REPORT OF FINDINGS

AN EVALUATION OF THE TRINITY AQUIFER WITHIN KENDALL COUNTY AND ANALYSIS OF THE TRINITY (HILL COUNTRY) GAM

FOR

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Section I: Executive Summary

The Trinity (Hill Country) GAM is the most comprehensive groundwater model created to date of the Trinity Aquifer within the Texas Hill County. Much information has been compiled and analyzed in the creation of the model including aquifer test data, water levels, production data and precipitation data. The model has done a good job in building the framework of a GAM that will help planners in the area.

The Cow Creek Groundwater Conservation District is tasked along with other districts in GMA 9 with formulating a DFC which will then be used by the TWDB to acquire a MAG number to determine the available amount of water for permitting. The GAM model is to be used as a tool in determining the DFC and as such, the goals of this study are to determine whether the Trinity (Hill Country) GAM overestimates, underestimates or accurately estimates the groundwater resources of the District based upon a comparison with real data.

Water level data were compiled and hydrographs were constructed and compared with production amounts from the TWDB Water Use Survey database. The resultant hydrographs have shown that water levels within the Middle Trinity Aquifer have been relatively stable in the majority of Kendall County for the past 30 years with no long term trend of increasing or decreasing water levels. There are areas of the county which have experienced a decreasing trend in water levels such as the Lower Trinity Aquifer around the Rio Frio Well in southeast Kendall County, the Middle Trinity Aquifer around the Turkey Knob and Diamond Ridge Wells in the southwest corner of the county and wells within the far northern portion of the county within the Middle Trinity Aquifer.

An analysis of pumpage within Kendall County coupled with water level data also indicate that there has not been large scale drawdowns (over 25 ft) occurring in southern and southeastern Kendall County near the City of Boerne under average conditions over the past 10 years as the Trinity (Hill Country) GAM has predicted. In fact, some wells within southern Kendall County have remained relatively stable and in some cases (Kendall Woods and Coveney Wells) have risen over the past seven years even though production has increased.

Recharge plays a large role and has great influence in determining the impacts of pumpage on water levels. The "average" recharge conditions used in the Trinity (Hill Country) GAM likely overestimate the impacts of drawdown because of the lower recharge coefficient used (4 percent of mean annual precipitation) than what was estimated based upon the best available data (9.45 percent of mean annual precipitation) and also overestimates the impacts of drawdown under "drought-of-record" conditions due to the lower recharge coefficient used (4 percent of mean annual precipitation) than what was estimated using our approach (6.79 percent of mean annual precipitation). It is recommended that the model be input with recharge numbers that more

accurately reflect the data and be recalibrated to better determine the impacts of pumpage on the aquifer.

Section II: Introduction

The Cow Creek Groundwater Conservation District (the District) was created via confirmation election in 2002. The District's boundaries include the entire portion of Kendall County which is located north of the City of San Antonio within the Texas Hill Country (Fig. 1). The District's mission as stated is:

"The Cow Creek Groundwater Conservation District was created for the purpose of conserving, preserving, recharging, protecting and preventing waste of groundwater from the aquifers within Kendall County. The District will conduct administrative and technical activities and programs to achieve these purposes. The District will collect and archive water well and aquifer data, regulate water well drilling and production from permitted, non-exempt wells, promote the capping or plugging of abandoned wells, provide information and educational material to local property owners, interact with other governmental or organizational entities, and incorporate other groundwater-related activities that may help meet the purposes of the District. The Texas Hill Country Area, which includes Kendall County, was declared a Critical Groundwater Area by the then Texas Water Commission in 1990. This declaration, now known as the Hill Country Priority Groundwater Management Area (PGMA), gave notice to the residents of the area that water availability and quality will be at risk within the next 50 years."

Groundwater Conservation Districts within the Texas Hill Country have been given a difficult task in juggling the interests of large development within a part of the State that is growing at a rapid rate and the interests of preserving the water resources of the area. Both interests are equally important for the economic growth of the area and maintaining the uniqueness and beauty. The Texas Hill Country is one of the most picturesque parts of the State but yet has limited groundwater resources.

The District is located within Regional Water Planning Group L (RWPG L) and is part of Groundwater Management Area 9 (GMA 9) (Fig. 2). Prior to House Bill 1763 (HB 1763), groundwater conservation districts were charged with determining the amount of groundwater available within their districts. With HB 1763, the legislature regionalized the decision making process of determining groundwater availability, mandated regional water planning groups to use the availability numbers determined by the GMA, and required a permitting process for groundwater production. The State is divided into sixteen GMA's, each groundwater conservation district within the GMA is tasked with working together to develop their own Desired Future Conditions (DFC). Once these DFCs are determined and submitted to the Texas

Water Development Board (TWDB), the TWDB will then determine the Managed Available Groundwater (MAG) amount for each groundwater conservation district. This MAG number will then be used within each groundwater district's management plan and also within the regional plans for each RWPG. What this process does is essentially determine a permitting cap for each groundwater conservation district.

As part of the DFC process, each GMA will use the Groundwater Availability Model (GAM) for the appropriate aquifer(s) within their area as a tool in determining their DFC. The Trinity Aquifer is the major groundwater source for the District area and the TWDB has completed a GAM for that aquifer called the Trinity (Hill Country) GAM.

This report discusses the Trinity (Hill Country) GAM (Mace and others, 2000) and specifically, will analyze the GAM and the results of the model runs with respect to available groundwater data within the District. This report will briefly discuss the Edwards Group of the Edwards-Trinity Aquifer and the Upper and Lower Trinity Aquifers, although the concentration of this study is on the Middle Trinity Aquifer.

The objectives of this study are:

1. To provide the District with the best available information on the groundwater resources of the District to be able to make an informed decision on the DFC of the area;

2. To estimate the recharge of the Trinity Aquifer within the District; and

3. To evaluate the Trinity (Hill Country) GAM by the TWDB to determine whether the GAM overestimates, underestimates or accurately estimates the groundwater resources of the District based upon a comparison with actual data.

Section III: Hydrogeology of Kendall County

Figure 3 provides a geologic map of Kendall County. The major aquifer located within Kendall County is the Trinity Aquifer. The Fort Terrett Member of the Edwards Limestone is present within southwestern Kendall County and at the northern portion of the county where it is part of the Edwards-Trinity Plateau Aquifer. All of the geologic units associated with the Aquifers were deposited during the Cretaceous period. The formations comprising the Trinity Aquifer in the area dip or slant downwards towards the southeast becoming thicker in that direction at approximately 100 ft per mile near the Balcones Fault Zone (Ashworth, 1983).

Within the Hill Country region, there are three structural occurrences that effect groundwater properties: the San Marcos Arch, the Llano Uplift and the Balcones Fault Zone. The San Marcos

Arch is a broad fold in the rock layers that exists within Hays County near San Marcos. The San Marcos Arch is an anticline related to the formation of the Llano Uplift and is known to cause thinning formations and restriction in groundwater flow. The Llano Uplift is a large plutonic dome, composed of primarily pre-Cambrian granitic rock and different metamorphic rocks, which serve as the source comprising some of the sands of the Hosston and Hensell Members of the Travis Peak Formation (Ashworth, 1983). These sediments provide the source of elevated radionuclide concentrations found within some wells in Gillespie and Kerr Counties. The Llano Uplift is a regional high in the area which causes the sediments comprising the Trinity Group to pinch out near its base.

The Balcones Fault Zone plays a role in the relationship between the Edwards Aquifer and the Trinity Aquifer in that it juxtaposes the Trinity Group against the Edwards Formation causing a connection between the two aquifers in certain areas. This fault zone is a series of normal en echelon faults that trend in a general northeast/southwest direction extending from Williamson County in the northeast to Kinney County in the west. Faulting associated with the Balcones Fault Zone has caused some rock units to be upthrown against others causing both barriers to flow and conduits for water to pass through. The faulting in the area is the central controlling factor determining the amount and quality of the groundwater that a given well will produce.

The Trinity Aquifer in the Hill Country area spans as far north as Gillespie County and as far south as Bexar, Comal and Hays County where fresh water can be produced. Figure 4 shows the location of the Trinity Aquifer with respect to other major aquifers in the area. The solid green portion reflects the recharge or unconfined zone of the Trinity Aquifer where water replenishes the aquifer. The green diagonal hatched region reflects the artesian or confined zone of the aquifer where the formations that make up the Trinity Aquifer are located beneath the ground surface. Wells located within the confined portion of the aquifer generally have relatively more stable water levels and produce at higher rates. Nearly all of Kendall County has areas of the Trinity Aquifer that are unconfined. For this reason production rates for wells in Kendall County are generally lower than production rates for wells in the confined zone.

Within the far northern portion of Kendall County lies the Fort Terrett Member of the Edwards Group (Fig. 3). The Edwards-Trinity Aquifer's boundaries in Kendall County are defined by the location of where the Edwards Group is saturated (Fig. 4). The Edwards Group provides relatively little water to wells and is not as significant a source of water to the county as the Trinity Aquifer and more specifically, the Middle Trinity Aquifer.

Figure 5 provides a stratigraphic column of the geologic units of Kendall County. The Trinity Aquifer is divided into three sections from oldest to youngest: the Lower, Middle and Upper Trinity Aquifers. Formations comprising the Lower Trinity Aquifer include, from oldest to youngest, the Hosston Sand Member and Sligo Limestone Member of the Travis Peak Formation. Above the Lower Trinity Aquifer is a confining unit separating the Lower Trinity Aquifer from the Middle Trinity Aquifer called the Hammett Shale, also known as the Pine

Island Shale. The Middle Trinity Aquifer is composed of from oldest to youngest, the Cow Creek Limestone, the Bexar Shale, and the Hensell Sand Members of the Travis Peak Formation and the Lower Glen Rose Formation. Above the Middle Trinity Aquifer is the Upper Trinity Aquifer composed of the Upper Glen Rose Formation. The Edwards Group composing the Edwards-Trinity Aquifer resides above the Upper Trinity Aquifer in the northern region of Kendall County where the Edwards Plateau is present.

The Upper Trinity Aquifer in some places produces poor quality water because of the presence of gypsum and anhydrite layers within the Upper Glen Rose Formation. The Middle Trinity Aquifer also contains the Glen Rose Limestone and is separated from the Upper Trinity Aquifer by the presence of a fossil marker bed called the Corbula Bed. The Corbula bed is a heavily fossiliferous layer that contains the small fossil clam called *Corbula martinae*. Typically, the highest yielding portion of the Trinity Aquifer is the Middle Trinity Aquifer and specifically the Lower Glen Rose Formation and the Cow Creek Limestone Member of the Travis Peak Formation. This is because these formations in some localities are fractured limestones. In some areas, the Lower Glen Rose Formation contains the presence of a reef deposit which greatly increases the yield of a well due to its high permeability.

The Lower Trinity Aquifer is composed of conglomerates, and sandstones that are cemented together. The degree of cementing of these sediments controls the ability of water to move through the aquifer and thereby limiting the ability to produce large yielding wells. In localized areas, the Lower Trinity Aquifer can produce wells with moderate yields, although regionally, the Middle Trinity Aquifer produces higher yielding wells with better quality water as compared to the lower Trinity Aquifer.

Section IV: Description of the Trinity (Hill Country) GAM

The Trinity (Hill Country) GAM is a groundwater model that covers the Hill County region of South Central Texas within all or parts of Uvalde, Medina, Bandera, Kerr, Gillespie, Kendall, Bexar, Comal, Blanco, Hays and Travis Counties. The groundwater model consists of three layers: Layer 1 is the Edwards Group; Layer 2 is the Upper Trinity Aquifer; and Layer 3 is the Middle Trinity Aquifer. The Lower Trinity Aquifer was not included in this GAM.

Conceptually, all three of the modeled aquifers are connected hydraulically to some degree or another. The vast majority of precipitation that falls over the area gets evaporated and transpired through vegetation. Some of the precipitation flows out of the area via stream flow and a certain percentage of that precipitation infiltrates into the aquifer. Where the Edwards Group is at the surface, streams that flow over the rocks will recharge the aquifer due to its highly fractured and permeable surface. Where the rock units of the Upper Trinity and Middle Trinity Aquifers are at the surface, precipitation can also enter as recharge.

Cross formational flow occurs between the three aquifers to some extent, although exact estimates of the volume of flow exchanged between each aquifer is unknown. This means that at under certain flow conditions depending upon the water level in each aquifer, water can flow into or out of the Edwards Group into the Upper Trinity Aquifer or visa versa and water can be exchanged between the Upper Trinity Aquifer and the Middle Trinity Aquifer.

Groundwater naturally discharges from each of the three aquifers through seeps and springs and within the Upper and Middle Trinity Aquifers, groundwater predominantly discharges into streams as baseflow. Water within the major rivers in the Hill Country area such as the Guadalupe River is maintained because of this discharge. Groundwater also discharges the aquifer via pumping from wells. Earlier, the associated faulting from the Balcones Fault Zone was said to play a role in the abutment of rock units of the Middle Trinity Aquifer and the Edwards Balcones Fault Zone (Edwards BFZ) Aquifer. This faulting also causes the movement of groundwater from the Middle Trinity Aquifer into the Edwards BFZ Aquifer. It is unknown as to the amount of water that flows from the Trinity Aquifer into the Edwards BFZ Aquifer, although some estimates say that this volume can be substantial.

General Model Construction

The Trinity (Hill Country) GAM consists of three layers from top to bottom: Layer 1) Edwards Group; Layer 2) Upper Trinity Aquifer; and Layer 3) Middle Trinity Aquifer. The main focus of the model was centered on the Middle Trinity Aquifer because of its widespread importance and usage within the area.

The GAM was modeled using MODFLOW-96 which is a three dimensional finite difference model code that was developed by the United States Geological Survey (USGS). The model splits the area that you want modeled into cells consisting of a grid made up of rows and columns that contain specific hydrologic information that is representative of that cell. Each cell in this model represents an area of 1 mi^2. Some of the aquifer parameters that are input into the model cell include hydraulic conductivity, specific storage, specific yield and recharge. What this means is that within each square mile, one value for hydraulic conductivity or recharge is used to represent the entire area. The model contains 3 layers with each layer consisting of 69 rows and 115 columns for a total of 23,805 cells of which 9,262 are active cells.

The structure of the model and thicknesses of each layer were determined by acquiring well logs and geophysical logs from wells completed in the area. The data points were then plotted and contoured to develop the tops and bottoms of each layers of the aquifer. Within Kendall County, approximately fourteen data points were used in developing the thicknesses of each layer of the aquifer.

