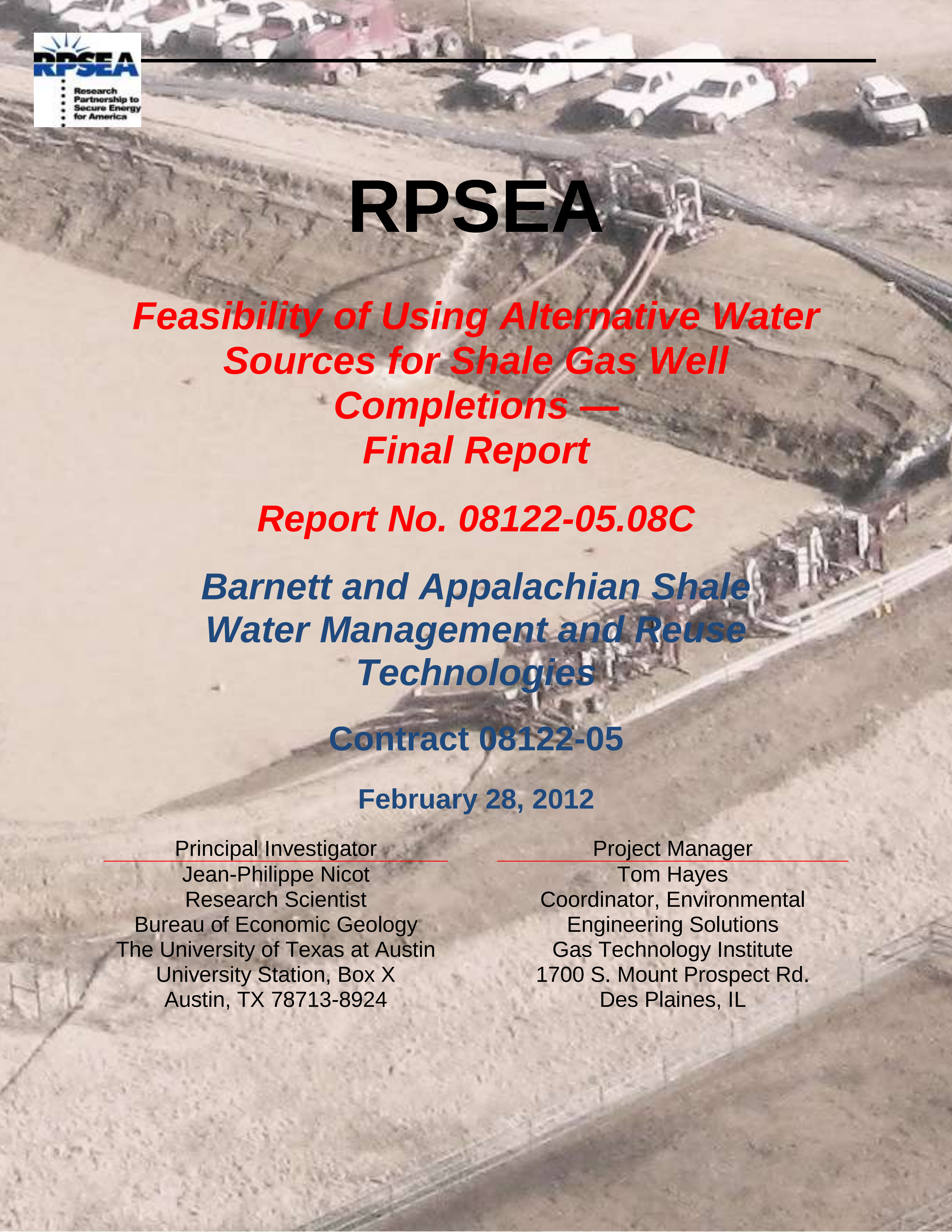

RPSEA

Feasibility of Using Alternative Water Sources for Shale Gas Well Completions — Final Report

Report No. 08122-05.08C

Barnett and Appalachian Shale Water Management and Reuse Technologies

Contract 08122-05

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Gas Technology Institute

Feasibility of Using Alternative Water Sources for Shale Gas Well Completions

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9 Attachment D: Study of North-Central Texas Paleozoic Aquifers

Evaluation of Paleozoic Aquifers of North Central Texas.
Part II: Groundwater Flow Model

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November, 2011

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1. INTRODUCTION

Barnet Shale, in the north-central Texas, west of Dallas-Fort Worth, is one of the largest gas plays in the US. It is under rapid development with hydraulic fracturing technique. The shale gas development using this technique currently use about 20,000 m^3 of water per well per year (Nicot et al. 2011). Water use for gas production is projected to rise in the next 20 plus years and gradually decrease for another 20 years. The region has seen gas production increase for the past decade and water stress is evident even in the current condition. Surface water supply is constrained by available water rights and more productive groundwater supply is only available to the east in Trinity/Woodbine aquifers or to the west in Seymour/Blaine aquifers. Therefore, feasibility of using Paleozoic aquifers for additional water supply is of practical interest. The objective of this modeling study is to evaluate this feasibility and quantitatively evaluate the potential effect of additional water withdrawal on the aquifers. The tasks include: 1) compile baseline data such as hydraulic conductivity, model structure (top and bottom elevations of hydrostratigraphic units), and sand distribution to characterize the water bearing units; 2) develop conceptual and numerical groundwater flow model; 3) evaluate feasibility and potential effect of additional withdrawal from the Paleozoic aquifers. Task 1 is documented in a companion report. This report document tasks 2 and 3.

2. STUDY AREA

The study area is located in North-Central Texas. The model area covers about 46,000 km^2, including all or part of 19 counties (Figure 2.1). Paleozoic units (from the youngest to the oldest, Wichita, Cisco, Canyon and Strawn) are the focus of this study. Those units dip generally to the west. To the east, Paleozoic units underlie the Cretaceous Trinity Units. To the west in the Permian Basin, Paleozoic units underlie Quaternary-age Seymour Formation. The model extends to the Red River in the northeast and San Saba or Leon Rivers to the southwest. Nine counties are of particular interest and they are Clay, Erath, Hood, Jack, Montague, Palo Pinto, Parker, Somervell, and Wise. Major rivers run across the model area mostly subparallel to the dip direction. The region in general has gentle terrain. As shown in Figure 2.2, the terrain slopes from west or southwest to east or northeast. The climate is classified as subtropical subhumid (Larkin and Bomar 1983). Annual precipitation is about 800 mm based on PRISM data (PRISM Climate Group 2004). The model area is dominated by grassland (50%). Others land use land cover types include woodland (27%), cultivated land (12%), and urban (7%).

3. LITERATURE REVIEW

The Paleozoic aquifers have not been a focus of any modeling studies. However, in the last decade, TWDB has initiated groundwater availability modeling (GAM) program and a series of groundwater flow models have been built for the minor and major aquifers in Texas. This includes GAM for the Trinity aquifer to the east (Bené and Harden 2004) and Seymour aquifer to the west of the study area (Ewing et al. 2004). The relative boundary of the Trinity North GAM, Seymour GAM and the model for Paleozoic aquifers (this study) is shown in Figure 3.1. It is noted that although Trinity North GAM covers this study area, Paleozoic units were not included in the Trinity North GAM. The boundary between Trinity and Paleozoic was set as no-flow in Trinity North GAM.

Seymour GAM included shallow portion of the Paleozoic units as one layer that has hydraulic connection with Seymour pods. The Paleozoic units included in Seymour GAM are the Quartermaster Formation, the Whitehorse Group, the Pease River Group, the Clear Fork Group and part of the Wichita Group.

4. REGIONAL HYDROLOGY

This section includes discussion of water levels, groundwater flow, recharge, and surface water features. Data compiled and analyzed in this section are used to support development of the conceptual model and numerical model for the Paleozoic aquifers.

4.1 Water levels and regional groundwater flow

Water-level data for the Paleozoic aquifers were obtained from the TWDB groundwater database. In order to evaluate the water levels with respect to each model layer, the layer into which the wells are completed was determined. This was done primarily based on reported stratigraphic unit into which the wells were completed. The distribution of wells was then checked visually in GIS. The revealed inconsistencies were corrected. For example, many wells completed in Archer City formation were labeled as Wichita wells in the database, but should be included as Cisco wells in this study. Well completion intervals were also compared with the developed top and bottom elevation of each group. However, due to uncertainty in top and bottom elevation estimates, classification will not change unless there is unambiguous evidence. Multiple completion wells were excluded in the selection. A total of 1270 wells were selected, 72 in Wichita, 922 in Cisco, 237 in Canyon and 39 in Strawn.

Water-levels are not measured regularly in wells. The coverage of water-level data for a particular month or year is sparse. In order to evaluate water level change with time, wells with more than 10 measurements were selected. Hydrographs of water level vs. time for wells that have coefficients of variation larger than 0.8 are shown in Figure 4.1. Those selections represent wells with largest variation of water levels over time. From the graph, it can be seen that no systematic trend is detected.

To simplify analysis, in the absence of systematic trend, average water level over time for each well is obtained. Water level elevation was posted for each layer as shown in Figure 4.2 through 4.5. A general pattern of groundwater flow in Paleozoic aquifers can be summarized. Groundwater flows from high elevation to low elevation and discharges to the rivers. Rivers could recharge the aquifer under favorable conditions. This observation is consistent with theoretical analysis of gravity-driven groundwater flows.

4.2 Estimating recharge using chloride mass balance

A variety of methods are available to estimate precipitation recharge to aquifers (Scanlon et al. 2002). In Trinity Northern GAM (Bené and Harden 2004), recharge was estimated based on annual precipitation and scaled by factors relating to land cover, soil permeability and underlying geology. For the outcrop area within Texas and near the major users, the average recharge rate input into the model is about 35 mm/yr (1.4 in/yr) with the majority of area less than 25 mm/yr (1 in/yr). In Seymour GAM (Ewing et al. 2004), recharge was estimated based on rainfall-runoff modeling. However, recharge estimates were then re-distributed based on topology. The calibrated recharge distribution averaged 48 mm/yr (1.9 in/yr) in Seymour and ranged from 20 to 65 mm/yr (0.8 to 2.5 in/yr) among Seymour pods. Unsaturated zone modeling by Keese et al. (2005) indicates diffuse recharge in the area about 10-30 mm/yr.

Chloride mass balance approach is used in this study. The basic principle is that chloride input from precipitation balances chloride output in recharge. Chloride concentrations in precipitation were obtained from the National Atmospheric Deposition Program. To account for dry fallout, chloride concentrations in precipitation were doubled, which is consistent with total chloride fallout based on pre-bomb $^{36}Cl/Cl$ ratios at Amarillo (Scanlon and Goldsmith 1997).

The study area was divided into 10 zones. Groundwater chloride concentrations were obtained from TWDB database using wells within those zones. Chloride concentration was limited to the measurements taken in the period from 1951 to 2000. A median value in each zone is used to represent average groundwater chloride concentration in that zone. Table 4.1 shows recharge rates by zones based on this analysis. Figure 4.6 shows distribution of recharge estimates by zone across the study area. Average recharge across the region is about 2.7 mm/yr. Lower recharge rates were observed in the southwest of the study area and higher recharge rates were observed in the area close to Trinity outcrops. However, spatial pattern is not consistent across the entire study region. For example, close to the Trinity outcrop, zone 2 has low recharge rate, indicating likely data bias. Recharge estimates using this approach were considered as long-term net recharge from precipitation.

4.3 Surface water features

Surface water features like rivers, streams, and lakes can interact with groundwater in various degrees. Rivers and streams can either lose water to or gain water from the underlying aquifer when they flow across the aquifer outcrops. Groundwater discharges through springs and seeps where the water table intersects the land surface. Lakes may provide a potential site of focused recharge or discharge depending on difference between the water table and the elevation of the lake.

