	1012835	HARRIS COUNTY MUD 278	1	5,915	110	650,650	650,650	-
HARRIS	1013063	HARRIS COUNTY MUD 280	0	2,413	119	287,147	-	-
HARRIS	1013178	HARRIS COUNTY MUD 281	2	1,801	119	214,319	590,171	-
HARRIS	1013375	HARRIS COUNTY MUD 282	0	565	157	88,705	-	-
HARRIS	1013114	HARRIS COUNTY MUD 284	1	3,568	99	353,232	353,232	-
HARRIS	1012677	HARRIS COUNTY MUD 285	1	7,205	124	893,420	178,684	714,736
HARRIS	1012532	HARRIS COUNTY MUD 286	2	752	733	551,216	157,372	393,844
HARRIS	1013385	HARRIS COUNTY MUD 287	0	857	87	74,559	-	-
HARRIS	1013294	HARRIS COUNTY MUD 290	0	4,037	103	415,811	-	-
HARRIS	1012941	HARRIS COUNTY MUD 304	1	3,980	172	684,560	684,560	-
HARRIS	1012804	HARRIS COUNTY MUD 316	0	824	179	147,496	-	105,386
HARRIS	1012542	HARRIS COUNTY MUD 322 FAIRFIELD VILLAGE	0	3,431	185	634,735	-	-
HARRIS	1011162	HARRIS COUNTY MUD 33	2	6,217	117	727,389	727,389	-
HARRIS	1012917	HARRIS COUNTY MUD 341	1	2,050	174	356,700	-	356,700
HARRIS	1012973	HARRIS COUNTY MUD 342	0	2,526	142	358,692	-	-
HARRIS	1012974	HARRIS COUNTY MUD 344	2	2,175	237	515,475	606,855	412,380
HARRIS	1012768	HARRIS COUNTY MUD 345	1	3,696	205	757,680	757,680	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1012965	HARRIS COUNTY MUD 354	0	6,004	157	942,628	-	-
HARRIS	1012969	HARRIS COUNTY MUD 358	5	-	-	-	2,189,977	-
HARRIS	1012000	HARRIS COUNTY MUD 36	1	749	273	204,477	204,477	-
HARRIS	1012897	HARRIS COUNTY MUD 360	2	3,737	173	646,501	646,501	-
HARRIS	1013123	HARRIS COUNTY MUD 361	0	2,198	66	145,068	-	-
HARRIS	1013132	HARRIS COUNTY MUD 364	1	5,076	135	685,260	685,260	-
HARRIS	1013009	HARRIS COUNTY MUD 365	2	3,625	180	652,500	652,500	-
HARRIS	1013040	HARRIS COUNTY MUD 367	1	5,534	272	1,505,248	429,748	1,075,500
HARRIS	1011908	HARRIS COUNTY MUD 368	4	8,902	93	827,886	236,361	591,525
HARRIS	1013113	HARRIS COUNTY MUD 370	1	4,144	155	642,320	43,967	598,353
HARRIS	1013107	HARRIS COUNTY MUD 371	2	2,252	166	373,832	728,033	-
HARRIS	1013141	HARRIS COUNTY MUD 372	0	2,292	395	905,340	-	-
HARRIS	1013450	HARRIS COUNTY MUD 374 CYPRESS CREEK LAKE	0	2,118	166	351,588	-	-
HARRIS	1013213	HARRIS COUNTY MUD 383	1	2,885	219	631,815	180,383	451,432
HARRIS	1013360	HARRIS COUNTY MUD 387	3	-	-	-	-	-
HARRIS	1013265	HARRIS COUNTY MUD 389	1	838	201	168,438	168,438	-
HARRIS	1013253	HARRIS COUNTY MUD 391	1	4,260	109	464,340	464,340	-
HARRIS	1013338	HARRIS COUNTY MUD 396	0	1,529	157	240,053	-	-
HARRIS	1013295	HARRIS COUNTY MUD 397	0	2,373	157	372,561	-	-
HARRIS	1013346	HARRIS COUNTY MUD 399	0	1,333	89	118,637	-	-
HARRIS	1013310	HARRIS COUNTY MUD 400 - WEST	1	2,529	162	409,698	409,698	-
HARRIS	1013289	HARRIS COUNTY MUD 401	1	-	-	-	24,605	-
HARRIS	1013362	HARRIS COUNTY MUD 405	2	145	218	31,610	31,610	-
HARRIS	1013354	HARRIS COUNTY MUD 412	1	1,676	107	179,332	179,332	-
HARRIS	1013329	HARRIS COUNTY MUD 418	2	-	-	-	403,878	-
HARRIS	1013335	HARRIS COUNTY MUD 419	0	2,433	166	403,878	-	-
HARRIS	1013399	HARRIS COUNTY MUD 420	0	1,025	100	102,500	-	102,500
HARRIS	1013376	HARRIS COUNTY MUD 421	0	144	143	20,592	-	20,592

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010565	HARRIS COUNTY MUD 43	1	4,889	89	435,121	435,121	-
HARRIS	1013378	HARRIS COUNTY MUD 432	1	335	159	53,265	53,265	-
HARRIS	1010718	HARRIS COUNTY MUD 44	2	2,014	194	390,716	442,583	-
HARRIS	1010903	HARRIS COUNTY MUD 46	1	4,044	129	521,676	521,676	-
HARRIS	1013369	HARRIS COUNTY MUD 468	0	471	555	261,405	-	186,774
HARRIS	1010896	HARRIS COUNTY MUD 48	0	383	139	53,237	-	38,038
HARRIS	1013400	HARRIS COUNTY MUD 480	1	38	143	5,434	5,434	-
HARRIS	1011462	HARRIS COUNTY MUD 49	2	3,993	106	423,258	423,258	-
HARRIS	1010500	HARRIS COUNTY MUD 5	2	6,395	138	882,510	882,510	-
HARRIS	1010719	HARRIS COUNTY MUD 50	3	2,387	124	295,988	59,198	236,790
HARRIS	1010720	HARRIS COUNTY MUD 53	3	18,755	89	1,669,195	-	1,669,195
HARRIS	1010678	HARRIS COUNTY MUD 55 HERITAGE PARK	2	14,616	110	1,607,760	321,552	1,286,208
HARRIS	1011704	HARRIS COUNTY MUD 58	2	1,027	193	198,211	198,211	-
HARRIS	1010496	HARRIS COUNTY MUD 6 CARRIAGE LANE	1	4,062	117	475,254	475,254	-
HARRIS	1010721	HARRIS COUNTY MUD 61	2	1,484	286	424,424	617,188	-
HARRIS	1012285	HARRIS COUNTY MUD 62	0	674	286	192,764	-	-
HARRIS	1011513	HARRIS COUNTY MUD 64	1	3,891	134	521,394	521,394	-
HARRIS	1011678	HARRIS COUNTY MUD 65	1	3,222	144	463,968	463,968	-
HARRIS	1010600	HARRIS COUNTY MUD 69 BONAIRE MEISTERWOOD	1	3,624	122	442,128	442,128	-
HARRIS	1011690	HARRIS COUNTY MUD 70	1	4,303	134	576,602	41,569	535,033
HARRIS	1011823	HARRIS COUNTY MUD 71	3	9,909	138	1,367,442	1,442,001	-
HARRIS	1010712	HARRIS COUNTY MUD 8	0	4,540	277	1,257,580	-	1,257,580
HARRIS	1010581	HARRIS COUNTY MUD 81	4	9,741	129	1,256,589	1,256,589	-
HARRIS	1010630	HARRIS COUNTY MUD 82	3	8,310	92	764,520	764,520	-
HARRIS	1012953	HARRIS COUNTY MUD 86	1	2,354	190	447,260	127,693	319,567
HARRIS	1013343	HARRIS COUNTY MUD 96	0	5,688	80	455,040	-	-
HARRIS	1011781	HARRIS COUNTY UTILITY DISTRICT 14	1	1,523	102	155,346	499,986	-
HARRIS	1011778	HARRIS COUNTY UTILITY DISTRICT 15	0	3,590	96	344,640	-	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1013156	HARRIS COUNTY UTILITY DISTRICT 16	1	3,072	95	291,840	291,840	-
HARRIS	1010501	HARRIS COUNTY UTILITY DISTRICT 6	2	8,456	142	1,200,752	483,552	717,200
HARRIS	1010159	HARRIS COUNTY WCID 1	2	5,801	117	678,717	67,872	610,845
HARRIS	1010359	HARRIS COUNTY WCID 109	3	7,177	278	1,995,206	584,830	1,425,575
HARRIS	1010482	HARRIS COUNTY WCID 110	3	5,521	227	1,253,267	357,808	895,459
HARRIS	1010274	HARRIS COUNTY WCID 113 ENCHANTED VILLAGE	2	1,006	138	138,828	138,828	-
HARRIS	1010317	HARRIS COUNTY WCID 114	3	4,944	182	899,808	256,895	642,913
HARRIS	1010507	HARRIS COUNTY WCID 116	2	2,158	352	759,616	216,870	542,746
HARRIS	1010509	HARRIS COUNTY WCID 119	3	7,270	115	836,050	238,692	597,358
HARRIS	1010413	HARRIS COUNTY WCID 132	1	2,466	244	601,704	171,786	429,918
HARRIS	1010210	HARRIS COUNTY WCID 133	2	6,013	104	625,352	625,352	-
HARRIS	1010355	HARRIS COUNTY WCID 136	1	2,834	107	303,238	303,238	-
HARRIS	1013147	HARRIS COUNTY WCID 156	0	1,124	159	178,716	-	178,716
HARRIS	1010769	HARRIS COUNTY WCID 21	2	9,229	130	1,199,770	-	1,199,770
HARRIS	1010239	HARRIS COUNTY WCID 36	4	14,194	55	780,670	-	780,670
HARRIS	1010241	HARRIS COUNTY WCID 50 EL LAGO	3	3,024	193	583,632	58,363	525,269
HARRIS	1010244	HARRIS COUNTY WCID 70	2	1,204	99	119,196	119,196	-
HARRIS	1010480	HARRIS COUNTY WCID 74	2	5,136	132	677,952	677,952	-
HARRIS	1010113	HARRIS COUNTY WCID 84	1	2,090	202	422,180	-	422,180
HARRIS	1012370	HARRIS COUNTY WCID 89	1	3,436	73	250,828	50,166	200,662
HARRIS	1010063	HARRIS COUNTY WCID 91	2	2,441	174	424,734	121,262	303,472
HARRIS	1010124	HARRIS COUNTY WCID 92	3	3,220	127	408,940	408,940	-
HARRIS	1013175	HARRIS COUNTY WCID 96	0	5,267	199	1,048,133	-	-
HARRIS	1010684	HARRIS COUNTY WCID 99	2	1,364	194	264,616	264,616	-
HARRIS	1010249	HARRIS COUNTY WCID FONDREN ROAD	3	2,718	93	252,774	50,555	202,219
HARRIS	1013365	HARRIS-FORT BEND COUNTIES MUD 3	1	1,400	112	156,800	156,800	-
HARRIS	1010419	HEATHER GLEN SUBDIVISION	2	3,832	143	547,976	547,976	-
HARRIS	1011302	HEATHERGATE PUBLIC UTILITY	1	231	74	17,094	17,094	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010548	HEATHERLOCH MUD	2	3,150	104	327,600	93,530	234,070
HARRIS	1013089	HERON LAKES ESTATES	3	2,244	143	320,892	320,892	-
HARRIS	1010012	HIDDEN VALLEY SUBDIVISION	2	4,183	143	598,169	598,169	-
HARRIS	1010157	HIGHLAND RIDGE SUBDIVISION	2	179	79	14,141	2,828	11,313
HARRIS	1011785	HORSEPEN BAYOU MUD	2	6,729	127	854,583	470,652	623,475
HARRIS	1012904	HOUSE CORRAL STREET WATER SYSTEM	1	35	105	3,675	3,675	-
HARRIS	1013198	HUFFMAN HOLLOW APARTMENTS	1	25	60	1,500	1,500	-
HARRIS	1010615	HUNTERS GLEN MUD	2	6,544	94	615,136	615,136	-
HARRIS	1013159	HUNTERS VILLAGE SUBDIVISION	1	48	137	6,576	1,315	5,261
HARRIS	1013180	HYDIES CROSSING	1	123	108	13,284	13,284	-
HARRIS	1013153	IMPERIAL VALLEY MHC	1	1,127	115	129,605	129,605	-
HARRIS	1012264	INTERSTATE MUD	2	3,261	203	661,983	661,983	-
HARRIS	1010172	INVERNESS FOREST IMPROVEMENT DISTRICT	3	1,993	129	257,097	257,097	-
HARRIS	1011684	J & L TERRY LANE	1	18	124	2,232	446	1,786
HARRIS	1010538	JACKRABBIT ROAD PUD	3	9,200	142	1,306,400	634,710	671,690
HARRIS	1012868	K ESTATES WATER SYSTEM	2	113	95	10,735	2,147	8,588
HARRIS	1012710	K LAKE TERRACE	2	157	124	19,468	3,894	15,574
HARRIS	1010163	KENWOOD SUBDIVISION WATER SYSTEM	1	185	117	21,645	21,645	-
HARRIS	1011766	KICKAPOO FARMS SUBDIVISION	2	81	87	7,047	7,047	-
HARRIS	1012865	KINGS MANOR MUD	1	3,313	202	669,226	669,226	-
HARRIS	1011567	KINGSLAND ESTATES WSC	1	388	201	77,988	77,988	-
HARRIS	1010439	KIRKMONT MUD	1	2,297	91	209,027	41,805	167,222
HARRIS	1011536	KITZWOOD SUBDIVISION	1	50	82	4,100	4,100	-
HARRIS	1011143	KLEIN PUD	2	3,020	210	634,200	181,064	453,136
HARRIS	1010440	KLEINWOOD MUD	3	3,307	374	1,236,818	353,112	883,706
HARRIS	1010648	LA CASITA HOMES II	1	-	137	-	-	-
HARRIS	1010494	LAKE FOREST UTILITY DISTRICT	2	5,327	224	1,193,248	1,193,248	-
HARRIS	1011741	LAKE MUD	0	3,058	78	238,524	-	238,524

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1013288	LAKES OF FAIRHAVEN	2	943	157	148,051	148,051	-
HARRIS	1013050	LAKES OF ROSEHILL WATER SYSTEM	4	1,208	99	119,592	119,592	-
HARRIS	1011249	LANGHAM CREEK UTILITY DISTRICT	3	11,820	107	1,264,740	404,999	859,741
HARRIS	1012438	LIM APARTMENTS	1	5	60	300	300	-
HARRIS	1012408	LONGHORN TOWN UTILITY DISTRICT	1	1,296	198	256,608	256,608	-
HARRIS	1011870	LOUETTA NORTH PUD	1	4,393	112	492,016	140,471	351,545
HARRIS	1010536	LOUETTA ROAD UTILITY DISTRICT	2	1,151	204	234,804	67,037	167,767
HARRIS	1010378	LUCE BAYOU PUD	1	319	131	41,789	41,789	-
HARRIS	1010517	MADING LANE WATER SYSTEM	2	192	164	31,488	31,488	-
HARRIS	1010495	MALCOMSON ROAD UTILITY DISTRICT	2	5,728	232	1,328,896	379,400	949,496
HARRIS	1010478	MAREK ROAD WATER SYSTEM	1	47	220	10,340	10,340	-
HARRIS	1011510	MARKS GLEN SUBDIVISION	1	101	120	12,120	12,120	-
HARRIS	1010100	MARY FRANCIS SUBDIVISION	3	1,905	103	196,215	196,215	-
HARRIS	1010379	MASON CREEK UTILITY DISTRICT	4	6,788	185	1,255,780	1,255,780	-
HARRIS	1011689	MAYDE CREEK MUD	2	5,747	168	965,496	965,496	-
HARRIS	1012982	MCFARLAND VILLAGE APARTMENTS	1	25	60	1,500	1,500	-
HARRIS	1012995	MCGEE PLACE	1	13	124	1,612	322	1,290
HARRIS	1010387	MEADOWHILL REGIONAL MUD	2	5,220	113	589,860	787,890	-
HARRIS	1010287	MEADOWLAKE ESTATES	1	459	85	39,015	7,803	31,212
HARRIS	1010279	MEMORIAL HILLS UTILITY DISTRICT	2	1,176	229	269,304	269,304	-
HARRIS	1011242	MEMORIAL MUD	2	6,156	110	677,160	677,160	-
HARRIS	1010148	MEMORIAL VILLAGES WATER AUTHORITY	5	9,645	438	4,224,510	844,902	3,379,608
HARRIS	1013245	MESQUITE MHP	1	1	86	86	86	-
HARRIS	1011107	MILLS ROAD MUD	3	4,837	108	522,396	522,396	-
HARRIS	1011718	MISSION BEND MUD 1	2	6,880	141	970,080	970,080	-
HARRIS	1011826	MISSION BEND MUD 2	2	7,667	156	1,196,052	1,196,052	-
HARRIS	1010288	MOBILE HOME ESTATES	3	514	86	44,204	44,204	-
HARRIS	1011685	MORTON ROAD MUD	2	3,067	127	389,509	389,509	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010728	MOUNT HOUSTON ROAD MUD	2	2,237	98	219,226	219,226	-
HARRIS	1010362	NEWPORT MUD	2	7,969	49	390,481	78,096	312,385
HARRIS	1010145	NITSCH & SON UTILITY	2	2,304	143	329,472	329,472	-
HARRIS	1011999	NORTH BELT FOREST SUBDIVISION WATER SYST	3	1,461	162	236,682	236,682	-
HARRIS	1011737	NORTH BELT UTILITY DISTRICT	2	1,850	139	257,150	257,150	-
HARRIS	1010298	NORTH FOREST MUD	1	1,350	138	186,300	186,300	-
HARRIS	1010331	NORTH GREEN MUD	3	2,955	94	277,770	277,770	-
HARRIS	1010745	NORTH PARK PUD	2	3,155	82	258,710	258,710	-
HARRIS	1010915	NORTH WOODS ESTATES	1	89	99	8,811	8,811	-
HARRIS	1010337	NORTHAMPTON MUD	3	3,828	215	823,020	823,020	-
HARRIS	1013449	NORTHEAST HARRIS COUNTY MUD 1 EDGEWOOD VILLAGE	0	178	124	22,072	-	22,072
HARRIS	1013448	NORTHEAST HARRIS COUNTY MUD 1 SHELDON RIDGE	0	89	124	11,036	-	8,829
HARRIS	1013077	NORTHGATE CROSSING MUD 1	1	1,332	151	201,132	201,132	-
HARRIS	1013078	NORTHGATE CROSSING MUD 2	1	3,069	151	463,419	463,419	-
HARRIS	1010117	NORTHLINE TERRACE SUBDIVISION	1	3,208	143	458,744	458,744	-
HARRIS	1011256	NORTHWEST FREEWAY MUD	3	2,665	83	221,195	221,195	-
HARRIS	1011649	NORTHWEST HARRIS COUNTY MUD 10	3	4,862	144	700,128	700,128	-
HARRIS	1011901	NORTHWEST HARRIS COUNTY MUD 12	1	2,474	92	227,608	227,608	-
HARRIS	1011600	NORTHWEST HARRIS COUNTY MUD 15	3	3,481	110	382,910	382,910	-
HARRIS	1011603	NORTHWEST HARRIS COUNTY MUD 16	1	2,380	113	268,940	268,940	-
HARRIS	1011927	NORTHWEST HARRIS COUNTY MUD 19	3	2,449	162	396,738	396,738	-
HARRIS	1011998	NORTHWEST HARRIS COUNTY MUD 20	2	2,116	114	241,224	68,869	172,355
HARRIS	1011744	NORTHWEST HARRIS COUNTY MUD 21	2	1,017	255	259,335	176,011	185,295
HARRIS	1011745	NORTHWEST HARRIS COUNTY MUD 22	0	3,338	107	357,166	-	255,195
HARRIS	1011746	NORTHWEST HARRIS COUNTY MUD 23	1	3,547	95	336,965	96,204	240,761
HARRIS	1012071	NORTHWEST HARRIS COUNTY MUD 24	2	1,034	106	109,604	31,292	78,312
HARRIS	1013258	NORTHWEST HARRIS COUNTY MUD 28	0	1,722	115	198,030	-	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1012293	NORTHWEST HARRIS COUNTY MUD 29	1	2,695	287	773,465	773,465	-
HARRIS	1012951	NORTHWEST HARRIS COUNTY MUD 30	1	3,006	199	598,194	170,784	427,410
HARRIS	1013034	NORTHWEST HARRIS COUNTY MUD 32	1	3,197	158	505,126	505,126	-
HARRIS	1012848	NORTHWEST HARRIS COUNTY MUD 36	2	1,993	350	697,550	697,550	-
HARRIS	1010884	NORTHWEST HARRIS COUNTY MUD 5	5	9,292	157	1,458,844	416,500	1,042,344
HARRIS	1011008	NORTHWEST HARRIS COUNTY MUD 6	1	1,820	125	227,500	64,951	162,549
HARRIS	1011599	NORTHWEST HARRIS COUNTY MUD 9	2	4,901	296	1,450,696	1,450,696	-
HARRIS	1010593	NORTHWEST PARK MUD	6	17,789	102	1,814,478	1,814,478	-
HARRIS	1012315	NOTTINGHAM COUNTRY MUD	2	6,886	182	1,253,252	1,253,252	-
HARRIS	1011633	OAK MANOR	1	186	119	22,134	22,134	-
HARRIS	1012981	OAKMONT PUD	1	1,441	125	180,125	180,125	-
HARRIS	1013066	OAKS OF ROSEHILL THE	2	93	247	22,971	22,971	-
HARRIS	1011803	OAKWOOD VILLAGE MOBILE HOME SUBDIVISION	1	164	108	17,712	17,712	-
HARRIS	1010870	ORANGE GROVE WATER SUPPLY	1	548	132	72,336	72,336	-
HARRIS	1013041	PARK FOREST WATER SYSTEM	1	228	135	30,780	30,780	-
HARRIS	1010192	PARKLAND ESTATES	2	186	126	23,436	23,436	-
HARRIS	1010750	PARKWAY UTILITY DISTRICT	1	6,196	85	526,660	105,332	421,328
HARRIS	1012281	PASADENA EL CARY ESTATES	0	288	198	57,024	-	57,024
HARRIS	1010751	PINE OAK FOREST WATER	1	105	230	24,150	24,150	-
HARRIS	1010535	PINE TRAILS UTILITY	1	6,338	111	703,518	-	703,518
HARRIS	1010901	PINE VILLAGE PUD	1	1,050	122	128,100	128,100	-
HARRIS	1010078	PITCAIRN WSC	1	221	117	25,857	25,857	-
HARRIS	1013097	PLAZA 290	1	510	183	93,330	93,330	-
HARRIS	1010384	PONDEROSA FOREST UTILITY DISTRICT	3	4,963	126	625,338	232,639	446,804
HARRIS	1010631	POSTWOOD MUD	1	2,771	80	221,680	221,680	-
HARRIS	1012986	POWDER MILL ESTATES	2	223	73	16,279	16,279	-
HARRIS	1010467	PRESTONWOOD FOREST UTILITY DISTRICT	2	3,817	285	1,087,845	310,580	777,265
HARRIS	1013036	PROVENCE WATER SYSTEM	1	244	55	13,420	13,420	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1013138	QUAIL OAK SUBDIVISION	1	68	95	6,460	6,460	-
HARRIS	1011475	QUAILWOOD WATER SYSTEM	1	77	95	7,315	7,315	-
HARRIS	1010196	RALSTON ACRES WATER SUPPLY CORPORATION	2	295	143	42,185	8,437	33,748
HARRIS	1011528	RAMBLEWOOD UTILITY & WSC	0	343	150	51,450	-	-
HARRIS	1012354	RANKIN ROAD WEST MUD	0	2,090	111	231,990	-	57,389
HARRIS	1010916	RED OAK TERRACE	1	83	109	9,047	9,047	-
HARRIS	1010872	REID ROAD MUD 1	3	6,482	162	1,050,084	1,050,084	-
HARRIS	1011928	REID ROAD MUD 2	2	3,218	151	485,918	485,918	-
HARRIS	1013074	REMINGTON MUD 1	2	13,562	100	1,356,200	312,816	1,043,384
HARRIS	1011834	RENN ROAD MUD	1	4,342	94	408,148	408,148	-
HARRIS	1010197	RESERVOIR ACRES SUBDIVISION	1	702	59	41,418	8,284	33,134
HARRIS	1012227	RICEWOOD MUD	1	4,950	162	801,900	801,900	-
HARRIS	1011929	RICHEY ROAD MUD	1	92	248	22,816	22,816	-
HARRIS	1010640	ROLAN HEIGHTS SUBDIVISION	1	29	50	1,450	290	1,160
HARRIS	1012877	ROLLING CREEK UTILITY DISTRICT	3	1,772	143	253,396	31,920	221,476
HARRIS	1010357	ROLLING FORK PUD	1	1,842	124	228,408	228,408	-
HARRIS	1011861	ROLLING OAKS	1	254	100	25,400	25,400	-
HARRIS	1010201	ROYALWOOD MUD	2	769	124	95,356	19,071	76,285
HARRIS	1010386	SAGEMEADOW UTILITY DISTRICT	2	6,313	90	568,170	113,634	454,536
HARRIS	1011071	SAN JACINTO BEND ESTATES	2	264	117	30,888	3,089	27,799
HARRIS	1010205	SEQUOIA IMPROVEMENT DISTRICT	1	1,428	114	162,792	162,792	-
HARRIS	1010388	SHASLA PUD	1	2,010	113	227,130	227,130	-
HARRIS	1010235	SHELDON ROAD MUD	3	1,571	78	122,538	26,715	98,030
HARRIS	1010877	SILVERWOODS SUBDIVISION	2	74	126	9,324	9,324	-
HARRIS	1011184	SOUTH TAYLOR LAKE VILLAGE WSC	0	140	99	13,860	-	13,860
HARRIS	1011911	SOUTHWEST HARRIS COUNTY MUD 1	1	1,534	94	144,196	28,839	115,357
HARRIS	1010389	SPANISH COVE PUD	1	266	225	59,850	59,850	-
HARRIS	1010654	SPENCER ROAD PUD	3	3,316	182	603,512	-	603,512

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1010334	SPRING CREEK FOREST	1	35	101	3,535	3,535	-
HARRIS	1010390	SPRING CREEK FOREST PUD	2	2,364	169	399,516	114,062	285,454
HARRIS	1011503	SPRING CREEK TRAILS	1	11	92	1,012	1,012	-
HARRIS	1010213	SPRING CREEK VALLEY ESTATES	3	319	73	23,287	23,287	-
HARRIS	1013261	SPRING MEADOWS MUD	0	2,920	60	175,200	-	175,200
HARRIS	1013017	SPRING WEST MUD	2	1,390	120	166,800	166,800	-
HARRIS	1010255	SPRINGMONT SUBDIVISION	2	132	162	21,384	21,384	-
HARRIS	1013103	STABLE GATES	1	473	157	74,261	74,261	-
HARRIS	1010216	STETNER ADDITION	1	80	120	9,600	9,600	-
HARRIS	1013187	SUMMER LAKE RANCH	1	286	142	40,612	40,612	-
HARRIS	1010292	SUNBELT FWSD HIGH MEADOWS SUBDIVISON	4	9,436	132	1,245,552	1,245,552	-
HARRIS	1010188	SUNBELT FWSD OAKGLEN SUBDIVISION	1	660	84	55,440	55,440	-
HARRIS	1010022	SUNBELT FWSD OAKWILDE SUBDIVISION	2	6,806	120	816,720	816,720	-
HARRIS	1010218	SWEA GARDENS ESTATES	1	55	81	4,455	4,455	-
HARRIS	1010220	TALL PINES UTILITY	2	254	123	31,242	31,242	-
HARRIS	1011865	TASFIELD	0	244	68	16,592	-	-
HARRIS	1010625	TATTOR ROAD MUD	1	4,839	117	566,163	566,163	-
HARRIS	1011226	TERRANOVA WEST MUD	1	2,078	174	361,572	103,229	258,343
HARRIS	1012978	THE COMMONS WATER SUPPLY INC	2	2,189	121	264,869	264,869	-
HARRIS	1013239	TIMBER CREEK ESTATES	1	29	127	3,683	3,683	-
HARRIS	1010447	TIMBERLAKE IMPROVEMENT DISTRICT	2	2,093	155	324,415	324,415	-
HARRIS	1010278	TIMBERLANE UTILITY DISTRICT	4	12,919	97	1,253,143	1,253,143	-
HARRIS	1012367	TIMBERWILDE MH SUBDIVISION	2	354	86	30,444	30,444	-
HARRIS	1011981	TOWER OAK BEND WSC	1	209	178	37,202	37,202	-
HARRIS	1010617	TRAIL OF THE LAKES MUD	2	6,359	103	654,977	654,977	-
HARRIS	1011521	TRAILWOOD SUBDIVISION	1	425	110	46,750	46,750	-
HARRIS	1012397	TREICHEL WOODS ESTATES	1	116	89	10,324	10,324	-
HARRIS	1010252	URBAN ACRES SUBDIVISION	2	109	100	10,900	10,900	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1011183	VILLA UTILITIES	1	65	42	2,730	546	2,184
HARRIS	1012795	VILLAGE OF NEW KENTUCKY	3	350	183	64,050	64,050	-
HARRIS	1013195	WALRAVEN SUBDIVISION	1	127	121	15,367	15,367	-
HARRIS	1011186	WAYNEWOOD PLACE CIVIC ASSOCIATION	2	193	210	40,530	40,530	-
HARRIS	1010925	WEST HARRIS COUNTY MUD 1	0	1,545	300	463,500	-	-
HARRIS	1012068	WEST HARRIS COUNTY MUD 10	2	6,829	121	826,309	826,309	-
HARRIS	1012858	WEST HARRIS COUNTY MUD 11	3	6,145	143	878,735	878,735	-
HARRIS	1012002	WEST HARRIS COUNTY MUD 14	0	2,819	113	318,547	-	318,547
HARRIS	1012001	WEST HARRIS COUNTY MUD 15	2	296	243	71,928	32,890	39,038
HARRIS	1012238	WEST HARRIS COUNTY MUD 17	1	2,225	168	373,800	373,800	-
HARRIS	1011029	WEST HARRIS COUNTY MUD 2 CHASE	1	3,587	93	333,591	333,591	-
HARRIS	1011825	WEST HARRIS COUNTY MUD 4	2	1,542	168	259,056	259,056	-
HARRIS	1013356	WEST HARRIS COUNTY MUD 5	1	487	87	42,369	42,369	-
HARRIS	1011258	WEST HARRIS COUNTY MUD 6	1	2,274	273	620,802	620,802	-
HARRIS	1012228	WEST HARRIS COUNTY MUD 7	1	4,313	64	276,032	276,032	-
HARRIS	1011798	WEST HARRIS COUNTY MUD 9	1	3,923	264	1,035,672	1,035,672	-
HARRIS	1010540	WEST MEMORIAL MUD	3	3,592	160	574,720	574,720	-
HARRIS	1010670	WEST MONTGOMERY UTILITY	2	1,714	114	195,396	195,396	-
HARRIS	1011930	WEST PARK MUD	2	1,076	162	174,312	174,312	-
HARRIS	1010277	WESTADOR MUD	1	3,227	230	742,210	211,901	530,309
HARRIS	1010028	WESTERN HOMES SUBDIVISION	3	878	140	122,920	122,920	-
HARRIS	1010230	WESTERN TRAILS SUBDIVISION	1	62	84	5,208	5,208	-
HARRIS	1010622	WESTGATE SUBDIVISION	2	158	68	10,744	10,744	-
HARRIS	1010635	WESTLAKE MUD 1	2	4,250	102	433,500	433,500	-
HARRIS	1010634	WESTON MUD	3	5,818	193	1,122,874	1,122,874	-
HARRIS	1011238	WHITE OAK BEND MUD	2	1,886	179	337,594	337,594	-
HARRIS	1010924	WINDFERN FOREST UTILITY DISTRICT	2	4,475	195	872,625	872,625	-
HARRIS	1010920	WINDWOOD WATER SYSTEM	1	203	305	61,915	61,915	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
HARRIS	1012015	WINTERHAVEN SUBDIVISION	2	92	232	21,344	21,344	-
HARRIS	1011237	WOODCREEK MUD	1	2,676	149	398,724	398,724	-
HARRIS	1010758	WOODLAND OAKS SUBDIVISION	1	6,919	143	989,417	989,417	-
MONTGOMERY	1700580	1485 LIMITED CRYSTAL SPRINGS WATER CO	1	18	86	1,548	1,548	-
MONTGOMERY	1700147	AFTON PARK WATER SYSTEM	1	130	102	13,260	13,260	-
MONTGOMERY	1700006	AIRPORT HEIGHTS	1	69	102	7,038	7,038	-
MONTGOMERY	1700187	ALLENDALE WATER SYSTEM	1	173	69	11,937	11,937	-
MONTGOMERY	1700131	ALLENWOOD SUBDIVISION	4	327	135	44,145	44,145	-
MONTGOMERY	1700171	ARROWHEAD LAKE & FRONTIER LAKE	2	222	91	20,202	20,202	-
MONTGOMERY	1700756	AUTUMN ACRES WATER SYSTEM	1	34	62	2,108	2,108	-
MONTGOMERY	1700708	BEAU VIEW UTILITIES	1	32	51	1,632	1,632	-
MONTGOMERY	1700678	BENDERS LANDING WATER PLANT 1 & 2	5	2,450	185	453,250	453,250	-
MONTGOMERY	1700290	BENNETT WOODS	2	387	69	26,703	26,703	-
MONTGOMERY	1700639	BIG OAKS RANCHETT SUBDIVISION	1	17	97	1,649	1,649	-
MONTGOMERY	1700316	BRIDGEPOINT SUBDIVISION	1	179	188	33,652	33,652	-
MONTGOMERY	1700601	BRUSHY CREEK UTILITY	2	169	106	17,914	17,914	-
MONTGOMERY	1700328	CANEY CREEK UTILITY	2	4	106	424	424	-
MONTGOMERY	1700065	CAPE MALIBU WSC	2	158	127	20,066	20,066	-
MONTGOMERY	1700279	CARRIAGE HILLS	2	1,609	154	247,786	247,786	-
MONTGOMERY	1700434	CHAPARRAL PLACE WATER SYSTEM	1	62	152	9,424	9,424	-
MONTGOMERY	1700008	CHATEAU WOODS MUD	5	873	92	80,316	80,316	-
MONTGOMERY	1700555	CIMARRON COUNTRY	2	948	128	121,344	121,344	-
MONTGOMERY	1700001	CITY OF CONROE	13	45,905	152	6,977,560	7,064,947	-
MONTGOMERY	1700592	CITY OF CUT AND SHOOT	4	8,848	154	1,362,592	1,362,592	-
MONTGOMERY	1700020	CITY OF MAGNOLIA	3	1,147	303	347,541	606,000	-
MONTGOMERY	1700022	CITY OF MONTGOMERY	3	515	192	98,880	98,880	-
MONTGOMERY	1700025	CITY OF OAK RIDGE NORTH	3	3,049	145	442,105	442,105	-
MONTGOMERY	1700026	CITY OF PANORAMA VILLAGE	3	2,701	204	551,004	551,004	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
MONTGOMERY	1700002	CITY OF SHENANDOAH	3	2,548	321	817,908	832,002	-
MONTGOMERY	1700087	CITY OF SPLENDORA	4	1,548	101	156,348	156,348	-
MONTGOMERY	1700003	CITY OF WILLIS	4	4,356	125	544,500	544,500	-
MONTGOMERY	1700304	CITY OF WOOD BRANCH VILLAGE	1	893	117	104,481	104,481	-
MONTGOMERY	1700437	CLEAR CREEK FOREST SECTION 12	3	1,219	84	102,396	102,396	-
MONTGOMERY	1700480	CLEAR WATER COVE INC	1	144	107	15,408	15,408	-
MONTGOMERY	1700589	CLOVER CREEK MUD	1	484	106	51,304	51,304	-
MONTGOMERY	1700318	COE COUNTRY	5	480	97	46,560	46,560	-
MONTGOMERY	1700225	CONROE BAY WATER SEWER SUPPLY	2	130	220	28,600	28,600	-
MONTGOMERY	1700416	CONROE RESORT	3	447	233	104,151	104,151	-
MONTGOMERY	1700152	CORINTHIAN POINT MUD 2	2	548	188	103,024	103,024	-
MONTGOMERY	1700680	CREEKSIDE ACRES WATER SYSTEM	1	141	48	6,768	6,768	-
MONTGOMERY	1700742	CREEKSIDE VILLAGE	2	1,456	94	136,864	136,864	-
MONTGOMERY	1700631	CRIGHTON RIDGE SUBDIVISION	3	1,291	135	174,285	174,285	-
MONTGOMERY	1700794	CRIGHTON WOODS SUBDIVISION	0	34	135	4,590	-	-
MONTGOMERY	1700781	CROWN RANCH SUBDIVISION	1	127	97	12,319	12,319	-
MONTGOMERY	1700096	CRYSTAL FOREST SUBDIVISION	3	677	77	52,129	52,129	-
MONTGOMERY	1700331	CRYSTAL SPRINGS SUBDIVISION	1	174	86	14,964	14,964	-
MONTGOMERY	1700622	CRYSTAL SPRINGS WATER COMPANY CHASEWOOD	1	109	67	7,303	7,303	-
MONTGOMERY	1700386	DECKER HILLS	5	569	72	40,968	40,968	-
MONTGOMERY	1700605	DECKER OAKS	1	410	83	34,030	34,030	-
MONTGOMERY	1700330	DECKER WOODS SUBDIVISION	3	538	86	46,268	46,268	-
MONTGOMERY	1700322	DEER GLEN WATER SYSTEM	4	1,698	86	146,028	146,028	-
MONTGOMERY	1700700	DEER RUN	2	273	88	24,024	24,024	-
MONTGOMERY	1700264	DEERWOOD SUBDIVISION	2	1,473	84	123,732	123,732	-
MONTGOMERY	1700690	DEL LAGO ESTATES UTILITY COMPANY	2	115	255	29,325	29,325	-
MONTGOMERY	1700143	DIAMOND HEAD WSC	2	168	155	26,040	26,040	-
MONTGOMERY	1700178	DOBBIN PLANTERSVILLE WSC 1	4	4,596	97	445,812	445,812	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
MONTGOMERY	1700129	DOGWOOD HILLS	3	603	101	60,903	60,903	-
MONTGOMERY	1700037	DOMESTIC WATER COMPANY ROYAL FOREST SUBD	3	1,467	70	102,690	102,690	-
MONTGOMERY	1700236	EAST MONTGOMERY COUNTY MUD 1	0	336	82	27,552	-	-
MONTGOMERY	1700283	EAST PLANTATION UTILITY DISTRICT	2	1,059	134	141,906	141,906	-
MONTGOMERY	1700617	ENCHANTED COVE WATER SYSTEM	1	112	82	9,184	9,184	-
MONTGOMERY	1700040	ENCHANTED FOREST	2	19	124	2,356	2,356	-
MONTGOMERY	1700702	ESTATES OF LEGENDS RANCH	1	862	103	88,786	88,786	-
MONTGOMERY	1700427	EVERETT SQUARE WINDCREST ESTATES	2	335	96	32,160	32,160	-
MONTGOMERY	1700011	FAR HILLS UTILITY DISTRICT	3	689	205	141,245	141,245	-
MONTGOMERY	1700042	FLAMINGO LAKES LOT OWNERS ASSOCIATION IN	1	30	79	2,370	2,370	-
MONTGOMERY	1700106	FOREST WOODS SUBDIVISION	1	98	97	9,506	9,506	-
MONTGOMERY	1700643	GRAND HARBOR WATER SYSTEM	3	1,191	281	334,671	334,671	-
MONTGOMERY	1700757	GRAND OAKS MUD	0	853	303	258,459	-	-
MONTGOMERY	1700665	GREENFIELD FOREST	1	105	96	10,080	10,080	-
MONTGOMERY	1700682	HARBORSIDE	1	158	255	40,290	40,290	-
MONTGOMERY	1700796	HARRIS MONTGOMERY COUNTIES MUD 386 MAY VALLEY	0	560	204	114,240	-	-
MONTGOMERY	1700588	HAVENSHIRE WATER SYSTEM	1	27	129	3,483	3,483	-
MONTGOMERY	1700013	HAZY HOLLOW EAST ESTATES	8	1,693	66	111,738	111,738	-
MONTGOMERY	1700121	HERITAGE OAKS SUBDIVISION	2	268	57	15,276	15,276	-
MONTGOMERY	1700173	HIDDEN FOREST ESTATES	1	152	70	10,640	10,640	-
MONTGOMERY	1700696	HIDDEN SPRINGS RANCH SUBDIVISION	1	265	91	24,115	24,115	-
MONTGOMERY	1700603	HIGH MEADOWS RANCH WATER SUPPLY	4	1,769	135	238,815	238,815	-
MONTGOMERY	1700676	HIGHLINE OAKS WATER UTILITY	1	197	84	16,548	16,548	-
MONTGOMERY	1700539	HILLGREEN SUBDIVISION WATER CO	1	134	154	20,636	20,636	-
MONTGOMERY	1700014	HULON LAKES SUBDIVISION	4	490	88	43,120	43,120	-
MONTGOMERY	1700576	INDIGO LAKES WATER SYSTEM	2	2,639	135	356,265	356,265	-
MONTGOMERY	1700651	INDIGO RANCH	1	571	160	91,360	91,360	-
MONTGOMERY	1700021	JOY VILLAGE	1	45	117	5,265	5,265	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
MONTGOMERY	1700005	KEENAN WSC	2	895	97	86,815	86,815	-
MONTGOMERY	1700228	KIPLING OAKS 1	5	662	76	50,312	50,312	-
MONTGOMERY	1700153	KIPLING OAKS AND TIMBERGREEN	5	1,031	76	78,356	78,356	-
MONTGOMERY	1700015	LAIRD ESTATES	1	51	117	5,967	5,967	-
MONTGOMERY	1700578	LAKE BONANZA WSC	2	1,500	85	127,500	127,500	-
MONTGOMERY	1700134	LAKE CONROE FOREST SUBDIVISION	2	438	85	37,230	37,230	-
MONTGOMERY	1700140	LAKE CONROE HILLS MUD	2	1,283	139	178,337	178,337	-
MONTGOMERY	1700543	LAKE CONROE VILLAGE	1	448	57	25,536	25,536	-
MONTGOMERY	1700041	LAKE CONROE WEST	1	79	101	7,979	7,979	-
MONTGOMERY	1700719	LAKE CREEK FALLS	1	234	82	19,188	19,188	-
MONTGOMERY	1700529	LAKE CREEK FOREST	1	628	110	69,080	69,080	-
MONTGOMERY	1700017	LAKE FOREST FALLS SUBDIVISION	3	167	93	15,531	15,531	-
MONTGOMERY	1700018	LAKE FOREST LODGE SUBDIVISION	4	1,046	129	134,934	134,934	-
MONTGOMERY	1700154	LAKE LORRAINE WS	2	18	173	3,114	3,114	-
MONTGOMERY	1700184	LAKE LOUISE SUBDIVISION	2	249	78	19,422	19,422	-
MONTGOMERY	1700713	LAKE SOUTH WSC	2	144	85	12,240	12,240	-
MONTGOMERY	1700624	LAKE WINDCREST WATER SYSTEM	5	2,306	159	366,654	366,654	-
MONTGOMERY	1700019	LAKELAND WATER SYSTEM	3	228	146	33,288	33,288	-
MONTGOMERY	1700414	LAKEVIEW POINTE APARTMENTS	1	504	85	42,840	42,840	-
MONTGOMERY	1700029	LAKEWOOD COLONY	1	116	86	9,976	9,976	-
MONTGOMERY	1700661	LAKEWOOD ON LAKE CONROE	2	21	188	3,948	3,948	-
MONTGOMERY	1700039	LAZY RIVER IMPROVEMENT DISTRICT	2	589	152	89,528	89,528	-
MONTGOMERY	1700198	LIVE OAK ESTATES	2	45	109	4,905	4,905	-
MONTGOMERY	1700148	LOCH NESS COVE SUBDIVISION WATER SYSTEM	1	106	103	10,918	10,918	-
MONTGOMERY	1700655	LONE STAR PUBLIC WATER SYSTEM	3	2,384	66	157,344	157,344	-
MONTGOMERY	1700183	MEACHEN MEADOWS SUBDIVISION WATER SYSTEM	1	114	87	9,918	9,918	-
MONTGOMERY	1700675	MILLERS CROSSING	1	99	134	13,266	13,266	-
MONTGOMERY	1700150	MINK BRANCH VALLEY	2	71	78	5,538	5,538	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
MONTGOMERY	1700142	MONTGOMERY COUNTY FWSD 6	2	181	100	18,100	18,100	-
MONTGOMERY	1700762	MONTGOMERY COUNTY MUD 112	1	233	305	71,065	71,065	-
MONTGOMERY	1700770	MONTGOMERY COUNTY MUD 115	0	1,763	140	246,820	-	-
MONTGOMERY	1700118	MONTGOMERY COUNTY MUD 15	2	2,581	149	384,569	384,569	-
MONTGOMERY	1700164	MONTGOMERY COUNTY MUD 16 WHITE OAK PLANT	1	424	139	58,936	58,936	-
MONTGOMERY	1700546	MONTGOMERY COUNTY MUD 18	2	3,035	281	852,835	852,835	-
MONTGOMERY	1700319	MONTGOMERY COUNTY MUD 19	3	2,093	128	267,904	267,904	-
MONTGOMERY	1700269	MONTGOMERY COUNTY MUD 24 COUNTRY COLONY	1	557	111	61,827	61,827	-
MONTGOMERY	1700139	MONTGOMERY COUNTY MUD 36	0	4,784	209	999,856	-	-
MONTGOMERY	1700332	MONTGOMERY COUNTY MUD 39	0	3,936	134	527,424	-	-
MONTGOMERY	1700308	MONTGOMERY COUNTY MUD 40	0	6,129	179	1,097,091	-	-
MONTGOMERY	1700320	MONTGOMERY COUNTY MUD 42	0	579	143	82,797	-	-
MONTGOMERY	1700348	MONTGOMERY COUNTY MUD 46	0	20,868	270	5,634,360	-	-
MONTGOMERY	1700458	MONTGOMERY COUNTY MUD 47	0	19,765	143	2,826,395	-	-
MONTGOMERY	1700489	MONTGOMERY COUNTY MUD 56	1	451	159	71,709	71,709	-
MONTGOMERY	1700090	MONTGOMERY COUNTY MUD 6	0	4,388	146	640,648	-	-
MONTGOMERY	1700470	MONTGOMERY COUNTY MUD 60	0	10,086	213	2,148,318	-	-
MONTGOMERY	1700554	MONTGOMERY COUNTY MUD 67	0	7,498	200	1,499,600	-	-
MONTGOMERY	1700169	MONTGOMERY COUNTY MUD 7	0	9,221	127	1,171,067	-	-
MONTGOMERY	1700176	MONTGOMERY COUNTY MUD 8	2	2,839	228	647,292	647,292	-
MONTGOMERY	1700581	MONTGOMERY COUNTY MUD 83	3	1,213	273	331,149	408,499	-
MONTGOMERY	1700743	MONTGOMERY COUNTY MUD 84	0	595	130	77,350	-	-
MONTGOMERY	1700717	MONTGOMERY COUNTY MUD 89	2	3,549	103	365,547	365,547	-
MONTGOMERY	1700220	MONTGOMERY COUNTY MUD 9	2	3,014	233	702,262	702,262	-
MONTGOMERY	1700716	MONTGOMERY COUNTY MUD 94	1	2,393	123	294,339	294,339	-
MONTGOMERY	1700746	MONTGOMERY COUNTY MUD 98	0	666	114	75,924	-	-
MONTGOMERY	1700749	MONTGOMERY COUNTY MUD 99	1	246	152	37,392	284,212	-
MONTGOMERY	1700115	MONTGOMERY COUNTY UD 2	2	1,600	193	308,800	308,800	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
MONTGOMERY	1700116	MONTGOMERY COUNTY UD 3	2	1,878	164	307,992	307,992	-
MONTGOMERY	1700286	MONTGOMERY COUNTY UD 4	2	2,769	224	620,256	620,256	-
MONTGOMERY	1700119	MONTGOMERY COUNTY WCID 1	4	2,794	105	293,370	293,370	-
MONTGOMERY	1700074	MONTGOMERY PLACE WATER SYSTEM	1	108	87	9,396	9,396	-
MONTGOMERY	1700638	MONTGOMERY TRACE WATER SYSTEM	5	592	129	76,368	76,368	-
MONTGOMERY	1700669	MOSTYN MANOR	2	427	152	64,904	64,904	-
MONTGOMERY	1700423	MOUNT PLEASANT VILLAGE WATER SYSTEM	1	1,094	152	166,288	166,288	-
MONTGOMERY	1700473	MOUNTAIN MAN	2	966	75	72,450	72,450	-
MONTGOMERY	1700101	NEW CANEY MUD	3	9,273	97	899,481	899,481	-
MONTGOMERY	1700623	NORTHCREST RANCH WATER SYSTEM	2	1,052	81	85,212	85,212	-
MONTGOMERY	1700160	NORTHWOOD WSC	2	399	101	40,299	40,299	-
MONTGOMERY	1700695	OAK TREE SUBDIVISION	1	191	100	19,100	19,100	-
MONTGOMERY	1700662	OLD MILL LAKE	2	271	305	82,655	82,655	-
MONTGOMERY	1700110	OLD TAMINA WSC	0	174	81	14,094	-	-
MONTGOMERY	1700628	PARADISE COVE WATER SYSTEM	1	267	220	58,740	58,740	-
MONTGOMERY	1700488	PATTON LAKE CLUB	1	36	117	4,212	4,212	-
MONTGOMERY	1700503	PATTON VILLAGE EAST WATER SYSTEM	1	641	75	48,075	48,075	-
MONTGOMERY	1700032	PATTON VILLAGE WEST WATER SYSTEM	1	565	78	44,070	44,070	-
MONTGOMERY	1700055	PEACH CREEK COLONY	1	108	117	12,636	12,636	-
MONTGOMERY	1700064	PEACH CREEK DAM & LAKE CLUB	1	158	69	10,902	10,902	-
MONTGOMERY	1700051	PEACH CREEK OAKS SUBDIVISION	1	111	81	8,991	8,991	-
MONTGOMERY	1700382	PINE LAKE SUBDIVISION NORTH WSC	1	44	173	7,612	7,612	-
MONTGOMERY	1700507	PINEHURST DECKER PRAIRIE WSC	1	1,150	83	95,450	95,450	-
MONTGOMERY	1700061	PINEY POINT SUBDIVISION	1	111	83	9,213	9,213	-
MONTGOMERY	1700114	PIONEER TRAILS SUBDIVISION	1	712	85	60,520	60,520	-
MONTGOMERY	1700245	PLEASANT FOREST SUBDIVISION	2	58	81	4,698	4,698	-
MONTGOMERY	1700060	POINT AQUARIUS MUD	3	1,678	188	315,464	315,464	-
MONTGOMERY	1700068	PORTER SUD	6	15,179	117	1,775,943	1,825,668	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
MONTGOMERY	1700161	PORTER TERRACE	1	374	83	31,042	31,042	-
MONTGOMERY	1700734	RANCH CREST SUBDIVISION	2	677	161	108,997	108,997	-
MONTGOMERY	1700334	RAYFORD ROAD MUD	2	7,996	103	823,588	823,588	-
MONTGOMERY	1700609	RED OAK RANCH WATER SYSTEM	2	453	153	69,309	69,309	-
MONTGOMERY	1700156	RIMWICK FOREST	2	190	107	20,330	20,330	-
MONTGOMERY	1700185	RIVER CLUB WATER CO	2	303	273	82,719	82,719	-
MONTGOMERY	1700028	RIVER PLANTATION MUD	3	2,013	165	332,145	332,145	-
MONTGOMERY	1700604	RIVERWALK SUBDIVISION	3	2,081	117	243,477	243,477	-
MONTGOMERY	1700590	ROGERS ROAD WATER SYSTEM	2	986	75	73,950	73,950	-
MONTGOMERY	1700684	ROLLING FOREST SUBDIVISION	1	146	97	14,162	14,162	-
MONTGOMERY	1700058	ROLLING HILLS OAKS SUBDIVISION	2	94	126	11,844	11,844	-
MONTGOMERY	1700071	ROMAN FOREST CONSOLIDATED MUD	1	1,488	120	178,560	216,069	-
MONTGOMERY	1700238	ROMAN FOREST PUD 3	0	27	121	3,267	-	-
MONTGOMERY	1700237	ROMAN FOREST PUD 4	0	30	223	6,690	-	-
MONTGOMERY	1700410	RUSTIC OAKS SUBDIVISION	1	41	165	6,765	6,765	-
MONTGOMERY	1700378	SADDLE & SURREY ACRES WSC	1	51	194	9,894	9,894	-
MONTGOMERY	1700197	SAN JACINTO RIVER AUTHORITY	36	-	-	-	16,979,984	-
MONTGOMERY	1700327	SAN JO UTILITIES	1	17	96	1,632	1,632	-
MONTGOMERY	1700565	SENDERA LAKE ESTATES	3	555	165	91,575	91,575	-
MONTGOMERY	1700577	SENDERA RANCH	2	989	138	136,482	136,482	-
MONTGOMERY	1700083	SHADY ACRES	0	22	66	1,452	-	-
MONTGOMERY	1700031	SHADY BROOK ACRES	1	93	70	6,510	6,510	-
MONTGOMERY	1700632	SHADY OAKS ESTATES	2	176	97	17,072	17,072	-
MONTGOMERY	1700763	SONOMA RIDGE-MCCALL SOUND	1	66	91	6,006	6,006	-
MONTGOMERY	1700073	SOUTHERN MONTGOMERY COUNTY MUD	4	6,272	291	1,825,152	1,825,152	-
MONTGOMERY	1700133	SPRING CREEK UTILITY DISTRICT	1	6,370	57	363,090	363,090	-
MONTGOMERY	1700033	SPRING FOREST SUBDIVISION	2	699	58	40,542	40,542	-
MONTGOMERY	1700097	STANLEY LAKE MUD	1	2,361	155	365,955	365,955	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
MONTGOMERY	1700677	STILLWATER ESTATES	1	151	97	14,647	14,647	-
MONTGOMERY	1700611	STONECREST RANCH	1	200	161	32,200	32,200	-
MONTGOMERY	1700102	STONEHEDGE ESTATES	1	28	154	4,312	4,312	-
MONTGOMERY	1700686	SUNRISE RANCH	1	39	73	2,847	2,847	-
MONTGOMERY	1700621	TEXABA SUBDIVISION	1	587	88	51,656	51,656	-
MONTGOMERY	1700744	TEXAS LANDING UTILITIES GOODE CITY	1	82	70	5,740	5,740	-
MONTGOMERY	1700207	TEXAS NATIONAL MUD	1	575	694	399,050	399,050	-
MONTGOMERY	1700626	THE OAKS	1	24	424	10,176	10,176	-
MONTGOMERY	1700309	THE WOODLANDS METRO CENTER MUD	0	698	321	224,058	-	-
MONTGOMERY	1700471	THE WOODLANDS MUD 2	0	711	297	211,167	-	-
MONTGOMERY	1700635	THOUSAND OAKS	2	809	204	165,036	165,036	-
MONTGOMERY	1700728	TIMBER LINE ESTATES	2	6	90	540	540	-
MONTGOMERY	1700697	TIMBER OAKS CROSSING	2	142	67	9,514	9,514	-
MONTGOMERY	1700612	TIMBERLAND ESTATES	3	861	60	51,660	51,660	-
MONTGOMERY	1700641	TIMBERLOCH ESTATES	1	489	78	38,142	38,142	-
MONTGOMERY	1700317	TOWERING OAKS AND ROSEWOOD HILLS SUBDIVI	6	1,478	91	134,498	134,498	-
MONTGOMERY	1700317	TOWERING OAKS AND ROSEWOOD HILLS SUBDIVI	6	1,478	91	134,498	134,498	-
MONTGOMERY	1700112	TOWN OF WOODLOCH	2	755	108	81,540	81,540	-
MONTGOMERY	1700752	VALLEY RANCH MUD 1	0	425	117	49,725	-	-
MONTGOMERY	1700694	VISTA VERDE WATER SYSTEMS	1	66	173	11,418	11,418	-
MONTGOMERY	1700128	WALNUT SPRINGS	3	487	91	44,317	45,769	-
MONTGOMERY	1700208	WASHINGTON COUNTY RAILROAD	2	397	72	28,584	28,584	-
MONTGOMERY	1700201	WESTWOOD I & II	1	1,411	72	101,592	101,592	-
MONTGOMERY	1700291	WESTWOOD NORTH WSC	4	1,982	96	190,272	190,272	-
MONTGOMERY	1700066	WHISPERING PINES	3	376	78	29,328	29,328	-
MONTGOMERY	1700616	WHITE OAK ESTATES WSC	2	1,183	92	108,836	108,836	-
MONTGOMERY	1700613	WHITE OAK HILLS	1	401	71	28,471	28,471	-
MONTGOMERY	1700670	WHITE OAK RANCH SECTION ONE	1	149	152	22,648	22,648	-

(1) COUNTY	(2) PWS ID	(3) PWS NAME	(4) NUMBER SOURCE WELLS	(5) 2010 POPULATION	(6) GPCD	(7) TOTAL WATER DEMAND (GAL/DAY)	(8) GW DEMAND ON OWN SYSTEM (GAL/DAY)	(9) SURFACE WATER DEMAND (GAL/DAY)
MONTGOMERY	1700036	WHITE OAK VALLEY ESTATES	3	622	63	39,186	39,186	-
MONTGOMERY	1700466	WINCHESTER PLACE	2	78	68	5,304	5,304	-
MONTGOMERY	1700481	WOODHAVEN ESTATES	3	74	66	4,884	4,884	-
MONTGOMERY	1700080	WOODLAND LAKES ESTATES WSC	2	218	161	35,098	35,098	-
MONTGOMERY	1700648	WOODLAND OAKS SUBDIVISION	3	2,270	72	163,440	163,440	-
MONTGOMERY	1700657	WOODLAND RANCH	1	250	92	23,000	23,000	-
MONTGOMERY	1700075	WOODRIDGE ESTATES WATER SYSTEM	1	174	100	17,400	17,400	-
MONTGOMERY	1700758	YESTERDAYS CROSSING	1	16	132	2,112	2,112	-

metrostudy
Housing Starts Here

3100 Wilcrest Ave, Suite 125
Houston, Texas 77042

phone 713.622.9909 ext. 126
fax 713.622-4834
email bcolliander@metrostudy.com
web www.metrostudy.com

January 6, 2012

Mr. Bill J. Thaman
Project Manager – Water Resources
Freese & Nichols
3100 Wilcrest Ave, Suite 200
Houston, TX 77042

Dear Bill,

Attached are the final annual population projections by census tract for the Houston Galveston Subsidence District (HGSD) 1999 Regulatory Plan Update: Work Order 4. The following pages will outline Metrostudy's purpose, methodology, and commentary on the key drivers of population growth within the surveyed area. The survey region includes the following counties; a map is shown on page 12:

- **Harris County**
- **Montgomery County**
- **Fort Bend County** – *Excluding Census Tract 6758*
- **Brazoria County** – *Excluding the Coastal Census Tracts*
- **Galveston County** – *Excluding the Coastal Census Tracts and Galveston Island*

In addition to the attached report, Metrostudy has provided digital copies of the projections to Freese and Nichols, Inc. to be incorporated with University of Houston's decadal population projections for the larger region H population projections.

Please call us at your convenience with any comments or questions regarding this report or any other matter relevant to your real estate market research needs.

Best regards,
Signed Electronically

Brad Colliander
Senior Market Analyst
Metrostudy, Consulting

COPYRIGHT © 2012

POLICY STATEMENT AND GUIDELINES USES OF METRO/STUDY DATA

The use of the data provided to sponsors of a METRO/STUDY Report is subject to the Copyright of American METRO/STUDY Corporation. The commercial use of METRO/STUDY data in the preparation of consulting reports, studies, appraisals, analysis or other types of consulting services, rendered for a fee, is strictly prohibited unless the sponsor has received **specific written approval** from a principal of American METRO/STUDY Corporation to utilize METRO/STUDY data for commercial purposes.

The reproduction of METRO/STUDY data, by electrostatic means through the use of copier or photographic or laser technology, or by electronic means through the use of computers, including computer storage, laser disc storage or other data processing oriented means is prohibited by our Copyright unless the sponsor has received specific written approval of such reproduction from a principal of American METRO/STUDY Corporation. The prohibition against duplication of METRO/STUDY data includes **all of the data contained within the report**, whether historical or current, whether analytical or specific.

The distribution or sharing of METRO/STUDY data with persons or entities who are not immediate employees or principals of the sponsoring entity is prohibited. This prohibition includes the loaning of METRO/STUDY data to outside persons or entities for any purpose, including the distribution of information to appraisers or consultants, to the news media, from lending institutions to their borrowers or from borrowers to their lenders, and between joint venture partners where one entity/partner is a METRO/STUDY sponsor and one entity/partner is not. While the distribution of METRO/STUDY data under this paragraph constitutes a violation of our Copyright**, the acceptance of such data by a non-sponsor immediately obligates that non-sponsor for the full cost of a sponsorship covering the period of time reflected in the data so distributed and received**.

The above clarification statements are in no way intended to limit the Copyright held by American METRO/STUDY Corporation, but are provided for the benefit of our sponsors in order to clarify the restrictions with respect to these three issues.

TABLE OF CONTENTS

METROSTUDY QUALIFICATIONS

Metrostudy is the leading provider of primary and secondary market information to the housing and related industries nationwide. In addition to providing information, the company is recognized for its consulting expertise on development, marketing and economic issues, and is a key source of research studies evaluating the marketability of residential and commercial real estate projects. Services are offered through an extensive network of offices strategically located in major metropolitan areas throughout the country. The company is based in Houston, Texas, and was established in 1975 by founders Michael Castleman, Sr. and Michael Inselmann.

When you partner with Metrostudy, we guarantee that you will know your market. Our research offers the most complete, accurate, and useful information available. And we not only provide the information -- we can analyze what it means, and help you apply it to your business.

Our research.

Metrostudy maintains the country's largest database of primary housing market information, using hundreds of dedicated field researchers and investing millions of dollars annually. Our researchers drive the streets of every platted new home subdivision, inspect every home site, and record primary data on housing activity every 90 days. You'll have the most complete and accurate information on undeveloped and vacant developed lots, housing starts and closings, product and pricing.

We then combine our research with secondary research -- data we obtain from other sources on future developments, demographics, job growth, and the economy. We then deliver all information to our clients via our line of Metrosearch products -- cutting edge computer applications so you can sort information, run reports, and create graphs and thematic maps on Market Maps you define, from one subdivision to an entire MSA.

Our analysis.

Metrostudy's consulting team will help your organization to be results-oriented and on-target. Using our research, marketing, and sales expertise, we'll deliver a highly personalized service with clear and relevant analysis from the best data available. We immerse ourselves in your marketplace, and we'll be attentive to your particular needs.

We're here to help you understand how to minimize risk and maximize profits for your business, so you can make decisions with confidence.

Metrostudy's consulting team has completed thousands of residential and commercial studies for builders, developers, lenders, Wall Street opportunity funds, retailers, utilities, and governmental agencies across the country, including 18 of the top 20 residential builders. We produce everything from quick preliminary analyses to fully documented studies, customized to your needs. For a complete list of major residential study types offered, see our Consulting Information.

COMPANY PRINCIPLES

Mike Inselmann
President
Metrostudy

Mr. Inselmann is co-founder and President of Metrostudy. With a finger on the pulse of the housing market, Inselmann has become a trusted advisor to his clients, a respected source of information for local and national media and a speaker of national note. He covers front-burner issues facing cities across the nation - from demographic changes and their impact on local markets to Smart Growth and New Urbanism. A widely respected authority on housing supply/demand characteristics, he is a primary source of information about housing trends for the National Association of Home Builders, as well as local and state home builder associations and governmental planning agencies.

A native of San Antonio, Inselmann is a graduate of Rice University. Active in community and industry affairs, he has served as a member of the board of directors of the Greater Houston Builders Association, and is a member of the National Association of Home Builders, the American Marketing Association, and the Urban Land Institute. In the past, he served on the Steering Committee of the Urban Land Institute to establish a professional association of real estate market analysts.

Mike Castleman
CEO
Metrostudy

Michael S. Castleman is Chairman of the Board and CEO of Metrostudy. Mr. Castleman is a 1965 graduate of the Business School of the University of Texas at Austin, Texas; he also attended South Texas College of Law, in Houston, Texas, in 1971 and 1972. With a background in banking, marketing, strategic planning and real estate consulting, Mr. Castleman co-founded American METRO/STUDY Corporation, now Metrostudy, for the purpose of conducting housing market research and providing accurate economic and market information to companies associated with the housing industry. He brought into the firm a thorough knowledge of real estate development, market analysis, and planning, which enabled him to provide valuable analysis of housing markets during a time of rapid economic expansion and contraction.

Since the company's inception in Houston, Texas in 1975, Mr. Castleman has expanded the availability of Metrostudy's accurate housing market information to major housing markets throughout the U.S.

Mr. Castleman's expertise includes strategic planning and forecasting housing market trends. Mr. Castleman has played an important role in helping Metrostudy clients anticipate changes in market conditions, before these conditions cause a negative impact on the clients' business. Mr. Castleman has also prepared feasibility studies and market studies for residential developments which range in size from fifty lots to more than 10,000 acres.

In addition to expanding Metrostudy geographically, Mr. Castleman has enhanced the information provided to the firm's clients by combining the availability of Metrostudy housing market data with public sector data and computerized mapping services, aerial photography and demographic data in the company's proprietary software program (**Metrosearch**) that provides Metrostudy clients with an electronic toolbox for use in managing the risks associated with real estate and the housing industry. Many of these software features are also available to Metrostudy clients through ***Metrosearch On-Line***.

PARTICIPATING PERSONNEL

Jack Inselmann
Vice President
US Central Division

Jack Inselmann, Vice President, US Central Division, is responsible for Metrostudy's Austin, Chicago, Dallas/Ft. Worth, Houston, and San Antonio markets. Over the past seventeen years, Mr. Inselmann has gained a reputation in the San Antonio and Austin housing industry for thorough analysis and thoughtful insight into the many factors that affect the outlook for the local housing and real estate markets in those cities. He regularly meets and consults with over 100 home builders, lenders, private investors and institutions concerning trends in the Austin and San Antonio economies and their effect on real estate values and the demand for housing in those markets.

Mr. Inselmann frequently speaks to industry and professional groups interested in his unique insight into the current status of the industry and his accurate forecasts of future trends. He is selected annually to deliver the housing forecast for the San Antonio market by the Greater San Antonio Builders Association, and has participated on discussion panels with numerous trade groups including the Greater San Antonio Board of Realtors, the San Antonio/Austin Mortgage Bankers Association, the Texas Capital Area Builders Association and others. A native of San Antonio, Mr. Inselmann is a graduate of Trinity University. He serves on the board of directors of the Greater San Antonio Builders Association and is involved with the YMCA and the Northside Suburban Little League Association. In the past, he has served the community as a member of the City Planning Commission of San Antonio.

David Jarvis
Director
Houston Market

Jarvis graduated from DePaul University with a B. A. in marketing and holds the Certified Commercial Investment Member (CCIM) designation. In 2000, he was admitted to the Institute of Residential Marketing (IRM) of the National Association of Home Builders.

His designation as a Member of the Institute of Residential Marketing (MIRM) is based on a combination of professional education and experience in the real estate industry.

With over 25 years of experience in the sale, marketing, management and development of residential real estate, David Jarvis is respected for his real-world experience as well as the extensive primary research he brings to the table. Utilizing Metrostudy's data base and conducting extensive research targeted to the specific needs of home builders, developers, and lenders, Jarvis assists clients in the development and implementation of marketing and sales management strategies and model home development and merchandising.

He has received numerous marketing and sales awards, including Sales and Marketing Director of the Year for the Greater Houston Builders Association; Sales Manager of the Year, also for the Greater Houston Builders Association; Sales Manager of the Year for the Dallas Homebuilders Association; and Regional Marketing Director of the Year for the National Association of Home Builders. Jarvis speaks frequently on sales and marketing techniques at industry trade conferences and events.

<u>Brad Colliander</u>
Senior Market Analyst
Metrostudy, Consulting

Brad Colliander is a Senior Market Analyst with Metrostudy Texas Consulting. Mr. Colliander is a graduate of Texas A&M University, where he received a Masters Degree in Real Estate through the Mays School of Business. Mr. Colliander first worked for Metrostudy in 2004, as part of a professional internship and joined Metrostudy full-time following graduation in 2005. Mr. Colliander’s real estate career has grown over the years, gaining professional expertise in all commercial and residential facets of the real estate industry.

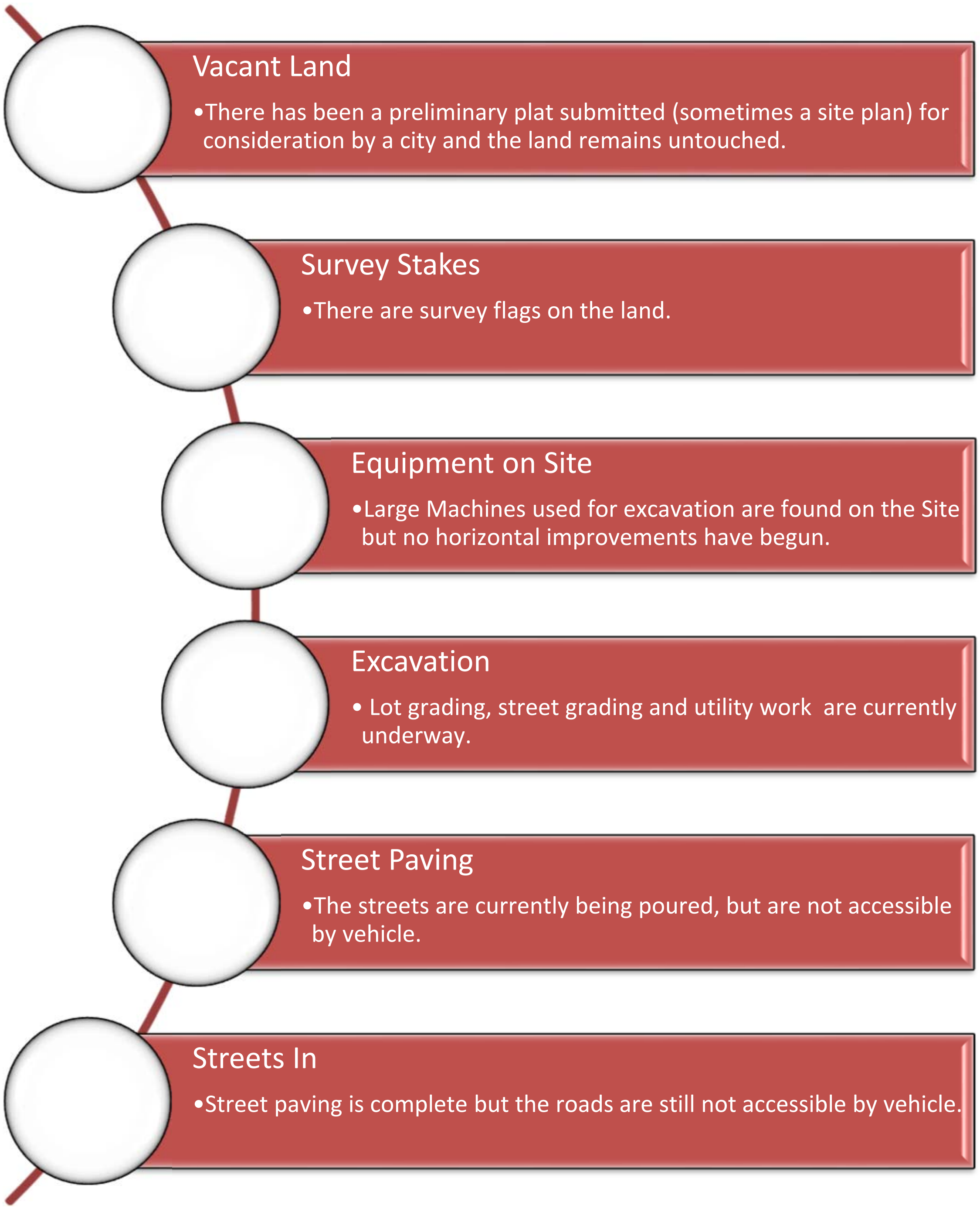
Since joining Metrostudy, he has completed and delivered hundreds of custom market studies throughout the state of Texas focusing on single-family and multi-family developments. Mr. Colliander has consulted with his clients on a wide variety services which include site selection, product positioning, product development, market demand analysis, lot pricing, business plan forecasts, and population and household projections.

METROSTUDY SURVEY PROCESS:

In order to create a household and population forecast for a given region, Metrostudy utilized its proprietary database of single-family housing activity. The creation of new households is the primary reflection of past and future population growth. Metrostudy's database is established upon a quarterly survey of all new single-family residential development in the study area. Metrostudy's surveyors visually inspect all known current and future developments and account for all stages of development activity within each subdivisions. Residential development activity is tracked for each subdivision from its conceptual stages through build-out. Metrostudy's database has over 35 years of history, giving us a unique ability to monitor the supply and demand characteristics for new household creations. Our longstanding presence within Houston and our extensive knowledge of the local housing market enables us to produce accurate household projections. This information is tracked within a Geographic Information System (GIS) Database at the subdivision level.

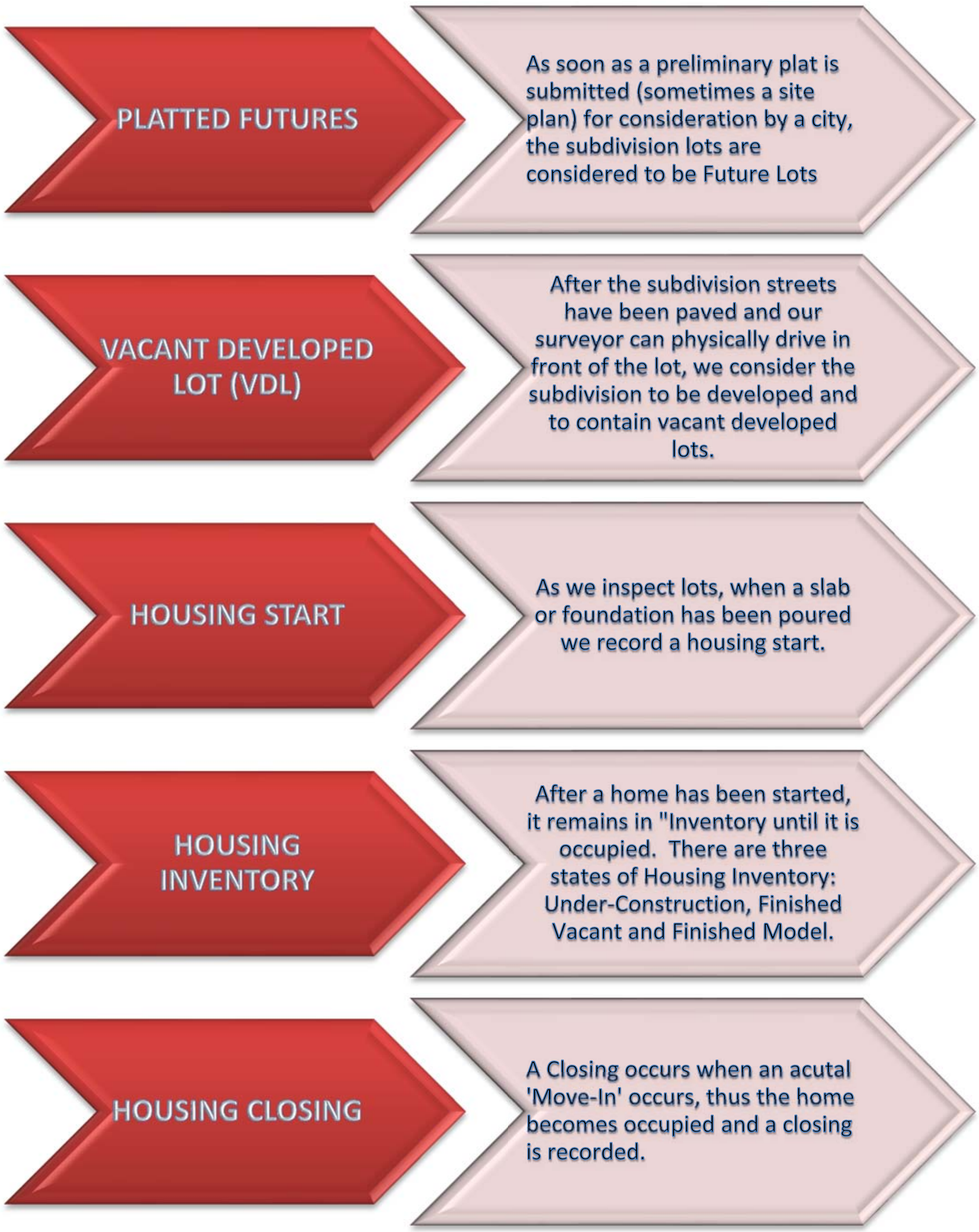
There are two cycles that Metrostudy tracks, the land/lot development and the new home development process. The land development cycle starts with the platted future lots. Platted Future lots are when a plat or a site plan has been submitted to the city or county for consideration. It is from this point that Metrostudy's survey team begins the quarterly survey process and tracts the development of the land through the various stages of development.

Figure 1: Land Development Process



Once a lot reaches the vacant developed lot stage, the new home survey process begins. A vacant developed lot is ready to accommodate a housing start. At the end of this process an occupied home is generated.

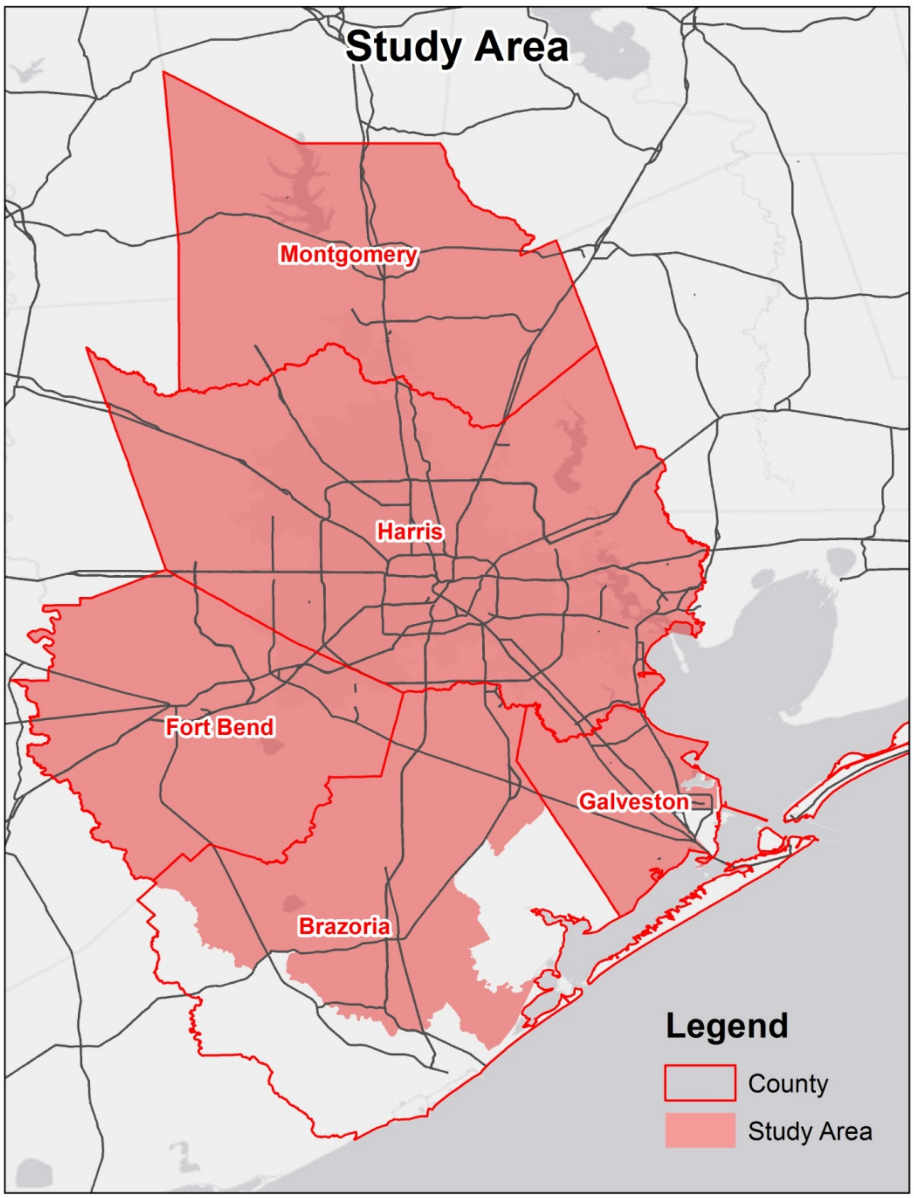
Figure 2: New Home Survey Process



PURPOSE

Metrostudy is working as a sub-contractor for Freese and Nichols in conjunction with Dr. Steven Craig from the University of Houston to provided updated population projections for the Houston-Galveston Subsidence District (HGSD). Metrostudy was retained to provide annual population projections by census tract from 2010 to 2020 for Brazoria, Fort Bend, Galveston, Harris and Montgomery Counties excluding some of the outlying census tracts as shown on the following page (the study area).

Figure 3: Study Area Map



METHODOLOGY

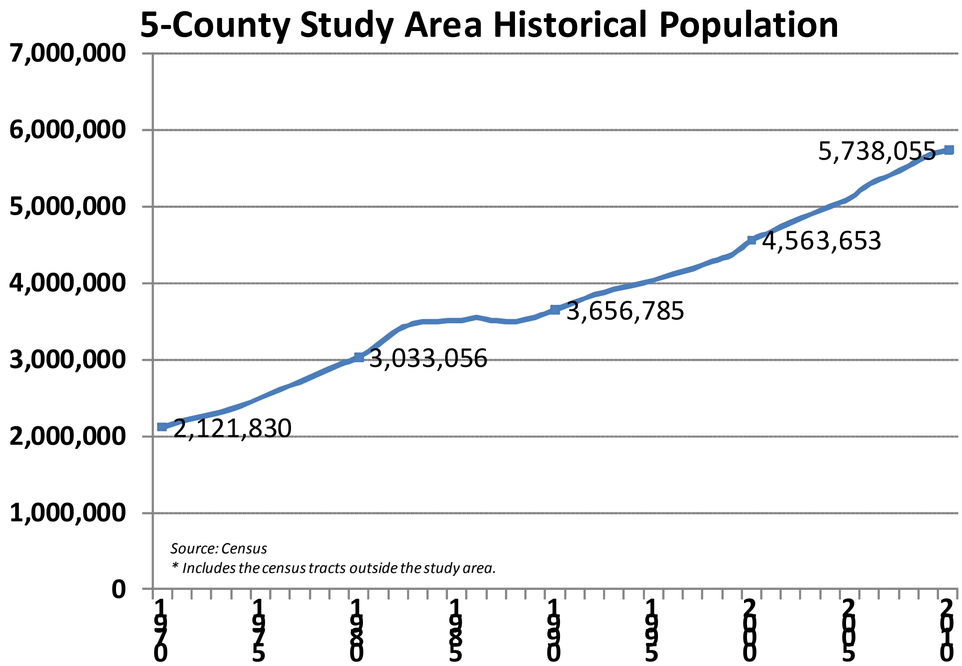
The following outline identifies the steps and methodology that Metrostudy took to generate the population forecasts to be utilized by Freese & Nichols for developing water demand tabulations for the HGSD. Metrostudy will provide annual population values for all the census tracts in the Study Area.

In addition to Metrostudy's Primary Housing Survey that was referenced above, secondary resources of information were also utilized. These secondary sources included the Census, Apartment Data Services, local land developers and engineers, and representatives from planning and zoning offices throughout the area and the Houston-Galveston Area Council (H-GAC).

Projecting Household Growth – County Control Totals

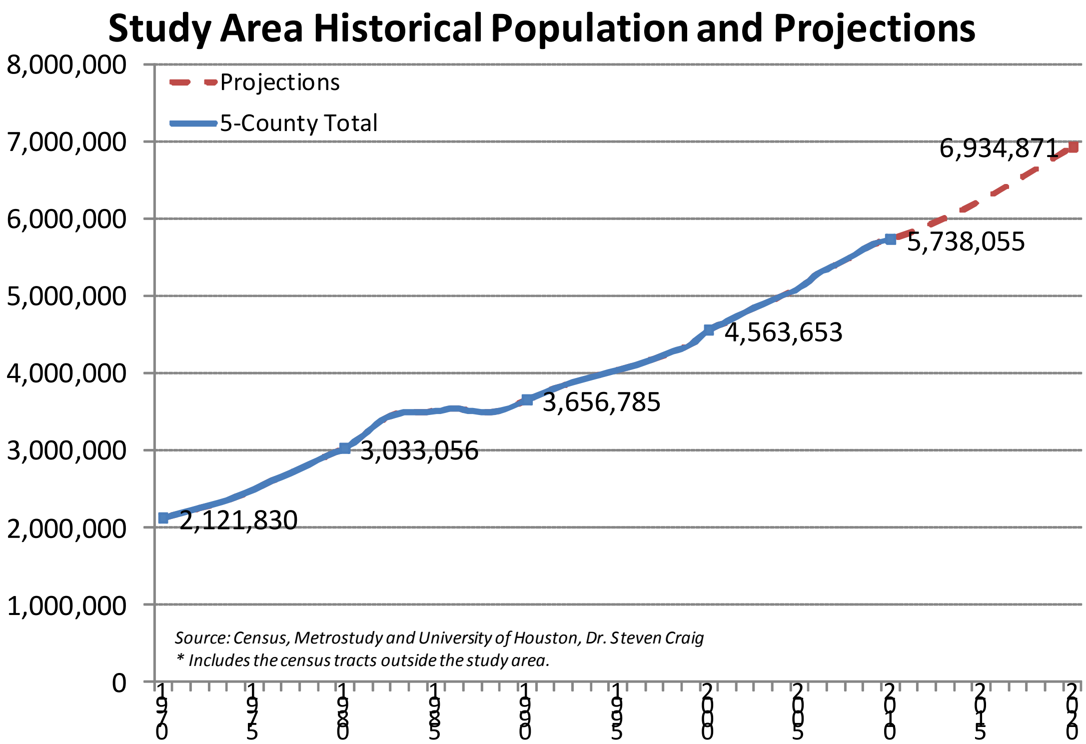
Metrostudy's first step was to examine past population growth for the Greater Houston Area and each of the surveyed counties. These trends were analyzed to provide a foundation or a control total for the population growth within each county. Metrostudy worked with Dr. Steven Craig at the University of Houston to help derive these county control totals. The following chart shows the historical population growth for the 5-county region from 1970 to 2010, with the decennial census numbers displayed.

Figure 4: Study Area Historical Population



After analyzing all of the pertinent local and national economic trends and comparing it to other third party population projections, the following population projections were derived as control totals for the study area. For the census tracts in Brazoria and Galveston Counties that were outside Metrostudy's study area, we substituted the 2020 population projections by Dr. Steven Craig from the University of Houston were utilized.

Figure 5: Study Area Projected Population



Analyzing Past Population to Household Growth Ratios

Metrostudy's next step was to analyze historical population and household growth as reported by the Census Bureau. Since 1970, the 5-county study area has grown from 2.1 million people to 5.7 million people in 2010, resulting in an annualized growth rate of 2.5%. However, the pace at which Houston has grown has slowed slightly to 2.3% annually over the past 20-years from 1990 to 2010.

Based on this information, Metrostudy calculated the number of new people it took to generate one new occupied household from 1990 to 2010, to determine the household formation rate for the study area and each county. This rate was used to convert the projected household growth to projected population growth. The table below shows the calculation for the study area.

Figure 6: Population to New Occupied Household Growth Rate For Study Area

$$\textit{New Occupied Household Rate} = \frac{(2010\ Population - 1990\ Population)}{(2010\ Occupied\ Households - 1990\ Occupied\ Households)}$$

$$\textit{Study Area} = \frac{5{,}738{,}055 - 3{,}634{,}927}{2{,}000{,}627 - 1{,}305{,}905} = \mathbf{3.02729}\ People\ per\ New\ Occupied\ Household$$

Based on this information, Metrostudy calculated the number of new people it took to generate one new occupied household from 1990 to 2010, to determine the household formation rate, for each county. This rate was used to convert the projected household growth to projected population growth.

Figure 7: Population to New Occupied Household Growth Rate By County

$$\textit{Brazoria} = \frac{313{,}166 - 191{,}707}{106{,}589 - 64{,}019} = \mathbf{2.85315}\ People\ per\ New\ Occupied\ Household$$

$$\textit{Fort Bend} = \frac{585{,}375 - 225{,}421}{187{,}384 - 70{,}424} = \mathbf{3.07758}\ People\ per\ New\ Occupied\ Household$$

$$\textit{Galveston} = \frac{291{,}309 - 217{,}399}{108{,}969 - 81{,}451} = \mathbf{2.68587}\ People\ per\ New\ Occupied\ Household$$

$$\textit{Harris} = \frac{4{,}092{,}459 - 2{,}818{,}199}{1{,}435{,}155 - 1{,}026{,}448} = \mathbf{3.11778}\ People\ per\ New\ Occupied\ Household$$

$$\textit{Montgomery} = \frac{455{,}746 - 182{,}201}{162{,}530 - 63{,}563} = \mathbf{2.76400}\ People\ per\ New\ Occupied\ Household$$

Projecting Household Growth – Single-Family

After the control totals were analyzed and the new population to occupied household ratio was calculated we started to project household growth within the study area. Metrostudy's projections started by looking at the historical single-family housing starts and closings trends for each of the subdivisions within our proprietary database. These historical trends allow Metrostudy to project the pace at which new homes will be closed (occupied) during the next 10-years. In addition, we also looked at the existing vacant developed lot supply as of 2010 to determine the extent and location of housing activity over the next ten years. It is Metrostudy's expectation, especially in today's economic climate when financing for lot development is difficult to achieve, that the existing lot supply will be absorbed first, prior to the development of raw land.

Metrostudy analyzed the Houston-Galveston Area Council (H-GAC) 2008 land use layer to determine the parcels that are developable and classified as "vacant" or "farm land". These parcels where then visually verified by using 2010 Bing Aerials to determine if any of these parcels had been developed since the land use layer was created.

Once the historical trends are analyzed and the existing lot supply is obtained, Metrostudy began to project the new households for each subdivision throughout the projection period. Regional developments such as the construction of the Grand Parkway and the opening of the Exxon campus were also taken into consideration in projecting new households. These projects have the potential to impact not only the amount of population growth Houston can achieve, but where the people can live.

In the end, Metrostudy ended up with an annual new household growth projection by subdivision for each of the active, future and concept subdivisions throughout the study area.

Projecting Household Growth – Multi-Family

Next, Metrostudy focused on analyzing the multi-family growth within the study area. Metrostudy utilized Apartment Data Services, a local apartment data service company. Apartment Data Services provides a macro-market analysis of all know apartment communities within the Greater Houston Area. On a monthly basis, Apartment Data Services tracts the projects that are under-construction and proposed as well as tracts the changes in occupancy and absorption rates for the existing multi-family projects throughout Houston. By analyzing the pace of construction and rate of absorption for these apartment units allows Metrostudy to project future multi-family projects throughout the study area. To help assist with the location of future multi-family projects, Metrostudy reviewed many of the larger planned communities to determine if any multi-family projects are planned. To help understand timing on these projects, Metrostudy also interviewed the developers of these projects for their estimations on timing.

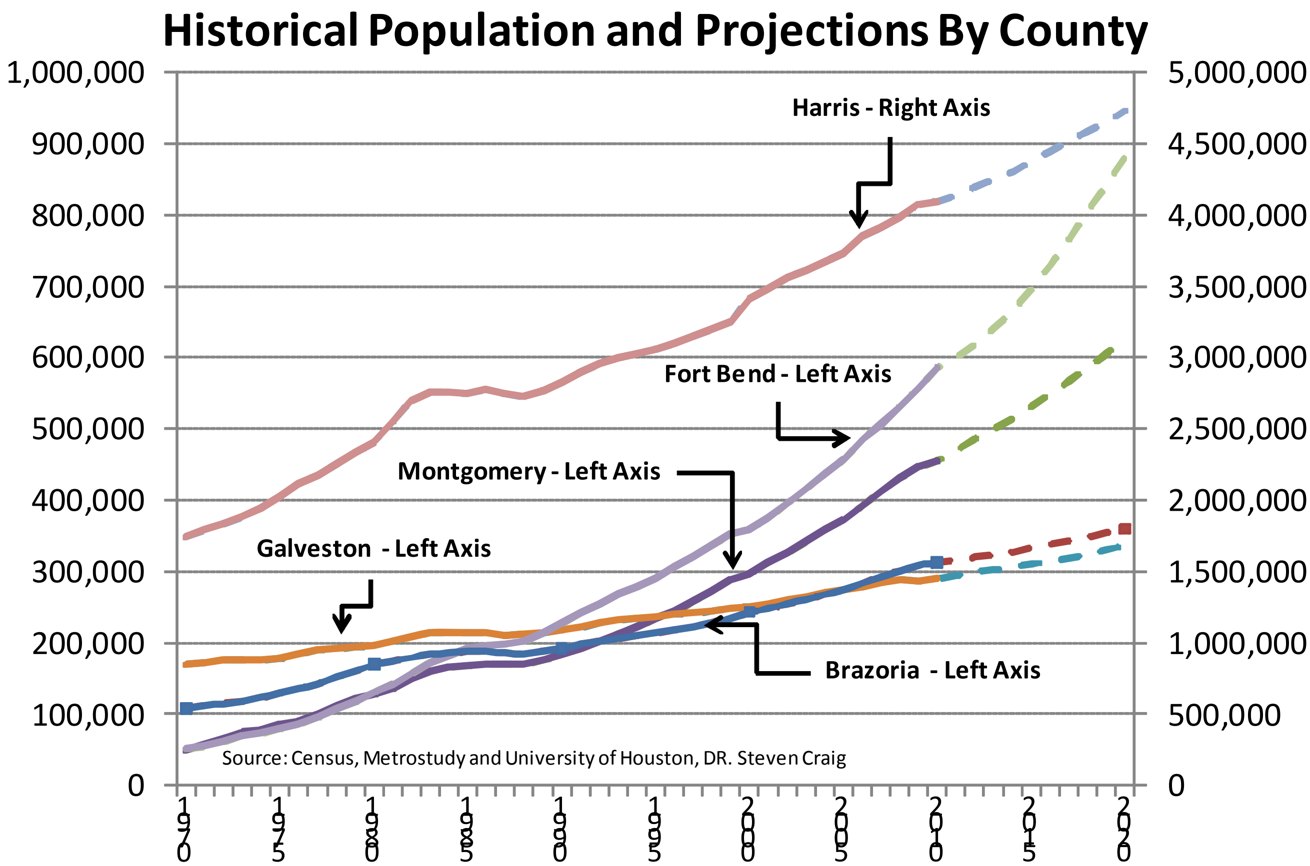
At the conclusion of this step, Metrostudy ended up with an annual projection of new multi-family projects over the next 10-years.

New Household Growth to Population

Once the single-family and multi-family projections were completed, Metrostudy aggregated the projected households to the 2010 Census Tracts. This aggregated household growth was then converted into population growth by applying the new occupied household ratio that was illustrated above.

The following pages illustrate the county level projections for Brazoria, Fort Bend, Galveston, Harris and Montgomery Counties. In the tables below, Metrostudy utilized the 2020 population projections from University of Houston, Dr. Steven Craig for the Census Tracts that are excluded from the study area.

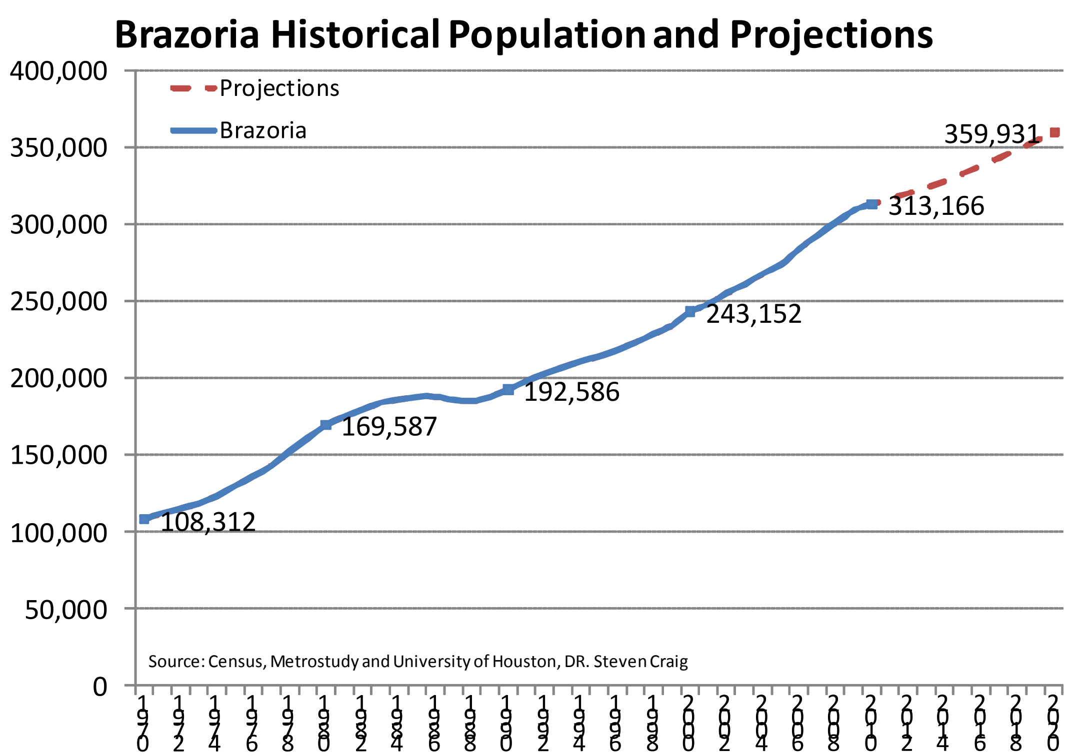
Figure 8: Population Projections by County



BRAZORIA COUNTY PROJECTIONS

Brazoria County is essentially a rural county with much of the southern portion of the county remaining as farm and ranchland or undeveloped. From 1970 to 2010, Brazoria Counties Population grew from 108,312 people to 313,166 people. Brazoria County will continue to grow over the next ten-years especially in the northern portion of the county where denser development is occurring. The northern portion of the county is more densely populated with some sizeable planned communities such as Rodeo Palms, Shadow Creek Ranch, Sedona Lakes and Sterling Lakes along Highway 288 and Kendall Lakes near the City of Alvin. As the Highway 288 corridor begins to build-out over the next several years, the ability for developers to build denser communities south of Highway 6 increases. One of the larger planned communities in Brazoria County will be the Seven Oaks Ranch has not yet been developed. Towards the end of this decade, Metrostudy believes that development will begin on the 3,000+ acre community.

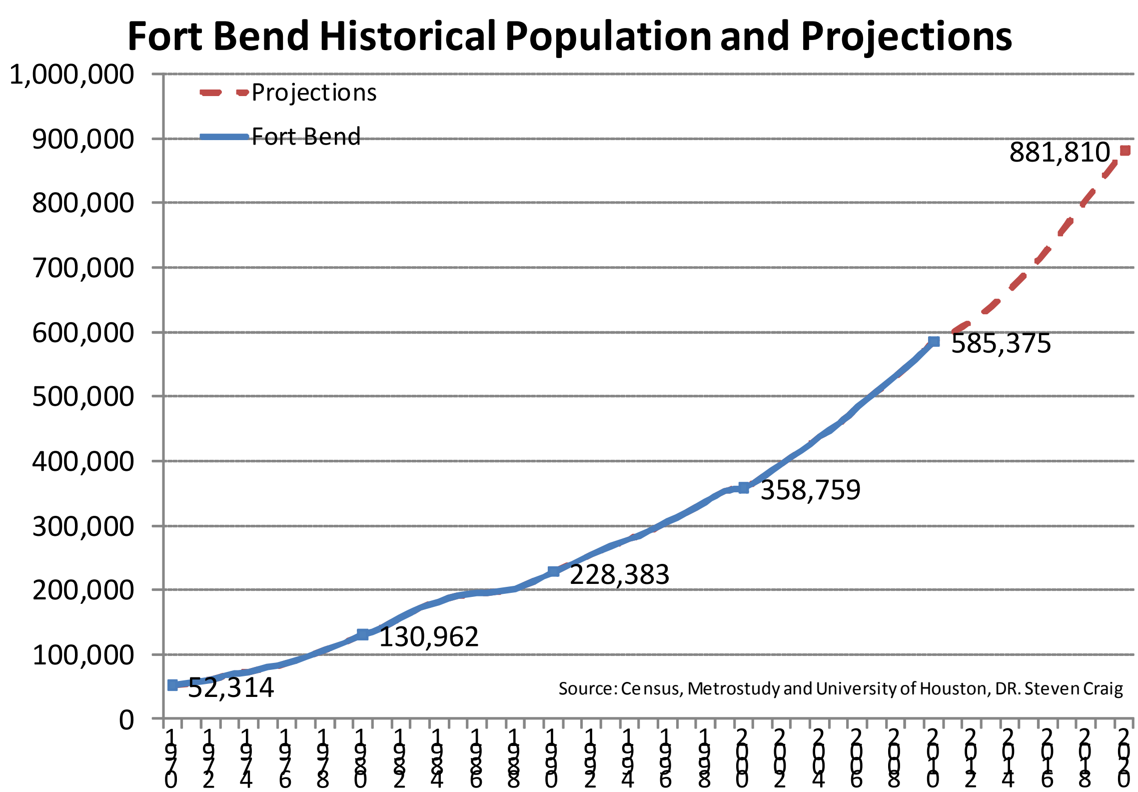
Figure 9: Brazoria County Projected Population



FORT BEND COUNT PROJECTIONS

During the past decade, Fort Bend County was one of the fast growing counties in the nation growing by 63% between 2000 and 2010. Fort Bend is attractive to many potential buyers due to the proximity to major employment centers, quality schools and available land. During the next decade, Fort Bend County will continue to be a leader in the Houston area. Many of Houston's top selling master-planned communities are located within Fort Bend county including: Aliana, Cinco Ranch, Cross Creek Ranch Riverstone, Sienna Plantation and Riverstone. These communities and their competition all provide value to the homebuyers by creating a sense of community through their extensive amenity package. This is the reason that master-planned communities are continuing to capture an increasing percentage of the Houston housing market.

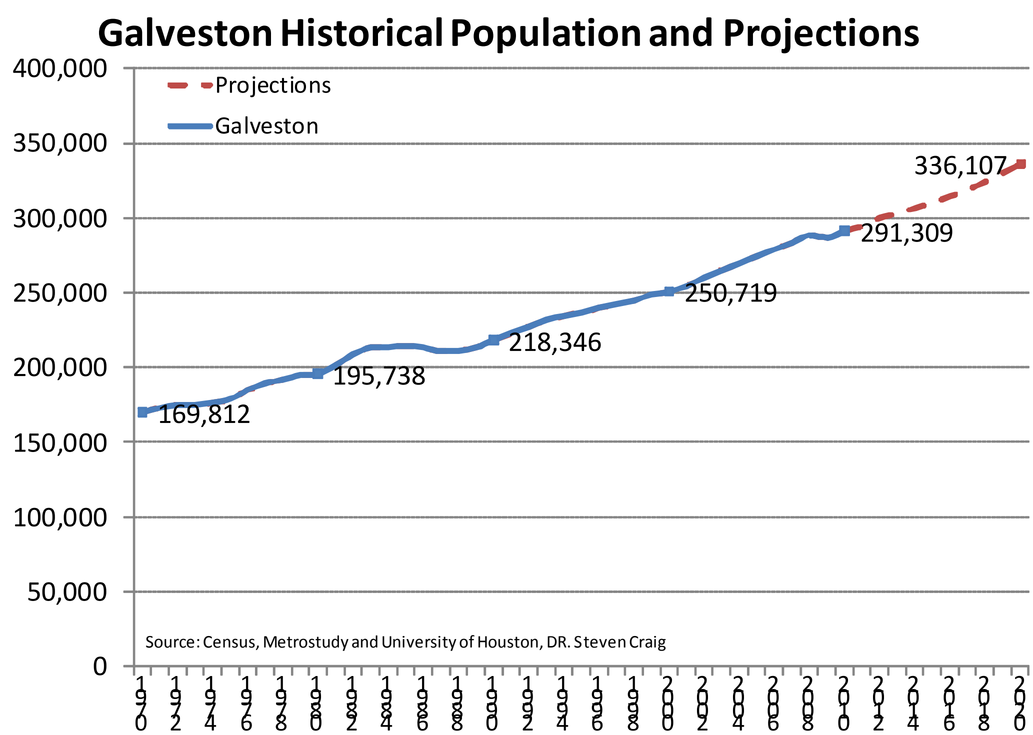
Figure 10: Fort Bend County Projected Population



GALVESTON COUNTY PROJECTIONS

The population growth in Galveston County has been relatively linear over the past 30-years growing from 169,812 people in 1970 to 291,309 in 2010. This population growth includes both the mainland and Galveston Island for which Metrostudy did not project population growth. The major job center in Galveston Island is NASA and the Johnson Space Center. Toward the later part of the 2000's NASA announced the retirement of the space shuttles and created an uncertainty of NASA's presence in Houston and the anticipated population growth in the County. Despite this drag on Galveston County, residents still have the University of Texas Medical Branch on Galveston Island and access to many major employment centers throughout Houston. In terms of population growth on the mainland, the Clear Lake Area will continue to attract the majority of the new population of the decade. Communities such as Mar Bella, Tuscan Lakes and West Ranch will lead the way in the near term, but there are still numerous large scale projects along Interstate 45 that will be developed during the next 10-years.

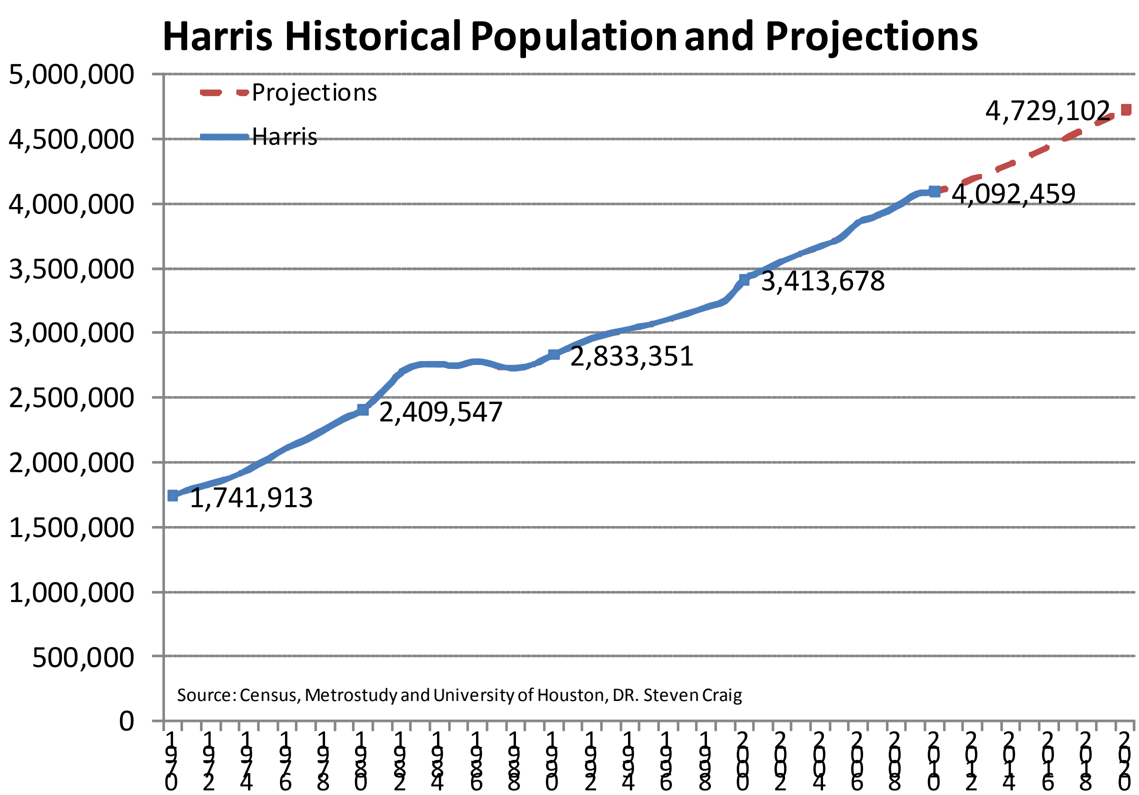
Figure 11: Galveston County Projected Population



HARRIS COUNTY PROJECTIONS

Harris County is the central county for the Houston MSA, and has the densest population in the region. Harris County's growth can be classified into two segments: urban growth or suburban growth. The urban growth in Harris County is located inside of Beltway 8, which is mostly built-out but infill and redevelopment is occurring and will continue to allow the urban core of Houston to grow. In contrast, the suburban fringes of Houston have an abundance of vacant land available to be developed. However, the majority of the development in Harris County is occurring on the west and northwest side of the county outside Beltway 8. This area has the potential to gain even more of the development activity as the slated construction of the Grand Parkway, which is anticipated to open by 2014, will open up more land for development and will provide mobility to many of Houston's major employment centers.

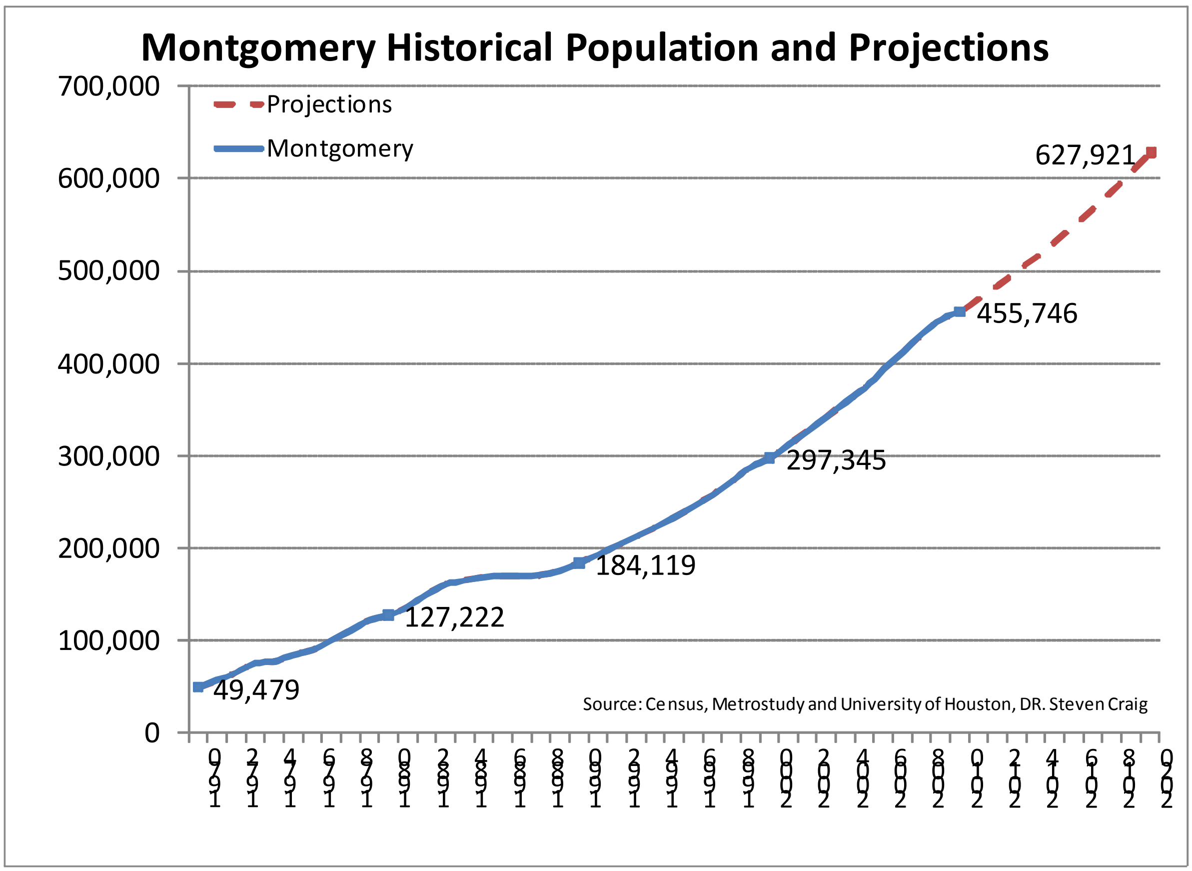
Figure 12: Harris County Projected Population



MONTGOMERY COUNTY PROJECTIONS

Montgomery County is the third most populous county in the Houston MSA as of 2010 with 455,746 people, which is an increase of 53% over the 297,345 people in 2000. Most of this growth in the past decade occurred in The Woodlands master-planned community. While The Woodlands is still active today, the development is now building in northern Harris County. However, there are several communities that are in place to replace The Woodlands, such as Woodforest and Harpers Landing. In addition, Montgomery County will benefit from the opening of the Exxon Campus in 2014, which will bring new jobs and residents to the area.

Figure 13: Montgomery County Projected Population



ASSUMPTIONS AND LIMITING CONDITIONS

The following contingencies and limiting conditions are noted as fundamental assumptions that may affect the validity of the analysis and conclusions reached in this report:

- All information contained in this report, while based upon information obtained from the client and other sources deemed to be reliable, is in no way warranted by Metrostudy.
- The Houston MSA, State of Texas, and the nation as a whole will not suffer any major economic shock during the time period of the forecast contained in this report.
- Population will continue to increase at or above Metrostudy's forecasted rate.
- The basic sources of statistical data and estimates used in this analysis are sufficiently accurate to be useful for planning purposes.
- The development, when completed, will be designed, promoted, and managed in a manner that will have an adequate impact on the local market.
- The recommendations set forth in this report will be acted upon within a reasonable period of time to preclude major changes in the conditions evaluated.

Radical changes in factors affecting the major assumptions noted above could alter the conclusions reached in this analysis or necessitate the re-evaluation of portions of this report.

SAM- HOUSTON

DESCRIPTION OF
SMALL AREA MODEL
POPULATION FORECASTS

EIGHT COUNTY METROPOLITAN AREA OF HOUSTON

Professor Steven G. Craig

Department of Economics
University of Houston
Houston, TX 77204-5019
(713)-743-3812
scraig@uh.edu

December, 2011

SAM- HOUSTON

Executive Overview

The goal of the **S**mall **A**rea **M**odel- Houston (SAM- Houston) is to allocate metropolitan-wide population and employment forecasts to each Census tract in the eight counties that form the core of the Houston metropolitan area, Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller Counties. SAM-Houston combines a unique modelling strategy with sophisticated statistical processing of a wide variety of data sources about the Houston area. The SAM- Houston model has four distinct advantages as a local forecasting tool:

*SAM-Houston forecasts are based on current theories of urban development. The premise underlying the SAM-Houston model is that all population must be supported by employment. Urban development theory predicts that employment growth will primarily occur in decentralized subcenters throughout the region. Population will locate based on the proximity to downtown, and to the spectrum of alternative employment concentrations.

*The SAM- Houston model puts theory into practice using advanced statistical (econometric) techniques appropriate for processing geographically based data. Employment subcenters are identified using locally weighted regression methods which identify statistically surprising concentrations of employment. The results are used to formulate the Statistical Module of SAM-Houston, which specifies the process of change using weighted cubic splines based on historical Census population data. These statistical processes incorporate the important elements of urban development theory including leapfrog development, where development often occurs unevenly as more distant locations are developed before areas nearer to downtown, and multi-centric business centers, where there are numerous concentrations of employment throughout the metropolitan area.

*SAM- Houston forecasts are statistically grounded by the present level of land use and development through formulation of a Land Use Module. The Land Use Module applies the forecast results from the Statistical Module based upon existing land use, and land use densities. Changes over time are based on urban development theory applied to current conditions, which allows for historical and policy forces to shape the urban environment. The underlying statistical process captures development and redevelopment consistent with the Houston-specific economic development experience.

*The SAM- Houston forecasts are flexible. The forecasts presented here are based upon metropolitan area totals from the Institute for Regional Forecasting at the University of Houston, though they have been modulated based on the results of the SAM-Houston modelling process, as well as comparisons to those of the Texas Water Development Board and the Texas State Data Center. The SAM-Houston model, however, can be re-applied to alternative growth scenarios to allocate growth in distinct areas. Further, SAM- Houston forecasts can be recombined using Census block data into various alternative geographic definitions, for example to water use districts, zip codes, voting precincts, and school zones.

The results of the SAM-Houston statistical forecasting process suggests that the recent

Houston experience, which is rapid growth of the counties nearest to Harris, will continue for several decades. While Fort Bend has experienced the most rapid growth rates in recent times, its growth rate will begin to slow as growth shifts north towards Montgomery, and then to other currently more rural areas. The long range view that emerges is that the overall metropolitan growth rate will slow as our area fills, which means that subsequent growth comes from the more expensive process of re-development which already characterizes the closer in sectors of Harris County. Eventually the necessity for redevelopment will affect all of the other counties. This is the growth process that, in a macro economic sense, has fueled growth in Texas and other southern and western parts of the U.S. as the northern central and eastern portions of the country aged.

SAM- HOUSTON

DESCRIPTION ACCOMPANYING EIGHT COUNTY POPULATION FORECASTS

The goal of the **S**mall **A**rea **M**odel- Houston (SAM- Houston) is to provide population and employment forecasts by Census tract for the Houston metropolitan area. This is an ambitious goal, as there has not been an available statistical methodology for projecting future population and employment at the micro-geographic level, especially for long time periods. The forecasts presented here, however, are a result of an innovative modelling strategy that has achieved the objective of providing a solid theoretical and statistical foundation upon which to determine how future growth will be allocated among various places in the Houston metropolitan area. SAM- Houston population and employment forecasts are currently available for the eight county region, including Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller Counties.

This discussion is intended to describe the primary features of the SAM- Houston model. The SAM- Houston model contains two modules. The first, the Statistical Module, is built on current urban development theory, and relies exclusively on statistical modeling representative of the application of the urban development theory to the Houston area. The Land Use Module is the second important element. It describes how the statistical results are modulated by current land use data. This segment relies on expressing the theory consistently with existing land uses, and with current land use densities, although the results are not formally unique from a mathematical perspective. The land use module ensures, however, that the population and employment forecasts are consistent with each other, and are consistent with the available vacant land in each neighborhood.

A. Modelling Strategy

This section describes the two separate components, or modules, of the SAM- Houston model. The statistical module is the core, as it translates established urban development theory into a statistical model for the Houston metropolitan area. The second module compares the statistical forecasts to the available developable land, and adjusts the forecasts to reflect current land use patterns and available vacant land. The goal of this modelling strategy is to develop a flexible planning tool, appropriate for widely disparate applications, that is nonetheless sensitive to current development within Houston.

1. The Statistical Module

The are four elements of the statistical module used to prepare the SAM- Houston forecasts. First, we statistically identify the employment subcenters throughout the Houston area, incorporating not only employment density but also influence on neighboring areas. Second, we estimate a model of population and employment allocation throughout the Houston metropolitan region. Third, we determine how the allocation of population and employment has changed over the last five decades. Fourth, we use an aggregate population and employment forecast for the metropolitan region, and allocate the forecast population and employment to individual Census tracts.

Employment subcenters are an important theoretical innovation in understanding urban economies over the last two decades. Specifically, firms tend to locate near each other to achieve what are called agglomeration economies. Agglomeration economies mean that it is cheaper and more effective for firms to locate near each other, although current research is still attempting to determine the relative importance of the several reasons for doing so. Among them are that firms can be suppliers and customers for each other, it is more efficient for customers to search among products, it is more efficient for firms and workers to search for each when they are in proximity, and technological innovation can occur more rapidly. The problem with grouping together, however, is the resulting congestion. As growth causes congestion to build, markets have responded by moving clusters of employment outside of the traditional downtown areas.

These new clusters are called employment subcenters, as firms attempt to achieve most of the advantages of agglomeration without the costs of congestion. Employment subcenters in general are the subject of much recent research, as the process and causes of attraction are not yet fully understood. Our research on Houston has nonetheless found that these subcenters are economically important, and further that they are generally diversified as to industry focus despite the real estate labels. Irrespective, however, subcenters have been growing in importance across the country, as well as in Houston in particular, and our forecasting methodology accounts for their continued growth as the Houston economy grows. Our identification of employment subcenters is accomplished through locally weighted regression, a semi-parametric technique that provides a detailed look at employment data to determine not only areas of higher than expected employment based on the relationship to downtown, but which is also based on the influence of a geographic point on employment in nearby areas. One of the interesting consequences of our modeling is that we find that only downtown has influence over the entire shape of Houston, the other employment subcenters (even the Galleria) have influence on less than the entire city. We take the limitations of subcenter influence into account in our modeling.

The second element of the statistical component of the SAM- Houston forecasting model is constructing an empirical description of the fundamental urban development theories. The foundation of the forecasting model uses economic theories that describe the distribution of population and employment throughout an urban area. In particular, all demographic change must be supported by employment opportunities. That is, all population change, whether from changes among the current resident population due to births and deaths, or from migration, must be supported economically. Employment opportunities arise because of demand for local products from economies in the rest of the world outside of Houston (called base employment), and from residents' demand for goods and services provided locally (called secondary employment). Base employment occurs in sectors that supply products to those outside the local economy, and represents the primary reason for a city's location. Base employment is generally concentrated in downtown, and in the other employment subcenters of the city.

Non-base employment, or secondary employment, provides goods and services to local businesses and residents. Its location pattern is actually similar to base employment, as it tends to be concentrated around base employment centers to serve both other businesses as well as the general population. In addition, however, secondary employment follows the population throughout the city for retail and other services. Resulting variations in both population and employment density as used to measure both the capacity utilization of available land, as well as the intensity with which land is utilized.

The third element of the statistical module involves determination of how population and employment dispersion has changed over time, and a forecast of how population and employment dispersion will change in the future. On average, cities throughout the country have been decentralizing at least since 1950. Two trends driving decentralization are decreases in transportation costs (especially travel time), and technological changes reducing the need for geographic proximity among firms

The rate of decentralization is determined by examining the rate of decentralization in the Houston area since 1970. The period from 1970 to 1980 was a prosperous period for Houston, but one in which population growth outpaced improvements in the transportation infrastructure. The opposite pattern was experienced in the 1980-90 period., as transportation development proceeded much more rapidly than population growth, resulting from both lags in the infrastructure process as well as the local economic depression of the period. The 1990-2000 period is when the city transitioned back to a growth mode, but at a much more moderate rate than the pattern from 70-80. Economic growth cause the city to continue to disperse, although toward the end of the period increases in congestion and other transportation costs slowed the trend toward decentralization. The 2000-2010 period has been the most difficult to model, as Houston has maintained its own economic cycles but nested within the influence of national shocks. Further, it appears that the City's growth westward is reaching a peak, and that future growth is veering northwards. Other trends, however, are also important for determining the rate of urban decentralization. In large part, decentralization does not involve people living in the city moving to the suburbs. Instead, decentralization occurs when new people moving to Houston disproportionately decide to move to the suburbs instead of into the central city. Thus decentralization can be accelerated by population growth, as the number of new residents indicates that people are mobile, and thus the shape of the city can change more quickly. A difficult forecasting element is that migration to Houston is as much a product of economic conditions elsewhere as the economic conditions in Houston. Finally, the policy health of each political jurisdiction is potentially important, and can markedly change how and where economic growth occurs.

Employment, both base and secondary, is generally more concentrated than is population. Employment has also tended to decentralize, although at a somewhat slower rate than population. While technological change may serve to accelerate the speed of employment decentralization, the growing influence of the employment subcenters is much more important in the new century than earlier. As with population, the speed of employment decentralization shows a significant decrease in the 1980s compared to earlier time periods, while the decades since the 1990s seems to exhibit a return to earlier patterns. Thus we expect that the rate of decentralization will proceed at a rate that is reflective of the last twenty years, as improvements in transportation will not be able to compensate completely for increases in costs, and increases in congestion. The somewhat unanswered question is the extent to which growth in the employment subcenters is independent of growth downtown. We believe these areas will remain linked in important ways, but this is an area in which future changes may be surprising given our statistical past. One of the indicators of this process is that we find the statistical distinction between counties is much less pronounced in 2010 than in the past, thus the entire eight county region seems firmly rooted to the same economic growth process. The Census Bureau continues to add counties to the definition of the Houston metropolitan region as an independent indicator the economy of the entire region is linked together.

The fourth element of the statistical module involves recognition of the growth allocation process that is the result of the SAM- Houston model described above. That is, the SAM- Houston model is structured to allocate metropolitan-wide population and employment forecasts among each of the various Census tracts within the metropolitan region. The actual forecasts for each Census tract of course depend on an aggregate forecast for the Houston metropolitan region.

The aggregate forecasts used to develop the current estimates for population and employment are developed by the Institute for Regional Forecasting (IRF) through the HEMS (Houston Economic Multi-Sector) model as well as their longer term forecasts.[1] The forecasts from the IRF have performed well in the past, and are based on objective economic criteria. On average, the forecasts from the IRF have generally been more accurate than other sources, although there is some variation by county. We compared the IRF forecasts to those of the Texas State Data Center, and the Texas Water Development Board. We therefore modulated the IRF forecasts based on the differences with these other sources, and based on our modeling of the Houston area, which indicates the relative strength of the counties conditional on expected growth in Harris.

An additional source of variation in the county forecasts is that the longest term forecast from the IRF is out to only 2040. For the purposes of the SAM model, we have extended the forecasts to 2070 by allowing the changes in growth trends of Harris County to continue. Thus the longer term forecasts (from 2050 and later) do not contain any additional economic information, they mirror the information already incorporated in the modelling results through 2040. What the very

[1] See the Institute for Regional Forecasting (IRF), at http://www.uh.edu/irf/index.htm.

long term forecasts do include, however, is the rate of change in changes. Thus, as Harris County grows and fills the "easy development" parcels, continuing development will become relatively more expensive, and thus relatively slower, compared to the outlying counties. This process will also operate in all of the other counties, based on their part growth rates. For example, because Fort Bend County experienced rapid growth earlier than other suburban counties, new growth there will begin to be in part a redevelopment process first among the suburban counties, and thus the Fort Bend growth rate will decelerate earlier than in some of the other suburban counties. An important part of the redevelopment process is that it allows land use densities to significantly increase, consistent with land becoming more expensive. For example, the entire Galleria area which is now the second densest employment center formerly consisted of small single family houses.

A particular caveat to all long range forecasts for Houston is that, at some point, the Petroleum age will begin to end. This will clearly be very important to the Houston economic region in two ways. One is that as the petrochemical industry starts to decline, the economic shape of the area will change (in fact, Houston has already benefitted from earlier changes, as the industry has tended to concentrate in Houston even as it shrinks nationwide). Second, the Houston region may benefit from a new industry as the petroleum sector declines. What that industry will be, and how it will affect the local economy, is of course an open question. Clearly the current forecasting model is based on the current economic shape of Houston.

2. The Land Use Module

This module is a statistical process designed to adapt the results from the statistical module to current land use patterns using two steps. First, basic land use data is used to evaluate the capacity of an area for development. Second, a re-allocation model is developed and utilized to adjust the forecasts to be consistent with the development capacity of the land.

The development capacity of an area depends on two fundamental elements. One is the amount of land available for development, and the other is the intensity with which the land is employed. The SAM- Houston forecasts thus must be modulated to be consistent with the available vacant land, and to be consistent with expected future intensity of land use.

Vacant land data used in the 2010 SAM-Houston forecasts is collected from the County Appraisal District (CAD) for each of the largest five counties in the Houston region, including Brazoria, Fort Bend, Galveston, Harris, and Montgomery. The CAD data is organized by parcel. We assign each parcel to a Census tract, and calculate the developable vacant land. In doing so, we allow agricultural land as well as land coded as vacant according to the CAD to be considered vacant. In some CADs, even vacant land is given a code (i.e. listed as vacant-commercial or vacant-residential). For the forecasting purposes of SAM-Houston, however, we assumed those designations are not binding on the ultimate use to which such land is put. Instead, the SAM-Houston model allocates commercial and residential land use within each tract consistently with the patterns existing for the parcels already developed. Developable land is designated according to gross land uses, as opposed to net. This means that land use in each tract is compared to total tract land, there is not a process which designates each specific parcel to a particular land use. A model which examines past land use, and which examines differences across tracts, is used to forecast gross land use intensity and how it will increase over time.

We find that land use intensity is directly related to land utilization. That is, areas with low amounts of vacant land are also likely to utilize the available land more intensely. Thus as Houston grows, land is likely to be used more intensely than in the past, and therefore the numbers of people and employment per land area would be expected to increase. The land use intensities, however, will vary depending on the initial use. Thus vacant land will be expected to develop closest to the optimal economic intensity, while already developed land will only intensify gradually as redevelopment occurs. Thus in the central areas of Houston, inside Loop 610 for example, changes in land use density would be expected to occur more slowly than in the outlying areas since many of the changes will be due to redevelopment rather than construction on vacant land.

The result of these processes is the land use intensity pattern. Specifically, while land use intensity will increase throughout the Houston area over time, it will increase more rapidly in the outlying areas than in the interior areas. In part, this reflects that most of the change in areas near to downtown are due to redevelopment as opposed to new. On the other hand, land prices are also an important component of land use intensity. Thus, land not only near to downtown, but also near to other employment subcenters will be expected to be utilized more intensely then land farther from desirable locations. Finally, the model permits areas used more or less intensely than average to remain so, presuming that these land intensities reflect current attributes of land parcels that make them more or less attractive.

Over most of the Houston area, land use controls are not restrictive, in that development will be permitted to occur at the economically relevant level. The model, however, allows land use in the incorporated areas with restrictive land use controls to increase more slowly than elsewhere.[2] There is not currently information on the extent to which existing neighborhood deed restrictions limit land use. Our response to this phenomenon is that the current restrictions are reflected in the current land use, and thus basing future changes on the existing patterns will allow this feature of Houston to be reflected in the final outcomes.

The measurement of vacant land combined with an analysis of land use densities allows determination of the population and employment capacity of an area. The final step in this determination is to split developable capacity between population and employment. We generally allow existing land use to dictate the proportion of an area devoted to population or employment. For relatively undeveloped areas we impute patterns of land use from similarly situated areas. In addition, however, we allow the basic SAM- Houston model to alter land use proportions to the extent certain areas are developing predominately in one or the other of the two potential land uses (population or employment).

The second step in the land use module is to adapt the forecasts from the statistical model to the capacity for development. The adaptation of the statistical forecasts is accomplished by re-allocating growth that cannot be accommodated by existing vacant (developable) land. Our reallocation process starts first by keeping "overflow" population or employment, that greater than can be accommodated by existing vacant land and the appropriate intensity, within the segment of the metropolitan area, and within the distance from downtown, consistent with the underlying statistical model. That is, overflow population or employment from one Census tract is first

[2] This primarily affects the villages in the Memorial area.

allocated proportionately to other, non-overflow, tracts within the same quadrant and within a band of only a few miles. Unlike past Census tract boundaries, the boundaries for the 2000 and 2010 Census are consistent with this modelling framework. In some areas in the southwest portion of Harris County, we in addition had to push population both to the northwest, and to the southeast, as well as slightly further away from the central city than would otherwise have been indicated. This process became more intense for forecasts farther into the future, and effected Fort Bend County as well. A problem is that for some later years Fort Bend County becomes completely full, which resulted in a lower population forecasts than we had allocated in the Statistical Module. We allocated overall population out of Fort Bend proportionately to growth in all of the remaining counties.

We believe restricting forecasts from the statistical model to be consistent with the developable capacity of each Census tract provides an important "reality check" to the forecasts. At the same time, we have taken a rather conservative approach to the reallocation process. That is, we have reallocated the minimum amount of population or employment consistent with the land use model. This is because Houston has been unique among cities in re-engineering its physical structure to accommodate the desires of the population as reflected through the market.

B. The Current Population and Employment Forecasts

The SAM-Houston model produces population forecasts by decade from 2020 through 2070, for each Census tract in the Houston eight county metropolitan region. Table 1 to this document shows the individual county population forecasts, as well as the rate of growth by decade. Further,

Table 1: COUNTY-WIDE FORECASTS USED IN THE SAM-HOUSTON FORECASTING MODEL

POPULATION LEVELS BY DECADE

	Actual Population					Forecast Population					
County Totals	1970	1980	1990	2000	2010	2020	2030	2040	2050	2060	2070
Brazoria	108,232	169,388	191,526	241,373	313,166	359,931	413,043	465,198	522,543	580,466	648,568
Chambers	12,187	18,532	20,088	26,031	35,096	45,158	61,668	89,363	106,833	128,264	136,045
Fort Bend	51,576	130,330	223,907	349,652	585,375	881,810	1,088,664	1,266,259	1,426,379	1,583,410	1,755,164
Galveston	169,372	195,628	217,399	250,158	291,309	336,107	376,894	406,825	429,031	448,736	465,193
Harris	1,747,476	2,413,688	2,821,494	3,403,600	4,092,459	4,729,102	5,107,123	5,422,070	5,712,874	5,995,992	6,272,346
Liberty	33,014	47,064	52,726	70,154	75,643	116,965	159,160	202,754	226,530	256,573	274,501
Montgomery	49,478	128,445	182,200	293,768	455,746	627,921	818,653	1,017,281	1,267,089	1,579,511	1,946,063
Waller	14,286	19,846	23,520	32,663	43,205	69,564	149,446	264,763	308,334	364,387	406,903
TOTAL	2,185,621	3,122,922	3,732,860	4,667,399	5,891,999	7,166,558	8,174,650	9,134,513	9,999,612	10,937,340	11,904,782

POPULATION GROWTH RATE BY DECADE

	Actual Growth Rates				Forecast Growth Rates					
COUNTY	1980-70	1990-80	2000-1990	2010-00	2020-10	2030-20	2040-30	2050-40	2060-50	2070-60
Brazoria	56.50%	13.07%	26.03%	29.74%	14.93%	14.76%	12.63%	12.33%	11.08%	11.73%
Chambers	52.06%	8.40%	29.58%	34.82%	28.67%	36.56%	44.91%	19.55%	20.06%	6.07%
Fort Bend	152.70%	71.80%	56.16%	67.42%	50.64%	23.46%	16.31%	12.65%	11.01%	10.85%
Galveston	15.50%	11.13%	15.07%	16.45%	15.38%	12.13%	7.94%	5.46%	4.59%	3.67%
Harris	38.12%	16.90%	20.63%	20.24%	15.56%	7.99%	6.17%	5.36%	4.96%	4.61%
Liberty	42.56%	12.03%	33.05%	7.82%	54.63%	36.08%	27.39%	11.73%	13.26%	6.99%
Montgomery	159.60%	41.85%	61.23%	55.14%	37.78%	30.38%	24.26%	24.56%	24.66%	23.21%
Waller	38.92%	18.51%	38.87%	32.28%	61.01%	114.83%	77.16%	16.46%	18.18%	11.67%
TOTAL	42.88%	19.53%	25.04%	26.24%	21.63%	14.07%	11.74%	9.47%	9.38%	8.85%

to provide perspective, we provide the actual population from 1970 to 2010.

The forecasts in Table 1 are those from the Institute for Regional Forecasting (IRF), adjusted based on three other inputs. One is the statistical process from the SAM- Houston model, as the statistical results we believe capture some of the basic trends. One such change is that the IRF forecasts for Brazoria are substantially higher than here. A second input is that the IRF forecasts only go through 2040. We extended the predictions through 2070 based on general statistical trends, taking into account the basic decentralization process that has shaped Houston over several decades. Finally, there were some relatively minor adjustments based on a collaborative project with Metrostudy funded through the Harris Galveston Subsidence District, which primarily impact the 2020 forecasts but nonetheless affects all of the forecasts presented in a minor way.

Examining the pattern of historical growth in the Houston region is illustrative of some of the general forces that are captured in the statistical process which underlies the SAM-Houston model. First, Harris County has had a slower growth rate than most of the other counties most years, which represents the basic urban decentralization process. Exceptions are mainly in the small more rural counties, such as Chambers from 1980 to 1990, and Liberty from 2000 to 2010. The small counties demonstrate quite variable growth rates, partly because their small size makes factors that affect growth timing more visible. Further, the economic collapse of the 1980s is evident in the significantly lower growth rate for the entire region, despite the boom in the early part of the 1980-90 decade.

A few of the modeling challenges also are evident in the county specific forecasts. Brazoria and Galveston counties both contain portions that are integrated into the Houston economy, and which are to some extent less so. In the case of Galveston County, new growth on the island is primarily driven by vacation demand, while the mainland portion of the county reflects to a much greater extent typical suburban demand for housing. Similarly, northern Brazoria County exhibits growth patterns like other suburban areas, while growth in the southern portion is much more dependent on the petrochemical and shipping complex there.

We have briefly mentioned above that Fort Bend County begins to reach the limits of its capacity in some areas in 2020, and by 2030 the forecasts begin to be driven by capacity limits in the County as a whole. The redevelopment portion of the Land Use Module thus ends up driving the forecast growth as the supply of vacant land is predicted to be exhausted. This process also has consequences for the growth rate of Montgomery County, as the small uptick in its growth rate in 2040 and 2050 is because of overflow population out of Fort Bend. The overall pattern, however, strongly reflects the underlying economic urban growth process. The suburban areas will grow more quickly than the center, until the vacant land is fully utilized. The less dense more rural counties will grow slightly later than those closer to Houston, but will eventually also develop. All of the forecasts, however, reflect what has been the underlying growth process of Houston for virtually the entire 20th and now 21rst century. At some point in time the pattern of urban growth will markedly change, but until then we believe the SAM-Houston statistical process reflects the underlying industrial shape of Houston.

C. Model Utilization and Caveats

We view the SAM-Houston forecasts as a central step in the development of planning capability in Houston for both the public and private sectors. Nonetheless, as with any population forecast, several caveats to their use are in order. First, sub-geographic forecasts are best used to indicate general trends and the existence of potential for growth, rather than specific growth estimates. That is, Census tracts that are projected to grow faster than average can generally be expected to represent good development opportunities. Whether the projected growth actually occurs depends on a host of specific factors, such as the existing infrastructure, the size of available land parcels, the activities of individual developers, or of particular public policy programs. One of the advantages of a model like the SAM-Houston forecast, however, is that it imposes a discipline on using location specific information. Specifically, if there is a strong reason to believe a particular area will experience growth sooner than another, the projected growth needs to be subtracted out of a similarly situated area elsewhere in the city.

Similarly, specific areas that are projected to grow more slowly than average may experience significant growth depending on specific factors, despite the general trend. Another important caveat is that the models underlying SAM- Houston generate a range of possible likely estimates. While we have used the most likely values in our analysis, they are sensitive to the overall projected rate of growth in the Houston metropolitan area. If Houston grows faster than expected in the overall numbers, it is an appropriate use of the model to accelerate the individual forecasts. For example, if Houston reaches the population forecast total level by 2020 that we expect in 2030, using the 2030 individual tract forecasts is better than increasing all of the 2020 forecasts by a fixed proportion.

The final element is that the SAM-Houston forecasts have been modified for the forecasting project underwritten by the Harris-Galveston Subsidence District. An important element to the forecasts developed in the context of this project has been access and accommodation with the forecasts out to 2020 by Metrostudy. The Metrostudy forecasts essentially represent a supply driven forecast, as the source of the information used to develop their projections are primarily from the perspective of real estate developers, using a variety of techniques including building permit information as well as current construction activity. The SAM-Houston model described above is essentially a demand driven model, which postulates that people will find a place to live based on their employment prospects. Clearly, as with all models, at some point the outcome of these two distinct processes needs to be the same. While the Metrostudy forecasts are generally short term, their emphasis on current activity was viewed by the implementing engineering firm as likely to be more informative than the long run forecasts of the SAM- Houston model. This view can be supported because the SAM- Houston model is not very particular about the timing of reaching a specific level of economic activity, its strength is in predicting the allocation of an activity level throughout the metropolitan region. Thus we altered the SAM- Houston forecasts to better fit some of the MetroStudy projections, especially in Fort Bend County, the source of the largest discrepancy between the two models. On the other hand, the interaction between the two models was also informative, and MetroStudy reduced their forecasts in northeast Harris County based on the statistical results of the SAM- Houston model. It is to be hoped that the combination is stronger than either model individually.

TO: Regional Groundwater Update Project Partners

CC:

FROM: William J. Thaman, P.E.

SUBJECT: Per Capita Demand Projections

DATE: March 5, 2012

The daily per capita demand for water, expressed as GPCD (Gallons Per Capita Daily), for municipal water providers is anticipated to decline over time due to a variety of factors: changes to the plumbing code which require installation of more efficient fixtures, impacts of water conservation efforts, the rising cost of water, and public education regarding water issues. This memorandum first examines some opportunities for estimating these impacts over time, and then examines how GPCDs have changed, on average, over the Regional Groundwater Update Project study area. Analyzing how GPCDs have actually changed over time can serve as a guide to projecting future GPCDs.

Alternative Methodologies for Projecting GPCD

Water demand projections in the 2012 State Water Plan (SWP) developed by the Texas Water Development Board (TWDB) were produced using per capita demands that demonstrate impacts over time resulting from the 1991 State Water-Efficient Plumbing Act. This methodology includes a gradual reduction in per capita demands over time due to the application of these practices. This methodology has been viewed as a minimum level of conservation that is anticipated over time.