The conceptual model of the Trinity Aquifer stated that baseflow within streams and rivers in the area are maintained because of the discharge of water from the Trinity Aquifer. This means that at equilibrium the amount of recharge coming into the aquifer would roughly equal the amount of discharge to the baseflow of rivers and streams. With this, Mace and others (2000) estimated recharge for the area by estimating baseflow for the drainage area between the Guadalupe River gaging stations at Comfort and Spring Branch. This is a similar methodology used by Ashworth (1983). They came up with an estimated recharge rate of 6.6 percent of mean annual precipitation for the area. The recharge was then input in the model using data from Kuniansky (1989) which included an analysis of baseflow within 11 sub-basins in the Hill Country region and incorporated rain gaging stations to distribute the recharge within each model cell as a recharge coefficient (percent of rainfall that recharges the aquifer). Recharge was then reduced at each model cell by 45% to better match estimates provided by Ashworth (1983), Bluntzer (1992) and their analysis (Mace and others, 2000). For Kendall County, the recharge coefficient's ranged from 3.0% of mean annual precipitation to approximately 4.5% of mean annual precipitation in the Comfort area. Most of the county had a recharge coefficient of 4.0% of mean annual precipitation. This means that 4.0% of the mean annual precipitation will enter the aquifer as recharge. Recharge will be discussed in greater detail later in the report.

Hydraulic properties of the aquifer such as hydraulic conductivity, specific yield and specific storage were collected from pump tests and specific capacity information from wells completed in each of the aquifers in the area. They (Mace and others, 2000) also conducted 35 aquifer tests. A statistical analysis on the acquired data was performed and the information was distributed within each aquifer using kriging which is a method of contouring data points spatially. In areas where they had no control points available they input the geometric mean from the statistical analysis. The resulting mean hydraulic conductivity for the Middle Trinity Aquifer from their analysis was 2.6 ft/day.

Discharge from the aquifer via well pumping was acquired for the years 1975, 1996 and 1997 from the TWDB Water Use Survey (WUS). The WUS database splits pumping into seven categories: 1) municipal; 2) manufacturing; 3) power; 4) mining; 5) unreported domestic; 6) livestock; and 7) irrigation. Mace and others (2000) then combined manufacturing, power and mining into one category they termed "industrial." The industrial and municipal usage was then related back to each corresponding well via the TWDB and TCEQ databases and telephone interviews. Domestic usage for 1975 was distributed using agricultural and land use maps from the USGS. Domestic pumpage for 1996 and 1997 was evenly distributed over drainage basins in each county excluding municipal areas. Vertical distribution of pumpage for each aquifer was distributed based upon the percentage of domestic wells completed in each aquifer. Mace and others' (2000) analysis suggested that approximately 10,000 acre-feet was produced from the aquifers in 1975 and approximately 36,000 acre-feet in 1997.

Calibration of the Trinity (Hill County) GAM

Groundwater models are generally constructed by first developing a conceptual model of the area. The conceptual model is a description in general terms of how and where water gets into the aquifer, where does the water move within the aquifer and where does it exit the aquifer. It describes the basic structure of the model. For example, the conceptual model of the Trinity (Hill Country) GAM describes where recharge occurs, what the general relationship between each aquifer is and how does the groundwater discharge. The conceptual model determines the framework of the model and helps in constructing the model.

The next step in groundwater modeling is the actual construction of the model and then inputting aquifer properties into each cell. For example, the conceptual model says that recharge will occur where the rock units of the aquifer are at the surface. Within the construction of the model, recharge values are placed within cells that represent the recharge zone. All pertinent data regarding the aquifer(s) are acquired which in part include well logs, pumping tests, water levels, and pumping amounts which are then input into the model.

Once the model is constructed, the next step is to calibrate the model to accurately determine the properties of the aquifer where no data points exist. Calibrating a groundwater model consists of inputting the properties of the aquifer (ie: hydraulic conductivity, specific storage, recharge, discharge and boundary conditions) into each cell of the model and running the groundwater model to see if the model can accurately predict conditions in the aquifer. Groundwater models are typically calibrated to known water levels at wells, spring flow and stream flow. The Trinity (Hill County) GAM was calibrated to water levels within wells and to a lesser degree stream flow within major rivers. The aquifer properties (ie: recharge, hydraulic conductivity and specific storage) are then adjusted until the model can match the calibration points.

The steady state model is first run for calibration and then the transient model. The steady state model is representative of the aquifer at a steady state or equilibrium. This means that the amount of water entering and exiting the aquifer is at equilibrium and that water levels do not change. A steady state model is first run in calibration because of its relative ease in obtaining calibration. Generally, a groundwater model is calibrated using water levels in the aquifer at a time before substantial groundwater production from wells occurred. The Trinity (Hill Country) GAM was calibrated to water levels from the latter part of 1975.

After the steady state model is calibrated, a transient model is run for calibration. A transient model, models the aquifer over a period of time when the aquifer is not at steady state meaning that water levels, spring flow and stream flow change over time. The results of the steady state model are input as starting conditions for the transient model. The longer period of time a transient model is accurately calibrated to, the more accurate the groundwater model will be in predicting future conditions in the aquifer. The Trinity (Hill Country) GAM's transient model represents the years 1996 and 1997.

Upon completion of calibration of the transient model, the groundwater model can then be used to predict aquifer conditions under various scenarios. The amount of actual data that is used in constructing a groundwater model, the assumptions used in the model and the accuracy of the aquifer properties (ie: hydraulic conductivity, recharge and specific storage) input from the calibration determine how believable the predictions are that a groundwater model provides.

Steady State Model

The steady state model of the Trinity (Hill Country) GAM was calibrated to represent water levels from the latter part of 1975. Available water level data was acquired for the Edwards Group, and the Upper and Middle Trinity Aquifers from wells within the modeled area which had water level measurements for the end of 1975. Few water level measurements were available for that time period, so the time interval for water level measurements was expanded to include measurements between 1965 and 1985.

The calibration of the steady state model first started with a determination of which parameters (recharge, hydraulic conductivity, specific storage) had the greatest effect on the output of water levels. Mace and others (2000) state that recharge had a large impact on the water levels in the Middle Trinity Aquifer based upon the model output. From their study, Mace and others (2000) determined that the model was most sensitive to recharge, hydraulic conductivity of the Middle Trinity Aquifer and vertical hydraulic conductivity of the Upper Trinity Aquifer.

The selected recharge rate, which will be discussed in greater detail later in this report plays a large role on the effect of pumpage on water levels. The selected recharge rate used in the model (4 percent of mean annual precipitation) was less than what was estimated by the report's analysis and is the same as that estimated by Ashworth (1983). Ashworth's (1983) estimate was based upon data taken between 1940 and 1960 that included the drought of record. The authors also stated that the calibration of the steady state model was not unique in that as long as the ratio of the recharge rate to the mean hydraulic conductivity was approximately 0.6, the model could be calibrated to water levels.

The water level within calibration target wells was compared to actual water level measurements and was found to have a Root-Mean Squared (RMS) error of 56 ft. This means that on average the water levels from the model differ from actual water levels by approximately +/- 56 ft. The RMS of the model is an important factor that should be taken into account by water planners when viewing the results of predictive model runs. For example, if the planner's goal is to set a DFC of not wanting to lower water levels more than 50 ft in the area, then an RMS of 56 ft could have a large impact on whether the modeled water level decline is accurate.

The calibrated steady state model within Kendall County generally underestimated water levels in the central and south central portion of the county near Boerne from 20 ft to as high as 80 ft, and overestimated the water levels in the northwestern portion of the county near Comfort from approximately 60 ft to 80 ft.

The steady state model was also calibrated to 19 springs of which four were located within Kendall County and to major rivers including the Guadalupe River and Cibolo Creek. The steady state model showed that approximately 303,000 acre-ft/yr of water flowed through the aquifers. 57 percent of that flow discharged to rivers, 21 percent flowed towards the Edwards BFZ Aquifer, 15 percent discharged to springs, 4 percent discharge to lakes and 3 percent was pumped out of the aquifers via wells. The recharge to the aquifers was 303,000 acre-ft, 61 percent of that total recharged the Upper Trinity Aquifer, 19 percent recharged the Edwards Group and approximately 20 percent recharged the Middle Trinity Aquifer. Taking into account cross formational flow between the aquifers, the Upper Trinity Aquifer had a total amount of 190,000 acre-ft of water flowing into it and the Middle Trinity Aquifer had approximately 131,000 acre-ft.

A sensitivity analysis of the steady state model indicated that water levels in the Middle Trinity Aquifer were most sensitive to recharge, horizontal hydraulic conductivity in the Middle Trinity Aquifer and vertical hydraulic conductivity of the Upper Trinity Aquifer (Mace and others, 2000). The vertical hydraulic conductivity of the Upper Trinity Aquifer controlled the amount of water that leaked into the Middle Trinity Aquifer. Lower recharge amounts and higher horizontal hydraulic conductivities resulted in lower water levels. Higher recharge amounts and lower horizontal hydraulic conductivities resulted in higher water levels. The steady state model used recharge rates that were lower than the estimated recharge rates calculated in the Trinity (Hill Country) GAM report (4 percent of mean annual precipitation versus 6.6 percent of mean annual precipitation) and higher horizontal hydraulic conductivities than the available data (geometric mean hydraulic conductivity of 7.5 ft/day versus 2.6 ft/day).

Transient Model

The transient model represents the years 1996 and 1997 and contains inputs to represent pumpage, recharge and water levels. The steady state model was used as a starting point in the calibration of the transient model. Specific storage and specific yield values were adjusted in the transient model until the model was calibrated to water levels within certain wells. Specific storage values of 1×10^{-5}, 1×10^{-6} and $^{1} \times 10^{-7}$ and specific yield values of 0.008, 0.0005 and 0.0008 were used for the Edwards Group, Upper Trinity Aquifer and middle Trinity Aquifer respectively. There was no information provided on the RMS error of the transient model.

Predictive Modeling

The purpose of the TWDB GAM's is to be able to predict what the impacts to an aquifer would be under various climatic and production scenarios. In addition, each GAM is also used to predict the impacts on the aquifer from a drought of record. The drought of record for the Texas Hill Country region is defined as the years 1950 to 1956 when precipitation was at its lowest. Mean annual precipitation at Boerne during this time was approximately 22 inches and for the years 1954 to 1956 the mean annual precipitation was approximately 13.9 inches (Mace and others, 2000). The predictive model included the transient model years (1996 and 1997) and had predictive modeling representing the years 1998 to 2050.

Six predictive model runs were conducted which are summarized as follows (from Mace and others, 2000):

1. Baseline Run – Average recharge through 2050;
2. 2010 Run – Average recharge through 2003 and drought of record recharge for the remaining seven years;
3. 2020 Run – Average recharge through 2013 and drought of record recharge for the remaining seven years;
4. 2030 Run – Average recharge through 2023 and drought of record recharge for the remaining seven years;
5. 2040 Run – Average recharge through 2033 and drought of record recharge for the remaining seven years;
6. 2050 Run – Average recharge through 2043 and drought of record recharge for the remaining seven years;

Average recharge was defined by using the recharge coefficients established as described earlier (4.0 percent of mean annual precipitation) multiplied by the average precipitation for the years 1960 to 1990. Drought of record recharge was defined by using the same recharge coefficients multiplied by the mean annual precipitation from rain gaging stations for the years 1950 to 1956. Average recharge for the modeled area amounted to approximately 294,700 acre-ft/yr and drought of record recharge was approximately 128,900 acre-ft/yr cumulatively for all the aquifers (Mace and others, 2000).

Water level declines were calculated at the end of each decade (2010, 2020, 2030, 2040 and 2050) by subtracting the water levels at the end of each decade of the predictive model runs from the water levels at the end of the transient model run (1997). Pumpage for each of the predictive model run years were input from the Regional Water Planning Group (RWPG) projections under dry conditions. This is the pumpage that would occur during a dry period in the year which would account for a higher amount of pumpage than under normal conditions. Mace and others (2000) state that the dry demand pumpage from the RWPG's are 2 to 20 percent higher than normal demands and that on average the difference is approximately 6 percent higher.

The predictive runs showed that the largest amount of drawdown occurred within southern Kendall County, northern Bexar County, western Comal County and in Hays and Travis Counties. Summaries of each run for Kendall County are as follows:

- 2010 Run- under average recharge the Boerne area experienced approximately 25 ft of drawdown while the southern portion of Kendall County experienced approximately 10 ft of drawdown. The northern portion of the county had less than 10 ft of drawdown.

  For average recharge through 2003 and drought of record recharge from 2004 to 2010 the Boerne area experienced over 100 ft of drawdown while most of the county experienced over 25 ft of drawdown.

- 2020 Run- under average recharge the Boerne area experienced approximately 25 ft of drawdown while the southern portion of Kendall County experienced approximately 10 ft of drawdown. The northern portion of the county had less than 10 ft of drawdown.

  For average recharge through 2013 and drought of record recharge from 2014 to 2020 the Boerne area experienced over 100 ft of drawdown while most of the county experienced over 25 ft of drawdown.

- 2030 Run- under average recharge the Boerne area experienced approximately 50 ft of drawdown while the southern portion of Kendall County experienced approximately 25 ft of drawdown. The northern portion of the county had approximately 10 ft of drawdown.

  For average recharge through 2023 and drought of record recharge from 2024 to 2030 the Boerne area and most of southern Kendall County experienced over 100 ft of drawdown while most of the county experienced over 25 ft of drawdown.

- 2040 Run- under average recharge the Boerne area experienced approximately 50 ft of drawdown while the southern portion of Kendall County experienced approximately 25 ft of drawdown. The northern portion of the county had approximately 10 ft of drawdown.

  For average recharge through 2033 and drought of record recharge from 2034 to 2040 the Boerne area and most of southern Kendall County experienced over 100 ft of drawdown while most of the county experienced over 25 ft of drawdown.

- 2050 Run- under average recharge the Boerne area experienced over 100 ft of drawdown while the southern portion of Kendall County experienced approximately 50 ft of drawdown. The northern portion of the county had approximately 10 ft of drawdown.

  For average recharge through 2043 and drought of record recharge from 2044 to 2050 the Boerne area and most of southern Kendall County experienced over 100 ft of drawdown while most of the county experienced over 25 ft of drawdown.

The drawdown around the Boerne area and northern Bexar County is the largest in the modeled area. Mace and others (2000) state that the groundwater flow to rivers might decrease 60 to 65 percent and discharges to springs might decrease 55 percent. According to the model, dry cells occurred in northern Bexar County on the border with southern Kendall County meaning that the aquifer went dry at these locations.