Data of major rivers in the study area comes from EPA Enhanced River Reach file version 2. Figure 4.7 shows the distribution of the stream network in the study area.

Stream gains or losses from the aquifer cannot be easily quantified. One major attempt was made by Slade et al. (2002). They compiled results of 366 gain/loss studies conducted throughout Texas since 1918. Within this study area, six sites were reported. All of them are located along upstream reaches of Hubbard Creek that drains into the Brazos River (Figure 4.8). The results are mixed – one reach is gaining while the next could be losing. This indicates active exchange between rivers and the aquifer if those numbers are representative. In addition, the flow reported in their study represents a snapshot of the condition during their study period, not the long-term average.

Several reservoirs are located in the active model domain. Reservoir storage changes over season and through water use. However, water use data are hardly available. In addition, reservoirs in this region experience significant amount of evaporation as well. Simple conceptualization about if a reservoir gain water or loss water to the aquifer is not attempted in this study. However, since reservoirs are located along rivers, it is assumed that reservoirs can be represented in the stream package.

4.4 Aquifer discharge through pumping

The population density in the study area is low except in a few small cities. TWDB groundwater database has one water level measurement in 1901, followed by about 60 water level measurements taken in 1937. It seems it is reasonable to assume the aquifer withdrawal started around 1900s.

TWDB conducted historical water use survey and has data from 1980. A summary of nine counties of interest is shown in figure 4.9. Pumping for power and manufacture uses was not included because they are negligible compared to other use categories. Most water uses are for public supply (municipal) and domestic (stock). Therefore, it is reasonable to obtain historical pumping by correlating with population.

Historical and projected population in the study area was obtained from TWDB. In developing State Water Plan, TWDB provided the projected amount of water use in each county. Based on this, linear interpolation was used to extrapolate the amount of pumping back to 1900. Figure 4.10 shows the variation of the amount of pumping estimated based on population. This amount of estimated pumping is termed "background pumping" in this study. Nicot et al. (2011) estimated the amount of frac pumping in the study area. The frac pumping is added on top of the background pumping and is also shown in Figure 4.10 as difference between the total and background pumping.

5. CONCEPTUAL MODEL OF GROUNDWATER FLOW IN THE AQUIFERS

The Paleozoic aquifer system is conceptualized as four units capable of producing groundwater at low rates (Well yield in some locations may be moderate). From youngest to oldest, the units are the Wichita Group, Cisco Group, Canyon Group and Strawn Group. These units lie conformably in that order but Trinity overlies unconformably on the Strawn Group to the east. Each group contains several formations. Most formations consist of a mixture of limestone, shale and sandstone. Although more productive sandstone and sometimes limestone units are identifiable in the study area, the model conceptualizes each group as a hydro-stratigraphic unit, i.e., a layer in the numerical model. Further vertical stratification is possible when more data becomes available.

Because of overall low permeability of the sediments and limited recharge in the region, the hydraulic interactions between those units are restricted. Groundwater flow in each unit can be strongly influenced by surface water features. However, the degree of surface water and groundwater interaction is unknown. A study done by Core Laboratories Inc. (1972) indicates high salinity content and gradient in the downdip direction. Therefore, while the outcrop portion of each group was included in the model as much as possible; the downdip portion of each group that was included in the model is only extended to the boundary marked by high salinity. Between the contact of Paleozoic and Trinity, exchange of flow could occur. Such flow may not be important to Trinity but could be an appreciable amount for the Paleozoic units. Explicit consideration is warranted in this model.

Other than precipitation recharge, leakage from streams is another source of aquifer inflow. Higher-order rivers and streams, mostly intermittent and perennial, were implemented as both recharge and discharge mechanism using streamflow routing package. Lower-order rivers and streams, mostly ephemeral, were implemented as drains.

Most recharge will discharge through baseflow or groundwater evapotranspiration. Some will become transient storage. Groundwater withdrawal for human consumption, including agricultural and industrial uses, represents additional discharge mechanism in the development period.

Pumping withdrawal from the Paleozoic aquifers has been relatively low. Drawdown is typically localized and regional water levels have not been highly impacted by development.

6. MODEL DESIGN

6.1 Grid and boundaries

The computer program selected for simulating the Paleozoic aquifer system is MODFLOW-2000 (Harbaugh et al. 2000). MODFLOW-2000 is a three-dimensional finite-difference groundwater flow simulation program with a modular design to incorporate various boundary conditions. Groundwater Vistas (Rumbaugh and Rumbaugh 2007), which is a GUI pre- and post-processor for MODFLOW, was used to construct the model.

The finite difference grid is 1x1 km throughout the model domain. The model has 180 rows and 256 columns. The grid was oriented so the main axis is aligned to the perceived main flow direction. Vertically, the model is divided into four model layers, representing each of those four groups.

The lateral extent of the model area is defined based on the study interest and physical or hydraulic boundaries. The interest area of this modeling exercise consists of nine counties (Figure 1.1). The northwest and southeast boundaries were set far away from the interest area to minimize the boundary effect on the interest area. Those boundaries were set as no flow. The northeast boundary is set at the Red River, a major river in the study area. The Red River is implemented as a constant head boundary condition. The southwest boundary is set at a watershed divide, a ridge along hills, and implemented as a no flow boundary.

The bottom boundary was set as no flow. The contact between Paleozoic and Trinity was implemented as head-dependent flow boundary condition using general head boundary (GHB) package.

6.2 Implementation of recharge and pumping discharge

Recharge estimated in Section 4.2 serves as basis for recharge used in the model. Since recharge estimates represent long-term average, recharge was not varied through time in the transient period. Recharge values in each polygon were assigned to corresponding outcrop cells. Recharge to the Trinity and to the inactive model domain was excluded.

Pumping discharge was allocated to top 50% high permeability cells. The amount of pumping varied annually in the transient period. Because pumping was calculated on a per county basis, some pumping shown in 4.10 was allocated outside the active model area.

6.3 Rivers and streams implementation

Stream network across the outcrops in the model region acts as a head-dependent flow boundary condition for the top active model cells. EPA Enhanced River Reach File 2 was used to identify the stream network. The streamflow routing package (Prudic 1989) was used to simulate stream/aquifer interaction. Streams were arranged by levels in the reach file and stream level less than three were selected for stream package implementation and others were implemented as drains.

The stream package allows stream gaining or losing by comparing the head in the stream cell and the head in the aquifer while keep tracking the amount of streamflow in the channel. The selected streams were numbered as reaches and segments as required by the stream package. Stream bed elevation was set as surface elevation minus 10 meters. The stream bed was assigned a two meter thickness. Streamflow rate at the starting reach of each segment was taken as mean flow rate for that segment in the Enhanced River Reach file. The conductance term were estimated based on physical parameters of the stream. The distribution of stream cells in the model area is shown in Figure 6.1.

The drain package allows groundwater discharge once the head in the aquifer is higher than the elevation of the drain. Elevation for a drain cell was set as surface elevation minus seven meters. The distribution of drain cells is also shown in Figure 6.1.

6.4 Implementation of constant head and GHB conditions

Red river cells were identified and the length of rivers within each cell was calculated. The boundary heads were set as surface elevation minus 5 meters. The distribution of constant head cells is shown in Figure 6.1.

Model cells in the active domain and overlain by Trinity were identified. A general head boundary condition (GHB) was implemented in each one to represent exchange of flow between the Paleozoic and Trinity. The boundary head values for the GHB were set as Trinity heads in 1890 condition and were obtained from Trinity North GAM. The distribution of GHB cells is shown in Figure 6.2.

6.5 Model geometric and hydraulic parameters

The development of the model structure (top and bottom elevations) and hydraulic conductivity data for each of the model units were documented in the companion report. Hydraulic conductivity was viewed as horizontally isotropic (Kx=Ky) but vertical anisotropy was set as 10. The specific yield was assumed to be homogeneous and was assigned a value of 0.05 for all geologic units. Meyers (1969) reported two storage coefficient values (2e-6 and 4e-6) from the pumping test conducted in Montague County but no information of screen interval was provided. Fisher et al. (1996) conducted study in Parker and Palo Pinto Counties and assumed storativity of 1e-5 for two pumping tests. The screen interval for both wells was 3 m. storativity values were divided by screen interval to obtain specific storage (3e-6 m^{-1}). This specific storage value is used for all geologic units.

7. MODELING APPROACHES

Because of data limitation and time constraints, the Paleozoic aquifer system model was set to be both interpretive and predictive. It is set as interpretive because the basic objective for this modeling exercise is to have a framework so the system dynamics can be understood further. This basic tenet dictates less concentration on model calibration but more on conceptual understanding and alternative parameterization. It is also set as predictive because the model is expected to approximate the physical system reasonably well. By incorporating stresses in the predictive mode, system responses can be evaluated.

8. RESULTS

The constructed model includes steady state simulation and transient simulation. The steady state model represents the long-term average before appreciable development began. The stresses do not include pumping withdrawal. The transient model simulates the system under annual stresses from 1900 to 2060.

8.1 Steady-state simulation

Volumetric water budget from steady-state simulation is summarized in table 8.1. The percentage error is -0.22. In summary, streams gain water from the aquifers. Red River also gains water from the aquifers. There is a small amount of flow from the Paleozoic aquifers to the Trinity.

Head targets were compared with simulated steady-state heads. Figure 8.1 to 8.4 show the comparison graphically. Residual mean is -21 m, standard deviation 28 m, minimum -322 m and maximum 56 m. The ratio of standard deviation over the observed range in target head values is 6%. The statistics excluded three cells that were dry in steady-state.

8.2 Transient simulation

Volumetric water budget changes with each stress period. As an example, water budget for 2010 is given in Table 8.2. Compared to the steady-state budget, flow to the rivers and flow to the Trinity were all reduced slightly. It is noted that pumping discharge in 2010 represents about 40% of recharge.

The transient simulation run included frac pumping from 2010 to 2038. Average drawdown between 2010 and 2060 is 0.76 m with a minimum of -31 m and a maximum of 18 m.

9. DISCUSSION

The groundwater flow model for the Paleozoic aquifers simulated water level at target locations reasonably well. Those targets are mostly located in outcrop area. Therefore, simulation of flow in the further downdip section (away from target locations) appears to be more uncertain. In the model development, some dry cell problems exit. Most dry cells are located in the edge of the outcrop. So it is likely those cells are physically dry or it is related to inaccurate representation of formation thickness. Some flooding (simulated water level elevations are higher than land surface elevations) cells are also noticed. Those are mostly in the region where recharge takes place in the very low permeability cells. So either inaccurate spatial distribution of recharge or permeability estimates contributed to the problem. However, those problems seem to be localized and it is not expected to have major effect on the overall performance of the model.

No formal calibration was conducted in the model development. Alternative parameterization or revised conceptual model was engaged when the model suggest a refinement is needed.

The numerical model is an abstraction of the real system. The development of the model for Paleozoic aquifers is limited by available data and our conceptual understanding of the system. Additional flow targets would further constrain the model. As the system simulated is mostly unconfined, an investigation of surface water and groundwater interaction in the region would enhance our conceptual understanding of the system.

10. CONCLUSIONS

The developed numerical model for the Paleozoic aquifers consists of four layers, representing Wichita, Cisco, Canyon, and Strawn groups. It included steady-state simulation and transient simulation. The model incorporated stresses such as surface water and groundwater interaction, exchange of flow between Trinity and Paleozoic, and pumping discharge. Simulated flow between Paleozoic and Trinity is small. While precipitation is the primary recharge mechanism, discharge to the streams is the primary discharge mechanism.

