APPENDIX A

Brief Summary of the Development of the Carrizo-Wilcox Aquifer in Each County
and
List of Reviewed Reports

This appendix provides a review of Carrizo-Wilcox aquifer development in the counties within the study area. The review will summarize the available literature on a county basis. A brief introduction will describe the history of development and the magnitude of water level declines using long-term historical water levels (hydrographs).

Development of groundwater from the Carrizo Sand and Wilcox Group began in the early 1900s in parts of the study area. The first flowing well was drilled in 1884 at Carrizo Springs in Dimmit County (Turner et al., 1960). Successful crop growth and available transport to market via railroads resulted in the rapid development of Carrizo and Wilcox waters in parts of the Wintergarden as early as 1910 (Moulder, 1957). Irrigation was greatest in Dimmit and Zavala Counties. White and Meinzer (1931) investigated groundwater conditions in southwestern Texas and show that the original extent of flowing wells was substantially reduced by 1930 in these two counties.

Our analysis of predevelopment conditions (Section 4.4.1 in the main body of this report) has shown that the largest water-level declines are in the western part of the study area with water-level declines of greater than 150 ft throughout the Wintergardent. Figure A.1 plots select long-term hydrographs in the western part of the study area including the Wintergarden area. In general, water-level declines are greatest in the confined portions of the aquifer. In LaSalle County we see the influence of a reduction of pumping in the early 1980's at the selected hydrograph. This is in contrast to the hydrographs from Frio, Zavala, Dimmit, McMullen, and Medina counties. Figure A.2 plots select hydrographs from the central and eastern portion of the study area. In general, historical water-level declines have been less severe in the eastern study area with the least amount of decline observed in Gonzales and Caldwell counties.

A discussion of Carrizo-Wilcox groundwater development for each county in the study area will follow.

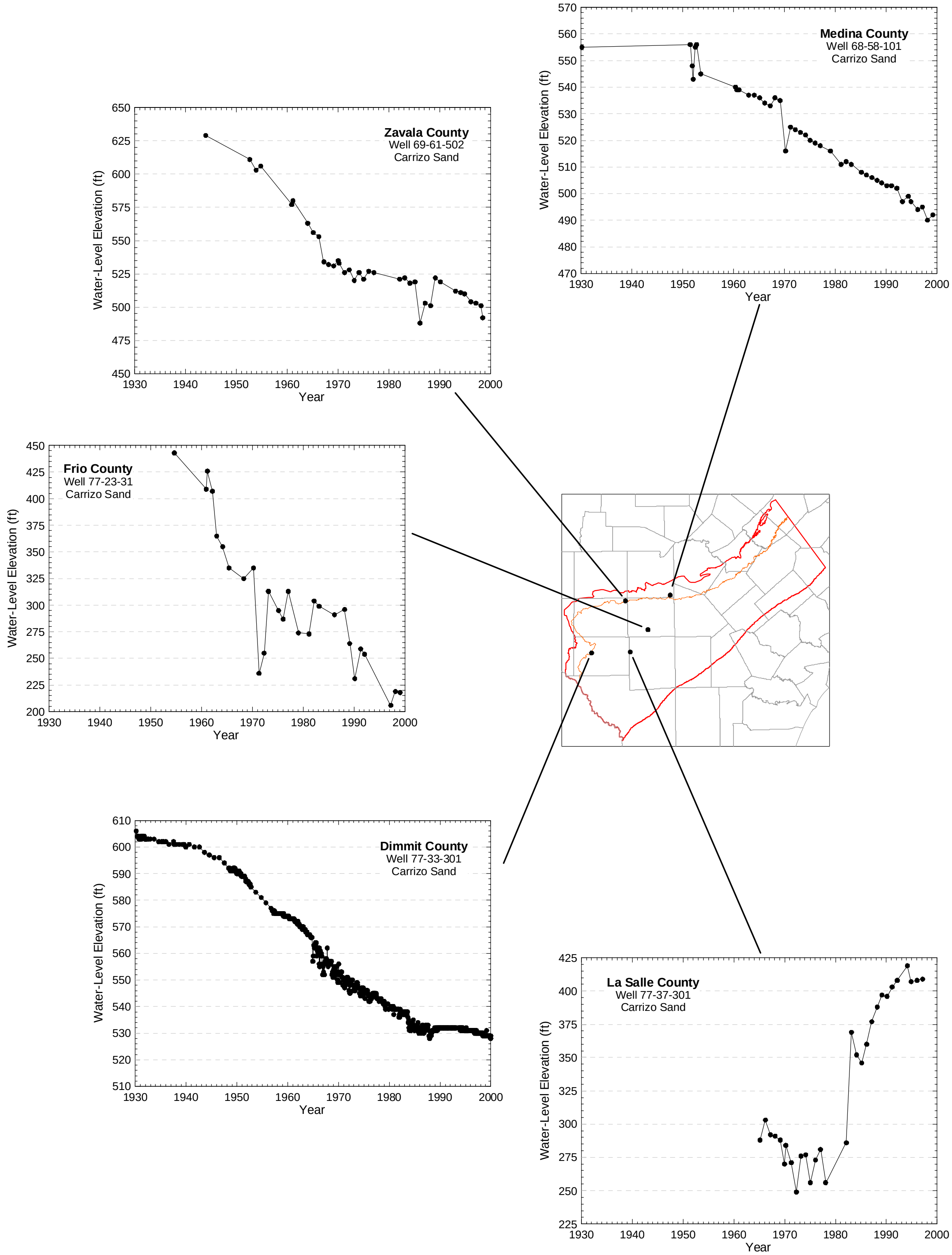

Figure A.1 Select long-term hydrographs in the western study area.

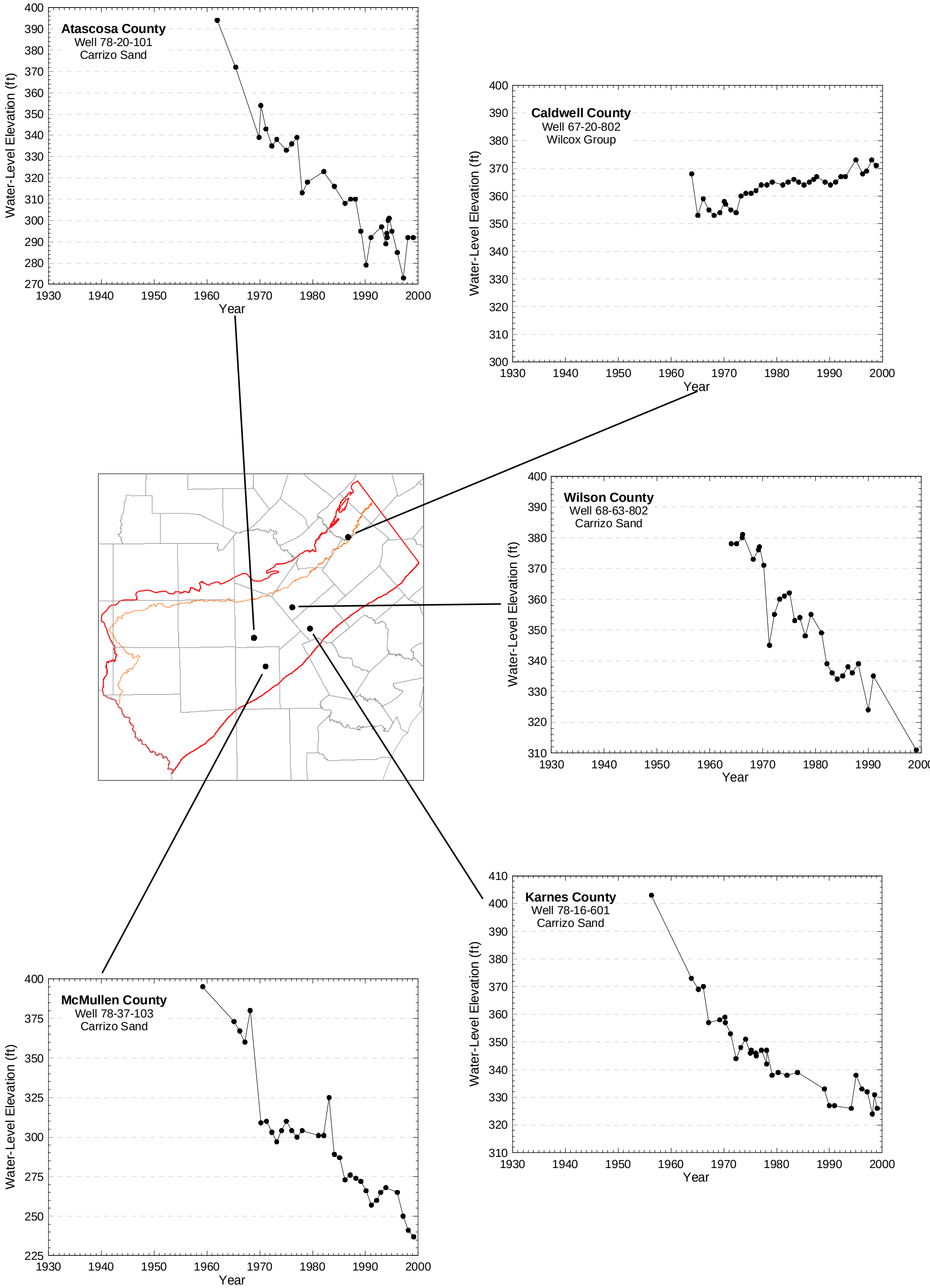

Figure A.2 Select long-term hydrographs in the eastern study area.

Atascosa County

The information regarding the history of development of the Carrizo Sand and Wilcox Group in Atascosa County comes from Lonsdale (1935). The following discussion is taken from that report. The Carrizo Sand is the principal aquifer in Atascosa County. Water from the Wilcox Group is fresh only in the area in and near the outcrop. Initial development in Atascosa County occurred near Poteet, Texas, which is located near the center of the county. The first well in that area was drilled in 1904. Nine additional wells were drilled by 1910 and another 40 wells by 1932. Most of the wells originally flowed. Lansdale (1935) estimates about a 25 ft drop in head in the Carrizo in the Poteet, Texas area between 1904 and 1932. Both Lansdale (1935) and Sundstrom and Follett (1950) indicate that uncontrolled flowing wells in the county wasted large volumes of water from the Carrizo. Sundstrom and Follett (1950) state, “From 1932 to 1944, withdrawals of water have increased materially and artesian pressures have declined in most of the county.” They also say that total withdrawal from the Carrizo increased by 63 percent from 1929-1930 to 1944-1945. The earliest water-level measurements found in the county reports and on the TWDB website are from 1908, 1909, and 1910. These three measurements were considered to be fairly representative of predevelopment conditions.

Bastrop County

Little information related to historical development of the Carrizo Sand and Wilcox Group in Bastrop County was found during the literature review. In Bastrop County, the Carrizo Sand and Wilcox Group act as a single aquifer (Follett, 1970). Follett (1970) states that the Carrizo-Wilcox aquifer has not been significantly developed in the county due to (1) little need for water because of the sparse population of the county in and southeast of the outcrop area, and (2) the presence of good water in the overlying Queen City Sand/Bigford Formation and younger aquifers. Water-level measurements for Bastrop County used to generate the predevelopment water-level elevations were taken in 1925 and 1950.

Bee County

Myers and Dale (1966) state that “The Carrizo Sand of Eocene age is not tapped by water wells in Bee County; however, electric logs indicate that slightly saline water (1000 to 2000 ppm dissolved solids) may be obtained from the Carrizo in an area of about 10 square miles in the extreme northwestern part of the county at a depth of about 6000 ft.”

Bexar County and San Antonio, Texas Area

The principal aquifer underlying Bexar County is the Edwards Limestone. Consequently, little historical information related to the development of the Carrizo Sand and Wilcox Group in Bexar County was found during the literature review. No water-level measurements from this county were used in generation of the predevelopment water-level elevations for the Carrizo-Wilcox aquifer.

Caldwell County

Little historical information related to the development of the Carrizo Sand and Wilcox Group in Caldwell County was found during the literature review. The Carrizo Sand and Wilcox Group act as a single aquifer in this county (Follett, 1966). Data on the TWDB website indicate wells were completed into the Carrizo-Wilcox aquifer as early as 1870. The first public use of Carrizo-Wilcox waters began in 1926 (Follett, 1966). At this time, approximately 30 wells tapped the Carrizo-Wilcox aquifer (TWDB, website). The two earliest water-levels measurements for Carrizo-Wilcox wells in Caldwell County were taken in 1906 and 1923 (TWDB, website). These two measurements were not consistent, and only the higher value from 1923 was used to generate the predevelopment contours.

De Witt, County

The Carrizo Sand and the sands of the Wilcox Group are not listed by Follett and Gabrysch (1965) in De Witt County.

Dimmit County

Unless stated otherwise, the historical information given here regarding development of the Carrizo Sand and Wilcox Group in Dimmit County comes from Mason (1960). The Carrizo Sand is the principal water-bearing unit in this county. Some water is withdrawn from the Wilcox Group for domestic and stock purposes in the outcrop area. Downdip of the outcrop, the waters of the Wilcox group are highly mineralized. The first flowing well was drilled in 1884 at Carrizo Springs, Texas. Sixty flowing wells were being used for irrigation and stock watering by 1907. The use of Carrizo waters for irrigation increased rapidly in the county. Between Dimmit and Zavala Counties, 250 irrigation wells were active by 1910. Of those, 35 flowed (Turner et al., 1960). Until about 1947, irrigation was wide-spread throughout the northern one-half of the county. After that time, irrigation was concentrated in a few locations in the northern half of the county.

The quantity of water removed from the Carrizo aquifer became a concern of some county residents as early as the 1920s. Mason (1960) estimates that between 1929 and 1957 the decline in water levels was approximately 1.1 ft/yr in the outcrop and as much as 230 ft total in the artesian section of the aquifer. In the outcrop areas, withdrawal from the Carrizo aquifer has exceeded recharge since 1929 (Mason, 1960). White and Meinzer (1931) provides a graphic showing that in the northern half of Dimmit County all wells originally flowed and that the area of flowing wells was drastically reduced by 1930.

The earliest water-level measurements for the Carrizo aquifer were taken in 1913 as given on the TWDB website. These measured depths to water yield water-level elevations that are below ground surface in the northern part of the county where it is known that wells originally flowed. Because none of the earliest water-level measurements reflected flowing conditions, the values for selected measurements were increased until the calculated water-level elevation was above ground surface. Those increased values were then used to generate the predevelopment water-level elevation contours (see Table 4.4-1).

Fayette County

Fresh to slightly saline water can be found in the Carrizo Sand and sands of the Wilcox Group in Fayette County (Rogers, 1967). However, the occurrence of fresh water in aquifers located at shallower depths has limited development of the Carrizo Sand and Wilcox Group in this county. Currently, two wells are completed to the Carrizo Sand in Fayette County (TWDB, website). The first was completed in 1917 and the second in 1980. The first recorded water level was measured in 1966 (TWDB, website). Due to the long period of time between the completion date and the date of the first water-level measurement, that measurement is not considered to represent predevelopment conditions.

Frio County

Unless stated otherwise, the following discussion regarding the history of development of the Carrizo Sand and the Wilcox Group in Frio County comes from Lonsdale (1935). The Carrizo Sand is the principal aquifer in Frio County. Water from the Wilcox Group is fresh only in the area in and near the outcrop. The first flowing well completed in the Carrizo was drilled in 1905. This well continued to flow until 1915 (Alexander and White, 1966). Between 1905 and 1932, 12 additional wells were drilled in the county; 10 for irrigation purposes and two for use as municipal supply wells. Water levels in all of the wells had declined by 1932 and some of the wells that originally flowed had stopped flowing by that time. Frio County experienced an increase in the use of Carrizo water for irrigation during the drought of 1950 to 1956. The earliest water-level measurements found for the county on the TWDB website were taken in 1928 and 1929. Several of those early measurements were used in generation of the predevelopment water-level elevation contours.

Gonzales County

Little information related to historical development of the Carrizo Sand and Wilcox Group in Gonzales County was found during the literature review. Shafer (1965) states that the Carrizo Sand is a major aquifer in Gonzales County and usable water for most purposes can be obtained from the Wilcox Group only in and near the outcrop area. Data on the TWDB website indicate wells were completed into the Carrizo aquifer as early as 1900. The two earliest water-levels measurements for Carrizo wells in Gonzales County were taken in 1901 and 1931 (TWDB, website). These two measurements were not consistent, and only the higher value from 1931 and another measurement from 1940 were used to generate the predevelopment contours.

Guadalupe County

Little information related to historical development of the Carrizo Sand and Wilcox Group in Guadalupe County was found during the literature review. At locations in the county were the Wilcox Group is overlain by the Carrizo Sand, the two are considered to be a single hydrologic unit (Shafer, 1966). Data on the TWDB website indicate wells were completed into the Carrizo-Wilcox aquifer as early as 1892. The two earliest water-levels measurements for Carrizo-Wilcox wells in Guadalupe County were taken in 1936 (TWDB, website). Several of the 1936 measurements, along with high measurements taken in 1982 and 2000, were used to generate the predevelopment water-level elevation contours for the Carrizo-Wilcox aquifer.

Karnes County

Little information related to historical development of the Carrizo Sand and Wilcox Group in Karnes County was found during the literature review. Due to the moderate to very high salinity of the water in the Wilcox Group, the undifferentiated sands and clays of the Wilcox Group are not considered to be an aquifer in Karnes County (Anders, 1960). Data on the TWDB website indicate that the first wells developed in the Carrizo aquifer were drilled in the 1940s. The first water-level measurement was taken in 1956 (TWDB, website). That measurement was used to generate the predevelopment water-level elevation contours for the Carrizo aquifer.

Lavaca County

The Carrizo Sand and the sands of the Wilcox Group are not sources of fresh water in Lavaca County (Loskot et al., 1982).

LaSalle County

Little information related to historical development of the Carrizo Sand and Wilcox Group in LaSalle County was found during the literature review. The Carrizo Sand is the principal aquifer in this county. Harris (1965) states that the Wilcox Group is "…not known to yield water to wells…" in this county. Development of the Carrizo aquifer for irrigation purposes occurred rapidly until 1920 (Moulder, 1957). At that time, the poor quality of the water and the high cost of drilling deep wells ended the drilling of irrigation wells in the Carrizo (Moulder, 1957). Moulder (1957) states, "The withdrawals from LaSalle County [for irrigation purposes] were considerably less in 1955 than in 1913." Some of the wells in LaSalle County show a rise in water level during 1959 to 1960 due to increased precipitation and decreased irrigation pumpage (Harris, 1965). Data on the TWDB website indicate that the first well developed in the Carrizo aquifer was drilled in 1909. The first water-level measurement was taken in 1942 (TWDB, website). This earliest measurements reflects the effects of pumpage. Therefore, water-level measurements taken during 1959 and 1960, when precipitation was high and irrigation pumping was low, were used in generation of the predevelopment contours. The depth to water for the 1960 measurement yields a water-level elevation below ground surface in the northwestern part of the county where it is known that wells originally flowed. Because this water-level measurement does not reflect flowing conditions, the measured value was increased until the calculated water-level elevation was above ground surface. That increased value, along with a 1959 measurement, was used to generate the predevelopment water-level elevation contours.

Live Oak County

Little information related to historical development of the Carrizo Sand and Wilcox Group in Live Oak County was found during the literature review. The Carrizo Sand is an aquifer for fresh to slightly saline water in this county. However, most of the water in this aquifer is found at depths greater than 4000 ft and is "too deeply buried to be economically developed for most uses" (Anders and Baker, 1961). Most ground-water in this county is obtained from younger, shallower aquifers. Data on the TWDB website list two Carrizo wells in Live Oak County. Both were drilled in 1948. Only one water-level measurement from 1965 is given for one of the wells. The other well has measurements of water levels from 1970 to 1996. Generation of the predevelopment water-level elevations did not use any water-level measurements for this county.

Maverick County

Little historical information related to the development of the Carrizo Sand and Wilcox Group in Maverick County was found during the literature review. Moulder (1957) states, "The Carrizo Sand and sands of the Wilcox age have not been extensively developed [for irrigation purposes] in Maverick…Count[y] because only a small part of the area is underlain by the sands [and] yields from wells have been small…". Withdrawal for irrigation was less in 1937-1938 than in 1929-1930, but more than doubled from 1938 to 1948 (Moulder, 1957). Taylor (1907) states, "So far as can be ascertained there are no artesian wells in Maverick County". Data on the TWDB website indicate that the earliest well completed into the Carrizo aquifer was drilled in 1900. The earliest water-levels measurements for Carrizo wells were taken in 1930 (TWDB, website). No water-level measurements from Maverick County were used to generate the predevelopment contours.

McMullen County

Little information related to historical development of the Carrizo Sand and Wilcox Group in McMullen County was found during the literature review. The Carrizo Sand is the principal aquifer in this county. Harris (1965) states that the Wilcox Group is "…not known to yield water to wells…" in this county. Little early development of the Carrizo aquifer for irrigation purposes occurred due to the poor quality of the water and the depth at which the water was located (Moulder, 1957). A rapid increase in development for irrigation occurred from 1949 to 1954 (Moulder, 1957). Some of the wells in McMullen County show a rise in water level during 1959 to 1960 due to increased precipitation and decreased irrigation pumpage (Harris, 1965). Data on the TWDB website indicate that the first wells developed in the Carrizo aquifer were drilled in the 1940s. The first water-level measurement was taken in 1958 (TWDB, website). Two water-level measurements taken during 1959, when precipitation was high and irrigation pumping was low, were used in generation of the predevelopment contours.

Medina County

Little historical information related to the development of the Carrizo Sand and Wilcox Group in Medina County was found during the literature review. In the southern portion of the county, enough water can be obtained from the Carrizo Sand for domestic and stock purposes. As of 1936, there were no irrigation wells completed in the Carrizo Sand or Wilcox Group in this county (Sayre, 1936). Data on the TWDB website indicate that the earliest well completed into the Carrizo aquifer was drilled in 1875. The earliest water-levels measurements for Carrizo wells were taken in 1930 (TWDB, website). Two of the 1930 water-level measurements were used to generate the predevelopment contours.

Uvalde County

Little historical information related to the development of the Carrizo Sand and Wilcox Group in Uvalde County was found during the literature review. The principal aquifer in this county is the Edwards and associated limestones (Welder and Reeves (1962). In the southern portion of the county, enough water can be obtained from the Carrizo Sand for domestic and stock purposes. As of 1936, there were no irrigation wells completed in the Carrizo Sand or Wilcox Group in this county (Sayre, 1936). The only Carrizo or Wilcox well listed in on the TWDB website as having a drilled date was drilled in 1984. The first recorded water-level measurement given on the TWDB website was taken in 1970. No water-level measurements from Uvalde County were used to generate the predevelopment contours.

Webb County

Little historical information related to the development of the Carrizo Sand and Wilcox Group in Webb County was found during the literature review. By 1932, there were four Carrizo wells in the outcrop and 10 Carrizo wells (non-flowing) east of the outcrop (Lonsdale and Day, 1937). The Carrizo Sand is a chief water-bearing unit in the county although it has not been as extensively developed as the shallower Cook Mountain Formation (Lonsdale and Day, 1937). Data on the TWDB website indicate that the earliest wells completed into the Carrizo Sand or Wilcox Group were drilled to the Carrizo Sand in 1908 and 1915. The earliest water-levels measurements for Carrizo wells were taken in 1947 (TWDB, website). The county report by Lonsdale and Day (1937) gives 13 water-level measurements for 1931. Because these 1931 data appeared to be effected by pumpage, no water-level data from Webb County was used to generate the predevelopment contours.

Wilson County

Little historical information related to the development of the Carrizo Sand and Wilcox Group in Wilson County was found during the literature review. The Carrizo Sand is the principal aquifer in Wilson County and the Wilcox Group is an aquifer of less importance in the county (Anders, 1957). Data on the TWDB website indicate that the earliest wells completed into the Carrizo Sand and Wilcox Group were drilled in 1900. The earliest water-level measurement for a Carrizo well was taken in 1910 (TWDB, website). Water-levels were then measured in both Carrizo and Wilcox wells in 1936. The 1910 water-level measurement from the Carrizo was used in generation of the predevelopment contours.

Zavala County

The historical information presented below regarding development of the Carrizo Sand and Wilcox Group in Zavala County comes from Moulder (1957) unless otherwise stated. It appears that the Carrizo Sand and Wilcox Group are hydraulically connected to some extent in this county. The use of Carrizo waters for irrigation developed rapidly in the early 1900s. Between Dimmit and Zavala Counties, 250 irrigation wells were active by 1910. Of those, 35 flowed (Turner et al., 1960). Until 1949, irrigation development was greater in Zavala County than in any other county in the Wintergarden District. The withdrawal of water for irrigation purposes was less in 1937-1938 than in 1929-1930. During the ten year period from 1938 to 1948, the amount of ground water withdrawn for the purposes of irrigation doubled in the county. Historically, the use of ground water for irrigation was greater in Zavala County than in any other county in the Wintergarden District. Data on the TWDB website indicate that the earliest wells completed to the Carrizo Sand or the Wilcox Group were drilled in 1904 and 1905. The earliest water-level measurements for Carrizo and Wilcox wells were taken in 1928 and

1929 (TWDB, website). The measured depths to water for the wells located in the southern portion of the county, where it is known that wells originally flowed, yield water-level elevations that are below ground surface in. Because none of the earliest water-level measurements in the southern part of the county reflected flowing conditions, the value for one measurement was increased until the calculated water-level elevation was above ground surface. That increased values was then used to generate the predevelopment water-level elevation contours. The actual values for several other water-level measurements taken in 1929 and 1931 in the northern portion of the county were also used in generation of the predevelopment contours.

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APPENDIX B

Standard Operating Procedures (SOPs) for Processing Historical Pumpage Data TWDB Groundwater Availability Modeling (GAM) Projects

Standard Operating Procedures (SOPs) for Processing Historical Pumpage Data TWDB Groundwater Availability Modeling (GAM) Projects

TABLE OF CONTENTS

1. Groundwater use source data - Groundwater use data is derived from three tables provided by the Texas Water Development Board (TWDB) in a MS Access 97 database and one spreadsheet provided in MS Excel format:

   1.1. **PumpagebyMajorAquifer1980-1997** – This table contains water use summaries, in acre-feet/year) from each major aquifer, county, and basin for the years 1980 and 1984-1997 for the water use categories:

   - IRR – irrigation
   - STK – livestock
   - MIN - mineral extraction
   - MFG – manufacturing
   - PWR – power generation
   - MUN – municipal water supply, and
   - C-O – county-other (rural domestic) use.

   1.2. **RawDataMUN_WaterUseSurvey** – This table contains reported annual and monthly self-generated groundwater use totals, in gallons, from each municipal water user for the years 1980-1999. Monthly totals are missing in many cases. The data originate from the annual water use surveys. The county, basin, and major aquifer of origin are reported, as well as the water user group ID, alphanumeric code of the water user, and line 1 of the address of the water user. The number of wells from which the water was pumped is reported in most cases.

   1.3. **RawDataMFG_WaterUseSurvey** – This table contains reported annual and monthly self-generated groundwater use totals, in gallons, from each manufacturing, power generation, or mining water user for the years 1980-1999. Monthly totals are missing in many cases. The data originate from the annual water use surveys. The county, basin, and major aquifer of origin are reported, as well as the water user group ID, alphanumeric code of the water user, and line 1 of the address of the water user. The number of wells from which the water was pumped is reported in most cases.

   1.4. **RuralDomestic_Master_Post1980_021502.xls** – This Excel spreadsheet contains summaries of annual rural domestic water use, by county-basin, from 1980 to 1997.

2. Initial Processing

   2.1. Completion of Monthly Pumpage Estimates for MUN, MFG, PWR, and MIN Uses - In the tables **RawDataMUN_WaterUseSurvey** and **RawDataMFG_WaterUseSurvey**, monthly pumpage estimates are reported for the majority, but not all, of the water users. For other users, only the annual total pumpage is reported. It is necessary to estimate the monthly pumpage totals for some water users via the following procedure.

2.1.1. First, export the tables **RawDataMFG_WaterUseSurvey** and **RawDataMUN_WaterUseSurvey** to Microsoft Excel. Append the records from the latter file to the former. Delete records with reported annual total water use (in gallons) of “0”.

2.1.2. In Excel, calculate the monthly fractions of annual total water use for each record for which monthly pumpage was reported. As an example, a monthly distribution factor of 1/12, or 0.0833, would result from a uniform annual distribution.

2.1.3. Calculate the average monthly distribution factor for each county-basin and water use category. Statistically review these average monthly fractions for outliers. Generally, monthly distribution factors fall within the range 0.035 to 0.15.

2.1.4. Next, for those water use records that contain an annual total water use but no monthly value, calculate estimated monthly water use values by multiplying annual total pumpage by the average monthly distribution factor for the same water use category (MUN, MFG, PWR, MIN) in the county-basin within which it was located. If the monthly distribution factor for its county basin and water use category was an outlier, usually due to the fact that only one or two water users were located in the county-basin, use the monthly distribution factor from the nearest adjacent county-basin. (Note: For Louisiana and Arkansas parishes/counties, for which no monthly values are available, use the values from the nearest Texas counties.)

2.1.5. Add an additional field, “Monthly Calculated” to the spreadsheet, with “N” entered in those records containing original, reported monthly pumpage values, and “Y” for those records with calculated monthly pumpage values.

2.1.6. Finally, re-import the Excel spreadsheet into the Access database as a table **MUN+MFG_WaterUseSurvey**.

2.2. Predicting historical pumpage for 1981-83 and 1997-1999 - In the table **PumpagebyMajorAquifer1980-1997**, groundwater use summaries were reported for the years 1980 and 1984-1997 for the categories MIN, MFG, PWR, STK, IRR, and MUN (actually MUN + C-O) for each major aquifer and county-basin. Water use summaries for the years 1981-1983 and 1998-1999 were not reported. In the spreadsheet **RuralDomestic_Master_Post1980_021502.xls**, water use is not reported for 1998 and 1999. The groundwater use for these years must be obtained by interpolation from existing data.

2.2.1. First, import the tables **PumpagebyMajorAquifer1980-1997** and **RuralDomestic_Master_Post1980_021502.xls** into SAS datasets.

2.2.2. Import into a SAS dataset the weather parameters “average annual temperature” and “total annual precipitation” for 1980-1999 from National Weather Service cooperative weather stations. Delete those stations that have valid measurements in less than 16 of the 20 years. Also, delete data from any stations that do not have valid measurements for at least 4 of the 5 years 1981, 1982, 1983, 1998, and 1999.

2.2.3. In Arcview, identify the weather station (with valid data for at least 16 of the 20 years) closest to each county-basin. Create a look-up table in SAS to link each county-basin with the closest weather station.

2.2.4. In SAS, apply linear regression in Proc REG with stepwise selection, to regress annual pumpage (dependent variable) vs. 1) year, 2) average annual temperature and 3) total annual precipitation from the nearest weather station, for each county-basin, major aquifer, and water use category, for the years 1980 and 1984-97. Select the best valid regression equation based on the statistic Mallow's Cp, which balances the improvement in regression fit as independent variables are added to the regression with the increasing uncertainty in the resulting dependent variable estimates. Transformations (e.g., natural logarithms) of the independent variables may yield a better regression equation. There should be a regression equation for each county-basin, and water use category.

2.2.5. Using the regression equations and weather data for the years 1981, 1982, 1983, 1998, and 1999, in SAS, calculate predicted pumping for these years each county-basin and water use category. If predicted values are less than zero, a value of zero is entered. Append the predicted water use for these five years to the reported water use for 1980 and 1984-1997. Export this table, then import it into the Access database as **PumpagebyMajorAquifer1980-1999.**

2.2.6. In general, this regression procedure is appropriate for pumpage changes that might be expected based on gradual annual changes (e.g., population) or year-to-year weather variability. It may not make good predictions when pumpage changes rapidly for non-weather-related factors. Review and inspect the regression-based pumpage estimates for 1981-83 and 1998-99 versus the TWBD-provided pumpage estimates for 1984-1997. Carefully inspect all between-year pumpage differences of more than 20%. Subjectively, if the predicted pumpage estimates do not make sense, replace the regression-based estimate with the TWDB pumpage estimate for the previous year.

2.2.7. Add a new column "Annual Source" to the table, and enter in it "Reported" for those years for which annual water use was reported, and "Regression" or "Previous Year" for those years for which pumpage sums were predicted from regression or previous years.

2.3. (OPTIONAL) Selecting Pumpage within the model domain – The tables contain pumpage estimates for the entire state, or the entire aquifer of interest. Ultimately, pumpage originating within the model domain will be made during attribution of data to model grid cells. To speed the analysis, it may be beneficial to create a subset of data for pumpage that will encompass the model domain, with a buffer. **WARNING:** Pumpage sometimes originates (e.g., wells exist) in a different geographic area from where water is used and reported. Be careful that this procedure does not exclude any reported pumpage!

2.3.1. Once the model domain has been identified by the modelers, it is overlain on the county GIS layer in Arcview, and all counties containing, or very near to, any part of the model domain are selected.

2.3.2. Next, in MS Access, a new field "Domain?" is added to the table **Reference_Countyname_number_FIPS**. A value of "Y" is entered in this field for records of counties within the model domain.

2.3.3. Using this table, in a select query with other tables or queries joined by county name, number, or FIPS (federal information processing system) code, one can specify "Domain='Y' as a condition to limit queries to those counties within the model domain.

2.4. Preparing a County-basin Arcview Shapefile and Associating Model Grid Cells with a County-Basin – Much of the reported pumpage is spatially divided into county-basin units, which consist of the area in the same county and river basin. Many counties are split between two or more river basins, thus, county-basins are smaller than counties.

2.4.1. To create a county-basin Arcview shapefile, in Arcview, load GIS shapefiles of counties and river basins in GAM projection. Intersect these two layers using the Geoprocessing Wizard to create a new shapefile **countybasins.shp**.

2.4.2. Associate each model grid cell with the county-basin it falls primarily within. This will be useful when we need to determine monthly distribution factors and water user group IDs (WUG IDs) for non-well-specific pumpage categories (IRR, STK, C-O). These monthly distribution factors are estimated as averages within a county-basin. **Note**: The primary county-basin is not used to spatially distribute pumpage among grid cells because it is inexact. A grid cell may be part of multiple county-basins. For spatial distribution purposes, this grid cell should be split by county-basin – then later aggregated.

2.4.2.1. Load the model grid shapefile in GAM projection. Union this shapefile with countybasins.shp using the Geoprocessing Wizard. Add a numeric field "fr_grdarea" to the attribute table, and use the field calculator function to enter its values (fr_grdarea = shape.returnarea/27878400). Here, 27878400 is the area, in square feet, of each grid cell. Export the table as a dbf file.

2.4.2.2. Import the dbf file into MS Access as a new table - **Table1**. Our goal is to identify, for each grid cell, the county-basin with which it is primarily associated.

2.4.2.3. Select by query the records with no value for the field "CountyBasin." Delete these records, as they are grid cells over Mexico or the ocean.

2.4.2.4. Run a make table query, sorting the table1 records by grid_id (ascending) and fr_grd_area (descending) to create a new table, **Table2**.

2.4.2.5. Copy **Table2**, and paste only the table structure as a new table –

Grid_countybasin.

2.4.2.6. In design view, make the field “grid_id” a primary key in the table **Grid_countybasin**.

2.4.2.7. Run an append query, to append all fields of the records from table 2 to **Grid_countybasin**. When the warning window comes up, say yes to proceed with the query. This appends only the first record for each grid_id to **Grid_countybasin**, leaving one record for each grid cell with the county basin with the largest value of “fr_grdarea”. The resulting table should have one record for each grid cell in the model grid, and the county-basin name for that model grid cell.

3. Matching Pumpage to Specific Wells

Historical groundwater use from the categories MUN, MIN, MFG, and PWR is to be matched with specific wells from which it was pumped. Reported groundwater use for these uses, from the annual water use surveys, is contained in the table **MUN+MFG_WaterUseSurvey**. For MUN, MFG, MIN, and PWR, water use is reported for each year from 1980 to 1999. These tables report total annual use and, in most cases, monthly use, for each water user. The water user is identified by a unique alphanumeric code “alphanum.” The tables also list the county and river basin, as well as their water user group ID, their regional water planning group, their water use category, the major aquifer from which the groundwater was pumped, and the number of wells from which the water was pumped. These tables do not indicate the specific location off the wells, well elevation, well depth, a specific aquifer name, or other information needed for groundwater modeling. This information must be retrieved from other sources. The primary source of well information is the state well database maintained by the TWDB. Secondary sources include well data found in the TNRCC public water supply database, and the USGS site inventory. A final source is the follow-up survey provided by the TWDB in October 2001.