Water conservation plans (WCPs) are required to include quantifiable conservation goals that may be measured on a routine basis. It is potentially possible to conduct a review of conservation plans to determine overall reductions in per capita demands. However, there are often issues in translating the information in the plans to data that can be used for planning processes. Primarily, WCPs often set targets as specific gpcd calculations for population-related, or residential, demands. These values may be calculated based on residential billing rather than overall system use, as is reflected in TWDB water use surveys and gpcds used in the RWPs. Finally, this methodology would be limited by the WCPs that have been developed and are available for review.

A third alternative to determining future per capita use would be to assume a steady, constant reduction over time to a target gpcd. The Texas Water Conservation Implementation Task Force (WCITF) recommends an annual reduction of 1 percent based in a 5-year average until reaching a target per capita demand of approximately 140 gpcd. This alternative would likely result in greater per capita reductions than the other methodologies discussed, which would not represent a conservative approach to projecting future water demands. Nonetheless, the limit of 140 gpcd is a benefit in that it prevents the reduction of demands beyond a reasonable level of conservation. This is especially critical for communities that may experience a minimal level of water demands already.

Recommended Methodology for Projecting GPCD

Given the advantages and disadvantages of the methodologies presented above, FNI recommends a hybridized version of the TWDB methodology and the WCITF target of 140 gpcd. This alternative would apply savings based on the TWDB plumbing code estimates for all entities above 140 gpcd until they reach that threshold per capita demand. Beyond that point, their per capita demands will be limited to no greater than 140 gpcd.

The original methodology developed by TWDB uses 1995 as a base year for developing savings from fixture replacements. Annually, 2% of the 1995 population is expected to convert to fixtures with reduced water use. These replacements are estimated to save, on average, 16 gallons per person per day. In addition, all population growth is expected to benefit from the per capita reduction in demand.

The methodology proposed in this document is described in the steps below. Population data from the years 2000 and 2010 are used to estimate the year 1995 population. In this year it is assumed no water efficient fixtures are installed. The retention of this base condition near the onset of the Water-Efficient Plumbing Act is crucial, as it helps to identify communities that may have been developed after the onset of regulation and would already have the benefits of water efficient fixtures included in their representative per capita demands.

The development of plumbing code savings (PCS) and impact to gpcd are described below:

- If representative per capita demand is 140 gpcd or less, retain the existing per capita demand for all decades.
- Linearly extrapolate the Year 1995 population from Year 2000 and Year populations. If the value is below 0, assume 1995 population is 0.
- Determine the Year 2010 Plumbing Code Savings (PCS) by the formula below to determine the percentage of the 2010 population that has water efficient fixtures installed and multiply that by the base gpcd savings.

$$PCS2010 = \left(\frac{(POP1995 * 30\%) + (POP2010 - POP1995)}{POP2010}\right) * 16\ GPCD \quad (Eq. 1)$$

- Determine the Year 2020 PCS using the formula below. Note that the Year 2010 PCS is subtracted to remove savings that took place before the base year of 2010.

$$PCS2020 = \left[\left(\frac{(POP1995 * 50\%) + (POP2020 - POP1995)}{POP2020}\right) * 16\ GPCD\right] - PCS2010\ (Eq. 2)$$

- Then, The Year 2020 GPCD is calculates using the Year 2020 PCS and the representative (2010) gpcd.

$$GPCD2020 = GPCDREP - PCS2020 \quad (Eq. 3)$$

- Calculations for subsequent years will follow a similar methodology. Note that all of the existing population (1995 population) will be converted by the year 2045 (50 years) and no new reductions in gpcd will occur beyond this time.
- At any point, if the calculated per capita demand reduces below 140 gpcd, a value of 140 gpcd should be retained as the minimum practical per capita demand as specified above.

Quantifying Historical Water Conservation Savings

As mentioned previously, GPCD is expected to decline over time due to a number of factors, including water conservation efforts. Before determining the potential future declines in GPCD due to conservation, it would be beneficial to know how GPCDs have declined in the past. To do this, the effects of non-conservation effects must be isolated to the extent possible; those effects include, but are not limited to, climate, economic conditions, and increases in the price of water.

TWDB, as the state agency responsible for developing the State Water Plan, initiated an effort to quantify the change in historical GPCD; the result of that effort is a report entitled "*Water Conservation Savings Quantification Study*", dated February 21, 2012, and prepared for TWDB by BB Research & Consulting and CH2M Hill[1]. The stated purpose of the report is to "identify and evaluate potential methods (or 'tools') to assist the TWDB and individual municipal water providers in evaluating the actual water savings being achieved by municipal water conservation efforts."

Three recommendations came out of the TWDB report, one of which is pertinent to this memo: an approach for developing consistent regional and statewide conservation savings. The approach is to develop a "top-down" statistical analysis based on data that TWDB already collects and other data that is readily available. The type of analysis recommended is known as an econometric "panel model" which attempts to isolate the effects of climate and economic conditions so that the effects of everything else (e.g. conservation, price, replacement of plumbing fixtures, etc.) can be estimated over time. This type of analysis was used to estimate the effects of conservation in the Regional Groundwater Update Study; the analysis is described below.

Panel Data Analysis

Panel data analysis is a method of studying a particular subject within multiple sites, periodically observed over a defined time frame[2]. Sites are usually referred to as "cross-sectional" units, and the periodic observations are variables that characterize the cross-sectional units over time. In the TWDB report referenced above, the cross-sectional unit in the panel data is planning region. In the case of this study, the cross-sectional unit is Public Water System (PWS). For the GPCD analysis, the time series data consists of the dependent variable (GPCD) and independent variables that describe climatic and economic conditions.

1 Downloaded from: http://www.twdb.texas.gov/wrpi/rwp/documents/Final%20Report%20022112.pdf
2 Yaffee, Robert (2003) *A Primer for Panel Data Analysis*. Retrieved February, 2012 from www.nyu.edu/its/pubs/connect/fall03/yaffee_primer.html

Data is organized into a Panel Dataset structure, which consists of blocks of cross-sections, each containing time series data. For this analysis, the annual time series variables for each PWS are listed in Table 1.

Table 1. Panel Dataset Time Series Variables

Variable	Description
UNEMP	Unemployment rate (by County)[3]
RAIN	Annual Rainfall (by County)[4]
RAIN_APR_JUL	Total rain Apr-Jul[4]
TEMP	Average Annual Temperature (Houston region)[5]
PMDI	Palmer Modified Drought Index, Annual Average (Houston region)[6]
PZNDX	Palmer Drought Index, Annual Average (Houston region)[6]
PZAPRJUL	Palmer Z-Index, Apr-July Average (Houston region)[6]
RAINSQD	RAIN-squared
T2R2	TEMP-squared / RAIN-squared
PMDIXT2R2	PMDI * T2R2
PZAPRJULT2R2	PZAPRJUL * T2R2

The panel dataset is analyzed using the Fixed Effects Model, also known as the Least Squares Dummy Variable Model (LSDV Model). In this case dummy variables are used to represent the cross-sectional units as well as time periods, and the panel analysis equation is solved using Ordinary Least Squares (OLS).

The Panel Analysis equation is:

$$GPCD = K + a_1 PWS_2 + \cdots + a_{m-1} PWS_m + b_{1993} YR_{1993} + \cdots + b_{2008} YR_{2008} + c_1 VAR_1 + \cdots + c_l VAR_l \quad (Eq. 4)$$

where: PWS is a series of dummy variables representing Public Water Systems; e.g. for the City of Houston PWS would be coded as a "1" for every data record for Houston and a "0" for all other systems. m is the total number of systems modeled.

YR is a series of dummy variables representing year; coded as a "1" for a given year, and "0" for every other year. n is the total number of years modeled.

VAR is a series of predictor variables representing the various time series variables listed in Table 1; e.g. UNEMP, RAIN, TEMP, etc. l is the total number of time series variables.

The coefficients K, a, b, and c are estimated using OLS in a statistical software package; in this case the software used was gretl (v. 1.9.7)[7]. The variables in Table 1 can be combined in a variety of ways, with the

3 Federal Reserve Bank of St. Louis (2012) *FRED Economic Data*, Retrieved February, 2012 from research.stlouisfed.org/fred2/categories/29898
4 Texas Water Development Board (2012) *Precipitation and Lake Evaporation Data for Texas*, Retrieved February, 2012 from http://midgewater.twdb.state.tx.us/Evaporation/evap.html
5 National Climatic Data Center (2012) *Temperature and Precipitation*, Retrieved February, 2012 from www.ncdc.noaa.gov/temp-and-precip/
6 National Climatic Data Center (2012) *Historical Palmer Drought Indices*, Retrieved February, 2012 from www.ncdc.noaa.gov/temp-and-precip/drought/historical-palmers.php

main goals being to achieve a reasonable coefficient of determination (r squared) for the least-squares regression while reducing the large variations in the GPCD that are largely a result of climate.

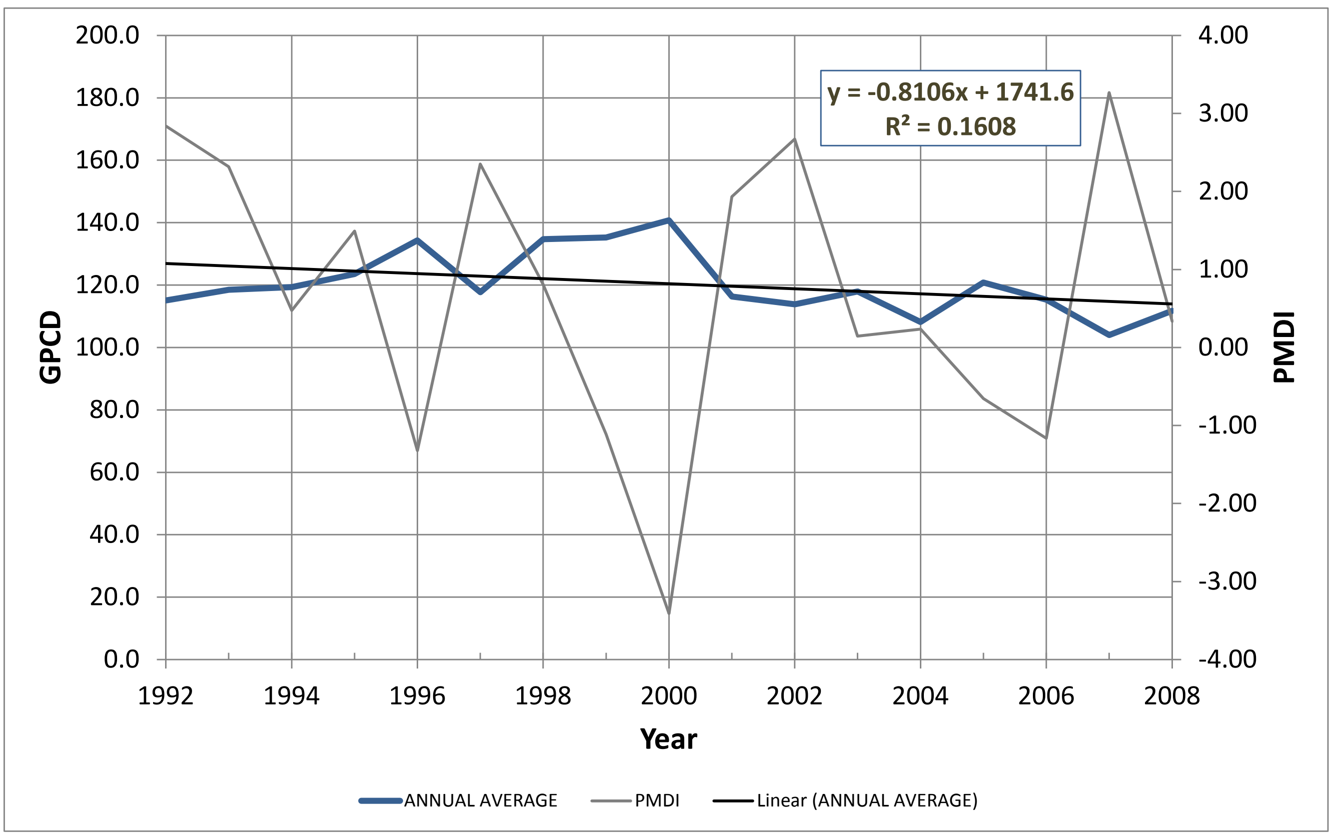
For the purposes of determining the change in GPCD over time, absent the effects of climate and the economy, the most important information that this type of analysis generates is the $b_{1993} - b_{2008}$ coefficients associated with the Year dummy variables. These coefficients indicate the average change in the dependent variable (GPCD) from year to year, while the economic and climate time series variables are held constant; e.g. if 1992 is the base year, and 1993 has a coefficient of -2, then the GPCD is predicted to decrease by two, on average, from 1992 to 1993 due to everything *but* the economic and climatic effects.

Estimated Trend in Historical GPCD

Using the panel model concept described above, the goal in data selection was to represent a relatively long period with GPCDs throughout the principal study counties. There were 111 PWSs that had no missing GPCD values from 1992 through 2008 (In Eq. 4, m=111, n=17).

The average GPCD, by year, and the Palmer Modified Drought Index (PMDI) are plotted in Figure 1. The 1992-2000 period shows a relatively flat trend in GPCD, while the 2001-2008 period is declining; the overall trend is declining as shown by the linear trend line. The r-squared for the trend line is relatively low at 0.16, which indicates that the confidence in predicting future GPCD using the linear equation is low.

Figure 1. Annual Average GPCD by Year



Climate has a large influence on the variation; the higher GPCDs generally correspond to drier years, and the lower GPCDs to average or wetter years. The average monthly Palmer Modified Drought Index (PMDI) is

7 Cottrell, Allin & Lucchetti, Riccardo (2011), *Gnu Regression, Econometrics and Time Series Library: gretl*, Software downloaded February, 2012 from http://gretl.sourceforge.net

negative (indicating drier conditions) in the years 1996 (-1.3), 1999 (-1.1), 2000 (-3.4), 2005 (-0.7), and 2006 (-1.2). The highest average GPCD occurs in 2000, which is the only year in the period that experienced severe drought (PMDI -3.00 to -3.99).

The year 1998 has the 3rd highest GPCD but has a mid-range PMDI of 0.81 and the 10th highest annual rainfall during the period. Something other than the PMDI and annual rainfall has to explain the high GPCD, and it seems that what's causing it is abnormally low rainfall during the months of April through July. For Harris County, the 1998 total rainfall for Apr-Jul is 4.1 inches, compared to 12.2 inches and 12.5 inches in 1999 and 2000 respectively. The Palmer Z-Index, which measures short-term drought on a monthly scale, is also much lower during that period: -2.3 for 1998; -0.3 and -0.9 for 1999 and 2000 respectively. A value between -2.00 and -2.74 indicates moderate drought. This is an indication that the Palmer Z-Index may be useful in predicting GPCD.

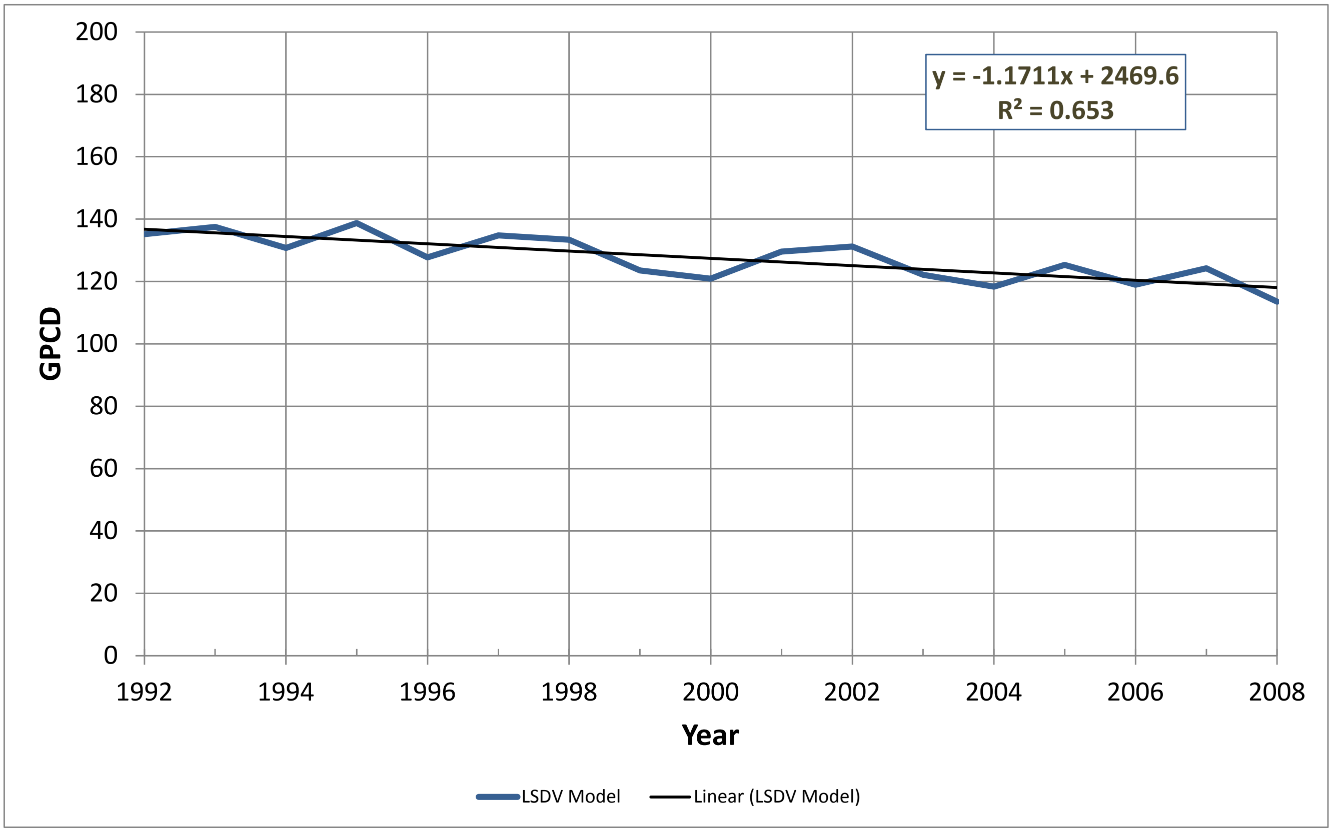
To determine the trend in GPCD that is not related to economic conditions and climate, LSDV models (discussed in the previous section) were used. Dummy variables were used for the PWSs and the Years in all models, while different combinations of time series variables from Table 1 were used in each model. The variable UNEMPT was used as the economic time series variable in all models. The variables that best dampen the effects of climate are PMDIXT2R2 and PZAPRJULT2R2. Both of these variables capture the effects of long-term and short-term drought, as well as annual temperature and rainfall. The model results for the year dummies and time series variables are shown in Table 2.

Table 2. Panel Dataset Time Series Variables

Variable	Coefficient
Constant, K	135.2
YR_{1993}	2.4
YR_{1994}	-4.4
YR_{1995}	3.6
YR_{1996}	-7.4
YR_{1997}	-0.4
YR_{1998}	-1.8
YR_{1999}	-11.7
YR_{2000}	-14.2
YR_{2001}	-5.6
YR_{2002}	-4.0
YR_{2003}	-13.0
YR_{2004}	-16.8
YR_{2005}	-9.9
YR_{2006}	-16.2
YR_{2007}	-10.9
YR_{2008}	-21.6
UNEMPRT	-1.2
PMDIXT2R2	-2.0
PZAPRJULYT2R2	-2.2
Adjusted R-squared	0.8

The constant term represents the average GPCD for the base year (1992), without considering unemployment and climate. The YR_x coefficients indicate the estimated change in GPCD, excluding the effects of changing economic and climatic conditions. For example, in 2008 the dummy variable coefficient is -21.6, meaning that the model predicts the average GPCD for 2008 would be 135.2 – 21.6 = 113.6, again, excluding the effects of changing economic conditions and climate. The YR coefficients represent average changes across all the PWSs used in the panel data; some systems will have experienced more or less change, but it is the average change that is represented. The GPCDs predicted due to all effects other than unemployment and climate are plotted in Figure 2.

Figure 2. Annual Average GPCD Absent Economic and Climate Effects (LSDV Model Results)



The linear trend line through the LSDV model results has a R-squared value of 0.65, indicating that the trend line equation is useful in making predictions. The slope of the trend line is -1.2, indicating that, on average, the GPCDs in the area in and around Harris County have dropped by 1.2 gpcd per year for the period 1992-2008 due to factors such as conservation, changes in the price of water, changes to rate structures, replacement of older plumbing fixtures, and any other factor not related to unemployment and climate. The 1.2 gpcd per year estimate contains some statistical uncertainty, and it does not isolate the effects of proactive water conservation efforts from the other effects such as replacing older fixtures and changes in water rates; the available data is far too limited to allow complete isolation of conservation.

As mentioned earlier, it is recommended that individual GPCDs not be allowed to decline below 140 when considering fixture replacement. An analysis of the panel data for systems with a max GPCD less than 150 showed that the average GPCD still declined over time, although at a much slower rate than 1.2 gpcd/year. The exact reason for a continuation in decline is not known, but there certainly is a minimum average GPCD that can be expected. The average rate of decline for systems with a max GPCD less than 150 was approximately a fourth that of systems with a max GPCD over 150, -0.43 gpcd/yr versus -1.65 gpcd/year.

To be conservative, the recommendation to not reduce future GPCDs for systems with a current GPCD of 140 or less should be maintained. For systems with a current GPCD greater than 140, the future GPCD should not be allowed to go lower than 140.

Summary and Conclusions

A statistical analysis of the historic GPCDs for the Houston region for the period 1992-2008 showed that, on average, GPCDs have declined by as much as 1.2 gpcd/year, absent the effects of changing economic and climatic conditions. The exact reason for this cannot be determined; part of it could be that the 1999-2000 drought spurred an overall increase in activity related to conservation programs and promoting conservation awareness, and that activity has paid off.

Currently, the TWDB projects GPCDs by estimating the savings due to fixture replacement. Using Eq. 1, and Census populations for Harris County as an example, the estimated plumbing code savings from 1995-2000 is 7.6 gpcd, or approximately 0.5 gpcd/year. Given the historical trend in GPCDs in the Houston region, there seems to be justification in assuming a more aggressive rate of GPCD decline.

The data analyzed does not include the 2011 drought, the worst one-year drought in the history of the State and the Houston region, but it will be interesting to see how that drought impacts per capita water use going forward. Once the region gets out of the current drought, it would be reasonable to expect GPCDs to continue to decline. The questions going forward are: How long will the current drought continue?, and; Will drought conditions occur much more frequently due to climate change as some climatologists are predicting? If either happens, it is unclear how the trend in GPCD will change. If drought conditions become more frequent, it may cause a shift in thinking toward more efficient landscape and irrigation practices, rainwater harvesting, tiered rate structures, and other water-saving practices, in which case GPCDs may continue to decline.

These unknowns make it difficult to settle on one set of projected GPCDs. It is recommended that, as different regulatory scenarios are developed later in this project, they include various assumptions on GPCDs. Some possibilities include:

- Baseline GPCD: Assume that, at a minimum, GPCDs decline to reflect the savings due to fixture replacement. Historical declines in GPCD suggest that GPCDs may decline faster, but this would be the minimum that could be expected, assuming that the region is not going into a situation where drought becomes the normal condition. Maintain 140 gpcd as the minimum, below which GPCDs are not expected to decline.
- Continuation of historical trend: Assume that the current rate of GPCD decline will continue. Assume that systems at the upper end of GPCD decline faster than those at the lower end. Allow GPCDs to decline for systems whose GPCD is at or below 140. This would be a “best case” scenario; drought conditions occur at the historical rate, and a conservation impacts exceed those of replacing fixtures.
- Increased drought intensity and frequency: Coordinate with TWDB to determine what the impact of the 2011 drought was on GPCD in general; it would not be assumed that GPCDs would stay at the 2011 level, but it could be informative as to where the long-term GPCDs should be set.

TO: Regional Groundwater Update Project Partners

CC:

FROM: William J. Thaman, P.E.

SUBJECT: Calculation and Spatial Distribution of Non-PWS Per Capita Water Demand (GPCD)

DATE: August 29, 2012

Introduction

For the Regional Groundwater Update Project (RGUP), per capita water demand, expressed in units of gallons per capita daily (GPCD), was established for all Public Water Systems (PWSs). If a PWS had historical data from the TWDB Water Use Survey, its GPCD was set to the average of annual GPCD for the years 2000 – 2008. If data was not available, the PWS' GPCD was set equal to that of the closest PWS.

Establishing a GPCD for each PWS is necessary to establish the water demands for existing water systems, but it is necessary to determine what the GPCD will be areas that are not currently developed but are projected to grow. In this situation all that is known is the projected population for any given 2010 Census Block (CB); unknowns include the type and density of development in areas outside of an existing PWS. The type of development will dictate the expected water demand; e.g. a master planned community with amenity ponds, large lots, and an average home price of $500,000 will require significantly more water per person than a zero-lot-line development with no water feature amenities, small lots, and an average home price of $125,000. Other types of development include trailer parks, apartments, and estate-size lots.

While the type of development may not be known ahead of time, it is reasonable to assume that, generally speaking, new development will be similar to the types of development nearby; this is not always the case of course, but an assumption is necessary in order to systematically assign GPCDs to currently undeveloped areas over a five-county region. This memo details the methodology used to establish a GPCD for every CB in the RGUP study area.

Methodology

The methodology is as follows:

1. Counties were divided into subareas, and a population-weighted GPCD was calculated for each subarea. Subareas are collections of Census Tracts. Population-weighted GPCD used where there are no nearby PWSs.
2. PWS boundaries were unioned with Census Blocks (CBs). Each unioned polygon has a GPCD.
3. For each CB, used GIS to determine the three nearest PWS boundaries, and the distance to each. The distance is between the closest points of the two boundary polygons.
4. If a CB intersects a PWS boundary, that CB gets the GPCD of the intersecting PWS. If a CB intersects more than one PWS boundary, the CB gets an area-weighted GPCD.
5. If a CB does not intersect a PWS boundary, the GPCD is calculated from the three nearest PWS GPCDs, weighting by the population and the inverse of the distance squared. If the minimum distance is greater than two miles then set GPCD equal to the population-weighted GPCD for the county subarea. The weighting is described in more detail below.

GPCD Weighting

For the county subareas, a population-weighted GPCD was calculated. For the individual CBs, a population and inverse distance squared weighting was calculated. In each case the calculation of the GPCD takes the following form:

$$GPCD = \sum_{i=1}^{n} w_i GPCD_i \quad (Equation. 1)$$

where n is the number of PWS values, w_i is the weighting function for each value, and $GPCD_i$ is the GPCD at each PWS.

For population-weighted GPCD, the weighting function w is:

$$w_i = \frac{P_i}{\sum_{j=1}^{n} P_j} \quad (Equation. 2)$$

where n is the number of PWS values and P is the population.

For population and inverse distance squared weighting, the weighting function is:

$$w_i = \frac{P_i d_i^{-2}}{\sum_{j=1}^{n} P_j d_j^{-2}} \quad (Equation. 3)$$

where n is the number of PWSs, P is the population, and d is the distance from the current CB and each PWS. In this case the calculated GPCD is directly proportional to the population and inversely proportional to the square of the distance. For this analysis the number of PWSs used in the GPCD calculation was three (3). A third weighting that could be used is simply inverse distance squared weighting; the weighting factor would be similar to Eqn. 3 with the population term removed.

The population-weighted GPCDs for each County subarea are shown in Figure 1.

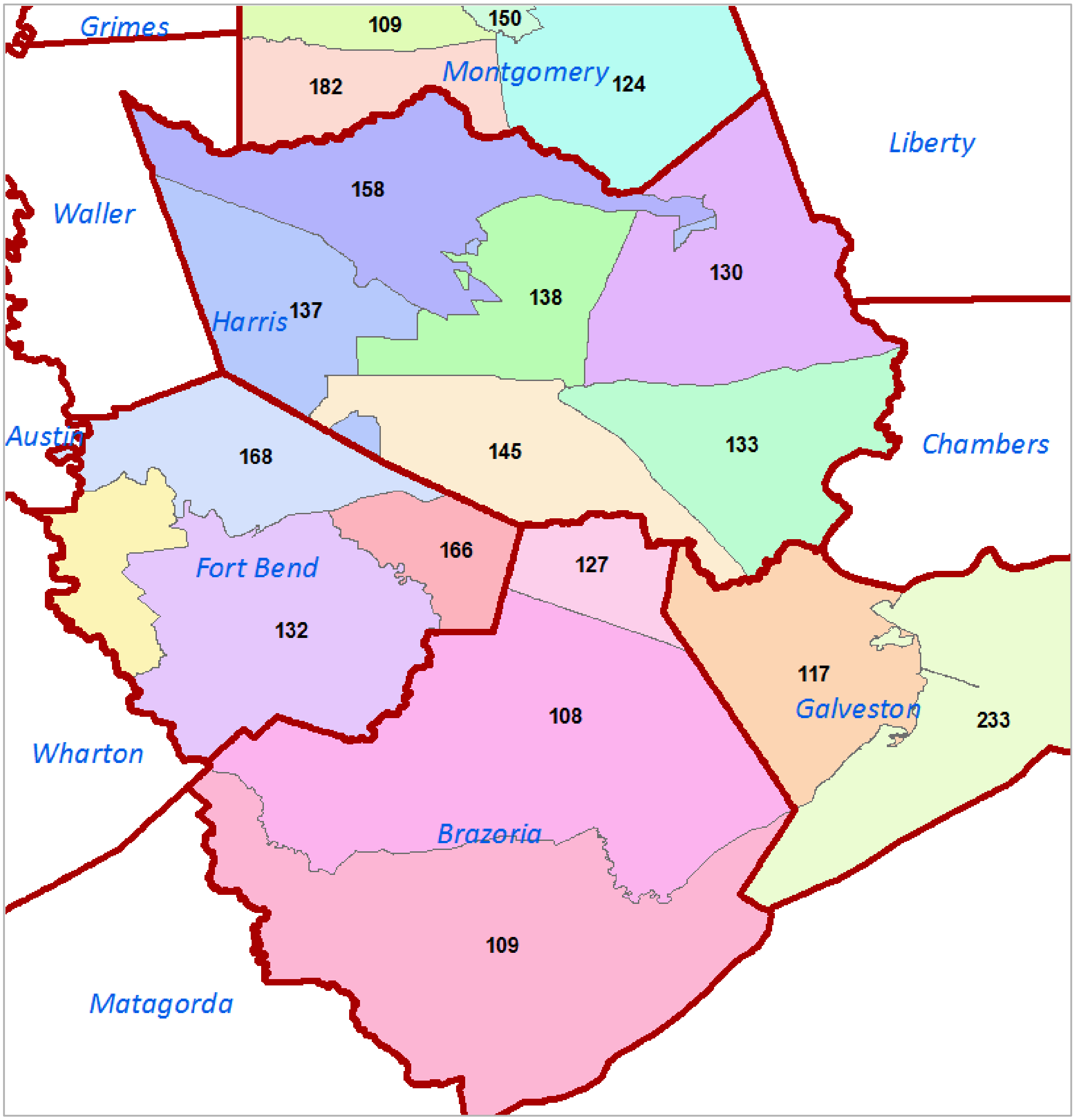


Figure 1. County Subarea GPCD

Table 1 shows an example using Equations. 1 and 3; the calculated GPCD is 139.4. In this example, the weighting factor is highest for PWS No. 2 because of the short distance.

Table 1. Sample Calculation Using Population and Inverse Distance Weighting

PWS No.	GPCD	Population	d (miles)	Pd^{-2}	$\sum Pd^{-2}$	w_i	w_i x GPCD
1	225	15,000	1.50	6,667	46,722	0.143	32.1
2	125	2,500	0.25	40,000	46,722	0.856	107.0
3	250	500	3.00	56	46,722	0.001	0.3
			Totals:	46,722	N/A	1.000	139.4

Table 2 shows how the calculated GPCD, using input data from Table 1, differs for alternative weighting methods.

Table 2. GPCD Calculated Using Alternative Weighting Methods

Weighting Method	GPCD
Population & Inverse Distance	139.4
Population	211.8
Inverse Distance	128.5

Figure 2 shows a snapshot of PWS boundaries (shaded polygons w/ black GPCD labels) and regions of Census Blocks with the same GPCD (dark red outlined polygons w/ dark red GPCD labels).

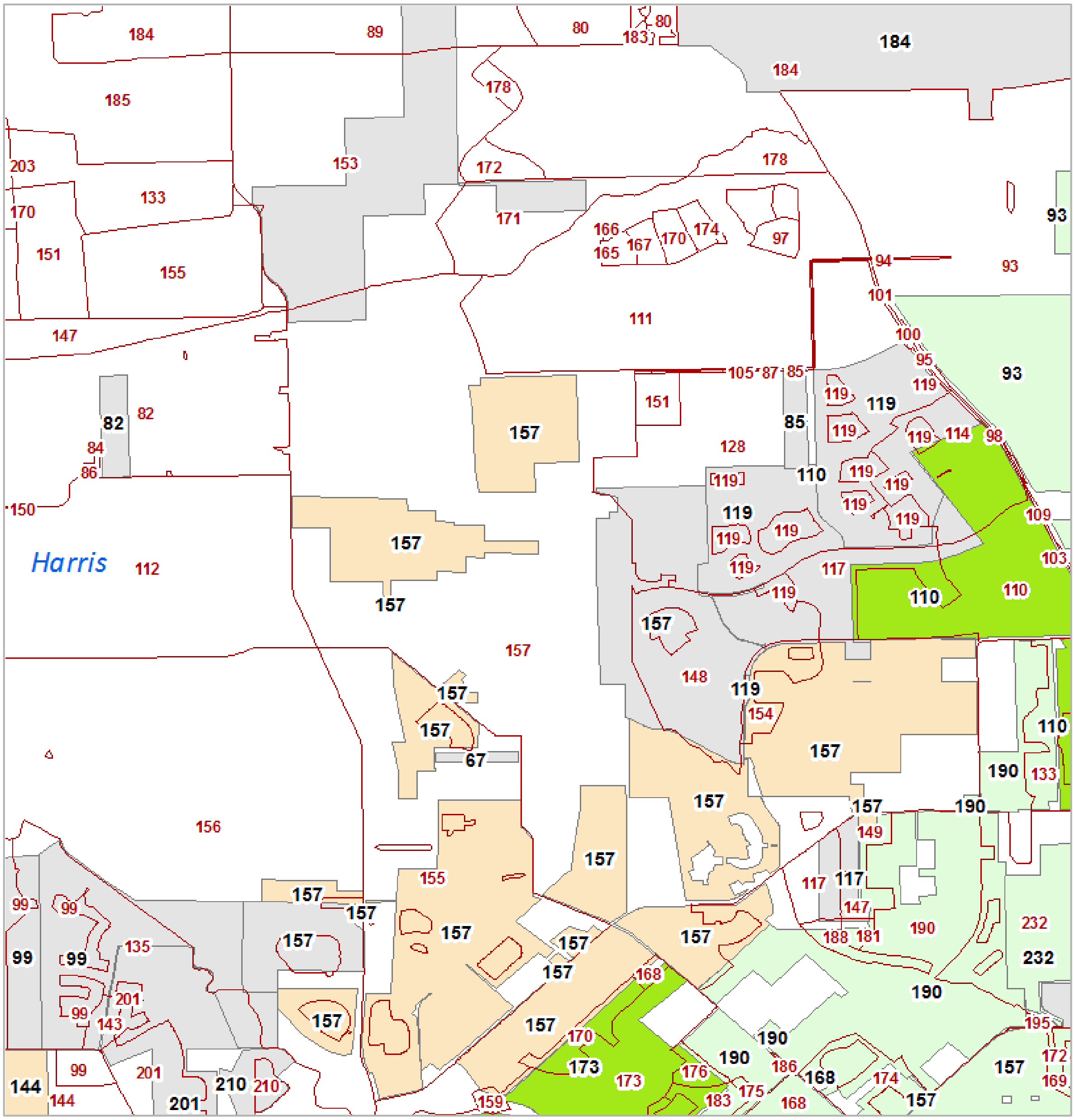


Figure 2. Census Block Level GPCD

All CBs have a GPCD calculated using the methodology described above, and each CB has a population projection; with that information, water demand can be calculated at each CB. In later stages, CBs are unioned with the Houston Area Groundwater Model (HAGM) grids and water demand is aggregated at the grid level.

Calculations

VB.NET with SQL Server database backend was used for the GPCD calculations. Two VB.NET procedures were developed: CalcGPCDMinZero() calculates GPCD for CBs that intersect one or more existing PWS boundaries, and CalcGPCDGTZero() calculates GPCD for CBs that do not intersect an existing PWS boundary. VB.NET code and SQL Server DDL are provided as attachments to this memo.

VB.NET Code

```
    Friend Sub CalcGPCDMinZero()
        Dim strCurrentGEOID10 As String = ""
        Dim dGPCD As Double = 0
        Dim dAREA_RATIO As Double = 0
        Dim dMUD_GPCD As Double = 0
        Dim dProduct As Double = 0
        Dim i As Integer = 0
        Dim j As Integer = 0
        Dim iNumRecords As Integer = 0

        openConnection_SDE(cnn)
        cmd1.CommandType = CommandType.Text
        cmd1.CommandText = "select * from near_data_min_zero order by geoid10"
        cmd1.Connection = cnn
        dr = cmd1.ExecuteReader

        openConnection_SDE(cnn2)
        cmd2.CommandType = CommandType.StoredProcedure
        cmd2.CommandText = "update_Near_Data_Min_Zero"
        cmd2.Connection = cnn2

        While dr.Read
            i += 1

            If dr("GEOID10") <> strCurrentGEOID10 And i > 1 Then
                'Calculate the GPCD for the current census block
                If j = 1 Then
                    dGPCD = dMUD_GPCD
                Else
                    If dAREA_RATIO = 0 Then
                        dGPCD = dMUD_GPCD / j
                    Else
                        dGPCD = dProduct / dAREA_RATIO
                    End If
                End If

                'Update [NEAR_DATA_MIN_ZERO]
                cmd2.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strCurrentGEOID10
                cmd2.Parameters.Add("@GPCD", SqlDbType.Float).Value = dGPCD
                cmd2.ExecuteNonQuery()
                cmd2.Parameters.Clear()

                'Reset everything
                dGPCD = 0
                dAREA_RATIO = 0
                dProduct = 0
                dMUD_GPCD = 0
                j = 0
            End If

            j += 1
            strCurrentGEOID10 = dr("GEOID10")
            dAREA_RATIO += dr("AREA_RATIO")
            dProduct += dr("AREA_RATIO") * dr("MUD_GPCD")
            dMUD_GPCD += dr("MUD_GPCD")

        End While

        'Since a DataReader (forward-only recordset) is being used, don't know which is the last record ↙
    until they're all read.
        'Calculate the last row
        If j = 1 Then
            dGPCD = dMUD_GPCD
        Else
            If dAREA_RATIO = 0 Then
                dGPCD = dMUD_GPCD / j
```

```
            Else
                dGPCD = dProduct / dAREA_RATIO
            End If
        End If

        'Update [NEAR_DATA_MIN_ZERO]
        cmd2.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strCurrentGEOID10
        cmd2.Parameters.Add("@GPCD", SqlDbType.Float).Value = dGPCD
        cmd2.ExecuteNonQuery()
        cmd2.Parameters.Clear()

        dr.Close()
        cnn.Close()
        cnn2.Close()

        MsgBox("Complete!")
    End Sub
    Friend Sub CalcGPCDGTZero()
        Dim strCurrentGEOID10 As String = ""
        Dim dGPCD As Double = 0
        Dim dAREA_RATIO As Double = 0
        Dim dMUD_GPCD As Double = 0
        Dim dProduct As Double = 0
        Dim dMinDist As Double = 999
        Dim dPopAveragedGPCD As Double = 0
        Dim i As Integer = 0
        Dim j As Integer = 0
        Dim iNumRecords As Integer = 0

        Dim dDistanceCoeff As Double = Main.txtDistancePower.Text
        Dim dPopulationCoeff As Double = Main.txtPopulation.Text
        Dim dNumerator As Double = 0
        Dim dDenominator As Double = 0

        openConnection_SDE(cnn)
        cmd1.CommandType = CommandType.Text
        cmd1.CommandText = "select a.*,b.POP_WEIGHTED_GPCD from near_data_gt_zero as a inner join " & _
                           "COUNTY_SUBAREA as b on a.COUNTY_SUBAREA_NAME = b.COUNTY_SUBAREA_NAME order by ↙
    geoid10"
        cmd1.Connection = cnn
        dr = cmd1.ExecuteReader

        openConnection_SDE(cnn2)
        cmd2.CommandType = CommandType.StoredProcedure
        cmd2.CommandText = "update_Near_Data_GT_Zero"
        cmd2.Connection = cnn2

        While dr.Read
            i += 1

            If dr("GEOID10") <> strCurrentGEOID10 And i > 1 Then
                'Calculate the GPCD for the current census block
                If dDenominator > 0 Then
                    dGPCD = dNumerator / dDenominator
                Else
                    MsgBox("Denominator = 0. Whyyyyyy!!!")
                End If

                'Set GPCD to the population averaged GPCD for the subarea if the minimum distance is       ↙
    greater than 2 miles
                If dMinDist > 2 Then
                    dGPCD = dPopAveragedGPCD
                End If

                'Update [NEAR_DATA_GT_ZERO]
                cmd2.Parameters.Clear()
```

```
                cmd2.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strCurrentGEOID10
                cmd2.Parameters.Add("@GPCD", SqlDbType.Float).Value = dGPCD
                cmd2.ExecuteNonQuery()
                cmd2.Parameters.Clear()

                'Reset everything
                dNumerator = 0
                dDenominator = 0
                dMinDist = 999
                j = 0
            End If

            strCurrentGEOID10 = dr("GEOID10")
            dPopAveragedGPCD = dr("POP_WEIGHTED_GPCD")

            If Not IsDBNull(dr("MUD_POP")) And Not IsDBNull(dr("MUD_GPCD")) Then
                j += 1
                dNumerator += dr("MUD_GPCD") * dr("MUD_POP") ^ dPopulationCoeff / dr("DIST") ^ ↙
    dDistanceCoeff
                dDenominator += dr("MUD_POP") ^ dPopulationCoeff / dr("DIST") ^ dDistanceCoeff
                If dr("DIST") < dMinDist Then dMinDist = dr("DIST")
            End If

        End While

        'Since a DataReader (forward-only recordset) is being used, don't know which is the last record ↙
    until they're all read.
        'Calculate the last row
        If dDenominator > 0 Then
            dGPCD = dNumerator / dDenominator
        Else
            MsgBox("Denominator = 0")
        End If

        'Update [NEAR_DATA_GT_ZERO]
        cmd2.Parameters.Clear()
        cmd2.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strCurrentGEOID10
        cmd2.Parameters.Add("@GPCD", SqlDbType.Float).Value = dGPCD
        cmd2.ExecuteNonQuery()

        dr.Close()
        cnn.Close()
        cnn2.Close()

        MsgBox("Complete!")
    End Sub
```

SQL Server Data Definition Language (DDL) .sql Scripts

```
USE [WJT_SDE]
GO
/****** Object:  Table [dbo].[NEAR_DATA_MIN_ZERO]    Script Date: 11/28/2012 09:46:27 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[NEAR_DATA_MIN_ZERO](
    [OBJECTID] [int] NOT NULL,
    [GEOID10] [nvarchar](15) NULL,
    [A1NAME] [nvarchar](100) NOT NULL,
    [PWS_ID] [nvarchar](25) NOT NULL,
    [DIST] [numeric](38, 8) NULL,
    [MUD_GPCD] [numeric](38, 8) NULL,
    [AREA_RATIO] [numeric](38, 8) NULL,
    [BLOCK_GPCD] [numeric](38, 8) NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[NEAR_DATA_GT_ZERO]    Script Date: 11/28/2012 09:46:27 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[NEAR_DATA_GT_ZERO](
    [OBJECTID] [int] NOT NULL,
    [GEOID10] [nvarchar](15) NULL,
    [COUNTY_SUBAREA_NAME] [nvarchar](50) NULL,
    [BlockPopulation] [numeric](38, 8) NULL,
    [A1NAME] [nvarchar](100) NOT NULL,
    [PWS_ID] [nvarchar](25) NOT NULL,
    [MUD_POP] [int] NULL,
    [MUD_GPCD] [numeric](38, 8) NULL,
    [DIST] [numeric](38, 8) NULL,
    [BLOCK_GPCD] [numeric](38, 8) NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[COUNTY_SUBAREA]    Script Date: 11/28/2012 09:46:27 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[COUNTY_SUBAREA](
    [COUNTY_SUBAREA_NAME] [nchar](50) NULL,
    [POP_WEIGHTED_GPCD] [float] NULL
) ON [PRIMARY]
GO
/****** Object:  StoredProcedure [dbo].[update_Near_Data_Min_Zero]    Script Date: 11/28/2012
09:46:28 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[update_Near_Data_Min_Zero]
    @GEOID10 nvarchar(15), @GPCD float
```

```
AS
    update NEAR_DATA_MIN_ZERO
    set block_gpcd = @GPCD
    where geoid10 = @GEOID10
GO
/****** Object:  StoredProcedure [dbo].[update_Near_Data_GT_Zero]    Script Date: 11/28/2012
09:46:28 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[update_Near_Data_GT_Zero]
    @GEOID10 nvarchar(15), @GPCD float
AS
    update NEAR_DATA_GT_ZERO
    set block_gpcd = @GPCD
    where geoid10 = @GEOID10
GO
```

TO: Regional Groundwater Update Project Partners

CC:

FROM: William J. Thaman, P.E.

SUBJECT: Distribution of Population from Census Tracts to Blocks

DATE: August 29, 2012

Introduction

Population projections for the primary counties (Harris, Galveston, Fort Bend, Montgomery, and Brazoria) in the Regional Groundwater Update Project (RGUP) were done at the 2010 Census Tract level. The projections covered the period 2020 – 2070, by decade. The spatial distribution of these projections has been refined by allocating Tract populations to the Census Blocks that make up each tract; this refined distribution increases the accuracy of population projections at the water system and regulatory levels.

The hierarchy of Census spatial data, in descending resolution is: State, County, Tract, Block Group, and Block. The Census Bureau assigned 2010 populations at the Block level; populations at other levels are determined by aggregating up to the Block Group, then to Tract, then to County, and finally to the State level. The size of Tracts can vary a great deal depending on the population density. A typical Tract near downtown Houston, for example, will be much smaller than a Tract in Northwest Harris County that is primarily farmland with a low population (see Figure 1). Where population in a large Tract is projected to grow, there becomes a need to understand where within that Tract that population will go.

There are 1,039 Census Tracts in the five primary counties. Census Blocks are at a much higher resolution (see Figure 2). There are 114,200 Blocks in the five primary counties; an average ratio of 110 Blocks for every Tract. This memo explains the methodology by which Tract-level populations are assigned to Census Blocks for the period 2020 – 2070, by decade.

Figure 1. Census Tracts in West Harris County

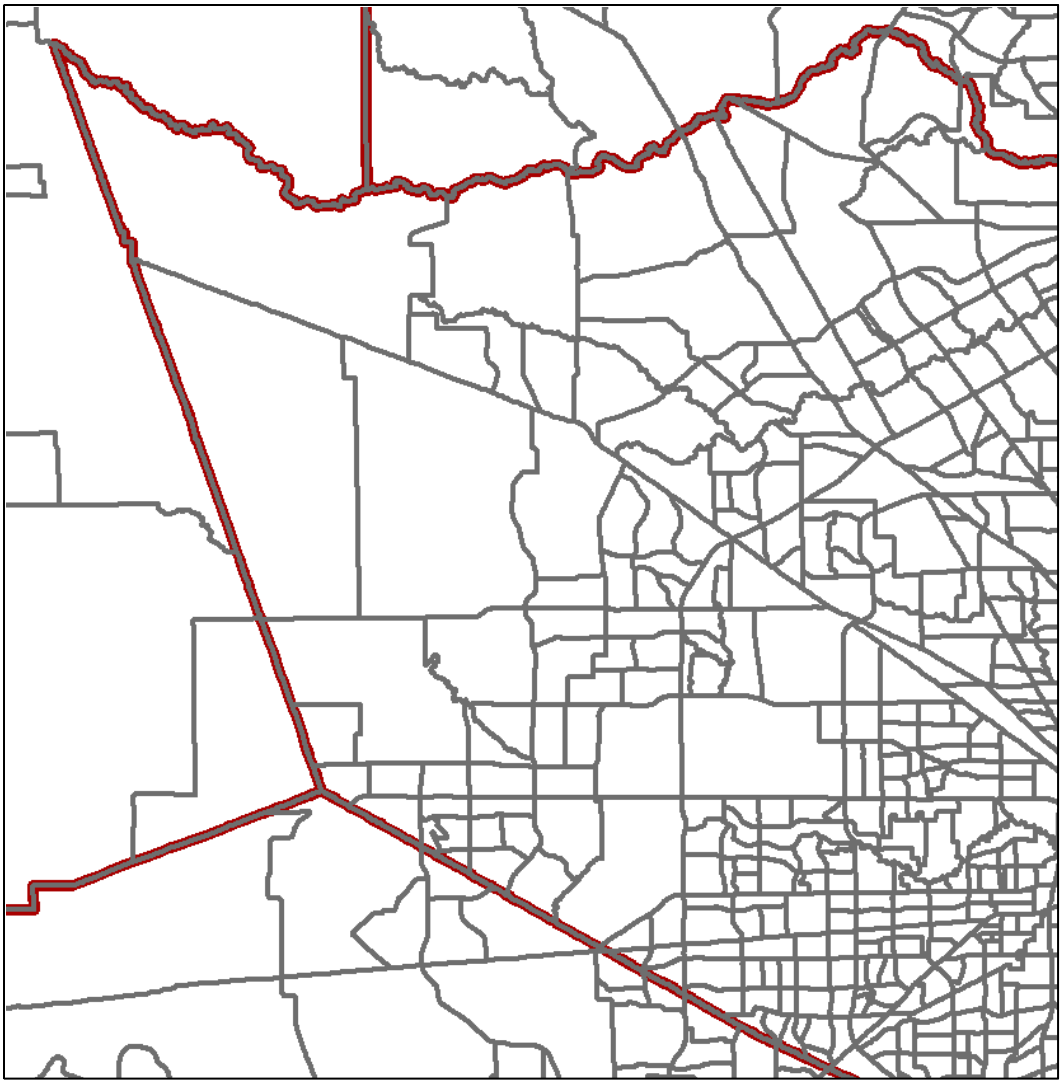
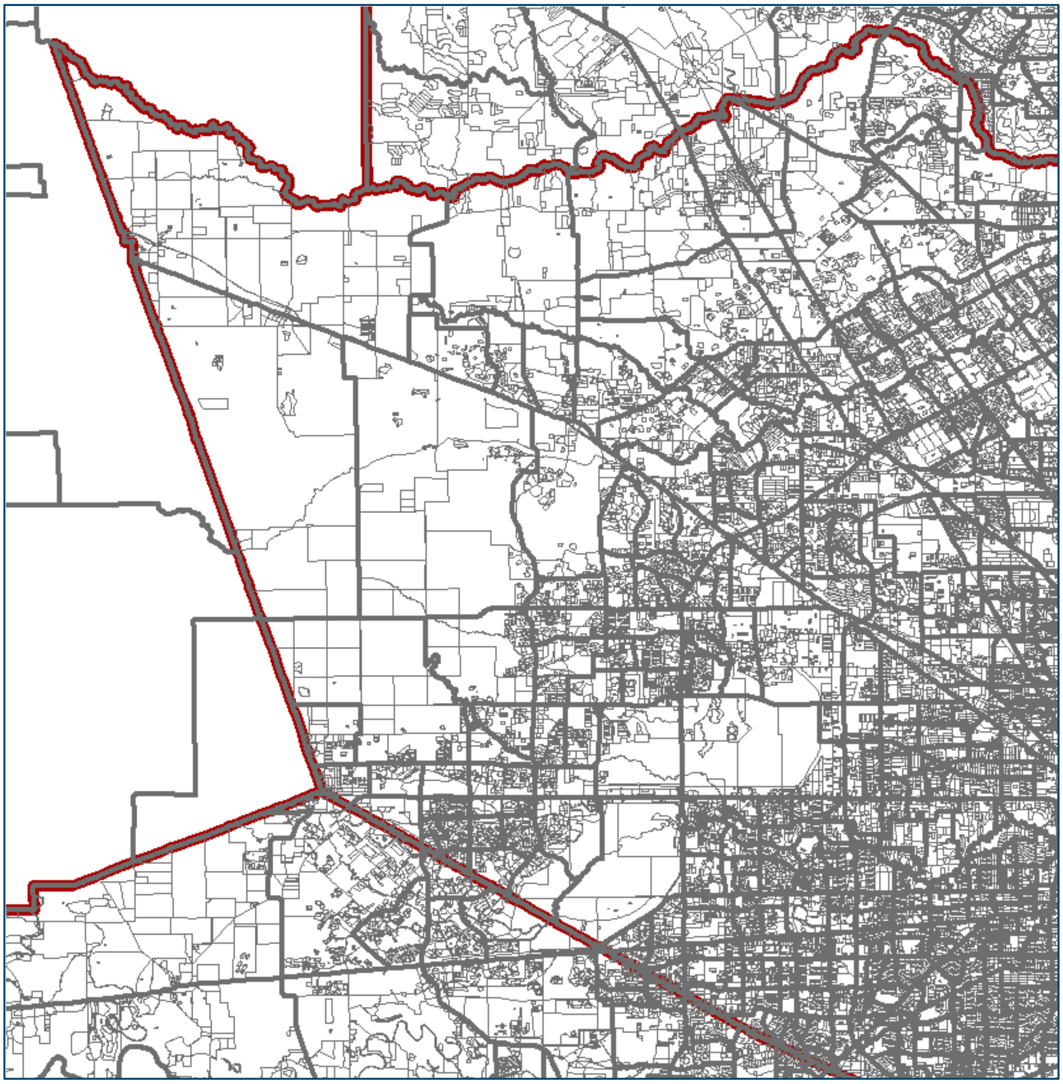


Figure 2. Census Blocks in West Harris County



Methodology

This section describes the methodology used to distribute Census Tract population to the Census Blocks making up the tract. The process goes sequentially through the decades; the methodology for the 2020 distribution is different than for the 2030 – 2070 decades.

Figure 3 shows the tracts in North Fort Bend County; this is an area that was not densely populated in 2010 and that has very large 2010 Census Tracts. Figure 4 shows the blocks in the same area shown in Figure 3. Figure 5 shows the Houston-Galveston Area Council (H-GAC) land use parcels for the area.

Figure 3. Census Tracts in North Fort Bend County

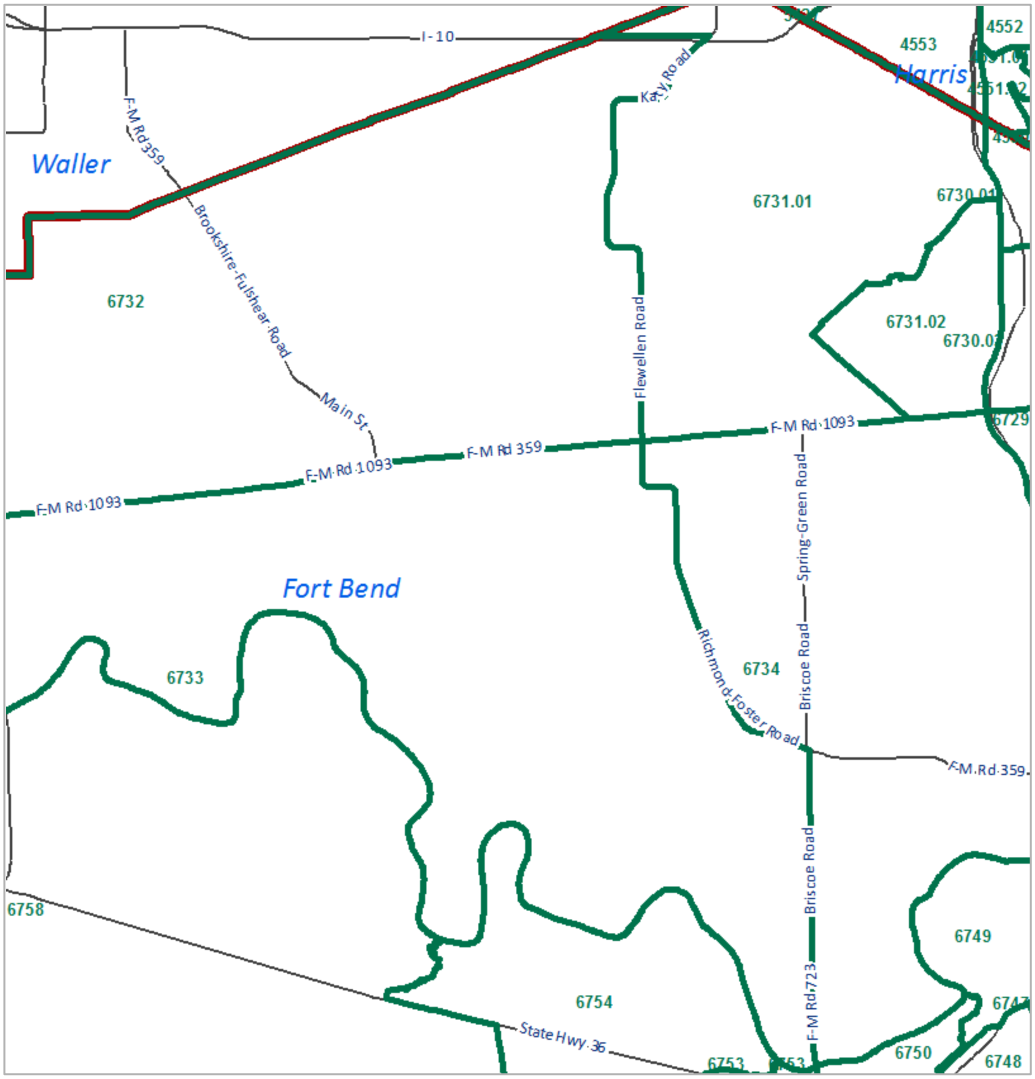


Figure 4. Census Blocks in North Fort Bend County

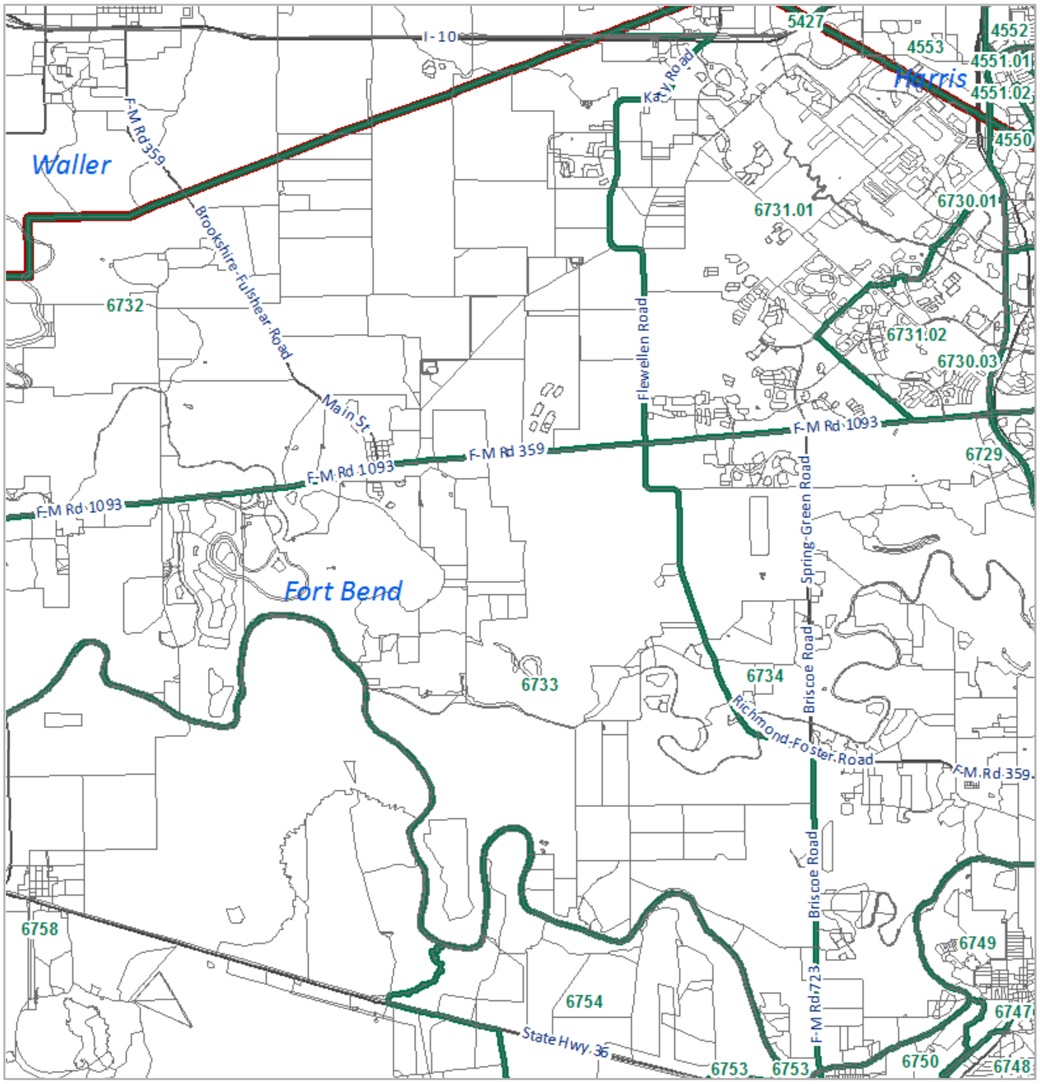
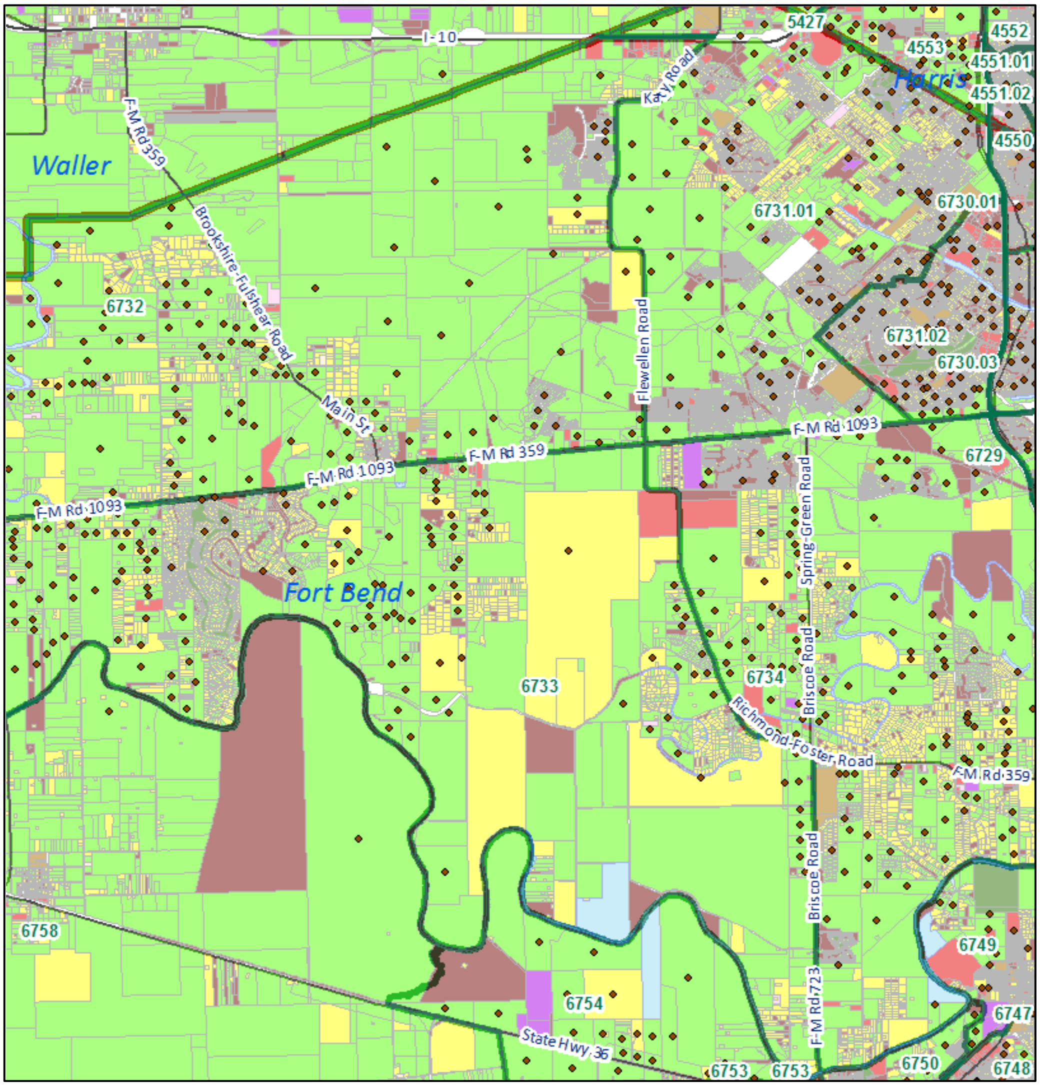


Figure 5. H-GAC Land Use Parcels in North Fort Bend County



Year 2020 Distribution

Metrostudy (www.metrostudy.com) provided the 2020 projections at the Census Tract level. The process used was to define points where future development is expected; each point represents a subdivision, subdivision section within a master-planned community, or other development. The data associated with each development point includes, by year from 2011 – 2020, the number of housing starts anticipated in that year, as well as the persons per household number for the county containing the point. The points within each Census Tract include information only for that tract; if there is a subdivision that straddles one or more tracts, individual points were created for each subdivision/tract combination. Generally, the 2010 – 2020 population increase in each tract is equal to the sum of the number of people indicated by the points, but that is not always so due to adjustments necessary to achieve county totals.

Figure 6 shows the Metrostudy subdivision points for the North Fort Bend County area shown previously. There is no defined boundary associated with each point, and no assumed development density. Thiessen polygons were used to define boundaries for each point. Thiessen polygons are drawn such that any point within a polygon is closer to that polygon's subdivision point than to any other subdivision point. Figure 7 shows the Thiessen polygons for the same area shown in Figure 6. The Thiessen polygons are drawn such that no polygon crosses its containing Census Tract.

Figure 6. Metrostudy Subdivision Points in North Fort Bend County

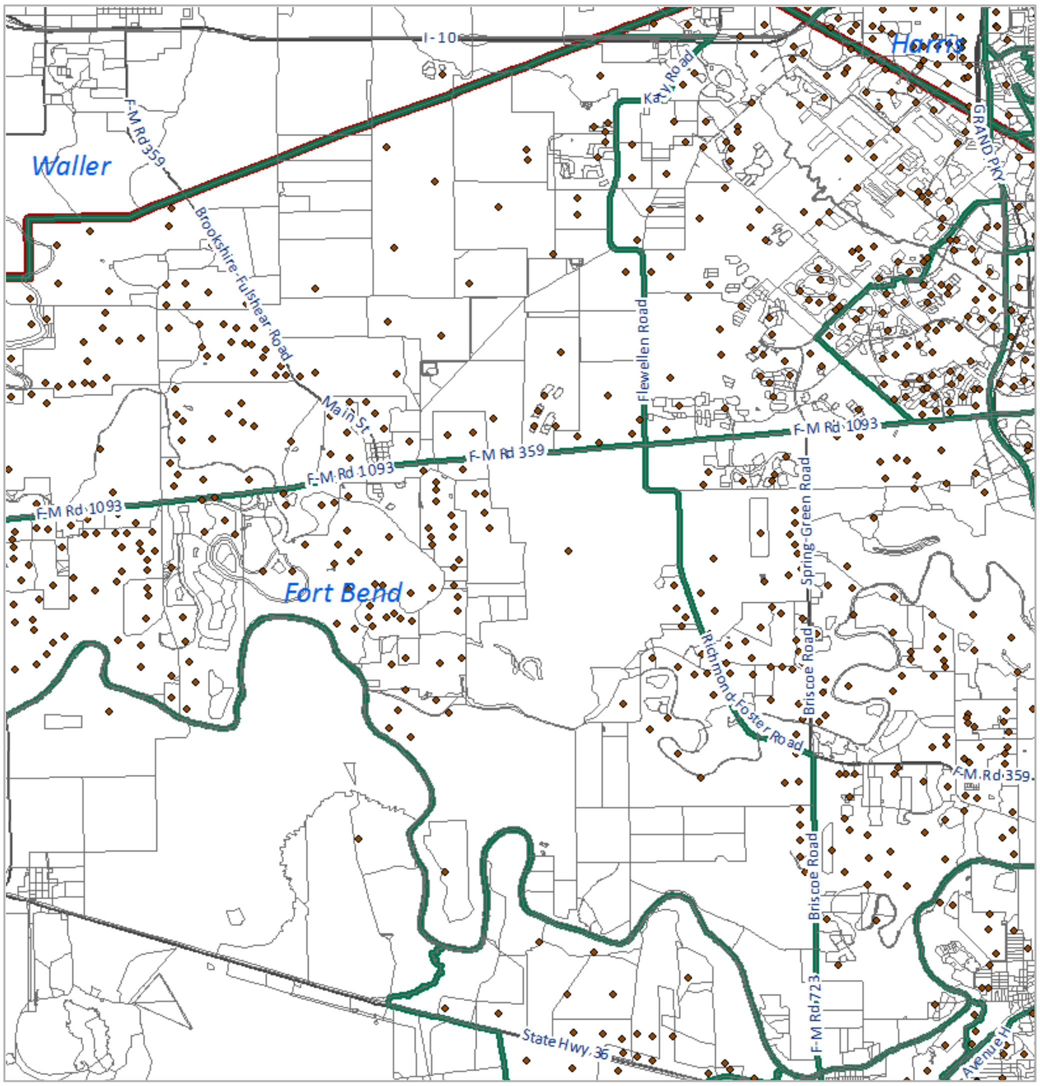
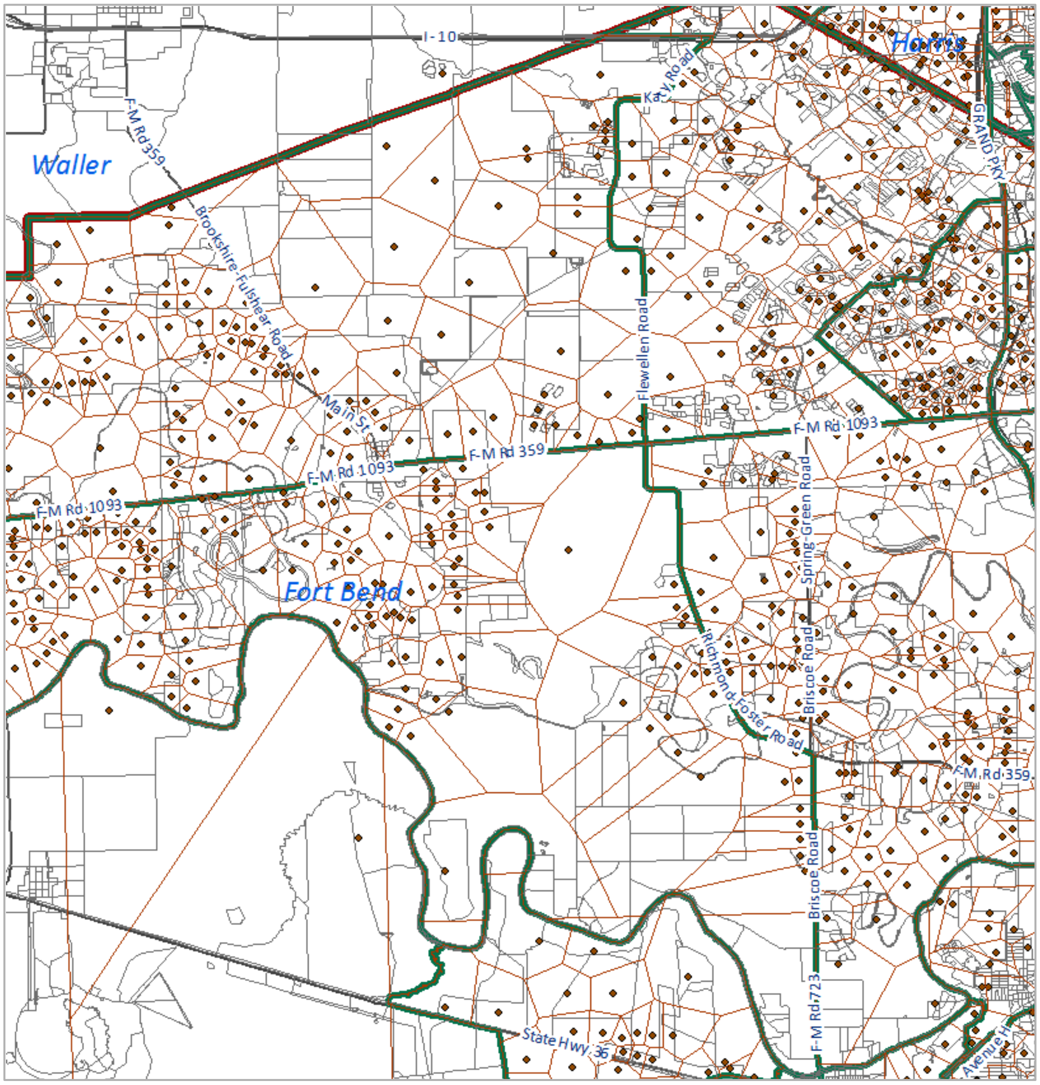


Figure 7. Thiessen Polygons



As shown in Figure 7, Thiessen polygons frequently cross Census Block boundaries. The following steps were completed to populate the data fields required to perform the population distribution:

1. For each Census Block (CB), calculate residential density as (population)/(CB area)
2. For each county, calculate the 75th Percentile density from the CB densities. This will be used when a block has been determined to primarily contain urbanized development.
3. For each county, calculate the maximum density to be used for raw land. This is defined as (persons per household) x (2 households per acre). The assumption of 2 households per acre for raw land is from Metrostudy.
4. Using H-GAC land use parcel data, calculate the developable area for each CB and Census Tract (CT).
5. For each CB, using H-GAC land use data, determine the maximum and average parcel area.
6. For each CB, determine the maximum density (MD) based on the max and average parcel area within the CB. If the max parcel area is greater than or equal to 10 acres, and the average parcel area is greater than or equal to 5 acres, then it is assumed that the CB is generally undeveloped and the max

density is defined by (number of persons per household) x (2 households per acre). Otherwise, the CB is assumed to be generally developed and the max density is defined as the 75^{th} Percentile residential density.

7. For each CB, calculate the weighted density (WD) as (CB developable area)/(CT developable area) x (MD).
8. For each CT, calculate the Tract Weighted Density (TWD) as the sum of WD within each CT.
9. Using ArcGIS, union the Thiessen Polygons (TPs) with Census Blocks (CBs). The GIS layer created is referred to hereafter as TPCB.
10. Ratio the growth indicated by the Metrostudy points to match the growth in each CT.
11. Using TPCB, use area ratios to determine the initial amount of growth from the Thiessen polygons assigned to each CB (GROWTH_FROM_PTS_2020_ADJUSTED).

After the initial data was developed using the steps above, custom software was written in VB.NET to perform the distribution from Census Tracts to Census Blocks. The VB.NET code and SQL Server Stored Procedures used are included as an attachment to this memo. The basic procedures used are as follows:

1. **Interp2020Pts() –** Perform spatial interpolation on Census Blocks (CBs) that comprise Census Tracts (CTs) containing Metrostudy subdivision points. If the CB does not have room for the initially assigned population, read through the adjacent CBs that are also intersected by the Thiessen polygons (TPs) that intersect that CB. Add population in CBs that have room for growth. Wherever population is added to a CB, decrement its available developable area by (population added)/(max density). Loop through all the blocks until all the population has been assigned. Stored Procedures are used extensively in this procedure. The Stored Procedure used are:
    a. readCENSUS_BLK
    b. readAdjacentBlocksAll
    c. updateThiessenBlk
    d. updateThiessenAllBlocksInTract
    e. updateThiessenUrbanTract
2. **Interp2020NonPts()** – Perform spatial interpolation on CBs that comprise CTs that do not contain Metrostudy subdivision points. All updates are done with the following SQL Server Stored Procedures:
    a. readCENSUS_TRACT_NO_PT_GROWTH
    b. updateThiessenRuralTract
    c. updateBlockRuralTract
    d. updateBlockUrbanTract

<u>Year 2030 Distribution</u>

The basic data needed for the 2020 distribution is the same for the 2030 distribution. Max densities remain the same, but the starting developable areas must be adjusted according to the population added in 2020. The Metrostudy subdivision points indicated the number of houses not constructed by 2020, but there is no indication of when the houses will be constructed. It is assumed that all houses will be constructed by 2030. The VB.NET procedures used are:

1. **Interp2030Pts** – Similar to Interp2020Pts, using the following Stored Procedures:

a. readCENSUS_BLK_2030
b. readAdjacentBlocksAll_2030
c. updateThiessenBlk_2030
d. updateThiessenAllBlocksInTract_2030
e. updateThiessenUrbanTract_2030

2. **Interp2030NonPts** – Similar to Interp2020NonPts, using the following Stored Procedures:
    a. readCENSUS_TRACT_NO_PT_GROWTH_2030
    b. updateThiessenRuralTract_2030
    c. updateBlockRuralTract_2030
    d. updateBlockUrbanTract_2030
    e. initializeTotalGrowth_2030
    f. updatePopulation_2030

Decades 2040-2070 Distribution

The Metrostudy subdivision points do not contain data beyond 2030. All interpolation for decades 2040-2070 was done using SQL Server queries. Additional population is apportioned according to remaining developable area.

VB.NET Code

```
    Public Sub openConnection(ByRef theCNN As System.Data.SqlClient.SqlConnection)
        Try
            'Connections string in Settings.settings:
            'Data Source=WJT2\SQLEXPRESS;AttachDbFilename=
            '"C:\Program Files\Microsoft SQL Server\MSSQL10.SQLEXPRESS\MSSQL\DATA\WJTMASTER.mdf";
            'Integrated Security=True;Connect Timeout=600;User Instance=True
            theCNN.ConnectionString = My.Settings.WJTMasterConnection3 'connection to WJTMASTER in the SQL Server Express data folder
            theCNN.Open()
        Catch ex As Exception
            MsgBox(ex.Message)
        End Try
    End Sub
```

```
    Friend Sub Interp2020Pts()
        Dim strGEOID10, strTRACTCE10, strCounty, strGEOID10Update() As String
        Dim sngBlockPop(), sngBlockAreaAc(), sngTotalGrowthToBlock() As Single
        Dim sngDevelopableArea(), sngPercentile_75th(), sngDensity(), sngAllowableAddtlGrowth() As Single
        Dim sngTotalAddtlGrowth, sngMainBlkTotalGrowthToBlock As Single
        Dim intMetroMaxBlockPop(), i, j, numrowsaffected As Integer
        Dim sngReduction As Single = 0
        Dim boolReduction_LT_CapacityForGrowth As Boolean = False
        Dim sngIndividualUpdateGrowth As Single = 0
        Dim sngRemainderToAssign As Single = 0
        Dim sngPopAdded As Single = 0
        Dim sngSumPopAdded As Single = 0
        Dim sngSumPopSubtracted As Single = 0

        Try
            openConnection(cnn)
            cmd1.CommandType = CommandType.StoredProcedure
            cmd1.CommandText = "readCENSUS_BLK"
            cmd1.Connection = cnn
            cmd1.CommandTimeout = 300

            openConnection(cnn2)
            cmd2.CommandType = CommandType.StoredProcedure
            cmd2.Connection = cnn2
            cmd2.CommandTimeout = 300

            openConnection(cnn3)
            cmd3.CommandType = CommandType.StoredProcedure
            cmd3.Connection = cnn3
            cmd3.CommandTimeout = 300

            'Read through all census blocks that have growth from points
            dr = cmd1.ExecuteReader
            Main.BindingSource1.DataSource = dr
            Main.DataGridView1.DataSource = Main.BindingSource1
            dr.Close()
            dr = cmd1.ExecuteReader
            While dr.Read

                strGEOID10 = dr("GEOID10")
                strTRACTCE10 = dr("TRACTCE10")
                strCounty = UCase(Trim(dr("County")))

                'Process only the "rural" blocks that have excess population
                If dr("TRACT_GROWTH_TYPE") = "RURAL" And (dr("DEVELOPABLE_AREA_2010") = 0 Or dr("GROWTH_FROM_PTS_2020") / dr( ↙
    "DEVELOPABLE_AREA_2010") > dr("PERCENTILE_75TH")) Then
                    'REAL: If statement: If dr("DEVELOPABLE_AREA_2010") = 0 Or dr("GROWTH_FROM_PTS_2020") / dr("DEVELOPABLE_AREA_2010") > dr( ↙
    "PERCENTILE_75TH") Then
```

```
'TEST: If dr("GEOID10")="482015414001069" then
'The block is overpopulated according to the amount of population from the points and the amount of developable area

cmd2.CommandText = "readAdjacentBlocksAll"
cmd2.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strGEOID10
dr2 = cmd2.ExecuteReader
i = 0
sngTotalAddtlGrowth = 0
'Loop through the union of Thiessen polygons and census blocks associated with the Thiessen polygon
'with the largest contribution to the census block in dr.Read
While dr2.Read
    'Find the blocks that have room for additional population
    If dr2("Blk_Developable_Area_2010") > 0 And dr2("TRACTCE10") = strTRACTCE10 Then
        If dr2("Total_Growth_to_Block_Adj") / dr2("Blk_Developable_Area_2010") < dr2("Percentile_75th") Then
            i += 1

            'Primary block to be updated
            ReDim Preserve strGEOID10Update(i)
            strGEOID10Update(i) = dr2("GEOID10")
            ReDim Preserve sngBlockPop(i)
            sngBlockPop(i) = dr2("BlockPopulation")
            ReDim Preserve sngBlockAreaAc(i)
            sngBlockAreaAc(i) = dr2("BlockAreaAcres")
            ReDim Preserve sngTotalGrowthToBlock(i)
            sngTotalGrowthToBlock(i) = dr2("Total_Growth_to_Block_Adj")
            ReDim Preserve sngPercentile_75th(i)
            sngPercentile_75th(i) = dr2("Percentile_75th")
            ReDim Preserve intMetroMaxBlockPop(i)
            intMetroMaxBlockPop(i) = dr2("Metro_Max_Block_Pop")
            ReDim Preserve sngDevelopableArea(i)
            sngDevelopableArea(i) = dr2("Blk_Developable_Area_2010")
            'Population density in the developable area
            'ReDim Preserve sngDensity(i)
            'sngDensity(i) = sngTotalGrowthToBlock(i) / sngDevelopableArea(i)
            'Allowable additional growth
            ReDim Preserve sngAllowableAddtlGrowth(i)
            sngAllowableAddtlGrowth(i) = Math.Max(sngDevelopableArea(i) * sngPercentile_75th(i) - sngTotalGrowthToBlock(i), 0)

            'Add up the total allowable additional growth for all blocks associated with the current thiessen polygon
            sngTotalAddtlGrowth += sngAllowableAddtlGrowth(i)
        End If
    End If
    'If the block in this inner loop (dr2) is the same as the block in the outer loop (dr), determine the amount
    'the population should be reduced for that block
    If dr("GEOID10") = dr2("GEOID10") Then
        'Reduction from what is initially assigned to the block
        'If there is no developable area, all the additional population will be assigned
        sngReduction = dr2("Total_Growth_to_Block_Adj") - dr2("Percentile_75th") * dr2("Blk_Developable_Area_2010")
```

```
                'Amount of additional population being assigned to the block in the outer loop (dr)
                sngMainBlkTotalGrowthToBlock = dr2("Total_Growth_to_Block_Adj")
            End If
        End While 'end inner dr2 loop

        'Close the datareader and clear the command parameters
        dr2.Close()
        cmd2.Parameters.Clear()
        cmd2.Dispose()

        'Check to see whether the amount of reduction is less than the room for additional growth and set flag
        'This will dictate how growth is distributed, and whether all growth can be distributed in one process
        If sngReduction <= sngTotalAddtlGrowth Then
            boolReduction_LT_CapacityForGrowth = True
        Else
            boolReduction_LT_CapacityForGrowth = False
        End If

        If boolReduction_LT_CapacityForGrowth Then
            'Perform updates to the main census block (dr loop), and the other blocks associated with the Thiessen polygon
            Try
                'Update outer block (dr loop)
                cmd3.CommandText = "updateThiessenBlk"
                cmd3.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strGEOID10
                cmd3.Parameters.Add("@TOTAL_GROWTH_TO_BLOCK", SqlDbType.Float).Value = sngMainBlkTotalGrowthToBlock - sngReduction
                numrowsaffected = cmd3.ExecuteNonQuery()
                cmd3.Parameters.Clear()

                sngSumPopSubtracted += sngReduction

                'Update all other associated blocks that have room for additional growth
                sngRemainderToAssign = sngReduction
                sngPopAdded = 0
                For j = 1 To i
                    'TESTING: Distribute to blocks in array proportional to remaining developable area
                    If strGEOID10Update(j) <> strGEOID10 Then
                        cmd3.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strGEOID10Update(j)

                        sngPopAdded = sngAllowableAddtlGrowth(j) / sngTotalAddtlGrowth * sngReduction

                        sngIndividualUpdateGrowth = _
                            sngTotalGrowthToBlock(j) + sngPopAdded

                        cmd3.Parameters.Add("@TOTAL_GROWTH_TO_BLOCK", SqlDbType.Float).Value = sngIndividualUpdateGrowth
                        numrowsaffected = cmd3.ExecuteNonQuery()
                        cmd3.Parameters.Clear()
                        sngSumPopAdded += sngPopAdded
```

```
                                    sngRemainderToAssign -= sngPopAdded
                                End If
                            Next
                        Catch ex As Exception
                            'display a message if there was an error
                            MsgBox("Error in update block of code = " & ex.Message)
                        End Try
                        cmd3.Parameters.Clear()
                        cmd3.Dispose()
                    Else
                        Try
                            'There is no room for available pop in the surrounding blocks.
                            'Distribute to all blocks in the tract where there is developable area
                            cmd3.CommandText = "updateThiessenAllBlocksInTract"
                            cmd3.Parameters.Add("@TRACTCE10", SqlDbType.NVarChar, 6).Value = strTRACTCE10
                            cmd3.Parameters.Add("@REDUCTION", SqlDbType.Float).Value = sngReduction
                            numrowsaffected = cmd3.ExecuteNonQuery
                            cmd3.Parameters.Clear()
                            cmd3.Dispose()

                            'Update the individual block in question
                            cmd3.CommandText = "updateThiessenBlk"
                            cmd3.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strGEOID10
                            cmd3.Parameters.Add("@TOTAL_GROWTH_TO_BLOCK", SqlDbType.Float).Value = sngMainBlkTotalGrowthToBlock - sngReduction
                            numrowsaffected = cmd3.ExecuteNonQuery()
                            cmd3.Parameters.Clear()
                            cmd3.Dispose()
                        Catch ex As Exception
                            MsgBox("Error in code block that redistributes to all blocks in tract: " & ex.Message)
                        End Try
                    End If
                ElseIf dr("TRACT_GROWTH_TYPE") = "URBAN" And (dr("DEVELOPABLE_AREA_2010") = 0 Or dr("GROWTH_FROM_PTS_2020") / dr(  ↙
    "DEVELOPABLE_AREA_2010") > dr("PERCENTILE_75TH")) Then
                    cmd3.CommandText = "updateThiessenUrbanTract"
                    cmd3.Parameters.Add("@TRACTCE10", SqlDbType.NVarChar, 6).Value = strTRACTCE10
                    numrowsaffected = cmd3.ExecuteNonQuery()
                    cmd3.Parameters.Clear()
                    cmd3.Dispose()
                End If
            End While 'end outer dr loop

            'Close the outer datareader and all connections
            dr.Close()
            cnn.Close()
            cnn2.Close()
            cnn3.Close()

            MsgBox("Interp2020Pts Complete!")
```

```
        Catch ex As Exception
            MsgBox("Error: " & ex.Message)
        End Try
    End Sub
    Friend Sub Interp2020NonPts()
        Dim strTRACTCE10 As String = ""
        Dim strTractGrowthType As String = ""
        Dim intP10 As Integer = 0
        Dim intP20 As Integer = 0
        Dim strCnty As String = ""
        Dim sngGrowthFromPts As Single = 0.0
        Dim numRowsAffected As Long
        Dim intOutsideMetroProjections As Integer = 0

        Try
            openConnection(cnn)
            cmd1.CommandType = CommandType.StoredProcedure
            cmd1.CommandText = "readCENSUS_TRACT_NO_PT_GROWTH"
            cmd1.Connection = cnn
            cmd1.CommandTimeout = 300

            openConnection(cnn2)
            cmd2.CommandType = CommandType.StoredProcedure
            cmd2.Connection = cnn2
            cmd2.CommandTimeout = 300

            dr = cmd1.ExecuteReader
            While dr.Read
                strTRACTCE10 = dr("TRACTCE10")
                intP10 = dr("P10")
                intP20 = dr("P20")
                strTractGrowthType = dr("TractGrowthType")
                strCnty = UCase(Trim(dr("Cnty")))
                sngGrowthFromPts = dr("GrowthFromPts")
                intOutsideMetroProjections = dr("Outside_Metro_Projections")

                'Process tracts with no point growth and where there is population growth
                If strTRACTCE10 = "720100" Or strTRACTCE10 = "721600" Or strTRACTCE10 = "721100" Or strTRACTCE10 = "720503" _
                Or strTRACTCE10 = "720501" Or strTRACTCE10 = "722300" Or strTRACTCE10 = "722100" Then 'Tracts with negative growth
                    'ORIGINAL IF: If sngGrowthFromPts = 0 And (strTRACTCE10 = "721600" Or strTRACTCE10 = "722300" Or (intP20 - intP10) > 0) Then
                    'There is growth in the tract, and no Metrostudy points to guide the distribution
                    If intOutsideMetroProjections = 0 And UCase(strTractGrowthType) = "RURAL" Then
                        cmd2.CommandText = "updateThiessenRuralTract"
                    ElseIf intOutsideMetroProjections = 0 And UCase(strTractGrowthType) = "URBAN" Then
                        cmd2.CommandText = "updateThiessenUrbanTract"
                    ElseIf intOutsideMetroProjections = 1 And UCase(strTractGrowthType) = "RURAL" Then
                        cmd2.CommandText = "updateBlockRuralTract"
                    ElseIf intOutsideMetroProjections = 1 And UCase(strTractGrowthType) = "URBAN" Then
```

```
                    cmd2.CommandText = "updateBlockUrbanTract"
                End If

                Try
                    cmd2.Parameters.Add("@TRACTCE10", SqlDbType.NVarChar, 6).Value = strTRACTCE10
                    numRowsAffected = cmd2.ExecuteNonQuery()
                    cmd2.Parameters.Clear()
                    cmd2.Dispose()
                Catch ex As Exception
                    MsgBox("Error in sproc execution: " & ex.Message)
                End Try
            End If

        End While 'dr.Read
        cnn.Close()
        dr.Close()
        cnn2.Close()
        MsgBox("Interp2020NonPts Complete!")
    Catch ex As Exception
        MsgBox("Error in interp2020NonPts: " & ex.Message)
    End Try

End Sub
Friend Sub Interp2030Pts()
    Dim strGEOID10 As String = ""
    Dim strTRACTCE10 As String = ""
    Dim strStartingGEOID10 As String = ""
    Dim strEndingGEOID10 As String = "999999999999999"
    Dim strCounty, strGEOID10Update() As String
    Dim sngBlockPop(), sngBlockAreaAc(), sngTotalGrowthToBlock() As Single
    Dim sngDevelopableArea(), sngPercentile_75th(), sngDensity(), sngAllowableAddtlGrowth() As Single
    Dim sngTotalAddtlGrowth, sngMainBlkTotalGrowthToBlock As Single
    Dim i, j, numrowsaffected As Integer
    Dim sngReduction As Single = 0
    Dim boolReduction_LT_CapacityForGrowth As Boolean = False
    Dim sngIndividualUpdateGrowth As Single = 0
    Dim sngRemainderToAssign As Single = 0
    Dim sngPopAdded As Single = 0
    Dim sngSumPopAdded As Single = 0
    Dim sngSumPopSubtracted As Single = 0

    Try
        'Set starting and ending GEOID10
        If Len(Main.txtGEOID10.Text) > 0 Then
            strStartingGEOID10 = Main.txtGEOID10.Text
        End If
        If Len(Main.txtEndingGEOID10.Text) > 0 Then
            strEndingGEOID10 = Main.txtEndingGEOID10.Text
```

```
        End If

        'Initialize Total Growth fields
        openConnection(cnn)
        cmd1.CommandType = CommandType.StoredProcedure
        cmd1.CommandText = "initializeTotalGrowth_2030"
        cmd1.Connection = cnn
        cmd1.CommandTimeout = 300
        'WARNING!!! RUNNING THIS CLEARS DATA ALREADY CALCULATED: cmd1.ExecuteNonQuery()

        openConnection(cnn2)
        cmd2.CommandType = CommandType.StoredProcedure
        cmd2.Connection = cnn2
        cmd2.CommandTimeout = 300

        openConnection(cnn3)
        cmd3.CommandType = CommandType.StoredProcedure
        cmd3.Connection = cnn3
        cmd3.CommandTimeout = 300

        'Read through all census blocks that have growth from points
        cmd1.CommandText = "readCENSUS_BLK_2030_RERUN"
        'cmd1.CommandText = "readCENSUS_BLK_2030"
        dr = cmd1.ExecuteReader
        Main.BindingSource1.DataSource = dr
        Main.DataGridView1.DataSource = Main.BindingSource1
        dr.Close()
        dr = cmd1.ExecuteReader
        While dr.Read

            strGEOID10 = dr("GEOID10")
            strTRACTCE10 = dr("TRACTCE10")
            strCounty = UCase(Trim(dr("County")))

            'Process only the "rural" blocks that have excess population
            If dr("TRACT_GROWTH_TYPE_2020") = "RURAL" And _
            strGEOID10 >= strStartingGEOID10 And _
            strGEOID10 <= strEndingGEOID10 And _
            (dr("DEVELOPABLE_AREA_2020") = 0 Or dr("GROWTH_FROM_PTS_2030") / dr("DEVELOPABLE_AREA_2020") > dr("PERCENTILE_75TH")) Then
                'If (strTRACTCE10 = "673200" Or strTRACTCE10 = "210600" Or strTRACTCE10 = "311600" Or strTRACTCE10 = "322700" Or strTRACTCE10 ↙
    = "422301") And (dr("TRACT_GROWTH_TYPE_2020") = "RURAL" And (dr("DEVELOPABLE_AREA_2020") = 0 Or dr("GROWTH_FROM_PTS_2030") / dr(          ↙
    "DEVELOPABLE_AREA_2020") > dr("PERCENTILE_75TH"))) Then
                'REAL: If statement: If dr("DEVELOPABLE_AREA_2010") = 0 Or dr("GROWTH_FROM_PTS_2020") / dr("DEVELOPABLE_AREA_2010") > dr(     ↙
    "PERCENTILE_75TH") Then
                'TEST: If dr("GEOID10")="482015414001069" then
                'The block is overpopulated according to the amount of population from the points and the amount of developable area

                cmd2.CommandText = "readAdjacentBlocksAll_2030"
```

```
                cmd2.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strGEOID10
                dr2 = cmd2.ExecuteReader
                i = 0
                sngTotalAddtlGrowth = 0
                'Loop through the union of Thiessen polygons and census blocks associated with the Thiessen polygon
                'with the largest contribution to the census block in dr.Read
                While dr2.Read
                    'Find the blocks that have room for additional population
                    If dr2("Blk_Developable_Area_2020") > 0 And dr2("TRACTCE10") = strTRACTCE10 Then
                        If dr2("Total_Growth_to_Block_Adj") / dr2("Blk_Developable_Area_2020") < dr2("Percentile_75th") Then
                            i += 1

                            'Primary block to be updated
                            ReDim Preserve strGEOID10Update(i)
                            strGEOID10Update(i) = dr2("GEOID10")
                            ReDim Preserve sngBlockPop(i)
                            sngBlockPop(i) = dr2("BlockPopulation")
                            ReDim Preserve sngBlockAreaAc(i)
                            sngBlockAreaAc(i) = dr2("BlockAreaAcres")
                            ReDim Preserve sngTotalGrowthToBlock(i)
                            sngTotalGrowthToBlock(i) = dr2("Total_Growth_to_Block_Adj")
                            ReDim Preserve sngPercentile_75th(i)
                            sngPercentile_75th(i) = dr2("Percentile_75th")
                            ReDim Preserve sngDevelopableArea(i)
                            sngDevelopableArea(i) = dr2("Blk_Developable_Area_2020")
                            'Allowable additional growth
                            ReDim Preserve sngAllowableAddtlGrowth(i)
                            sngAllowableAddtlGrowth(i) = Math.Max(sngDevelopableArea(i) * sngPercentile_75th(i) - sngTotalGrowthToBlock(i), 0)

                            'Add up the total allowable additional growth for all blocks associated with the current thiessen polygon
                            sngTotalAddtlGrowth += sngAllowableAddtlGrowth(i)
                        End If
                    End If
                    'If the block in this inner loop (dr2) is the same as the block in the outer loop (dr), determine the amount
                    'the population should be reduced for that block
                    If dr("GEOID10") = dr2("GEOID10") Then
                        'Reduction from what is initially assigned to the block
                        'If there is no developable area, all the additional population will be assigned
                        sngReduction = dr2("Total_Growth_to_Block_Adj") - dr2("Percentile_75th") * dr2("Blk_Developable_Area_2020")
                        'Amount of additional population being assigned to the block in the outer loop (dr)
                        sngMainBlkTotalGrowthToBlock = dr2("Total_Growth_to_Block_Adj")
                    End If
                End While 'end inner dr2 loop

                'Close the datareader and clear the command parameters
                dr2.Close()
                cmd2.Parameters.Clear()
                cmd2.Dispose()
```

```
            'Check to see whether the amount of reduction is less than the room for additional growth and set flag
            'This will dictate how growth is distributed, and whether all growth can be distributed in one process
            If sngReduction <= sngTotalAddtlGrowth Then
                boolReduction_LT_CapacityForGrowth = True
            Else
                boolReduction_LT_CapacityForGrowth = False
            End If

            If boolReduction_LT_CapacityForGrowth Then
                'Perform updates to the main census block (dr loop), and the other blocks associated with the Thiessen polygon
                Try
                    'Update outer block (dr loop)
                    cmd3.CommandText = "updateThiessenBlk_2030"
                    cmd3.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strGEOID10
                    cmd3.Parameters.Add("@TOTAL_GROWTH_TO_BLOCK", SqlDbType.Float).Value = sngMainBlkTotalGrowthToBlock - sngReduction
                    Try
                        numrowsaffected = cmd3.ExecuteNonQuery()
                    Catch ex As Exception
                        MsgBox("Error in updateThiessenBlk_2030: " & ex.Message)
                    End Try
                    cmd3.Parameters.Clear()

                    sngSumPopSubtracted += sngReduction

                    'Update all other associated blocks that have room for additional growth
                    sngRemainderToAssign = sngReduction
                    sngPopAdded = 0
                    For j = 1 To i
                        'TESTING: Distribute to blocks in array proportional to remaining developable area
                        If strGEOID10Update(j) <> strGEOID10 Then
                            cmd3.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strGEOID10Update(j)

                            sngPopAdded = sngAllowableAddtlGrowth(j) / sngTotalAddtlGrowth * sngReduction

                            sngIndividualUpdateGrowth = _
                                sngTotalGrowthToBlock(j) + sngPopAdded

                            cmd3.Parameters.Add("@TOTAL_GROWTH_TO_BLOCK", SqlDbType.Float).Value = sngIndividualUpdateGrowth
                            Try
                                numrowsaffected = cmd3.ExecuteNonQuery()
                            Catch ex As Exception
                                MsgBox("Error in updateThiessenBlk_2030: " & ex.Message)
                            End Try
                            cmd3.Parameters.Clear()
                            sngSumPopAdded += sngPopAdded

                            sngRemainderToAssign -= sngPopAdded
```

```
                        End If
                    Next
                Catch ex As Exception
                    'display a message if there was an error
                    MsgBox("GEOID10 = " & strGEOID10 & ", Error in update block of code = " & ex.Message)
                End Try
                cmd3.Parameters.Clear()
                cmd3.Dispose()
            Else
                Try
                    'There is no room for available pop in the surrounding blocks.
                    'Distribute to all blocks in the tract where there is developable area
                    cmd3.CommandText = "updateThiessenAllBlocksInTract_2030"
                    cmd3.Parameters.Add("@TRACTCE10", SqlDbType.NVarChar, 6).Value = strTRACTCE10
                    cmd3.Parameters.Add("@REDUCTION", SqlDbType.Float).Value = sngReduction
                    Try
                        numrowsaffected = cmd3.ExecuteNonQuery
                    Catch ex As Exception
                        MsgBox("updateThiessenAllBlocksInTract_2030, Error: " & ex.Message)
                    End Try
                    cmd3.Parameters.Clear()
                    cmd3.Dispose()

                    'Update the individual block in question
                    cmd3.CommandText = "updateThiessenBlk_2030"
                    cmd3.Parameters.Add("@GEOID10", SqlDbType.NVarChar, 15).Value = strGEOID10
                    cmd3.Parameters.Add("@TOTAL_GROWTH_TO_BLOCK", SqlDbType.Float).Value = sngMainBlkTotalGrowthToBlock - sngReduction
                    Try
                        numrowsaffected = cmd3.ExecuteNonQuery()
                    Catch ex As Exception
                        MsgBox("updateThiessenBlk_2030, Error: " & ex.Message)
                    End Try
                    cmd3.Parameters.Clear()
                    cmd3.Dispose()
                Catch ex As Exception
                    MsgBox("GEOID10 = " & strGEOID10 & ", Error in code block that redistributes to all blocks in tract: " & ex.Message)
                End Try
            End If
        ElseIf dr("TRACT_GROWTH_TYPE_2020") = "URBAN" And _
        strGEOID10 >= strStartingGEOID10 And _
        strGEOID10 <= strEndingGEOID10 And _
        (dr("DEVELOPABLE_AREA_2020") = 0 Or dr("GROWTH_FROM_PTS_2030") / dr("DEVELOPABLE_AREA_2020") > dr("PERCENTILE_75TH")) Then
            'ElseIf (strTRACTCE10 = "673200" Or strTRACTCE10 = "210600" Or strTRACTCE10 = "311600" Or strTRACTCE10 = "322700" Or ↙
    strTRACTCE10 = "422301") And (dr("TRACT_GROWTH_TYPE_2020") = "URBAN" And (dr("DEVELOPABLE_AREA_2020") = 0 Or dr("GROWTH_FROM_PTS_2030") / dr( ↙
    "DEVELOPABLE_AREA_2020") > dr("PERCENTILE_75TH"))) Then
            cmd3.CommandText = "updateThiessenUrbanTract_2030"
            cmd3.Parameters.Add("@TRACTCE10", SqlDbType.NVarChar, 6).Value = strTRACTCE10
            Try
```

```
                        numrowsaffected = cmd3.ExecuteNonQuery()
                    Catch ex As Exception
                        MsgBox("updateThiessenUrbanTract_2030, Error: " & ex.Message)
                    End Try
                    cmd3.Parameters.Clear()
                    cmd3.Dispose()
                End If
            End While 'end outer dr loop

            dr.Close()
            cmd1.CommandText = "updatePopulation_2030"
            'cmd1.ExecuteNonQuery()

            'Close all connections
            cnn.Close()
            cnn2.Close()
            cnn3.Close()

            MsgBox("Interp2030Pts Complete!")
        Catch ex As Exception
            MsgBox("GEOID10 = " & strGEOID10 & ", Error: " & ex.Message)
        End Try
    End Sub
    Friend Sub Interp2030NonPtGrowth()
        Dim strTRACTCE10 As String = ""
        Dim strTractGrowthType As String = ""
        Dim strCnty As String = ""
        Dim intOutsideMetroProjections As Integer = 0
        Dim sngTractNonPtGrowth As Single = 0.0
        Dim sngTractGrowth As Single = 0.0
        Dim numRowsAffected As Long = 0

        Try
            openConnection(cnn)
            cmd1.CommandType = CommandType.StoredProcedure
            cmd1.CommandText = "readCENSUS_TRACT_NO_PT_GROWTH_2030_RERUN"
            'cmd1.CommandText = "readCENSUS_TRACT_NO_PT_GROWTH_2030"
            cmd1.Connection = cnn
            cmd1.CommandTimeout = 300

            openConnection(cnn2)
            cmd2.CommandType = CommandType.StoredProcedure
            cmd2.Connection = cnn2
            cmd2.CommandTimeout = 300

            dr = cmd1.ExecuteReader
            While dr.Read
                strTRACTCE10 = dr("TRACTCE10")
```

```
                strTractGrowthType = dr("TractGrowthType")
                strCnty = UCase(Trim(dr("County")))
                sngTractGrowth = dr("Tract_Growth_2030")
                intOutsideMetroProjections = dr("OutsideMetroProjections")
                If IsDBNull(dr("Tract_NonPt_Growth_2030")) Then
                    sngTractNonPtGrowth = -999
                Else
                    sngTractNonPtGrowth = dr("Tract_NonPt_Growth_2030")
                End If

                'Process tracts with non-point growth and where there is population growth
                'Tracts 721600 and 722300 have negative growth
                If (sngTractNonPtGrowth > 0 Or sngTractNonPtGrowth = -999) And sngTractGrowth > 0 Then
                    'And strTRACTCE10 = "312100" Then
                    'There is growth in the tract, and no Metrostudy points to guide the distribution
                    If intOutsideMetroProjections = 0 And UCase(strTractGrowthType) = "RURAL" Then
                        cmd2.CommandText = "updateThiessenRuralTract_2030"
                        cmd2.Parameters.Add("@AMOUNT", SqlDbType.Float, 6).Value = sngTractNonPtGrowth
                    ElseIf intOutsideMetroProjections = 0 And UCase(strTractGrowthType) = "URBAN" Then
                        cmd2.CommandText = "updateThiessenUrbanTract_2030"
                    ElseIf intOutsideMetroProjections = 1 And UCase(strTractGrowthType) = "RURAL" Then
                        cmd2.CommandText = "updateBlockRuralTract_2030"
                    ElseIf intOutsideMetroProjections = 1 And UCase(strTractGrowthType) = "URBAN" Then
                        cmd2.CommandText = "updateBlockUrbanTract_2030"
                    End If

                    Try
                        cmd2.Parameters.Add("@TRACTCE10", SqlDbType.NVarChar, 6).Value = strTRACTCE10
                        numRowsAffected = cmd2.ExecuteNonQuery()
                        cmd2.Parameters.Clear()
                        cmd2.Dispose()
                    Catch ex As Exception
                        MsgBox("Error in sproc execution: " & ex.Message)
                    End Try
                End If

            End While 'dr.Read
            dr.Close()

            cmd1.CommandText = "updatePopulation_2030"
            cmd1.ExecuteNonQuery()

            cnn.Close()
            cnn2.Close()
            MsgBox("Interp2030NonPts Complete!")
        Catch ex As Exception
            MsgBox("Error in interp2030NonPts: " & ex.Message)
        End Try
```

```
    End Sub
```

SQL Server Stored Procedures .sql Scripts

```
USE [WJTMASTER]
GO
/****** Object:  StoredProcedure [dbo].[updateBlockRuralTract]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateBlockRuralTract]
    @TRACTCE10 nvarchar(6)
AS
    DECLARE @SUMDEVELOPABLE float

    update CENSUS_BLK
    set TOTAL_GROWTH_TO_BLOCK_2020 = 0
    where TRACTCE10 = @TRACTCE10

    select @SUMDEVELOPABLE = SUM(DEVELOPABLE_AREA_2010)
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    IF @SUMDEVELOPABLE = 0
        BEGIN
        update CENSUS_BLK
        set Total_Growth_to_Block_2020 = 0
        where TRACTCE10 = @TRACTCE10
        END
    ELSE
        BEGIN
        update CENSUS_BLK
        set Total_Growth_to_Block_2020 = DEVELOPABLE_AREA_2010 /@SUMDEVELOPABLE * (TRACTPOP2020
        - TRACTPOP2010)
        where TRACTCE10 = @TRACTCE10
        END ;
GO
/****** Object:  StoredProcedure [dbo].[readCENSUS_BLK]    Script Date: 11/21/2012 08:52:34
******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
-- =============================================
-- Author:      <Author,,Name>
-- Create date: <Create Date,,>
-- Description: <Description,,>
-- =============================================
CREATE PROCEDURE [dbo].[readCENSUS_BLK]
AS
    SELECT GEOID10, TRACTCE10, POPULATION, TRACTPOP2020,
    GROWTH_FROM_PTS_2020, GROWTH_FROM_PTS_2020_ADJUSTED,
    BLOCK_ACRES, PERCENTILE_75TH, TRACT_GROWTH_TYPE,
    DEVELOPABLE_AREA_2010, RESIDENTIAL_AREA_2010, COUNTY
    FROM CENSUS_BLK
```

```
    WHERE GROWTH_FROM_PTS_2020 > 0
    ORDER BY GEOID10
GO
/****** Object:  StoredProcedure [dbo].[readAdjacentBlocksAll]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[readAdjacentBlocksAll]
    @GEOID10 nvarchar(15)
AS
    SELECT DISTINCT GEOID10,TRACTCE10,Total_Growth_to_Block,Blk_Developable_Area_2010,
    Percentile_75th,BlockPopulation,BlockAreaAcres,Metro_Max_Block_Pop,
    Total_Growth_to_Block_Adj
    FROM THIESSEN_BLK
    WHERE Thiessen_Poly_ID IN
    (SELECT THIESSEN_POLY_ID
    FROM THIESSEN_BLK
    WHERE GEOID10 = @GEOID10)
    ORDER BY Blk_Developable_Area_2010 DESC
GO
/****** Object:  StoredProcedure [dbo].[readCENSUS_TRACT_NO_PT_GROWTH]    Script Date:
11/21/2012 08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
-- =============================================
-- Author:      <Author,,Name>
-- Create date: <Create Date,,>
-- Description: <Description,,>
-- =============================================
CREATE PROCEDURE [dbo].[readCENSUS_TRACT_NO_PT_GROWTH]
AS
    select TRACTCE10, MAX(GROWTH_FROM_PTS_2020) as GrowthFromPts,
    MAX(GROWTH_FROM_PTS_2020_ADJUSTED) as GrowthFromPtsAdj,
    max(TRACTPOP2010) as P10, max(tract_growth_type) as TractGrowthType,
    max(TRACTPOP2020) as P20, MAX(county) as Cnty, MAX(Outside_Metro_Projections) as
    Outside_Metro_Projections
    from CENSUS_BLK
    where COUNTY is not null
    group by TRACTCE10
    order by TRACTCE10
GO
/****** Object:  StoredProcedure [dbo].[updateBlockUrbanTract]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateBlockUrbanTract]
    @TRACTCE10 nvarchar(6)
AS
```

```
    DECLARE @SUMRES float, @SUMDEV float, @MAX_TO_DEV float, @REMAINDER_TO_RES float

    update CENSUS_BLK
    set TOTAL_GROWTH_TO_BLOCK_2020 = 0
    where TRACTCE10 = @TRACTCE10

    select @SUMRES = SUM(RESIDENTIAL_AREA_2010)
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @SUMDEV = SUM(DEVELOPABLE_AREA_2010)
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @MAX_TO_DEV = @SUMDEV * MAX(PERCENTILE_75TH)
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @REMAINDER_TO_RES = max(TRACTPOP2020) - max(TRACTPOP2010) - @MAX_TO_DEV
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    IF @SUMRES = 0 OR @SUMDEV = 0
        BEGIN
        IF @SUMDEV = 0 AND @SUMRES > 0
            BEGIN
            update CENSUS_BLK
            set Total_Growth_to_Block_2020 = Total_Growth_to_Block_2020 + Residential_Area_2010
            /@SUMRES * @REMAINDER_TO_RES
            where TRACTCE10 = @TRACTCE10
            END
        ELSE IF @SUMRES = 0 AND @SUMDEV > 0
            BEGIN
            update CENSUS_BLK
            set Total_Growth_to_Block_2020 = Total_Growth_to_Block_2020 + Developable_Area_2010
            /@SUMDEV * @MAX_TO_DEV
            where TRACTCE10 = @TRACTCE10
            END
        ELSE IF @SUMDEV = 0 AND @SUMRES = 0
            BEGIN
            update CENSUS_BLK
            set Total_Growth_to_Block_2020 = Total_Growth_to_Block_2020
            where TRACTCE10 = @TRACTCE10
            END
        END
    ELSE
        BEGIN
        update CENSUS_BLK
        set Total_Growth_to_Block_2020 = Total_Growth_to_Block_2020 + Developable_Area_2010 /@
        SUMDEV * @MAX_TO_DEV +
```

```
        Residential_Area_2010 /@SUMRES * @REMAINDER_TO_RES
        where TRACTCE10 = @TRACTCE10
        END ;
GO
/****** Object:  StoredProcedure [dbo].[updateThiessenAllBlocksInTract]    Script Date:
11/21/2012 08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateThiessenAllBlocksInTract]
    @TRACTCE10 nvarchar(6), @REDUCTION float
AS
    DECLARE @SUMADDTLGROWTH float

    select @SUMADDTLGROWTH =
    sum(A.Blk_Developable_Area_2010 * A.PERCENTILE_75TH - A.Total_Growth_to_Block_Adj)
    from
    (select distinct geoid10, tractce10, Blk_Developable_Area_2010, percentile_75th,
    total_growth_to_block_adj
        from THIESSEN_BLK) A
    where A.Blk_Developable_Area_2010 > 0
    and A.Blk_Developable_Area_2010 * A.PERCENTILE_75TH - A.Total_Growth_to_Block_Adj > 0
    AND A.TRACTCE10 = @TRACTCE10
    group by A.TRACTCE10

    update THIESSEN_BLK
    set Total_Growth_to_Block_Adj =
    Total_Growth_to_Block_Adj + (Blk_Developable_Area_2010 * Percentile_75th -
    Total_Growth_to_Block_Adj)/@SUMADDTLGROWTH * @REDUCTION
    where TRACTCE10 = @TRACTCE10
    and Blk_Developable_Area_2010 * Percentile_75th - Total_Growth_to_Block_Adj > 0
GO
/****** Object:  StoredProcedure [dbo].[updateThiessenBlk]    Script Date: 11/21/2012 08:52:34
******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateThiessenBlk]
    @GEOID10 nvarchar(15), @TOTAL_GROWTH_TO_BLOCK numeric(18,2)
AS
    UPDATE THIESSEN_BLK
    SET Total_Growth_to_Block_Adj = @TOTAL_GROWTH_TO_BLOCK
    WHERE GEOID10 = @GEOID10
GO
/****** Object:  StoredProcedure [dbo].[updateThiessenRuralTract]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateThiessenRuralTract]
    @TRACTCE10 nvarchar(6)
```

```
AS
    DECLARE @SUMDEVELOPABLE float

    update THIESSEN_BLK
    set Total_Growth_to_Block_Adj = 0
    where TRACTCE10 = @TRACTCE10

    select @SUMDEVELOPABLE = SUM(DEVELOPABLE_AREA_2010)
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    update THIESSEN_BLK
    set Total_Growth_to_Block_Adj = Blk_Developable_Area_2010 /@SUMDEVELOPABLE * Change10_20
    where TRACTCE10 = @TRACTCE10
GO
/****** Object:  StoredProcedure [dbo].[updateThiessenUrbanTract]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateThiessenUrbanTract]
    @TRACTCE10 nvarchar(6)
AS
    DECLARE @SUMRES float, @SUMDEV float, @MAX_TO_DEV float, @REMAINDER_TO_RES float

    update THIESSEN_BLK
    set Total_Growth_to_Block_Adj = 0
    where TRACTCE10 = @TRACTCE10

    select @SUMRES = SUM(RESIDENTIAL_AREA_2010)
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @SUMDEV = SUM(DEVELOPABLE_AREA_2010)
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @MAX_TO_DEV = @SUMDEV * MAX(PERCENTILE_75TH)
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @REMAINDER_TO_RES = max(TRACTPOP2020) - max(TRACTPOP2010) - @MAX_TO_DEV
    from CENSUS_BLK
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    update THIESSEN_BLK
    set Total_Growth_to_Block_Adj = Total_Growth_to_Block_Adj + Blk_Developable_Area_2010 /@
    SUMDEV * @MAX_TO_DEV +
```

```
    Blk_Residential_Area_2010 /@SUMRES * @REMAINDER_TO_RES
    where TRACTCE10 = @TRACTCE10
GO
/****** Object:  StoredProcedure [dbo].[updateThiessenUrbanTract_2030]    Script Date:
11/21/2012 08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateThiessenUrbanTract_2030]
    @TRACTCE10 nvarchar(6)
AS
    DECLARE @SUMRES float, @SUMDEV float, @MAX_TO_DEV float, @REMAINDER_TO_RES float, @
    TRACT_GROWTH float

    update THIESSEN_BLK_2030
    set Total_Growth_to_Block_Adj = 0
    where TRACTCE10 = @TRACTCE10

    select @TRACT_GROWTH = max(TRACTPOP2030) - max(TRACTPOP2020)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @SUMRES = SUM(RESIDENTIAL_AREA_2020)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @SUMDEV = SUM(DEVELOPABLE_AREA_2020)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @MAX_TO_DEV = @SUMDEV * MAX(PERCENTILE_75TH)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @REMAINDER_TO_RES = max(TRACTPOP2030) - max(TRACTPOP2020) - @MAX_TO_DEV
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    IF @SUMRES = 0 OR @SUMDEV = 0
        BEGIN
        IF @SUMDEV = 0 AND @SUMRES > 0
            BEGIN
            update THIESSEN_BLK_2030
            set Total_Growth_to_Block_Adj = Total_Growth_to_Block_Adj +
            Blk_Residential_Area_2020 /@SUMRES * @TRACT_GROWTH
            where TRACTCE10 = @TRACTCE10
            END
        ELSE IF @SUMRES = 0 AND @SUMDEV > 0
```

```
            BEGIN
            update THIESSEN_BLK_2030
            set Total_Growth_to_Block_Adj = Total_Growth_to_Block_Adj +
                Blk_Developable_Area_2020 /@SUMDEV * @TRACT_GROWTH
            where TRACTCE10 = @TRACTCE10
            END
        ELSE IF @SUMDEV = 0 AND @SUMRES = 0
            BEGIN
            update THIESSEN_BLK_2030
            set Total_Growth_to_Block_Adj = BlockAreaAcres / TractAreaAcres * @TRACT_GROWTH
            where TRACTCE10 = @TRACTCE10
            END
        END
    ELSE
        BEGIN
        update THIESSEN_BLK_2030
        set Total_Growth_to_Block_Adj = Total_Growth_to_Block_Adj + Blk_Developable_Area_2020 /@
        SUMDEV * @MAX_TO_DEV +
        Blk_Residential_Area_2020 /@SUMRES * @REMAINDER_TO_RES
        where TRACTCE10 = @TRACTCE10
        END ;
GO
/****** Object:  StoredProcedure [dbo].[updateThiessenRuralTract_2030]    Script Date:
11/21/2012 08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateThiessenRuralTract_2030]
    @TRACTCE10 nvarchar(6), @AMOUNT float
AS
    DECLARE @SUMDEVELOPABLE float

    select @SUMDEVELOPABLE = SUM(DEVELOPABLE_AREA_2020)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    update THIESSEN_BLK_2030
    set Total_Growth_to_Block_Adj = Total_Growth_to_Block_Adj + Blk_Developable_Area_2020 /@
    SUMDEVELOPABLE * @AMOUNT
    where TRACTCE10 = @TRACTCE10
GO
/****** Object:  StoredProcedure [dbo].[updateThiessenBlk_2030]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateThiessenBlk_2030]
    @GEOID10 nvarchar(15), @TOTAL_GROWTH_TO_BLOCK numeric(18,2)
AS
    UPDATE THIESSEN_BLK_2030
    SET Total_Growth_to_Block_Adj = @TOTAL_GROWTH_TO_BLOCK
```

```
    WHERE GEOID10 = @GEOID10
GO
/****** Object:  StoredProcedure [dbo].[updateThiessenAllBlocksInTract_2030]    Script Date:
11/21/2012 08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateThiessenAllBlocksInTract_2030]
    @TRACTCE10 nvarchar(6), @REDUCTION float
AS
    DECLARE @SUMADDTLGROWTH float

    select @SUMADDTLGROWTH =
    sum(A.Blk_Developable_Area_2020 * A.PERCENTILE_75TH - A.Total_Growth_to_Block_Adj)
    from
    (select distinct geoid10, tractce10, Blk_Developable_Area_2020, percentile_75th,
    total_growth_to_block_adj
        from THIESSEN_BLK_2030) A
    where A.Blk_Developable_Area_2020 > 0
    and A.Blk_Developable_Area_2020 * A.PERCENTILE_75TH - A.Total_Growth_to_Block_Adj > 0
    AND A.TRACTCE10 = @TRACTCE10
    group by A.TRACTCE10

    update THIESSEN_BLK_2030
    set Total_Growth_to_Block_Adj =
    Total_Growth_to_Block_Adj + (Blk_Developable_Area_2020 * Percentile_75th -
    Total_Growth_to_Block_Adj)/@SUMADDTLGROWTH * @REDUCTION
    where TRACTCE10 = @TRACTCE10
    and Blk_Developable_Area_2020 * Percentile_75th - Total_Growth_to_Block_Adj > 0
GO
/****** Object:  StoredProcedure [dbo].[updatePopulation_2030]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updatePopulation_2030]
AS
    update a
    set a.TOTAL_GROWTH_TO_BLOCK_2030 = b.Total_Growth_to_Block_Adj
    from CENSUS_BLK_2030 as a inner join THIESSEN_BLK_2030 as b
    on a.GEOID10 = b.GEOID10

    update CENSUS_BLK_2030 set POP2030 = 0

    update CENSUS_BLK_2030 set POP2030 = POP2020 + TOTAL_GROWTH_TO_BLOCK_2030
GO
/****** Object:  StoredProcedure [dbo].[updateBlockUrbanTract_2030]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
```

```
CREATE PROCEDURE [dbo].[updateBlockUrbanTract_2030]
    @TRACTCE10 nvarchar(6)
AS
    DECLARE @SUMRES float, @SUMDEV float, @MAX_TO_DEV float, @REMAINDER_TO_RES float, @
    TRACT_GROWTH float

    update CENSUS_BLK_2030
    set TOTAL_GROWTH_TO_BLOCK_2030 = 0
    where TRACTCE10 = @TRACTCE10

    select @TRACT_GROWTH = max(TRACTPOP2030) - max(TRACTPOP2020)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @SUMRES = SUM(RESIDENTIAL_AREA_2020)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @SUMDEV = SUM(DEVELOPABLE_AREA_2020)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @MAX_TO_DEV = @SUMDEV * MAX(PERCENTILE_75TH)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    select @REMAINDER_TO_RES = max(TRACTPOP2030) - max(TRACTPOP2020) - @MAX_TO_DEV
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    IF @SUMRES = 0 OR @SUMDEV = 0
        BEGIN
        IF @SUMDEV = 0 AND @SUMRES > 0
            BEGIN
            update CENSUS_BLK_2030
            set TOTAL_GROWTH_TO_BLOCK_2030 = TOTAL_GROWTH_TO_BLOCK_2030 + Residential_Area_2020
            /@SUMRES * @TRACT_GROWTH
            where TRACTCE10 = @TRACTCE10
            END
        ELSE IF @SUMRES = 0 AND @SUMDEV > 0
            BEGIN
            update CENSUS_BLK_2030
            set TOTAL_GROWTH_TO_BLOCK_2030 = TOTAL_GROWTH_TO_BLOCK_2030 + DEVELOPABLE_AREA_2020
            /@SUMDEV * @TRACT_GROWTH
            where TRACTCE10 = @TRACTCE10
            END
        ELSE IF @SUMDEV = 0 AND @SUMRES = 0
            BEGIN
            update CENSUS_BLK_2030
```

```
            set TOTAL_GROWTH_TO_BLOCK_2030 = BLOCK_ACRES / TRACT_AREA_AC * @TRACT_GROWTH
            where TRACTCE10 = @TRACTCE10
            END
        END
    ELSE
        BEGIN
        update CENSUS_BLK_2030
        set TOTAL_GROWTH_TO_BLOCK_2030 = TOTAL_GROWTH_TO_BLOCK_2030 + DEVELOPABLE_AREA_2020 /@
        SUMDEV * @MAX_TO_DEV +
        Residential_Area_2020 /@SUMRES * @REMAINDER_TO_RES
        where TRACTCE10 = @TRACTCE10
        END ;
GO
/****** Object:  StoredProcedure [dbo].[updateBlockRuralTract_2030]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[updateBlockRuralTract_2030]
    @TRACTCE10 nvarchar(6)
AS
    DECLARE @SUMDEVELOPABLE float

    update CENSUS_BLK_2030
    set TOTAL_GROWTH_TO_BLOCK_2030 = 0
    where TRACTCE10 = @TRACTCE10

    select @SUMDEVELOPABLE = SUM(DEVELOPABLE_AREA_2020)
    from CENSUS_BLK_2030
    where TRACTCE10 = @TRACTCE10
    group by TRACTCE10

    IF @SUMDEVELOPABLE = 0
        BEGIN
        update CENSUS_BLK_2030
        set TOTAL_GROWTH_TO_BLOCK_2030 = 0
        where TRACTCE10 = @TRACTCE10
        END
    ELSE
        BEGIN
        update CENSUS_BLK_2030
        set TOTAL_GROWTH_TO_BLOCK_2030 = DEVELOPABLE_AREA_2020 /@SUMDEVELOPABLE * (TRACTPOP2030
        - TRACTPOP2020)
        where TRACTCE10 = @TRACTCE10
        END ;
GO
/****** Object:  StoredProcedure [dbo].[readCENSUS_BLK_2030]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
-- ============================================
```

```
-- Author:      <Author,,Name>
-- Create date: <Create Date,,>
-- Description: <Description,,>
-- =============================================
CREATE PROCEDURE [dbo].[readCENSUS_BLK_2030]
AS
    SELECT GEOID10, TRACTCE10, POPULATION, TRACTPOP2020, TRACTPOP2030,
    GROWTH_FROM_PTS_2030, GROWTH_FROM_PTS_2030_ADJ,
    BLOCK_ACRES, PERCENTILE_75TH, TRACT_GROWTH_TYPE_2020,
    DEVELOPABLE_AREA_2020, COUNTY
    FROM CENSUS_BLK_2030
    WHERE GROWTH_FROM_PTS_2030 > 0
    AND (TRACTPOP2030 - TRACTPOP2020) > 0
    ORDER BY GEOID10
GO
/****** Object:  StoredProcedure [dbo].[initializeTotalGrowth_2030]    Script Date: 11/21/2012
08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE PROCEDURE [dbo].[initializeTotalGrowth_2030]
AS
    update CENSUS_BLK_2030
    set GROWTH_FROM_PTS_2030_ADJ = GROWTH_FROM_PTS_2030

    update a
    set a.Total_Growth_to_Block_Adj = b.GROWTH_FROM_PTS_2030
    from THIESSEN_BLK_2030 as a inner join CENSUS_BLK_2030 as b
    on a.GEOID10 = b.GEOID10

    update CENSUS_BLK_2030 set TOTAL_GROWTH_TO_BLOCK_2030 = 0
GO
/****** Object:  StoredProcedure [dbo].[readCENSUS_TRACT_NO_PT_GROWTH_2030]    Script Date:
11/21/2012 08:52:34 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
-- =============================================
-- Author:      <Author,,Name>
-- Create date: <Create Date,,>
-- Description: <Description,,>
-- =============================================
CREATE PROCEDURE [dbo].[readCENSUS_TRACT_NO_PT_GROWTH_2030]
AS


    select distinct
    a.TRACTCE10 as TRACTCE10,
    a.COUNTY as County,
    a.Outside_Metro_Projections as OutsideMetroProjections,
    a.TRACT_GROWTH_TYPE_2020 as TractGrowthType,
    (a.TRACTPOP2030 - a.TRACTPOP2020) as Tract_Growth_2030,
```

```
    tb.Tract_Pop_Change_20_30,
    tb.Tract_Pt_Growth_2030,
    tb.Tract_NonPt_Growth_2030 as Tract_NonPt_Growth_2030,
    tb.Metro_Growth_GT_Tract_Delta
    from census_blk_2030 as a left join
        (select distinct
        TRACTCE10,
        Tract_Pop_Change_20_30,
        Metro_Growth_GT_Tract_Delta,
        Tract_Pt_Growth_2030,
        Tract_NonPt_Growth_2030
        from THIESSEN_BLK_2030) as TB
    on a.TRACTCE10 = tb.TRACTCE10
    where a.COUNTY in ('Harris','Galveston','Montgomery','Fort Bend','Brazoria')
    order by a.TRACTCE10
GO
```

SQL Server Create Table Scripts

```
USE [WJTMASTER]
GO
/****** Object:  Table [dbo].[THIESSEN_BLK_2030]    Script Date: 11/21/2012 09:03:46 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[THIESSEN_BLK_2030](
    [OBJECTID] [int] NOT NULL,
    [TRACTCE10] [nvarchar](6) NULL,
    [BLOCKCE10] [nvarchar](4) NULL,
    [GEOID10] [nvarchar](15) NULL,
    [BlockPopulation] [numeric](38, 8) NULL,
    [TractAreaAcres] [numeric](38, 8) NULL,
    [BlockAreaAcres] [numeric](38, 8) NULL,
    [County] [nvarchar](40) NULL,
    [ThiessenAcres] [numeric](38, 8) NULL,
    [Thiessen_Poly_ID] [smallint] NULL,
    [UNIONED_AREA_AC] [numeric](38, 8) NULL,
    [Percentile_75th] [numeric](18, 2) NULL,
    [Blk_Developable_Area_2010] [float] NULL,
    [Blk_Developable_Area_2020] [float] NULL,
    [Pt_Growth_2030] [float] NULL,
    [Remaining_Balance_Persons] [float] NULL,
    [Tract_Pop_Change_20_30] [int] NULL,
    [Metro_2030_Growth_Ratio] [float] NULL,
    [Metro_Growth_GT_Tract_Delta] [tinyint] NULL,
    [Tract_Pt_Growth_2030] [float] NULL,
    [Tract_NonPt_Growth_2030] [float] NULL,
    [Growth_to_Block] [float] NULL,
    [Total_Growth_to_Block] [float] NULL,
    [Total_Growth_to_Block_Adj] [float] NULL,
    [Blk_Residential_Area_2020] [float] NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[THIESSEN_BLK_2020]    Script Date: 11/21/2012 09:03:46 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[THIESSEN_BLK_2020](
    [OBJECTID] [int] NOT NULL,
    [TRACTCE10] [nvarchar](6) NULL,
    [BLOCKCE10] [nvarchar](4) NULL,
    [GEOID10] [nvarchar](15) NULL,
    [BlockPopulation] [numeric](38, 8) NULL,
    [POP2010] [numeric](38, 8) NULL,
    [METRO2015] [numeric](38, 8) NULL,
    [METRO2020] [numeric](38, 8) NULL,
    [TractAreaAcres] [numeric](38, 8) NULL,
    [BlockAreaAcres] [numeric](38, 8) NULL,
    [Change10_20] [int] NULL,
    [HHPerAcre] [smallint] NULL,
    [Pop_Per_HH] [numeric](38, 8) NULL,
```

```
    [County] [nvarchar](40) NULL,
    [Households_Total] [numeric](38, 8) NULL,
    [ThiessenAcres] [numeric](38, 8) NULL,
    [CumulativeSubdPtGrowth2020] [numeric](38, 8) NULL,
    [Thiessen_Poly_ID] [smallint] NULL,
    [UNIONED_AREA_AC] [numeric](38, 8) NULL,
    [Ratio_for_Pt_Growth] [numeric](38, 4) NULL,
    [Ratioed_Pt_Growth] [numeric](38, 4) NULL,
    [Num_Subd_Pts_in_Tract] [smallint] NULL,
    [HasPointGrowth] [bit] NULL,
    [Metro_Max_Block_Pop] [int] NULL,
    [Growth_to_Block] [numeric](38, 4) NULL,
    [Total_Growth_to_Block] [numeric](18, 2) NULL,
    [Percentile_75th] [numeric](18, 2) NULL,
    [Blk_Developable_Area_2010] [float] NULL,
    [Blk_Residential_Area_2010] [float] NULL,
    [Total_Growth_to_Block_Adj] [numeric](18, 4) NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[CENSUS_BLK_2030]    Script Date: 11/21/2012 09:03:46 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
SET ANSI_PADDING ON
GO
CREATE TABLE [dbo].[CENSUS_BLK_2030](
    [XCoord] [varchar](50) NULL,
    [YCoord] [varchar](50) NULL,
    [OBJECTID] [varchar](50) NULL,
    [GEOID10] [varchar](50) NULL,
    [POPULATION] [int] NULL,
    [SHAPE_AREA] [decimal](38, 6) NULL,
    [BLOCK_ACRES] [decimal](18, 3) NULL,
    [GROWTH_FROM_PTS_2020] [numeric](38, 4) NULL,
    [COUNTY] [nchar](15) NULL,
    [PERCENTILE_75TH] [numeric](18, 2) NULL,
    [LATDEC] [float] NULL,
    [LONDEC] [float] NULL,
    [TRACTCE10] [nvarchar](6) NULL,
    [DEVELOPABLE_AREA_2010] [float] NULL,
    [TRACTPOP2020] [int] NULL,
    [TRACT_GROWTH_TYPE_2010] [varchar](5) NULL,
    [GROWTH_FROM_PTS_2020_ADJUSTED] [numeric](18, 4) NULL,
    [TRACTPOP2010] [int] NULL,
    [TOTAL_GROWTH_TO_BLOCK_2020] [float] NULL,
    [Outside_Metro_Projections] [smallint] NULL,
    [POP2020] [float] NULL,
    [TRACT_AREA_AC] [float] NULL,
    [POP2030] [float] NULL,
    [DEVELOPABLE_AREA_2020] [float] NULL,
    [TRACTPOP2030] [int] NULL,
    [GROWTH_FROM_PTS_2030] [float] NULL,
    [GROWTH_FROM_PTS_2030_ADJ] [float] NULL,
```

```
    [TOTAL_GROWTH_TO_BLOCK_2030] [float] NULL,
    [TRACT_GROWTH_TYPE_2020] [varchar](5) NULL,
    [RESIDENTIAL_AREA_2020] [float] NULL
) ON [PRIMARY]
GO
SET ANSI_PADDING OFF
GO
/****** Object:  Table [dbo].[CENSUS_BLK_2020]    Script Date: 11/21/2012 09:03:46 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
SET ANSI_PADDING ON
GO
CREATE TABLE [dbo].[CENSUS_BLK_2020](
    [XCoord] [varchar](50) NULL,
    [YCoord] [varchar](50) NULL,
    [OBJECTID] [varchar](50) NULL,
    [GEOID10] [varchar](50) NULL,
    [POPULATION] [int] NULL,
    [HOUSING_UNITS_TOTAL] [int] NULL,
    [HOUSING_UNITS_OCCUPIED] [int] NULL,
    [SHAPE_AREA] [decimal](38, 6) NULL,
    [BLOCK_ACRES] [decimal](18, 3) NULL,
    [GROWTH_FROM_PTS_2020] [numeric](38, 4) NULL,
    [MAX_POP_METRO_CRITERIA] [int] NULL,
    [COUNTY] [nchar](15) NULL,
    [PERCENTILE_75TH] [numeric](18, 2) NULL,
    [LATDEC] [float] NULL,
    [LONDEC] [float] NULL,
    [TRACTCE10] [nvarchar](6) NULL,
    [DEVELOPABLE_AREA_2010] [float] NULL,
    [RESIDENTIAL_AREA_2010] [float] NULL,
    [TRACTPOP2020] [int] NULL,
    [TRACT_GROWTH_TYPE] [varchar](5) NULL,
    [GROWTH_FROM_PTS_2020_ADJUSTED] [numeric](18, 4) NULL,
    [TRACTPOP2010] [int] NULL,
    [TOTAL_GROWTH_TO_BLOCK_2020] [float] NULL,
    [Outside_Metro_Projections] [smallint] NULL,
    [POP2020] [float] NULL,
    [TRACT_AREA_AC] [float] NULL
) ON [PRIMARY]
GO
SET ANSI_PADDING OFF
GO
```

2040-2070 Interpolation Queries

```
-- _SELECT_DATA_FOR_GROWTH_TYPE.sql
USE WJTMASTER

select
TRACTCE10,
max(COUNTY) as COUNTY,
max(TRACTPOP2020) as P20,
max(TRACTPOP2030) as P30,
max(TRACTPOP2040) as P40,
(max(TRACTPOP2040) - max(TRACTPOP2030)) as GROWTH_2030_TO_2040,
sum(DEVELOPABLE_AREA_2020) as DEV_AREA_2020,
sum(DEVELOPABLE_AREA_2030) as DEV_AREA_2030,
max(PERCENTILE_75TH) AS MAX_DENSITY
from CENSUS_BLK_2040
WHERE COUNTY IN ('Harris','Galveston','Montgomery','Fort Bend','Brazoria')
group by TRACTCE10
ORDER BY TRACTCE10
```

```
-- _UPDATE_DEVELOPABLE_AND_RESIDENTIAL_AREAS.sql
USE WJTMASTER

UPDATE CENSUS_BLK_2040
SET DEVELOPABLE_AREA_2030 = 0, RESIDENTIAL_AREA_2030 = 0

UPDATE CENSUS_BLK_2040
SET DEVELOPABLE_AREA_2030 = DEVELOPABLE_AREA_2020 - (POP2030 - POP2020)/PERCENTILE_75TH

UPDATE CENSUS_BLK_2040
SET DEVELOPABLE_AREA_2030 = 0
WHERE DEVELOPABLE_AREA_2030 < 0

UPDATE CENSUS_BLK_2040
SET RESIDENTIAL_AREA_2030 = RESIDENTIAL_AREA_2020 + (DEVELOPABLE_AREA_2020 -
DEVELOPABLE_AREA_2030)
```

```sql
-- Interp2040.sql
USE WJTMASTER

-- Set SUMDEV and SUMRES
--/*
update a
set a.TRACT_DEVELOPABLE_AREA = sums.SUMDEV,
a.TRACT_RESIDENTIAL_AREA = sums.SUMRES
from CENSUS_BLK_2040 as a inner join
(select
TRACTCE10,
sum(DEVELOPABLE_AREA_2030) as SUMDEV,
sum(RESIDENTIAL_AREA_2030) as SUMRES
from CENSUS_BLK_2040
where COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')
group  by TRACTCE10) as sums
on a.TRACTCE10 = sums.TRACTCE10
--*/

-- Set MAX_DEV and REMAINDER_TO_RES
--/*
update CENSUS_BLK_2040
set MAX_TO_DEV = TRACT_DEVELOPABLE_AREA * PERCENTILE_75TH

update CENSUS_BLK_2040
set REMAINDER_TO_RES = TRACTPOP2040 - TRACTPOP2030 - MAX_TO_DEV

update CENSUS_BLK_2040
set REMAINDER_TO_RES = 0
where REMAINDER_TO_RES < 0

select TRACTCE10,
max(tractpop2040) - MAX(tractpop2030) as Growth,
max(MAX_TO_DEV) as MAXTODEV,
max(REMAINDER_TO_RES) as REMAINDERTORES
from CENSUS_BLK_2040
where COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')
group by TRACTCE10
order by TRACTCE10
--*/

-----------------------------------------------------------------
--  INTERPOLATE 2040
-----------------------------------------------------------------
update CENSUS_BLK_2040 set TOTAL_GROWTH_TO_BLOCK_2040 = 0

--Urban: sumdev = 0 and sumres > 0
update CENSUS_BLK_2040
set TOTAL_GROWTH_TO_BLOCK_2040 = TOTAL_GROWTH_TO_BLOCK_2040 + RESIDENTIAL_AREA_2030 /
TRACT_RESIDENTIAL_AREA * (TRACTPOP2040 - TRACTPOP2030)
where TRACT_GROWTH_TYPE_2030 = 'URBAN'
and (TRACTPOP2040 - TRACTPOP2030) > 0
and TRACT_DEVELOPABLE_AREA = 0 and TRACT_RESIDENTIAL_AREA > 0
and COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')
```

```
--Urban: sumres = 0 and sumdev > 0
update CENSUS_BLK_2040
set TOTAL_GROWTH_TO_BLOCK_2040 = TOTAL_GROWTH_TO_BLOCK_2040 + DEVELOPABLE_AREA_2030 /
TRACT_DEVELOPABLE_AREA * (TRACTPOP2040 - TRACTPOP2030)
where TRACT_GROWTH_TYPE_2030 = 'URBAN'
and (TRACTPOP2040 - TRACTPOP2030) > 0
and TRACT_DEVELOPABLE_AREA > 0 and TRACT_RESIDENTIAL_AREA = 0
and COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')

--Urban: sumdev = 0 and sumres = 0
update CENSUS_BLK_2040
set TOTAL_GROWTH_TO_BLOCK_2040 = TOTAL_GROWTH_TO_BLOCK_2040 + BLOCK_ACRES / TRACT_AREA_AC * (
TRACTPOP2040 - TRACTPOP2030)
where TRACT_GROWTH_TYPE_2030 = 'URBAN'
and (TRACTPOP2040 - TRACTPOP2030) > 0
and TRACT_DEVELOPABLE_AREA = 0 and TRACT_RESIDENTIAL_AREA = 0
and COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')

--Urban: sumdev > 0 and sumres . 0
update CENSUS_BLK_2040
set TOTAL_GROWTH_TO_BLOCK_2040 = TOTAL_GROWTH_TO_BLOCK_2040 + DEVELOPABLE_AREA_2030 /
TRACT_DEVELOPABLE_AREA * MAX_TO_DEV +
RESIDENTIAL_AREA_2030 /TRACT_RESIDENTIAL_AREA * REMAINDER_TO_RES
where TRACT_GROWTH_TYPE_2030 = 'URBAN'
and (TRACTPOP2040 - TRACTPOP2030) > 0
and TRACT_DEVELOPABLE_AREA > 0 and TRACT_RESIDENTIAL_AREA > 0
and COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')

--Rural
update CENSUS_BLK_2040
set TOTAL_GROWTH_TO_BLOCK_2040 = TOTAL_GROWTH_TO_BLOCK_2040 + DEVELOPABLE_AREA_2030 /
TRACT_DEVELOPABLE_AREA * (TRACTPOP2040 - TRACTPOP2030)
where TRACT_GROWTH_TYPE_2030 = 'RURAL'
and (TRACTPOP2040 - TRACTPOP2030) > 0
and TRACT_DEVELOPABLE_AREA > 0
and COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')

update CENSUS_BLK_2040
set TOTAL_GROWTH_TO_BLOCK_2040 = TOTAL_GROWTH_TO_BLOCK_2040 + BLOCK_ACRES / TRACT_AREA_AC * (
TRACTPOP2040 - TRACTPOP2030)
where TRACT_GROWTH_TYPE_2030 = 'RURAL'
and (TRACTPOP2040 - TRACTPOP2030) > 0
and TRACT_DEVELOPABLE_AREA = 0
and COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')

-- Update Populations
update CENSUS_BLK_2040
set POP2040 = POP2030 + TOTAL_GROWTH_TO_BLOCK_2040
where COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')

-- Check the results
select
TRACTCE10,
```

```
max(TRACTPOP2040) as Tract_Pop_2040,
round(sum(POP2040),0) as SumBlockPop_2040,
round(SUM(POP2040),0) - round(MAX(TRACTPOP2040),0) as Delta
from CENSUS_BLK_2040
where COUNTY in ('Harris','Galveston','Fort Bend','Montgomery','Brazoria')
group by TRACTCE10
order by TRACTCE10
```

10497 Town and Country Way, Suite 600 • Houston, Texas 77024 • 713-600-6800 • fax 713-600-6801 www.freese.com

TO: Regional Groundwater Update Project Partners

CC:

FROM: William J. Thaman, P.E.