The Paleozoic aquifers have been an important resource for small community and rural residents. The model results suggest some additional development is plausible. The model distributed the pumping stress spatially in a manner that may not be realistic in order to obtain an average effect. Distribution of more permeable sandstone units also shows high spatial variation. Large development in one specific region needs to be carefully evaluated in the context of local hydrology.

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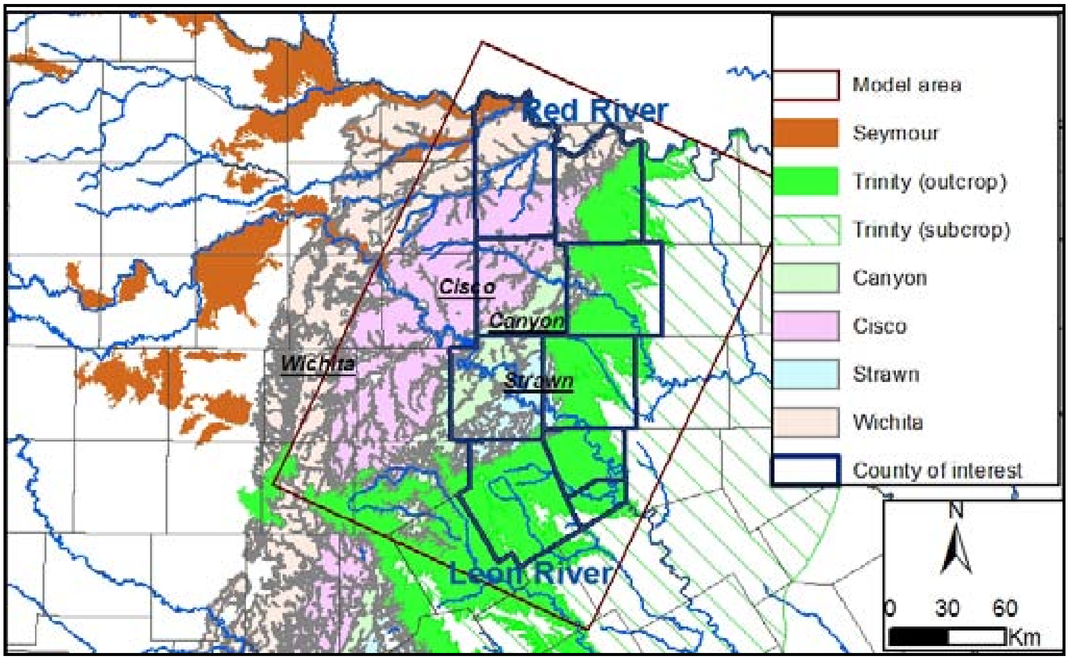

Figure 2.1 Study area and generalized geological units

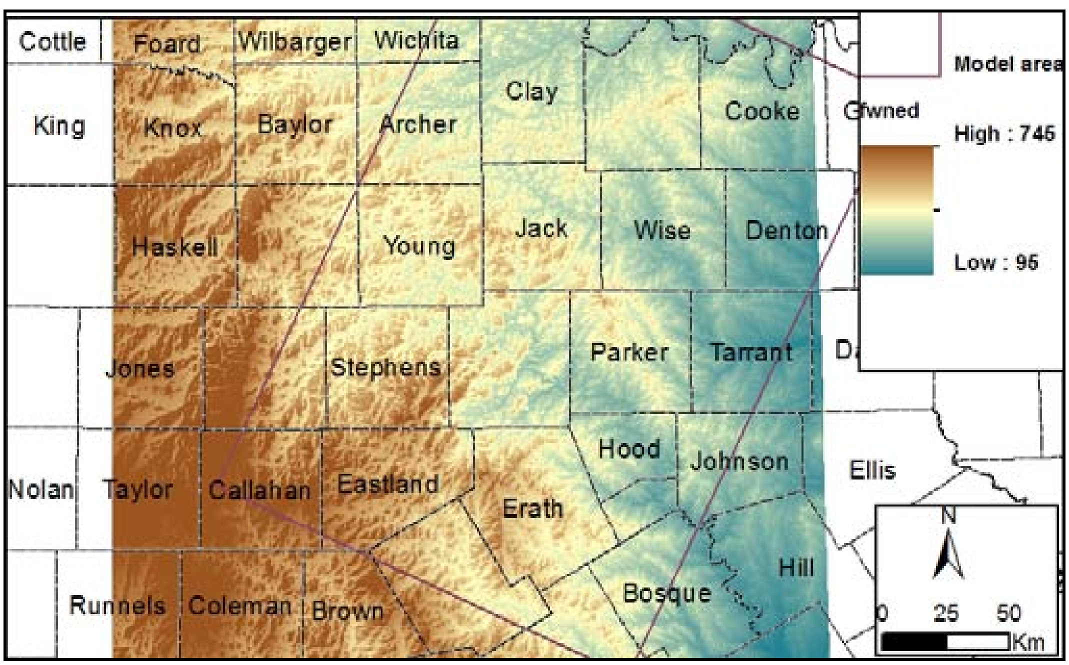

Figure 2.2 Land surface elevations (m amsl) in the study area

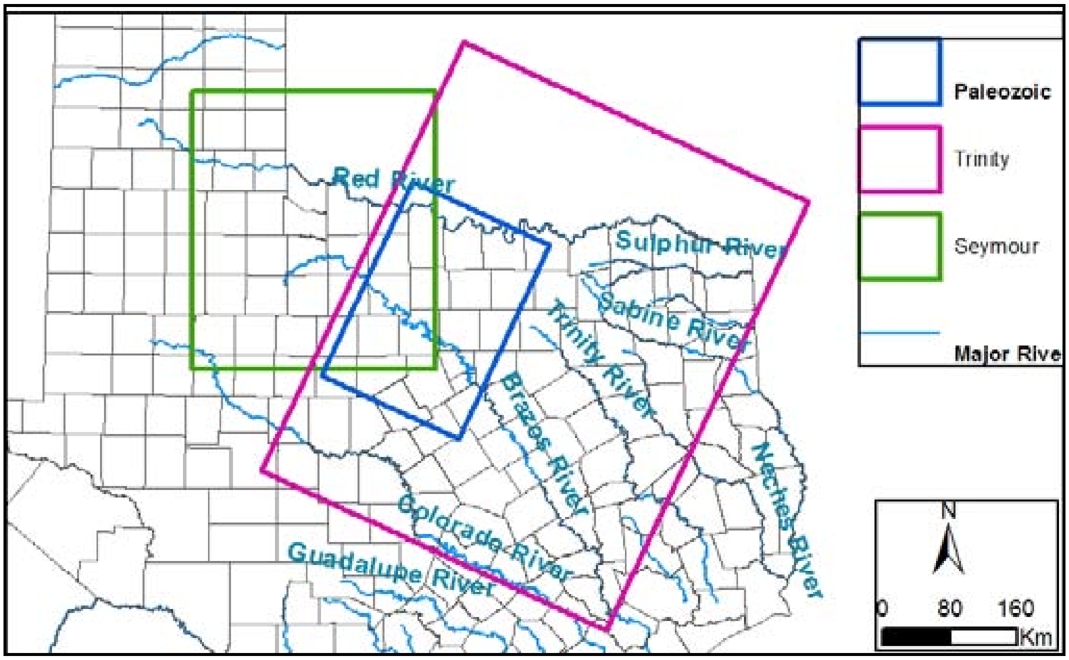

Figure 3.1 Boundary of previous modeling studies that overlap the current study area and extent of Paleozoic aquifer model

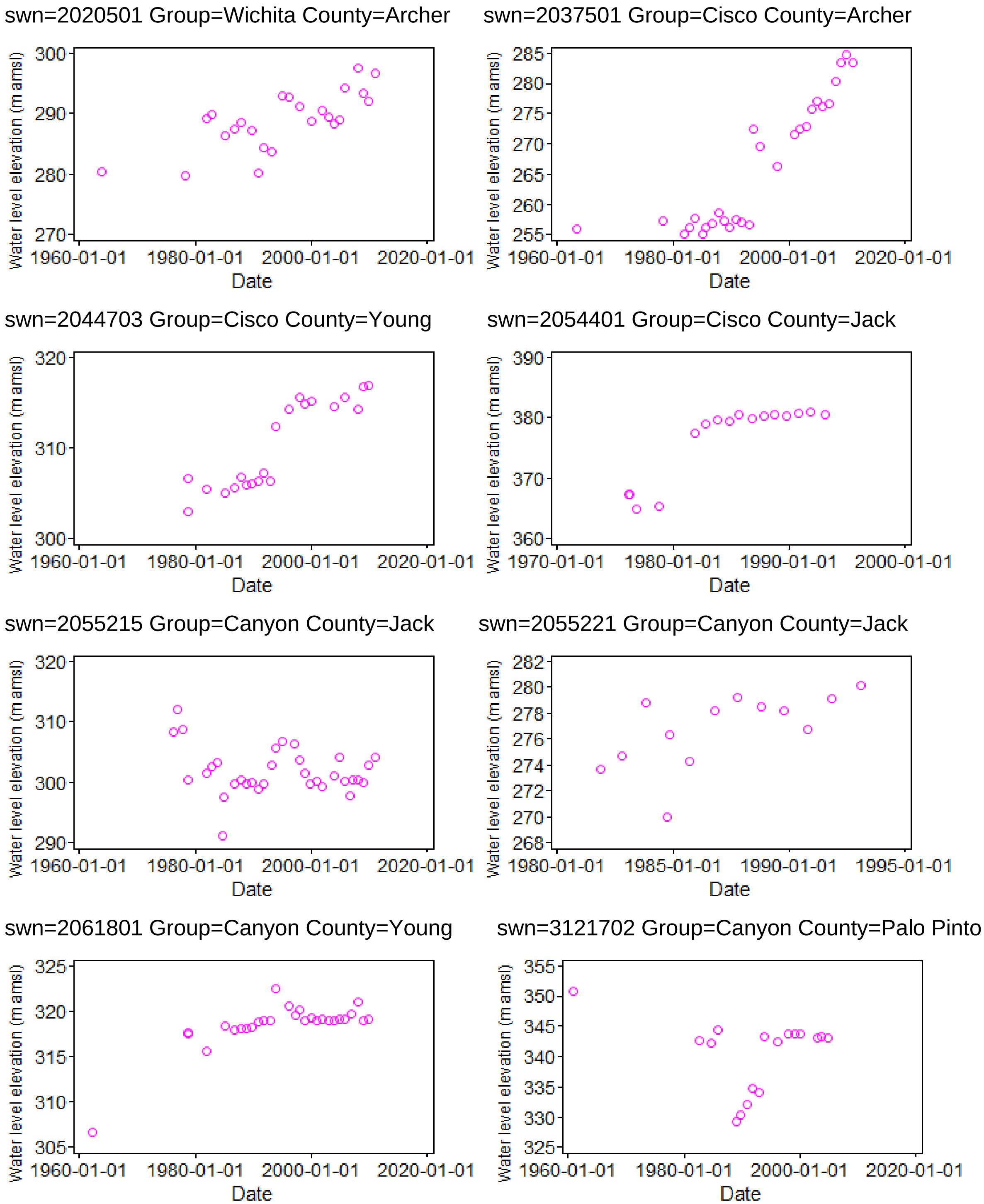

Figure 4.1 Hydrograph of selected wells with large water level variation over time. Swn=state well numer