GAM Run 7-18

The TWDB in a report dated January 13, 2007 updated the Trinity (Hill Country) GAM and reran the predictive model runs under the name GAM Run 7-18. The modifications to the model included:

- Changing the drain conductance in two cells representing springs to reduce water budget errors;
- Updated the pumpage for the stress period representing 2043;

The predictive model runs were unable to converge when run with 59 stress periods (representing 1996 to 2030) and 49 stress periods (representing 1996 to 2020).

The updated changes to the model produced similar results as the original model although the 50 ft and 100 ft drawdown areas experienced in the southern Kendall County, northern Bexar County and western Comal County expanded slightly. The results of the GAM Run 7-18 indicated that results of the two modeling efforts were similar with the exception of the increased area that experienced 50 ft and 100 ft drawdown and that the amount of recharge under drought of record conditions in the GAM run 7-18 was slightly lower.

Section V: Water Levels within Kendall County and Comparison to the Trinity (Hill Country) GAM

Regionally, within the Middle Trinity Aquifer water flows from the recharge zone under gradient south and southeast towards the confined zone generally following the topography. The groundwater flows from areas of higher potential head to lower and can vary considerably on a localized scale dependant upon fracture orientation and connectivity.

As discussed earlier, the Middle Trinity Aquifer dips towards the southeast becoming thicker towards the confined zone of the aquifer where it is under pressure. The further downdip one travels, the larger the water column will be within the well and generally, the more stable the water level. Water levels within the Middle Trinity Aquifer especially those of shallow wells within the recharge zone can vary seasonally up to tens of feet with a response to drought or a precipitation event. The recharge zone of the Trinity Aquifer shown in Figure 4, is located throughout Kendall County with the confined portion of the aquifer located further south within southeastern Bexar, Comal and Hays Counties.

The Middle Trinity Aquifer naturally discharges water through seeps and springs and through flow into the Upper and Lower Trinity Aquifer depending upon water level conditions. Water levels in an aquifer will rise and fall with changes in the amount of storage in the aquifer. When recharge to the aquifer is low, water is taken from storage thereby lowering the water level. When recharge occurs, water is added to storage thereby causing the water level to increase.

Because the unconfined zone is closest to areas where recharge occurs and also the furthest updip in the aquifer, these areas will have the biggest changes in water level with response to a decrease or increase in recharge. Changes in water levels in the unconfined zone of the aquifer occur because water is taken out of storage by vertical drainage of the aquifer. The aquifer is not fully saturated in the unconfined zone and thus the water level decrease causes the saturated thickness of the aquifer to decline. The confined zone however, has more stable water level because it responds to changes in storage differently. In the confined zone, the aquifer is under pressure and the entire rock formation is saturated. When water level declines in the confined portion of the aquifer water is released from storage but the aquifer is still fully saturated. This is because the formation contracts with a lowering in pressure which releases water from storage.

Water levels whether in the unconfined or confined zone are impacted by pumping from wells. The transmissivity of an aquifer also has an impact on determining the extent to which water level will decline or increase at a well. Transmissivity in plain words is a measure of the ability of an aquifer to allow water to move within itself. The higher the transmissivity of an aquifer, the faster water can flow within it. When water level declines due to pumpage in a well, water flows from the aquifer towards the well due to a change in pressure. If the transmissivity of the aquifer is high, water will flow to the well faster, causing less drawdown in the well. How stable the water level at a well location will be, depends upon where the well is located in the aquifer, (unconfined or confined zone), recharge to that aquifer and the transmissivity of the aquifer.

As the Hill County has become more populated and the need for water has increased, water levels have been more impacted especially during drought because of the number of wells and the fact that many of these wells are shallow wells located in the unconfined zone. During drought, well production decreases rapidly in these areas because the wells are shallow and the pumps cannot be lowered further down the well, thus with the decrease in head, the pump cannot produce at the same rate it once did. These areas are hardest hit during drought for this reason. Public water systems in these areas suffer because production decreases rapidly and cannot be increased in the well until large rain events occur to replenish the aquifer. Wells deeper in the Middle Trinity Aquifer within the confined zone do not decrease in water level to the same extent that wells in the unconfined zone do during drought. Wells in the confined zone with properly sized pumps, will show decrease in water level during drought to some degree, but well production in most cases can be maintained because of the large amount of water column in the well.

Figure 6 provides a potentiometric surface map of the Middle Trinity Aquifer from water level elevations within wells for the winter of 1975 and Figure 7 provides the potentiometric surface map for the Middle Trinity Aquifer for the summer of 2006. These two dates were chosen to produce water level maps because during 1975 relatively less pumping was occurring within the aquifer so it represents to some degree pre-development conditions within the aquifer and the summer of 2006 was chosen because it represents conditions in the aquifer during increased development and drought. At the Boerne rain gaging station, the reported precipitation between September 2005 and September 2006 was 18.32 inches, which was approximately 15.7 inches less precipitation than the annual average of 34 inches.

Water level elevations were acquired from the TWDB water well database for Figure 6 and Figure 7. For water level elevations representing the winter of 1975, wells with available data for that time period were first acquired and plotted. Because of the limited amount of data representing the winter of 1975, available water level elevations for the years 1973 to 1976 were added to the dataset. Water level elevations representing the summer of 2006 were acquired in a similar manner with available data from wells for the summer of 2006 first plotted and then additional data added to the dataset representing the winter of 2005 through January 2007.

Based upon the data in Figure 6 and Figure 7, the water level elevation of the Middle Trinity Aquifer between the winter of 1975 and the summer of 2006 has remained relatively similar. Both water level maps show the general direction of groundwater movement towards the southeast with small cones of pumpage around Comfort and Boerne. The differences in water level stability updip within the aquifer versus further downdip in the aquifer and between pre-development conditions (Fig. 6) and development conditions (Fig. 7) during drought is illustrated by looking at the water level elevations in the northern portion of Kendall County versus the southeastern area of the county. Greater water level changes have been experienced in the shallower portion of the aquifer to the north versus the southeast where the aquifer is thickest.

The northern portion of the county experienced a greater difference in water level compared to the southeastern portion in part because of where the two areas are located within the Middle Trinity Aquifer. The north side of Kendall County is located updip in the Middle Trinity Aquifer in an area where the aquifer is thinner and has less saturated thickness. The Boerne area by comparison is located in a relatively thicker portion of the aquifer with greater saturated thickness. As described earlier the thickness of the Middle Trinity Aquifer increases in the downdip direction towards the southeast and wells closer to the confined zone of the aquifer will generally show more stable water levels.

Although the differences in water level elevation in the Middle Trinity Aquifer in Figure 6 and Figure 7 show a decrease in some areas, this does not necessarily mean that the aquifer is being dewatered by production. The water level within the Middle Trinity Aquifer will rise and fall throughout Kendall County naturally dependent upon the amount of rainfall. To be able to determine the extent of production on the aquifer, long term hydrographs of wells need to be analyzed. If the hydrographs show a long term decrease in water level, then this may point to increased production slowly dewatering the aquifer over time. If the hydrographs show a continued pattern of rising and falling water levels with no trend of a decrease in water level, then this would point to the aquifer remaining relatively stable. Because the Middle Trinity Aquifer is a karst aquifer, water levels will respond quickly to drought or precipitation. It is natural for the aquifer to experience higher water levels during increased precipitation and lower water levels during drought.

Figures 8a, 8b, 8c and 8d are hydrographs from selected Middle Trinity Aquifer wells throughout Kendall County except for one Upper Trinity Well (FM 3351 Well) and one Lower Trinity Well (Rio Frio Well). Water levels for Figure 8a were taken from the TWDB water well database and bi-monthly data for the remaining figures were provided from the District between 2001 and 2008.

The well hydrographs illustrate the differences in water level stability and well location within Kendall County. All of the Middle Trinity wells located in the southeast portion of the county (Coveney Fig. 8b; Kendall Woods Fig. 8b; Rio Cordillera Fig. 8c; and Cordillera Trace Fig. 8c) exhibit the most stable water levels within the Middle Trinity Aquifer and show no signs of a downward trend in water level.

State Well No. 6811708 (Fig. 8a), the Bergenplatz Well (Fig. 8d), Twin Canyon Well (Fig. 8d) and the Schwope Well (Fig. 8d), also exhibit stable water levels with no long term decreasing trend in water level. These wells show a somewhat larger change in water level between dry and wet periods.

Further updip within the central portion of the county, the Comfort Well (Fig. 8a) and State Well No. 6802609 (Fig. 8a) both show relatively stable water levels with greater differences in water level between periods of precipitation and drought. These wells are located in a thinner portion of the aquifer as compared to the southeast and although water levels have remained relatively stable, the highs and lows in water level are exaggerated more so in this area.

Four of the wells in Figure 8 show a downward trend in water levels; State Well No. 5758706 (Fig. 8a), the Turkey Knob Well (Fig 8c), Diamond Ridge Well (Fig. 8c) and the Rio Frio Well (Fig. 8b). The Turkey Knob and Diamond Ridge wells are both Middle Trinity Wells located in the deeper portion of the aquifer in the southwest corner of Kendall County and since 2002, in the Turkey Knob Well and 2004, in the Diamond Ridge Well water levels in these wells have been experiencing a decline of approximately fifteen to twenty feet. Since the drought in 2006, both wells have had declines in water level but have yet to rebound. It is unknown whether development in these areas is causing the decline since there appears to be no large scale development in the area or whether the wells are just slow in rebounding water level since they are further downdip in the aquifer. State Well No. 5758706 completed within the Hensell Sand, located in northern Kendall County has also shown a steady decline in water level since approximately 1990. The Rio Frio Well is a Lower Trinity Well that is located in the southeast corner of Kendall County. The decline in water level in the Rio Frio Well may be attributed to the relatively smaller amount of recharge to the Lower Trinity Aquifer and the lower permeability of the aquifer which affects the rate of recovery of water levels in the aquifer from a precipitation event. In addition, conversations with District staff (Micah Voulgaris personal communication) and the Texas Department of Licensing and Regulation (TDLR) well database have indicated that there are other domestic wells completed in the area around the Rio Frio Well within the Lower Trinity Aquifer which may be causing an impact on the water levels of the aquifer locally.

One Upper Trinity well (FM 3351; Fig. 8b) located near the Rio Frio well in southeastern Kendall County has exhibit stable water levels with no long term trend showing a decrease in water level.

The predictive model runs of the Trinity (Hill Country) GAM at average recharge conditions had forecast over 25 ft of drawdown in the City of Boerne area between 1996 and 2010. To be able to determine the accuracy of these predictions, a comparison of the Trinity (Hill Country) GAM's predictions to the hydrographs provided in Figure 8 were conducted. The GAM used a pumpage amount of 3,686 acre-ft in Kendall County for the year 2000. By comparison the TWDB WUS estimates have shown that approximately 3,499 acre-ft were pumped from wells in the Trinity Aquifer for the Year 2000. The GAM's pumpage predictions for the year 2000 were very close to actual pumpage. The GAM predicted a drawdown of over 25 ft in the Boerne and surrounding southern Kendall County area between 1996 and 2010 for average recharge conditions. By comparison, the hydrographs of State Well No. 6811708 and the Schwope Well, both located within the City of Boerne do not indicate the large amount of drawdown that the GAM predicts during a time span which experienced two droughts (1996 and 2006).

State Well No. 6811708 has a decline in water level between Feb. 1996 and Feb. 2007 of 10.84 ft (Fig. 8a) and the Schwope Well has a decline in water level from March 2002 and March 2008 of 8.42 ft (Fig. 8d). Although both wells show a decline in water level between the dates indicated, the Middle Trinity Aquifer does not behave like a sand aquifer such as the Carrizo Aquifer where water levels gradually decline. If other dates were selected in the hydrographs of these two wells it can be shown that water levels have increased. For example, between Feb. 1990 and Feb. 2008 State Well No. 6811708 has experienced an increase in water level of 4.65 ft (Fig. 8a) and the Schwope Well has increased 11.95 ft between Sept. 2003 and Sept. 2005 (Fig. d).

The hydrographs in Figure 8 are representative of how water levels react within the Middle Trinity Aquifer. The water level in the wells will rise and fall dependant upon the amount of precipitation occurring. Generally, wells further downdip will have more stable water levels than wells further updip. Even with the large changes in water level, there appears to be no long term trend of increasing or decreasing water levels in the Middle Trinity Aquifer based upon the water level data provided in Kendall County. This is because precipitation, which plays a large role in water levels is cyclic in the Texas Hill Country region, thus well hydrographs will show relatively short term peaks and valleys associated with wet and dry times, while the long term trend of water level within the aquifer remains moderately stable.

The data also indicate that water levels have remained relatively stable over the past twenty-five years in the Comfort area (Fig. 8a) and the past thirty-four years in the Boerne area (Fig. 8a). There are areas of the county which have experienced a decreasing trend in water levels such as the Lower Trinity Aquifer around the Rio Frio Well (Fig. 8d) and the southwest corner of the county near the Turkey Knob and Diamond Ridge wells (Fig. 8c).

Section VI: Recharge within Kendall County and Comparison to the Trinity (Hill Country) GAM

Recharge to the Trinity Aquifer is primarily through rainfall on the aquifer where the rock units are at the surface and through stream and lake losses. The karst nature of the rock units that compose the Trinity Aquifer allow for very rapid recharge to the aquifer. In this respect, the Trinity Aquifer is similar to the Edwards Aquifer in that recharge from large precipitation events can refill the aquifer very quickly. Figure 9 provides a map showing the average annual precipitation in Kendall County and the location of rain gages within the county.

In Kendall County, recharge occurs throughout the county; in the northern portion of the county where the Fort Terrett Member of the Edwards Group is at the surface (Fig. 3) recharge to the Edwards-Trinity Aquifer occurs and in the rest of the county, recharge to the Upper and Middle Trinity Aquifer occur where the Upper Glen Rose and Lower Glen Rose Formations are located (Fig. 3).

Recharge is the most important factor involved in determining what the effects of pumpage will be on the aquifer and for a water planner, what the allowable amount of water to permit. Obtaining an accurate estimate of recharge to the Trinity Aquifer will allow the District to better determine the sustainable yield of the aquifer. In addition, recharge input into a groundwater model plays a large role in determining the amount of drawdown that will occur under various scenarios. Mace and others (2000) stated that based upon their sensitivity analysis of the aquifer, water levels in the model were most sensitive to recharge, horizontal hydraulic conductivity of the Middle Trinity Aquifer and vertical hydraulic conductivity of the Upper Trinity Aquifer and that water levels were less sensitive to pumping than other model parameters.