3.1. Create **All_wells** table –

3.1.1. Download the state well database as a table **weldta.txt** for the entire state (under the menu “all counties combined”) from the TWDB web site http://www.twdb.state.tx.us/publications/reports/GroundWaterReports/GWDatabaseReports/GWdatabaserpt.htm. Import this table into MS Access as a new table **All_Wells**.

3.1.2. The TNRCC public water supply database includes data for some wells that are not found in the TWDB state well database. Retrieve this database from the TNRCC. Create a query to link the required well data, and append the well data to **All_wells**, exercising care to match fields appropriately.

3.1.3. The USGS site inventory http://waterdata.usgs.gov/tx/nwis/inventory contains data for wells that may not be found from other sources. Run a query for the state of Texas with site type = ‘ground water’ to download the well data and append it to **All_wells**. Be careful to match fields appropriately.

3.1.4. Delete any oil, gas, geothermal, or observation wells, anodes, drains, or springs after a query of the attribute table on the fields "GW_type_cd" or "Site_use1_cd".

3.2. Linking water use data to the state well database – Using a make-table query to create a new table **MUN+MFG_linkedwithwellinfo**, all fields from the water use survey are merged with all fields from the state well database by joining the field "alphanum," in the table **MUN+MFG_WaterUseSurvey,** to the field "user code econ," in the state well database table **All_wells**. In many cases, several different wells may have the same "user code econ," making a one-to-many match (this is expected, since one city may own multiple wells). Add a field "Location Source" to the table **MUN+MFG_linkedwithwellinfo**. For the pumpage records with one or more matched well, enter the text "state well database" in this field.

3.3. Locating unmatched pumpage 1 – Identify the pumpage records without a matching well using a **Find Unmatched** query. Check the field "alphanum" in unmatched pumpage records of the table **MUN+MFG_WaterUseSurvey,** and "user_code_econ" in the table **All_Wells** for obvious errors that prevent automatic matching, and correct any found and repeat the steps to make the table above. Next, manually search the **All Wells** table for wells in the same county and basin, for which the user name field "owner_1" matches the field "line1" in **MUN+MFG_WaterUseSurvey**. When a match is found, add a field to the well table, and copy the "alphanum" field from the water use survey, to facilitate match-merging. Next, match this new field in the well database to "alphanum" of the water use survey, and append these matched records to the table **MUN+MFG_linkedwithwellinfo**. Enter "state well database manual match" for the field "Location Source" for these new appended records.

3.4. Locating unmatched pumpage 2 – For those pumpage records not matched via the above procedures, open the TNRCC public water supply database and attempt to manually match the water user to specific wells based on the county, aquifer_id, and owner name - "A1Name." When a match is found, add a field to the well table, copy the "alphanum" field from the water use survey, perform a match-merging query, and update these new matched records to the table **MUN+MFG_linkedwithwellinfo**. Enter "TNRCC PWS database" for the field "Location Source" for these new appended records.

3.5. Locating unmatched pumpage 3 - For those pumpage records, if any, still not matched in the above procedures, manually search the TWDB follow-up survey data. When a match is found, this data must be manually copied to the table **MUN+MFG_linkedwithwellinfo** because the table format is substantially different. Enter "TWDB followup survey" for the field "Location Source" for these new appended records.

3.6. Locating unmatched pumpage 4 - For those pumpage records, if any, still not matched in the above procedures, it may be possible to identify an approximate well location via the EPA's Envirofacts facility database. In an internet browser, go to http://www.epa.gov/enviro/html/fii/fii_query_java.html and perform a facility information query using a characteristic part of the facility name in the query field "facility site name." If a single facility of matching name is located in the same county, copy the facility latitude and longitude, in degrees, minutes, seconds into the appropriate fields of the table **MUN+MFG_linkedwithwellinfo**. Enter “facility centroid” in the field “Location Source” if Envirofacts lists that as the source of the latitude and longitude, or “facility zip code centroid” if Envirofacts lists that as the source of the latitude and longitude. Note that the median size of a zip code in Texas is approximately 5.5 square miles. Thus, pumpage located based on a zip code centroid may be very uncertain, especially in rural areas, and should be used with caution. However, it was felt that having an approximate location was better than leaving them out of the model. Note: Because this step is labor-intensive, it may be acceptable to perform this procedure for only the “major” water users, as indicated by volume used.

3.7. Count wells matched - Count the number of wells matched to <u>each</u> pumpage record via a crosstab query on **MUN+MFG_linkedwithwellinfo**.

3.8. Apportion water use between matched wells –

3.8.1. For that water use matched to more than one well, compare the number of matched wells to the number of wells reported as used in the water use survey. If the number of matched wells exceeds the number reportedly used, inspect the well data, including the county, basin, aquifer_id, well_type, drill_date, and other fields to see if some of the wells can be excluded from consideration as the source form which the water was reportedly pumped. If so, remove that well from the table.

3.8.2. Next, we need to apportion the reported pumpage among the wells matched. Since we don’t have data indicating otherwise, pumpage will be divided equally between wells. Create a new query that 1) adds a column “Num Wells Matched” indicating the number of wells matched (based on the aforementioned crosstab query) to the table **MUN+MFG_linkedwithwellinfo**, and 2) if one or more wells are matched, divides the reported pumpage in the fields “annual total in gallons” and “jan” – “dec” by the number of wells matched. Add another field “Corrected for Numwells” with a value of “Y” if the original pumpage sum for the water user was divided by two or more wells, and “N” otherwise.

3.8.3. Quality control check – In a query, summarize total annual water use by county-basin-year in the table **MUN+MFG_linkedwithwellinfo**. Make sure that these match the corresponding totals from the original table **MUN+MFG_WaterUseSurvey**. If not, correct the situation, which may occur by double-matching some water use records to wells.

3.9. Calculate Additional Fields - In a new make-table query, create the table **Well-specific_pumpage** based on **MUN+MFG_linkedwithwellinfo,** calculate latitude and longitude as decimal degrees from degrees-minutes-seconds in new fields “lat_dd” and “long_dd.” Also in the same query, calculate water use in acre-feet from gallons in new fields “Annual total in acre-ft”, “JAN in acre-ft”, “FEB in acre-ft”,….,”DEC in acre-ft.”

3.10. Append Out-of-State Data - Append the well-specific Louisiana and Arkansas water use, in acre-ft, from LADEQ and USGS, to the table **Well-specific_pumpage**.

3.11. Summarize well-specific matching completeness – Perform queries to calculate the sum of matched water use by county-basin-year, and the total water use (matched and unmatched) by county-basin-year. Based on these queries, calculate the volumetric percent completeness of matching by county, basin, and year. Completeness should be high (e.g., >80%) to facilitate accurate accounting for water use in the model.

4. Spatial Allocation of Groundwater Pumpage to the Model Grid - The model grid is comprised of an equal-spaced grid with a size of one mile by one mile. The grid has 3 dimensions- row, column, and model layer. Each cell of the model grid is labeled with a 7-digit integer "grid_id". The first digit represents the model layer. Digits 2 through 4 represent the row number. Digits 5 through 7 represent the column. The model grid is represented in a MS Access table linked to an Arcview shapefile via the field "grid_id".

4.1. Spatial allocation of well-specific groundwater pumpage from the categories MUN, MFG, MIN, and PWR

4.1.1. Distribute pumpage into grid cells

4.1.1.1. In MS Access, verify that all records in the table **Well-specific_pumpage** have x,y coordinates in decimal degrees.

4.1.1.2. In Access, add a new autonumbered, long integer field "Unique ID" to the table **Well-specific_pumpage**.

4.1.1.3. In Arcview, enable the Database Access extension. Add a new table **PtSrcTbl** to an ArcView project via SQL connect, including only the fields "unique_id", "well_depth", "lat_dd", and "long_dd". To perform an SQL connect, select the "SQL connect" menu item under the Project menu. Then navigate to the correct database and select the table **Well-specific_pumpage**.

4.1.1.4. Add **PtSrcTbl** as an event theme named **Wellpts** to a view based on lat/long coordinates. To do this, from the view menu, select the "add event theme" menu item, and choose long_dd for x field and lat_dd for y field in the dialog. Re-project the view to GAM projection using the View->Properties dialog box according to GAM Technical Memo 01-01 (rev A), then save it as a shapefile **Wellpts.shp**. Load **Wellpts.shp** and the model grid, also as a shapefile in GAM projection, into a new view.

4.1.1.5. Spatially join the model Grid table to the **WellPts** table. To do this make the "shape" fields of each table active, and with the **WellPts** table active, choose "join" from the table menu. This will join the 1 mile grid cell records to all of the **WellPts** records that are contained with that grid cell.

4.1.1.6. Migrate the GridId to the **WellPts** table. Do this by first adding a new 7-digit, no decimal, field to the **WellPts** table called "Grid_Id". Then, with the new field active, using the field calculator button make the new field equal to the "GridId" field from the joined table.

4.1.1.7. Delete those pumpage records outside the model domain with a "Grid_ID" of "0".

4.1.1.8. Vertical Distribution: Follow procedures outlined in sections 4.5.

4.1.2. Import the Arcview attribute table **Wellpts.dbf** to the MS Access database. Change the data type for the fields "Unique ID" and "Grid_ID" back to long integer if they were converted to double length real numbers during the import operation.

4.1.3. Run an update query to update the empty values of "Grid ID" in the table **Well-specific_pumpage** with the "Grid_ID" values from the table **Wellpts**, using an inner join on the field "Unique ID."

4.1.4. The table **Well-specific_pumpage** now has only the grid_id of the upper model, i.e., the first digit is 1. The actual vertical distribution data is in the fields "per1" to "per*x*" where x is the number of vertical layers (L) in the model. Copy the table x-1 times in an append query, incrementing the first digit of the grid id, to create a record for each model layer. There now should be L times the original number of records in the table. For example, for the northwestmost grid cells of a model with four layers, the following grid id's should now exist: 1001001, 2001001, 3001001, and 4001001; whereas only 1001001 was in the original table.

4.1.5. Calculate for each year the actual pumpage for each record as the product of the pumpage for a given year multiplied by the percent of pumpage from that model layer (from the fields "per1" – "per4", for a model with 4 layers).

4.1.6. Create a new summary query **gridsum_well_specific** to summarize the pumpage for each grid_id and year from the table **Well-specific pumpage**.

4.2. Spatial allocation of irrigation groundwater pumpage – Irrigation pumpage is distributed between the USGS MRLC land use types 61 (orchard/vineyard), 82 (row crops), and 83 (small grains) within each county-basin based on area. The distribution is further weighted based on proximity to the irrigated farmlands mapped from the 1989 or 1994 irrigated farmlands survey. The weighting factor is the natural logarithm of distance in miles to an irrigated polygon. However, this weighting factor is manually constrained to be between 0.5 and 2, in order to limit the effect of weighting to a factor of 4. All grid cells further than roughly 7.4 miles from an irrigated polygon will have a weight of 0.5, while all grid cells nearer than 1.6 miles from an irrigated polygon will have a weight of 2.

4.2.1. Create shapefile for MRLC land use categories 61, 82, and 83.

4.2.1.1. In ArcView, load MRLC grid. Resample grid with a larger grid size to make the file more manageable (use x4 factor and set the analysis extent to the model domain). Select, in the new resampled grid, values 61, 82, and 83, and convert to shapefile. Call it "mrlc_irrigated.shp."

4.2.2. Create "distance grids" for the irrigated farmlands 89 and 94 shapefiles. These will be grid files that contain the distance from each grid cell to the nearest irrigated farmlands polygon.

4.2.2.1. Add "irr_farms89.shp" to a view, and make it active. With Spatial Analyst extension activated, select "find distance" from the analysis menu. Choose a grid cell size of 1 mile, and set the extent to the model domain. This will generate a grid of distance values to the nearest irrigated farm. Repeat for "irr_farms94.shp." Call them "dist_irr*yy*."

4.2.3. Using the Geoprocessing Wizard, intersect county-basin boundaries with "mrlc_irrigated.shp" to create "mrlc_cb.shp." Create a unique id "cb_irr_id" so that, if necessary, these unique polygons can be queried.

4.2.4. Intersect "mrlc_cb.shp" with the 1 mi. sq. grid cells.

4.2.4.1. Select only the 1 mile grid cells that are above the aquifer of concern's extents (The county-basin irrigation pumpage totals are aquifer specific, so the pumpage should only be distributed where the proper underlying aquifer is present).

4.2.4.2. It is also necessary to distribute across the entire county-basin area where the underlying aquifer is present, and not limited to the model domain in counties partly within the model domain. Therefore, if a county-basin is intersected by the model domain boundary, the pumpage total must be distributed across the entire county-basin so that only the proper percentage gets distributed inside the model domain. To insure that this happens, select the county-basins on the perimeter that get intersected by the model domain boundaries. With the Geoprocessing Wizard, intersect these county-basins with the subsurface aquifer boundaries, the resulting file will be county-basins above the aquifer. Clip out the areas that reside inside the model domain (Union with model domain and delete that which is inside). What is left, (county-basins above aquifer of concern and outside of model domain) can be dissolved into one polygon and merged with the 1 mile grid cells. Give this new polygon a grid_id of "9999999" (later when pumpage values are summed by grid id the "9999999" values will fall out).

4.2.4.3. Add the new record "9999999" to the selected set from 4.3.4.1. Using Geoprocessing Wizard, intersect the selected 1 mile grid cells with the "mrlc_cb.shp" file. The result will be all of the irrigated land with the proper grid_id and county-basin name. Call it "mrlc_cb_grid.shp".

4.2.4.4. Add field "un_area_gd" and calculate the polygons' areas in sq. miles using the field calculator ("un_area_gd" = [shape].returnarea/27878400).

4.2.5. Determine weighting factor for each polygon based on area and proximity with irrigated farms.

4.2.5.1. Add fields "dist_irr89", "dist_fact89", "ardisfac89", "sumcbfac89", "w_ar_dis89".

4.2.5.2. Populate the distance to irrigated farmland field ("dist_irr89") using the values from the "dist_irr89" grid file.

4.2.5.3. Calculate the distance to irrigated farms factor using the field calculator ("dist_fact89"=1/(1+[dist_irr89]).ln + 0.0001). Select all values that are greater than 2 and change them to 2, and select all values that are less than 0.5 and change to 0.5 so that the range is 0.5 – 2.

4.2.5.4. Calculate the area-distance factor using the field calculator ("ardisfac89" = "un_area_gd" * "dist_fact89").

4.2.5.5. Create a summary table by county-basin that summarizes the "ardisfac89" field. Link the summary table back up by county-basin and migrate the summed values into "sumcbfac89".

4.2.5.6. Calculate the distribution weighting factor for area of irrigated land (mrlc land use) and distance to irrigated farmland (farmland survey) using the field calculator ("w_ar_dis89" = "ardisfac89" / "sumcbfac89"). This is basically the fraction of the total county-basin pumpage that will be distributed to a specific polygon.

4.2.5.7. Repeat section 4.3.5 for irrigated farmland 94.

4.2.6. Calculate unique pumpage values for 1 mile grid cells.

4.2.6.1. Create 20 new fields (1 for each year: "pmp_80" – "pmp_99".

4.2.6.2. Using SQL Connect, query the Access table **PumpagebyMajorAquifer1980-1999** for all years.

4.2.6.3. Query the records (by the year column) for each year and specific aquifer (by aquifer code column) and export each query as a separate *.dbf file. "Pump_by_cb_*yyyy_aquifer*.dbf." These tables will have a column for each use category, and can therefore also be used in livestock calculations for the same aquifer of concern.

4.2.6.4. Join the table "pump_by_cb_1980_cw.dbf" to the attribute table "mrlc_cb_grid.shp" by countybasin. (make certain that all countybasin names are spelled the same).

4.2.6.5. Calculate "pmp_80" using the field Calculator (pmp_80 = w_ar_dis89 * irrigation). Irrigation is the column of the joined table "pump_by_cb_1980" that contains the countybasin annual pumpage totals for irrigation use. Use "w_ar_dis89" for years 80-89 and use "w_ar_dis94" for years 90-99.

4.2.6.6. Repeat 4.2.6.4 – 4.2.6.5 for all years.

4.2.7. Summarize all unique pumpage totals by grid cell id.

4.2.7.1. Summarize all the "pump_un*yy*" fields by grid cell id, by using the summarize button and adding "pmp_80" (sum) through "pmp_99" (sum) in the dialog box. Name this summary file ***area*_irr_pumpbygrid_80_99**. (i.e. **sw_irr_pumpbygrid_80_99.dbf**).

4.2.8. Vertical Distribution: Follow procedures outlined in sections 4.5.

4.2.9. Import irrigation pumpage table back into MS Access database as a table ***area*_irrigation_total**, e.g., **sw_irrigation_total**

4.2.9.1. In MS Access, import the attribute table for the Arcview shape file **grid_irr_*yy*.dbf** as a dbase file. This table should include one record for each possible Grid_ID, and at least the fields "Grid_ID", "year", and "pump*yy*_IRR."

4.2.10. The table ***area*_irrigation_total** now has only the grid_id of the upper model, i.e., the first digit is 1. The actual vertical distribution data is in the fields "per1" to "per*x*" where x is the number of vertical layers in the model. Copy the table x-1 times in an append query, incrementing the first digit of the grid id, to create a record for each model layer. There now should be L times the original number of records in the table. For example, for the northwestmost grid cells of a model with four layers, the following grid id's should now exist: 1001001, 2001001, 3001001, and 4001001; whereas only 1001001 was in the original table.

4.2.11. Calculate for each year the actual pumpage for each record as the product of the pumpage for a given year multiplied by the percent of pumpage from that model layer (from the fields "per1" – "per4", for a model with 4 layers).

4.2.12. Create a new summary query **Irrigation_annual_*area*** to summarize the pumpage for each grid_id and year from the table ***area*_irrigation_total**.

4.3. Spatial allocation of livestock groundwater pumpage – Livestock groundwater use within each county-basin is distributed evenly to all rangeland, Anderson Level II land use codes 31 (herbaceous rangeland), 32 (shrub and brush rangeland), and 33 (mixed rangeland) of the USGS 1:250,000 land use land cover data set (http://edcwww.cr.usgs.gov/glis/hyper/guide/1_250_lulc).

4.3.1. Determine rangeland within each county-basin

4.3.1.1. In Arcview, create a rangeland-only land use shapefile by loading the USGS land use shapefiles by quadrangle, merging them as required to cover the model domain, selecting the land use codes 31, 32, and 33 in a query, then saving the theme as a new shapefile **Rangeland.shp**.

4.3.1.2. Using the Geoprocessing Wizard, intersect the Rangeland shapefile with the County-basin shapefile (make sure to use entire county basin areas, and not the "clipped to domain" version) to make a new intersection shapefile **range_countybasin.shp**.

4.3.1.3. Calculate the unique area (in square miles) of the new intersected polygons "area_un1" using the field calculator (area_un1=shape.returnarea/27878400).

4.3.1.4. Summarize the unique area by county-basin (total area of rangeland within county-basin) using the summary button.

4.3.1.5. Link the summary table back to the range_countybasin shape file and migrate it into a new field "rg_cb_tot" using the field calculator.

4.3.1.6. Determine weighted area factor "w_area1" for each polygon using the field calculator (w_area1)=(area_un1 / rg_cb_tot). W_area1 is, for each rangeland polygon, the fraction of the total rangeland area within the county-basin.

4.3.2. Intersect the rangeland/countybasin polygons with the Model Grid and set up for unique pumpage calculations.

4.3.2.1. Using the Geoprocessing Wizard, intersect the shapefiles range_countybasin and Model Grid to create a new shape file **rng_cb_mg.shp**.

4.3.2.2. Calculate the unique area of "intersected" polygons (area_un_grid) using the field calculator (area_un_grid=shape.returnarea/27878400). Double check that no values are greater that 1.

4.3.2.3. Determine the weighted area factor (w_area_grid) = (area_un_grid/area_un1).

4.3.3. Calculate unique pumpage "pump_un_yy" for the intersected polygons for every year (80-99).

4.3.3.1. Add the fields "pump_un80" – "pump_un99" to the **rng_cb_mg** attribute table.

4.3.3.2. Using SQL Connect, query the Access table **PumpagebyMajorAquifer1980-1999** for all years.

4.3.3.3. Query the records (by the year column) for each year, and specific aquifer (by aquifer code column) and export each query as a separate .dbf file. "Pump_by_cb_*yyyy_aquifer*.dbf." These tables will have a column for each use category, and can therefore be used in the irrigation calculations for the same aquifer of concern.

4.3.3.4. Join the table "pump_by_cb_1980.dbf" to the attribute table "rng_cb_mg" by countybasin. (make certain that all countybasin names are spelled the same).

4.3.3.5. Calculate "pump_un80" using the field Calculator (pump_un80 = w_area_grid * (w_area_1 * livestock)). (livestock is the column of the joined table "pump_by_cb_1980" that contains the countybasin annual pumpage totals for livestock use).

4.3.3.6. Repeat 4.3.3.4 – 4.3.3.5 for all years.

4.3.4. Summarize all unique pumpage totals by grid cell id.

4.3.4.1. Summarize all the "pump_un*yy*" fields by grid cell id, by using the summarize button and adding "pump_un_80" (sum) through "pump_un_99" (sum) in the dialog box. Name this summary file "*area*_stk_pumpbygrid_80_99." (i.e. sw_stk_pumpbygrid_80_90.dbf).

4.3.5. Vertical Distribution: Follow procedures outlined in sections 4.5.

4.3.6. Import livestock pumpage summary table back into MS Access database as a table **area_livestock_total**, e.g, **sw_livestock_total**.

4.3.7. The table ***area*_livestock_total** now has only the grid_id of the upper model, i.e., the first digit is 1. The actual vertical distribution data is in the fields "per1" to "per*x*" where x is the number of vertical layers in the model. Copy the table x-1 times in an append query, incrementing the first digit of the grid id, to create a record for each model layer. There now should be L times the original number of records in the table. For example, for the northwestmost grid cells of a model with four layers, the following grid id's should now exist: 1001001, 2001001, 3001001, and 4001001; whereas only 1001001 was in the original table.

4.3.8. Calculate for each year the actual pumpage for each record as the product of the pumpage for a given year multiplied by the percent of pumpage from that model layer (from the fields "per1" – "per4", for a model with 4 layers).

4.3.9. Create a new summary query **Livestock_annual_*area*** to summarize the pumpage for each grid_id and year from the table ***area*_irrigation_total**.

4.4. Spatial allocation of rural domestic (C-O) groundwater pumpage.

4.4.1. Calculate the Population in each 1 mile grid cell.

4.4.1.1. In Arcview, load the 1990 block-level census population shapefile.

4.4.1.2. Load Arcview polygon shapefiles for cities. Select census blocks that fall with in city boundaries and delete those records so that rural domestic pumpage does not get distributed to cities. (Note: we're assuming that city boundaries are good surrogates for the extent of the area served by public water supply systems, whose pumpage is reported under the category "MUN").

Repeat this process for the reservoir areas.

4.4.1.3. Calculate the area of census blocks in sq. miles in a new field “blk_area” using the Field Calculator function (blk_area=shape.returnarea / 27878400).

4.4.1.4. Load the model grid, model domain, and county-basins shapefile. Select all county-basins that are intersected by the model domain boundary. Union the selected county-basins with the model domain boundary. In the resulting shapefile, delete the polygons that are inside the model domain, leaving only areas of the county-basins that are outside of the model domain. Dissolve these polygons into one and merge with the model grid shapefile. Give this new record a grid_id of 9999999. (Adding this new area will insure that, when the county-basin total populations are calculated, the population outside of the model domain will be included).

4.4.1.5. In the Geoprocessing Wizard, intersect the census block shapefile with the model grid shapefile to create a new shape file **intrsct*90*.shp**. (Note: Because the model grid size is 1 square mile, no intersected polygon (inside the model domain) should be larger than 1 square mile. Make sure that this is the case before proceeding).

4.4.1.6. Calculate the unique area of all intersected polygons in square miles as a new field “area_un1” using the Field Calculator function (area_un1=shape.returnarea / 27878400). (so that one grid cell has an area of 1).

4.4.1.7. Add a new numeric field “pop_un1” – the unique Population of the intersected polygons. Using the Field Calculator, calculate its value as (POP_un1 = pop*90* * area_un1 / blk_area) where pop*90* is the block Population from the census file.

4.4.1.8. Sum the field “pop_un1” by grid_id using the Field Summarize function to calculate the total population within each grid cell. Join this summary table to the original grid table by grid_id and copy value into new field “pop_90”.

4.4.1.9. Repeat steps 4.5.1.1 – 4.5.1.8 (no need to repeat step 4.5.1.4, just use the grid file that was used for previous iteration).

4.4.2. Calculate the rural domestic pumpage for each 1 mile grid cell.

4.4.2.1. Intersect the county-basins shapefile with the model grid (which now has census populations for 1990 and 2000) to create a new shapefile **grid_cb_pop**.

4.4.2.2. Create new field “area_un2” and calculate unique area using field calculator (“area_un2” = [shape].returnarea/27878400)

4.4.2.3. Create two new fields “pop_un90” and “pop_un00”. Calculate using the field calculator (“pop_un*yy*” = “area_un2”/ “pop_*yy*”)

4.4.2.4. Using SQL Connect, query the Access table **PumpagebyMajorAquifer1980-1999** for all years.

4.4.2.5. Query the records (by the year column) for each year (because Rural Domestic pumpage data is not aquifer specific, there is no need to query by aquifer) and export each query as a separate .dbf file. “Pump_by_cb_*yyyy*.dbf.”

4.4.2.6. Join table “pump_by_cb_1980.dbf” to grid_cb_pop.dbf by county-basin.

4.4.2.7. Add field “pmp80.” Using field calculator, calculate “pmp80” (pmp80=CO*pop_un90/cb_pop90).

4.4.2.8. Repeat steps 4.5.2.6 – 4.5.2.7 for each year. Use pop90 for years 1980-1989 and use pop00 for years 1990-1999.

4.4.2.9. As a quality control check, sum the values of “rdom_pump” for each county-basin and make sure it matches the total for the county-basin from the Access table.

4.4.2.10. Summarize pmp80 through pmp99 by grid id. Link summary back to model grid file and migrate pumpage values.

4.4.3. Vertical Distribution: Follow procedures outlined in section 4.5.

4.4.4. Import the rural domestic pumpage table into the MS Access database as a table ***area*_rurdom_total**, e.g., **sw_rurdom_total**.

4.4.5. The table ***area*_rurdom_total** now has only the grid_id of the upper model, i.e., the first digit is 1. The actual vertical distribution data is in the fields “per1” to “per*x*” where x is the number of vertical layers in the model. Copy the table x-1 times in an append query, incrementing the first digit of the grid id, to create a record for each model layer. There now should be L times the original number of records in the table. For example, for the northwestmost grid cells of a model with four layers, the following grid id’s should now exist: 1001001, 2001001, 3001001, and 4001001; whereas only 1001001 was in the original table.

4.4.6. Calculate for each year the actual pumpage for each record as the product of the pumpage for a given year multiplied by the percent of pumpage from that model layer (from the fields “per1” – “per4”, for a model with 4 layers).

4.4.7. Create a new summary query **Rurdom_annual_*area*** to summarize the pumpage for each grid_id and year from the table ***area*_rurdom_total**.

4.5. Vertical Distribution of groundwater pumpage. *Note: These procedures are for all use categories, and this section is referenced multiple times. Take care, and perform only the operations that apply to that particular use.

4.5.1. Assign default well depths to model grid cells – Most, but not all, well-specific pumpage from the categories MUN, MFG, PWR, and MIN are associated with a reported well depth, screened interval, land surface elevation, which are used to attribute the pumpage to a specific vertical model layer. For those wells whose depth, screened interval, or land surface elevation is unknown, and for the non-well-specific pumpage in the categories C-O, STK, and IRR, it is necessary to interpolate these depths/elevations to assign the pumpage to a specific model layer. In this procedure, the approach is to interpolate on the basis of the depths of nearby (<10 miles) wells. On average, municipal, industrial, and irrigation water wells tend to be deeper than rural domestic or livestock wells. Thus, if there are nearby wells in the same water use category, the interpolation is based on these wells. In the absence of nearby wells of the same use category, the interpolation is based on nearby wells of any water use category. ***The procedures outlined in section 4.5.1 cover all use categories, and therefore, only need to be done once per model area.***

4.5.1.1.In Arcview, using SQL Connect, query the MS Access database table **All_wells** for all wells in the major aquifer of concern (based on the field “aqfr_id_1”). Save this query as a table ***AQ*_wells**, where ***AQ*** is a 2-character code representing the aquifer of interest.

4.5.1.2.Load these wells in a View as an event theme, using the fields lat_dd as y-coordinate and long_dd as x-coordinate. Convert the event theme to GAM projection as per GAM Technical Memo 1-01, then save this theme as a shape file.

4.5.1.3.Query the shape file’s attribute table for all domestic water wells (water_use_1 = “domestic”).

4.5.1.4.Using Arcview Spatial Analyst, under the Analyst, Properties menu, set analysis extent and grid size to be equal to the GAM model grid.

4.5.1.5.Next, under the Surface menu, interpolate a grid with values of interpolated well depth, via the inverse distance weighting method, within a fixed radius of 10 miles, with a power of 2.

4.5.1.6.Repeat steps 4.5.1.3 – 4.5.1.5 to create an interpolated well depth grid for each of the other water use categories MUN, MFG, PWR, MIN, STK, and IRR, as well as a well depth grid for all water use categories combined.

4.5.1.7.When a depth was not reported for a well, these grid values can be used as an estimated well depth. A new text field “depth source” is added to the well table to indicate that the well depth was estimated by interpolation, not reported. This allows a hydrogeologist or modeler to review these wells to make sure they fall in the proper model layer. When a well depth is checked and corrected manually, a value of “manual” is entered in the field “depth source’. Valid values of depth source include “reported”, “interpolated”, or "manual".

4.5.2. Assign default screened intervals to wells – For wells with no reported screened interval, calculate the well screened interval. The lower boundary is the well depth, while the upper boundary of the screened interval is calculated as the well depth minus an estimated screen length. The default screen lengths will be estimated from other wells in the same aquifer for which the screened interval is known.

4.5.2.1. An Excel file ***Screened_Interval.xls*** is provided by the modelers. It contains the land surface elevation and depths to the top and bottom of the screen for each well. The screened interval is calculated as the difference between the top and bottom depths. This file is loaded in Arcview and joined to the ***AQ_Wells*** table by state well number. Next, under the Surface menu, interpolate a grid with values of interpolated screened interval, via the inverse distance weighting method, within a fixed radius of 10 miles, with a power of 2.

4.5.2.2. When a screened interval is not reported for a well, these grid values can be used to estimate the upper depth of the screened interval, assuming that the well depth is the bottom of the interval. A new text field "screen_source" is added to the well table to indicate that the well depth was estimated by interpolation, not reported. Valid values of screen source include "reported" or "interpolated", or "manual".

4.5.3. Assign land surface elevations to wells – For wells without a reported land surface elevation (in the field "elev of lsd") a land surface elevation must be estimated. For this purpose, a 30-meter digital elevation model (DEM) grid is added to an Arcview project with the well data table. The Arcview script "getgridvalue" in Appendix 2 is run to return the value of the land surface elevation for the well.

4.5.4. Estimate the screened interval for non-well-specific pumpage - For the non-well-specific uses STK, IRR, and C-O, in order to distribute the pumpage vertically, each model grid cell may be treated as a well. Using the centroids of the model grid cells as if they were wells, copy the interpolated values of well depth, screened interval, and land surface elevation to each grid cell as described above.

4.5.5. Convert depths to elevations - In order to compare to model layers, which are reported as elevation (feet above mean sea level), it is necessary to convert the depths of the top and bottom of screened intervals to elevations. To do this, subtract the depths from the land surface elevation, in feet above mean sea level.

4.5.6. Determine vertical distribution of pumpage totals by comparing the elevations of the top and bottom of the well screened interval to model layer elevations. (For point source water use categories, this will be done for each specific well. For non-point source this will be done for each 1 mile grid cell).

4.5.7. Spatially join the flow layer structure (model grid cells with tops of aquifer elevations) to the wells. (for non-point source join by grid id).

4.5.8. Run vertical distribution avenue script on points (see appendix for code). This script will place a "pumpage percentage" in the flow layer percentage columns (per1 – per6). This value is actually the percentage of the total length of the screened interval that resides in each flow layer (possible 0 – 100).

4.5.9. Once script is successfully run, a series of QA checks must be run, and in certain cases percentage values must be altered manually. Field "calc_code" will be given a specific code for each case of manual alteration.

4.5.9.1. Query records that have a value of "99999" for every layer elevation (i.e. layer doesn't exist at that location). Set calc_code to "N".

4.5.9.2. Query records whose top of screen elevation is shallower than the top of the shallowest existing layer. (i.e. (top of layer 2 = 999999 and per2 > 0)). The script automatically puts a value in per2 if the top of screen is shallower than layer 3, but if layer 2 doesn't exist there then per2 should be zero and the value should be shifted down. In this case, calc_code should be set to "S3". This will tell someone that the screen is shallower than the shallowest layer which is layer 3.

4.5.9.3. Query records whose depth is deeper than the bottom layer. (i.e. depth<bottom layer). Put the remainder of the pumpage that was lost below into the bottom layer and set calc_code to "D".

4.5.9.4. Query records whose screened interval spans layer 1 or 2 and enters layer 3 (Carrizo). (i.e. per3>0 and per2>0). It is assumed that if the screened interval reaches the Carrizo then all of the water is being taken from that layer and not the above layers of inferior quality. Set per1 and per2 to zero and add their values to per3. Set calc_code to "C".

4.5.9.5. Query records whose reported top of screen elevation is less than the bottom of screen elevation. Manually set the appropriate layer percentage to 100%. Set calc_code to "E".

4.5.9.6. Query records whose top of screen elevation exactly equals one of the layer top elevations. This is very rare, but if it happens, the percentage value must be manually entered. Set calc_code to "=".

4.5.9.7. Query records whose total percentage is less than 100% by less than .5%. Due to a program glitch values of 99.5% get rounded to 100% and the rest is left out. Manually set percentage value to 100%. Set calc_code to "R".

4.5.9.8. Query all other records (records that don't have a calc_code value and whose tot_per = 100%). Set calc_code to "NP" for no problems.

5. Temporal Distribution of Rural Domestic, Livestock, and Irrigation Groundwater Use

5.1. Temporal distribution of livestock pumpage - Because we have only annual total groundwater pumpage estimates for STK, we need to derive monthly pumpage estimates. According to TWDB GAM Technical Memo 01-06, annual total livestock pumpage may be distributed uniformly to months since the water needs of livestock are not likely to vary significantly over the course of a year.

5.1.1. In the MS Access database, create a new table called Monthly Factors with the fields “countyname”, “basinname”, “countynumber”, “basinnumber”, “data_cat”, “year”, and “month”. The table should include a record for every county-basin within the model domain, water use category “data_cat”, year (1980-1999), and month (1-12), as well as an additional annual total record (month=”0”) for each county-basin, year, and water use category. Add 2 new fields “mfraction” and “Monthly distribution factor source” to the new table. The former is the numeric monthly distribution factor, while the latter is a text field indicating the source of the distribution factor. For all monthly livestock water use records (data_cat=STK, month in 1-12), enter an mfactor of “0.0833” (1/12) and a monthly distribution factor source of “Tech Memo 01-06”. For all annual total water use records (data_cat=STK, month =0), enter an mfactor of “1” and a monthly distribution factor source of “NA”.

5.2. Temporal distribution of irrigation (IRR) pumpage - Because we have only annual total groundwater pumpage estimates for IRR, we need to derive monthly pumpage estimates. Monthly distribution factors will be derived separately for rice-farming counties and non-rice-farming counties.

5.2.1. Temporal distribution of groundwater used for non-rice irrigation –

5.2.1.1. Record monthly crop evapotranspiration (ET), or total water demand, for each of the Texas Crop Reporting Districts (TCRDs) that occur within the model domain, from the report “Mean Crop Consumptive Use and Free-Water Evaporation for Texas” by J. Borrelli, C.B. Fedler, and J.M. Gregory, Feb. 1, 1998 (TWDB Grant No. 95-483-137). Use these values for all years.