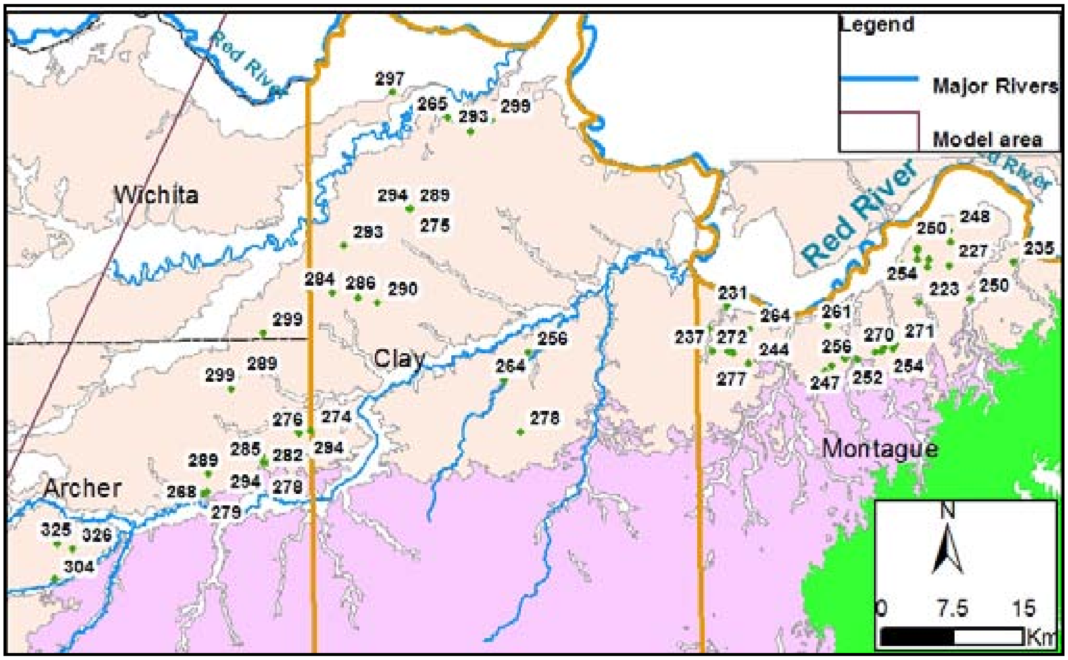

Figure 4.2 Wichita wells with water level (m amsl)

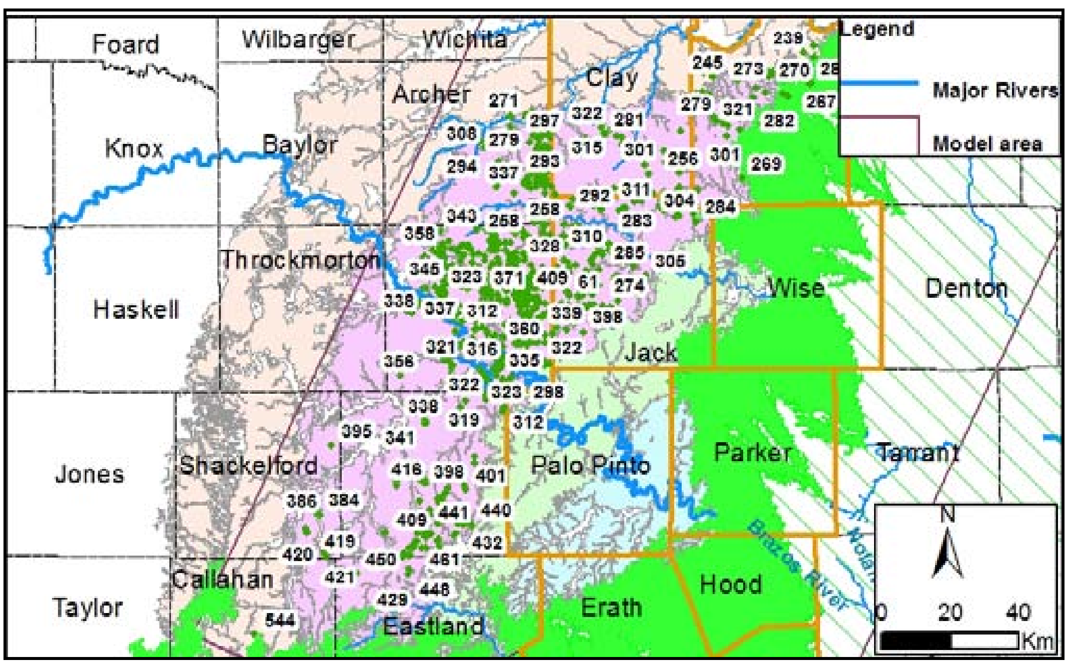

Figure 4.3 Cisco wells with water level (m amsl)

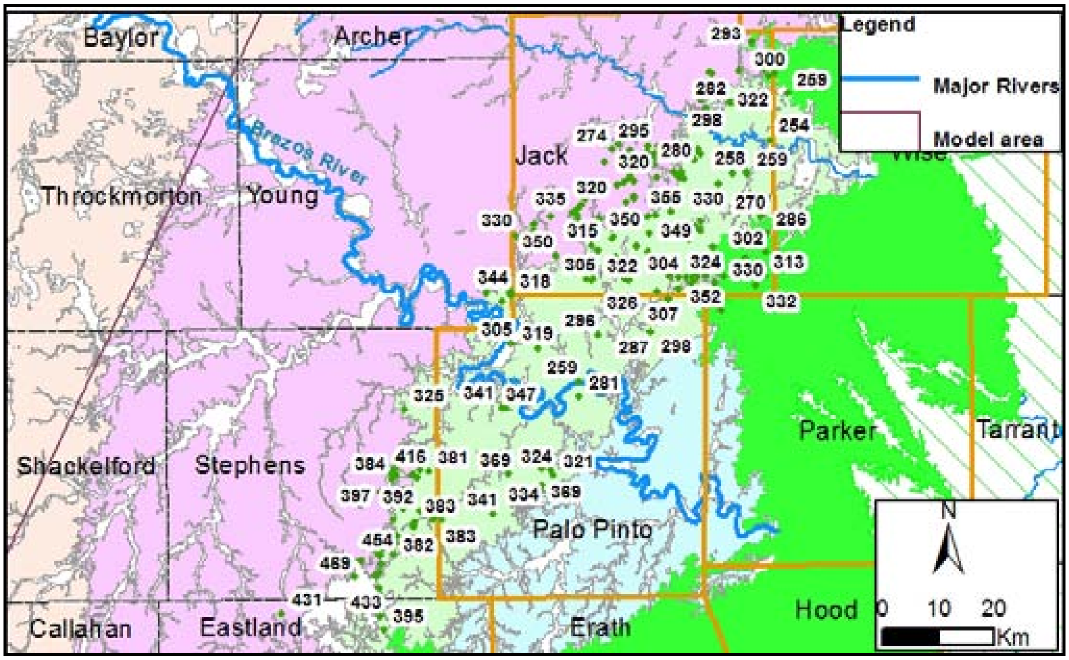

Figure 4.4 Canyon wells with water level (m amsl)

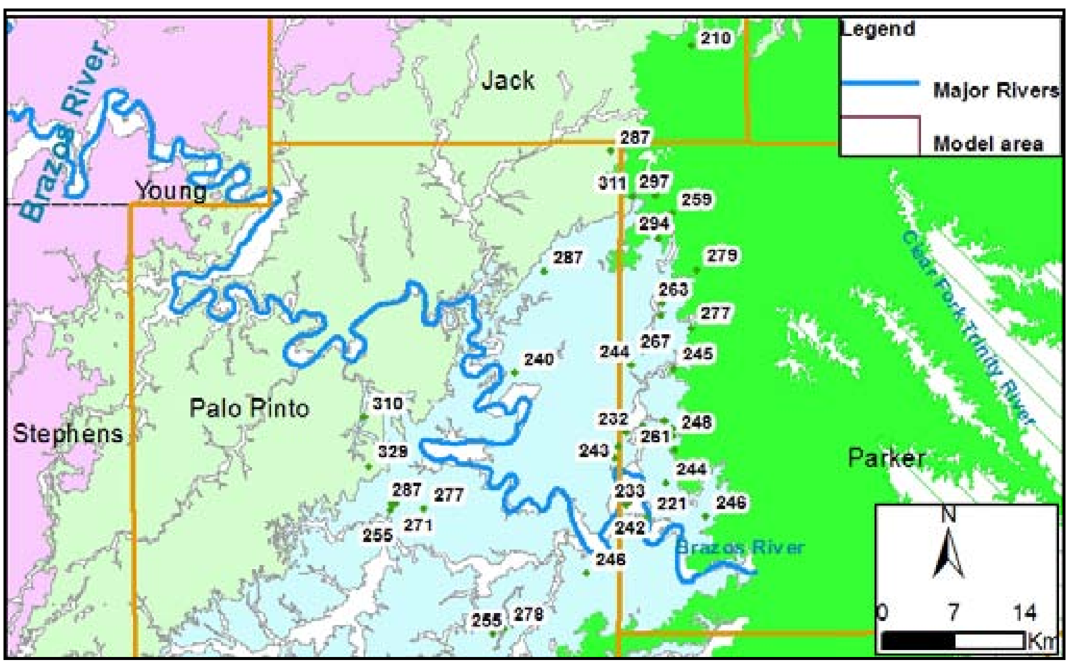

Figure 4.5 Strawn wells with water level (m amsl)

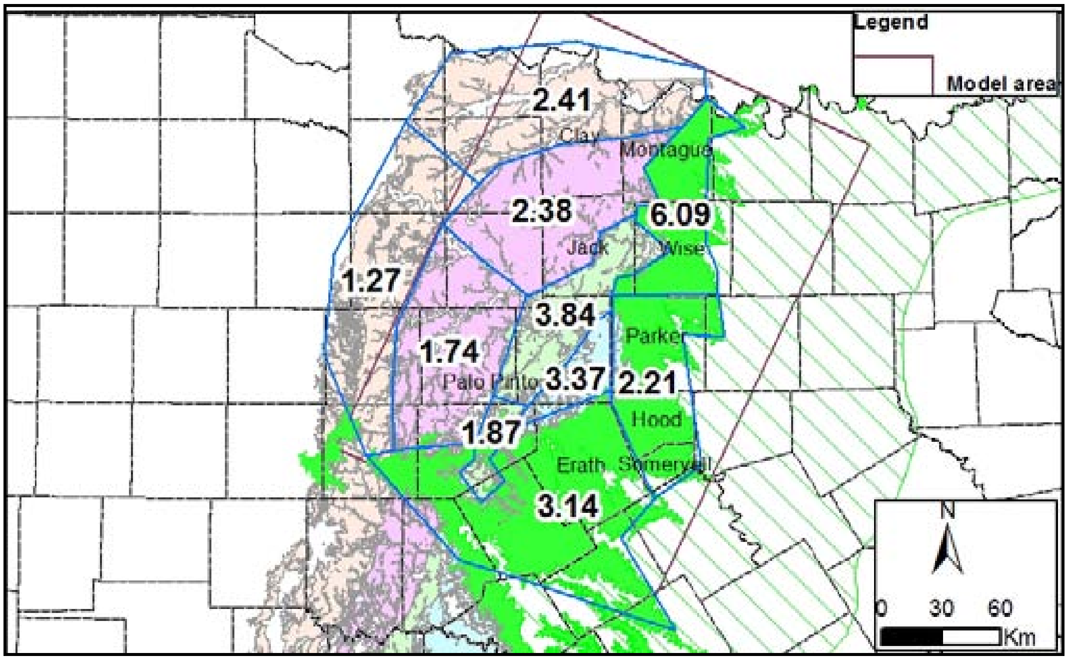

Figure 4.6 Recharge rates by zone based on chloride mass balance analysis (cm/yr)