Almost all of the estimates of recharge to the Trinity Aquifer have been based upon stream baseflow and have been reported with respect to percent of mean annual precipitation. This relationship of recharge to stream baseflow is appropriate because most all of the streams in the Texas Hill Country are gaining streams receiving flow from the aquifer. In areas of low pumpage, the amount of baseflow gained by the stream through discharge of the aquifer should therefore approximately equal the amount of recharge (Ashworth, 1973). Recharge estimates to the Trinity Aquifer by other studies have ranged from 1.5 percent of mean annual precipitation (Muller and Price, 1979) up to 11 percent of mean annual precipitation (Kuniansky, 1989). Ashworth (1983) estimated recharge to the Trinity Aquifer to be 4 percent of mean annual precipitation by analyzing baseflow of the Guadalupe River between the Comfort gage and Spring Branch gage between 1940 and 1960. Mace and others (2000) used a similar approach to Ashworth's (1983). They employed an automated digital hydrograph-separation technique from Nathan and McMahon (1990) and Arnold and others (1995) to estimate a recharge rate of 6.6 percent of mean annual precipitation. They later reduced this recharge rate to 4 percent to be able to calibrate the Trinity (Hill Country) GAM.

Recharge in the Trinity (Hill Country) GAM played a larger role in determining the impacts to water levels than did pumpage. Therefore, to have the utmost confidence in the GAM's predictive model runs, it is most important to obtain the most accurate value of recharge possible. When calibrating the model, Mace and others (2000) state *"If we honored the mean hydraulic conductivity of the Middle Trinity Aquifer based on measured values (2.6 ft/day), we could calibrate the model with a recharge rate of about 1.5 percent of mean annual* *precipitation. If we honored the estimated recharge rate (6.6 percent of mean annual precipitation), we could calibrate the model with a mean hydraulic conductivity of about 13 ft/day for the Middle Trinity Aquifer. For the final calibration, we selected a recharge rate of 4 percent of mean annual precipitation and a geometric mean hydraulic conductivity of 7.5 ft/day for the Middle Trinity Aquifer."*

The recharge rate used in the GAM (4 percent of mean annual precipitation) was the same rate estimated by Ashworth (1983) which included much of the data during the drought of the 1950's. This recharge rate was then applied throughout the predictive model runs in the Trinity (Hill Country) GAM which resulted in drawdowns of over 100 ft in the Boerne area. The predictive model runs were run with what was termed "average" recharge conditions and "drought-of-record" recharge conditions. The model applied recharge by assigning a recharge coefficient to each model cell. A recharge coefficient is simply the percent of mean annual precipitation that will recharge the aquifer represented in decimal format. Mean annual precipitation is then input into the model distributed by rain gage data in the area, so that the recharge applied in the model is the result of the recharge coefficient multiplied by the mean annual precipitation amount.

When the predictive modeling was run, the "average" recharge conditions were in actuality at a recharge coefficient that represented drought conditions multiplied by average rainfall, and the "drought-of-record" conditions were at a recharge coefficient representing drought conditions multiplied by low rainfall.

To be able to gain a better understanding of recharge to Kendall County, we used a similar approach to Ashworth (1983) using a hydrograph-separation technique based upon Nathan and McMahon (1990) and Arnold and others (1995) in addition to using Kunaiansky's (1989) area of the sub-basin between the Comfort gage and the Spring Branch gage along the Guadalupe River. Stream flow data for these two gages were then used to estimate recharge for the years 1940 through 2007 (Table 1). Table 1 provides our estimates for recharge to Kendall County both as a volume and as a percent of mean annual precipitation. Figure 10 shows the location of the gages used in our recharge estimate in addition to the sub-basin of the Guadalupe River after Kuniansky (1989).

Recharge was calculated using a recursive formula known as the Recursive Digital Filter. The purpose of this filter is to subtract the rainfall run off from the total stream flow at both the Comfort gage and the Spring Branch gage to determine the baseflow component of the Guadalupe River within this strectch (baseflow = total stream flow – rainfall run off). This method of separating rainfall run off from base flow was taken from Nathan and McMahon (1990) and Arnold and others (1995).

The following equation is used in determining rainfall run off (Nathan and McMahon, 1990):

$$q_t = .925 * q_{t-1} + .9625 * (Q_t - Q_{t-1})$$

where: q_t is the rain fall run off for the day given;

q_{t-1} is the rain fall run off for the day before the day given;

Q_t is the total stream flow for the day given; and

Q_{t-1} is the total stream flow for the day before the day given.

Ashworth's (1983) estimated recharge rate of 4 percent of mean annual precipitation for the years 1940 through 1960 by comparison is less than our estimate of 6.79 percent of mean annual precipitation for those same years using the Recursive Digital Filter method. Between the years 1940 and 2007 our estimated recharge rate to the Trinity Aquifer is 9.45 percent of mean annual precipitation which is greater than the 6.6 percent estimated by Mace and others (2000) and the 4 percent used in the Trinity (Hill Country) GAM.

The "average" recharge conditions used in the GAM likely overestimate the impacts of drawdown because of the lower recharge coefficient used (4 percent of mean annual precipitation) than what was estimated based upon our approach (9.45 percent of mean annual precipitation) and also overestimates the impacts of drawdown under "drought-of-record" conditions due to the lower recharge coefficient used (4 percent of mean annual precipitation) than what was estimated using our approach (6.79 percent of mean annual precipitation). To more accurately reflect recharge in the GAM, separate recharge coefficients should be used reflecting "average" and "drought-of record" conditions.

Section VII: Discharge within Kendall County and Comparison to the Trinity (Hill Country) GAM

Production from wells over 25,000 gallons per day (gpd) within Kendall County is regulated by the District. To date there is currently 3,627.02 acre-ft/yr of operating permits allocated to users within the District. The District's Management Plan states that there is 905 acre-ft/yr of water available within the Edwards-Trinity Aquifer and 3,935 acre-ft/yr available within the Trinity Aquifer. There are also many unmetered exempt wells located throughout the District which are able to produce up to 25,000 gpd for livestock or domestic uses. Because most of Kendall County is rural with relatively few public water systems serving the county, much of the production of groundwater is under exempt permits making it difficult to quantify the total amount of groundwater produced on an annual basis.

Table 2 provides pumpage amounts from 1980 to 2003 within Kendall County from the Trinity Aquifer based upon the TWDB's Water Use Survey (WUS). Based upon the WUS, production within the county has slowly increased over time from approximately 2,000 acre-ft/yr in the early 1980's to near 4,000 acre-feet/yr of production in early 2000, with the majority of pumpage used for municipal purposes mainly within the City of Boerne and Comfort. To be able to fully understand the impacts of pumpage and to better determine the availability of groundwater the exempt well production within the District needs to be better quantified.

As discussed within Section V (*Water Levels within Kendall County and Comparison to the Trinity (Hill Country) GAM*), the water levels within the Middle Trinity Aquifer in most of the District have remained relatively stable since the mid to late 1970's. The decline in water level within wells appears to be impacted more so by a lack of precipitation than actual pumpage. The aquifer in many cases will regulate itself during drought in that during dry periods, water levels will drop substantially and the well will not be able to produce the same volume of water it did during wetter times, thereby reducing production out of the aquifer. When large scale precipitation occurs the aquifer will rise in water level and thereby increasing its production capability.

The Trinity (Hill Country) GAM has modeled production out of Kendall County in its predictive model runs from the year 2000 thru 2050. Table 3 provides the production amounts used in the GAM for the predictive model runs split into various usage categories. The GAM estimates 5,581 acre-ft/yr of production in the year 2010 and up to 13,156 acre-ft/yr of production in 2050 (Table 3). These production amounts were taken from the TWDB WUS for dry demand production, meaning demand during periods of dry times usually summer time production.

Currently, production out of the District including exempt well usage has been near the 5,581 acre-ft/yr production rate used in the GAM predictive model runs for 2010. According to the GAM, under average recharge conditions the water level in southern Kendall County will drawdown over 25 ft at this production rate after 10 years of pumpage. In reality, the water levels in southern Kendall County have remained relatively stable and in some cases (Kendall Woods and Coveney Wells: Fig. 8b) have risen over the past seven years even though production has increased.

Section VIII: Conclusions

The Trinity (Hill Country) GAM is the most comprehensive groundwater model created to date of the Trinity Aquifer within Texas Hill County. Much data has been compiled and also obtained in the creation of the model including pump test, water level, production and precipitation data. The model has done an excellent job in building the framework of a GAM that will help planners in the area. As with most groundwater models, recharge is one of, if not the most controlling factor in determining the amount of drawdown that occurs due to pumpage. Because of this, the recharge amounts used in the model need to be as accurate as possible using the best available information.

The District is tasked along with other districts in GMA 9 with determining a DFC which will then be used by the TWDB to acquire a MAG number to allocate the available amount of water for permitting. The GAM model is to be used as a tool in determining the DFC and as such the goals of this study are to determine whether the Trinity (Hill Country) GAM overestimates, underestimates or accurately estimates the groundwater resources of the District based upon a comparison with actual data.

The data gathered within this study which includes well hydrographs, an analysis of discharge and an estimation of recharge using a Recursive Digital Filter approach were compared to the input data for the Trinity (Hill Country) GAM and the results of the predictive model runs. Based upon our gathered data it appears that the Trinity (Hill Country) GAM likely overestimates the amount of drawdown that would be experienced within the predictive model runs. This is for several reasons:

- Well hydrograph data indicate that water levels in the southern and southeastern portion of the county have remained relatively stable over the past 30 years; there appears to be no long term trend of increasing or decreasing water levels in the Middle Trinity Aquifer in this portion of the county. This is because precipitation, which plays a large role in water levels is cyclic in the Texas Hill Country region, thus well hydrographs will show relatively short term peaks and valleys associated with wet and dry times, while the long term trend of water level within the aquifer remains moderately stable;

- There are areas within Kendall County which are showing water level declines, this includes the Lower Trinity Aquifer in the area surrounding the Rio Frio Well, the southwest corner of the county within the Middle Trinity Aquifer near the Diamond Ridge and Turkey Knob wells and in the northern portion of the county within the Middle Trinity Aquifer near State Well No. 5758706;

- An analysis of pumpage within Kendall County coupled with water level data indicate that there has not been large scale drawdown occurring in southern Kendall County near the City of Boerne as the Trinity (Hill Country) GAM has predicted at similar production rates; and

- The "average" recharge conditions used in the GAM likely overestimate the impacts of drawdown because of the lower recharge coefficient used (4 percent of mean annual precipitation) than what was estimated based upon our approach (9.45 percent of mean annual precipitation) and also overestimates the impacts of drawdown under "drought-of-record" conditions due to the lower recharge coefficient used (4 percent of mean annual precipitation) than what was estimated using our approach (6.79 percent of mean annual precipitation). To more accurately reflect recharge in the GAM, separate recharge coefficients should be used reflecting "average" and "drought-of record" conditions.

The Trinity (Hill Country) GAM seems to be an appropriate tool for predicting water levels in the Trinity Aquifer under various pumping scenarios for the most part. Based upon the analysis in this study, the results of the predictive modeling appear to overestimate the impact of pumping likely due to the use of conservative recharge numbers in the model. It is recommended that the model be input with recharge numbers that more accurately reflect the data and be recalibrated to better determine the impacts of pumpage on the aquifer.

Section IX: Bibliography

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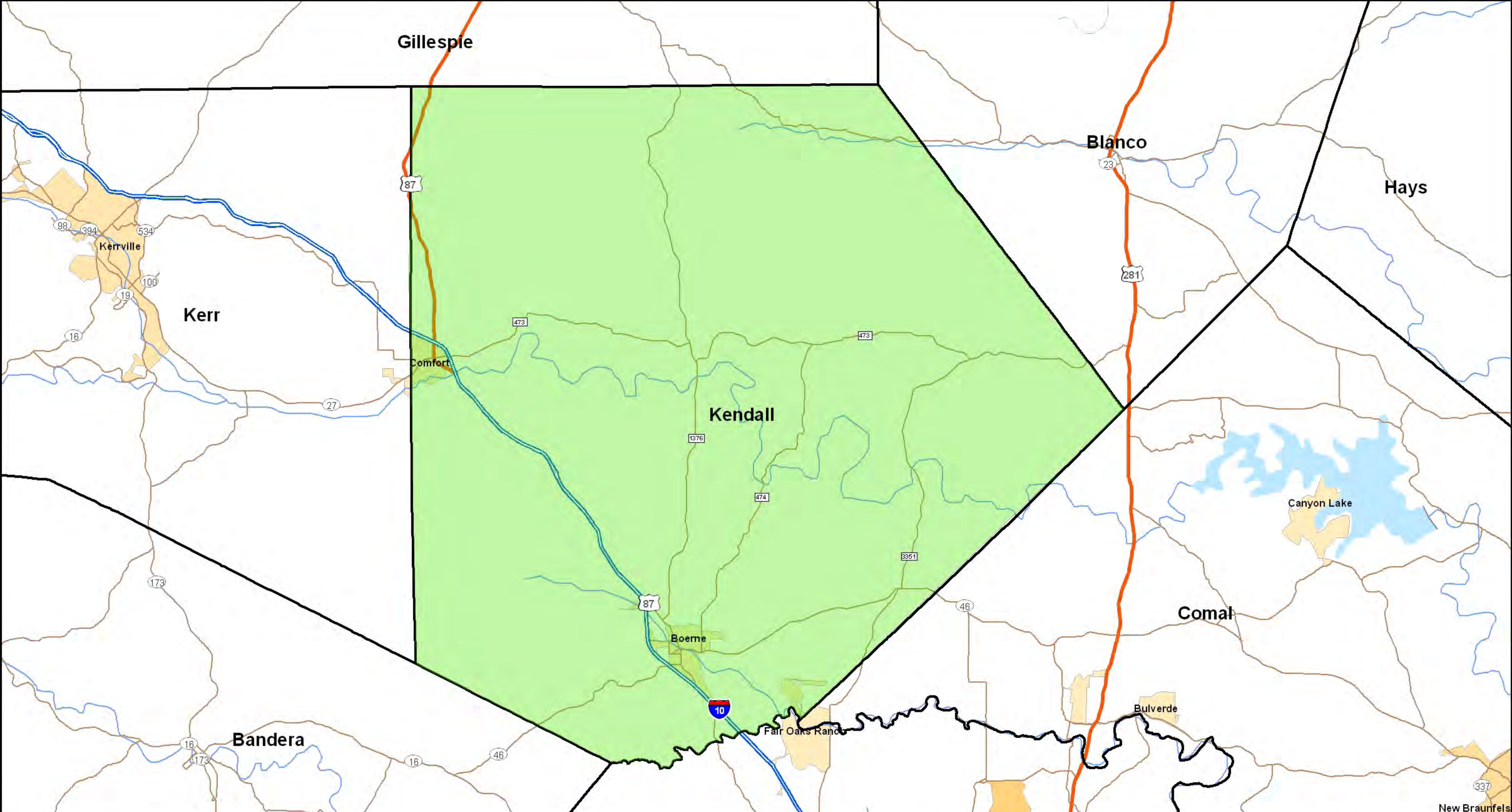
Figures