5.2.1.2. Next, determine monthly precipitation (P) for the period 1980-1999 for the locale within each of the TCRDs that occur within the model domain.

5.2.1.3. Determine the monthly water deficit for each month of the two periods 1980-1989 and 1990-1999 by subtracting the P values from the ET values for each TCRD. Replace negative values with zero. Sum all water deficit values by month for each of the two periods, and divide by the number of months in each period to obtain an average non-rice monthly distribution factor for each month for the two periods 1980-89 and 1990-99.

5.2.2. Temporal distribution of groundwater used for rice irrigation –

5.2.2.1. First, identify the counties within the model area where rice is irrigated, using the 1989 and 1994 irrigation reports. Include only those counties in this analysis.

5.2.2.2.Next, using monthly pump power usage records provided by rice farmers, calculate monthly distribution factors for total annual power usage. Average all distribution factors within a county to get an average rice irrigation distribution factor.

5.2.3. Develop composite irrigation monthly distribution factors for each county and year based on the monthly factors for rice and non-rice irrigation, and the fraction of irrigation for rice in that county.

5.2.3.1.The TWDB irrigation survey data files Irr1989.xls and Irr1994.xls contain reported irrigation water use estimates for each crop and county. From these tables, calculate the fraction of irrigation water for rice in each county for the 1980s (based on 1989) and the 1990's (based on 1994).

5.2.3.2.Calculate the composite monthly distribution factor (MF_{comp}) for irrigation for each county as:

$$MF_{comp} = MF_{rice} * X + MF_{non\text{-}rice} * (1 - X)$$

where X is the fraction of water used for rice, and MF_{rice} and $MF_{non\text{-}rice}$ are the monthly distribution factors for rice and non-rice crops determined in steps 5.2.1 and 5.2.2, above.

5.2.4. For the county-basins where rice is not irrigated, enter the monthly distribution factors from step 5.2.3, above, in the table **Monthly Factors** for each year, county, basin, using "data_cat"="IRR", and "Monthly Distribution Factor Source"="ET/P Water Deficit Analysis."

5.2.5. For the county-basins where rice is irrigated, enter the monthly distribution factors from step 5.2.3, above, in the table **Monthly Factors** for each year, county, basin, using "data_cat"="IRR", and "Monthly Distribution Factor Source"="ET/P + Power Usage Analysis."

5.3. Temporal distribution of rural domestic (C-O) pumpage - Because we have only annual total groundwater pumpage estimates for C-O, we need to derive monthly pumpage estimates. According to TWDB GAM Technical Memo 01-06, annual rural domestic pumpage may be distributed based on the average monthly distribution of all municipal water use within the same county-basin.

5.3.1. In a MS Access query based on the table **RawDataMUN_linkedwithwellinfo**, calculate the sum of the fields "Annual total in gallons", "jan", "feb",…..,"dec" for each county, basin, and year.

5.3.2. Next, calculate "mfraction," the fraction of the annual total for each month, by dividing the columns "sum of jan", "sum of feb",….,"sum of dec" by the "sum of annual total in gallons.". Transpose this table via a query to make a table with the following fields: "countyname", "basinname", "year", "month", "mfraction", "data_cat," and "monthly distribution factor source." A value of "C-O" should be entered in the field “data_cat”, and the value of “monthly distribution factor source”=”this county-basin mun.”

5.3.3. The values of “mfraction” are statistically reviewed for outliers. Generally, monthly distribution factors fall within the range 0.035 to 0.15. Higher or lower values can be found when there is little municipal water use in a county-basin. In this case, substitute the values of “mfraction” from an adjacent county-basin, preferably from within the same county. Update the field “monthly distribution factor source” with the name of the county-basin used as a source.

5.3.4. For Louisiana and Arkansas parishes and counties, use the monthly distribution factors of the nearest Texas county-basin.

5.3.5. Add an annual total record for each county-basin-year, with “data_cat”=“C-O”, “month”=”0”, “mfraction”=“1”, and “monthly distribution factor source”=“NA.”

5.3.6. Using an append query, append these records to the table **Monthly Factors**.

6. Summarize Pumpage Information

6.1. Summary Queries

6.1.1. Queries for livestock - Create a new select query **MMMYY_STK** to calculate pumpage for the month and year of interest by multiplying the monthly factor for that month, year, and water use category, in the table **Monthly Factors**, by each entry in the imported table **Livestock_annual_CGC**. For any specified month (MMM) and year(YY), the SQL for the query **MMMYY_STK** is:

SELECT Livestock_annual_CGC.GRID_ID, Livestock_annual_CGC.DATA_CAT, Livestock_annual_CGC.Year, Livestock_annual_CGC.MODEL, [MONTHLY FACTORS].MONTH, [SumPumpageAF]*[mfraction] AS PumpageAF

FROM Livestock_annual_CGC LEFT JOIN [MONTHLY FACTORS] ON (Livestock_annual_CGC.Year = [MONTHLY FACTORS].YEAR) AND (Livestock_annual_CGC.DATA_CAT = [MONTHLY FACTORS].DATA_CAT) AND (Livestock_annual_CGC.basinnum = [MONTHLY FACTORS].basinnum) AND (Livestock_annual_CGC.CountyNumber = [MONTHLY FACTORS].countynum)

WHERE (((Livestock_annual_CGC.DATA_CAT)="STK") AND ((Livestock_annual_CGC.Year)=1980) AND ((Livestock_annual_CGC.MODEL)="CGC") AND (([MONTHLY FACTORS].MONTH)=1))

ORDER BY [SumPumpageAF]*[mfraction];

6.1.2. Queries for irrigation – Create a new select query **MMMYY_IRR** to calculate pumpage for the month and year of interest by multiplying the monthly factor for that month, year, and water use category, in the table **Monthly Factors**, by each entry in the imported table **Irrigation_annual_CGC.** For any specified month (MMM) and year(YY), the SQL for the query **MMMYY_IRR** is:

SELECT Irrigation_annual_CGC.GRID_ID, Irrigation_annual_CGC.DATA_CAT, Irrigation_annual_CGC.Year, Irrigation_annual_CGC.MODEL, [MONTHLY FACTORS].MONTH, [SumPumpageAF]*[mfraction] AS PumpageAF

FROM Irrigation_annual_CGC LEFT JOIN [MONTHLY FACTORS] ON (Irrigation_annual_CGC.basinnum = [MONTHLY FACTORS].basinnum) AND (Irrigation_annual_CGC.CountyNumber = [MONTHLY FACTORS].countynum) AND (Irrigation_annual_CGC.Year = [MONTHLY FACTORS].YEAR) AND (Irrigation_annual_CGC.DATA_CAT = [MONTHLY FACTORS].DATA_CAT)

WHERE (((Irrigation_annual_CGC.DATA_CAT)="IRR") AND ((Irrigation_annual_CGC.Year)=1980) AND ((Irrigation_annual_CGC.MODEL)="CGC") AND (([MONTHLY FACTORS].MONTH)=1))

ORDER BY [SumPumpageAF]*[mfraction];

6.1.3. Queries to summarize rural domestic (county-other) - Create a new select query **MMMYY_C-O** to calculate pumpage for the month and year of interest by multiplying the monthly factor for that month, year, and water use category, in the table **Monthly Factors**, by each entry in the imported table **Rurdom_annual_CGC**. For any selected month (MMM) and year(YY), the SQL for the query **MMMYY_C-O** is:

SELECT Rurdom_annual_CGC.GRID_ID, Rurdom_annual_CGC.DATA_CAT, Rurdom_annual_CGC.Year, Rurdom_annual_CGC.MODEL, [MONTHLY FACTORS].MONTH, [SumPumpageAF]*[mfraction] AS PumpageAF

FROM Rurdom_annual_CGC LEFT JOIN [MONTHLY FACTORS] ON (Rurdom_annual_CGC.DATA_CAT = [MONTHLY FACTORS].DATA_CAT) AND (Rurdom_annual_CGC.Year = [MONTHLY FACTORS].YEAR) AND (Rurdom_annual_CGC.CountyNumber = [MONTHLY FACTORS].countynum) AND (Rurdom_annual_CGC.basinnum = [MONTHLY FACTORS].basinnum)

WHERE (((Rurdom_annual_CGC.DATA_CAT)="C-O") AND ((Rurdom_annual_CGC.Year)=1980) AND ((Rurdom_annual_CGC.MODEL)="CGC") AND (([MONTHLY FACTORS].MONTH)=1))

ORDER BY [SumPumpageAF]*[mfraction];

6.1.4. Query to summarize well-specific pumpage - Create a new select query in MS Access **MMMYYWell-SpecificSum** to summarize the well-specific pumpage from all wells within a grid cell for the desired month or year. For any specified month and year, the SQL query for well-specific pumpage would be:

```
SELECT CGC_gridsum_well_specific.GRID_ID, "WS" AS DATA_CAT,
CGC_gridsum_well_specific.year, CGC_gridsum_well_specific.Model,
CGC_gridsum_well_specific.month,
CGC_gridsum_well_specific.SumPumpage_af AS PumpageAF

FROM CGC_gridsum_well_specific

WHERE (((CGC_gridsum_well_specific.year)=[Enter year]) AND
((CGC_gridsum_well_specific.Model)="CGC") AND
((CGC_gridsum_well_specific.month)=[Enter month]))

ORDER BY CGC_gridsum_well_specific.SumPumpage_af;
```

6.1.5. In order to ensure that each grid cell is included in the final summary queries, even if there is no pumpage from the cell, we must create a full grid with values of zero.

6.1.5.1. Create a new table **Zero_grid_annual** in a make-table query based on the table **grid_lkup_*area*** with one record for each grid cell and year. For instance, a model with 212 rows, 180 columns, and 6 layers, for 20 years would be create a table with 212 x 180 x 6 x 20= 4,579,200 records. In the make-table query, add a field “SumPumpageAF” with a value of zero for each record.

6.1.5.2. Create a new query **MMMYY_ZeroGrid** to provide zero values for each grid cell for each month. You can use any of the monthly factors, as all results will equal zero. As an example, the SQL query for January 1980 would be:

```
SELECT Zero_Grid_Annual.GRID_ID, Zero_Grid_Annual.DATA_CAT,
Zero_Grid_Annual.Year, Zero_Grid_Annual.MODEL, [MONTHLY
FACTORS].MONTH, Zero_Grid_Annual.SumPumpageAF

FROM Zero_Grid_Annual LEFT JOIN [MONTHLY FACTORS] ON
(Zero_Grid_Annual.basinnum = [MONTHLY FACTORS].basinnum) AND
(Zero_Grid_Annual.CountyNumber = [MONTHLY FACTORS].countynum)
AND (Zero_Grid_Annual.Year = [MONTHLY FACTORS].YEAR)

WHERE (((Zero_Grid_Annual.Year)=[Enter year]) AND (([MONTHLY
FACTORS].MONTH)=[Enter month]) AND (([MONTHLY
FACTORS].DATA_CAT)="IRR"))

ORDER BY Zero_Grid_Annual.GRID_ID;
```

6.1.6. In Access, create a new union query **MMMYYUnionofPumpage** to combine the domestic, livestock, rural domestic, and well-specific pumpage sums, as well as the zero value, for each grid cell. As an example, the SQL for any given year and month is:

```
SELECT * FROM [MMMYY_C-O] UNION ALL SELECT * FROM [MMMYY_IRR] UNION ALL SELECT * FROM [MMMYY_STK] UNION ALL SELECT * FROM [MMMYY_ZeroGrid] UNION ALL SELECT * FROM [MMMYYWell-specificSum];
```

6.1.7. Create a new select query **SumPumpageGrid_MMMYY** to summarize all pumpage by grid cell, grouping by grid_id, month, and year the pumpage from the above union query. As an example, the SQL for January 1980 is:

```
SELECT MMMYYUnionofPumpage.GRID_ID,
MMMYYUnionofPumpage.Year, MMMYYUnionofPumpage.MONTH,
Sum(MMMYYUnionofPumpage.PumpageAF) AS SumOfPumpageAF,
Sum([PumpageAF]*[MGDfromAF]) AS PumpageMGD

FROM MMMYYUnionofPumpage LEFT JOIN UnitConversion ON
MMMYYUnionofPumpage.MONTH = UnitConversion.Month

GROUP BY MMMYYUnionofPumpage.GRID_ID,
MMMYYUnionofPumpage.Year, MMMYYUnionofPumpage.MONTH

ORDER BY MMMYYUnionofPumpage.GRID_ID;
```

6.2. Join pumpage queries to Arcview shapefile if visual display of the results for a month or year is desired.

6.2.1. In Arcview, import the MS Access query **SumPumpageGrid_MMMYY**, and join it to the model grid cells in the Arcview shapefile based on the field “Grid_ID.”

6.2.2. In Arcview, import the MS Access queries **MMMYY_STK, MMMYY_IRR, MMMYY_C-O**, and **Well-specificpumpage.** Link these tables to the model grid cells in the Arcview shapefile based on the field “Grid_ID” and, for well-specific pumpage, “year.” Selection of a grid cell in Arcview will then also select the records in each of these tables that pump from the grid cell selected.

Appendix 1 - Vertical Distribution Avenue Script

```
theView = Av.GetActiveDoc
theTheme = theView.findTheme("wells")
theFtab = theTheme.GetFtab

'get elevation values for layers
theLay1Field = theFtab.findField("top_younge")
theLay2Field = theFtab.findField("top_reklaw")
theLay3Field = theFtab.findField("top_carriz")
theLay4Field = theFtab.findField("top_uwilco")
theLay5Field = theFtab.findField("top_mwilco")
theLay6Field = theFtab.findField("top_lwilco")
theBottomField = theFtab.findField("bas_lwilco")

'get percentfield holders
thePer1Field = theFtab.findField("per1")
thePer2Field = theFtab.findField("per2")
thePer3Field = theFtab.findField("per3")
thePer4Field = theFtab.findField("per4")
thePer5Field = theFtab.findField("per5")
thePer6Field = theFtab.findField("per6")
theTotPerField = theFtab.findField("tot_per")

'get well values
theScreenField  = theFtab.findField("Screen")
theDepthField  = theFtab.findField("depth")

theSel = theFtab.GetSelection

for each rec in theSel
  ct = 0
  totPerVal = 0
  cumPerVal = 0
    theDepthVal = theFtab.ReturnValue(theDepthfield,rec)
    theScreenVal = theFtab.ReturnValue(theScreenfield,rec)
    screenLengthVal = (theScreenVal - theDepthVal).abs

    theLay1Val = theFtab.ReturnValue(theLay1field,rec)
    theLay2Val = theFtab.ReturnValue(theLay2field,rec)
    theLay3Val = theFtab.ReturnValue(theLay3field,rec)
    theLay4Val = theFtab.ReturnValue(theLay4field,rec)
    theLay5Val = theFtab.ReturnValue(theLay5field,rec)
    theLay6Val = theFtab.ReturnValue(theLay6field,rec)
    theBotVal =  theFtab.ReturnValue(theBottomField,rec)

    if ((theScreenVal < theLay1Val ) And (theScreenVal > theLay2Val)) then
      if (theDepthVal < theLay2Val) then
         per1 =  (((theLay2Val - theScreenVal) / screenLengthVal) * 100).abs
         theFtab.SetValue(thePer1field,rec,per1)
         cumPerVal = cumPerVal + per1
      else
         per1 = (100 - cumPerVal)
         cumPerVal = cumPerVal + per1
```

```
        theFtab.SetValue(thePer1field,rec,per1)
      end
    else
         per1 = 0
         theFtab.SetValue(thePer1field,rec,per1)
    end
'--------------------------------------------layer 2
    if (cumperval.round = 100) then
       'continue
       ct=ct+1
       per2 = 0
       theFtab.SetValue(thePer2field,rec,per2)
    else
     if ((theScreenVal < theLay2Val ) And (theScreenVal > theLay3Val)) then
       if (theDepthVal < theLay3Val) then
          per2 =  (((theScreenVal - theLay3Val) / screenLengthVal) * 100).abs
          cumPerVal = cumPerVal + per2
          theFtab.SetValue(thePer2field,rec,per2)
       else
          per2 = (100 - cumPerVal)
          cumPerVal = cumPerVal + per2
          theFtab.SetValue(thePer2field,rec,per2)
       end
     else
       if (cumPerVal > 0) then  'if continuing
         if (theDepthVal < theLay3Val) then
            per2 =  (((theLay3Val - theLay2Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per2
            theFtab.SetValue(thePer2field,rec,per2)
         else
            per2 =  (((theDepthVal - theLay2Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per2
            theFtab.SetValue(thePer2field,rec,per2)
         end
       else
         per2 = 0
         theFtab.SetValue(thePer2field,rec,per2)
       end
     end
    end
'--------------------------------------------layer 3
   if (cumperval.round = 100) then
       'continue
       ct=ct+1
       per3 = 0
       theFtab.SetValue(thePer3field,rec,per3)
    else
     if ((theScreenVal < theLay3Val ) And (theScreenVal > theLay4Val)) then
       if (theDepthVal < theLay4Val) then
          per3 =  (((theScreenVal - theLay4Val) / screenLengthVal) * 100).abs
          cumPerVal = cumPerVal + per3
          theFtab.SetValue(thePer3field,rec,per3)
       else
          per3 = (100 - cumPerVal)
          cumPerVal = cumPerVal + per3
          theFtab.SetValue(thePer3field,rec,per3)
```

```
      end
    else
      if (cumPerVal > 0) then  'if continuing
        if (theDepthVal < theLay4Val) then
            per3 =  (((theLay4Val - theLay3Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per3
            theFtab.SetValue(thePer3field,rec,per3)
        else
            per3 =  (((theDepthVal - theLay3Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per3
            theFtab.SetValue(thePer3field,rec,per3)
        end
      else
        per3 = 0
        theFtab.SetValue(thePer3field,rec,per3)
      end
    end
  end
'----------------------------------------------layer 4
  if (cumperval.round = 100) then
     'continue
     ct=ct+1
     per4 = 0
     theFtab.SetValue(thePer4field,rec,per4)
  else
    if ((theScreenVal < theLay4Val ) And (theScreenVal > theLay5Val)) then
      if (theDepthVal < theLay5Val) then
          per4 =  (((theScreenVal - theLay5Val) / screenLengthVal) * 100).abs
          cumPerVal = cumPerVal + per4
          theFtab.SetValue(thePer4field,rec,per4)
      else
          per4 = (100 - cumPerVal)
          cumPerVal = cumPerVal + per4
          theFtab.SetValue(thePer4field,rec,per4)
      end
    else
      if (cumPerVal > 0) then  'if continuing
        if (theDepthVal < theLay5Val) then
            per4 =  (((theLay5Val - theLay4Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per4
            theFtab.SetValue(thePer4field,rec,per4)
        else
            per4 =  (((theDepthVal - theLay4Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per4
            theFtab.SetValue(thePer4field,rec,per4)
        end
      else
        per4 = 0
        theFtab.SetValue(thePer4field,rec,per4)
      end
    end
  end
'----------------------------------------------layer 5
  if (cumperval.round = 100) then
     'continue
     ct = ct+1
```

```
      per5 = 0
      theFtab.SetValue(thePer5field,rec,per5)
    else
     if ((theScreenVal < theLay5Val ) And (theScreenVal > theLay6Val)) then
       if (theDepthVal < theLay6Val) then
          per5 =  (((theScreenVal - theLay6Val) / screenLengthVal) * 100).abs
          cumPerVal = cumPerVal + per5
          theFtab.SetValue(thePer5field,rec,per5)
       else
          per5 = (100 - cumPerVal)
          cumPerVal = cumPerVal + per5
          theFtab.SetValue(thePer5field,rec,per5)
       end
     else
       if (cumPerVal > 0) then  'if continuing
         if (theDepthVal < theLay6Val) then
            per5 =  (((theLay6Val - theLay5Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per5
            theFtab.SetValue(thePer5field,rec,per5)
         else
            per5 =  (((theDepthVal - theLay5Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per5
            theFtab.SetValue(thePer5field,rec,per5)
         end
       else
         per5 = 0
         theFtab.SetValue(thePer5field,rec,per5)
       end
     end
    end
'----------------------------------------------layer 6
 if (cumPerVal.round = 100) then
      'continue
      ct = ct+1
      per6 = 0
      theFtab.SetValue(thePer6field,rec,per6)
    else
     if ((theScreenVal < theLay6Val ) And (theScreenVal > theBotVal)) then
       if (theDepthVal < theBotVal) then
          per6 =  (((theScreenVal - theBotVal) / screenLengthVal) * 100).abs
          cumPerVal = cumPerVal + per6
          theFtab.SetValue(thePer6field,rec,per6)
       else
          per6 = (100 - cumPerVal)
          cumPerVal = cumPerVal + per6
          theFtab.SetValue(thePer6field,rec,per6)
       end
     else
       if (cumPerVal > 0) then  'if continuing
         if (theDepthVal < theBotVal) then
            per6 =  (((theBotVal - theLay6Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per6
            theFtab.SetValue(thePer6field,rec,per6)
         else
            per6 =  (((theDepthVal - theLay6Val) / screenLengthVal) * 100).abs
            cumPerVal = cumPerVal + per6
```

```
        theFtab.SetValue(thePer6field,rec,per6)
      end
     else
      per6 = 0
      theFtab.SetValue(thePer6field,rec,per6)
     end
   end
  end
theFtab.SetValue(theTotPerField,rec,cumPerVal)
end 'end for loop
```

Appendix 2 – Arcview script to return land surface elevation for a well from a DEM grid

```
'-------------------------------------------------------
' Name: getgridvalue.ave
' Date: 991004
'
' Description: Moves copies values from a grid to a
' feature theme. The values from the grid are placed
' in a user defined field. If the feature theme isn't
' a point theme, then the feature gets the grid value
' from the value under it's centroid point.
'
' Requires: Spatial Analyst
'
'
' Author: Originally written by Mikael Elmquist (mikael@swegis.com), but later
' modified by Jeremy Davies (jeremy.davies@noaa.gov)
'
'-------------------------------------------------------


theView = av.GetActiveDoc
theThemes={}



'-----------------
'Choose in theme
'-----------------
themeList = theView.GetThemes
rep = 0
stupid = 0
while (rep = 0)
  theTheme = MsgBox.ChoiceAsString(themeList,"Select theme that shall get values from the grid
theme.","GetGridValue")
  if (theTheme = NIL) then
    exit
  end
  if (theTheme.Is(Ftheme).Not) then
    stupid = stupid+1
    if (stupid = 4) then
      msgBox.Info("Dear ArcView GIS user. Try to select a valid theme","Problem?")
    end
    msgBox.Error("Not a valid theme","Error")
  else
    rep = 1
    theFtab = theTheme.GetFtab
  end
end
rep = 0
stupid = 0


theThemes={}
if (theFtab.CanEdit) then
  theFTab.SetEditable(true)
```

```
  if ((theFTab.CanAddFields).Not) then
    MsgBox.Info("Can't add fields to the table."+NL+"Check write permission.","Can't add grid values")
    exit
  end
else
  MsgBox.Info("Can't modify the feature table."+NL+
  "Check write permission.","Can't add grid values")
  exit
end

'-----------------
'Choose grid theme
'-----------------

for each TargetTheme in theView.GetThemes
  if (TargetTheme.Is(Gtheme)) then
    theThemes.Add(TargetTheme)
  end
end
theGtheme = MsgBox.ChoiceAsString(theThemes,"Select grid that shall assign values to the point
theme.","GetGridValue")
if (theGtheme = Nil) then
  exit
end
theGrid = theGtheme.Clone.GetGrid.Clone
thePrj = Prj.MakeNull


'------------------
' Add the new field
'------------------

'enter name of new field name and parameters
newField = MsgBox.Input( "Enter new field name:", "Value", "" )
fieldsize = MsgBox.Input( "Enter new field width:", "Value", "10" )
precision = MsgBox.Input( "Enter number of decimals places in new field:", "Value", "4" )

gridvalueField = Field.Make (newField,#FIELD_DECIMAL,fieldsize.asNumber,precision.asNumber)
theShapeField = theFtab.FindField("shape")
theFTab.AddFields({gridvalueField})


'------------------
' Copy values
'------------------
av.ShowMsg("Calculating values")
av.SetStatus(0)
sstatus = theFtab.GetNumRecords.Clone
for each aRec in theFtab
  av.SetStatus(aRec/sstatus*100)
  theValue = theGrid.CellValue(theFtab.returnValue(theShapeField,aRec).ReturnCenter,thePrj)
  av.SetStatus(aRec/sstatus*100)
  if (theValue<>Nil) then
    theFtab.SetValue(gridvalueField,aRec,theValue)
  end
```

```
end


'------------------
'Reset arcview
'------------------
theFtab.Flush
theFtab.Refresh
theFTab.SetEditable(False)
av.purgeobjects
av.ClearStatus
av.ClearMsg
```

APPENDIX C

Standard Operating Procedures (SOPs) for Processing Predictive Pumpage Data TWDB Groundwater Availability Modeling (GAM) Projects

Standard Operating Procedures (SOPs) for Processing Predictive Pumpage Data TWDB Groundwater Availability Modeling (GAM) Projects

TABLE OF CONTENTS

1. Background – These procedures were developed to further implement the guidance provided by the Texas Water Development Board (TWDB) in their Technical Memorandum 02-01 "Development of Predictive Pumpage Data Set for GAM." The information in that technical memorandum will not be repeated here, and readers should first consult that document.

2. Groundwater Use Source Data - To the extent possible, procedures for predictive pumpage distribution among model grid cells mimiced the procedures for historical pumpage data. Predicted future groundwater use estimates are derived from one spreadsheet (**GAMPredictivePumpage_2002SWP.xls)** provided by the Texas Water Development Board (TWDB), as well as the previously developed historical pumpage datasets. This spreadsheet contains water use estimates from the state water plans for each water user group for the years 2000, 2010, 2020, 2030, 2040, and 2050. Water user groups are generally assigned for each water user category (IRR, STK, MIN, MFG, PWR, MUN, and C-O) in each county-basin. However, individual municipal water supplies within a county-basin are assigned identified as separate water user groups. The water use categories are listed below:

    - IRR – irrigation
    - STK – livestock
    - MIN - mineral extraction
    - MFG – manufacturing
    - PWR – power generation
    - MUN – municipal water supply, and
    - C-O – county-other (rural domestic) use.

    Historical groundwater use records from the categories MIN, MFG, PWR, and MUN are available for each specific water user, each assigned an alphanumeric water user code (aka "alphanum") in historical water use data tables. Specific locations and wells from which this groundwater was pumped were identified in historical pumpage records. These are known as "well-specific" water use categories. However, the particular locations of historical groundwater pumpage were generally not known for the use categories IRR, STK, and C-O. These categories are known as "non-well-specific" water use categories. This pumpage was distributed spatially based on population density, land use, and other factors.

    The spreadsheet **GAMPredictivePumpage_2002SWP.xls** was downloaded from the TWDB web site. The spreadsheet file was then imported into a new Microsoft Access database file **Predictive Pumpage**.

3. Initial Processing

    3.1. Create a sub-set of data for the modeled aquifer and geographic area – The table

Predictive Pumpage_2002SWP was queried for water use in the aquifer of interest based on the aquifer's major aquifer code, as well as the code "99." Other records were deleted. Next, the table was queried for those records within source county ID's found in the modeling domain. Records for water pumpage outside the model domain were deleted.

3.2. Split water use between surface and ground water – Some records contain an aggregate of surface and ground water use, as indicated by a value of "04" in the field "SO_TYPE_ID_NEW." A new field "PERCENT GROUNDWATER" was added to the table and assigned a value from 0 to 1 based on information in the field "ADDTL COMMENTS."

3.3. Interpolate pumpage estimates for all years 2000-2050 – The table **Predictive Pumpage_2002SWP** only contains water use estimates for the years 2000, 2010, 2020, 2030, 2040, and 2050. Water use estimates for the intervening years are calculated by linear interpolation. This can be calculated in a query as for example:

$$Pumpage_{2001} = Pumpage_{2000} + modulus(2001,10)*[(Pumpage_{2010}-Pumpage_{2000})/10]$$

4. Spatially distribute well-specific pumpage –

4.1. Identify locations of new wells – If the field "Possible_New_Wells" contained a flag "NW", it was necessary to identify the location of the new wells. The Regional Water Plan was consulted to identify the location of the new wells (a map showing the projected locations of the new wells was available). Using Arcview, the latitude and longitude of the well(s) were estimated and copied into a new field "KD_comment." This latitude and longitude were used to identify the model grid_id(s) from which the well was expected to pump. These grid_id's were copied into a new field "grid_id" in the predictive pumpage table.

4.2. Matching Predictive to Historical Locations by "Alphanum" - We assumed that a water user would tend to pump water in the future from the same locations from which they had pumped groundwater historically. A specific water user can best be identified in the TWDB predictive pumpage data using the field "WUG_Prime_Alpha", or, if the water was purchased, the field "Seller Alpha."

4.2.1. A new field "Source_Alpha" was created and populated with the value from the field "WUG_Prime_Alpha" or, if available, the value from the field "Seller Alpha."

4.2.2. In many cases, no value of alpha_num was provided in the table for a well-specific WUG_ID, typically for MIN, MFG, and PWR. Therefore, the value(s) of "alphanum" associated with that WUG_ID in the historical pumpage table was copied to the predictive pumpage table.

In the case that multiple values of "alphanum" were identified for a given "WUG_ID" in the historical data, we first made replicate copies of the record in the predictive pumpage table for each value of alphanum, copied each alphanum into the field "Source_Alpha", and entered in the field "percent groundwater" the fraction of pumpage for each alphanum for the period 1995-1999 from the historical table. An explanation was entered in the field "KD_comment."

4.2.3. The value of "Source_Alpha" was matched manually to the field "alphanum" in the historical pumpage datasets, and the model grid_id identified for this water user in historical pumpage distribution was manually copied to the field "Grid_ID" in the predictive pumpage table.

In many cases, more than one grid was associated with a given "alphanum". The predictive pumpage for each alphanum was distributed among multiple Grid ID's in an identical manner as the average for the period 1995-1999. Additional copies of predictive pumpage records were added to equal the number of grid_id's, and a field "grid_frac" was added to the predictive pumpage table, and assigned a value from 0 to 1, calculated as the average of the 1995-1999 fraction of pumpage from that grid_id for that alphanum in the historical pumpage dataset. The values of grid_frac summed to 1 for each "source_alpha."

4.3. Create new tables for each well-specific water use category –

4.3.1. Create a new table or query for the water use category MUN containing a value of MUN pumpage for each grid_id for each year from 2000 to 2050. The pumpage for each record is calculated as the total pumpage for the year of interest multiplied by the fields "grid_frac" and "percent groundwater."

4.3.2. Create a new table or query for the water use category MFG containing a value of MFG pumpage for each grid_id for each year from 2000 to 2050. The pumpage for each record is calculated as the total pumpage for the year of interest multiplied by the fields "grid_frac" and "percent groundwater."

4.3.3. Create a new table or query for the water use category MIN containing a value of MIN pumpage for each grid_id for each year from 2000 to 2050. The pumpage for each record is calculated as the total pumpage for the year of interest multiplied by the fields "grid_frac" and "percent groundwater."

4.3.4. Create a new table or query for the water use category PWR containing a value of PWR pumpage for each grid_id for each year from 2000 to 2050. The pumpage for each record is calculated as the total pumpage for the year of interest multiplied by the fields "grid_frac" and "percent groundwater."

5. Spatially distribute non-well-specific pumpage – We assume that groundwater pumpage in the future would be distributed within each county-basin in a similar way that it has been done in the recent past. While we do not discount the impact of changes in population and land use due to urban growth, sprawl, and other factors, we cannot reliably predict the spatial locations of these changes.

5.1. Calculate the fraction of groundwater pumpage for "C-O" use from each grid cell within a county-basin from 1999.

5.1.1. Run a query to summarize "C-O" groundwater pumpage in 1999 for each county-basin within the model domain.

5.1.2. For each grid_id within each county-basin, divide the "C-O" pumpage value for the year 1999 by the total "C-O" pumpage for that county-basin. Save this as a new field "Fr_pumpage" for each grid_id.

5.1.3. As a quality check, sum the values of "Fr_pumpage" for C-O by county-basin to ensure they sum to 1.

5.1.4. Create a new table or query for the water use category "C-O" containing a value of C-O pumpage for each grid_id for each year from 2000 to 2050. The pumpage for each record is calculated as the total pumpage for the year of interest (from the TWDB-provided table **GAMPredictivePumpage_2002SWP.xls**, with interpolated values for intervening years**)** multiplied by the fields "percent groundwater" (from the same table) and the field "Fr_pumpage" from the previous three steps.

5.2. Calculate the fraction of groundwater pumpage for "IRR" use from each grid cell within a county-basin from 1999.

5.2.1. Run a query to summarize "IRR" groundwater pumpage in 1999 for each county-basin within the model domain.

5.2.2. For each grid_id within each county-basin, divide the "IRR" pumpage value for the year 1999 by the total "IRR" pumpage for that county-basin. Save this as a new field "Fr_pumpage" for each grid_id.

5.2.3. As a quality check, sum the values of "Fr_pumpage" for IRR by county-basin to ensure they sum to 1.

5.2.4. Create a new table or query for the water use category "IRR" containing a value of IRR pumpage for each grid_id for each year from 2000 to 2050. The pumpage for each record is calculated as the total pumpage for the year of interest (from the TWDB-provided table **GAMPredictivePumpage_2002SWP.xls**, with interpolated values for intervening years**)** multiplied by the fields "percent groundwater" (from the same table) and the field "Fr_pumpage" from the previous three steps.

5.3. Calculate the fraction of groundwater pumpage for "STK" use from each grid cell within a county-basin from 1999.

5.3.1. Run a query to summarize "STK" groundwater pumpage in 1999 for each county-basin within the model domain.

5.3.2. For each grid_id within each county-basin, divide the "STK" pumpage value for the year 1999 by the total "STK" pumpage for that county-basin. Save this as a new field "Fr_pumpage" for each grid_id.

5.3.3. As a quality check, sum the values of "Fr_pumpage" for STK by county-basin to ensure they sum to 1.

5.3.4. Create a new table or query for the water use category "STK" containing a value of STK pumpage for each grid_id for each year from 2000 to 2050. The pumpage for each record is calculated as the total pumpage for the year of interest (from the TWDB-provided table **GAMPredictivePumpage_2002SWP.xls**, with interpolated values for intervening years**)** multiplied by the fields "percent groundwater" (from the same table) and the field "Fr_pumpage" from the previous three steps.

5.4. Note: The result of this step should be three tables (or queries), one each for C-O, IRR, and STK. Each should contain, at a minimum, the fields "Grid_ID", "county_name", "basin_name", "year", "data_cat", and "pumpage."

6. Monthly Distribution of Annual Pumpage Totals - We assume that the historical average of monthly water use distribution is a valid predictor of future monthly distribution.

   Monthly factors are calculated for each county-basin and data_cat as the average of mfraction for the period 1995-1999 (in the historical pumpage table "MONTHLY FACTORS") in a new table **PredictiveMonthlyFactors**. There should be a monthly factor for each combination of the seven water use categories and county-basin. If no monthly factor can be calculated because there was no historical pumpage, then the monthly factor for that data_cat in the nearest other county-basin should be used.

7. Summarize Pumpage Information to Create Model Input Files - Summary queries for a given year and/or month should be performed as described in the SOP for historical pumpage data.

8. Handling Non-Texas Pumpage – Predictions of future pumpage for portions of the model domain outside of Texas are not available from the Texas Regional Water Plans. In this case, we will assume that the average pumpage for the period 1995-1999 is the best estimate of future pumpage for the water use categories MFG, MIN, PWR, STK, and IRR. Because population projections are available, however, we can project future water use for MUN and C-O based on the 1990 water use for each county or parish and the ratio of projected future county/parish population to its 1990 population.

8.1. Download from the respective state census data center or the U.S. census bureau population estimates from each county or parish through 2050. Linearly interpolate values for intervening years if necessary.

8.2. For each year from 2000 to 2050, calculate the ratio of projected population for each year to that in 2000 for each county or parish.

8.3. Multiply the historical pumpage value from C-O or MUN out-of-Texas records in 1999 by the factor to obtain a projected pumpage estimate for that year.