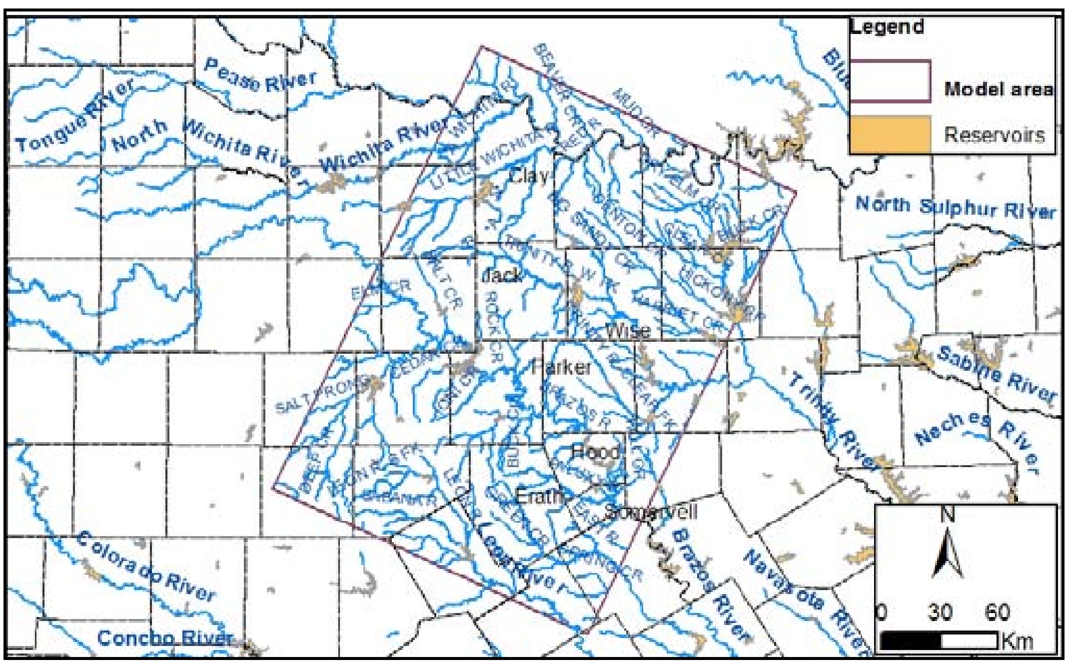

Figure 4.7 Surface water features in or near the study area. The stream network shown in the model area is based on EPA Enhanced river reach file version 2.

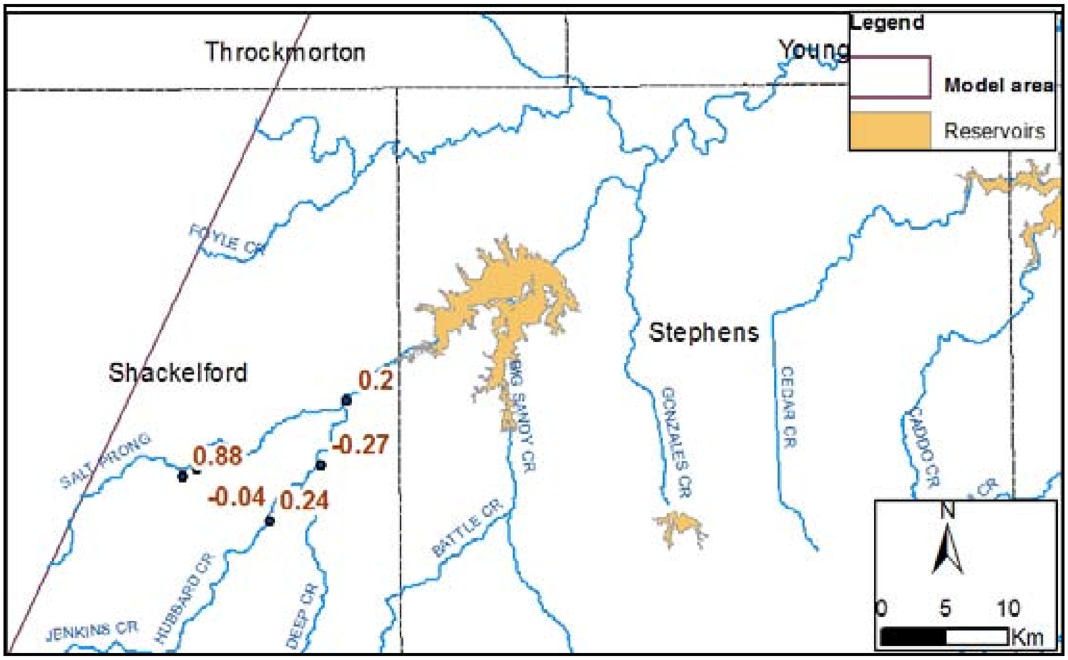

Figure 4.8 Gain loss along river reaches as reported by Slade (2002) in the active model area.

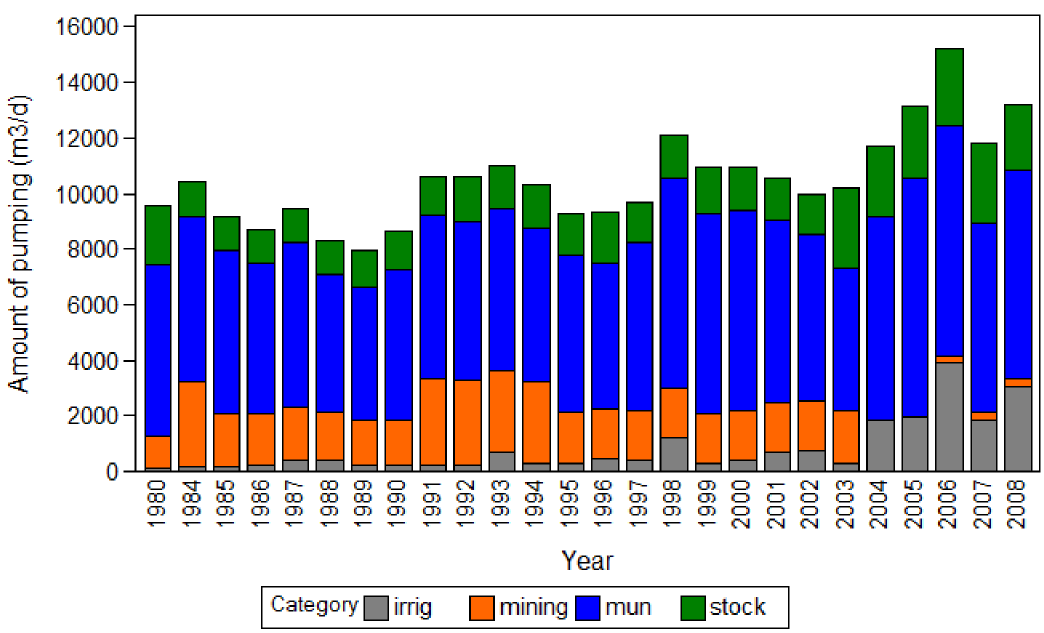

Figure 4.9 Total amount of pumping in nine counties by category. Data from TWDB water use survey.