SUBJECT: RGUP Census Tract Level Population Projections: 2010-2070

DATE: January 30, 2013

Introduction

This memo describes the population projection process and methodology. The Regional Groundwater Update Project (RGUP) technical team met with a number of entities regarding their experience and methodology used in performing regional population projections. This process, and the rationale for selection, is described in a previous report to the RGUP Project Partners.

A single set of decadal population projections, at the Census 2010 Tract level, were developed by combining projections made by Metrostudy and the University of Houston Center for Public Policy (UHCPP). Each used the 2010 U.S. Census data as the starting point; Metrostudy developed annual projections from 2011-2020, and UHCPP developed decadal projections from 2020-2070.

The distribution of projections from the Census Tract level to the Census Block level was done by the project team, and is not covered in a separate report.

Methodology

Both Metrostudy and UHCPP started with a similar approach to developing regional and county-level projections; as such, their county level projections were similar at 2020. Their respective methodologies used to distribute the growth to the Census tract level were very different however. Their methodologies are included as an attachment to this memo. Both Metrostudy and UHCPP provided electronic files containing Census Tract-level projections: Metrostudy provided annual projections for 2011-2020, and UHCPP decadal projections for 2020-2070.

While Metrostudy and UHCPP used entirely different approaches and assumptions in the spatial distribution of their county projections, they coordinated with each other to match 2020 projections as closely as possible at sub-county groupings of Census tracts. The twenty sub-county groupings were defined by the project team, and are shown in Figure 1. The team attempted to follow as closely as possible Regional Water Authority boundaries in Harris and Fort Bend Counties. Since Census tracts themselves follow county lines and major land features such as major highways, freeways, major creeks, and rivers, sub-county groups follow the same features. No Census tracts were divided by this process.

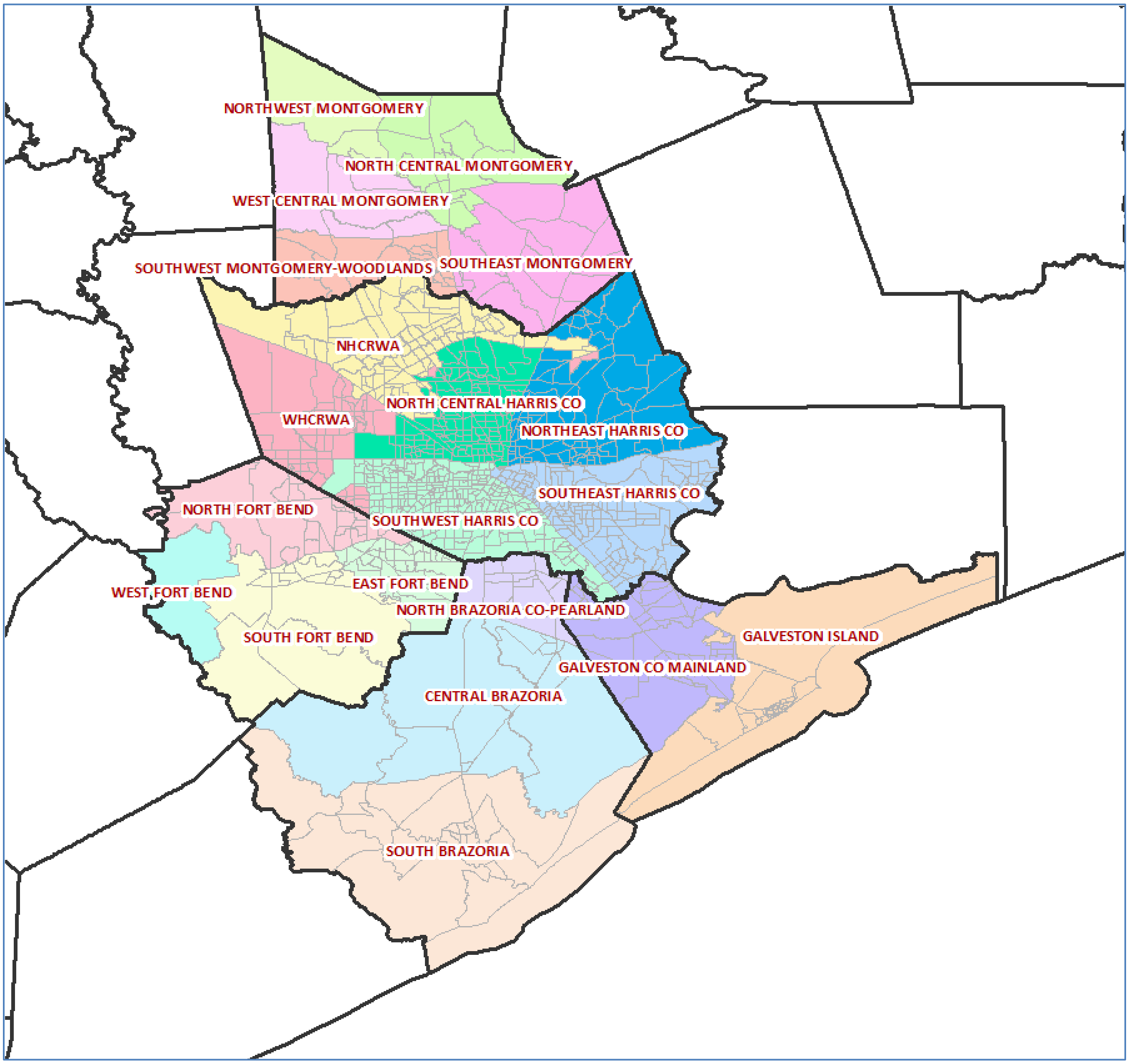


Figure 1. Sub-County Census Tract Groups

The goal of matching Metrostudy and UHCPP 2020 projections at the sub-county level was necessary to provide consistency at the common 2020 point; differing methodologies made it impractical to match at the individual

Census tract level, and matching only at the County level would have resulted in too broad a comparison. Because of the differences at the individual Census tract level, adjustments were necessary to ensure that the growth curve at each tract was consistent (e.g. tract population did not go down from 2020 to 2030, and then back up from 2030 to 2070). These adjustments were made by fixing the sub-county totals at year 2070, and adjusting the 2030-2060 individual tract numbers. Harris-Galveston Area Council (H-GAC) land use data was used to constrain the amount of growth to only developable area within each Census tract.

Results

Population projections, by county sub-area, are shown in Table 1. County-level comparisons between RGUP, Region H, HGSD 1995 study, and H-GAC are shown in Figures 2-6.

Table 1. Sub-County and County Population Projections

County	Subarea	2010	2020	2030	2040	2050	2060	2070
Fort Bend	North Fort Bend	258,547	424,878	521,872	565,764	600,249	629,077	654,043
Fort Bend	East Fort Bend	220,585	284,440	348,345	412,251	474,303	524,031	559,871
Fort Bend	South Fort Bend	102,851	163,814	212,402	263,593	322,330	395,216	491,062
Fort Bend	West Fort Bend	3,392	8,834	12,504	17,698	25,051	35,458	50,188
Fort Bend County Totals:		585,375	881,966	1,095,123	1,259,307	1,421,933	1,583,782	1,755,164
Harris	NHCRWA	662,362	847,173	901,157	944,818	981,385	1,013,122	1,041,821
Harris	WHCRWA	483,223	663,930	696,302	719,621	738,284	753,926	767,530
Harris	Southwest Harris Co	1,221,147	1,327,441	1,459,460	1,588,270	1,717,662	1,850,838	1,990,784
Harris	Southeast Harris Co	602,553	631,661	655,351	679,055	701,751	724,691	748,058
Harris	North Central Harris Co	682,232	737,723	806,332	872,979	939,674	1,007,582	1,077,888
Harris	Northeast Harris Co	440,942	499,942	539,542	571,356	599,486	623,909	646,264
Harris County Totals:		4,092,459	4,707,870	5,058,144	5,376,099	5,678,242	5,974,068	6,272,344
Montgomery	Southwest Montgomery-Woodlands	150,516	182,954	225,733	279,431	352,603	453,573	594,197
Montgomery	Southeast Montgomery	146,364	218,829	287,827	363,607	448,257	544,549	630,403
Montgomery	West Central Montgomery	33,407	53,570	69,865	87,006	105,933	127,675	155,053
Montgomery	North Central Montgomery	102,229	139,519	183,071	231,779	289,699	363,308	456,235
Montgomery	Northwest Montgomery	23,230	33,045	44,756	57,455	71,424	87,029	110,175
Montgomery County Totals:		455,746	627,917	811,252	1,019,278	1,267,916	1,576,135	1,946,063
Brazoria	North Brazoria Co-Pearland	135,976	159,811	188,543	220,789	257,827	301,425	350,608
Brazoria	Central Brazoria	81,508	94,838	106,890	116,594	124,569	131,274	137,054
Brazoria	South Brazoria	95,682	105,286	115,953	126,503	137,301	148,669	160,906
Brazoria County Totals:		313,166	359,935	411,387	463,886	519,696	581,368	648,568
Galveston	Galveston Island	51,143	55,240	59,198	63,079	66,987	70,926	75,193
Galveston	Galveston Co Mainland	240,166	288,330	318,174	340,741	360,559	376,200	390,000
Galveston County Totals:		291,309	343,570	377,373	403,820	427,547	447,126	465,193

Note: Sub-areas NHCRWA and WHCRWA approximately represent the water authority boundaries. The projections are not intended to represent the number of customers that each Authority will serve or represent.

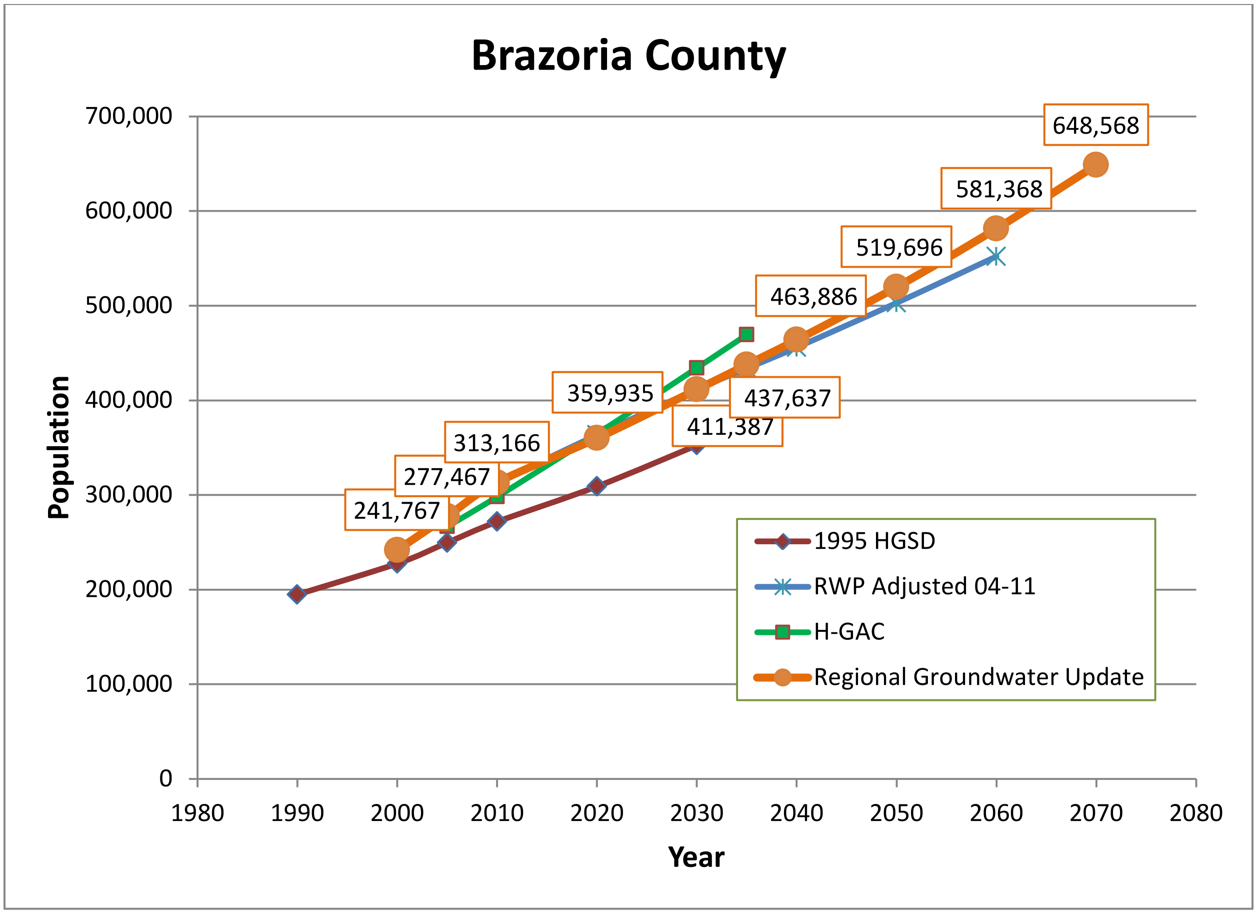


Figure 2. Brazoria County Population Projections

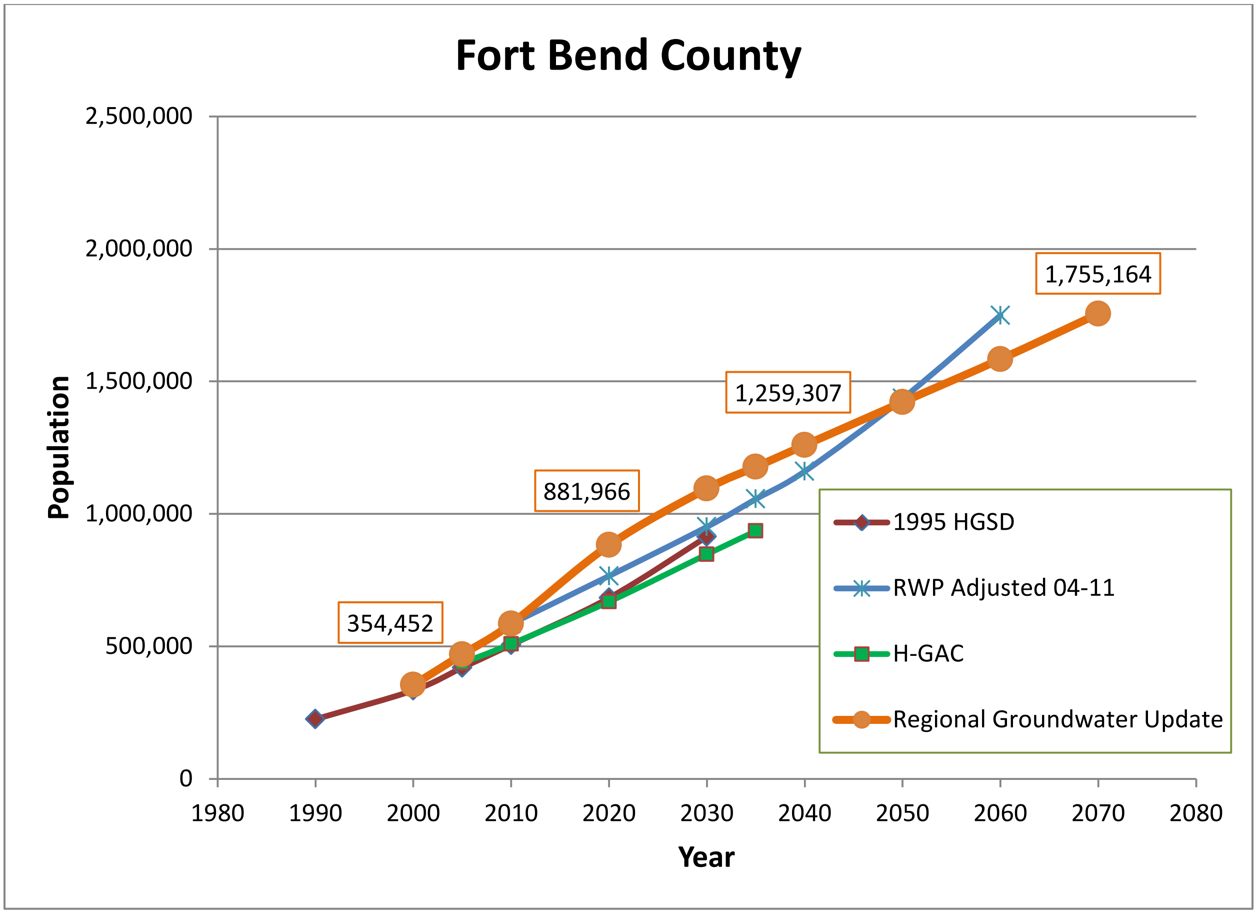


Figure 3. Fort Bend County Population Projections

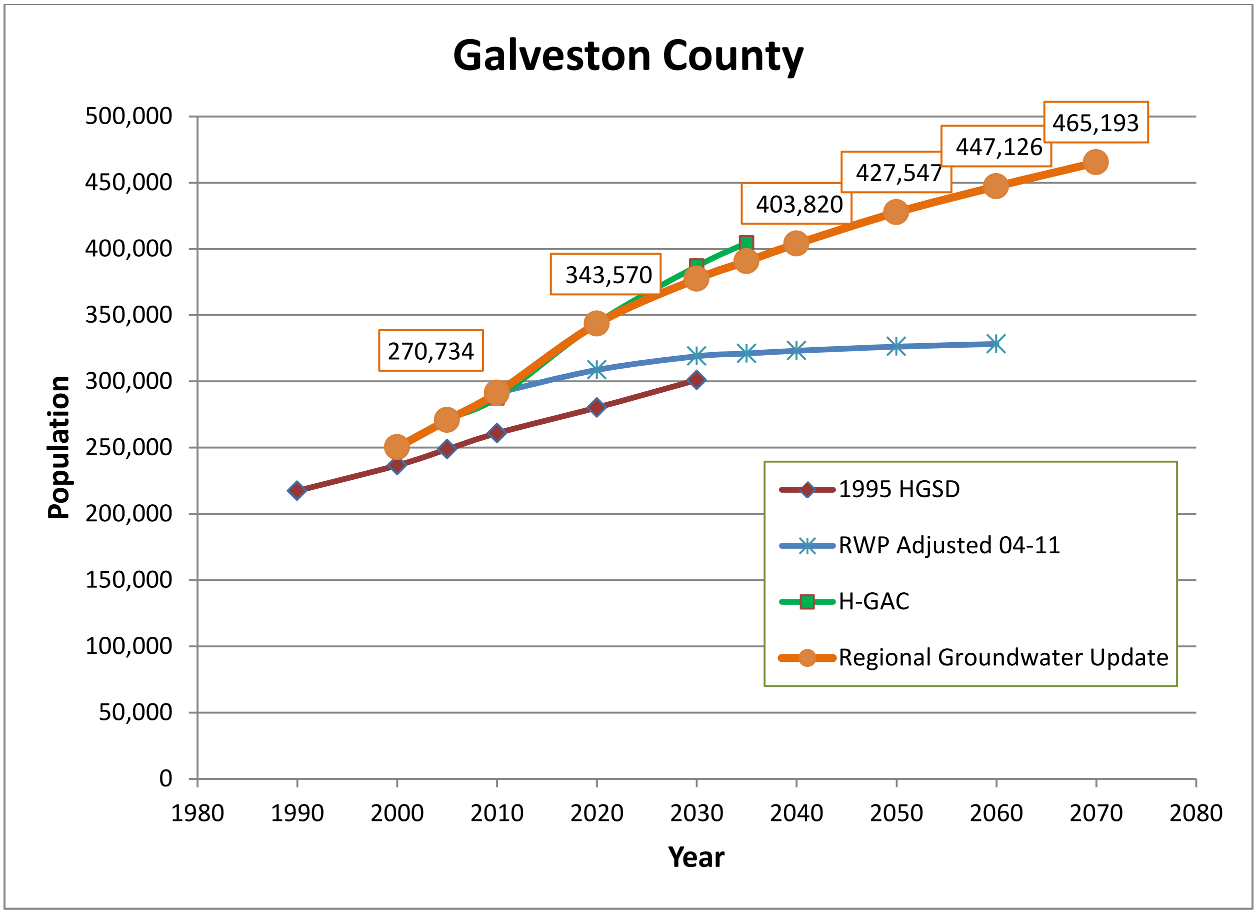


Figure 4. Galveston County Population Projections

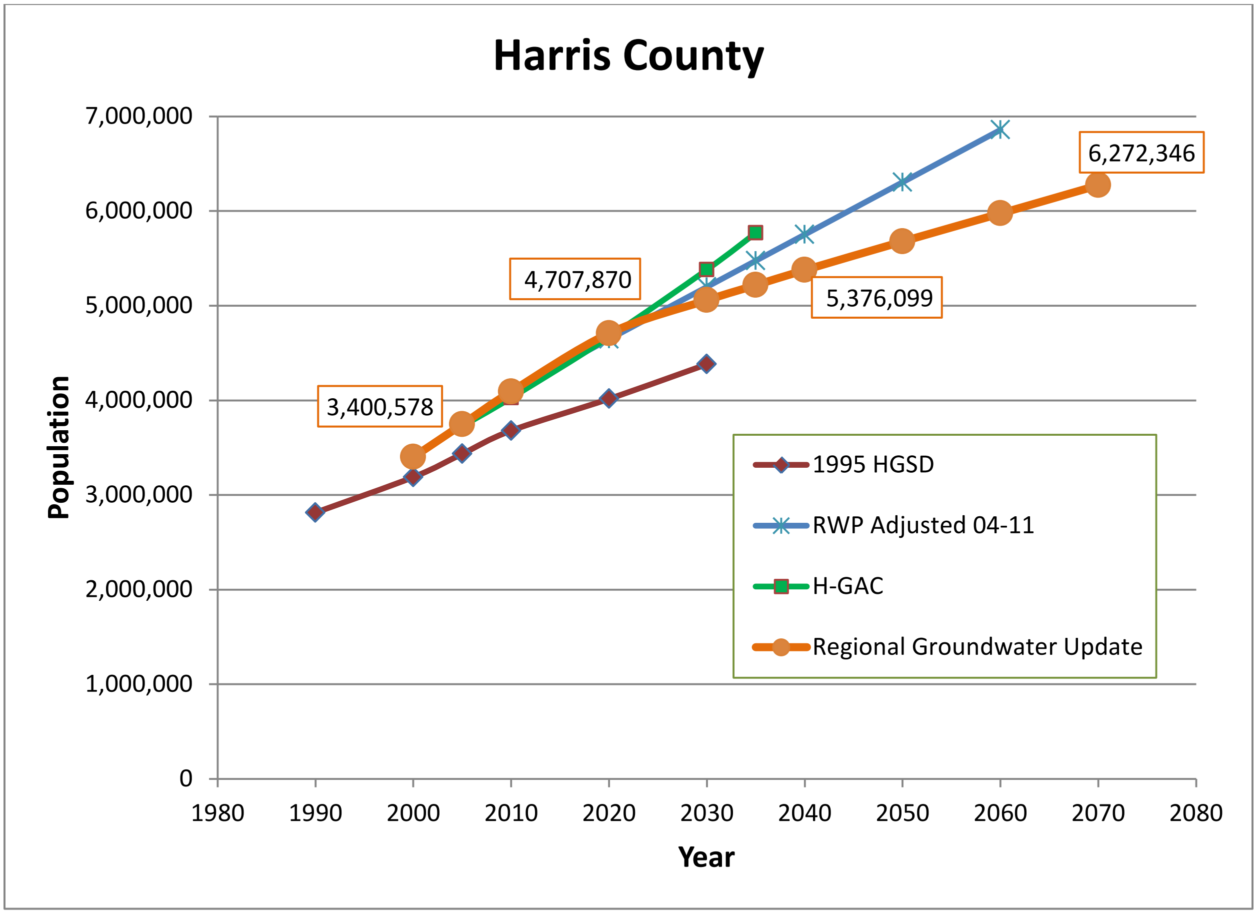


Figure 5. Harris County Population Projections

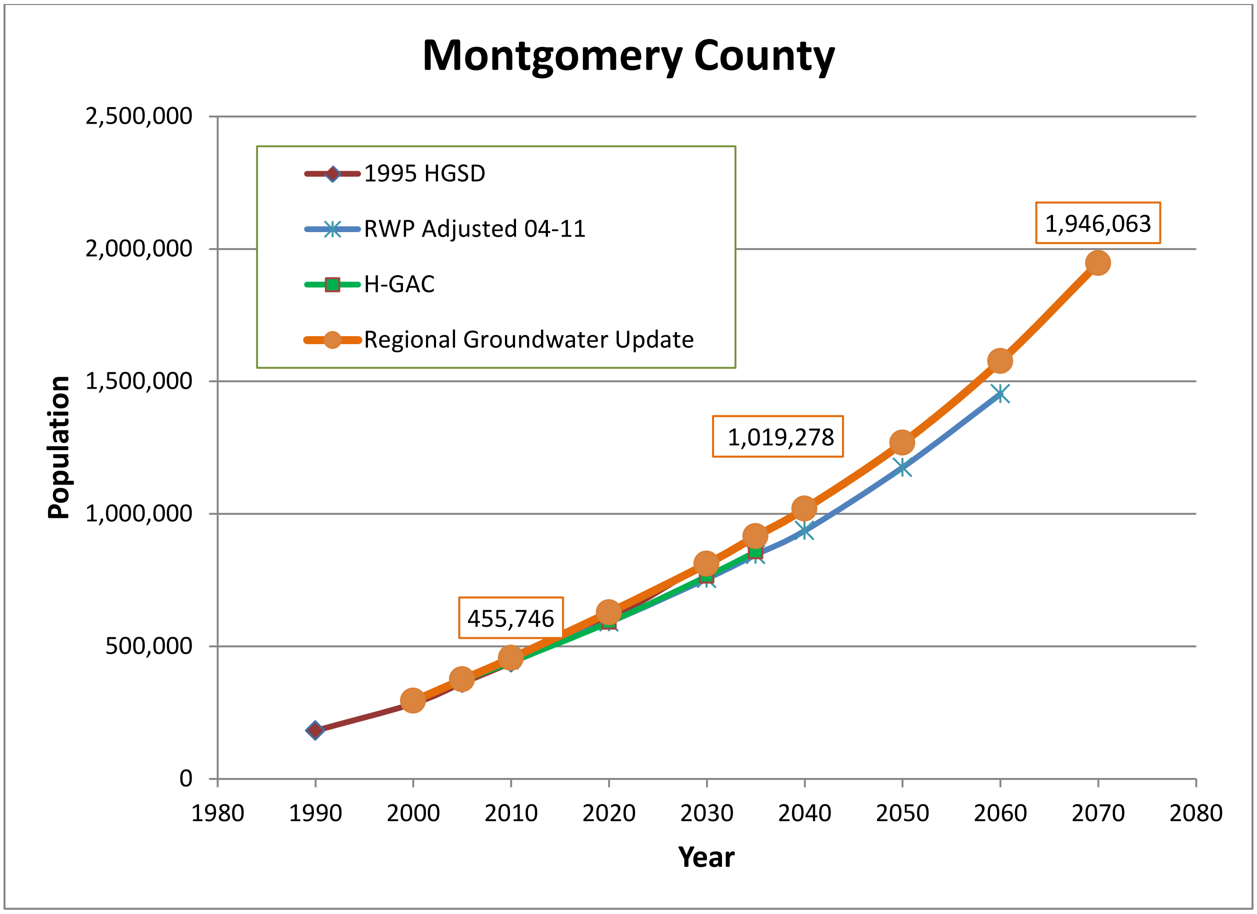


Figure 6. Montgomery County Population Projections

metrostudy
Housing Starts Here

3100 Wilcrest Ave, Suite 125
Houston, Texas 77042

phone 713.622.9909 ext. 126
fax 713.622-4834
email bcolliander@metrostudy.com
web www.metrostudy.com

January 6, 2012

Mr. Bill J. Thaman
Project Manager – Water Resources
Freese & Nichols
3100 Wilcrest Ave, Suite 200
Houston, TX 77042

Dear Bill,

Attached are the final annual population projections by census tract for the Houston Galveston Subsidence District (HGSD) 1999 Regulatory Plan Update: Work Order 4. The following pages will outline Metrostudy's purpose, methodology, and commentary on the key drivers of population growth within the surveyed area. The survey region includes the following counties; a map is shown on page 12:

- **Harris County**
- **Montgomery County**
- **Fort Bend County** – *Excluding Census Tract 6758*
- **Brazoria County** – *Excluding the Coastal Census Tracts*
- **Galveston County** – *Excluding the Coastal Census Tracts and Galveston Island*

In addition to the attached report, Metrostudy has provided digital copies of the projections to Freese and Nichols, Inc. to be incorporated with University of Houston's decadal population projections for the larger region H population projections.

Please call us at your convenience with any comments or questions regarding this report or any other matter relevant to your real estate market research needs.

Best regards,
Signed Electronically

Brad Colliander
Senior Market Analyst
Metrostudy, Consulting

COPYRIGHT © 2012

POLICY STATEMENT AND GUIDELINES USES OF METRO/STUDY DATA

The use of the data provided to sponsors of a METRO/STUDY Report is subject to the Copyright of American METRO/STUDY Corporation. The commercial use of METRO/STUDY data in the preparation of consulting reports, studies, appraisals, analysis or other types of consulting services, rendered for a fee, is strictly prohibited unless the sponsor has received **specific written approval** from a principal of American METRO/STUDY Corporation to utilize METRO/STUDY data for commercial purposes.

The reproduction of METRO/STUDY data, by electrostatic means through the use of copier or photographic or laser technology, or by electronic means through the use of computers, including computer storage, laser disc storage or other data processing oriented means is prohibited by our Copyright unless the sponsor has received specific written approval of such reproduction from a principal of American METRO/STUDY Corporation. The prohibition against duplication of METRO/STUDY data includes **all of the data contained within the report**, whether historical or current, whether analytical or specific.

The distribution or sharing of METRO/STUDY data with persons or entities who are not immediate employees or principals of the sponsoring entity is prohibited. This prohibition includes the loaning of METRO/STUDY data to outside persons or entities for any purpose, including the distribution of information to appraisers or consultants, to the news media, from lending institutions to their borrowers or from borrowers to their lenders, and between joint venture partners where one entity/partner is a METRO/STUDY sponsor and one entity/partner is not. While the distribution of METRO/STUDY data under this paragraph constitutes a violation of our Copyright**, the acceptance of such data by a non-sponsor immediately obligates that non-sponsor for the full cost of a sponsorship covering the period of time reflected in the data so distributed and received**.

The above clarification statements are in no way intended to limit the Copyright held by American METRO/STUDY Corporation, but are provided for the benefit of our sponsors in order to clarify the restrictions with respect to these three issues.

TABLE OF CONTENTS

METROSTUDY QUALIFICATIONS

Metrostudy is the leading provider of primary and secondary market information to the housing and related industries nationwide. In addition to providing information, the company is recognized for its consulting expertise on development, marketing and economic issues, and is a key source of research studies evaluating the marketability of residential and commercial real estate projects. Services are offered through an extensive network of offices strategically located in major metropolitan areas throughout the country. The company is based in Houston, Texas, and was established in 1975 by founders Michael Castleman, Sr. and Michael Inselmann.

When you partner with Metrostudy, we guarantee that you will know your market. Our research offers the most complete, accurate, and useful information available. And we not only provide the information -- we can analyze what it means, and help you apply it to your business.

Our research.

Metrostudy maintains the country's largest database of primary housing market information, using hundreds of dedicated field researchers and investing millions of dollars annually. Our researchers drive the streets of every platted new home subdivision, inspect every home site, and record primary data on housing activity every 90 days. You'll have the most complete and accurate information on undeveloped and vacant developed lots, housing starts and closings, product and pricing.

We then combine our research with secondary research -- data we obtain from other sources on future developments, demographics, job growth, and the economy. We then deliver all information to our clients via our line of Metrosearch products -- cutting edge computer applications so you can sort information, run reports, and create graphs and thematic maps on Market Maps you define, from one subdivision to an entire MSA.

Our analysis.

Metrostudy's consulting team will help your organization to be results-oriented and on-target. Using our research, marketing, and sales expertise, we'll deliver a highly personalized service with clear and relevant analysis from the best data available. We immerse ourselves in your marketplace, and we'll be attentive to your particular needs.

We're here to help you understand how to minimize risk and maximize profits for your business, so you can make decisions with confidence.

Metrostudy's consulting team has completed thousands of residential and commercial studies for builders, developers, lenders, Wall Street opportunity funds, retailers, utilities, and governmental agencies across the country, including 18 of the top 20 residential builders. We produce everything from quick preliminary analyses to fully documented studies, customized to your needs. For a complete list of major residential study types offered, see our Consulting Information.

COMPANY PRINCIPLES

Mike Inselmann
President
Metrostudy

Mr. Inselmann is co-founder and President of Metrostudy. With a finger on the pulse of the housing market, Inselmann has become a trusted advisor to his clients, a respected source of information for local and national media and a speaker of national note. He covers front-burner issues facing cities across the nation - from demographic changes and their impact on local markets to Smart Growth and New Urbanism. A widely respected authority on housing supply/demand characteristics, he is a primary source of information about housing trends for the National Association of Home Builders, as well as local and state home builder associations and governmental planning agencies.

A native of San Antonio, Inselmann is a graduate of Rice University. Active in community and industry affairs, he has served as a member of the board of directors of the Greater Houston Builders Association, and is a member of the National Association of Home Builders, the American Marketing Association, and the Urban Land Institute. In the past, he served on the Steering Committee of the Urban Land Institute to establish a professional association of real estate market analysts.

Mike Castleman
CEO
Metrostudy

Michael S. Castleman is Chairman of the Board and CEO of Metrostudy. Mr. Castleman is a 1965 graduate of the Business School of the University of Texas at Austin, Texas; he also attended South Texas College of Law, in Houston, Texas, in 1971 and 1972. With a background in banking, marketing, strategic planning and real estate consulting, Mr. Castleman co-founded American METRO/STUDY Corporation, now Metrostudy, for the purpose of conducting housing market research and providing accurate economic and market information to companies associated with the housing industry. He brought into the firm a thorough knowledge of real estate development, market analysis, and planning, which enabled him to provide valuable analysis of housing markets during a time of rapid economic expansion and contraction.

Since the company's inception in Houston, Texas in 1975, Mr. Castleman has expanded the availability of Metrostudy's accurate housing market information to major housing markets throughout the U.S.

Mr. Castleman's expertise includes strategic planning and forecasting housing market trends. Mr. Castleman has played an important role in helping Metrostudy clients anticipate changes in market conditions, before these conditions cause a negative impact on the clients' business. Mr. Castleman has also prepared feasibility studies and market studies for residential developments which range in size from fifty lots to more than 10,000 acres.

In addition to expanding Metrostudy geographically, Mr. Castleman has enhanced the information provided to the firm's clients by combining the availability of Metrostudy housing market data with public sector data and computerized mapping services, aerial photography and demographic data in the company's proprietary software program (**Metrosearch**) that provides Metrostudy clients with an electronic toolbox for use in managing the risks associated with real estate and the housing industry. Many of these software features are also available to Metrostudy clients through ***Metrosearch On-Line***.

PARTICIPATING PERSONNEL

Jack Inselmann
Vice President
US Central Division

Jack Inselmann, Vice President, US Central Division, is responsible for Metrostudy's Austin, Chicago, Dallas/Ft. Worth, Houston, and San Antonio markets. Over the past seventeen years, Mr. Inselmann has gained a reputation in the San Antonio and Austin housing industry for thorough analysis and thoughtful insight into the many factors that affect the outlook for the local housing and real estate markets in those cities. He regularly meets and consults with over 100 home builders, lenders, private investors and institutions concerning trends in the Austin and San Antonio economies and their effect on real estate values and the demand for housing in those markets.

Mr. Inselmann frequently speaks to industry and professional groups interested in his unique insight into the current status of the industry and his accurate forecasts of future trends. He is selected annually to deliver the housing forecast for the San Antonio market by the Greater San Antonio Builders Association, and has participated on discussion panels with numerous trade groups including the Greater San Antonio Board of Realtors, the San Antonio/Austin Mortgage Bankers Association, the Texas Capital Area Builders Association and others. A native of San Antonio, Mr. Inselmann is a graduate of Trinity University. He serves on the board of directors of the Greater San Antonio Builders Association and is involved with the YMCA and the Northside Suburban Little League Association. In the past, he has served the community as a member of the City Planning Commission of San Antonio.

David Jarvis
Director
Houston Market

Jarvis graduated from DePaul University with a B. A. in marketing and holds the Certified Commercial Investment Member (CCIM) designation. In 2000, he was admitted to the Institute of Residential Marketing (IRM) of the National Association of Home Builders.

His designation as a Member of the Institute of Residential Marketing (MIRM) is based on a combination of professional education and experience in the real estate industry.

With over 25 years of experience in the sale, marketing, management and development of residential real estate, David Jarvis is respected for his real-world experience as well as the extensive primary research he brings to the table. Utilizing Metrostudy's data base and conducting extensive research targeted to the specific needs of home builders, developers, and lenders, Jarvis assists clients in the development and implementation of marketing and sales management strategies and model home development and merchandising.

He has received numerous marketing and sales awards, including Sales and Marketing Director of the Year for the Greater Houston Builders Association; Sales Manager of the Year, also for the Greater Houston Builders Association; Sales Manager of the Year for the Dallas Homebuilders Association; and Regional Marketing Director of the Year for the National Association of Home Builders. Jarvis speaks frequently on sales and marketing techniques at industry trade conferences and events.

Brad Colliander
Senior Market Analyst
Metrostudy, Consulting

Brad Colliander is a Senior Market Analyst with Metrostudy Texas Consulting. Mr. Colliander is a graduate of Texas A&M University, where he received a Masters Degree in Real Estate through the Mays School of Business. Mr. Colliander first worked for Metrostudy in 2004, as part of a professional internship and joined Metrostudy full-time following graduation in 2005. Mr. Colliander’s real estate career has grown over the years, gaining professional expertise in all commercial and residential facets of the real estate industry.

Since joining Metrostudy, he has completed and delivered hundreds of custom market studies throughout the state of Texas focusing on single-family and multi-family developments. Mr. Colliander has consulted with his clients on a wide variety services which include site selection, product positioning, product development, market demand analysis, lot pricing, business plan forecasts, and population and household projections.

METROSTUDY SURVEY PROCESS:

In order to create a household and population forecast for a given region, Metrostudy utilized its proprietary database of single-family housing activity. The creation of new households is the primary reflection of past and future population growth. Metrostudy's database is established upon a quarterly survey of all new single-family residential development in the study area. Metrostudy's surveyors visually inspect all known current and future developments and account for all stages of development activity within each subdivisions. Residential development activity is tracked for each subdivision from its conceptual stages through build-out. Metrostudy's database has over 35 years of history, giving us a unique ability to monitor the supply and demand characteristics for new household creations. Our longstanding presence within Houston and our extensive knowledge of the local housing market enables us to produce accurate household projections. This information is tracked within a Geographic Information System (GIS) Database at the subdivision level.

There are two cycles that Metrostudy tracks, the land/lot development and the new home development process. The land development cycle starts with the platted future lots. Platted Future lots are when a plat or a site plan has been submitted to the city or county for consideration. It is from this point that Metrostudy's survey team begins the quarterly survey process and tracts the development of the land through the various stages of development.

Figure 1: Land Development Process

Vacant Land
- There has been a preliminary plat submitted (sometimes a site plan) for consideration by a city and the land remains untouched.

Survey Stakes
- There are survey flags on the land.

Equipment on Site
- Large Machines used for excavation are found on the Site but no horizontal improvements have begun.

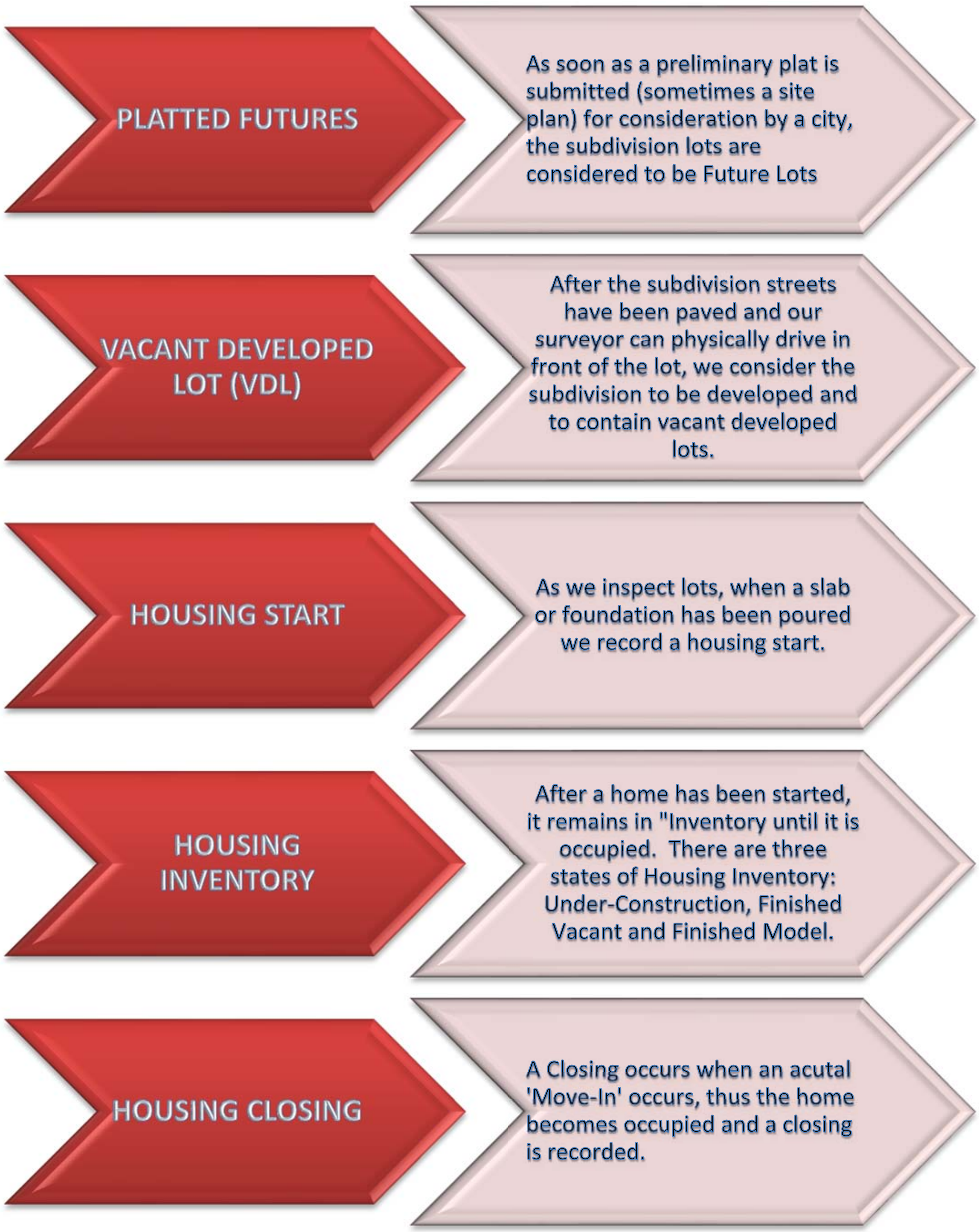
Excavation
- Lot grading, street grading and utility work are currently underway.

Street Paving
- The streets are currently being poured, but are not accessible by vehicle.

Streets In
- Street paving is complete but the roads are still not accessible by vehicle.

Once a lot reaches the vacant developed lot stage, the new home survey process begins. A vacant developed lot is ready to accommodate a housing start. At the end of this process an occupied home is generated.

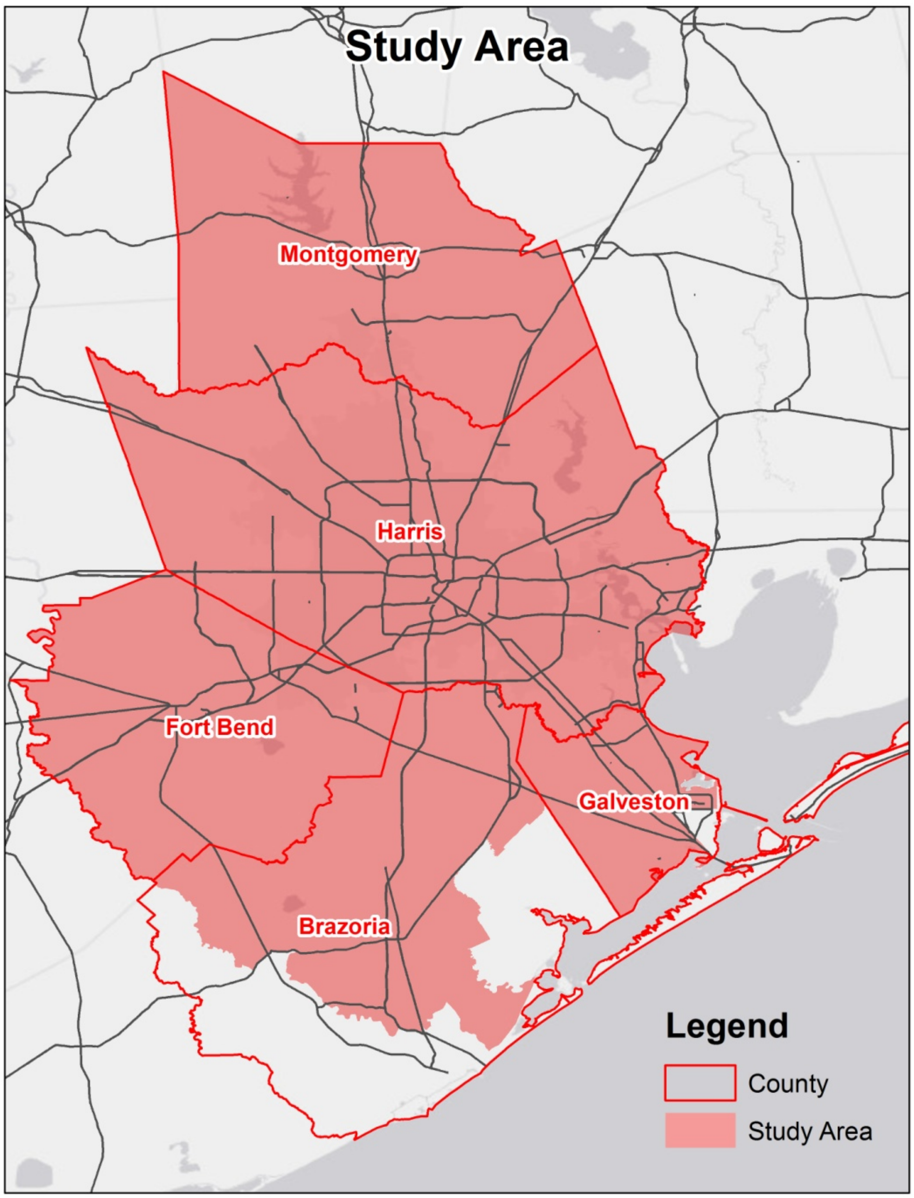
Figure 2: New Home Survey Process



PURPOSE

Metrostudy is working as a sub-contractor for Freese and Nichols in conjunction with Dr. Steven Craig from the University of Houston to provided updated population projections for the Houston-Galveston Subsidence District (HGSD). Metrostudy was retained to provide annual population projections by census tract from 2010 to 2020 for Brazoria, Fort Bend, Galveston, Harris and Montgomery Counties excluding some of the outlying census tracts as shown on the following page (the study area).

Figure 3: Study Area Map



METHODOLOGY

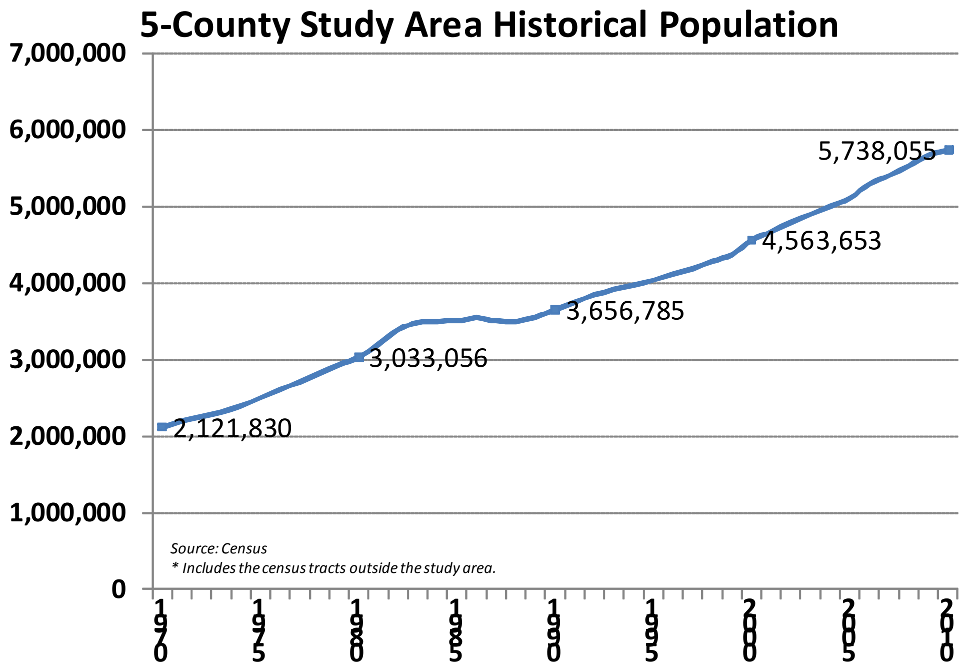
The following outline identifies the steps and methodology that Metrostudy took to generate the population forecasts to be utilized by Freese & Nichols for developing water demand tabulations for the HGSD. Metrostudy will provide annual population values for all the census tracts in the Study Area.

In addition to Metrostudy's Primary Housing Survey that was referenced above, secondary resources of information were also utilized. These secondary sources included the Census, Apartment Data Services, local land developers and engineers, and representatives from planning and zoning offices throughout the area and the Houston-Galveston Area Council (H-GAC).

Projecting Household Growth – County Control Totals

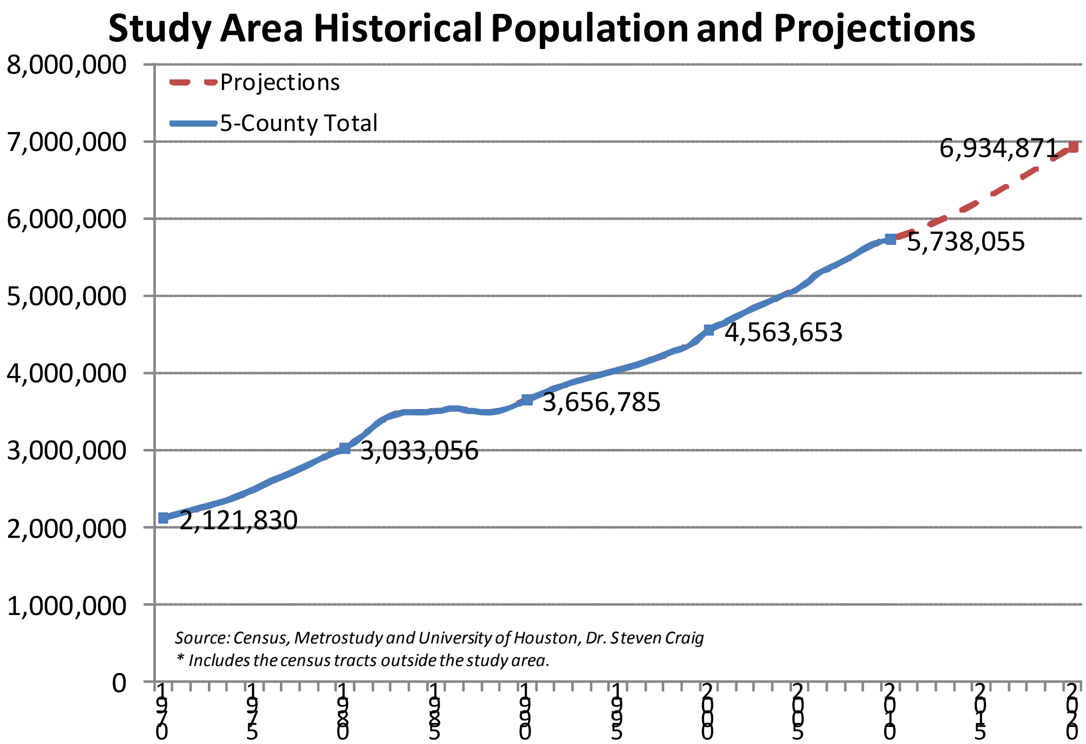
Metrostudy's first step was to examine past population growth for the Greater Houston Area and each of the surveyed counties. These trends were analyzed to provide a foundation or a control total for the population growth within each county. Metrostudy worked with Dr. Steven Craig at the University of Houston to help derive these county control totals. The following chart shows the historical population growth for the 5-county region from 1970 to 2010, with the decennial census numbers displayed.

Figure 4: Study Area Historical Population



After analyzing all of the pertinent local and national economic trends and comparing it to other third party population projections, the following population projections were derived as control totals for the study area. For the census tracts in Brazoria and Galveston Counties that were outside Metrostudy's study area, we substituted the 2020 population projections by Dr. Steven Craig from the University of Houston were utilized.

Figure 5: Study Area Projected Population



Analyzing Past Population to Household Growth Ratios

Metrostudy's next step was to analyze historical population and household growth as reported by the Census Bureau. Since 1970, the 5-county study area has grown from 2.1 million people to 5.7 million people in 2010, resulting in an annualized growth rate of 2.5%. However, the pace at which Houston has grown has slowed slightly to 2.3% annually over the past 20-years from 1990 to 2010.

Based on this information, Metrostudy calculated the number of new people it took to generate one new occupied household from 1990 to 2010, to determine the household formation rate for the study area and each county. This rate was used to convert the projected household growth to projected population growth. The table below shows the calculation for the study area.

Figure 6: Population to New Occupied Household Growth Rate For Study Area

$$\textbf{New Occupied Household Rate} = \frac{(2010\ Population - 1990\ Population)}{(2010\ Occupied\ Households - 1990\ Occupied\ Households)}$$

$$\textbf{Study Area} = \frac{5{,}738{,}055 - 3{,}634{,}927}{2{,}000{,}627 - 1{,}305{,}905} = \mathbf{3.02729}\ People\ per\ New\ Occupied\ Household$$

Based on this information, Metrostudy calculated the number of new people it took to generate one new occupied household from 1990 to 2010, to determine the household formation rate, for each county. This rate was used to convert the projected household growth to projected population growth.

Figure 7: Population to New Occupied Household Growth Rate By County

$$\textbf{Brazoria} = \frac{313{,}166 - 191{,}707}{106{,}589 - 64{,}019} = \mathbf{2.85315}\ People\ per\ New\ Occupied\ Household$$

$$\textbf{Fort Bend} = \frac{585{,}375 - 225{,}421}{187{,}384 - 70{,}424} = \mathbf{3.07758}\ People\ per\ New\ Occupied\ Household$$

$$\textbf{Galveston} = \frac{291{,}309 - 217{,}399}{108{,}969 - 81{,}451} = \mathbf{2.68587}\ People\ per\ New\ Occupied\ Household$$

$$\textbf{Harris} = \frac{4{,}092{,}459 - 2{,}818{,}199}{1{,}435{,}155 - 1{,}026{,}448} = \mathbf{3.11778}\ People\ per\ New\ Occupied\ Household$$

$$\textbf{Montgomery} = \frac{455{,}746 - 182{,}201}{162{,}530 - 63{,}563} = \mathbf{2.76400}\ People\ per\ New\ Occupied\ Household$$

<u>Projecting Household Growth – Single-Family</u>

After the control totals were analyzed and the new population to occupied household ratio was calculated we started to project household growth within the study area. Metrostudy's projections started by looking at the historical single-family housing starts and closings trends for each of the subdivisions within our proprietary database. These historical trends allow Metrostudy to project the pace at which new homes will be closed (occupied) during the next 10-years. In addition, we also looked at the existing vacant developed lot supply as of 2010 to determine the extent and location of housing activity over the next ten years. It is Metrostudy's expectation, especially in today's economic climate when financing for lot development is difficult to achieve, that the existing lot supply will be absorbed first, prior to the development of raw land.

Metrostudy analyzed the Houston-Galveston Area Council (H-GAC) 2008 land use layer to determine the parcels that are developable and classified as "vacant" or "farm land". These parcels where then visually verified by using 2010 Bing Aerials to determine if any of these parcels had been developed since the land use layer was created.

Once the historical trends are analyzed and the existing lot supply is obtained, Metrostudy began to project the new households for each subdivision throughout the projection period. Regional developments such as the construction of the Grand Parkway and the opening of the Exxon campus were also taken into consideration in projecting new households. These projects have the potential to impact not only the amount of population growth Houston can achieve, but where the people can live.

In the end, Metrostudy ended up with an annual new household growth projection by subdivision for each of the active, future and concept subdivisions throughout the study area.

<u>Projecting Household Growth – Multi-Family</u>

Next, Metrostudy focused on analyzing the multi-family growth within the study area. Metrostudy utilized Apartment Data Services, a local apartment data service company. Apartment Data Services provides a macro-market analysis of all know apartment communities within the Greater Houston Area. On a monthly basis, Apartment Data Services tracts the projects that are under-construction and proposed as well as tracts the changes in occupancy and absorption rates for the existing multi-family projects throughout Houston. By analyzing the pace of construction and rate of absorption for these apartment units allows Metrostudy to project future multi-family projects throughout the study area. To help assist with the location of future multi-family projects, Metrostudy reviewed many of the larger planned communities to determine if any multi-family projects are planned. To help understand timing on these projects, Metrostudy also interviewed the developers of these projects for their estimations on timing.

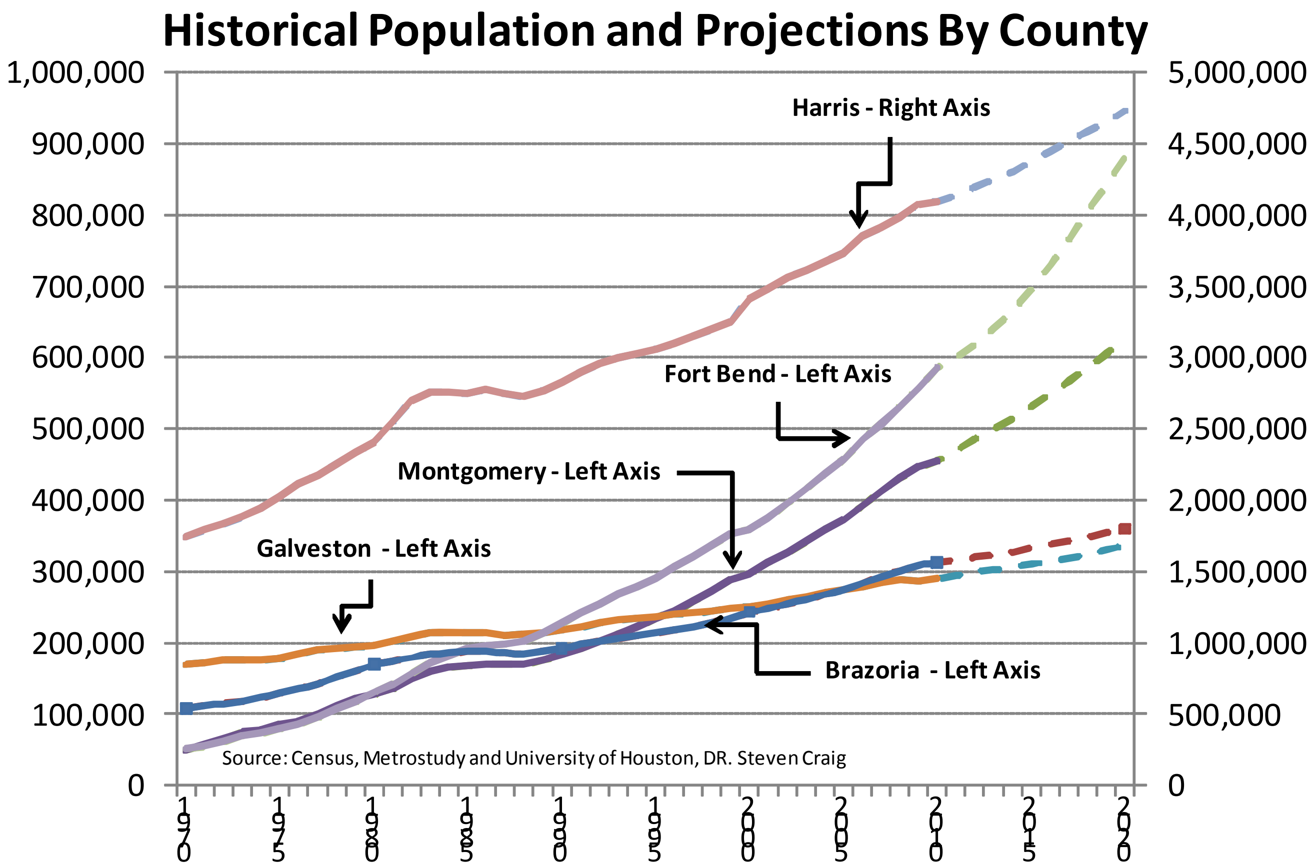
At the conclusion of this step, Metrostudy ended up with an annual projection of new multi-family projects over the next 10-years.

New Household Growth to Population

Once the single-family and multi-family projections were completed, Metrostudy aggregated the projected households to the 2010 Census Tracts. This aggregated household growth was then converted into population growth by applying the new occupied household ratio that was illustrated above.

The following pages illustrate the county level projections for Brazoria, Fort Bend, Galveston, Harris and Montgomery Counties. In the tables below, Metrostudy utilized the 2020 population projections from University of Houston, Dr. Steven Craig for the Census Tracts that are excluded from the study area.

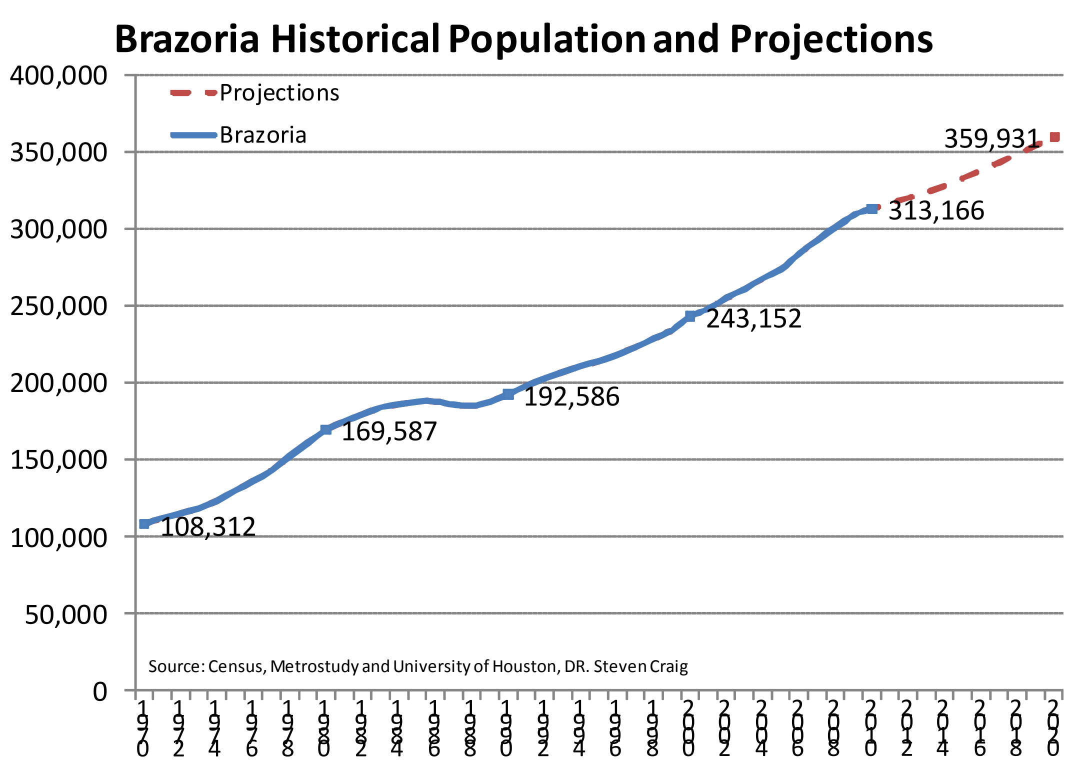
Figure 8: Population Projections by County



BRAZORIA COUNTY PROJECTIONS

Brazoria County is essentially a rural county with much of the southern portion of the county remaining as farm and ranchland or undeveloped. From 1970 to 2010, Brazoria Counties Population grew from 108,312 people to 313,166 people. Brazoria County will continue to grow over the next ten-years especially in the northern portion of the county where denser development is occurring. The northern portion of the county is more densely populated with some sizeable planned communities such as Rodeo Palms, Shadow Creek Ranch, Sedona Lakes and Sterling Lakes along Highway 288 and Kendall Lakes near the City of Alvin. As the Highway 288 corridor begins to build-out over the next several years, the ability for developers to build denser communities south of Highway 6 increases. One of the larger planned communities in Brazoria County will be the Seven Oaks Ranch has not yet been developed. Towards the end of this decade, Metrostudy believes that development will begin on the 3,000+ acre community.

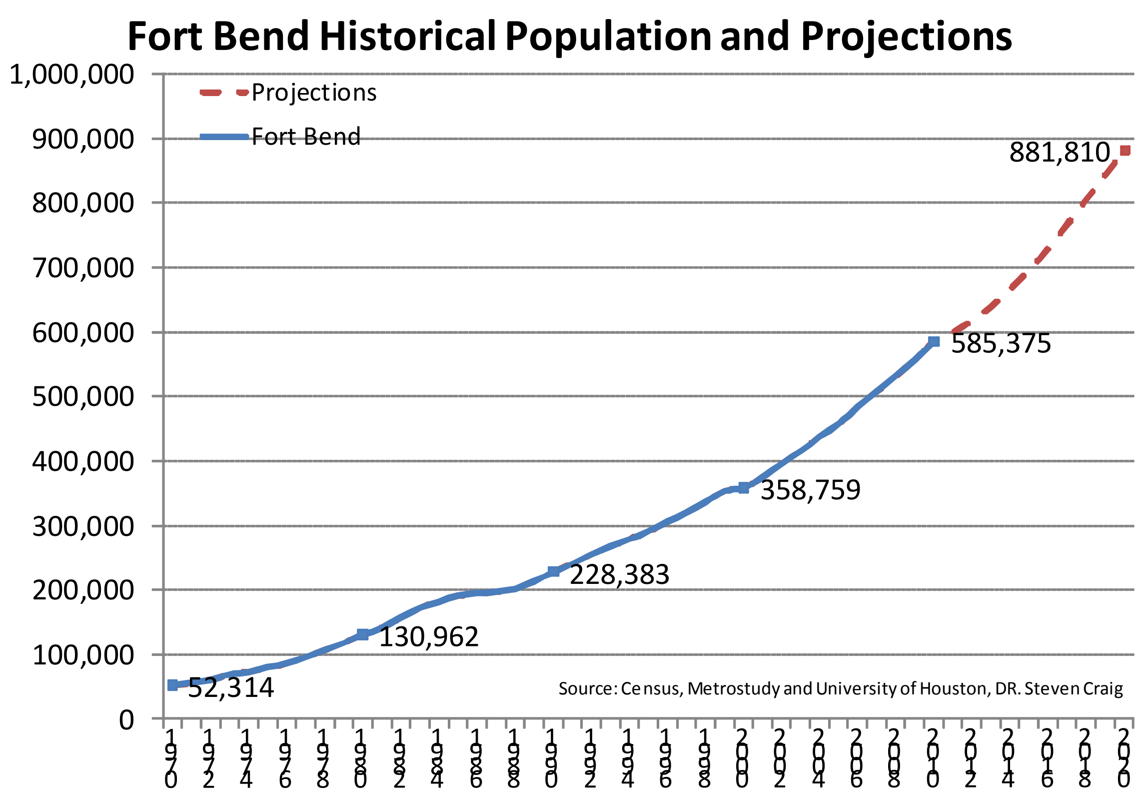
Figure 9: Brazoria County Projected Population



FORT BEND COUNT PROJECTIONS

During the past decade, Fort Bend County was one of the fast growing counties in the nation growing by 63% between 2000 and 2010. Fort Bend is attractive to many potential buyers due to the proximity to major employment centers, quality schools and available land. During the next decade, Fort Bend County will continue to be a leader in the Houston area. Many of Houston's top selling master-planned communities are located within Fort Bend county including: Aliana, Cinco Ranch, Cross Creek Ranch Riverstone, Sienna Plantation and Riverstone. These communities and their competition all provide value to the homebuyers by creating a sense of community through their extensive amenity package. This is the reason that master-planned communities are continuing to capture an increasing percentage of the Houston housing market.

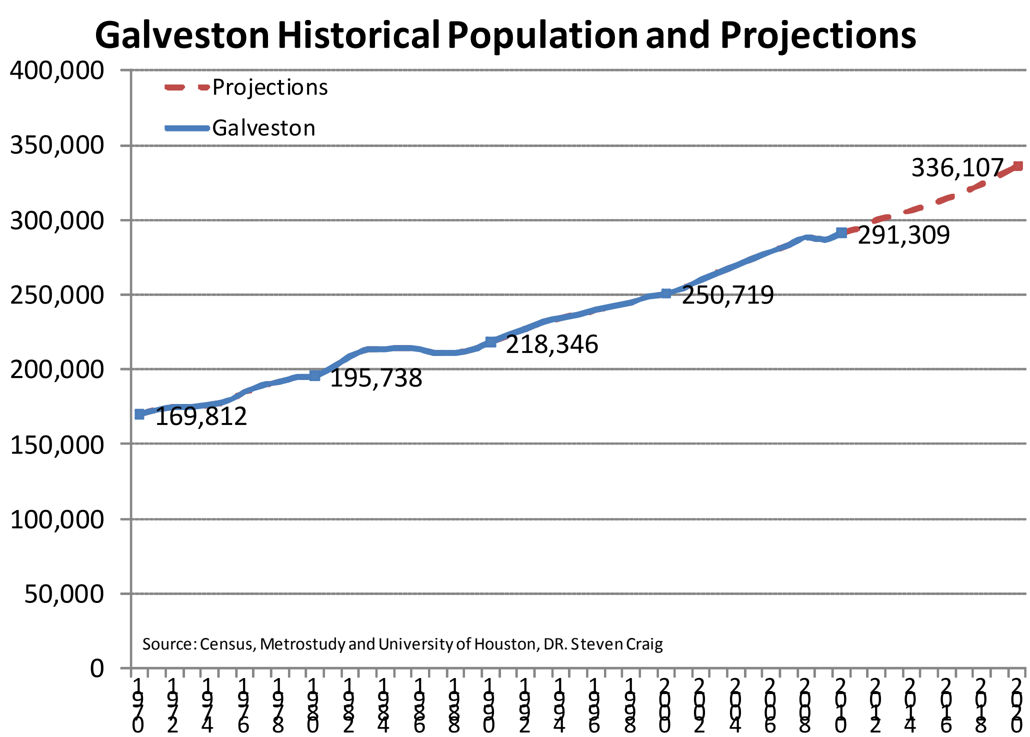
Figure 10: Fort Bend County Projected Population



GALVESTON COUNTY PROJECTIONS

The population growth in Galveston County has been relatively linear over the past 30-years growing from 169,812 people in 1970 to 291,309 in 2010. This population growth includes both the mainland and Galveston Island for which Metrostudy did not project population growth. The major job center in Galveston Island is NASA and the Johnson Space Center. Toward the later part of the 2000's NASA announced the retirement of the space shuttles and created an uncertainty of NASA's presence in Houston and the anticipated population growth in the County. Despite this drag on Galveston County, residents still have the University of Texas Medical Branch on Galveston Island and access to many major employment centers throughout Houston. In terms of population growth on the mainland, the Clear Lake Area will continue to attract the majority of the new population of the decade. Communities such as Mar Bella, Tuscan Lakes and West Ranch will lead the way in the near term, but there are still numerous large scale projects along Interstate 45 that will be developed during the next 10-years.

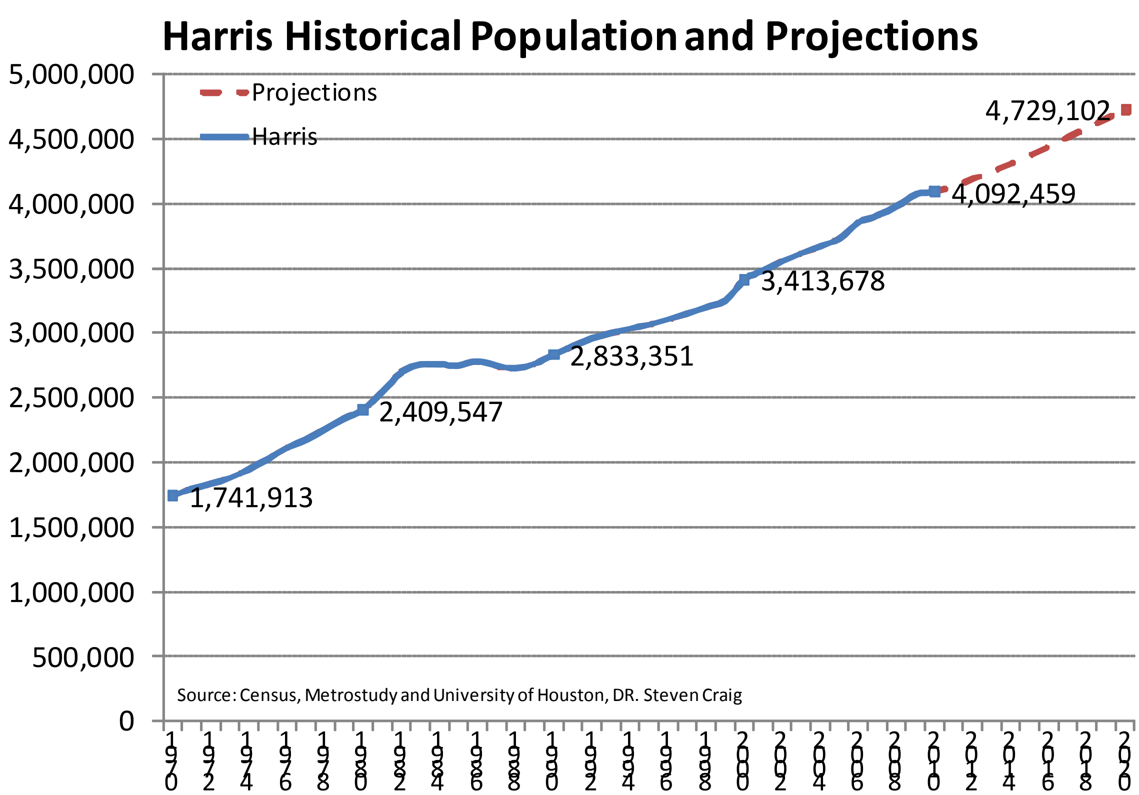
Figure 11: Galveston County Projected Population



HARRIS COUNTY PROJECTIONS

Harris County is the central county for the Houston MSA, and has the densest population in the region. Harris County's growth can be classified into two segments: urban growth or suburban growth. The urban growth in Harris County is located inside of Beltway 8, which is mostly built-out but infill and redevelopment is occurring and will continue to allow the urban core of Houston to grow. In contrast, the suburban fringes of Houston have an abundance of vacant land available to be developed. However, the majority of the development in Harris County is occurring on the west and northwest side of the county outside Beltway 8. This area has the potential to gain even more of the development activity as the slated construction of the Grand Parkway, which is anticipated to open by 2014, will open up more land for development and will provide mobility to many of Houston's major employment centers.

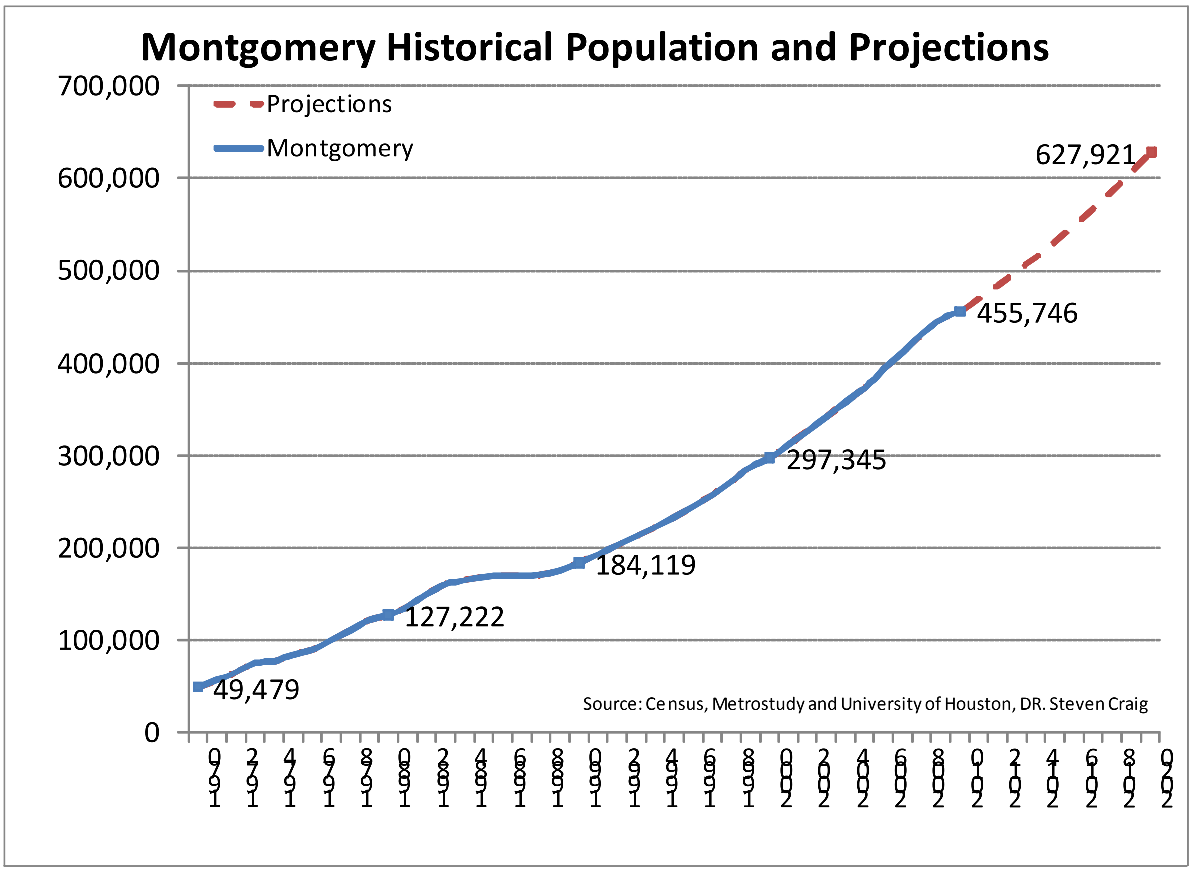
Figure 12: Harris County Projected Population



MONTGOMERY COUNTY PROJECTIONS

Montgomery County is the third most populous county in the Houston MSA as of 2010 with 455,746 people, which is an increase of 53% over the 297,345 people in 2000. Most of this growth in the past decade occurred in The Woodlands master-planned community. While The Woodlands is still active today, the development is now building in northern Harris County. However, there are several communities that are in place to replace The Woodlands, such as Woodforest and Harpers Landing. In addition, Montgomery County will benefit from the opening of the Exxon Campus in 2014, which will bring new jobs and residents to the area.

Figure 13: Montgomery County Projected Population



ASSUMPTIONS AND LIMITING CONDITIONS

The following contingencies and limiting conditions are noted as fundamental assumptions that may affect the validity of the analysis and conclusions reached in this report:

- All information contained in this report, while based upon information obtained from the client and other sources deemed to be reliable, is in no way warranted by Metrostudy.
- The Houston MSA, State of Texas, and the nation as a whole will not suffer any major economic shock during the time period of the forecast contained in this report.
- Population will continue to increase at or above Metrostudy's forecasted rate.
- The basic sources of statistical data and estimates used in this analysis are sufficiently accurate to be useful for planning purposes.
- The development, when completed, will be designed, promoted, and managed in a manner that will have an adequate impact on the local market.
- The recommendations set forth in this report will be acted upon within a reasonable period of time to preclude major changes in the conditions evaluated.

Radical changes in factors affecting the major assumptions noted above could alter the conclusions reached in this analysis or necessitate the re-evaluation of portions of this report.

SAM- HOUSTON

DESCRIPTION OF
SMALL AREA MODEL
POPULATION FORECASTS

EIGHT COUNTY METROPOLITAN AREA OF HOUSTON

Professor Steven G. Craig

Department of Economics
University of Houston
Houston, TX 77204-5019
(713)-743-3812
scraig@uh.edu

December, 2011

SAM- HOUSTON

Executive Overview

The goal of the **S**mall **A**rea **M**odel- Houston (SAM- Houston) is to allocate metropolitan-wide population and employment forecasts to each Census tract in the eight counties that form the core of the Houston metropolitan area, Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller Counties. SAM-Houston combines a unique modelling strategy with sophisticated statistical processing of a wide variety of data sources about the Houston area. The SAM- Houston model has four distinct advantages as a local forecasting tool:

*SAM-Houston forecasts are based on current theories of urban development. The premise underlying the SAM-Houston model is that all population must be supported by employment. Urban development theory predicts that employment growth will primarily occur in decentralized subcenters throughout the region. Population will locate based on the proximity to downtown, and to the spectrum of alternative employment concentrations.

*The SAM- Houston model puts theory into practice using advanced statistical (econometric) techniques appropriate for processing geographically based data. Employment subcenters are identified using locally weighted regression methods which identify statistically surprising concentrations of employment. The results are used to formulate the Statistical Module of SAM-Houston, which specifies the process of change using weighted cubic splines based on historical Census population data. These statistical processes incorporate the important elements of urban development theory including leapfrog development, where development often occurs unevenly as more distant locations are developed before areas nearer to downtown, and multi-centric business centers, where there are numerous concentrations of employment throughout the metropolitan area.

*SAM- Houston forecasts are statistically grounded by the present level of land use and development through formulation of a Land Use Module. The Land Use Module applies the forecast results from the Statistical Module based upon existing land use, and land use densities. Changes over time are based on urban development theory applied to current conditions, which allows for historical and policy forces to shape the urban environment. The underlying statistical process captures development and redevelopment consistent with the Houston-specific economic development experience.

*The SAM- Houston forecasts are flexible. The forecasts presented here are based upon metropolitan area totals from the Institute for Regional Forecasting at the University of Houston, though they have been modulated based on the results of the SAM-Houston modelling process, as well as comparisons to those of the Texas Water Development Board and the Texas State Data Center. The SAM-Houston model, however, can be re-applied to alternative growth scenarios to allocate growth in distinct areas. Further, SAM- Houston forecasts can be recombined using Census block data into various alternative geographic definitions, for example to water use districts, zip codes, voting precincts, and school zones.

The results of the SAM-Houston statistical forecasting process suggests that the recent

Houston experience, which is rapid growth of the counties nearest to Harris, will continue for several decades. While Fort Bend has experienced the most rapid growth rates in recent times, its growth rate will begin to slow as growth shifts north towards Montgomery, and then to other currently more rural areas. The long range view that emerges is that the overall metropolitan growth rate will slow as our area fills, which means that subsequent growth comes from the more expensive process of re-development which already characterizes the closer in sectors of Harris County. Eventually the necessity for redevelopment will affect all of the other counties. This is the growth process that, in a macro economic sense, has fueled growth in Texas and other southern and western parts of the U.S. as the northern central and eastern portions of the country aged.

SAM- HOUSTON

DESCRIPTION ACCOMPANYING EIGHT COUNTY POPULATION FORECASTS

The goal of the **S**mall **A**rea **M**odel- Houston (SAM- Houston) is to provide population and employment forecasts by Census tract for the Houston metropolitan area. This is an ambitious goal, as there has not been an available statistical methodology for projecting future population and employment at the micro-geographic level, especially for long time periods. The forecasts presented here, however, are a result of an innovative modelling strategy that has achieved the objective of providing a solid theoretical and statistical foundation upon which to determine how future growth will be allocated among various places in the Houston metropolitan area. SAM- Houston population and employment forecasts are currently available for the eight county region, including Brazoria, Chambers, Fort Bend, Galveston, Harris, Liberty, Montgomery, and Waller Counties.

This discussion is intended to describe the primary features of the SAM- Houston model. The SAM- Houston model contains two modules. The first, the Statistical Module, is built on current urban development theory, and relies exclusively on statistical modeling representative of the application of the urban development theory to the Houston area. The Land Use Module is the second important element. It describes how the statistical results are modulated by current land use data. This segment relies on expressing the theory consistently with existing land uses, and with current land use densities, although the results are not formally unique from a mathematical perspective. The land use module ensures, however, that the population and employment forecasts are consistent with each other, and are consistent with the available vacant land in each neighborhood.

A. Modelling Strategy

This section describes the two separate components, or modules, of the SAM- Houston model. The statistical module is the core, as it translates established urban development theory into a statistical model for the Houston metropolitan area. The second module compares the statistical forecasts to the available developable land, and adjusts the forecasts to reflect current land use patterns and available vacant land. The goal of this modelling strategy is to develop a flexible planning tool, appropriate for widely disparate applications, that is nonetheless sensitive to current development within Houston.

1. The Statistical Module

The are four elements of the statistical module used to prepare the SAM- Houston forecasts. First, we statistically identify the employment subcenters throughout the Houston area, incorporating not only employment density but also influence on neighboring areas. Second, we estimate a model of population and employment allocation throughout the Houston metropolitan region. Third, we determine how the allocation of population and employment has changed over the last five decades. Fourth, we use an aggregate population and employment forecast for the metropolitan region, and allocate the forecast population and employment to individual Census tracts.

Employment subcenters are an important theoretical innovation in understanding urban economies over the last two decades. Specifically, firms tend to locate near each other to achieve what are called agglomeration economies. Agglomeration economies mean that it is cheaper and more effective for firms to locate near each other, although current research is still attempting to determine the relative importance of the several reasons for doing so. Among them are that firms can be suppliers and customers for each other, it is more efficient for customers to search among products, it is more efficient for firms and workers to search for each when they are in proximity, and technological innovation can occur more rapidly. The problem with grouping together, however, is the resulting congestion. As growth causes congestion to build, markets have responded by moving clusters of employment outside of the traditional downtown areas.

These new clusters are called employment subcenters, as firms attempt to achieve most of the advantages of agglomeration without the costs of congestion. Employment subcenters in general are the subject of much recent research, as the process and causes of attraction are not yet fully understood. Our research on Houston has nonetheless found that these subcenters are economically important, and further that they are generally diversified as to industry focus despite the real estate labels. Irrespective, however, subcenters have been growing in importance across the country, as well as in Houston in particular, and our forecasting methodology accounts for their continued growth as the Houston economy grows. Our identification of employment subcenters is accomplished through locally weighted regression, a semi-parametric technique that provides a detailed look at employment data to determine not only areas of higher than expected employment based on the relationship to downtown, but which is also based on the influence of a geographic point on employment in nearby areas. One of the interesting consequences of our modeling is that we find that only downtown has influence over the entire shape of Houston, the other employment subcenters (even the Galleria) have influence on less than the entire city. We take the limitations of subcenter influence into account in our modeling.

The second element of the statistical component of the SAM- Houston forecasting model is constructing an empirical description of the fundamental urban development theories. The foundation of the forecasting model uses economic theories that describe the distribution of population and employment throughout an urban area. In particular, all demographic change must be supported by employment opportunities. That is, all population change, whether from changes among the current resident population due to births and deaths, or from migration, must be supported economically. Employment opportunities arise because of demand for local products from economies in the rest of the world outside of Houston (called base employment), and from residents' demand for goods and services provided locally (called secondary employment). Base employment occurs in sectors that supply products to those outside the local economy, and represents the primary reason for a city's location. Base employment is generally concentrated in downtown, and in the other employment subcenters of the city.

Non-base employment, or secondary employment, provides goods and services to local businesses and residents. Its location pattern is actually similar to base employment, as it tends to be concentrated around base employment centers to serve both other businesses as well as the general population. In addition, however, secondary employment follows the population throughout the city for retail and other services. Resulting variations in both population and employment density as used to measure both the capacity utilization of available land, as well as the intensity with which land is utilized.

The third element of the statistical module involves determination of how population and employment dispersion has changed over time, and a forecast of how population and employment dispersion will change in the future. On average, cities throughout the country have been decentralizing at least since 1950. Two trends driving decentralization are decreases in transportation costs (especially travel time), and technological changes reducing the need for geographic proximity among firms

The rate of decentralization is determined by examining the rate of decentralization in the Houston area since 1970. The period from 1970 to 1980 was a prosperous period for Houston, but one in which population growth outpaced improvements in the transportation infrastructure. The opposite pattern was experienced in the 1980-90 period., as transportation development proceeded much more rapidly than population growth, resulting from both lags in the infrastructure process as well as the local economic depression of the period. The 1990-2000 period is when the city transitioned back to a growth mode, but at a much more moderate rate than the pattern from 70-80. Economic growth cause the city to continue to disperse, although toward the end of the period increases in congestion and other transportation costs slowed the trend toward decentralization. The 2000-2010 period has been the most difficult to model, as Houston has maintained its own economic cycles but nested within the influence of national shocks. Further, it appears that the City's growth westward is reaching a peak, and that future growth is veering northwards. Other trends, however, are also important for determining the rate of urban decentralization. In large part, decentralization does not involve people living in the city moving to the suburbs. Instead, decentralization occurs when new people moving to Houston disproportionately decide to move to the suburbs instead of into the central city. Thus decentralization can be accelerated by population growth, as the number of new residents indicates that people are mobile, and thus the shape of the city can change more quickly. A difficult forecasting element is that migration to Houston is as much a product of economic conditions elsewhere as the economic conditions in Houston. Finally, the policy health of each political jurisdiction is potentially important, and can markedly change how and where economic growth occurs.

Employment, both base and secondary, is generally more concentrated than is population. Employment has also tended to decentralize, although at a somewhat slower rate than population. While technological change may serve to accelerate the speed of employment decentralization, the growing influence of the employment subcenters is much more important in the new century than earlier. As with population, the speed of employment decentralization shows a significant decrease in the 1980s compared to earlier time periods, while the decades since the 1990s seems to exhibit a return to earlier patterns. Thus we expect that the rate of decentralization will proceed at a rate that is reflective of the last twenty years, as improvements in transportation will not be able to compensate completely for increases in costs, and increases in congestion. The somewhat unanswered question is the extent to which growth in the employment subcenters is independent of growth downtown. We believe these areas will remain linked in important ways, but this is an area in which future changes may be surprising given our statistical past. One of the indicators of this process is that we find the statistical distinction between counties is much less pronounced in 2010 than in the past, thus the entire eight county region seems firmly rooted to the same economic growth process. The Census Bureau continues to add counties to the definition of the Houston metropolitan region as an independent indicator the economy of the entire region is linked together.

The fourth element of the statistical module involves recognition of the growth allocation process that is the result of the SAM- Houston model described above. That is, the SAM- Houston model is structured to allocate metropolitan-wide population and employment forecasts among each of the various Census tracts within the metropolitan region. The actual forecasts for each Census tract of course depend on an aggregate forecast for the Houston metropolitan region.

The aggregate forecasts used to develop the current estimates for population and employment are developed by the Institute for Regional Forecasting (IRF) through the HEMS (Houston Economic Multi-Sector) model as well as their longer term forecasts.[1] The forecasts from the IRF have performed well in the past, and are based on objective economic criteria. On average, the forecasts from the IRF have generally been more accurate than other sources, although there is some variation by county. We compared the IRF forecasts to those of the Texas State Data Center, and the Texas Water Development Board. We therefore modulated the IRF forecasts based on the differences with these other sources, and based on our modeling of the Houston area, which indicates the relative strength of the counties conditional on expected growth in Harris.

An additional source of variation in the county forecasts is that the longest term forecast from the IRF is out to only 2040. For the purposes of the SAM model, we have extended the forecasts to 2070 by allowing the changes in growth trends of Harris County to continue. Thus the longer term forecasts (from 2050 and later) do not contain any additional economic information, they mirror the information already incorporated in the modelling results through 2040. What the very

---

[1] See the Institute for Regional Forecasting (IRF), at http://www.uh.edu/irf/index.htm.

long term forecasts do include, however, is the rate of change in changes. Thus, as Harris County grows and fills the "easy development" parcels, continuing development will become relatively more expensive, and thus relatively slower, compared to the outlying counties. This process will also operate in all of the other counties, based on their part growth rates. For example, because Fort Bend County experienced rapid growth earlier than other suburban counties, new growth there will begin to be in part a redevelopment process first among the suburban counties, and thus the Fort Bend growth rate will decelerate earlier than in some of the other suburban counties. An important part of the redevelopment process is that it allows land use densities to significantly increase, consistent with land becoming more expensive. For example, the entire Galleria area which is now the second densest employment center formerly consisted of small single family houses.

A particular caveat to all long range forecasts for Houston is that, at some point, the Petroleum age will begin to end. This will clearly be very important to the Houston economic region in two ways. One is that as the petrochemical industry starts to decline, the economic shape of the area will change (in fact, Houston has already benefitted from earlier changes, as the industry has tended to concentrate in Houston even as it shrinks nationwide). Second, the Houston region may benefit from a new industry as the petroleum sector declines. What that industry will be, and how it will affect the local economy, is of course an open question. Clearly the current forecasting model is based on the current economic shape of Houston.

2. The Land Use Module

This module is a statistical process designed to adapt the results from the statistical module to current land use patterns using two steps. First, basic land use data is used to evaluate the capacity of an area for development. Second, a re-allocation model is developed and utilized to adjust the forecasts to be consistent with the development capacity of the land.

The development capacity of an area depends on two fundamental elements. One is the amount of land available for development, and the other is the intensity with which the land is employed. The SAM- Houston forecasts thus must be modulated to be consistent with the available vacant land, and to be consistent with expected future intensity of land use.

Vacant land data used in the 2010 SAM-Houston forecasts is collected from the County Appraisal District (CAD) for each of the largest five counties in the Houston region, including Brazoria, Fort Bend, Galveston, Harris, and Montgomery. The CAD data is organized by parcel. We assign each parcel to a Census tract, and calculate the developable vacant land. In doing so, we allow agricultural land as well as land coded as vacant according to the CAD to be considered vacant. In some CADs, even vacant land is given a code (i.e. listed as vacant-commercial or vacant-residential). For the forecasting purposes of SAM-Houston, however, we assumed those designations are not binding on the ultimate use to which such land is put. Instead, the SAM-Houston model allocates commercial and residential land use within each tract consistently with the patterns existing for the parcels already developed. Developable land is designated according to gross land uses, as opposed to net. This means that land use in each tract is compared to total tract land, there is not a process which designates each specific parcel to a particular land use. A model which examines past land use, and which examines differences across tracts, is used to forecast gross land use intensity and how it will increase over time.

We find that land use intensity is directly related to land utilization. That is, areas with low amounts of vacant land are also likely to utilize the available land more intensely. Thus as Houston grows, land is likely to be used more intensely than in the past, and therefore the numbers of people and employment per land area would be expected to increase. The land use intensities, however, will vary depending on the initial use. Thus vacant land will be expected to develop closest to the optimal economic intensity, while already developed land will only intensify gradually as redevelopment occurs. Thus in the central areas of Houston, inside Loop 610 for example, changes in land use density would be expected to occur more slowly than in the outlying areas since many of the changes will be due to redevelopment rather than construction on vacant land.

The result of these processes is the land use intensity pattern. Specifically, while land use intensity will increase throughout the Houston area over time, it will increase more rapidly in the outlying areas than in the interior areas. In part, this reflects that most of the change in areas near to downtown are due to redevelopment as opposed to new. On the other hand, land prices are also an important component of land use intensity. Thus, land not only near to downtown, but also near to other employment subcenters will be expected to be utilized more intensely then land farther from desirable locations. Finally, the model permits areas used more or less intensely than average to remain so, presuming that these land intensities reflect current attributes of land parcels that make them more or less attractive.

Over most of the Houston area, land use controls are not restrictive, in that development will be permitted to occur at the economically relevant level. The model, however, allows land use in the incorporated areas with restrictive land use controls to increase more slowly than elsewhere.[2] There is not currently information on the extent to which existing neighborhood deed restrictions limit land use. Our response to this phenomenon is that the current restrictions are reflected in the current land use, and thus basing future changes on the existing patterns will allow this feature of Houston to be reflected in the final outcomes.

The measurement of vacant land combined with an analysis of land use densities allows determination of the population and employment capacity of an area. The final step in this determination is to split developable capacity between population and employment. We generally allow existing land use to dictate the proportion of an area devoted to population or employment. For relatively undeveloped areas we impute patterns of land use from similarly situated areas. In addition, however, we allow the basic SAM- Houston model to alter land use proportions to the extent certain areas are developing predominately in one or the other of the two potential land uses (population or employment).

The second step in the land use module is to adapt the forecasts from the statistical model to the capacity for development. The adaptation of the statistical forecasts is accomplished by re-allocating growth that cannot be accommodated by existing vacant (developable) land. Our reallocation process starts first by keeping "overflow" population or employment, that greater than can be accommodated by existing vacant land and the appropriate intensity, within the segment of the metropolitan area, and within the distance from downtown, consistent with the underlying statistical model. That is, overflow population or employment from one Census tract is first

[2] This primarily affects the villages in the Memorial area.

allocated proportionately to other, non-overflow, tracts within the same quadrant and within a band of only a few miles. Unlike past Census tract boundaries, the boundaries for the 2000 and 2010 Census are consistent with this modelling framework. In some areas in the southwest portion of Harris County, we in addition had to push population both to the northwest, and to the southeast, as well as slightly further away from the central city than would otherwise have been indicated. This process became more intense for forecasts farther into the future, and effected Fort Bend County as well. A problem is that for some later years Fort Bend County becomes completely full, which resulted in a lower population forecasts than we had allocated in the Statistical Module. We allocated overall population out of Fort Bend proportionately to growth in all of the remaining counties.

We believe restricting forecasts from the statistical model to be consistent with the developable capacity of each Census tract provides an important "reality check" to the forecasts. At the same time, we have taken a rather conservative approach to the reallocation process. That is, we have reallocated the minimum amount of population or employment consistent with the land use model. This is because Houston has been unique among cities in re-engineering its physical structure to accommodate the desires of the population as reflected through the market.

B. The Current Population and Employment Forecasts

The SAM-Houston model produces population forecasts by decade from 2020 through 2070, for each Census tract in the Houston eight county metropolitan region. Table 1 to this document shows the individual county population forecasts, as well as the rate of growth by decade. Further,

Table 1: COUNTY-WIDE FORECASTS USED IN THE SAM-HOUSTON FORECASTING MODEL

POPULATION LEVELS BY DECADE

	Actual Population					Forecast Population					
County Totals	1970	1980	1990	2000	2010	2020	2030	2040	2050	2060	2070
Brazoria	108,232	169,388	191,526	241,373	313,166	359,931	413,043	465,198	522,543	580,466	648,568
Chambers	12,187	18,532	20,088	26,031	35,096	45,158	61,668	89,363	106,833	128,264	136,045
Fort Bend	51,576	130,330	223,907	349,652	585,375	881,810	1,088,664	1,266,259	1,426,379	1,583,410	1,755,164
Galveston	169,372	195,628	217,399	250,158	291,309	336,107	376,894	406,825	429,031	448,736	465,193
Harris	1,747,476	2,413,688	2,821,494	3,403,600	4,092,459	4,729,102	5,107,123	5,422,070	5,712,874	5,995,992	6,272,346
Liberty	33,014	47,064	52,726	70,154	75,643	116,965	159,160	202,754	226,530	256,573	274,501
Montgomery	49,478	128,445	182,200	293,768	455,746	627,921	818,653	1,017,281	1,267,089	1,579,511	1,946,063
Waller	14,286	19,846	23,520	32,663	43,205	69,564	149,446	264,763	308,334	364,387	406,903
TOTAL	2,185,621	3,122,922	3,732,860	4,667,399	5,891,999	7,166,558	8,174,650	9,134,513	9,999,612	10,937,340	11,904,782

POPULATION GROWTH RATE BY DECADE

	Actual Growth Rates				Forecast Growth Rates					
COUNTY	1980-70	1990-80	2000-1990	2010-00	2020-10	2030-20	2040-30	2050-40	2060-50	2070-60
Brazoria	56.50%	13.07%	26.03%	29.74%	14.93%	14.76%	12.63%	12.33%	11.08%	11.73%
Chambers	52.06%	8.40%	29.58%	34.82%	28.67%	36.56%	44.91%	19.55%	20.06%	6.07%
Fort Bend	152.70%	71.80%	56.16%	67.42%	50.64%	23.46%	16.31%	12.65%	11.01%	10.85%
Galveston	15.50%	11.13%	15.07%	16.45%	15.38%	12.13%	7.94%	5.46%	4.59%	3.67%
Harris	38.12%	16.90%	20.63%	20.24%	15.56%	7.99%	6.17%	5.36%	4.96%	4.61%
Liberty	42.56%	12.03%	33.05%	7.82%	54.63%	36.08%	27.39%	11.73%	13.26%	6.99%
Montgomery	159.60%	41.85%	61.23%	55.14%	37.78%	30.38%	24.26%	24.56%	24.66%	23.21%
Waller	38.92%	18.51%	38.87%	32.28%	61.01%	114.83%	77.16%	16.46%	18.18%	11.67%
TOTAL	42.88%	19.53%	25.04%	26.24%	21.63%	14.07%	11.74%	9.47%	9.38%	8.85%

to provide perspective, we provide the actual population from 1970 to 2010.

The forecasts in Table 1 are those from the Institute for Regional Forecasting (IRF), adjusted based on three other inputs. One is the statistical process from the SAM- Houston model, as the statistical results we believe capture some of the basic trends. One such change is that the IRF forecasts for Brazoria are substantially higher than here. A second input is that the IRF forecasts only go through 2040. We extended the predictions through 2070 based on general statistical trends, taking into account the basic decentralization process that has shaped Houston over several decades. Finally, there were some relatively minor adjustments based on a collaborative project with Metrostudy funded through the Harris Galveston Subsidence District, which primarily impact the 2020 forecasts but nonetheless affects all of the forecasts presented in a minor way.

Examining the pattern of historical growth in the Houston region is illustrative of some of the general forces that are captured in the statistical process which underlies the SAM-Houston model. First, Harris County has had a slower growth rate than most of the other counties most years, which represents the basic urban decentralization process. Exceptions are mainly in the small more rural counties, such as Chambers from 1980 to 1990, and Liberty from 2000 to 2010. The small counties demonstrate quite variable growth rates, partly because their small size makes factors that affect growth timing more visible. Further, the economic collapse of the 1980s is evident in the significantly lower growth rate for the entire region, despite the boom in the early part of the 1980-90 decade.

A few of the modeling challenges also are evident in the county specific forecasts. Brazoria and Galveston counties both contain portions that are integrated into the Houston economy, and which are to some extent less so. In the case of Galveston County, new growth on the island is primarily driven by vacation demand, while the mainland portion of the county reflects to a much greater extent typical suburban demand for housing. Similarly, northern Brazoria County exhibits growth patterns like other suburban areas, while growth in the southern portion is much more dependent on the petrochemical and shipping complex there.

We have briefly mentioned above that Fort Bend County begins to reach the limits of its capacity in some areas in 2020, and by 2030 the forecasts begin to be driven by capacity limits in the County as a whole. The redevelopment portion of the Land Use Module thus ends up driving the forecast growth as the supply of vacant land is predicted to be exhausted. This process also has consequences for the growth rate of Montgomery County, as the small uptick in its growth rate in 2040 and 2050 is because of overflow population out of Fort Bend. The overall pattern, however, strongly reflects the underlying economic urban growth process. The suburban areas will grow more quickly than the center, until the vacant land is fully utilized. The less dense more rural counties will grow slightly later than those closer to Houston, but will eventually also develop. All of the forecasts, however, reflect what has been the underlying growth process of Houston for virtually the entire 20^{th} and now 21rst century. At some point in time the pattern of urban growth will markedly change, but until then we believe the SAM-Houston statistical process reflects the underlying industrial shape of Houston.

C. Model Utilization and Caveats

We view the SAM-Houston forecasts as a central step in the development of planning capability in Houston for both the public and private sectors. Nonetheless, as with any population forecast, several caveats to their use are in order. First, sub-geographic forecasts are best used to indicate general trends and the existence of potential for growth, rather than specific growth estimates. That is, Census tracts that are projected to grow faster than average can generally be expected to represent good development opportunities. Whether the projected growth actually occurs depends on a host of specific factors, such as the existing infrastructure, the size of available land parcels, the activities of individual developers, or of particular public policy programs. One of the advantages of a model like the SAM-Houston forecast, however, is that it imposes a discipline on using location specific information. Specifically, if there is a strong reason to believe a particular area will experience growth sooner than another, the projected growth needs to be subtracted out of a similarly situated area elsewhere in the city.

Similarly, specific areas that are projected to grow more slowly than average may experience significant growth depending on specific factors, despite the general trend. Another important caveat is that the models underlying SAM- Houston generate a range of possible likely estimates. While we have used the most likely values in our analysis, they are sensitive to the overall projected rate of growth in the Houston metropolitan area. If Houston grows faster than expected in the overall numbers, it is an appropriate use of the model to accelerate the individual forecasts. For example, if Houston reaches the population forecast total level by 2020 that we expect in 2030, using the 2030 individual tract forecasts is better than increasing all of the 2020 forecasts by a fixed proportion.

The final element is that the SAM-Houston forecasts have been modified for the forecasting project underwritten by the Harris-Galveston Subsidence District. An important element to the forecasts developed in the context of this project has been access and accommodation with the forecasts out to 2020 by Metrostudy. The Metrostudy forecasts essentially represent a supply driven forecast, as the source of the information used to develop their projections are primarily from the perspective of real estate developers, using a variety of techniques including building permit information as well as current construction activity. The SAM-Houston model described above is essentially a demand driven model, which postulates that people will find a place to live based on their employment prospects. Clearly, as with all models, at some point the outcome of these two distinct processes needs to be the same. While the Metrostudy forecasts are generally short term, their emphasis on current activity was viewed by the implementing engineering firm as likely to be more informative than the long run forecasts of the SAM- Houston model. This view can be supported because the SAM- Houston model is not very particular about the timing of reaching a specific level of economic activity, its strength is in predicting the allocation of an activity level throughout the metropolitan region. Thus we altered the SAM- Houston forecasts to better fit some of the MetroStudy projections, especially in Fort Bend County, the source of the largest discrepancy between the two models. On the other hand, the interaction between the two models was also informative, and MetroStudy reduced their forecasts in northeast Harris County based on the statistical results of the SAM- Houston model. It is to be hoped that the combination is stronger than either model individually.

Prepared in cooperation with the Harris–Galveston Subsidence District, the Fort Bend Subsidence District, and the Lone Star Groundwater Conservation District

Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System, Texas, 1891–2009

Scientific Investigations Report 2012–5154
Revised November 2012

U.S. Department of the Interior
U.S. Geological Survey

Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System, Texas, 1891–2009

By Mark C. Kasmarek

Prepared in cooperation with the Harris–Galveston Subsidence District,
the Fort Bend Subsidence District, and
the Lone Star Groundwater Conservation District

Scientific Investigations Report 2012–5154
Revised November 2012

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012
Revised: November 2012

This and other USGS information products are available at http://store.usgs.gov/

U.S. Geological Survey
Box 25286, Denver Federal Center
Denver, CO 80225

To learn about the USGS and its information products visit http://www.usgs.gov/
1-888-ASK-USGS

Suggested citation:
Kasmarek, M.C., 2012, Hydrogeology and simulation of groundwater flow and land-surface subsidence in the northern part of the Gulf Coast aquifer system, Texas, 1891–2009: U.S. Geological Survey Scientific Investigations Report 2012–5154, 55 p. Revised November 2012.

Acknowledgments

The author thanks Robert Gabrycsh (U.S. Geological Survey, retired) and Stan A. Leake (U.S. Geological Survey) for contributing their insights and expertise on modeling and the mechanism of land-surface subsidence, as well as Jeffery W. East, Michaela R. Johnson, and Barclay W. Shoemaker (U.S. Geological Survey) for assisting with computer programming, modeling, and geographic information system applications. Mike Reedy of Freese and Nichols Inc., John Siefert of LBG-Guyton Associates, and Scott Marr from Fugro–McClelland (Southwest), Inc., provided information pertaining to historical water use, subsidence-related data, and other information helpful during the modeling process. The author also recognizes the Harris–Galveston Subsidence District, the Fort Bend Subsidence District, the Lone Star Groundwater Conservation District, the Texas Water Development Board, and the San Jacinto River Authority for their updated water-use data used in the Houston Area Groundwater Model. Finally, the author would like to thank James Rumbaugh and Doug Rumbaugh of Environmental Simulations, Inc., for their timely updates and modification to their graphical user interface used with the MODFLOW-2000 Subsidence and Aquifer-System Compaction package that made the calibration process more efficient.

Contents

Figures

Tables

Conversion Factors and Datums

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m^3)
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic foot (ft^3)	0.02832	cubic meter (m^3)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
	Flow rate	
gallon per minute (gal/min)	0.06309	liter per second (L/s)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Pressure	
pound per square foot (lb/ft^2)	0.04788	kilopascal (kPa)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter (g/cm^3)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Transmissivity*	
foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

SI to Inch/Pound

Multiply	By	To obtain
	Volume	
liter (L)	33.82	ounce, fluid (fl. oz)
liter (L)	2.113	pint (pt)
liter (L)	1.057	quart (qt)
liter (L)	0.2642	gallon (gal)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C=(°F-32)/1.8$$

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Altitude, as used in this report, refers to distance above or below the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [(ft^3/d)/ft^2] ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System, Texas, 1891–2009

By Mark C. Kasmarek

Abstract

In cooperation with the Harris–Galveston Subsidence District, Fort Bend Subsidence District, and Lone Star Groundwater Conservation District, the U.S. Geological Survey developed and calibrated the Houston Area Groundwater Model (HAGM), which simulates groundwater flow and land-surface subsidence in the northern part of the Gulf Coast aquifer system in Texas from predevelopment (before 1891) through 2009. Withdrawal of groundwater since development of the aquifer system has resulted in potentiometric surface (hydraulic head, or head) declines in the Gulf Coast aquifer system and land-surface subsidence (primarily in the Houston area) from depressurization and compaction of clay layers interbedded in the aquifer sediments.

The MODFLOW-2000 groundwater flow model described in this report comprises four layers, one for each of the hydrogeologic units of the aquifer system except the Catahoula confining system, the assumed no-flow base of the system. The HAGM is composed of 137 rows and 245 columns of 1-square-mile grid cells with lateral no-flow boundaries at the extent of each hydrogeologic unit to the northwest, at groundwater divides associated with large rivers to the southwest and northeast, and at the downdip limit of freshwater to the southeast. The model was calibrated within the specified criteria by using trial-and-error adjustment of selected model-input data in a series of transient simulations until the model output (potentiometric surfaces, land-surface subsidence, and selected water-budget components) acceptably reproduced field measured (or estimated) aquifer responses including water level and subsidence. The HAGM-simulated subsidence generally compared well to 26 Predictions Relating Effective Stress to Subsidence (PRESS) models in Harris, Galveston, and Fort Bend Counties. Simulated HAGM results indicate that as much as 10 feet (ft) of subsidence has occurred in southeastern Harris County. Measured subsidence and model results indicate that a larger geographic area encompassing this area of maximum subsidence and much of central to southeastern Harris County has subsided at least 6 ft. For the western part of the study area, the HAGM simulated as much as 3 ft of subsidence in Wharton, Jackson, and Matagorda Counties. For the eastern part of the study area, the HAGM simulated as much as 3 ft of subsidence at the boundary of Hardin and Jasper Counties. Additionally, in the southeastern part of the study area in Orange County, the HAGM simulated as much as 3 ft of subsidence. Measured subsidence for these areas in the western and eastern parts of the HAGM has not been documented.

Introduction

The availability of groundwater for municipal, industrial, and agricultural uses, as well as the potential subsidence associated with groundwater use, has been of concern in the Houston, Texas, area for decades (Lang and Winslow, 1950; Doyel and Winslow, 1954; Wood, 1956; Wood and others, 1963; Wood and Gabrysch, 1965; Jorgenson, 1975; Gabrysch and Bonnett, 1975; Gabrysch, 1982). In 2004, in cooperation with Texas Water Development Board and Harris–Galveston Coastal Subsidence District (now known as the Harris–Galveston Subsidence District), the U.S. Geological Survey (USGS) developed a groundwater flow model referred to as the "Northern Gulf Coast Groundwater Availability Model" (GAM) (Kasmarek and Robinson, 2004), which simulated the potentiometric surface (hydraulic head, or head) and clay compaction in the main water-bearing units of the Gulf Coast aquifer system from 1891 to 2000. Because areal distribution of groundwater withdrawals has changed in the study area (and subsequently, areas undergoing land-surface subsidence as a result) since 2000, a need was identified by water managers in the greater Houston area to update the GAM (Kasmarek and Robinson, 2004) to more accurately reflect recent (2009) conditions. Accordingly, the USGS, in cooperation with the Harris–Galveston Subsidence District (HGSD), the Fort Bend Subsidence District (FBSD), and the Lone Star Groundwater Conservation District (LSGCD), prepared a groundwater model of the Houston area, referred to hereinafter as the Houston Area Groundwater Model (HAGM). The objective of the HAGM is to accurately simulate and provide reliable, timely data on groundwater availability and land-surface subsidence in the Houston area through 2009. 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. The previous model (GAM) simulated groundwater flow in the Chicot and Evangeline aquifers and in parts of the Burkeville confining unit and Jasper aquifer that contain freshwater (Kasmarek and Robinson, 2004, figs. 20 and 21) and simulated land-surface subsidence in the Chicot and Evangeline aquifers. Like the GAM, the HAGM simulates groundwater flow in the Chicot and Evangeline aquifers and parts of the Jasper aquifer and Burkeville confining unit, but unlike the GAM the HAGM also simulates subsidence in the Jasper aquifer and the Burkeville confining unit.

Purpose and Scope

The purpose of this report is to describe the hydrogeology and simulation of groundwater flow and land-surface subsidence in the northern part of the Gulf Coast aquifer system in the HAGM study area (fig. 1). Additionally, this report documents changes made to the previous model (GAM), the parent model of the HAGM. For this report, “predevelopment” refers to conditions prior to 1891, and “postdevelopment” refers to 1891–2009. The hydrogeologic units, hydraulic properties, flow conditions, and development (groundwater withdrawals) of the HAGM are based on available information and have been modified from the original GAM as necessary. The hydrogeologic units from land surface downward are the Chicot aquifer, Evangeline aquifer, Burkeville confining unit, Jasper aquifer, and Catahoula confining system. Little mention of the Catahoula confining system is included because it was not simulated in the model. Groundwater flow was simulated for parts of the hydrogeologic units that contain freshwater.

Previous Studies

The Gulf Coast aquifer system in the Houston region has been extensively studied. Nine previous groundwater-flow-modeling studies, including two that simulated land-surface subsidence, have been completed in all or parts of the HAGM study area. From the earliest to most recent, the models were authored by Wood and Gabrysch (1965); Jorgensen (1975); Meyer and Carr (1979); Trescott (1975); Espey, Huston and Associates, Inc. (1982); Carr and others (1985); LBG-Guyton and Associates (1997); Kasmarek and Strom (2002); and Kasmarek and Robinson (2004). LBG-Guyton and Associates (1997) were the first to use the USGS groundwater-flow model MODFLOW to simulate water levels (heads) in the Houston area (McDonald and Harbaugh, 1988; Harbaugh and McDonald, 1996).

The first model to simulate land-surface subsidence is known as the Predictions Relating Effective Stress to Subsidence (PRESS) model, which uses a modified version of the compaction (COMPAC) code developed by Helm (1975; 1976a, b; 1978). A model of land-surface subsidence (Fugro–McClelland [Southwest], Inc., 1997) was designed to be used with, but was not part of, the LBG-Guyton Associates (1997) groundwater-flow model. Similar to the model by Espey, Huston and Associates, Inc. (1982), the model by Fugro–McClelland (Southwest), Inc. (1997), used the PRESS code to simulate land-surface subsidence. The simulated water-level declines from the LBG-Guyton Associates (1997) groundwater-flow model were used as input data for PRESS models at 22 separate sites in the Houston area. Kasmarek and Strom (2002) and Kasmarek and Robinson (2004) used MODFLOW (Harbaugh and McDonald, 1996) to simulate groundwater flow in the Chicot and Evangeline aquifers of the Houston–Galveston region and the northern part of the Gulf Coast aquifer system, respectively, and the Interbed-Storage (IBS) package (Leake and Prudic, 1991) was used to simulate clay compaction and storage in the aquifers. Additional summary information about the previous models described in this section is presented in Kasmarek and Robinson (2004).

Description of Study Area for the Houston Area Groundwater Model

The HAGM study area (fig. 1) includes all or parts of 38 counties in southeastern Texas. The HAGM area is a gently sloping coastal plain, and land-surface elevations are topographically highest along the northwestern boundary. The vegetation in the northern parts of the HAGM area generally is composed of hardwood and pine forests, but as land-surface altitude decreases toward the coast, the vegetation becomes increasingly dominated by shrubs and grasses. Numerous constructed lakes and reservoirs are in the HAGM area, but those surficial water bodies generally only influence the water table on a local scale. The Gulf of Mexico and Galveston Bay have a large effect on the downdip groundwater-flow system and climate of the area. Winters in the HAGM area are mild with few days of freezing temperatures. During winter, moisture-laden Pacific and Canadian air masses produce regionally extensive bands of moderate rainfall. Summers are hot with high relative humidity, and prevailing winds are from the south to southwest (Kasmarek and Robinson, 2004). During summer, atmospheric convective cells can produce rates of precipitation from light to extreme (0.01 inches [in.] per hour to 2.0 in. per hour or more) (Federal Aviation Agency, 2007). Infrequently, moisture-laden tropical air masses produce light to extreme rates of precipitation with a reported rate of 38.8 in. being recorded from June 5 to June 9, 2001, related to Tropical Storm Allison (National Oceanic and Atmospheric Administration, 2012a). The average annual rainfall for the greater Houston area is 47.84 in., and the average annual temperature is about 68.8 degrees Fahrenheit (National Oceanic and Atmospheric Administration, 2012).

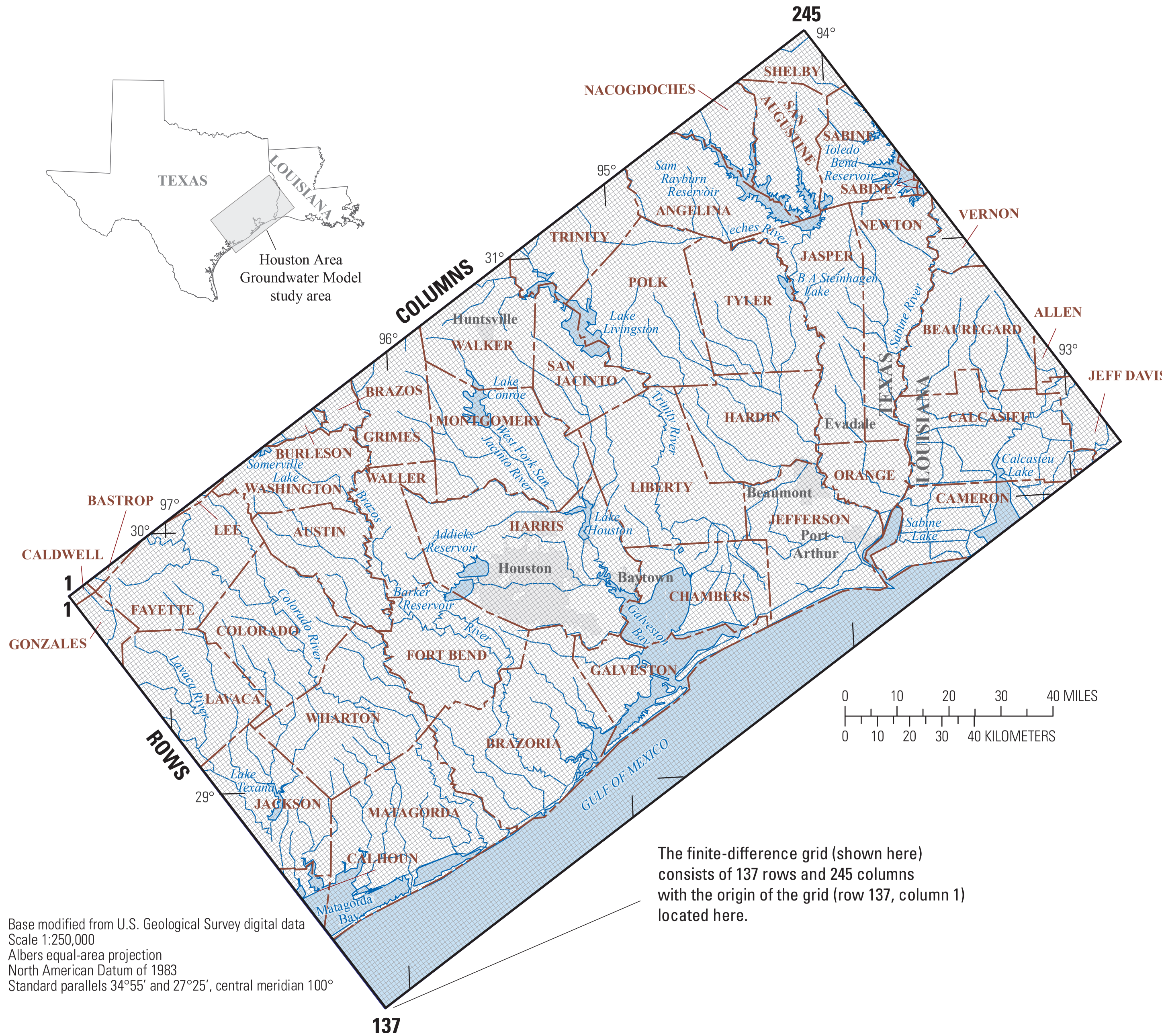


Figure 1. Location of the Houston Area Groundwater Model study area and finite-difference grid, southeastern Texas and southwestern Louisiana.

Hydrogeology

In a generalized conceptual model of the Gulf Coast aquifer system, the fraction of precipitation that does not evaporate, transpire through plants, or run off the land surface to streams enters the groundwater-flow system in topographically high updip outcrop areas of the hydrogeologic units in the northwestern part of the system. Most precipitation infiltrating into the saturated zone flows relatively short distances through shallow zones and then discharges to streams. The remainder of the water flows to intermediate and deep zones of the system southeastward of the outcrop areas where it is discharged by wells (in the developed system) and by upward leakage in topographically low areas near or along the coast (in both predevelopment and postdevelopment, but appreciably less in postdevelopment). Near the coast and at depth, saline water is present. The saline water causes less-dense freshwater that has not been captured and discharged by wells to be redirected upward as diffuse leakage to shallow zones of the aquifer system and ultimately to be discharged to coastal water bodies. Because groundwater flow was simulated in the HAGM only as far as the downdip limit of freshwater, only the parts of the hydrogeologic units containing freshwater are described in this report (Kasmarek and Robinson, 2004).

Hydrogeologic Units and Geologic Setting

The thicknesses of the four stratigraphic units used in the HAGM coincide with the GAM of Kasmarek and Robinson (2004) and originated from Strom and others (2003c). From land surface downward, the Chicot aquifer, the Evangeline aquifer, the Burkeville confining unit, the Jasper aquifer, and the Catahoula confining system are the hydrogeologic units of the Gulf Coast aquifer system (fig. 2), as described by Baker (1979, 1986) and by Ashworth and Hopkins (1995). In general, where the hydrogeologic units crop out, they do so parallel to the coast and thicken downdip to the southeast with the older units having a greater dip angle (fig. 2). The correlation of hydrogeologic units with stratigraphic units is shown in figure 3. The Chicot aquifer comprises (youngest to oldest) the alluvium, Beaumont Formation, Montgomery Formation, Bentley Formation, and Willis Formation. The Evangeline aquifer comprises (youngest to oldest) the Goliad Sand and the upper part of the Fleming Formation. The Burkeville confining unit consists entirely of the Fleming Formation. The Jasper aquifer comprises (youngest to oldest) the lower part of the Fleming Formation throughout its subsurface extent and the upper part of the Catahoula Sandstone in its outcrop and updip parts (fig. 3). The basal unit for this report is the Catahoula confining system, which comprises the Catahoula Sandstone and, downdip, the Anahuac and Frio Formations (Kasmarek and Robinson, 2004).

The updip limit of the Chicot aquifer is an undulating boundary approximately parallel to the coast and extending as far north as Lavaca, Colorado, Austin, Waller, Grimes, Montgomery, San Jacinto, Polk, Tyler, Jasper, and Newton Counties (fig. 4). To the southeast, the freshwater part of the aquifer extends beneath the Gulf of Mexico. The altitude of the top of the Chicot aquifer in the HAGM study area approximates the land-surface altitude and ranges from the North American Vertical Datum of 1988 (NAVD 88, hereinafter, datum) at the coast to as much as 445 feet (ft) above datum at its updip limit (Kasmarek and Robinson, 2004, fig. 9). The altitude of the base of the Chicot aquifer in the HAGM study area (Kasmarek and Robinson, 2004, fig. 10) ranges from more than 1,500 ft below Datum southeast of the coast to more than 420 ft above Datum in the outcrop area and varies locally because of numerous salt domes in the study area (Kasmarek and Robinson, 2004, fig. 27). The altitude of the base of the Chicot aquifer was constructed from hydrogeologic digital data of Strom and others (2003a). The original cumulative clay thickness of the Chicot aquifer (Kasmarek and Robinson, 2004, fig. 12) was subtracted from aquifer thickness to construct cumulative sand thickness (Kasmarek and Robinson, 2004, fig. 13).

The updip limit of the Evangeline aquifer is an undulating boundary approximately parallel to the coast and extending as far north as Lavaca, Fayette, Austin, Washington, Grimes, Montgomery, Walker, San Jacinto, Polk, Tyler, Jasper, and Newton Counties (fig. 5). The downdip limit of freshwater is approximately coincident with the coast. The altitude of the top of the Evangeline aquifer in the HAGM study area ranges from more than 1,440 ft below datum to as much as 469 ft above datum at its updip limit (Kasmarek and Robinson, 2004, fig. 15). The altitude of the base of the Evangeline aquifer in the HAGM study area (Kasmarek and Robinson, 2004, fig. 16) ranges from more than 5,300 ft below datum at the coast to 430 ft above datum in the outcrop area and varies locally because of numerous salt domes (Kasmarek and Robinson, 2004, fig. 27). The base of the Evangeline aquifer transgresses the stratigraphic boundary between the Goliad Sand and the Fleming Formation. (This transgression is not shown in the section depicted in figure 2, as only outcropping stratigraphic units are shown.) The altitude of the base of the Evangeline aquifer is presented in Strom and others (2003b). The original cumulative clay thickness of the Evangeline aquifer (Kasmarek and Robinson, 2004, fig. 18) is from Gabrysch (1982, fig. 37) and was subtracted from aquifer thickness to construct cumulative sand thickness (Kasmarek and Robinson, 2004, fig. 19).

The updip limit of the Burkeville confining unit is an undulating boundary approximately parallel to the coast and extending as far north as Lavaca, Fayette, Austin, Washington, Grimes, Montgomery, Walker, San Jacinto, Polk, Tyler, Jasper, and Newton Counties (fig. 6). The Burkeville confining unit lies stratigraphically below the Evangeline aquifer and above the Jasper aquifer (fig. 2) and restricts flow between the Evangeline and Jasper aquifers because of its relatively large percentage of silt and clay compared to the percentages of the adjacent aquifers (Baker, 1979). Southeast of the

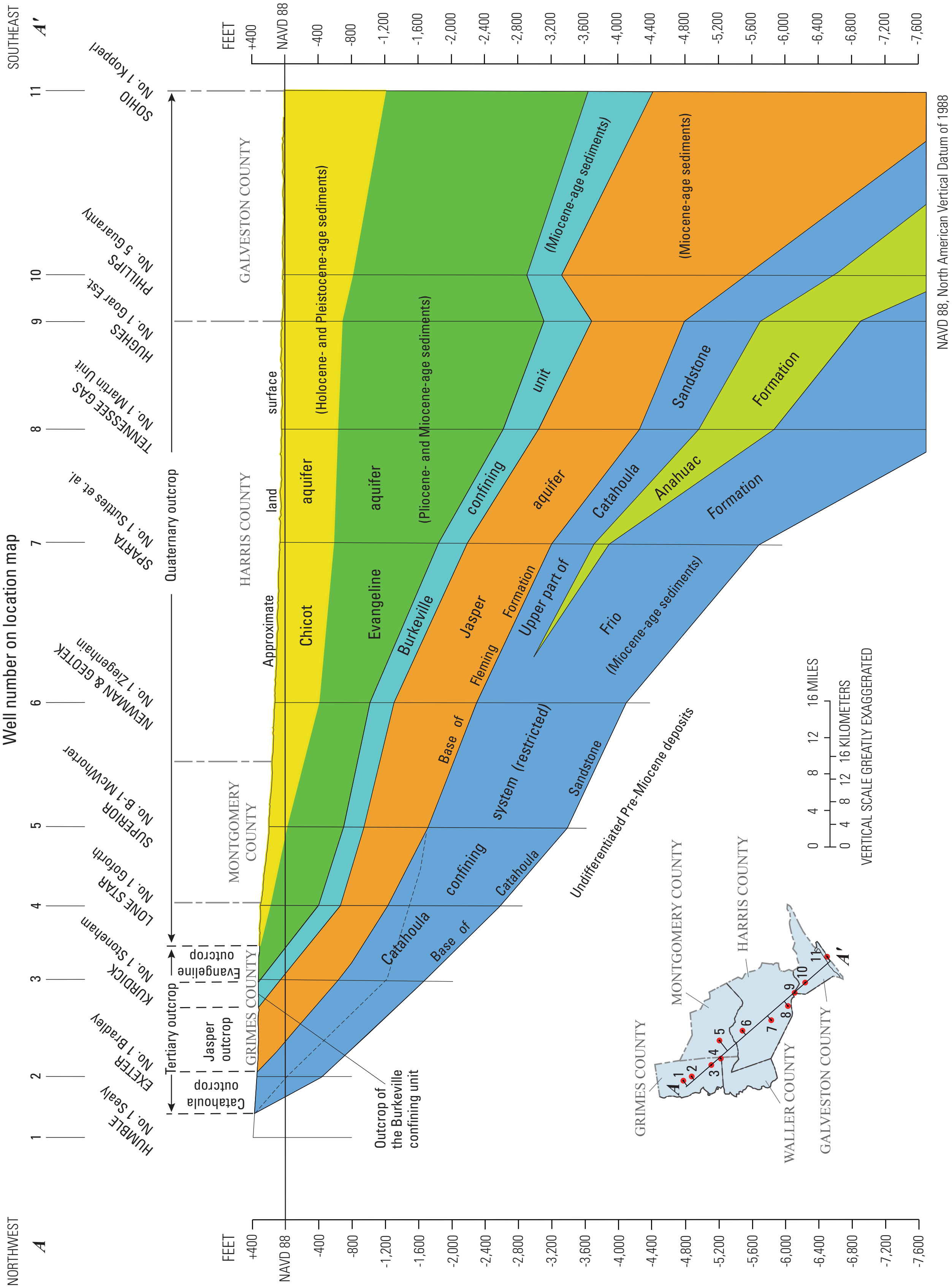


Figure 2. Hydrogeologic section of the Gulf Coast aquifer system in Harris County and adjacent counties, Texas.

Geologic (stratigraphic) units			Hydrogeologic units	Model layer
System	**Series**	**Formation**	**Aquifers and confining units**	
Quaternary	Holocene	Alluvium	Chicot aquifer	1
	Pleistocene	Beaumont Formation		
		Montgomery Formation		
		Bentley Formation		
		Willis Formation		
Tertiary	Pliocene	Goliad Sand	Evangeline aquifer	2
	Miocene	Fleming Formation	Evangeline aquifer; Burkeville confining unit; Jasper aquifer	2; 3; 4
		Oakville Sandstone	Jasper aquifer	4
		Catahoula Sandstone	Jasper aquifer; Catahoula confining system	
		Anahuac Formation[1]	Catahoula confining system	
		Frio Formation[1]		

[1]Present only in subsurface.

Figure 3. Correlation of stratigraphic and hydrogeologic units in the Houston Area Groundwater Model study area.

downdip limit of freshwater (fig. 6), this unit is considered (for HAGM simulation purposes) a no-flow unit that prevents diffuse upward leakage of saline water from the Jasper aquifer. In updip areas of the Burkeville confining unit (fig. 6), the sediments are slightly more transmissive and thus able to supply small quantities of water for domestic use. In the outcrop area, the altitude of the top of the Burkeville confining unit is equal to the land-surface altitude, and in the subcrop area, the top of the Burkeville confining unit is coincident with the base of the Evangeline aquifer. The altitude of the base of the Burkeville confining unit is coincident with the top of the Jasper aquifer and varies locally because of the numerous salt domes in the area (Kasmarek and Robinson, 2004, fig. 27).

The updip limit of the Jasper aquifer is an undulating boundary approximately parallel to the coast and extending as far north as Lavaca, Gonzales, Fayette, Washington,

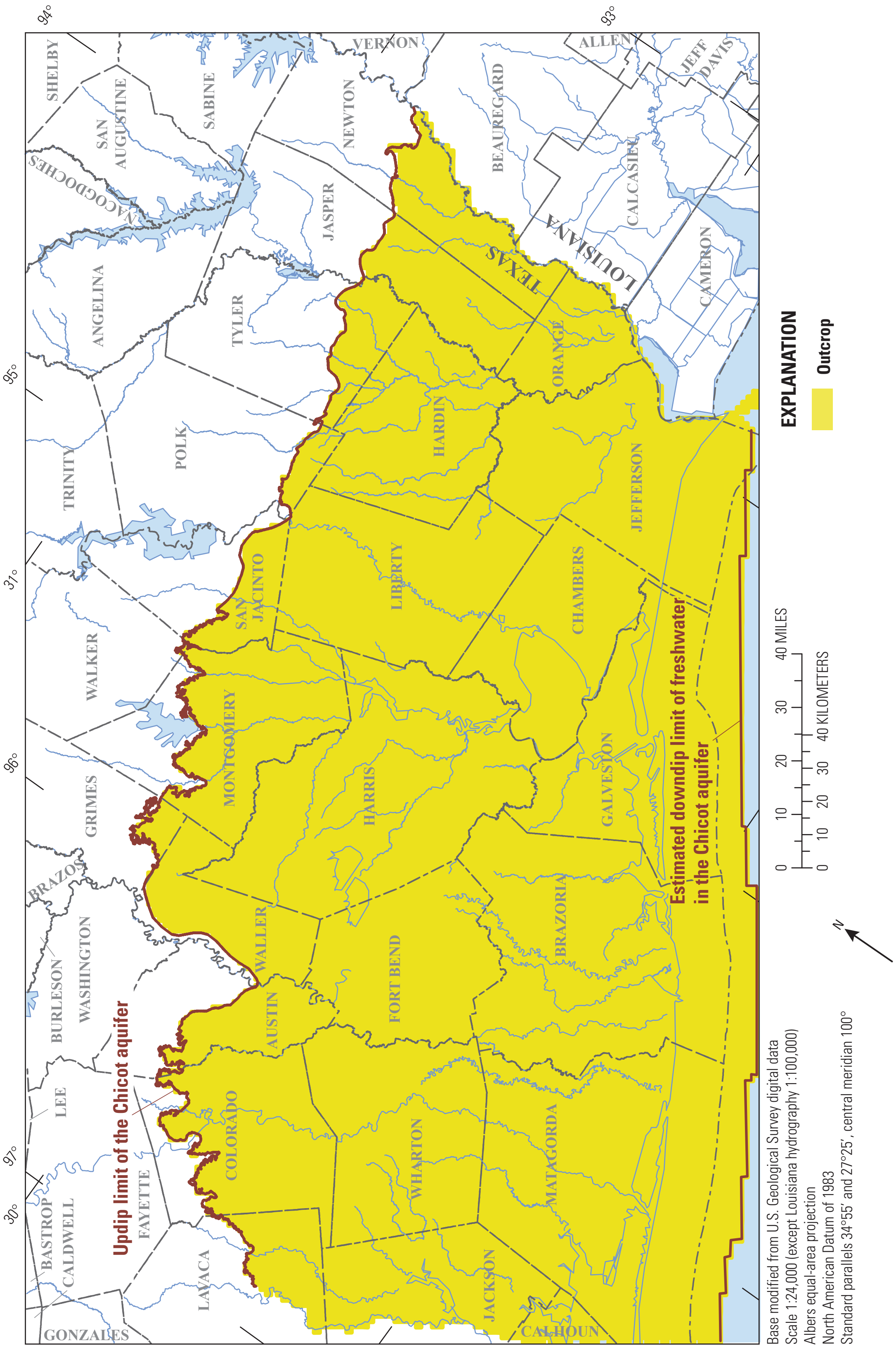


Figure 4. Extent and outcrop area of the Chicot aquifer in the Houston Area Groundwater Model study area.

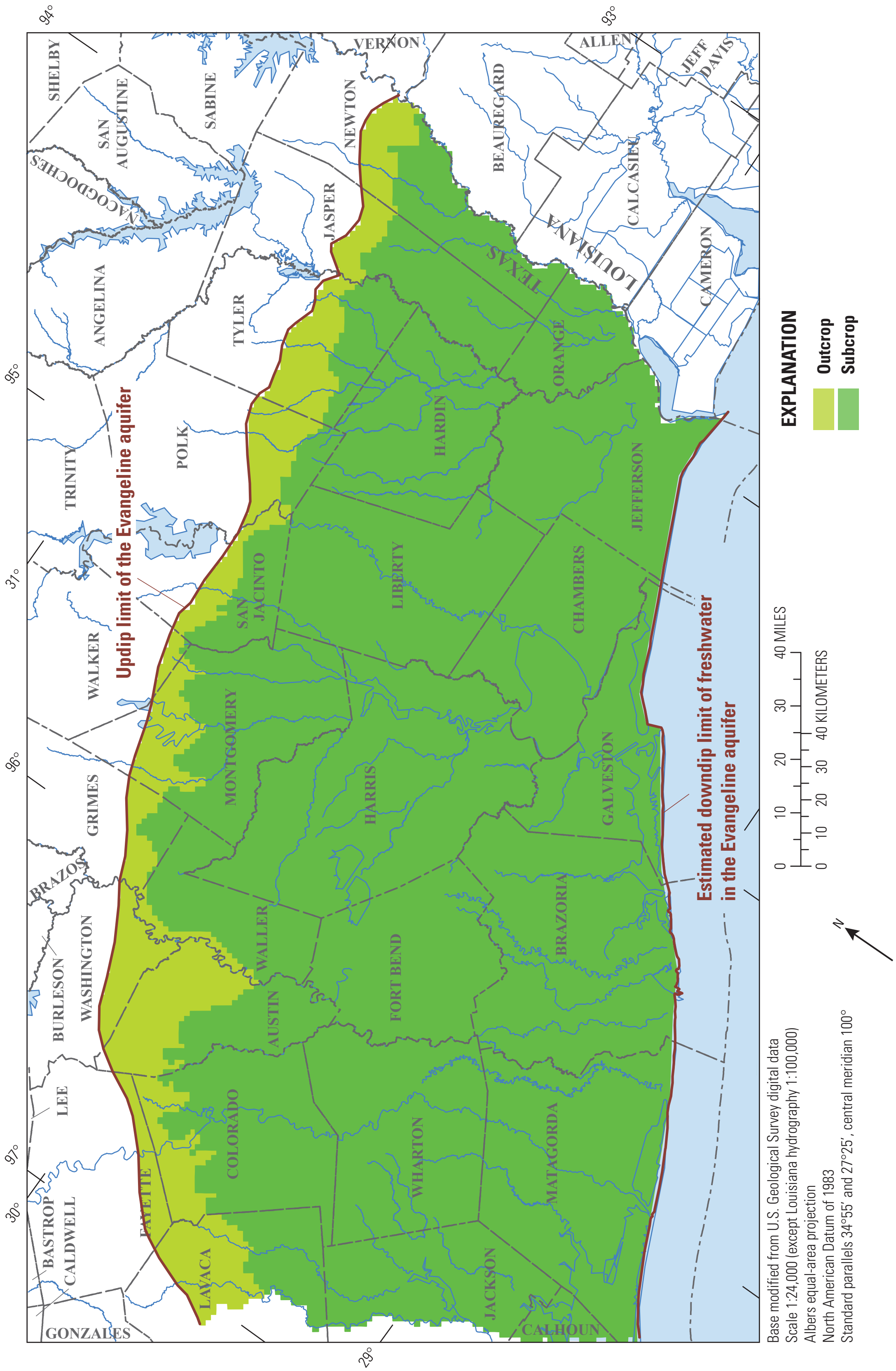


Figure 5. Extent, outcrop area, and subcrop area of the Evangeline aquifer in the Houston Area Groundwater Model study area.