APPENDIX D1

Tabulated Groundwater Withdrawal Estimates for the Carrizo-Wilcox for 1980, 1990, 2000, 2010, 2020, 2030, 2040, and 2050

Table D1.1

Rate of groundwater withdrawal (acre-feet per year) from flow layer 1 of the Carrizo-Wilcox aquifer for counties within the study area

Municipal and Industrial*

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	0	0	0	0	0	0	0	0
BASTROP	0	0	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	0	0	0	0	0	0	0	0
CALDWELL	0	0	0	0	0	0	0	0
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	0	0	0	0	0	0	0	0
FAYETTE	0	0	0	0	0	0	0	0
FRIO	0	0	0	0	0	0	0	0
GONZALES	0	0	0	0	0	0	0	0
GUADALUPE	0	0	584	651	697	739	803	867
KARNES	0	0	1296	1214	1241	1315	1376	1446
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	0	0	288	209	145	100	79	82
WILSON	0	0	0	0	0	0	0	0
ZAVALA	0	0	0	0	0	0	0	0

*industrial includes manufacturing, mining, and power generation

County – Other (Non-reported Domestic)

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	163	200	175	196	231	170	199	209
BASTROP	9	18	56	67	77	89	103	128
BEE	0	0	80	81	80	82	84	88
BEXAR	0	0	0	0	0	0	0	0
CALDWELL	1	1	2	2	3	2	2	2
DEWITT	3	4	0	0	0	0	0	0
DIMMIT	0	0	0	0	0	0	0	0
FAYETTE	80	100	0	0	0	0	0	0
FRIO	269	372	410	415	415	306	315	321
GONZALES	716	918	631	601	580	563	566	573
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	478	545	762	701	704	625	655	663
LA SALLE	152	182	325	334	340	319	324	320
LAVACA	1	1	0	0	0	0	0	0
LIVE OAK	1	3	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	45	32	30	27	21	14	10	7
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	142	404	75	80	81	81	81	81
WILSON	250	305	413	521	569	600	717	835
ZAVALA	110	72	41	48	50	54	69	93

Table D1.1 *(continued)*

Livestock

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	74	66	0	0	0	0	0	0
BASTROP	21	20	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	0	0	0	0	0	0	0	0
CALDWELL	1	0	0	0	0	0	0	0
DEWITT	5	1	0	0	0	0	0	0
DIMMIT	70	81	0	0	0	0	0	0
FAYETTE	4	2	0	0	0	0	0	0
FRIO	28	14	0	0	0	0	0	0
GONZALES	756	157	0	0	0	0	0	0
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	58	46	0	0	0	0	0	0
LA SALLE	53	44	0	0	0	0	0	0
LAVACA	3	1	0	0	0	0	0	0
LIVE OAK	1	1	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	43	23	307	307	307	307	307	307
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	34	33	442	442	442	439	439	439
WILSON	100	70	0	0	0	0	0	0
ZAVALA	12	2	0	0	0	0	0	0

Irrigation

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	1813	1229	94	93	91	0	0	0
BASTROP	0	0	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	0	0	0	0	0	0	0	0
CALDWELL	0	0	0	0	0	0	0	0
DEWITT	1	4	0	0	0	0	0	0
DIMMIT	0	0	0	0	0	0	0	0
FAYETTE	2	2	8	8	7	7	6	6
FRIO	228	282	59	59	59	7	7	7
GONZALES	275	1107	671	579	499	423	365	315
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	8	15	902	726	567	424	294	176
LA SALLE	50	37	22	20	19	17	15	14
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	114	77	171	171	171	171	171	171
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	0	1	3	3	3	2	2	2
WILSON	976	1886	1585	1399	1048	777	699	637
ZAVALA	0	0	0	0	0	0	0	0

Table D1.2
Rate of groundwater withdrawal (acre-feet per year) from flow layer 2 of the Carrizo-Wilcox aquifer for counties within the study area

Municipal and Industrial*

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	0	0	1564	1564	1564	76	403	1798
BASTROP	0	0	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	0	0	0	0	0	0	0	0
CALDWELL	0	0	0	0	0	0	0	0
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	0	0	0	0	0	0	0	0
FAYETTE	0	0	0	0	0	0	0	0
FRIO	0	0	0	0	0	0	0	0
GONZALES	0	0	0	0	0	0	0	0
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	1101	52	21	9	4	2	1	1
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	73	1207	0	0	0	0	0	0
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	0	0	0	0	0	0	0	0
WILSON	0	0	0	0	0	0	0	0
ZAVALA	0	0	0	0	0	0	0	0

*industrial includes manufacturing, mining, and power generation

County – Other (Non-reported Domestic)

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	260	348	307	343	405	298	349	366
BASTROP	11	24	36	42	49	56	65	81
BEE	0	0	0	0	0	0	0	0
BEXAR	1	1	2	3	3	2	2	1
CALDWELL	10	14	37	39	40	38	35	31
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	16	14	9	8	8	8	9	10
FAYETTE	0	0	0	0	0	0	0	0
FRIO	66	53	58	59	59	43	45	46
GONZALES	54	66	46	43	42	41	41	41
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	29	11	19	19	20	18	19	18
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	6	3	3	3	2	1	1	1
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	80	21	4	4	4	4	4	4
WILSON	129	194	270	345	379	405	487	568
ZAVALA	157	230	130	154	161	172	220	296

Table D1.2 *(continued)*

Livestock

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	24	21	0	0	0	0	0	0
BASTROP	12	11	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	0	0	0	0	0	0	0	0
CALDWELL	5	0	0	0	0	0	0	0
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	208	243	0	0	0	0	0	0
FAYETTE	0	0	0	0	0	0	0	0
FRIO	101	51	0	0	0	0	0	0
GONZALES	91	19	0	0	0	0	0	0
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	21	18	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	1	0	5	5	5	5	5	5
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	20	19	217	217	217	215	215	215
WILSON	46	32	0	0	0	0	0	0
ZAVALA	174	32	0	0	0	0	0	0

Irrigation

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	1752	1094	83	83	81	0	0	0
BASTROP	4	2	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	0	0	0	0	0	0	0	0
CALDWELL	0	5	11	10	9	8	7	6
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	284	97	105	99	95	93	87	80
FAYETTE	0	0	0	0	0	0	0	0
FRIO	2116	2246	470	472	473	53	53	54
GONZALES	55	206	126	109	94	80	69	59
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	3	5	0	0	0	0	0	0
LA SALLE	880	538	310	292	275	237	222	208
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	7	146	445	422	403	234	255	280
WILSON	494	895	662	584	454	332	297	269
ZAVALA	5025	4708	1389	1393	1394	195	196	196

Table D1.3

Rate of groundwater withdrawal (acre-feet per year) from flow layer 3 of the Carrizo-Wilcox aquifer for counties within the study area

Municipal and Industrial*

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	3102	8712	12265	12559	12874	7351	9242	15331
BASTROP	0	0	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	0	0	17013	17576	18046	18325	18614	18914
CALDWELL	0	0	0	0	0	0	0	0
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	1652	1322	1695	1821	1947	2207	2468	2766
FAYETTE	0	0	0	0	0	0	0	0
FRIO	3179	2717	3205	3234	3265	3283	3375	3449
GONZALES	996	1207	1179	1191	1202	1213	1268	1320
GUADALUPE	0	0	8041	8284	8426	9335	10294	11321
KARNES	0	176	319	280	264	223	229	244
LA SALLE	636	673	612	609	599	609	625	642
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	259	290	226	154	121	99	78	63
MEDINA	0	0	397	408	422	440	452	464
UVALDE	0	0	0	0	0	0	0	0
WEBB	0	0	100	118	135	164	159	155
WILSON	1454	1785	2243	2262	2323	2424	2553	2721
ZAVALA	1127	1291	1308	1227	1145	1162	1154	1151

*industrial includes manufacturing, mining, and power generation

County – Other (Non-reported Domestic)

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	559	837	736	825	973	716	839	880
BASTROP	14	31	156	185	215	246	286	356
BEE	0	0	0	0	0	0	0	0
BEXAR	340	714	2110	2365	2285	1333	1336	1077
CALDWELL	9	15	41	43	45	42	39	35
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	130	117	72	67	64	70	78	85
FAYETTE	0	0	0	0	0	0	0	0
FRIO	106	69	76	77	77	57	59	60
GONZALES	117	131	91	87	84	81	82	82
GUADALUPE	36	74	198	274	346	407	438	467
KARNES	2	1	2	2	2	2	2	2
LA SALLE	7	5	9	9	9	9	9	9
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	3	1	2	2	2	2	2	2
MCMULLEN	3	2	2	2	2	1	1	1
MEDINA	171	272	451	469	477	438	453	481
UVALDE	0	0	0	0	0	0	0	0
WEBB	18	6	2	2	2	2	2	2
WILSON	377	675	1019	1355	1498	1655	2019	2372
ZAVALA	69	96	56	66	68	73	94	126

Table D1.3 *(continued)*

Livestock

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	34	30	0	0	0	0	0	0
BASTROP	24	22	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	2	1	0	0	0	0	0	0
CALDWELL	5	0	0	0	0	0	0	0
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	197	230	0	0	0	0	0	0
FAYETTE	0	0	0	0	0	0	0	0
FRIO	43	22	0	0	0	0	0	0
GONZALES	215	45	0	0	0	0	0	0
GUADALUPE	4	2	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	12	10	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	4	4	15	15	15	10	10	10
MCMULLEN	1	0	5	5	5	5	5	5
MEDINA	14	9	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	17	17	163	163	163	161	161	161
WILSON	81	57	0	0	0	0	0	0
ZAVALA	97	19	0	0	0	0	0	0

Irrigation

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	61657	40811	3108	3094	3028	0	0	0
BASTROP	7	3	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	1156	678	0	0	0	0	0	0
CALDWELL	2	20	47	41	36	32	28	24
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	7638	2616	2691	2544	2432	2389	2224	2054
FAYETTE	0	0	0	0	0	0	0	0
FRIO	64338	70106	14672	14730	14751	1666	1669	1672
GONZALES	197	681	417	360	310	263	227	196
GUADALUPE	5	7	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	4373	3440	2020	1903	1790	1545	1448	1353
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	482	1509	16	245	474	458	399	346
MCMULLEN	2	2	0	0	0	0	0	0
MEDINA	2096	344	1460	1464	1464	208	208	207
UVALDE	0	0	0	0	0	0	0	0
WEBB	0	36	112	106	101	59	64	70
WILSON	5161	8321	5590	4935	3937	2854	2549	2296
ZAVALA	54968	51345	15151	15188	15199	2131	2135	2136

Table D1.4
Rate of groundwater withdrawal (acre-feet per year) from flow layer 4 of the Carrizo-Wilcox aquifer for counties within the study area

Municipal and Industrial*

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	93	0	0	0	0	0	0	0
BASTROP	0	0	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	0	0	0	0	0	0	0	0
CALDWELL	0	0	0	0	0	0	0	0
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	951	805	2003	1924	2116	2305	2497	2726
FAYETTE	0	0	0	0	0	0	0	0
FRIO	0	0	0	0	0	0	0	0
GONZALES	0	0	0	0	0	0	0	0
GUADALUPE	0	0	251	242	232	254	272	277
KARNES	0	0	0	0	0	0	0	0
LA SALLE	175	185	389	400	404	416	431	446
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	0	0	2	5477	7213	10951	10951	10951
WILSON	0	0	0	0	0	0	0	0
ZAVALA	681	781	1017	974	925	954	951	954

*industrial includes manufacturing, mining, and power generation

County – Other (Non-reported Domestic)

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	10	11	9	10	12	9	11	11
BASTROP	2	3	16	19	22	25	29	37
BEE	0	0	0	0	0	0	0	0
BEXAR	16	31	94	95	85	51	51	39
CALDWELL	0	1	2	2	2	2	2	2
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	172	246	149	139	133	145	163	176
FAYETTE	0	0	0	0	0	0	0	0
FRIO	1	0	0	0	0	0	0	0
GONZALES	4	2	1	1	1	1	1	1
GUADALUPE	2	5	12	17	22	27	29	31
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	1	0	1	1	1	1	1	1
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	9	12	20	21	22	20	20	22
UVALDE	0	0	0	0	0	0	0	0
WEBB	12	13	2	2	2	2	2	2
WILSON	38	92	139	185	205	227	277	326
ZAVALA	42	99	56	67	69	74	95	128

Table D1.4 *(continued)*

Livestock

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	0	0	0	0	0	0	0	0
BASTROP	1	1	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	0	0	0	0	0	0	0	0
CALDWELL	0	0	0	0	0	0	0	0
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	122	143	0	0	0	0	0	0
FAYETTE	0	0	0	0	0	0	0	0
FRIO	1	0	0	0	0	0	0	0
GONZALES	2	0	0	0	0	0	0	0
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	1	1	4	4	4	2	2	2
MCMULLEN	1	0	5	5	5	5	5	5
MEDINA	3	2	0	0	0	0	0	0
UVALDE	0	0	0	0	0	0	0	0
WEBB	15	14	164	164	164	163	163	163
WILSON	1	1	0	0	0	0	0	0
ZAVALA	27	6	0	0	0	0	0	0

Irrigation

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	50	33	3	2	2	0	0	0
BASTROP	0	0	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	1	1	0	0	0	0	0	0
CALDWELL	0	0	1	1	1	1	1	1
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	8938	2693	2863	2707	2588	2542	2366	2180
FAYETTE	0	0	0	0	0	0	0	0
FRIO	4186	4554	953	957	958	108	108	109
GONZALES	1	3	2	2	2	1	1	1
GUADALUPE	0	1	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	2679	2176	1235	1164	1095	945	885	827
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	224	721	7	117	226	219	191	165
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	62	5	38	38	38	5	5	5
UVALDE	0	0	0	0	0	0	0	0
WEBB	0	0	0	0	0	0	0	0
WILSON	19	36	30	27	20	15	13	12
ZAVALA	14442	13416	3952	3962	3965	556	557	557

Table D1.5
Rate of groundwater withdrawal (acre-feet per year) from flow layer 5 of the Carrizo-Wilcox aquifer for counties within the study area

Municipal and Industrial*

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	0	0	0	0	0	0	0	0
BASTROP	0	0	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	26	36	5034	5205	6088	5896	6129	6122
CALDWELL	270	347	1763	2001	2224	2538	2806	3101
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	0	0	0	0	0	0	0	0
FAYETTE	0	0	0	0	0	0	0	0
FRIO	0	0	0	0	0	0	0	0
GONZALES	0	0	0	0	0	0	0	0
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	0	0	11	5	3	1	0	0
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	0	0	0	0	0	0	0	0
UVALDE	0	0	241	232	270	173	200	233
WEBB	0	0	0	0	0	0	0	0
WILSON	26	36	56	58	59	64	69	72
ZAVALA	1242	1523	1566	1657	1729	1795	1939	2071

*industrial includes manufacturing, mining, and power generation

County – Other (Non-reported Domestic)

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	95	190	185	203	230	197	223	229
BASTROP	115	225	1441	1709	1976	2267	2634	3284
BEE	0	0	0	0	0	0	0	0
BEXAR	921	1095	3356	3406	3068	1826	1838	1410
CALDWELL	210	259	716	748	772	733	679	609
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	15	22	13	12	11	12	14	15
FAYETTE	0	0	0	0	0	0	0	0
FRIO	7	19	21	22	22	16	16	17
GONZALES	18	19	13	13	12	12	12	12
GUADALUPE	212	371	1001	1381	1785	2141	2366	2469
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	1	0	0	0	1	0	0	0
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	171	258	428	445	453	416	430	457
UVALDE	5	1	3	3	2	1	1	1
WEBB	0	0	0	0	0	0	0	0
WILSON	314	564	854	1138	1259	1395	1704	2003
ZAVALA	10	9	5	7	7	7	9	12

Table D1.5 *(continued)*

Livestock

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	2	1	0	0	0	0	0	0
BASTROP	95	88	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	1	1	0	0	0	0	0	0
CALDWELL	43	3	0	0	0	0	0	0
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	38	44	0	0	0	0	0	0
FAYETTE	0	0	0	0	0	0	0	0
FRIO	3	2	0	0	0	0	0	0
GONZALES	12	3	0	0	0	0	0	0
GUADALUPE	38	24	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	4	3	14	14	14	9	9	9
MCMULLEN	0	0	3	3	3	3	3	3
MEDINA	26	16	0	0	0	0	0	0
UVALDE	1	1	0	0	0	0	0	0
WEBB	2	2	18	18	18	18	18	18
WILSON	16	12	0	0	0	0	0	0
ZAVALA	27	5	0	0	0	0	0	0

Irrigation

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	612	507	52	52	52	0	0	0
BASTROP	30	13	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	47	48	0	0	0	0	0	0
CALDWELL	16	136	313	276	243	213	187	163
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	1684	583	737	697	666	654	609	563
FAYETTE	0	0	0	0	0	0	0	0
FRIO	2830	3068	642	645	646	73	73	73
GONZALES	7	25	15	13	11	10	8	7
GUADALUPE	219	212	144	138	131	125	119	113
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	107	348	4	56	109	105	92	80
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	774	79	483	485	485	69	69	69
UVALDE	173	55	1789	1794	1775	560	547	531
WEBB	0	0	0	0	0	0	0	0
WILSON	194	357	302	267	199	148	133	121
ZAVALA	6506	5956	1750	1754	1755	246	247	247

Table D1.6

Rate of groundwater withdrawal (acre-feet per year) from flow layer 6 of the Carrizo-Wilcox aquifer for counties within the study area

Municipal and Industrial*

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	0	0	0	0	0	0	0	0
BASTROP	0	0	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	51	72	155	146	139	131	124	121
CALDWELL	1223	1497	2075	2266	2444	2684	2725	2750
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	0	0	0	0	0	0	0	0
FAYETTE	0	0	0	0	0	0	0	0
FRIO	0	0	0	0	0	0	0	0
GONZALES	0	0	0	0	0	0	0	0
GUADALUPE	0	0	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	0	0	0	0	0	0	0	0
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	0	0	68	54	53	45	46	47
UVALDE	0	0	0	0	0	0	0	0
WEBB	0	0	0	0	0	0	0	0
WILSON	79	107	169	173	176	191	207	215
ZAVALA	0	0	97	42	25	8	2	0

*industrial includes manufacturing, mining, and power generation

County – Other (Non-reported Domestic)

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	56	84	81	89	100	87	98	101
BASTROP	275	607	3907	4633	5359	6146	7142	8906
BEE	0	0	0	0	0	0	0	0
BEXAR	3125	2974	8834	8903	7975	4754	4788	3657
CALDWELL	2872	528	1470	1540	1593	1526	1420	1286
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	8	1	1	1	1	1	1	1
FAYETTE	0	0	0	0	0	0	0	0
FRIO	0	0	0	0	0	0	0	0
GONZALES	0	0	0	0	0	0	0	0
GUADALUPE	476	807	2189	3015	3965	4816	5408	5567
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	6	12	320	322	323	318	319	322
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	172	234	402	417	425	382	395	420
UVALDE	160	232	509	450	408	214	203	182
WEBB	0	0	0	0	0	0	0	0
WILSON	5	9	12	16	18	20	24	29
ZAVALA	5	2	1	1	2	2	2	3

Table D1.6 *(continued)*

Livestock

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	7	6	0	0	0	0	0	0
BASTROP	151	139	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	28	37	0	0	0	0	0	0
CALDWELL	73	10	0	0	0	0	0	0
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	34	39	0	0	0	0	0	0
FAYETTE	0	0	0	0	0	0	0	0
FRIO	1	0	0	0	0	0	0	0
GONZALES	0	0	0	0	0	0	0	0
GUADALUPE	77	49	0	0	0	0	0	0
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	45	33	119	119	119	79	79	79
MCMULLEN	0	0	1	1	1	1	1	1
MEDINA	47	30	0	0	0	0	0	0
UVALDE	30	19	0	0	0	0	0	0
WEBB	0	0	2	2	2	2	2	2
WILSON	10	7	0	0	0	0	0	0
ZAVALA	60	11	0	0	0	0	0	0

Irrigation

COUNTY	1980	1990	2000	2010	2020	2030	2040	2050
ATASCOSA	0	2312	2283	276	275	273	0	0
BASTROP	60	26	0	0	0	0	0	0
BEE	0	0	0	0	0	0	0	0
BEXAR	1944	993	0	0	0	0	0	0
CALDWELL	33	327	726	639	562	494	433	379
DEWITT	0	0	0	0	0	0	0	0
DIMMIT	166	54	54	51	49	48	45	41
FAYETTE	0	0	0	0	0	0	0	0
FRIO	46	48	10	10	10	1	1	1
GONZALES	0	0	0	0	0	0	0	0
GUADALUPE	989	1129	782	173	165	157	149	142
KARNES	0	0	0	0	0	0	0	0
LA SALLE	0	0	0	0	0	0	0	0
LAVACA	0	0	0	0	0	0	0	0
LIVE OAK	0	0	0	0	0	0	0	0
MAVERICK	326	992	10	161	312	301	262	227
MCMULLEN	0	0	0	0	0	0	0	0
MEDINA	4888	369	2802	2811	2811	400	399	398
UVALDE	4372	58	1906	1910	1890	896	582	565
WEBB	0	0	0	0	0	0	0	0
WILSON	262	439	347	306	229	170	153	139
ZAVALA	961	845	249	250	250	35	35	35

APPENDIX D2

Post Plots of Groundwater Withdrawal Estimates for the Carrizo-Wilcox for 1980, 1990, 2000, 2010, 2020, 2030, 2040, and 2050

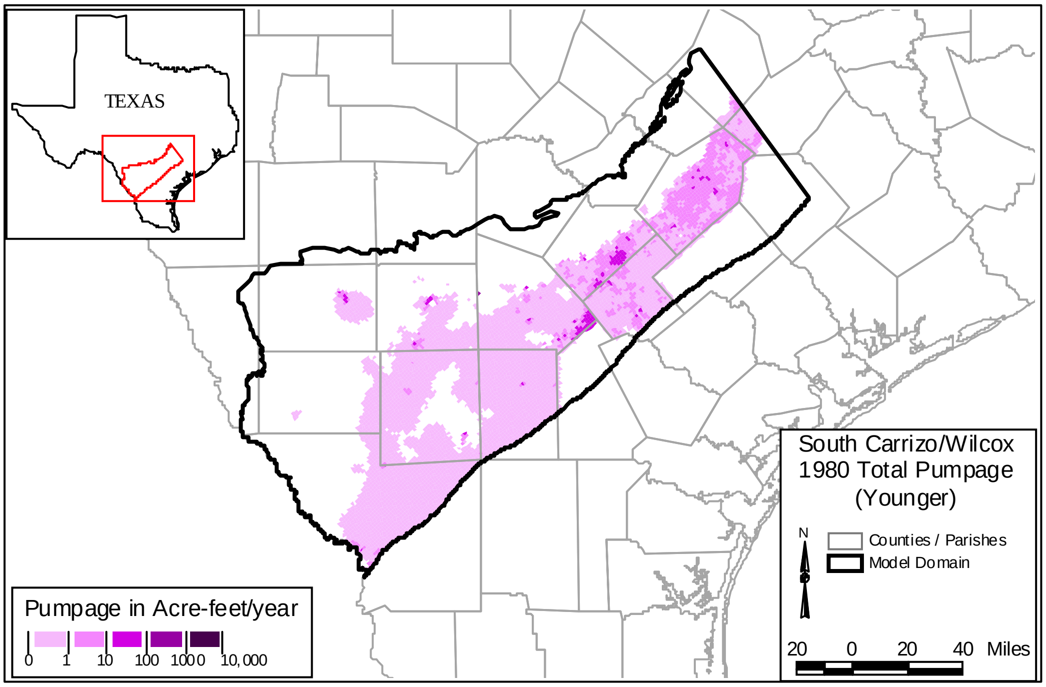


Figure D.2.1 Younger (Layer 1) Pumpage, 1980 (AFY)

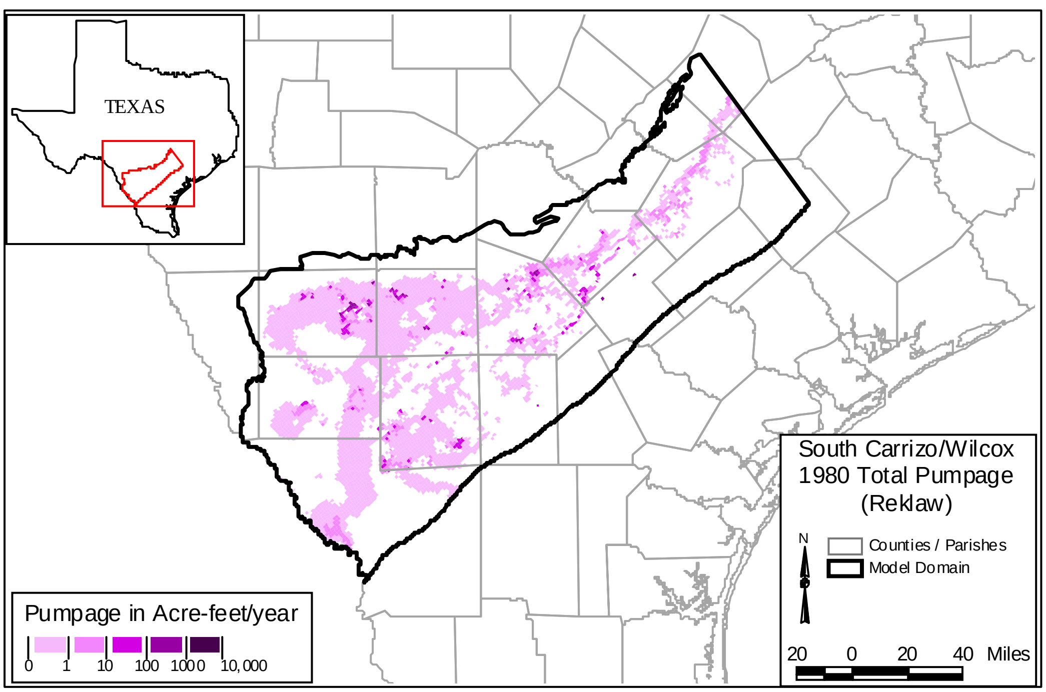


Figure D.2.2 Reklaw (Layer 2) Pumpage, 1980 (AFY)

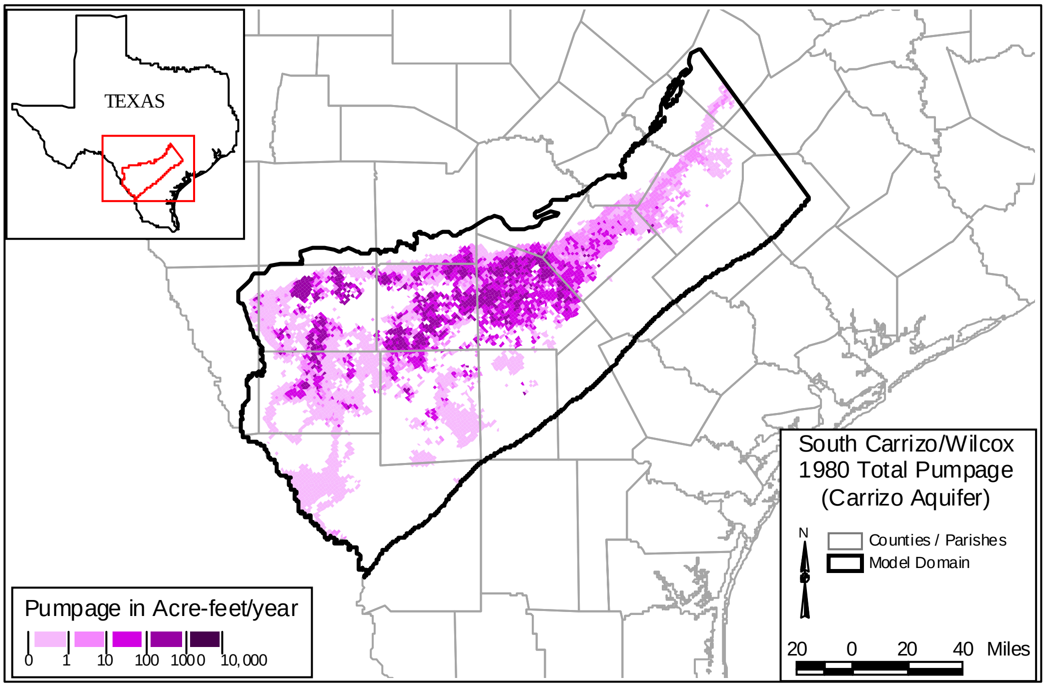


Figure D.2.3 Carrizo (Layer 3) Pumpage, 1980 (AFY)

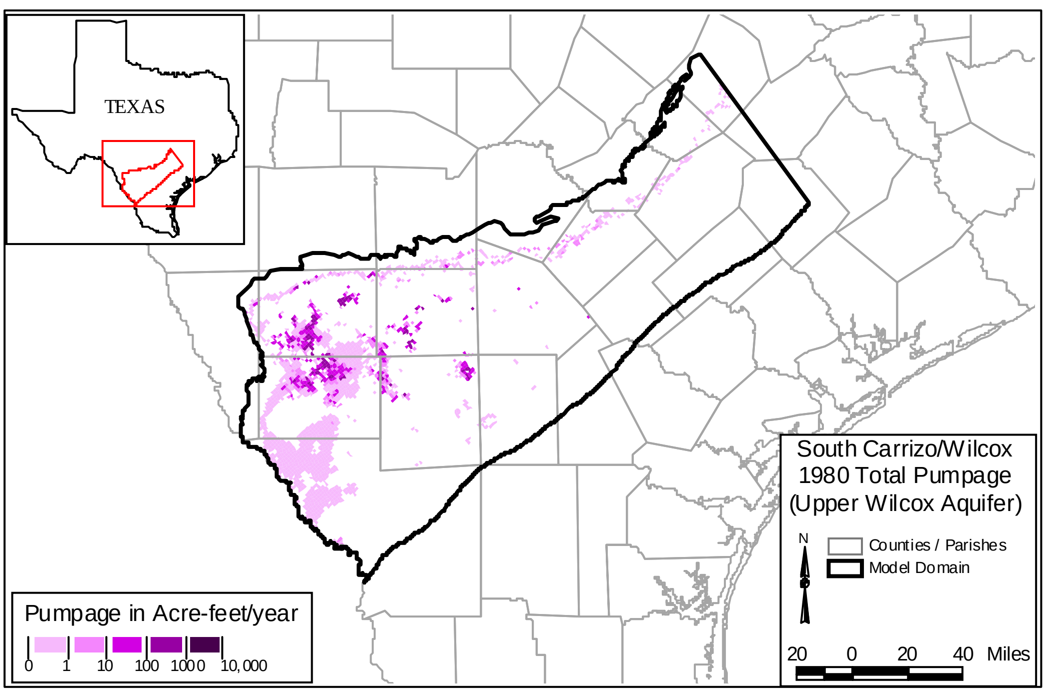


Figure D.2.4 Upper Wilcox (Layer 4) Pumpage, 1980 (AFY)

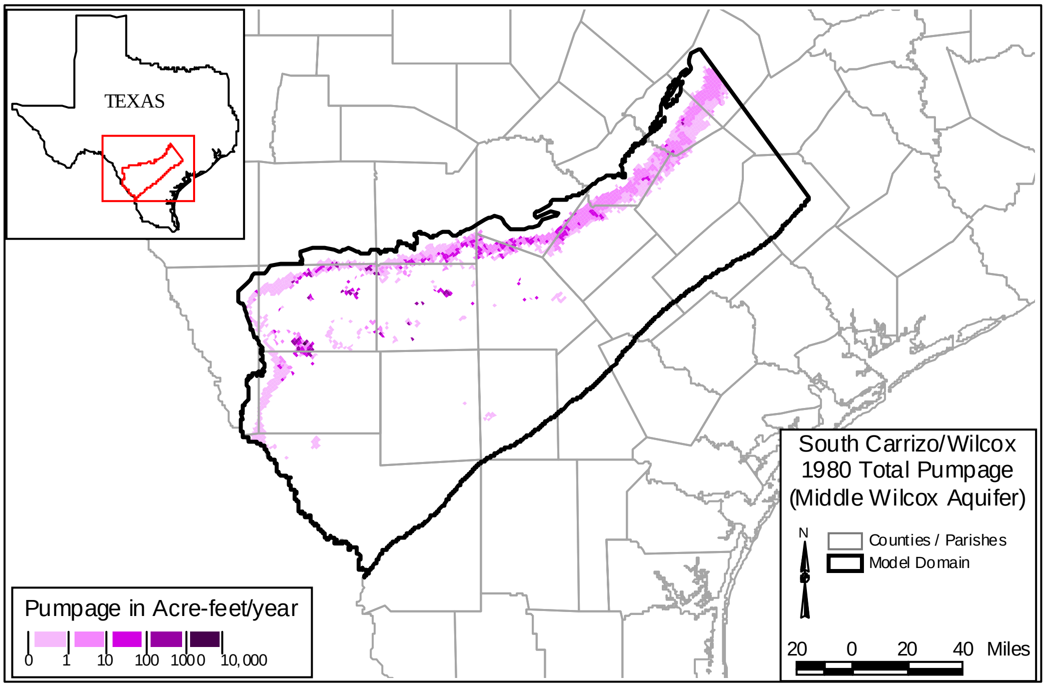


Figure D.2.5 Middle Wilcox (Layer 5) Pumpage, 1990 (AFY)

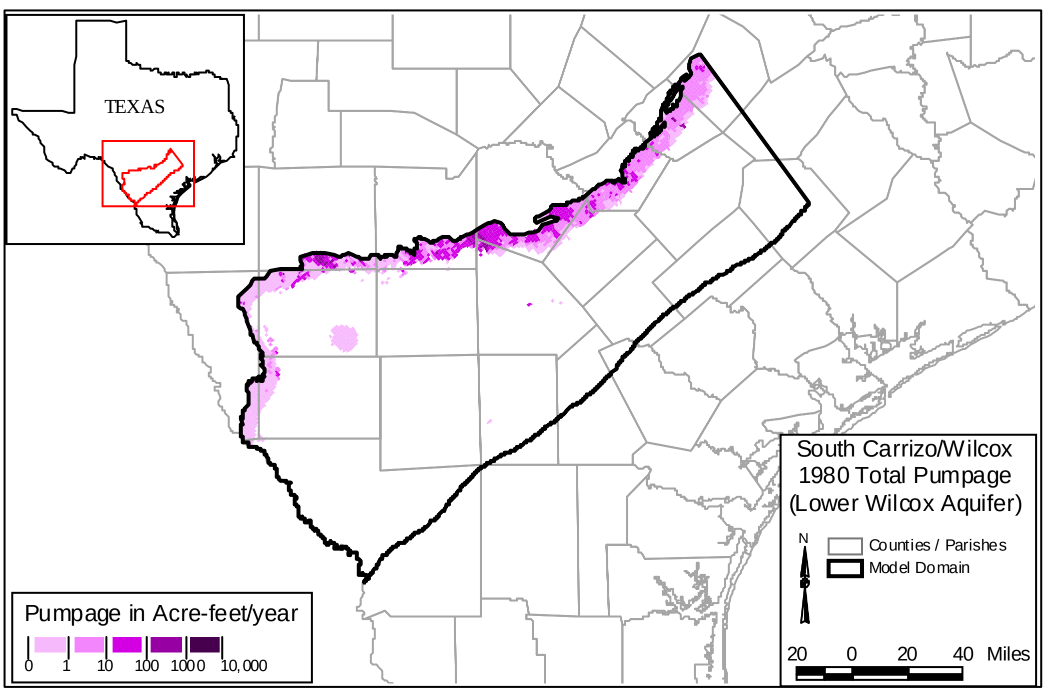


Figure D.2.6 Lower Wilcox (Layer 6) Pumpage, 1990 (AFY)