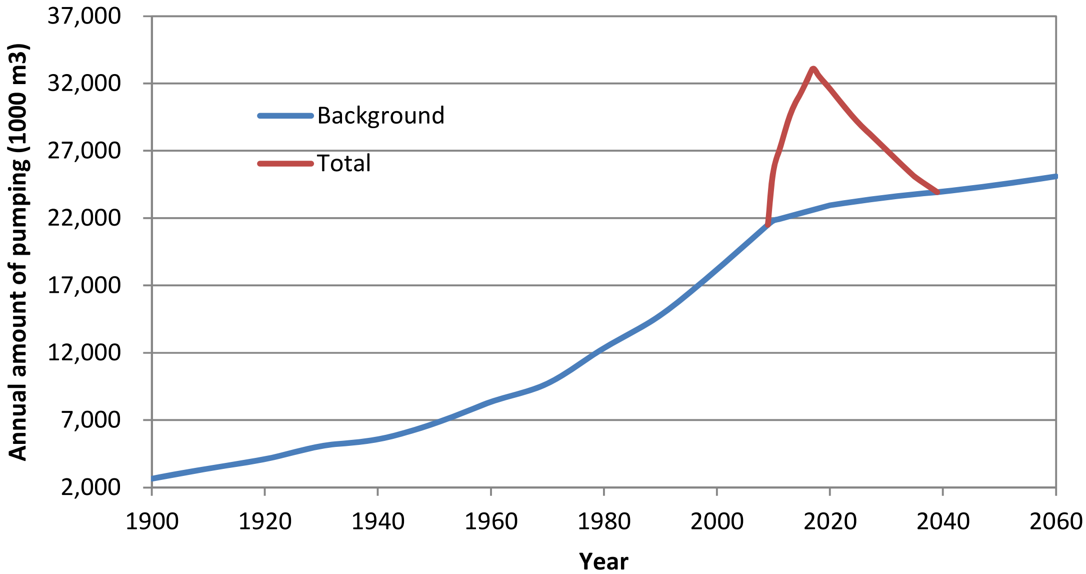

Figure 4.10. Groundwater withdrawal from the Paleozoic aquifers

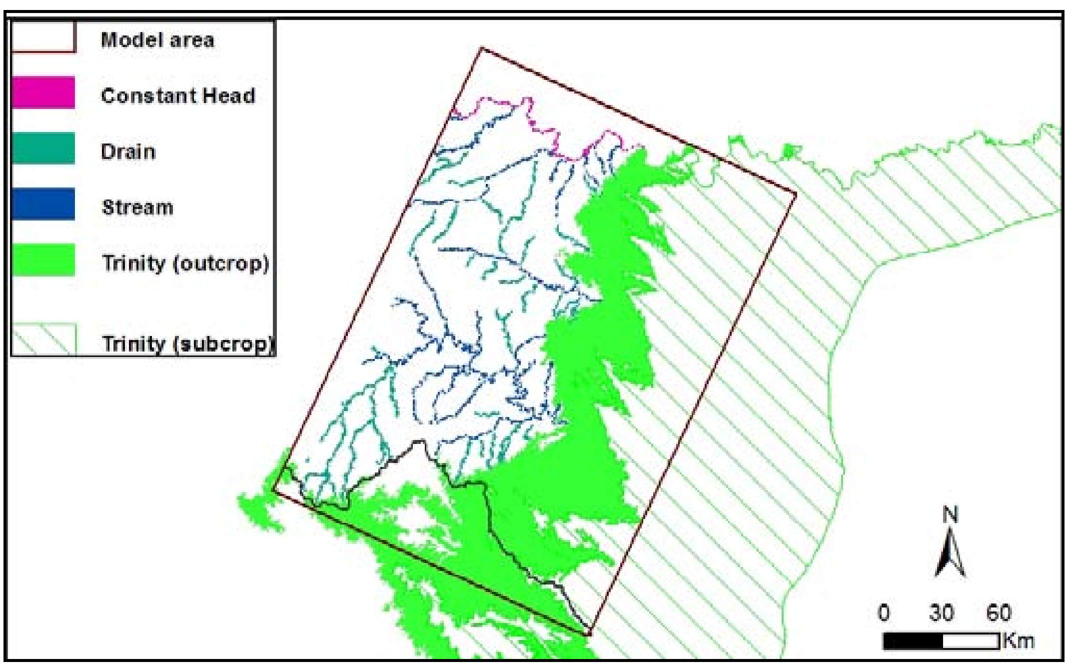

Figure 6.1 Distribution of stream, drain, and constant head cells

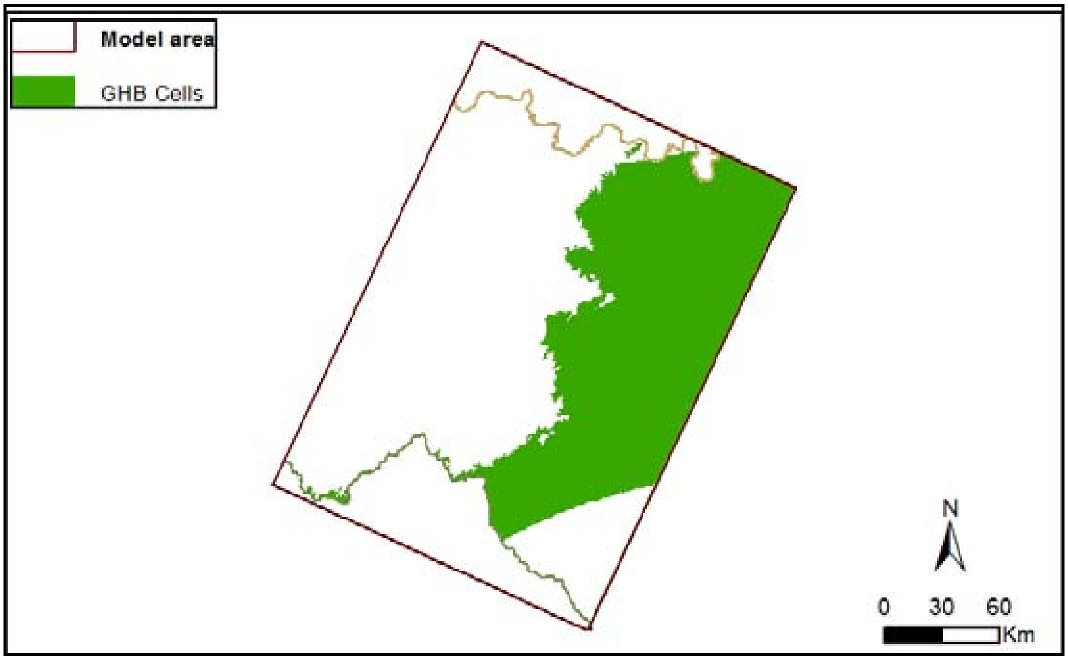

Figure 6.2 Distribution of general head boundary cells

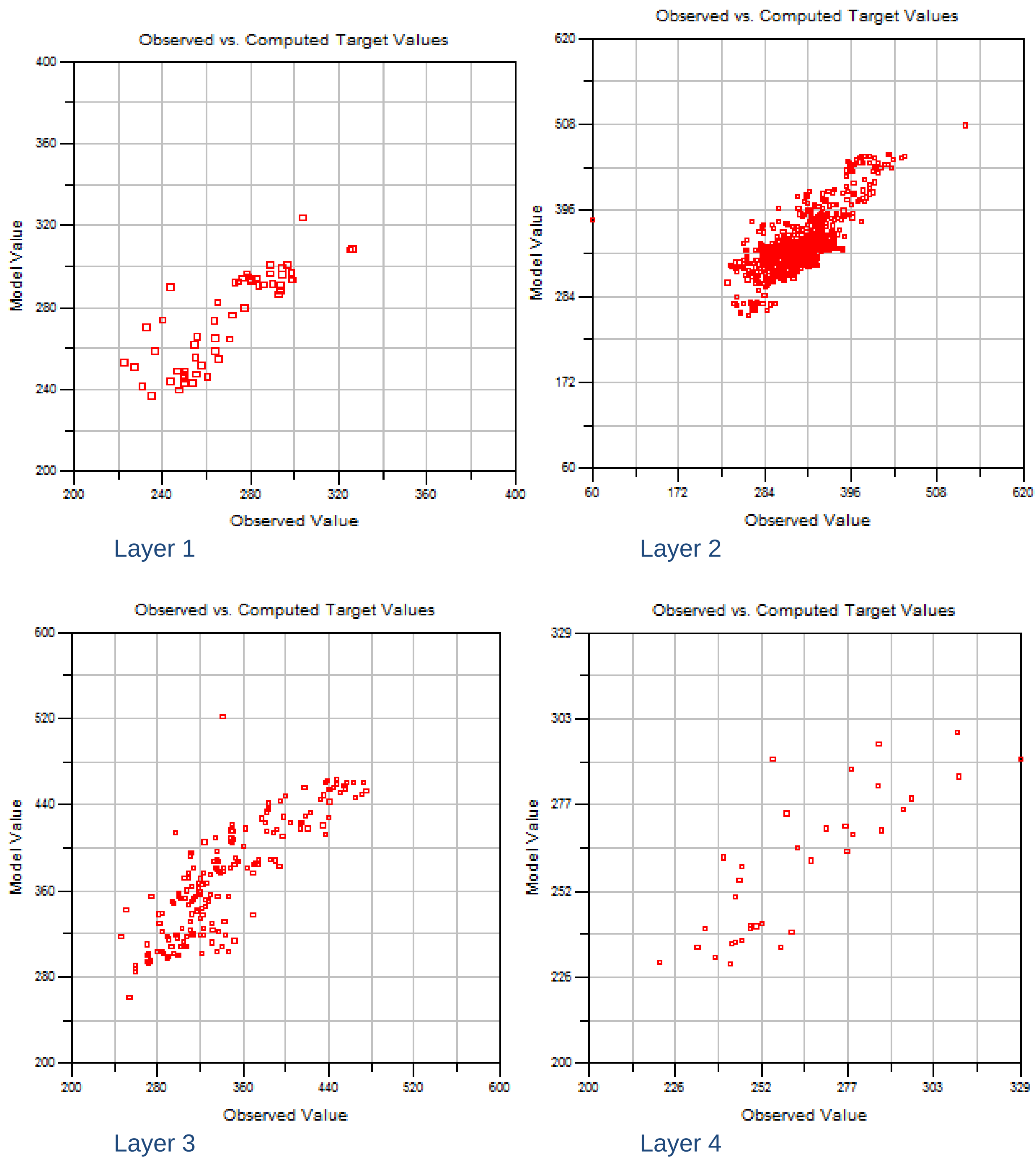

Figure 8.1 Observed and simulated heads at target locations in four layers

Table 4.1 Recharge rates based on chloride mass balance analysis of groundwater chloride concentration

Zone	area (km2)	precipitation (mm/yr)	CLin (mg/L)	CLgw (mg/L)	Recharge (mm/yr)
1	2,927	899	0.444	66	6.09
2	3,899	851	0.516	199	2.21
3	9,076	775	0.586	145	3.14
4	1,162	797	0.508	120	3.37
5	3,020	816	0.48	102	3.84
6	729	742	0.546	217	1.87
7	5,435	798	0.454	152	2.38
8	5,214	719	0.504	208	1.74
9	6,877	788	0.424	139	2.41
10	5,973	692	0.472	258	1.27

CLin= chloride concentration from input; and CLgw=chloride concentration in groundwater

Table 8.1 Steady-state volumetric water budget for the entire model area (m^3/day)

	GHB	Stream	Constant Head	Recharge	Drain	Total
In	804	7,964	2,402	128,298	0	139,469
Out	940	95,796	5,515	0	37,522	-139,774
Net	-137	-87,832	-3,113	128,298	-37,522	279,242

Table 8.2 Transient simulation (2010) volumetric water budget for the entire model area (m^3/day)

	GHB	Stream	Constant Head	Storage	Recharge	Well	Drain	Total
In	839	8,308	2,450	41,669	128,298	0	0	181,564
Out	922	88,510	5,389	2,683	0	51,081	33,311	181,896
Net	-83	-80,201	-2,939	38,985	128,298	-51,081	-33,311	-331

10 Attachment E: Year 1 Milestone Report

This attachment contains, for completeness and easy reference, the interim report submitted at the end of Year 1.

Feasibility of Using Alternative Water Sources for Shale Gas Well Completions — A Preliminary Guidance Document on Current Practices in the Barnett

Report No. 08122-05.02

Barnett and Appalachian Shale Water Management and Reuse Technologies

Contract 08122-05

February 22, 2011

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Milestone Report

ABSTRACT

This document presents early results of a study investigating alternative sources of water to be used in the last completion phase (so-called "fracing") of gas wells in the Barnett Shale play. Millions of gallons is needed to perform the fracing operation, and in the past few years gas operators have used (1) groundwater from dedicated supply wells, (2) surface water from water-rights owners (private or state agencies such as river authorities), (3) surface water from private ponds and other water bodies, (4) treated water from municipalities and industrial users, and (5) water recycled from previous fracing operations. As gas production moves away from the core area (Denton, Johnson, Tarrant, and Wise Counties) toward the north, south, and west to access the remainder of the play, gas operators are faced with two challenges: (1) increased water scarcity and (2) measured reluctance to impact domestic and public water supplies. This study analyzes three potential sources able to meet those goals: (1) small ponds outside the State regulation of surface water, (2) smallish groundwater aquifers west of the more plentiful Trinity aquifer, and (3) treated wastewater outfalls. Different alternative sources were inventoried through orthoimagery coverage to detect all non-State-water bodies, an analysis of the groundwater literature supplemented by perusal of State agency databases, and a thorough examination of relevant wastewater databases (State and Federal), respectively.

Historical data and projections estimated that as much as 40,000 AF of water could be used every year to frac wells. This figure compares well with water available from non-State-surface-water bodies (>100,000 AF at any given time), groundwater (>25,000 AF available per year), and wastewater outfall (>100,000 AF/ yr).

Signature

Date

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LIST OF ACRONYMS

AF	Acre-foot
BSWCMC	Barnett Shale Water Conservation and Management Committee
GCD	Groundwater conservation district
gpm	Gallon per minute
MGD	Million gallons per day
PWS	Public water system
SES	Steam electric station
TCEQ	Texas Commission on Environmental Quality
TDS	Total dissolved solids
TNRIS	Texas Natural Resources Information System
TSS	Total suspended solids
TWDB	Texas Water Development Board
WWTP	Wastewater treatment plant

1 Introduction

This report documents preliminary results of year 1 of Task 6.0, “Determine Feasibility of Using Alternative Water Sources.” The impetus of the work was a realization that development for gas production in the Barnett Shale area is expanding to the west, north, and south of the core area into areas with few known groundwater resources and with some of the surface-water resources tied up for municipal use (Figure 1 shows footprint of the Trinity aquifer, Figure 2 depicts Barnett Shale well location as of early 2011, Figure 3 displays surface-water features, and Figure 4 shows the counties of interest). There is a clear need for a coordinated approach to locating alternate sources of water and evaluating various means of water delivery to alleviate potential water-availability constraints on Barnett Shale production over the next 20 yr. The objectives of the study as a whole are to

1. Gather baseline data and determine current and predicted water use for all purposes,
2. Review water-quality specifications required to perform frac jobs developed by the Barnett Shale Water Conservation and Management Committee (BSWCMC) Frac Job Expert Panel and determine technical and economic feasibility of utilizing alternate sources of water,
3. Inventory sources of surface water,
4. Inventory nonconventional water sources: desalination concentrates, reclaimed water from treatment plants, low-salinity produced water, dewatering activities, etc.,
5. Interview and interact with industry operators to learn about current practices of locating alternate sources of water in counties with water limitations,
6. Determine water compositions of alternate water sources by obtaining existing data (from TWDB and TCEQ), and
7. Determine possible interactions between sources.