SCALE: 1 in = 4 miles

DRAWN BY: LKF DATE: 4/08

CHECKED BY: KK DATE: 4/08

PROJECT NO: 055-002-08

Legend

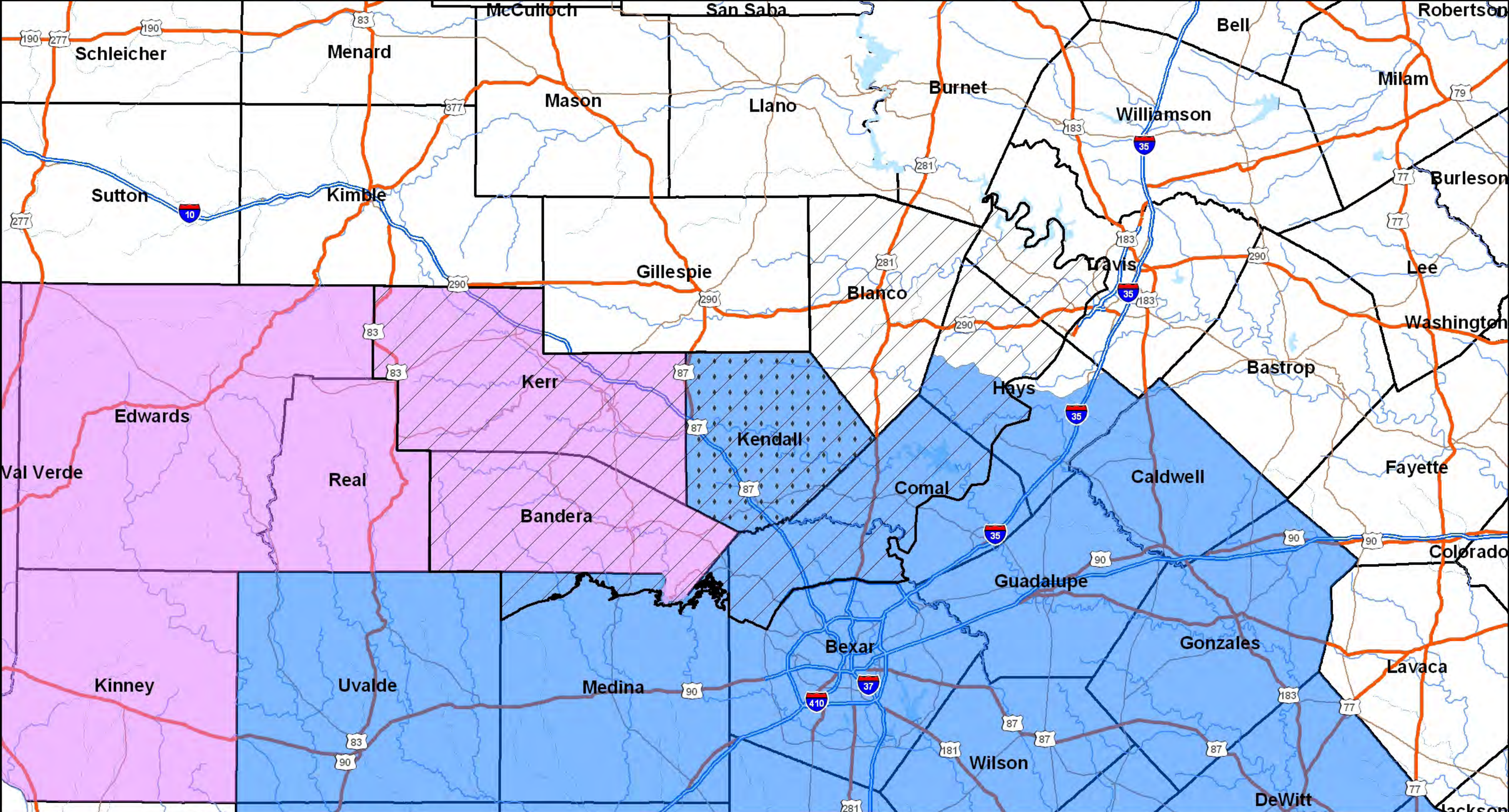
Cow Creek Groundwater Conservation District

FIGURE 1: COW CREEK GROUNDWATER CONSERVATION DISTRICT BOUNDARY

COW CREEK GCD

KENDALL COUNTY, TEXAS

WET ROCK GROUNDWATER SERVICES, L.L.C.
GROUNDWATER SPECIALISTS
P.O. BOX 163144 AUSTIN, TEXAS 78716
PH: (512) 773-3226 FAX: (512) 879-6809



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DRAWN BY: LKF DATE: 4/08
CHECKED BY: KK DATE: 4/08
PROJECT NO: 055-002-08

Legend

- Cow Creek Groundwater Conservation District
- Groundwater Management Area 9
- Regional Water Planning Group J
- Regional Water Planning Group L

FIGURE 2: MAP OF REGULATORY BOUNDARIES

COW CREEK GCD

KENDALL COUNTY, TEXAS

WET ROCK GROUNDWATER SERVICES, L.L.C.
GROUNDWATER SPECIALISTS
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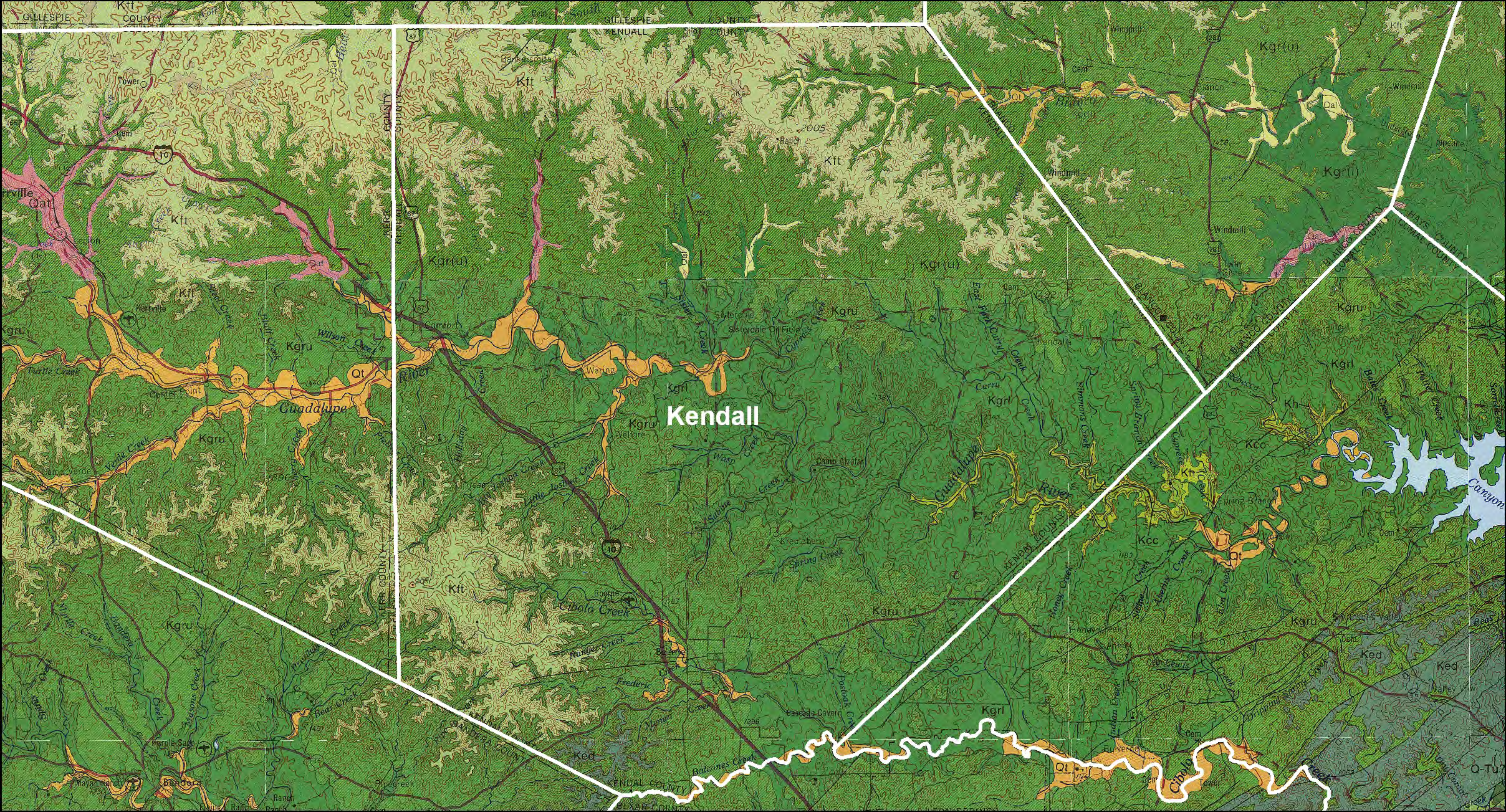

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PROJECT NO: 055-002-08	

FIGURE 3: COW CREEK GROUNDWATER CONSERVATION DISTRICT - GEOLOGIC MAP

COW CREEK GCD

KENDALL COUNTY, TEXAS

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GROUNDWATER SPECIALISTS
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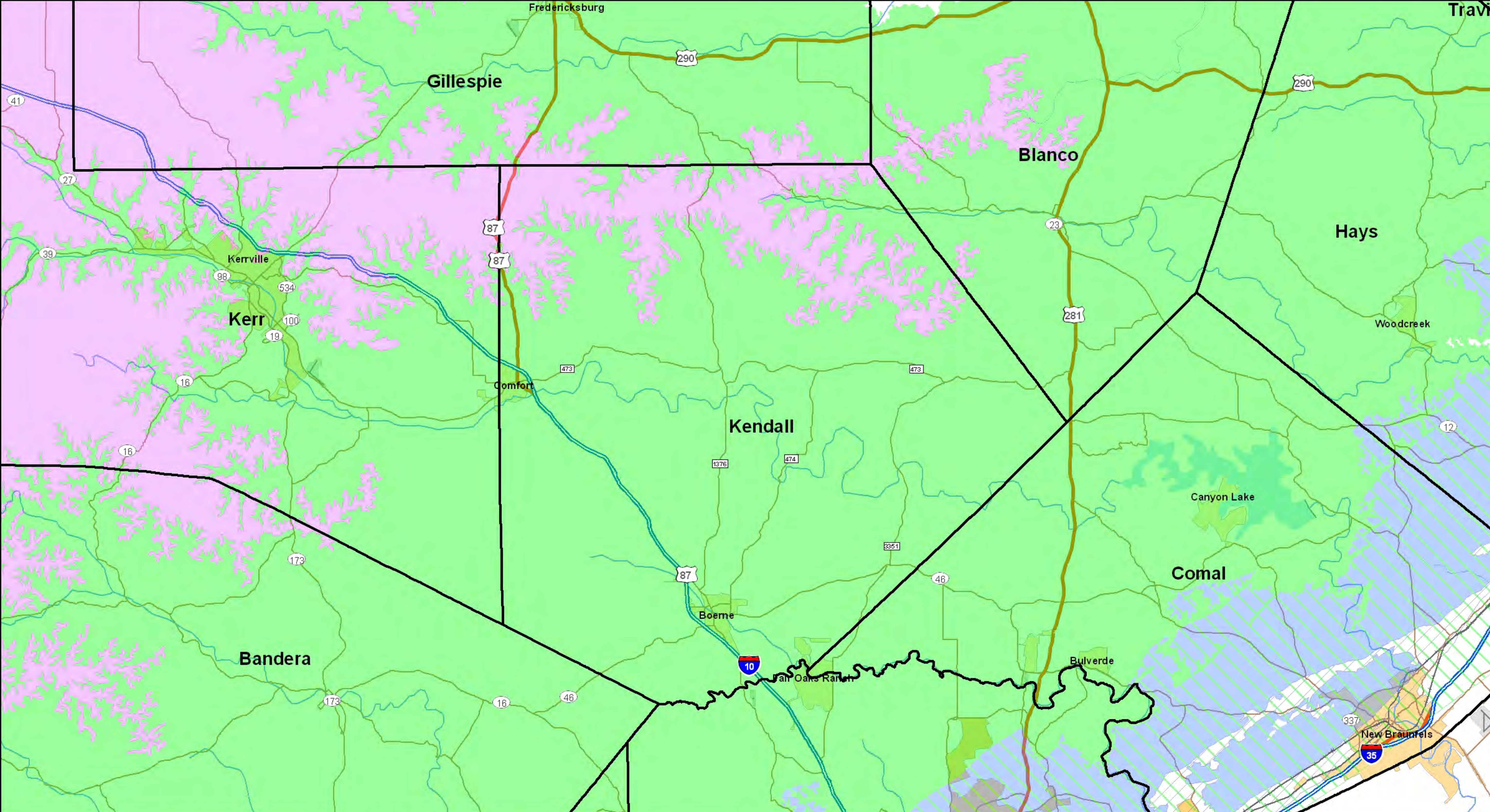
PH: (512) 773-3226 FAX: (512) 879-6809



SCALE: 1 in = 5 miles

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PROJECT NO: 055-002-08

Legend

- Edwards - Trinity Plateau (outcrop)
- Edwards BFZ (Recharge Zone)
- Edwards BFZ (Confined Zone)
- Trinity (Recharge Zone)
- Trinity (Confined Zone)

FIGURE 4: COW CREEK GROUNDWATER CONSERVATION DISTRICT - AQUIFER MAP

COW CREEK GCD

KENDALL COUNTY, TEXAS

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PH: (512) 773-3226 FAX: (512) 879-6809