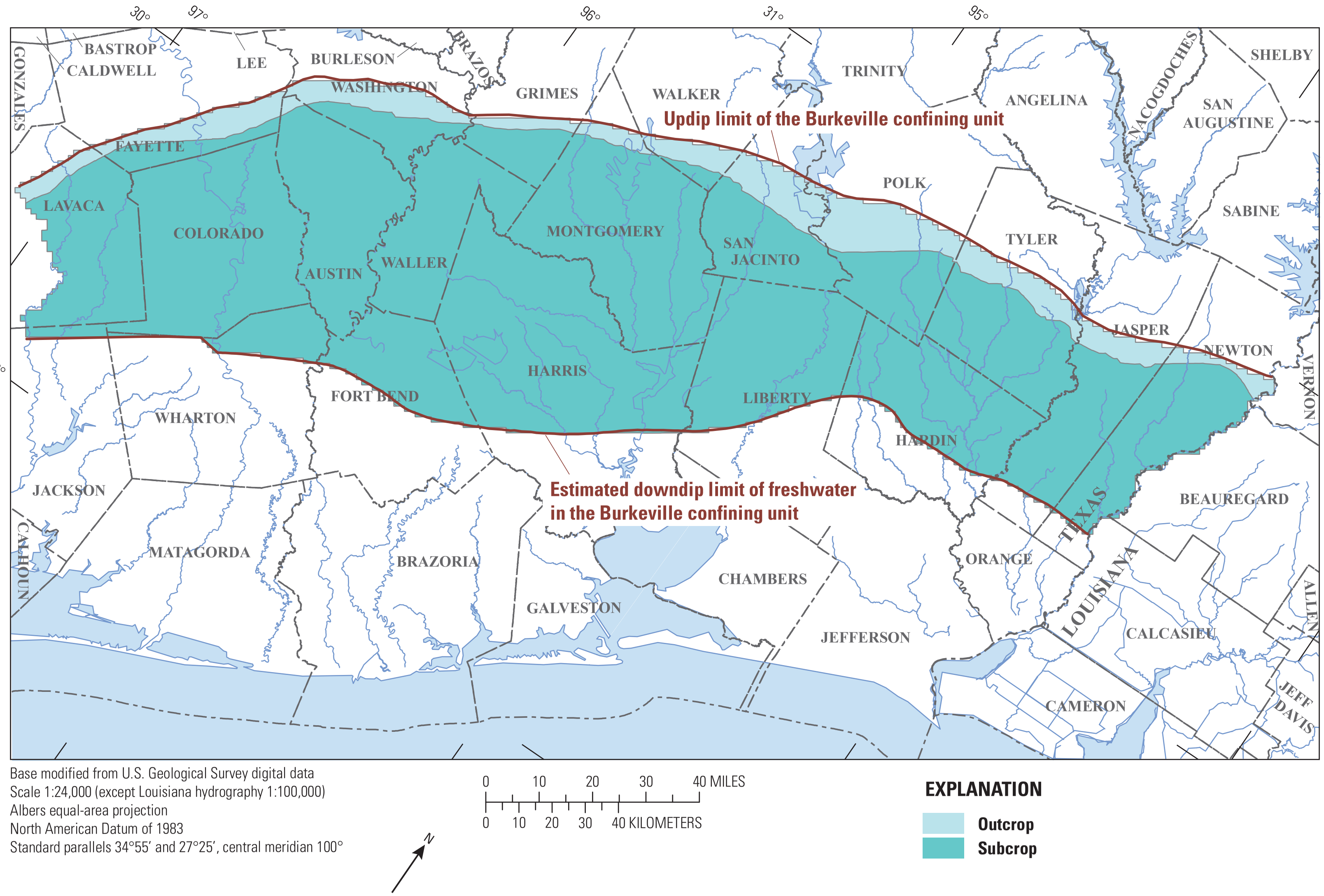


Figure 6. Extent, outcrop area, and subcrop area of the Burkeville confining unit in the Houston Area Groundwater Model study area.

Brazos, Grimes, Walker, Trinity, Polk, Tyler, Angelina, Jasper, Newton, and Sabine Counties (fig. 7). Southeast of the downdip limit of freshwater, this unit is considered (for HAGM simulation purposes) a no-flow unit that prevents diffuse upward leakage of saline water. The altitude of the top of the Jasper aquifer in the HAGM study area ranges from less than 2,800 ft below datum to about 900 ft above datum at its updip limit (Kasmarek and Robinson, 2004, fig. 22). The altitude of the base of the freshwater part of the Jasper aquifer (Kasmarek and Robinson, 2004, fig. 23) ranges from about 3,800 ft below datum near the downdip limit of freshwater to about 500 ft above datum in the outcrop area and varies locally because of numerous salt domes (Kasmarek and Robinson, 2004, fig. 27). The base of the Jasper aquifer in updip areas transgresses the stratigraphic boundary between the Fleming Formation and the Catahoula Sandstone (figs. 2 and 3). Strom and others (2003c) estimated the altitudes of the top and base of the Jasper aquifer and evaluated the thickness of the aquifer (Kasmarek and Robinson, 2004, fig. 24). The original cumulative clay thickness of the Jasper aquifer (Kasmarek and Robinson, 2004, fig. 25) was subtracted from aquifer thickness to construct the cumulative sand thickness (Kasmarek and Robinson, 2004, fig. 26). The basal unit for the HAGM (fig. 2) is the Catahoula confining system, which comprises the Catahoula Sandstone and, downdip, the Anahuac and Frio Formations. The Jasper aquifer is underlain by the Catahoula confining system, which is composed mostly of clay or tuff. The Catahoula confining system impedes substantial exchange of water between the Jasper aquifer and underlying units (Baker, 1986).

The paleodepositional environment of the sediments that formed the Gulf Coast aquifer system was a fluvial-deltaic or shallow-marine environment that produced interlayered, discontinuous sequences of clay, silt, sand, and gravel (Kasmarek and Robinson, 2004). (In this report, the term “sand” refers to coarse-grained sand and gravel sediments, whereas “clay” refers to fine-grained sediments including clay and silt.) Changes in land-surface altitudes related to naturally occurring land-surface subsidence of the depositional basin and sea-level transgressions and regressions created cyclical sedimentation facies. During periods when the sea level declined, fluvial deltaic processes deposited continental sediments, but as the sea level rose, the deposited continental sediments were reworked, and marine sediments were deposited. Because of this complex depositional process, the facies alternate cyclically from the predominantly continental sediments that compose the aquifers to the predominantly marine sediments that compose the confining units and clay layers within aquifers; therefore, the Gulf Coast aquifer system has a high degree of heterogeneity in both lateral and vertical extents (Sellards and others, 1932).

Normal growth faults are common throughout the unconsolidated sediments of the HAGM study area, and traces of some of these faults have been mapped and named. Based on the study of well logs and seismic-line data, these faults have been delineated to depths of 3,000–12,000 ft below land surface (Verbeek and others, 1979). The presence of most of these faults is associated with natural geologic processes. The scale of fault movement is insufficient to completely offset entire hydrogeologic units; however, if an offset results in the juxtaposition of relatively more permeable sediments against relatively less permeable sediments, the rate and direction of groundwater flow could be affected. Although growth faults are common in the study area, the exact locations and frequency with which associated offsets appreciably affect groundwater flow is unknown. Because the distribution and magnitude of such occurrences in the study area are unknown, accounting for them in the HAGM was not possible. Numerous salt domes originating from the Jurassic-age Louann Salt have risen through the overlying strata (Halbouty, 1967) and have been mapped in the HAGM area (Beckman and Williamson, 1990). In some areas, the salt domes have penetrated the aquifers. The upward intrusions of the salt domes decrease the thickness of the adjacent aquifer sediments and radially alter the prevailing hydraulic characteristics and flow paths in the adjacent aquifer sediments. These widely distributed salt domes increase the heterogeneity of the hydraulic characteristics of the aquifers (Kasmarek and Robinson, 2004).

Hydraulic Properties

Carr and others (1985) estimated transmissivity and storativity of the Chicot and Evangeline aquifers from simulation and are approximately the same as that used in the HAGM. Estimated transmissivity of the Chicot aquifer ranged from about 3,000 to about 50,000 square feet per day (ft^2/d), and storativity ranged from about 0.0004 to 0.1(dimensionless). Estimated transmissivity of the Evangeline aquifer ranges from about 3,000 to about 15,000 ft^2/d, and storativity ranged from about 0.00005 to 0.1. For both aquifers, the simulations indicated that the larger storativities are in the updip outcrop areas that are under water-table conditions; the smaller storativities are in downdip areas that are under confined conditions. Baker (1986) estimated transmissivity of the Jasper aquifer from simulation for an area coincident with most of the Jasper aquifer in the HAGM area; the transmissivity of the Jasper aquifer simulated in that study ranged from less than 2,500 to about 35,000 ft^2/d. Wesselman (1967) estimated transmissivity for all three aquifers and storativity for the Chicot and Evangeline aquifers from aquifer tests in Jasper, Newton, Orange, and Hardin Counties. Transmissivities of the Chicot aquifer ranged from 12,300 to 68,000 ft^2/d; the Evangeline aquifer, 2,130 to 14,800 ft^2/d; and the Jasper aquifer, 1,070 to 14,000 ft^2/d. Wesselman (1967) also estimated storativities of the Evangeline aquifer ranging from 0.00063 to 0.0015 and of the Jasper aquifer ranging from 0.000382 to 0.00119. Strom and others (2003c) reported storativities for the Jasper aquifer as large as 0.2. Several other previous studies (for example Jorgensen, 1975) estimated transmissivity in aquifers for parts of counties in the HAGM study area; those estimates generally are within the ranges listed above.

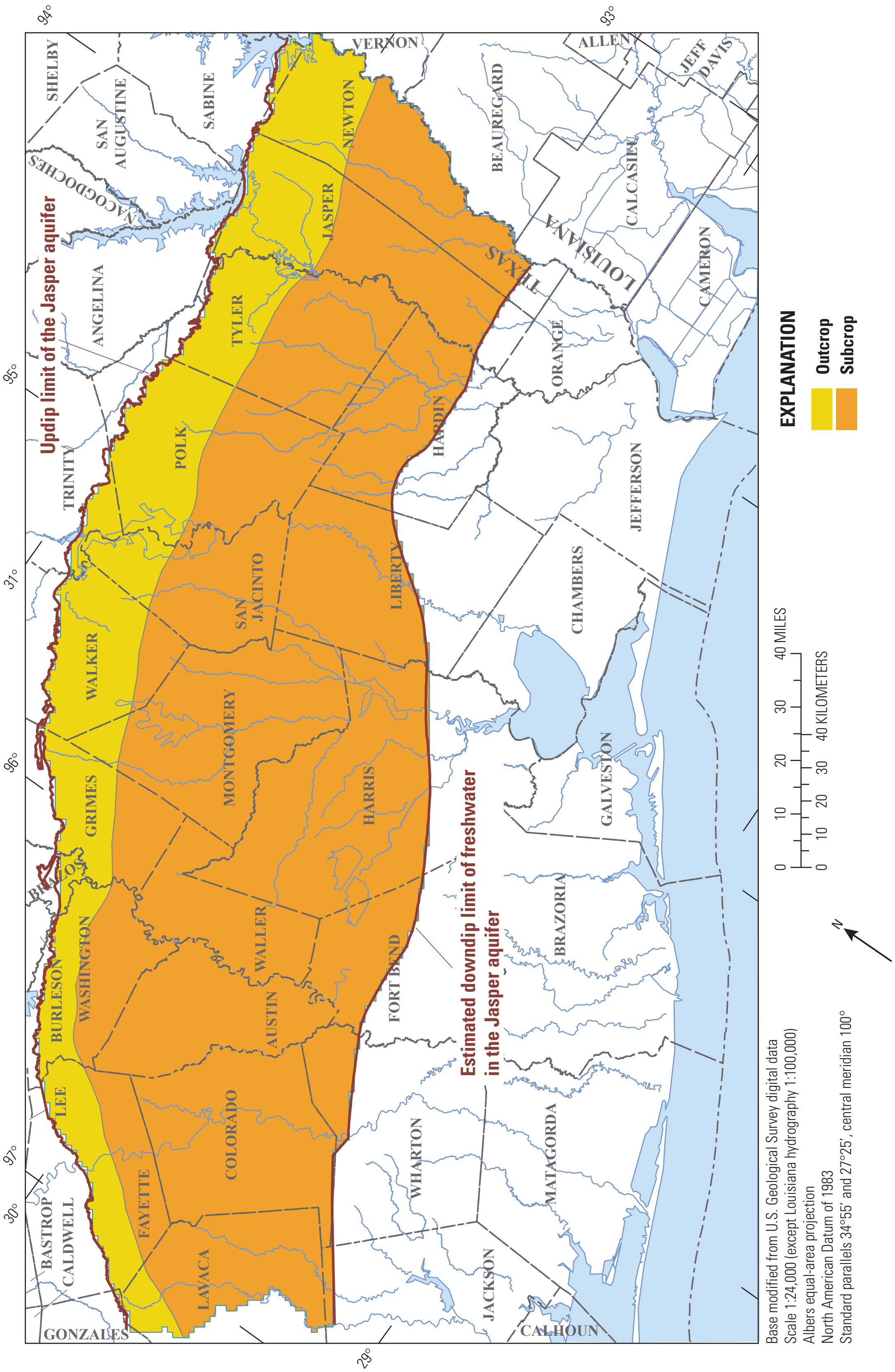


Figure 7. Extent, outcrop area, and subcrop area of the Jasper aquifer in the Houston Area Groundwater Model study area.

The transmissivity of an aquifer is equal to the hydraulic conductivity multiplied by the thickness of the aquifer (Freeze and Cherry, 1979, p. 59); “hydraulic conductivity” is used extensively in this report. Initial transmissivity distributions for the aquifers were constructed with data from Wesselman (1967), Carr and others (1985), Baker (1986), and Kasmarek and Strom (2002) by using geographic information system (GIS) applications. The initial transmissivity of the Burkeville confining unit was computed by multiplying values of hydraulic conductivity representative of a midrange between silty sand and marine clay (average of 0.01 foot per day [ft/d]) (Freeze and Cherry, 1979, table 2.2, p. 29) by the areally distributed thickness of the confining unit. In this report, hydraulic conductivity refers to horizontal hydraulic conductivity, unless otherwise noted.

Groundwater Flow Conditions, Recharge, and Discharge

The uppermost parts of the Gulf Coast aquifer system (shallow zones), which include outcrop areas, are under shallow, unconfined water-table conditions. As depth increases in the aquifer system and the cumulative thicknesses of the interbedded sand and clay increase, water-table conditions transition to confined potentiometric conditions. Thus, the lowermost parts of the aquifer system (deep zones) are under confined conditions. The middle parts of the aquifer system (intermediate zones) therefore are under semiconfined conditions. Because the transition from water table to confined conditions incrementally increases with depth, assigning specific depth horizons to shallow, intermediate, and deep zones is problematic (Kasmarek and Robinson, 2004).

Assuming that groundwater flows downgradient and perpendicular to equipotential lines, simulated predevelopment potentiometric surfaces of the Chicot, Evangeline, and Jasper aquifers (Kasmarek and Robinson, 2004, figs. 62–64) confirm the generalized conceptual model of the natural groundwater-flow system. Recharge enters the system in topographically high updip outcrops of the hydrogeologic units in the northwestern parts of the HAGM study area and either flows relatively short distances discharging into topographically lower areas to features such as streams or flows longer distances southeastward through deeper zones, where it is discharged by diffuse-upward leakage in topographically low areas along coastal areas.

As first described by Tóth (1963) and summarized by Johnston (1999) relative to regional aquifer systems, natural (predevelopment) groundwater flow can be subdivided into local, intermediate, and regional flow systems. Local flow follows relatively short flow paths in shallow zones and is controlled mainly by topography. Recharge to local flow systems occurs in topographically high areas, and discharge occurs in nearby, topographically low areas. Intermediate flow moves along relatively deeper flow paths compared to local flow, with groundwater flowing from recharge areas through intermediate zones to downgradient discharge areas. Regional flow follows relatively long flow paths from regional recharge areas through deep zones to distal discharge areas such as the downgradient limits of an aquifer system. Referring to the local, intermediate, and deep flow systems of the aquifer is a basic way to explain the groundwater flow in the aquifer system, but the true nature of the flow system is more complex because of the paleodepositional environment and the stresses of groundwater withdrawals on the aquifer. Tóth (1963) noted that to assume an exact, one-to-one correspondence among local, intermediate, and regional flow systems would be an oversimplification.

If this concept of subdividing natural groundwater flow is applied to the Gulf Coast aquifer system, the implications are that an appreciable amount of the precipitation that infiltrates the subsurface (total recharge) in the relatively topographically high outcrop areas of the hydrogeologic units joins local flow systems. Thus, much of the total precipitation enters from and exits to the shallow subsurface by streams and in topographically low areas. A proportionally smaller amount of the total recharge joins intermediate flow systems, and an even smaller amount of the total recharge joins regional flow systems. Wood (1956, p. 30–33), in an early study of the availability of groundwater in the Gulf Coast region of Texas, stated that, “Within the rainfall belts of 40–50 inches per year, probably 1 inch or more of the water that enters the outcrop of the aquifers updip from the heavily pumped areas is discharged to the streams in the outcrop area as base flow or rejected recharge.”

The natural groundwater-flow system has been altered in places (the Houston area, for example) by decades of substantial and concentrated withdrawals in the Chicot and Evangeline aquifers. By 1977, water levels had declined to as much as 250 ft and 350 ft below datum in the Chicot and Evangeline aquifers, respectively (Gabrysch, 1979). Because the Chicot and Evangeline aquifers are hydraulically connected, in these areas, withdrawals have increased vertical-head gradients and have induced downward flow from local and intermediate flow systems into the regional flow system, thus capturing some flow that would have discharged naturally (Gabrysch, 1979).

Few studies that focus specifically on recharge to the system in the HAGM study area are available. For example, Baker (1986) and a study of potential recharge in the Houston area by the U.S. Geological Survey Robert K. Gabrysch [retired] and Fred Liscum [retired], U.S. Geological Survey, written commun., 1995) estimated that the recharge rate across the area ranged from 0.25 in. per year (in./yr) to 7 in./yr. A few additional studies report recharge rates within this range (Tarver, 1968; Sandeen, 1972; Loskot and others, 1982). An in-depth discussion of the results from previous recharge studies in the study area is available in Kasmarek and Robinson (2004).

Groundwater Development

Rates of recharge to and discharge from the Chicot, Evangeline, and Jasper aquifers are affected by groundwater withdrawals from those aquifers. “Predevelopment” relative to the HAGM refers to aquifer conditions before 1891 or before the aquifers were measurably stressed by groundwater withdrawals; “postdevelopment” refers to aquifer conditions after the stress of withdrawals became measurable. Initially, the principal areas of concentrated groundwater withdrawals from the aquifer system in the HAGM study area were located in Harris, Galveston, and Fort Bend Counties (the Houston area). Much of the early groundwater-use information for the area, as summarized here, is from Lang and Winslow (1950) and Wood and Gabrysch (1965).

In the area of Houston (founded in 1836), surface water was initially used to meet water-supply demands. In 1886, the first well was drilled to a depth of 140 ft and was reported as free flowing at more than 1,000 gallons per minute (gal/min) (Lang and Winslow, 1950). By 1906, groundwater withdrawals had the capacity of as much as 19 million gallons per day (Mgal/d). By 1935, withdrawals averaged 24.5 Mgal/d and by 1941 had increased to 27.2 Mgal/d. From 1941 to 1950, groundwater use more than doubled. In 1954, water released from the newly constructed Lake Houston began to be used to augment groundwater supplies. The additional surface-water supply from Lake Houston resulted in reduced groundwater withdrawals from 1954 to 1960. From the early 1960s to the mid-1970s, however, groundwater withdrawals increased at rates comparable to pre-1954 rates (Lang and Winslow, 1950). In 1975, because of increasing groundwater withdrawals and subsequent land-surface subsidence in Harris and Galveston Counties, the Harris–Galveston Coastal Subsidence District (HGCSD) was created and began to control land-surface subsidence by regulating groundwater withdrawals. In late 1976, groundwater withdrawals began to decrease in eastern Harris County because part of the demand began to be supplied by water from Lake Livingston. The policies of the newly created HGCSD resulted in decreased groundwater withdrawals in the Baytown and southeastern Harris County areas. The groundwater withdrawal rate exceeded 450 Mgal/d in 1976 and decreased to about 390 Mgal/d in the early 1980s, but the trend reversed, and by 1990, withdrawals had increased to 493 Mgal/d. A downward trend began again in the 1990s when withdrawals were about 463 Mgal/d by 1996. By 2000, withdrawals were about 895 Mgal/d (Harris–Galveston Subsidence District, 2012).

Potentiometric Surfaces and Land-Surface Subsidence

In the updip outcrop area of the Chicot aquifer and the outcrop areas of the Evangeline and Jasper aquifers and Burkeville confining unit (figs. 4–7), water-table conditions generally exist. The water table is assumed to be a subdued replica of the topography (Williams and Williamson, 1989). In outcrops of the Chicot and Evangeline aquifers in parts of Harris and Montgomery Counties, a seismic refraction investigation indicated that the water table ranges from about 10 to 30 ft below land surface (Noble and others, 1996). Hydrographs of water levels in wells screened in the water table of the Chicot and Evangeline aquifers indicate that the water levels were not influenced by increased groundwater withdrawal in the area and have remained fairly stable (Kasmarek and Robinson, 2004, fig. 28). The USGS annually has measured water levels in wells and constructed maps of potentiometric surfaces of the Chicot and Evangeline aquifers in the greater Houston area since 1977 (Gabrysch, 1979) and of the Jasper aquifer since 2000. Related to groundwater withdrawal in the HAGM study area, the 2009 report (Kasmarek, Houston, and Ramage, 2009) in this series indicates that water-level-altitude contours ranged from 250 ft below datum (hereinafter, datum) in a small area in southwestern Harris County to 200 ft above datum in central to southwestern Montgomery County in the Chicot aquifer; from 300 ft below datum in south-central Montgomery County to 200 ft above datum at the intersecting borders of Waller, Montgomery, and Grimes Counties in the Evangeline aquifer; and from 175 ft below datum in south-central Montgomery County to 250 ft above datum in east-central Grimes County in the Jasper aquifer (Kasmarek, Houston, and Ramage, 2009).

In the 1830s, before groundwater withdrawals from the aquifer system occurred in the HAGM study area, the potentiometric surfaces in the confined parts of the aquifers were higher than land surface. This was demonstrated by a well in Houston that was drilled to 140 ft and flowed at more than 1,000 gal/min. Groundwater development has caused substantial declines of as much as 350 ft below datum (Gabrysch, 1979) of the potentiometric surfaces of the aquifers (and subsequent land-surface subsidence), primarily in Harris, Galveston, and Fort Bend Counties (Kasmarek and Robinson, 2004, figs. 48 and 49). These potentiometric-surface declines in unconsolidated confined aquifers cause a decrease in hydraulic pressure that creates a load on the skeletal matrix of the aquifer (Galloway and others, 1999, p. 9). Because coarse-grained sediments (sand layers) are more transmissive and less compressible than are fine-grained sediments (clay layers), the depressurization of sand layers is relatively rapid compared to that of clay layers and causes only slight skeletal-matrix consolidation. The depressuring and subsequent dewatering of clay layers requires more time compared to that of the sand layers, however, and is dependent on the thickness of the clay layers, the hydraulic characteristics of the clay layers, and the vertical-stress load of the sediment overburden. The delayed drainage of the clay layers continues to occur until the residual excess (transient) pore pressure in the clay layers equals the pore pressure of the adjacent sand layers. Until pressure equilibrium is attained, dewatering of the clay layers continues to apply a load to the skeletal matrix of the clay layers. This loading process is similar to what occurs in the sand layers, but additionally, the reorientation of the individual clay grains occurs, becoming perpendicular to the applied vertical load (Galloway and others, 1999, p. 9). Therefore, the dewatering caused by the depressurization of the clay layers combined with clay-grain realignment reduces the porosity and groundwater-storage capacity of the clay layers, which in turn allows them to inelastically and permanently compact. More than 10 ft of land-surface subsidence has been documented in the Baytown area in southwestern Harris County (Gabrysch and Neighbors, 2005; Kasmarek, Gabrysch, and Johnson, 2009). Because of the weight (sediment load) of the overburden and the inelastic compaction characteristics of the clay layers, about 90 percent of the compaction is permanent (Gabrysch and Bonnett, 1975). Thus, when potentiometric surfaces rise and repressure compacted clay layers, there is little, if any, rebound of the land surface (Gabrysch and Bonnett, 1975). Although the compaction of one clay layer generally will not cause a noticeable decrease in the land-surface altitude, if numerous stacked clay-layer sequences (which are characteristic of the Gulf Coast aquifer system) depressure and compact, then appreciable decreases in land-surface altitude can and do occur (Gabrysch and Bonnett, 1975). A substantial amount of the total water withdrawn is derived from dewatering of the numerous clay layers of the aquifer: model simulations indicated that as much as 19 and 10 percent of the total water budget of the Chicot and Evangeline aquifers, respectively, is derived from the dewatering of the clay layers of the aquifers (Kasmarek and Strom, 2002).

Simulation of Groundwater Flow and Land-Surface Subsidence

Model Description

The finite-difference computer code MODFLOW-2000 (Harbaugh and others, 2000) was used to create and calibrate the HAGM to simulate groundwater flow and land-surface subsidence in the northern Gulf Coast aquifer system from predevelopment (1891) through 2009. The Subsidence and Aquifer-System Compaction (SUB) package designed for the MODFLOW-2000 model (Hoffman and others, 2003) was used to simulate clay compaction and storage, and thus land-surface subsidence, in the Chicot, Evangeline, and Jasper aquifers and the Burkeville confining unit. The Chicot, Evangeline, and Jasper aquifers and the Burkeville confining unit were simulated as four separate layers and discretized into two-dimensional finite-difference grids (fig. 1). By using GIS applications, model input data were georeferenced and assigned to model grid cells.

Mathematical Representation

The MODFLOW-2000 model uses finite-difference methods to solve the partial differential equation for three-dimensional movement of groundwater of constant density through heterogeneous, anisotropic porous materials. The equation can be written as follows:

$$\frac{\partial}{\partial x}\left(Kxx\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(Kyy\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(Kzz\frac{\partial h}{\partial z}\right)-W=Ss\frac{\partial h}{\partial t} \qquad (1)$$

where

K_{xx}, K_{yy}, and K_{zz} represent the hydraulic conductivity along the x, y, and z coordinate axes, which are assumed parallel to the major axes of hydraulic conductivity (Lt^{-1});
h is hydraulic head (Lt^{-1});
W is a volumetric flux per unit volume representing sources and/or sinks of water, with $W < 0.0$ for flow out of the groundwater system and $W > 0.0$ for flow in (Lt^{-1});
S_s is specific storage of the porous material (L^{-1});
L is length;
t is time; and
Lt^{-1} is length divided by time

(Harbaugh and McDonald, 1996). This equation, with specification of appropriate boundary and initial conditions, constitutes a mathematical representation of the groundwater-flow system. In this application, the aquifer system was assumed to be horizontally isotropic; thus, there was no preferred direction of hydraulic conductivity in the horizontal.

The storage coefficient (S_s) in equation 1 is particularly important in a confined and unlithified aquifer system like the Gulf Coast aquifer system. Because the aquifers do not have a rigid skeletal matrix, water is released not only from coarse-grained sediments like sand and gravel but also from fine-grained sediments like clay and silt. Therefore, the compressibility of water (S_w) is necessarily considered, computed as

$$S_w = S_{sw} \times b, \qquad (2)$$

where

S_{sw} is specific storage due to compressibility of water (L);
S_{sw} is computed as $S_{sw} = q \times g_w / E_w$ (L); and
b is thickness of the layer (L)

where

θ is porosity (dimensionless);
γ_w is unit weight of water (62.4 pounds [lb] per cubic foot [ft^3]);
E_w is the bulk modulus of elasticity of water (4.5×10^7 lb/ft^2); and
L is length (modified from Leake and Prudic, 1991).

An additional important component of the aquifer system is the compressibility of the sediment skeleton, or S_k, computed as

$$S_k = S_{sk} \times b, \quad (3)$$

where

S_{sk} is specific storage due to compressibility of water, and

b is thickness of sediments (L) (modified from Leake and Prudic, 1991).

As in equation 2, equation 3 is relevant to coarse- and fine-grained sediments, and thickness of the aquifer (b) is present. Thus, as the thickness of the aquifer increases, the storage coefficient from compressibility of water (S_w) and storage coefficient from compressibility of the sediment skeleton (S_k) correspondingly increase, providing a greater volume of water from storage in the downdip areas of the aquifers along the coast. In the Layer-Property Flow package of MODFLOW (LPF), a single combined specific storage value, $S_s = S_{sw} + S_{sk}$, is specified and multiplied by layer thickness for the case where head is above the top of a model layer (confined conditions). Where the aquifer is unconfined (head is below the top of the layer), LPF applies a value of specific yield in formulation of the equations for groundwater flow. Use of the confined storage coefficient, $S = S_s \times b$, is appropriate where compression and expansion of the aquifer skeleton and water are elastic; however, if inelastic (nonrecoverable) compaction of fine-grained sediments occurs and is important, an add-on package such as the SUB package (Hoffman and others, 2003) should be used with the no-delay interbeds option for the Gulf Coast aquifer system. For details on representing all storage properties in a model with aquifer-system compaction, see Leake and Prudic (1991).

Grid Design

The finite-difference grid (fig. 1) for the HAGM covers 33,565 square miles (mi^2) in southeastern Texas and southwestern Louisiana. The model grid was rotated 37.6 degrees clockwise so that the orientation of the model closely coincides with the natural groundwater divides, model boundaries, and predevelopment and postdevelopment flow paths. The four layers of the model together contain 134,260 grid blocks. Each layer consists of 137 rows and 245 columns. Layer 1 represents the Chicot aquifer, layer 2 the Evangeline aquifer, layer 3 the Burkeville confining unit, and layer 4 the Jasper aquifer. The grid blocks are uniformly spaced with each model cell area equal to 1 mi^2.

Boundaries

Model boundaries control where and how much water enters and exits the simulated aquifer system. The selection of model boundaries for the aquifers in this model was based on a conceptual interpretation of the flow system developed by using information reported by Meyer and Carr (1979), Carr and others (1985), Williamson and others (1990), and Strom and others (2003a, b, c). The northwestern boundaries of the three aquifers and the Burkeville confining unit are the northwestern extent of the updip outcrop sediments for each unit (Kasmarek and Robinson, 2004, figs. 8, 14, 20, 21). Northwest of these boundaries, the model grid blocks were assigned a hydraulic conductivity of zero to simulate no-flow boundaries. The downdip limit of freshwater (defined for this study as the location where the dissolved solids concentration is as much as 10,000 milligrams per liter [mg/L]) was chosen as the southeastern boundary of flow in each hydrogeologic unit. Southeast of these limits, the model grid blocks were assigned a hydraulic conductivity of zero to simulate no-flow boundaries. The location of the 10,000-mg/L line in each hydrogeologic unit was estimated from geophysical log data and from the coastward extent of freshwater withdrawals (Kasmarek and Robinson, 2004). A no-flow boundary at specified locations reflects an assumption of a stable downdip freshwater/saline-water interface. Along the coast in most of the HAGM study area, this assumption probably is valid: little or no human-induced stresses on the aquifer system in most of the coastal region likely have allowed long-term equilibrium to be established between the freshwater and the slightly more dense saline water that lies laterally adjacent to and beneath the freshwater. The southwestern and northeastern lateral boundaries for the Chicot, Evangeline, and Jasper aquifers and the Burkeville confining unit were selected to coincide with groundwater-flow divides associated with major rivers in the study area. The southwestern lateral boundary was located generally along the Lavaca River, and the northeastern lateral boundary was located in the general vicinity of the Sabine River (fig. 1). The assumption is that little lateral flow occurs across these boundaries, and thus they can reasonably be simulated as no-flow boundaries. The Catahoula confining system underlies the Jasper aquifer. The assumption is that the brackish water within the Catahoula confining system sufficiently impedes the exchange of water between the Jasper aquifer and deeper units, so the Catahoula confining system can reasonably be simulated as a no-flow base-of-system boundary.

Recharge and Discharge

The MODFLOW General-Head Boundary (GHB) package was used to simulate recharge and discharge in the outcrops of the Chicot, Evangeline, and Jasper aquifers and the Burkeville confining unit. This package allows the simulated water table of an aquifer system to function as a head-dependent flux (flow per unit area) boundary (Franke and others, 1987); that is, a condition in which the rate of flow between the water table and the adjacent deeper zone of the system is controlled by the difference between the water table (constant head) and the head in the adjacent deeper zone (which changes with model simulation time) and by the vertical hydraulic conductance between the water table and the immediately adjacent deeper zone. In interstream outcrop areas, the head differences indicate general downward flow or areas of recharge, and in stream and downdip areas along the coast, the head differences generally indicate upward flow or areas of discharge. Simulating the water table as a constant-head source (or sink) of water to the system requires an assumption that no long-term trends in the water table are indicated, as shown in the example hydrographs in Kasmarek and Robinson (2004, fig. 28). These hydrographs indicate that the water table remains stable even during documented periods of drought that occurred during 1932–34, 1938–40, 1947–48, 1950–57, and 1960–67 (State of Texas Drought Preparedness Council, 2006). Water-table-altitude data for the shallow zones of the hydrogeologic units from the model of Kasmarek and Robinson (2004) were used for HAGM model grid blocks in areas where the two models are coincident. These water-table-altitude data were originally created by using the method described by Williams and Williamson (1989) that used multiple linear regressions of depth-to-water data and topographic data to derive relations between depth to water and topography. This assumption is believed reasonable over most of the HAGM study area.

Flow between streams and the aquifer system (essentially discharge from aquifers to incised streams in outcrops) was not explicitly simulated in the model. The rationale for this approach is that the GHB package, assuming that the model is adequately calibrated, would account for stream discharge to the level of accuracy that such discharge is known. Additionally, few measured data are available on streamflow gains or losses for the major streams that flow across the outcrops of the Gulf Coast aquifer system. Because aquifer discharge to streams is not well known, such data are not particularly helpful for comparison with simulated data for purposes of calibration; there was little incentive to add more complexity to an already complex model by explicitly computing flow between streams to the aquifers. Although some additional recharge rates have recently been determined (Tarver, 1968; Sandeen, 1972; Loskot and others, 1982; Baker, 1986; and Kasmarek and Robinson, 2004), the additional complexity of including that information specifically, by substituting the GHB package with the River or Stream package and the Recharge package, was determined to be beyond the scope of this report.

Initial Conditions

Initial conditions, including heads and spatial distributions of hydraulic conductivity, leakance, sand storativity, clay storativity, and general-head boundary conductance from Kasmarek and Robinson (2004), provided the initial data before model calibration began. The leakance parameter is equivalent to vertical hydraulic conductivity divided by the vertical distance between the centers of model layers. The spatial distributions of head in each hydrogeologic unit for the initial predevelopment steady-state simulation also were coincident with Kasmarek and Robinson (2004). Additionally, the simulated values of head from the stress period associated with the year 2000 in the GAM (Kasmarek and Robinson, 2004) were consistent with the initial heads of the HAGM in year 2001. For more detailed information on the initial development of these datasets, refer to Kasmarek and Robinson (2004).

Land-Surface Subsidence and Storage in Clays

Simulation of land-surface subsidence (actually, compaction of clays) and release of water from storage in the clays of the Chicot, Evangeline, and Jasper aquifers and the Burkeville confining unit was accomplished by using the SUB package designed for use with MODFLOW-2000 by Hoffman and others (2003). As explained in Leake and Prudic (1991), effective stress is defined as the difference between geostatic pressure (overburden load) and fluid pressure (head). Head decreases in a confined aquifer do not change geostatic pressure if, as assumed in this application, water-table heads remain constant. With constant geostatic pressure, effective stress thus will increase by the same amount that heads decrease. Previous studies (Riley, 1969; Helm, 1975) indicate that compaction (or expansion) of interbedded clays is proportional, or nearly so, to change in effective stress. For sediments in confined aquifers with constant geostatic pressure, compaction also is proportional, or nearly so, to change in head. The relation is

$$\Delta b = \Delta h S_s b_o, \tag{4}$$

where

Δb is the amount of compaction or expansion (L);
Δh is the change in head (L);
S_s is the skeletal (sand and clay) component of elastic or inelastic specific storage (L^{-1});
b_o is the thickness of the interbed (L); and
L is length (modified from Leake and Prudic, 1991).

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. For the HAGM, an initial value of preconsolidation head of about 70 ft below the starting head was used.

A preconsolidation head of about 70 ft was used by Meyer and Carr (1979), Carr and others (1985), Kasmarek and Strom (2002), and Kasmarek and Robinson (2004). For the Chicot and Evangeline aquifers in the HAGM study area, the initial values of elastic- and inelastic-clay storativity were coincident with the model of Kasmarek and Robinson (2004). The initial values of elastic-clay storativity used in the HAGM for the Burkeville confining unit and the Jasper aquifer were calculated by multiplying existing GAM values of clay thickness by 1.0×10^{-6}. The initial values of inelastic-clay storativity for the Burkeville confining unit and Jasper aquifer were derived by multiplying the values of elastic-clay storativity by 100.

Withdrawals

The primary sources of updated water-use data used in the HAGM are as follows: the Harris–Galveston Subsidence District (Harris and Galveston Counties); the Fort Bend Subsidence District (Fort Bend County); and the Lone Star Groundwater Conservation District, the Texas Water Development Board, and the San Jacinto River Authority (Montgomery County). HAGM simulations were made under transient conditions from 10,000 years before 1891 through 2009 for 78 groundwater withdrawal (stress) periods of variable length (fig. 8 and table 1). Stress period 1 has a long duration without withdrawals, thereby enhancing model stability prior to actual withdrawals that began in stress period 2. For the years 1980, 1982, and 1988, monthly stress periods were applied. Substantially lower than average precipitation was recorded in the HAGM study area for those years. Monthly rather than annual stress periods allows the model to represent groundwater withdrawals on a monthly or seasonal basis if the model is used to simulate hypothetical drought scenarios in the future. Total groundwater withdrawals increased from an estimated 41 Mgal/d in 1891 to about 1,130 Mgal/d in 1976, peaked at about 1,135 Mgal/d in 1980, and varied during the next 20 years but generally trended downward to about 895 Mgal/d in 2000. Water-use data from 2001 to 2009 were compiled and provided by LBG-Guyton and Associates, and subsequently, the USGS joined these data with the GAM water-use dataset of Kasmarek and Robinson (2004). Evaluation of these data indicates that groundwater withdrawals varied from 799 Mgal/d in 2001 to 869 Mgal/d in 2009. The lowest withdrawals, 747 Mgal/d, occurred in 2007, and the highest withdrawals, 876 Mgal/d, occurred in 2005. Additional water-use data (compiled by LBG-Guyton and Associates) was combined with the GAM water-use dataset for the Evangeline and Jasper aquifers in Montgomery County for the periods 1955–2000 and 1969–2000, respectively.

Model Calibration

Before calibration began, an initial predevelopment (no withdrawals) steady-state simulation was run to obtain starting heads for the hydrogeologic units for transient calibration simulations. Periodically during calibration, predevelopment steady-state simulations were run with the most current input data to obtain starting heads for successive transient calibration simulations. The input data that were adjusted from initial values on the basis of model output from successive transient simulations were hydraulic conductivity (transmissivity divided by aquifer thickness) of the aquifers, storativity of sands, vertical hydraulic conductance (leakance) between the water table and deeper zones of each hydrogeologic unit in outcrop areas, leakance between hydrogeologic units in subcrop areas, and inelastic-clay storativity (actually, inelastic-clay-specific storage, which is multiplied by aquifer or confining unit thickness) in the Chicot, Evangeline, and Jasper aquifers and the Burkeville confining unit. Water-table heads, hydraulic conductivity, and storativity of the Burkeville confining unit, storativity of the Jasper aquifer, and temporal and spatial distributions of withdrawals were adjusted. Elastic-specific storage of clays in the Chicot and Evangeline aquifers were computed by multiplying inelastic-clay storativities by 0.01.

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. Transient model calibration comprised eight elements:

1. qualitative comparison of simulated and measured potentiometric surfaces of the Chicot, Evangeline, and Jasper aquifers for 2009 (Kasmarek, Houston, and Ramage, 2009);
2. quantitative comparison of simulated water levels and annually measured water levels of selected wells screened in the Chicot, Evangeline, and Jasper aquifers (calibration targets) by computing and evaluating the areal distribution of the root-mean-square error (RMSE) (square root of the sum of the squares of the differences between simulated and measured heads divided by the total number of calibration targets) of 497 sites for the three aquifers for 2009;
3. qualitative comparison of hydrographs of simulated and measured water levels for each aquifer;
4. quantitative comparison of simulated and measured subsidence by computation and areal distribution of the RMSE for 474 calibration target sites was performed—RMSE values were calculated by using standard GIS techniques, whereby a gridded surface of the 2000 land-surface subsidence data (Gabrysch and Neighbors, 2005) was intersected with the simulated subsidence data for model cells coinciding with the locations of the 474 calibration targets, providing a spatial distribution of RMSE;
5. qualitative comparison of simulated subsidence from the 1890s through 2000 was compared to measured cumulative long-term land-surface subsidence from 1906 to 2000 (Gabrysch and Neighbors, 2005);
6. qualitative comparison of simulated predevelopment potentiometric surfaces of the aquifers to conceptualized configurations of the predevelopment surfaces based on hydrogeologic knowledge of the Gulf Coast aquifer system;
7. quantitative comparison of simulated water-budget components—primarily recharge and withdrawal rates. The simulated recharge rate was compared to the range

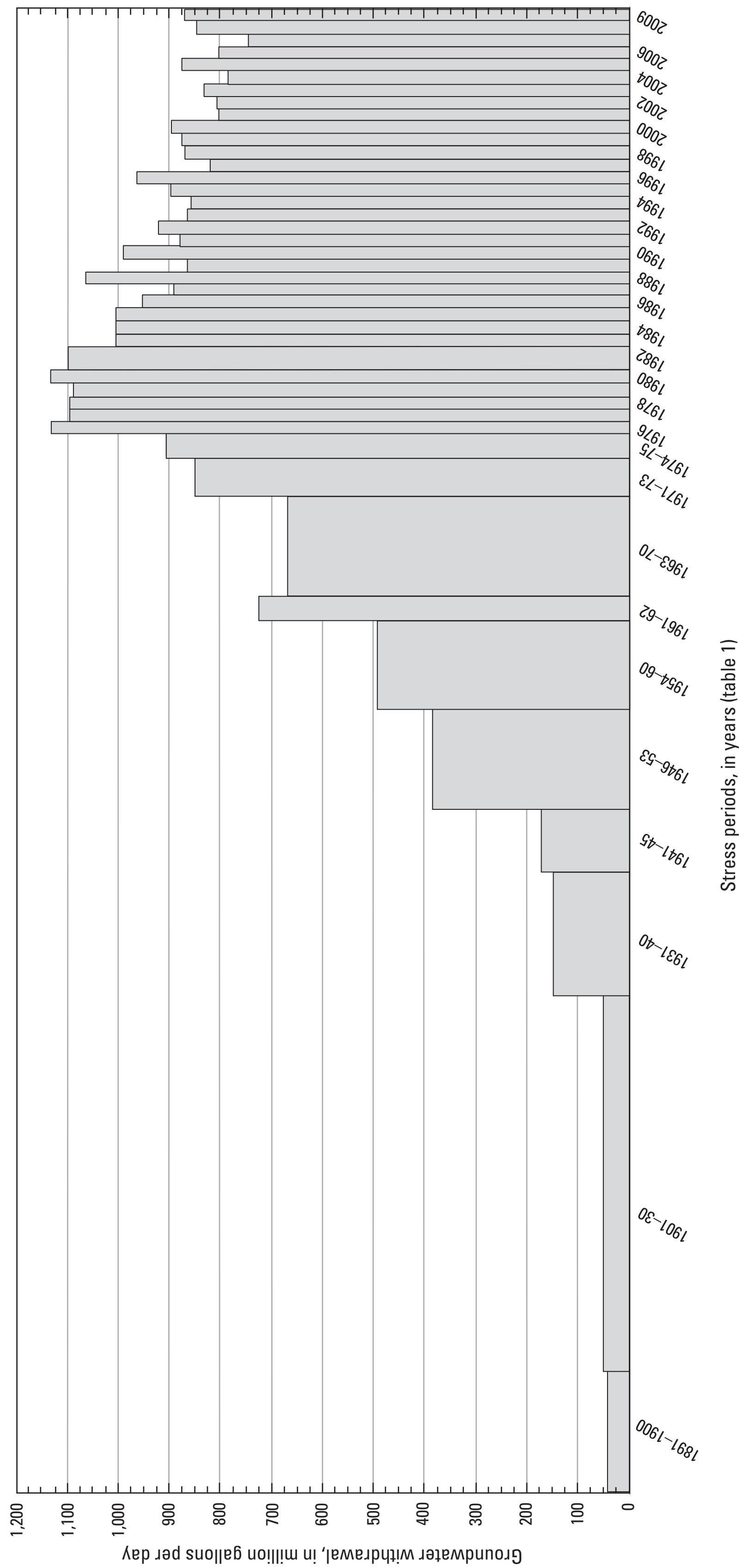


Figure 8. Total groundwater withdrawals used during transient Houston Area Groundwater Model simulations, by stress periods, 1891–2009.

Table 1. Groundwater withdrawal (stress) periods used in the Houston Area Groundwater Model.

Stress period	Length of time (years)	Time interval	Stress period	Length of time (years)	Time interval	Stress period	Length of time (years)	Time interval
1	Transient state[1]	10,000 years	27	0.085	Dec. 1980	53	0.085	Aug. 1988
2	10	1891–1900	28	1	1981	54	0.082	Sept. 1988
3	30	1901–30	29	0.085	Jan. 1982	55	0.085	Oct. 1988
4	10	1931–40	30	0.077	Feb. 1982	56	0.082	Nov. 1988
5	5	1941–45	31	0.085	Mar. 1982	57	0.085	Dec. 1988
6	8	1946–53	32	0.082	Apr. 1982	58	1	1989
7	7	1954–60	33	0.085	May 1982	59	1	1990
8	2	1961–62	34	0.082	June 1982	60	1	1991
9	8	1963–70	35	0.085	July 1982	61	1	1992
10	3	1971–73	36	0.085	Aug. 1982	62	1	1993
11	2	1974–75	37	0.082	Sept. 1982	63	1	1994
12	1	1976	38	0.085	Oct. 1982	64	1	1995
13	1	1977	39	0.082	Nov. 1982	65	1	1996
14	1	1978	40	0.085	Dec. 1982	66	1	1997
15	1	1979	41	1	1983	67	1	1998
16	0.085	Jan. 1980	42	1	1984	68	1	1999
17	0.077	Feb. 1980	43	1	1985	69	1	2000
18	0.085	Mar. 1980	44	1	1986	70	1	2001
19	0.082	Apr. 1980	45	1	1987	71	1	2002
20	0.085	May 1980	46	0.085	Jan. 1988	72	1	2003
21	0.082	June 1980	47	0.077	Feb. 1988	73	1	2004
22	0.085	July 1980	48	0.085	Mar. 1988	74	1	2005
23	0.085	Aug. 1980	49	0.082	Apr. 1988	75	1	2006
24	0.082	Sept. 1980	50	0.085	May 1988	76	1	2007
25	0.085	Oct. 1980	51	0.082	June 1988	77	1	2008
26	0.082	Nov. 1980	52	0.085	July 1988	78	1	2009

[1]A 10,000-year transient period was used without withdrawals for model stability.

of rates from previous recharge studies (see "Ground-Water-Flow Conditions, Recharge, and Discharge" section in Kasmarek and Robinson, 2004) to ensure that the value was reasonable. Similarly, simulated groundwater withdrawal rates were compared to the cumulative withdrawal rates published by HGSD, FBSD, and LSGCD for accuracy. Additionally, comparisons of simulated spatial distributions of recharge and discharge in the outcrops of aquifers to estimates of physically reasonable distributions based on knowledge of the hydrology of the Gulf Coast aquifer system also were used.

8. quantitative determination to ensure that the calibrated RMSE for each aquifer is 10 percent or less of the total range of calibrated simulated head.

Calibrated model parameters of the four layers of the GAM (Kasmarek and Robinson, 2004) and HAGM were compared to quantify the parameter differences (table 2). The additional water-use data (2001–9) used in the HAGM since the GAM was finalized required modification of the calibrated parameters, particularly in layer 4 (Jasper aquifer), to achieve recalibration.

The maximum value of simulated GHB conductance in layer 1 (Chicot aquifer) was decreased by more than two orders of magnitude, but the minimum value was increased by two orders of magnitude. All other maximum and minimum values of conductance in layer 2 (Evangeline aquifer), layer 3 (Burkeville confining unit), and layer 4 (Jasper aquifer) were unchanged (table 2).

The maximum value of inelastic-clay storativity (inelastic storage coefficient) was increased by about one

Table 2. Comparison of calibrated-parameter values used in the Groundwater Availability Model (GAM) (2004) and the Houston Area Groundwater Model (HAGM).

[min, minimum; max, maximum; GHB, general head boundary; ICS, inelastic-clay storativity; HC, hydraulic conductivity; ft, feet; ft^2/day, square feet per day; n/s, not simulated; <, less than; n/a, not applicable; ft^3/day, cubic feet per day]

Simulated parameter	GAM min	GAM max	HAGM min	HAGM max
GHB conductance, in ft^2/day				
Chicot aquifer GHB	1.0×10^{-6}	51,776	1.46×10^{-4}	199
Evangeline aquifer GHB	1.202	69,700	1.202	69,700
Burkeville confining unit GHB	2.2×10^{-2}	9.4×10^{-1}	2.2×10^{-2}	9.4×10^{-1}
Jasper aquifer GHB	6.34	1,500	6.34	1,500
ICS (dimensionless)				
Chicot aquifer ISC	2.06×10^{-7}	5.18×10^{-3}	5.3×10^{-6}	1.49×10^{-2}
Evangeline aquifer ISC	1.03×10^{-6}	1.08×10^{-3}	2.28×10^{-7}	1.49×10^{-1}
Burkeville confining unit ISC	n/s	n/s	2.05×10^{-6}	9.24×10^{-5}
Jasper aquifer ISC	n/s	n/s	1.0×10^{-6}	9.47×10^{-4}
HC, in ft^2/day				
Chicot aquifer HC	1.0×10^{-1}	2,877	4.0×10^{-3}	39.9
Evangline aquifer HC	2.0×10^{-1}	49.5	3.9×10^{-1}	30.8
Burkeville confining unit HC	9.0×10^{-6}	2.1×10^{-2}	9.0×10^{-6}	2.1×10^{-2}
Jasper aquifer HC	9.1×10^{-5}	47.6	1.0×10^{-2}	19.7
Storativity (dimensionless)				
Chicot aquifer storativity	2.0×10^{-3}	1.578×10^{-1}	2.0×10^{-3}	1.56×10^{-1}
Evangeline aquifer storativity	2.0×10^{-4}	1.8×10^{-1}	1.0×10^{-3}	1.82×10^{-1}
Burkeville confining unit storativity	1.0×10^{-5}	5.0×10^{-2}	1.0×10^{-5}	5.0×10^{-2}
Jasper aquifer storativity	2.0×10^{-5}	2.0×10^{-2}	4.1×10^{-6}	2.01×10^{-1}
Leakance, in foot per day per foot				
Chicot aquifer leakance	$2.0.0\times10^{-11}$	4.43×10^{-4}	1.1×10^{-7}	4.43×10^{-4}
Evangeline aquifer leakance	$5.0.0\times10^{-11}$	5.0×10^{-3}	9.0×10^{-8}	5.0×10^{-3}
Burkeville confining unit leakance	$4.47.0\times10^{-11}$	2.06×10^{-4}	$7.18.0\times10^{-11}$	2.06×10^{-5}
Jasper aquifer leakance	n/a	n/a	n/a	n/a
Total groundwater withdrawals for each aquifer	Chicot aquifer	Evangeline aquifer	Burkeville confining unit	Jasper aquifer
Total 2000 withdrawal, ft^3/day	67,806,324	41,553,744	Negligible	9,380,838
Total 2009 withdrawal, ft^3/day	51,383,890	55,668,241	Negligible	9,102,101
Change in withdrawls from 2000 to 2009	-16,422,434	14,114,497		-278,737

order of magnitude in layer 1 and was increased by about two orders of magnitude for layer 2. The minimum inelastic-clay storativity was increased by about one order of magnitude in layer 1 but decreased by about one order of magnitude in layer 2. A comparison of inelastic-clay storativity values for layers 3 and 4 was not possible because clay compaction was not simulated for these layers in the GAM.

The maximum value of simulated hydraulic conductivity (HC) value decreased about two orders of magnitude in layer 1, decreased slightly for layer 2, remained constant in layer 3, and decreased by about half in layer 4. The minimum HC was decreased by about two orders of magnitude for the layer 1, increased slightly for layer 2, remained the same for the layer 3, and increased by about three orders of magnitude for layer 4.

The maximum value of simulated storativity (sand storage) remained about constant for layers 1, 2, and 3 but increased by about one order of magnitude for layer 4. The minimum values of storativity for layers 1 and 3 remained constant, increased by about one order of magnitude for layer 2, and decreased by about one order of magnitude for layer 4.

The maximum value of simulated leakance for layers 1, 2, and 3 remained constant between the GAM and HAGM calibrated models. The minimum leakance in layer 1 was increased by about four orders of magnitude, was increased by about three orders of magnitude in layer 2, and remained about constant in layer 3. Additionally, a comparison of groundwater withdrawals for 2000 and 2009 for the four model layers indicates withdrawals decreased by 16,422,434 ft^3/d for layer 1, increased by 14,114,497 cubic feet per day (ft^3/d) for layer 2, and decreased by 278,737 ft^3/day for layer 4. Water-use data for the Burkeville confining unit were unreported, therefore unknown, but are thought to be negligible.

Model Results

Simulated Hydraulic Properties Associated with Groundwater Flow and Subsidence

The calibrated spatial distributions of simulated hydraulic conductivity in the Chicot, Evangeline, and Jasper aquifers are shown in figures 9–11 and listed in table 2. Hydraulic conductivities of the Chicot aquifer ranged from 4.0×10^{-3} to 39.91 ft/d, with the larger values located in Harris, Fort Bend, Liberty, Chambers, Galveston, Wharton, Colorado, Tyler, Jasper, and Newton Counties. Hydraulic conductivities of the Evangeline aquifer ranged from 3.9×10^{-1} to 30.79 ft/d, with largest values located in southeast Fort Bend County. Hydraulic conductivities of the Burkeville confining unit are coincident with values used in the GAM (Kasmarek and Robinson, 2004). Hydraulic conductivities of the Jasper aquifer ranged from 1.0×10^{-2} to 19.67 ft/d, with the larger values located in northern Harris and Montgomery Counties. Spatial distributions of hydraulic conductivity indicate that, generally, the largest values are coincident with areas of large withdrawals and are consistent with previous studies (Wesselman, 1972; Jorgensen, 1975; Carr and others, 1985; Baker, 1986; Kasmarek and Strom, 2002; Ryder and Ardis, 2002; see “Initial Conditions,” Kasmarek and Robinson, 2004).

Simulated sand storativities of the Chicot and Evangeline aquifers (2.0×10^{-3} to 1.56×10^{-1} and 1.0×10^{-3} to 1.82×10^{-1}, figs. 12 and 13, respectively) reflect aquifer conditions from confined to semiconfined to water table. Sand storativities of the Chicot and Evangeline aquifers (figs. 12 and 13) generally are largest in the updip, outcrop areas, where water-table conditions prevail. Storativities of the Burkeville confining unit are coincident with values used in the GAM (Kasmarek and Robinson, 2004). Storativities of the Jasper aquifer (4.1×10^{-6} to 2.01×10^{-1}) are generally largest in the updip, outcrop areas associated with water-table conditions (fig. 14).

The simulated calibrated spatial distributions of inelastic-clay storativity for the Chicot aquifer, the Evangeline aquifer, the Burkeville confining unit, and the Jasper aquifer are shown in figures 15–18, respectively. Because a large area of land-surface subsidence has been documented (Gabrysch and Neighbors, 2005; Kasmarek, Gabrysch, and Johnson, 2009) in Harris County and parts of Galveston, Fort Bend, Montgomery, Brazoria, Waller, Liberty, and Chambers Counties, only these areas of the model study area can be considered calibrated for elastic- and inelastic-clay storativity. Inelastic-clay storativities for the Chicot aquifer, the Evangeline aquifer, the Burkeville confining unit, and the Jasper aquifer range from 5.3×10^{-6} to 1.49×10^{-2}, from 2.28×10^{-7} to 1.49×10^{-1}, from 2.05×10^{-6} to 9.24×10^{-5}, and from 1.0×10^{-6} to 9.47×10^{-4}, respectively. A total of 474 calibration-target sites in Harris and surrounding counties were used to evaluate simulated subsidence compared to measured subsidence. After numerous iterative trial-and-error transient model simulations, the final RMSE was 0.37 ft.

The simulated potentiometric surfaces of the Chicot, Evangeline, and Jasper aquifers for 2009 (figs. 19–21; also shown are the selected wells used as calibration targets) indicate general agreement with measured potentiometric surfaces from Kasmarek, Houston, and Ramage (2009). The simulated 2009 potentiometric surfaces of the aquifers are shown in this report, but the simulated potentiometric surfaces for 1977, 1990, and 2000 compare favorably with coincident published water-level-altitude maps for 1977 (Gabrysch, 1979); 1990 (Kasmarek, 1997); and 2000 (Coplin and Santos, 2000: Chicot and Evangeline aquifer water-level altitudes; Kasmarek and Houston, 2007: 2000 Jasper aquifer water-level altitude). The RMSE of the simulated water levels for the three aquifers for 2009 were about 31.06 ft for the Chicot aquifer, about 33.73 ft for the Evangeline aquifer, and about 23.32 ft for the Jasper aquifer (table 3). The RMSE were calculated to be about 8, 6, and 6 percent, respectively, for the total range in simulated heads for the three aquifers, with a -0.03 percent water-budget difference between the total simulated inflow and the total simulated outflow.

Water levels were measured from December 2008 through March 2009 in wells completed in the Chicot, Evangeline, and Jasper aquifers (Kasmarek, Houston, and Ramage, 2009). Simulated heads were compared to measured heads to evaluate the calibration validity of the groundwater-flow model. This comparison of simulated and measured heads of the Chicot aquifer, 2009 (fig. 22), indicates that the model is acceptable throughout the range of measured heads; however, simulated heads are lower than measured heads for values of measured head from about +60 ft to about -120 ft. Similarly, for the simulated and measured heads of the Evangeline aquifer, 2009 (fig. 22), the model is acceptable throughout the range of heads, but simulated heads are lower than measured heads for values of measured head from about -105 ft to about -235 ft. Comparisons of simulated and measured heads for the Jasper aquifer, 2009 (fig. 22), indicate close correlation. These graphical comparisons between the simulated and measured heads correlate well with the RMSE shown in table 3.

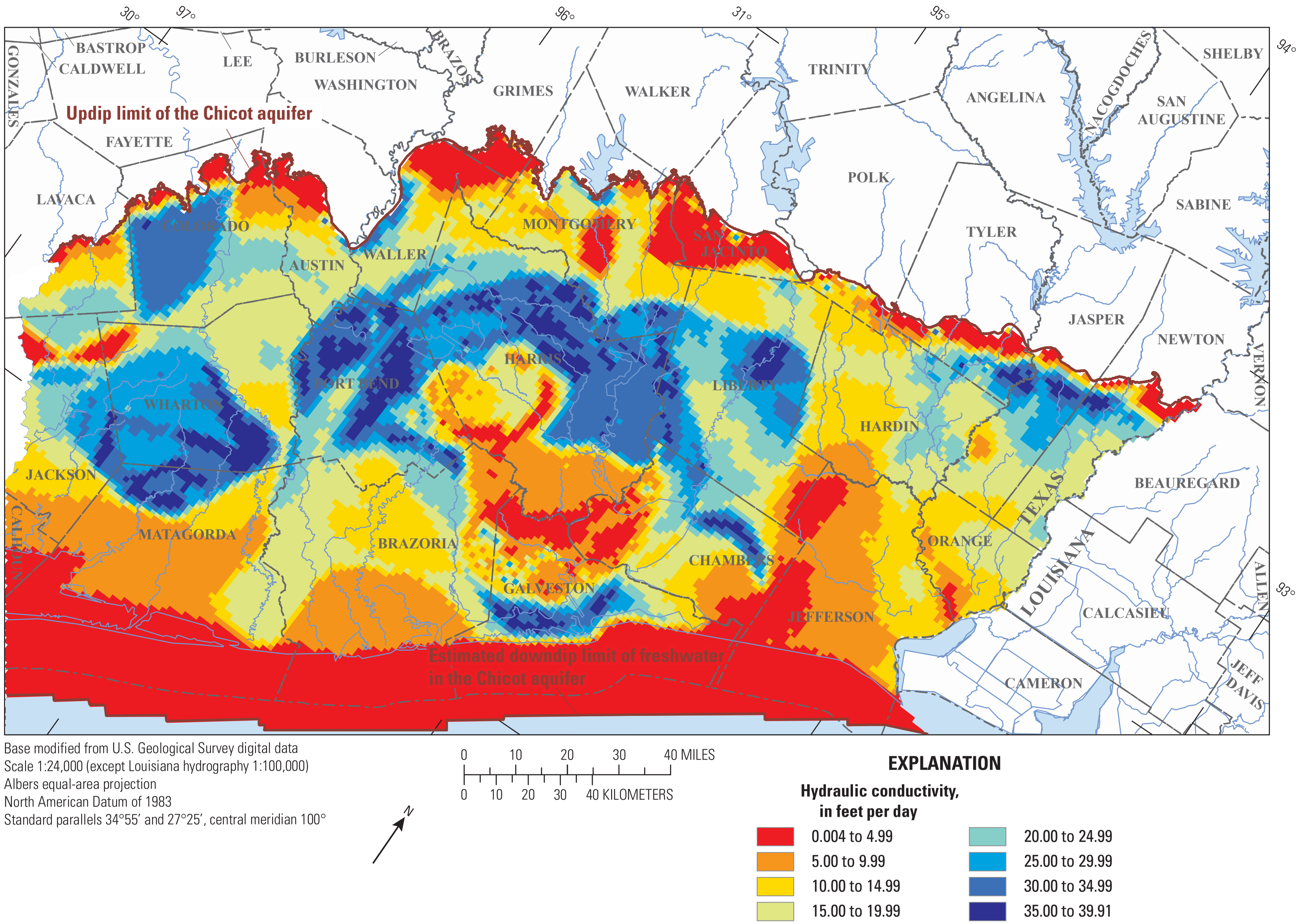
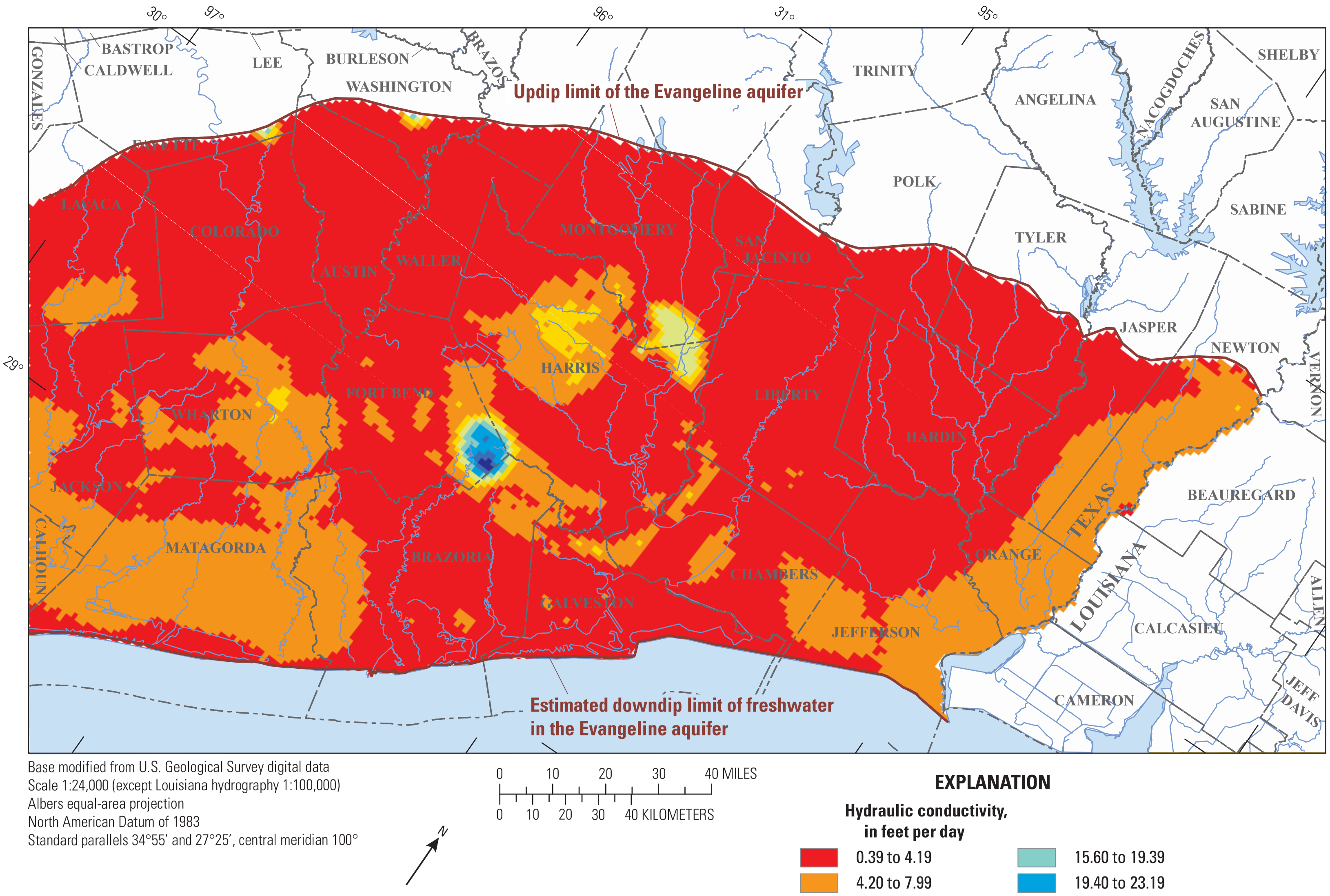


Figure 9. Simulated hydraulic conductivity of the Chicot aquifer in the Houston Area Groundwater Model study area.



Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection
North American Datum of 1983
Standard parallels 34°55′ and 27°25′, central meridian 100°

Figure 10. Simulated hydraulic conductivity of the Evangeline aquifer in Houston Area Groundwater Model study area.

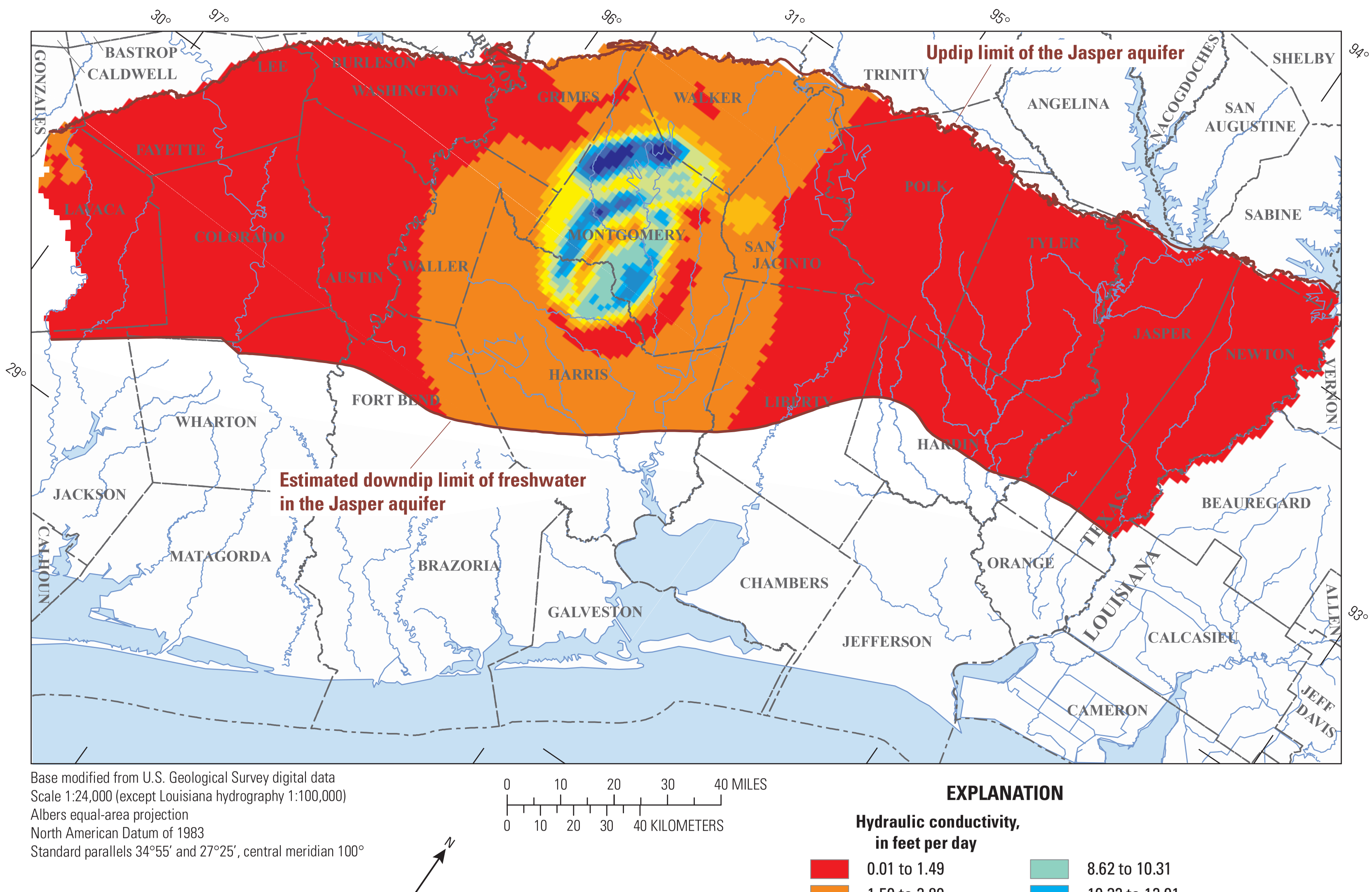


Figure 11. Simulated hydraulic conductivity of the Jasper aquifer in the Houston Area Groundwater Model study area.

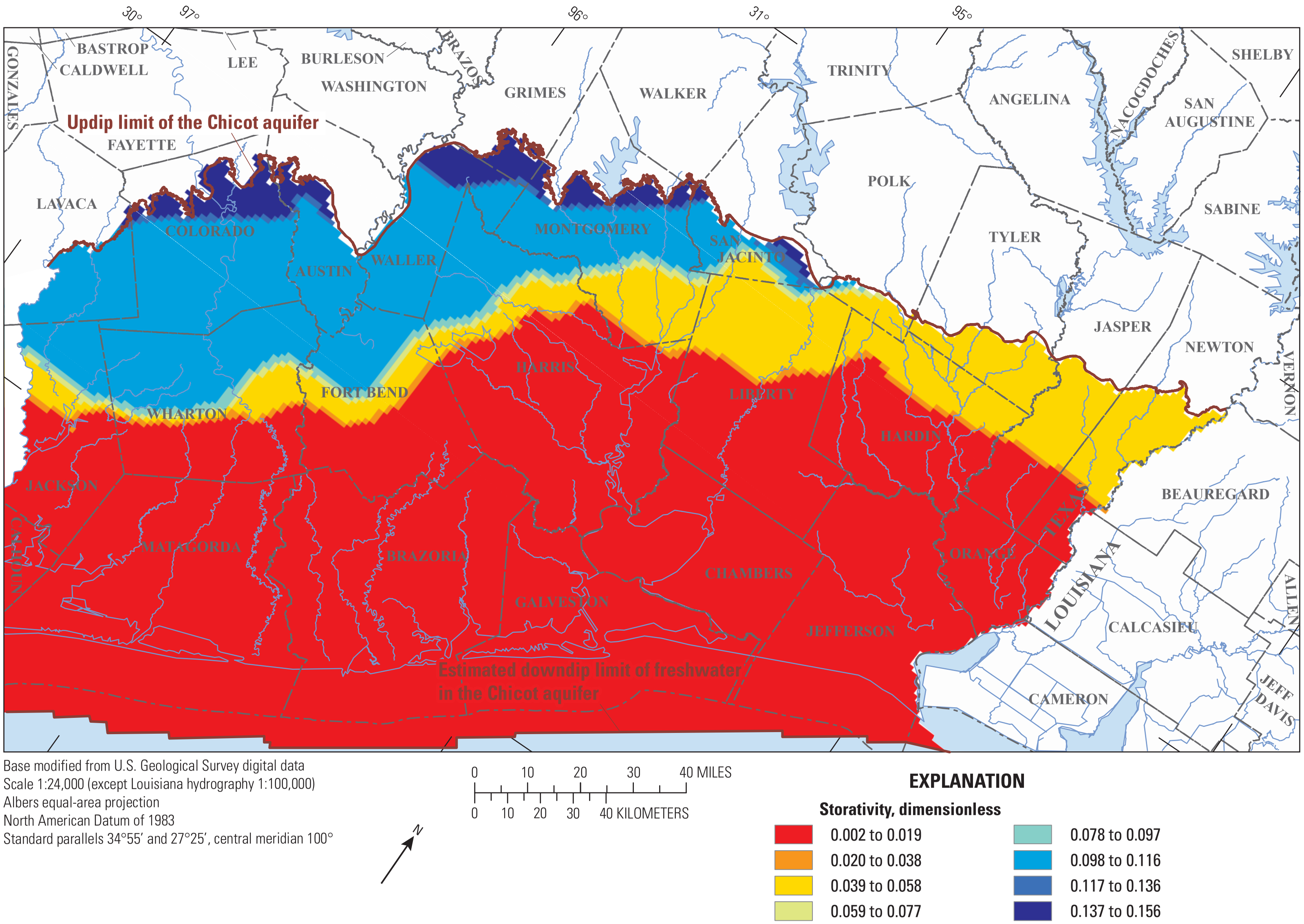


Figure 12. Simulated sand storativity of the Chicot aquifer in the Houston Area Groundwater Model study area.

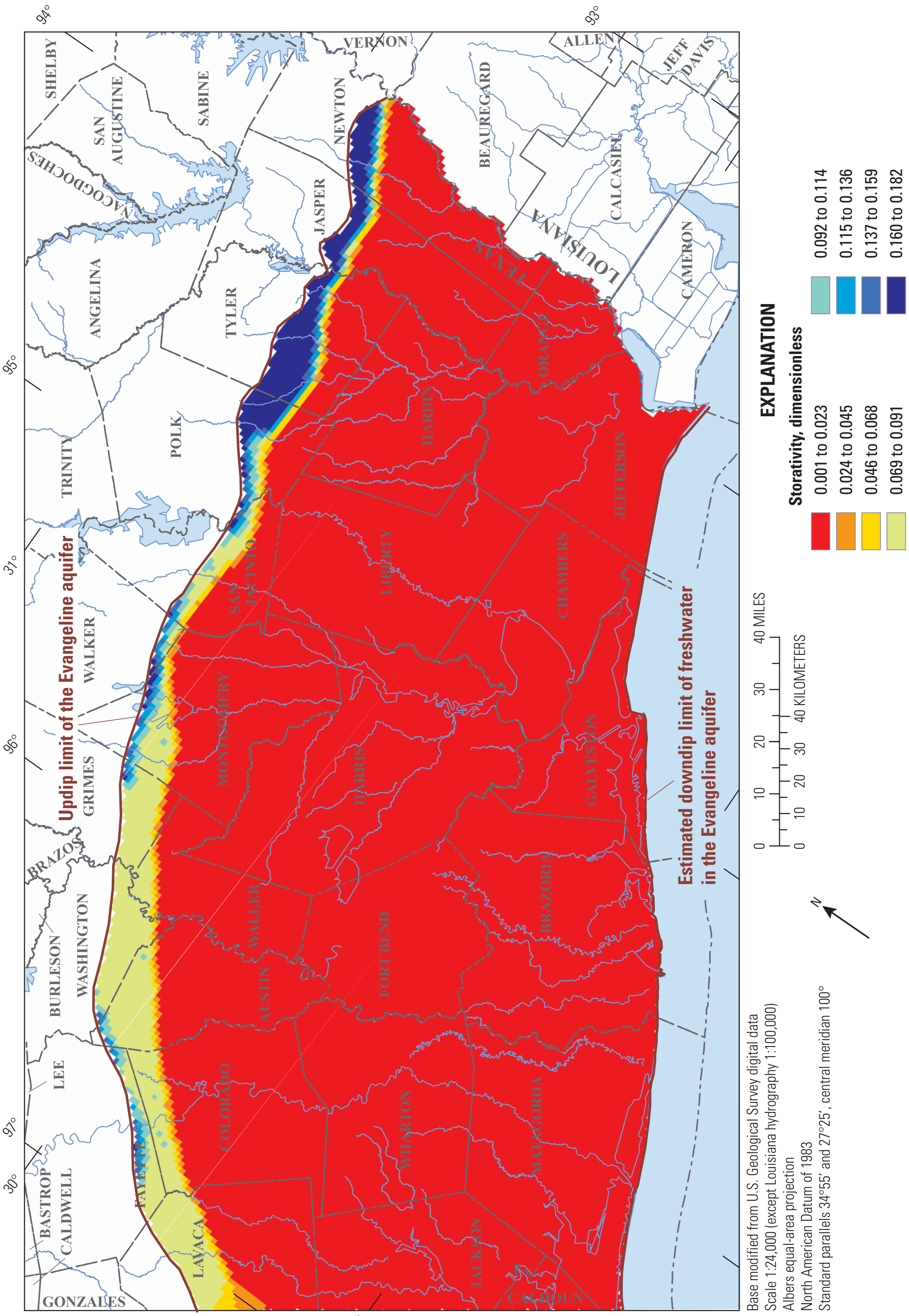


Figure 13. Simulated sand storativity of the Evangeline aquifer in the Houston Area Groundwater Model study area.

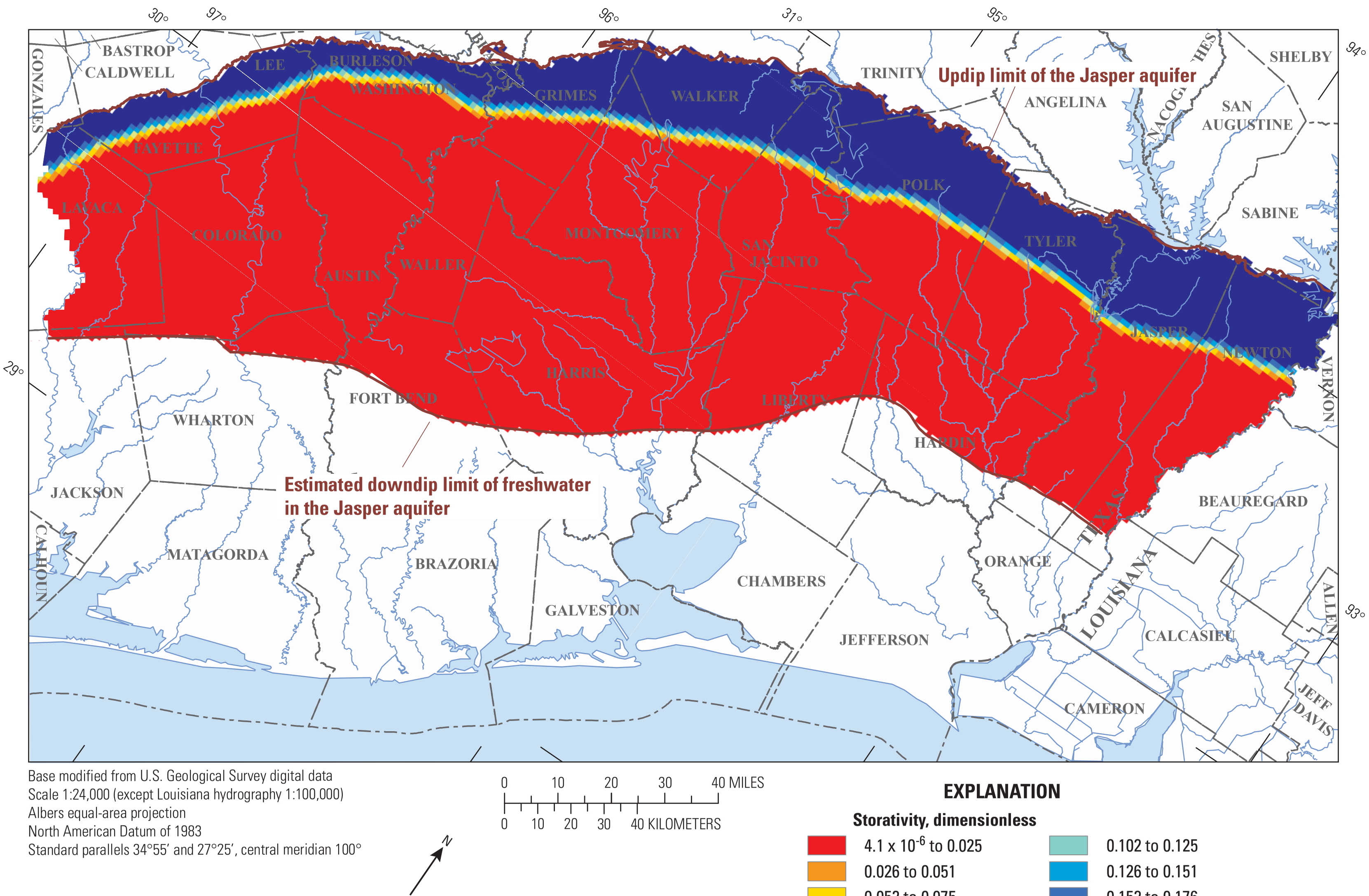
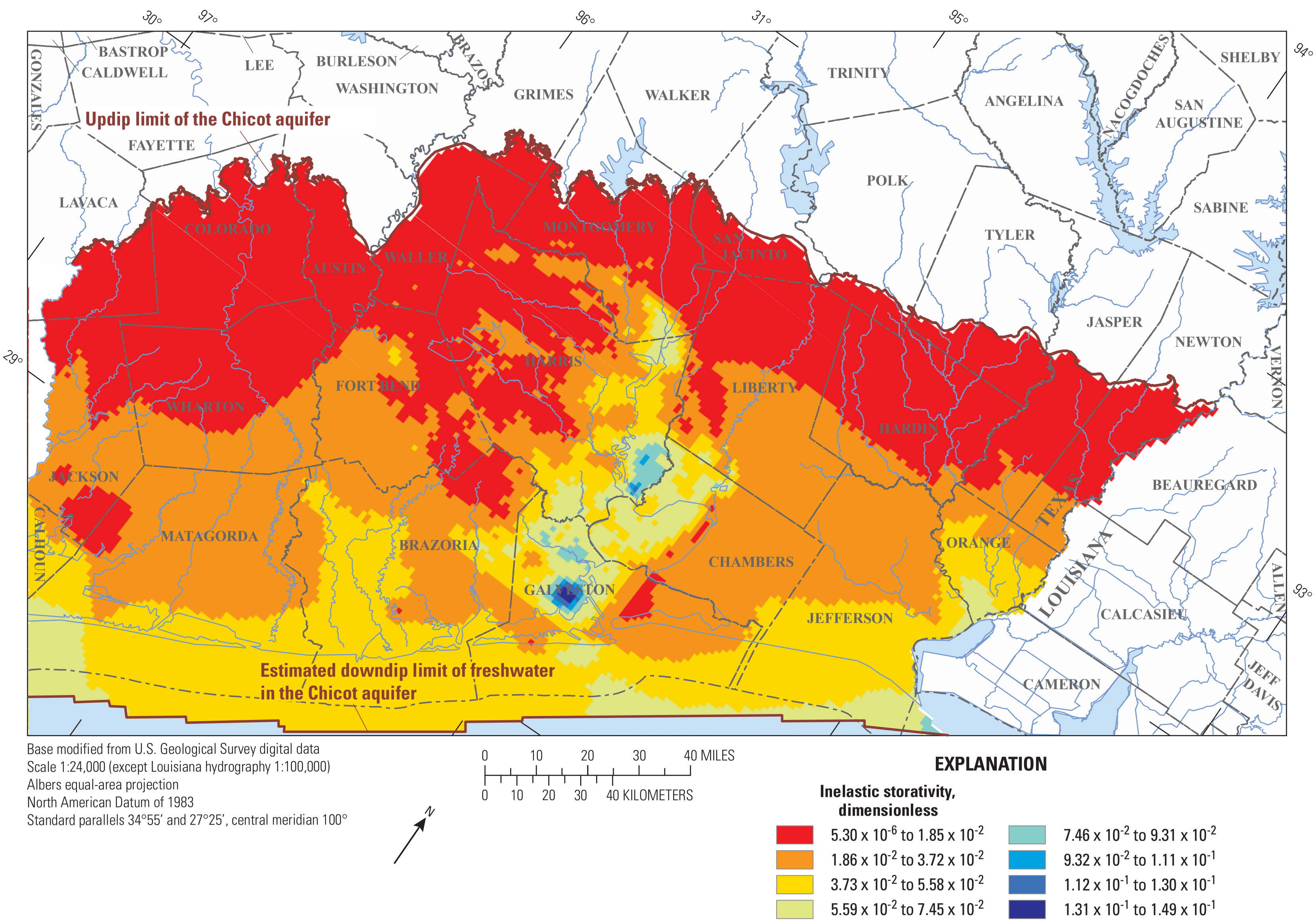


Figure 14. Simulated sand storativity of the Jasper aquifer in the Houston Area Groundwater Model study area.



Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection
North American Datum of 1983
Standard parallels 34°55′ and 27°25′, central meridian 100°

Figure 15. Simulated inelastic-clay storativity of the Chicot aquifer in the Houston Area Groundwater Model study area.

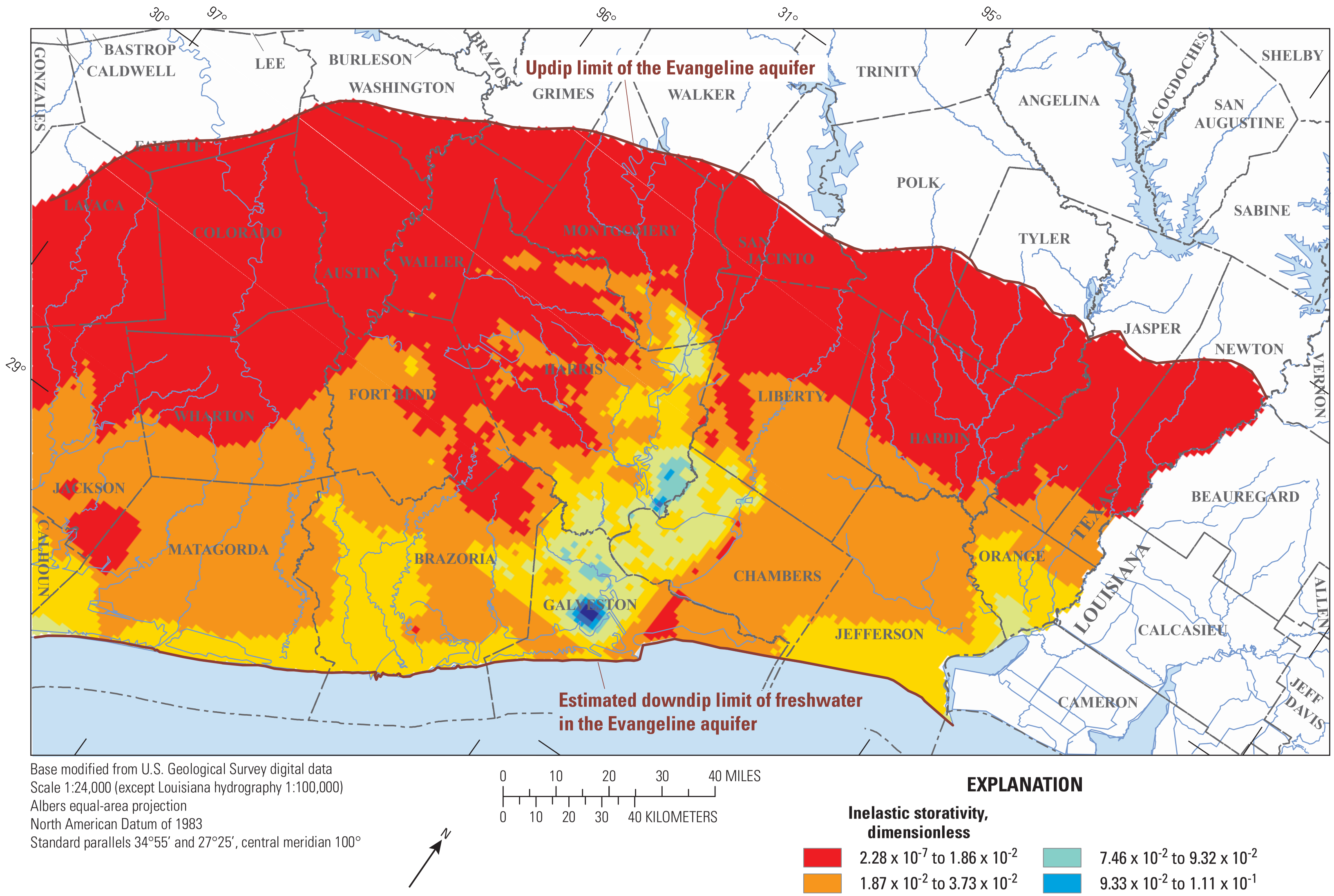


Figure 16. Simulated inelastic-clay storativity of the Evangeline aquifer in the Houston Area Groundwater Model study area.

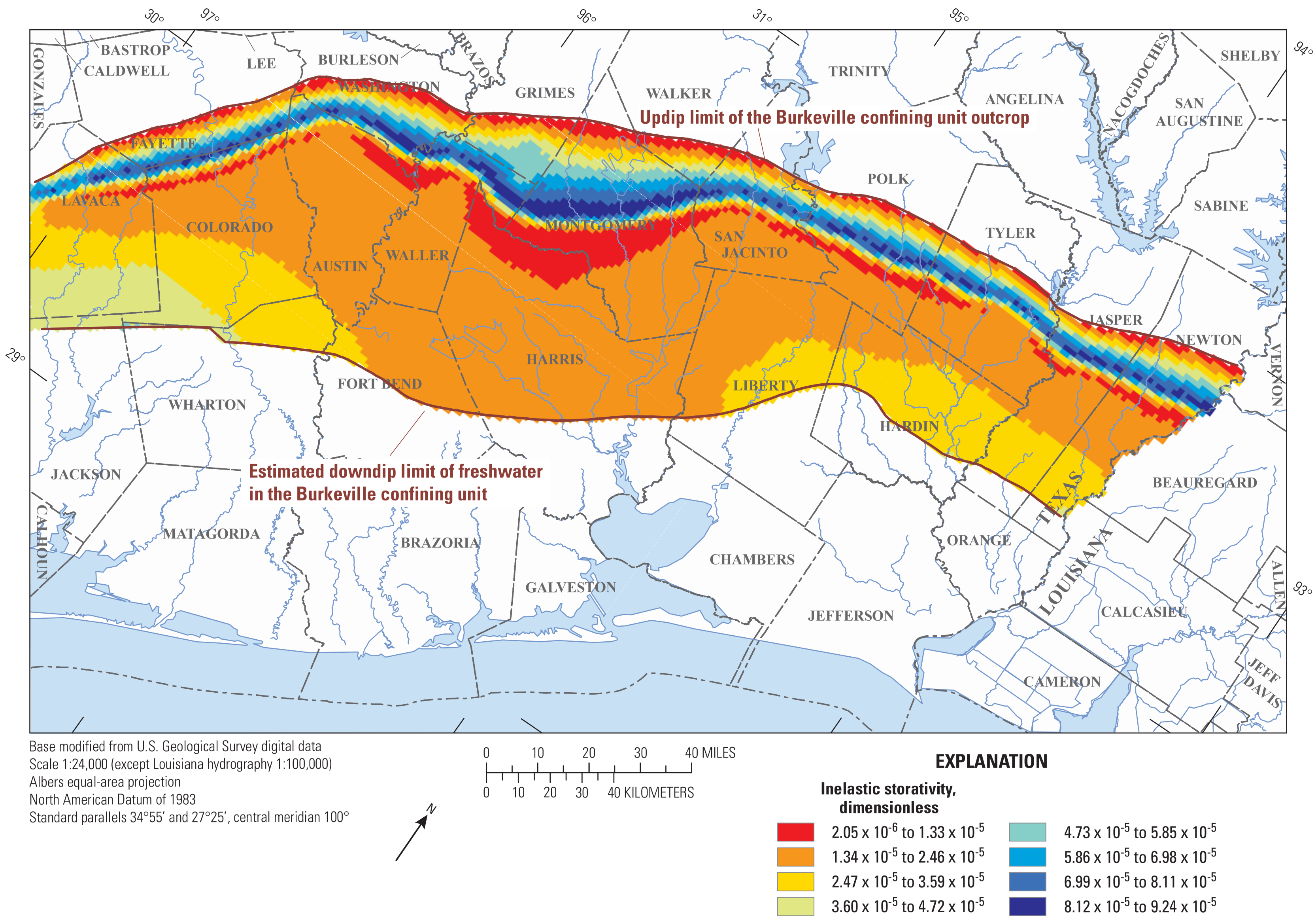


Figure 17. Simulated inelastic-clay storativity of the Burkeville confining unit in the Houston Area Groundwater Model study area.

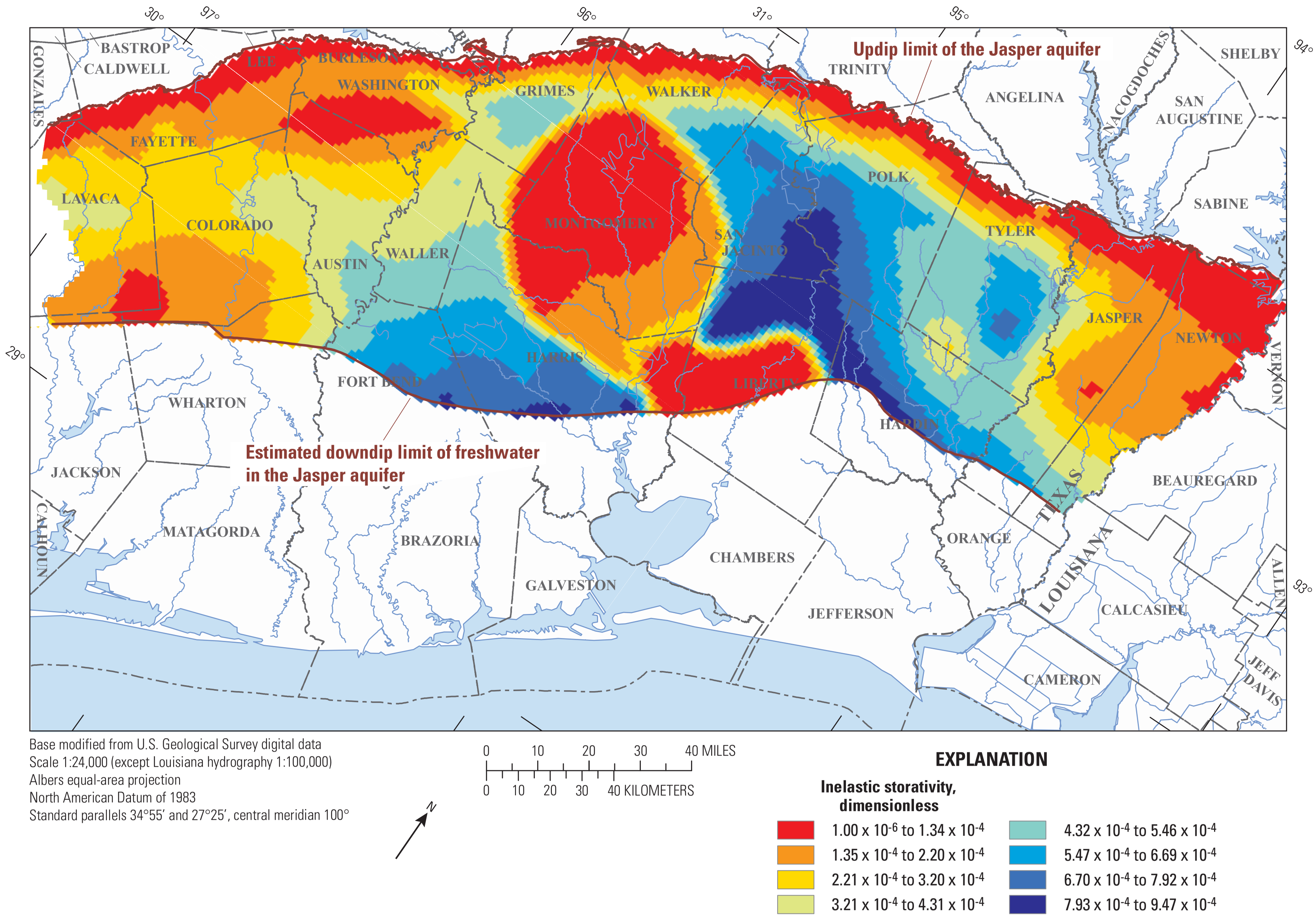


Figure 18. Simulated inelastic-clay storativity of the Jasper aquifer in the Houston Area Groundwater Model study area.

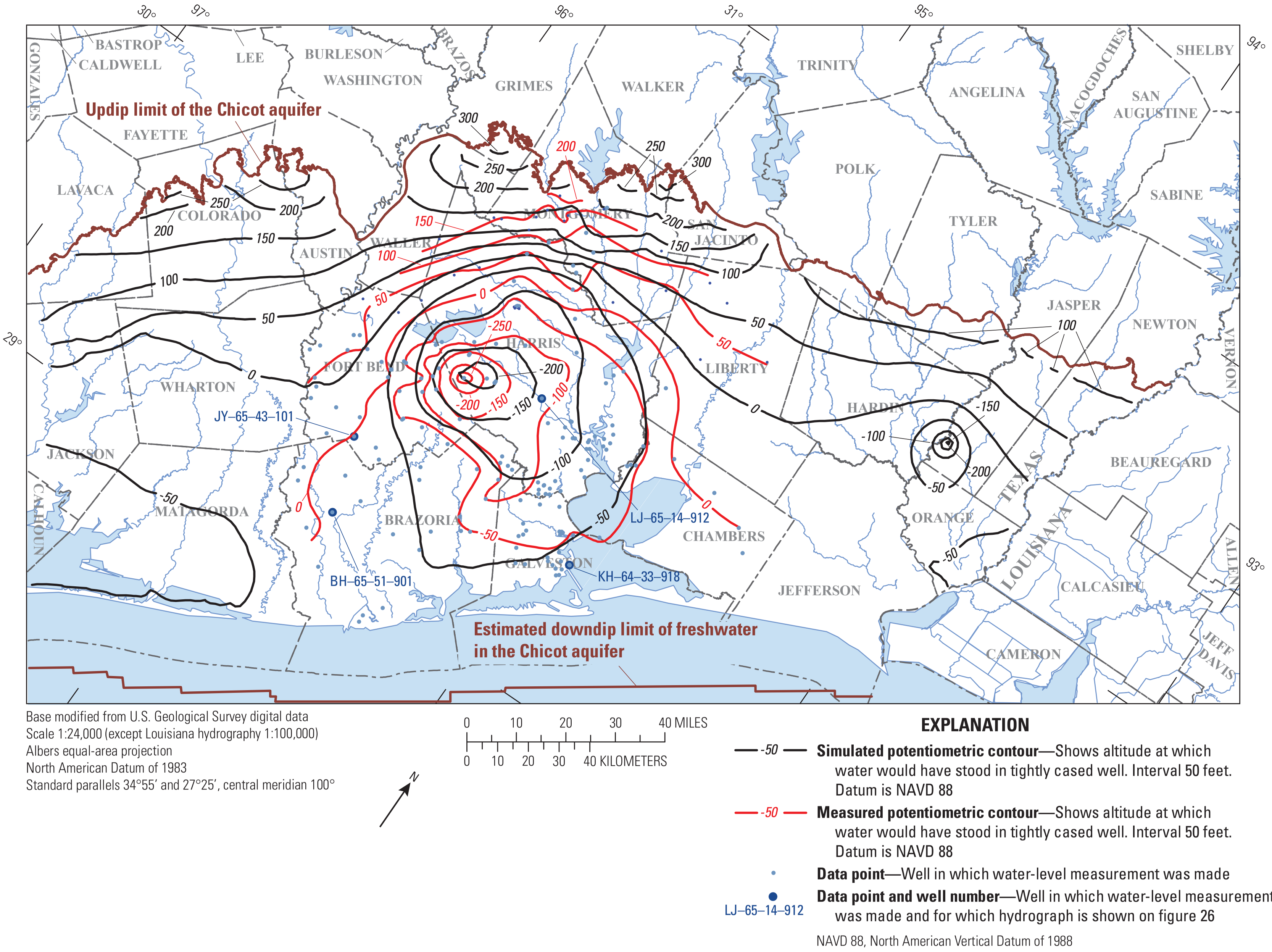
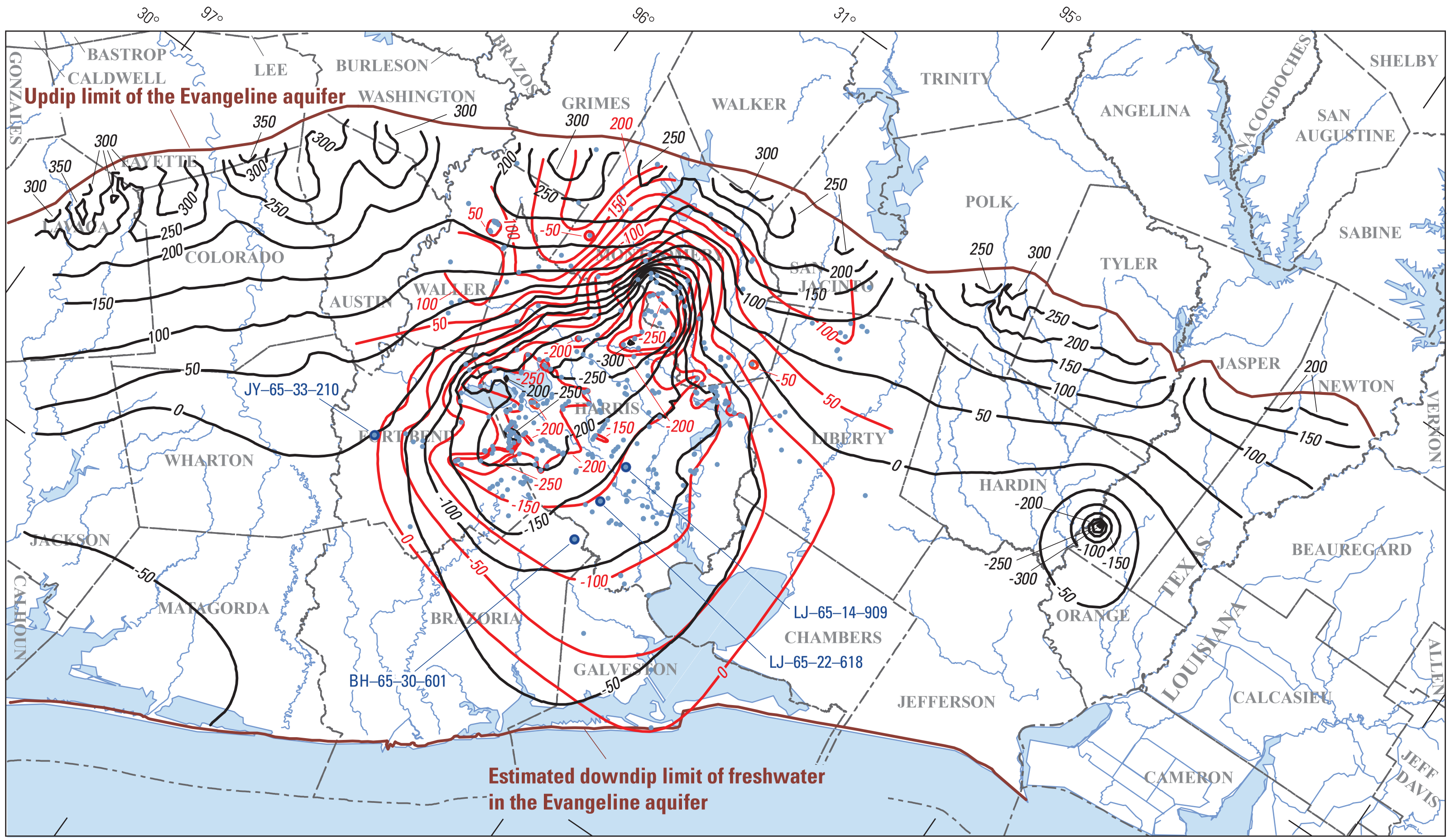


Figure 19. Simulated and measured potentiometric surfaces of the Chicot aquifer, 2009, and location of monitoring wells in the Houston Area Groundwater Model study area.



Base modified from U.S. Geological Survey digital data
Scale 1:24,000 (except Louisiana hydrography 1:100,000)
Albers equal-area projection
North American Datum of 1983
Standard parallels 34°55′ and 27°25′, central meridian 100°

0 10 20 30 40 MILES
0 10 20 30 40 KILOMETERS

N

EXPLANATION

-50 **Simulated potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Interval 50 feet. Datum is NAVD 88

-50 **Measured potentiometric contour**—Shows altitude at which water would have stood in tightly cased well. Intervals 50, 100, and 250 feet. Datum is NAVD 88

Data point—Well in which water-level measurement was made

LJ–65–14–909 **Data point and well number**—Well in which water-level measurement was made and for which hydrograph is shown on figure 27

NAVD 88, North American Vertical Datum of 1988

Figure 20. Simulated and measured potentiometric surfaces of the Evangeline aquifer, 2009, and location of monitoring wells in the Houston Area Groundwater Model study area.

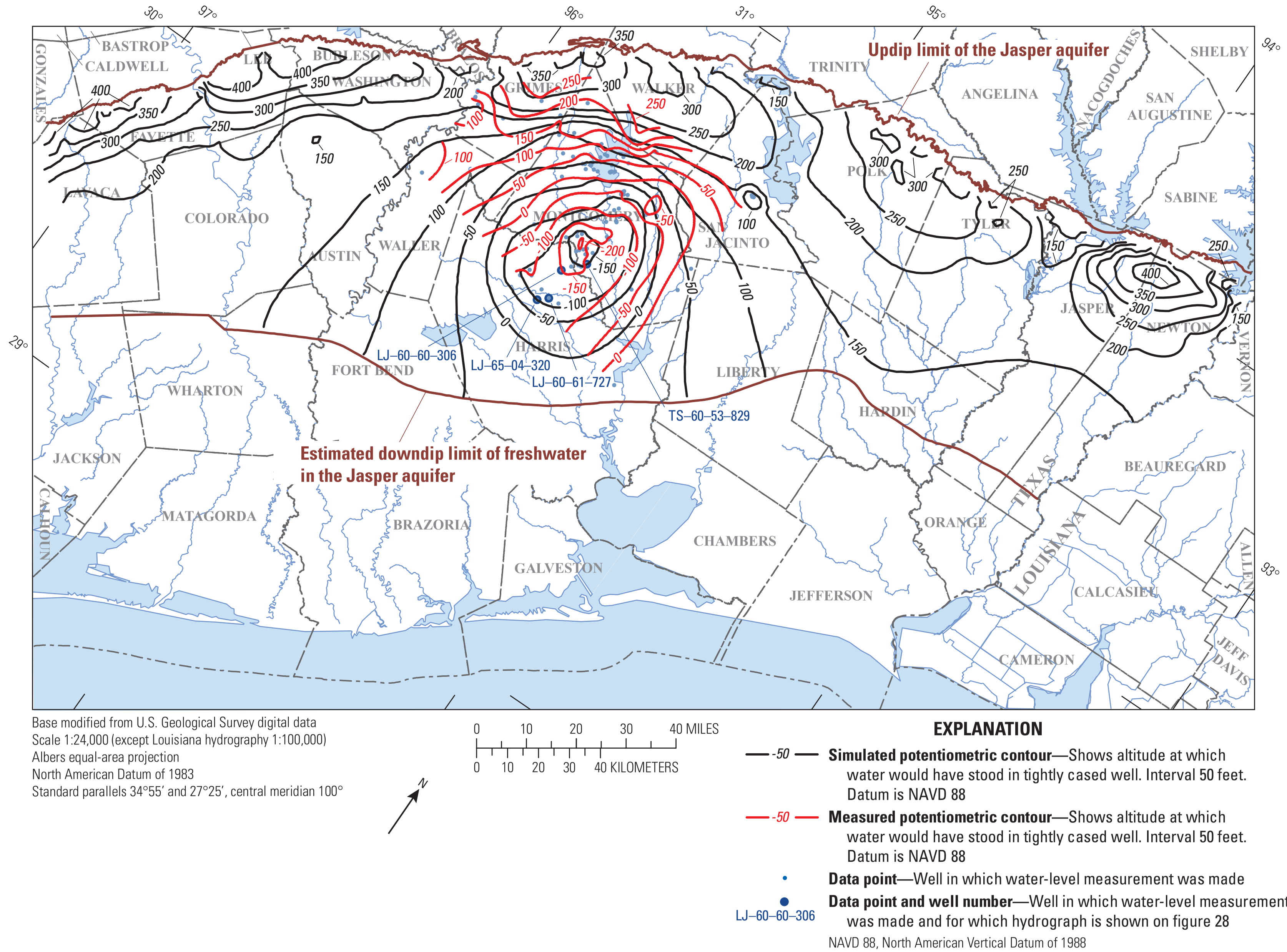


Figure 21. Simulated and measured potentiometric surfaces of the Jasper aquifer, 2009, and location of monitoring wells in the Houston Area Groundwater Model study area.

Table 3. Number of water-level (head) measurements, root-mean-square errors of simulated head, and range of total simulated head in the Chicot, Evangeline, and Jasper aquifers, 2009.

Aquifer	Number of water-level measurements	Root-mean-square error of simulated water levels (feet)	Range of total simulated head (feet)
Chicot	165	31.06	366
Evangeline	251	33.73	541
Jasper	81	23.32	414

The spatial distribution of water-level residuals (measured values of head minus simulated values of head) for the Chicot aquifer (fig. 23) indicates that most residuals are positive in the area of the model that contains monitoring wells, which means that the model computes head below the measured value. In other areas of the Fort Bend, Brazoria, Galveston, southwest Harris, Chambers, Liberty and Montgomery Counties, areas of negative and positive residual values are prevalent, which means that the model computes head above the measured value in these areas. From a spatial distribution of water-level (head) residuals for the Evangeline aquifer (fig. 24), most of the residuals are positive, with isolated areas of negative residuals in southeast Harris, northern Galveston, western Chambers, northern Waller, and southeast Grimes Counties; an area of negative residuals also extends from northern Waller County into Montgomery County. The spatial distribution of water-level (head) residuals for the Jasper aquifer (fig. 25) indicates an almost even distribution between negative and positive residuals. These residual values are less than residual values of the Chicot and Evangeline aquifers (figs. 23 and 24).

Simulated and Measured Hydrographs

Hydrographs of simulated and measured water levels for observation wells in Brazoria, Galveston, Harris, and Fort Bend Counties in wells screened in the Chicot aquifer (fig. 26) indicate that simulated and measured water levels match closely. The hydrographs for Galveston and Harris Counties (fig. 26*B* and *C*) reflect generally declining heads through the mid- to late 1970s followed by rises associated with decreased withdrawals. The hydrographs of simulated and measured water levels in observation wells in Brazoria and Fort Bend Counties for the Evangeline aquifer (fig. 27*A* and *B*) also match closely. The two hydrographs from wells in Harris County (fig. 27*C* and *D*) indicate similar matches between simulated and measured water levels from about 1998 through 2009, which spans the calibration period used for the HAGM. The hydrographs of simulated heads and measured heads in observation wells in Harris and Montgomery Counties for the Jasper aquifer (fig. 28) have similar water-level trends and become almost coincident in 2008 and 2009.

Simulated and Estimated Water-Budget Components

Simulated recharge and discharge in outcrops of the hydrogeologic units, vertical leakage between units, changes in storage, and withdrawals for 2009 are summarized in figure 29. The diagram indicates a net recharge (total recharge minus natural discharge) of 779.6 cubic feet per second (ft^3/s) (about 0.56 in./yr) in the Chicot aquifer outcrop, 35.0 ft^3/s (about 0.68 in./yr) in the Evangeline aquifer outcrop, negligible net recharge in the Burkeville confining unit outcrop, and 16.8 ft^3/s (about 0.26 in./yr) in the Jasper aquifer outcrop. For the entire system, the simulated total recharge for 2009 was 945.4 ft^3/s (about 0.51 in./yr) in the outcrop areas. As a comparison, the simulated total recharge for the GAM in 2000 was 995 ft^3/s (about 0.54 in./yr) (Kasmarek and Robinson, 2004, p. 90). In terms of a water balance (within 2.8 ft^3/s because of rounding error) for the entire system in 2009, 945.4 ft^3/s of total recharge plus 391.5 ft^3/s from depletion of water in coarse-grained sediments (sands) and 102.5 ft^3/s from inelastic compaction of clays is offset by 114.0 ft^3/s of natural discharge and 1,328.2 ft^3/s (about 858.4 Mgal/d) of groundwater withdrawal. The net difference between total recharge (945.4 ft^3/s) and withdrawal (1,328.2 ft^3/s) is 382.8 ft^3/s (about 247.4 Mgal/d), and the volume of withdrawal from the Chicot, Evangeline, and Jasper aquifers was about 44, 48, and 8 percent, respectively. The volumetric budget (expressed in cubic feet per day) for the transient simulation for the HAGM in 2009, at the end of stress period 78, is shown in table 4.

Simulated and Measured Land-Surface Subsidence

Simulated land-surface subsidence from 1891 (predevelopment) to 2000 and measured land-surface subsidence from 1906 to 2000 is shown in figure 30. In Harris County and counties immediately adjacent, where the main area of subsidence has been measured, the simulated and measured values of subsidence match closely. As much as 10 ft of measured subsidence has occurred in southeastern Harris County. A larger geographic area encompassing the maximum measured land-surface subsidence area and much of central to southeastern Harris County has subsided at least 6 ft. In the western part of the HAGM study area, another area of simulated subsidence centered in Wharton County has as much as 3 ft of subsidence. In the eastern part of the HAGM study area, at the boundary of Hardin and Jasper Counties, an area of subsidence with as much as 3 ft of subsidence was simulated. An isolated area with as much as 3 ft of simulated

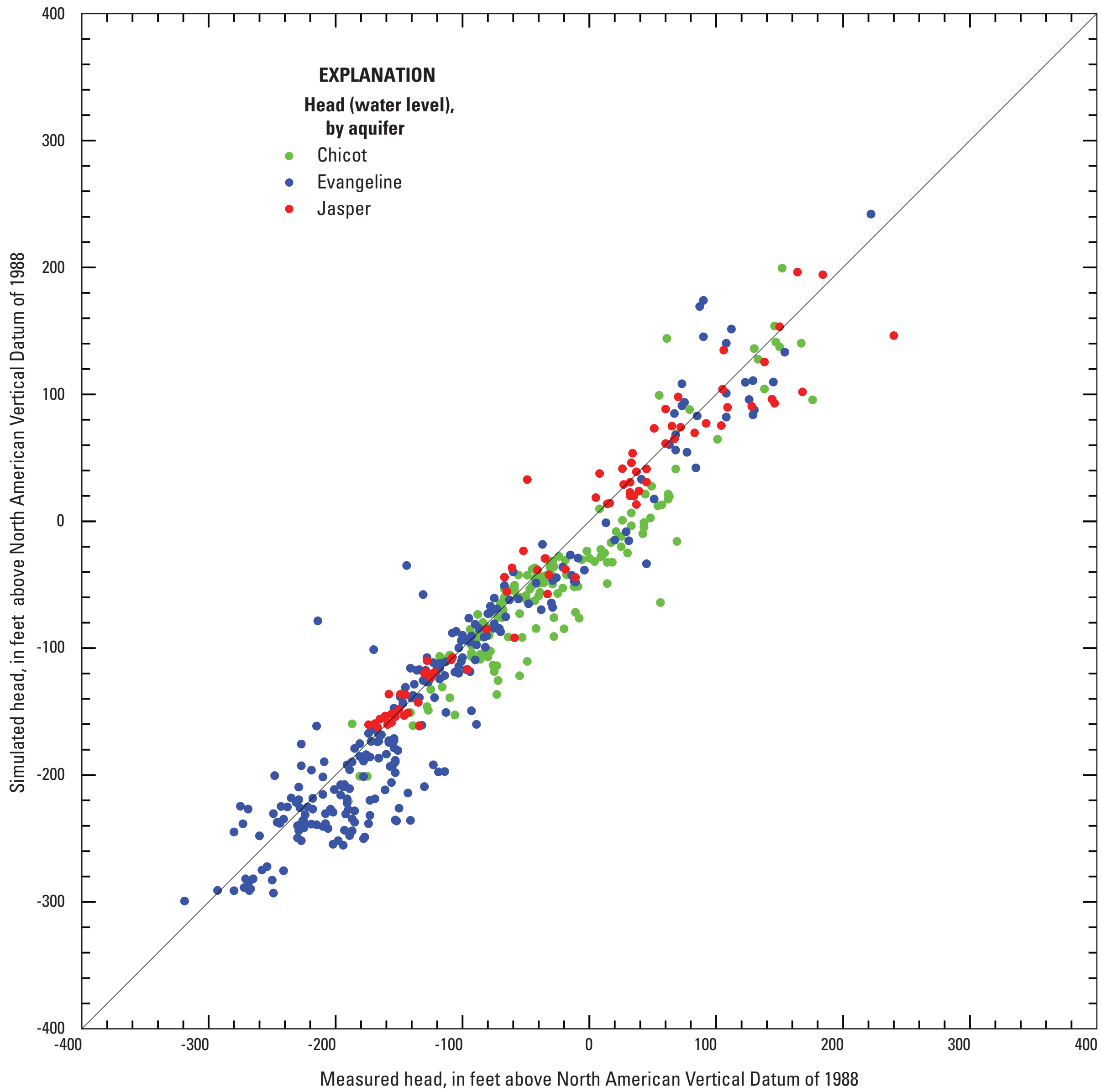


Figure 22. Relation between simulated and measured heads for the Chicot, Evangeline, and Jasper aquifers, 2009, in the Houston Area Groundwater Model study area.

subsidence is located in southeast Orange County. Measured subsidence has not been documented for these western and eastern areas of the HAGM study area. Measured compaction of subsurface sediments at 11 borehole extensometer sites in Harris and Galveston Counties has been continually recorded since as early as 1973 (Kasmarek and others, 2009).

Simulated land-surface subsidence (1891–2009) and measured land-surface subsidence (1906–2000) is shown in figure 31. For these periods in Harris County and counties immediately adjacent, where the main area of measured subsidence is present, the simulated and measured subsidence match closely, but not as closely as in figure 30. The most recent areas of simulated subsidence are generally in southern Montgomery, northwest Harris, and Fort Bend Counties, where water demand has increased and has resulted in sustained groundwater withdrawals during 2001–9. The two distal areas with as much as 3 ft of simulated subsidence in the eastern and western areas of the HAGM study area depicted in figure 31 are similar to the areal extent of simulated subsidence shown for 2000 in figure 30.

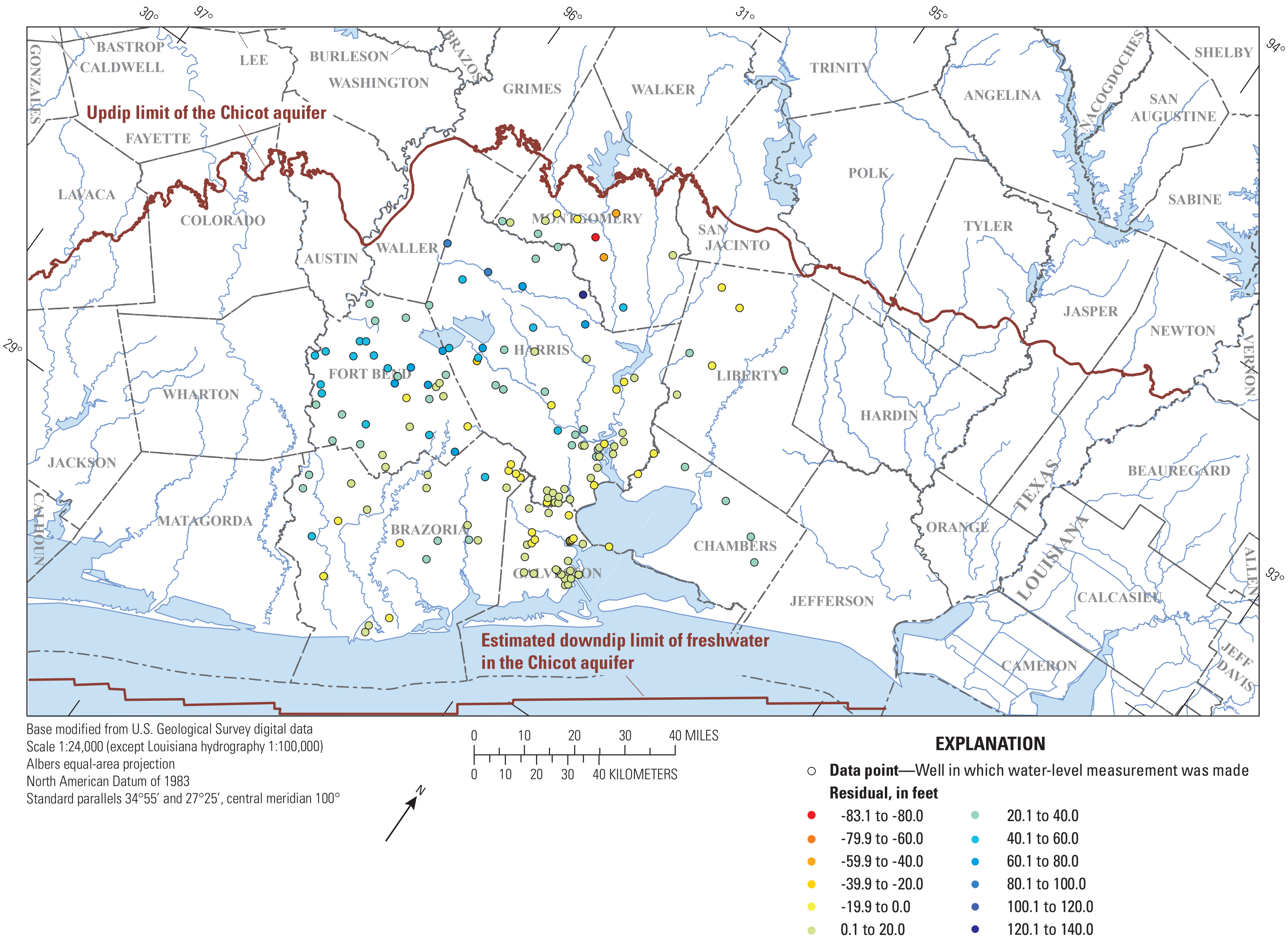


Figure 23. Spatial distribution of water-level (head) residuals (measured minus simulated heads) for the Chicot aquifer, 2009, in the Houston Area Groundwater Model study area.

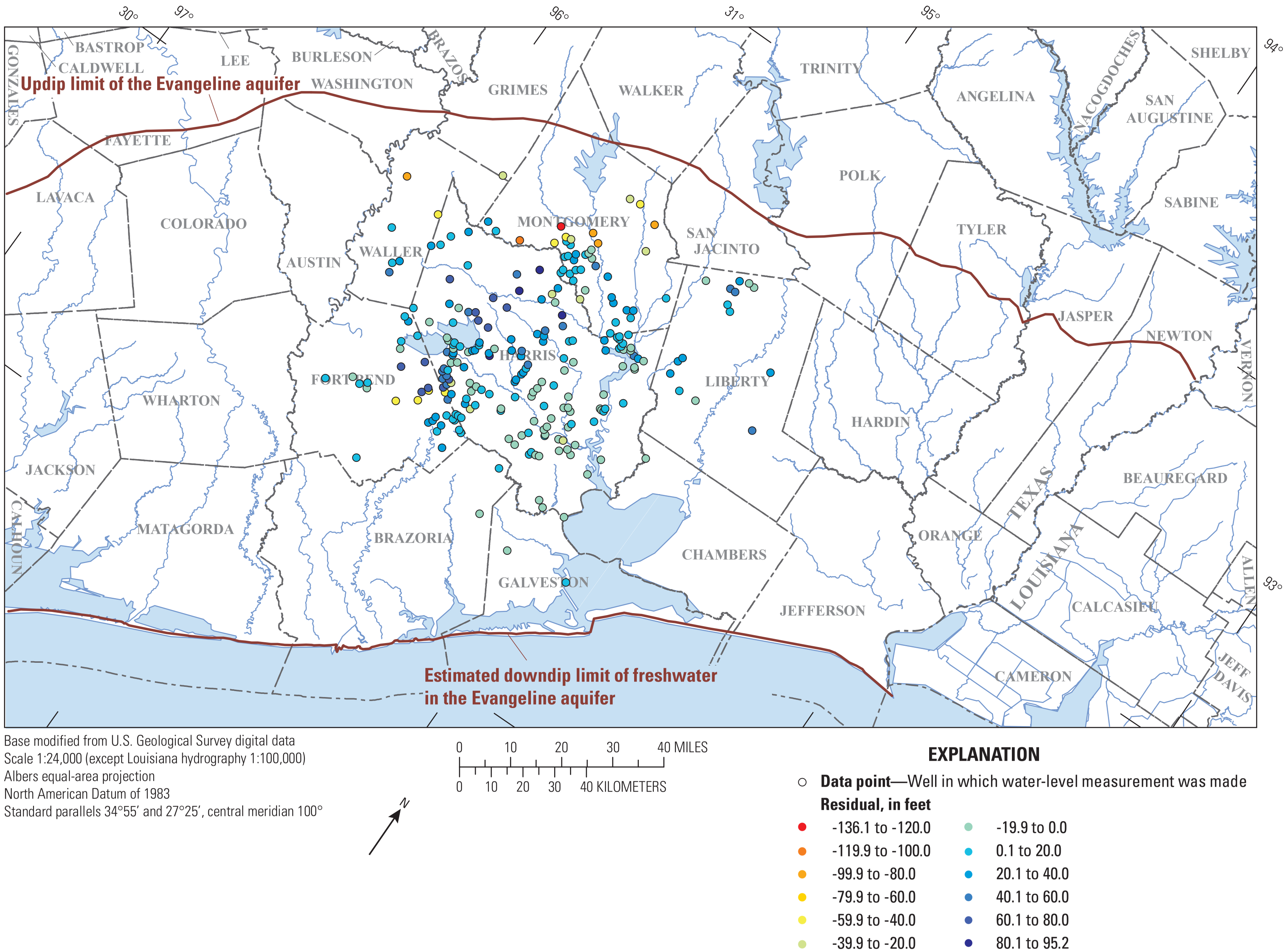


Figure 24. Spatial distribution of water-level (head) residuals (measured minus simulated heads) for the Evangeline aquifer, 2009, in the Houston Area Groundwater Model study area.

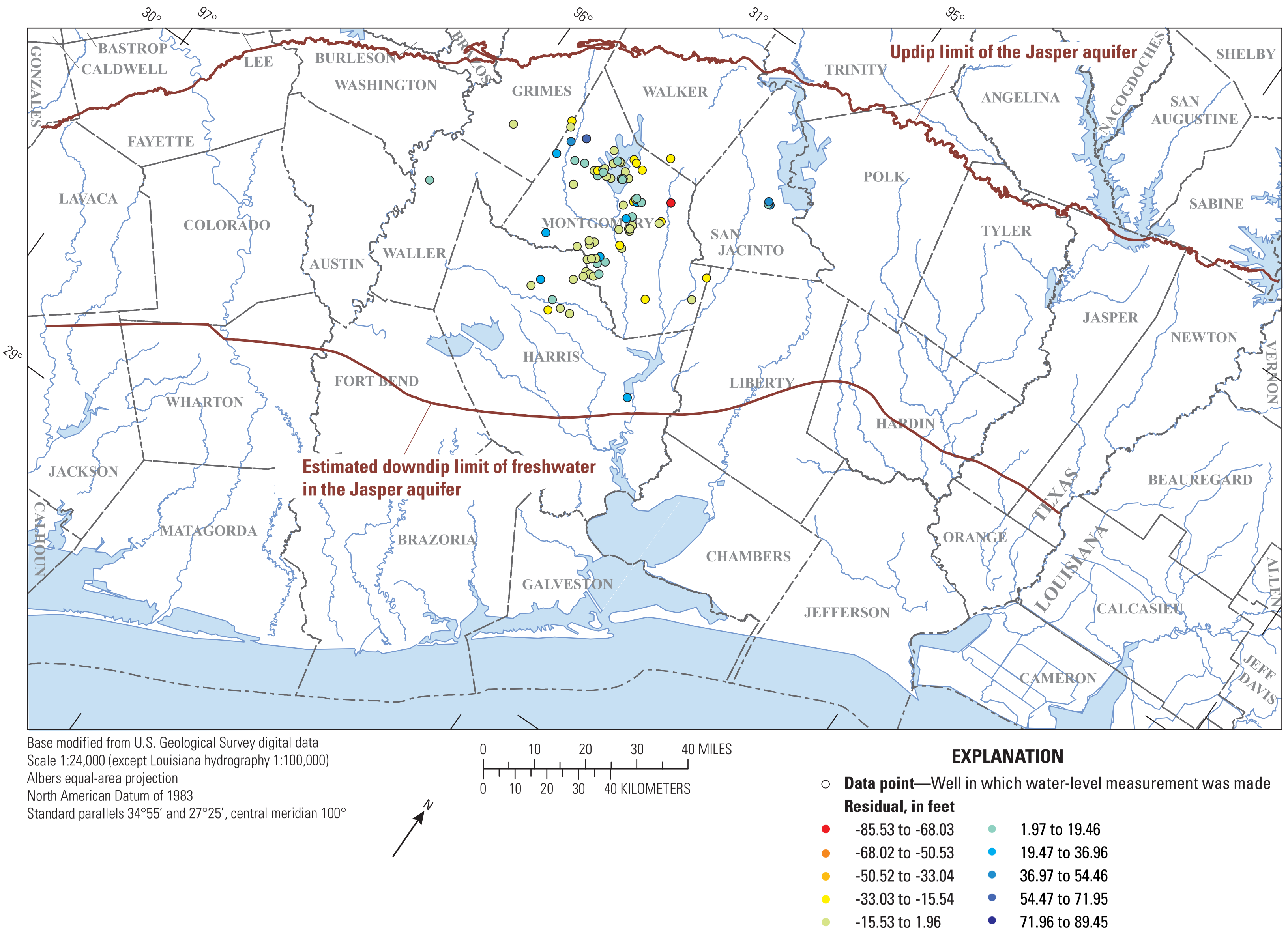


Figure 25. Spatial distribution of water-level (head) residuals (measured minus simulated heads) for the Jasper aquifer, 2009, in the Houston Area Groundwater Model study area.

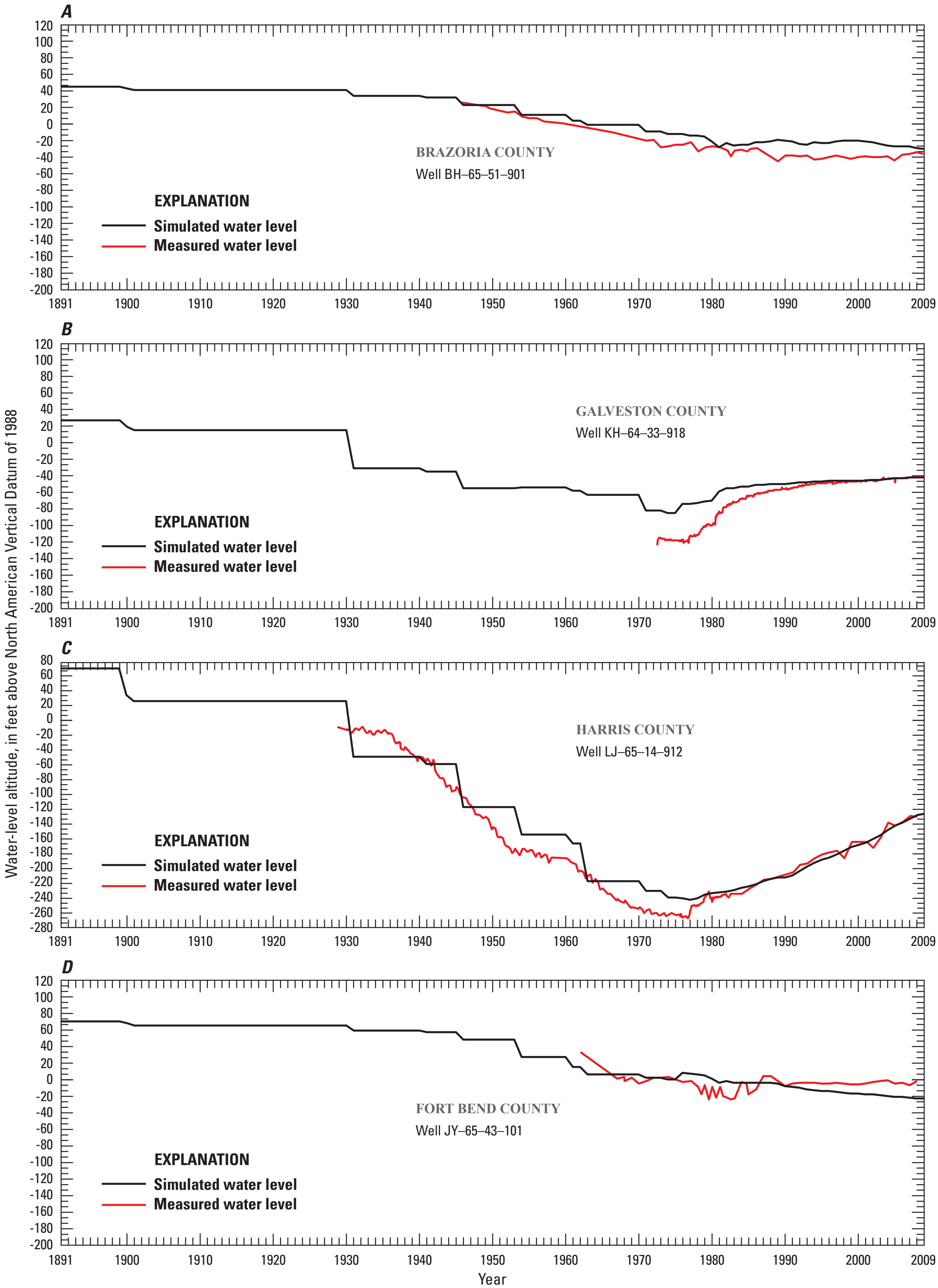


Figure 26. Hydrographs showing simulated and measured water levels in selected observation wells screened in the Chicot aquifer in *A*, Brazoria, *B*, Galveston, *C*, Harris, and *D*, Fort Bend Counties in the Houston Area Groundwater Model study area.

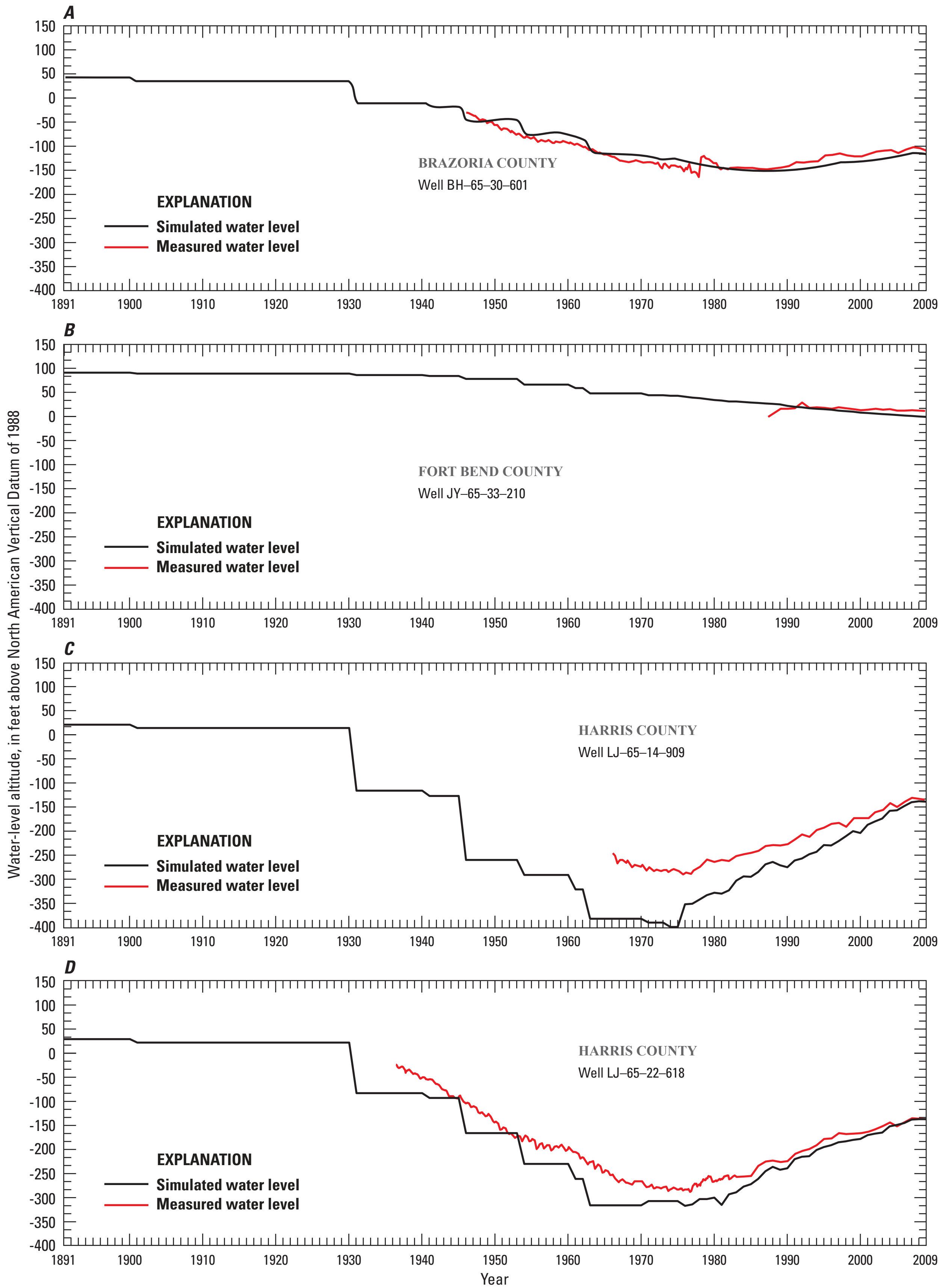


Figure 27. Hydrographs showing simulated and measured water levels in selected observation wells screened in the Evangeline aquifer in *A*, Brazoria, *B*, Fort Bend, and *C*, *D*, Harris Counties in the Houston Area Groundwater Model study area.