The overall goal is for BSWCMC/RPSEA/GTI to visualize water availability and quality below some cost threshold from any location in the study area. This interim report focuses on Subtask 5 but could not be completed without input and results from Subtasks 1 through 4, which set the stage. Subtasks 1 through 5 will be revisited in the final topical report because operators’ approaches and technologies evolve fairly quickly in the play. An interesting development is the current focus on the so-called combo play located in Clay and Montague Counties in the north section of the Barnett Shale footprint. The combined production of oil and gas makes the area more attractive, given currently depressed gas prices. Subtasks 6 and 7 will be fully addressed in the final topical report. The spatial focus of this study includes 14 counties with significant gas production: Bosque, Dallas, Denton, Erath, Hill, Hood, Jack, Johnson, Montague, Palo Pinto, Parker, Somervell, Tarrant, and Wise.

This preliminary guidance document mostly follows subtasks in the order that they are listed: (1) a section on background information of current water use in the Barnett Shale and relevant conclusions from the expert panel on water quality, (2) a discussion of surface-water bodies, and (3) a discussion of nonconventional water sources. Contributors to the work include Steve Walden and Russ Baier from Steve Walden Consulting and Cliff Lam, undergraduate at UT, for the WWTP study; Teresa Howard from the Center for Space Research at UT for the water features study; Ed McGlynn, graduate student at UT, for the groundwater study; and Cari Breton at BEG for help on the GIS work. Some of the contacts were made through the BSWCMC (http://www.barnettshalewater.org/index.html)

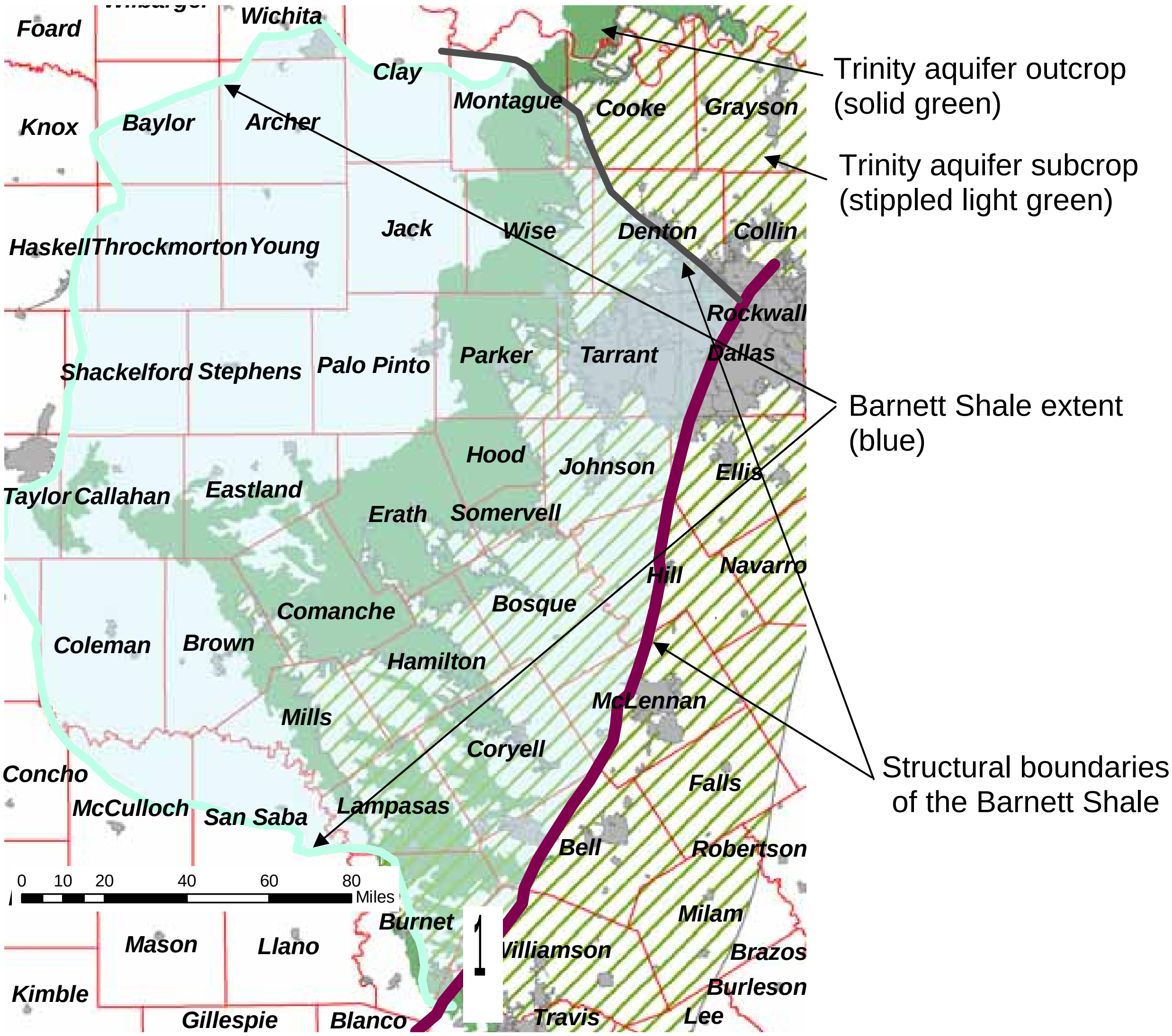
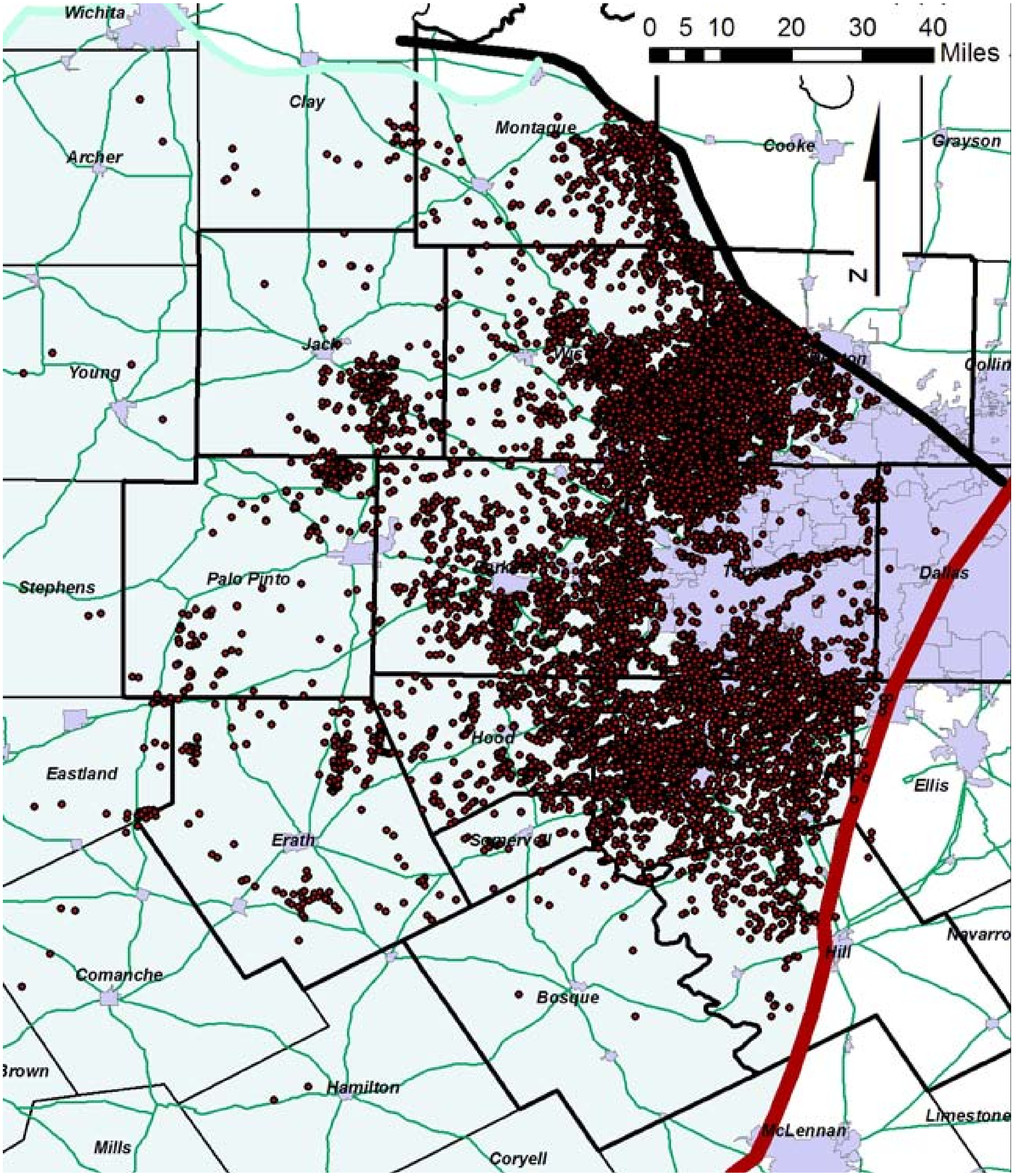


Figure 1. Barnett Shale and Trinity aquifer extents.



Note: county boundaries of area of study highlighted by thicker solid lines

Figure 2. Barnett Shale well locations (>15,000 wells as of end of 2010)