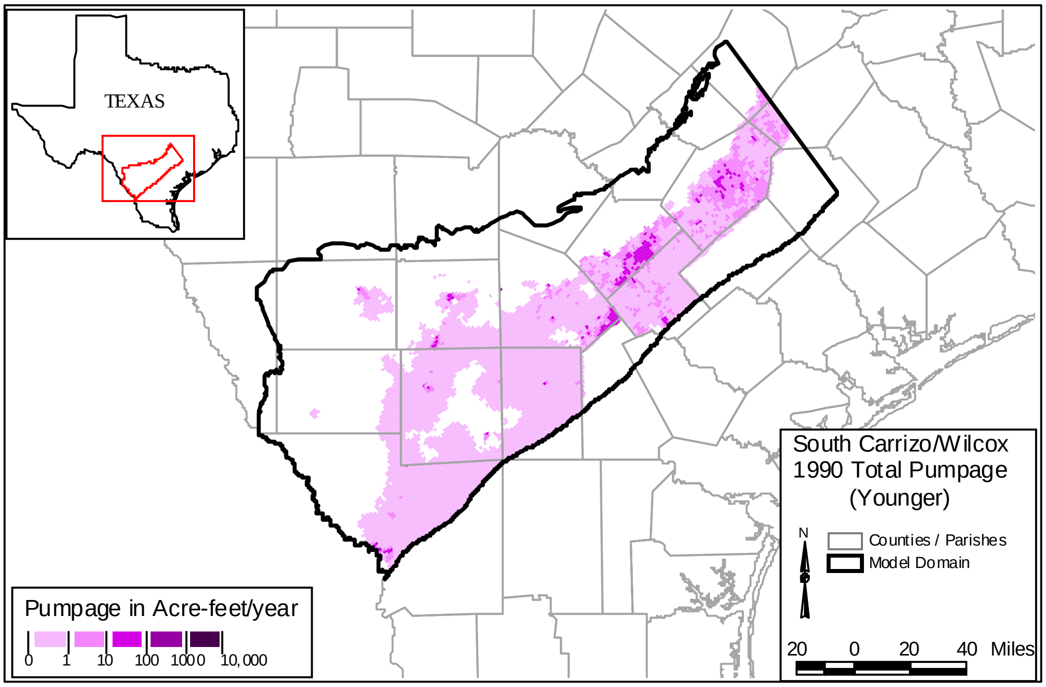


Figure D.2.7 Younger (Layer 1) Pumpage, 1990 (AFY)

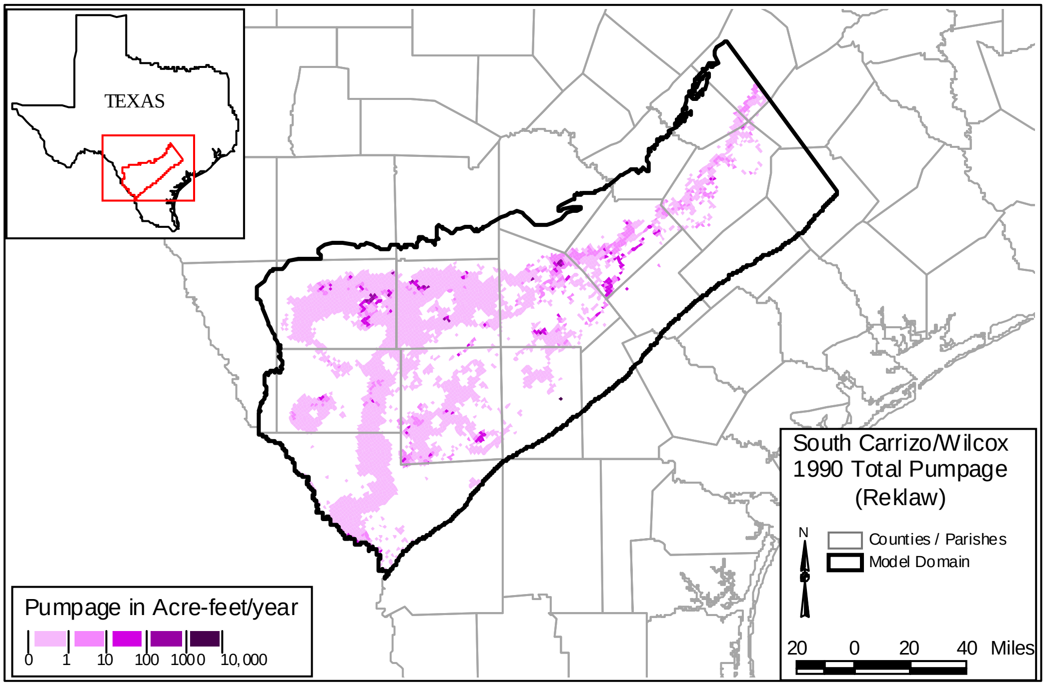


Figure D.2.8 Reklaw (Layer 2) Pumpage, 1990 (AFY)

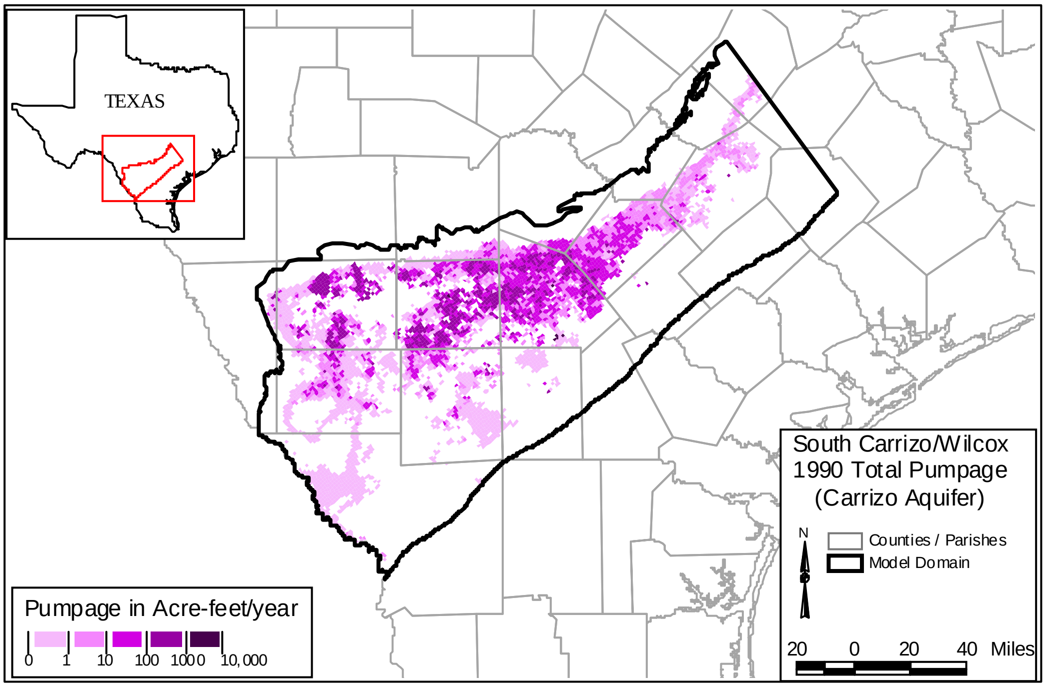


Figure D.2.9 Carrizo (Layer 3) Pumpage, 1990 (AFY)

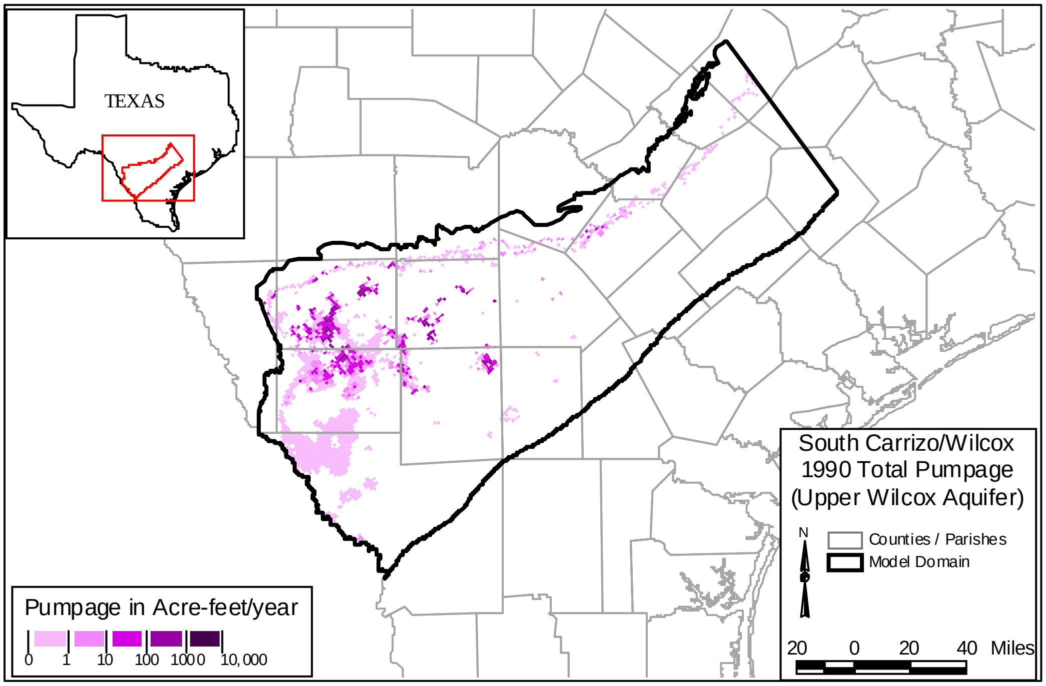


Figure D.2.10 Upper Wilcox (Layer 4) Pumpage, 1990 (AFY)

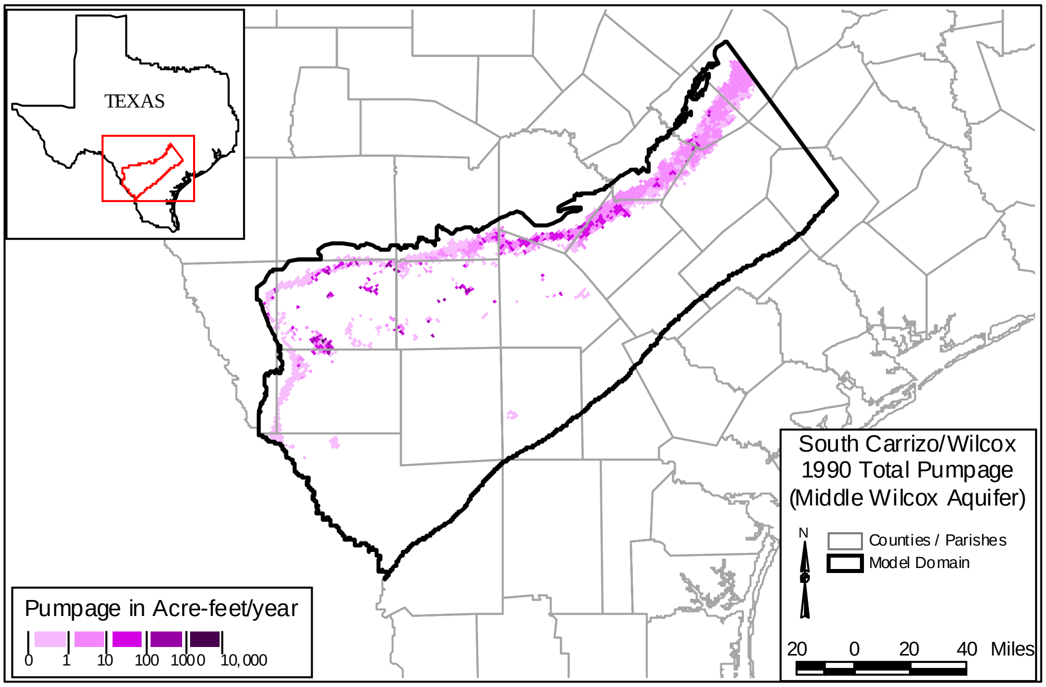


Figure D.2.11 Middle Wilcox (Layer 5) Pumpage, 1990 (AFY)

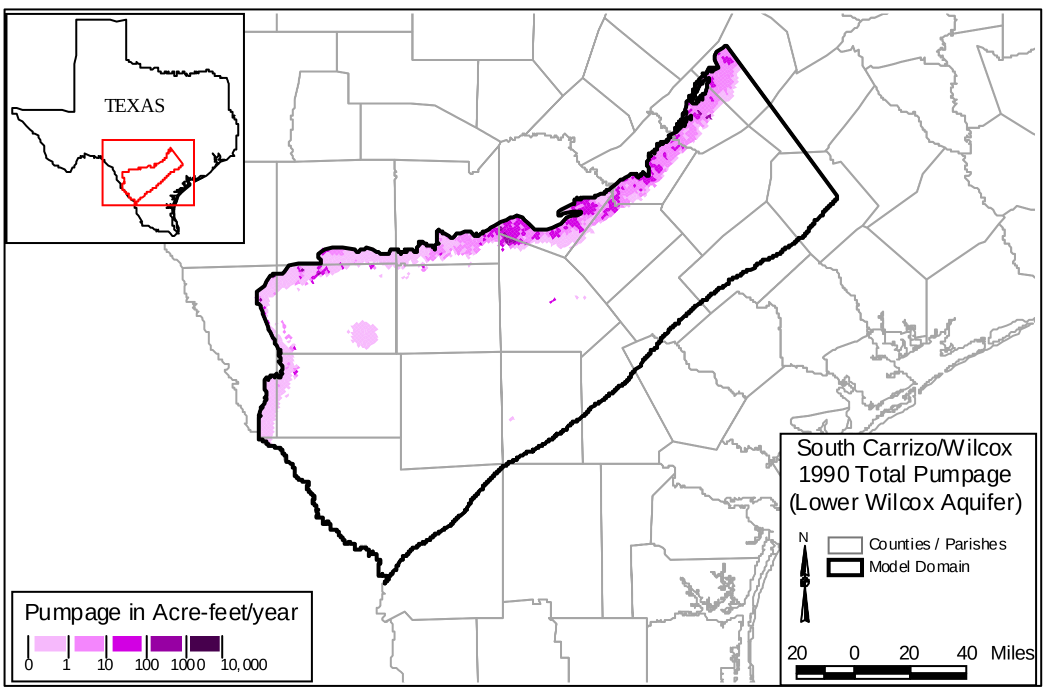


Figure D.2.12 Lower Wilcox (Layer 6) Pumpage, 1990 (AFY)

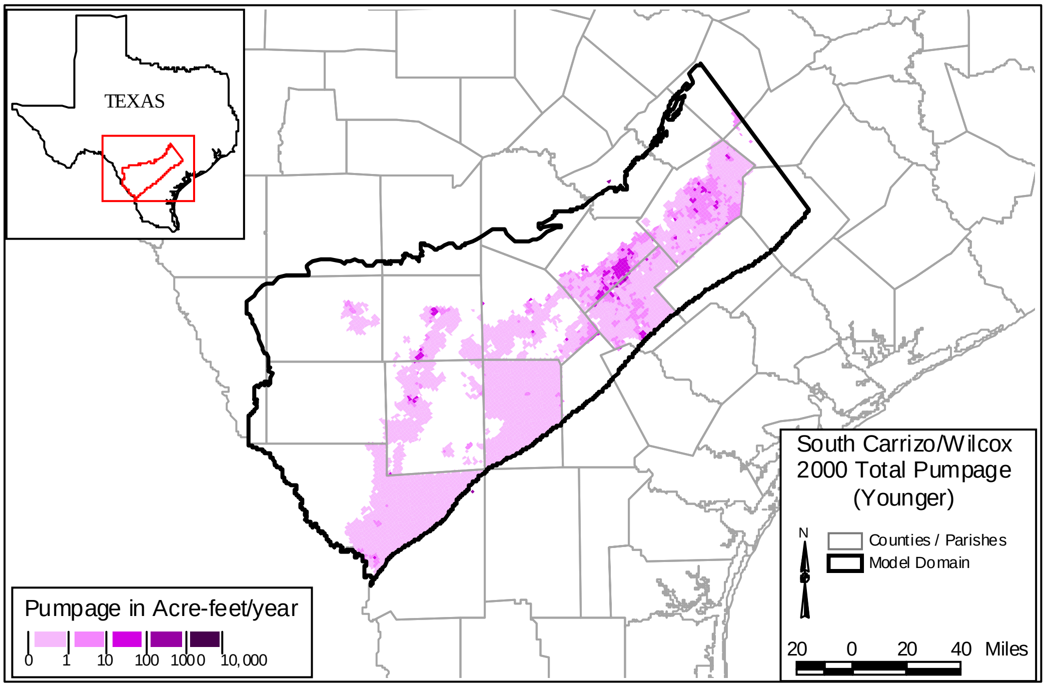


Figure D.2.13 Younger (Layer 1) Pumpage, 2000 (AFY)

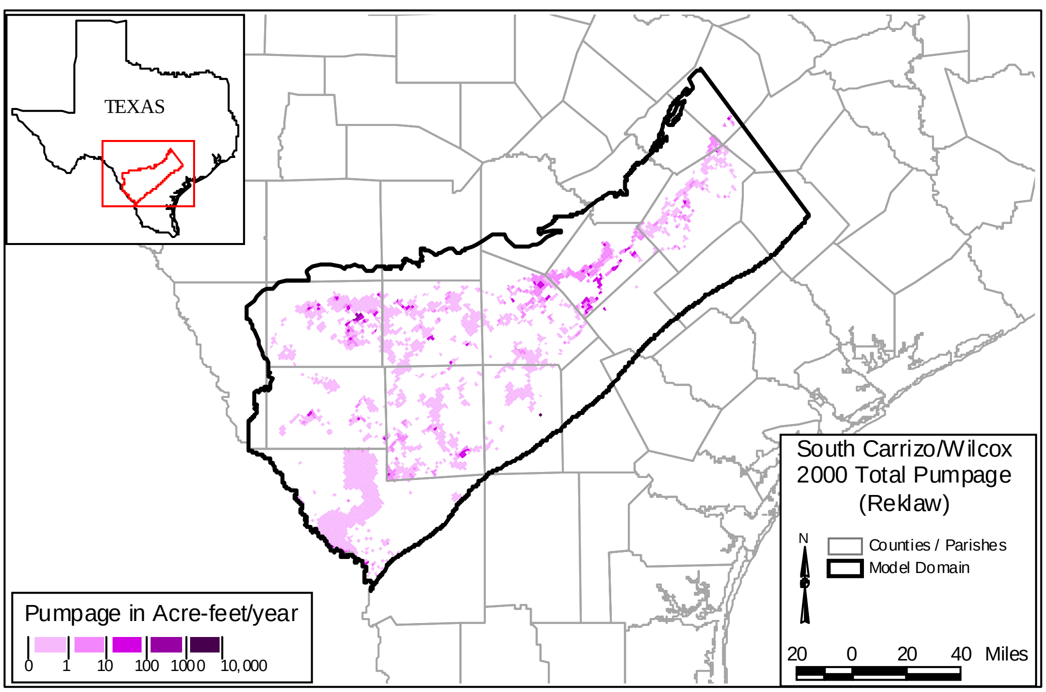


Figure D.2.14 Reklaw (Layer 2) Pumpage, 2000 (AFY)

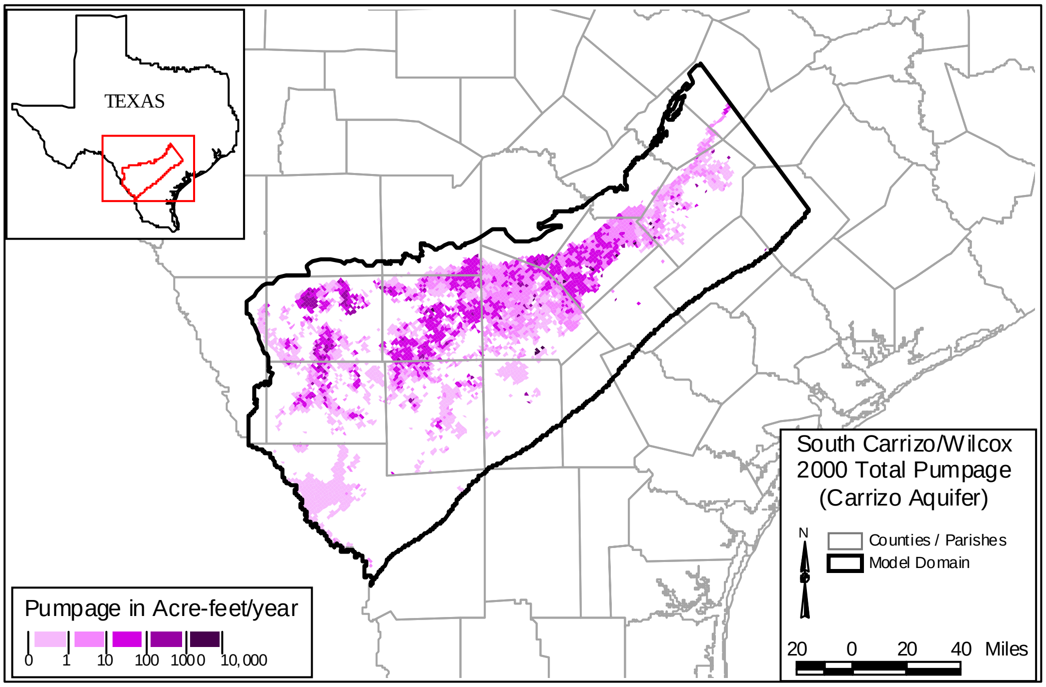


Figure D.2.15 Carrizo (Layer 3) Pumpage, 2000 (AFY)

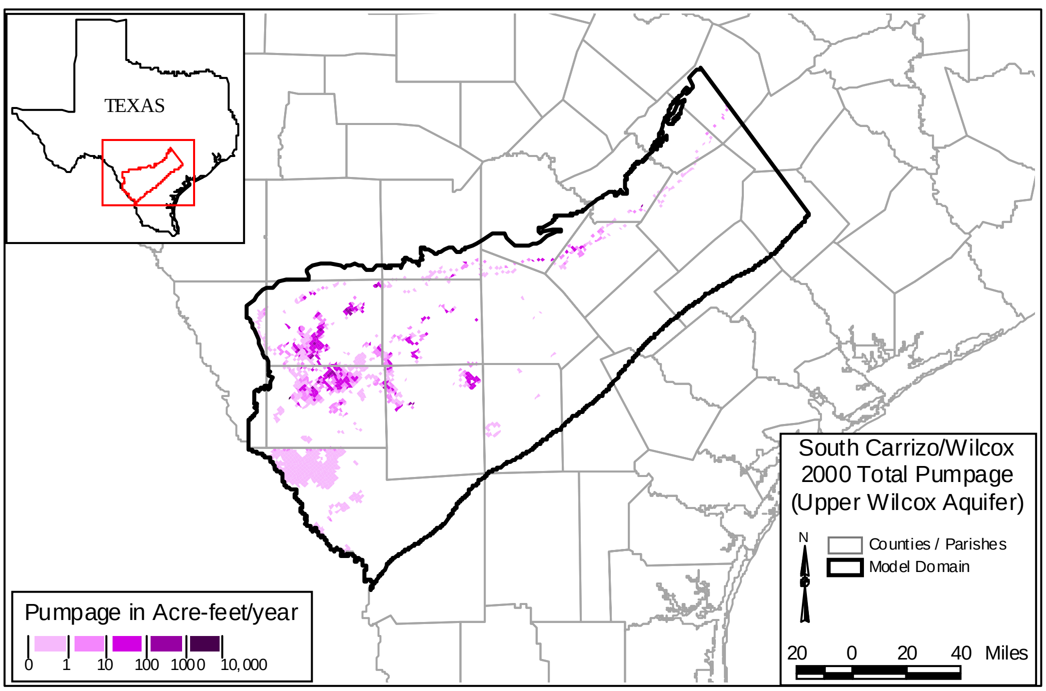


Figure D.2.16 Upper Wilcox (Layer 4) Pumpage, 2000 (AFY)

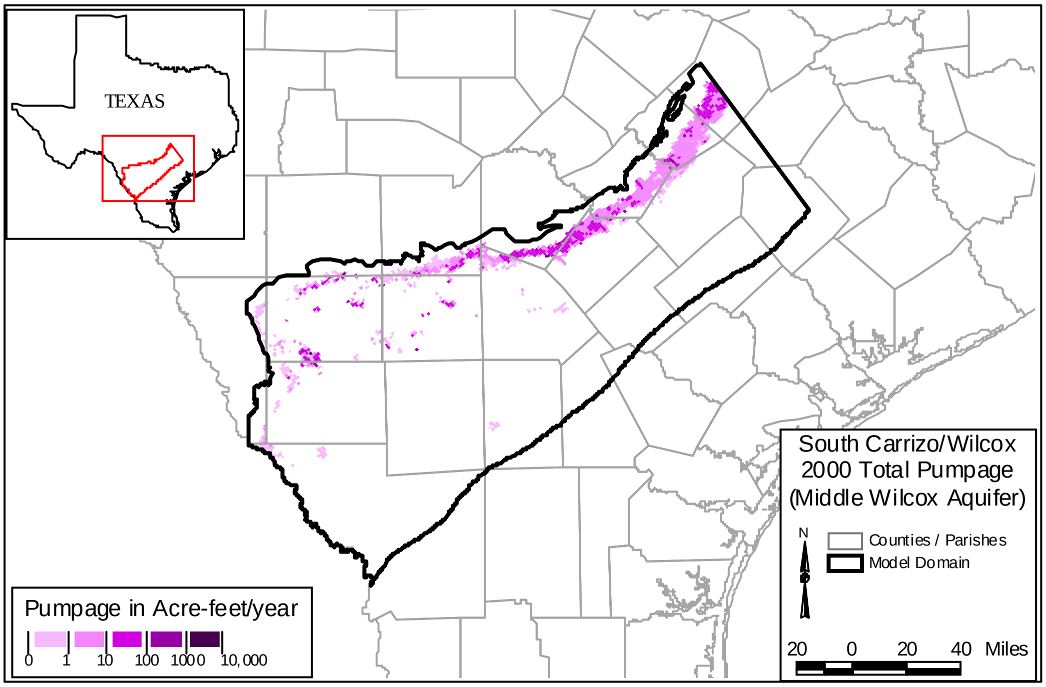


Figure D.2.17 Middle Wilcox (Layer 5) Pumpage, 2000 (AFY)

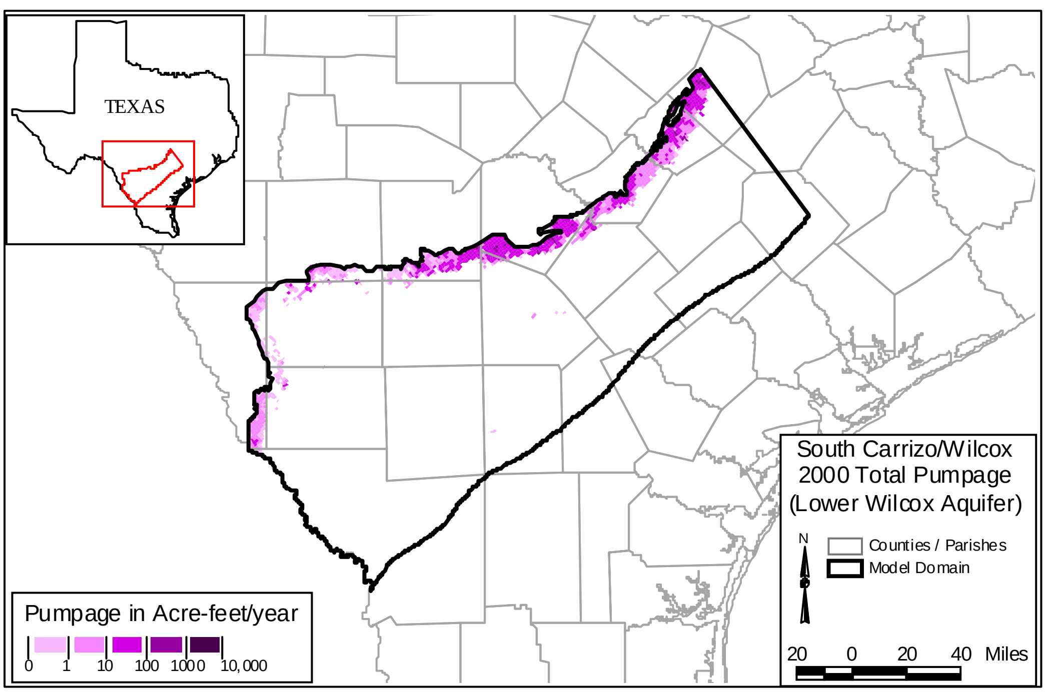


Figure D.2.18 Lower Wilcox (Layer 6) Pumpage, 2000 (AFY)

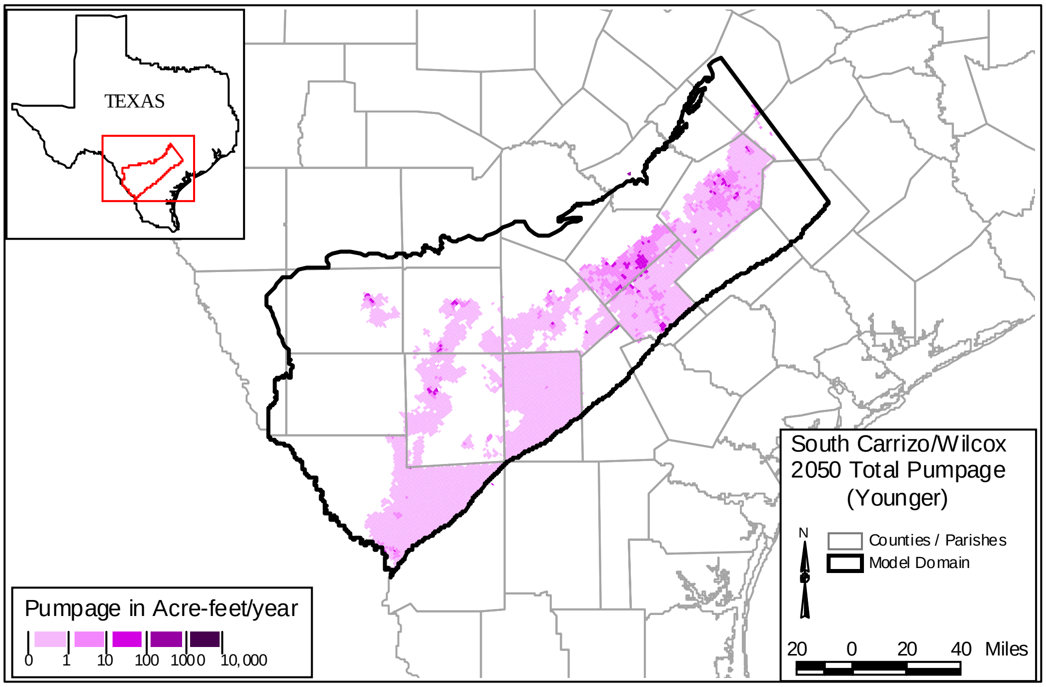


Figure D.2.19 Younger (Layer 1) Pumpage, 2050 (AFY)

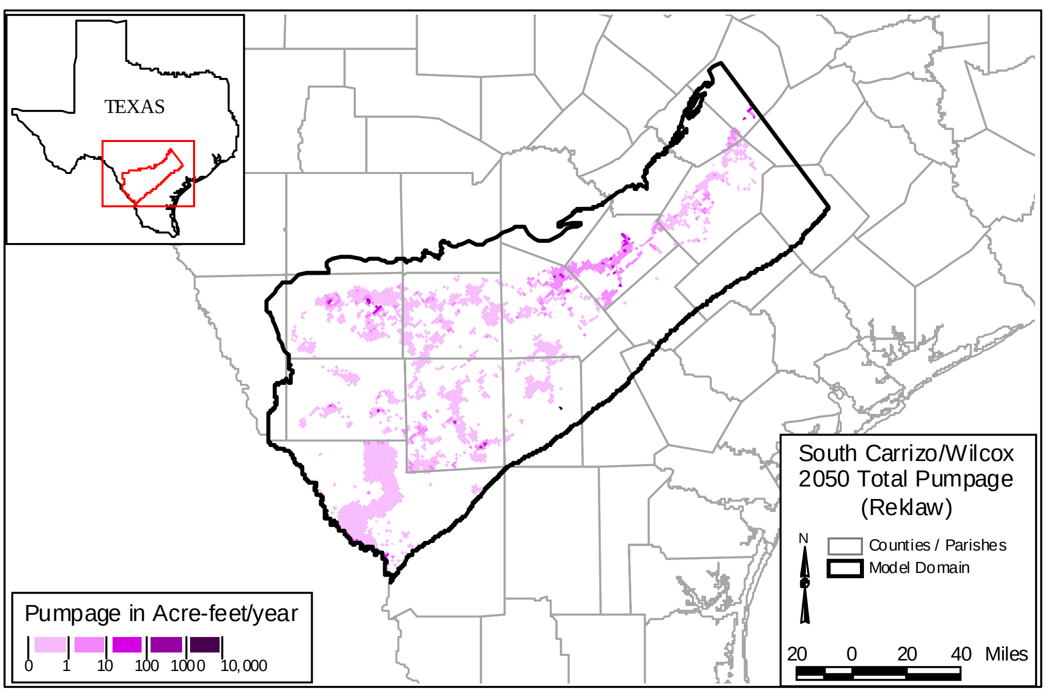


Figure D.2.20 Reklaw (Layer 2) Pumpage, 2050 (AFY)

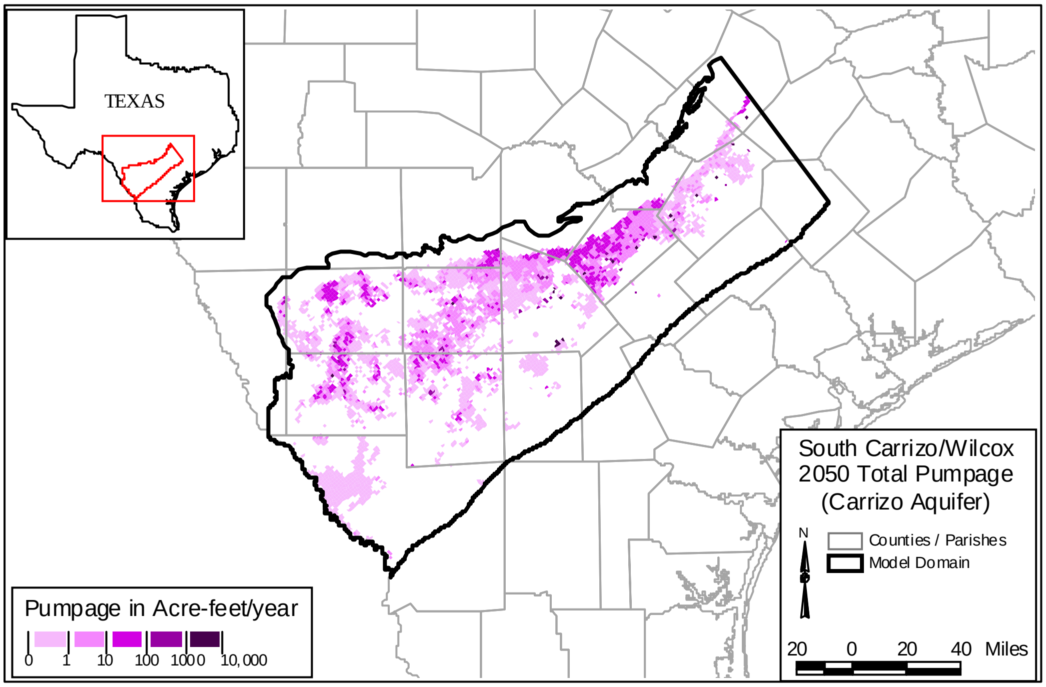


Figure D.2.21 Carrizo (Layer 3) Pumpage, 2050 (AFY)