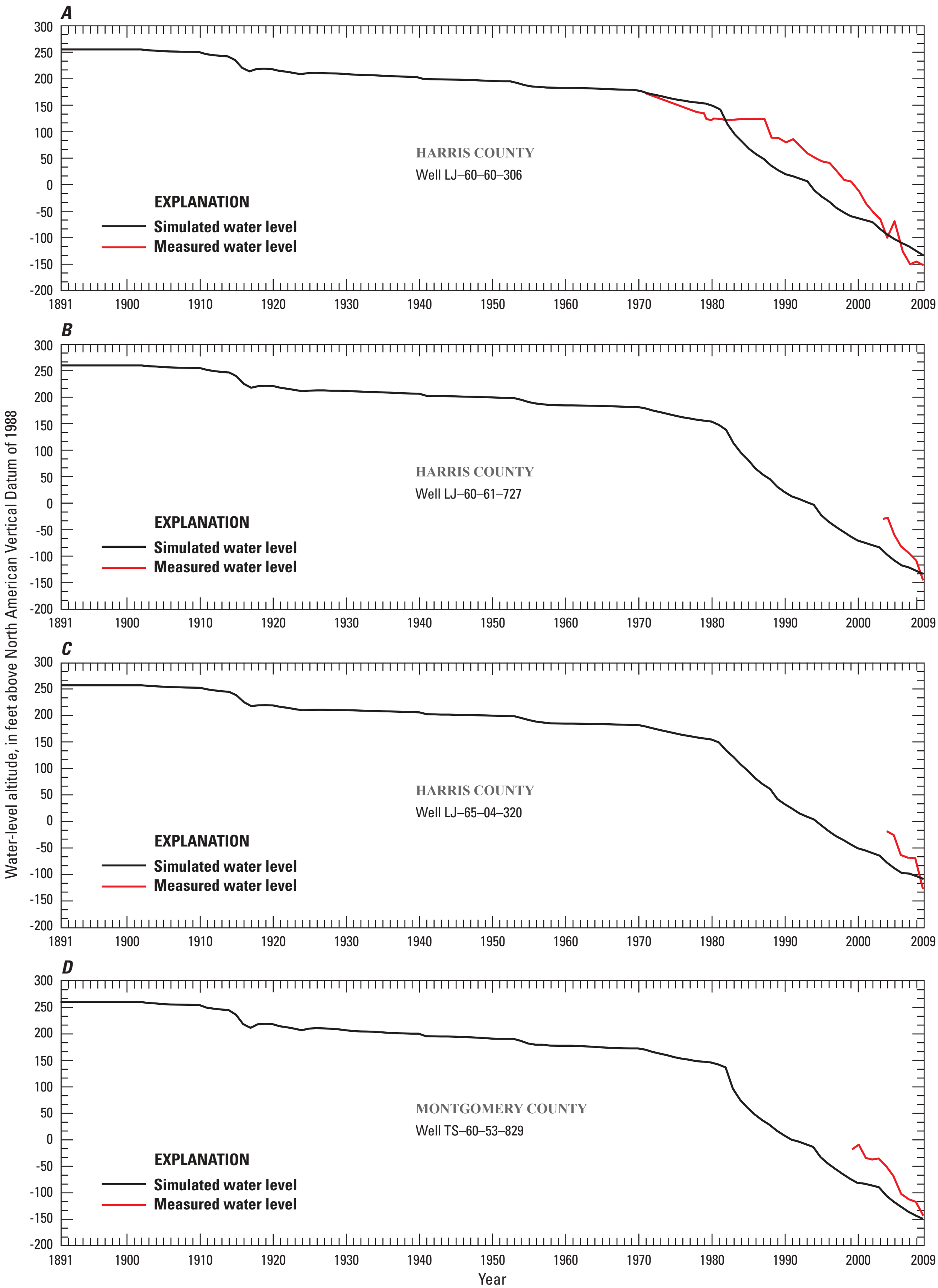
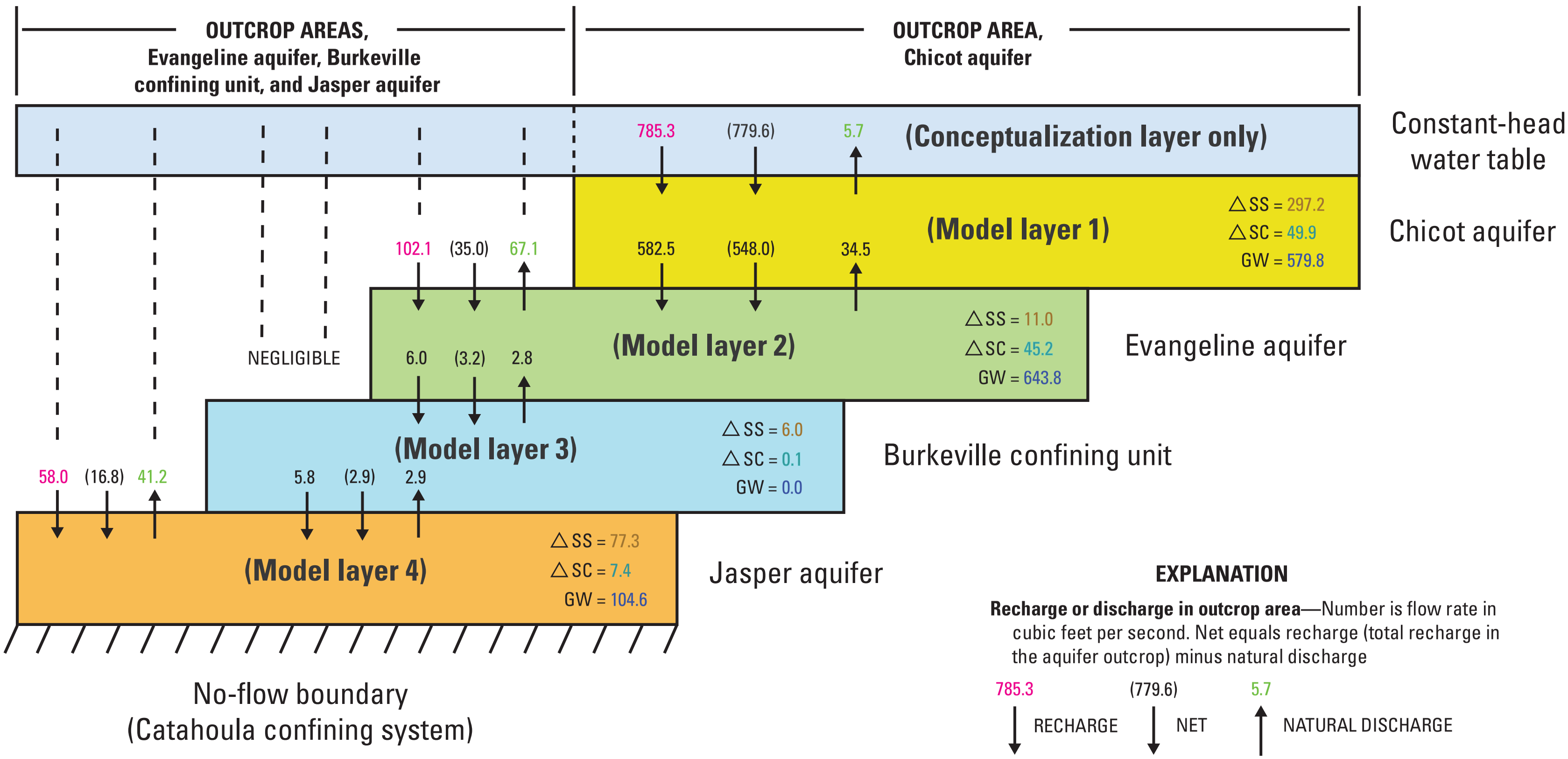


Figure 28. Hydrographs showing simulated and measured water levels in selected observation wells screened in the Jasper aquifer in *A*, *B*, *C*, Harris and *D*, Montgomery Counties in the Houston Area Groundwater Model study area.



WATER BALANCE[1]

RECHARGE + △SS + △SC = NATURAL DISCHARGE + GW

945.4 + 391.5 + 102.5 = 114.0 + 1,328.2

1,439.4 = 1,442.2

[1] 2.8 cubic feet per second difference because of numeric rounding.

EXPLANATION

Recharge or discharge in outcrop area—Number is flow rate in cubic feet per second. Net equals recharge (total recharge in the aquifer outcrop) minus natural discharge

785.3 ↓ RECHARGE (779.6) ↓ NET 5.7 ↑ NATURAL DISCHARGE

Leakage through top or bottom of vertically adjacent hydrogeologic units—Number is flow rate in cubic feet per second. Net equals downward minus upward

582.5 ↓ DOWNWARD (548.0) ↓ NET 34.5 ↑ UPWARD

△SS Net rate of water depleted from coarse-grained sediments, in cubic feet per second

△SC Net rate of water released from clay storage (clay compaction), in cubic feet per second

GW Groundwater withdrawal rate, in cubic feet per second

Figure 29. Simulated 2009 water-budget components of the hydrogeologic units of the Houston Area Groundwater Model.

Table 4. Volumetric budget for the Houston Area Groundwater Model at the end of stress period 78, 2009.

[ft^3/day, cubic feet per day; E, exponent]

Cumulative volumetric budget	Sand storage	Groundwater withdrawal	Recharge and natural discharge	Clay storage	Total volume
Volume inflow (ft^3/day)	1.016E+12	0.000E+00	7.701E+13	4.416E+11	7.846E+13
Volume outflow (ft^3/day)	1.496E+11	2.580E+12	7.563E+13	5.290E+09	7.836E+13
Cumulative volumetric percent error					0.13
2009 volumetric budget					
Volume inflow (ft^3/day)	3.474E+07	0.000E+00	8.168E+07	9.112E+06	1.255E+08
Volume outflow (ft^3/day)	9.169E+05	1.148E+08	9.850E+06	4.234E+04	1.256E+08
2009 volumetric percent error					-0.03

An additional approach of simulating subsidence in Harris, Galveston, and Fort Bend Counties was the use of PRESS models developed by Helm (1975; 1976a, b; 1978). This model solves the Terzaghi equations of consolidation based on constant, one-dimensional total stress and transient changes of pore pressure at specific sites (Kasmarek and Strom, 2002). PRESS models were developed for 26 sites (fig. 32) by Freese and Nichols Inc. (Mike Reedy, Freese and Nichols Inc., written commun., 2011). For each PRESS site, a hydrograph was created by using coincident model cells of the simulated water-level data of the HAGM, and a value of subsidence was determined. A good correlation exists between the PRESS and HAGM simulated subsidence values. For example, the Pasadena site (fig. 32) indicates a PRESS determined subsidence value of 10.523 ft, and immediately adjacent to that site is a HAGM-simulated isolated 10-ft contour. Because the PRESS site locations (shown as polygons on fig. 32) encompass numerous model cells and may or may not extend across individual subsidence contours, a direct cell-by-cell or contour comparison is not a feasible evaluation. Instead, a more general areal comparison is appropriate.

Sensitivity Analysis

The sensitivity of calibrated model responses to changes in input data (the aquifer properties that control flow, recharge [general head boundary in the HAGM], discharge, subsidence, and storage, plus withdrawals) was evaluated. The values of selected model input data were iteratively and individually varied over ranges that may reflect plausible uncertainty (potential lack of accuracy of estimated or simulated values) in a series of simulations to present the effects of the uncertainty on simulated heads and subsidence. The effects of those changes on simulated 2009 water levels and land-surface subsidence were measured in terms of increases in RMSE (figs. 33 and 34, respectively). The plots depicting sensitivity of simulated water levels to changes in selected calibrated model input data (fig. 33) indicate that the model is more sensitive to groundwater withdrawals than to inelastic-clay storativity. In contrast, the plots depicting sensitivity of simulated land-surface subsidence to changes in selected calibrated model input data (fig. 34) indicate that the model is more sensitive to both groundwater withdrawals and sand storativity than to leakance. This analysis has implications if the HAGM is used for prediction of aquifer responses to future stresses. For example, the plots on figures 33 and 34 indicate that accurate estimates of withdrawals are more important to reliable predictions of heads and subsidence compared to accurate estimates of sand storativity.

Model Limitations

Several factors limit, or detract from, the ability of the HAGM to reliably simulate aquifer responses to groundwater withdrawals. The HAGM, like any nonlinear numeric model, is a simplification of the actual, complex aquifer system it simulates. As Brooks and others (1994) explain, simplification not only is necessary to make the problem tractable but also is necessary because the structure, properties, modeled boundaries, and stresses on the aquifer system can never be fully known. Simplifications involve assumptions about the actual system and the way it functions. Knowledge (or lack of knowledge) of the system is reflected in the quality and quantity of input data. The scale of the model, which is associated with the necessity to discretize a continuous system in space, also affects the ability of a model to produce reliable results.

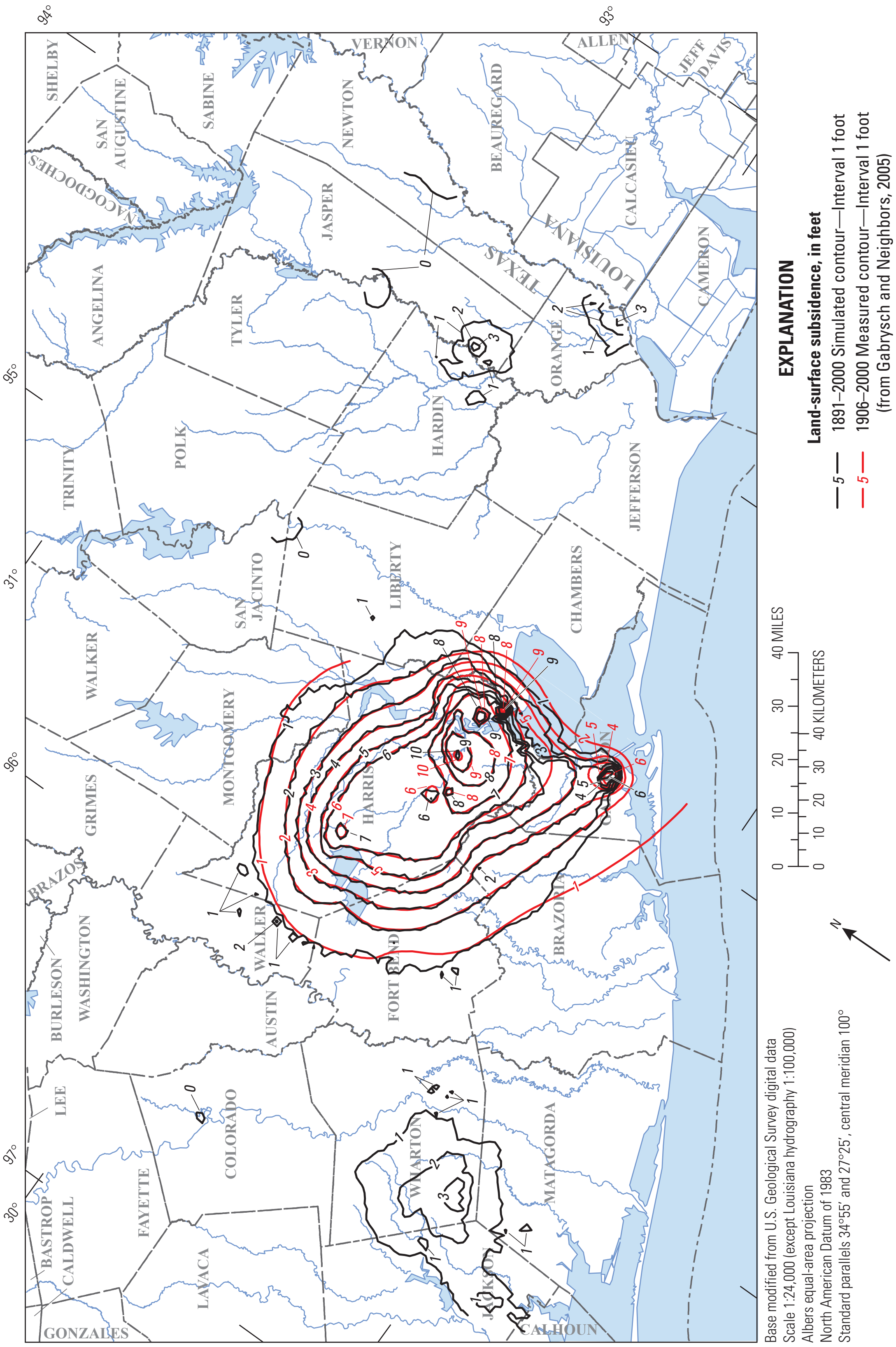


Figure 30. Simulated (1891–2000) and measured (1906–2000) land-surface subsidence in the Houston Area Groundwater Model study area.

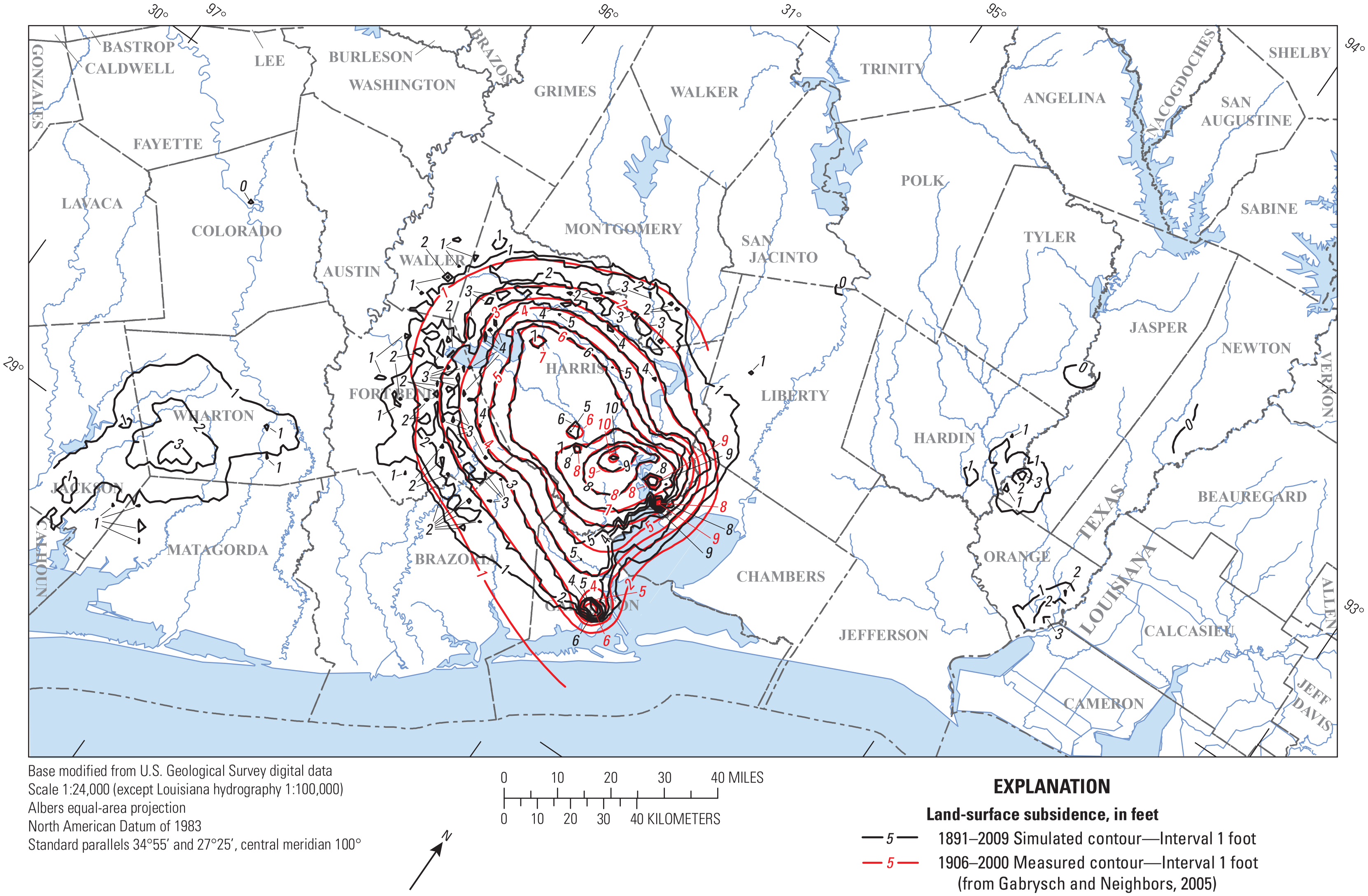


Figure 31. Simulated (1891–2009) and measured (1906–2000) land-surface subsidence in the Houston Area Groundwater Model study area.

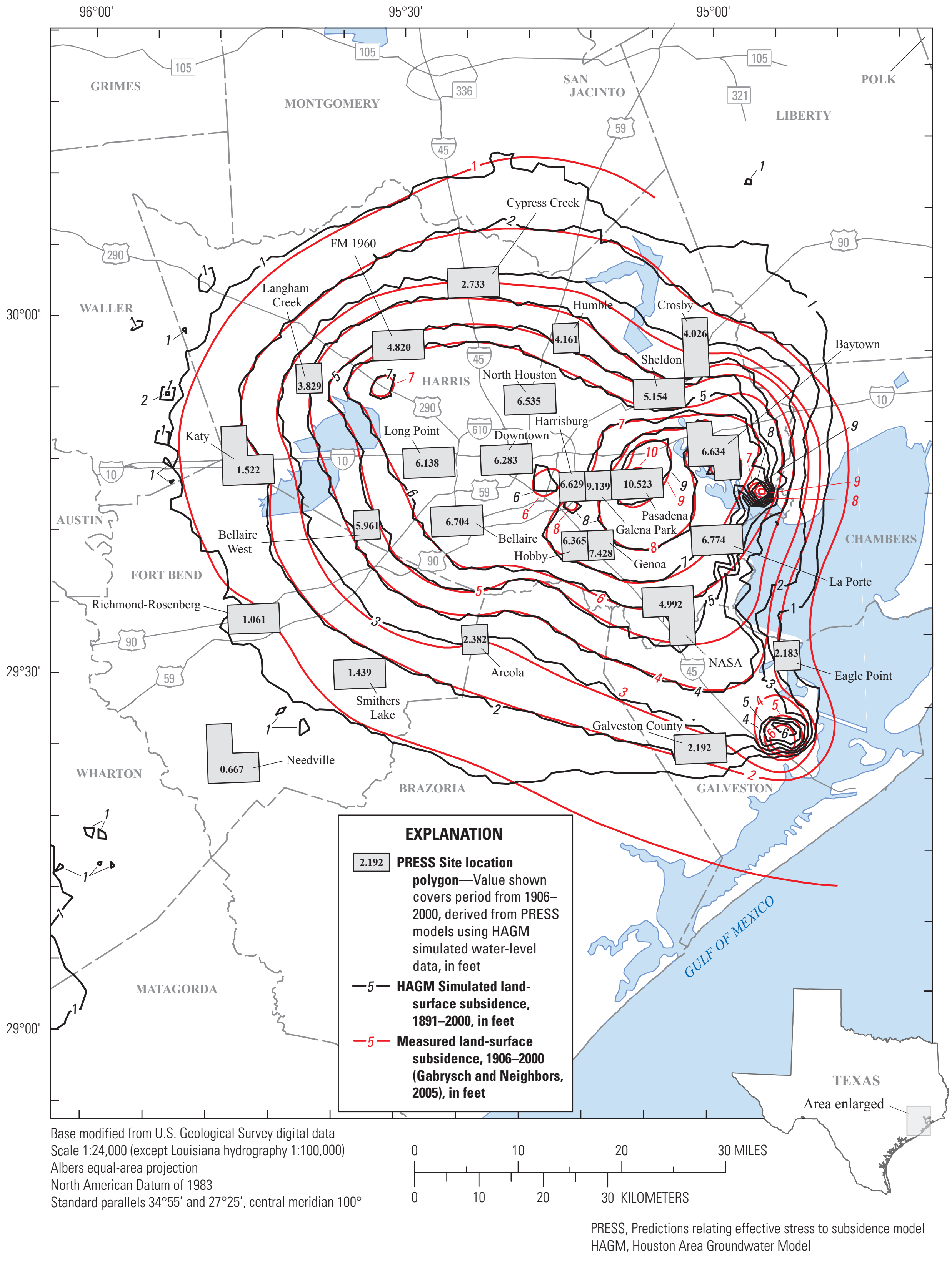


Figure 32. Predictions Relating Effective Stress to Subsidence (PRESS) model site locations and PRESS simulated land-surface subsidence, 1906–2000 (Mike Reedy, Freese and Nichols Inc., written commun., 2011), and Houston Area Groundwater Model simulated land-surface subsidence (1891–2009) and measured land-surface subsidence (1906–2000) in the Houston Area Groundwater Model study area.

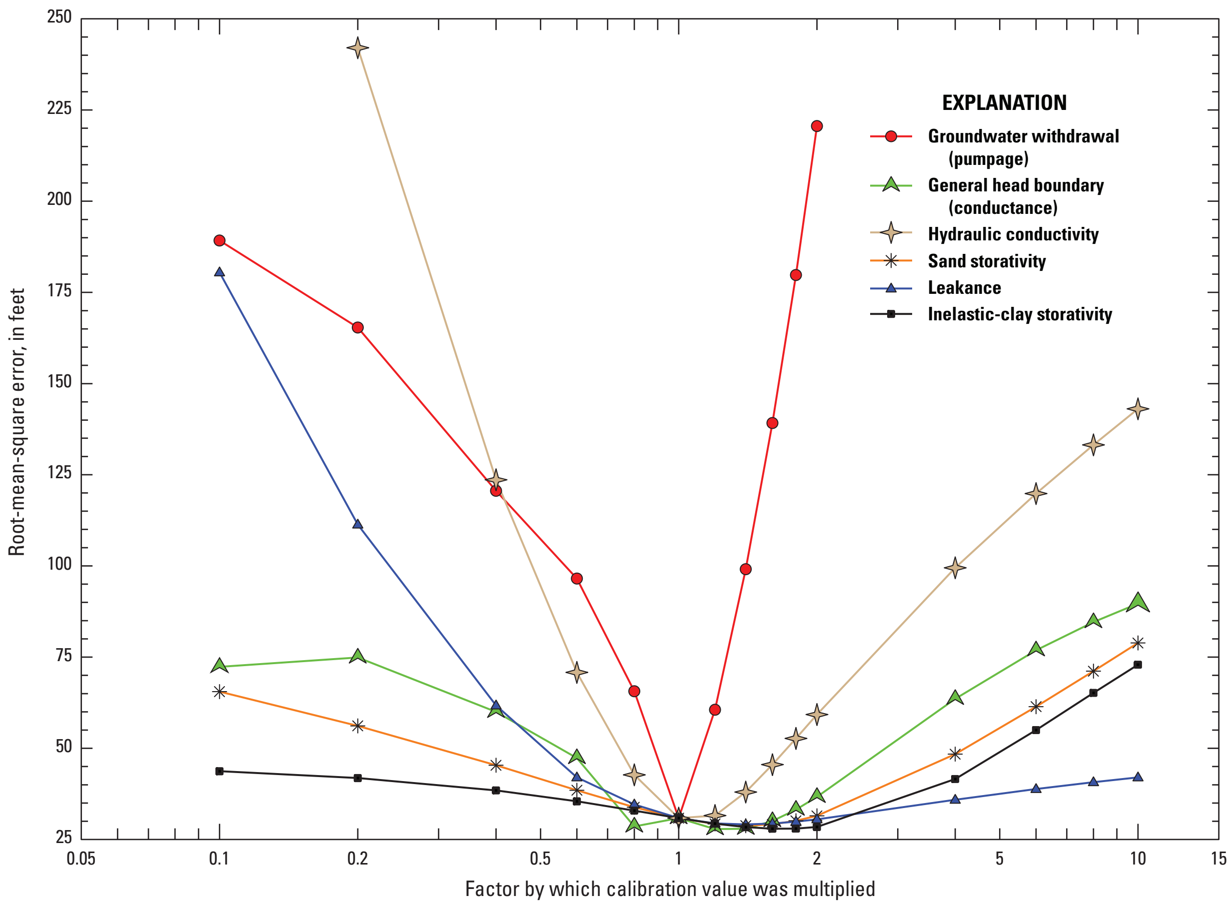


Figure 33. Sensitivity of simulated water levels to changes in selected calibrated model input data of the Houston Area Groundwater Model.

Assumption

A basic assumption is that the hydrogeologic units of the Gulf Coast aquifer system can be adequately represented by four discrete layers. This simplification is made because in the actual aquifer system the change from one aquifer to another with depth likely is transitional rather than abrupt. Other assumptions pertain to the boundary conditions. The conceptualization of the downdip boundaries of each hydrogeologic unit as the downdip limit of freshwater flow probably is realistic—salinity increases and flow becomes increasingly sluggish with distance downdip in each unit; however, the simplifying assumption that the downdip limit of freshwater flow in each unit is a sharp interface across which no flow occurs, the position of which is known and static over time, is more tenuous, as was discussed in the section "Hydrogeologic Units and Geologic Setting." The assumption of the southwestern and northeastern aquifer-system boundaries as no-flow, coincident with the Lavaca and Sabine Rivers, respectively, is not entirely realistic. Although those rivers likely represent effective groundwater-flow divides in the shallow subsurface, the vertical extent of their influence on groundwater flow is unknown. Those lateral boundaries are far enough from areas of major withdrawals, however, so that they likely have negligible influence on the simulated response of the aquifer to withdrawals. The base of the Jasper aquifer is assumed to be a no-flow boundary, although in the actual aquifer system, a relatively small amount of water probably flows between the Jasper aquifer and the underlying Catahoula confining system. Another assumption is that in areas of large withdrawals and substantial declines in the potentiometric surface of an aquifer, the overlying water table has not declined in response to increased downward gradients; water-table heads are held constant during simulations. If this assumption is not valid, then more recharge than actually occurs in the actual system could be simulated in such areas, which also could result in simulated heads higher than actual heads. Although the validity of this assumption has not been studied, that annual rainfall is likely sufficient to keep any actual long-term water-table declines to a minimum. As noted in the section on "Land-Surface Subsidence and Storage in Clays," assuming a constant-head water table also means constant geostatic pressure, which in turn makes changes in effective stress a function only of changes in head. If the

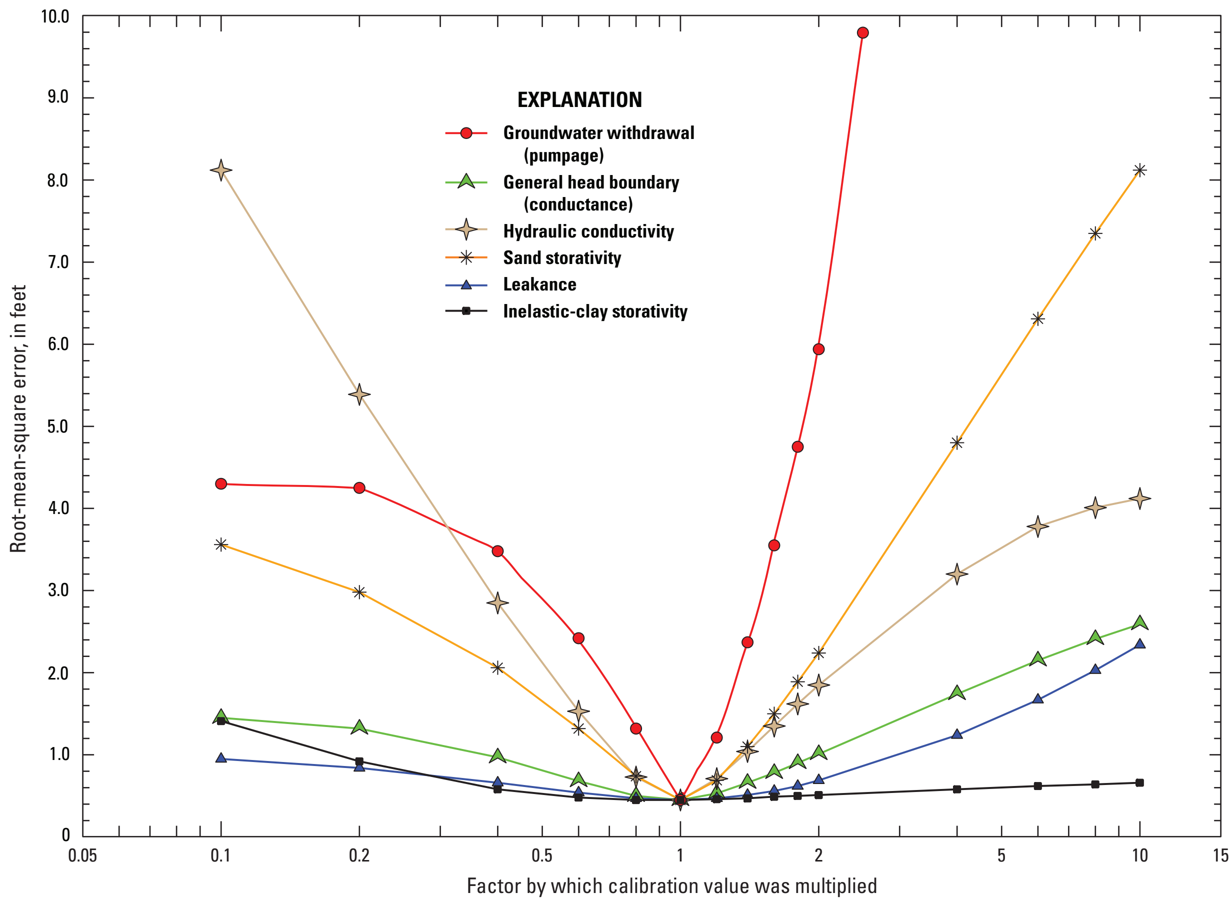


Figure 34. Sensitivity of simulated land-surface subsidence to changes in selected calibrated model input data of the Houston Area Groundwater Model.

assumption of a constant water table was not valid and the water table in the actual system was to decline appreciably, then the model could overestimate effective stress and thus overestimate compaction (subsidence). Also pertaining to the simulation of land-surface subsidence, the assumption was made that head changes within a model time step in the aquifer sands are the same as those in the interbedded clays; in other words, head changes in the clays do not lag those in the sands. If simulated time steps are too short to allow for dissipation of all excess-residual-pore pressure in the clays of the actual system, then the amount of water released by the clays in the simulated system will be unrealistically large for the time step. Leake and Prudic (1991, p. 7) provide an equation for the upper limit on the time required for excess-residual-pore pressure in the actual system to dissipate on the basis of interbedded clay properties, which can be compared to the length of model time steps. Computations for the interbedded clays in the aquifer system indicate that excess-residual-pore pressure will dissipate in about 300 days. Thus the 1-year model time steps that were applied for all of the transient period except for 1980, 1982, and 1988 appear to be adequate, but the 1-month model time steps during those 3 years probably are not, which implies that the simulated amount of water released by the clays for each of those 3 years probably is greater than the actual amount.

Input Data

Associated with each of the input datasets is a level of uncertainty and a degree of bias, neither of which is quantitatively known. The uncertainty arises from the fact that point measurements or estimates of the input data represent regions around the points. The bias originates from the facts that some properties are better known than others are and individual properties are better known in some areas than in others (data points commonly are concentrated in some areas and are sparse in others). The result is that the optimum (but non-unique) spatial distributions of input data arrived at through calibration, or history matching, are distributions of effective properties, not actual properties; that is, the set of property distributions for the calibrated model is one of potentially many plausible sets that would allow simulated heads, subsidence, and water-budget components to reasonably match those of the actual system under selected conditions. In all likelihood, the property distributions reflect the order of magnitude of the actual-system properties but not the true distributions of the actual-system properties. For example, the simulated spatial distributions of hydraulic conductivity of the Chicot, Evangeline, and Jasper aquifers (figs. 9–11), while generally of the correct orders of magnitude, indicate larger values and generally more “definition” in areas coincident with large withdrawals. The distributions reflect the availability of more historical information for those areas and thus more attention to those areas during calibration. It is likely that if comparable groundwater development, subsurface information, head data, and calibration attention were focused on the system in other parts of the HAGM study area, the distributions of hydraulic conductivity in those areas would reflect that situation and be different from the distributions of figures 9, 10, and 11. What can be said about the spatial distributions of aquifer-system properties after calibration is that, collectively, they are one set of probably multiple sets of input data that allows the model to reasonably reproduce selected historical heads, land-surface subsidence, and groundwater flow. The possibility of multiple sets of input data implies that the reliability of the model for predictive simulation is uncertain.

Scale of Application

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 area into 1-mi^2 grid blocks in which aquifer properties and conditions are assumed to be averages over the area of each grid block precludes site-specific analyses. For example, the simulated head in a grid block encompassing one or more pumping wells will represent an average head in the actual grid-block area rather than the head at or near the pumping well, which is much lower. An implication of simulated areal average heads is that, for calibration, comparison of simulated heads to measured heads might not always be comparable. Although explicit care is taken to ensure that static (nonpumping) water-level data are collected, undoubtedly some measured heads are influenced by nearby pumping or by antecedent pumping conditions or for other reasons are not representative of an average head in the grid-block area. Another scale-related issue—the “scale problem” as defined by Johnston (1999)—was described in the “Groundwater-Flow Conditions, Recharge, and Discharge” section. Because flow that enters and exits the actual system within the area encompassed by a single grid block cannot be simulated except by superposition of sources or sinks, which would be impractical over a regional area, the model does not simulate total recharge (and thus total [actual-system] groundwater flow). The fraction of total flow simulated is unknown, but the fraction of total flow simulated decreases as the grid-block size increases. This unknown flow fraction implies that any simulated components of flow not explicitly specified (for example, natural recharge and discharge) will be less than their actual-system counterparts. Explicitly specified components (for example, withdrawals) are based on measured or estimated actual-system data and therefore will more closely approximate actual-system magnitudes.

Summary

The availability of groundwater for municipal, industrial, and agricultural uses, as well as the potential subsidence associated with groundwater use, has been a concern in the Houston, Texas, area for decades. In cooperation with the Harris–Galveston Subsidence District, Fort Bend Subsidence District, and Lone Star Groundwater Conservation District, the U.S. Geological Survey developed and calibrated the Houston Area Groundwater Model (HAGM). Groundwater flow and land-surface subsidence in the northern part of the Gulf Coast aquifer system in Texas from predevelopment (before 1891) through 2009 were simulated; the objective of the HAGM is to accurately simulate and provide reliable, timely data on groundwater availability and land-surface subsidence in the Houston area through 2009. Results from the HAGM can be used to simulate aquifer response (changes in water levels and clay compaction) to future estimated water demands.

In a generalized conceptual model of the Gulf Coast aquifer system, the fraction of precipitation that does not evaporate, transpire through plants, or run off the land surface to streams enters the groundwater-flow system in topographically high updip outcrop areas of the hydrogeologic units in the northwestern part of the system. Most precipitation infiltrating into the saturated zone flows relatively short distances through shallow zones and then discharges to streams. The remainder of the water flows to intermediate and deep zones of the system southeastward of the outcrop areas where it is discharged by wells (in the developed system) and by upward leakage in topographically low areas near or along the coast. Because groundwater flow was simulated in the HAGM only as far as the downdip limit of freshwater, only the parts of the hydrogeologic units containing freshwater are described in this report.

The HAGM was developed to simulate groundwater flow and land-surface subsidence in the northern Gulf Coast aquifer system (Chicot aquifer, Evangeline aquifer, Burkeville confining unit, and Jasper aquifer) from predevelopment (1891) through 2009. The finite-difference computer code MODFLOW-2000 was used in this application. The finite-difference grid for the numerical model covers 33,565 square miles in southeastern Texas and southwestern Louisiana. The model grid was rotated 37.6 degrees clockwise so that the orientation of the model closely coincides with the natural groundwater divides, model boundaries, and predevelopment and postdevelopment flow paths. The four layers of the model together contain 134,260 grid blocks. Each layer consists of 137 rows and 245 columns. Layer 1 represents the Chicot aquifer, layer 2 the Evangeline aquifer, layer 3 the Burkeville confining unit, and layer 4 the Jasper aquifer. The grid blocks are uniformly spaced with each model cell area equal to

1 square mile. The MODFLOW General-Head Boundary package was used to simulate recharge and discharge in the outcrops of the Chicot, Evangeline, and Jasper aquifers and the Burkeville confining unit. This package allows the water table of an aquifer system to function as a head-dependent flux. Initial conditions, including heads and hydraulic properties, provided a starting point for the model simulation. The initial conditions for head and hydraulic properties were coincident with the calibrated groundwater flow model previously created (2004) for the northern Gulf Coast by the USGS and cooperators.

Simulation of land-surface subsidence (actually, compaction of clays) and release of water from storage in the clays of the Chicot, Evangeline, and Jasper aquifers and the Burkeville confining unit was accomplished by using the Subsidence and Aquifer-System Compaction package designed for use with MODFLOW-2000. Simulations were made under transient conditions from 1891 through 2009 for 78 withdrawal (stress) periods of variable length. Total groundwater withdrawals increased from an estimated 41 million gallons per day in 1891 to about 869 million gallons per day in 2009.

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, land-surface subsidence, selected water-budget components) reasonably reproduced field measured aquifer responses.

Calibrated model parameters from each layer within the GAM and HAGM were compared to identify any differences in values. Generally, the additional data available in the model area since the development of the GAM required substantial modification of GAM parameters, particularly in the Jasper aquifer, for a complete calibration. Maximum general-head boundary conductance in the Chicot aquifer was reduced by more than two orders of magnitude, whereas general-head boundary conductance values in the other model layers remained unchanged. Inelastic-clay storativity maximum and minimum values varied slightly between the two models in the Chicot and Evangeline aquifers but were of a consistent magnitude. Minimum hydraulic conductivity values decreased about two orders of magnitude in the Chicot aquifer, increased less than an order of magnitude in the Evangeline aquifer, and increased about three orders of magnitude in the Jasper aquifer. Maximum hydraulic conductivity values decreased nearly two orders of magnitude in the Chicot and less than one order of magnitude in the Evangeline and Jasper aquifers. Spatial distributions of simulated parameters of specific storage and leakance were similar between the GAM and HAGM calibrated models.

Hydraulic conductivities of the Chicot aquifer ranged from 4.0×10^{-3} to 39.91 feet per day (ft/d), with the larger values located in Harris, Fort Bend, Liberty, Chambers, Galveston, Wharton, Colorado Tyler, Jasper, and Newton Counties. Hydraulic conductivities of the Evangeline aquifer ranged from 3.9×10^{-1} to 30.79 ft/d, with largest values located in northeast Fort Bend County. Hydraulic conductivities of the Burkeville confining unit are coincident with values used in the GAM. Hydraulic conductivities of the Jasper aquifer ranged from 1.0×10^{-2} to 19.67 ft/d, with the larger values located in northern Harris and Montgomery Counties.

Simulated sand storativities of the Chicot and Evangeline aquifers (2×10^{-3} to 1.56×10^{-1} and 1×10^{-3} to 1.82×10^{-1}, respectively) reflect aquifer conditions from confined to semiconfined to water table. Sand storativities of the Chicot and Evangeline aquifers generally are largest in the updip, outcrop areas where water-table conditions prevail. Storativities of the Burkeville confining unit are coincident with values used in the GAM. Storativities of the Jasper aquifer (4.1×10^{-6} to 2.01×10^{-1}) are generally largest in the updip, outcrop areas associated with water-table conditions.

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-clay storativity. Inelastic-clay storativities for the Chicot aquifer, the Evangeline aquifer, the Burkeville confining unit, and the Jasper aquifer range from 5.3×10^{-6} to 1.49×10^{-2}, from 2.28×10^{-7} to 1.49×10^{-1}, from 2.05×10^{-6} to 9.24×10^{-5}, and from 1.0×10^{-6} to 9.47×10^{-4}, respectively. A total of 474 sites located in Harris and surrounding counties were used to evaluate simulated subsidence compared to measured subsidence. After numerous iterative trial-and-error transient model simulations, the final land-surface subsidence RMSE was 0.37 ft.

The simulated potentiometric surfaces of the Chicot, Evangeline, and Jasper aquifers for 2009 indicate general agreement with the measured potentiometric surfaces. The RMSE of the three aquifer potentiometric surfaces for 2009 were 31.06 ft for the Chicot aquifer, 33.73 ft for the Evangeline aquifer, and 23.32 ft for the Jasper aquifer. The RMSE were about 8, 6, and 6 percent, respectively, for the total range in simulated heads for the three aquifers, with a -0.03 percent water-budget difference between the total simulated inflow and the total simulated outflow.

Hydrographs were used to compare simulated and measured water levels; selected water wells with screened intervals in the Chicot, Evangeline, and Jasper aquifers match closely relative to the ranges of water-level change. Simulated water budget components for 2009 indicate that a net recharge (total recharge minus natural discharge) of 779.6 cubic feet per second (ft^3/s) (about 0.56 inches per year [in./yr]) in the Chicot aquifer outcrop, 35.0 ft^3/s (about 0.68 in./yr) in the Evangeline aquifer outcrop, negligible net recharge in the Burkeville confining unit outcrop, and 16.8 ft^3/s (about 0.26 in./yr) in the Jasper aquifer outcrop. For the entire system, the simulated total recharge for 2009 was 945.4 ft^3/s (about 0.51 in./yr).

In Harris County and counties immediately adjacent, where the main area of subsidence has been measured, the 1891–2000 simulated subsidence matches closely with the 1906–2000 measured subsidence. As much as 10 ft of subsidence has occurred in southeastern Harris County near the northern end of Galveston Bay. A larger geographic area encompassing the maximum land-surface subsidence area and much of central to southeastern Harris County has subsided at least 6 ft. Again, in Harris County and counties immediately adjacent, where the main area of subsidence is present, the 1891–2009 simulated subsidence matches closely with the 1906–2000 measured subsidence, but not as closely as the simulated subsidence for 1891–2000. The most recent areas of subsidence are approximately located in southern Montgomery, northwest Harris, and Fort Bend Counties, where development has occurred and required sustained groundwater withdrawals during 2001–9.

An additional approach of simulating and predicting subsidence in Harris, Galveston, and Fort Bend Counties was the use of Predictions Relating Effective Stress to Subsidence (PRESS) model. For each PRESS site, a hydrograph was created by using coincident model cells of the simulated water-level data of the HAGM, and a value of subsidence was determined. A good correlation exists between the PRESS and HAGM simulated subsidence values. For example, at the Pasadena PRESS site, the simulated value is 10.523 ft and the site is located immediately adjacent to a HAGM-simulated isolated 10 ft contour.

The sensitivity of calibrated-model responses to changes in input data (the aquifer properties that control flow, recharge, discharge, subsidence, and storage, plus withdrawals) was evaluated. The HAGM sensitivity results indicate that accurate estimates of hydraulic conductivity and withdrawals are more important to reliable predictions of heads and subsidence compared to accurate estimates of sand storativity.

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.

Associated with each of the input datasets are a level of uncertainty and a degree of bias, neither of which is quantitatively known. The uncertainty arises from the fact that point measurements or estimates of the input data represent regions around the points. The bias originates from the facts that some properties are better known than others are and individual properties are better known in some areas than in others (data points commonly are concentrated in some areas and are sparse in others). The result is that the optimum (but non-unique) spatial distributions of input data arrived at through calibration, or history matching, are distributions of effective properties, not actual properties; that is, the set of property distributions for the calibrated model is one of potentially many plausible sets that would allow simulated heads, subsidence, and water-budget components to reasonably match those of the actual system under selected conditions.

A basic assumption is that the hydrogeologic units of the Gulf Coast aquifer system can be adequately represented by four discrete layers, a simplification because, in the actual system, the change from one aquifer to another with depth likely is transitional rather than abrupt. Downdip salinity changes and lateral boundary conditions also are not absolutely known.

References

Ashworth, J.B., and Hopkins, Janie, 1995, Aquifers of Texas: Texas Water Development Board Report 345, 69 p.

Baker, E.T., Jr., 1979, Stratigraphic and hydrogeologic framework of part of the Coastal Plain of Texas: Texas Department of Water Resources Report 236, 43 p.

Baker, E.T., Jr., 1986, Hydrology of the Jasper aquifer in the southeast Texas Coastal Plain: Texas Water Development Board Report 295, 64 p.

Beckman, J.D., and Williamson, A.K., 1990, Salt-dome locations in the Gulf Coastal Plain, south-central United States: U.S. Geological Survey Water-Resources Investigations Report 90–4060, 44 p.

Brooks, R.J., Lerner, D.N., and Tobias, A.M., 1994, Determining the range of predictions of a groundwater model which arises from alternative calibrations: Water Resources Research, v. 30, no. 11, p. 2993–3000.

Carr, J.E., Meyer, W.R., Sandeen, W.M., and McLane, I.R., 1985, Digital models for simulation of groundwater hydrology of the Chicot and Evangeline aquifers along the Gulf Coast of Texas: Texas Department of Water Resources Report 289, 101 p.

Doyel, W.W., and Winslow, A.C., 1954, Pumpage of ground water and decline of artesian pressure in the Houston District, Texas, during 1951 and 1952: Texas Board of Water Engineers Bulletin 5401, 28 p.

Espey, Huston and Associates Inc., 1982, Phase II—Water management study: Prepared for Harris–Galveston Coastal Subsidence District, Friendswood, Texas [variously paged].

Federal Aviation Agency, 2007, Information for Operators: Accessed July 5, 2012, at: http://www.faa.gov/other_visit/aviation_industry/airline_operators/airline_safety/info/all_infos/media/2007/info07008.pdf.

Fort Bend Subsidence District, 2010, Fort Bend Subsidence District 2003 regulatory plan: 14 p., accessed May 11, 2010, at http://www.fbsubsidence.org/assets/pdf/FBRegPlan.pdf.

Franke, O.L., Reilly, T.E., and Bennett, G.D., 1987, Definition of boundary and initial conditions in the analysis of saturated groundwater flow systems—An introduction: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. B5, 15 p.

Freeze, R.A., and Cherry, J.A., 1979, Groundwater: Englewood Cliffs, N.J., Prentice-Hall, 604 p.

Fugro–McClelland (Southwest) Inc., 1997, Recalibration of PRESS models and development of two new models in Harris and Galveston Counties: Report no. 0401–3134 [variously paged].

Gabrysch, R.K., 1979, Approximate altitude of water levels in wells in the Chicot and Evangeline aquifers in the Houston area, Texas, spring 1977 and spring 1978: U.S. Geological Survey Open-File Report 79–334, 4 sheets.

Gabrysch, R.K., 1982, Ground-water withdrawals and changes in water levels in the Houston District, Texas, 1975–79: U.S. Geological Survey Open-File Report 82–431, 39 p.

Gabrysch, R.K., and Bonnett, C.W., 1975, Land-surface subsidence in the Houston-Galveston Region, Texas: U.S. Geological Survey in cooperation with the Texas Water Development Board Report 188, 18 p.

Gabrysch, R.K., and Neighbors, R.J., 2005, Measuring a century of subsidence in the Houston-Galveston region, Texas, USA, *in* Seventh International Symposium on Land Subsidence, Shanghai, P.R. China, October 23–28, 2005, Proceedings: p. 379–387.

Galloway, Devin, Jones, D.R., and Ingebritsen, S.E., eds., 1999, Land subsidence in the United States: U.S. Geological Survey Circular 1182, 177 p.

Halbouty, M.T., 1967, Salt domes—Gulf region, United States and Mexico: Houston, Gulf Publishing Co., 425 p.

Harbaugh, A.W., Banta, E.R., Hill, M.C., and McDonald, M.G., 2000, MODFLOW-2000, the U.S. Geological Survey modular groundwater model—User guide to modularization concepts and the groundwater flow process: U.S. Geological Survey Open-File Report 00–92, 121 p.

Harbaugh, A.W., and McDonald, M.G., 1996, User's documentation for MODFLOW–96, an update to the U.S. Geological Survey modular finite-difference groundwater flow model: U.S. Geological Survey Open-File Report 96–485, 56 p.

Harris–Galveston Subsidence District, 2012, Annual Groundwater Report 2012: accessed June 25, 2012, at http://www.hgsubsidence.org/documents/index.html.

Helm, D.C., 1975, One-dimensional simulation of aquifer system compaction near Pixley, California—Part 1, Constant parameters: Water Resources Research, v. 11, no. 3, p. 465–478.

Helm, D.C., 1976a, Estimating parameters of compacting fine grained interbeds within a confined aquifer system for a one dimensional simulation of field observations, *in* Johnson, A.I., ed., Land subsidence: International Association of Hydrological Sciences, Publication 121, p. 145–156.

Helm, D.C., 1976b, One dimensional simulation of aquifer system compaction near Pixley, California—Part 2, Stress dependent parameters: Water Resources Research, v. 12, no. 3, p. 375–391.

Helm, D.C., 1978, Field verification of a one-dimensional mathematical model for transient compaction and expansion of a confined aquifer system, *in* 26th Hydraulic Division Specialty Conference on Verification of Mathematical and Physical Models in Hydraulic Engineering, College Park, Md., Aug. 9–11, 1978, Proceedings: American Society of Civil Engineers, p. 189–196.

Hoffman, J., Leake, S.A., Galloway, D.L., and Wilson, A.M., 2003, MODFLOW-2000 Groundwater Model—User guide to the Subsidence and Aquifer-System Compaction (SUB) Package: U.S. Geological Survey Open-File Report 03–233, 46 p.

Johnston, R.H., 1999 [revised], Hydrologic budgets of regional aquifer systems of the United States for predevelopment and development conditions: U.S. Geological Survey Professional Paper 1425, 34 p.

Jorgensen, D.G., 1975, Analog-model studies of groundwater hydrology in the Houston district, Texas: Texas Water Development Board Report 190, 84 p.

Kasmarek, M.C., 1997, Water-level altitudes in wells completed in the Chicot and Evangeline aquifers, Fort Bend County and adjacent areas, Texas, January–February 1990: U.S. Geological Survey Open-File Report 97–784, 2 sheets.

Kasmarek, M.C., Gabrysch, R.K., and Johnson, M.R., 2009, Estimated land-surface subsidence in Harris County, Texas, 1915–17 to 2001: U.S. Geological Survey Scientific Investigations Map 3097, 2 sheets.

Kasmarek, M.C., and Houston, N.A., 2007, Water-level altitudes 2007 and water-level changes in the Chicot, Evangeline, and Jasper aquifers and compaction 1973–2006 in the Chicot and Evangeline Aquifers, Houston-Galveston Region, Texas: U.S. Geological Survey Scientific Investigations Map 2968, 4 p., 18 sheets.

Kasmarek, M.C., Houston, N.A., and Ramage, J.K., 2009, Water-level altitudes 2009 and water-level changes in the Chicot, Evangeline, and Jasper aquifers and compaction 1973–2008 in the Chicot and Evangeline aquifers, Houston-Galveston region, Texas: U.S. Geological Survey Scientific Investigations Map 3081, 3 p., 16 sheets.

Kasmarek, M.C., and Robinson, J.L., 2004, Hydrogeology and simulation of groundwater flow and land-surface subsidence in the northern part of the Gulf Coast aquifer system, Texas: U.S. Geological Survey Scientific Investigations Report 2004–5102, 111 p.

Kasmarek, M.C., and Strom, E.W., 2002, Hydrogeology and simulation of groundwater flow and land-surface subsidence in the Chicot and Evangeline aquifers, Houston area, Texas: U.S. Geological Survey Water-Resources Investigations Report 02–4022, 61 p.

LBG-Guyton Associates, 1997, Groundwater model review and conversion: Prepared for Harris–Galveston Coastal Subsidence District, Friendswood, Tex., 18 p.

Lang, J.W., and Winslow, A.G. (in collaboration with W.N. White), 1950, Geology and ground-water resources of the Houston district, Texas: Texas State Board of Water Engineers Bulletin 5001, 55 p.

Leake, S.A., and Prudic, D.E., 1991, Documentation of a computer program to simulate aquifer-system compaction using the modular finite-difference groundwater flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A2, 68 p.

Lone Star Groundwater Conservation District, 2010, Lone Star Groundwater Conservation District rules and bylaws: accessed May 11, 2010, at http://www.lonestargcd.org/management_plan.html.

Loskot, C.L., Sandeen, W.M., and Follett, C.R., 1982, Groundwater resources of Colorado, Lavaca, and Wharton Counties, Texas: Texas Department of Water Resources Report 270, 240 p.

McDonald, M.G., and Harbaugh, A.W., 1988, A modular three dimensional finite-difference groundwater flow model: U.S. Geological Survey Techniques of Water-Resources Investigations, book 6, chap. A1, 586 p.

Meyer, W.R., and Carr, J.E., 1979, A digital model for simulation of groundwater hydrology in the Houston area, Texas: Texas Department of Water Resources Limited Publication LP–103, 133 p.

National Oceanic and Atmospheric Administration, 2012a, Tropical Storm Allison Heavy Rains and Floods Texas and Louisiana, June 2001: Accessed June 25, 2012, at http://www.nws.noaa.gov/os/assessments/pdfs/allison.pdf.

National Oceanic and Atmospheric Administration, 2012b, Comparative Climate Data for the United States Through 2011: Accessed June, 26, 2012, at http://www1.ncdc.noaa.gov/pub/data/ccd-data/CCD-2011.pdf.

Noble, J.E., Bush, P.W., Kasmarek, M.C., and Barbie, D.L., 1996, Estimated depth to the water table and estimated rate of recharge in outcrops of the Chicot and Evangeline aquifers near Houston, Texas: U.S. Geological Survey Water-Resources Investigations Report 96–4018, 19 p.

Riley, F.S., 1969, Analysis of borehole extensometer data from central California, *in* Tison, L.J., ed., Land subsidence—Volume 2: International Association of Scientific Hydrology, Publication 89, p. 423–431.

Ryder, P.D., and Ardis, A.F., 2002, Hydrology of the Texas Gulf Coast aquifer systems: U.S. Geological Survey Professional Paper 1416–E, 77 p.

State of Texas Drought Preparedness Plan, 2006, accessed June 24, 2012, at http://www.txdps.state.tx.us/dem/CouncilsCommittees/droughtCouncil/droughtPrepPlan.pdf.

Strom, E.W., Houston, N.A., and Garcia, C.A., 2003a, Selected hydrogeologic datasets for the Chicot aquifer, Texas: U.S. Geological Survey Open-File Report 03–297, 1 CD–ROM.

Strom, E.W., Houston, N.A., and Garcia, C.A., 2003b, Selected hydrogeologic datasets for the Evangeline aquifer, Texas: U.S. Geological Survey Open-File Report 03–298, 1 CD–ROM.

Strom, E.W., Houston, N.A., and Garcia, C.A., 2003c, Selected hydrogeologic datasets for the Jasper aquifer, Texas: U.S. Geological Survey Open-File Report 03–299, 1 CD–ROM.

Tarver, G.R., 1968, Ground-water resources of Polk County, Texas: Texas Water Development Board Report 82, 109 p.

Trescott, P.C., 1975, Documentation of finite-difference model for simulation of three-dimensional groundwater flow: U.S. Geological Survey Open-File Report 75–438, 30 p.

Sandeen, W.M., 1972, Ground-water resources of Washington County, Texas: Texas Water Development Board Report 162, 111 p.

Sellards, E.H., Adkins, W.S., and Plummer, F.B., 1932, The geology of Texas—Volume I, Stratigraphy: Austin, The University of Texas, Bureau of Economic Geology Bulletin 3232, 1,007 p.

Tóth, J., 1963, A theoretical analysis of groundwater flow in small drainage basins: Journal of Geophysical Research, v. 68, no. 16, p. 4795–4812.

Verbeek, E.R., Ratzlaff, K.W., and Clanton, U.S., 1979, Faults in parts of north-central and western Houston metropolitan area, Texas: U.S. Geological Survey Miscellaneous Field Studies Map MF–1136, 1 sheet.

Wesselman, J.B., 1967, Ground-water resources of Jasper and Newton Counties, Texas: Texas Water Development Board Report 59, 177 p.

Wesselman, J.B., 1972, Groundwater resources of Fort Bend County, Texas: Texas Water Development Board Report 155, 176 p.

Williams, T.A., and Williamson, A.K., 1989, Estimating water-table altitudes for regional groundwater flow modeling, U.S. Gulf Coast: Ground Water, v. 27, no. 3, p. 333–340.

Williamson, A.K., Grubb, H.F., and Weiss, J.S., 1990, Ground-water flow in the Gulf Coast aquifer systems, south central United States–A preliminary analysis: U.S. Geological Survey Water-Resource Investigations Report 89–4071, 124 p.

Wood, L.A., 1956, Availability of ground water in the Gulf Coast region of Texas: U.S. Geological Survey unnumbered open-file report, 55 p.

Wood, L.A., Gabrysch, R.K., 1965, Analog model study of groundwater hydrology in the Houston district, Texas, *with a section on* Design, construction, and use of electric analog models, by E.P. Patten, Jr.: Texas Water Commission Bulletin 6508, 103 p.

Wood, L.A., Gabrysch, R.K., and Marvin, Richard, 1963, Reconnaissance investigations of the ground-water resources of the Gulf Coast Region, Texas: U.S. Geological Survey Open-File Report in cooperation with the Texas Water Commission, Bulletin 6305, 114 p.

Publishing support provided by
Lafayette Publishing Service Center

Information regarding water resources in Texas is available at
http://tx.usgs.gov/

USGS

Kasmarek—**Hydrogeology and Simulation of Groundwater Flow and Land-Surface Subsidence in the Northern Part of the Gulf Coast Aquifer System**—SIR 2012–5154

Printed on recycled paper

FREESE AND NICHOLS
Innovative approaches
Practical results
Outstanding service
3100 Wilcrest Drive, Suite 200 • Houston, Texas 77042 • 713-600-6800 • fax 713-600-6801 www.freese.com

TO: Regional Groundwater Update Project Partners

CC:

FROM: William J. Thaman, P.E.

SUBJECT: Regulatory Scenario Development, Analysis, and Results

DATE: October 1, 2012

INTRODUCTION

One of the major components of the Regional Groundwater Update Project (RGUP) is the prediction of subsidence that would result from current and potential future regulations, based on available information and information/modeling developed as part of the RGUP. Impacts are determined by developing and analyzing various regulatory scenarios for the RGUP project partners: Harris-Galveston Subsidence District (HGSD), Fort Bend Subsidence District (FBSD), and Lone Star Groundwater Conservation District (LSGCD).

Each of the RGUP project partners currently have regulations in place that limit the amount of groundwater that their customers can withdraw on an annual basis. The HGSD regulatory plan was adopted in 1999, FBSD's in 2003, and LSGCD's in phases from 2006 through 2010. These regulations were based on now-outdated information and modeling capabilities; the current analysis provides the project partners with a decision making tool that will allow them to update their regulations to reflect up to 10 years of additional water level and subsidence measurements, updated and more detailed population projections based on the 2010 US Census, and more accurate groundwater modeling capabilities.

The regulatory scenario analysis performed under RGUP uses information and groundwater/subsidence models as shown in Table 1.

Table 1. Data and Models Used in RGUP Regulatory Scenario Analysis

Data/Model	Description
2010 Population	2010 U.S. Census. Data at the Census Block level used in this analysis.
2020-2070 Population Projections by Census Tract	2020 projections from Metrostudy, 2030-2070 projections from University of Houston Center for Public Policy. A Census Tract is made up of multiple Census Blocks.
2020-2070 Population Projections by Census Block	Interpolation of Census Tract projections by Freese & Nichols using Houston-Galveston Area Council (H-GAC) parcel-based land use data
Historical Groundwater Level Measurements	Updated to 2009 from US Geological Service (USGS) monitoring wells
Historical Subsidence measurements	Updated to 2009 using HGSD/FBSD subsidence measurement network (benchmarks, extensometers, GPS measurements) data
Groundwater Model	Houston Area Groundwater Model (HAGM) developed in 2012 by USGS and LBG-Guyton. Calibrated to groundwater level measurements 1906-2009
Subsidence Models	PRESS models developed by Fugro and calibrated to historical subsidence 1906-2009

The regulatory areas for each project participant were established in their currently adopted regulatory plans. These regulatory areas, shown in Figure 1, were kept the same in the analysis of RGUP regulatory scenarios.

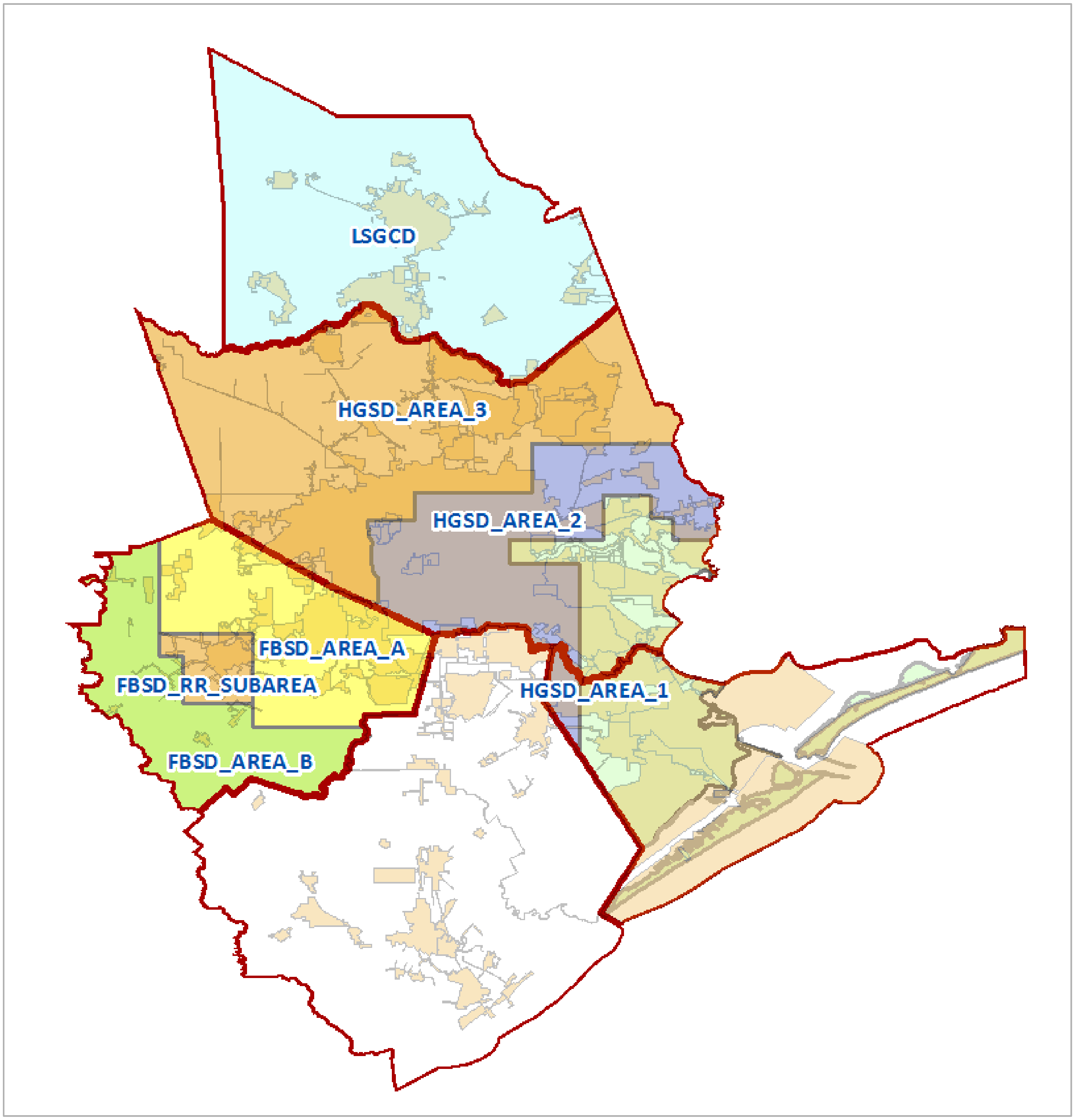


Figure 1. HGSD and FBSD Regulatory Areas

The regulatory plans require major groundwater users to submit a Groundwater Reduction Plan (GRP), which outlines how that entity will comply with the regulations. Affected groundwater users can either submit an individual GRP, or join a joint GRP where the entity that owns the joint GRP is responsible for the conversion of all of the GRP's members.

During the RGUP, entities that owned major joint GRPs and that would be significantly affected by future regulations were identified as key stakeholders (shown in Figure 2). When the current regulatory plans were developed, it was not known how the conversions would take place under the joint GRPs, and some of the joint GRPs were developed by entities that were not in existence before the regulations were adopted. North Harris County Regional Water Authority (NHCRWA), West Harris County Regional Water Authority (WHCRWA), North Fort Bend Water Authority (NFBWA), and Central Harris County Regional Water Authority (CHCRWA) were created in response to the HGSD 1999 Regulatory Plan, and the FBSD 2003 Regulatory Plan. Each was created by Texas legislative action: NHCRWA by the 76^{th} legislature in 1999, WHCRWA by the 77^{th} legislature in 2001, CHCRWA and NFBWA by the 79^{th} legislature in 2005.

All of the GRPs required by regulations were submitted prior to the start of the RGUP; as such, the regulatory scenario analyses take into account how conversions have or will have taken place.

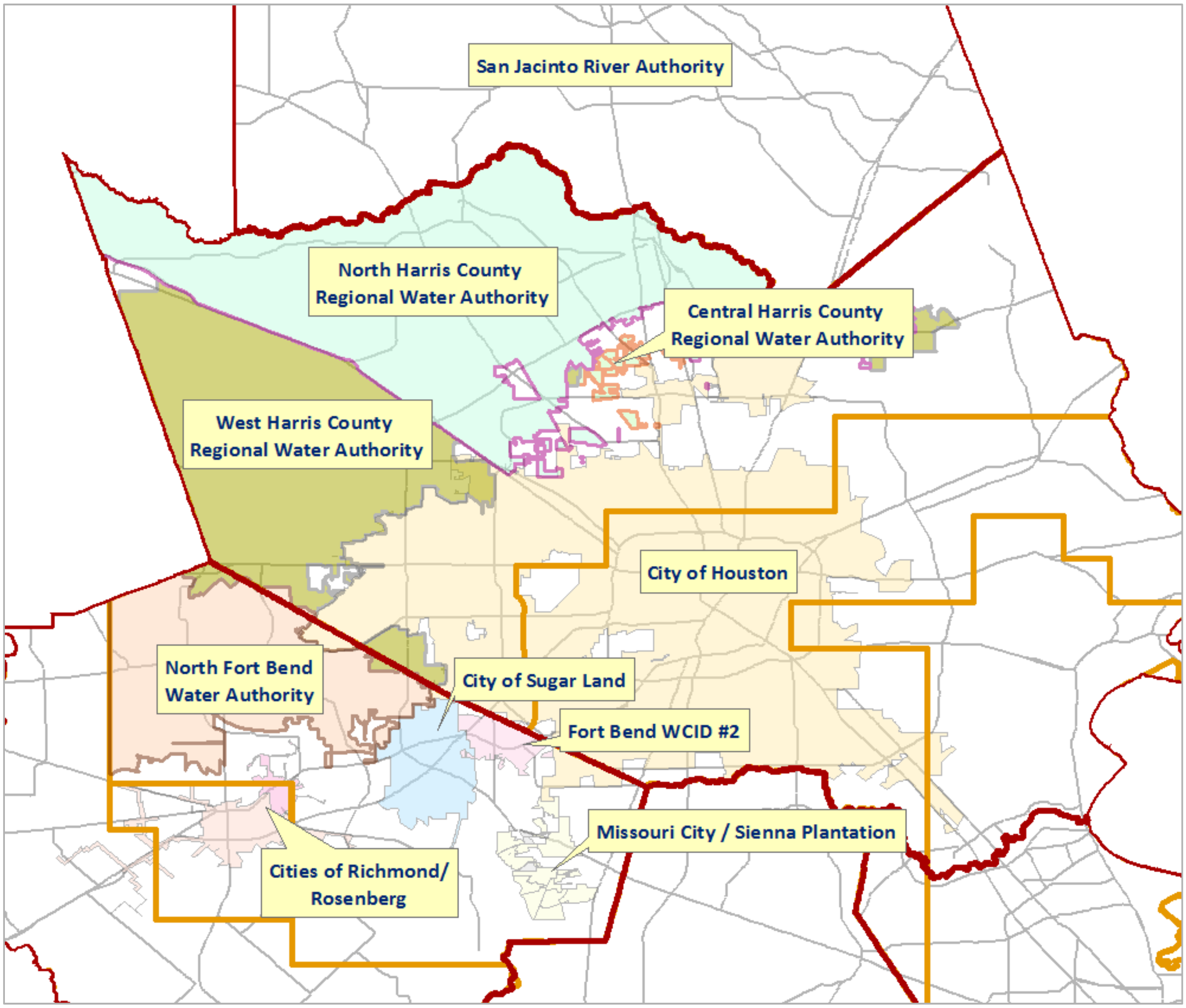


Figure 2. Key Stakeholders

This report details the methodology by which regulatory scenarios are analyzed, and the results of the analyses. The results stand on their own; this report is meant to be technical in nature and does not draw conclusions or make assertions as to the preferences of the RGUP project participants.

METHODOLOGY

The development and analysis of a regulatory scenario includes the following major steps:

1. Define the scenario at a high level by establishing major conversion dates and targets for each regulatory zone. This is done by the project partners.

2. Set the total demand at each HAGM grid cell. This only needs to happen once if the scenarios each have the same assumptions regarding per capita water demand and industrial water demand.

3. Create scenario definition at the HAGM grid cell level. Define the conversion areas and annual target conversions, establish conversion percentages for each groundwater model cell necessary to achieve the overall conversion targets, and convert total demand to allowable groundwater production in each cell (explained in previous section).

4. Execute the HAGM model to obtain predicted water levels.

5. Execute the PRESS models for each of the 26 PRESS sites.

6. Generate subsidence contours.

The following sections describe steps 2 and 3 in detail, and steps 4-6 at a high level; step 1 is not discussed in this memo.

TOTAL DEMAND AT HAGM GRID CELLS

Each scenario analysis starts with total water demand assigned to each HAGM grid cell. Database queries are used to transfer total municipal demand to the model grid cells, and then add to that the non-municipal demand.

A Geographic Information System (GIS) Spatial Database Engine (SDE) Database was used to store the spatial features and data. The SDE feature classes used and their relationships are shown in the diagram in Figure 3.

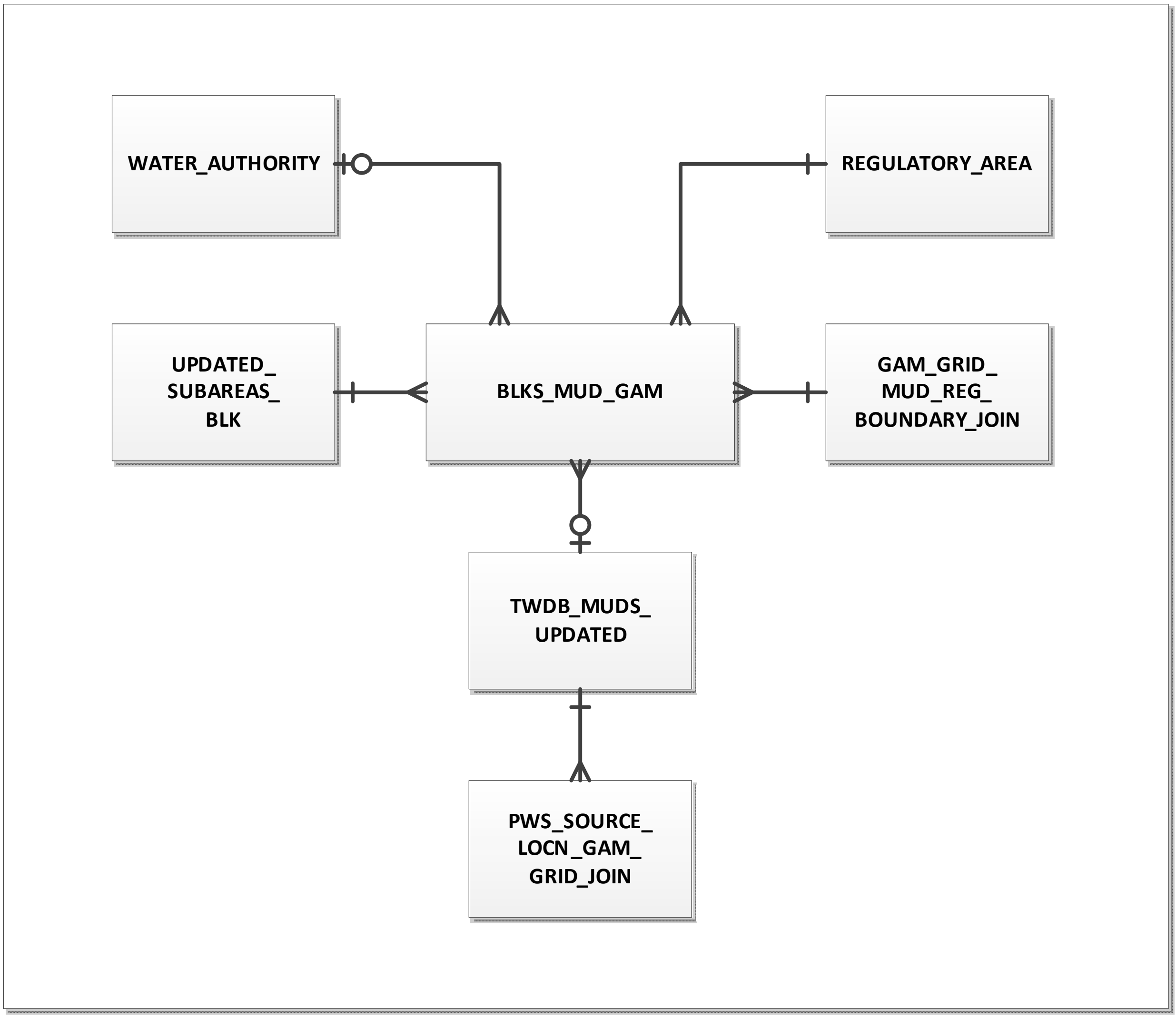


Figure 3. Scenario Development SDE Entity Relationship Diagram

The data is stored as Microsoft SQL Server tables within the SDE database. Table 2 describes the feature classes.

Table 2. Regulatory Scenario Database Tables

Table	Description
BLKS_MUD_GAM	SDE Feature Class representing the union between Census 2010 Blocks, TWDB Water System Map boundaries (TWDB_MUDS_UPDATED), and HAGM grid cells (GAM_GRID_MUD_REG_BOUNDARY_JOIN). Each polygon has a 2010-2070 decadal population and total water demand. Population and water demand can be summed up for the various boundaries associated with the related tables shown in Figure 3.
WATER_AUTHORITY	SDE Feature Class representing the Regional Water Authorities; e.g. North Harris County Regional Water Authority, West Harris County Regional Water Authority, etc.
REGULATORY_AREA	SDE Feature Class representing HGSD and FBSD regulatory boundaries as shown in Figure 1.
UPDATED_SUBAREAS_BLK	SDE Feature Class representing Census 2010 Blocks with assigned County Subareas. County subareas are not used in the Scenario Analysis, but the relationship to this table allows summing population demand at this level.
GAM_GRID_MUD_REG_BOUNDARY_JOIN	SDE Feature Class representing the HAGM grid cells spatially joined with REGULATORY_AREAs.
TWDB_MUDS_UPDATED	SDE Feature Class representing the TWDB State Water Map PWS boundaries.
PWS_SOURCE_LOCN_GAM_GRID_JOIN	SDE Feature Class representing PWS source wells that have been spatially joined with the HAGM grid cells.

In Figure 3, the symbols at the end of each line joining the entities indicates the cardinality of the relationship; all of the relationships are one-to-many, with the crows-foot symbol indicating the "many" side. For example, the relationship between [BLKS_MUD_GAM] and [TWDB_MUDS_UPDATED] can be read in one direction as "for each [TWDB_MUDS_UPDATED] there are many [BLKS_MUD_GAM]" and in the other direction "for each [BLKS_MUD_GAM] there is optionally one [TWDB_MUDS_UPDATED]" (the circle symbol at the end of the line at [TWDB_MUDS_UPDATED] indicates optionality).

The total demand is established by executing a series of seven (7) SQL Server .sql files as follows:

1. **STEP_1_UPDATE_PWS_SOURCE_LOCN_2020_2070.sql** – Updates Public Water System (PWS) wells in [PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND] with the total demand for each PWS, except City of Houston, from [BLKS_MUD_GAM].

2. **STEP_2_UPDATE_PWS_SOURCE_LOCN_COH_2020_2070.sql** – Updates City of Houston PWS wells using [TOTAL_DEMAND_BY_A1NAME_REGAREA] which contains the total City of Houston demand broken down by Regulatory Area.

3. **STEP_3_UPDATE_GAM_GRID_PWS_NO_WELLS_2020_2070.sql** – Updates the HAGM grid cell table [GAM_GRID_REG_BOUNDARY_JOIN_TOTAL_DEMAND] with PWS demands where the PWS has no wells.

4. **STEP_4_UPDATE_GAM_GRID_WELL_DEMAND_2020_2070.sql** – Updates the HAGM grid cell table [GAM_GRID_REG_BOUNDARY_JOIN_TOTAL_DEMAND] with PWS well demands in [PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND].

5. **STEP_5_UPDATE_GAM_GRID_NO_PWS_2020_2070.sql** – Updates the HAGM grid cell table [GAM_GRID_REG_BOUNDARY_JOIN_TOTAL_DEMAND] with demands that are outside of a MUD/City (i.e. outside of a PWS boundary).

6. **STEP_6_UPDATE_GAM_GRID_OTHER_IRRIGATION.sql** – Updates the HAGM grid cell table [GAM_GRID_REG_BOUNDARY_JOIN_TOTAL_DEMAND] with values from the table [OTHER_IRRIGATION]. The [OTHER_IRRIGATION] table contains 2010 pumpage data from HGSD, FBSD, and LSGCD for amenity ponds and other HOA/POA uses, golf courses, schools, and churches. It also projects amenity pond demand using and average of 2 gpcd for future population.

7. **STEP_7_UPDATE_GAM_GRID_NON_MUNI_DEMANDS.sql** – Updates the HAGM grid cell table [GAM_GRID_REG_BOUNDARY_JOIN_TOTAL_DEMAND] with values from the tables [NON_MUNI_EXCEPT_HG] and [HG_INDUSTRIAL]. This is adding in industrial demand.

Upon execution of the seven (7) .sql files outlined above, total water demand is set for each HAGM grid cell. Each .sql file contains multiple SELECT and/or UPDATE queries. The contents of each sql file are included as an attachment to this memo.

A table with total demand, by HGSD & FBSD regulatory areas, is included as an attachment to this memo.

SCENARIO GRID CELL DEFINITION

HGSD and FBSD regulations specify that the total groundwater production in a given regulatory area be no more than a certain percentage of total water demand. The procedure for developing total water demand is outlined in the previous section. This section describes how a scenario is defined such that the total demand is “converted” into allowable groundwater production based on the regulatory language in that scenario.

The approach is to designate each HAGM grid cell in the table [GAM_GRID_MUD_REG_BOUNDARY_JOIN] with a descriptor indicating what entity will convert the demands in the cell and, if applicable, when it will be converted. Two tables, [CONVERSION_ENTITY] and [CONVERSION_SCHEDULE] relate to the HAGM grids and indicate how conversion will take place with each cell. The relationships between the grid cells and the conversion tables are shown in Figure 4.

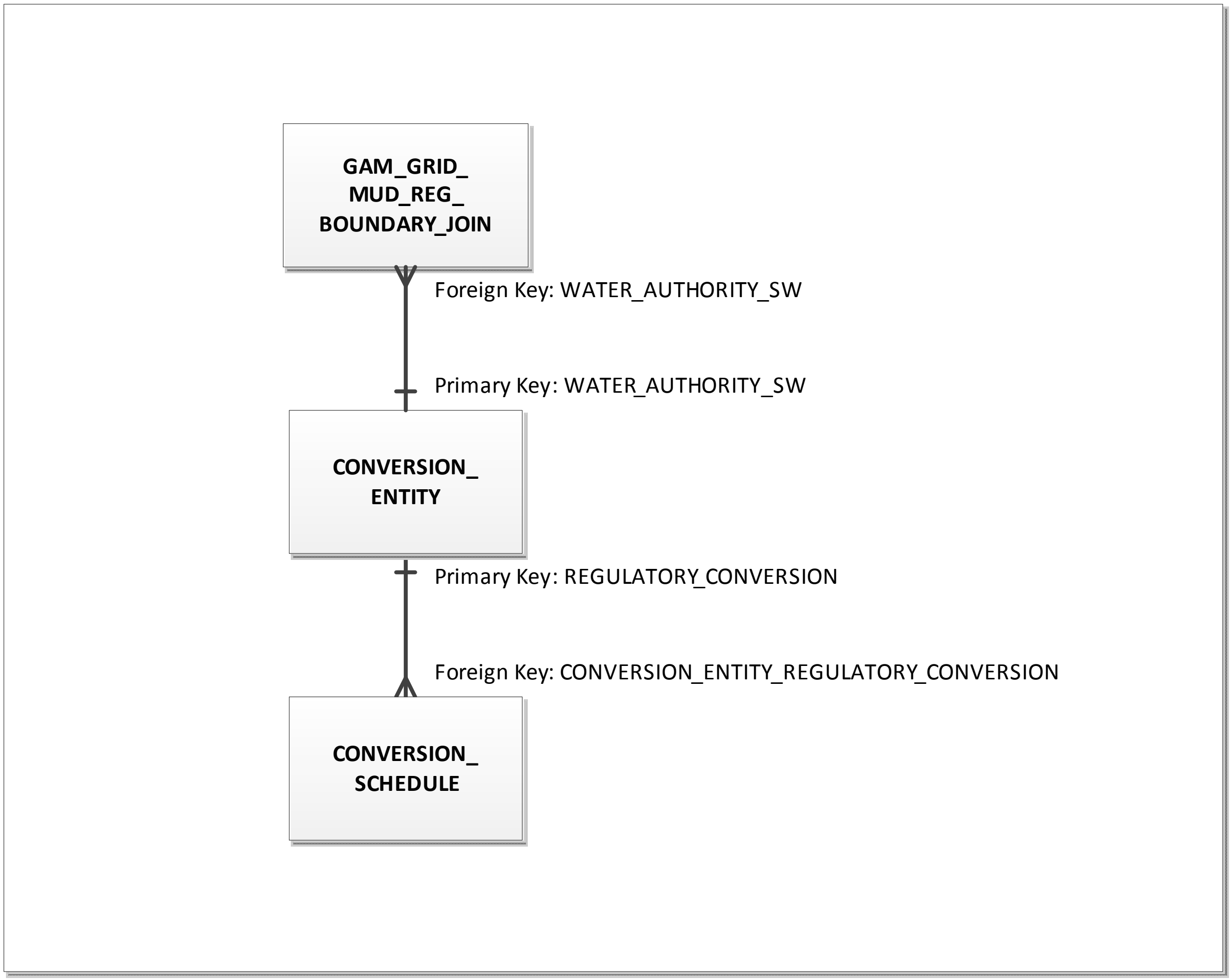


Figure 4. Regulatory Conversion SDE Entity Relationship Diagram

- [CONVERSION_ENTITY] has two fields: [WATER_AUTHORITY_SW] indicates what entity it belongs to and can indicate when it converts; [REGULATORY_CONVERSION] links to the table [CONVERSION_SCHEDULE] which provides the annual percentage groundwater to be applied to that area.
    - Example 1: [WATER_AUTHORITY_SW] = "RICHMOND" and [REGULATORY_CONVERSION] = "FBSD_RR_SUBAREA"; the conversion schedule for "FBSD_RR_SUBAREA" indicates how "RICHMOND" converts.
    - Example 2: [WATER_AUTHORITY] = "NHCRWA_2020" and [REGULATORY_CONVERSION] = "NHCRWA_2020"; this indicates that cells identified as "NHCRWA_2020" follow a conversion schedule that is unique for those cells; i.e. they do not follow a basic conversion target due to over-conversion.
- [CONVERSION_SCHEDULE] indicates how all areas convert on an annual basis by specifying the percentage of groundwater allowed for that area.

- Example 1: If the area is not in a regional water authority, but inside HGSD Regulatory Area 1, [CONVERSION_ENTITY_WATER_AUTHORITY_SW] = "HGSD_AREA_1" AND [PCT_GW] = 0.1 for all years (2010-2070).

- Example 2: If the area is inside a regional water authority such as NHCRWA, the authority will not convert its entire area at once, but will over-convert some areas to cover the overall target. In this case, [CONVERSION_ENTITY_REGULATORY_CONVERSION] might equal "NHCRWA_2020" which would specify a [PCT_GW] that would enable that area to meet its conversion; i.e. it would be something higher than the regulatory area's target percentage.

The conversions entities for North Fort Bend County are shown in Figure 5.

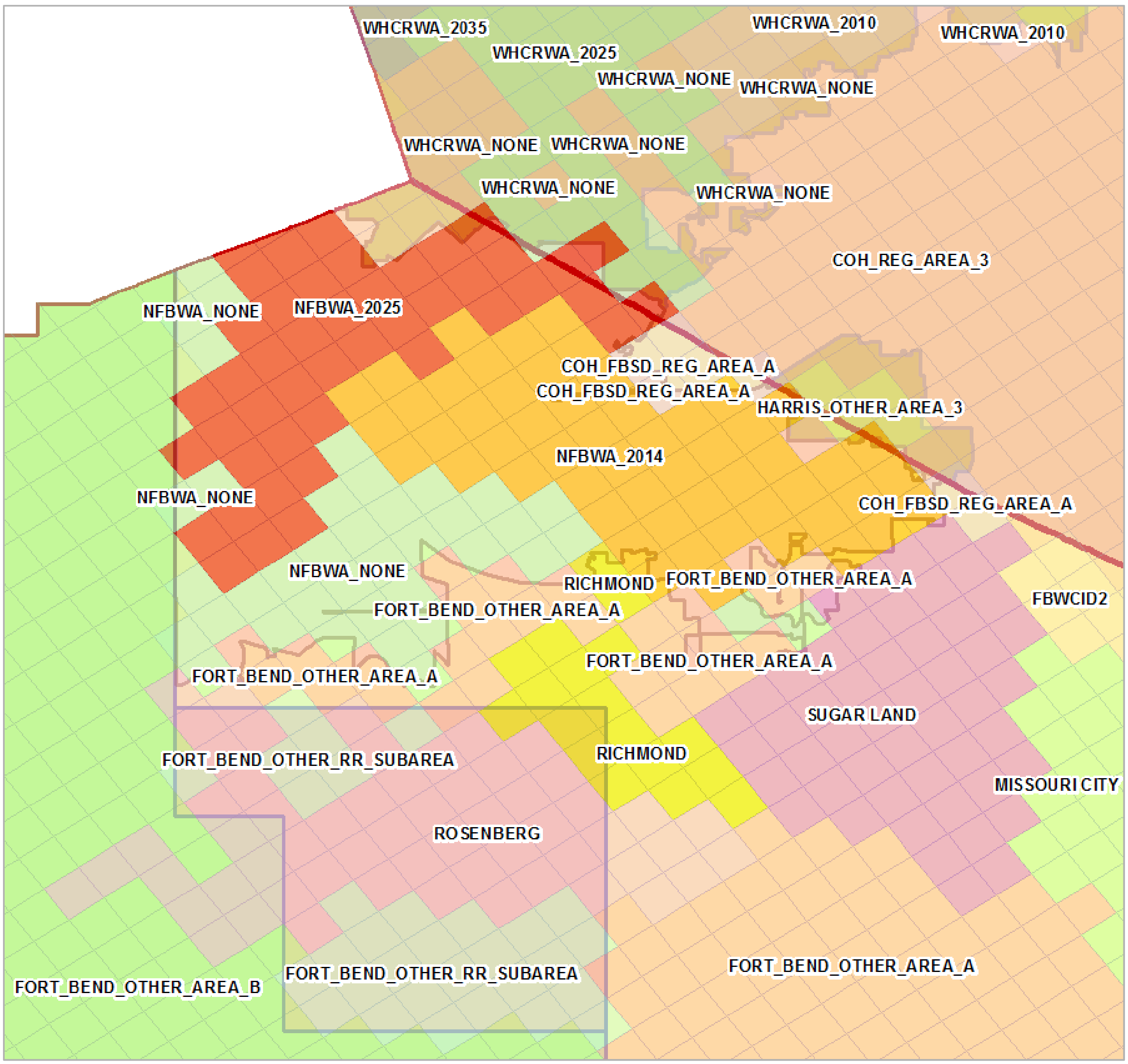


Figure 5. North Fort Bend County Conversion Entities

The field [PCT_GW] was calculated by populating an Excel worksheet with total demands aggregated by [WATER_AUTHORITY_SW] (termed "available demand"), then determining the ratio of target demand to total available demand.

Once the allowable percentages of groundwater are set, custom software coded in Microsoft Visual Basic.NET was used to set the annual groundwater withdrawals by cell and year for the years 2010-2070. Two modules were created: one to interpolate total demands for each year between decades, and one to automate the execution of queries setting annual demand equal to (total demand) x (percentage groundwater). The code is included as an attachment to this memo.

The total allowable withdrawals by cell and year are the starting point for subsidence prediction, which is discussed in the next section.

SUBSIDENCE PREDICTION

This memo only discusses subsidence prediction at a high level to show how it fits in to the scenario analysis process. Once the allowable withdrawals for the scenario are established at the HAGM grid level, the remaining steps are as follows:

1. Distribute allowable groundwater production in each cell between the vertical layers in the groundwater model. For the HAGM, the layers are Chicot, Evangeline, Burkeville, and Jasper. The vertically distributed groundwater withdrawals are the input to the HAGM.

2. Execute HAGM and generate representative hydrographs at each of the 26 PRESS sites for the years 2010-2070. The hydrographs are used as input to the PRESS models.

3. Append the 2010-2070 hydrographs to the design hydrographs, adjusting the appended hydrograph starting points to match the design hydrograph end points. The design hydrographs cover the historical period 1904?-2009.

4. Execute the PRESS models for each of the 26 PRESS sites (shown in Figure 6).

5. Create subsidence contours based on computer-generated contouring of the 26 PRESS sites, with manual modifications based on additional information (predicted water level declines, geology, SUBS package results) and professional judgment.

The 26 PRESS sites are shown in Figure 6.

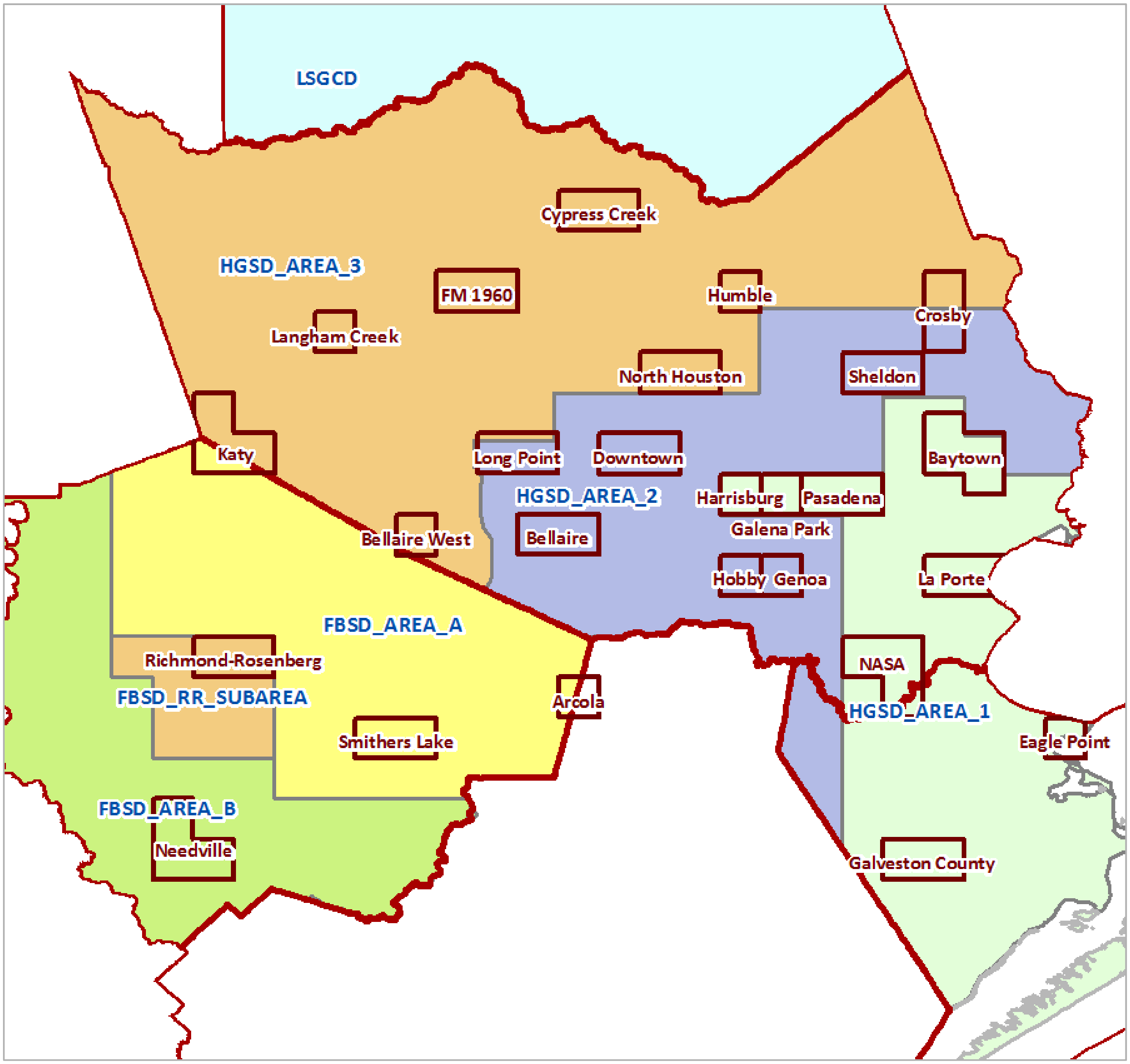


Figure 6. PRESS Site Locations

REGULATORY SCENARIOS

Five regulatory scenarios were developed: Scenarios 1, 2, Revised Scenario 3, and Scenario 4. The textual scenario descriptions are provided below, and the results of each scenario are provided as an attachment to this report.

SCENARIO 1: GROWTH BEYOND 2010 ON GROUNDWATER (NO ADDITIONAL SW)

- Harris and Galveston Counties (HGSD)
  - No increase in surface water supply beyond 2010 conversions.
  - No assumed reductions in surface water supply and all future increases in water demand are met with groundwater (Areas 1, 2, and 3).
  - Does not include Area 3 2020 70% groundwater reductions or 2030 80% groundwater reductions.
  - Future growth beyond 2010 supplied by groundwater in Areas 1 and 2.
- Fort Bend County (FBSD)
  - Assumes no conversions in 2014, 2016, or 2025. All future growth supplied with groundwater.
- Montgomery County (LSGCD)
  - No groundwater reductions in Montgomery County.
- Brazoria County (BCGCD)
  - No groundwater reductions in Brazoria County.

SCENARIO 2: CURRENT ADOPTED REGULATIONS

- Harris and Galveston Counties (HGSD 1999 Regulatory Plan)
  - Area 1 = 90% conversion
  - Area 2 = 80% conversion
  - Area 3 = 30% conversion current to 2019
  - Area 3 = 70% conversion 2020 to 2029
  - Area 3 = 80% conversion 2030 and beyond
- Fort Bend County (FBSD 2003 Regulatory Plan)
  - Area A = 30% conversion 2014 to 2024
  - R/R Sub-Area = 30% conversion 2016 to 2024
  - Area A and R/R Sub-Area = 60% conversion 2025 and beyond
  - Area B remains on 100% groundwater.
- Montgomery County (LSGCD 2009 Regulatory Plan)
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond.
- Brazoria County (BCGCD)
  - No groundwater reduction regulations adopted in Brazoria County.

SCENARIO 3: MODIFICATIONS TO CURRENT ADOPTED REGULATIONS

- Harris and Galveston Counties (HGSD 1999 Regulatory Plan)
  - Area 1 = 90% conversion (same as Scenario 2)
  - Area 2 = 80% conversion (same as Scenario 2)
  - **Area 3 = 30% conversion current to 2024**
  - **Area 3 = 60% conversion 2025 to 2034**
  - **Area 3 = 80% conversion 2035 and beyond**
- Fort Bend County (FBSD 2003 Regulatory Plan)

- Area A = 30% conversion 2014 to 2024 (same as Scenario 2)
- R/R Sub-Area = 30% conversion 2016 to 2024 (same as Scenario 2)
- **Area A and R/R Sub-Area = 50% conversion 2025 to 2034**
- **Area A and R/R Sub-Area = 65% conversion 2035 and beyond**
- Area B remains on 100% groundwater (same as Scenario 2).

- Montgomery County (LSGCD 2009 Regulatory Plan)
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond (same as Scenario 2).
- Brazoria County (BCGCD)
  - No groundwater reduction regulations adopted in Brazoria County (same as Scenario 2).

REVISED SCENARIO 3: SCENARIO 3 WITH PEARLAND CONVERSION

- Harris and Galveston Counties (HGSD 1999 Regulatory Plan)
  - Area 1 = 90% conversion (same as Scenario 2)
  - Area 2 = 80% conversion (same as Scenario 2)
  - **Area 3 = 30% conversion current to 2024**
  - **Area 3 = 60% conversion 2025 to 2034**
  - **Area 3 = 80% conversion 2035 and beyond**
- Fort Bend County (FBSD 2003 Regulatory Plan)
  - Area A = 30% conversion 2014 to 2024 (same as Scenario 2)
  - R/R Sub-Area = 30% conversion 2016 to 2024 (same as Scenario 2)
  - **Area A and R/R Sub-Area = 50% conversion 2025 to 2034**
  - **Area A and R/R Sub-Area = 65% conversion 2035 and beyond**
  - Area B remains on 100% groundwater (same as Scenario 2).
- Montgomery County (LSGCD 2009 Regulatory Plan)
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond (same as Scenario 2).
- Brazoria County (BCGCD)
  - **Assume City of Pearland (including ETJ) converts to 50% surface water by 2016 and beyond.**

SCENARIO 4: MODIFICATIONS TO CURRENT ADOPTED REGULATIONS

- Harris and Galveston Counties (HGSD 1999 Regulatory Plan)
  - Area 1 = 90% conversion (same as Scenario 2)
  - Area 2 = 80% conversion (same as Scenario 2)
  - **Area 3 = 30% conversion current to 2024 (same as Scenario 3)**
  - **Area 3 = 55% conversion 2025 to 2039**
  - **Area 3 = 80% conversion 2040 and beyond**
- Fort Bend County (FBSD 2003 Regulatory Plan)
  - Area A = 30% conversion 2014 to 2024 (same as Scenario 2)
  - **Area A = 50% conversion 2025 and beyond**
  - **R/R Sub-Area = 30% conversion 2025 and beyond**
  - Area B remains on 100% groundwater (same as Scenario 2).
- Montgomery County (LSGCD 2009 Regulatory Plan)
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond (same as Scenario 2).
- Brazoria County (BCGCD)

- No groundwater reduction regulations adopted in Brazoria County (same as Scenario 2).

Regulatory Scenario Results

Scenario 1 - Growth Beyond 2010 on Groundwater (No Additional Surface Water)

- **Harris and Galveston Counties (HGSD)**
  - No increase in surface water supply beyond 2010 conversions.
  - No assumed reductions in surface water supply and all future increases in water demand are met with groundwater (Areas 1, 2, and 3).
  - Does not include Area 3 2020 70% groundwater reductions or 2030 80% groundwater reductions.
  - Future growth beyond 2010 supplied by groundwater in Areas 1 and 2.

- **Fort Bend County (FBSD)**
  - Assumes no conversions in 2014, 2016, or 2025. All future growth supplied with groundwater.

- **Montgomery County (LSGCD)**
  - No groundwater reductions in Montgomery County.

- **Brazoria County (BCGCD)**
  - No groundwater reductions in Brazoria County.

Scenario 2 – Current Adopted Regulations

- **Harris and Galveston Counties (HGSD 1999 Regulatory Plan)**
  - Area 1 = 90% conversion
  - Area 2 = 80% conversion
  - Area 3 = 30% conversion current to 2019
  - Area 3 = 70% conversion 2020 to 2029
  - Area 3 = 80% conversion 2030 and beyond

- **Fort Bend County (FBSD 2003 Regulatory Plan)**
  - Area A = 30% conversion 2014 to 2024
  - R/R Sub-Area = 30% conversion 2016 to 2024
  - Area A and R/R Sub-Area = 60% conversion 2025 and beyond
  - Area B remains on 100% groundwater.

- **Montgomery County (LSGCD 2009 Regulatory Plan)**
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond.

- **Brazoria County (BCGCD)**
  - No groundwater reduction regulations adopted in Brazoria County.

Scenario 3 – Modifications to Current Adopted Regulations

- **Harris and Galveston Counties (HGSD 1999 Regulatory Plan)**
  - Area 1 = 90% conversion (same as Scenario 2)
  - Area 2 = 80% conversion (same as Scenario 2)
  - Area 3 = 30% conversion current to 2024
  - Area 3 = 60% conversion 2025 to 2034
  - Area 3 = 80% conversion 2035 and beyond

- **Fort Bend County (FBSD 2003 Regulatory Plan)**
  - Area A = 30% conversion 2014 to 2024 (same as Scenario 2)
  - R/R Sub-Area = 30% conversion 2016 to 2024 (same as Scenario 2)
  - Area A and R/R Sub-Area = 50% conversion 2025 to 2034
  - Area A and R/R Sub-Area = 65% conversion 2035 and beyond
  - Area B remains on 100% groundwater (same as Scenario 2).

- **Montgomery County (LSGCD 2009 Regulatory Plan)**
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond (same as Scenario 2).

- **Brazoria County (BCGCD)**
  - No groundwater reduction regulations adopted in Brazoria County (same as Scenario 2).

Revised Scenario 3 – Modifications to Current Adopted Regulations

- **Harris and Galveston Counties (HGSD 1999 Regulatory Plan)**
  - Area 1 = 90% conversion (same as Scenario 2)
  - Area 2 = 80% conversion (same as Scenario 2)
  - Area 3 = 30% conversion current to 2024
  - Area 3 = 60% conversion 2025 to 2034
  - Area 3 = 80% conversion 2035 and beyond

- **Fort Bend County (FBSD 2003 Regulatory Plan)**
  - Area A = 30% conversion 2014 to 2024 (same as Scenario 2)
  - R/R Sub-Area = 30% conversion 2016 to 2024 (same as Scenario 2)
  - Area A and R/R Sub-Area = 50% conversion 2025 to 2034
  - Area A and R/R Sub-Area = 65% conversion 2035 and beyond
  - Area B remains on 100% groundwater (same as Scenario 2).

- **Montgomery County (LSGCD 2009 Regulatory Plan)**
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond (same as Scenario 2).

- **Brazoria County (BCGCD)**
  - Assume City of Pearland (including ETJ) converts to 50% surface water by 2016 and beyond.

Scenario 4 – Modifications to Current Adopted Regulations

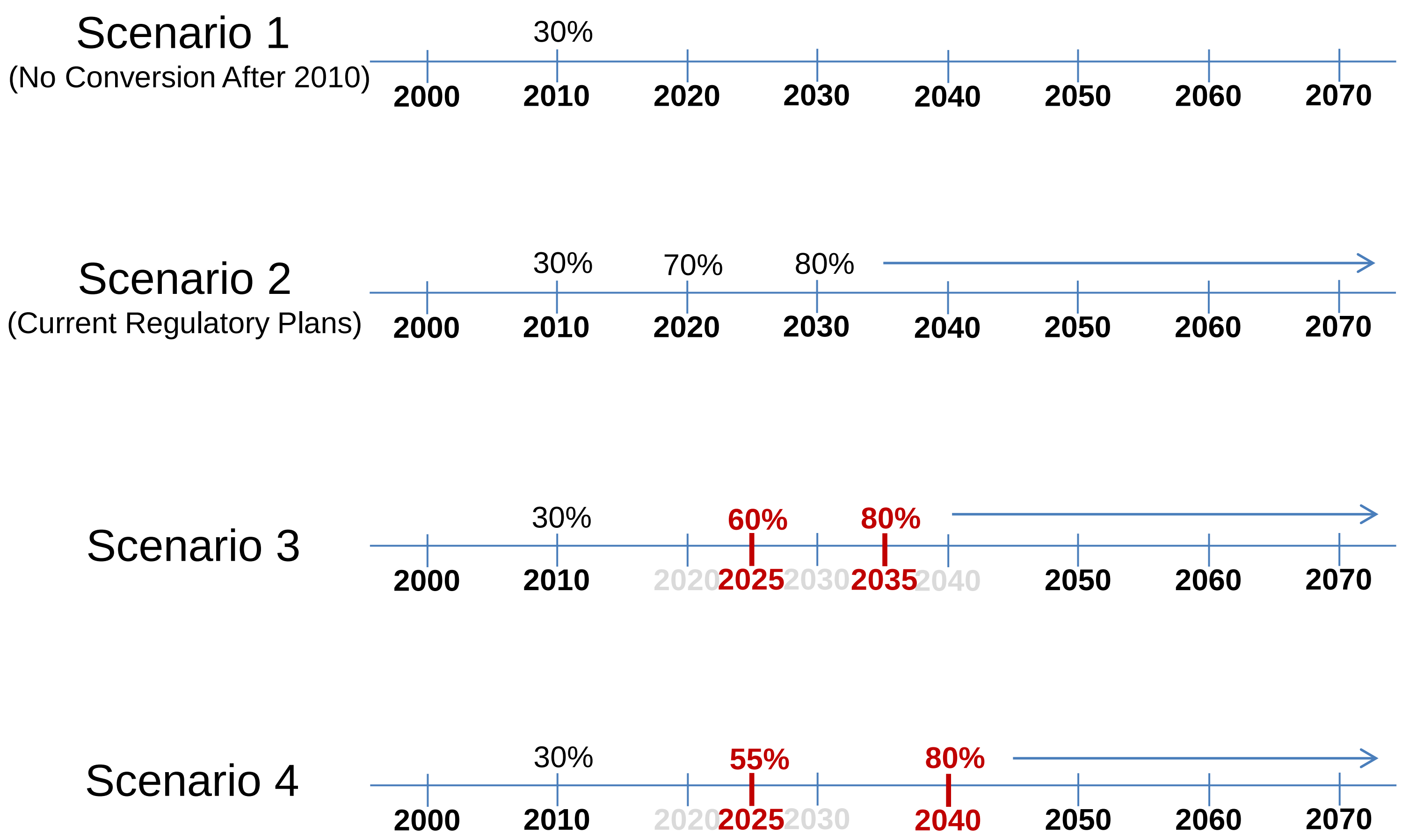
- **Harris and Galveston Counties (HGSD 1999 Regulatory Plan)**
  – Area 1 = 90% conversion (same as Scenario 2)
  – Area 2 = 80% conversion (same as Scenario 2)
  – Area 3 = 30% conversion current to 2024 (same as Scenario 3)
  – Area 3 = 55% conversion 2025 to 2039
  – Area 3 = 80% conversion 2040 and beyond

- **Fort Bend County (FBSD 2003 Regulatory Plan)**
  – Area A = 30% conversion 2014 to 2024 (same as Scenario 2)
  – Area A = 50% conversion 2025 and beyond
  – R/R Sub-Area = 30% conversion 2025 and beyond
  – Area B remains on 100% groundwater (same as Scenario 2).

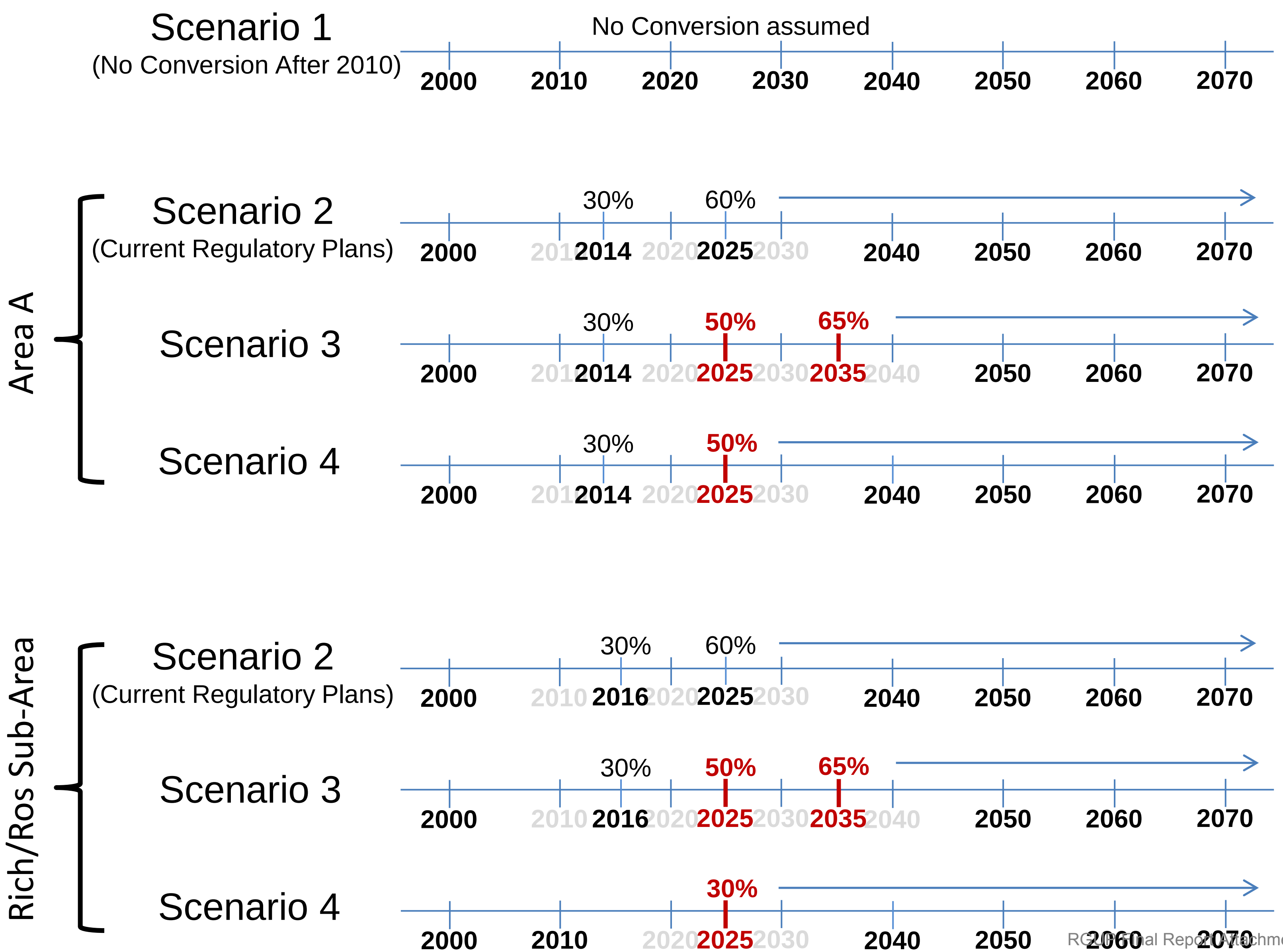
- **Montgomery County (LSGCD 2009 Regulatory Plan)**
  – 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond (same as Scenario 2).

- **Brazoria County (BCGCD)**
  – No groundwater reduction regulations adopted in Brazoria County (same as Scenario 2).

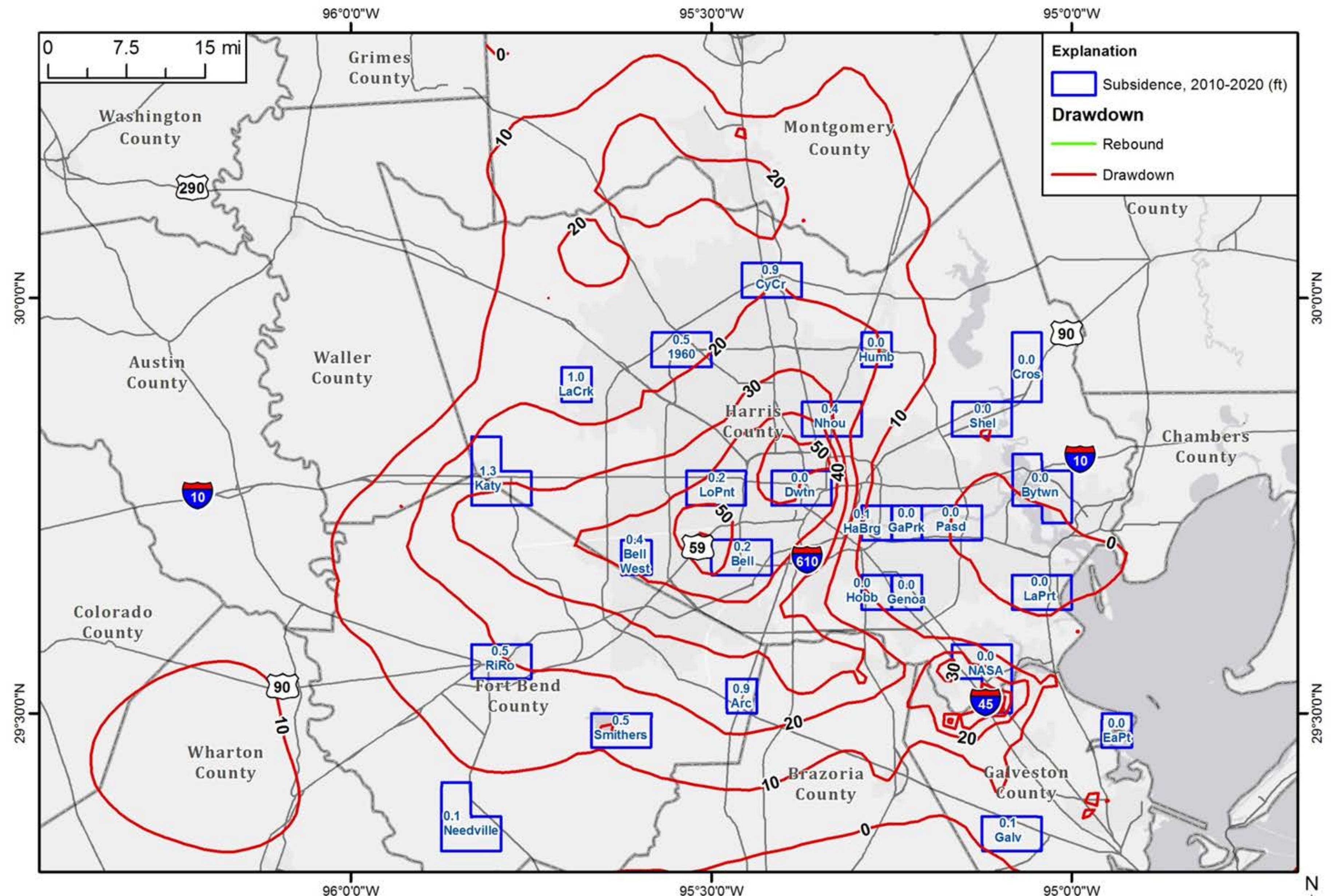
HGSD Area 3 Conversion Comparisons



FBSD Area A & Rich/Ros Sub-Area Conversion Comparisons



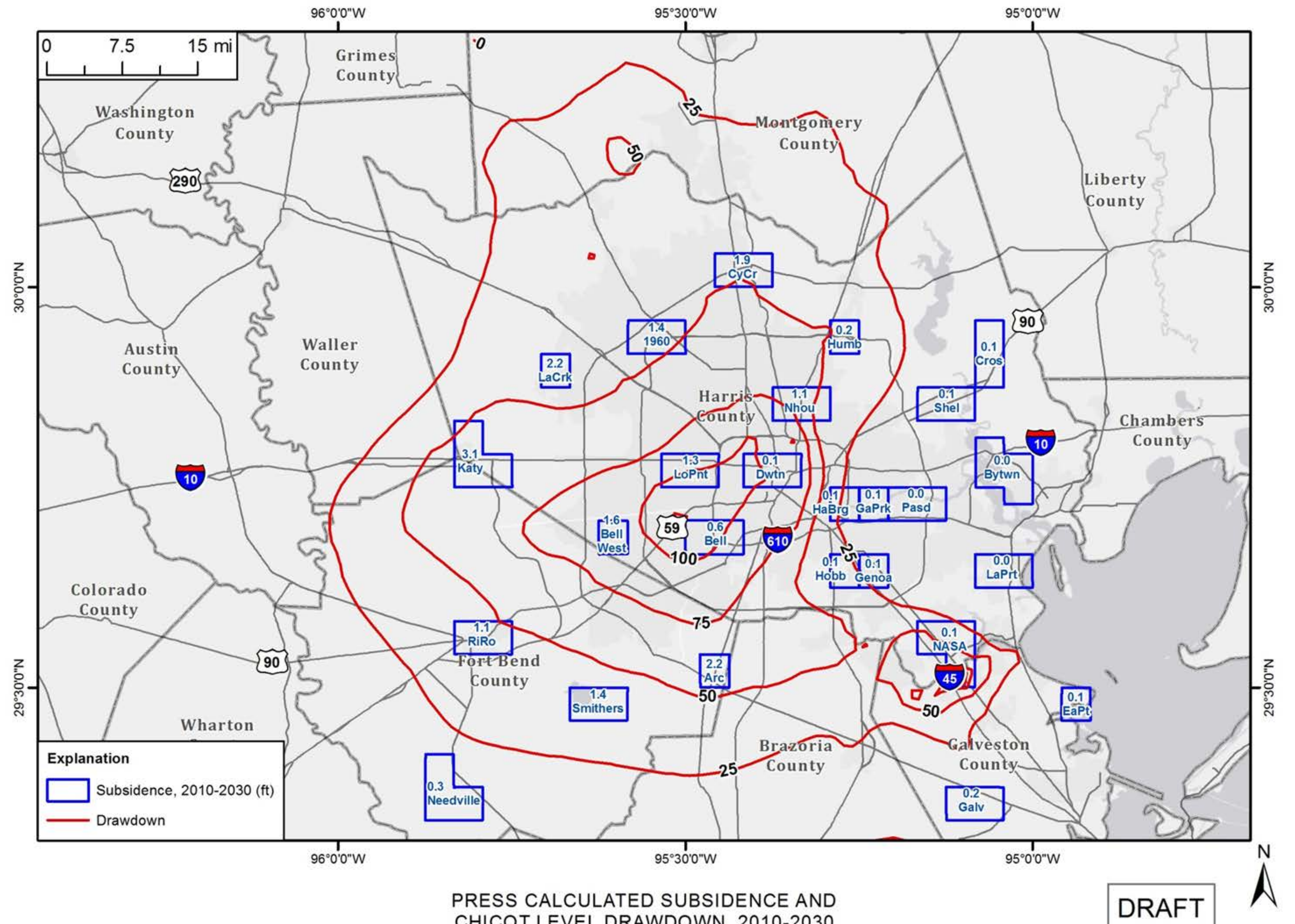
Scenario 1
Chicot Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND CHICOT LEVEL DRAWDOWN, 2010-2020

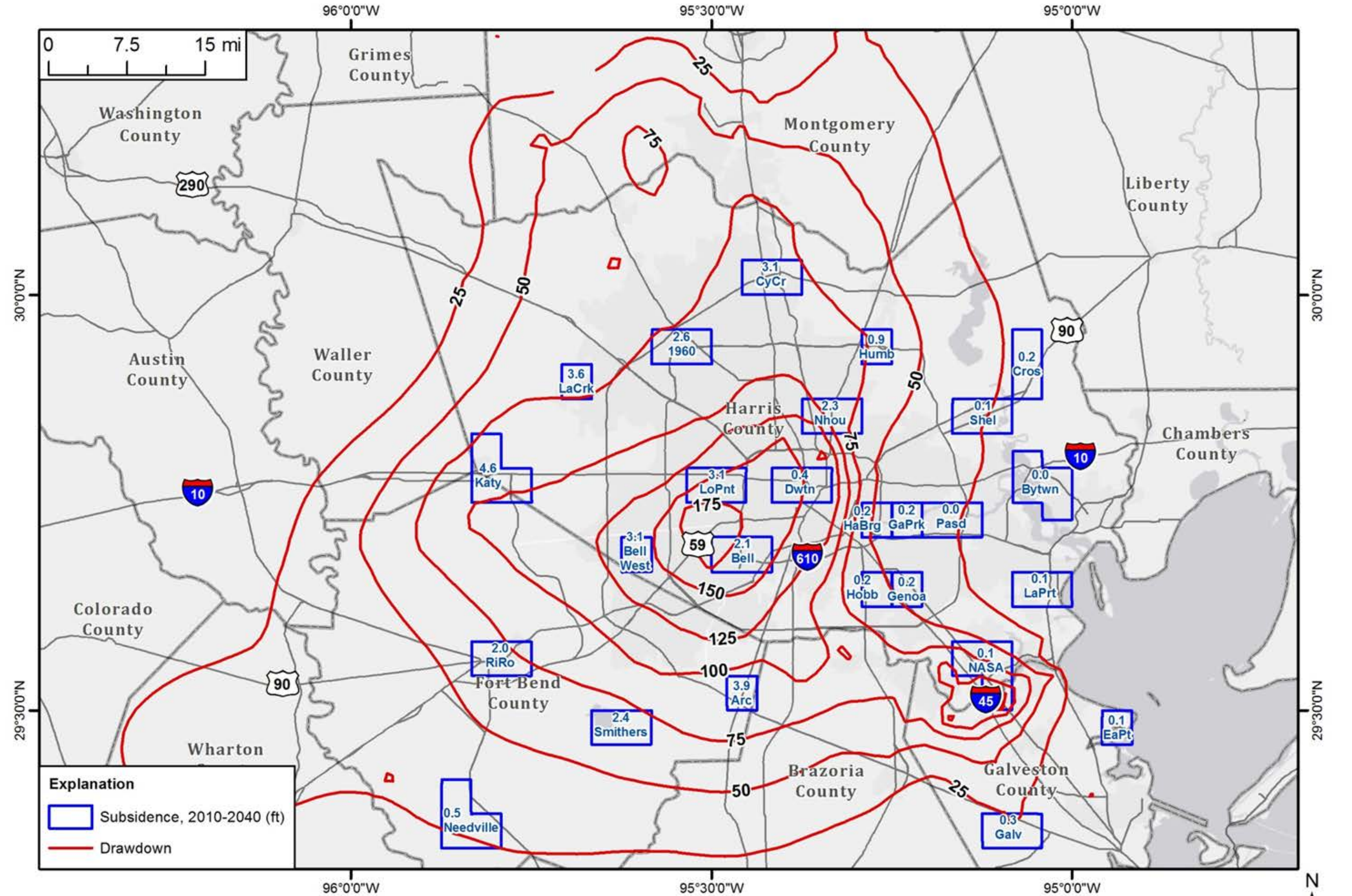
Scenario 1

DRAFT



PRESS CALCULATED SUBSIDENCE AND
CHICOT LEVEL DRAWDOWN, 2010-2030

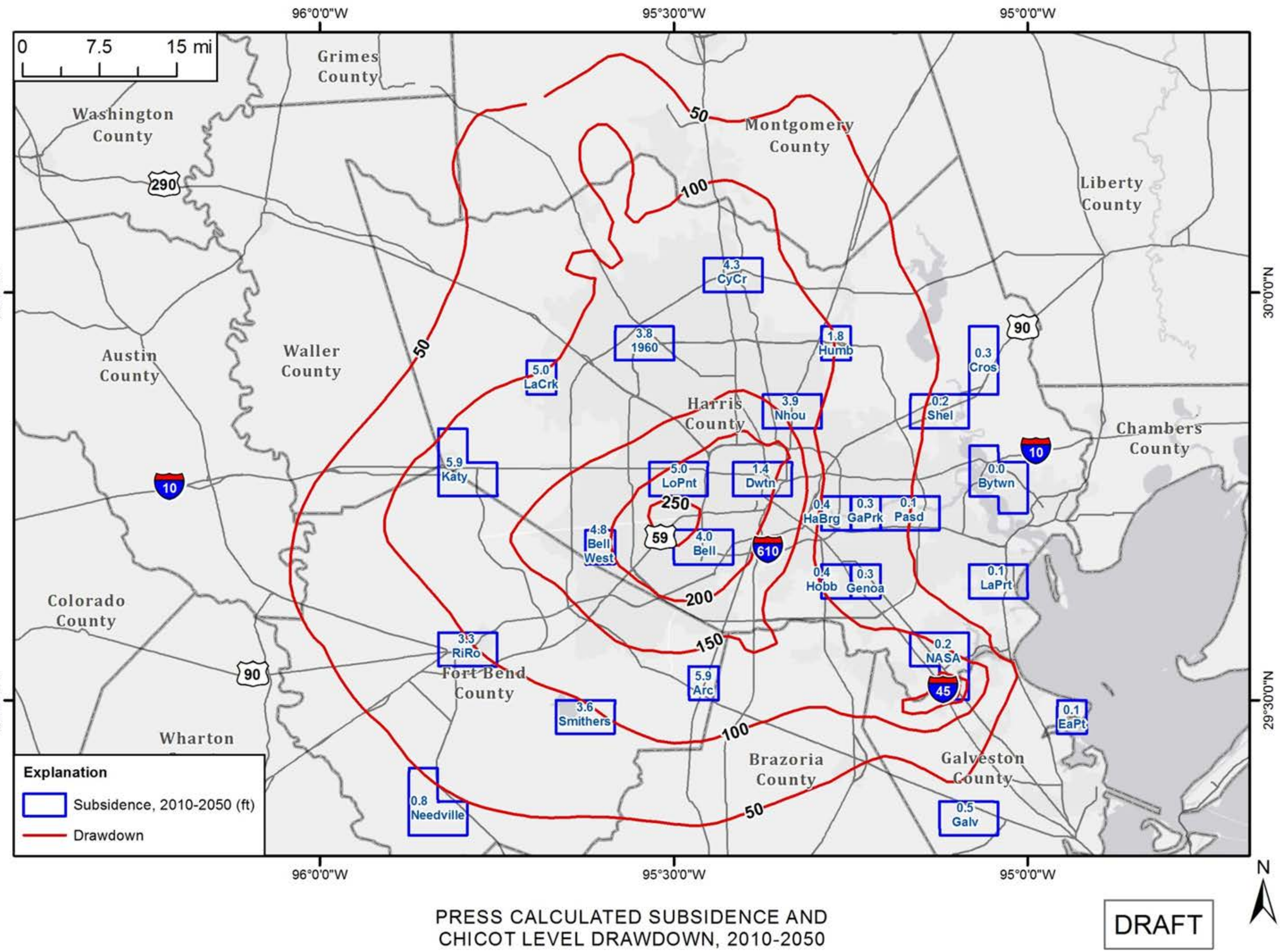
Scenario 1



PRESS CALCULATED SUBSIDENCE AND CHICOT LEVEL DRAWDOWN, 2010-2040

Scenario 1

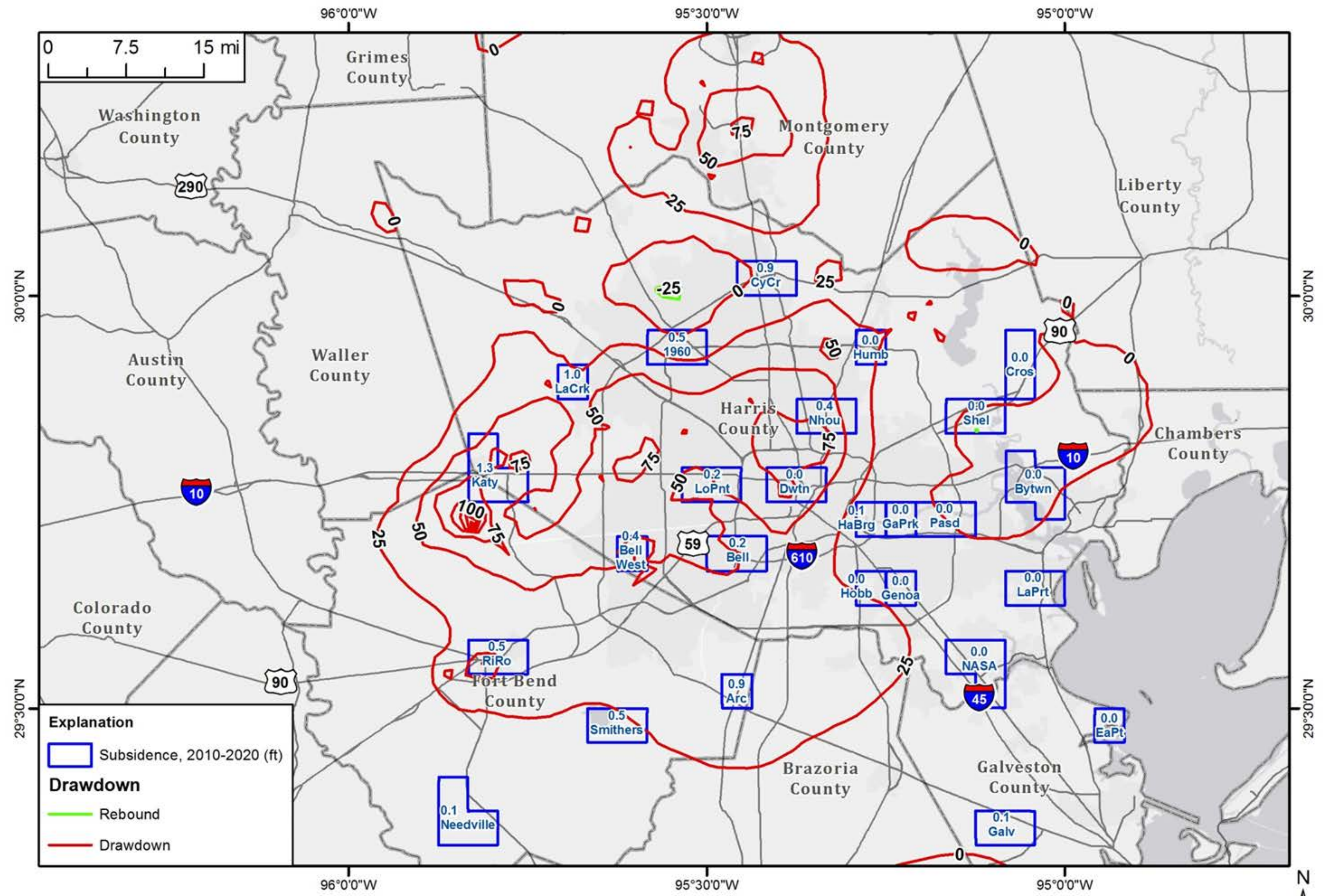
DRAFT



PRESS CALCULATED SUBSIDENCE AND
CHICOT LEVEL DRAWDOWN, 2010-2050

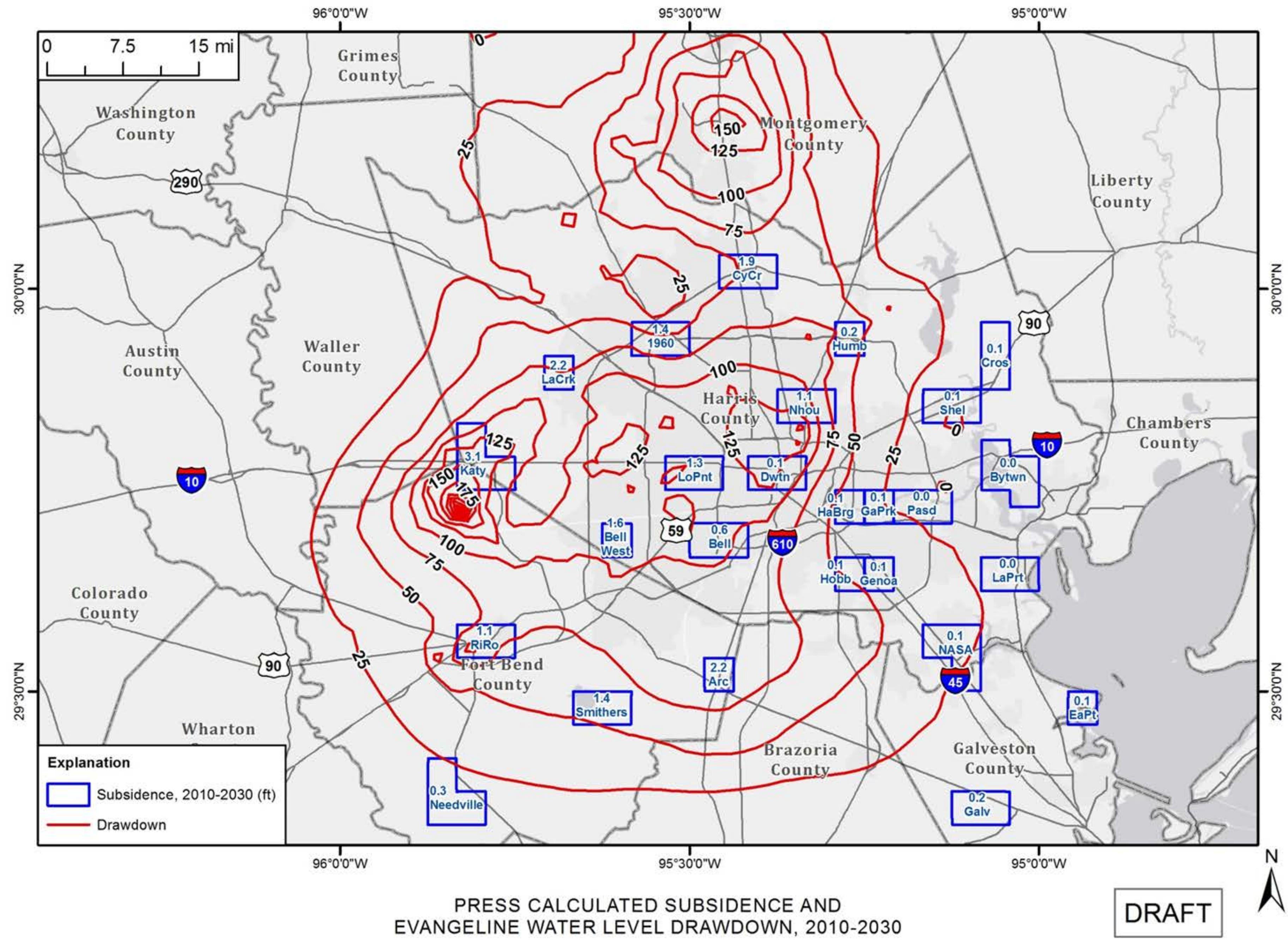
Scenario 1

Scenario 1
Evangeline Aquifer
Groundwater Drawdown Maps



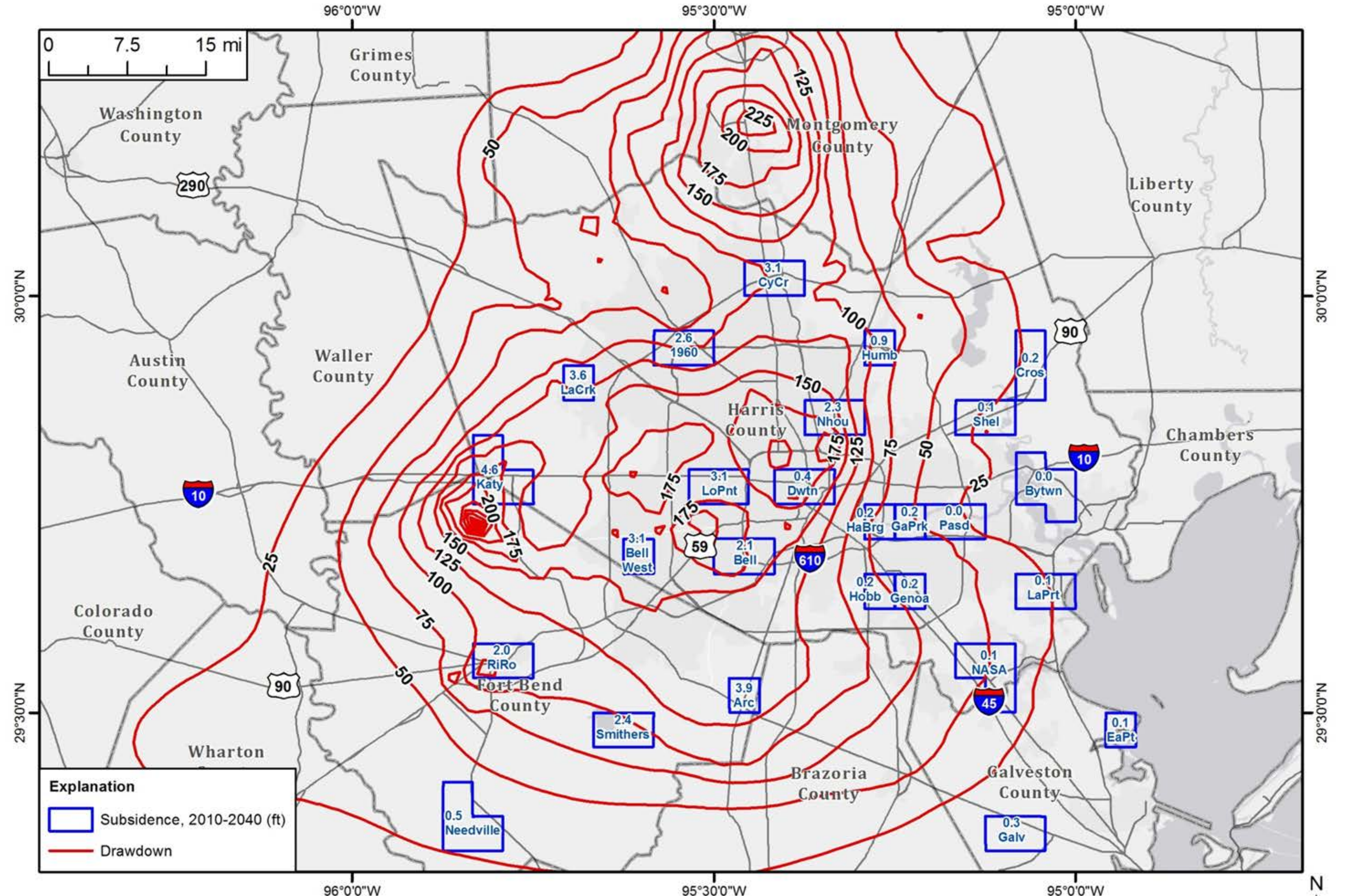
PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2020