Geologic Units					Hydrologic Units	Approximate Range in Thickness (feet)
ERA	System	Group	Formation	Member or Unit		
Cenozioc	Quarternary	Pliestocene to recent floodplain, terrace and fan alluvial deposits			Very Local Alluvial Aquifers	0-50
Mesozoic	Cretaceous	Fredricksburg	Edwards Formation	Segovia Member	Edwards Aquifer	170 - 380
				Comanche Peak Limestone		150 - 300
				Walnut Clay		
		Trinity Group	Glen Rose Formation	Upper Glen Rose Formation	Upper Trinity Aquifer	0 - 515
				Lower Glen Rose Formation	Middle Trinity Aquifer	0 - 400
			Travis Peak Formation	Hensell Sand Member / Bexar Shale Member		10 - 300
				Cow Creek Limestone Member		0 - 100
				Hammett Shale Member		0 - 60
				Sligo Limestone Member	Lower Trinity Aquifer	0-120
				Hosston Sand Member		330-350
Pre-Cretaceous Rocks						

Scale: none

FIGURE 5: GEOLOGIC AND HYDROGEOLOGIC UNITS OF KENDALL COUNTY

DRAWN BY: LKF DATE: 4/08

CHECKED BY: KK DATE: 4/08

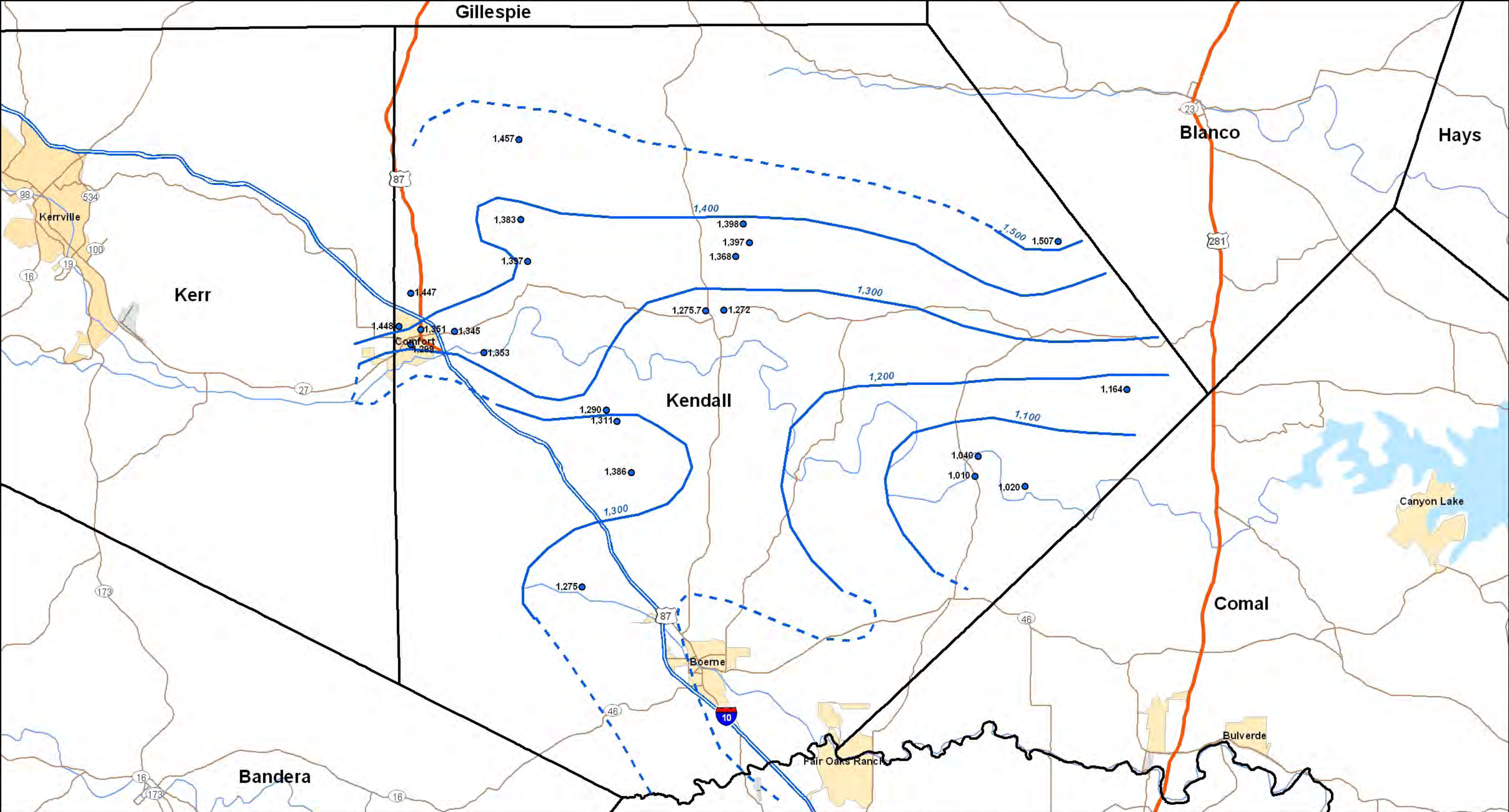
PROJECT NO: 055-002-08

COW CREEK GCD

KENDALL COUNTY, TEXAS

WET ROCK GROUNDWATER SERVICES, L.L.C.
Groundwater Specialists
P.O. Box 163144 Austin, Texas 78716
PH: 512-773-3226 FAX: 512-879-6809

Sources: TWDB Numbered Reports 60 (Reeves , 1967), 273 (Ashworth 1983) and 339 (Bluntzer, 1992)



SCALE: 1 in = 3.5 miles

DRAWN BY: LKF DATE: 4/08

CHECKED BY: KK DATE: 4/08

PROJECT NO: 055-002-08

Legend

1,400 ● Water Wells with Water Level Elevation in Feet Above Mean Sea Level

Water Level Elevation (ft MSL)

Inferred Water Level Elevations (ft MSL)

FIGURE 6: KENDALL COUNTY MIDDLE TRINITY WATER LEVEL ELEVATIONS - WINTER 1975

COW CREEK GCD

KENDALL COUNTY, TEXAS

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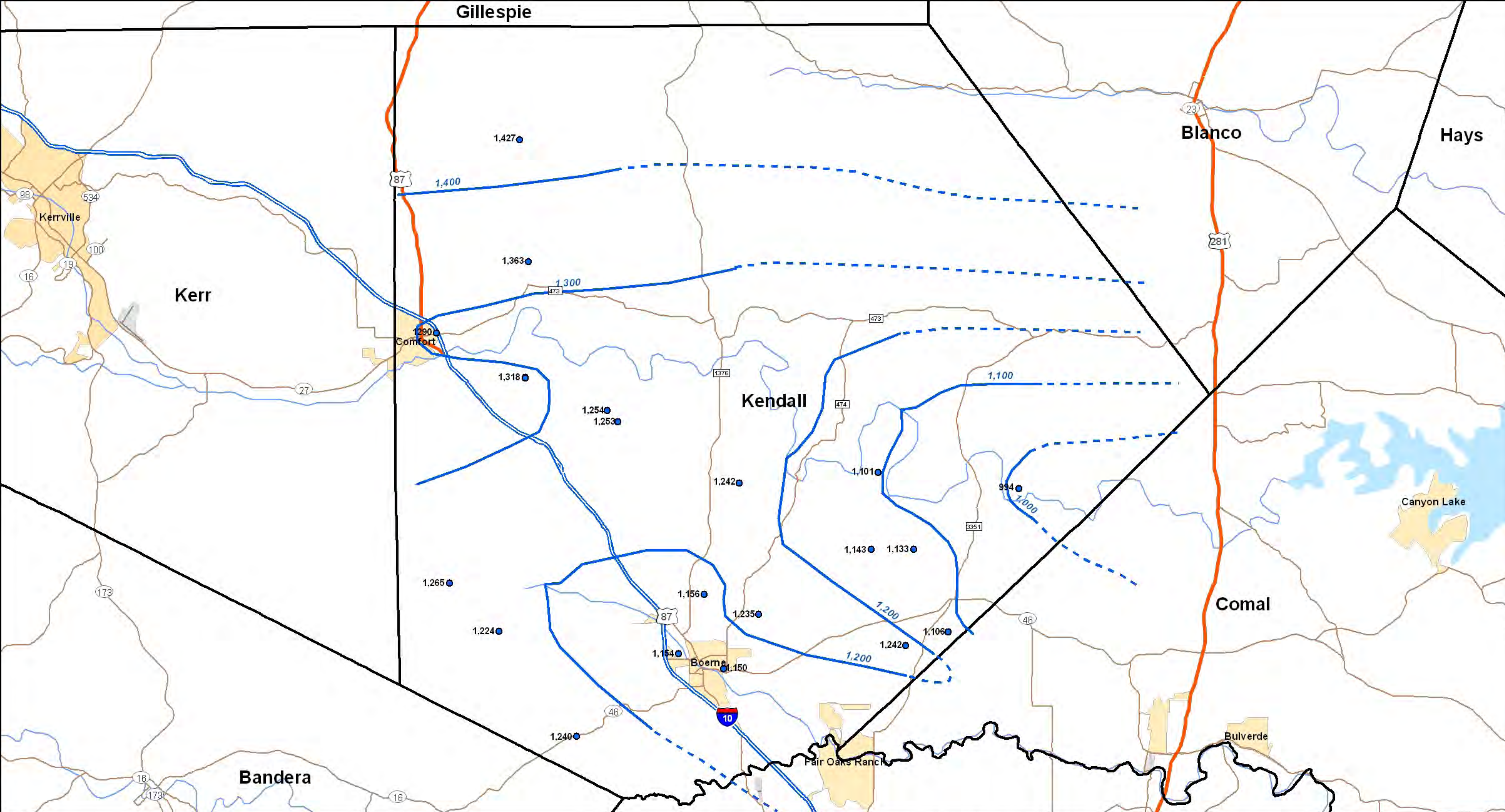

SCALE: 1 in = 3.5 miles

DRAWN BY: LKF DATE: 4/08

CHECKED BY: KK DATE: 4/08

PROJECT NO: 055-002-08

Legend

- 1,400 ● Water Wells with Water Level Elevation in Feet Above Mean Sea Level
- Water Level Elevation (ft MSL)
- Inferred Water Level Elevations (ft MSL)

FIGURE 7: KENDALL COUNTY MIDDLE TRINITY WATER LEVEL ELEVATIONS - SUMMER OF 2006

COW CREEK GCD

KENDALL COUNTY, TEXAS

WET ROCK GROUNDWATER SERVICES, L.L.C.

GROUNDWATER SPECIALISTS

P.O. BOX 163144 AUSTIN, TEXAS 78716

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Figure 8a: Hydrographs of Wells Within Kendall County