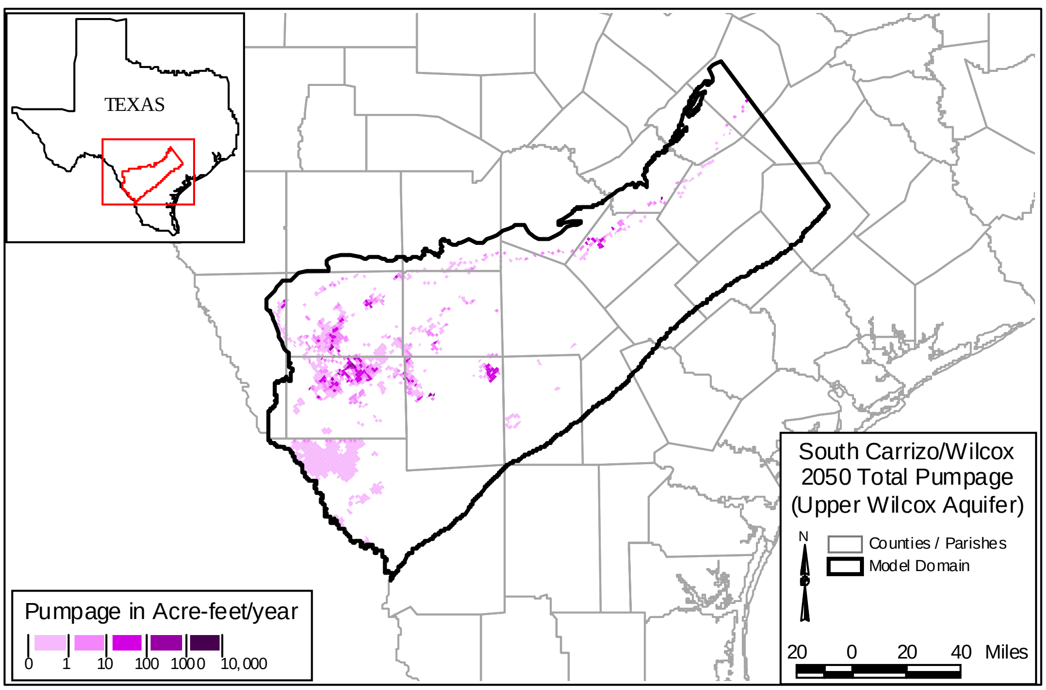


Figure D.2.22 Upper Wilcox (Layer 4) Pumpage, 2050 (AFY)

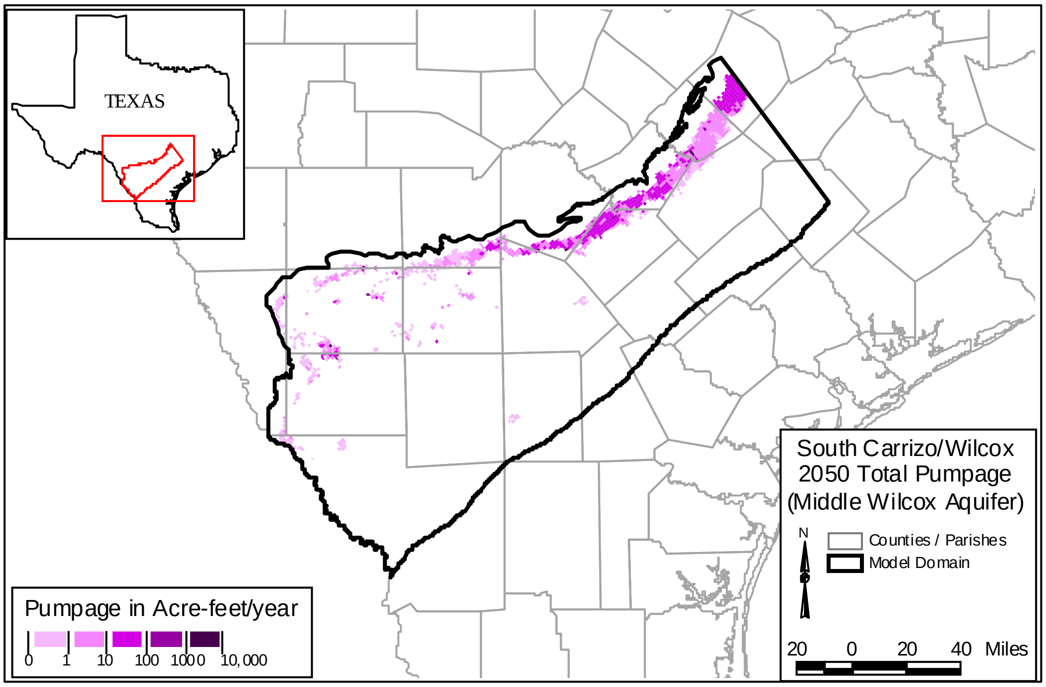


Figure D.2.23 Upper Wilcox (Layer 5) Pumpage, 2050 (AFY)

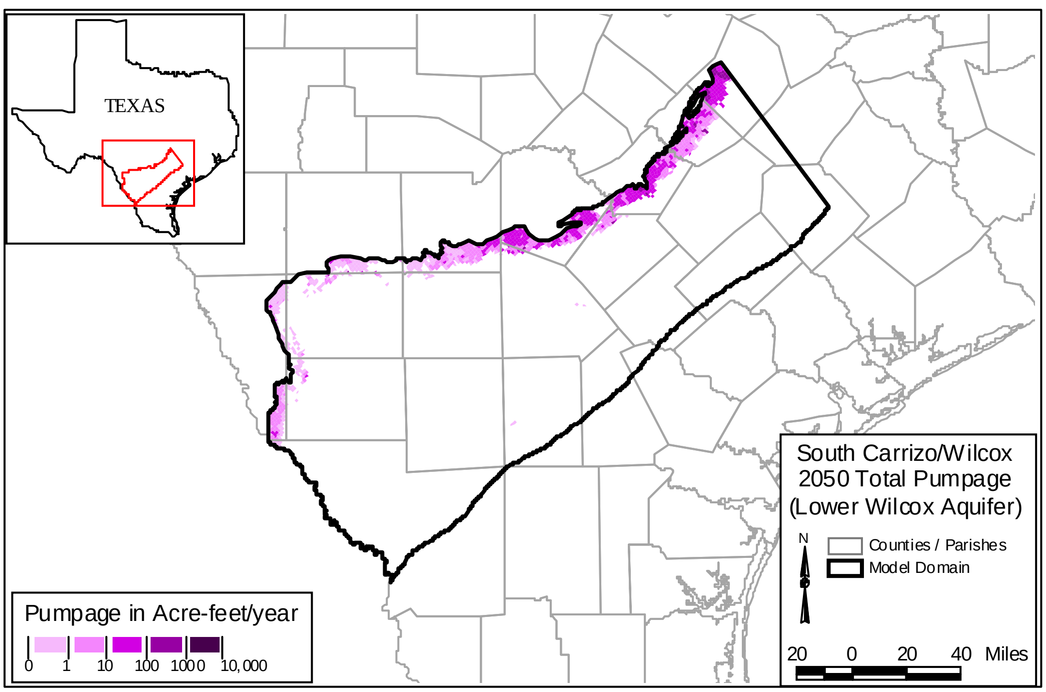
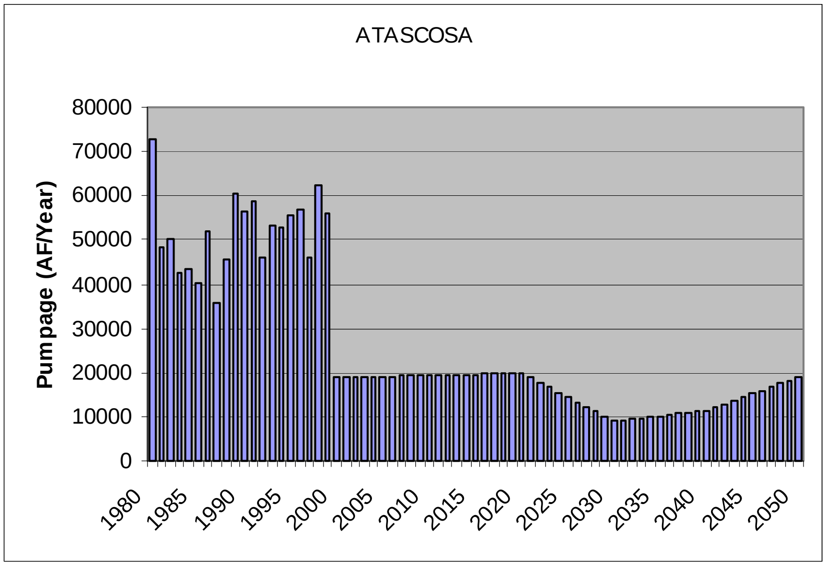
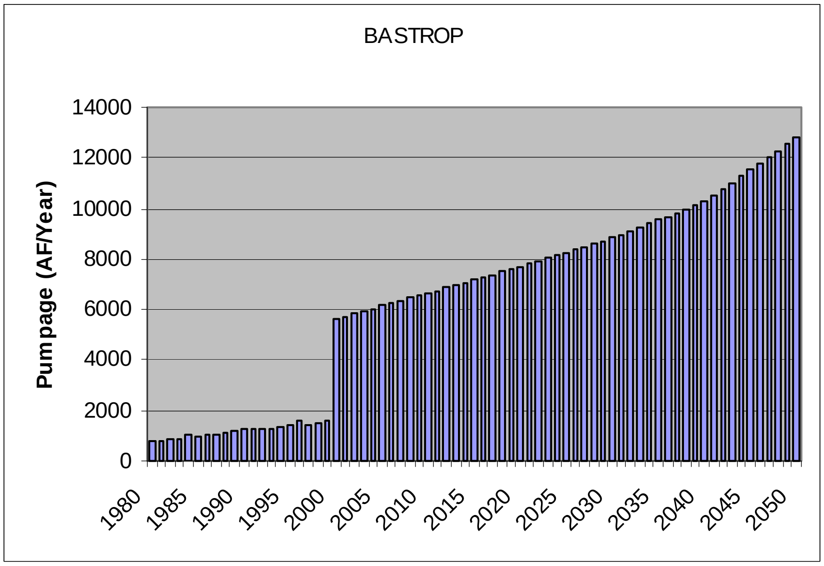


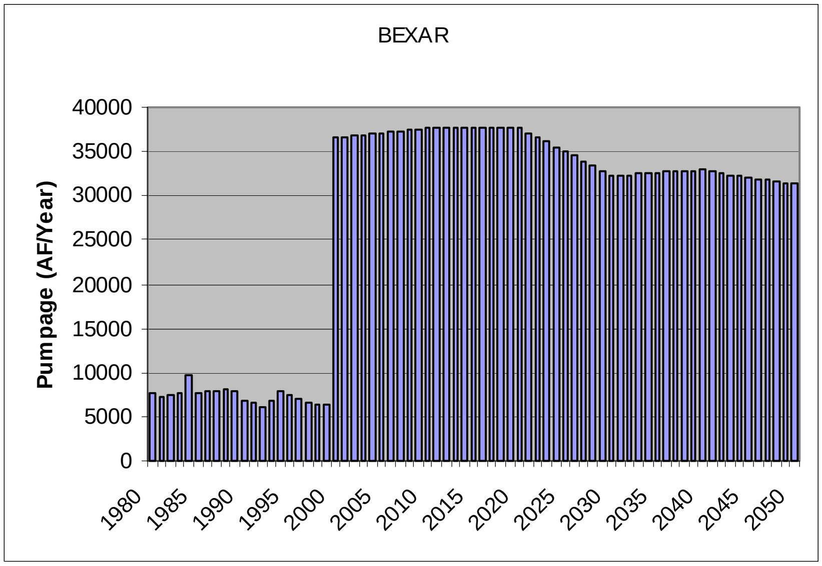
Figure D.2.24 Lower Wilcox (Layer 6) Pumpage, 2050 (AFY)

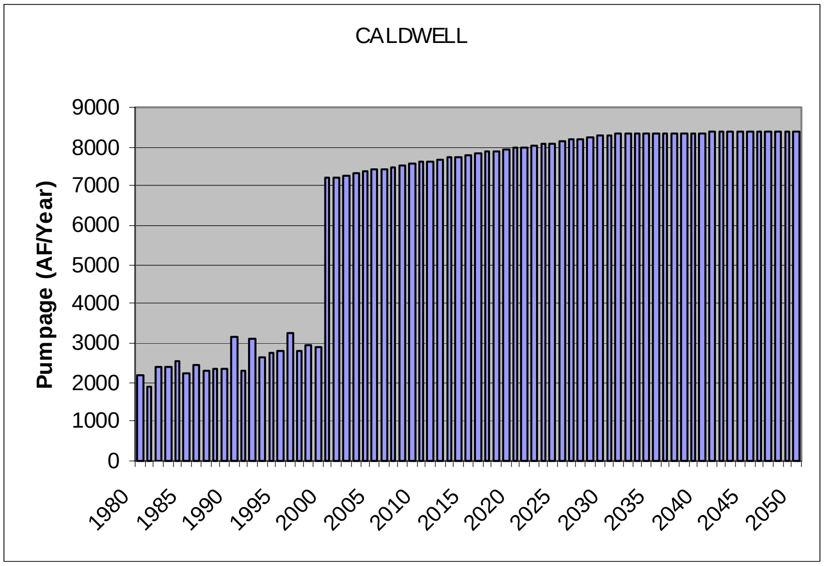
APPENDIX D3

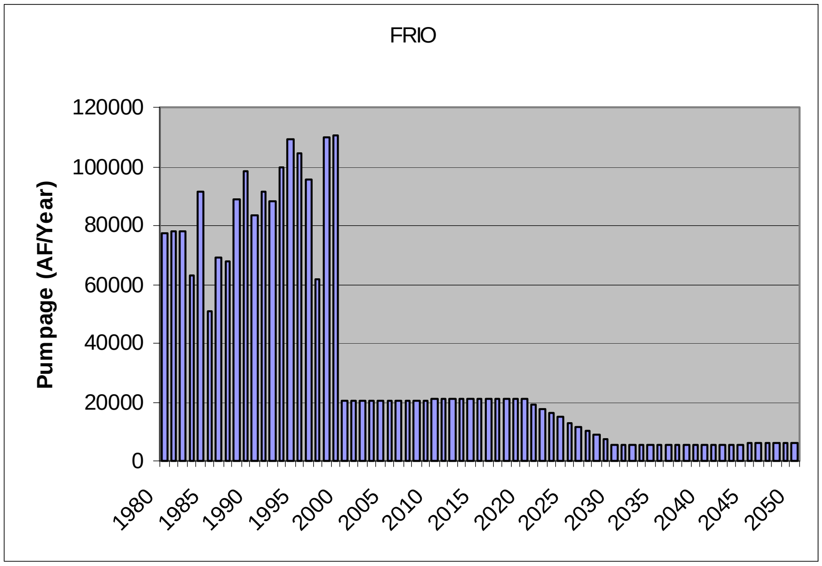
Carrizo-Wilcox Groundwater Withdrawal Distributions by County


ATASCOSA
Pumpage (AF/Year)
80000
70000
60000
50000
40000
30000
20000
10000
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050


BASTROP
Pumpage (AF/Year)
14000
12000
10000
8000
6000
4000
2000
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050


BEXAR
Pumpage (AF/Year)
40000
35000
30000
25000
20000
15000
10000
5000
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050


CALDWELL
Pumpage (AF/Year)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1980
1985
1990
1995
2000
2005
2010
2015
2020
2025
2030
2035
2040
2045
2050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Pumpage (AF/Year)
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80000
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40000
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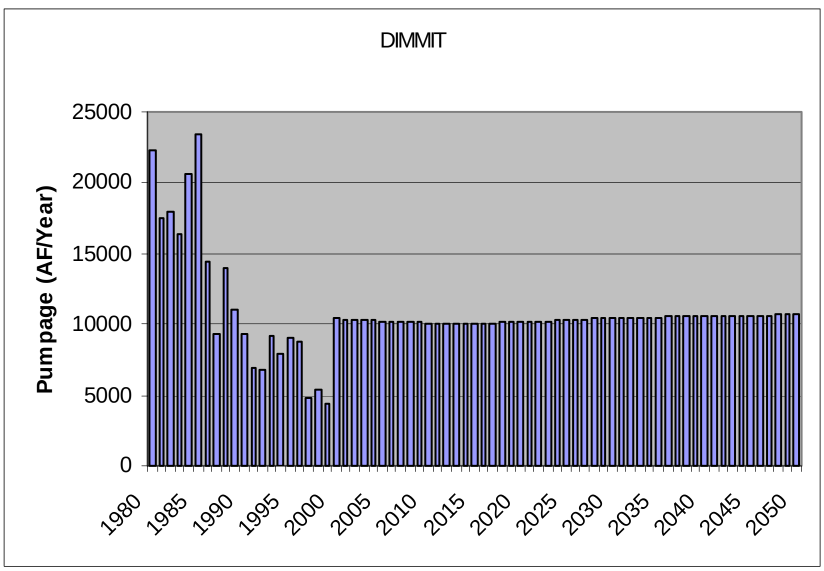
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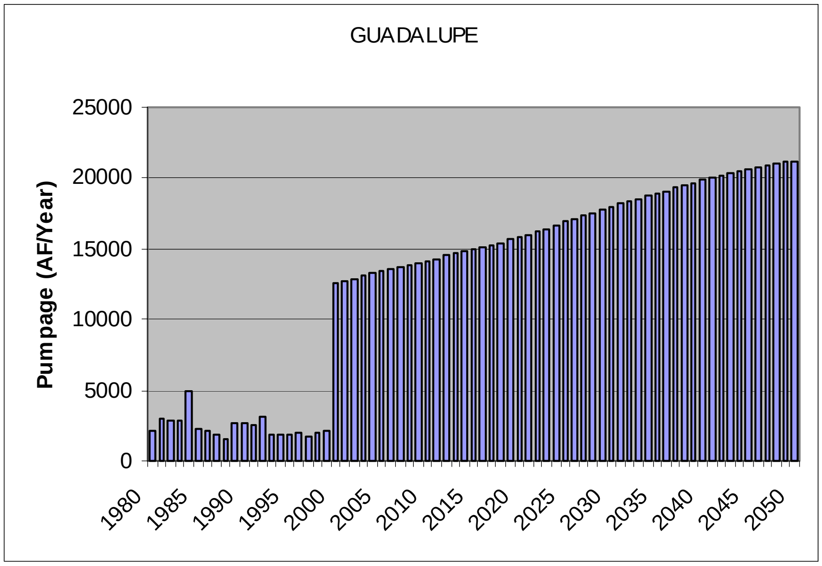
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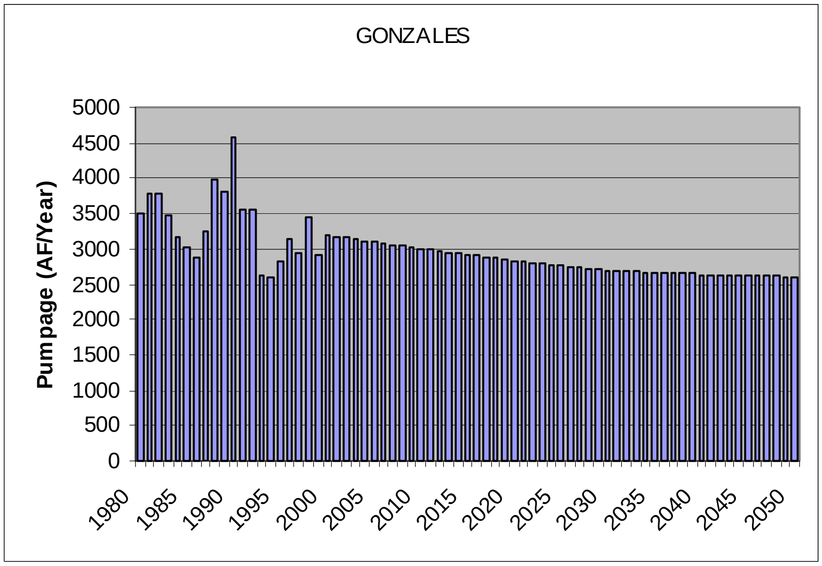
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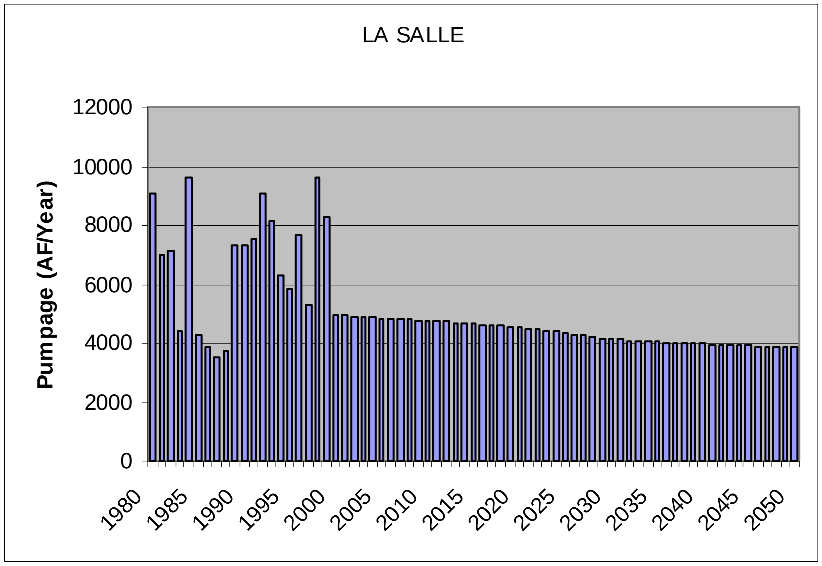
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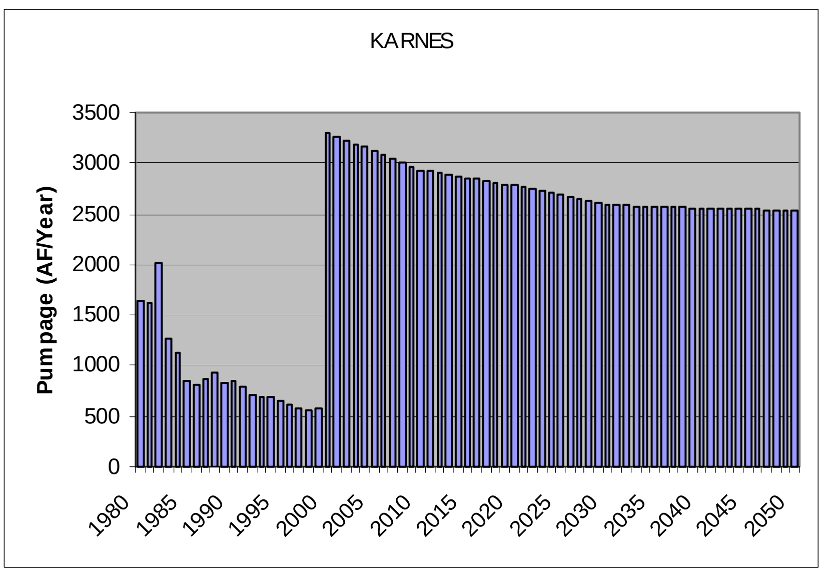
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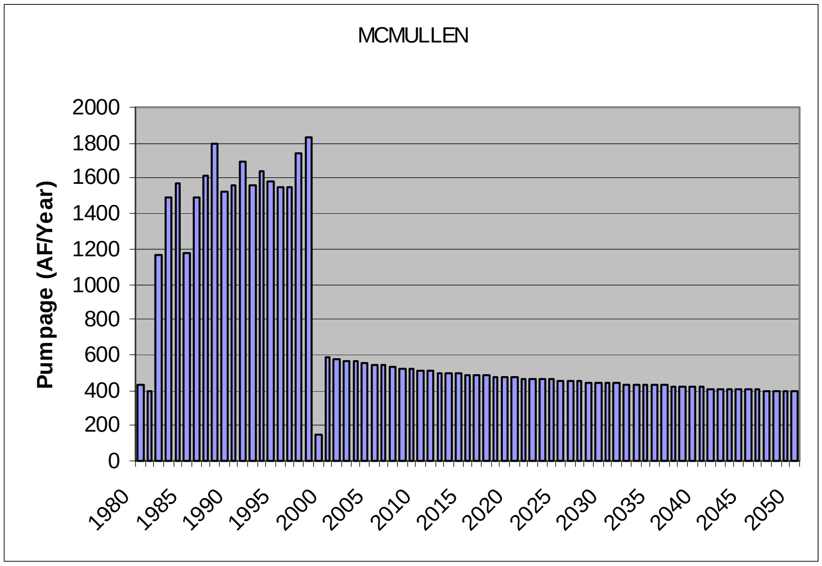
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Pumpage (AF/Year)
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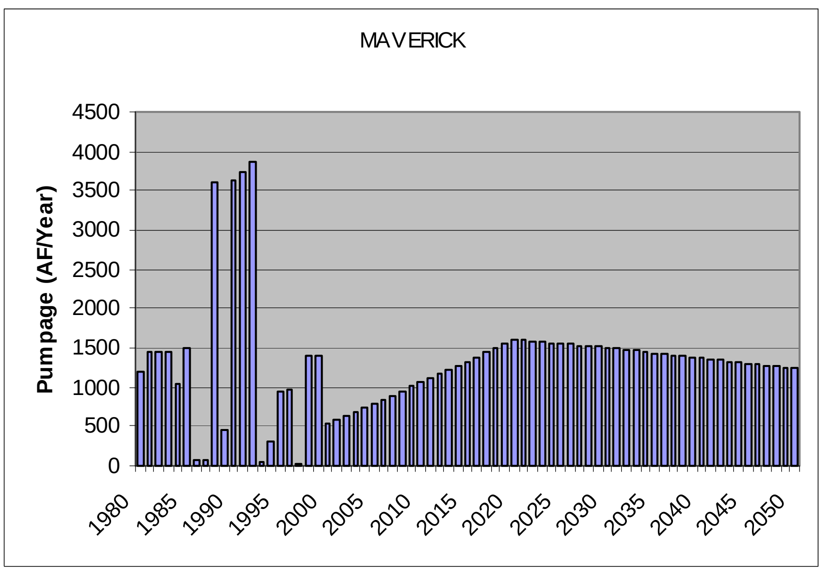
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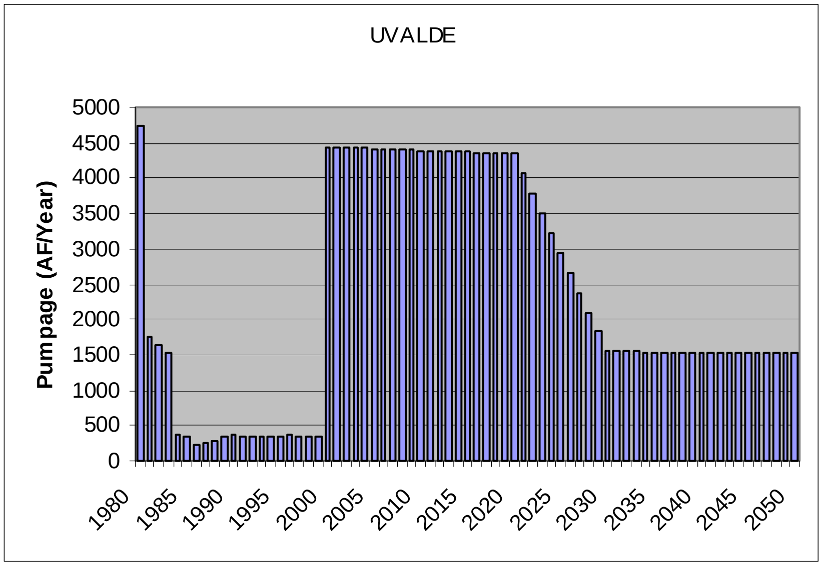
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Pumpage (AF/Year)
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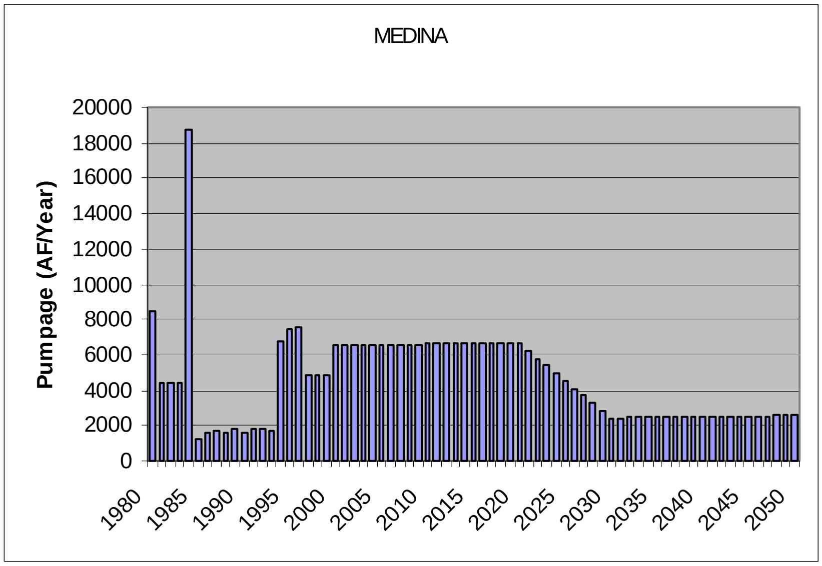
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Pumpage (AF/Year)
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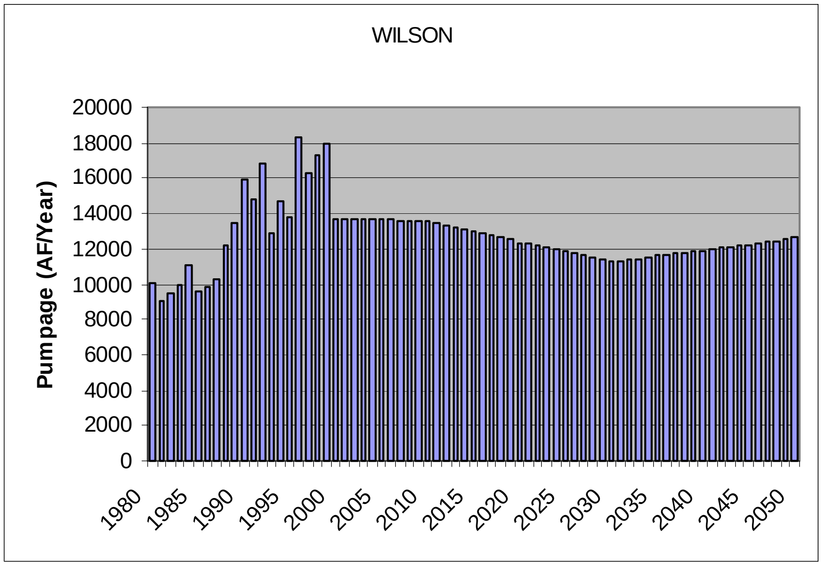
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Pumpage (AF/Year)
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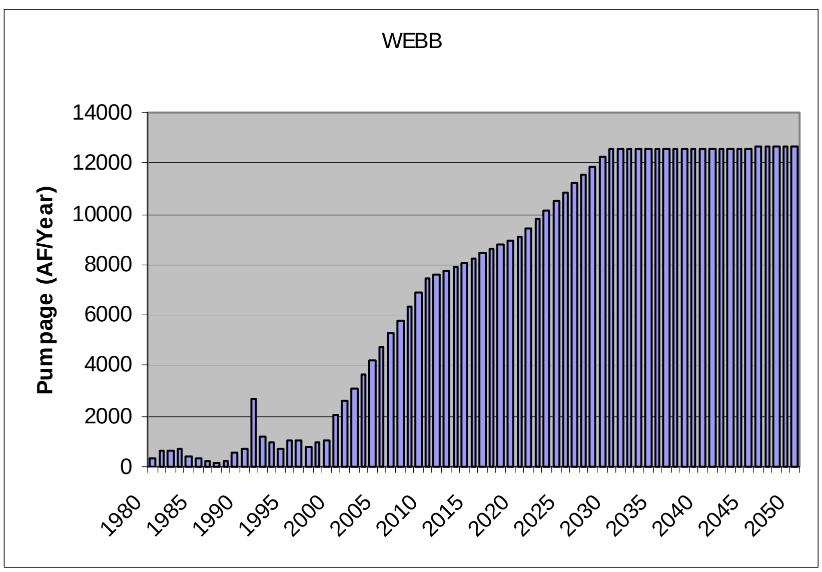
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Pumpage (AF/Year)
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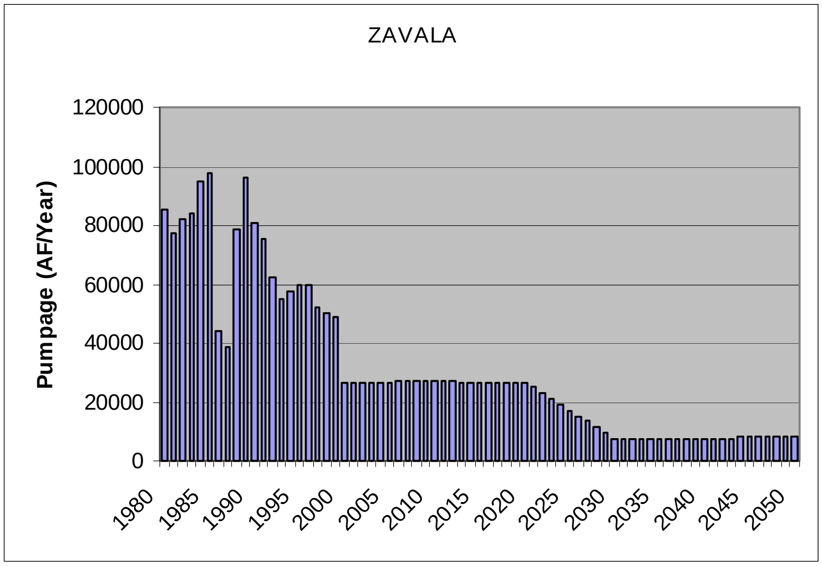
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Pumpage (AF/Year)
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APPENDIX E

Using SWAT with MODFLOW in a Decoupled Environment

Appendix E
Using SWAT with MODFLOW in a Decoupled Environment

Background:

Our goal is to use the recharge/evapotranspiration estimates from a SWAT simulation to estimate recharge/evapotranspiration inputs to a MODFLOW simulation. We do not want to do any iteration and are not allowed real-time updating between the two.

The following is a general description of how these physical processes are implemented in the two models.

<u>Recharge/Evapotranspiration in MODFLOW</u>:

In MODFLOW, recharge is input in length/time units. This rate of water is added directly to the uppermost active layer during each stress period. The rate can be varied spatially for each grid block, and temporally for each stress period.

In MODFLOW, evapotranspiration removes water directly from the uppermost saturated layer. When the water table is at or above a specified elevation (called the "ET surface"), water is removed at the specified maximum rate. If the water table is below the ET surface, but above a specified extinction depth, then water is removed at a rate that decreases linearly from a maximum at the ET surface to zero at the extinction depth. Below the extinction depth, no water is removed. Figure 1 illustrates this approach.

<u>Recharge/Evapotranspiration in SWAT:</u>

In SWAT, basically

Change in Soil Water = Infiltration - Evapotranspiration - Recharge

where

Infiltration = Precipitation - Runoff

A running soil water balance is calculated during the simulation. Precipitation is separated into infiltration and runoff using the SCS Curve Number method. Evapotranspiration requires more complex calculations. The following is a summary of how evapotranspiration is calculated in SWAT (skipping some of the minor details):

First, a potential (or more correctly, "reference") evapotranspiration, $E_{t,0}$, is calculated, typically using some flavor of the Penman approach. This reference evapotranspiration is that which would occur for some reference grass with no soil water limitation. Three separate steps are required to estimate an actual evapotranspiration from this potential evapotranspiration.

Step 1: Account for vegetative differences -- since not all vegetation is reference grass, differences in growing cycles, size, and water use are accounted for by correlating the maximum daily transpiration with the leaf area index (LAI) of the plant, i.e.

$$E_{t,max} = \frac{(LAI)(E_{t,0})}{3.0} \qquad 0<LAI<3.0$$

$$E_{t,max} = E_{t,0} \qquad LAI > 3.0$$

The LAI changes with plant type, growth cycle, growing conditions, etc.

Step 2: Account for decreasing potential with increasing root zone depth -- root density is assumed to be greatest near the soil surface, and decreases with depth. With default SWAT parameters, about 50% of the water uptake occurs in the top 6% of the root zone.

Step 3: Account for soil water limitation -- plants cannot remove water from the soil if the soil water content is at the plant wilting point. So the $E_{t,max}$ that is calculated in Step 1 has to be limited by soil water.

Without writing down all of the equations, we just note that

$$E_{t,actual} = f(E_{t,max}, depth, soil\ moisture)$$

Note that this explanation applies to the unsaturated zone only. SWAT does allow for calculation of groundwater transpiration (called "revap" in SWAT). However, SWAT has a very crude implementation of groundwater modeling, so the relative height of the water table is unlikely to be consistent. Therefore, we do not calculate groundwater evapotranspiration in SWAT.