Scenario 1



PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2030

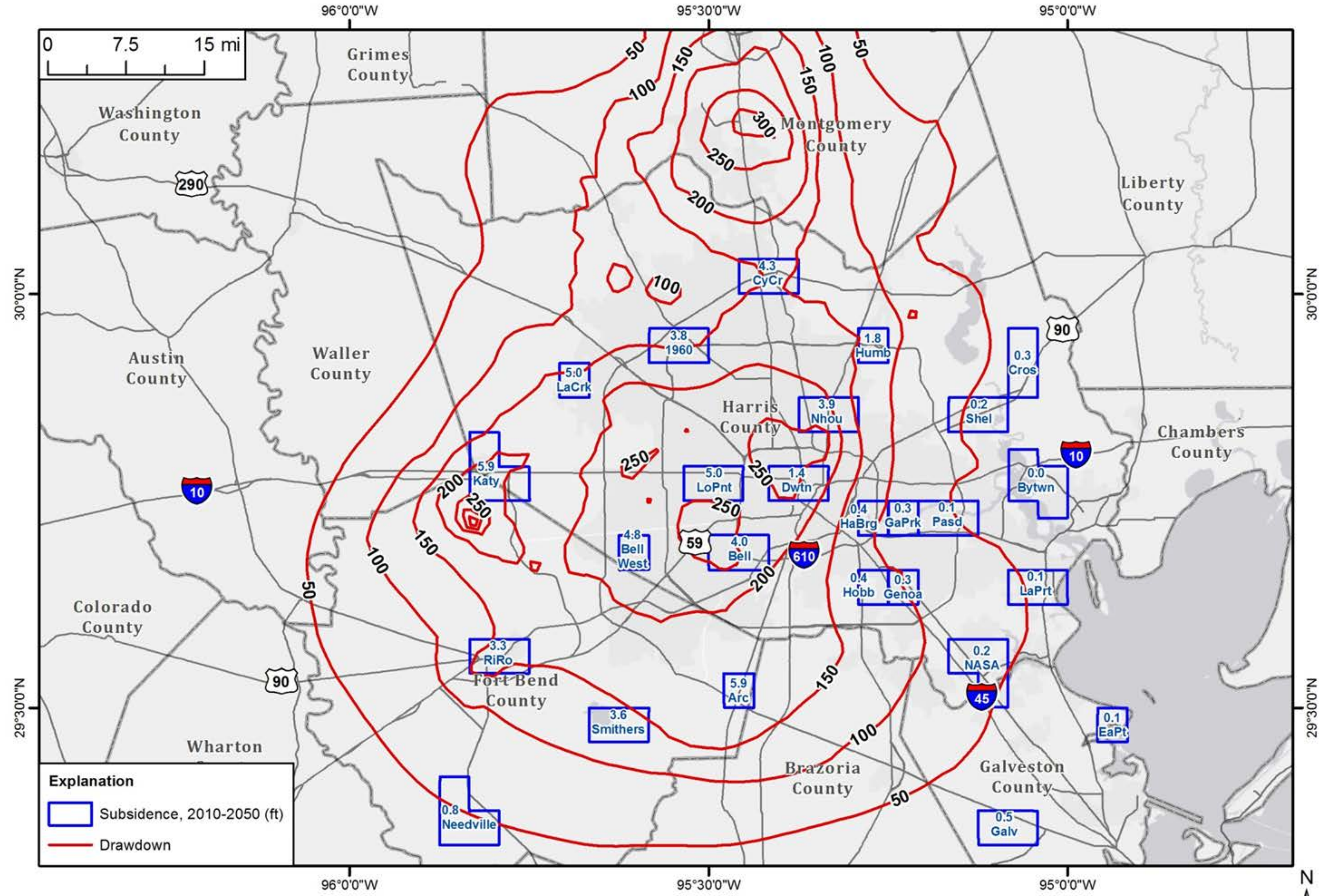
Scenario 1



PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2040

Scenario 1

DRAFT

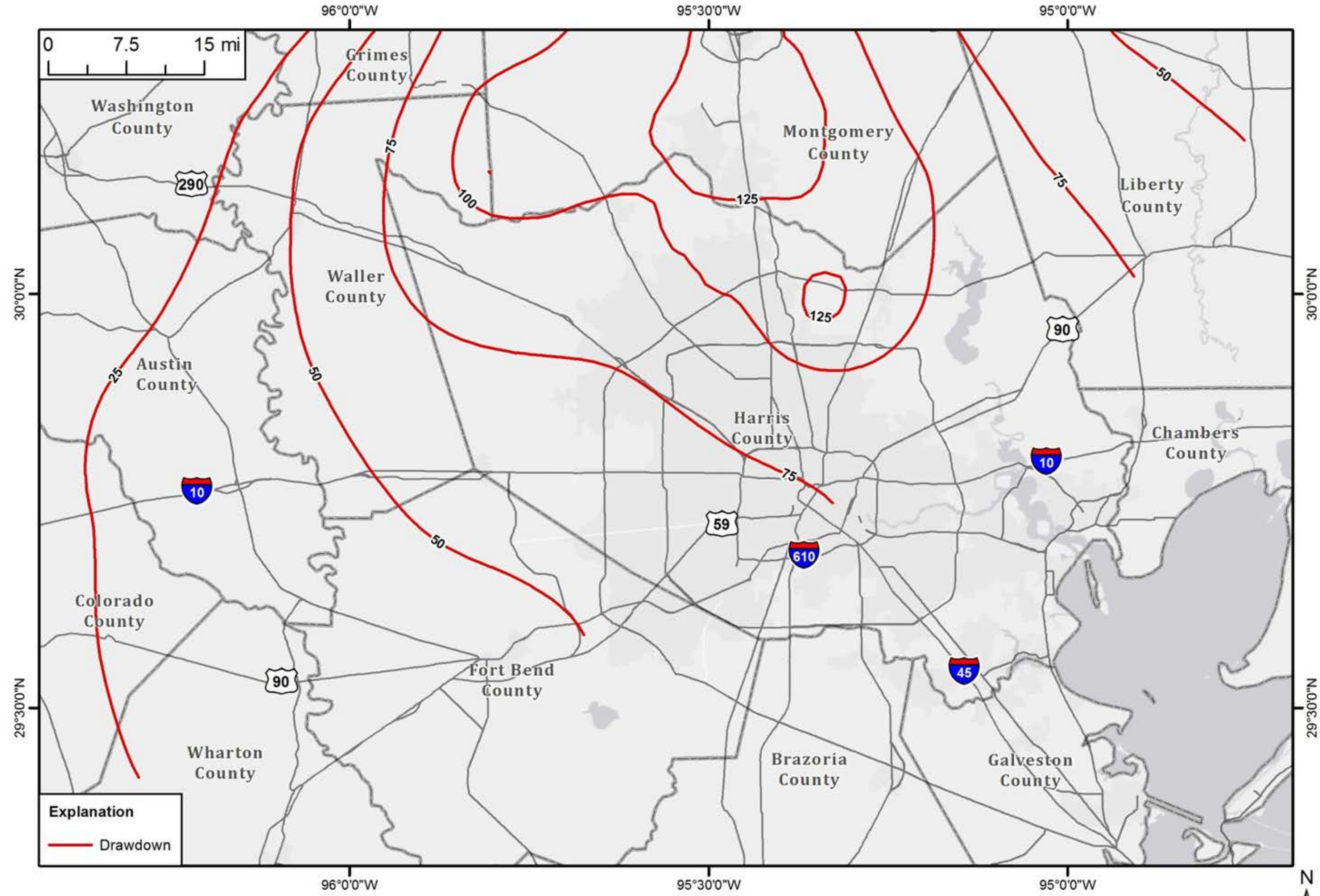


PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2050

Scenario 1

DRAFT

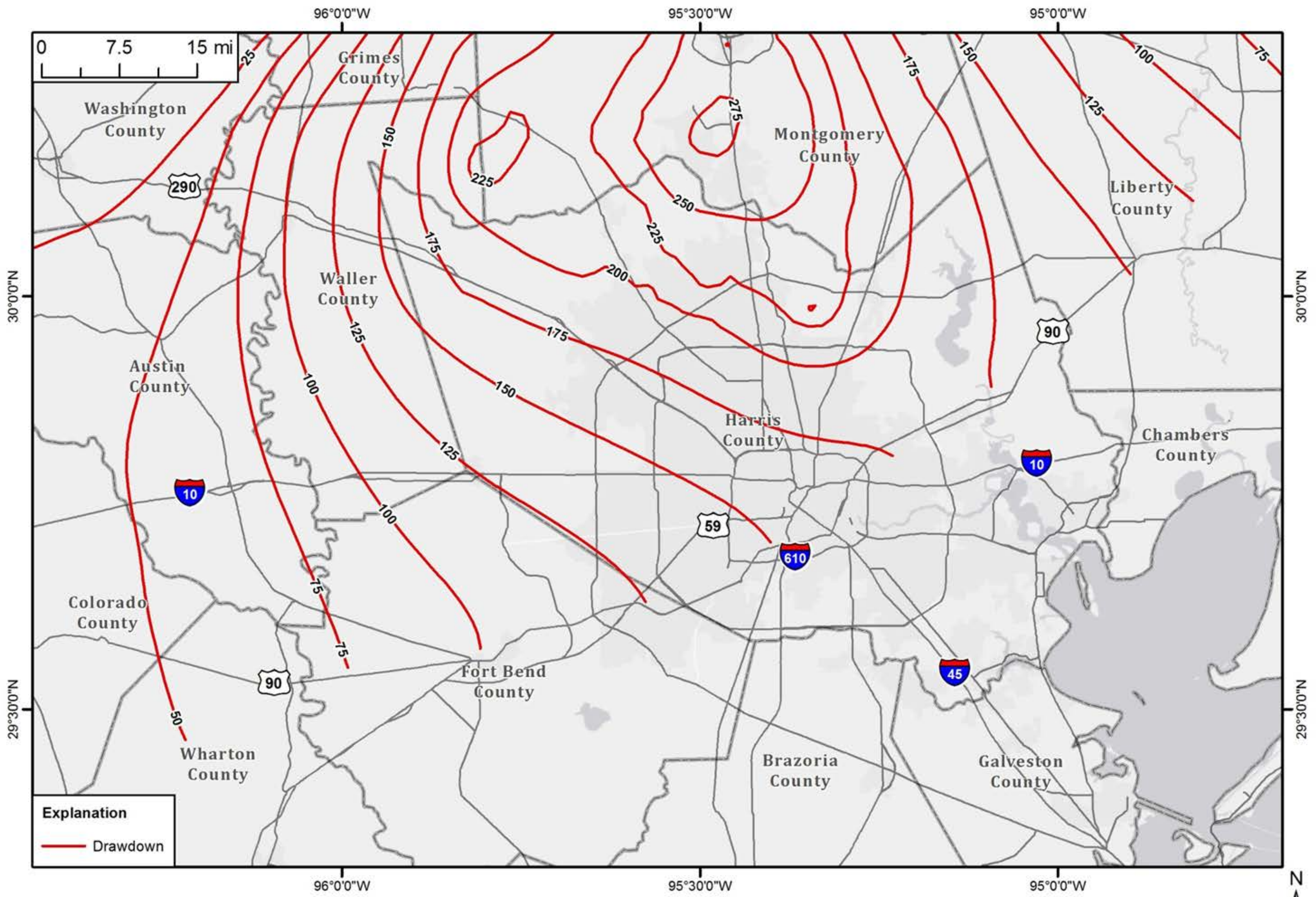
Scenario 1
Jasper Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2020

Scenario 1

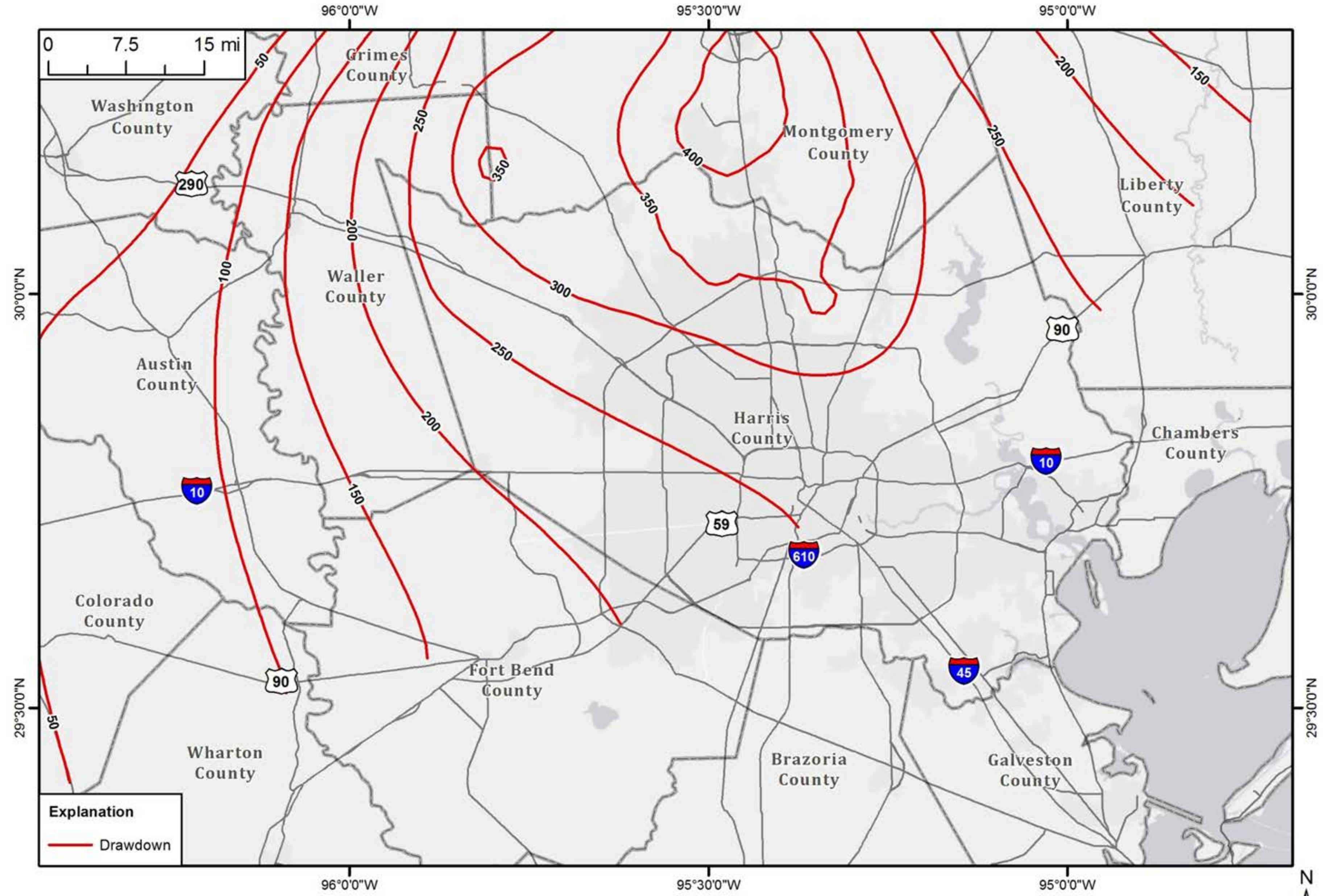
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2030

Scenario 1

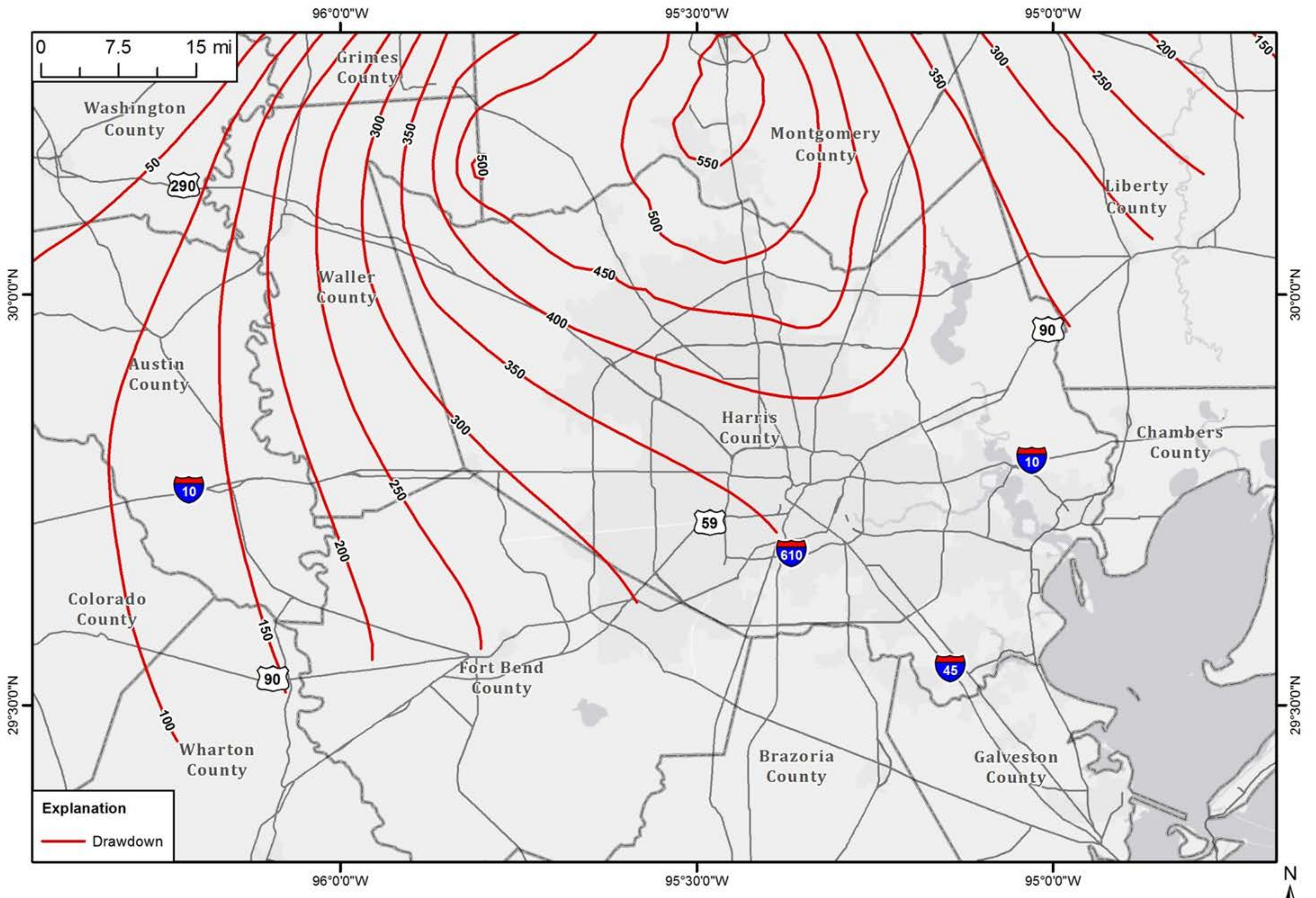
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2040

Scenario 1

DRAFT

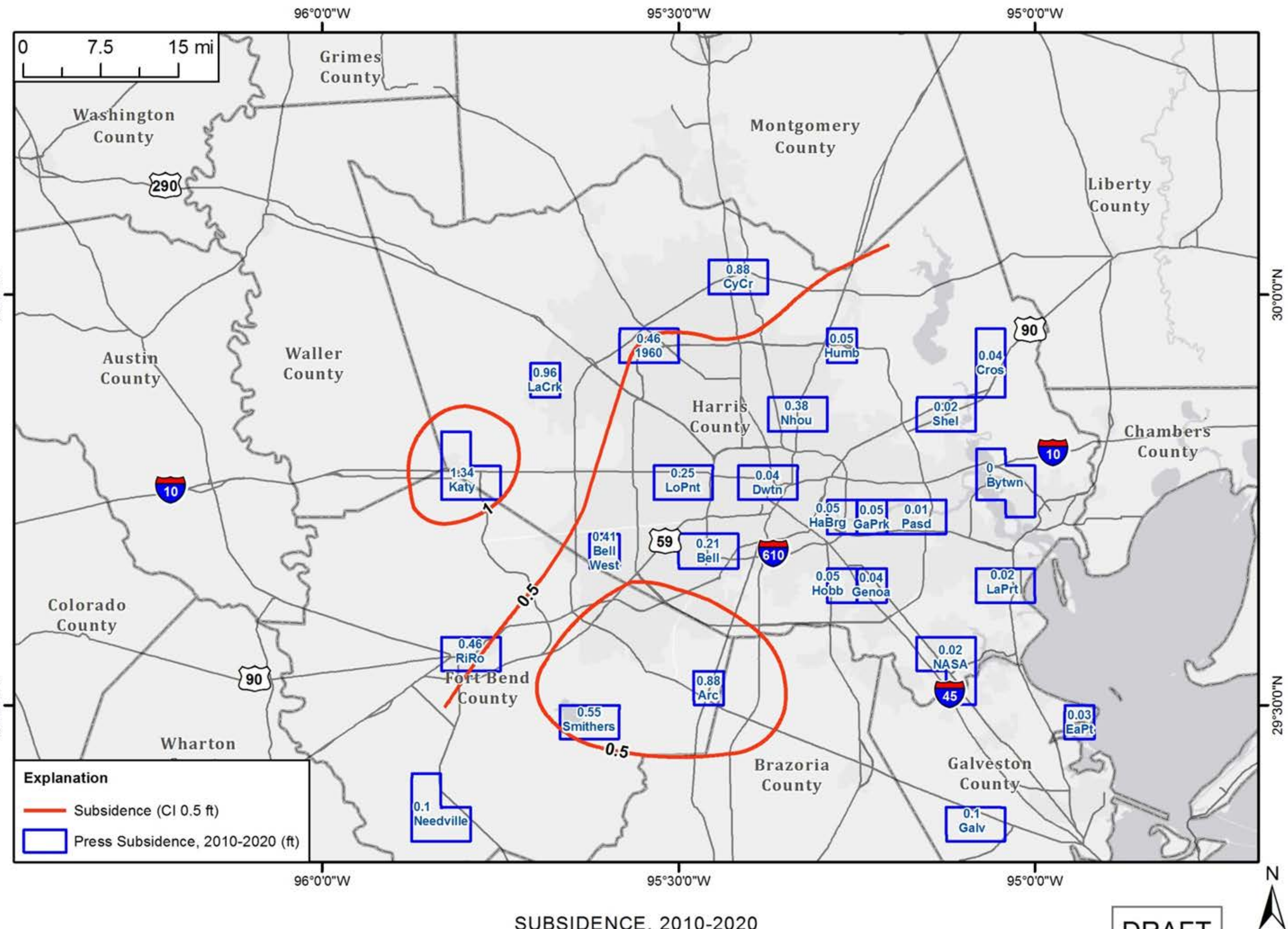


DRAFT

PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2050

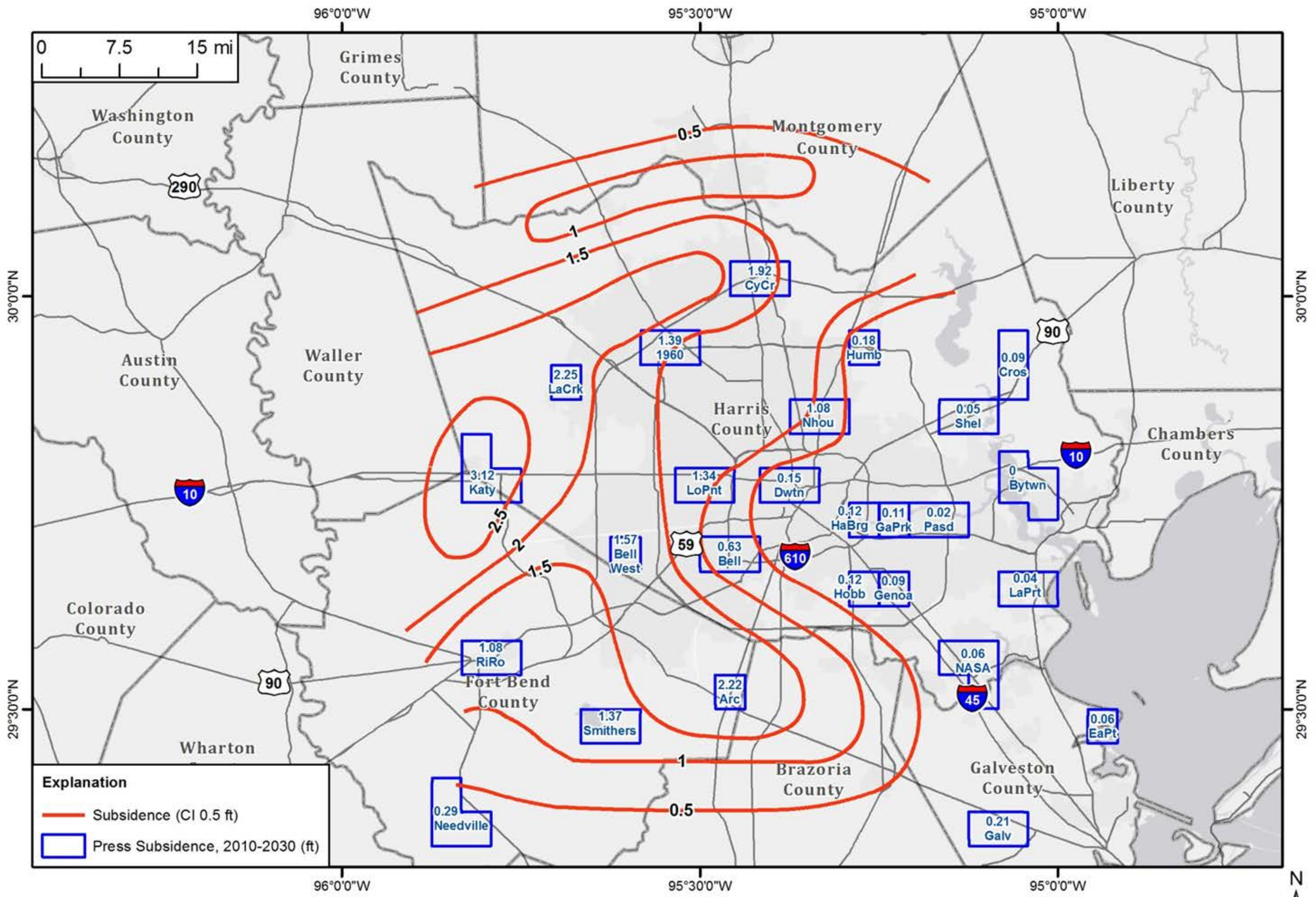
Scenario 1

Scenario 1
Predicted Subsidence Contour Maps



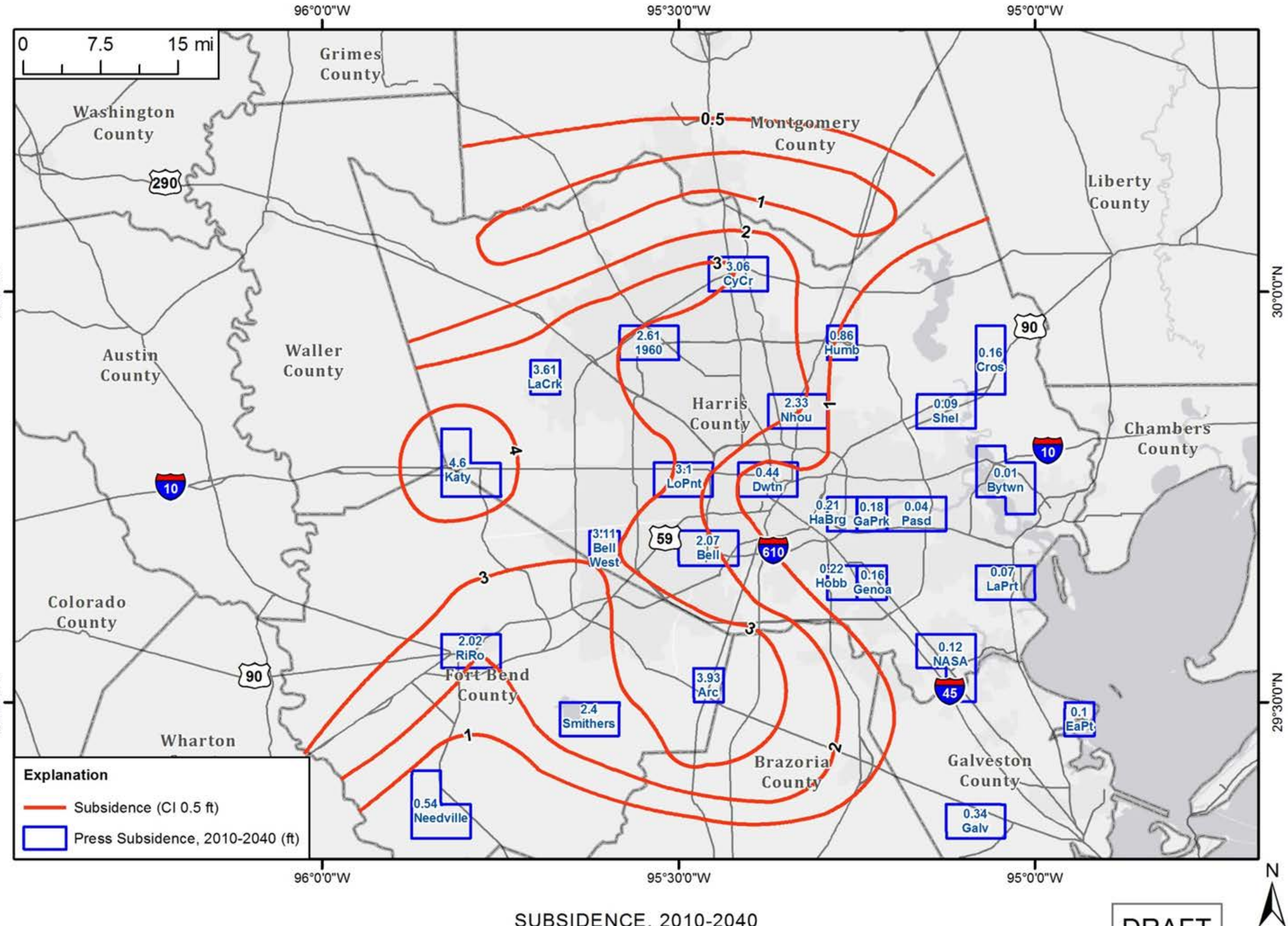
SUBSIDENCE, 2010-2020

Scenario 1



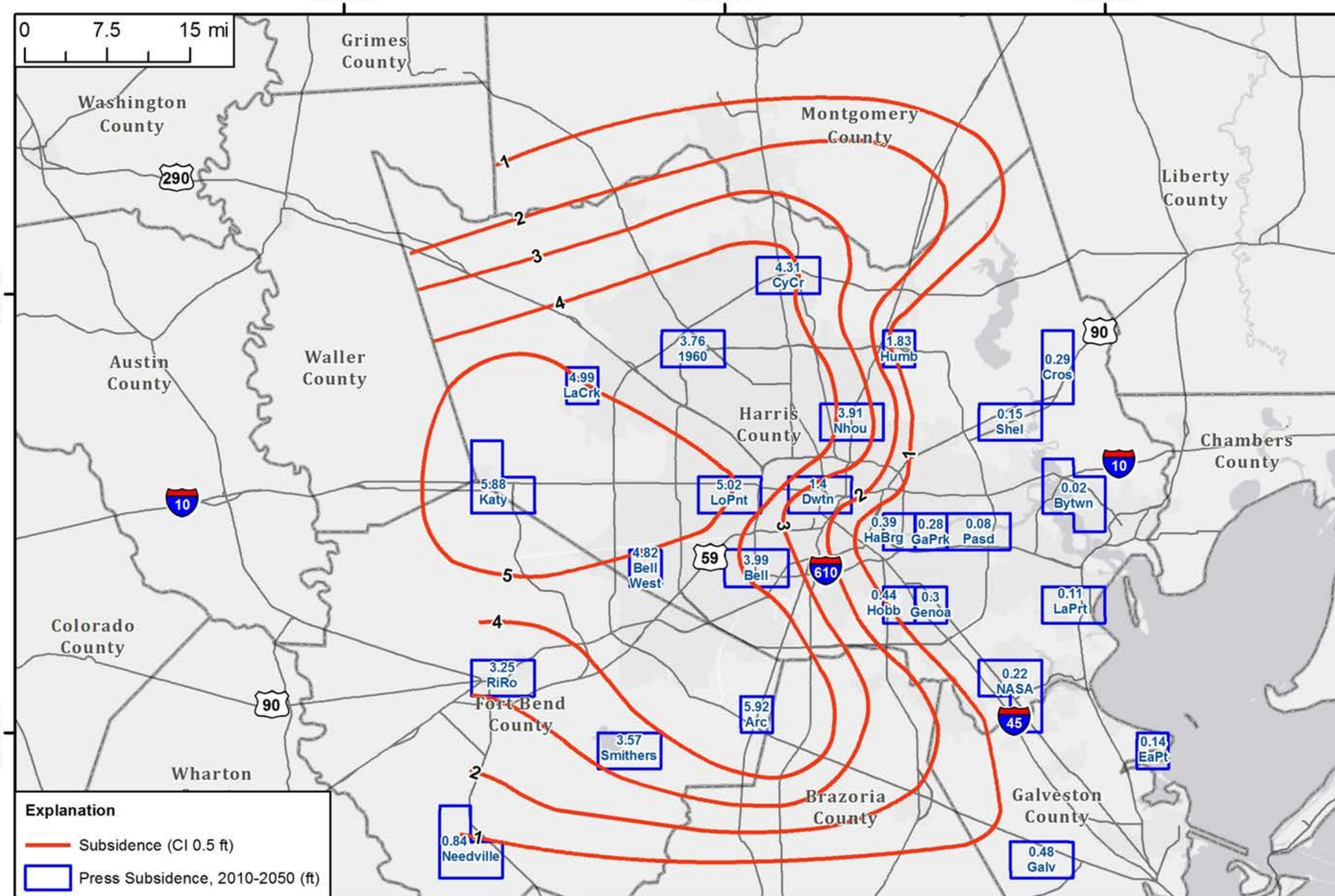
SUBSIDENCE, 2010-2030

Scenario 1



SUBSIDENCE, 2010-2040

Scenario 1



SUBSIDENCE, 2010-2050

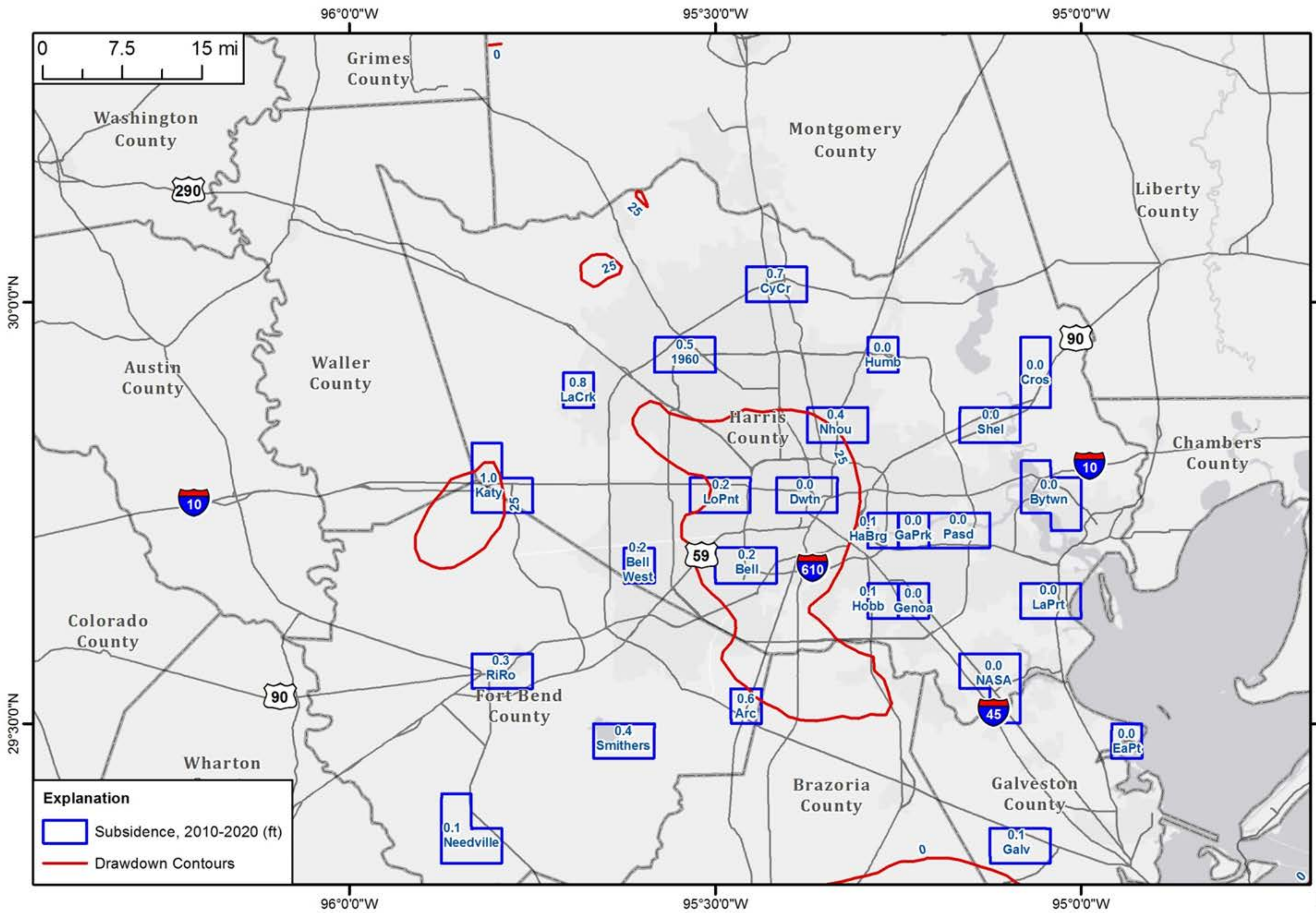
DRAFT

Scenario 1

Scenario 2 – Current Adopted Regulations

- **Harris and Galveston Counties (HGSD 1999 Regulatory Plan)**
  - Area 1 = 90% conversion
  - Area 2 = 80% conversion
  - Area 3 = 30% conversion current to 2019
  - Area 3 = 70% conversion 2020 to 2029
  - Area 3 = 80% conversion 2030 and beyond
- **Fort Bend County (FBSD 2003 Regulatory Plan)**
  - Area A = 30% conversion 2014 to 2024
  - R/R Sub-Area = 30% conversion 2016 to 2024
  - Area A and R/R Sub-Area = 60% conversion 2025 and beyond
  - Area B remains on 100% groundwater.
- **Montgomery County (LSGCD 2009 Regulatory Plan)**
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond.
- **Brazoria County (BCGCD)**
  - No groundwater reduction regulations adopted in Brazoria County.

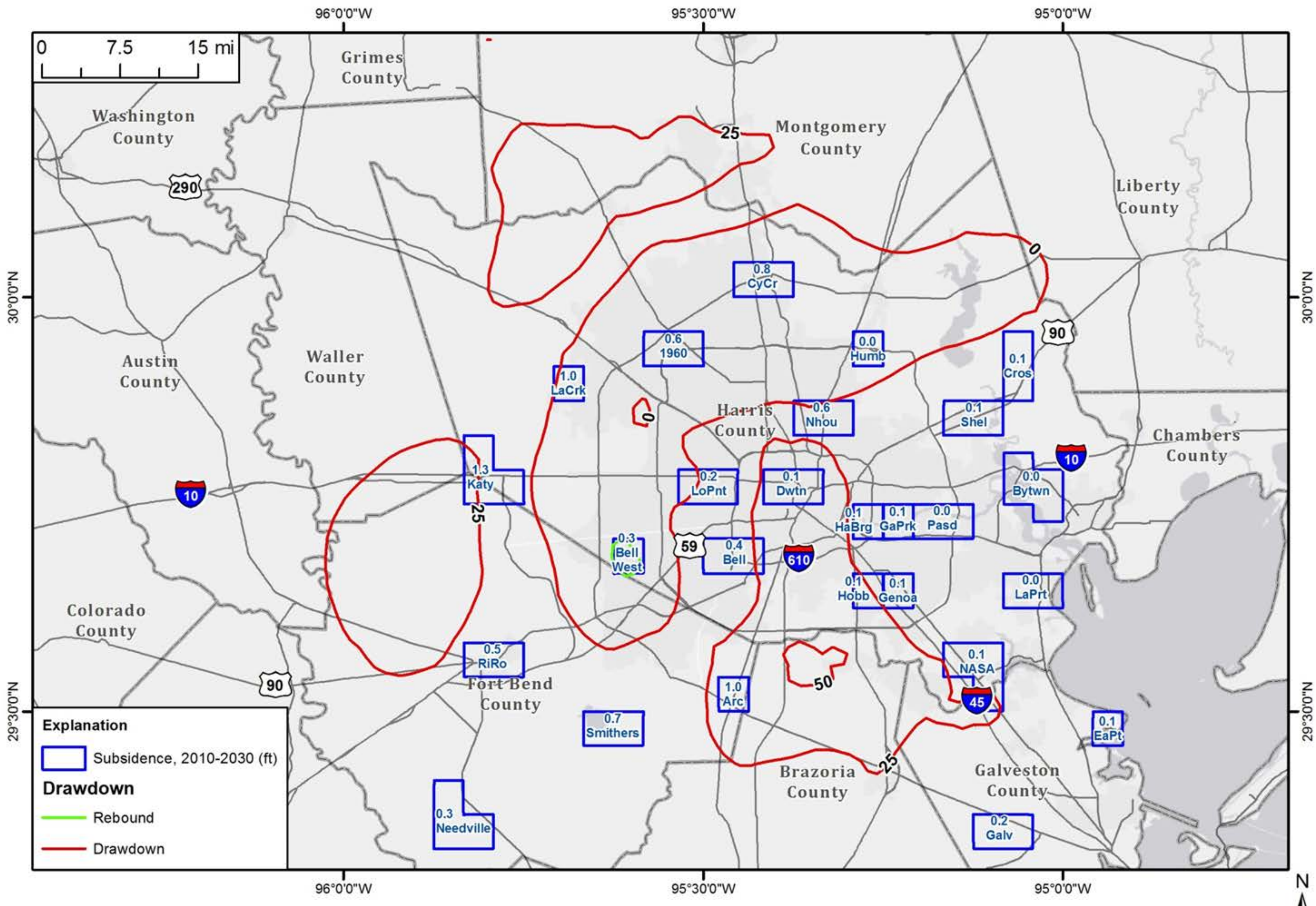
Scenario 2
Chicot Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2020

Scenario 2

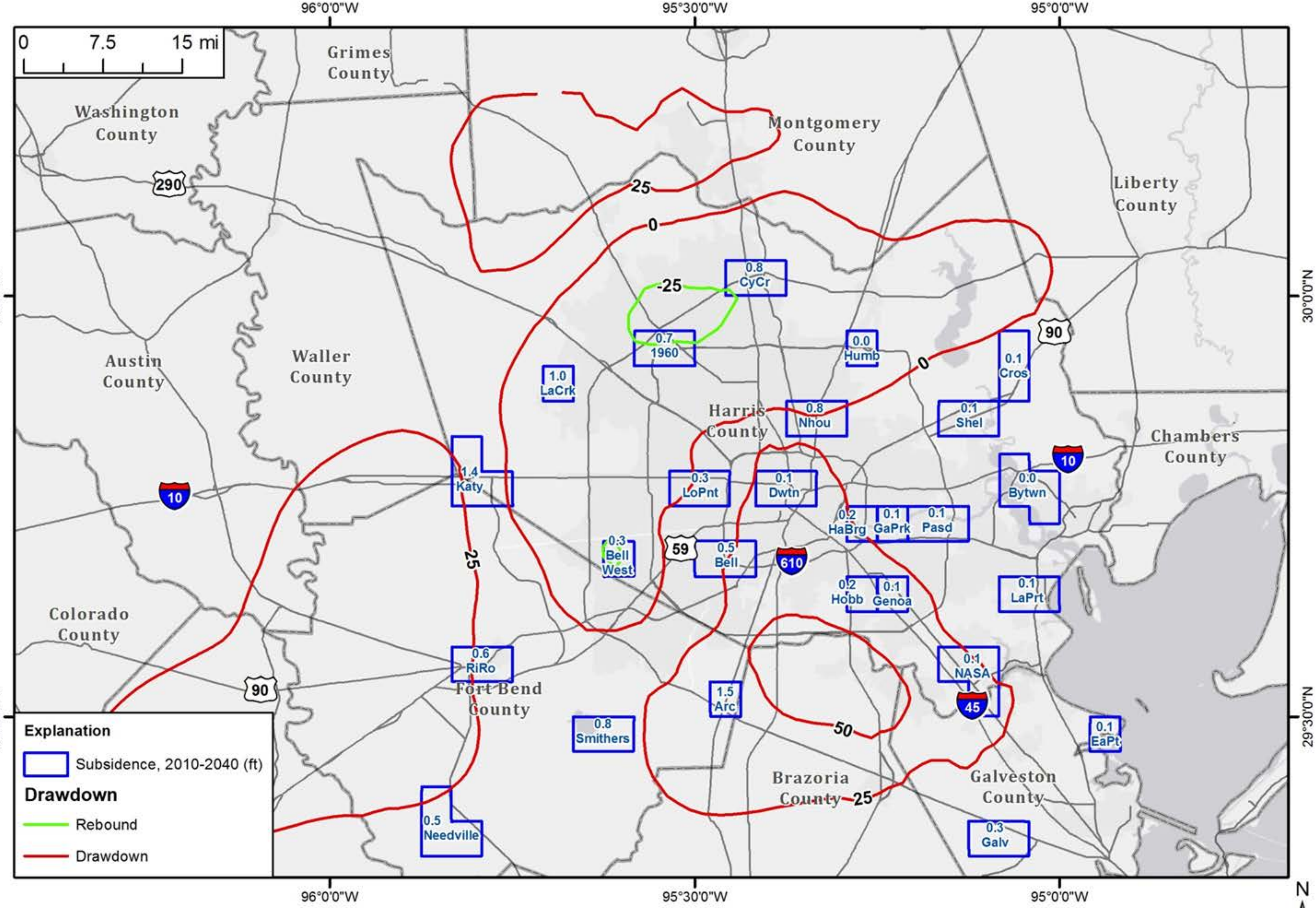
DRAFT



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2030

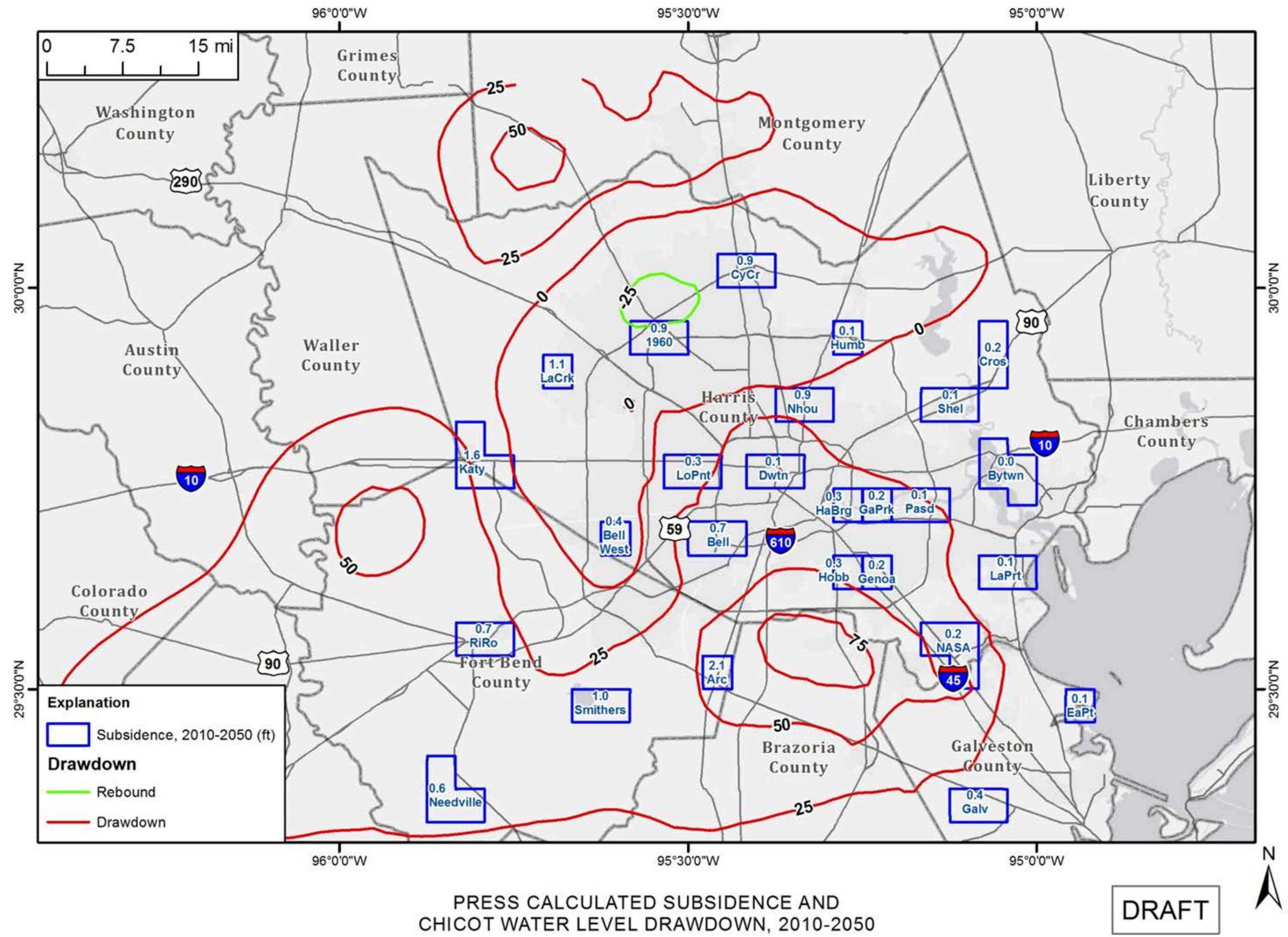
Scenario 2

DRAFT



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2040

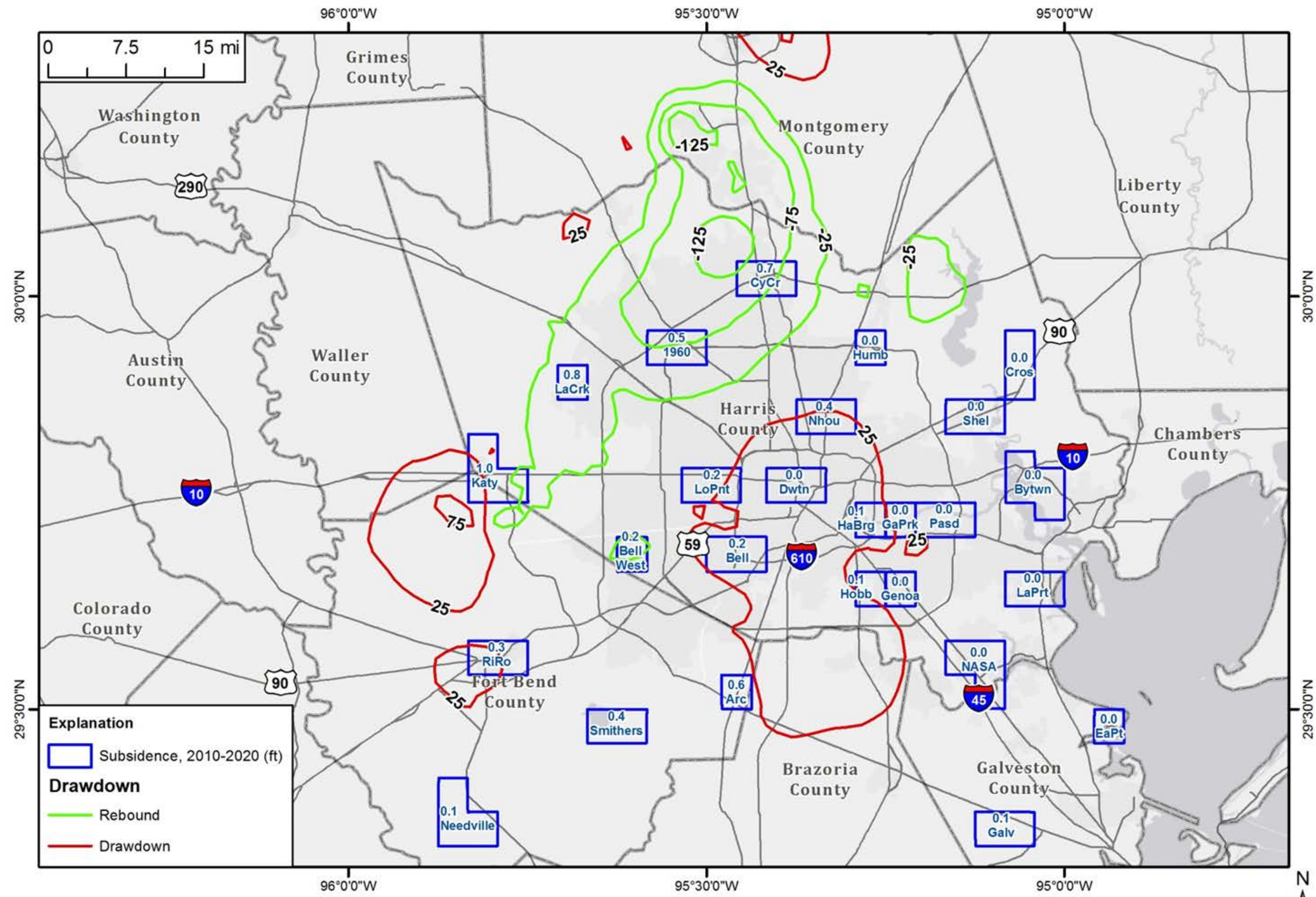
Scenario 2



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2050

Scenario 2

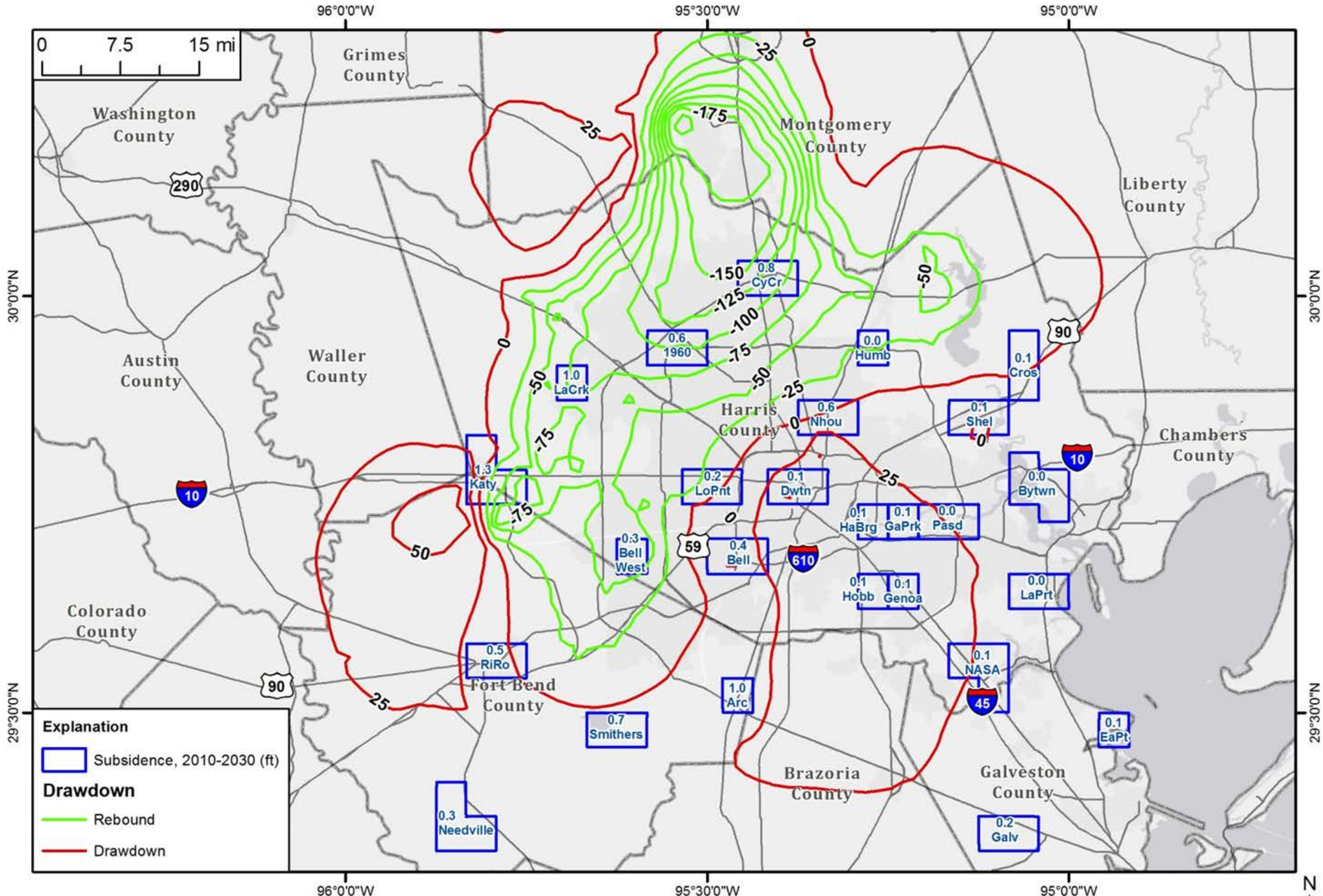
Scenario 2
Evangeline Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2020

Scenario 2

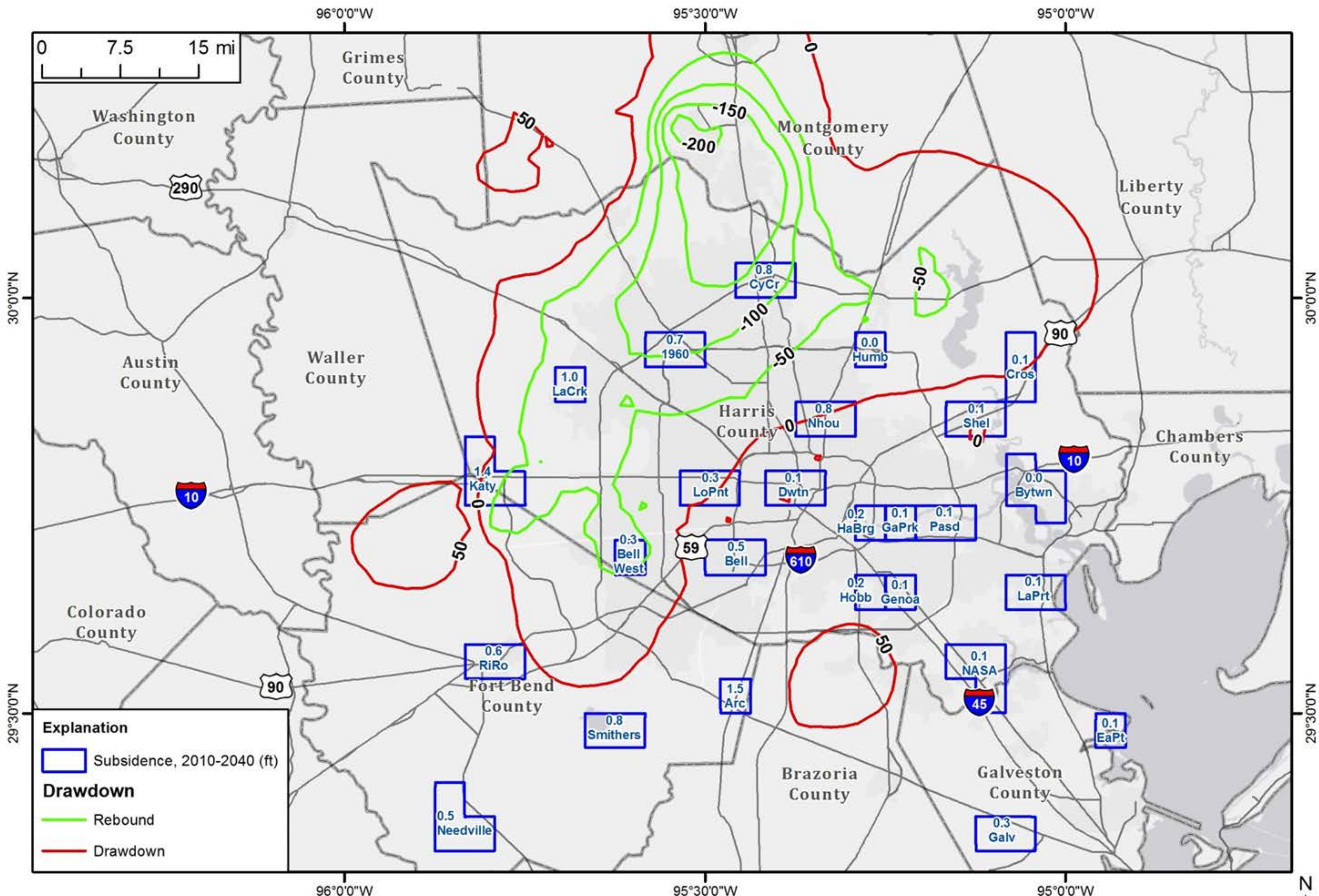
DRAFT



PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2030

Scenario 2

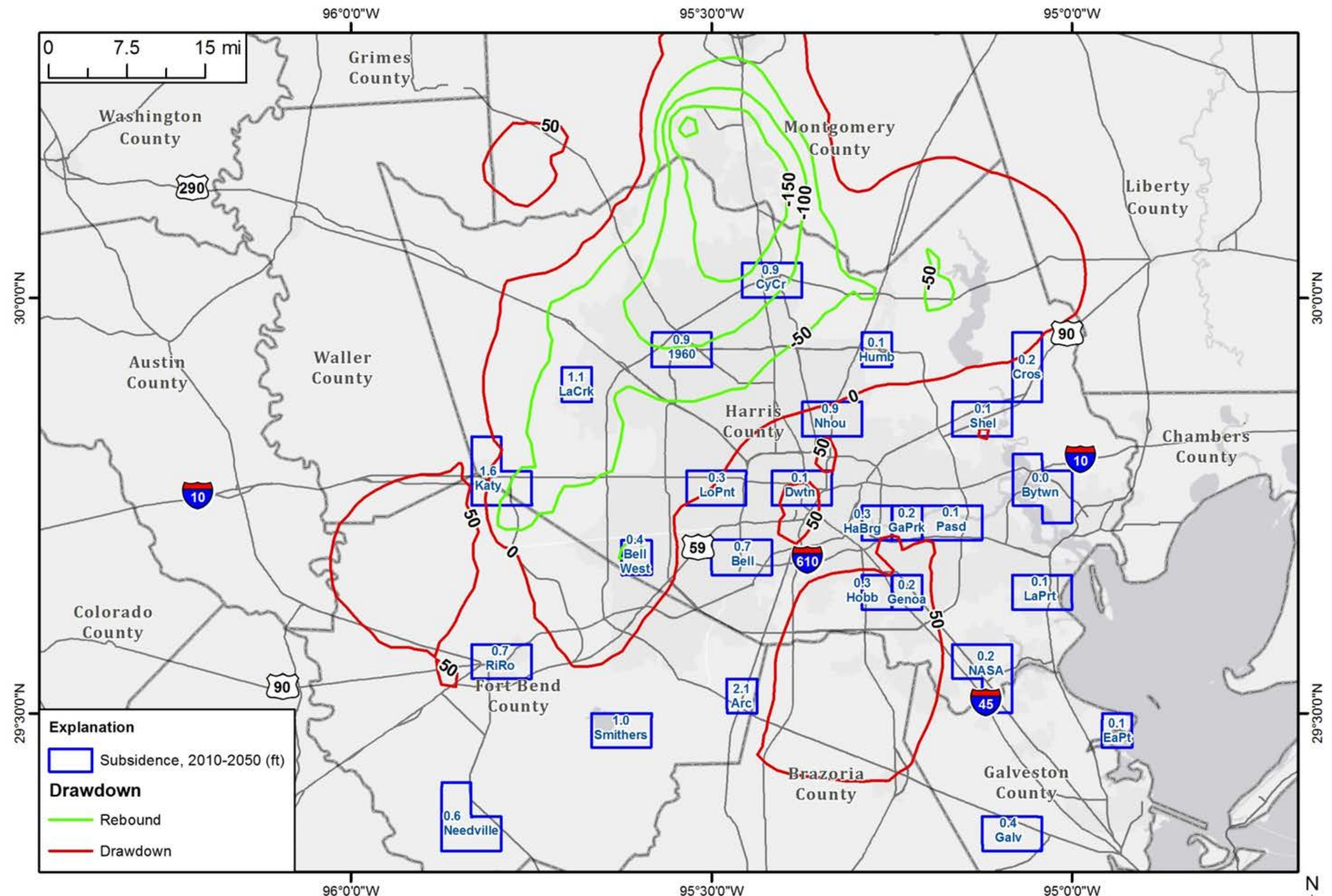
DRAFT



PRESS CALCULATED SUBSIDENCE AND EVANGELINE WATER LEVEL DRAWDOWN, 2010-2040

Scenario 2

DRAFT

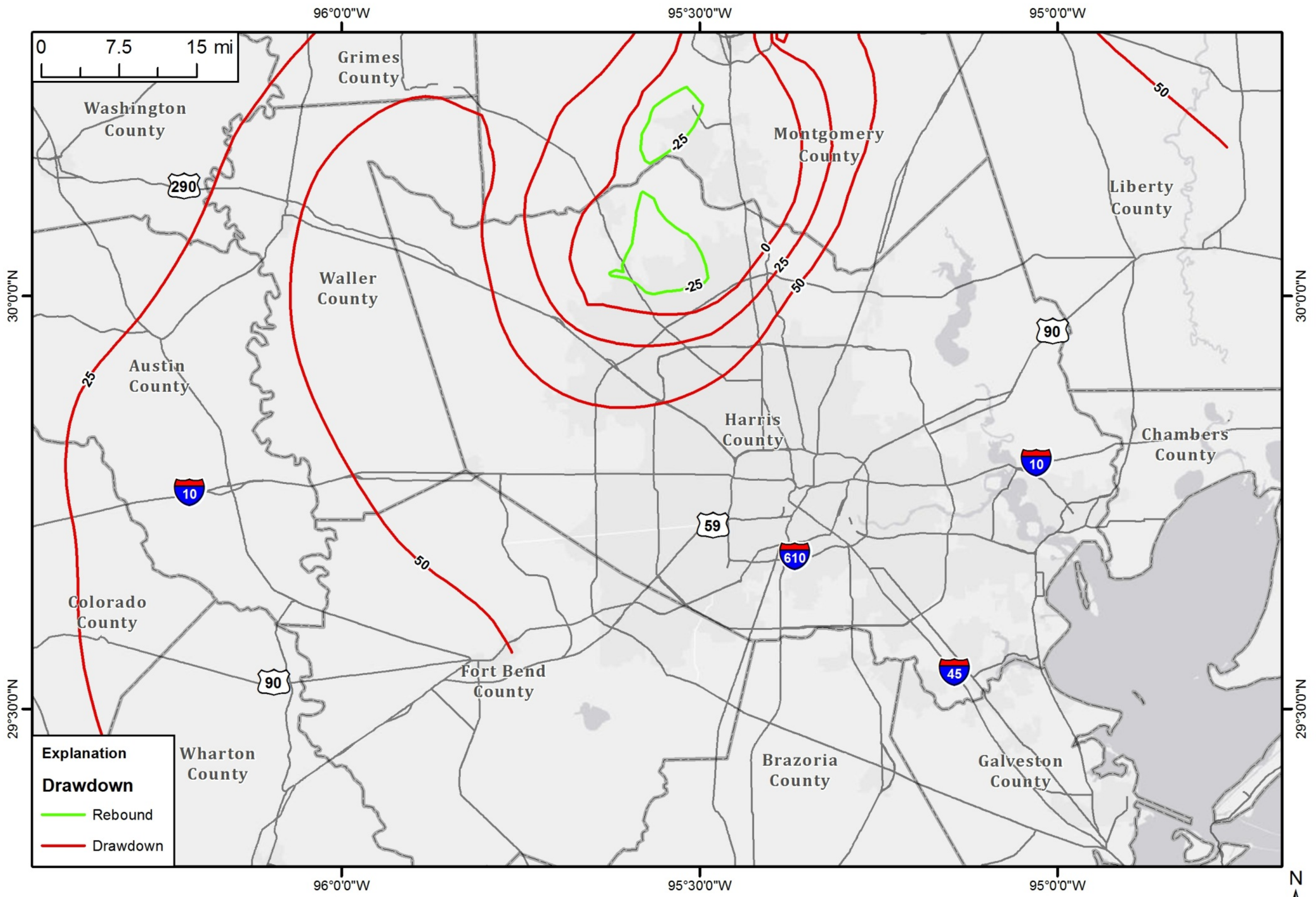


PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2050

Scenario 2

DRAFT

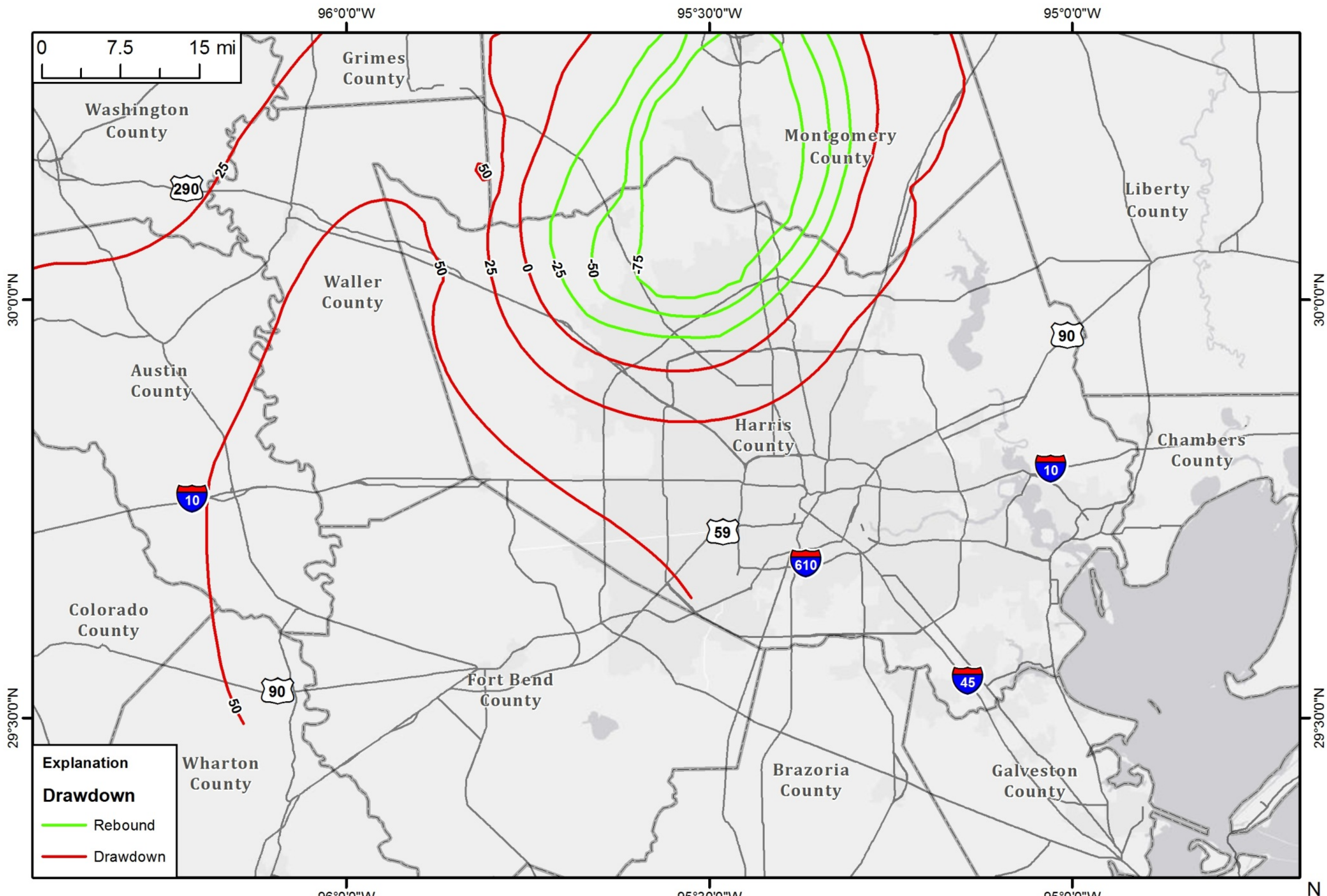
Scenario 2
Jasper Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2020

Scenario 2

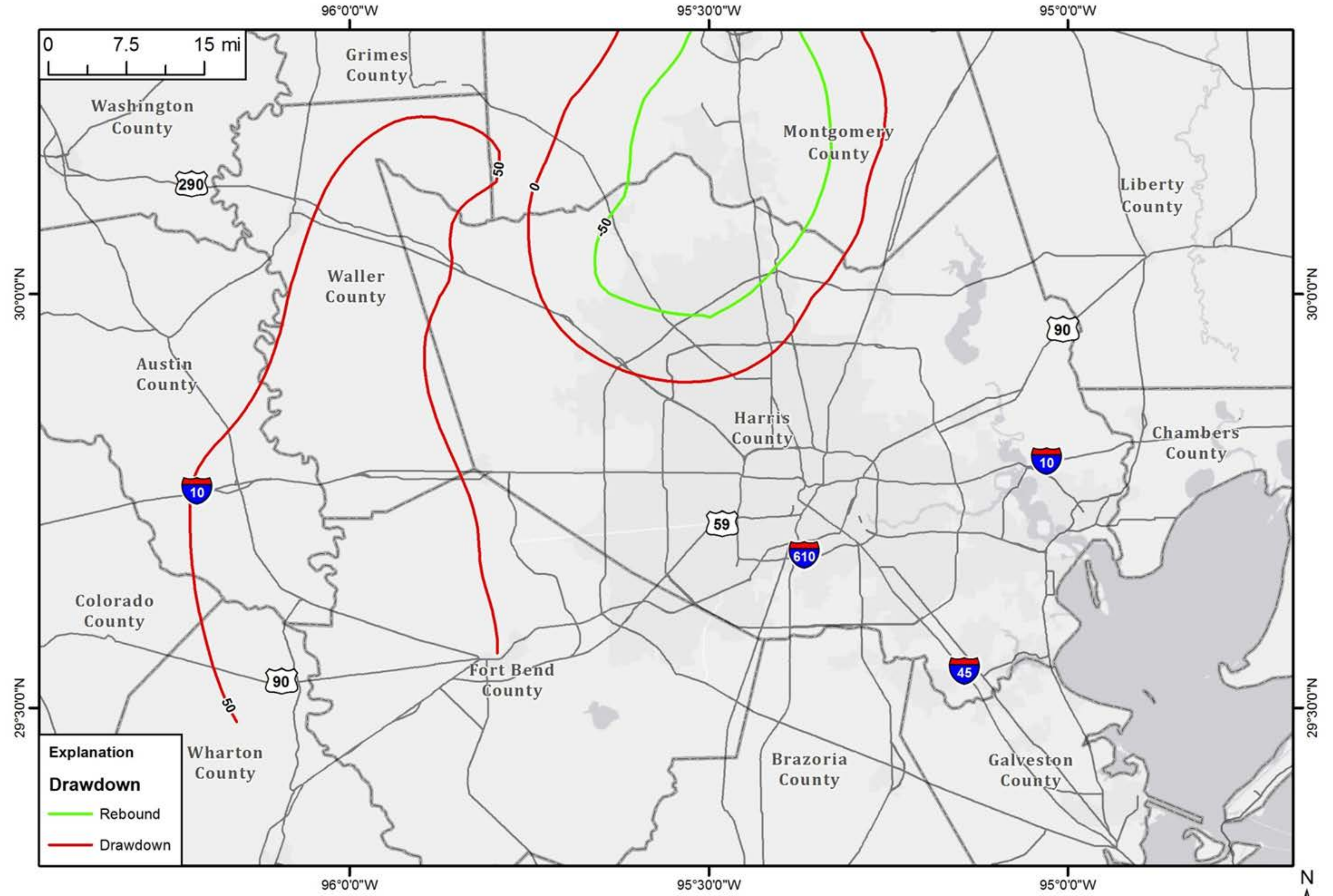
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2030

Scenario 2

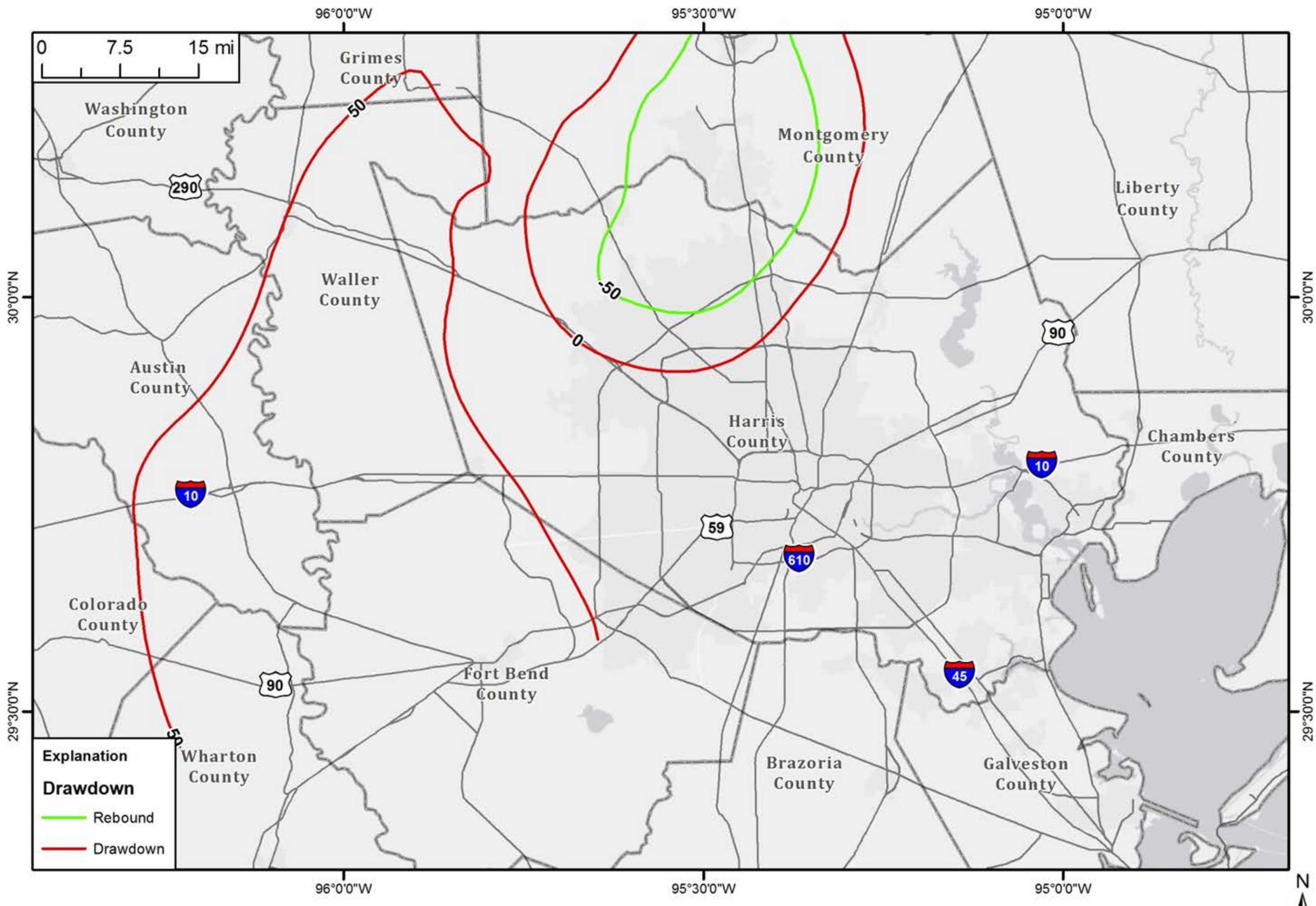
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2040

Scenario 2

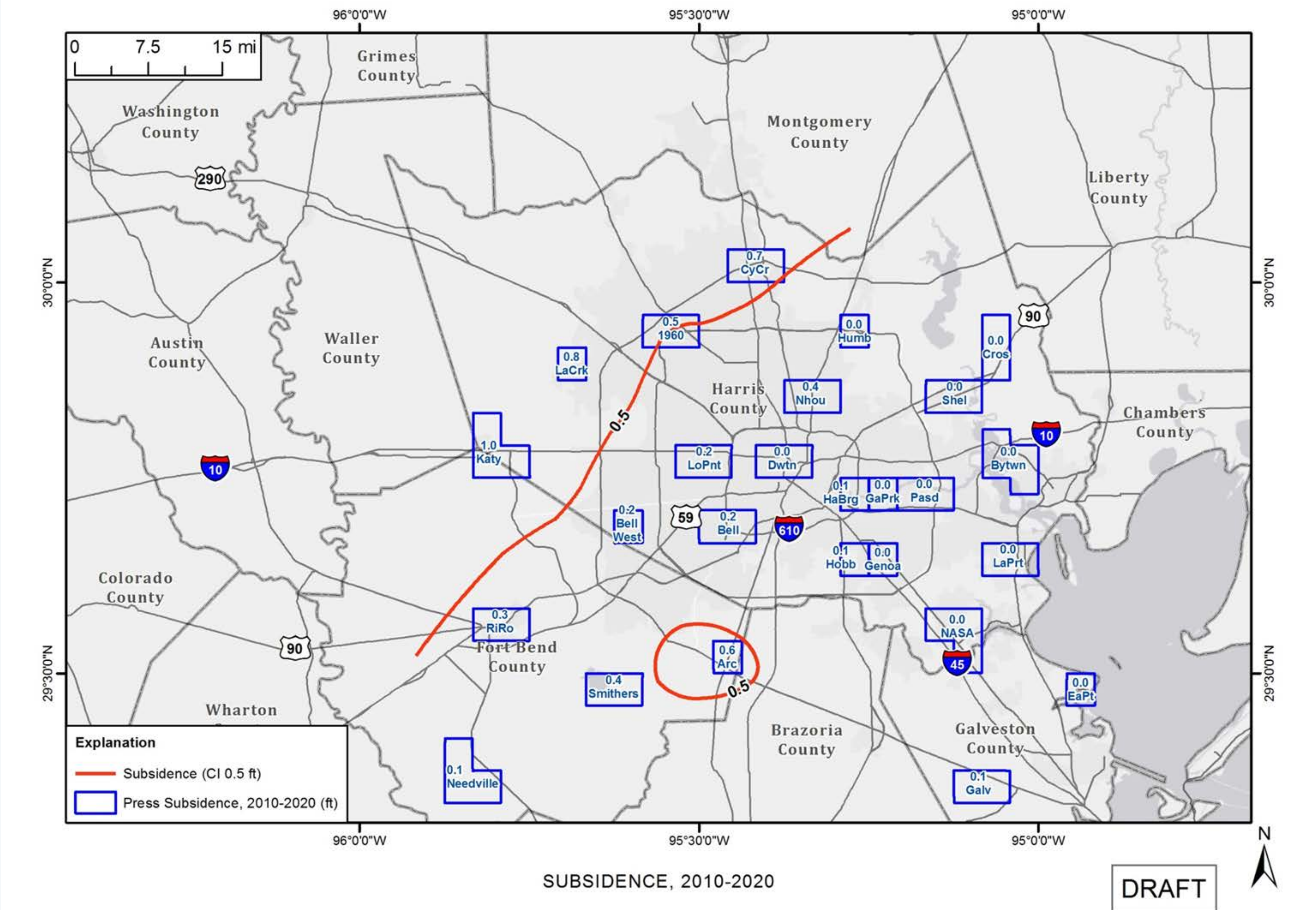
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2050

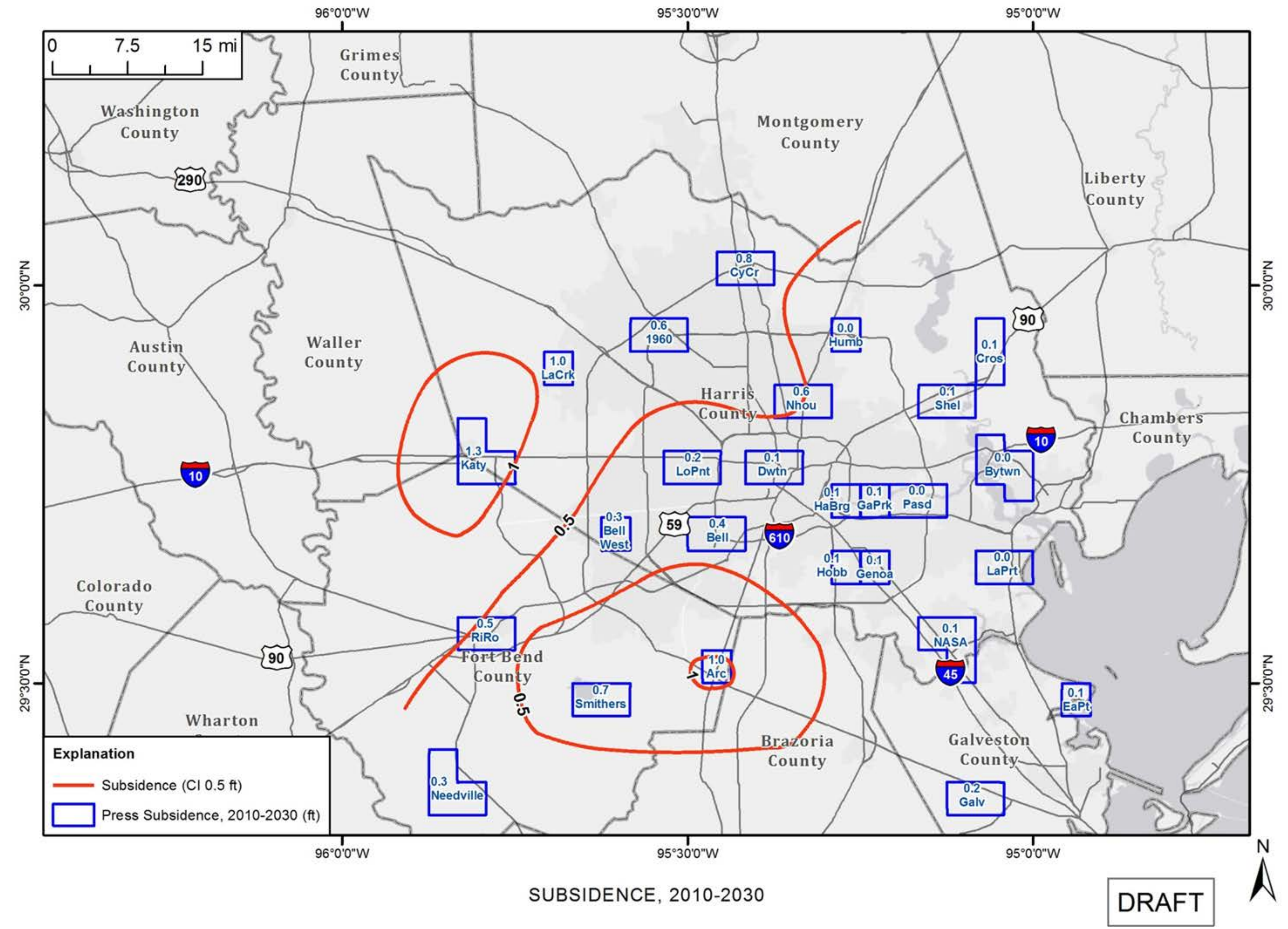
Scenario 2

Scenario 2
Predicted Subsidence Contour Maps



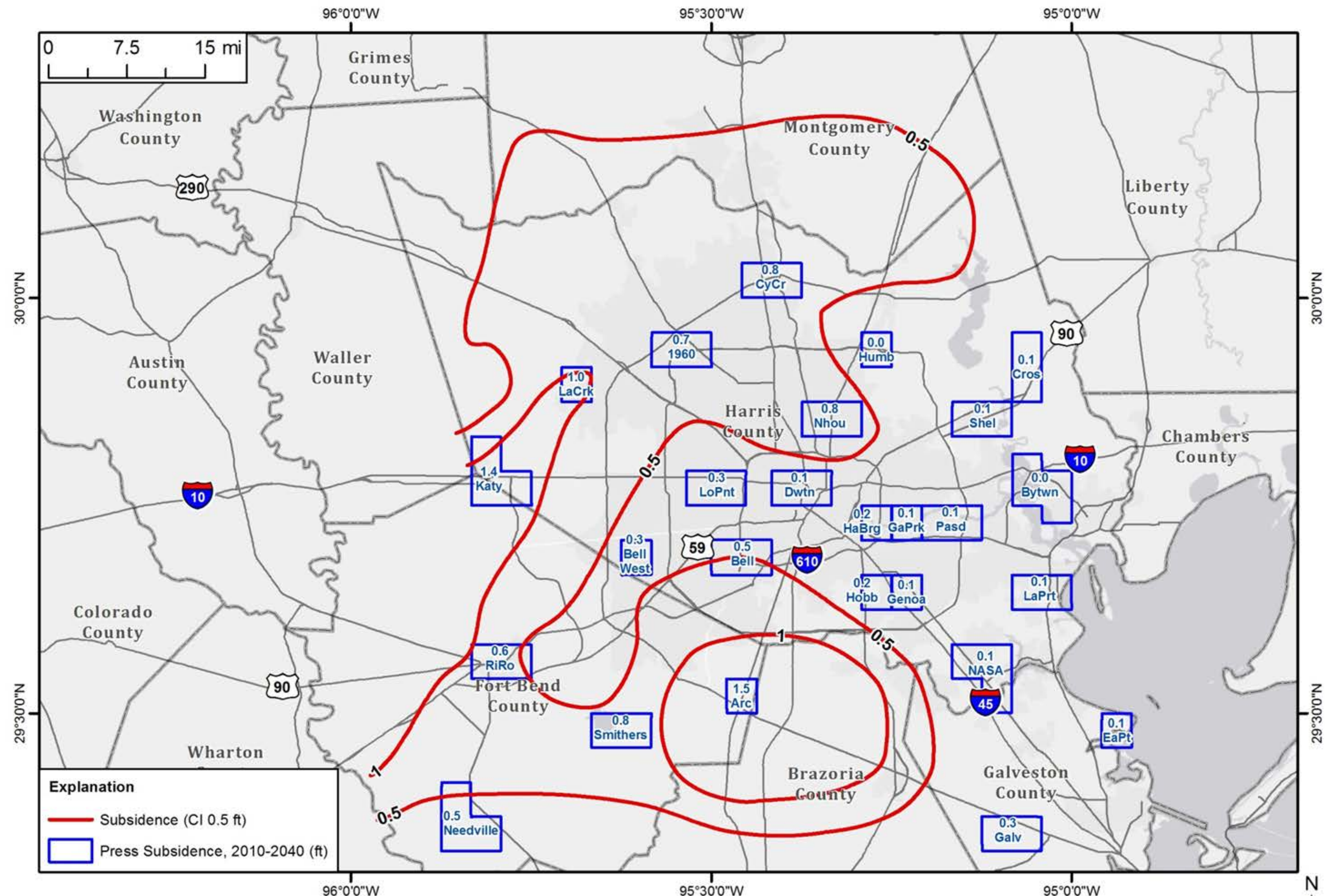
SUBSIDENCE, 2010-2020

Scenario 2



SUBSIDENCE, 2010-2030

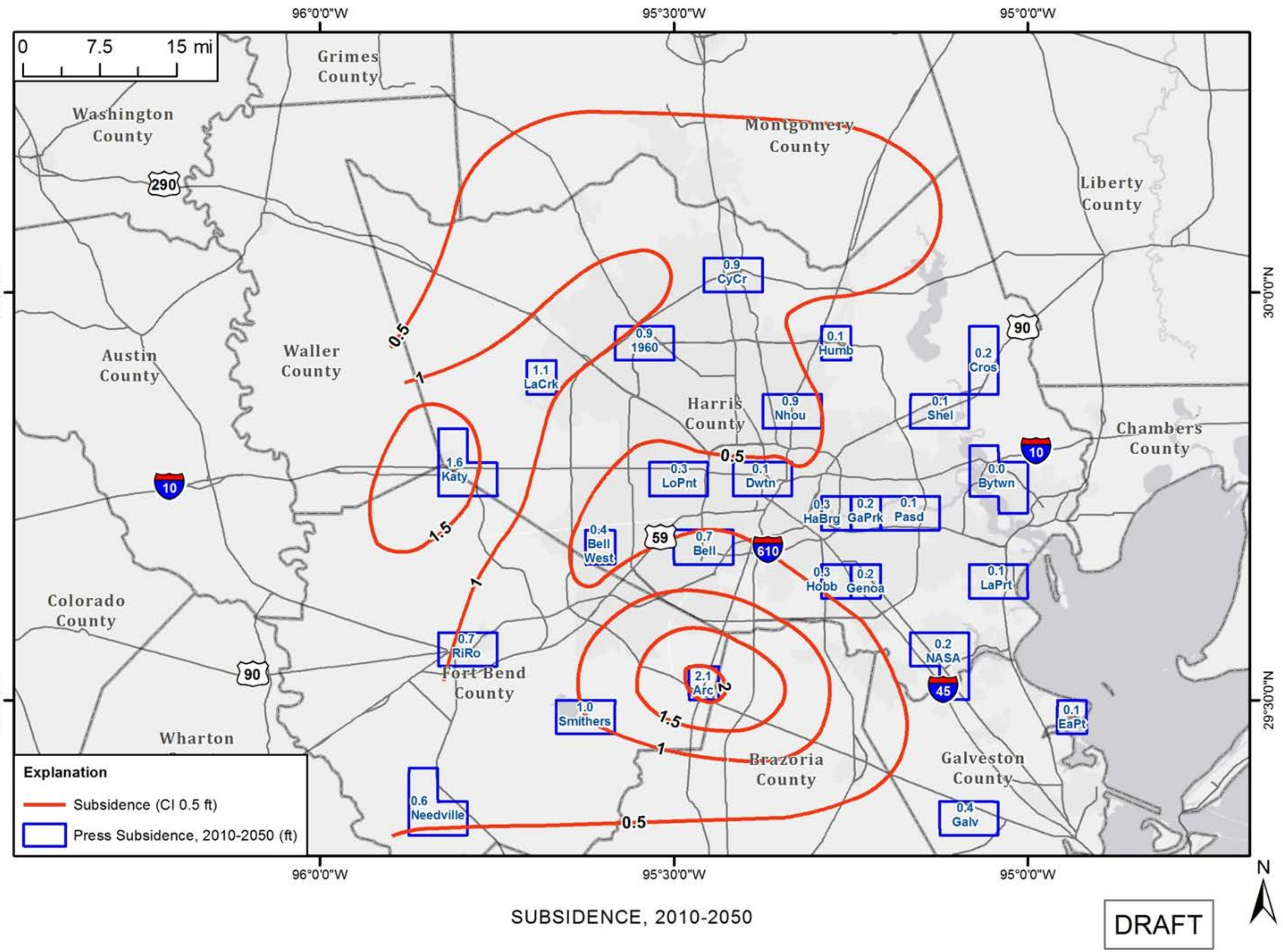
Scenario 2



SUBSIDENCE, 2010-2040

DRAFT

Scenario 2



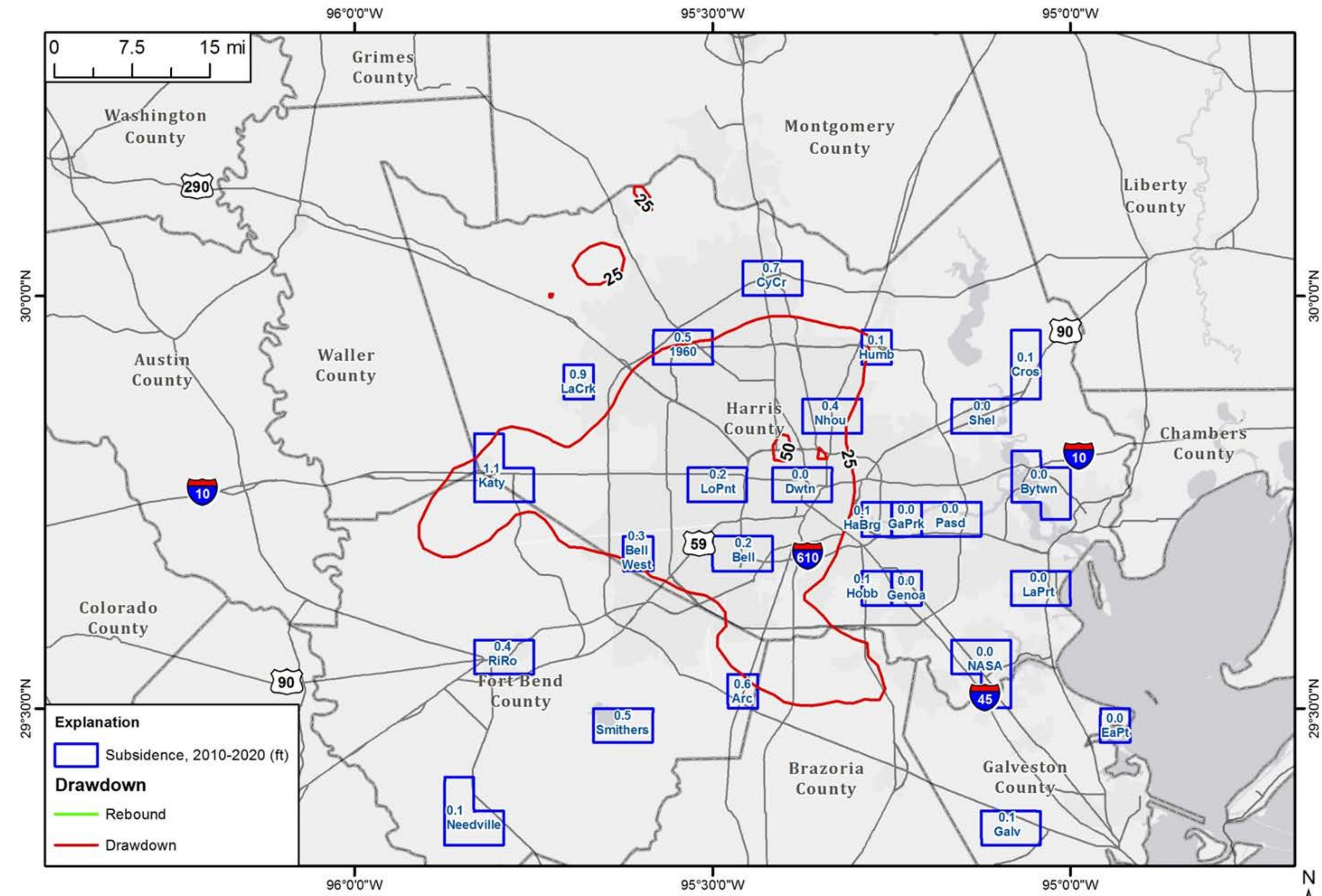
SUBSIDENCE, 2010-2050

Scenario 2

Scenario 3 – Modifications to Current Adopted Regulations

- **Harris and Galveston Counties (HGSD 1999 Regulatory Plan)**
  - Area 1 = 90% conversion (same as Scenario 2)
  - Area 2 = 80% conversion (same as Scenario 2)
  - Area 3 = 30% conversion current to 2024
  - Area 3 = 60% conversion 2025 to 2034
  - Area 3 = 80% conversion 2035 and beyond
- **Fort Bend County (FBSD 2003 Regulatory Plan)**
  - Area A = 30% conversion 2014 to 2024 (same as Scenario 2)
  - R/R Sub-Area = 30% conversion 2016 to 2024 (same as Scenario 2)
  - Area A and R/R Sub-Area = 50% conversion 2025 to 2034
  - Area A and R/R Sub-Area = 65% conversion 2035 and beyond
  - Area B remains on 100% groundwater (same as Scenario 2).
- **Montgomery County (LSGCD 2009 Regulatory Plan)**
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond (same as Scenario 2).
- **Brazoria County (BCGCD)**
  - No groundwater reduction regulations adopted in Brazoria County (same as Scenario 2).

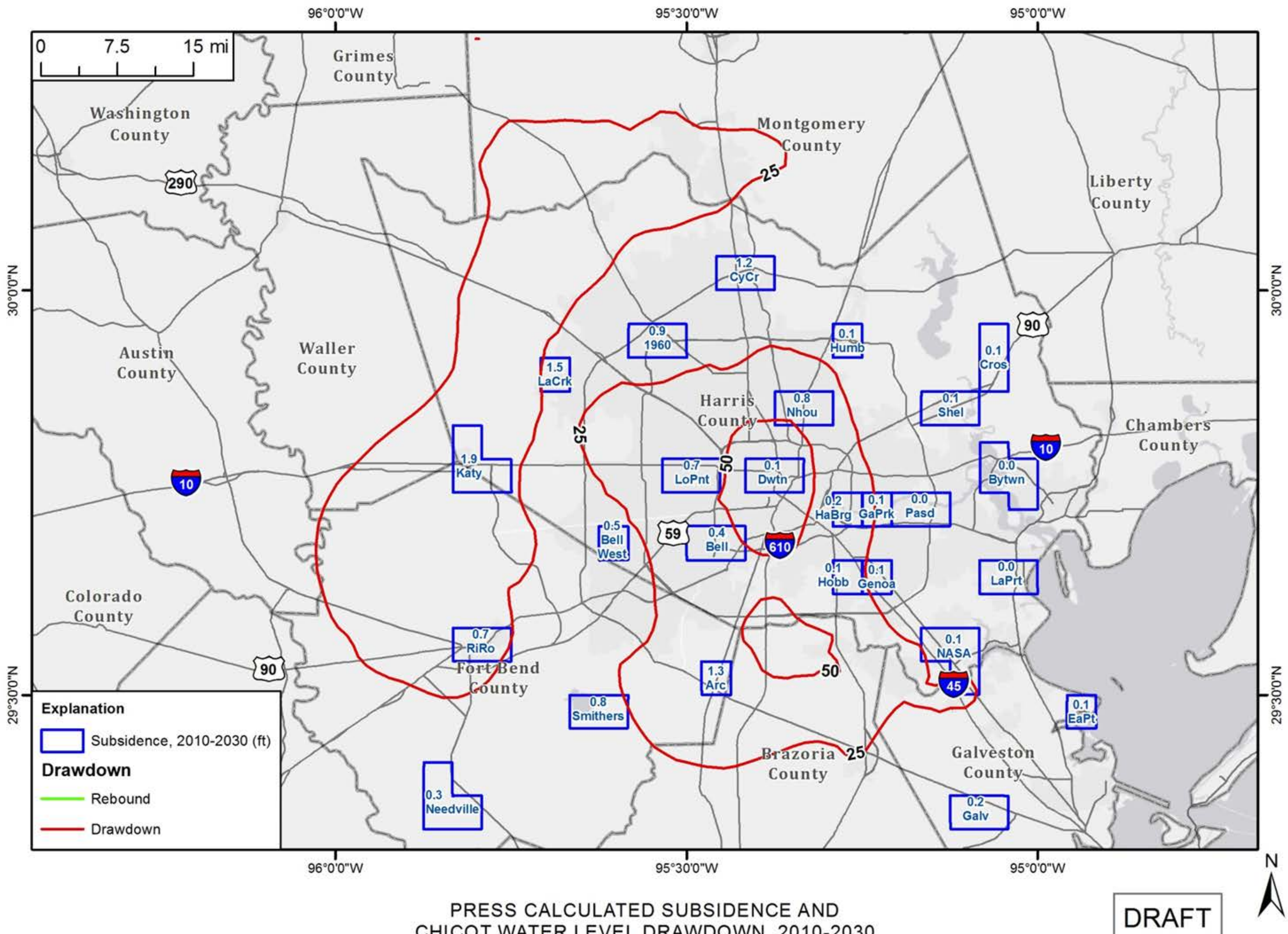
Scenario 3
Chicot Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2020

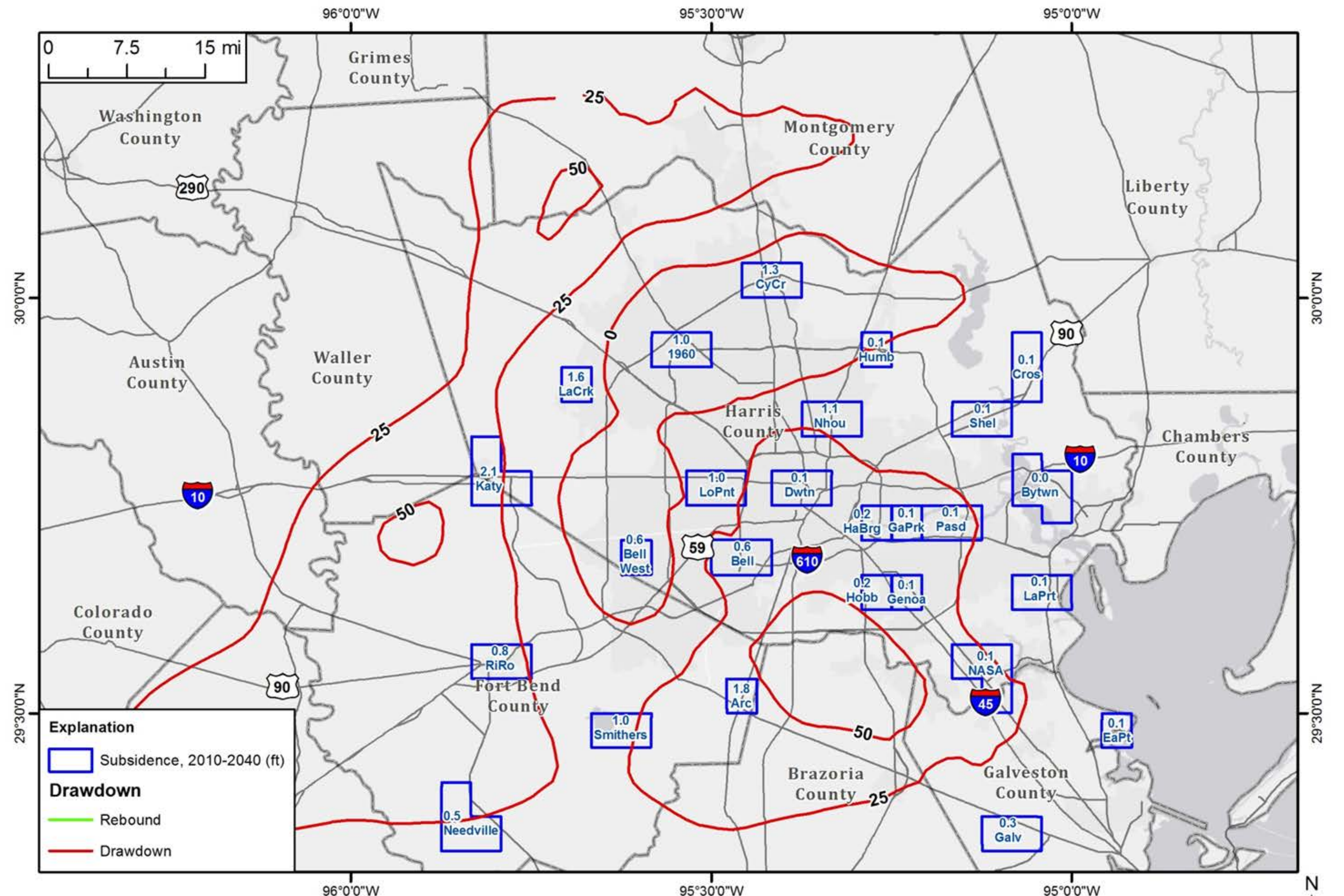
Scenario 3

DRAFT



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2030

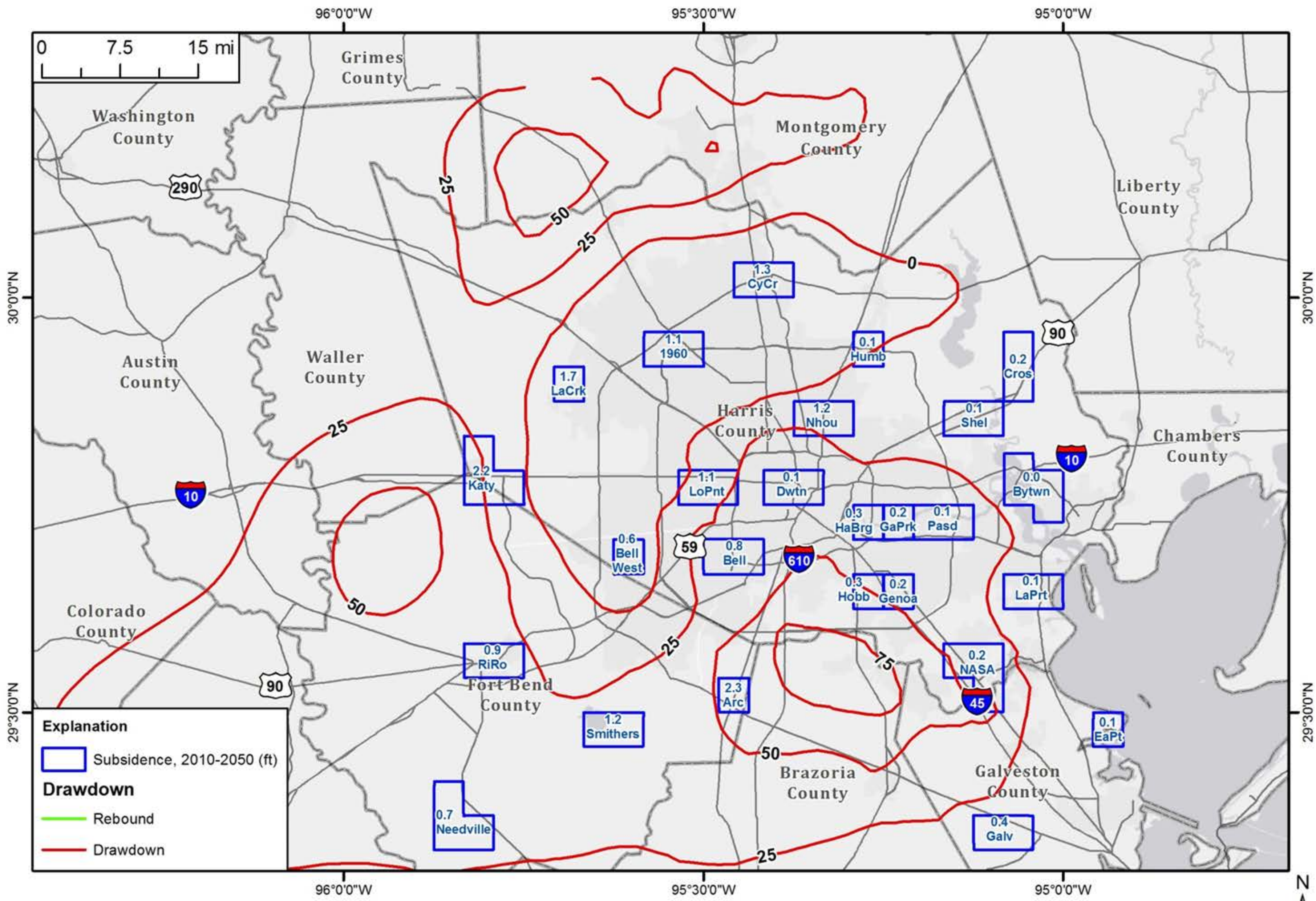
Scenario 3



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2040

Scenario 3

DRAFT

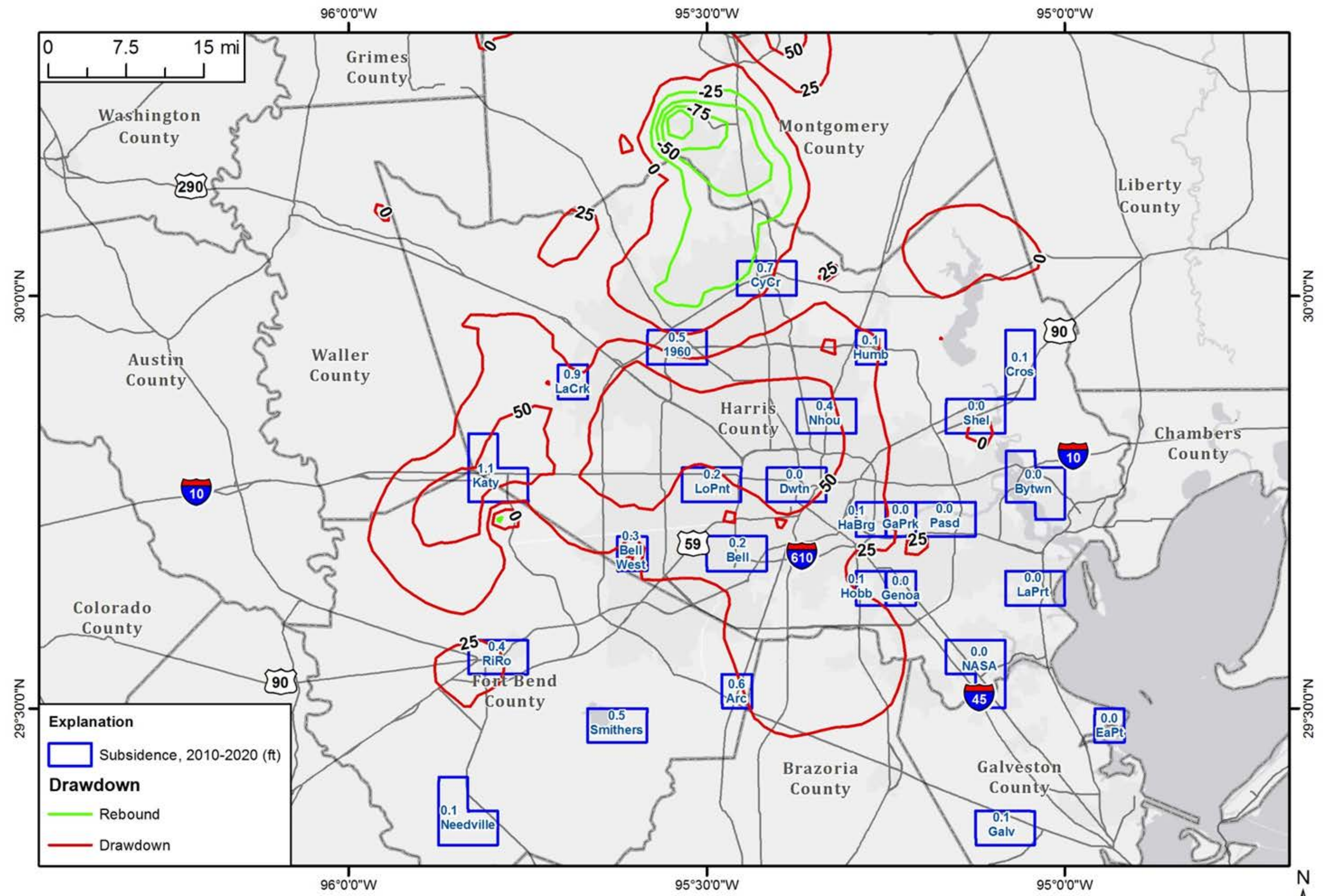


PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2050

Scenario 3

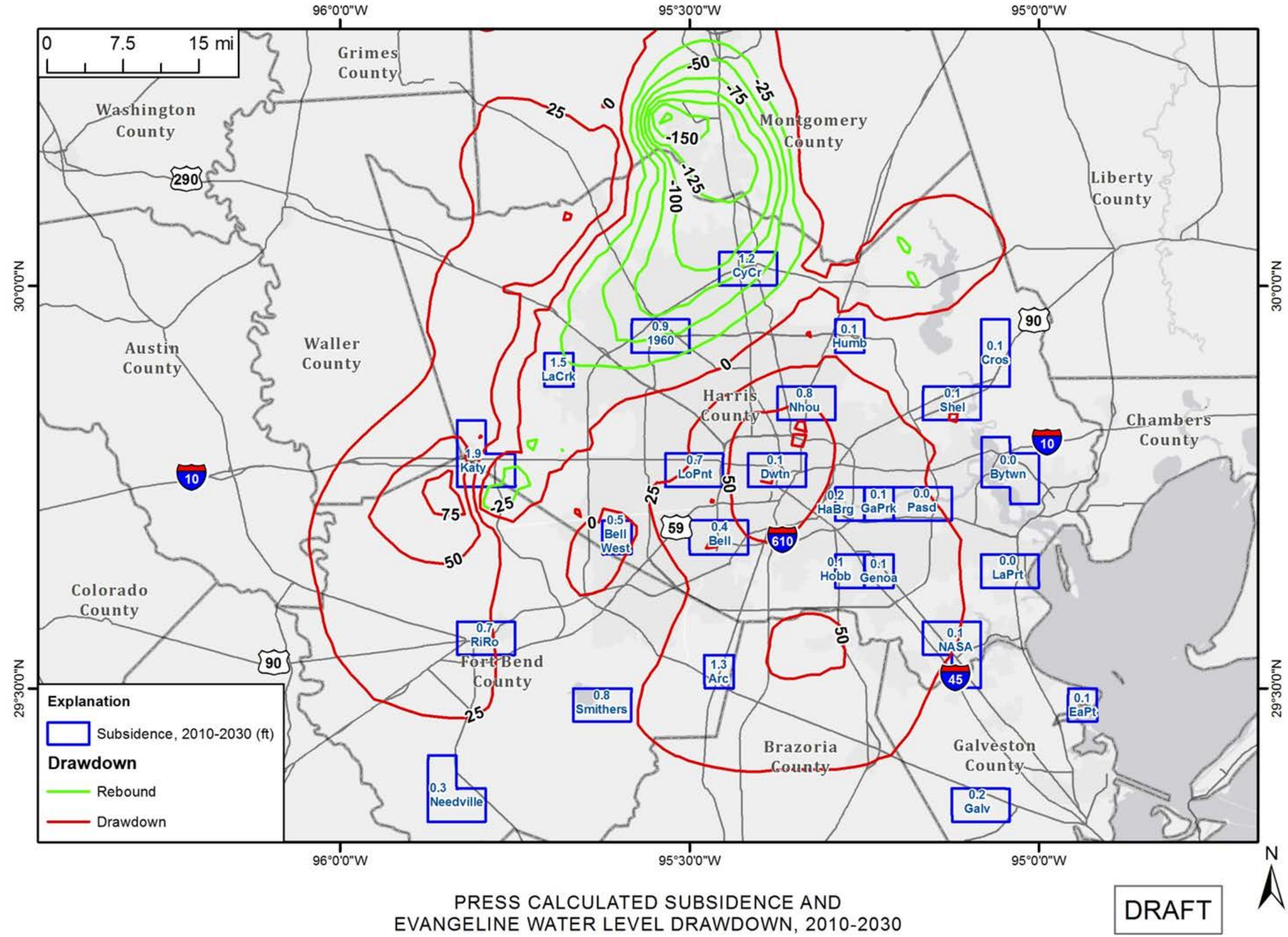
DRAFT

Scenario 3
Evangeline Aquifer
Groundwater Drawdown Maps



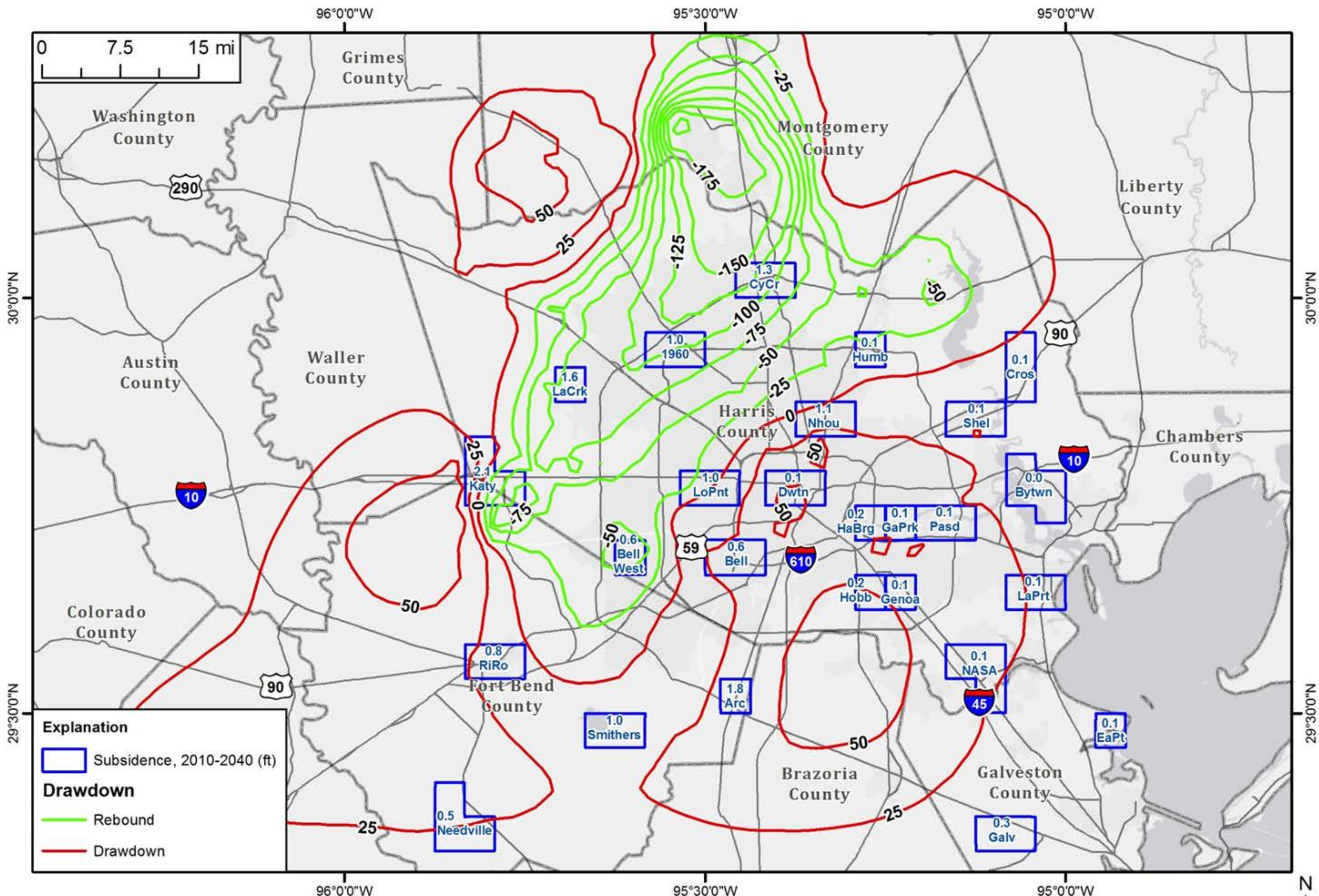
PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2020

Scenario 3



PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2030

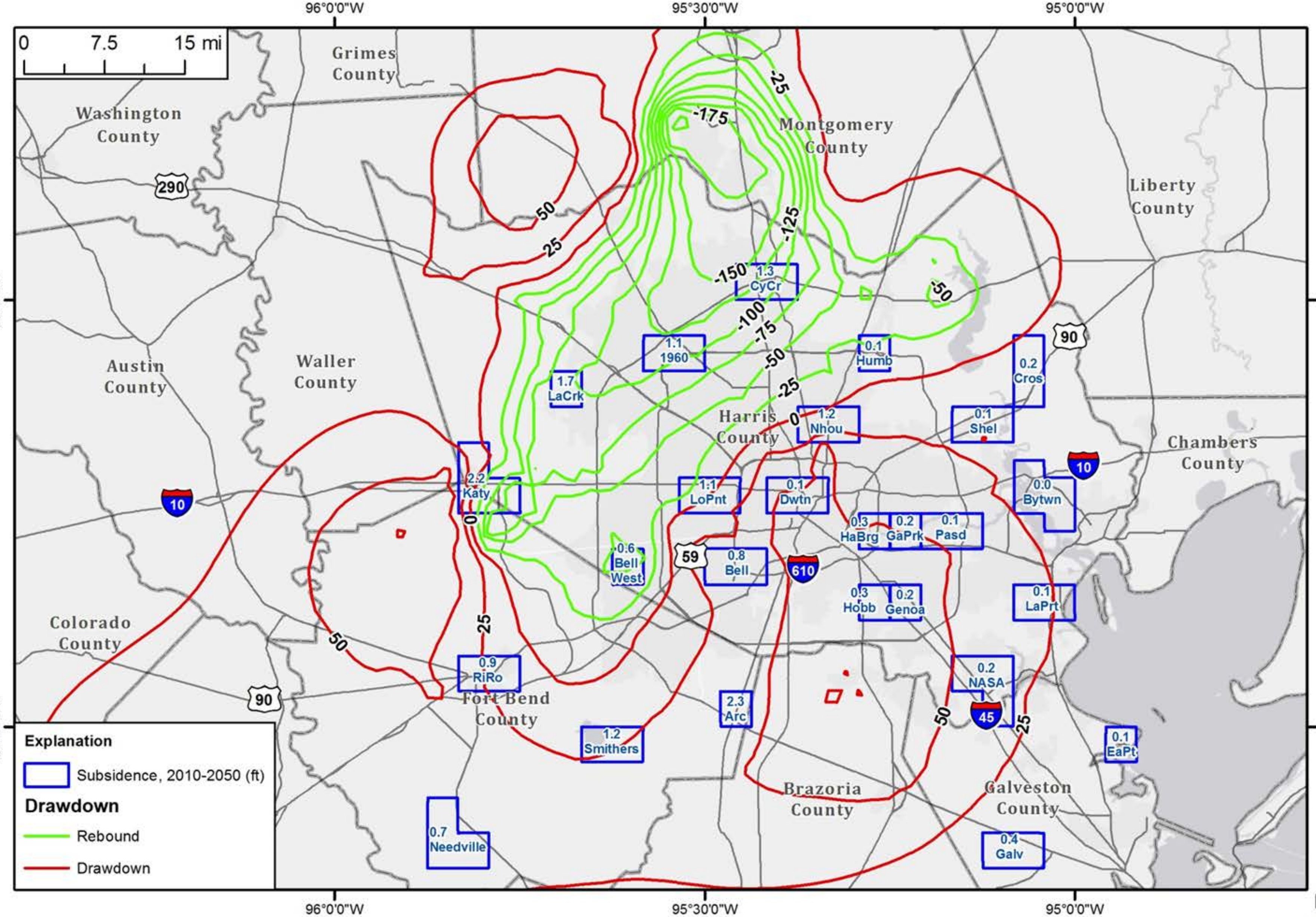
Scenario 3



PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2040

Scenario 3

DRAFT

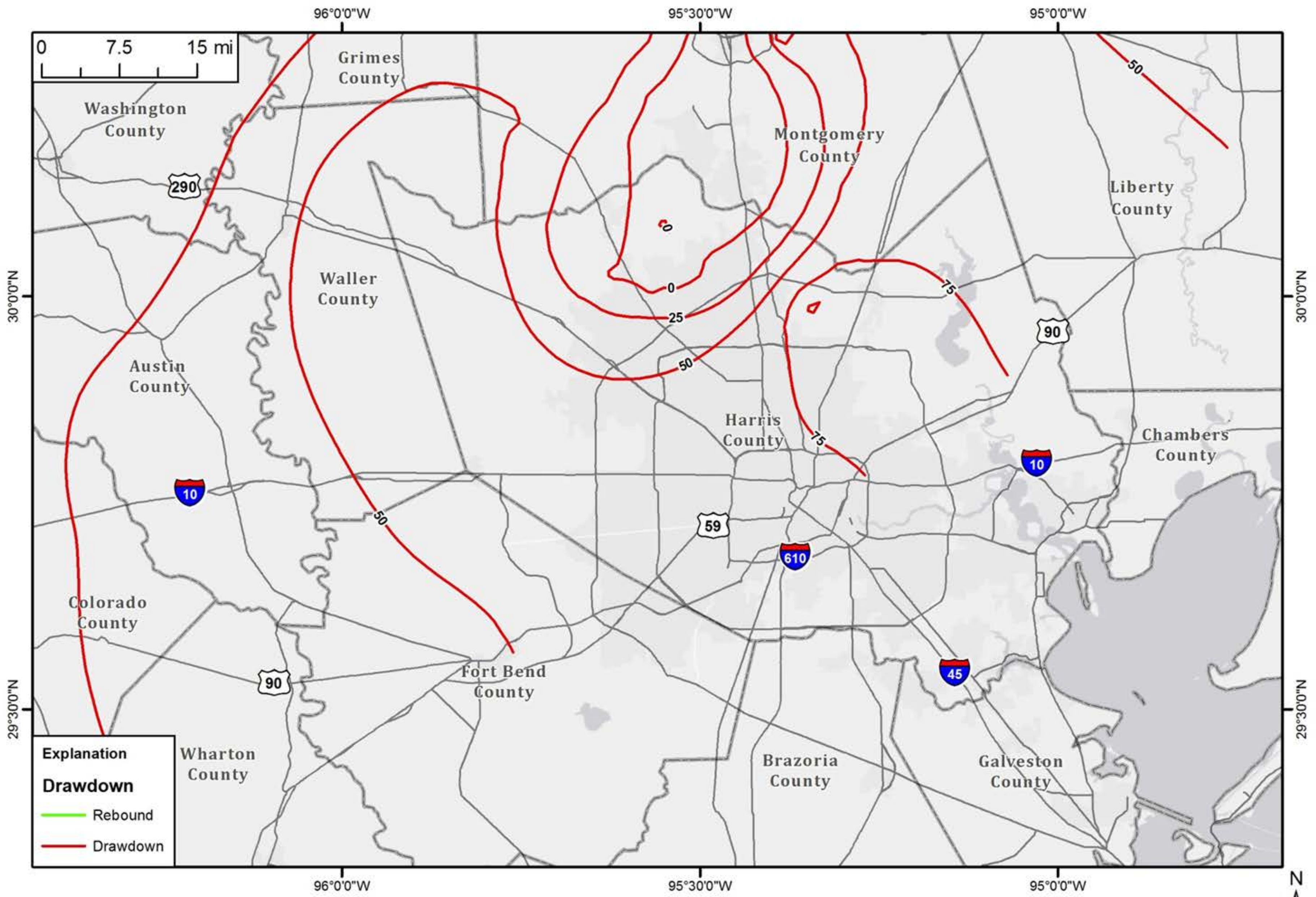


PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2050

Scenario 3

DRAFT

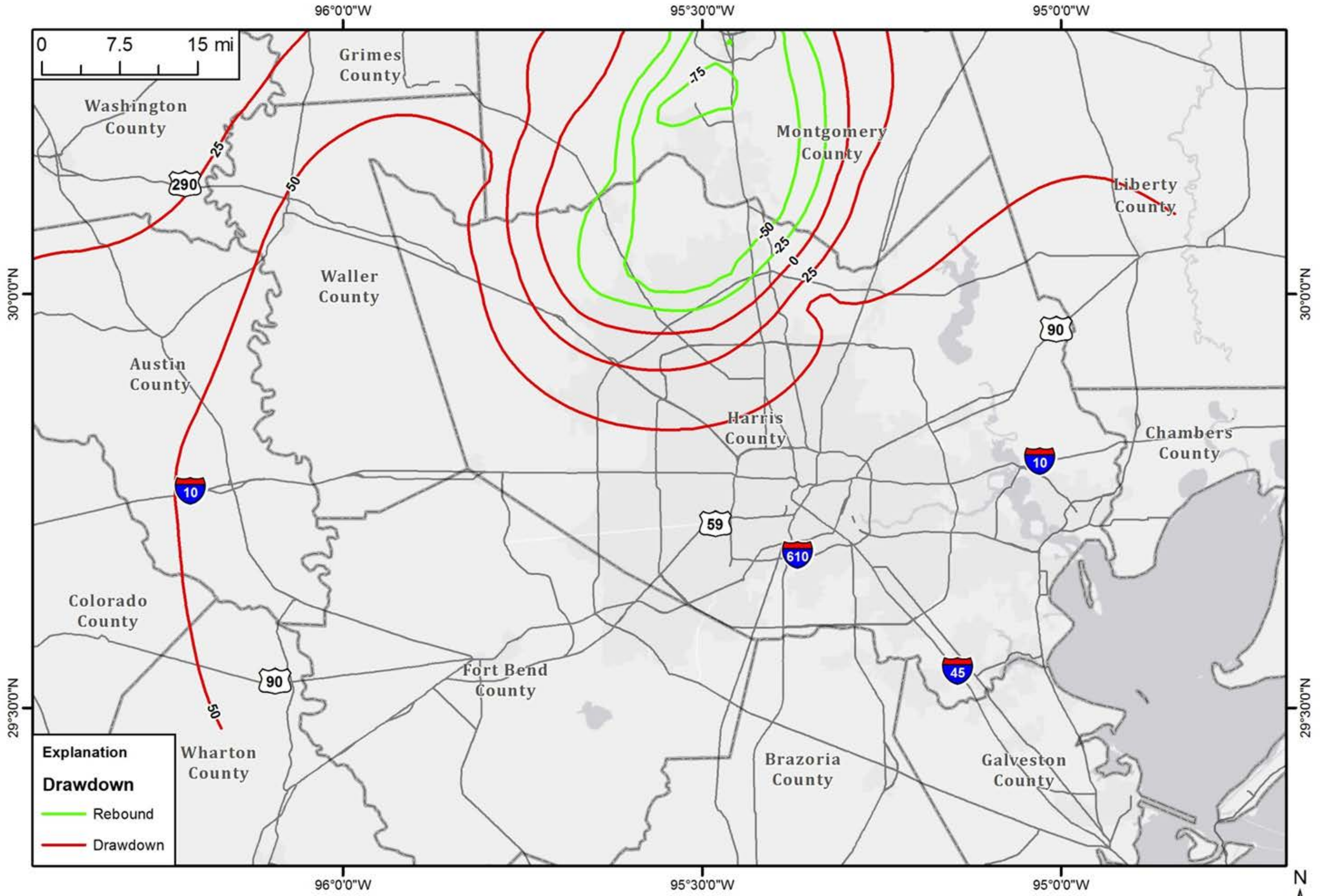
Scenario 3
Jasper Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2020

DRAFT

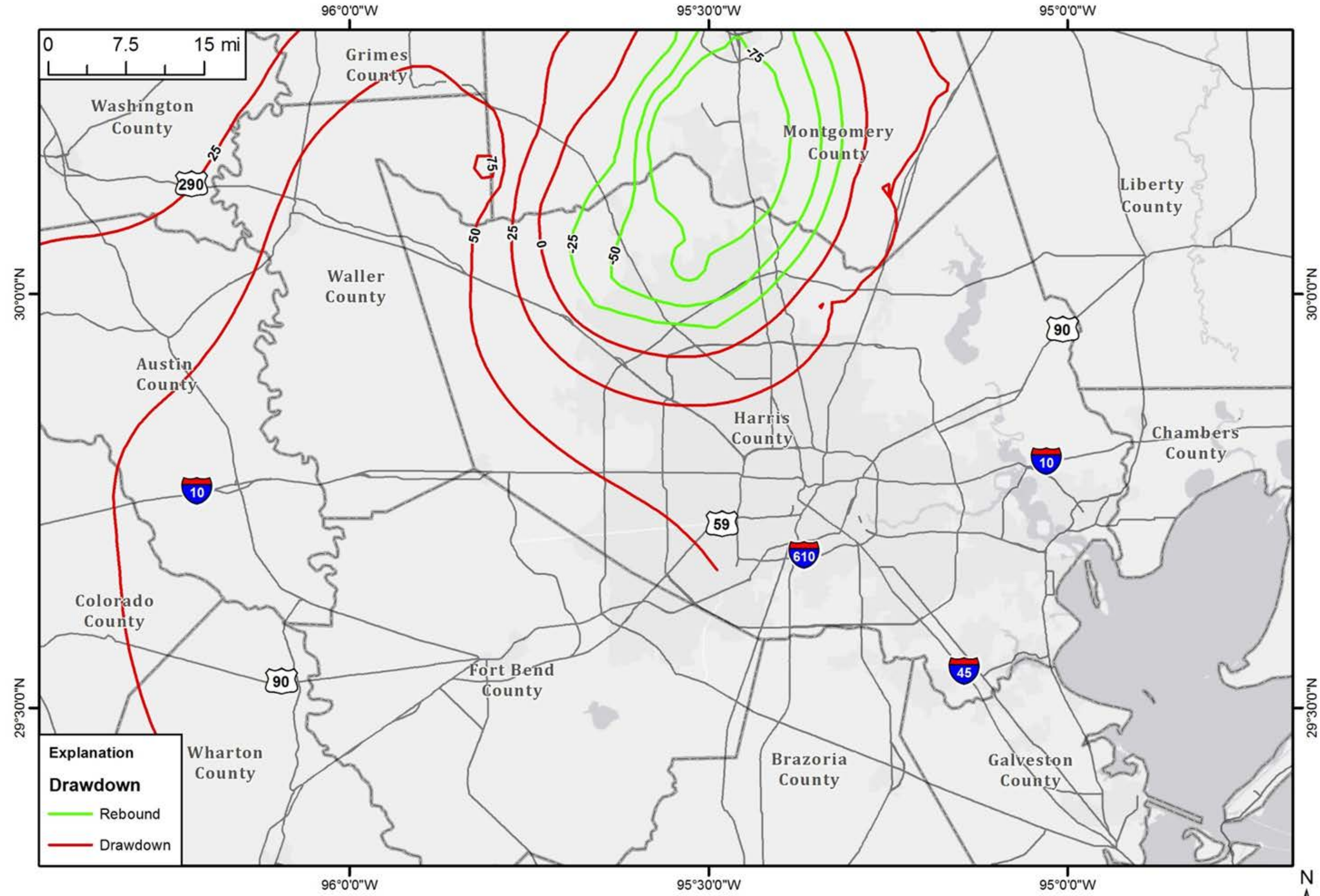
Scenario 3



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2030

Scenario 3

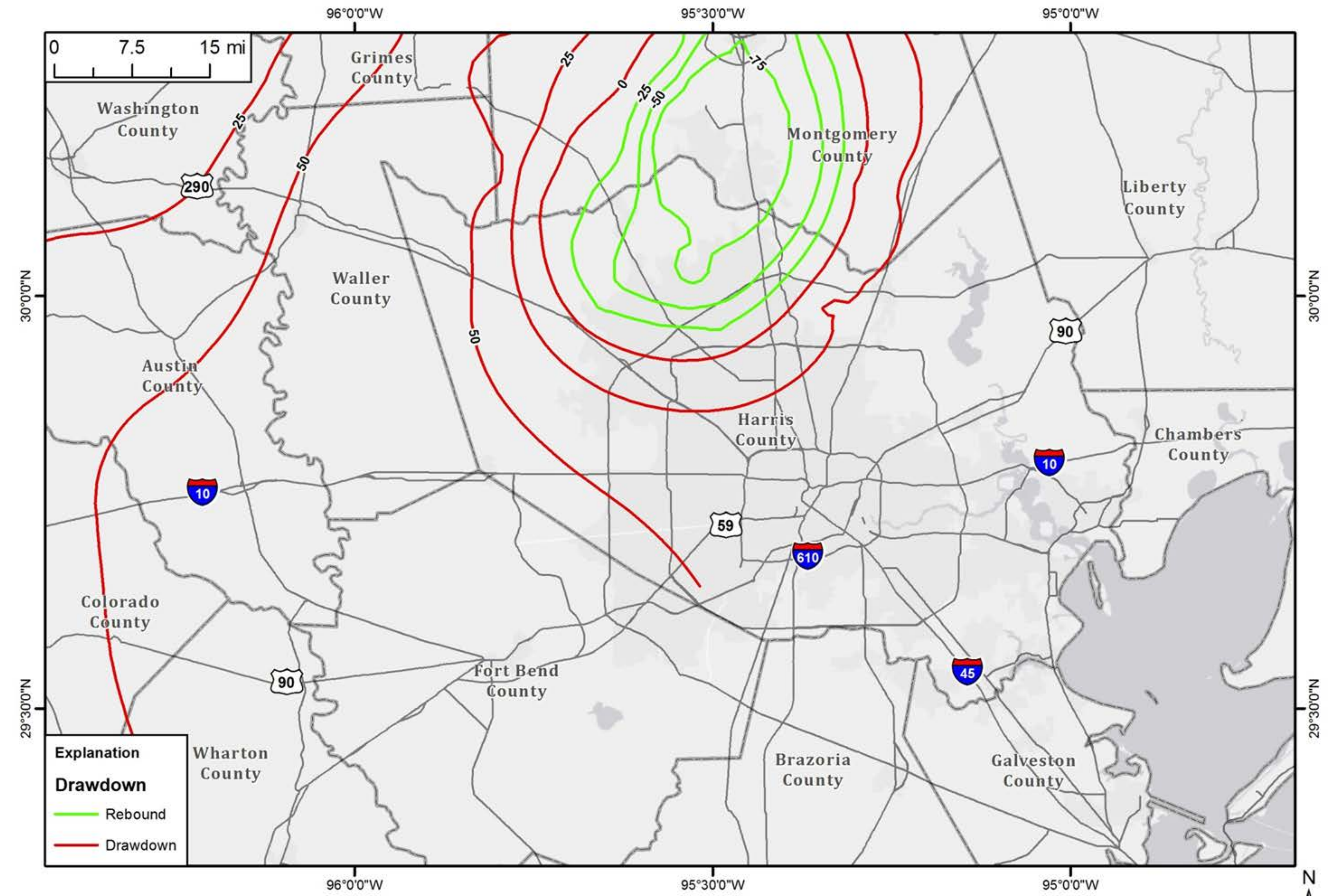
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2040

Scenario 3

DRAFT

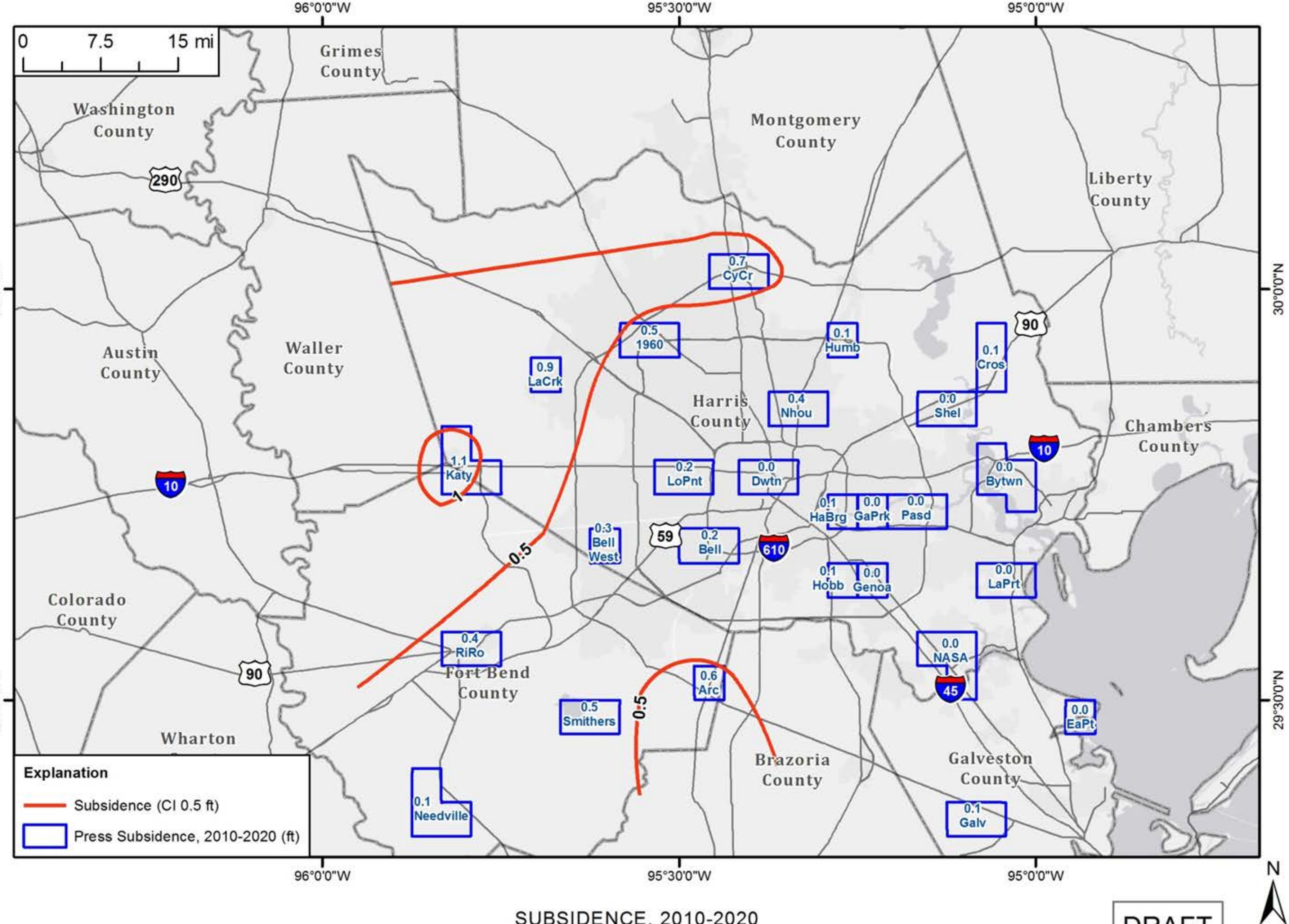


PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2050

Scenario 3

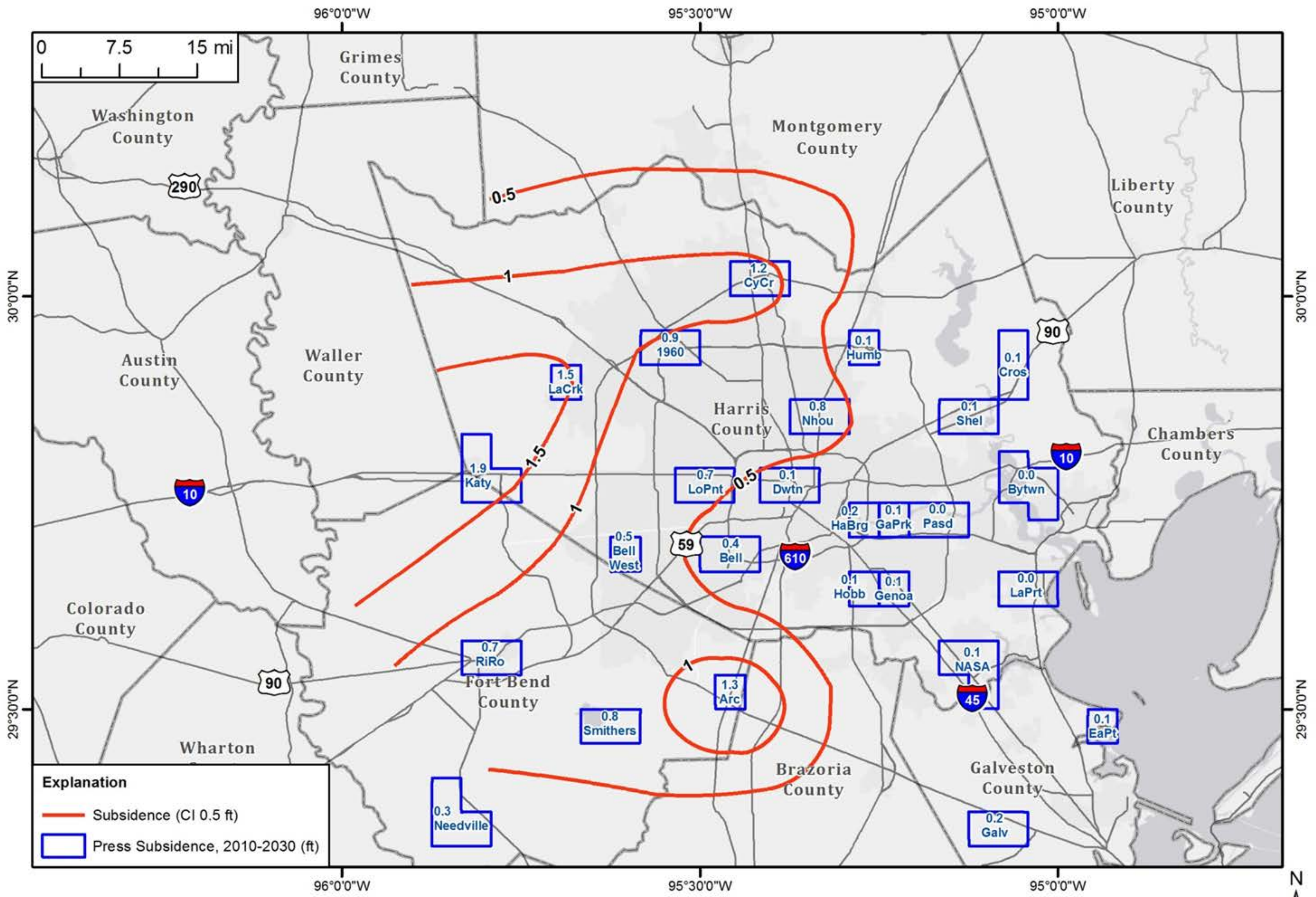
DRAFT

Scenario 3
Predicted Subsidence Contour Maps



SUBSIDENCE, 2010-2020

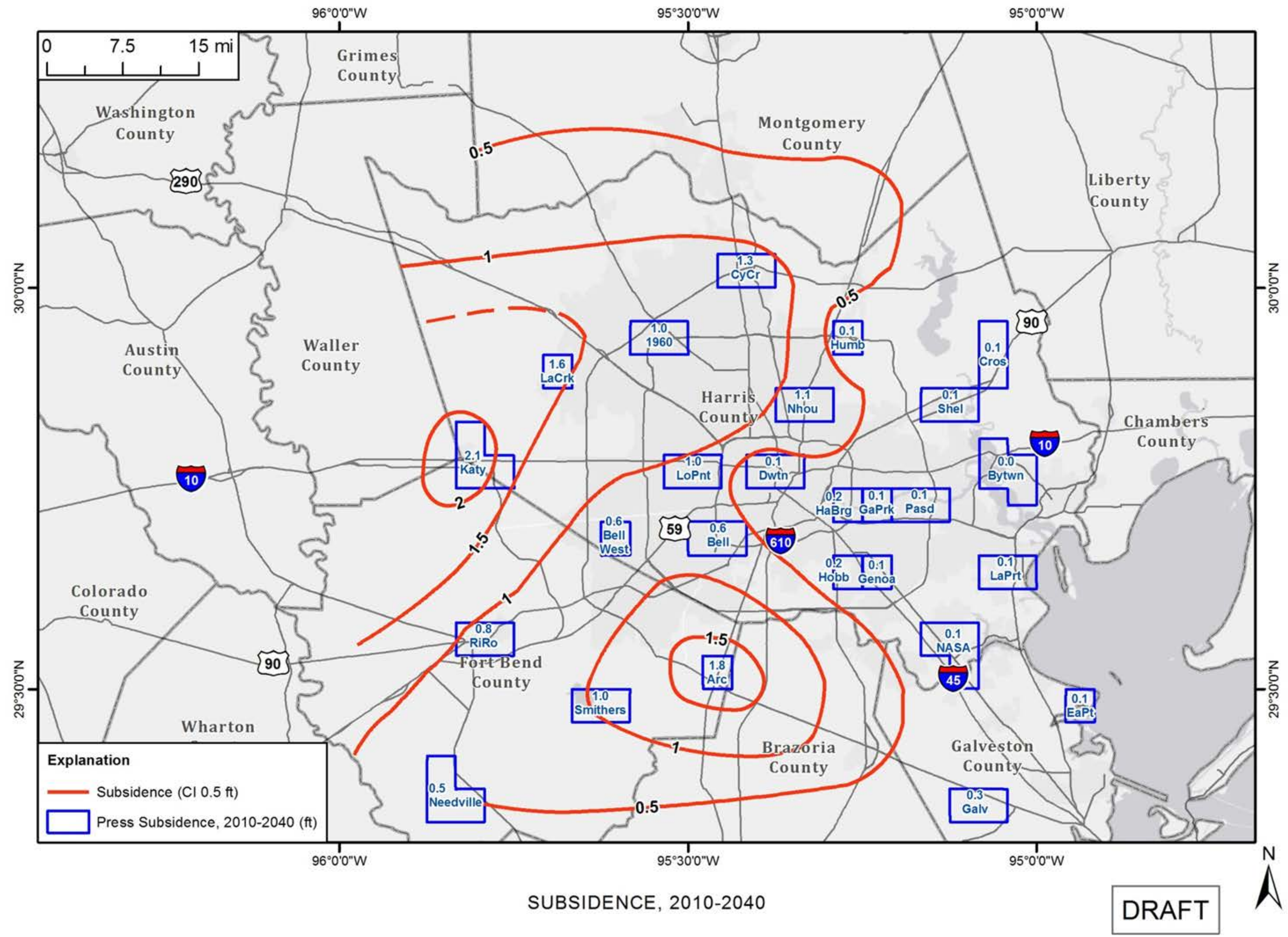
Scenario 3



SUBSIDENCE, 2010-2030

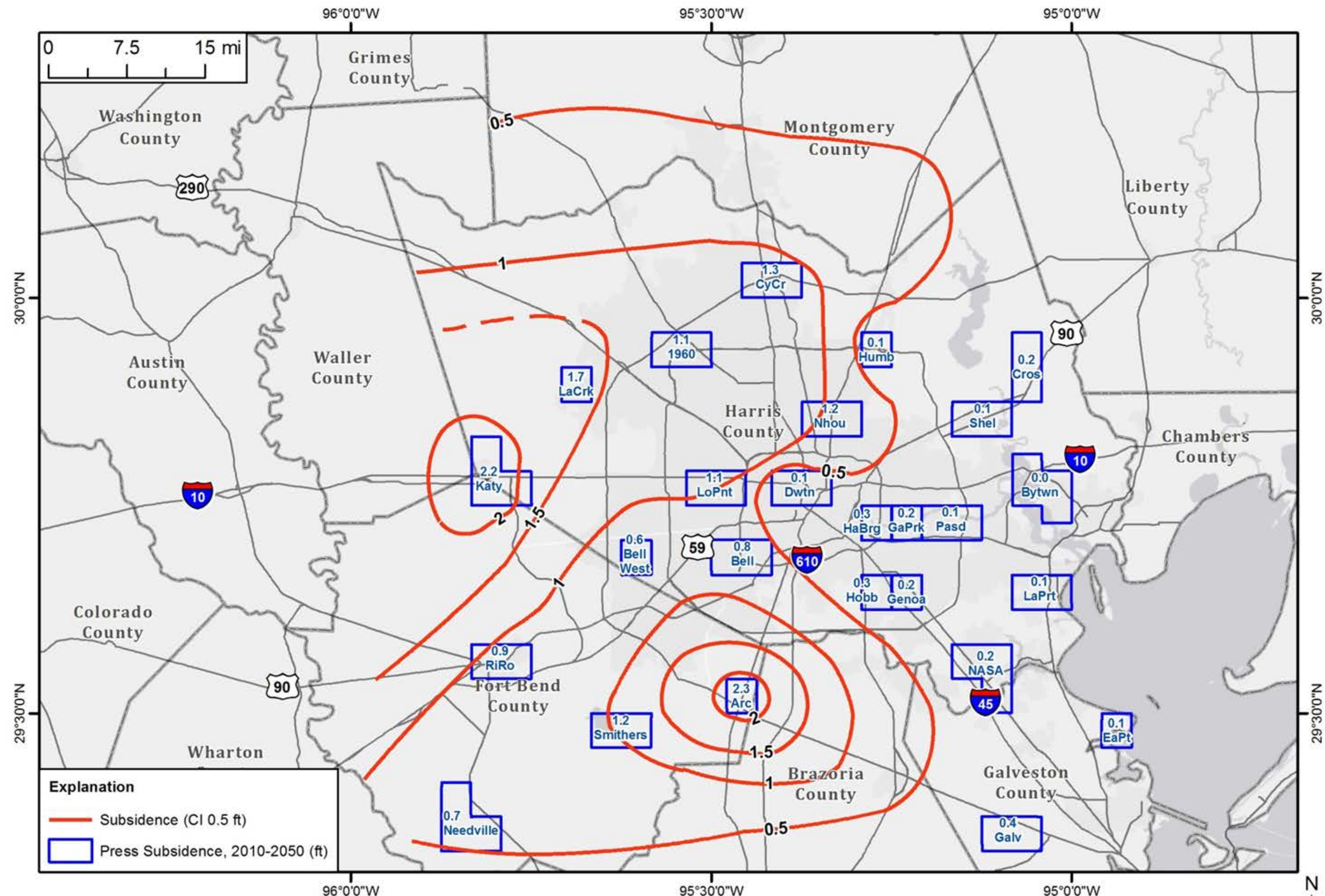
DRAFT

Scenario 3



SUBSIDENCE, 2010-2040

Scenario 3



SUBSIDENCE, 2010-2050

DRAFT

Scenario 3

Revised Scenario 3 – Modifications to Current Adopted Regulations

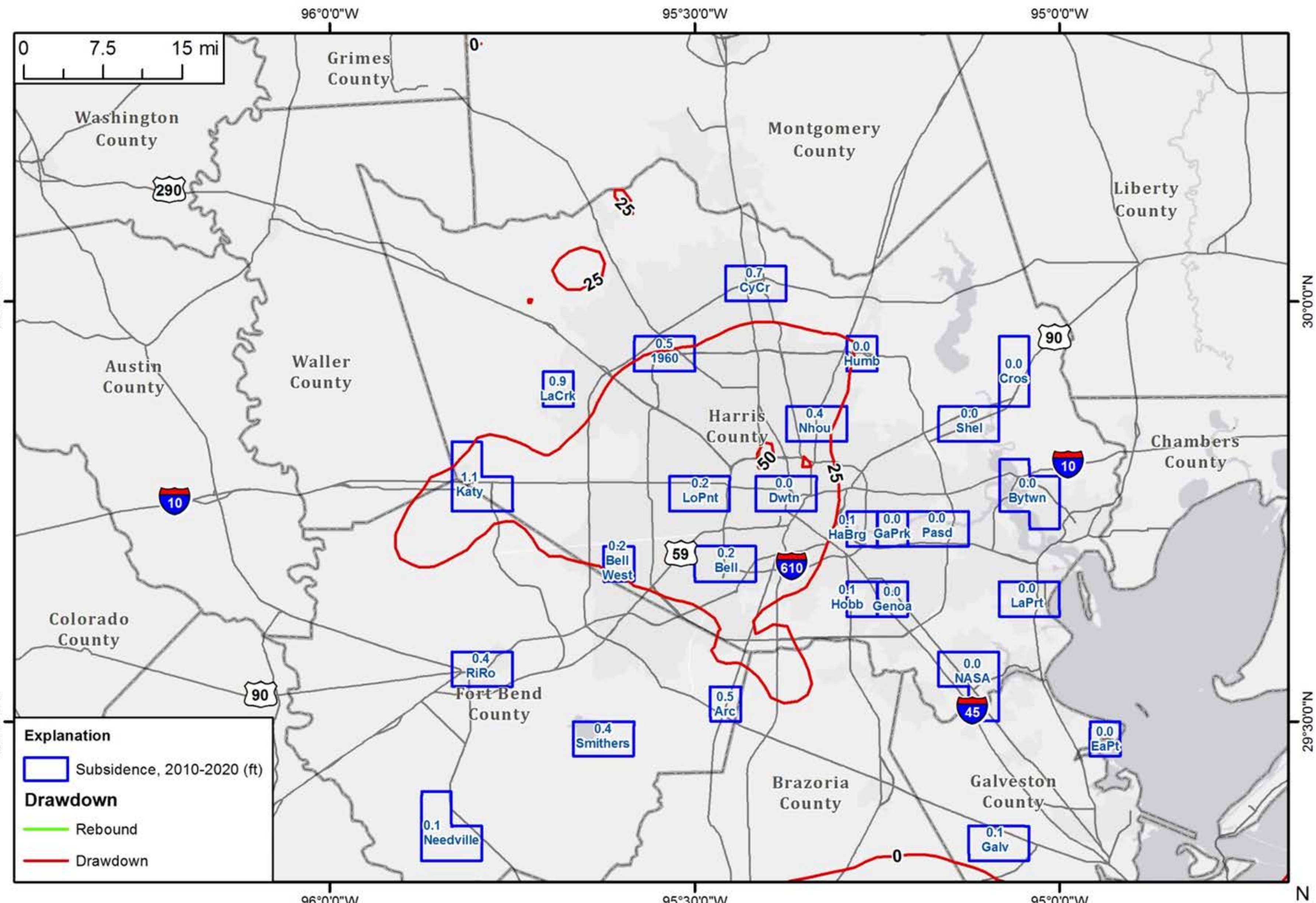
- **Harris and Galveston Counties (HGSD 1999 Regulatory Plan)**
  - Area 1 = 90% conversion (same as Scenario 2)
  - Area 2 = 80% conversion (same as Scenario 2)
  - Area 3 = 30% conversion current to 2024
  - Area 3 = 60% conversion 2025 to 2034
  - Area 3 = 80% conversion 2035 and beyond

- **Fort Bend County (FBSD 2003 Regulatory Plan)**
  - Area A = 30% conversion 2014 to 2024 (same as Scenario 2)
  - R/R Sub-Area = 30% conversion 2016 to 2024 (same as Scenario 2)
  - Area A and R/R Sub-Area = 50% conversion 2025 to 2034
  - Area A and R/R Sub-Area = 65% conversion 2035 and beyond
  - Area B remains on 100% groundwater (same as Scenario 2).