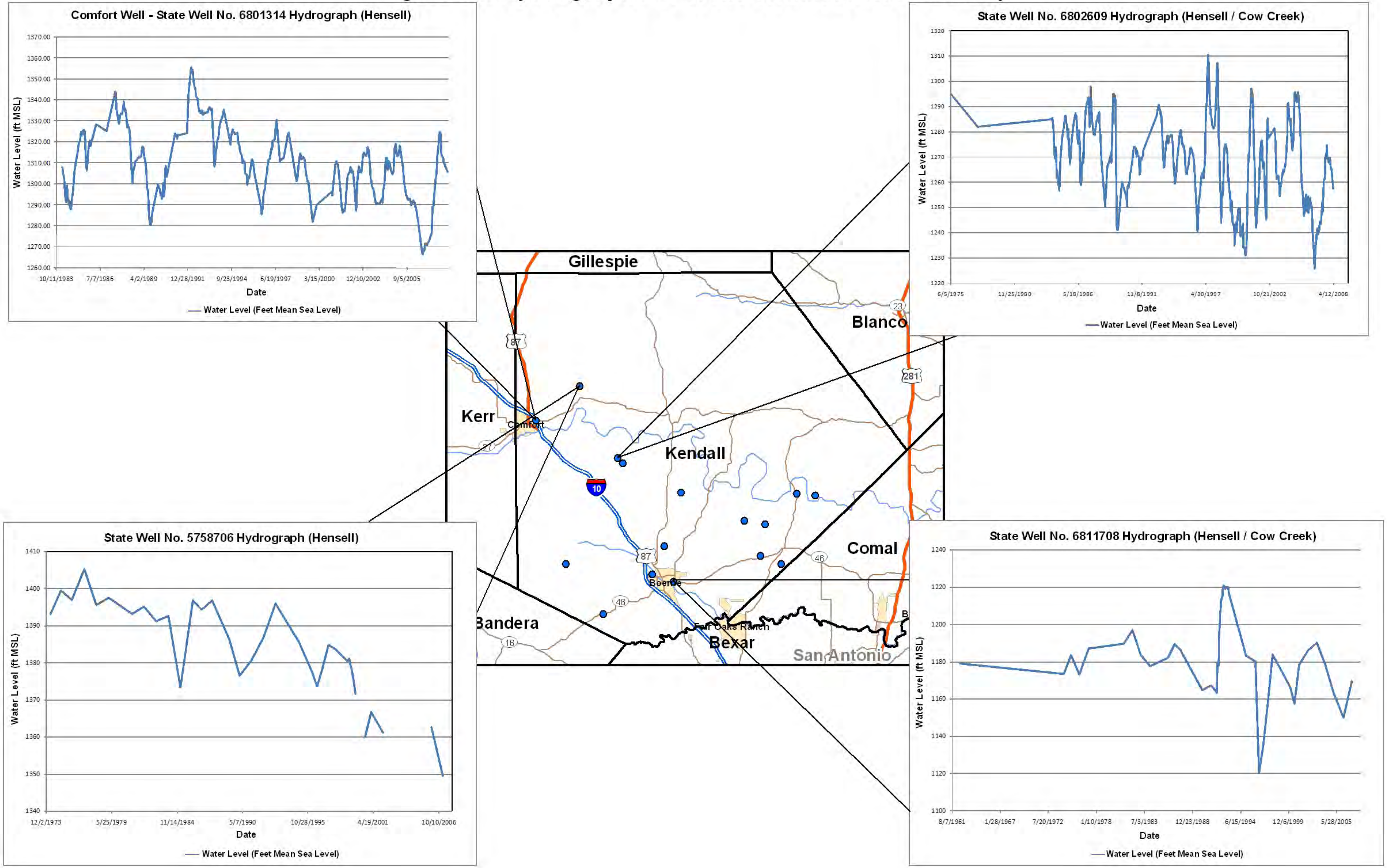


Figure 8b: Hydrographs of Wells Within Kendall County

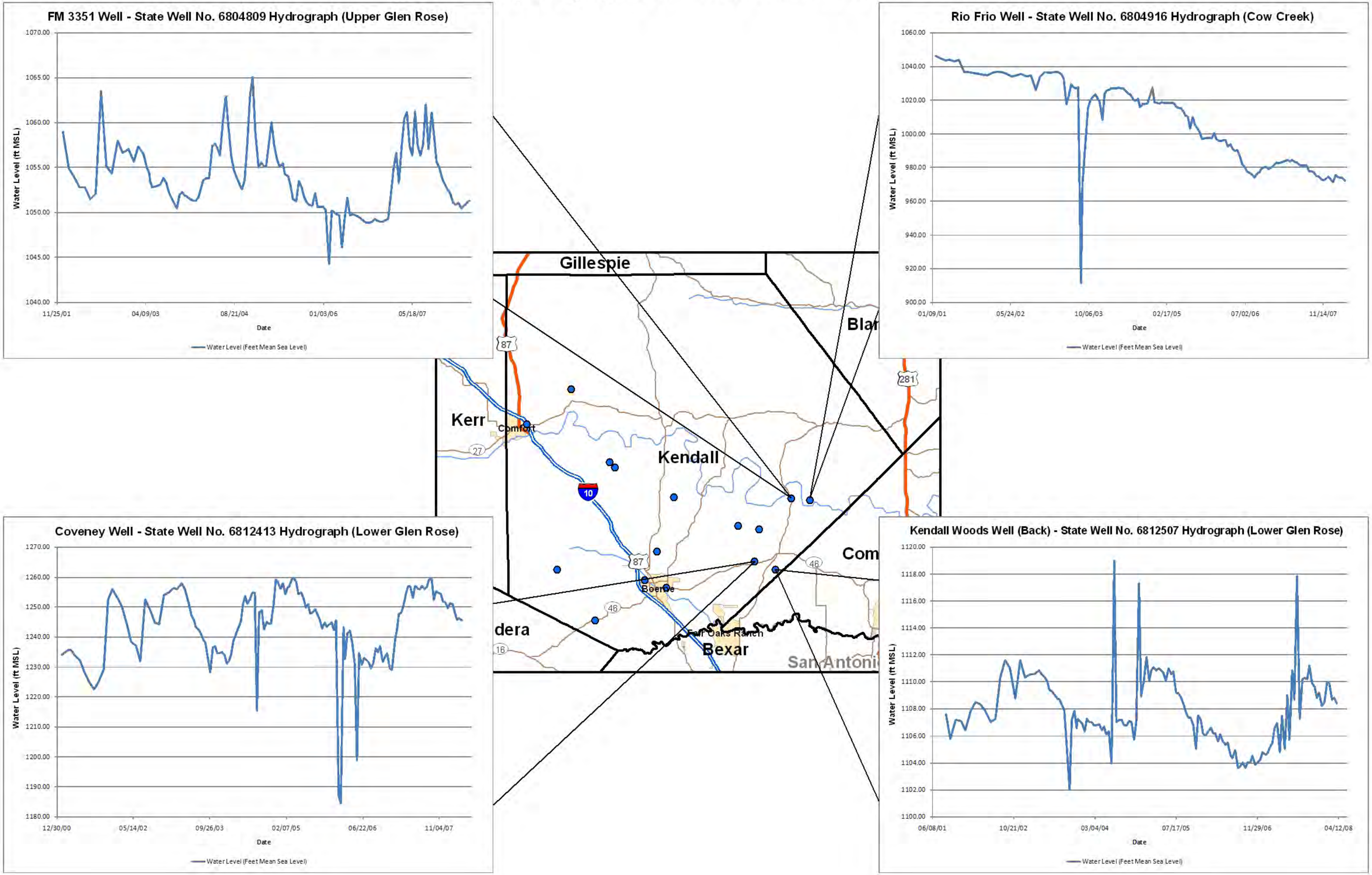


Figure 8c: Hydrographs of Wells Within Kendall County

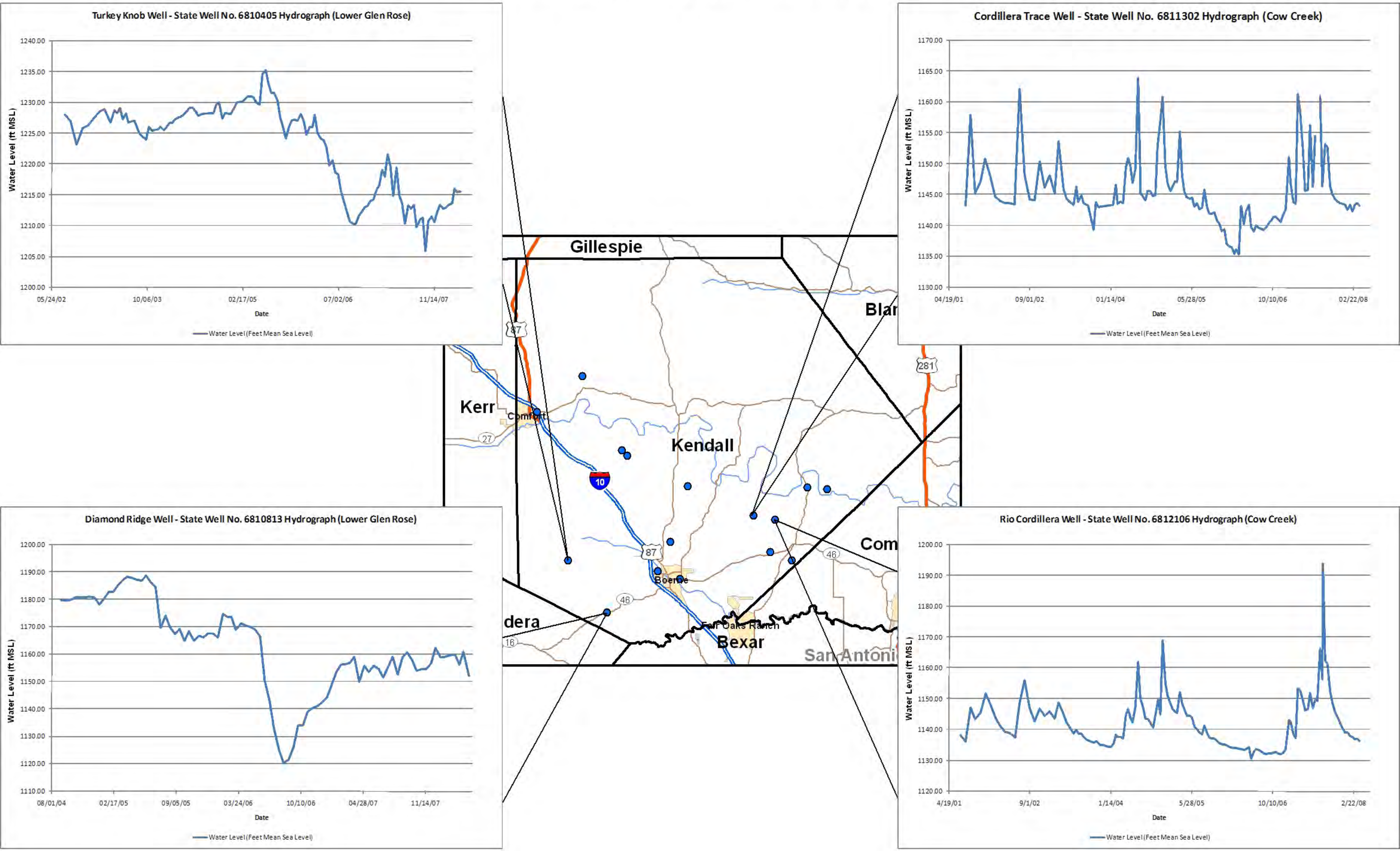
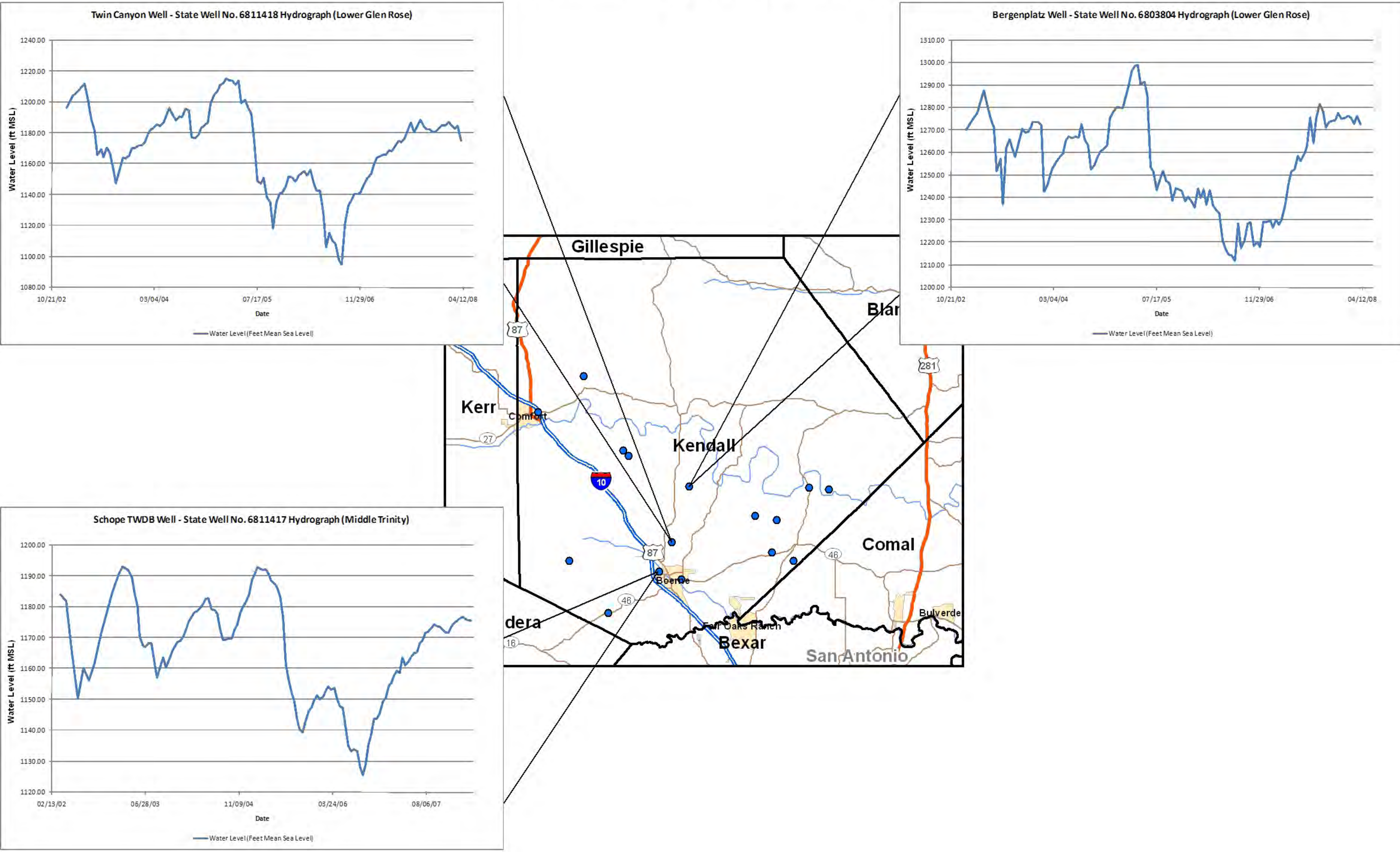
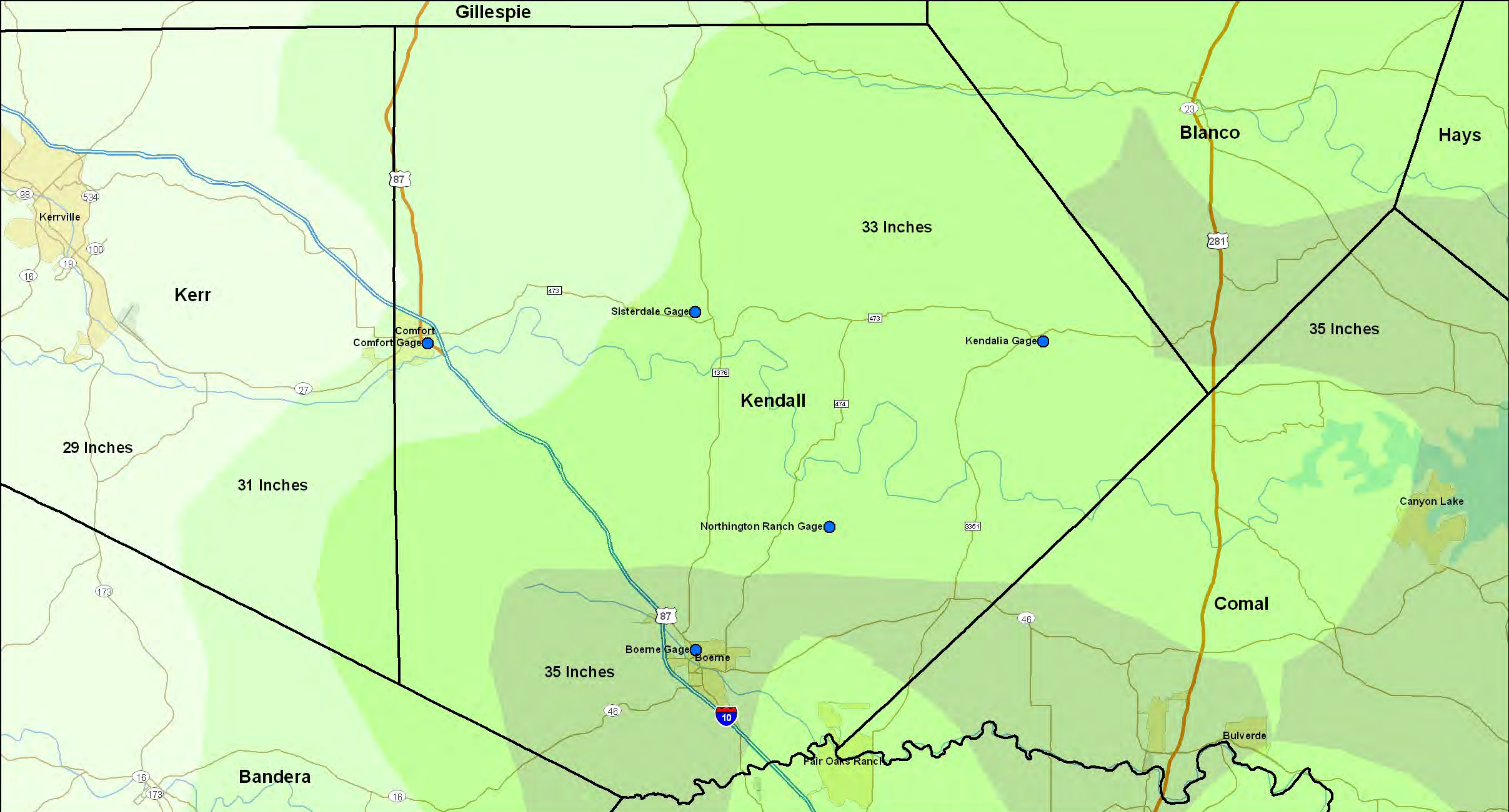