The Approach

So if we apply the recharge from SWAT directly MODFLOW, we neglect groundwater transpiration. The greatest error will occur when SWAT is predicting dry soil conditions and MODFLOW is predicting a near-surface water table (i.e. within the root zone). When these conditions occur, SWAT will underpredict actual ET.

What we will do to rectify this is to apply the "unused" ET (that is, the difference between maximum ET and actual ET) as ET in MODFLOW. In MODFLOW, we set

Recharge = Recharge from SWAT
ET = ($E_{t,max}$ - $E_{t,actual}$) from SWAT

The four main scenarios are discussed below:

Scenario 1: Infiltration > Evapotranspiration, water table below extinction depth

This scenario should be fine, with no MODFLOW ET (since the water table is below the extinction depth), but with recharge being estimated by SWAT. The SWAT estimate does not include groundwater ET of course, but with the water table below the extinction depth, there should be no groundwater ET.

Scenario 2: Infiltration > Evapotranspiration, water table above extinction depth

In this scenario, MODFLOW starts to draw water from the water table based on the difference between the maximum transpiration and the actual transpiration estimated by SWAT. However, the MODFLOW ET shouldn't have much impact in this case because with infiltration occurring, soil moisture should be high, $E_{t,actual}$ will be similar to $E_{t,max}$, and the difference will be near zero.

Scenario 3: Infiltration < Evapotranspiration, water table below extinction depth

In this scenario, there will be no recharge, and MODFLOW will have shut down ET.

Scenario 4: Infiltration < Evapotranspiration, water table above extinction depth

In this scenario, SWAT will have set recharge to zero, and will not remove water from the soil profile below the wilting point. SWAT will not account for the fact that the groundwater evapotranspiration should be occurring. However, the ET in MODFLOW will be pulling water off of the water table at a rate near $E_{t,max}$, (since $E_{t,actual}$ will be small due to low soil moisture) which is a good estimate for this situation.

Figure 2 shows an example of preliminary SWAT results from a deciduous forest area for the year 1975 in the northern model region. Note that actual evapotranspiration is primarily due to soil evaporation in the winter months. In the spring and summer, transpiration begins to dominate the ET, and when soil water is high, actual transpiration is similar to maximum potential transpiration. Note that in late summer, the precipitation is inconsistent and soil water is decreasing, so the difference between maximum and actual transpiration is significant on some days.

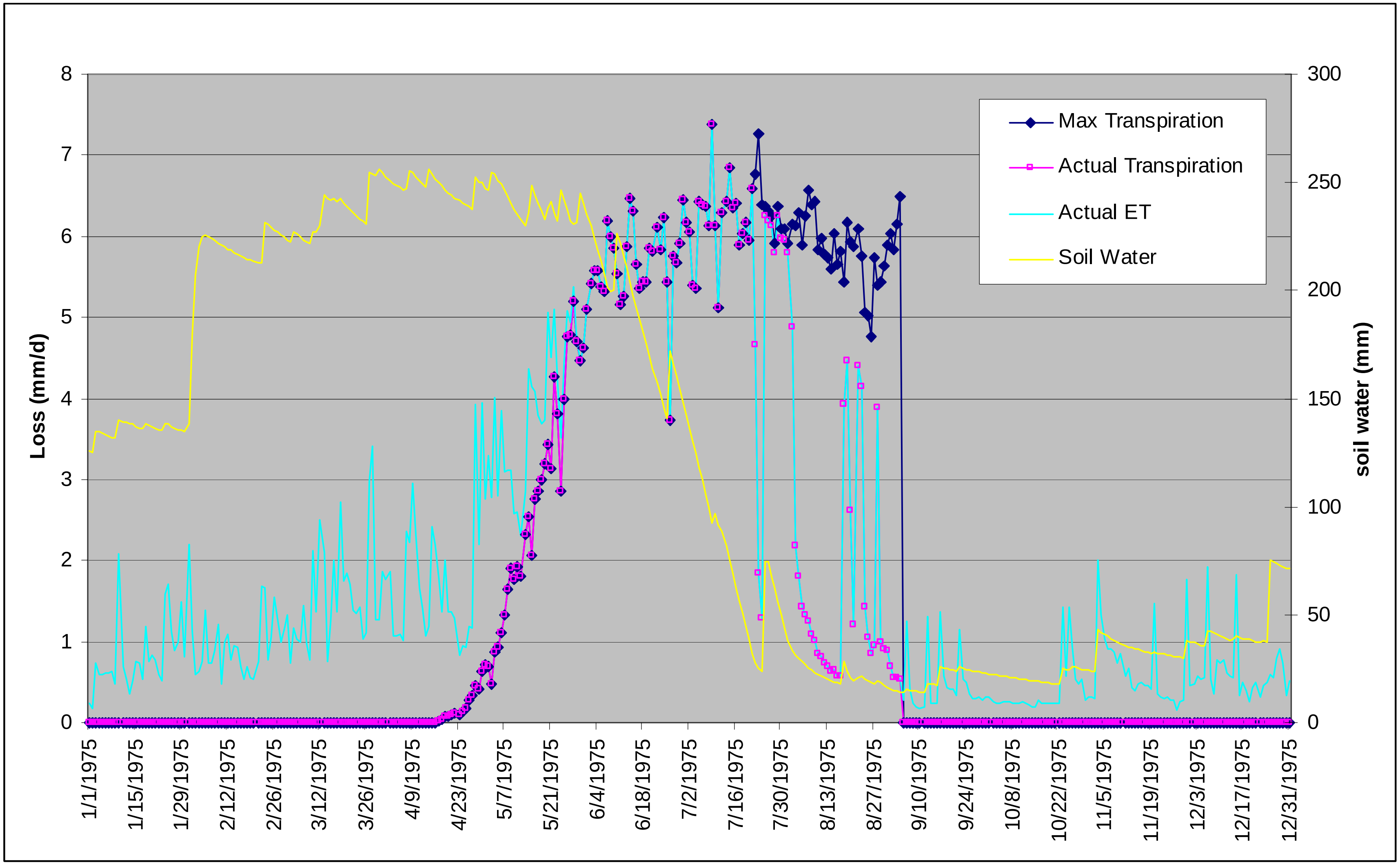

Figure E.1 Example SWAT results

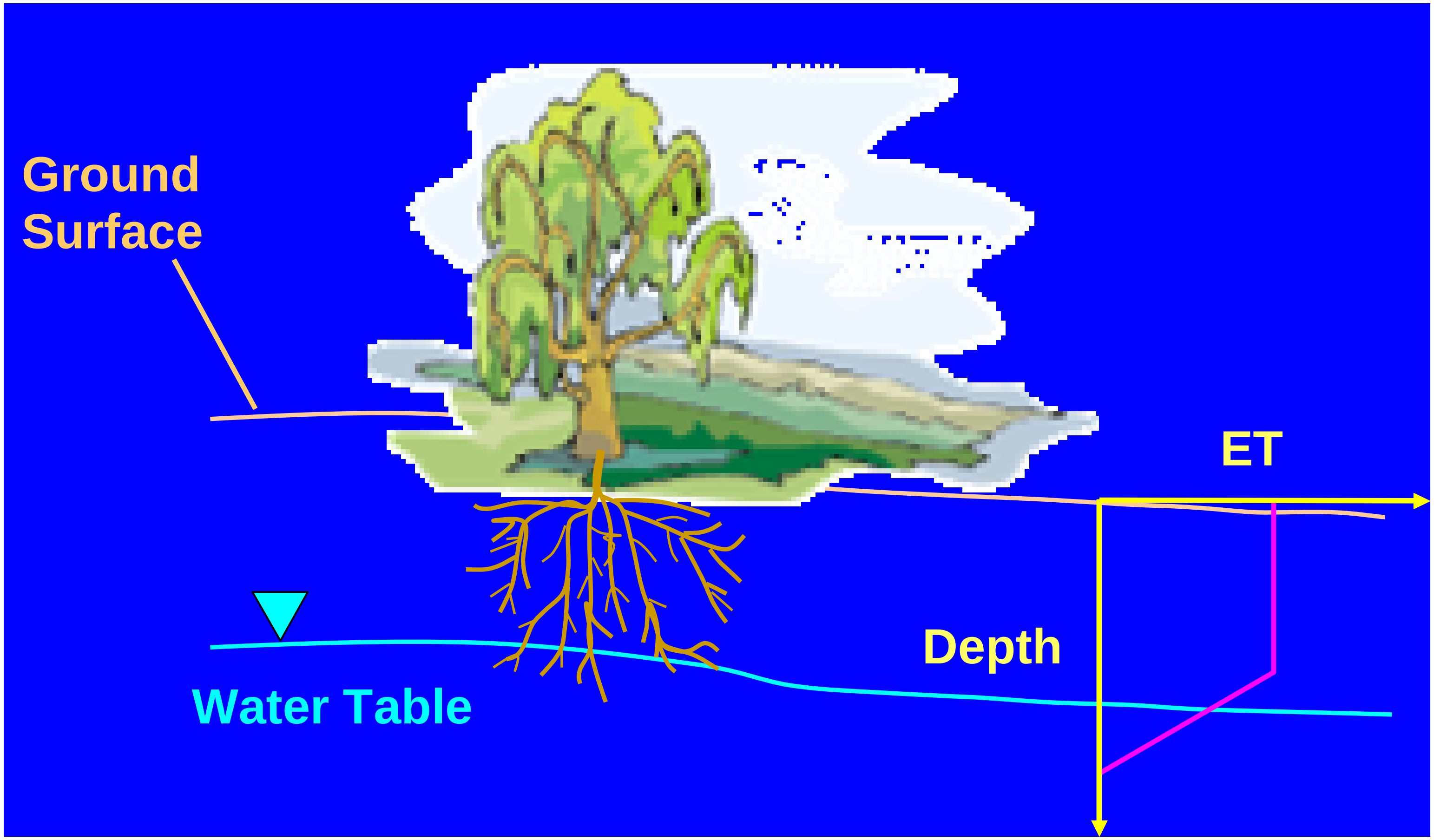

Figure E.2 MODFLOW approach to groundwater evapotranspiration

APPENDIX F

Water Quality

Appendix F

Water Quality

Ground water in the southern Carrizo-Wilcox aquifer was evaluated for its quality as a drinking water supply, for irrigation of crops, and for industrial purposes, by comparing the measured chemical and physical properties of the water to screening levels. Water quality measurements were retrieved for the entire available historical record, from about 1920 through 2001, from databases maintained by the Texas Water Development Board, the U.S. Geological Survey, and the Texas Commission on Environmental Quality's Public Water System. The percentages of wells in the aquifer with one or more measurements exceeding individual screening levels are illustrated in Table F.1. Table F.2 indicates the percentage of wells in the southern Carrizo-Wilcox aquifer from each county that exceeded at least one screening level for drinking water, irrigation, or industrial uses.

Concentration levels of selected constituents were evaluated for well data from the identified databases. They are presented in Figures F.1 through F.7 for radium, alpha activity, nitrate nitrogen, iron, sodium hazard, total dissolved solids, and hardness, respectively. Each column in the figures reflects the highest observed measurement in a single well. The height of the column, and its color, represent the magnitude of the concentration. A general discussion of drinking, irrigation, and industrial water quality within the southern Carrizo-Wilcox GAM area is presented below.

Drinking Water Quality - Screening levels for drinking water supply are based on the maximum contaminant levels (MCLs) established in National Primary Drinking Water Regulations and National Secondary Drinking Water Regulations. National Primary Drinking Water Regulations are legally enforceable standards that apply to public water systems to protect human health from contaminants in drinking water. National Secondary Drinking Water Regulations are non-enforceable guidelines for drinking water contaminants that may cause aesthetic effects (taste, color, odor, foaming), cosmetic effects (skin or tooth discoloration), and technical effects (e.g., corrosivity, expensive water treatment, plumbing fixture staining, scaling, and sediment).

Total dissolved solids (TDS) is a measure of water saltiness, the sum of concentrations of all dissolved ions (such as sodium, calcium, magnesium, potassium, chloride, sulfate, carbonates) plus silica. Some dissolved solids, such as calcium, give water a pleasant taste, but most make water taste salty, bitter, or metallic. Dissolved solids can also increase its corrosiveness. TDS levels have exceeded the secondary MCL, the maximum contaminant level allowed in National Secondary Drinking Water Standards) in approximately 44% of the wells in the southern Carrizo-Wilcox aquifer. There are zones in the aquifer (Webb, LaSalle, Dimmit, Zavalla counties) that consistently have concentrations of total dissolved solids that exceed 1,000 mg/L and chlorides that exceed 300 mg/L.

Elevated levels of iron and manganese adversely impact water quality in approximately 30% of the wells in the southern Carrizo-Wilcox aquifer. Water containing iron in excess of the secondary MCL of 0.3 mg/L and manganese in excess of 0.05 mg/L may cause reddish-brown or blackish-gray stains on laundry, utensils, and plumbing fixtures, as well as color, taste and odor problems.

Radium is a naturally-occurring radionuclide with two radioactive isotopes that can cause cancer. While there have been few measurements historically of radium activity, approximately 20% of these have exceeded the primary MCL of 5 picoCuries per liter (pCi/L). These wells were primarily located in Medina, Frio, Zavala, and Dimmit counties.

Alpha particles are one type of naturally-occurring radionuclide that can cause cancer. Alpha activity that exceeds the primary MCL of 15 pCi/L was recorded in approximately 7% of the wells. The greatest percentages of radioactive MCL exceedances were found in the Carrizo sand in Zavala County.

High concentrations of nitrate nitrogen can cause serious illness in infants younger than 6 months old. Nitrate nitrogen levels that exceed the primary MCL of 10 mg/L were detected in about 6% of the wells. The greatest percentage of nitrate nitrogen MCL exceedances was found in Uvalde and Medina counties.

Fluoride is a naturally-occurring element found in most rocks. At very low concentrations, fluoride is a beneficial nutrient. At a concentration of 1 mg/L, fluoride helps to prevent dental cavities. However, at concentrations above the secondary MCL of 2 mg/L, fluoride can stain children’s teeth. Approximately 3% of wells in the southern Carrizo-Wilcox aquifer have exceeded this level. At concentrations above the primary MCL of 4 mg/L, fluoride can cause a type of bone disease. Less than 1% of wells have exceeded 4 mg/L fluoride.

Overall, approximately 8% of the wells in the southern Carrizo-Wilcox aquifer are deemed to have unsuitable drinking water quality for health reasons, and approximately 40% of the wells have water that may be unpalatable for drinking, cause stains to teeth, plumbing fixtures, and laundry, or cause scaling or corrosion in plumbing without prior treatment.

Irrigation Water Quality - The utility of groundwater for crop irrigation was evaluated based on the concentrations of boron, chloride, and total dissolved solids, as well as the salinity hazard, the sodium hazard, and the sodium absorption ratio. Various soils and plants differ in their tolerance of salts. This tolerance is also affected by the abundance of rainfall and frequency of irrigation. In the absence of consensus standards for water quality for irrigation, we attempted to identify thresholds that would be unsuitable for long-term use on most types of plants and soils.

Boron may cause toxicity to many plants at levels above 2 mg/L (van der Leeden et al., 1990). Boron levels in the southern Carrizo-Wilcox aquifer exceed this level in approximately 5% of wells. Most crops cannot tolerate chloride levels above 1000 mg/L for an extended period of time (Tanji, 1990), a level exceeded in about 2% of wells in the southern Carrizo-Wilcox aquifer.

Salinity, as measured by total dissolved solids (TDS) or electrical conductivity, can also be toxic to plants by making plants unable to take up water. James et al. (1982) consider TDS levels above 2100 unsuitable for most irrigation. The salinity hazard classification system of the U.S. Salinity Laboratory (1954) indicates that waters with electrical conductivity over 750 micromhos present a high salinity hazard, and those with electrical conductivity over 2250 micromhos present a very high salinity hazard. Irrigation water containing large amounts of sodium cause a breakdown in the physical structure of soil such that movement of water through the soil is restricted. The sodium absorption ratio (SAR) is an indication of the sodium hazard to soils. An SAR of greater than 18 is generally considered unsuitable for continuous use in irrigation, but the sodium hazard depends on both the SAR and water salinity. The sodium hazard was calculated based on the classification system developed by the U.S. Salinity Laboratory (1954).

Overall, approximately 20% of the wells in the southern Carrizo-Wilcox aquifer are deemed to have unsuitable water quality for irrigation of many types of crops.

Industrial Water Quality - The quality of water for most industrial purposes is indicated by the content of dissolved solids, as well as its corrosivity and tendency to form scale and sediment in boilers and cooling systems. Some constituents responsible for scaling are hardness (calcium and magnesium), silica, and iron. Water temperature and pH also have a direct effect on how quickly and severely these constituents cause scaling or corrosion. pH values below 6.5 may enhance corrosion, while pH values above 8.5 will contribute to scaling and sediment. Waters with a silica concentration of 40 mg/L or higher are considered unsuitable for use in most steam boilers. Waters with a hardness of 180 mg/L (as calcium carbonate) or higher are considered very hard, and are unsuitable for many industrial purposes because water softening becomes uneconomical.

Overall, approximately 63% of the wells in the southern Carrizo-Wilcox aquifer are deemed to have unsuitable water quality for many industrial purposes without substantial pre-treatment, such as water softening.

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Shafer, G.H. 1968. Ground-water Resources of Nueces and San Patricio Counties, Texas. Report 73. Texas Water Development Board, Austin, Texas

Tanji, K.K. 1990. Agricultural Salinity Assessment and Management. American Society of Civil Engineers. Manuals and Reports on Engineering Practice Number 71.

U.S. Salinity Laboratory Staff. 1954. Diagnosis and Improvement of Saline and Alkali Soils. U.S. Department of Agriculture, Agricultural. Handbook 60.

Van der Leeden, F., F.L. Troise, and D.K. Todd. 1990. The Water Encyclopedia. Lewis Publishers.

Table F.1 Occurrence and levels of some commonly-measured groundwater quality constituents in the southern Carrizo-Wilcox aquifer.

Constituent	Number Of Wells	Screening Level (mg/L)	Type	Percent Of Wells Exceeding Screening Level*
Radium 226+228 Activity, pCi/L	66	5	1° MCL	20%
Alpha Activity, pCi/L	197	15	1° MCL	7.1%
Nitrate Nitrogen	1521	10	1° MCL	6.4%
Chromium	311	0.1	1° MCL	1.0%
Selenium	319	0.05	1° MCL	0.6%
Arsenic	318	0.01	1° MCL	0.6%
Beta Activity, pCi/L	189	50	1° MCL	0.5%
Fluoride	1442	4	1° MCL	0.5%
Lead	319	0.015	1° MCL	0.3%
Beryllium	201	0.004	1° MCL	0.0%
Cadmium	311	0.005	1° MCL	0.0%
Barium	318	2	1° MCL	0.0%
Copper	318	1.3	1° MCL	0.0%
Antimony	201	0.006	1° MCL	0.0%
Mercury	210	0.002	1° MCL	0.0%
Nitrite Nitrogen	195	1	1° MCL	0.0%
Thallium	193	0.002	1° MCL	0.0%
Total Dissolved Solids	1624	500	2° MCL	44%
Iron	553	0.3	2° MCL	31%
Manganese	387	0.05	2° MCL	27%
Chloride	1659	250	2° MCL	15%
Sulfate	1626	250	2° MCL	11%
Fluoride	1442	2	2° MCL	2.8%
Aluminum	291	0.2	2° MCL	1.0%
Zinc	318	5	2° MCL	0.0%
Copper	318	1.0	2° MCL	0.0%
Silver	209	0.1	2° MCL	0.0%
Salinity Hazard	1499	Very High (Sp. Cond. >2250)	Irrigation	12%
		High Or Very High (Sp. Cond. > 750)	Irrigation	53%
Sodium (Alkali) Hazard	1596	Very High (SAR>26)	Irrigation	15%
		High Or Very High (SAR>18)	Irrigation	17%
Boron	575	2	Irrigation	5.2%
Total Dissolved Solids	1624	2100	Irrigation	5.2%
Chloride	1659	1000	Irrigation	2.4%
Hardness	1783	180	Industrial	50%
PH	1525	<6.5 OR >8.5	Industrial	15%
Silica	1529	40	Industrial	9.1%

* percentage of wells with one or more measurements of the parameter that exceeded the screening level.

Table F.2 County-level water quality in the southern Carrizo-Wilcox aquifer.

			% of Wells Exceeding One or More Screening Levels			
County Name	**RWPG**	**Wells Sampled**	**PMCL**	**SMCL**	**Irrigation**	**Industrial**
Atascosa	L	249	2%	29%	12%	50%
Bastrop	K	190	6%	46%	9%	73%
Bexar	L	22	5%	77%	9%	95%
Caldwell	L	177	11%	46%	28%	81%
Dimmit	L	166	7%	28%	15%	42%
Fayette	K	2	0%	100%	100%	100%
Frio	L	169	4%	27%	8%	86%
Gonzales	L	78	4%	42%	21%	25%
Guadalupe	L	84	22%	46%	20%	89%
Karnes	L	11	11%	70%	90%	45%
La Salle	L	66	3%	38%	63%	14%
Live Oak	N	1	0%	100%	100%	0%
Maverick	M	20	22%	61%	44%	85%
McMullen	N	17	0%	76%	100%	59%
Medina	L	61	32%	48%	26%	92%
Uvalde	L	2	50%	0%	0%	100%
Webb	M	32	10%	63%	83%	47%
Williamson	G	4	0%	25%	25%	75%
Wilson	L	119	0%	33%	8%	46%
Zavala	L	179	16%	25%	13%	88%
Grand Total		1649	8%	39%	20%	63%

Figure F.1 Maximum observed radium levels.

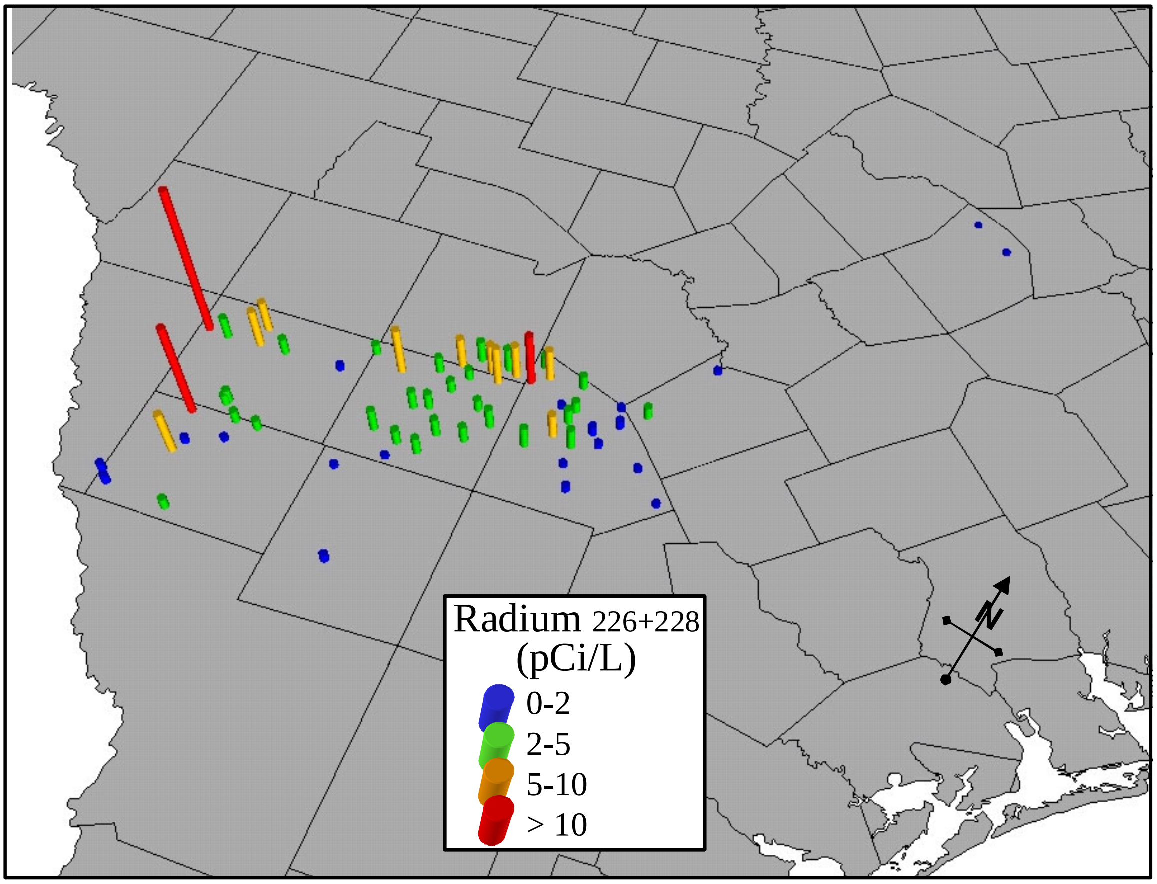


Figure F.2 Maximum observed alpha activity levels.

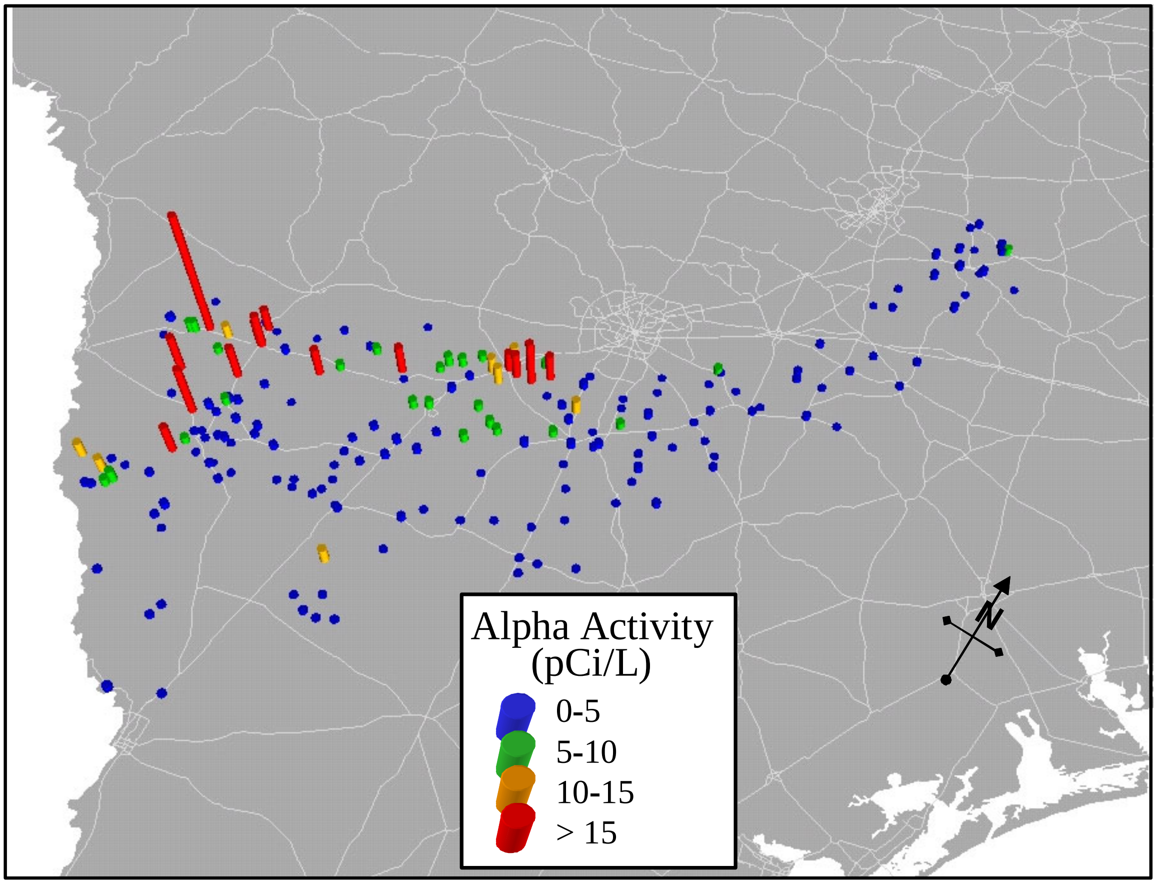


Figure F.3 Maximum observed nitrate nitrogen levels.

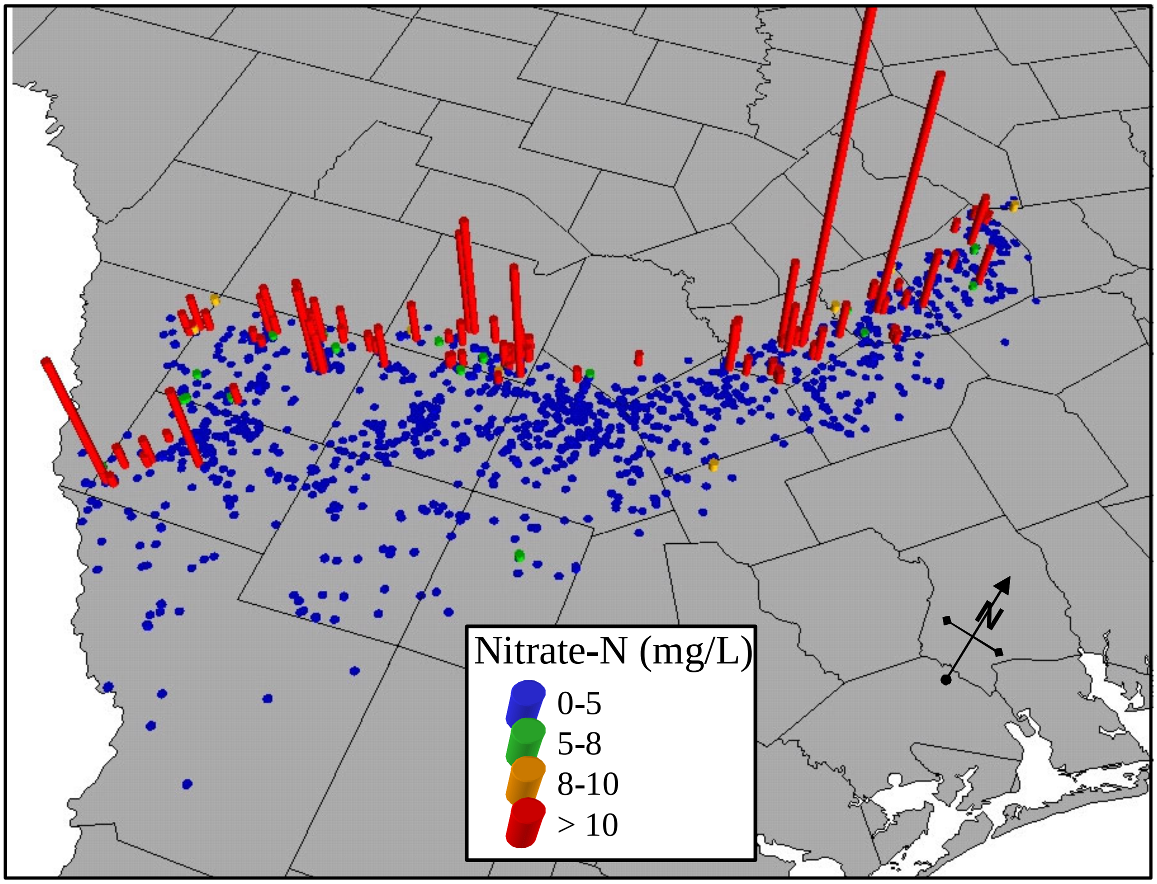


Figure F.4 Maximum observed iron levels.

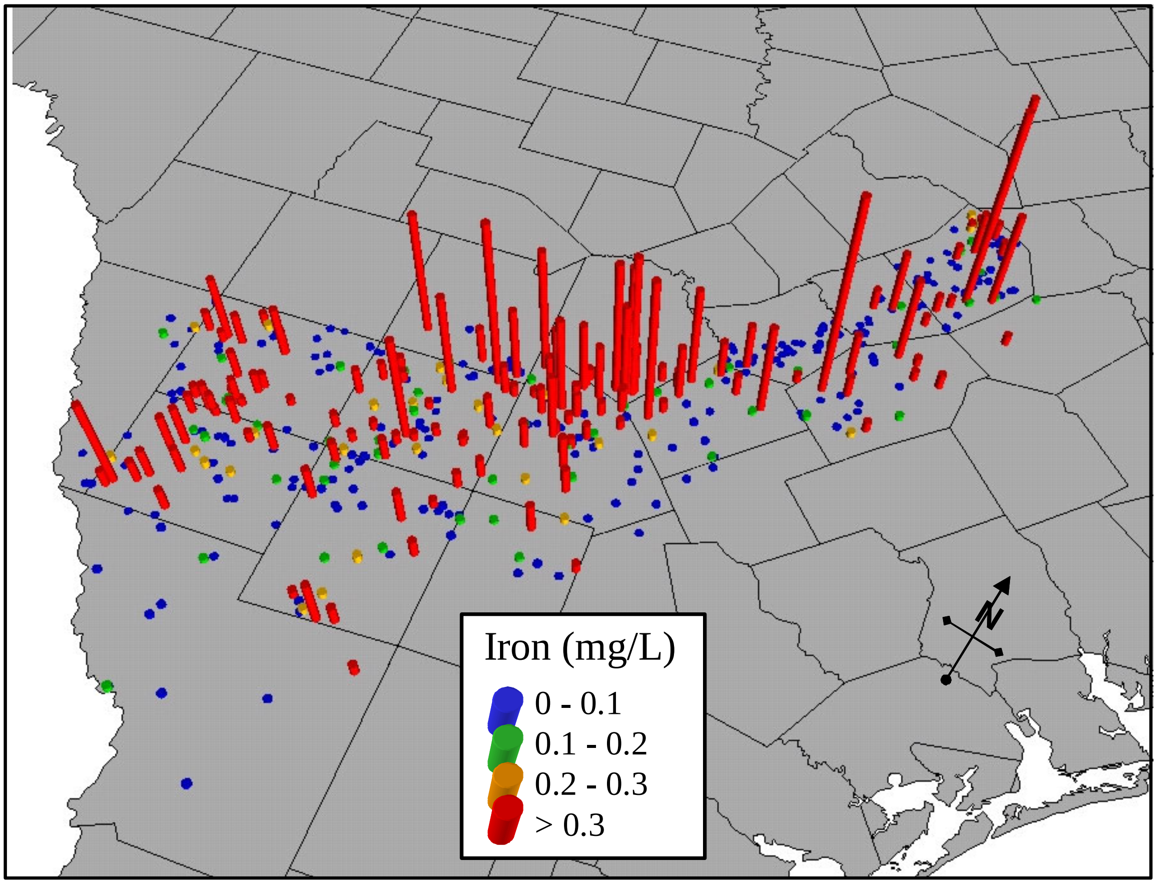


Figure F.5 Maximum observed sodium hazard levels.