- **Montgomery County (LSGCD 2009 Regulatory Plan)**
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond (same as Scenario 2).

- **Brazoria County (BCGCD)**
  - Assume City of Pearland (including ETJ) converts to 50% surface water by 2016 and beyond.

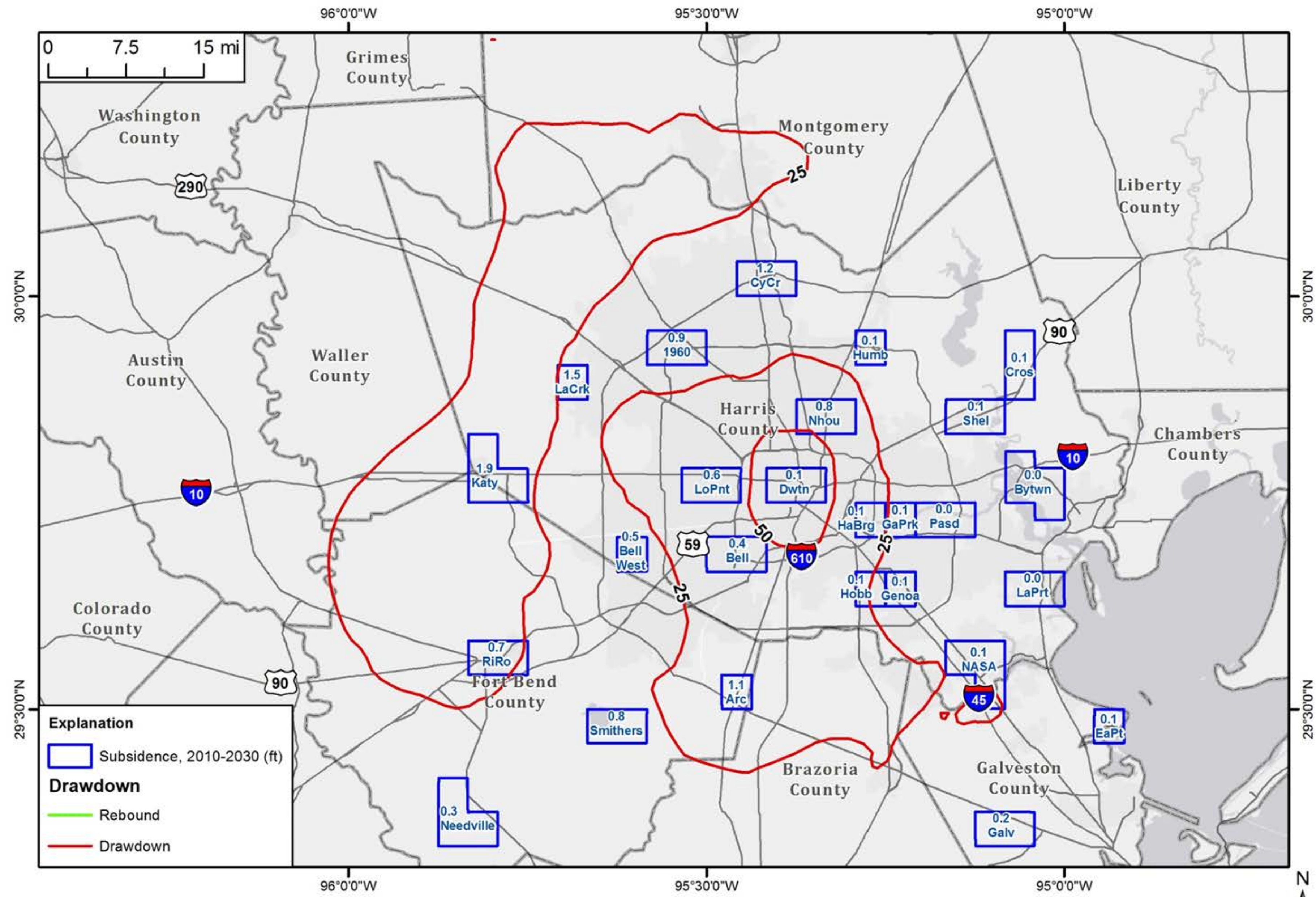
Revised Scenario 3
Chicot Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2020

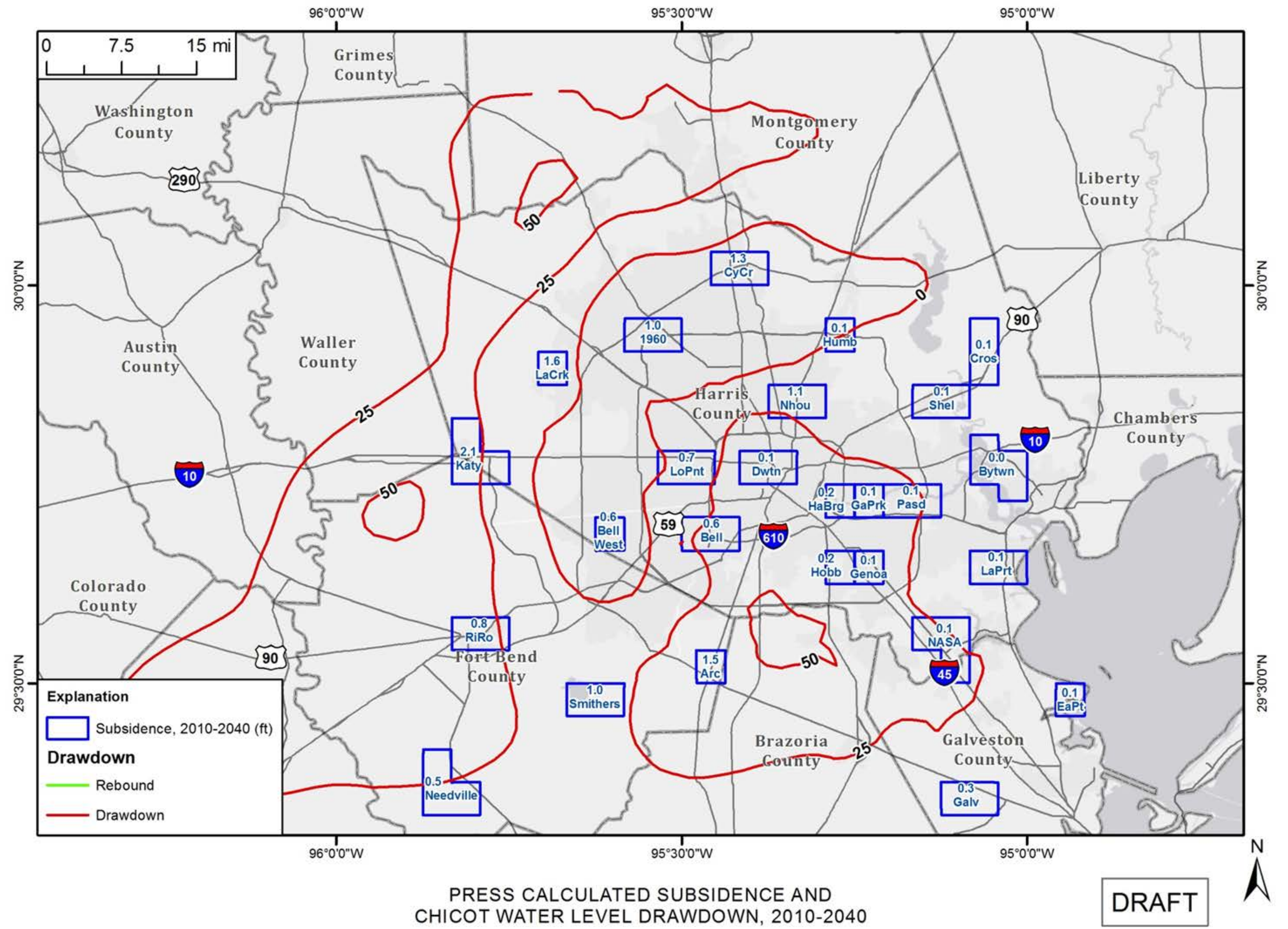
Revised Scenario 3

DRAFT



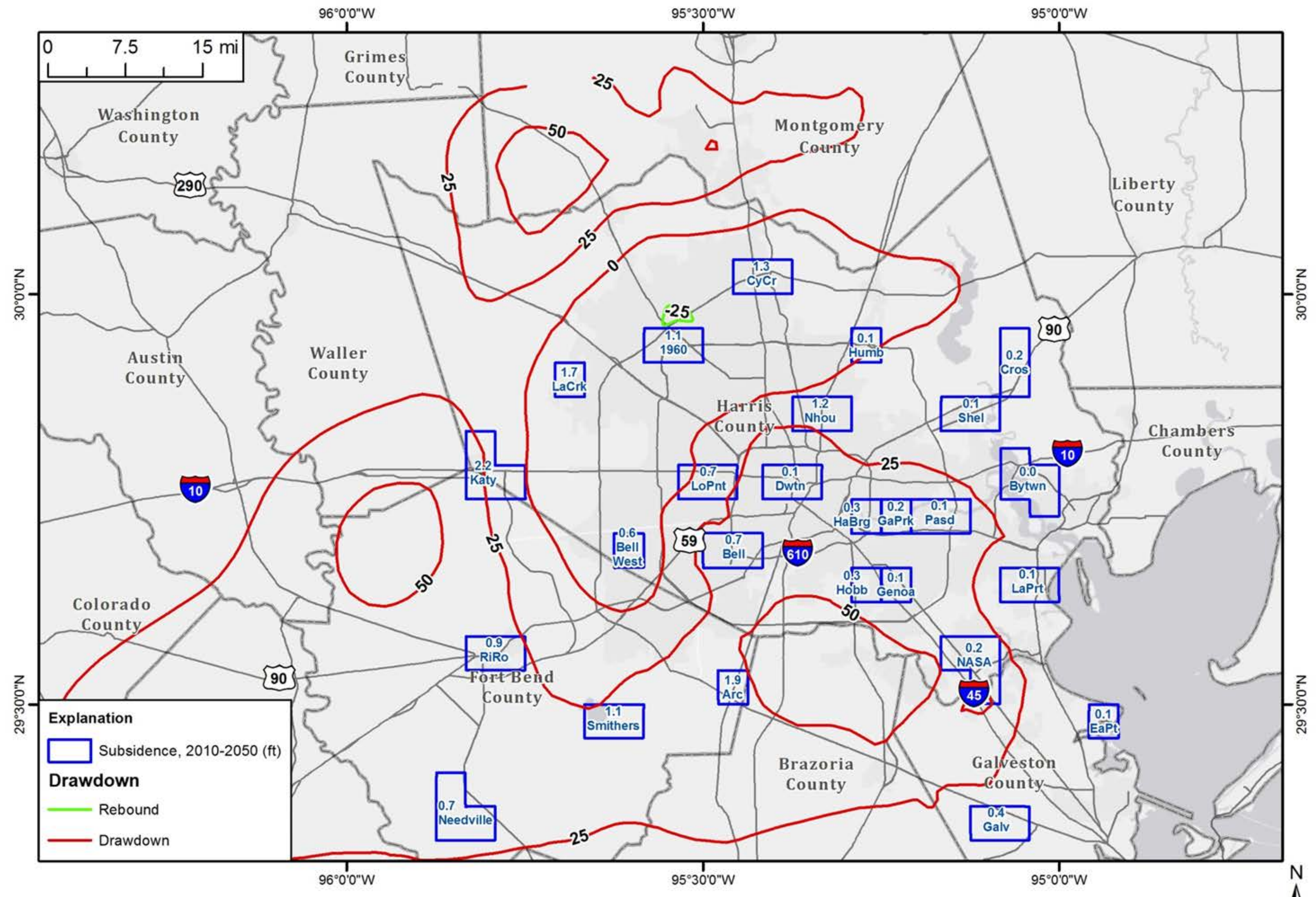
PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2030

Revised Scenario 3



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2040

Revised Scenario 3

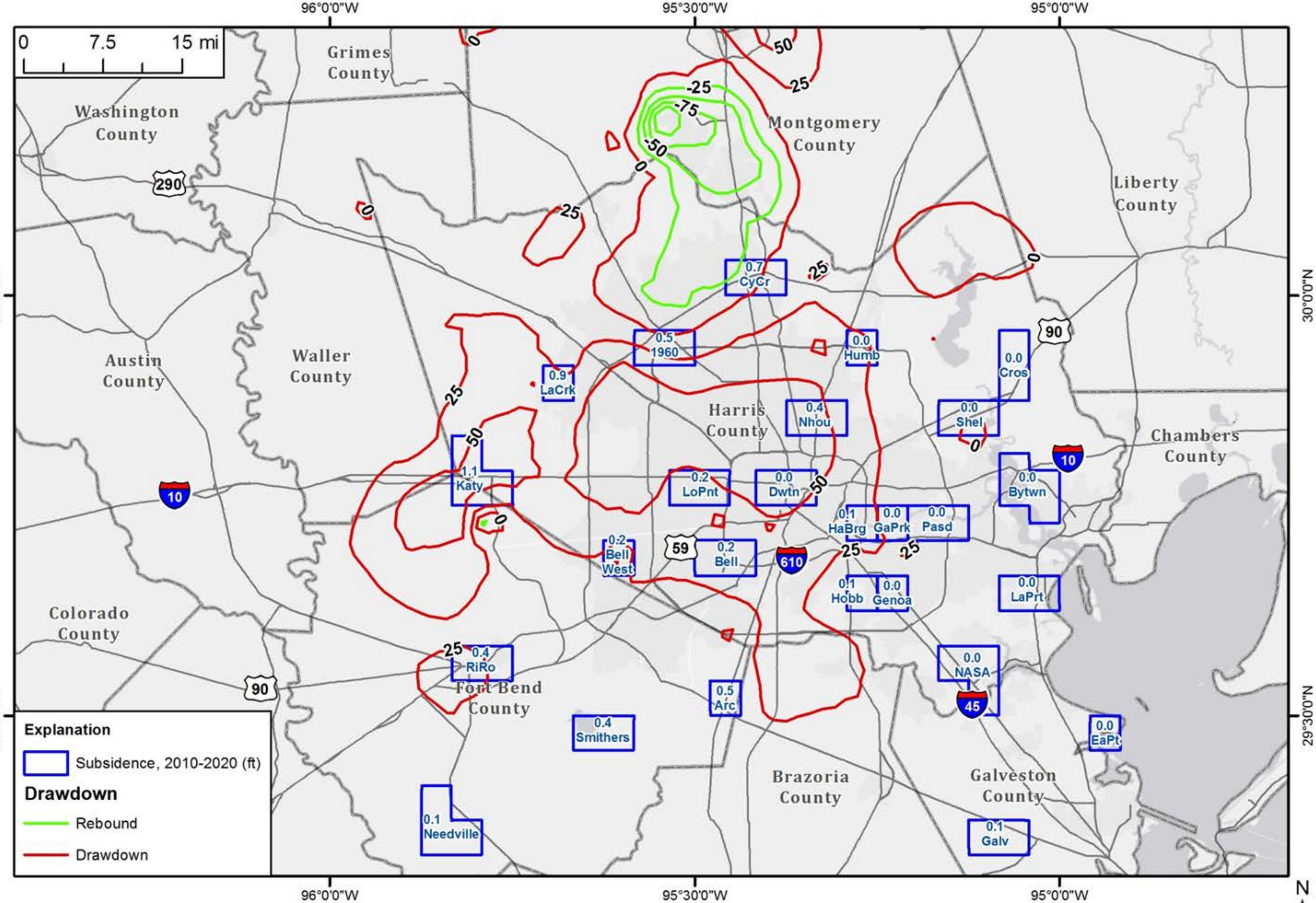


PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2050

Revised Scenario 3

DRAFT

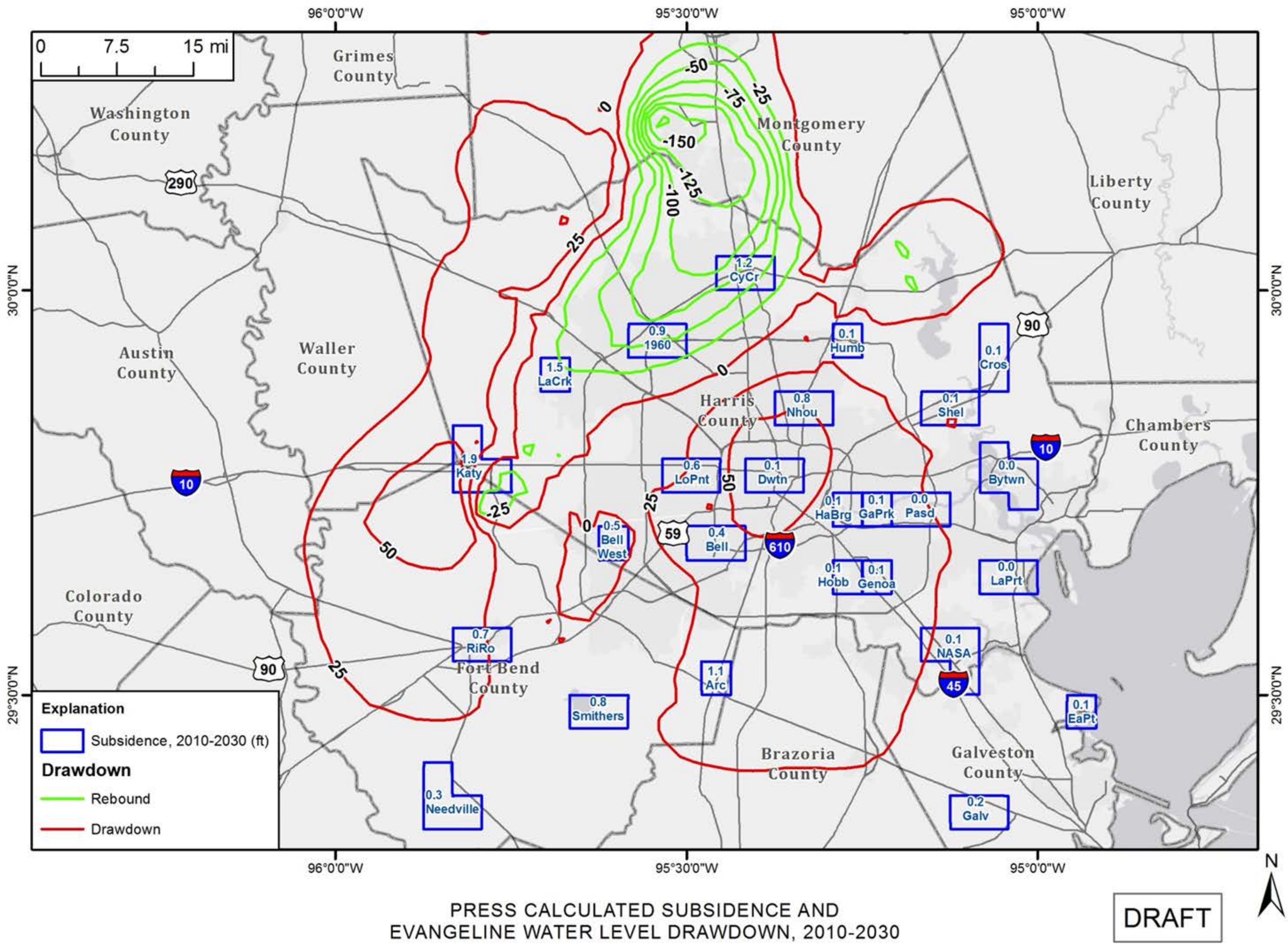
Revised Scenario 3
Evangeline Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND EVANGELINE WATER LEVEL DRAWDOWN, 2010-2020

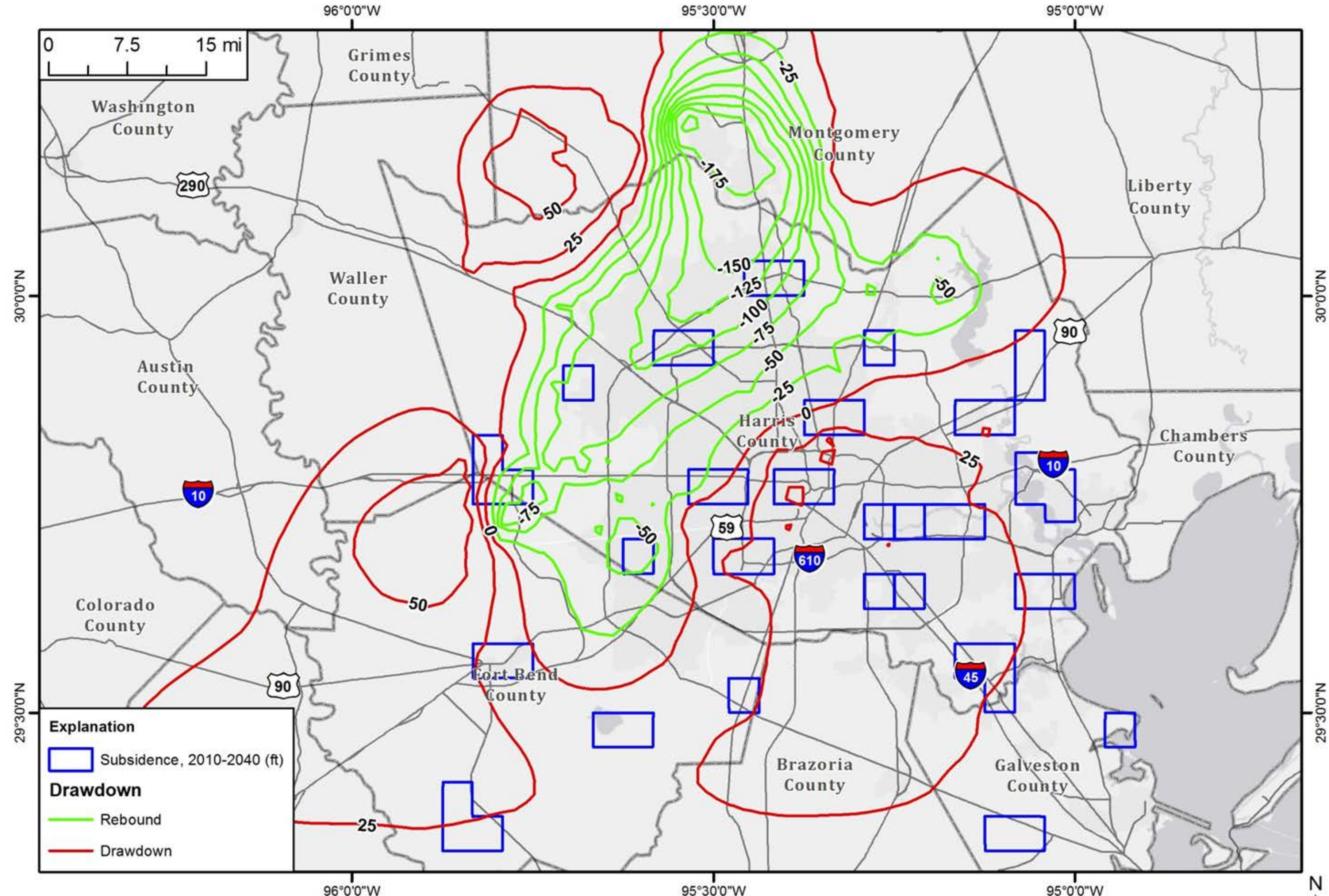
Revised Scenario 3

DRAFT



PRESS CALCULATED SUBSIDENCE AND EVANGELINE WATER LEVEL DRAWDOWN, 2010-2030

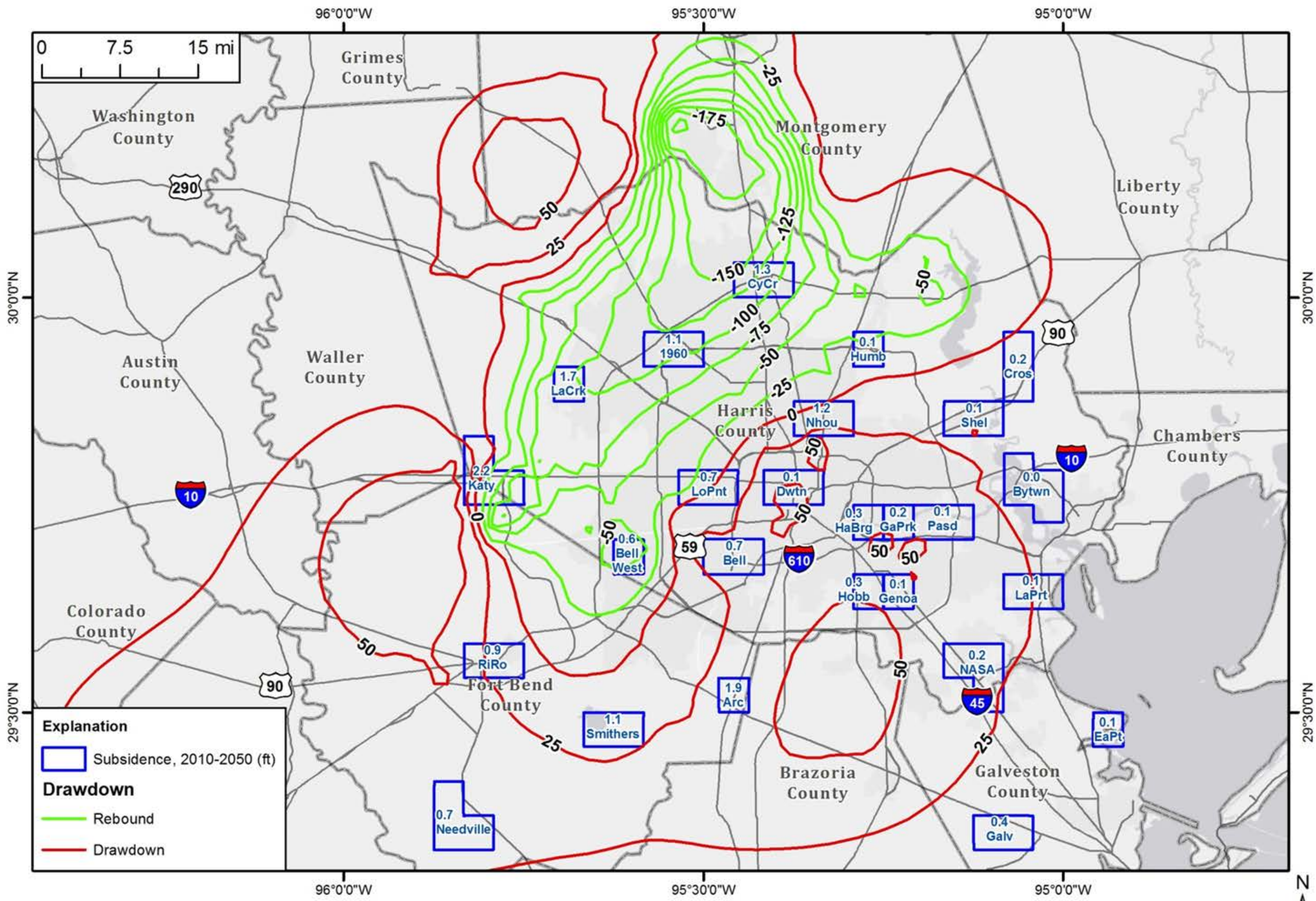
Revised Scenario 3



PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2040

Revised Scenario 3

DRAFT

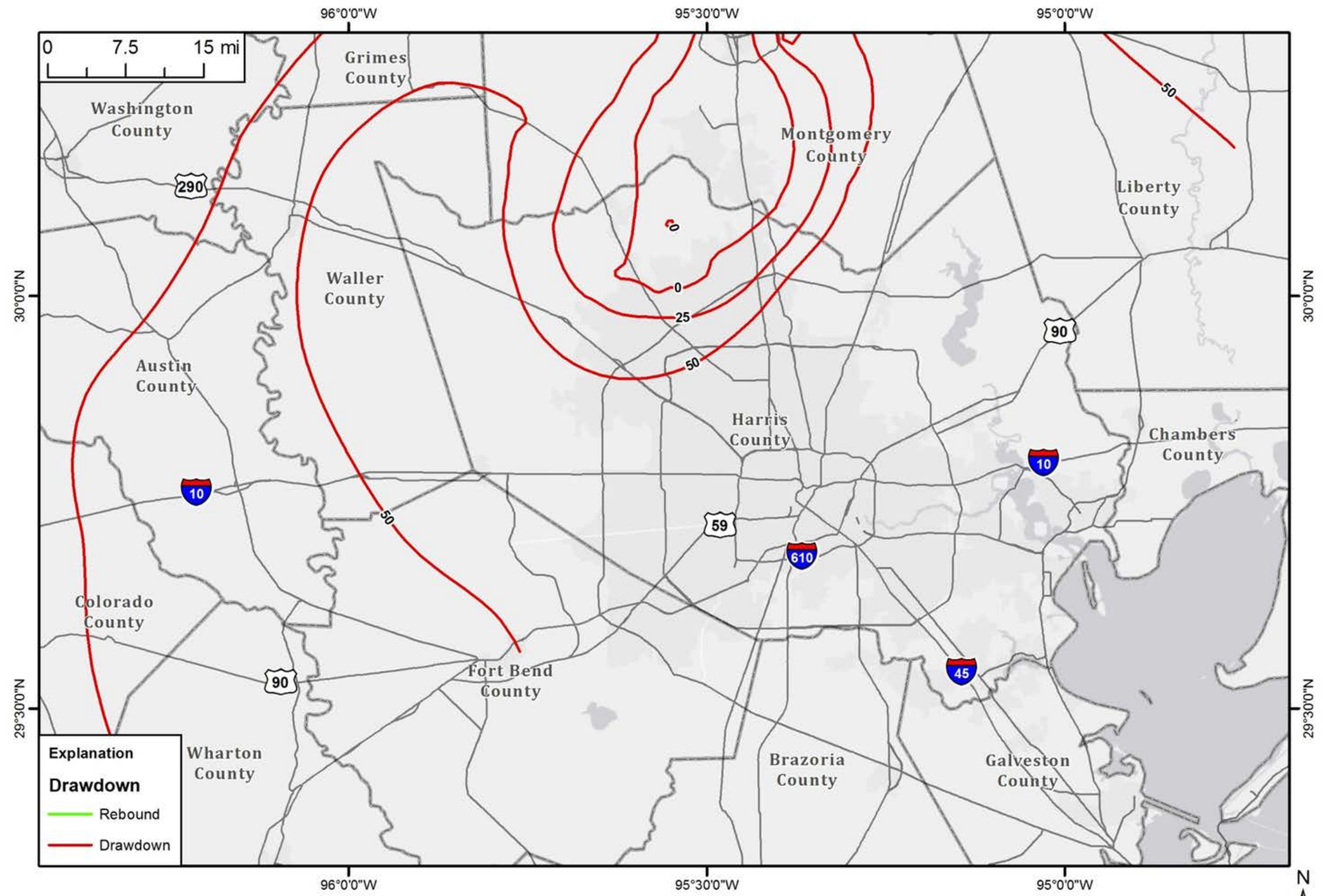


PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2050

Revised Scenario 3

DRAFT

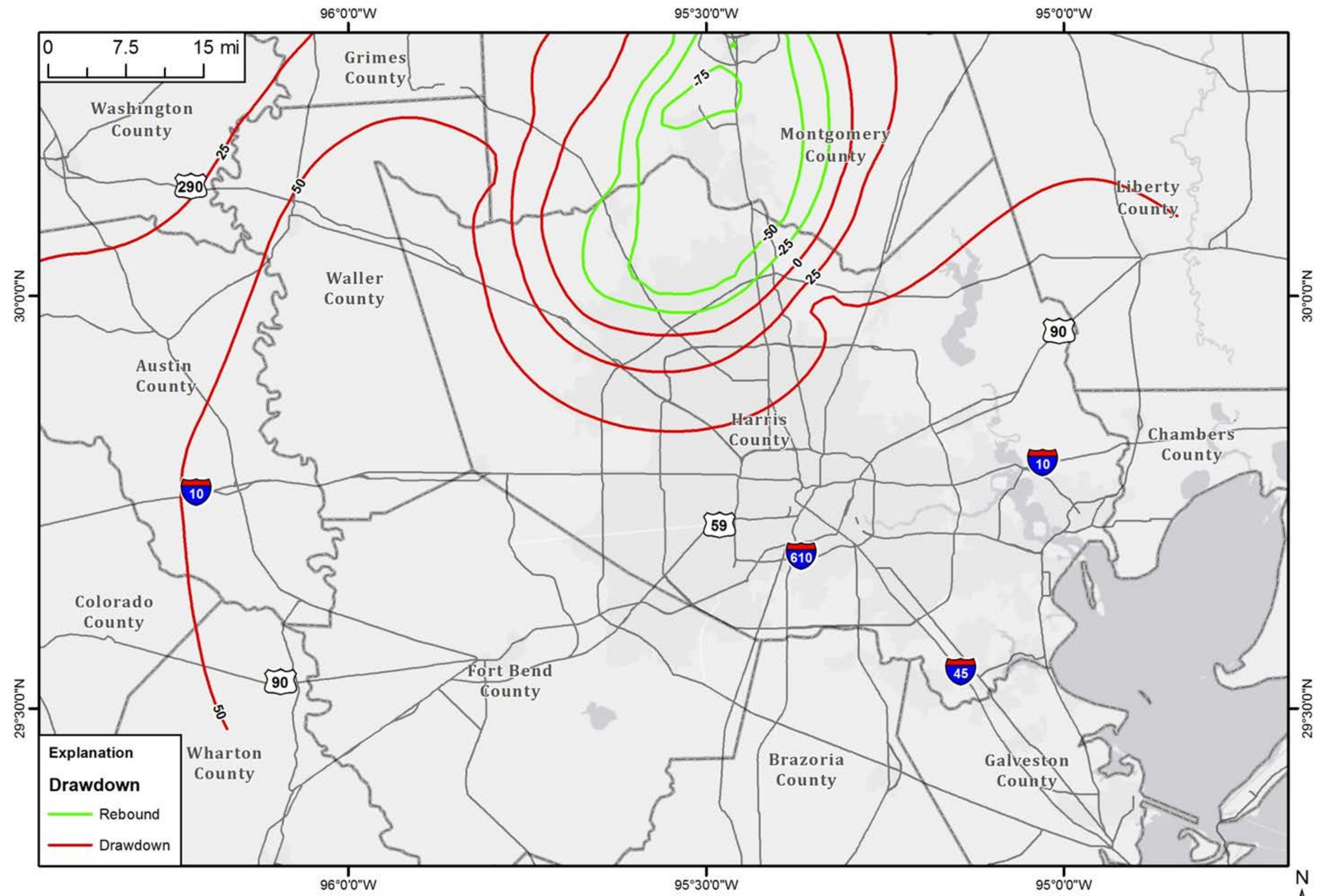
Revised Scenario 3
Jasper Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2020

Revised Scenario 3

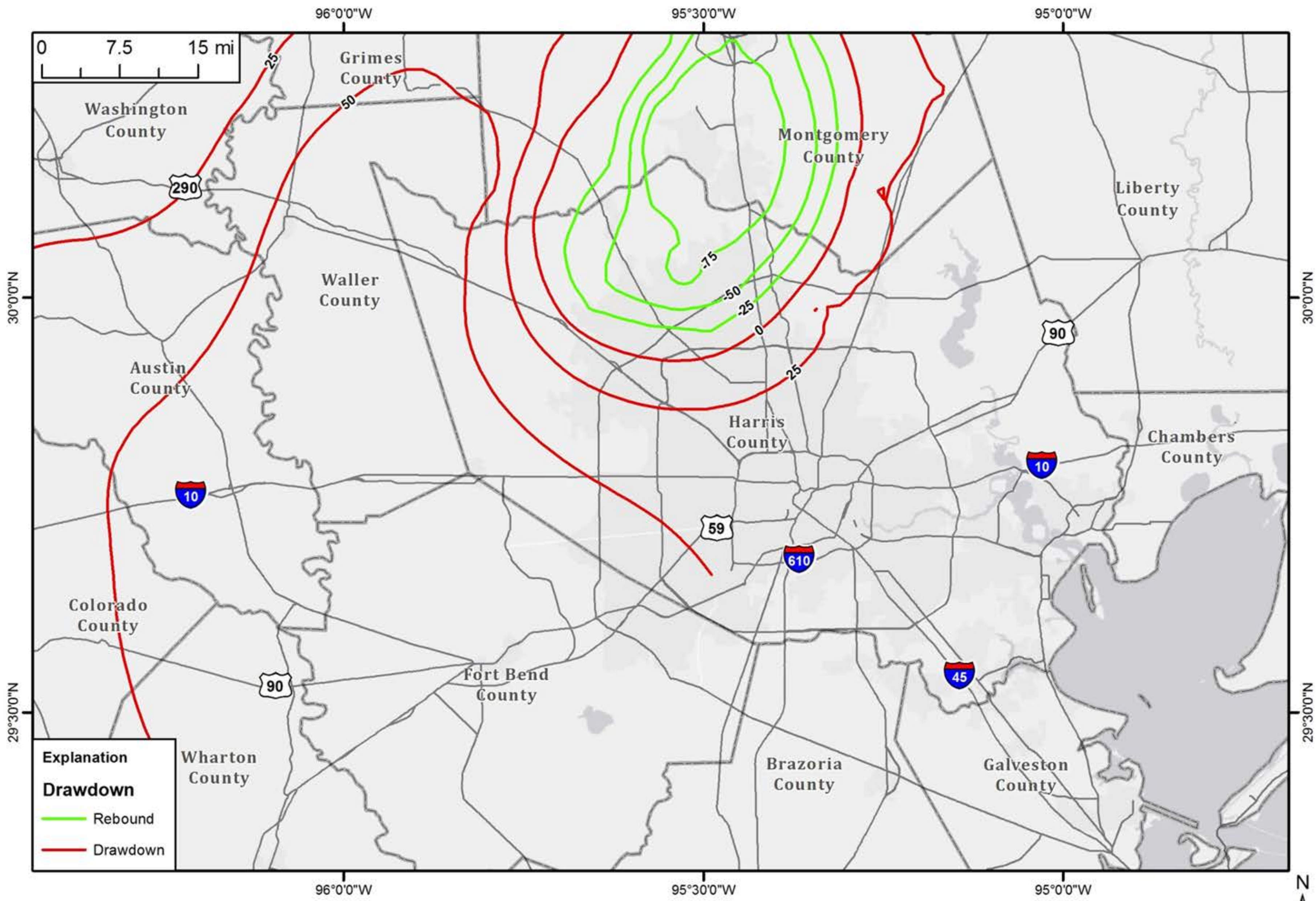
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2030

Revised Scenario 3

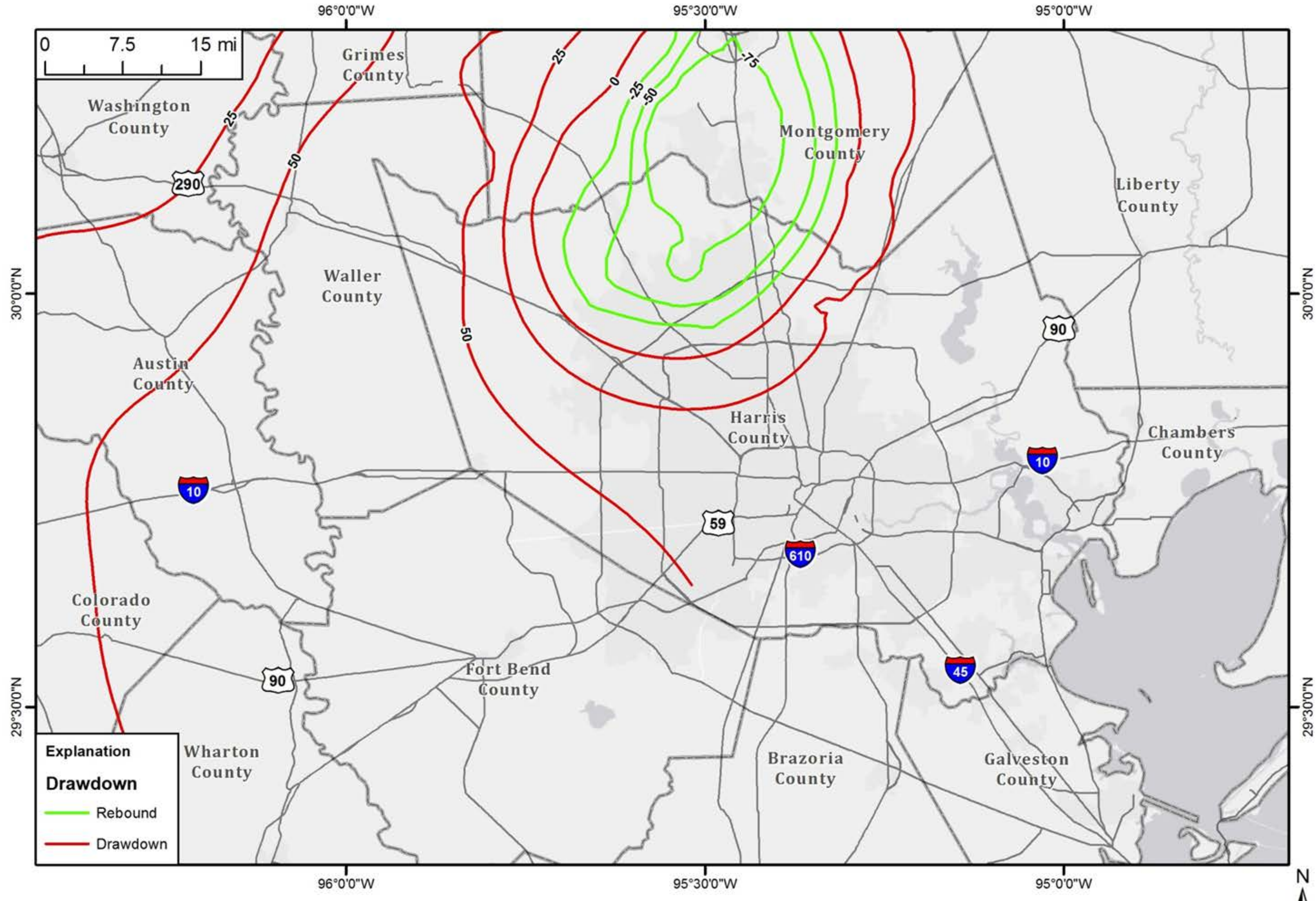
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2040

Revised Scenario 3

DRAFT

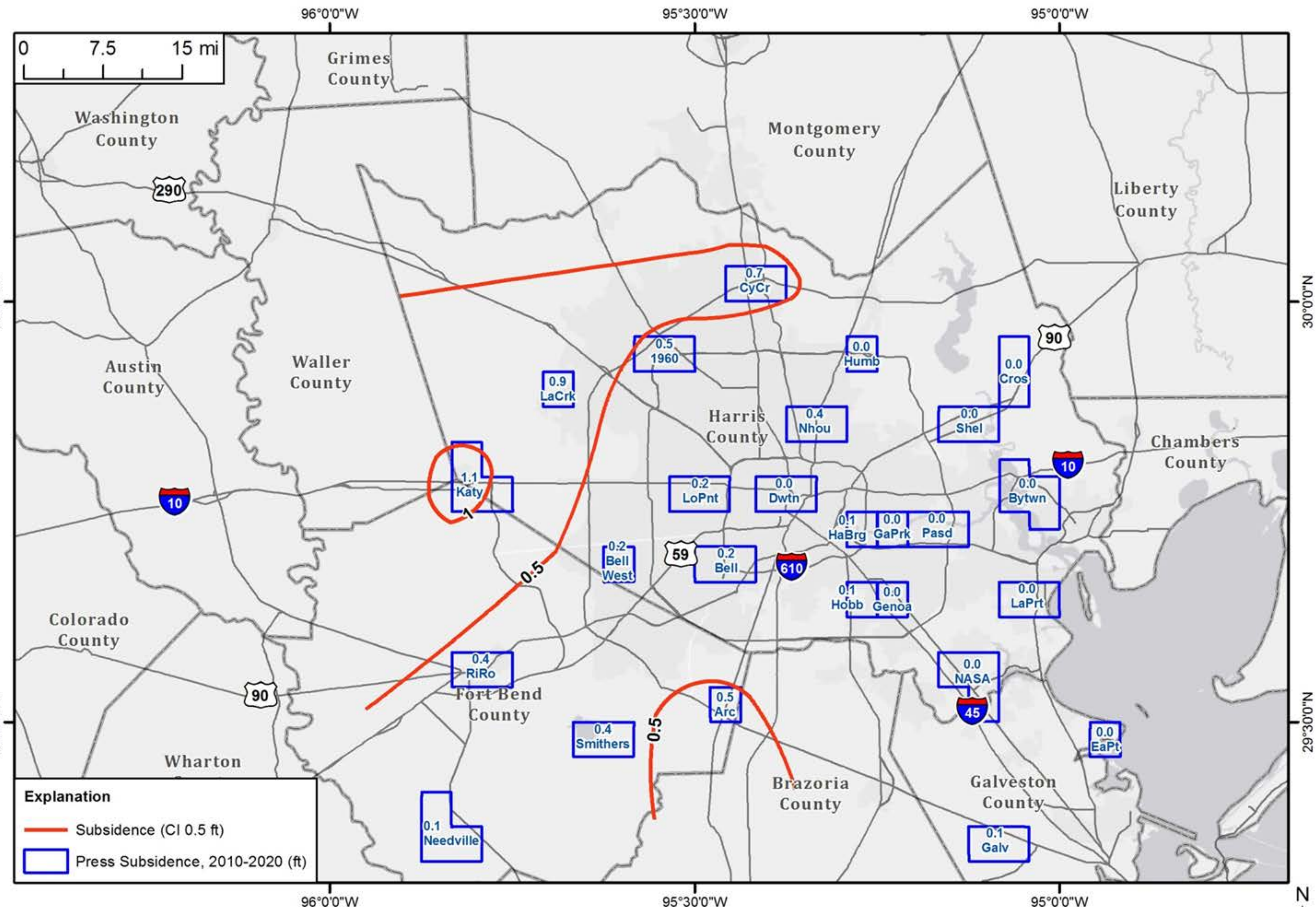


PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2050

Revised Scenario 3

DRAFT

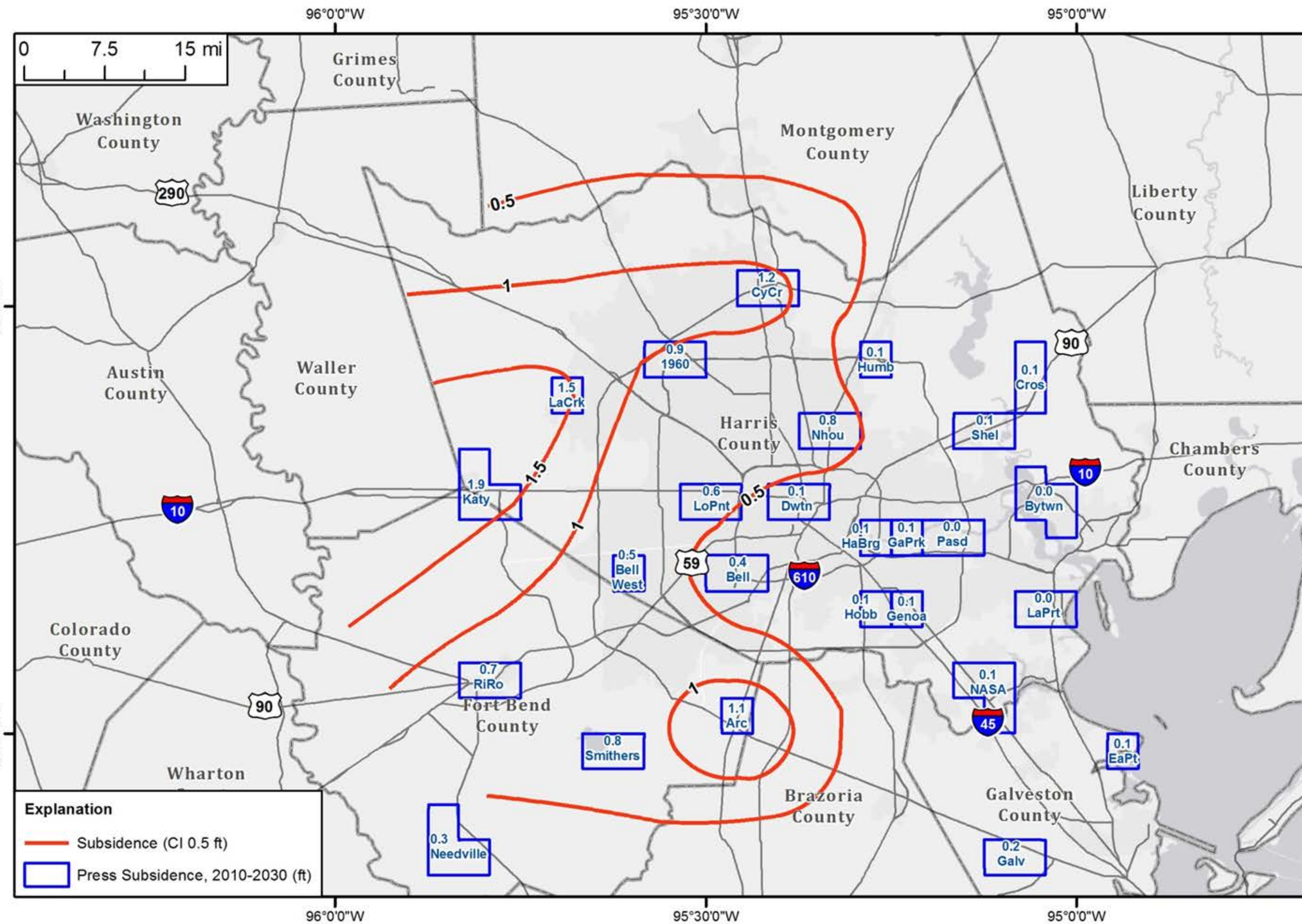
Revised Scenario 3
Predicted Subsidence Contour Maps



SUBSIDENCE, 2010-2020

DRAFT

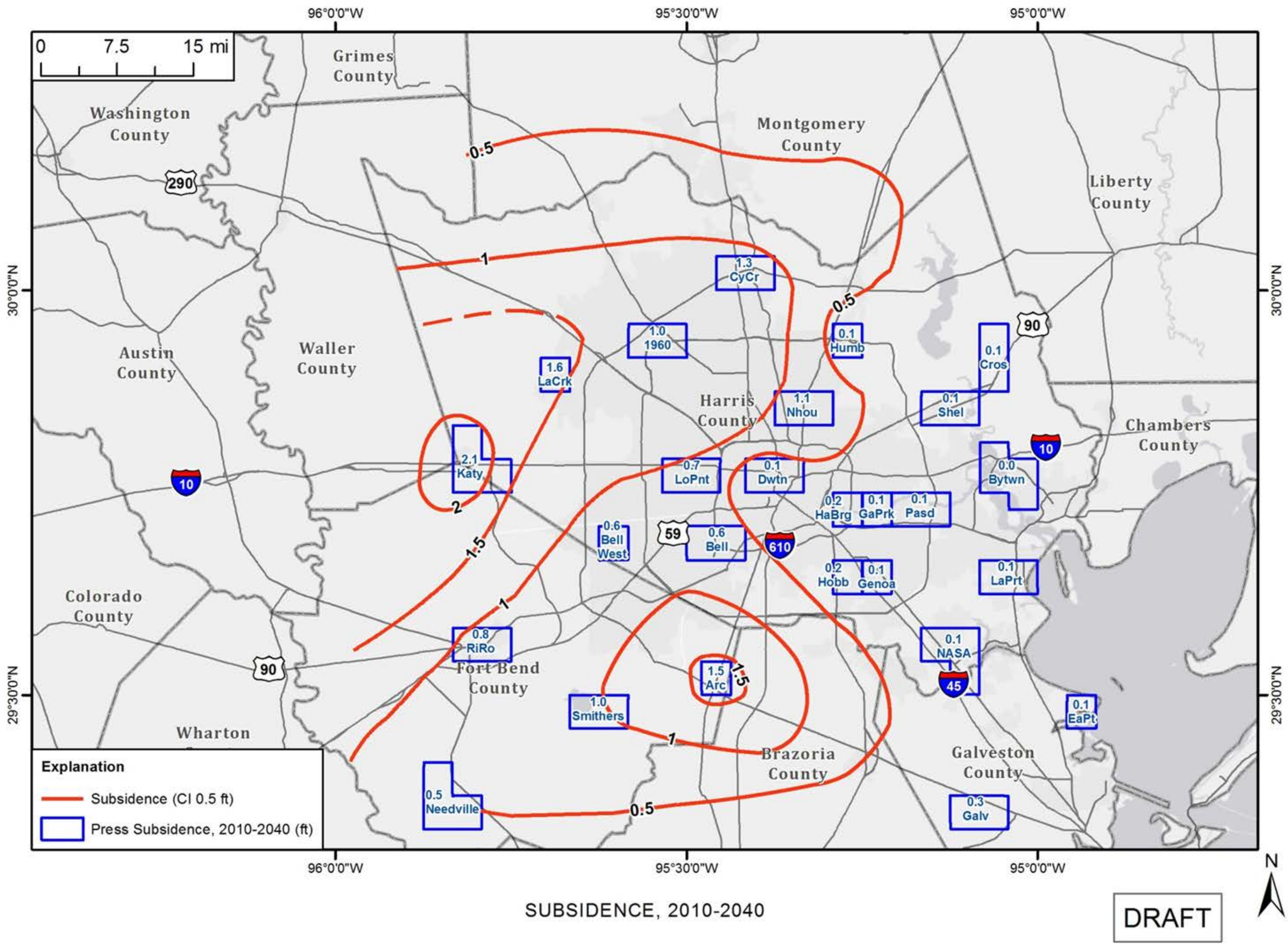
Revised Scenario 3



SUBSIDENCE, 2010-2030

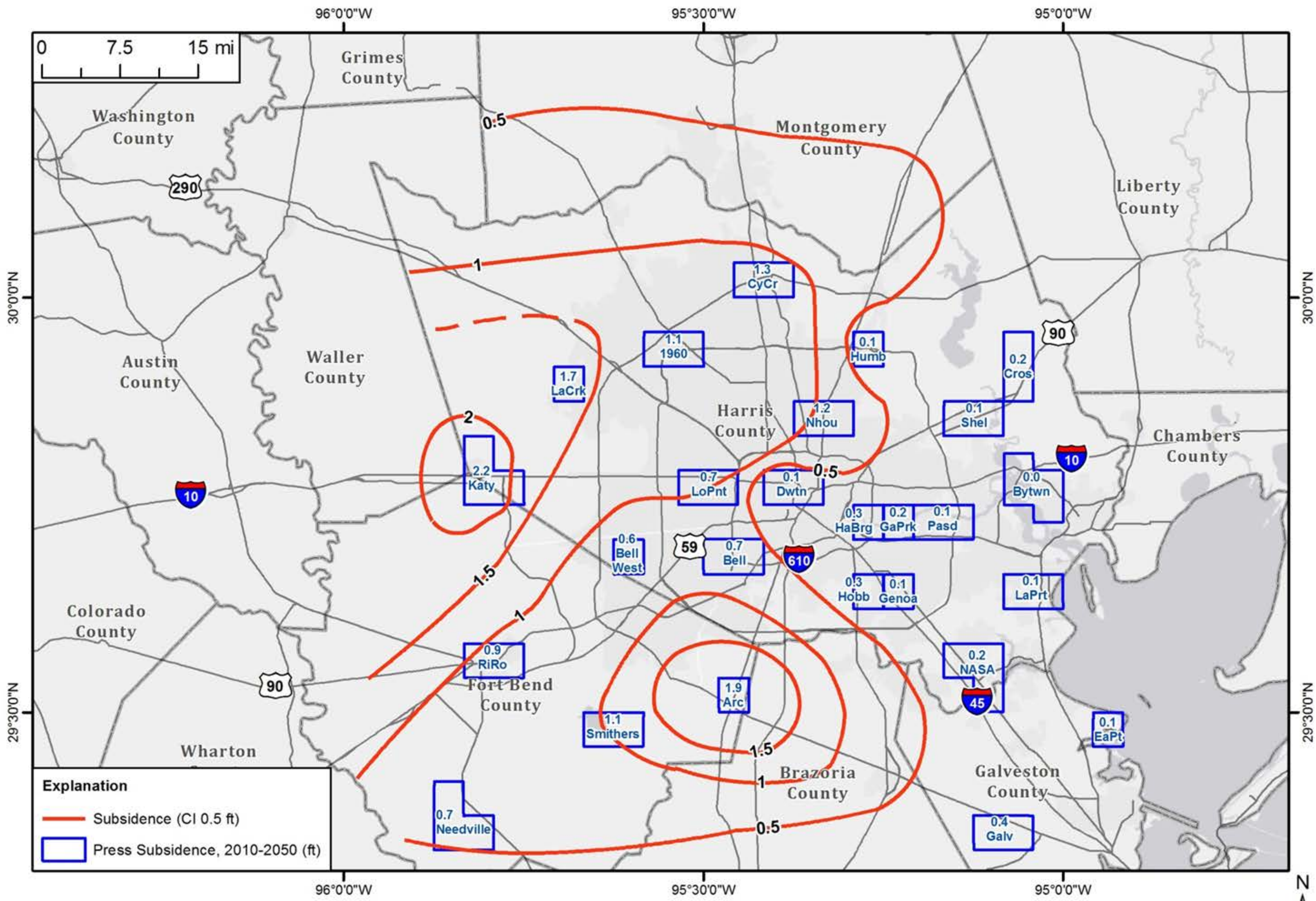
DRAFT

Revised Scenario 3



SUBSIDENCE, 2010-2040

Revised Scenario 3



SUBSIDENCE, 2010-2050

DRAFT

Revised Scenario 3

Scenario 4 – Modifications to Current Adopted Regulations

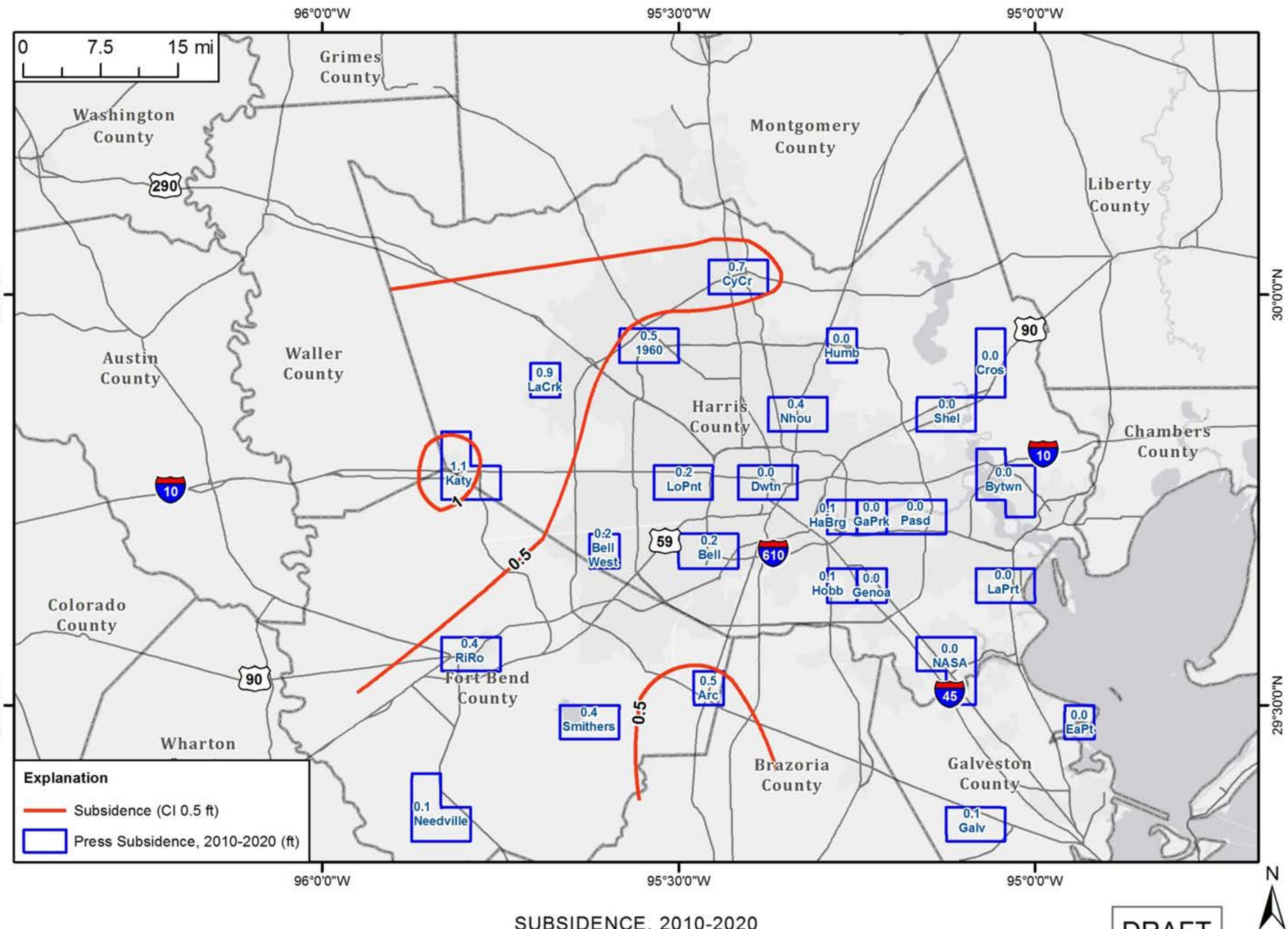
- **Harris and Galveston Counties (HGSD 1999 Regulatory Plan)**
  - Area 1 = 90% conversion (same as Scenario 2)
  - Area 2 = 80% conversion (same as Scenario 2)
  - Area 3 = 30% conversion current to 2024 (same as Scenario 3)
  - Area 3 = 55% conversion 2025 to 2039
  - Area 3 = 80% conversion 2040 and beyond

- **Fort Bend County (FBSD 2003 Regulatory Plan)**
  - Area A = 30% conversion 2014 to 2024 (same as Scenario 2)
  - Area A = 50% conversion 2025 and beyond
  - R/R Sub-Area = 30% conversion 2025 and beyond
  - Area B remains on 100% groundwater (same as Scenario 2).

- **Montgomery County (LSGCD 2009 Regulatory Plan)**
  - 30% conversion in 2016 based on 2009 demands. Groundwater capped at 64,000 acre-feet per year for 2017 and beyond (same as Scenario 2).

- **Brazoria County (BCGCD)**
  - No groundwater reduction regulations adopted in Brazoria County (same as Scenario 2).

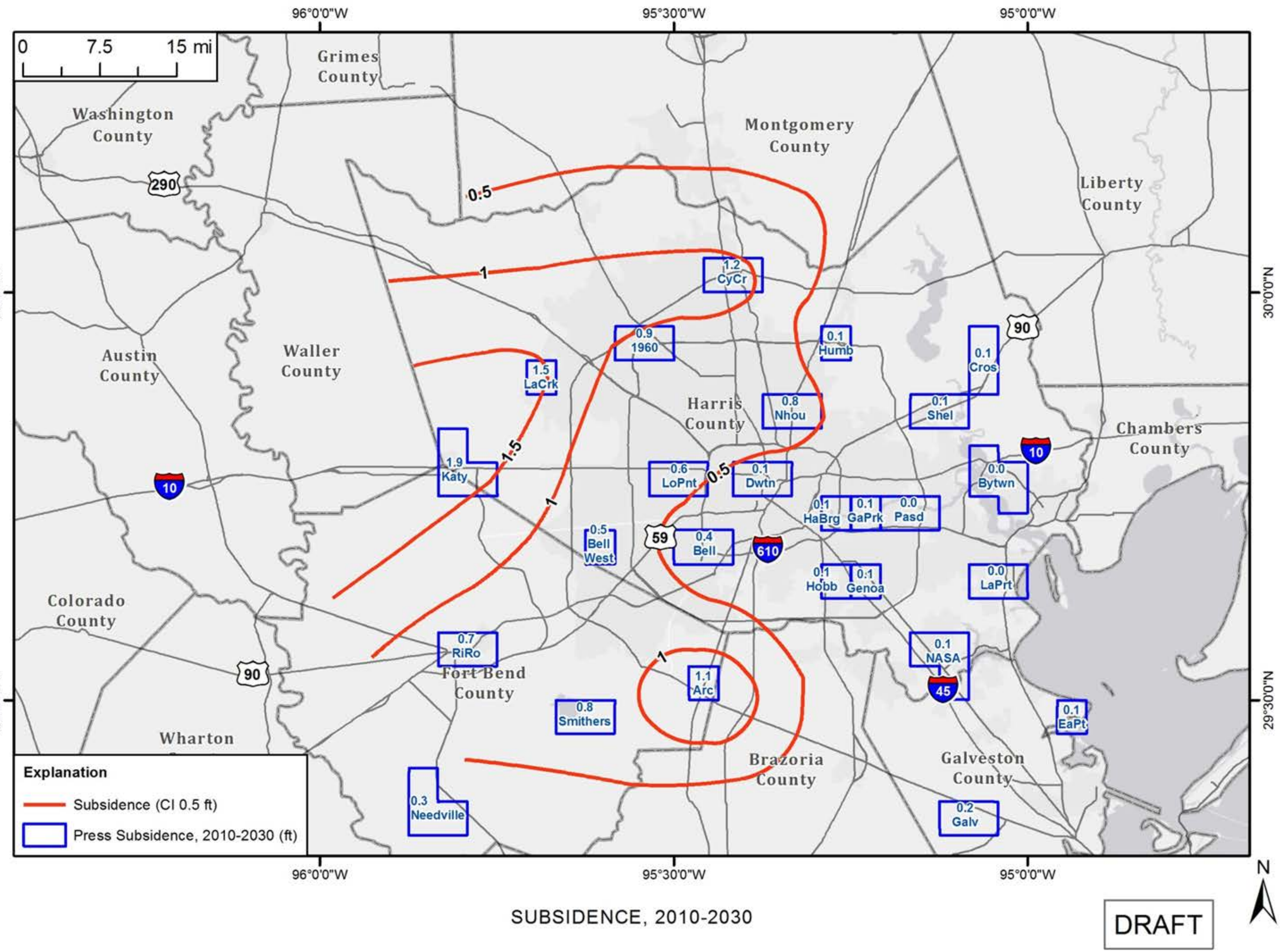
Scenario 4
Chicot Aquifer
Groundwater Drawdown Maps



SUBSIDENCE, 2010-2020

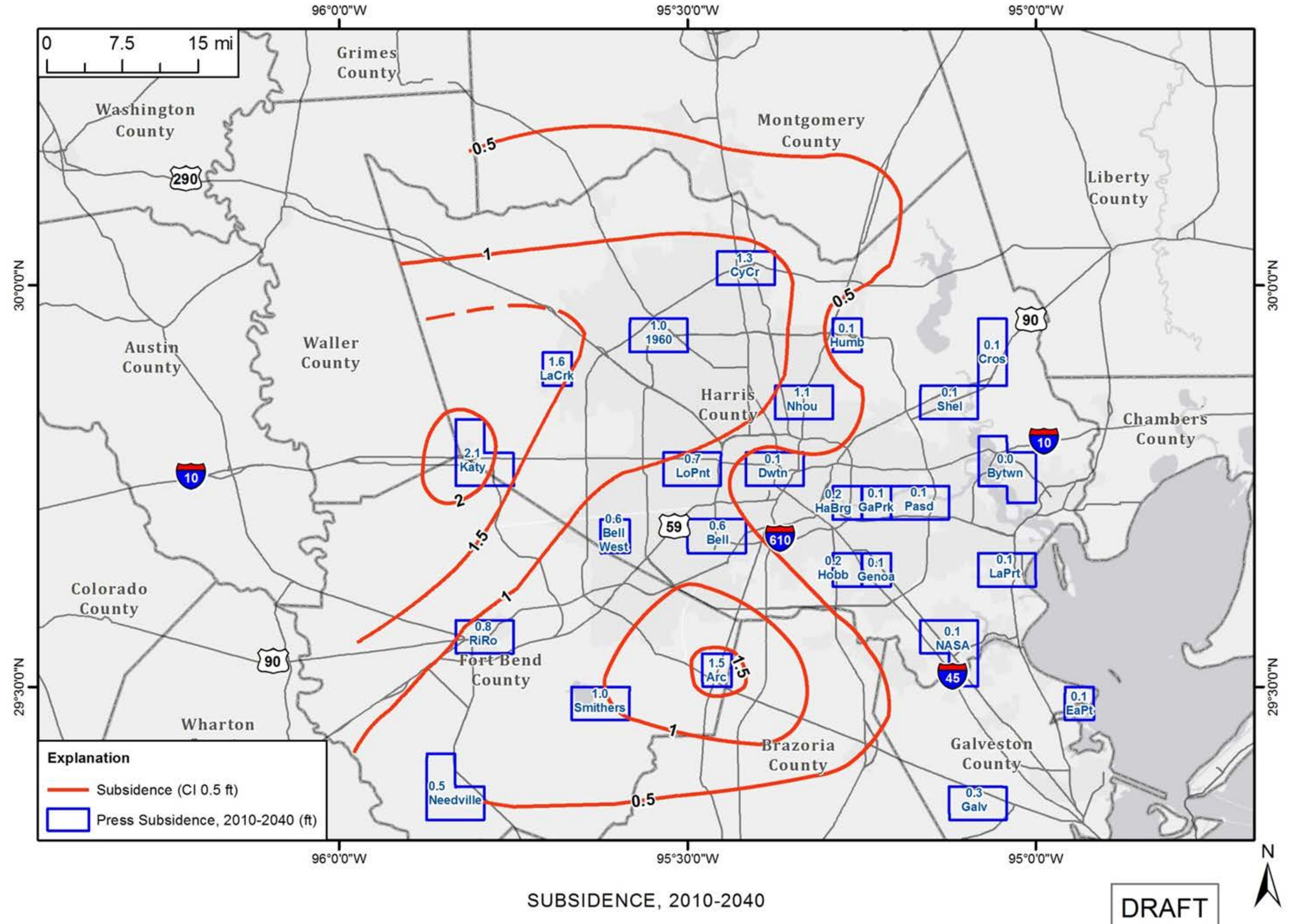
DRAFT

Revised Scenario 3



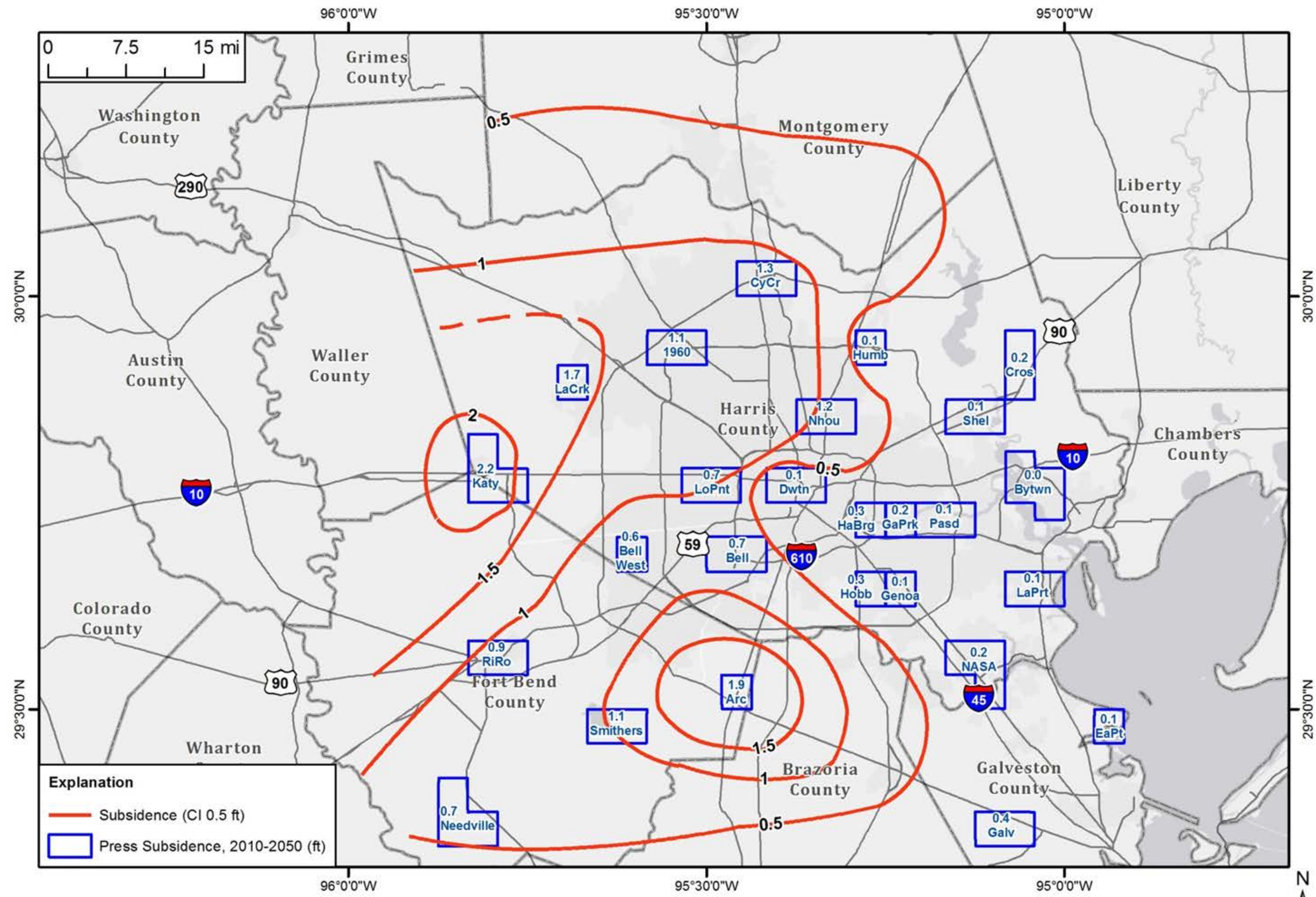
SUBSIDENCE, 2010-2030

Revised Scenario 3



SUBSIDENCE, 2010-2040

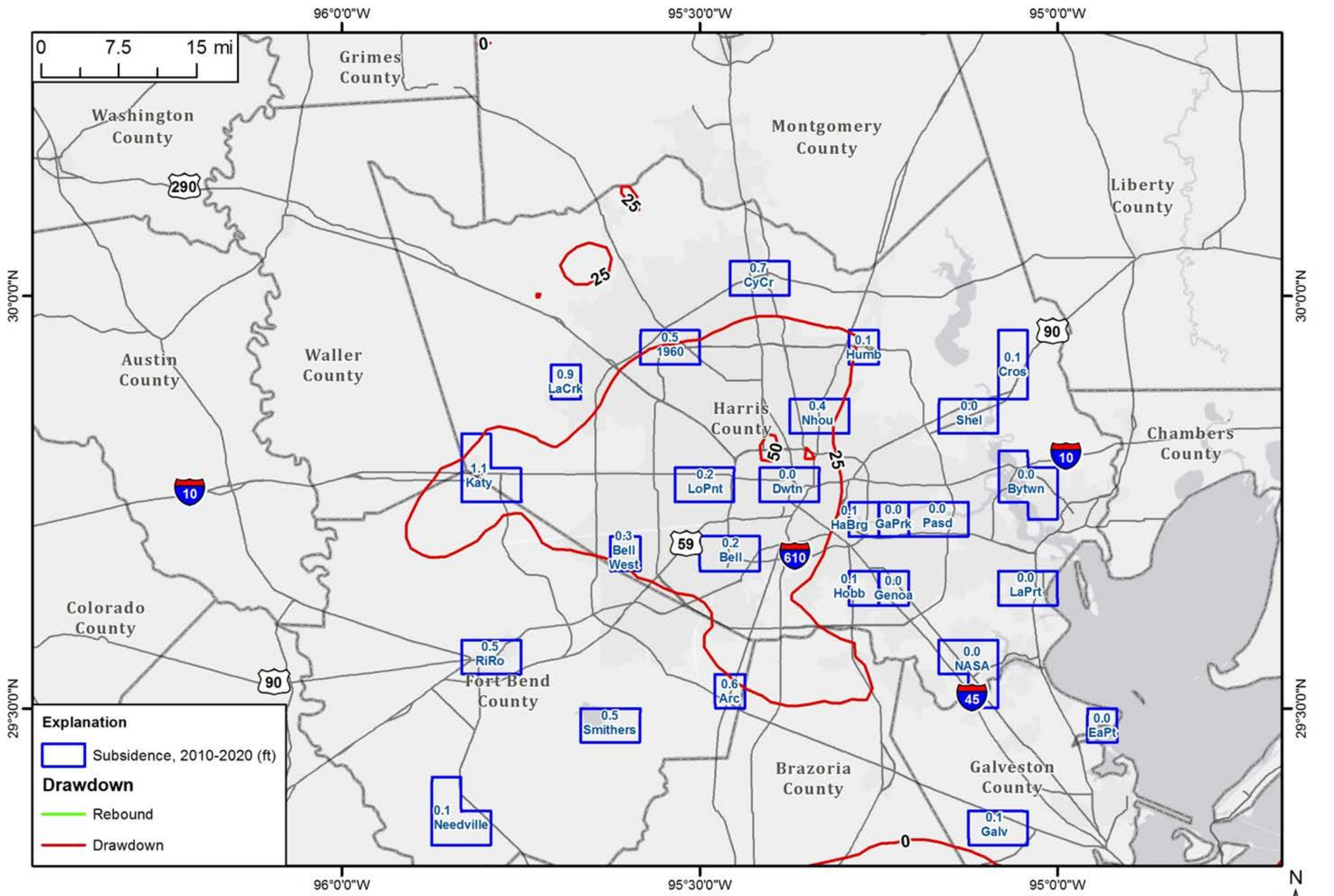
Revised Scenario 3



SUBSIDENCE, 2010-2050

DRAFT

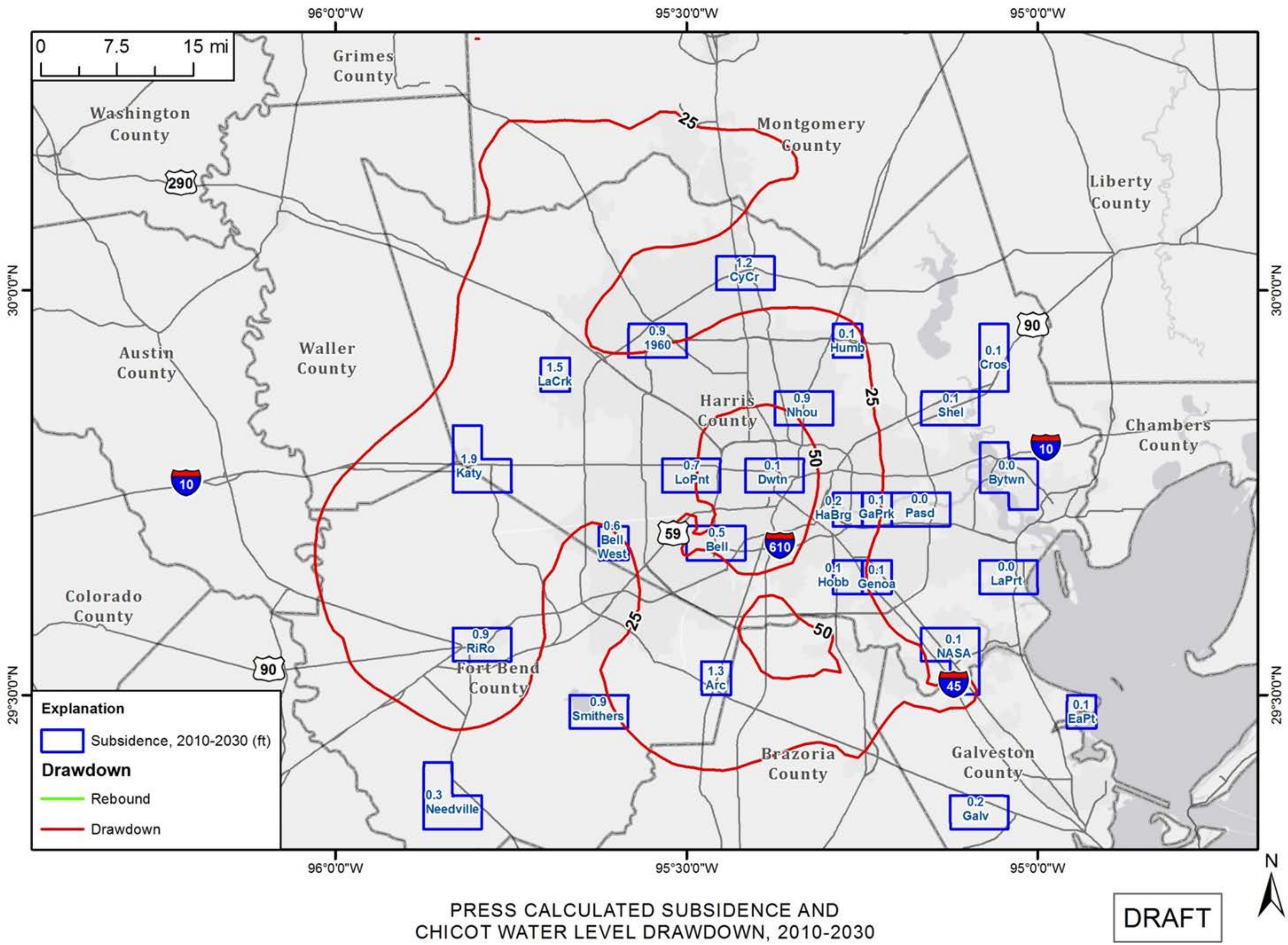
Revised Scenario 3



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2020

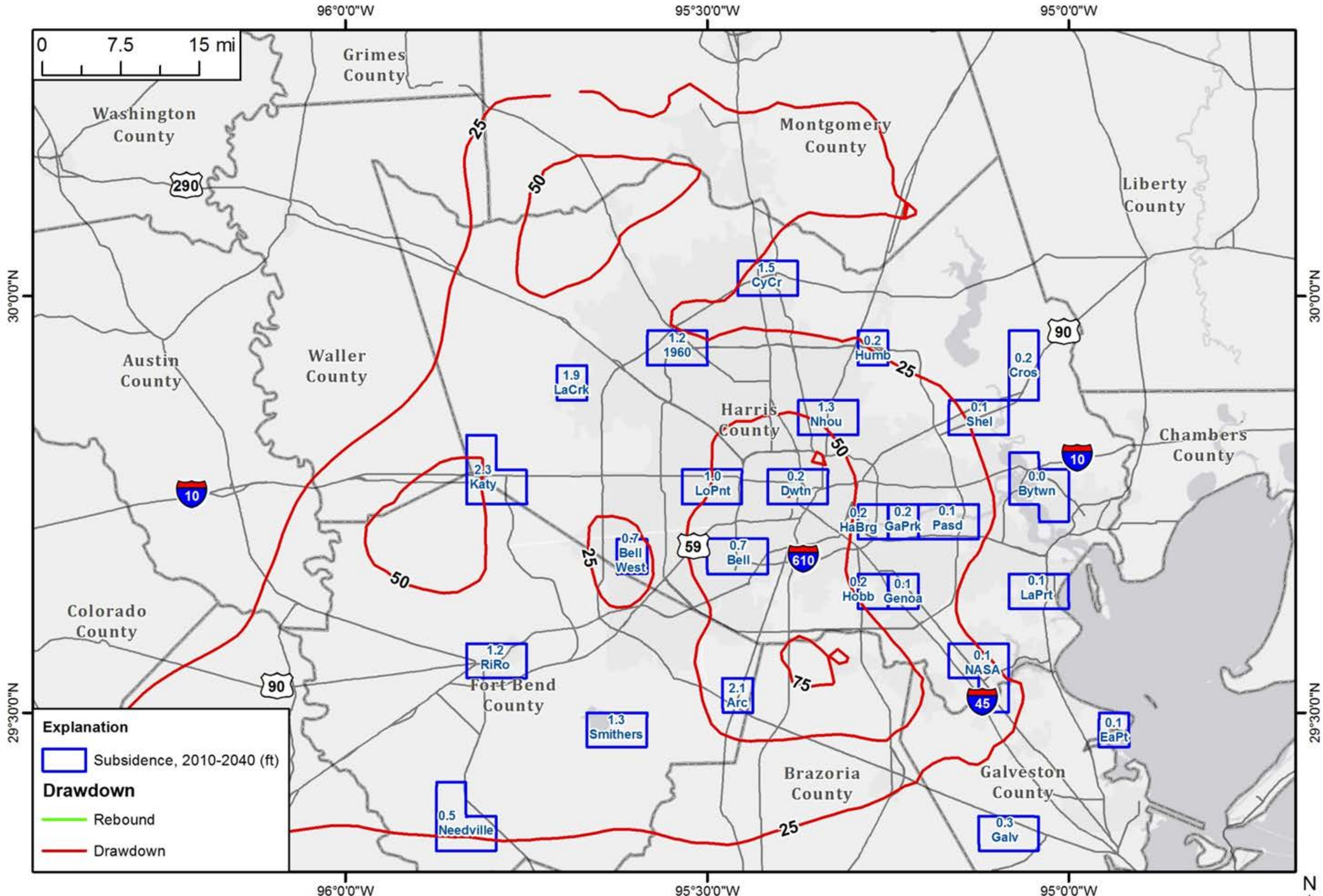
Scenario 4

DRAFT



PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2030

Scenario 4

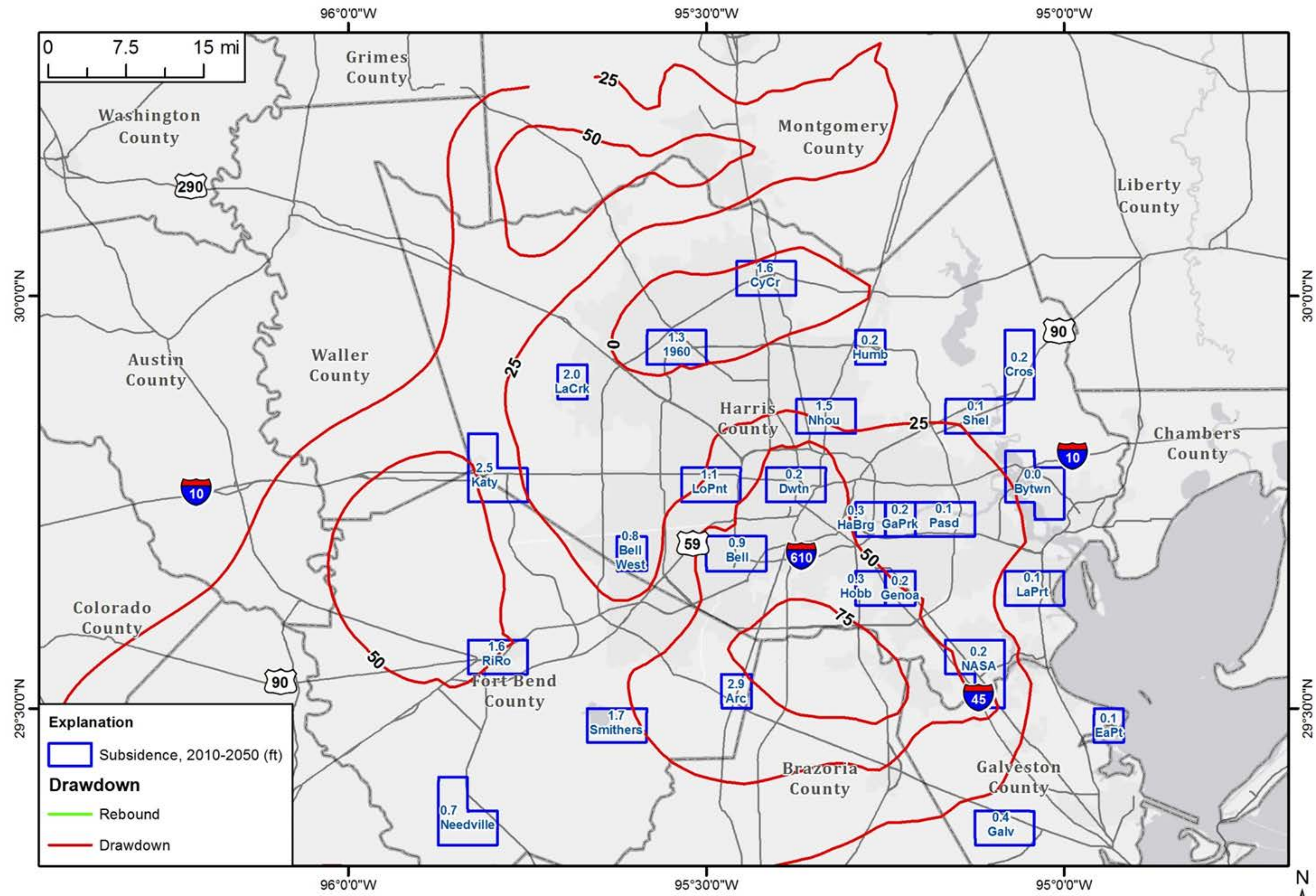


PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2040

Scenario 4

DRAFT

N

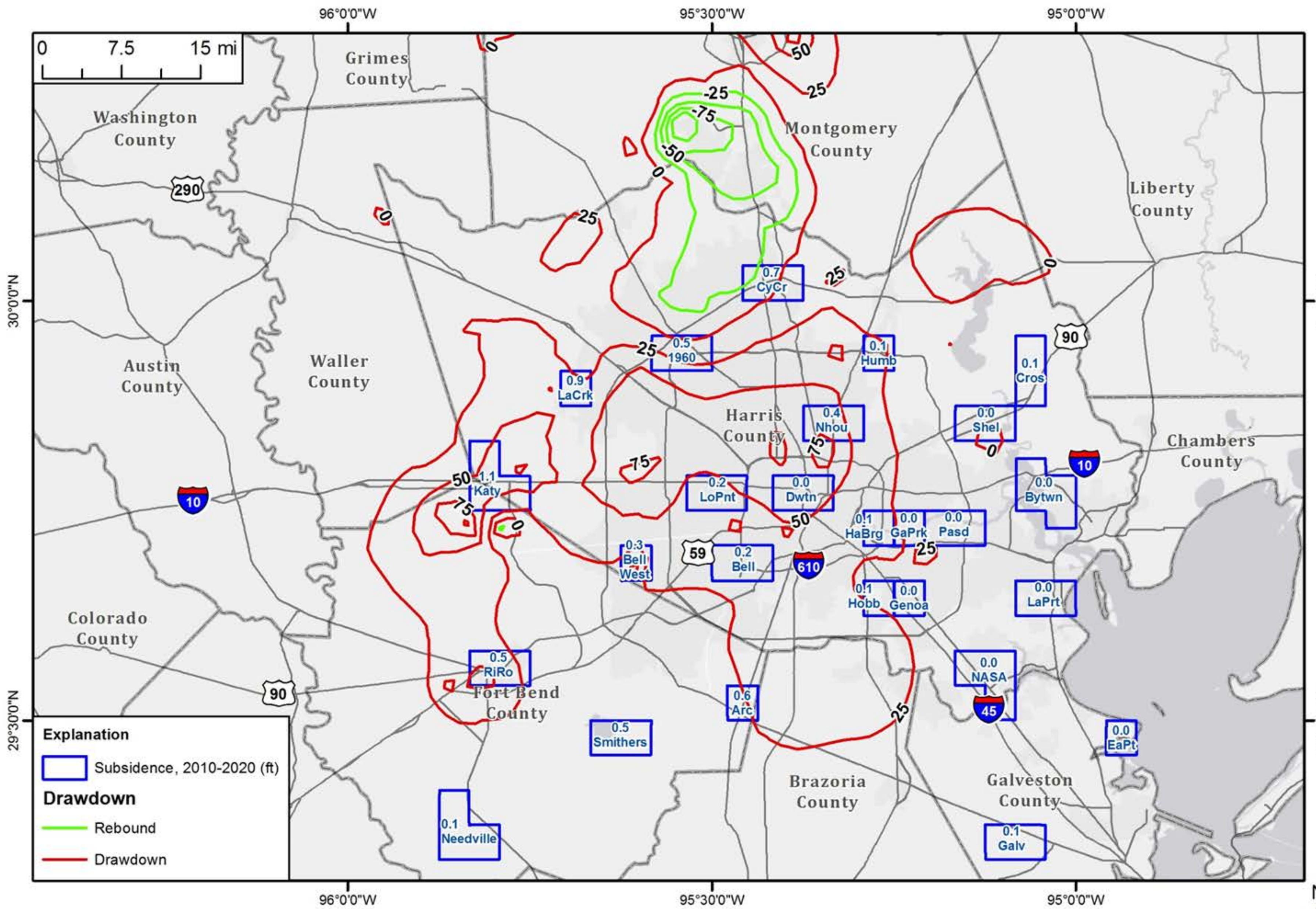


PRESS CALCULATED SUBSIDENCE AND
CHICOT WATER LEVEL DRAWDOWN, 2010-2050

Scenario 4

DRAFT

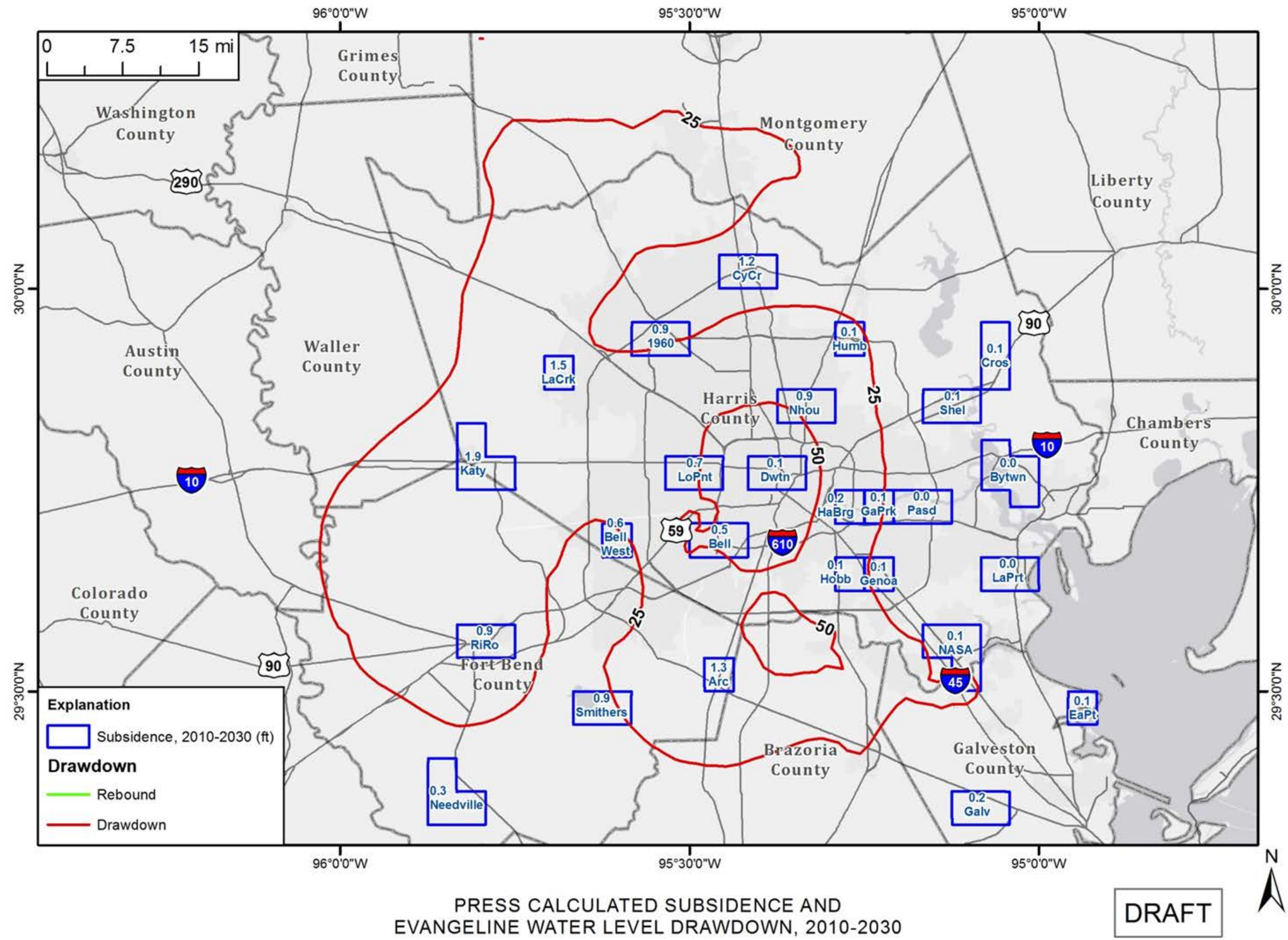
Scenario 4
Evangeline Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND EVANGELINE WATER LEVEL DRAWDOWN, 2010-2020

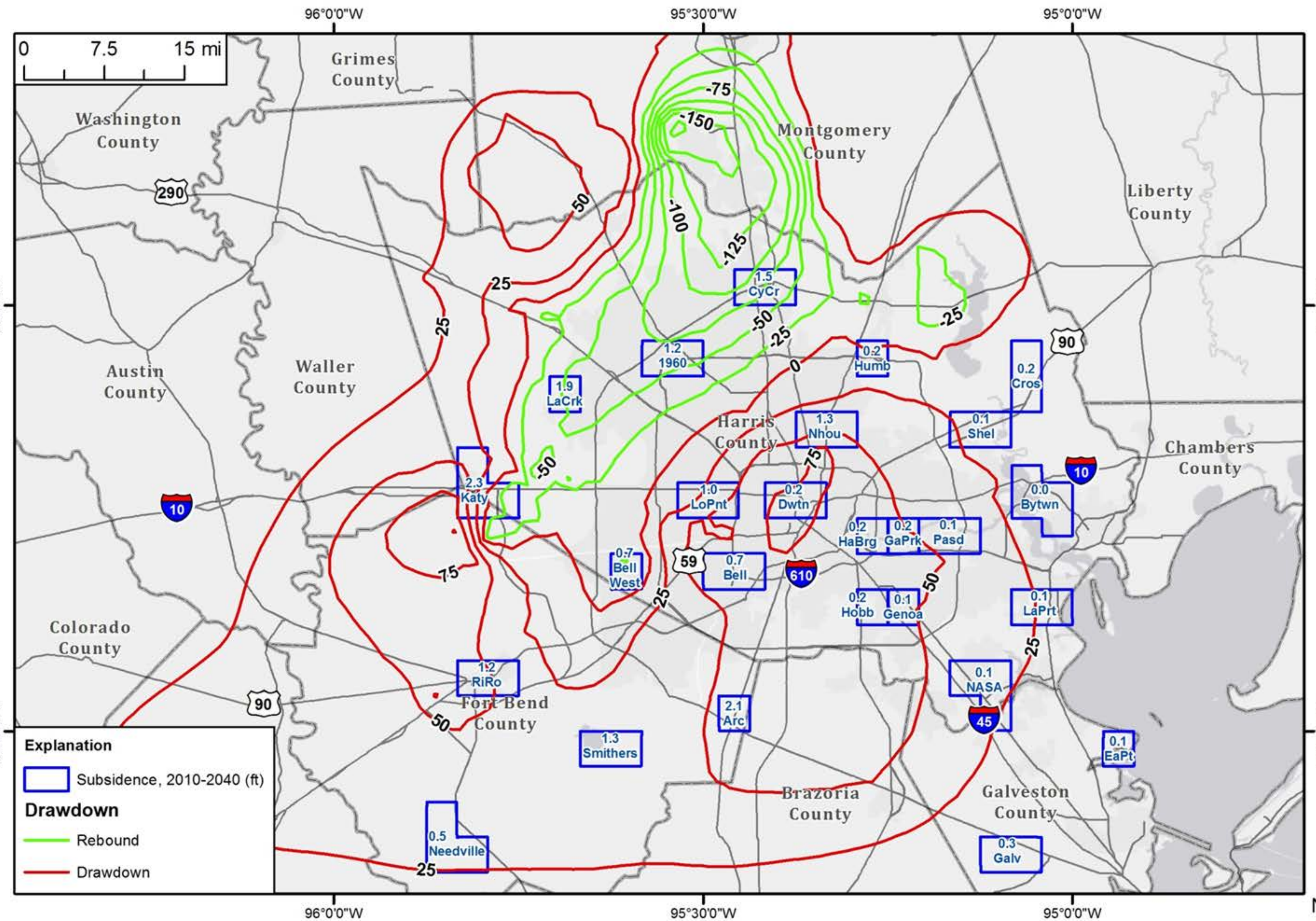
Scenario 4

DRAFT



PRESS CALCULATED SUBSIDENCE AND
EVANGELINE WATER LEVEL DRAWDOWN, 2010-2030

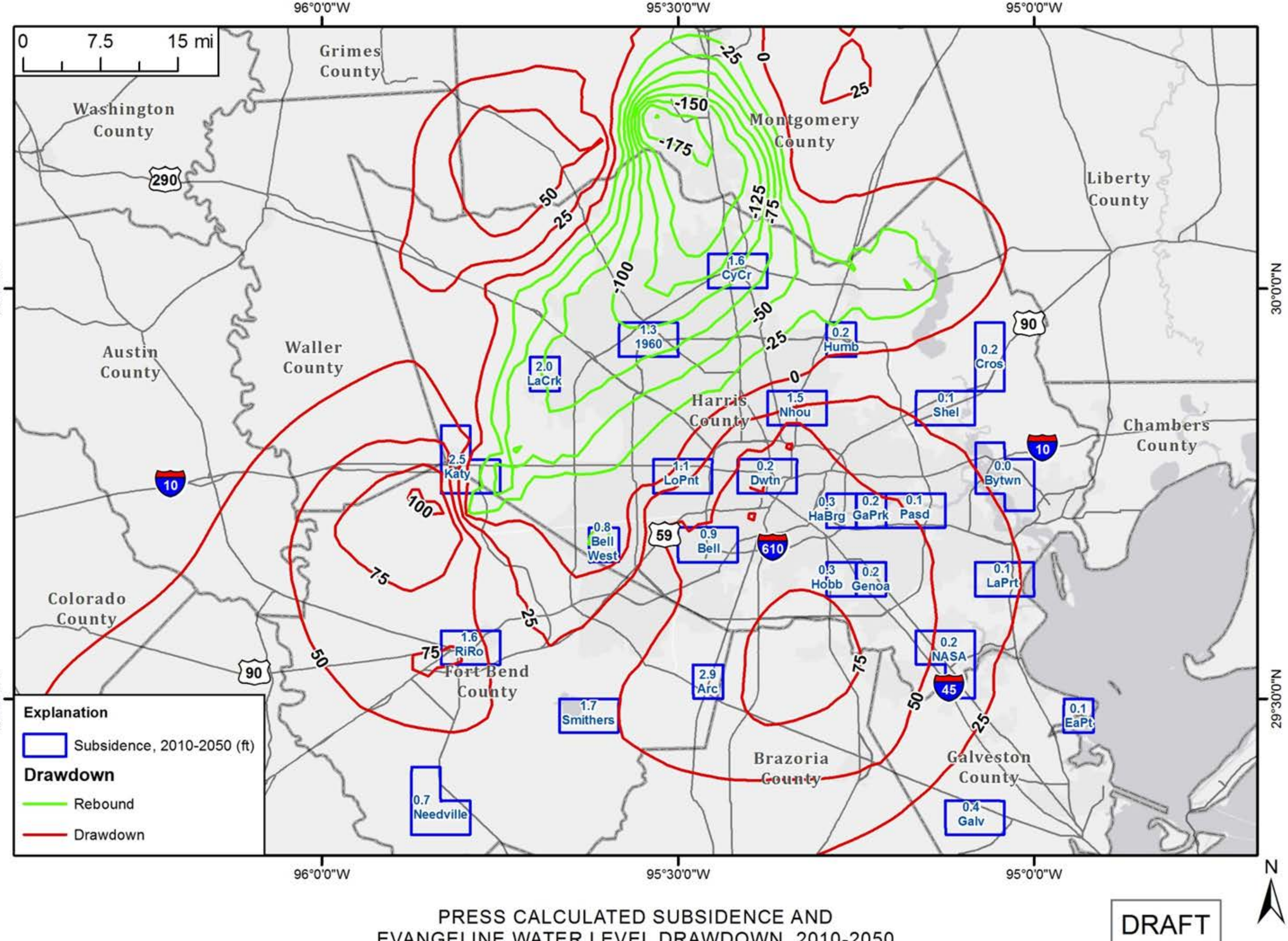
Scenario 4



PRESS CALCULATED SUBSIDENCE AND EVANGELINE WATER LEVEL DRAWDOWN, 2010-2040

Scenario 4

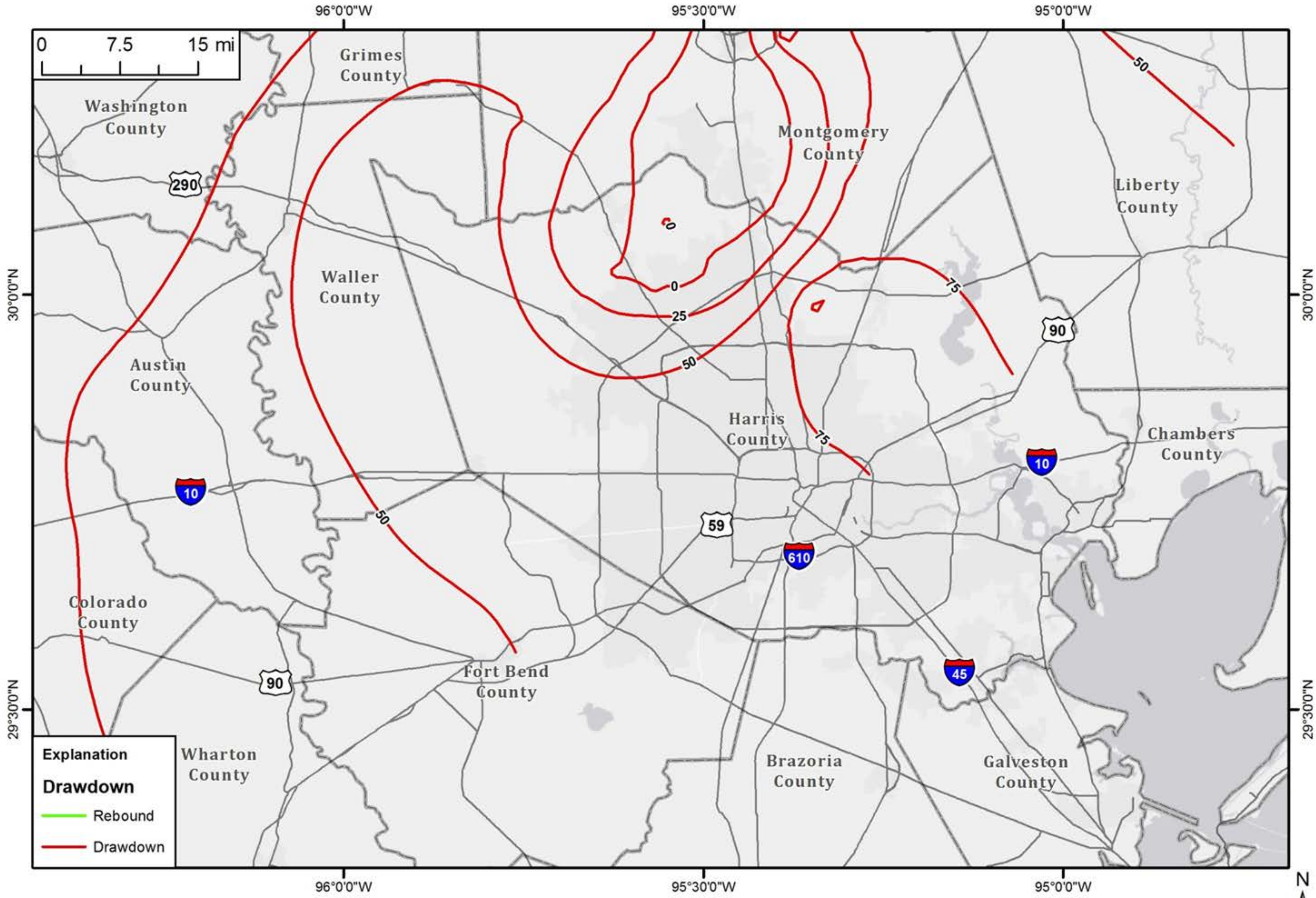
DRAFT



PRESS CALCULATED SUBSIDENCE AND EVANGELINE WATER LEVEL DRAWDOWN, 2010-2050

Scenario 4

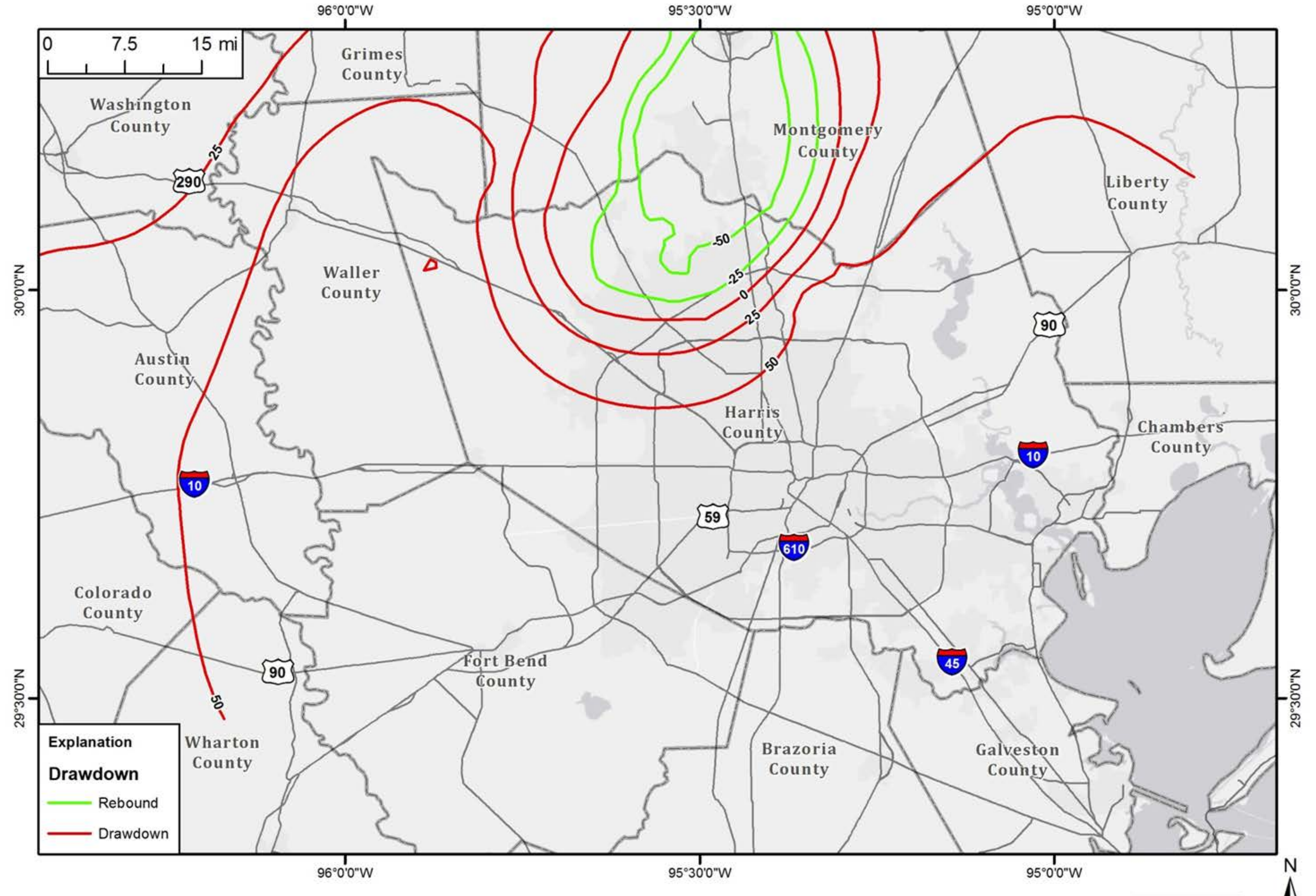
Scenario 4
Jasper Aquifer
Groundwater Drawdown Maps



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2020

Scenario 4

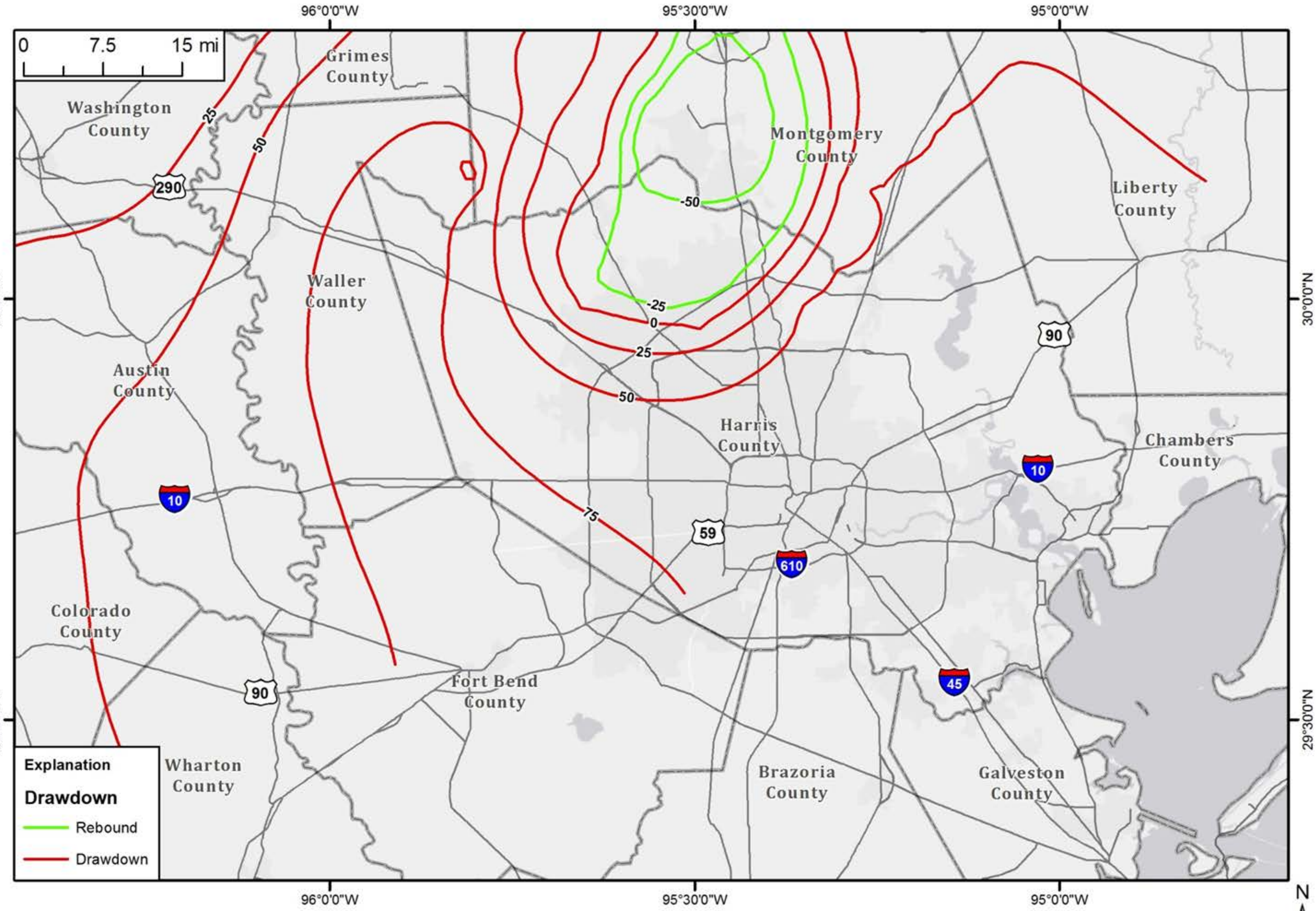
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2030

Scenario 4

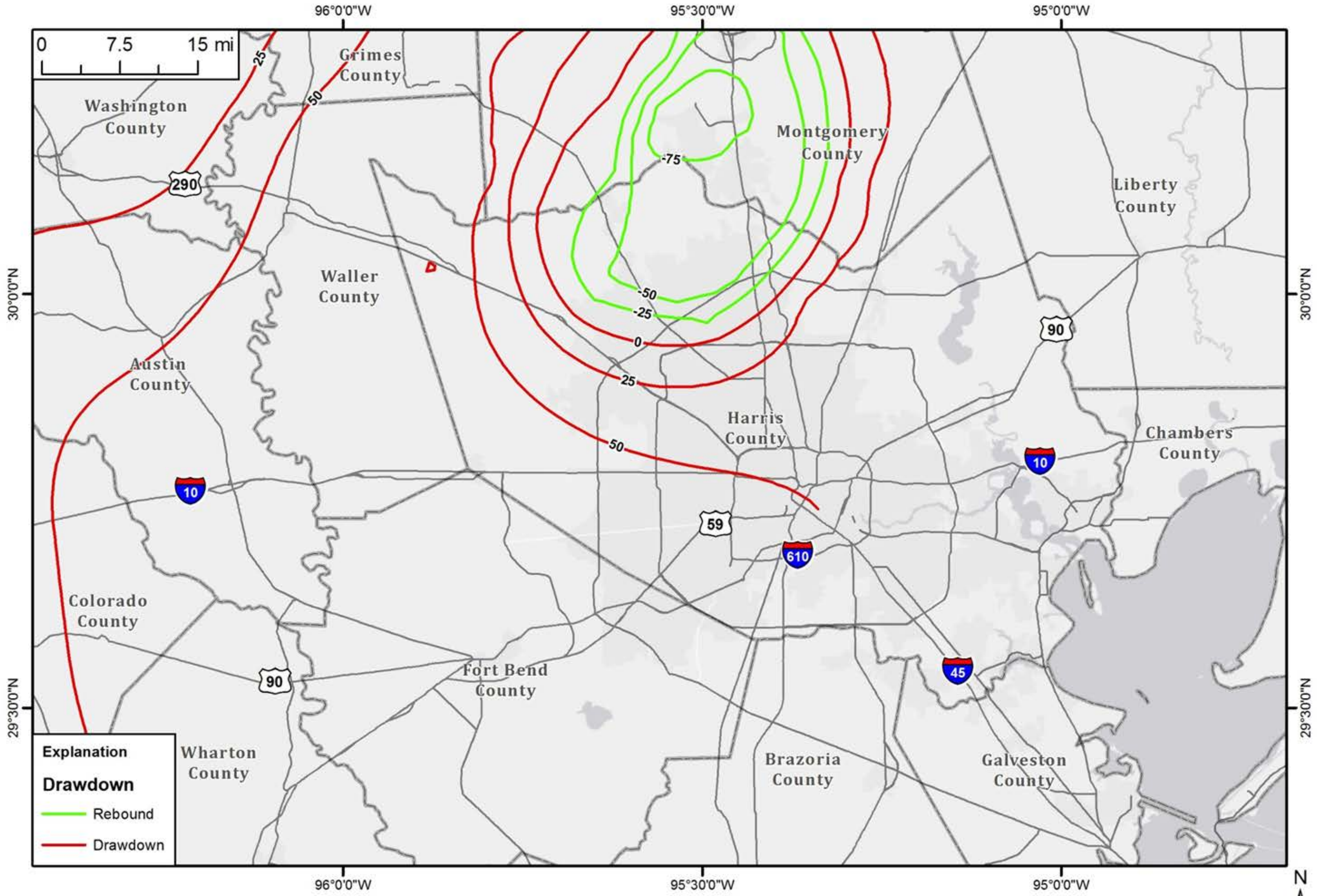
DRAFT



PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2040

Scenario 4

DRAFT

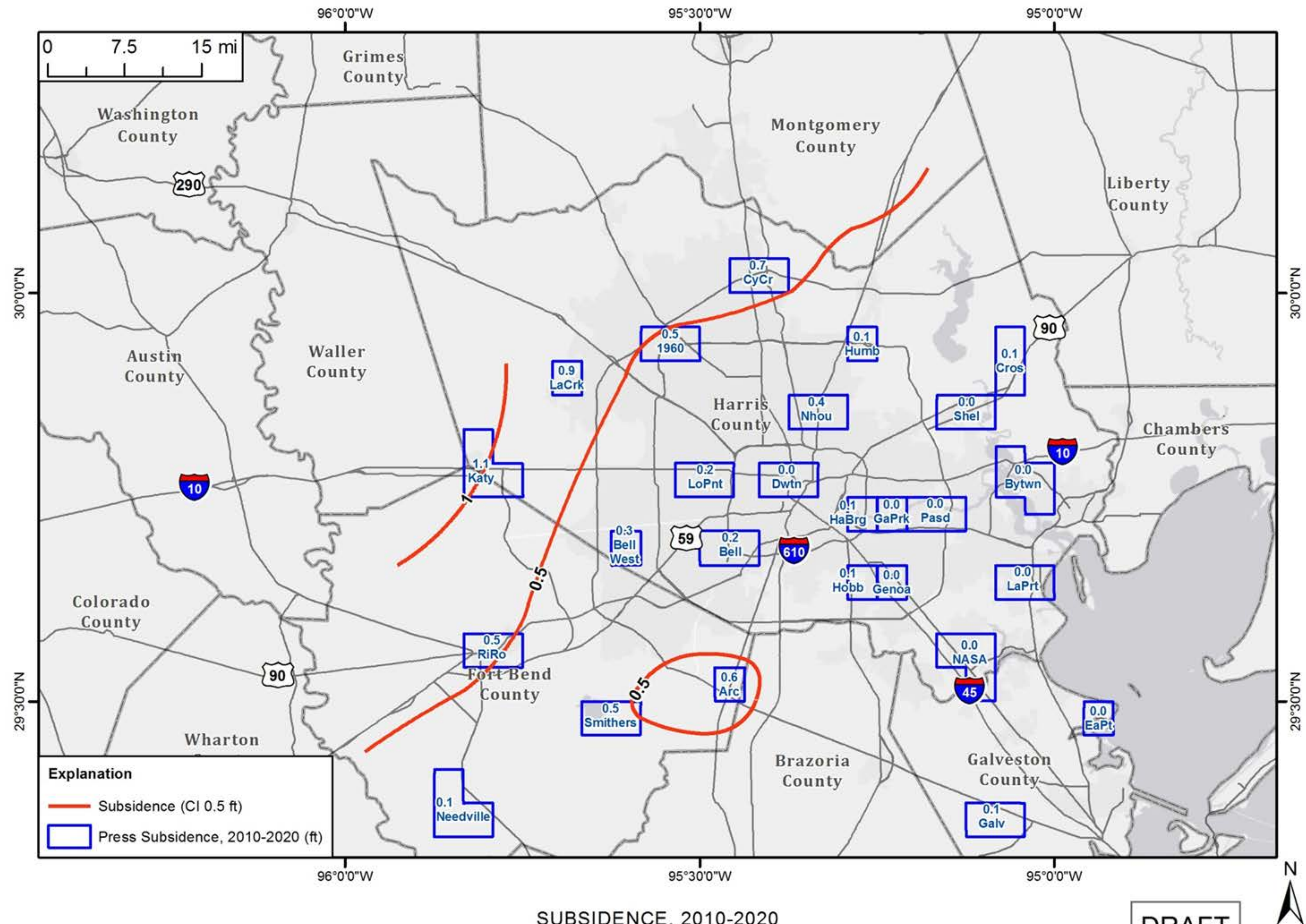


PRESS CALCULATED SUBSIDENCE AND
JASPER WATER LEVEL DRAWDOWN, 2010-2050

Scenario 4

DRAFT

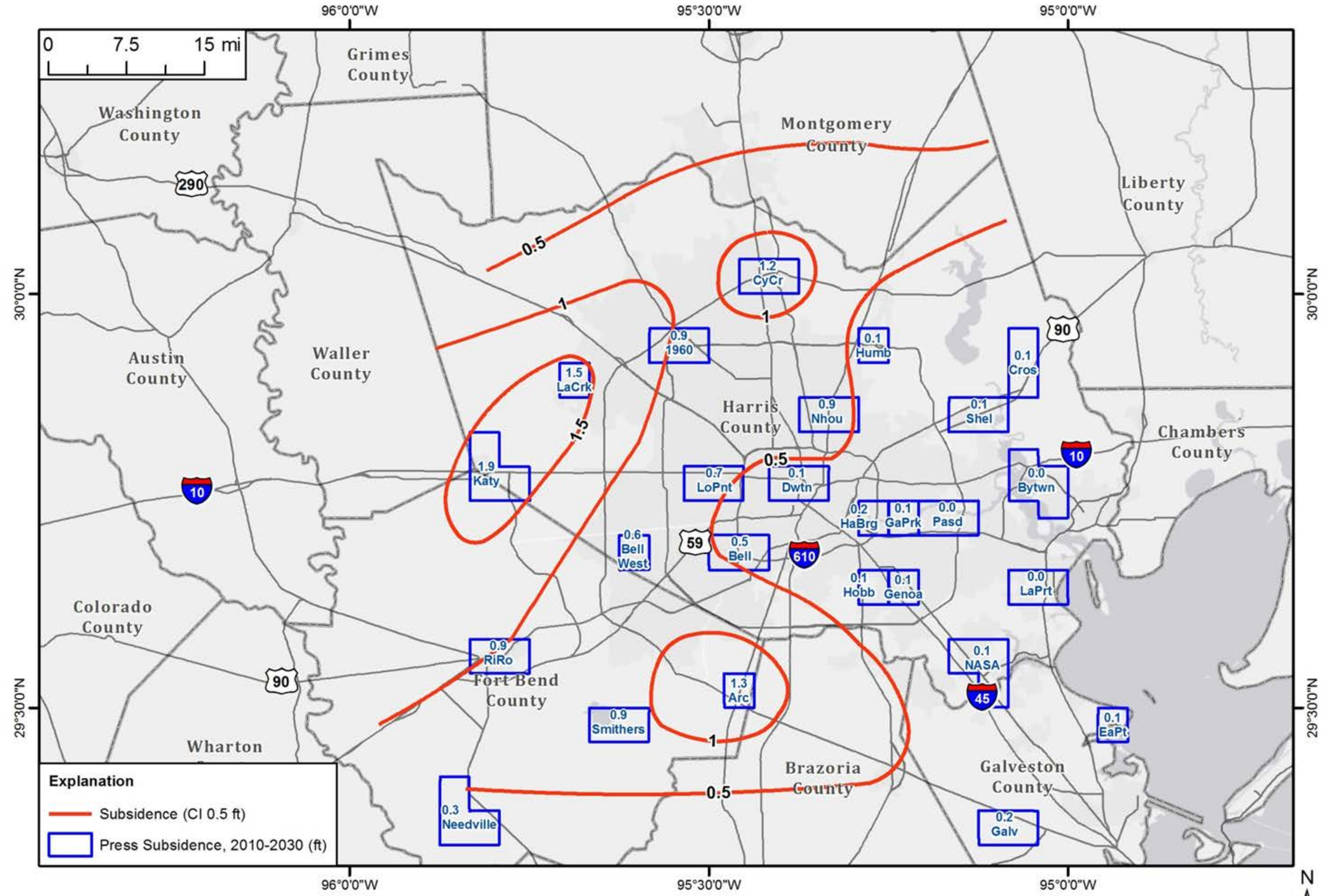
Scenario 4
Predicted Subsidence Contour Maps