Figure 8d: Hydrographs of Wells Within Kendall County





SCALE: 1 in = 3.5 miles

DRAWN BY: LKF DATE: 4/08

CHECKED BY: KK DATE: 4/08

PROJECT NO: 055-002-08

Legend

- 29 Inch Annual Precipitation
- 31 Inch Annual Precipitation
- 33 Inch Annual Precipitation
- 35 Inch Annual Precipitation
- Rain Gage

Source: TWDB

FIGURE 9: AVERAGE ANNUAL PRECIPITATION WITHIN KENDALL COUNTY

COW CREEK GCD

KENDALL COUNTY, TEXAS

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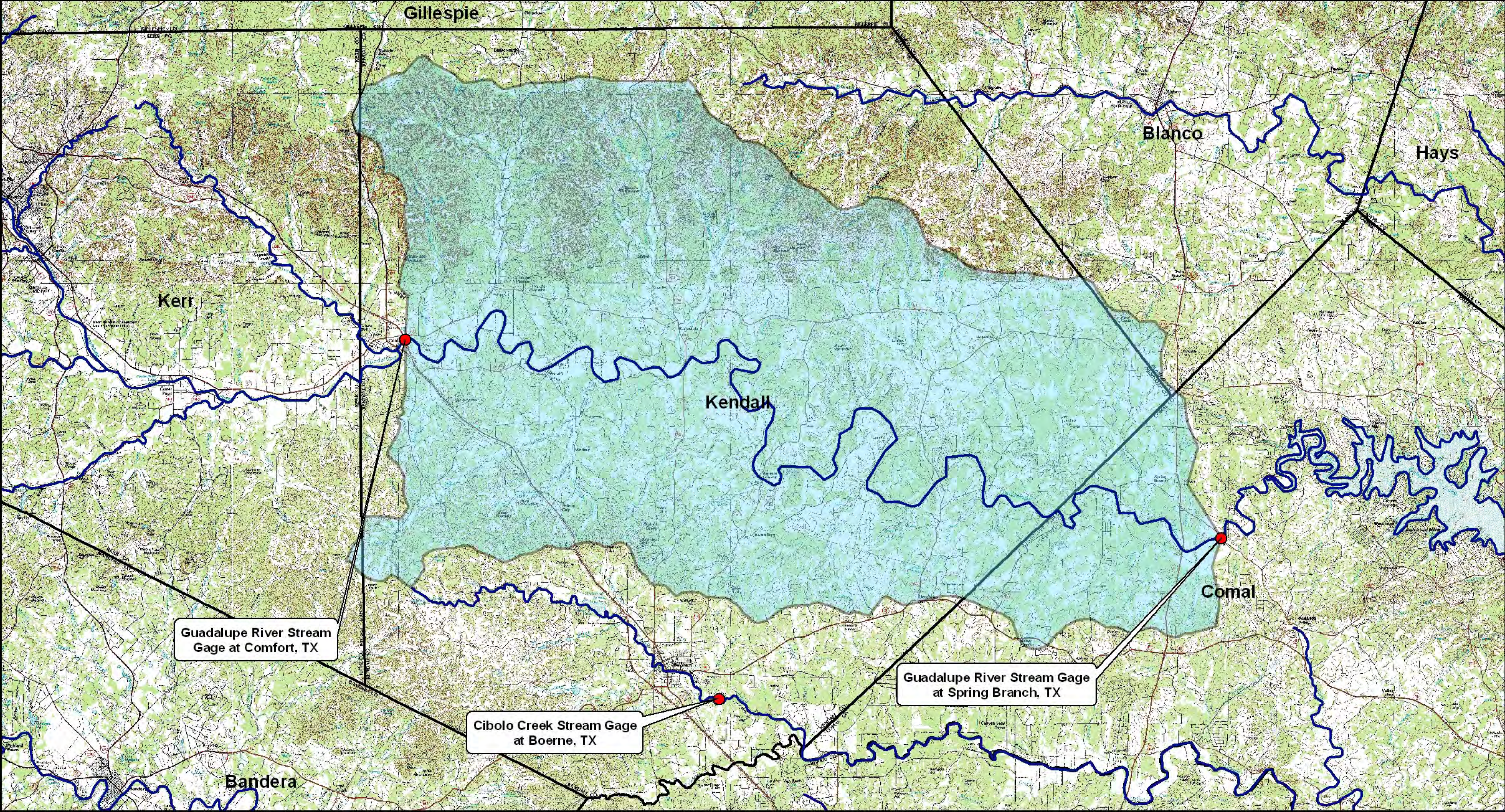

SCALE: 1 in = 3.5 miles

DRAWN BY: LKF DATE: 4/08

CHECKED BY: KK DATE: 4/08

PROJECT NO: 055-002-08

Legend

Sub-Basin of the Guadalupe River Used in the Recharge Calculation (after Kuniansky, 1989)

Location of Stream Gages

Basemap: USGS Topographic Map

FIGURE 10: LOCATION OF THE SUB-BASIN OF THE GUADALUPE RIVER BASIN USED IN RECHARGE CALCULATION

COW CREEK GCD

KENDALL COUNTY, TEXAS

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Tables

Table 1: Average Annual Recharge within the Trinity Aquifer: Kendall County 1940 to 2007

Year	Basin[1,2] Recharge (acre-feet)	Kendall County[3] Recharge (acre-feet)	Boerne Precipitation (inches)	Kendall County Precipitation (acre-feet)	Recharge Rate (% of Mean Annual Precipitation)
1940	23,009.23	32,251.84	32.29	1,141,774.40	2.82
1941	189,280.69	265,313.11	41.60	1,470,976.00	18.04
1942	60,733.65	85,129.83	31.12	1,100,403.20	7.74
1943	32,044.84	44,916.97	26.33	931,028.80	4.82
1944	110,562.00	154,973.80	42.98	1,519,772.80	10.20
1945	129,281.55	181,212.83	33.50	1,184,560.00	15.30
1946	90,724.88	127,168.28	45.64	1,613,830.40	7.88
1947	88,010.99	123,364.24	25.01*	884,353.60	13.95
1948	11,188.04	15,682.18	23.77	840,507.20	1.87
1949	28,229.24	39,568.68	41.15	1,455,064.00	2.72
1950	13,696.50	19,198.27	24.94	881,878.40	2.18
1951	1,648.50	2,310.69	18.76	663,353.60	0.35
1952	32,833.97	46,023.09	37.54	1,327,414.40	3.47
1953	22,422.09	31,428.85	21.42	757,411.20	4.15
1954	3,370.49	4,724.39	10.29	363,854.40	1.30
1955	3,102.24	4,348.38	19.27	681,387.20	0.64
1956	247.15	346.43	12.05	426,088.00	0.08
1957	132,464.08	185,673.76	52.55	1,858,168.00	9.99
1958	190,116.60	266,484.79	40.94	1,447,638.40	18.41
1959	58,214.92	81,599.35	35.64	1,260,230.40	6.47
1960	83,663.31	117,270.14	32.55	1,150,968.00	10.19
1961	94,975.33	133,126.10	25.45	899,912.00	14.79
1962	12,664.08	17,751.13	25.26	893,193.60	1.99
1963	8,133.82	11,401.11	20.66	730,537.60	1.56
1964	23,787.72	33,343.04	27.36	967,449.60	3.45
1965	96,761.21	135,629.35	42.41	1,499,617.60	9.04
1966	59,681.50	83,655.05	29.05	1,027,208.00	8.14
1967	33,260.24	46,620.60	26.75	945,880.00	4.93
1968	129,013.27	180,836.78	35.14	1,242,550.40	14.55
1969	65,398.39	91,668.35	38.07	1,346,155.20	6.81
1970	92,885.34	130,196.58	27.79	982,654.40	13.25
1971	74,128.06	103,904.65	45.24	1,599,686.40	6.50
1972	89,901.59	126,014.28	35.09	1,240,782.40	10.16
1973	209,033.98	293,001.12	50.93	1,800,884.80	16.27
1974	84,377.53	118,271.25	41.80	1,478,048.00	8.00
1975	193,097.17	270,662.63	33.49	1,184,206.40	22.86
1976	118,142.23	165,598.93	45.24	1,599,686.40	10.35
1977	141,814.64	198,780.36	32.43	1,146,724.80	17.33
1978	59,584.32	83,518.82	35.17	1,243,611.20	6.72
1979	260,049.72	364,509.43	39.97	1,413,339.20	25.79
1980	32,495.06	45,548.05	29.02	1,026,147.20	4.44
1981	130,235.98	182,550.64	41.05	1,451,528.00	12.58
1982	31,862.05	44,660.76	27.64	977,350.40	4.57

*** Some missing data, total rainfall projected for the year.**

Table 1: Average Annual Recharge within the Trinity Aquifer: Kendall County 1940 to 2007

Year	Basin[1,2] Recharge (acre-feet)	Kendall County[3] Recharge (acre-feet)	Boerne Precipitation (inches)	Kendall County Precipitation (acre-feet)	Recharge Rate (% of Mean Annual Precipitation)
1983	34,554.44	48,434.65	34.60	1,223,456.00	3.96
1984	16,659.26	23,351.14	26.97	953,659.20	2.45
1985	151,959.10	212,999.75	41.2*	1,456,832.00	14.62
1986	166,768.69	233,758.23	35.93*	1,270,484.80	18.40
1987	303,971.34	426,074.00	39.86	1,409,449.60	30.23
1988	20,053.72	28,109.13	19.54	690,934.40	4.07
1989	4,032.26	5,651.99	25.14	888,950.40	0.64
1990	50,295.33	70,498.53	42.51	1,503,153.60	4.69
1991	102,066.83	143,066.19	48.22	1,705,059.20	8.39
1992	409,711.41	574,288.93	64.17	2,269,051.20	25.31
1993	76,462.10	107,176.26	24.02	849,347.20	12.62
1994	49,694.88	69,656.88	40.98	1,449,052.80	4.81
1995	50,910.49	71,360.79	30.29	1,071,054.40	6.66
1996	9,127.17	12,793.48	24.57	868,795.20	1.47
1997	203,563.06	285,332.58	52.72	1,864,179.20	15.31
1998	127,284.09	178,413.01	45.74	1,617,366.40	11.03
1999	24,108.96	33,793.32	18.67	660,171.20	5.12
2000	40,929.08	57,369.94	46.30	1,637,168.00	3.50
2001	164,198.36	230,155.42	53.91	1,906,257.60	12.07
2002	241,423.39	338,401.07	62.41	2,206,817.60	15.33
2003	97,200.86	136,245.60	28.55	1,009,528.00	13.50
2004	302,944.06	424,634.06	60.50	2,139,280.00	19.85
2005	134,570.40	188,626.17	25.36	896,729.60	21.03
2006	5,182.53	7,264.31	24.24	857,126.40	0.85
2007	288,632.84	404,574.16	56.34	1,992,182.40	20.31
Avg: 1940 - 1960	**62,135.47**	**87,094.76**	**31.22**	**1,093,364.88**	**6.79**
Avg: 1940 - 2007	**94,447.54**	**132,386.30**	**35.00**	**1,236,086.80**	**9.45**

1 Drainage basin area for the Guadalupe River between Spring Branch and Comfort gages based upon Kuniansky, 1989.

2 Stream flow data taken from USGS: Guadalupe River at Comfort gage and Guadalupe River at Spring Branch gage.

3 Kendall County area taken from the United States Census Bureau.

*** Some missing data, total rainfall projected for the year.**

Table 2: Historical Groundwater Pumpage Summary for Kendall County in Acre-Feet per Year

Year	Aquifer	Municipal	Manufacturing	Steam Electric	Irrigation	Mining	Livestock	Total
1980	Trinity	1,110	0	0	200	0	441	1,751
1984	Trinity	1,610	7	0	282	0	330	2,229
1985	Trinity	1,521	9	0	132	0	326	1,988
1986	Trinity	1,574	8	0	176	0	228	1,986
1987	Trinity	1,412	2	0	176	0	249	1,839
1988	Trinity	1,607	2	0	440	0	276	2,325
1989	Trinity	1,792	2	0	369	0	274	2,437
1990	Trinity	1,672	2	0	274	0	312	2,260
1991	Trinity	1,469	2	0	274	6	319	2,070
1992	Trinity	1,526	7	0	274	6	410	2,223
1993	Trinity	1,730	9	0	808	6	407	2,960
1994	Trinity	1,913	8	0	718	6	386	3,031
1995	Trinity	2,048	0	0	808	6	374	3,236
1996	Trinity	2,201	6	0	808	6	303	3,324
1997	Trinity	2,694	5	0	808	6	298	3,811
1998	Trinity	2,855	0	0	808	6	302	3,971
1999	Trinity	3,042	0	0	808	6	360	4,216
2000	Trinity	2,766	0	0	286	6	357	3,415
2001	Trinity	3,243	0	0	726	6	353	4,328
2002	Trinity	2,721	0	0	726	6	309	3,762
2003	Trinity	2,547	0	0	131	6	268	2,952

Data taken from the Texas Water Development Board Water Use Survey

Table 3: Historical and Projected Groundwater Pumpage Used in the Trinity (Hill Country) GAM in Acre-Feet per Year

Type of Use	1975	1996	1997	2000	2010	2020	2030	2040	2050
Municipal and Industrial	675	1,348	1,638	2,070	2,704	2,659	3,216	3,934	4,850
Domestic	473	1,767	1,664	1,645	2,244	3,581	5,002	6,441	7,709
Stock	647	300	295	405	405	405	405	405	405
Irrigation	0	813	813	238	228	218	209	200	192
Total	*1,795*	*4,228*	*4,410*	*4,358*	*5,581*	*6,863*	*8,832*	*10,980*	*13,156*

From: Mace and others, 2000