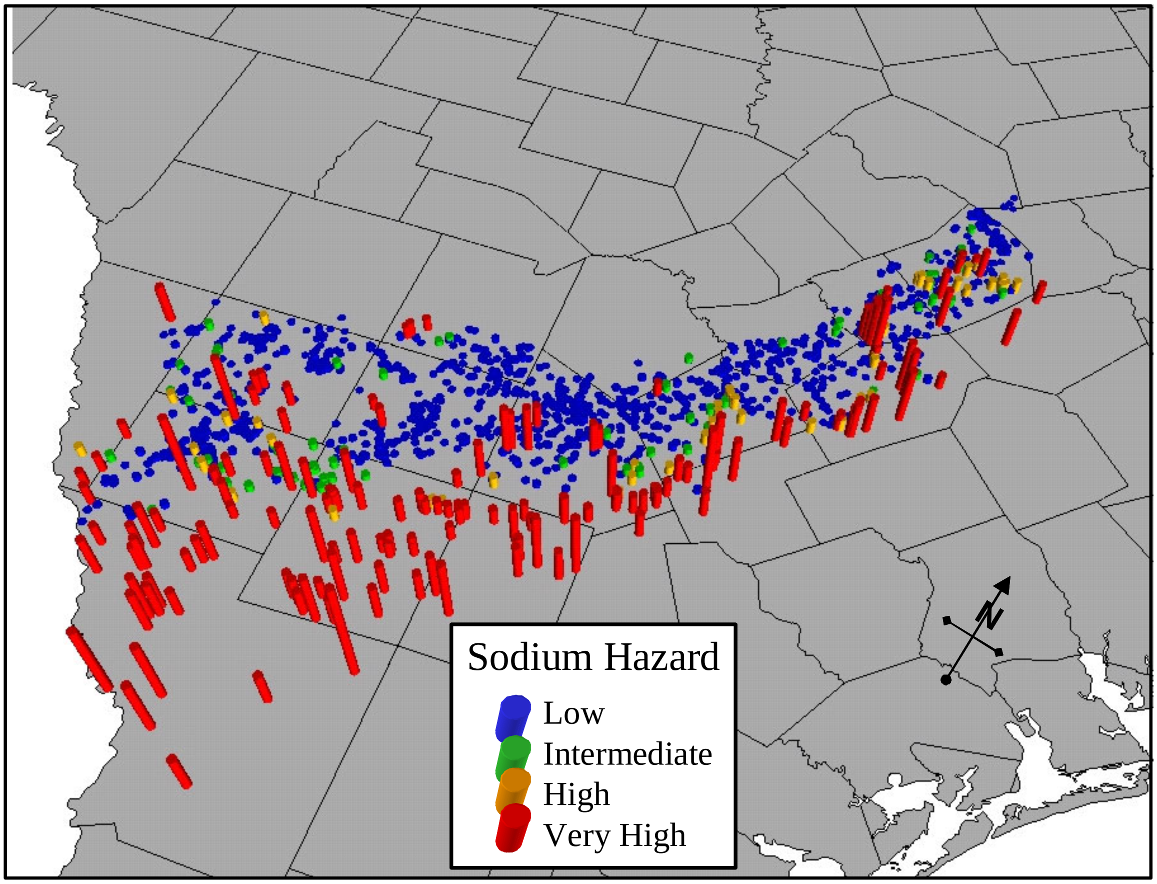


Figure F.6 Maximum observed total dissolved solids levels.

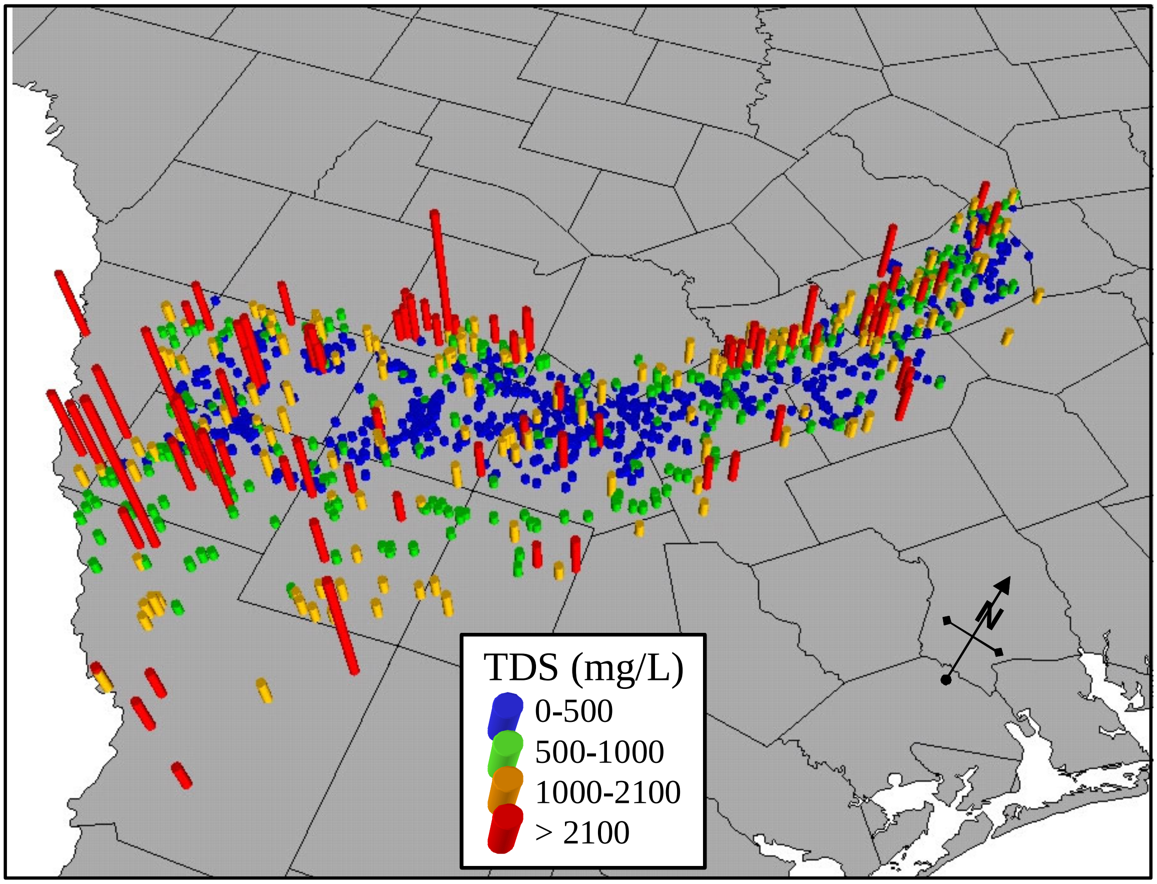
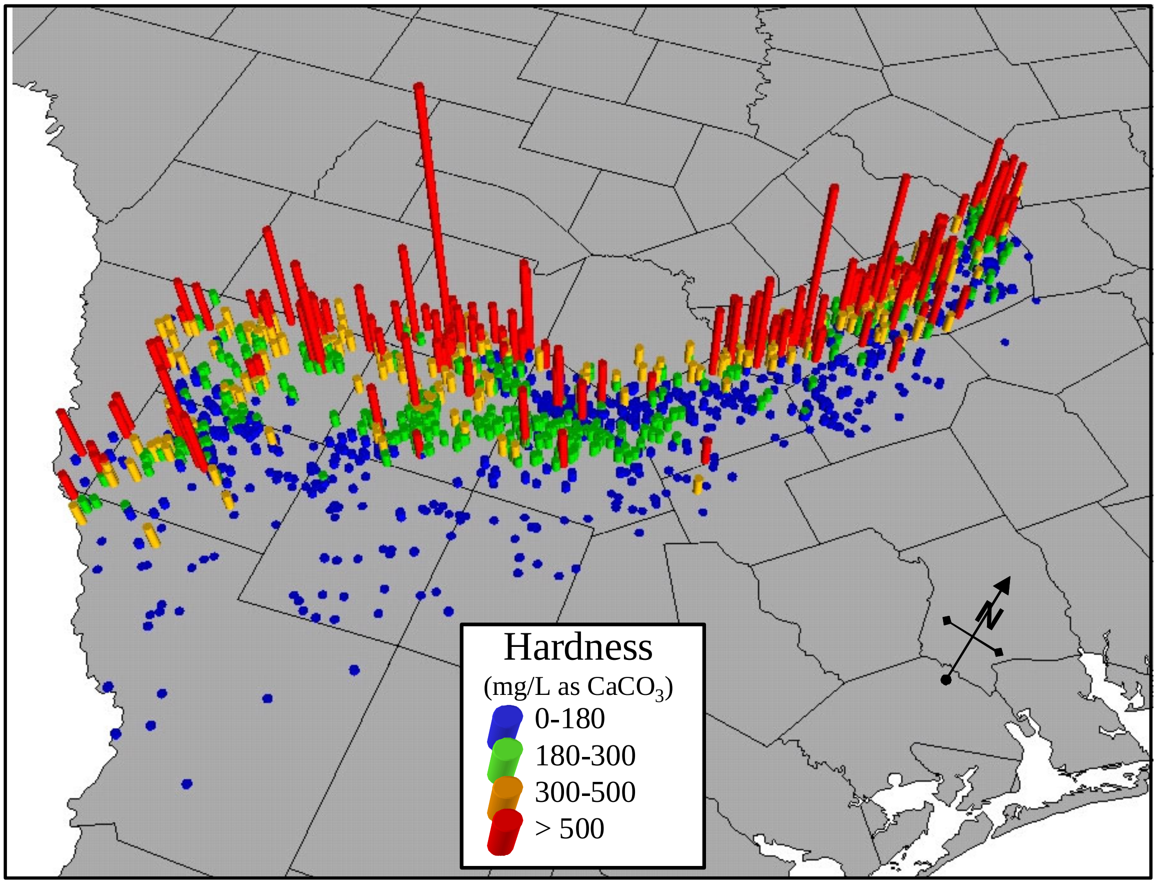


Figure F.7 Maximum observed hardness levels.



APPENDIX G

Draft Report Comments and Responses

TEXAS WATER DEVELOPMENT BOARD
Review of the Draft Final Report: Contract No. 2001-483-381
" Groundwater Availability Model for the Southern Carrizo-Wilcox Aquifer"

DRAFT REPORT TECHNICAL/ADMINISTRATIVE COMMENTS:

GENERAL

Consider using higher resolution graphics. Many of the graphics are pixelated and therefore difficult to understand.
Completed.

Include an authorship list.
Completed. See authorship list.

DRAFT REPORT - SECTION 2: STUDY AREA

1. Section 2.1 Please briefly discuss river basins and tabulate or list basin areas (Figure 2.6).
   Completed. See text at bottom of page 2-2 and Table 2.1.

2. Figure 2.12 Surface Geology. This map is unreadable in black and white.
   Due to the size of the model area and the detail presented in this figure, it will not be possible to make this figure readable in black and white at the model scale required for an 8.5x11 figure. The TWDB agreed that this figure would not have to be legible in black in white.

3. Page 2-1, second paragraph, line 6, list of counties in model area, add Bastrop, Fayette, Duval, Lavaca and Medina counties to the list.
   Completed. See page 2-1, second paragraph.

4. Page 2-7, Figure 2.5 EAA district boundaries need to be corrected. The boundary of EAA covers all of Bexar, Medina and Uvalde counties.
   Completed. See Figure 2.5.

5. Page 2-6, first paragraph, add to the list of GCDs in the model area, Pecan Valley, Lavaca County and Fayette County, GCDs.
   Completed See page 2-2, first paragraph.

DRAFT REPORT - SECTION 4: HYDROLOGIC SETTING

1. Section 4.3.3: Spatial Distribution of Hydraulic Property Data: Please explain how K was kriged. The distribution does not look like a simple-kriged distribution.
   Completed. See page 4-28, last paragraph. The following text has been added, ". . .is then produced by ordinary kriging".

2. Section 4.3.3: Spatial Distribution of Hydraulic Property Data: Please include a discussion on horizontal anisotropy.
   Completed. See page 4-28, first paragraph.

3. Section 4.5: Recharge: Please discuss possible temporal variations in recharge.
   Completed. See page 4-86, second paragraph.

4. Section 4.0: Hydrogeologic Setting: Please include a sub-section on the water quality work done for the project.
   Completed. See section 4.8.

5. Section 4.3: Please discuss information about anisotropy of horizontal hydraulic conductivity. ((See RFP Appendix 1, page 8/40, Section 3.1.8)
   See #2 above. It is redundant to include this text here also.

6. Section 4.3.4: In addition to sand map of Carrizo please include map for upper Wilcox.
   Completed. See figure 4.3.11.

7. Section 4.2: Please briefly discuss structural and tectonic history.
   Completed. See page 4-5, first paragraph.

8. Section 4.2: Were USGS DEM's used for land surface elevation and top of outcrop? If so, please explicitly state this. If not, explain what was used and why.
   Completed. See page 4-5, last paragraph.

9. Section 4.4.4: Extend period for some hydrographs further back than 1978.
   Completed. See page 4-50, last paragraph which refers to Appendix A.

10. Section 4.6: Were results from TCEQ's (formerly TNRCC) WAM model incorporated into surface-water/groundwater interaction analysis? If yes please discuss. If not, please explain why not. (See RFP Appendix 1, page 7/40, Section 3.1.7).
    The TCEQ WAM models were reviewed for use in the GAM studies. Because the WAM models are appropriation models that have to do with routing, they held little information that could be exploited in the GAMs. The underlying assumptions for the WAMs were unrepresentative of actual stream flow conditions at times or conditions needed in the GAM models. This explanation is limited to the comments and was not added to the text.

11. Section 4.7: Please include the map of rural population density used to distribute the county-other water use.
    Completed. See figure 4.7.1.

DRAFT REPORT- SECTION 5: CONCEPTUAL MODEL

1. Page 5-1, 1st paragraph: Please clarify the last sentence about additional arrows in Figure 5.1.
   Completed. See page 5-1, first paragraph.

DRAFT REPORT - SECTION 6: MODEL DESIGN

1. Page 6-15, 2nd paragraph: Please briefly explain the SCS Curve Number Method, Hargreaves Method and the NRCS curve-number method.
   The purposes of the NRCS (SCS) curve number method for estimating runoff and infiltration, and the Hargreaves method for estimating reference evapotranspiration are given in the report (see page 6-10, first paragraph) The theory behind these methods is beyond the scope of this report, but can be readily found in the SWAT references.

2. Page 6-15, 3rd paragraph: This is the only time in the report that the ramp-up period (1975-1980) is mentioned. It should also be discussed in Section 9.0 along with a discussion of the initial conditions used for the transient simulation.
   Completed. Text added to sections 7.1 and 9.0 regarding "ramp up" period.

DRAFT REPORT - SECTION 8: STEADY-STATE MODEL

1. Section 8.2 Simulation Results: Please include MAE and ME along with RMS.
   Completed. See table 8.2.1.

2. Section 8.2.2 Streams: Please include an assessment of how well simulated stream baseflow matches measured streamflow.
   Completed. See section 8.2.2.

3. Please include a detailed water budget for:
   - steady-state
     Please see Tables 8.2.1 and 8.2.2.
   - beginning of calibration period
     Please see Table 9.2.3.
   - the drought of the calibration period
     Completed. Added to Table 9.2.3.
   - end of the calibration period
     Please see Table 9.2.3.
   - end of the verification period
     Please see Table 9.2.3.
   - end of 2000, 2010, 2020,2030,2040, and 2050.
     Please see Table 10.3.1.

4. Page 8-18, 4th paragraph, 5th line down: "…cross-formational flow through the top of the Reklaw"? Shouldn't it be through the bottom of the Reklaw?
   Completed See page 8-18, last paragraph..

5. Figure 8.2.8: Large 20 on the figure. Is this supposed to be 20,000 years? Please clarify in caption or on figure.
   Completed. See figure 8.2.9.

6. Sections 8.2.1 and 9.2.1: Please, in addition to the RMS, also report the mean absolute error and the mean error (See RFP Appendix 1, page 13/40, Section 3.3).
   Completed See table 8.2.1 and table 9.2.1.

7. Section 8.2.1: For at least layer 3 please compare observed head surface with simulated rather than just posting residuals.
   Completed. See figure 8.2.4.

8. Sections 8.2.3 and 9.2.3: Please report the difference between simulated net inflow and simulated net outflow as a percent.
   Completed. See page 8-18, last paragraph.

9. Sections 8.3 and 9.3: Please add sensitivity of assigned hydraulic head on ghb's to sensitivity analysis. (See RFP Appendix 1, page 16/40, Section 3.3).
Head values assigned to GHBs were set to water table elevations as estimated using the regression equations of Williams and Williamson (1989). We feel that varying these estimated water table elevations would not be appropriate since it could result in heads above ground surface or unreasonably deep for the model area. This explanation is found at page 8-32, second paragraph.

DRAFT REPORT- SECTION 9: TRANSIENT MODEL

1. Section 9.2 Simulation Results: Please include MAE and ME along with RMS.
Completed. See table 9.2.1.

2. Figure 9.2.4: The calibration of the Carrizo layer is drifting with time. This is a concern because the Carrizo aquifer is the primary aquifer in the area. Page 9-7 points out the issue but does not indicate what may be causing the divergence or what you did to keep it from happening.
Heads are initialized to be representative of 1980 conditions. In the Wintergarden Area, drawdowns are very large and the model has difficulty sustaining the deepest drawdown in the area. Our approach to dealing with this considered a two-tiered approach. First, we lowered the vertical hydraulic conductivity of the overlying and underlying formations to limit cross-formational flow and pressure support. In the initial stages of calibration, the model was most sensitive to vertical hydraulic conductivity. Once we got the vertical resistance low enough to be close to the model target RMS, we then re-visited our initialization to see if we could find evidence to suggest that the Carrizo was initialized at heads too low. This step resulted in very little model improvement. At the current calibrated condition, the transient model is most sensitive to horizontal hydraulic conductivity and pumping. Further adjustment of one, or both of these parameters may improve model fit. However, because both of these parameters are uncertain at the model scale and the model currently meets calibration metrics, we felt it was best to identify the need for further study in determining which parameter (conductivity or pumping) is best used to improve calibration. We believe our approach is consistent with the RFP which requests that model not be over-calibrated. This explanation is provided in the text, in sections 9.1 and 9.2.1. It is also discussed in section 11, model limitations.

3. Please include in the appendix all of the transient plots comparing simulated to measured for the model. The reader should also be able to identify where these plots spatially relate to.
This comment was amended upon discussion with TWDB. All hydrographs are part of the data model.

4. Page 9-8, 3rd paragraph, 3rd line from bottom: Are the percentiles for statistics of spatial stream loss/gain or temporal stream loss/gain over the simulation period or both? Please clarify.
Completed. See page 9-9, first paragraph.

5. Section 9: The initial conditions for the transient simulation should be discussed. According to the RFP (Appendix 1, page 15/40 the steady-state model should be contained within the transient with a very long stress period). Please explain what the transient initial conditions were and if the steady-state heads were not used please explain why.

Additional discussion of initial conditions for the transient model were added (see sections 4.4, 7.1, and parts of 9. As discussed with the TWDB early in the development of the conceptual model, we implemented predevelopment conditions in the steady-state model. Since significant drawdown occurred between predevelopment (early 1900's) and 1980, estimates of pumping rates prior to 1980 would be necessary to use the steady-state heads as initial conditions. Because this pumping information is not available, we chose to initialize the model using TWDB head data for the time period between 1977 and 1983.

The stated purpose of including the steady-state model within the transient model was to ensure that any changes made to the model during transient calibration would propagate to the steady-state model (RFP Appendix 1, pages 15 and 16). As noted in the report, we accomplished this goal through an iterative approach to calibration.

6. Section 9.2.1: Please give RMS of hydrograph fits. (See RFP Appendix 1, page 15/40, Section 3.3)
   Completed. See table 9.2.2.

7. Section 9.2.2: Please explain why fluxes were not a calibrated parameters and give some quantitative comparison between stream loss/gain and other studies. (See RFP Appendix 1, page 14/40, Section 3.3)
   Slade et al. (2002) note that the potential error in stream flow measurements is typically about 5 to 8 percent. Since this error is possible at both ends of a gain/loss subreach, the potential error in gain/loss can equal a significant fraction of the total flow in the subreach. Comparing the available gain/loss values to mean stream flows from the EPA River Reach data set shows that almost all of the gain/loss values are less than 5 percent of the mean stream flow. This suggests that the gain/loss values are uncertain and can be only used qualitatively. Figure 9.2.15 shows the comparison between field measured and simulated gain/loss. Table 9.2.3 shows a comparison to the LBG-Guyton and HDR (1998) model.

8. Sections 9.2.3 and 10.3: Please discuss the number of cells that go dry during the simulation period. Also explain how the dry cells were handled. (See RFP Appendix 1, page 15/40, Section 3.3).
   Completed. See page 9-8, last paragraph.

9. Section 9.2.3: Please include a water budget for the estimated end-time of the 1980s drought ~ mid 1980s.
   Completed. See table 9.2.4.

10. Section 9.3: Please include impact of sensitivity analyses on several hydrographs. (See RFP Appendix 1, page 16/40, Section 3.3).
    Completed. See figures 9.3.11 and 9.3.12.

DRAFT REPORT - SECTION 10: PREDICTIONS

1. Section 10.2: Please also include head surfaces for all layers for simulations in 2010, 2020, 2030, 2040 with no drought of record.
   This comment was amended upon discussion with TWDB. Head surfaces for layers with >50 ft of drawdown are shown. See additional figures 10.2.15-10.2.18.

2. Section 10.2: Please include saturated thickness maps for 2010, 2020, 2030, 2040, 2050 for the DOR and no DOR scenarios. (See RFP Appendix 1, page 27/40, Section 5.4).
   This comment was amended upon discussion with the TWDB. Saturated thickness maps for 2000 and 2050 are shown in figures 10.2.23 and 10.2.24.

3. Section 10.2: Please include some discussion of predictive modeling results on assumed boundary conditions. (See RFP Appendix 1, page 23/40, Section 5.4).
   Completed. See page 10-9, second paragraph.

DRAFT REPORT - APPENDICES

Appendix C: Water Levels

1. Appendices C and D: Please briefly explain how pumpage that is exported to another region was determined and included in the modeled pumping. (e.g. through consultation with RWPGs).
   Basically, this work was already done for us by the TWDB (Cindy Ridgeway) when they put together the predictive pumpage data sets(GAMPredictivePumpage_2002SWP.xls). This spreadsheet lists the water user group ID, county, basin, and RWPG of the water source as well as the water user. The pumping SOP utilized the water source for the spatial distibution of pumpage, not the water user, when distributing predicted pumpage.

   The use of the "source county ID" and "source alpha" for matching to well locations from historical pumpage data was explicitly stated in the SOP. Also, paragraph 1 of the SOP stated that the purpose of the SOP was only to provide additional procedures to implement the TWDB guidance in Tech Memo 2-1, and would not re-state the info in Tech Memo 2-1. Tech Memo 2-1 instructed to roll water sold by one water user group to another to the seller's water use for spatial distribution, which is what we did. This explanation is limited to the comments and was not added to the text.

DRAFT REPORT EDITORIAL COMMENTS:

Page ix (Abstract): 7th line from bottom: Suggest changing “significant pumping declines predicted” to “significant decrease in pumping”
Completed.

DRAFT REPORT- SECTION 1: INTRODUCTION

1. Page 1-2 1st paragraph, 8th line from bottom: “steady-state and transient models” “s” missing.
   Completed See page 1-2, first paragraph.

DRAFT REPORT - SECTION 2: STUDY AREA

1. Page 2-1 1st paragraph, 4th line down: “Carrizo-Wilcox”, hyphen missing.
   Completed. See page 2-1, first paragraph.

2. Page 2-1 2nd paragraph, 4th line down: Suggest changing “These models possess” to “These models have”.
   Completed. See page 2-1, second paragraph.

3. Page 2-13, second paragraph, line 12: change “ syndepositional gravity tectonics and halokinesis” to “growth faults and salt dome development”.
   Completed. See page 2-18, first paragraph.

4. Figure 2.2: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer). See figure 2.2.

5. Figure 2.3: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer). See figure 2.3.

6. Figure 2.7: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Due to the size of the model area and the detail presented in this figure, it will not be possible to make this figure readable in black and white at the model scale required for an 8.5x11 figure. TWDB agreed to allow this figure to be legible only in color.

7. Figure 2.9: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer). Resolution enhanced, see figure 2.10.

8. Page 2-13 2nd paragraph end: Suggest language be rewritten for a non-geologist audience. (e.g., halokinesis ?)
   Completed. See page 2-18, first paragraph.

9. Figure 2.10: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer). See figure 2.11.

10. Figure 2.12: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
    Due to the size of the model area and the detail presented in this figure, it will not be possible to make this figure readable in black and white at the model scale required for an 8.5x11 figure.

DRAFT REPORT - SECTION 3: PREVIOUS WORK

1. Page 3-1 1st paragraph: Suggest changing first sentence to “….by many investigators and numerous groundwater bulletins have been developed …”
   Completed. See page 3-1, first paragraph.

2. Figure 3.1: What does SW in SW GAM Model refer to? It is called the southern GAM model everywhere else.
   Completed SW was changed to Southern. See figure 3-1.

3. Page 3-3 2nd paragraph, last sentence: “as documented in the TWDB State Water Plan of the time.” Please give specific year of plan referred to.
   Completed. See page 3-2, second paragraph.

DRAFT REPORT - SECTION 4: HYDROLOGIC SETTING

1. Figure 4.2.2 caption: space missing between "the" and "Wilcox".
   Completed. See figure 4.2.2.

2. Figure 4.2.9 – 4.2.15: Contour labels in dark regions do not photocopy well.
   Completed (acceptable from black and white laser printer).

3. Figure 4.3.3 – 4.3.9: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer). Now figures 4.3.4-4.3.10.

4. Page 4-36, 1st paragraph, 2nd line: Suggest "more transmissive zones" rather than "higher transmissive zones"
   Completed. See page 4-30, second paragraph.

5. Figures 4.3.7 and 4.3.8 captions 1st line: Carrizo misspelled.
   Completed. Now figures 4.3.8 and 4.3.9.

6. Page 4-42 3rd paragraph: Freeze and Cherry reference date is 1979 not 1975.
   Completed. See page 4-33, first paragraph.

7. Figures 4.4.2 and 4.4.3 and page 4-46 2nd paragraph: Legend says elevations from DEM, but the text says it's from the TWDB database?
   Completed. Text changed to indicate DEM data used. See page 4-48, second paragraph.

8. Figures 4.4.5 and 4.4.6: Pink and gray are not readable when photocopied (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer).

9. Figures 4.4.8: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer).

10. Tables 4.4.3 and 4.4.4: Missing parenthesis on title (continued")".
    Completed.

11. Page 4-89, 2nd paragraph, 5th sentence from bottom: Suggest, "…with stream loss occurring more in summer and stream gain occurring more in winter."
    Completed. See page 4-93, first paragraph.

12. Figure 4.6.1 and 4.6.2: Photocopy poorly in black and white (re: Attachment 1 of RFP page 25/40).
    Completed (acceptable from black and white laser printer).

13. Tables 4.6.1: Missing parenthesis on title (continued").
    Completed.

14. Figures 4.7.1 - 4.7.6: Photocopies poorly in black and white (re: Attachment 1 of RFP page.
    Completed (acceptable from black and white laser printer).

15. Page 4-14, 4th paragraph from the top: “Gonzales County underground water conservation District” should be “Gonzales County Underground Water Conservation District”.
    Completed. See page 4-6, last paragraph.

DRAFT REPORT- SECTION 5: CONCEPTUAL MODEL

1. Page 5-2, last line: typo “…is offset by a decrease…” not “at decrease”.
   Completed. See page 5-3, first paragraph.

2. Page 5-3, 4th paragraph: “…is generally downdip “ rather than “…is generally to the downdip”.
   Completed. See page 5-3, last paragraph.

3. Page 5-4, 1st paragraph, 1st line: “…where the dip of the strata increase” not “increased.”
   Completed. See page 5-4, first paragraph.

4. Page 5-4, 1st paragraph, 3rd line: “…(TDS) southeast of the strike-oriented faults….”
   Completed. See page 5-4, first paragraph.

5. Page 5-4, 1st paragraph, last line: “….in the study area…”
   Completed. See page 5-4, first paragraph.

DRAFT REPORT - SECTION 6: MODEL DESIGN

1. Page 6-2, last line: “…. The model grid at the county scale”.
   Completed See page 6-3, first paragraph..

2. Page 6-14, last paragraph, 3rd line from bottom: “a really” should be “areally”.
   Completed.See page 6-9, third paragraph.

3. Page 6-17, 1st paragraph: “…provided in Section 4.7” (not 5.7).
   Completed See page 6-11, last paragraph..

4. Page 6-17, 1st paragraph, 2nd line: “For details of how the…”
   Completed. See page 6-11, last paragraph.

5. Page 6-19, 1st paragraph, last sentence: “…we considered the decreasing...” and “ data are not available”
   Completed. See page 6-19, third paragraph.

6. Page 6-21, last sentence: “….In storativity ~~parameters~~ from 2x10^{-4}…..”.
   Completed. See page 6-22, first paragraph.

DRAFT REPORT - SECTION 8: STEADY-STATE MODEL

1. Page 8-1, 1st paragraph, 2nd line: “….Streams is ~~being~~ balanced...”
   Completed. See page 8-1, first paragraph.

2. Page 8-1, 2nd paragraph: “…steady-state model is described below.”
   Completed. See page 8-1, second paragraph.

3. Page 8-5, 2nd paragraph, 4th line from bottom: River misspelled.
   Completed.

4. Figures 8.1.1 – 8.1.10: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer).

5. Page 8-18, 4th paragraph, 4th line down: predevelopment misspelled.
   Completed.

6. Figure 8.2.3, mislabeled as 8.2.2: (page 8-23).
   Completed.

DRAFT REPORT- SECTION 9: TRANSIENT MODEL

1. Page 9-2, 2nd paragraph: Reference to Figures 9.1.2 and 9.1.3 should be switched in text.
   Completed.

2. Figure 9.1.3: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer).

3. Figure 9.2.14: Photocopies poorly in black and white (re: Attachment 1 of RFP page 25/40).
   Completed (acceptable from black and white laser printer).

DRAFT MODEL RUNS:

This review addresses three questions:

1. Were all model files included?
2. Does the model run?
3. Do the results of the model match what is in the draft report?

Question 1:

All model files were included for running the steady-state simulation, 1975 – 1999 transient simulation, and 2000 – 2050 predictive simulations. However, borehole files *.bor were not included for comparing simulated and observed water levels at well locations.

Question 2:

Both the steady-state, transient, and predictive models run and converge with no errors.

Question 3:

Three items were evaluated to compare the model output with the results presented in the draft report – i) head surface maps, ii) hydrographs (transient only) and iii) groundwater budget.

For the steady-state model, both the water budget and the head surface maps of all six model layers exactly match what is presented in the draft report.

For the 1975 – 1999 transient model two head surface maps were presented in the draft report. The Carrizo (model layer 3) in 1989 and 1999. The model output at 180 stress periods (assumed to be 1989) and 300 stress periods (assumed to be 1999) match the results in Figures 9.2.1 and 9.2.2. One stress period is equal to one month in the model simulation.

Five boreholes were added to PMWIN data set and hydrographs at the five wells were compared for the period 1980 – 1999. The simulated results match the simulated hydrographs presented in the report (Figures 9.2.7 – 9.2.13).

The groundwater budget also matched that presented in the report for 1999 (Table 9.2.3).

Head surfaces for the predictive 2050 simulations were compared against Figures 10.2.1 (layer 1), 10.2.3 (layer 3), 10.2.5 (layer 4), 10.2.7 (layer 5), and 10.2.9 (layer 6), the results match those Figures. Figures 10.2.11 and 10.2.13 (layer 3 at 2010 and 2030) were also compared to simulation results and they match. A borehole file containing the six wells in Figure 10.2.15 was created and the simulation results match Figure 10.2.15.

Finally the groundwater budget was compared for the 2050 and the results match those in Table 10.3.1.

In summary,

- All model files were included, except borehole or observations well files. ***Borehole and observation files were added to the data model.***

- All models, steady-state, transient, and predictive converge and run with no errors.

The model results including head surfaces, groundwater budgets and hydrographs match those in the report for the steady-state, transient, and predictive simulations.

DRAFT DATA SOURCE FILES COMMENTS:

GENERAL

All files need to be in Access97. We are unable to evaluate data because the format is incorrect.

Did we get all of the data files we requested? NO
Is the data organized in the way we requested? YES

Review Summary:

The data provided by the contractor is missing some required data sets as listed in sections below. File lists are needed within each folder/directory listing all file names or groups of file names and their contents.
File descriptions were added where necessary.

The contractor did follow the requirements as set forth in Attachments 1 & 2 of the RFP for the most part. However a few of the metadata files had incorrect spatial reference information or missing altogether.
Existing metadata was checked and some added to the data model.

Furthermore, the SWAT model and all data used within the SWAT model must be provided in a separate folder/directory tree structure if used to calculate parameters for the ET, streamflow-routing, and/or recharge packages of MODFLOW.
SWAT model input/output datasets were added to the data model under a separate directory.

DRIVE:\CZWX_s\grddata\input\hydraul

Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access database file converted to Access97.

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Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access database file converted to Access97.

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Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

n/a.

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Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access97 table added.

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Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access database file converted to Access97.

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Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

n/a.

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Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access97 tables added.

DRIVE:\CZWX_s\grddata\input\storage

Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access97 tables added.

DRIVE:\CZWX_s\grddata\input\stress\ststate\well

Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access97 tables added.

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Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

n/a.

DRIVE:\CZWX_s\grddata\input\stress\trans\evt

Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access97 tables added.

DRIVE:\CZWX_s\grddata\input\stress\trans\rech

Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access97 tables added.

DRIVE:\CZWX_s\grddata\input\stress\trans\res

Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access97 tables added.

DRIVE:\CZWX_s\grddata\input\stress\trans\strm

Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access97 tables added.

DRIVE:\CZWX_s\grddata\input\stress\trans\well

Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access97 tables added.

DRIVE:\CZWX_s\grddata\input\struct

Unable to evaluate data because Access file format not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access database file converted to Access97.

DRIVE:\CZWX_s\modflow\modfl_96\input\ststate

These files are acceptable.

DRIVE:\CZWX_s\modflow\modfl_96\input\trans

These files are acceptable.

DRIVE:\CZWX_s\modflow\pmwin_50\input\ststate

These files are acceptable except for missing calibration borehole file.

boreholes.bor and observations.obs files added

DRIVE:\CZWX_s\modflow\pmwin_50\input\trans

These files are acceptable except for missing calibration borehole file.

boreholes.bor and observations.obs files added

DRIVE:\CZWX_s\modflow\pmwin_50\refdxf

These files are acceptable.

DRIVE:\CZWX_s\scrdata\bndy

Need a file listing name of each file or grouped set of files and their contents or purpose.

Descriptors added.

Aquifers and groundwater conservation districts coverages have incorrect spatial reference in metadata file and SW_Boundary coverage has no metadata file.

Metadata edited. SW_Boundary was added in error to the draft model. This coverage was subsequently removed.

DRIVE:\CZWX_s\scrdata\clim

Need a file listing name of each file or grouped set of files and their contents or purpose.

Descriptors added.

All coverages need a completed metadata file.

Metadata added.

The monthly precipitation Access database must be compatible with Access97.

Access database file converted to Access97.

DRIVE:\CZWX_s\scrdata\cnsv

Need a file listing name of each file or grouped set of files and their contents or purpose.

Descriptors added.

DRIVE:\CZWX_s\scrdata\geol

Need a file listing name of each file or grouped set of files and their contents or purpose.

Descriptors added.

The outcrop delineations coverages and net sand coverages need metadata file or readme document describing the metadata and purpose of the coverages.

Descriptors added.

Must make Access database files compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access database file converted to Access97.

No cross-sections used in study? If yes, cross-sections must be provided under this folder.

n/a.

DRIVE:\CZWX_s\scrdata\geom

Need a file listing name of each file or grouped set of files and their contents or purpose.

Descriptors added.

The DEM needs a completed metadata file and must be in units of feet rather than meters.

Coverage converted. Metadata file added.

A physiography coverage is required by RFP.

Coverage added.

DRIVE:\CZWX_s\scrdata\geop

NO DATA FOUND – geophysical data should go here if used in study.

n/a.

DRIVE:\CZWX_s\scrdata\soil

Need a file listing name of each file or grouped set of files and their contents or purpose.

Descriptors added.

No spatial reference information for soils coverage metadata file.

Metadata added.

The runoff raster data for Texas needs a metadata file.

Coverage added to draft data model in error. Coverage was subsequently removed.

DRIVE:\CZWX_s\scrdata\subhyd

Need a file listing name of each file or grouped set of files and their contents or purpose.

Descriptors added.

Except for Predictive Pumpage data set, unable to evaluate most data because Access file formats not compatible with Access97. Must make Access database file compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access database files converted to Access97.

Need metadata for all coverages and Access databases.

Metadata added.

Need source and intermediate derivative coverages used to spatially distribute pumpage data here.

Pumping databases added.

Need source and intermediate derivative coverages used to spatially distribute water level data here.

Water level databases added.

Need source and intermediate derivative coverages used to spatially distribute conductivity data here.

Previously in place.

Need source and intermediate derivative coverages used to spatially distribute specific yield and porosity if available.

n/a.

Need point coverage of calibration target boreholes and hydrographs.

Coverage added.

DRIVE:\CZWX_s\scrdata\surhyd

Need a file listing name of each file or grouped set of files and their contents or purpose.

Descriptors added.

Must make Access database files compatible with Access97 as stated in Attachments 1 and 2 of RFP.

Access database files converted to Access97.

DRIVE:\CZWX_s\scrdata\tran

Need a file listing name of each file or grouped set of files and their contents or purpose otherwise, these files are acceptable.

Descriptors added.