SUBSIDENCE, 2010-2020

DRAFT

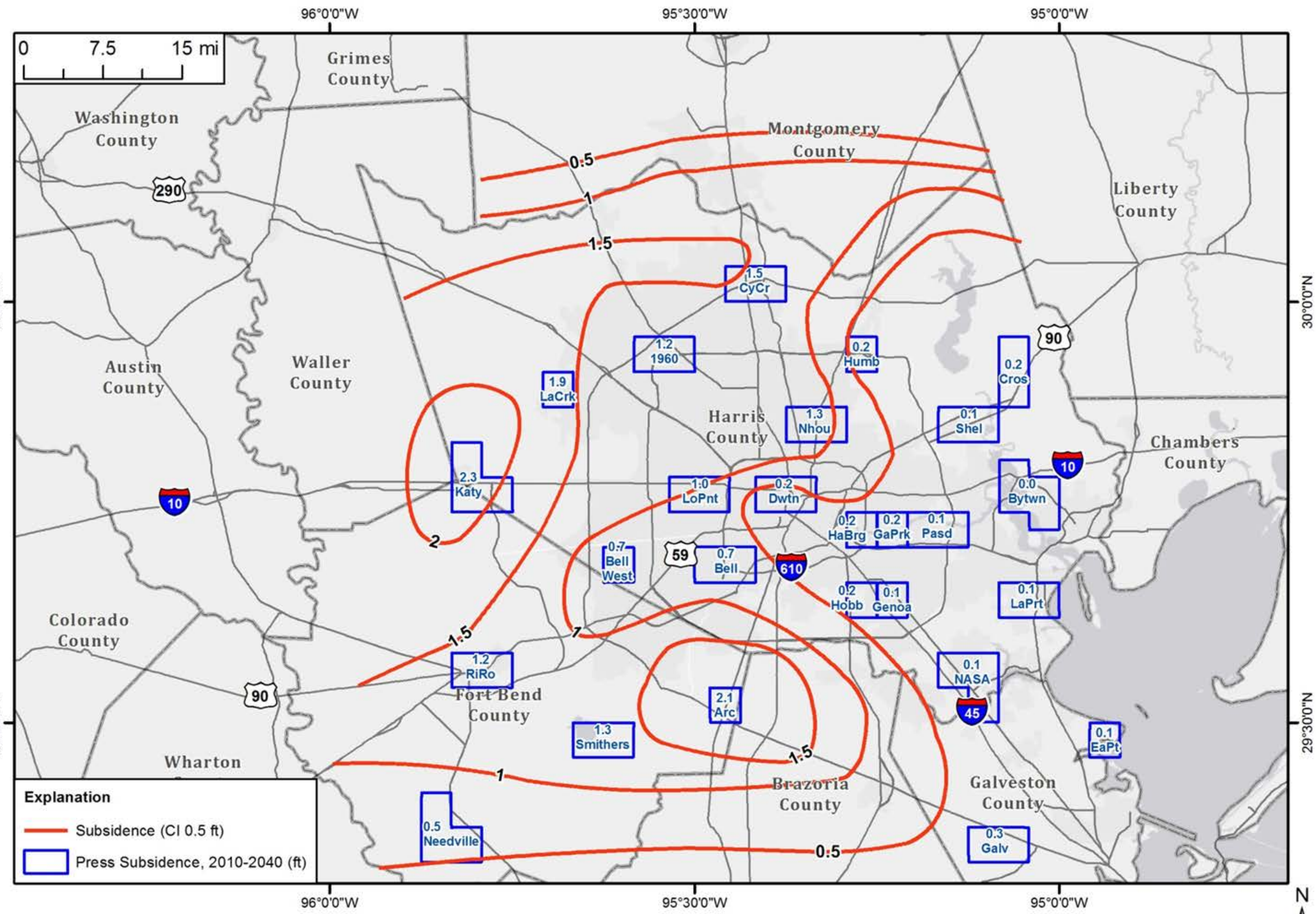
Scenario 4



SUBSIDENCE, 2010-2030

DRAFT

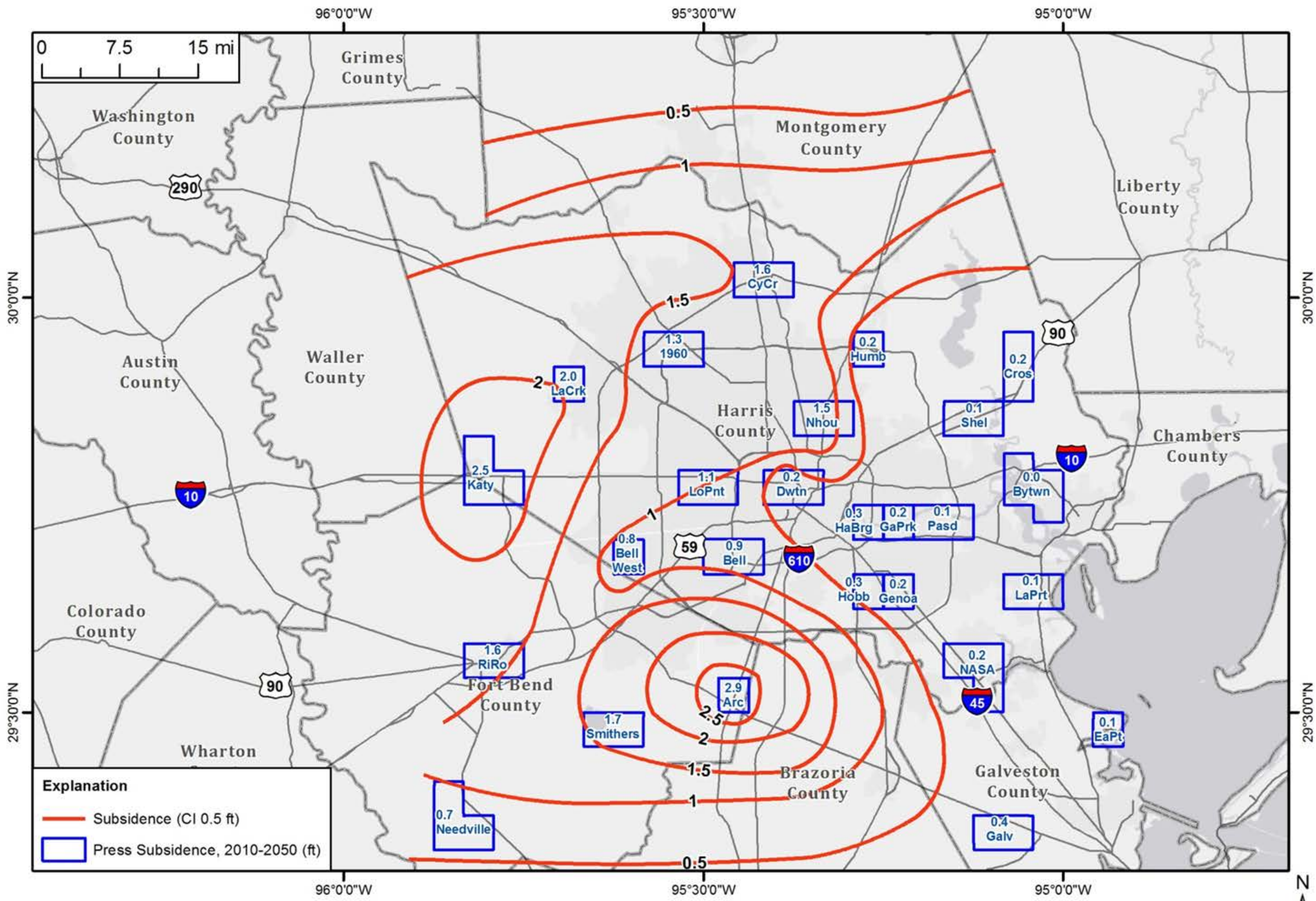
Scenario 4



SUBSIDENCE, 2010-2040

DRAFT

Scenario 4

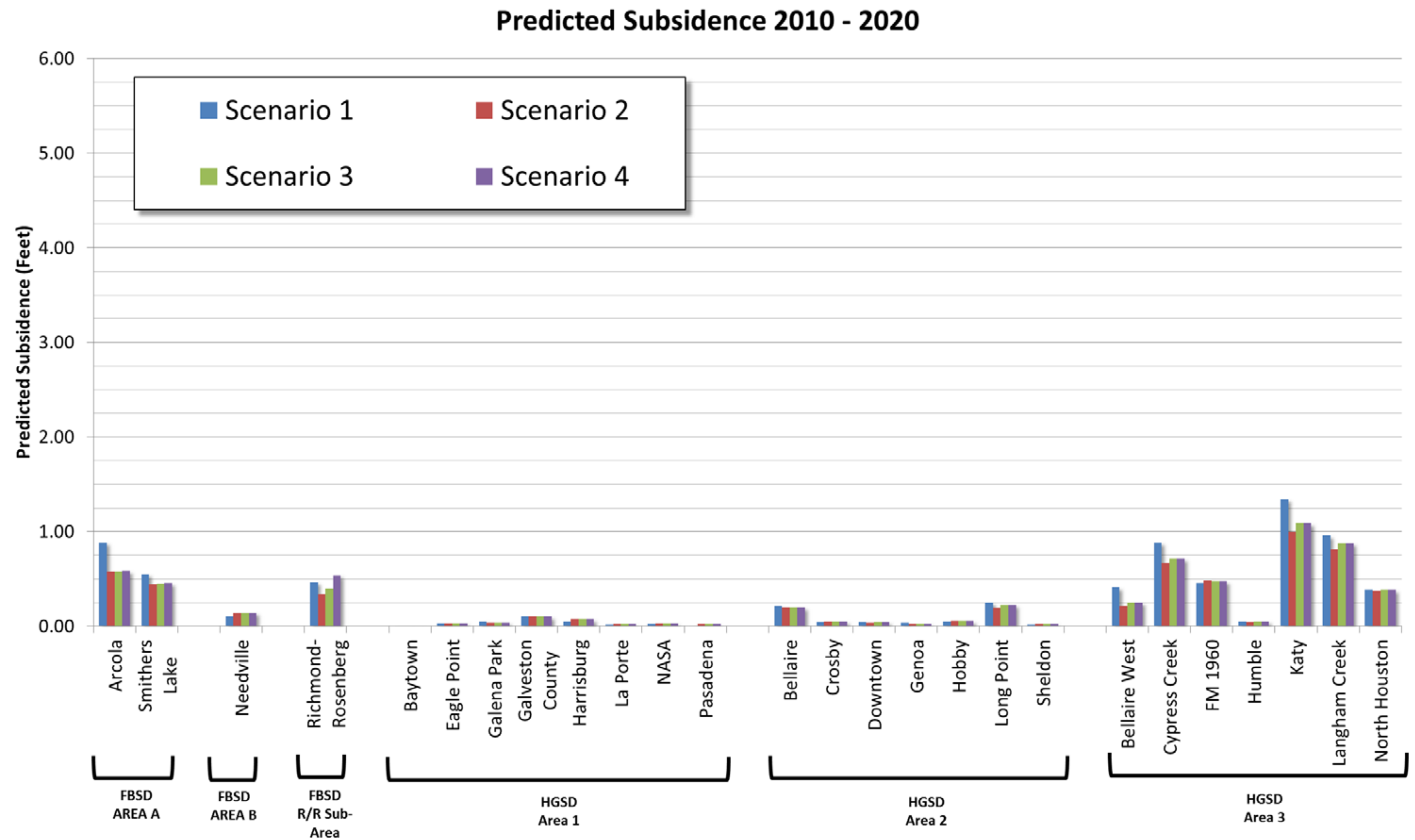


SUBSIDENCE, 2010-2050

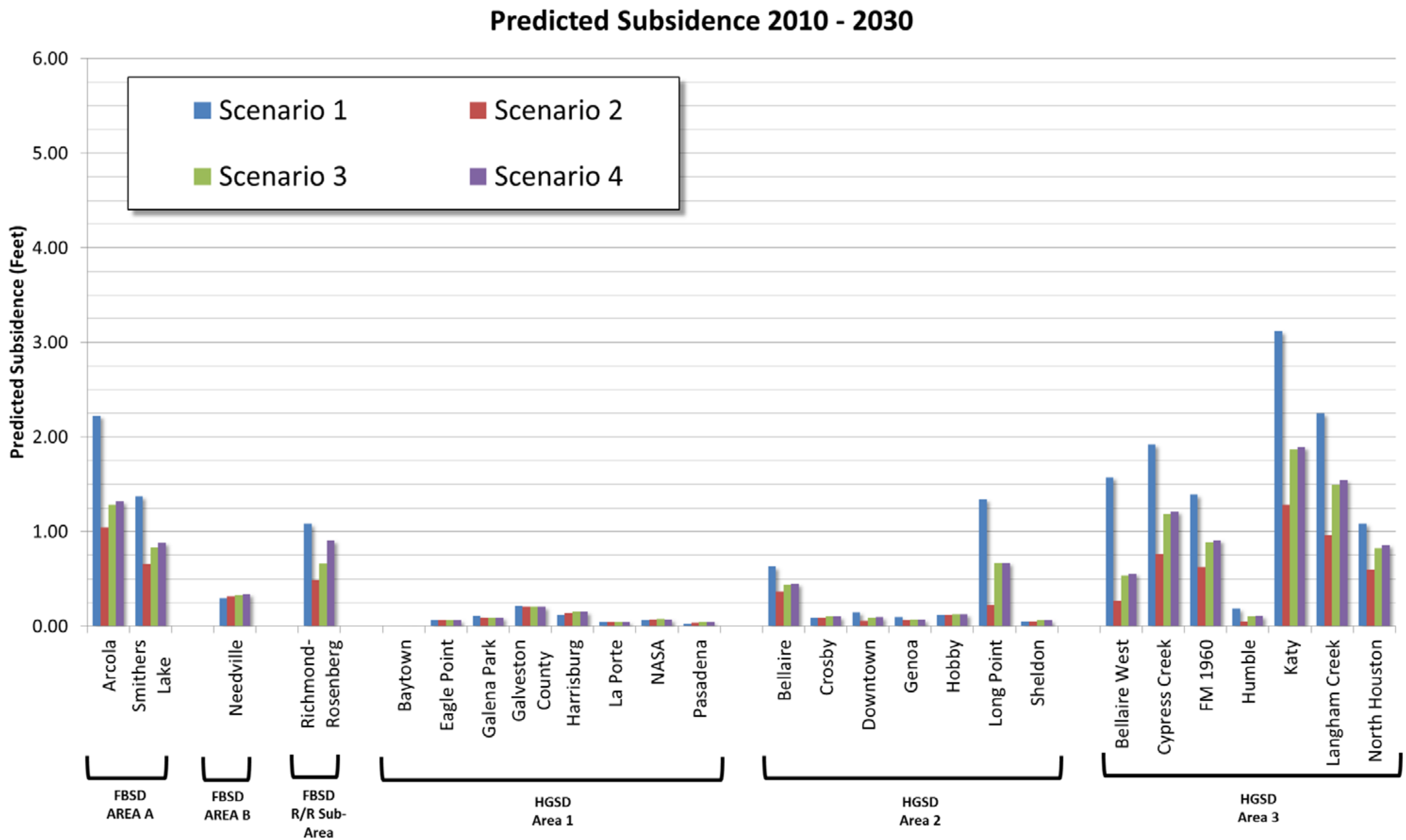
DRAFT

Scenario 4

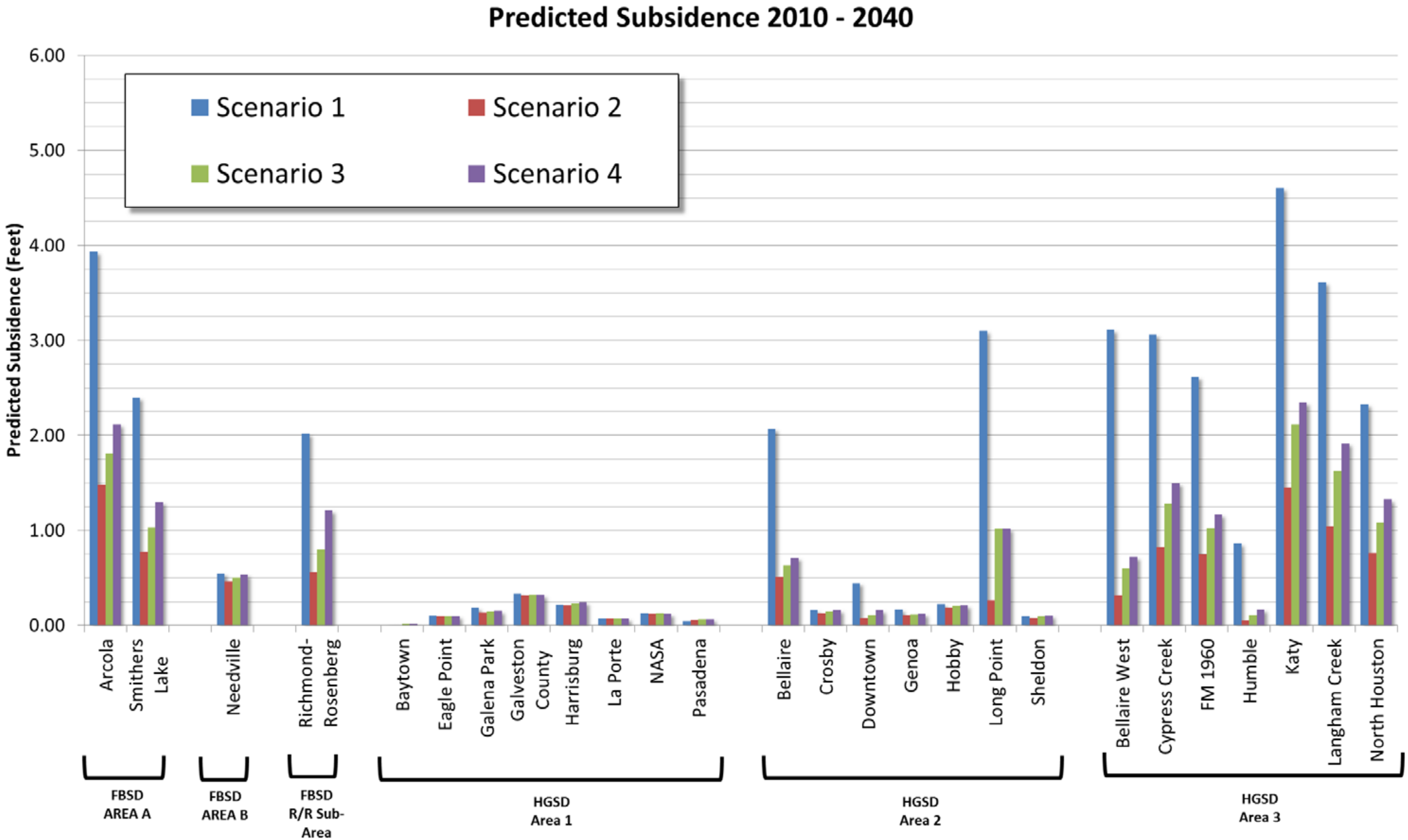
Comparison of Subsidence Predictions
Scenarios 1, 2, 3, and 4



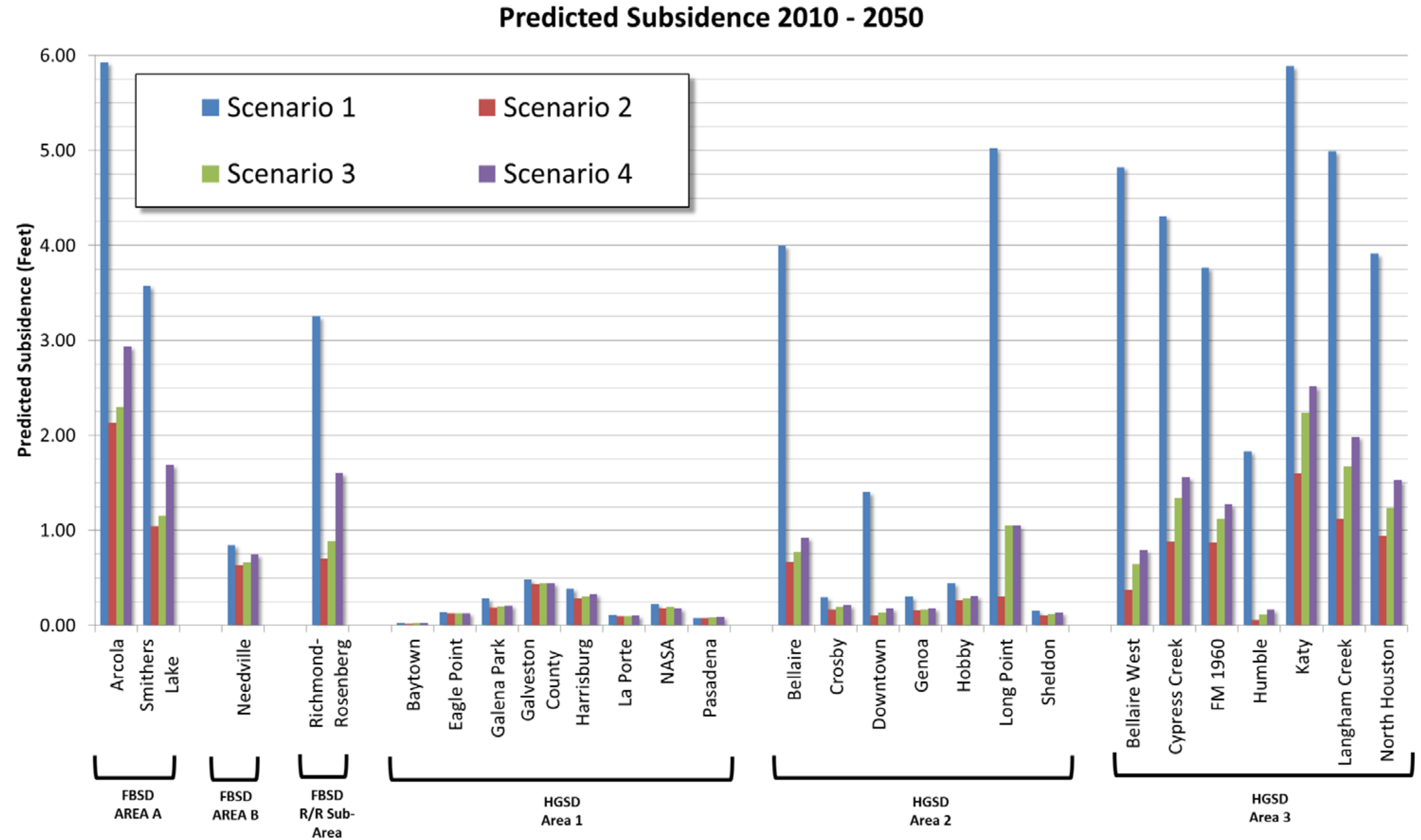
Predicted Subsidence 2010 - 2020
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Predicted Subsidence (Feet)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3



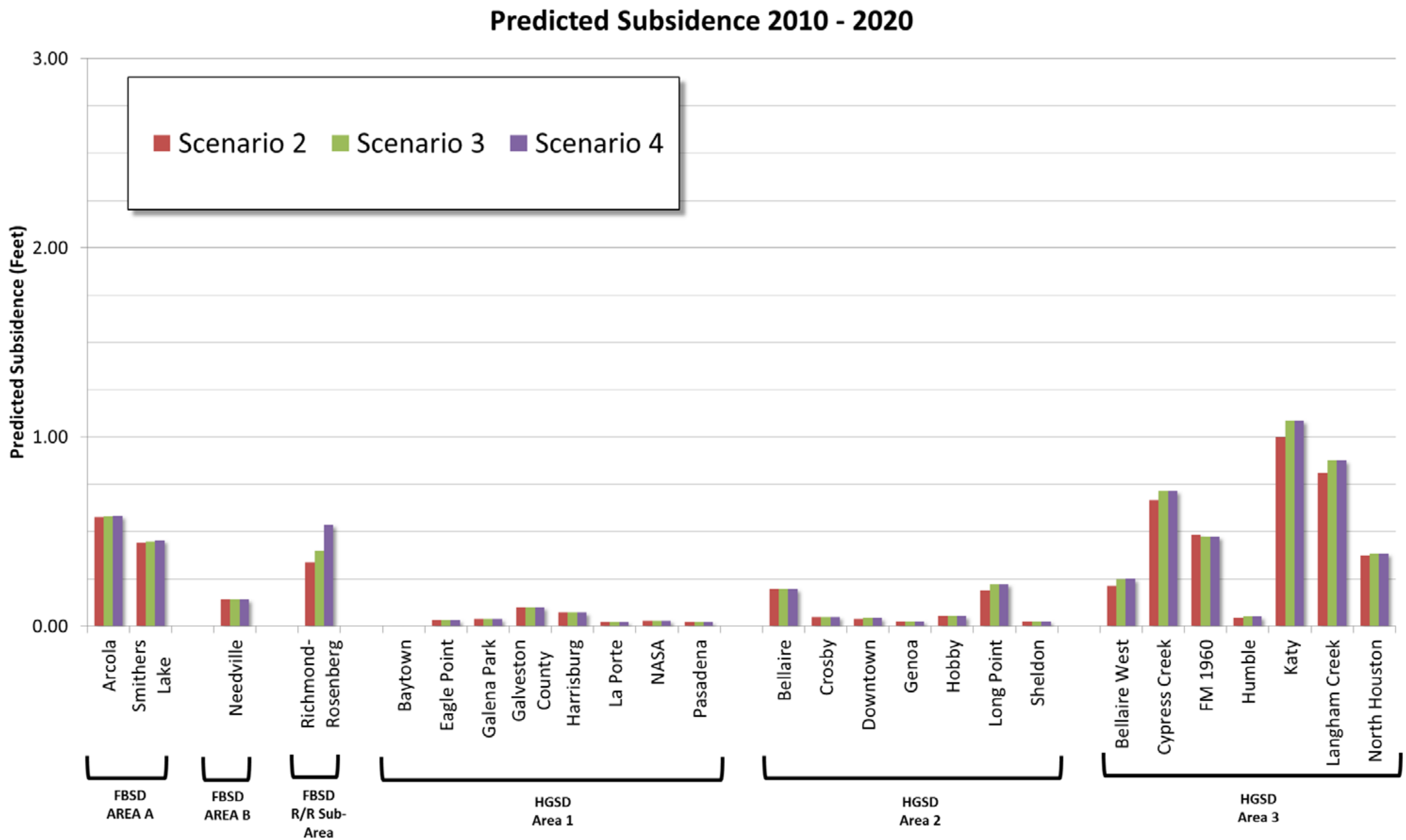
Predicted Subsidence 2010 - 2030
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Predicted Subsidence (Feet)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3

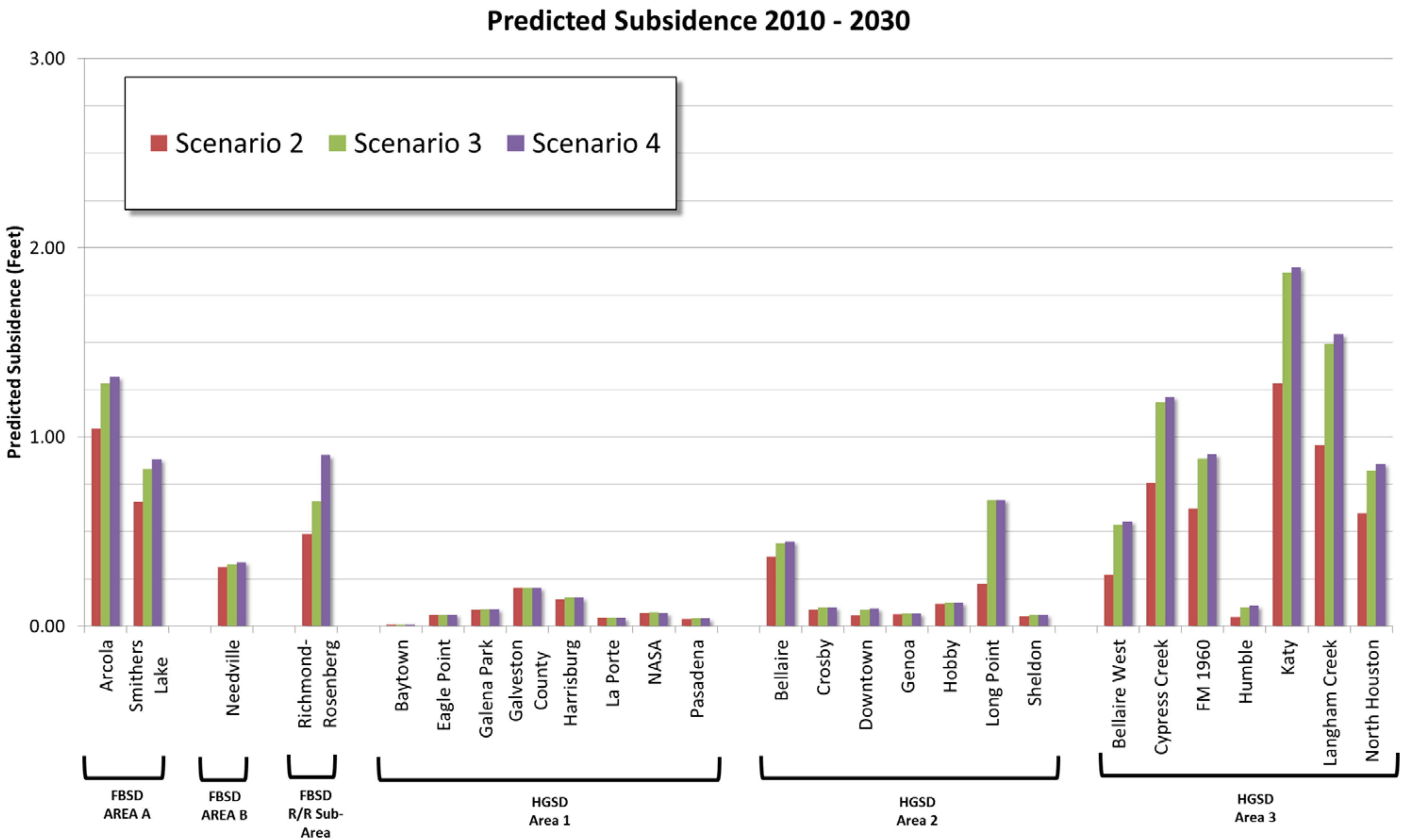


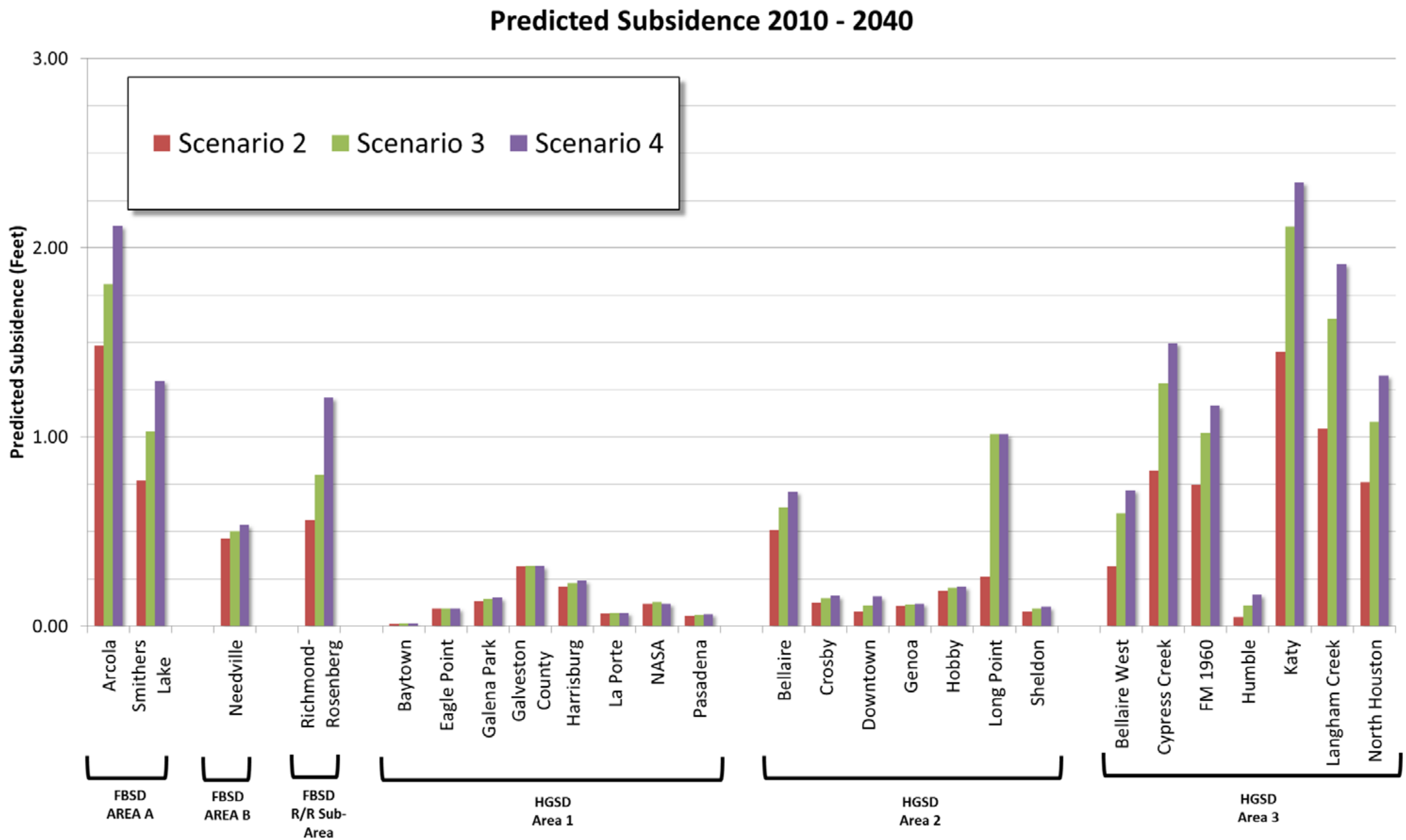
Predicted Subsidence 2010 - 2040
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Predicted Subsidence (Feet)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3


Predicted Subsidence 2010 - 2050
Scenario 1
Scenario 2
Scenario 3
Scenario 4
Predicted Subsidence (Feet)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3

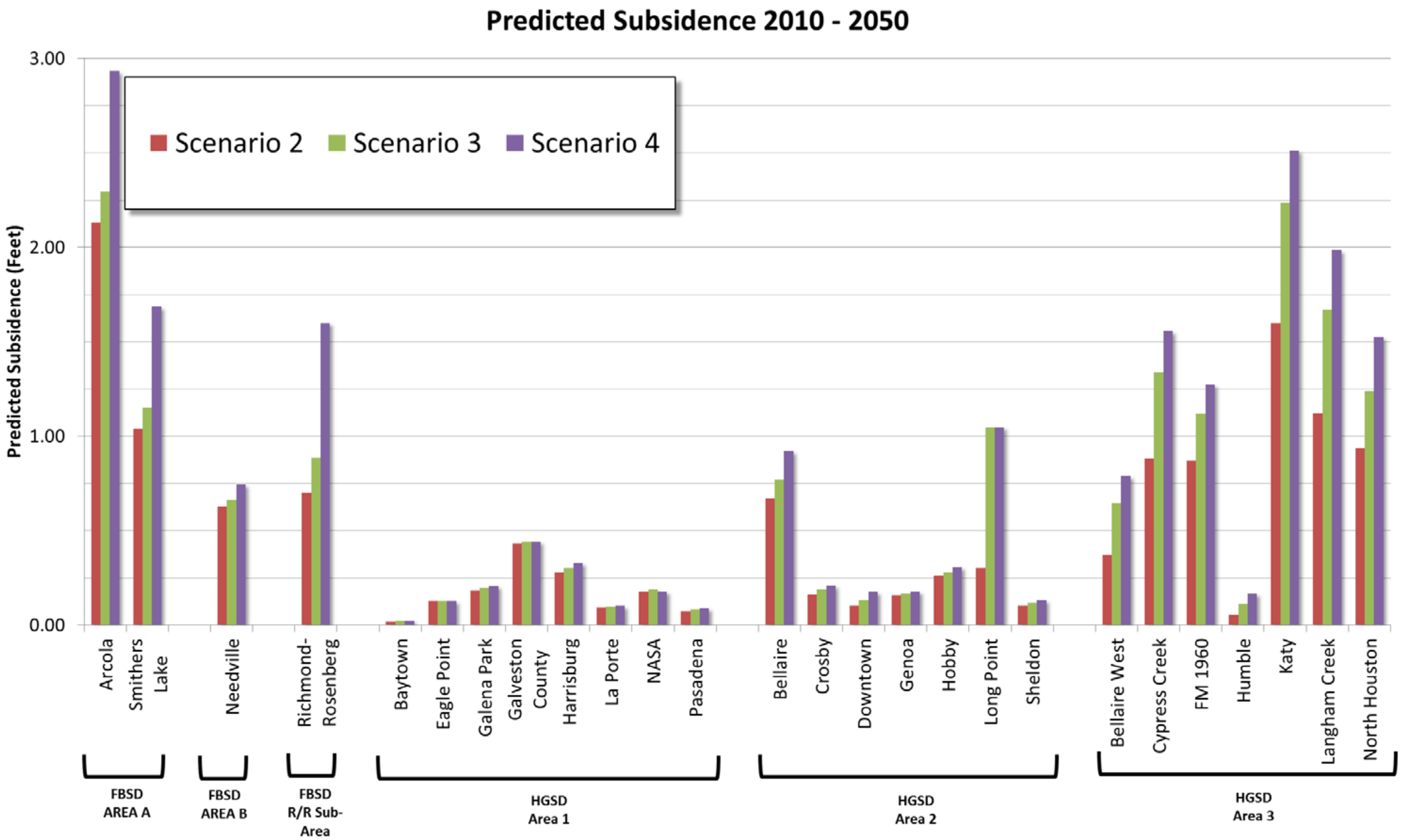
Comparison of Subsidence Predictions
Scenarios 2, 3, and 4


Predicted Subsidence 2010 - 2020
Scenario 2
Scenario 3
Scenario 4
Predicted Subsidence (Feet)
3.00
2.00
1.00
0.00
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3


Predicted Subsidence 2010 - 2030
Scenario 2
Scenario 3
Scenario 4
Predicted Subsidence (Feet)
3.00
2.00
1.00
0.00
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3



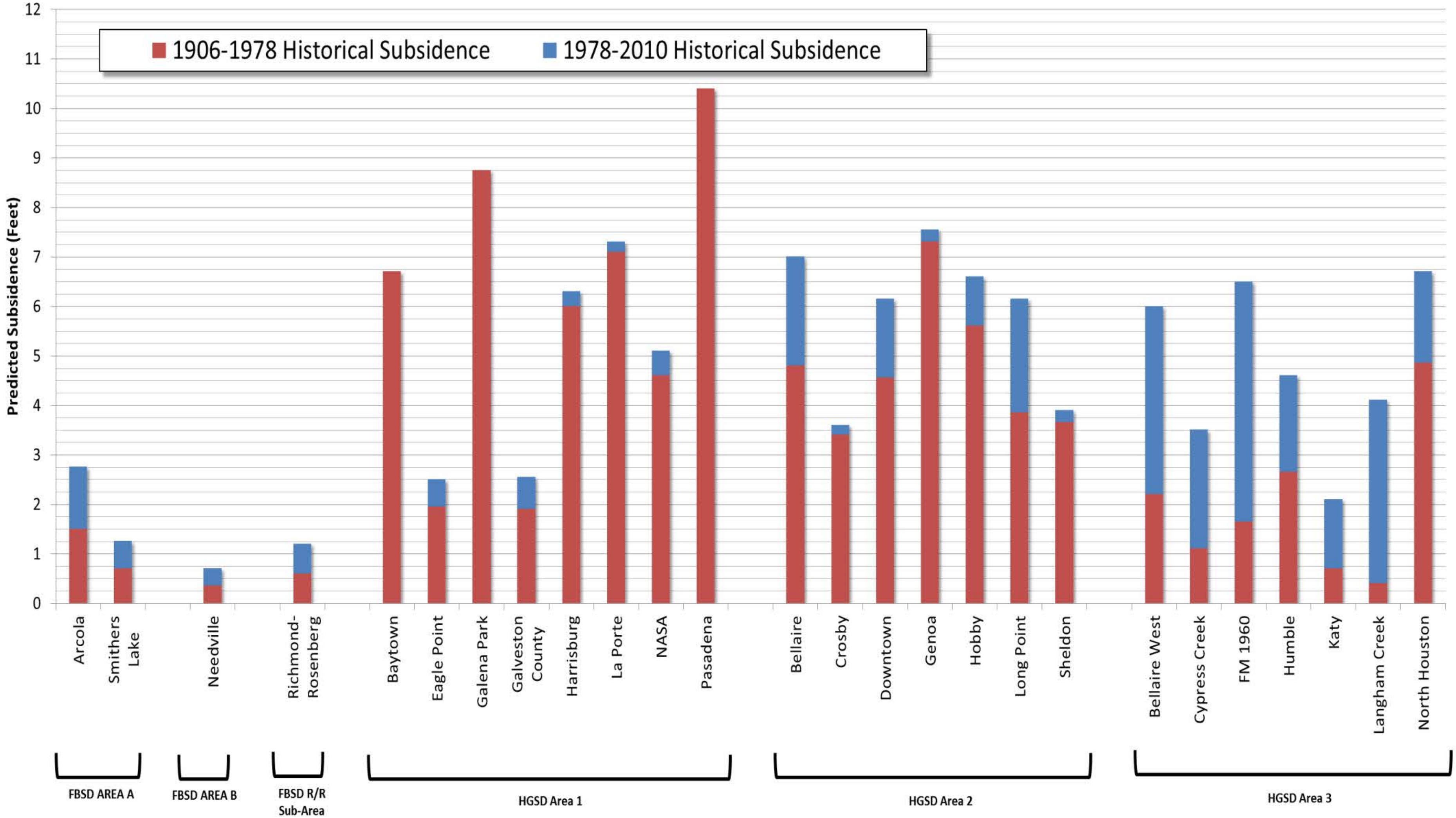
Predicted Subsidence 2010 - 2040
Scenario 2
Scenario 3
Scenario 4
Predicted Subsidence (Feet)
3.00
2.00
1.00
0.00
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3

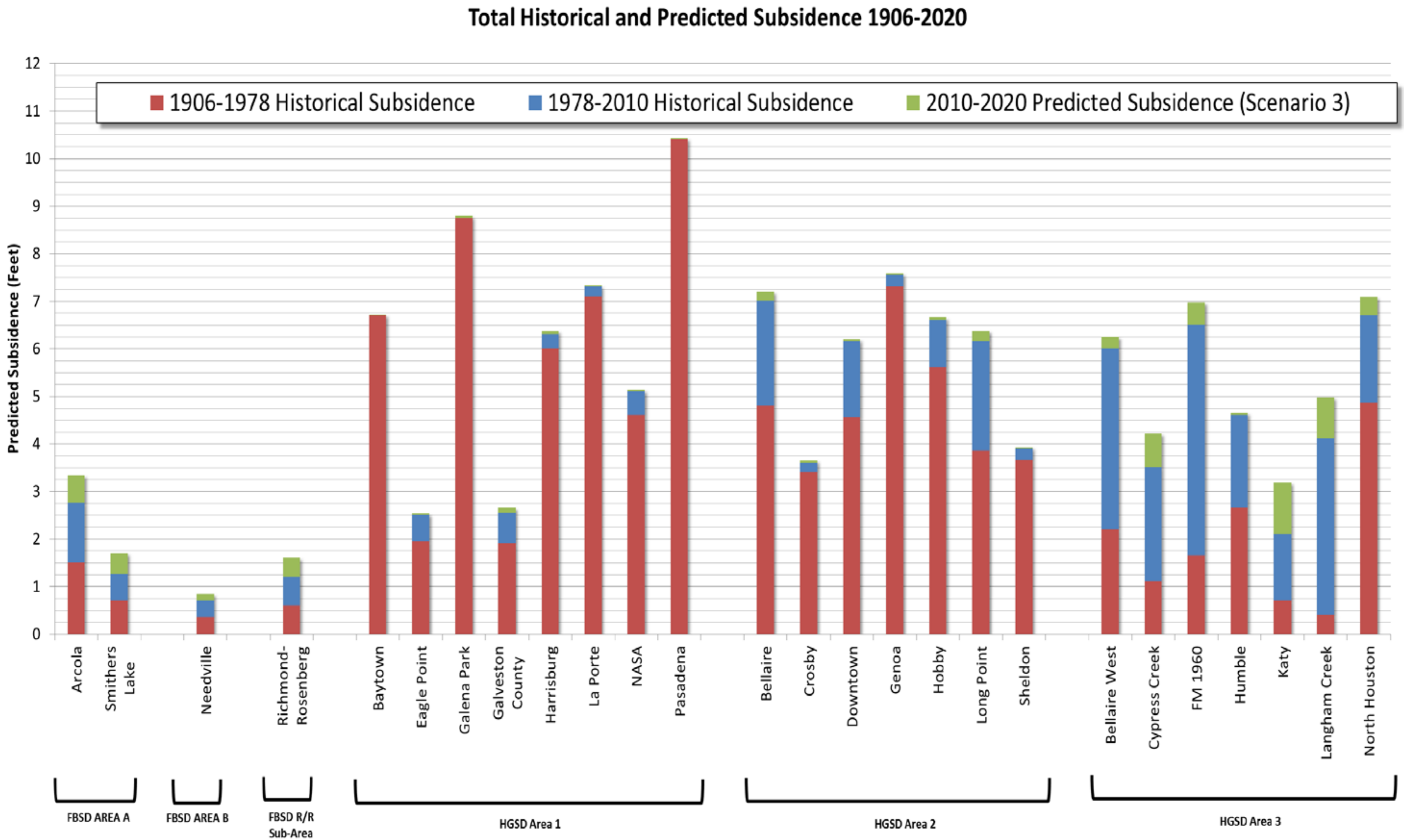


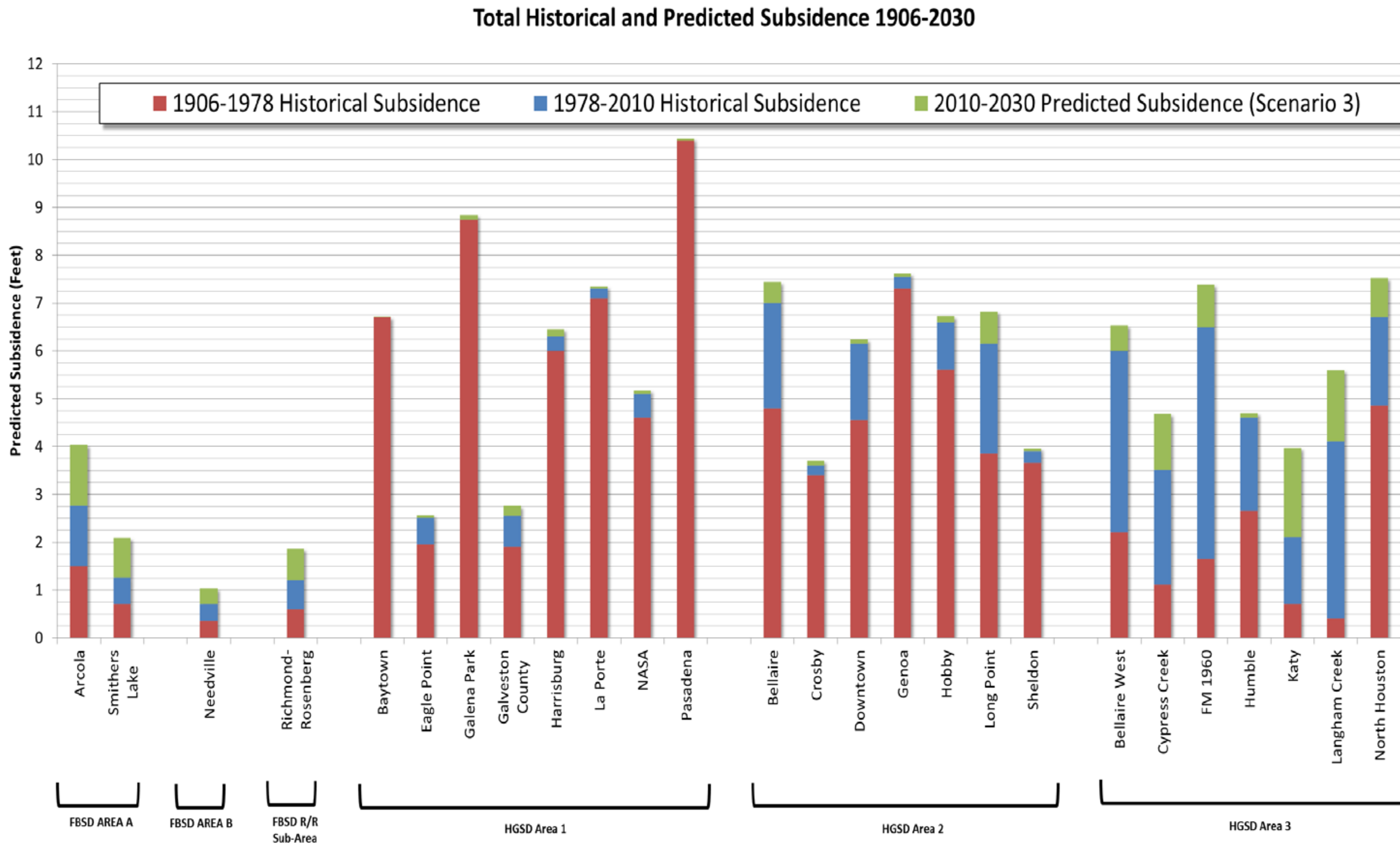
Predicted Subsidence 2010 - 2050
Scenario 2
Scenario 3
Scenario 4
Predicted Subsidence (Feet)
3.00
2.00
1.00
0.00
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3

Historical Measured Subsidence

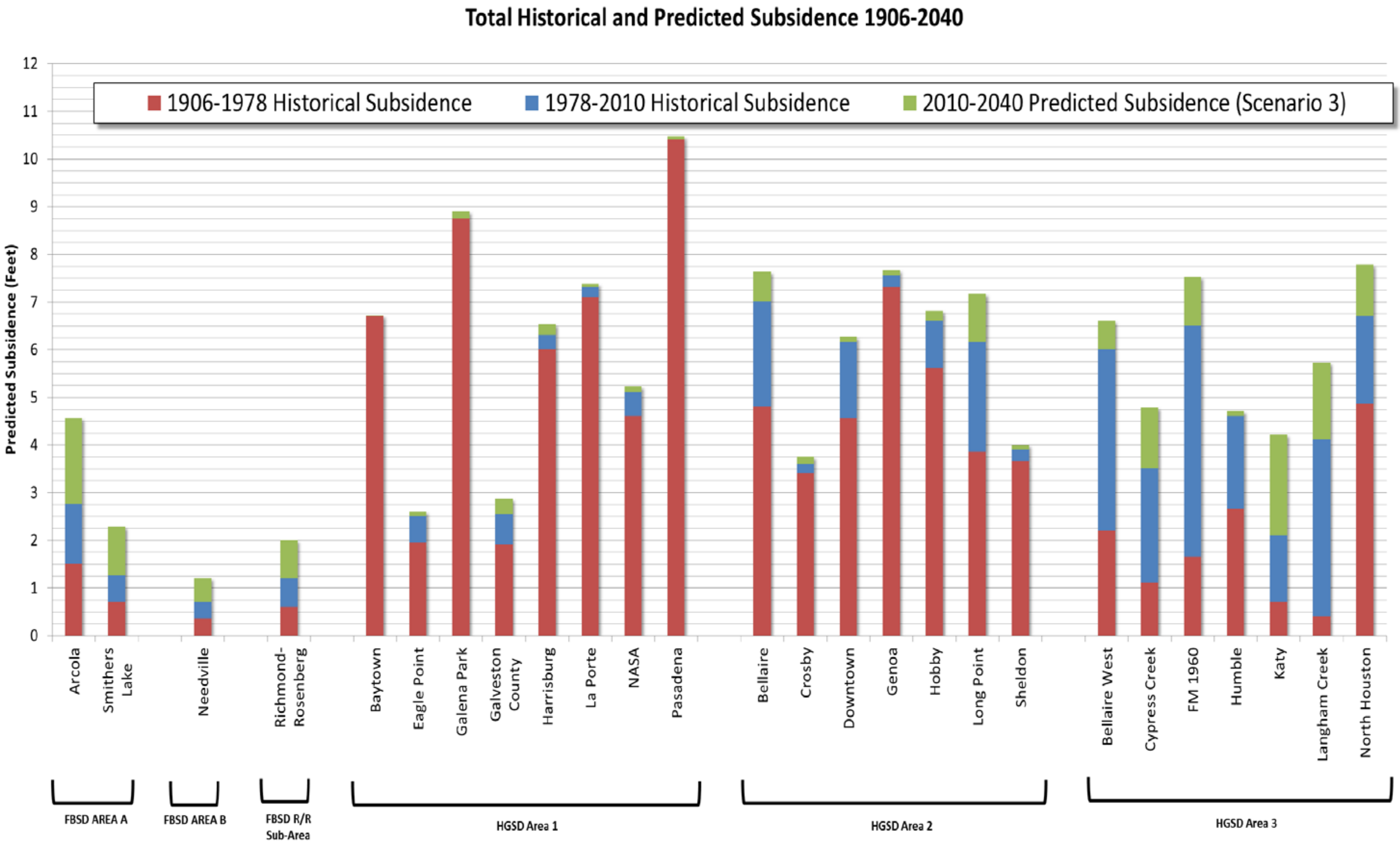
Measured Historical Subsidence 1906 - 2010

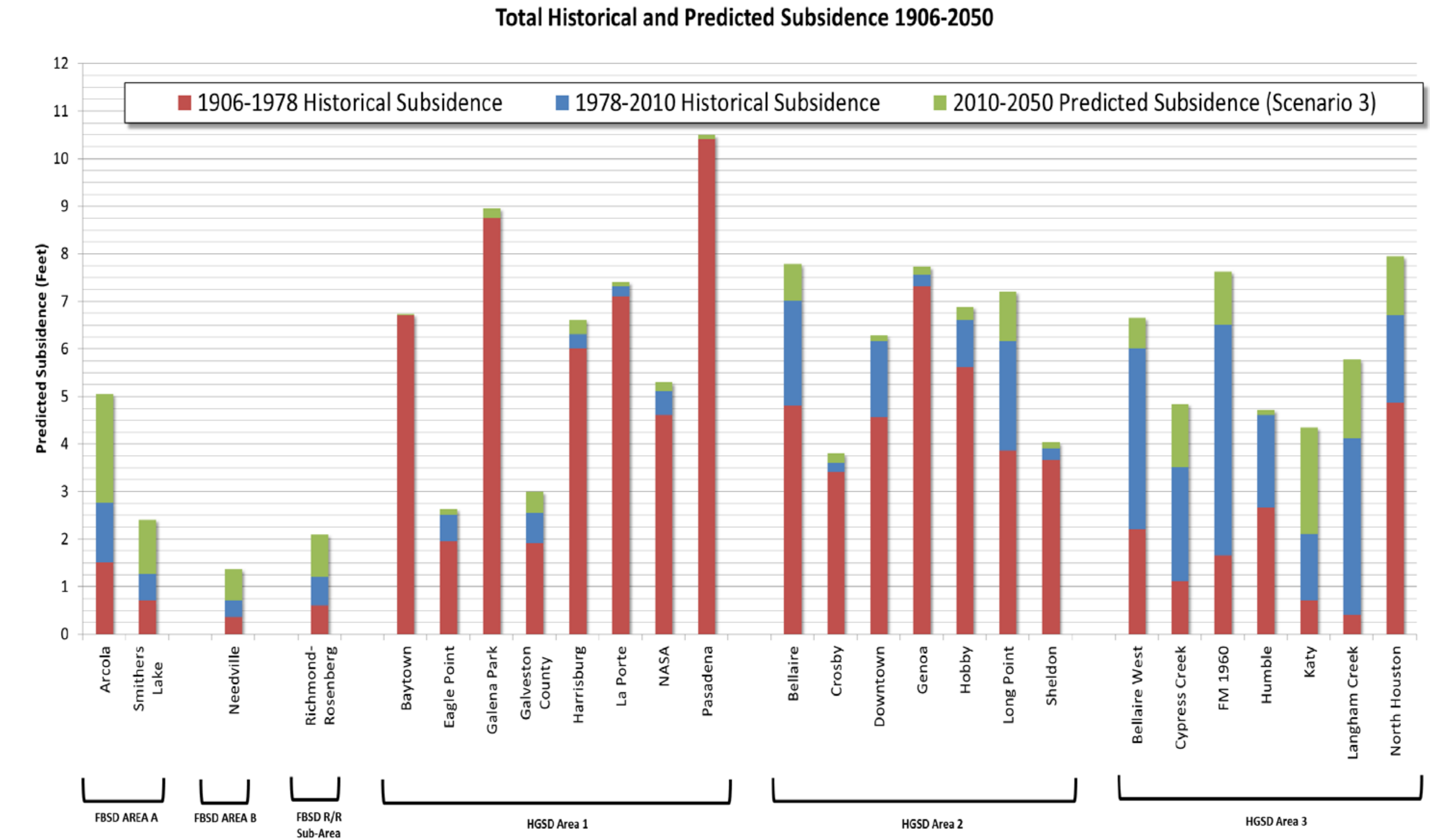



Total Historical and Predicted Subsidence 1906-2020
1906-1978 Historical Subsidence
1978-2010 Historical Subsidence
2010-2020 Predicted Subsidence (Scenario 3)
Predicted Subsidence (Feet)
0
1
2
3
4
5
6
7
8
9
10
11
12
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3



Total Historical and Predicted Subsidence 1906-2030
1906-1978 Historical Subsidence
1978-2010 Historical Subsidence
2010-2030 Predicted Subsidence (Scenario 3)
Predicted Subsidence (Feet)
0
1
2
3
4
5
6
7
8
9
10
11
12
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3


Total Historical and Predicted Subsidence 1906-2040
1906-1978 Historical Subsidence
1978-2010 Historical Subsidence
2010-2040 Predicted Subsidence (Scenario 3)
Predicted Subsidence (Feet)
0
1
2
3
4
5
6
7
8
9
10
11
12
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3



Total Historical and Predicted Subsidence 1906-2050
1906-1978 Historical Subsidence
1978-2010 Historical Subsidence
2010-2050 Predicted Subsidence (Scenario 3)
Predicted Subsidence (Feet)
0
1
2
3
4
5
6
7
8
9
10
11
12
Arcola
Smithers Lake
Needville
Richmond-Rosenberg
Baytown
Eagle Point
Galena Park
Galveston County
Harrisburg
La Porte
NASA
Pasadena
Bellaire
Crosby
Downtown
Genoa
Hobby
Long Point
Sheldon
Bellaire West
Cypress Creek
FM 1960
Humble
Katy
Langham Creek
North Houston
FBSD AREA A
FBSD AREA B
FBSD R/R Sub-Area
HGSD Area 1
HGSD Area 2
HGSD Area 3

Total Water Demand

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2010	2011	2012	2013	2014	2015
HGSD AREA_1	84,854,777	87,675,720	90,496,663	93,317,606	96,138,549	98,959,491
HGSD AREA_2	206,862,784	210,468,977	214,075,171	217,681,364	221,287,558	224,893,751
HGSD AREA_3	325,665,928	335,627,326	345,588,724	355,550,122	365,511,520	375,472,918
FBSD AREA_A	88,800,450	93,051,846	97,303,243	101,554,640	105,806,036	110,057,433
FBSD AREA_B	11,330,517	11,717,908	12,105,298	12,492,688	12,880,079	13,267,469
FBSD RR SUBAREA	9,024,369	9,539,573	10,054,776	10,569,980	11,085,184	11,600,388
LSGCD (MONT. CO.)	81,909,048	84,706,628	87,504,207	90,301,787	93,099,367	95,896,946
BRAZORIA CO.	37,534,833	38,432,275	39,329,716	40,227,158	41,124,600	42,022,042

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2016	2017	2018	2019	2020	2021
HGSD AREA_1	101,780,434	104,601,377	107,422,320	110,243,263	113,064,205	114,420,899
HGSD AREA_2	228,499,945	232,106,139	235,712,332	239,318,526	242,924,719	245,531,775
HGSD AREA_3	385,434,316	395,395,714	405,357,112	415,318,510	425,279,908	429,424,985
FBSD AREA_A	114,308,830	118,560,226	122,811,623	127,063,019	131,314,416	134,091,810
FBSD AREA_B	13,654,859	14,042,249	14,429,640	14,817,030	15,204,420	15,696,952
FBSD RR SUBAREA	12,115,592	12,630,796	13,146,000	13,661,204	14,176,408	14,387,346
LSGCD (MONT. CO.)	98,694,526	101,492,105	104,289,685	107,087,265	109,884,844	112,688,857
BRAZORIA CO.	42,919,483	43,816,925	44,714,367	45,611,809	46,509,250	47,242,081

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2022	2023	2024	2025	2026	2027
HGSD AREA_1	115,777,593	117,134,287	118,490,982	119,847,676	121,204,370	122,561,064
HGSD AREA_2	248,138,831	250,745,886	253,352,942	255,959,998	258,567,054	261,174,109
HGSD AREA_3	433,570,062	437,715,139	441,860,216	446,005,293	450,150,370	454,295,446
FBSD AREA_A	136,869,203	139,646,596	142,423,990	145,201,383	147,978,776	150,756,170
FBSD AREA_B	16,189,484	16,682,016	17,174,547	17,667,079	18,159,611	18,652,143
FBSD RR SUBAREA	14,598,284	14,809,222	15,020,160	15,231,098	15,442,036	15,652,975
LSGCD (MONT. CO.)	115,492,870	118,296,883	121,100,896	123,904,909	126,708,923	129,512,936
BRAZORIA CO.	47,974,912	48,707,743	49,440,574	50,173,404	50,906,235	51,639,066

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2028	2029	2030	2031	2032	2033
HGSD AREA_1	123,917,758	125,274,452	126,631,146	127,839,437	129,047,727	130,256,018
HGSD AREA_2	263,781,165	266,388,221	268,995,276	271,464,981	273,934,686	276,404,391
HGSD AREA_3	458,440,523	462,585,600	466,730,677	470,349,029	473,967,380	477,585,732
FBSD AREA_A	153,533,563	156,310,956	159,088,350	161,008,917	162,929,484	164,850,051
FBSD AREA_B	19,144,674	19,637,206	20,129,738	20,679,683	21,229,628	21,779,573
FBSD RR SUBAREA	15,863,913	16,074,851	16,285,789	16,463,399	16,641,009	16,818,620
LSGCD (MONT. CO.)	132,316,949	135,120,962	137,924,975	141,072,973	144,220,972	147,368,970
BRAZORIA CO.	52,371,897	53,104,728	53,837,559	54,557,823	55,278,087	55,998,351

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2034	2035	2036	2037	2038	2039
HGSD AREA_1	131,464,308	132,672,599	133,880,890	135,089,180	136,297,471	137,505,761
HGSD AREA_2	278,874,096	281,343,801	283,813,505	286,283,210	288,752,915	291,222,620
HGSD AREA_3	481,204,083	484,822,435	488,440,787	492,059,138	495,677,490	499,295,841
FBSD AREA_A	166,770,618	168,691,185	170,611,752	172,532,319	174,452,886	176,373,453
FBSD AREA_B	22,329,518	22,879,464	23,429,409	23,979,354	24,529,299	25,079,244
FBSD RR SUBAREA	16,996,230	17,173,841	17,351,451	17,529,061	17,706,672	17,884,282
LSGCD (MONT. CO.)	150,516,969	153,664,967	156,812,966	159,960,964	163,108,963	166,256,961
BRAZORIA CO.	56,718,615	57,438,880	58,159,144	58,879,408	59,599,672	60,319,937

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2040	2041	2042	2043	2044	2045
HGSD AREA_1	138,714,052	139,832,641	140,951,230	142,069,819	143,188,407	144,306,996
HGSD AREA_2	293,692,325	296,049,221	298,406,117	300,763,013	303,119,909	305,476,805
HGSD AREA_3	502,914,193	506,141,758	509,369,323	512,596,887	515,824,452	519,052,017
FBSD AREA_A	178,294,020	179,982,537	181,671,053	183,359,570	185,048,086	186,736,602
FBSD AREA_B	25,629,189	26,257,779	26,886,368	27,514,957	28,143,547	28,772,136
FBSD RR SUBAREA	18,061,893	18,267,677	18,473,462	18,679,246	18,885,031	19,090,815
LSGCD (MONT. CO.)	169,404,960	173,192,888	176,980,816	180,768,744	184,556,672	188,344,599
BRAZORIA CO.	61,040,201	61,781,626	62,523,050	63,264,475	64,005,900	64,747,325

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2046	2047	2048	2049	2050	2051
HGSD AREA_1	145,425,585	146,544,174	147,662,763	148,781,352	149,899,941	150,622,910
HGSD AREA_2	307,833,701	310,190,598	312,547,494	314,904,390	317,261,286	319,134,156
HGSD AREA_3	522,279,582	525,507,146	528,734,711	531,962,276	535,189,841	537,290,347
FBSD AREA_A	188,425,119	190,113,635	191,802,152	193,490,668	195,179,185	196,584,872
FBSD AREA_B	29,400,725	30,029,315	30,657,904	31,286,493	31,915,083	32,697,782
FBSD RR SUBAREA	19,296,600	19,502,384	19,708,169	19,913,953	20,119,738	20,351,630
LSGCD (MONT. CO.)	192,132,527	195,920,455	199,708,383	203,496,311	207,284,239	212,017,675
BRAZORIA CO.	65,488,750	66,230,175	66,971,599	67,713,024	68,454,449	69,249,546

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2052	2053	2054	2055	2056	2057
HGSD AREA_1	151,345,880	152,068,850	152,791,820	153,514,789	154,237,759	154,960,729
HGSD AREA_2	321,007,026	322,879,896	324,752,766	326,625,636	328,498,506	330,371,376
HGSD AREA_3	539,390,854	541,491,360	543,591,867	545,692,373	547,792,880	549,893,386
FBSD AREA_A	197,990,559	199,396,246	200,801,933	202,207,620	203,613,307	205,018,994
FBSD AREA_B	33,480,482	34,263,182	35,045,882	35,828,582	36,611,281	37,393,981
FBSD RR SUBAREA	20,583,522	20,815,414	21,047,307	21,279,199	21,511,091	21,742,983
LSGCD (MONT. CO.)	216,751,110	221,484,546	226,217,982	230,951,417	235,684,853	240,418,289
BRAZORIA CO.	70,044,644	70,839,741	71,634,838	72,429,936	73,225,033	74,020,130

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2058	2059	2060	2061	2062	2063
HGSD AREA_1	155,683,698	156,406,668	157,129,638	157,841,198	158,552,759	159,264,319
HGSD AREA_2	332,244,245	334,117,115	335,989,985	337,942,589	339,895,192	341,847,796
HGSD AREA_3	551,993,892	554,094,399	556,194,905	558,229,198	560,263,490	562,297,782
FBSD AREA_A	206,424,682	207,830,369	209,236,056	210,363,134	211,490,212	212,617,289
FBSD AREA_B	38,176,681	38,959,381	39,742,080	40,781,570	41,821,059	42,860,548
FBSD RR SUBAREA	21,974,875	22,206,767	22,438,660	22,713,939	22,989,218	23,264,497
LSGCD (MONT. CO.)	245,151,724	249,885,160	254,618,596	260,526,844	266,435,092	272,343,340
BRAZORIA CO.	74,815,227	75,610,325	76,405,422	77,278,439	78,151,455	79,024,472

REGULATORY AREA	TOTAL DEMAND (GAL/DAY)					
	2064	2065	2066	2067	2068	2069
HGSD AREA_1	159,975,880	160,687,440	161,399,001	162,110,561	162,822,122	163,533,682
HGSD AREA_2	343,800,399	345,753,003	347,705,606	349,658,210	351,610,813	353,563,417
HGSD AREA_3	564,332,075	566,366,367	568,400,660	570,434,952	572,469,244	574,503,537
FBSD AREA_A	213,744,367	214,871,445	215,998,523	217,125,601	218,252,679	219,379,757
FBSD AREA_B	43,900,038	44,939,527	45,979,016	47,018,506	48,057,995	49,097,484
FBSD RR SUBAREA	23,539,776	23,815,055	24,090,334	24,365,613	24,640,892	24,916,171
LSGCD (MONT. CO.)	278,251,589	284,159,837	290,068,085	295,976,333	301,884,581	307,792,829
BRAZORIA CO.	79,897,489	80,770,505	81,643,522	82,516,539	83,389,555	84,262,572

REGULATORY AREA	GAL/DAY
	2070
HGSD AREA_1	164,245,242
HGSD AREA_2	355,516,020
HGSD AREA_3	576,537,829
FBSD AREA_A	220,506,835
FBSD AREA_B	50,136,974
FBSD RR SUBAREA	25,191,450
LSGCD (MONT. CO.)	313,701,078
BRAZORIA CO.	85,135,589

VB.NET Code

```
Module Module1
    Public cnn As System.Data.SqlClient.SqlConnection = New System.Data.SqlClient.SqlConnection
    Public cnn2 As System.Data.SqlClient.SqlConnection = New System.Data.SqlClient.SqlConnection
    Public cnn3 As System.Data.SqlClient.SqlConnection = New System.Data.SqlClient.SqlConnection
    Public cnn4 As System.Data.SqlClient.SqlConnection = New System.Data.SqlClient.SqlConnection
    Dim cmd1 As System.Data.SqlClient.SqlCommand = New System.Data.SqlClient.SqlCommand
    Dim cmd2 As System.Data.SqlClient.SqlCommand = New System.Data.SqlClient.SqlCommand
    Dim cmd3 As System.Data.SqlClient.SqlCommand = New System.Data.SqlClient.SqlCommand
    Dim cmd4 As System.Data.SqlClient.SqlCommand = New System.Data.SqlClient.SqlCommand
    Dim dr As System.Data.SqlClient.SqlDataReader
    Dim dr2 As System.Data.SqlClient.SqlDataReader
    Dim dr3 As System.Data.SqlClient.SqlDataReader
    Dim dr4 As System.Data.SqlClient.SqlDataReader
    Dim tran As System.Data.SqlClient.SqlTransaction
    Dim cnnString As String = ""
    Public Sub RunProcedures()
        InterpGAM_GRID()
        UPDATE_SCENARIO_3B_GW_DEMAND()
    End Sub
    Friend Sub InterpGAM_GRID()
        Dim strFldMin As String = ""
        Dim strFldMax As String = ""
        Dim strFldInterp As String = ""
        Dim i As Integer = 0
        Dim j As Integer = 0
        Dim valMin As Double = 0
        Dim valMax As Double = 0
        Dim valInterp As Double = 0
        Dim intCELL_ID As Long = 0

        openConnection_SDE(cnn)
        cmd1.CommandType = CommandType.Text
        cmd1.Connection = cnn

        openConnection_SDE(cnn2)
        cmd2.CommandType = CommandType.StoredProcedure
        cmd2.Connection = cnn2
        cmd2.CommandText = "updateGAMGRID_1"
```

```
        'cmd2.ExecuteNonQuery() 'Do not need to do this the way Scenario 2 is set up.

        cmd2.CommandType = CommandType.Text

        For i = 1 To 6
            For j = 1 To 9
                strFldMin = "D" & i * 10
                strFldMax = "D" & (i + 1) * 10
                strFldInterp = "D" & i * 10 + j

                cmd2.CommandText = "UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND SET " & strFldInterp & " = 0 WHERE " &
                strFldMin & " = 0 AND " & _
                strFldMax & " = 0"
                cmd2.ExecuteNonQuery()

                cmd2.CommandText = "UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND SET " & strFldInterp & " = " &
                strFldMin & " WHERE (" & _
                strFldMin & " <> 0 OR " & strFldMax & " <> 0) AND " & strFldMin & " = " & strFldMax
                cmd2.ExecuteNonQuery()

                cmd2.CommandText = "UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND SET " & strFldInterp & " = " & _
                strFldMin & " + " & CDbl(j) & "/10.0 * (" & strFldMax & " - " & strFldMin & ")" & _
                " WHERE (" & strFldMin & " <> 0 OR " & strFldMax & " <> 0) AND " & strFldMin & " <> " & strFldMax
                cmd2.ExecuteNonQuery()
            Next
        Next

        cnn2.Close()

        MsgBox("COMPLETED!")

    End Sub
    Friend Sub UPDATE_SCENARIO_3B_GW_DEMAND()
        Dim strFldToSet As String = ""
        Dim intYear As Integer = 0
        Dim i As Integer = 0

        openConnection_SDE(cnn2)
        cmd2.Connection = cnn2
        cmd2.CommandType = CommandType.Text
```

```
        For i = 10 To 70
            strFldToSet = "PCT_GW_" & i
            intYear = i + 2000

            'Initialize the Scenario 3B GRID demands to the total demand for each year for final table
            cmd2.CommandText = "UPDATE A SET A.D" & i & " = B.D" & i & _
                " FROM GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_3B AS A INNER JOIN GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
                AS B" & _
                " ON A.CELL_ID = B.CELL_ID"
            cmd2.ExecuteNonQuery()

            'Set the percentage groundwater from the conversion schedule; this is tied to WATER_AUTHORITY_SW
            cmd2.CommandText = "UPDATE A SET A." & strFldToSet & " = B.PCT_GW" & _
                " FROM GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_3B AS A INNER JOIN v_Conversion_Schedule AS B" & _
                " ON A.WATER_AUTHORITY_SW = B.WATER_AUTHORITY_SW WHERE B.YEAR = " & intYear
            cmd2.ExecuteNonQuery()

            'If the percentage groundwater is NULL, set it to 1
            cmd2.CommandText = "UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_3B SET " & strFldToSet & " = 1 WHERE " &
            strFldToSet & " IS NULL"
            cmd2.ExecuteNonQuery()

            'If the percentage groundwater is less than 0, set it to 0 (this should be very uncommon)
            cmd2.CommandText = "UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_3B SET " & strFldToSet & " = 0 WHERE " &
            strFldToSet & " < 0"
            cmd2.ExecuteNonQuery()

            'Set demand = (total demand) * (percentage groundwater)
            cmd2.CommandText = "UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_3B SET D" & i & " = D" & i & " * PCT_GW_" & i
            cmd2.ExecuteNonQuery()

            'Add baseline non-municipal demand from Harris and Galveston County
            cmd2.CommandText = "UPDATE A SET A.D" & i & " = A.D" & i & " + (B.ACTUAL_2010 / 365) FROM
            GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_3B AS A INNER JOIN HG_INDUSTRIAL AS B ON A.CELL_ID = B.CELL_ID WHERE
            A.COUNTYNAME IN ('HARRIS', 'GALVESTON') AND B.ACTUAL_2010 IS NOT NULL"
            cmd2.ExecuteNonQuery()

            'Add baseline non-municipal demand from Brazoria County
            cmd2.CommandText = "UPDATE A SET A.D" & i & " = A.D" & i & " + (-B.D" & i & "*7.48) FROM
```

```
            GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_3B AS A INNER JOIN BRAZORIA_NON_MUNI AS B ON A.CELL_ID = B.CELL_ID WHERE
            A.COUNTYNAME = 'BRAZORIA'"
            cmd2.ExecuteNonQuery()

        Next

        cnn2.Close()

        MsgBox("Done!")

    End Sub

    Friend Sub UPDATE_SCENARIO_4_GW_DEMAND()
        Dim strFldToSet As String = ""
        Dim intYear As Integer = 0
        Dim i As Integer = 0

        openConnection_SDE(cnn2)
        cmd2.Connection = cnn2
        cmd2.CommandType = CommandType.Text

        For i = 10 To 70
            strFldToSet = "PCT_GW_" & i
            intYear = i + 2000

            'Initialize the Scenario 2 GRID demands to the total demand for each year for final table
            cmd2.CommandText = "UPDATE A SET A.D" & i & " = B.D" & i & _
                " FROM GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_4 AS A INNER JOIN GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
                AS B" & _
                " ON A.CELL_ID = B.CELL_ID"
            cmd2.ExecuteNonQuery()

            'Set the percentage groundwater from the conversion schedule; this is tied to WATER_AUTHORITY_SW
            cmd2.CommandText = "UPDATE A SET A." & strFldToSet & " = B.PCT_GW" & _
                " FROM GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_4 AS A INNER JOIN v_Conversion_Schedule AS B" & _
                " ON A.WATER_AUTHORITY_SW = B.WATER_AUTHORITY_SW WHERE B.YEAR = " & intYear
            cmd2.ExecuteNonQuery()

            'If the percentage groundwater is NULL, set it to 1
            cmd2.CommandText = "UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_4 SET " & strFldToSet & " = 1 WHERE " &
```

```
            strFldToSet & " IS NULL"
            cmd2.ExecuteNonQuery()

            'If the percentage groundwater is less than 0, set it to 0 (this should be very uncommon)
            cmd2.CommandText = "UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_4 SET " & strFldToSet & " = 0 WHERE " &
            strFldToSet & " < 0"
            cmd2.ExecuteNonQuery()

            'Set demand = (total demand) * (percentage groundwater)
            cmd2.CommandText = "UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_4 SET D" & i & " = D" & i & " * PCT_GW_" & i
            cmd2.ExecuteNonQuery()

            'Add baseline non-municipal demand from Harris and Galveston County
            cmd2.CommandText = "UPDATE A SET A.D" & i & " = A.D" & i & " + (B.ACTUAL_2010 / 365) FROM
            GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_4 AS A INNER JOIN HG_INDUSTRIAL AS B ON A.CELL_ID = B.CELL_ID WHERE
            A.COUNTYNAME IN ('HARRIS', 'GALVESTON') AND B.ACTUAL_2010 IS NOT NULL"
            cmd2.ExecuteNonQuery()

            'Add baseline non-municipal demand from Brazoria County
            cmd2.CommandText = "UPDATE A SET A.D" & i & " = A.D" & i & " + (-B.D" & i & "*7.48) FROM
            GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_4 AS A INNER JOIN BRAZORIA_NON_MUNI AS B ON A.CELL_ID = B.CELL_ID WHERE
            A.COUNTYNAME = 'BRAZORIA'"
            cmd2.ExecuteNonQuery()

        Next

        cnn2.Close()

        MsgBox("Done!")

    End Sub
End Module
```

SQL Server Create Table Scripts

```
USE [S2_V3]
GO
/****** Object:  Table [dbo].[CONVERSION_SCHEDULE]    Script Date: 12/11/2012 10:24:24 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[CONVERSION_SCHEDULE](
    [CONVERSION_ENTITY_WATER_AUTHORITY_SW] [nvarchar](255) NULL,
    [YEAR] [float] NULL,
    [PCT_GW] [float] NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[CONVERSION_ENTITY]    Script Date: 12/11/2012 10:24:24 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[CONVERSION_ENTITY](
    [WATER_AUTHORITY_SW] [nvarchar](255) NULL,
    [REGULATORY_CONVERSION] [nvarchar](255) NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[TOTAL_DEMAND_BY_A1NAME_REGAREA]    Script Date: 12/11/2012
10:24:25 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[TOTAL_DEMAND_BY_A1NAME_REGAREA](
    [OBJECTID] [int] NOT NULL,
    [A1NAME] [nvarchar](100) NOT NULL,
    [REG_AREA] [nvarchar](50) NULL,
    [WELL_COUNT] [int] NULL,
    [PWSID_SUPPLYING_WATER] [nvarchar](15) NULL,
    [PWSID_WATER_TYPE_SUPPLIED] [nvarchar](10) NULL,
    [PWS_ID] [nvarchar](25) NULL,
    [PWS_STATUS] [nvarchar](255) NULL,
    [D10] [float] NULL,
    [D20] [float] NULL,
    [D30] [float] NULL,
    [D40] [float] NULL,
    [D50] [float] NULL,
    [D60] [float] NULL,
    [D70] [float] NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[TOTAL_DEMAND_BY_A1NAME]    Script Date: 12/11/2012 10:24:25 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[TOTAL_DEMAND_BY_A1NAME](
    [OBJECTID] [int] NOT NULL,
```

```
    [A1NAME] [nvarchar](100) NOT NULL,
    [WELL_COUNT] [int] NULL,
    [PWSID_SUPPLYING_WATER] [nvarchar](15) NULL,
    [PWSID_WATER_TYPE_SUPPLIED] [nvarchar](10) NULL,
    [PWS_ID] [nvarchar](25) NULL,
    [PWS_STATUS] [nvarchar](255) NULL,
    [D10] [numeric](38, 8) NULL,
    [D20] [numeric](38, 8) NULL,
    [D30] [numeric](38, 8) NULL,
    [D40] [numeric](38, 8) NULL,
    [D50] [numeric](38, 8) NULL,
    [D60] [numeric](38, 8) NULL,
    [D70] [numeric](38, 8) NULL,
    [NUM_WELLS_SUPPLYING_WATER] [int] NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND]    Script Date: 
12/11/2012 10:24:24 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND](
    [OBJECTID] [int] NOT NULL,
    [Join_Count] [int] NULL,
    [TARGET_FID] [int] NULL,
    [pwsid] [nvarchar](15) NULL,
    [pwsname] [nvarchar](255) NULL,
    [PWS_COUNTY] [nvarchar](25) NULL,
    [PWS_SYSTEM_TYPE] [nvarchar](25) NULL,
    [PWS_OWNER_TYPE] [nvarchar](25) NULL,
    [ACTIVITY_STATUS] [nvarchar](15) NULL,
    [ASSOCIATED_SYSTEM] [smallint] NULL,
    [DEMAND_2010_GPD] [numeric](38, 8) NULL,
    [SOLD_DEMAND_2010_GPD] [numeric](38, 8) NULL,
    [sourceid] [nvarchar](15) NULL,
    [epid] [nvarchar](15) NULL,
    [type] [nvarchar](2) NULL,
    [waterbody] [nvarchar](35) NULL,
    [segment] [nvarchar](4) NULL,
    [constr] [nvarchar](1) NULL,
    [confine] [nvarchar](1) NULL,
    [opstat] [nvarchar](1) NULL,
    [gpm] [int] NULL,
    [scrnbot] [numeric](38, 8) NULL,
    [scrntop] [numeric](38, 8) NULL,
    [drill_date] [nvarchar](8) NULL,
    [latdd] [numeric](38, 8) NULL,
    [longdd] [numeric](38, 8) NULL,
    [hdatum] [nvarchar](2) NULL,
    [alluvial] [nvarchar](1) NULL,
    [compliant] [nvarchar](1) NULL,
    [HGSD_Regulatory_Area] [smallint] NULL,
    [Join_Count_1] [int] NULL,
```

```
    [TARGET_FID_1] [int] NULL,
    [Join_Count_12] [int] NULL,
    [TARGET_FID_12] [int] NULL,
    [OBJECTID_1] [int] NULL,
    [ROW] [smallint] NULL,
    [COL] [smallint] NULL,
    [CELL_ID] [int] NULL,
    [PWS_ID] [nvarchar](25) NULL,
    [A1NAME] [nvarchar](100) NULL,
    [REG_AREA_NAME] [nvarchar](50) NULL,
    [DEMAND_2020_GPD] [numeric](38, 8) NULL,
    [DEMAND_2030_GPD] [numeric](38, 8) NULL,
    [DEMAND_2040_GPD] [numeric](38, 8) NULL,
    [DEMAND_2050_GPD] [numeric](38, 8) NULL,
    [DEMAND_2060_GPD] [numeric](38, 8) NULL,
    [DEMAND_2070_GPD] [numeric](38, 8) NULL,
    [Shape] [int] NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[HG_INDUSTRIAL]    Script Date: 12/11/2012 10:24:24 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[HG_INDUSTRIAL](
    [OBJECTID_1] [int] NOT NULL,
    [OBJECTID] [int] NULL,
    [ROW] [smallint] NULL,
    [COL] [smallint] NULL,
    [CELL_ID] [int] NULL,
    [CountyName] [nvarchar](50) NULL,
    [CountyNum] [smallint] NULL,
    [GCD_Name] [nvarchar](100) NULL,
    [GCD_Num] [int] NULL,
    [BasinName] [nvarchar](50) NULL,
    [BasinNum] [smallint] NULL,
    [IBND1] [smallint] NULL,
    [IBND2] [smallint] NULL,
    [IBND3] [smallint] NULL,
    [IBND4] [smallint] NULL,
    [CentroidX] [numeric](38, 8) NULL,
    [CentroidY] [numeric](38, 8) NULL,
    [uGCD] [nvarchar](69) NULL,
    [GMA] [smallint] NULL,
    [PGMA] [nvarchar](40) NULL,
    [RA_SLD] [nvarchar](100) NULL,
    [REG_NAME] [nvarchar](25) NULL,
    [LETTER] [nvarchar](1) NULL,
    [REG_NUM] [smallint] NULL,
    [CntyBsnReg] [int] NULL,
    [VistaCode] [smallint] NULL,
    [GeoArea] [smallint] NULL,
    [Shape_Leng] [numeric](38, 8) NULL,
    [Shape] [int] NULL,
```

```
    [INDUS_WELL_COUNT] [numeric](38, 8) NULL,
    [INC_D20] [numeric](38, 8) NULL,
    [INC_D30] [numeric](38, 8) NULL,
    [INC_D40] [numeric](38, 8) NULL,
    [INC_D50] [numeric](38, 8) NULL,
    [INC_D60] [numeric](38, 8) NULL,
    [INC_D70] [numeric](38, 8) NULL,
    [ACTUAL_2010] [numeric](38, 8) NULL
) ON [PRIMARY]
GO
/****** Object:  View [dbo].[v_Conversion_Schedule]    Script Date: 12/11/2012 10:24:25 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE VIEW [dbo].[v_Conversion_Schedule]
AS
SELECT     TOP (100) PERCENT A.WATER_AUTHORITY_SW, B.CONVERSION_ENTITY_WATER_AUTHORITY_SW, B.
YEAR, B.PCT_GW
FROM         dbo.CONVERSION_ENTITY AS A LEFT OUTER JOIN
                      dbo.CONVERSION_SCHEDULE AS B ON A.REGULATORY_CONVERSION = B.
                      CONVERSION_ENTITY_WATER_AUTHORITY_SW
ORDER BY A.WATER_AUTHORITY_SW, B.YEAR
GO
EXEC sys.sp_addextendedproperty @name=N'MS_DiagramPane1', @value=N
'[0E232FF0-B466-11cf-A24F-00AA00A3EFFF, 1.00]
Begin DesignProperties =
   Begin PaneConfigurations =
      Begin PaneConfiguration = 0
         NumPanes = 4
         Configuration = "(H (1[40] 4[20] 2[20] 3) )"
      End
      Begin PaneConfiguration = 1
         NumPanes = 3
         Configuration = "(H (1 [50] 4 [25] 3))"
      End
      Begin PaneConfiguration = 2
         NumPanes = 3
         Configuration = "(H (1 [50] 2 [25] 3))"
      End
      Begin PaneConfiguration = 3
         NumPanes = 3
         Configuration = "(H (4 [30] 2 [40] 3))"
      End
      Begin PaneConfiguration = 4
         NumPanes = 2
         Configuration = "(H (1 [56] 3))"
      End
      Begin PaneConfiguration = 5
         NumPanes = 2
         Configuration = "(H (2 [66] 3))"
      End
      Begin PaneConfiguration = 6
         NumPanes = 2
```

```
      Configuration = "(H (4 [50] 3))"
   End
   Begin PaneConfiguration = 7
      NumPanes = 1
      Configuration = "(V (3))"
   End
   Begin PaneConfiguration = 8
      NumPanes = 3
      Configuration = "(H (1[56] 4[18] 2) )"
   End
   Begin PaneConfiguration = 9
      NumPanes = 2
      Configuration = "(H (1 [75] 4))"
   End
   Begin PaneConfiguration = 10
      NumPanes = 2
      Configuration = "(H (1[66] 2) )"
   End
   Begin PaneConfiguration = 11
      NumPanes = 2
      Configuration = "(H (4 [60] 2))"
   End
   Begin PaneConfiguration = 12
      NumPanes = 1
      Configuration = "(H (1) )"
   End
   Begin PaneConfiguration = 13
      NumPanes = 1
      Configuration = "(V (4))"
   End
   Begin PaneConfiguration = 14
      NumPanes = 1
      Configuration = "(V (2))"
   End
   ActivePaneConfig = 0
End
Begin DiagramPane =
   Begin Origin =
      Top = 0
      Left = 0
   End
   Begin Tables =
      Begin Table = "A"
         Begin Extent =
            Top = 6
            Left = 38
            Bottom = 95
            Right = 265
         End
         DisplayFlags = 280
         TopColumn = 0
      End
      Begin Table = "B"
         Begin Extent =
```

```
               Top = 6
               Left = 303
               Bottom = 110
               Right = 627
            End
            DisplayFlags = 280
            TopColumn = 0
         End
      End
   End
   Begin SQLPane =
   End
   Begin DataPane =
      Begin ParameterDefaults = ""
      End
   End
   Begin CriteriaPane =
      Begin ColumnWidths = 11
         Column = 1440
         Alias = 900
         Table = 1170
         Output = 720
         Append = 1400
         NewValue = 1170
         SortType = 1350
         SortOrder = 1410
         GroupBy = 1350
         Filter = 1350
         Or = 1350
         Or = 1350
         Or = 1350
      End
   End
End
' , @level0type=N'SCHEMA',@level0name=N'dbo', @level1type=N'VIEW',@level1name=N
'v_Conversion_Schedule'
GO
EXEC sys.sp_addextendedproperty @name=N'MS_DiagramPaneCount', @value=1 , @level0type=N'SCHEMA',@
level0name=N'dbo', @level1type=N'VIEW',@level1name=N'v_Conversion_Schedule'
GO
/****** Object:  Table [dbo].[GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND]    Script Date:
12/11/2012 10:24:24 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND](
    [OBJECTID_1] [int] NOT NULL,
    [Join_Count] [int] NULL,
    [TARGET_FID] [int] NULL,
    [Join_Count_1] [int] NULL,
    [TARGET_FID_1] [int] NULL,
    [OBJECTID] [int] NULL,
    [ROW] [smallint] NULL,
```

```
    [COL] [smallint] NULL,
    [CELL_ID] [int] NULL,
    [CountyName] [nvarchar](50) NULL,
    [CountyNum] [smallint] NULL,
    [GCD_Name] [nvarchar](100) NULL,
    [GCD_Num] [int] NULL,
    [BasinName] [nvarchar](50) NULL,
    [BasinNum] [smallint] NULL,
    [IBND1] [smallint] NULL,
    [IBND2] [smallint] NULL,
    [IBND3] [smallint] NULL,
    [IBND4] [smallint] NULL,
    [CentroidX] [numeric](38, 8) NULL,
    [CentroidY] [numeric](38, 8) NULL,
    [uGCD] [nvarchar](69) NULL,
    [GMA] [smallint] NULL,
    [PGMA] [nvarchar](40) NULL,
    [RA_SLD] [nvarchar](100) NULL,
    [REG_NAME] [nvarchar](25) NULL,
    [LETTER] [nvarchar](1) NULL,
    [REG_NUM] [smallint] NULL,
    [CntyBsnReg] [int] NULL,
    [VistaCode] [smallint] NULL,
    [AQ_Active1] [smallint] NULL,
    [AQ_Active2] [smallint] NULL,
    [AQ_Active3] [smallint] NULL,
    [AQ_Active4] [smallint] NULL,
    [GeoArea] [smallint] NULL,
    [Shape_Leng] [numeric](38, 8) NULL,
    [Map_Display_Value] [numeric](38, 8) NULL,
    [FID_TWDB_MUD_BOUNDARIES_CLIP] [int] NULL,
    [PWS_ID] [nvarchar](25) NULL,
    [A1NAME] [nvarchar](100) NULL,
    [REG_AREA_NAME] [nvarchar](50) NULL,
    [BLK9_ROW] [int] NULL,
    [BLK9_COL] [int] NULL,
    [WELL_CNT_2010] [int] NULL,
    [WELL_GPM_2010] [int] NULL,
    [D10] [numeric](38, 8) NULL,
    [D11] [numeric](38, 8) NULL,
    [D12] [numeric](38, 8) NULL,
    [D13] [numeric](38, 8) NULL,
    [D14] [numeric](38, 8) NULL,
    [D15] [numeric](38, 8) NULL,
    [D16] [numeric](38, 8) NULL,
    [D17] [numeric](38, 8) NULL,
    [D18] [numeric](38, 8) NULL,
    [D19] [numeric](38, 8) NULL,
    [D20] [numeric](38, 8) NULL,
    [D21] [numeric](38, 8) NULL,
    [D22] [numeric](38, 8) NULL,
    [D23] [numeric](38, 8) NULL,
    [D24] [numeric](38, 8) NULL,
    [D25] [numeric](38, 8) NULL,
```

```
    [D26] [numeric](38, 8) NULL,
    [D27] [numeric](38, 8) NULL,
    [D28] [numeric](38, 8) NULL,
    [D29] [numeric](38, 8) NULL,
    [D30] [numeric](38, 8) NULL,
    [D31] [numeric](38, 8) NULL,
    [D32] [numeric](38, 8) NULL,
    [D33] [numeric](38, 8) NULL,
    [D34] [numeric](38, 8) NULL,
    [D35] [numeric](38, 8) NULL,
    [D36] [numeric](38, 8) NULL,
    [D37] [numeric](38, 8) NULL,
    [D38] [numeric](38, 8) NULL,
    [D39] [numeric](38, 8) NULL,
    [D40] [numeric](38, 8) NULL,
    [D41] [numeric](38, 8) NULL,
    [D42] [numeric](38, 8) NULL,
    [D43] [numeric](38, 8) NULL,
    [D44] [numeric](38, 8) NULL,
    [D45] [numeric](38, 8) NULL,
    [D46] [numeric](38, 8) NULL,
    [D47] [numeric](38, 8) NULL,
    [D48] [numeric](38, 8) NULL,
    [D49] [numeric](38, 8) NULL,
    [D50] [numeric](38, 8) NULL,
    [D51] [numeric](38, 8) NULL,
    [D52] [numeric](38, 8) NULL,
    [D53] [numeric](38, 8) NULL,
    [D54] [numeric](38, 8) NULL,
    [D55] [numeric](38, 8) NULL,
    [D56] [numeric](38, 8) NULL,
    [D57] [numeric](38, 8) NULL,
    [D58] [numeric](38, 8) NULL,
    [D59] [numeric](38, 8) NULL,
    [D60] [numeric](38, 8) NULL,
    [D61] [numeric](38, 8) NULL,
    [D62] [numeric](38, 8) NULL,
    [D63] [numeric](38, 8) NULL,
    [D64] [numeric](38, 8) NULL,
    [D65] [numeric](38, 8) NULL,
    [D66] [numeric](38, 8) NULL,
    [D67] [numeric](38, 8) NULL,
    [D68] [numeric](38, 8) NULL,
    [D69] [numeric](38, 8) NULL,
    [D70] [numeric](38, 8) NULL,
    [WATER_AUTHORITY_SW] [nvarchar](50) NULL,
    [LSGCD_GT_100MGY] [smallint] NULL,
    [FRAC_OUTSIDE_MUD] [numeric](38, 8) NULL,
    [Shape] [int] NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_V2]    Script Date:
12/11/2012 10:24:24 ******/
SET ANSI_NULLS ON
```

```
GO
SET QUOTED_IDENTIFIER ON
GO
SET ANSI_PADDING ON
GO
CREATE TABLE [dbo].[GAM_GRID_MUD_REG_BOUNDARY_JOIN_SCENARIO_V2](
    [OBJECTID_1] [int] NOT NULL,
    [Join_Count] [int] NULL,
    [TARGET_FID] [int] NULL,
    [Join_Count_1] [int] NULL,
    [TARGET_FID_1] [int] NULL,
    [OBJECTID] [int] NULL,
    [ROW] [smallint] NULL,
    [COL] [smallint] NULL,
    [CELL_ID] [int] NULL,
    [CountyName] [nvarchar](50) NULL,
    [CountyNum] [smallint] NULL,
    [GCD_Name] [nvarchar](100) NULL,
    [GCD_Num] [int] NULL,
    [BasinName] [nvarchar](50) NULL,
    [BasinNum] [smallint] NULL,
    [IBND1] [smallint] NULL,
    [IBND2] [smallint] NULL,
    [IBND3] [smallint] NULL,
    [IBND4] [smallint] NULL,
    [CentroidX] [numeric](38, 8) NULL,
    [CentroidY] [numeric](38, 8) NULL,
    [uGCD] [nvarchar](69) NULL,
    [GMA] [smallint] NULL,
    [PGMA] [nvarchar](40) NULL,
    [RA_SLD] [nvarchar](100) NULL,
    [REG_NAME] [nvarchar](25) NULL,
    [LETTER] [nvarchar](1) NULL,
    [REG_NUM] [smallint] NULL,
    [CntyBsnReg] [int] NULL,
    [VistaCode] [smallint] NULL,
    [AQ_Active1] [smallint] NULL,
    [AQ_Active2] [smallint] NULL,
    [AQ_Active3] [smallint] NULL,
    [AQ_Active4] [smallint] NULL,
    [GeoArea] [smallint] NULL,
    [Shape_Leng] [numeric](38, 8) NULL,
    [Map_Display_Value] [numeric](38, 8) NULL,
    [FID_TWDB_MUD_BOUNDARIES_CLIP] [int] NULL,
    [PWS_ID] [nvarchar](25) NULL,
    [A1NAME] [nvarchar](100) NULL,
    [REG_AREA_NAME] [nvarchar](50) NULL,
    [BLK9_ROW] [int] NULL,
    [BLK9_COL] [int] NULL,
    [WELL_CNT_2010] [int] NULL,
    [WELL_GPM_2010] [int] NULL,
    [D10] [numeric](38, 8) NULL,
    [D11] [numeric](38, 8) NULL,
    [D12] [numeric](38, 8) NULL,
```

```
    [D13] [numeric](38, 8) NULL,
    [D14] [numeric](38, 8) NULL,
    [D15] [numeric](38, 8) NULL,
    [D16] [numeric](38, 8) NULL,
    [D17] [numeric](38, 8) NULL,
    [D18] [numeric](38, 8) NULL,
    [D19] [numeric](38, 8) NULL,
    [D20] [numeric](38, 8) NULL,
    [D21] [numeric](38, 8) NULL,
    [D22] [numeric](38, 8) NULL,
    [D23] [numeric](38, 8) NULL,
    [D24] [numeric](38, 8) NULL,
    [D25] [numeric](38, 8) NULL,
    [D26] [numeric](38, 8) NULL,
    [D27] [numeric](38, 8) NULL,
    [D28] [numeric](38, 8) NULL,
    [D29] [numeric](38, 8) NULL,
    [D30] [numeric](38, 8) NULL,
    [D31] [numeric](38, 8) NULL,
    [D32] [numeric](38, 8) NULL,
    [D33] [numeric](38, 8) NULL,
    [D34] [numeric](38, 8) NULL,
    [D35] [numeric](38, 8) NULL,
    [D36] [numeric](38, 8) NULL,
    [D37] [numeric](38, 8) NULL,
    [D38] [numeric](38, 8) NULL,
    [D39] [numeric](38, 8) NULL,
    [D40] [numeric](38, 8) NULL,
    [D41] [numeric](38, 8) NULL,
    [D42] [numeric](38, 8) NULL,
    [D43] [numeric](38, 8) NULL,
    [D44] [numeric](38, 8) NULL,
    [D45] [numeric](38, 8) NULL,
    [D46] [numeric](38, 8) NULL,
    [D47] [numeric](38, 8) NULL,
    [D48] [numeric](38, 8) NULL,
    [D49] [numeric](38, 8) NULL,
    [D50] [numeric](38, 8) NULL,
    [D51] [numeric](38, 8) NULL,
    [D52] [numeric](38, 8) NULL,
    [D53] [numeric](38, 8) NULL,
    [D54] [numeric](38, 8) NULL,
    [D55] [numeric](38, 8) NULL,
    [D56] [numeric](38, 8) NULL,
    [D57] [numeric](38, 8) NULL,
    [D58] [numeric](38, 8) NULL,
    [D59] [numeric](38, 8) NULL,
    [D60] [numeric](38, 8) NULL,
    [D61] [numeric](38, 8) NULL,
    [D62] [numeric](38, 8) NULL,
    [D63] [numeric](38, 8) NULL,
    [D64] [numeric](38, 8) NULL,
    [D65] [numeric](38, 8) NULL,
    [D66] [numeric](38, 8) NULL,
```

```
    [D67] [numeric](38, 8) NULL,
    [D68] [numeric](38, 8) NULL,
    [D69] [numeric](38, 8) NULL,
    [D70] [numeric](38, 8) NULL,
    [WATER_AUTHORITY_SW] [nvarchar](50) NULL,
    [PCT_GW_10] [numeric](38, 8) NULL,
    [PCT_GW_11] [numeric](38, 8) NULL,
    [PCT_GW_12] [numeric](38, 8) NULL,
    [PCT_GW_13] [numeric](38, 8) NULL,
    [PCT_GW_14] [numeric](38, 8) NULL,
    [PCT_GW_15] [numeric](38, 8) NULL,
    [PCT_GW_16] [numeric](38, 8) NULL,
    [PCT_GW_17] [numeric](38, 8) NULL,
    [PCT_GW_18] [numeric](38, 8) NULL,
    [PCT_GW_19] [numeric](38, 8) NULL,
    [PCT_GW_20] [numeric](38, 8) NULL,
    [PCT_GW_21] [numeric](38, 8) NULL,
    [PCT_GW_22] [numeric](38, 8) NULL,
    [PCT_GW_23] [numeric](38, 8) NULL,
    [PCT_GW_24] [numeric](38, 8) NULL,
    [PCT_GW_25] [numeric](38, 8) NULL,
    [PCT_GW_26] [numeric](38, 8) NULL,
    [PCT_GW_27] [numeric](38, 8) NULL,
    [PCT_GW_28] [numeric](38, 8) NULL,
    [PCT_GW_29] [numeric](38, 8) NULL,
    [PCT_GW_30] [numeric](38, 8) NULL,
    [PCT_GW_31] [numeric](38, 8) NULL,
    [PCT_GW_32] [numeric](38, 8) NULL,
    [PCT_GW_33] [numeric](38, 8) NULL,
    [PCT_GW_34] [numeric](38, 8) NULL,
    [PCT_GW_35] [numeric](38, 8) NULL,
    [PCT_GW_36] [numeric](38, 8) NULL,
    [PCT_GW_37] [numeric](38, 8) NULL,
    [PCT_GW_38] [numeric](38, 8) NULL,
    [PCT_GW_39] [numeric](38, 8) NULL,
    [PCT_GW_40] [numeric](38, 8) NULL,
    [PCT_GW_41] [numeric](38, 8) NULL,
    [PCT_GW_42] [numeric](38, 8) NULL,
    [PCT_GW_43] [numeric](38, 8) NULL,
    [PCT_GW_44] [numeric](38, 8) NULL,
    [PCT_GW_45] [numeric](38, 8) NULL,
    [PCT_GW_46] [numeric](38, 8) NULL,
    [PCT_GW_47] [numeric](38, 8) NULL,
    [PCT_GW_48] [numeric](38, 8) NULL,
    [PCT_GW_49] [numeric](38, 8) NULL,
    [PCT_GW_50] [numeric](38, 8) NULL,
    [PCT_GW_51] [numeric](38, 8) NULL,
    [PCT_GW_52] [numeric](38, 8) NULL,
    [PCT_GW_53] [numeric](38, 8) NULL,
    [PCT_GW_54] [numeric](38, 8) NULL,
    [PCT_GW_55] [numeric](38, 8) NULL,
    [PCT_GW_56] [numeric](38, 8) NULL,
    [PCT_GW_57] [numeric](38, 8) NULL,
    [PCT_GW_58] [numeric](38, 8) NULL,
```

```
    [PCT_GW_59] [numeric](38, 8) NULL,
    [PCT_GW_60] [numeric](38, 8) NULL,
    [PCT_GW_61] [numeric](38, 8) NULL,
    [PCT_GW_62] [numeric](38, 8) NULL,
    [PCT_GW_63] [numeric](38, 8) NULL,
    [PCT_GW_64] [numeric](38, 8) NULL,
    [PCT_GW_65] [numeric](38, 8) NULL,
    [PCT_GW_66] [numeric](38, 8) NULL,
    [PCT_GW_67] [numeric](38, 8) NULL,
    [PCT_GW_68] [numeric](38, 8) NULL,
    [PCT_GW_69] [numeric](38, 8) NULL,
    [PCT_GW_70] [numeric](38, 8) NULL,
    [LSGCD_GT_10MGY] [int] NULL,
    [Shape] [int] NULL,
    [RuleID] [int] NULL,
    [Override] [varbinary](max) NULL,
    [NEW_PUMPAGE_IN_CELL] [nvarchar](255) NULL
) ON [PRIMARY]
GO
SET ANSI_PADDING OFF
GO
/****** Object:  Table [dbo].[OTHER_IRRIGATION]    Script Date: 12/11/2012 10:24:24 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[OTHER_IRRIGATION](
    [OBJECTID_12] [int] NOT NULL,
    [OBJECTID_1] [int] NULL,
    [OBJECTID] [numeric](10, 0) NULL,
    [DISTRICT] [nvarchar](50) NULL,
    [DISTRICT_I] [nvarchar](50) NULL,
    [USE_CODE] [nvarchar](50) NULL,
    [MUNI_NON_P] [nvarchar](1) NULL,
    [COUNTYFP10] [nvarchar](3) NULL,
    [NAME10] [nvarchar](100) NULL,
    [ALAND10] [numeric](26, 8) NULL,
    [AWATER10] [numeric](26, 8) NULL,
    [INTPTLAT10] [nvarchar](11) NULL,
    [INTPTLON10] [nvarchar](12) NULL,
    [Shape_Leng] [numeric](26, 8) NULL,
    [PUMPAGE_20] [numeric](26, 8) NULL,
    [TARGET_F_1] [numeric](10, 0) NULL,
    [ROW] [int] NULL,
    [COL] [int] NULL,
    [CELL_ID] [numeric](10, 0) NULL,
    [GCD_Num] [numeric](10, 0) NULL,
    [BasinName] [nvarchar](50) NULL,
    [BasinNum] [int] NULL,
    [IBND1] [int] NULL,
    [IBND2] [int] NULL,
    [IBND3] [int] NULL,
    [IBND4] [int] NULL,
    [CentroidX] [numeric](26, 8) NULL,
```

```
    [CentroidY] [numeric](26, 8) NULL,
    [uGCD] [nvarchar](69) NULL,
    [GMA] [int] NULL,
    [PGMA] [nvarchar](40) NULL,
    [RA_SLD] [nvarchar](100) NULL,
    [REG_NAME] [nvarchar](25) NULL,
    [LETTER] [nvarchar](1) NULL,
    [REG_NUM] [int] NULL,
    [CntyBsnReg] [numeric](10, 0) NULL,
    [VistaCode] [int] NULL,
    [AQ_Active1] [int] NULL,
    [AQ_Active2] [int] NULL,
    [AQ_Active3] [int] NULL,
    [AQ_Active4] [int] NULL,
    [GeoArea] [int] NULL,
    [Shape_Le_1] [numeric](26, 8) NULL,
    [Map_Displa] [numeric](26, 8) NULL,
    [FID_TWDB_M] [numeric](10, 0) NULL,
    [PWS_ID] [nvarchar](25) NULL,
    [A1NAME] [nvarchar](100) NULL,
    [REG_AREA_N] [nvarchar](50) NULL,
    [BLK9_ROW] [numeric](10, 0) NULL,
    [BLK9_COL] [numeric](10, 0) NULL,
    [WELL_CNT_2] [numeric](10, 0) NULL,
    [WELL_GPM_2] [numeric](10, 0) NULL,
    [D31] [numeric](26, 8) NULL,
    [D32] [numeric](26, 8) NULL,
    [D33] [numeric](26, 8) NULL,
    [D34] [numeric](26, 8) NULL,
    [D35] [numeric](26, 8) NULL,
    [D36] [numeric](26, 8) NULL,
    [D37] [numeric](26, 8) NULL,
    [D38] [numeric](26, 8) NULL,
    [D39] [numeric](26, 8) NULL,
    [D40] [numeric](26, 8) NULL,
    [D41] [numeric](26, 8) NULL,
    [D42] [numeric](26, 8) NULL,
    [D43] [numeric](26, 8) NULL,
    [D44] [numeric](26, 8) NULL,
    [D45] [numeric](26, 8) NULL,
    [D46] [numeric](26, 8) NULL,
    [D47] [numeric](26, 8) NULL,
    [D48] [numeric](26, 8) NULL,
    [D49] [numeric](26, 8) NULL,
    [D50] [numeric](26, 8) NULL,
    [D51] [numeric](26, 8) NULL,
    [D52] [numeric](26, 8) NULL,
    [D53] [numeric](26, 8) NULL,
    [D54] [numeric](26, 8) NULL,
    [D55] [numeric](26, 8) NULL,
    [D56] [numeric](26, 8) NULL,
    [D57] [numeric](26, 8) NULL,
    [D58] [numeric](26, 8) NULL,
    [D59] [numeric](26, 8) NULL,
```

```
    [D60] [numeric](26, 8) NULL,
    [D61] [numeric](26, 8) NULL,
    [D62] [numeric](26, 8) NULL,
    [D63] [numeric](26, 8) NULL,
    [D64] [numeric](26, 8) NULL,
    [D65] [numeric](26, 8) NULL,
    [D66] [numeric](26, 8) NULL,
    [D67] [numeric](26, 8) NULL,
    [D68] [numeric](26, 8) NULL,
    [D69] [numeric](26, 8) NULL,
    [D70] [numeric](26, 8) NULL,
    [WATER_AUTH] [nvarchar](50) NULL,
    [LSGCD_GT_1] [int] NULL,
    [area] [numeric](38, 8) NULL,
    [len] [numeric](38, 8) NULL,
    [Shape] [int] NULL
) ON [PRIMARY]
GO
/****** Object:  Table [dbo].[BLKS_MUD_GAM]    Script Date: 12/11/2012 10:24:24 ******/
SET ANSI_NULLS ON
GO
SET QUOTED_IDENTIFIER ON
GO
CREATE TABLE [dbo].[BLKS_MUD_GAM](
    [OBJECTID] [int] NOT NULL,
    [FID_CensusBlocks] [int] NULL,
    [TRACTCE10] [nvarchar](6) NULL,
    [BLOCKCE10] [nvarchar](4) NULL,
    [GEOID10] [nvarchar](15) NULL,
    [BlockPopulation] [numeric](38, 8) NULL,
    [TractAreaAcres] [numeric](38, 8) NULL,
    [BlockAreaAcres] [numeric](38, 8) NULL,
    [GEOID10_1] [nvarchar](15) NULL,
    [COUNTY_SUBAREA] [nvarchar](25) NULL,
    [COUNTY_SUBAREA_NAME] [nvarchar](50) NULL,
    [JoinBros_area] [numeric](38, 8) NULL,
    [FID_WaterAuthorities] [int] NULL,
    [Authority] [nvarchar](50) NULL,
    [FID_NGC_GAM_grid] [int] NULL,
    [ROW] [smallint] NULL,
    [COL] [smallint] NULL,
    [CELL_ID] [int] NULL,
    [CountyName] [nvarchar](50) NULL,
    [CountyNum] [smallint] NULL,
    [Shape_Leng] [numeric](38, 8) NULL,
    [FID_MUDS] [int] NULL,
    [FID_TWDB_MUD_BOUNDARIES_CLIP] [int] NULL,
    [PWS_ID] [nvarchar](25) NOT NULL,
    [A1NAME] [nvarchar](100) NOT NULL,
    [PWS_STATUS] [nvarchar](255) NULL,
    [NUMBER_SOURCE_WELLS] [int] NULL,
    [NUMBER_SW_SOURCES] [int] NULL,
    [WATER_AUTHORITY_SW] [nvarchar](255) NULL,
    [GPCD] [numeric](38, 8) NULL,
```

```
    [GPCD_METHOD] [nvarchar](255) NULL,
    [MUD_POP_2010] [int] NULL,
    [TOTAL_DEMAND_2010_GPD] [numeric](38, 8) NULL,
    [OWN_GW_DEMAND_2010_GPD] [numeric](38, 8) NULL,
    [SOLD_GW_DEMAND_2010_GPD] [numeric](38, 8) NULL,
    [TOTAL_GW_DEMAND_ON_OWN_WELLS] [numeric](38, 8) NULL,
    [OWN_SW_DEMAND_2010_GPD] [numeric](38, 8) NULL,
    [PWSID_SUPPLYING_WATER] [nvarchar](15) NULL,
    [PWSID_WATER_TYPE_SUPPLIED] [nvarchar](255) NULL,
    [COUNTY] [nvarchar](50) NULL,
    [UNION_AREA_AC] [numeric](38, 8) NULL,
    [POP_BLK_10] [numeric](38, 8) NULL,
    [POP_BLK_20] [numeric](38, 8) NULL,
    [POP_BLK_30] [numeric](38, 8) NULL,
    [POP_BLK_40] [numeric](38, 8) NULL,
    [POP_BLK_50] [numeric](38, 8) NULL,
    [POP_BLK_60] [numeric](38, 8) NULL,
    [POP_BLK_70] [numeric](38, 8) NULL,
    [BLOCK_GPCD] [numeric](38, 8) NULL,
    [POP_UNION_10] [numeric](38, 8) NULL,
    [POP_UNION_20] [numeric](38, 8) NULL,
    [POP_UNION_30] [numeric](38, 8) NULL,
    [POP_UNION_40] [numeric](38, 8) NULL,
    [POP_UNION_50] [numeric](38, 8) NULL,
    [POP_UNION_60] [numeric](38, 8) NULL,
    [POP_UNION_70] [numeric](38, 8) NULL,
    [CENSUS_PLACE] [nvarchar](50) NULL,
    [REG_AREA] [nvarchar](50) NULL,
    [DEMAND_GPD_10] [numeric](38, 8) NULL,
    [DEMAND_GPD_20] [numeric](38, 8) NULL,
    [DEMAND_GPD_30] [numeric](38, 8) NULL,
    [DEMAND_GPD_40] [numeric](38, 8) NULL,
    [DEMAND_GPD_50] [numeric](38, 8) NULL,
    [DEMAND_GPD_60] [numeric](38, 8) NULL,
    [DEMAND_GPD_70] [numeric](38, 8) NULL,
    [GW_DEMAND_10] [numeric](38, 8) NULL,
    [GW_DEMAND_11] [numeric](38, 8) NULL,
    [GW_DEMAND_12] [numeric](38, 8) NULL,
    [GW_DEMAND_13] [numeric](38, 8) NULL,
    [GW_DEMAND_14] [numeric](38, 8) NULL,
    [GW_DEMAND_15] [numeric](38, 8) NULL,
    [GW_DEMAND_16] [numeric](38, 8) NULL,
    [GW_DEMAND_17] [numeric](38, 8) NULL,
    [GW_DEMAND_18] [numeric](38, 8) NULL,
    [GW_DEMAND_19] [numeric](38, 8) NULL,
    [GW_DEMAND_20] [numeric](38, 8) NULL,
    [GW_DEMAND_21] [numeric](38, 8) NULL,
    [GW_DEMAND_22] [numeric](38, 8) NULL,
    [GW_DEMAND_23] [numeric](38, 8) NULL,
    [GW_DEMAND_24] [numeric](38, 8) NULL,
    [GW_DEMAND_25] [numeric](38, 8) NULL,
    [GW_DEMAND_26] [numeric](38, 8) NULL,
    [GW_DEMAND_27] [numeric](38, 8) NULL,
    [GW_DEMAND_28] [numeric](38, 8) NULL,
```

```
    [GW_DEMAND_29] [numeric](38, 8) NULL,
    [GW_DEMAND_30] [numeric](38, 8) NULL,
    [GW_DEMAND_31] [numeric](38, 8) NULL,
    [GW_DEMAND_32] [numeric](38, 8) NULL,
    [GW_DEMAND_33] [numeric](38, 8) NULL,
    [GW_DEMAND_34] [numeric](38, 8) NULL,
    [GW_DEMAND_35] [numeric](38, 8) NULL,
    [GW_DEMAND_36] [numeric](38, 8) NULL,
    [GW_DEMAND_37] [numeric](38, 8) NULL,
    [GW_DEMAND_38] [numeric](38, 8) NULL,
    [GW_DEMAND_39] [numeric](38, 8) NULL,
    [GW_DEMAND_40] [numeric](38, 8) NULL,
    [GW_DEMAND_41] [numeric](38, 8) NULL,
    [GW_DEMAND_42] [numeric](38, 8) NULL,
    [GW_DEMAND_43] [numeric](38, 8) NULL,
    [GW_DEMAND_44] [numeric](38, 8) NULL,
    [GW_DEMAND_45] [numeric](38, 8) NULL,
    [GW_DEMAND_46] [numeric](38, 8) NULL,
    [GW_DEMAND_47] [numeric](38, 8) NULL,
    [GW_DEMAND_48] [numeric](38, 8) NULL,
    [GW_DEMAND_49] [numeric](38, 8) NULL,
    [GW_DEMAND_50] [numeric](38, 8) NULL,
    [GW_DEMAND_51] [numeric](38, 8) NULL,
    [GW_DEMAND_52] [numeric](38, 8) NULL,
    [GW_DEMAND_53] [numeric](38, 8) NULL,
    [GW_DEMAND_54] [numeric](38, 8) NULL,
    [GW_DEMAND_55] [numeric](38, 8) NULL,
    [GW_DEMAND_56] [numeric](38, 8) NULL,
    [GW_DEMAND_57] [numeric](38, 8) NULL,
    [GW_DEMAND_58] [numeric](38, 8) NULL,
    [GW_DEMAND_59] [numeric](38, 8) NULL,
    [GW_DEMAND_60] [numeric](38, 8) NULL,
    [GW_DEMAND_61] [numeric](38, 8) NULL,
    [GW_DEMAND_62] [numeric](38, 8) NULL,
    [GW_DEMAND_63] [numeric](38, 8) NULL,
    [GW_DEMAND_64] [numeric](38, 8) NULL,
    [GW_DEMAND_65] [numeric](38, 8) NULL,
    [GW_DEMAND_66] [numeric](38, 8) NULL,
    [GW_DEMAND_67] [numeric](38, 8) NULL,
    [GW_DEMAND_68] [numeric](38, 8) NULL,
    [GW_DEMAND_69] [numeric](38, 8) NULL,
    [GW_DEMAND_70] [numeric](38, 8) NULL,
    [Shape] [int] NULL
) ON [PRIMARY]
GO
```

Interpolation Queries

```sql
USE S2_V3
--STEP 1: Update PWS wells with demands

--Refresh demand values in 'TOTAL_DEMAND_BY_A1NAME' from BLKS_MUD_GAM

UPDATE A
SET
A.D10 = B.D10,
A.D20 = B.D20,
A.D30 = B.D30,
A.D40 = B.D40,
A.D50 = B.D50,
A.D60 = B.D60,
A.D70 = B.D70
FROM
TOTAL_DEMAND_BY_A1NAME AS A
INNER JOIN
(SELECT
A1NAME,
SUM(DEMAND_GPD_10) AS D10,
SUM(DEMAND_GPD_20) AS D20,
SUM(DEMAND_GPD_30) AS D30,
SUM(DEMAND_GPD_40) AS D40,
SUM(DEMAND_GPD_50) AS D50,
SUM(DEMAND_GPD_60) AS D60,
SUM(DEMAND_GPD_70) AS D70
FROM BLKS_MUD_GAM
WHERE LEN(A1NAME) > 1 AND SUBSTRING(GEOID10,3,3) IN ('039','157','167','201','339')
GROUP BY A1NAME) AS B
ON A.A1NAME = B.A1NAME

--Set 2020-2070 demand to zero
UPDATE PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND SET
DEMAND_2010_GPD = 0,
DEMAND_2020_GPD = 0,
DEMAND_2030_GPD = 0,
DEMAND_2040_GPD = 0,
DEMAND_2050_GPD = 0,
DEMAND_2060_GPD = 0,
DEMAND_2070_GPD = 0

--Update PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND
UPDATE A
SET
A.DEMAND_2010_GPD = B.D10 / B.WELL_COUNT,
A.DEMAND_2020_GPD = B.D20 / B.WELL_COUNT,
A.DEMAND_2030_GPD = B.D30 / B.WELL_COUNT,
A.DEMAND_2040_GPD = B.D40 / B.WELL_COUNT,
A.DEMAND_2050_GPD = B.D50 / B.WELL_COUNT,
A.DEMAND_2060_GPD = B.D60 / B.WELL_COUNT,
A.DEMAND_2070_GPD = B.D70 / B.WELL_COUNT
FROM
PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND AS A
INNER JOIN
```

```
(SELECT
PWSID_SUPPLYING_WATER,
SUM(D10) AS D10,
SUM(D20) AS D20,
SUM(D30) AS D30,
SUM(D40) AS D40,
SUM(D50) AS D50,
SUM(D60) AS D60,
SUM(D70) AS D70,
MAX(NUM_WELLS_SUPPLYING_WATER) AS WELL_COUNT
FROM TOTAL_DEMAND_BY_A1NAME
GROUP BY PWSID_SUPPLYING_WATER) AS B
ON A.PWSID = B.PWSID_SUPPLYING_WATER
WHERE B.WELL_COUNT > 0
AND A.pwsname <> 'CITY OF HOUSTON'
```

```
USE S2_V3

--STEP 2: Update PWS wells for City of Houston with demands specific to each regulatory zone


--Refresh the table TOTAL_DEMAND_BY_A1NAME_REGAREA
UPDATE A
SET
A.D10 = B.D10,
A.D20 = B.D20,
A.D30 = B.D30,
A.D40 = B.D40,
A.D50 = B.D50,
A.D60 = B.D60,
A.D70 = B.D70
FROM
TOTAL_DEMAND_BY_A1NAME_REGAREA AS A
INNER JOIN
(SELECT
A1NAME,
REG_AREA,
SUM(DEMAND_GPD_10) AS D10,
SUM(DEMAND_GPD_20) AS D20,
SUM(DEMAND_GPD_30) AS D30,
SUM(DEMAND_GPD_40) AS D40,
SUM(DEMAND_GPD_50) AS D50,
SUM(DEMAND_GPD_60) AS D60,
SUM(DEMAND_GPD_70) AS D70
FROM BLKS_MUD_GAM
WHERE A1NAME = 'CITY OF HOUSTON'
GROUP BY A1NAME, REG_AREA) AS B
ON A.A1NAME = B.A1NAME AND A.REG_AREA = B.REG_AREA

--2010-2070
UPDATE PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND SET
DEMAND_2010_GPD = 0,
DEMAND_2020_GPD = 0,
DEMAND_2030_GPD = 0,
DEMAND_2040_GPD = 0,
DEMAND_2050_GPD = 0,
DEMAND_2060_GPD = 0,
DEMAND_2070_GPD = 0
WHERE pwsname = 'CITY OF HOUSTON'

UPDATE A
SET
A.DEMAND_2010_GPD = B.D10 / B.WELL_COUNT,
A.DEMAND_2020_GPD = B.D20 / B.WELL_COUNT,
A.DEMAND_2030_GPD = B.D30 / B.WELL_COUNT,
A.DEMAND_2040_GPD = B.D40 / B.WELL_COUNT,
A.DEMAND_2050_GPD = B.D50 / B.WELL_COUNT,
A.DEMAND_2060_GPD = B.D60 / B.WELL_COUNT,
A.DEMAND_2070_GPD = B.D70 / B.WELL_COUNT
FROM
```

```
PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND AS A
INNER JOIN
(SELECT
A1NAME,
REG_AREA,
SUM(D10) AS D10,
SUM(D20) AS D20,
SUM(D30) AS D30,
SUM(D40) AS D40,
SUM(D50) AS D50,
SUM(D60) AS D60,
SUM(D70) AS D70,
MAX(WELL_COUNT) AS WELL_COUNT
FROM
TOTAL_DEMAND_BY_A1NAME_REGAREA
GROUP BY A1NAME, REG_AREA) AS B
ON A.pwsname = B.A1NAME AND A.REG_AREA_NAME = B.REG_AREA
WHERE A.pwsname = 'CITY OF HOUSTON'
```

```
USE S2_V3

--STEP 3: Update the GAM GRID with PWS demands where the PWS has no wells
-------------------------------------
--              2020-2070
-------------------------------------
    update GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
    set
    D10 = 0,
    D20 = 0,
    D30 = 0,
    D40 = 0,
    D50 = 0,
    D60 = 0,
    D70 = 0

    UPDATE A
    SET
    A.D10 = B.D10,
    A.D20 = B.D20,
    A.D30 = B.D30,
    A.D40 = B.D40,
    A.D50 = B.D50,
    A.D60 = B.D60,
    A.D70 = B.D70
    FROM
    GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND AS A
    INNER JOIN
    (SELECT A1NAME, CELL_ID,
    SUM(DEMAND_GPD_10) AS D10,
    SUM(DEMAND_GPD_20) AS D20,
    SUM(DEMAND_GPD_30) AS D30,
    SUM(DEMAND_GPD_40) AS D40,
    SUM(DEMAND_GPD_50) AS D50,
    SUM(DEMAND_GPD_60) AS D60,
    SUM(DEMAND_GPD_70) AS D70
    FROM BLKS_MUD_GAM
    GROUP BY A1NAME, CELL_ID) AS B
    ON A.CELL_ID = B.CELL_ID
    WHERE B.A1NAME IN
    (SELECT A1NAME FROM TOTAL_DEMAND_BY_A1NAME
    WHERE WELL_COUNT = 0
    AND PWSID_SUPPLYING_WATER = PWS_ID AND PWS_ID <> '0790438')

--UPDATE GAM GRIDS EVENLY AROUND CINCO SOUTHWEST MUDS WITH THE TOTAL DEMAND ASSIGNED
--TO CINCO SOUTHWEST MUD 1
DECLARE @SUMD float
--2020
SELECT @SUMD =
SUM(D20)
FROM TOTAL_DEMAND_BY_A1NAME
WHERE PWSID_SUPPLYING_WATER = '0790438'
GROUP BY PWSID_SUPPLYING_WATER
```

```
UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D20 = @SUMD/5
WHERE CELL_ID IN (1060076, 1060077, 1061076, 1061077, 1062077)

--2030
SELECT @SUMD =
SUM(D30)
FROM TOTAL_DEMAND_BY_A1NAME
WHERE PWSID_SUPPLYING_WATER = '0790438'
GROUP BY PWSID_SUPPLYING_WATER

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D30 = @SUMD/5
WHERE CELL_ID IN (1060076, 1060077, 1061076, 1061077, 1062077)

--2040
SELECT @SUMD =
SUM(D40)
FROM TOTAL_DEMAND_BY_A1NAME
WHERE PWSID_SUPPLYING_WATER = '0790438'
GROUP BY PWSID_SUPPLYING_WATER

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D40 = @SUMD/5
WHERE CELL_ID IN (1060076, 1060077, 1061076, 1061077, 1062077)

--2050
SELECT @SUMD =
SUM(D50)
FROM TOTAL_DEMAND_BY_A1NAME
WHERE PWSID_SUPPLYING_WATER = '0790438'
GROUP BY PWSID_SUPPLYING_WATER

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D50 = @SUMD/5
WHERE CELL_ID IN (1060076, 1060077, 1061076, 1061077, 1062077)

--2060
SELECT @SUMD =
SUM(D60)
FROM TOTAL_DEMAND_BY_A1NAME
WHERE PWSID_SUPPLYING_WATER = '0790438'
GROUP BY PWSID_SUPPLYING_WATER

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D60 = @SUMD/5
WHERE CELL_ID IN (1060076, 1060077, 1061076, 1061077, 1062077)

--2070
SELECT @SUMD =
SUM(D70)
FROM TOTAL_DEMAND_BY_A1NAME
WHERE PWSID_SUPPLYING_WATER = '0790438'
GROUP BY PWSID_SUPPLYING_WATER
```

```
UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D70 = @SUMD/5
WHERE CELL_ID IN (1060076, 1060077, 1061076, 1061077, 1062077)
```

```
USE S2_V3
--STEP 4: Update the GAM GRID with PWS well demands
--------------------------------------------
--              2020-2070
--------------------------------------------
update A
set
A.D10 = A.D10 + B.D10,
A.D20 = A.D20 + B.D20,
A.D30 = A.D30 + B.D30,
A.D40 = A.D40 + B.D40,
A.D50 = A.D50 + B.D50,
A.D60 = A.D60 + B.D60,
A.D70 = A.D70 + B.D70
from
GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND as A
inner join
(select
CELL_ID,
sum(DEMAND_2010_GPD) as D10,
sum(DEMAND_2020_GPD) as D20,
sum(DEMAND_2030_GPD) as D30,
sum(DEMAND_2040_GPD) as D40,
sum(DEMAND_2050_GPD) as D50,
sum(DEMAND_2060_GPD) as D60,
sum(DEMAND_2070_GPD) as D70
from
PWS_SOURCE_LOCN_GAM_GRID_JOIN_TOTAL_DEMAND
group by CELL_ID) as B
on A.CELL_ID = B.CELL_ID
```

```sql
USE S2_V3

--STEP 5: Update the GAM GRID with demands outside of a MUD/City

-------------------------------------------------
--                   2020-2070
-------------------------------------------------
UPDATE A
SET
A.D10 = A.D10 + B.D10,
A.D20 = A.D20 + B.D20,
A.D30 = A.D30 + B.D30,
A.D40 = A.D40 + B.D40,
A.D50 = A.D50 + B.D50,
A.D60 = A.D60 + B.D60,
A.D70 = A.D70 + B.D70
FROM GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND AS A
INNER JOIN
(SELECT
CELL_ID,
SUM(DEMAND_GPD_10) AS D10,
SUM(DEMAND_GPD_20) AS D20,
SUM(DEMAND_GPD_30) AS D30,
SUM(DEMAND_GPD_40) AS D40,
SUM(DEMAND_GPD_50) AS D50,
SUM(DEMAND_GPD_60) AS D60,
SUM(DEMAND_GPD_70) AS D70
FROM BLKS_MUD_GAM
WHERE (LEN(A1NAME) < 1 OR PWS_STATUS = 'PROPOSED') AND SUBSTRING(GEOID10,3,3) IN ('039','157',
'167','201','339')
GROUP BY CELL_ID) AS B
ON A.CELL_ID = B.CELL_ID
```

```
USE S2_V3

--STEP 6: Update the GAM GRID with 'other irrigation' demands

--2010-2070 Assign baseline actual "other irrigation" pumpage numbers to grid cells (EXCEPT
GOLF WORLD GRID CELL)
UPDATE A
SET
A.D10 = A.D10 + B.D10,
A.D20 = A.D20 + B.D10,
A.D30 = A.D30 + B.D10,
A.D40 = A.D40 + B.D10,
A.D50 = A.D50 + B.D10,
A.D60 = A.D60 + B.D10,
A.D70 = A.D70 + B.D10
FROM GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND AS A
INNER JOIN
(SELECT
CELL_ID,
(SUM(PUMPAGE_20)/365) AS D10 --PUMPAGE_20 IS PUMPAGE_2010
FROM OTHER_IRRIGATION
GROUP BY CELL_ID) AS B
ON A.CELL_ID = B.CELL_ID
WHERE A.CELL_ID <> 1060090 AND B.D10 IS NOT NULL

--ASSIGN GOLF WORLD BASELINE DEMAND TO SURROUNDING GRID CELLS
DECLARE @SUMD float
--2010
SELECT @SUMD =
SUM(PUMPAGE_20) /365
FROM OTHER_IRRIGATION
WHERE CELL_ID = 1060090
GROUP BY CELL_ID

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D10 = D10 + @SUMD/4
WHERE CELL_ID IN (1060090, 1060091, 1061090, 1061091)

--2020
SELECT @SUMD =
SUM(PUMPAGE_20) /365
FROM OTHER_IRRIGATION
WHERE CELL_ID = 1060090
GROUP BY CELL_ID

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D20 = D20 + @SUMD/4
WHERE CELL_ID IN (1060090, 1060091, 1061090, 1061091)

--2030
SELECT @SUMD =
SUM(PUMPAGE_20) /365
FROM OTHER_IRRIGATION
WHERE CELL_ID = 1060090
```

```
GROUP BY CELL_ID

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D30 = D30 + @SUMD/4
WHERE CELL_ID IN (1060090, 1060091, 1061090, 1061091)

--2040
SELECT @SUMD =
SUM(PUMPAGE_20) /365
FROM OTHER_IRRIGATION
WHERE CELL_ID = 1060090
GROUP BY CELL_ID

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D40 = D40 + @SUMD/4
WHERE CELL_ID IN (1060090, 1060091, 1061090, 1061091)

--2050
SELECT @SUMD =
SUM(PUMPAGE_20) /365
FROM OTHER_IRRIGATION
WHERE CELL_ID = 1060090
GROUP BY CELL_ID

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D50 = D50 + @SUMD/4
WHERE CELL_ID IN (1060090, 1060091, 1061090, 1061091)

--2060
SELECT @SUMD =
SUM(PUMPAGE_20) /365
FROM OTHER_IRRIGATION
WHERE CELL_ID = 1060090
GROUP BY CELL_ID

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D60 = D60 + @SUMD/4
WHERE CELL_ID IN (1060090, 1060091, 1061090, 1061091)

--2070
SELECT @SUMD =
SUM(PUMPAGE_20) /365
FROM OTHER_IRRIGATION
WHERE CELL_ID = 1060090
GROUP BY CELL_ID

UPDATE GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND
SET D70 = D70 + @SUMD/4
WHERE CELL_ID IN (1060090, 1060091, 1061090, 1061091)


--PROJECT ADDITIONAL "OTHER IRRIGATION" DEMANDS
UPDATE A
SET
```

```
A.D20 = A.D20 + ((B.POP20 - B.POP10) * A.FRAC_OUTSIDE_MUD * 2),
A.D30 = A.D30 + ((B.POP30 - B.POP10) * A.FRAC_OUTSIDE_MUD * 2),
A.D40 = A.D40 + ((B.POP40 - B.POP10) * A.FRAC_OUTSIDE_MUD * 2),
A.D50 = A.D50 + ((B.POP50 - B.POP10) * A.FRAC_OUTSIDE_MUD * 2),
A.D60 = A.D60 + ((B.POP60 - B.POP10) * A.FRAC_OUTSIDE_MUD * 2),
A.D70 = A.D70 + ((B.POP70 - B.POP10) * A.FRAC_OUTSIDE_MUD * 2)
FROM GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND AS A
INNER JOIN
(SELECT
CELL_ID,
SUM(POP_UNION_10) AS POP10,
SUM(POP_UNION_20) AS POP20,
SUM(POP_UNION_30) AS POP30,
SUM(POP_UNION_40) AS POP40,
SUM(POP_UNION_50) AS POP50,
SUM(POP_UNION_60) AS POP60,
SUM(POP_UNION_70) AS POP70
FROM BLKS_MUD_GAM
GROUP BY CELL_ID) AS B
ON A.CELL_ID = B.CELL_ID
WHERE B.POP10 IS NOT NULL
```

```sql
Use S2_V3
--STEP 7: Bring in the non-municipal values to the GAM grid



--BRING IN EVERYTHING EXCEPT THE HARRIS AND GALVESTON DEMANDS
Update A
Set
A.D10 = A.D10 + (B.Projected2010_Total / 365),
A.D20 = A.D20 + (B.Projected2020_Total / 365),
A.D30 = A.D30 + (B.Projected2030_Total / 365),
A.D40 = A.D40 + (B.Projected2040_Total / 365),
A.D50 = A.D50 + (B.Projected2050_Total / 365),
A.D60 = A.D60 + (B.Projected2060_Total / 365),
A.D70 = A.D70 + (B.Projected2070_Total / 365)
From GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND As A
Inner Join
NON_MUNI_DEMANDS_EXCEPT_HG As B
On A.CELL_ID = B.CELL_ID
WHERE A.CountyName NOT IN ('HARRIS', 'GALVESTON')


--BRING IN HARRIS AND GALVESTON INCREMENTAL DEMANDS
UPDATE A
SET
A.D20 = A.D20 + B.INC_D20,
A.D30 = A.D30 + B.INC_D30,
A.D40 = A.D40 + B.INC_D40,
A.D50 = A.D50 + B.INC_D50,
A.D60 = A.D60 + B.INC_D60,
A.D70 = A.D70 + B.INC_D70
FROM GAM_GRID_MUD_REG_BOUNDARY_JOIN_TOTAL_DEMAND As A
INNER JOIN
HG_INDUSTRIAL AS B
ON A.CELL_ID = B.CELL_ID
WHERE A.COUNTYNAME IN ('HARRIS', 'GALVESTON')
```