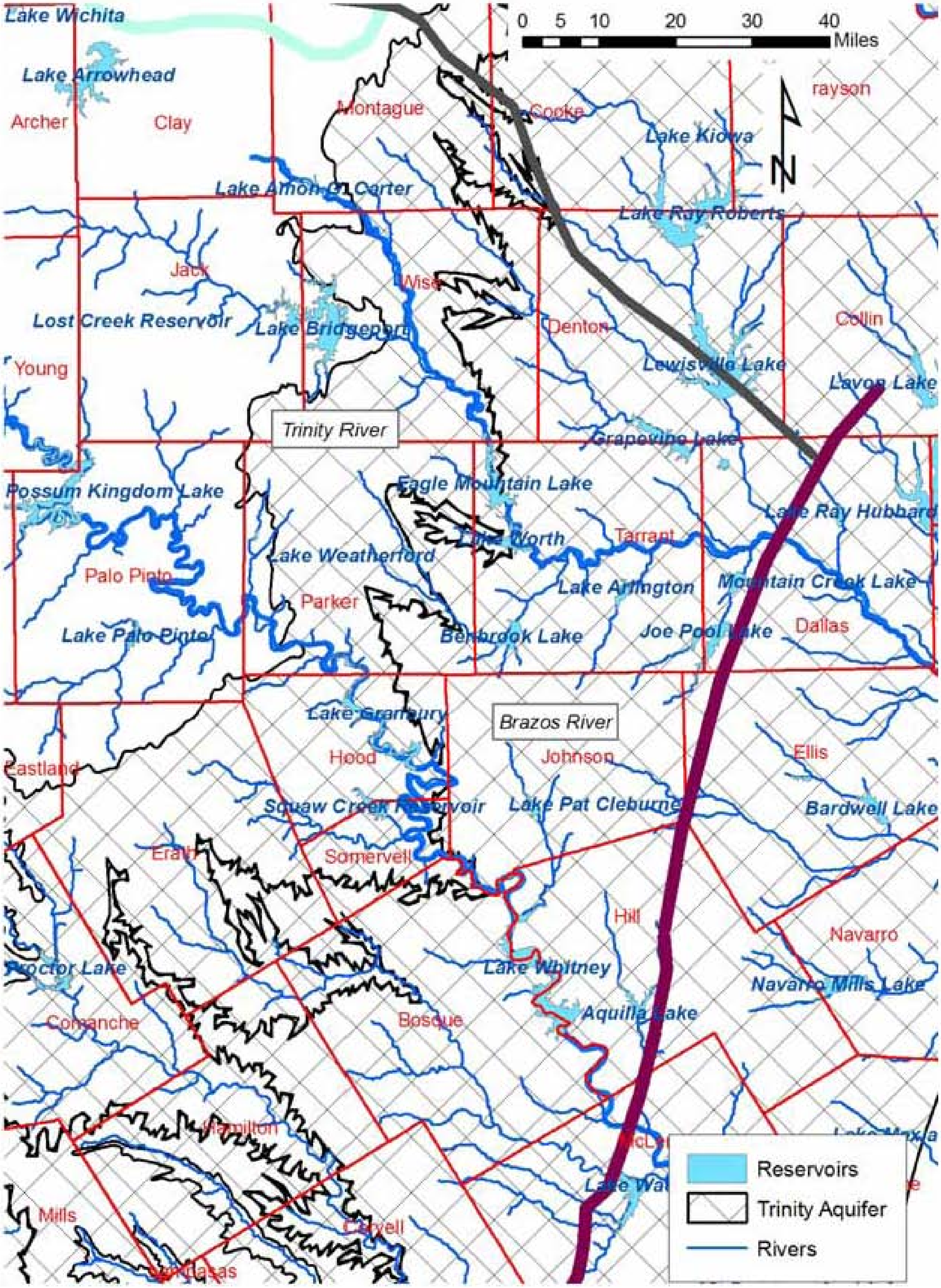
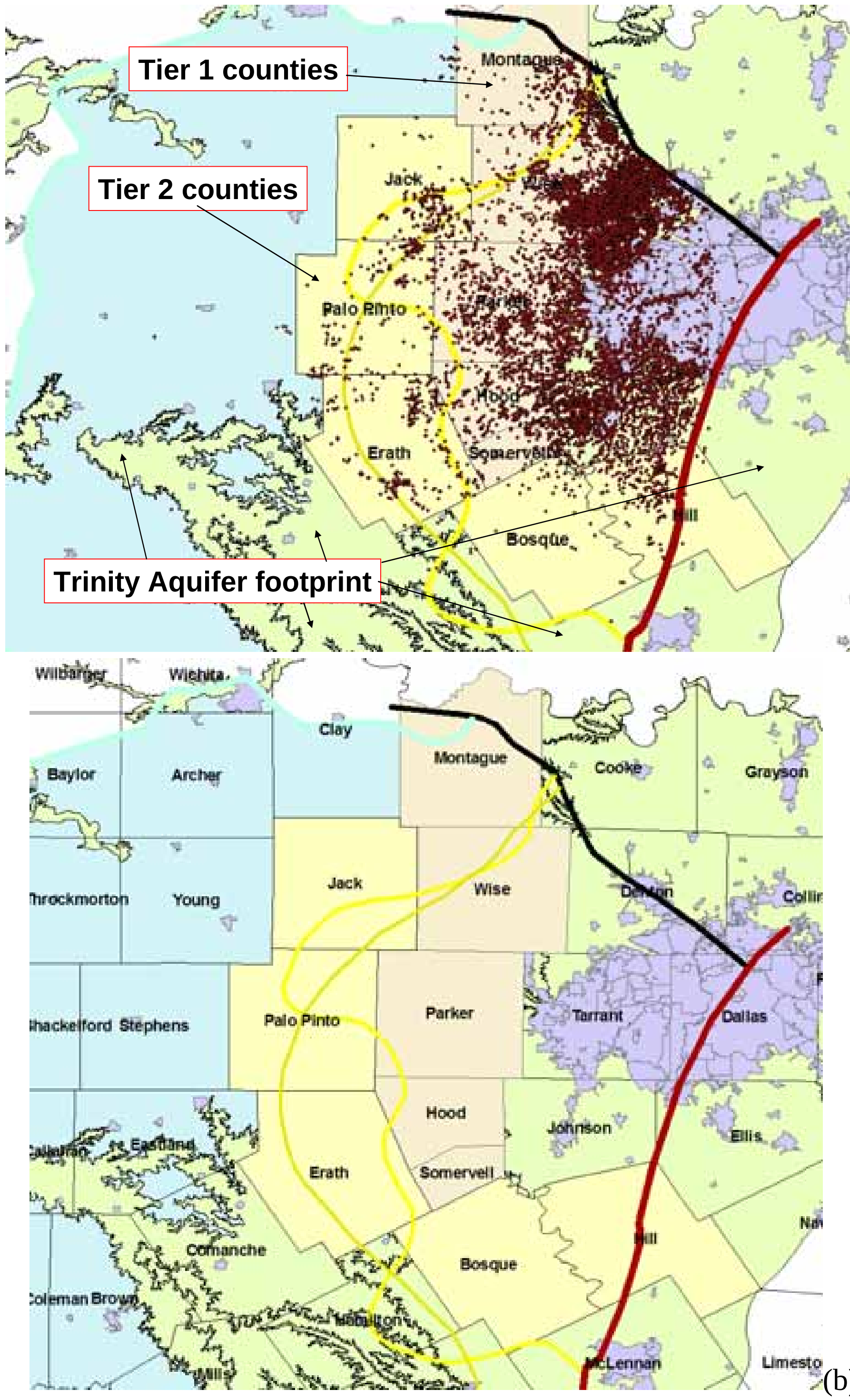


Figure 3. Rivers and reservoirs in the study area.



Note: Maps show Barnett Shale footprint, Dallas-Fort Worth metroplex, and gas-well locations through 2008. The 10 counties of initial interest are also shown: Tier1, the closest to the core area (Montague, Wise, Parker, Wood, and Somervell) and Tier2 (Jack, Palo Pinto, Erath, Bosque, and Hill). Area approximately delimited by yellow lines represents sections of shale with sufficient thermal maturity. (b) Addition of Denton, Tarrant, Johnson, and Dallas Counties.

Figure 4. Map displaying counties of interest.

2 Current Practices

Although operators typically declare to the State legal authority (RRC) how much water and how much proppant they use during well stimulation, there is no legal requirement to declare the source of frac makeup water or the quality of the water being used. Although known anecdotally, comprehensive information is hard to obtain. The general picture emerging from conversations with operators is that the search for water is done in a mostly ad hoc fashion, with operators at the corporate level not tracking the source of the frac water very well or unwilling to share to ensure their competitive advantage. In other words, access to and knowledge of the different approaches to satisfy water needs are possible, but more quantitative results with breakup figures among the different approaches are more difficult to compile.

There are several ways to access information about current practices put forward by gas operators to obtain water for frac jobs: formal surveys, literature review and conference proceedings and attendance, and direct interaction with managers or technical experts in charge of well completions. The first option was not retained because of the typical low return as experienced by BEG in previous projects. The second option is appropriate, and a lot could be gained because, in general, the information is dense, consistent, and thorough. A drawback might be that data could be outdated. The third option is likely the best if the person of interest has time to devote to answering questions, which is unfortunately rarely the case.

Information used in this document was gleaned from literature search, interactions with experts at conferences or other private meetings, and phone calls. In 2010, the top 10 producers were, in decreasing order of production, Devon, Chesapeake, XTO (Exxon), EOG, Quicksilver, Encana, Range, Carrizo, Williams, and Burlington (Conoco-Phillips), with the first three dominating the play (RRC website). Information was also obtained through direct interaction with staff members of some of these companies.

Water sources fall into three broad categories: surface water, groundwater, and a composite group. Typically water is either trucked or piped to location. Needed injection rates cannot be matched by truck traffic or pipeline-flow rate, so water is generally stored on site in a tank battery or in an impoundment. For example, Chesapeake uses ponds holding several millions of gallons of water that can be used to drill and frac several wells within a radius of 1 or 2 miles.

Surface waters include lakes and rivers, for which a permit is needed, but also artificial ponds, whose water originates from the subsurface, and impoundments. Groundwater is pumped from wells drilled by the operator or owned by a nearby landowner. The last category is composed of what could be termed unconventional or alternative sources of water, including municipal water (which initially may be groundwater, surface water, or a mix of both) and wastewater from municipal or industrial facilities, to which recycled flowback water can be added. Another source not commonly present in the Barnett footprint is acid mine drainage.

The latest reliable piece of information on groundwater–surface water split dates back a few years. The source of fresh water was nearly even in 2005 between surface water and groundwater (estimated at 53% and 47%, respectively), and it was projected that by 2007 the fraction of fresh water from surface water would rise to ~59% as drilling activity expanded in the Fort Worth metropolitan area (Galusky, 2007). Information from other shale-gas plays can also reveal other companies' approaches to water management in the Barnett play. For example, Veil (2010) reported on water management in the Marcellus but focused mostly on the disposal of wastewater and Gaudlip et al. (2008) investigated approaches used in the Marcellus a few years ago.

Table 1 summarizes qualitatively current approaches. Large surface-water bodies and groundwater are likely conventional targets. Surface-water bodies can be managed by municipal, State, State-initiated, or Federal entities (U.S. Department of Agriculture, U.S. Corps of Engineers). Operators can, for example, contract with the Brazos River Authority (BRA), which controls surface water in the south section of the study area (Figure 3) or with the Trinity River or Red River Authority which controls surface water farther north. As far as we know, water use by category for river authorities is not specific enough to carve out the part related to fracing. For example, BRA sells ~2% of the water (that it is allowed by the State to sell) for mining use that includes fracing but possibly other uses. Municipal water is also a target of choice, especially in urban environments with no access to surface water and limited access to groundwater. For example, the City of Arlington, Tarrant County, provides a maximum of 3% of its 140-MGD capacity to gas operators (J. J. Hunt, Arlington Water Utilities, oral communication, 2010). This amount is apparently enough to frac 300+ wells every year, but how much of that water is actually used for fracing is unclear.

As an example, Chesapeake (2008 presentation) has the following approximate source breakdown: surface water 35% (Brazos River Authority, Trinity River Authority, U.S. Corps of Engineers), private water 25% (private lakes and ponds and stock tanks), water-supply wells 25% (all but three had already been drilled), municipal water purchases 15% (Arlington, Burleson, Cleburne, Crowley, Keene, Fort Worth, and Grand Prairie), and reuse/wastewater < 1%.

There is also a move toward using brackish and saline water, including flowback, produced water, and water originating from shallow and deep aquifers. In some cases, operators might then run into obstacles (see Section 3.2). Recycling is also an option but not hotly pursued in the Barnett play because disposal (mostly into the underlying Ellenburger) is more convenient and, currently, cheaper. On a per-well basis, initial flowback water requiring limited treatment amounts to 200,000 gal (M. Mantell, Chesapeake, GWPC Conference, January 2010), or only ~5% of the amount injected. Transporting such a small fraction of the water needed to frac another well causes logistical problems, unless the well is on a multiwell pad. The 20 to 30% flowback recovered in the 2 weeks following stimulation can be reused, but, for some of it, only after having received a more expensive treatment to remove the excess salinity through evaporative thermal or membrane reverse osmosis processes. More innovative approaches yielding lesser volumes of water include reuse of drilling wastewater and use of excess water collected during wet months or heavy precipitations events. Blending of water from different sources, and particularly of different quality, has become more widespread in the past few years (and has compounded geochemical compatibility and scaling issues).

The work in this report is described along three fronts: (1) groundwater not related to the Trinity aquifer (the regional aquifer tapped by municipalities), (2) non-State surface waters, and (3) municipal and industrial sources. Groundwater and surface water, being broadly distributed, natural water sources, are less controllable in terms of quantity and quality through time. The next section (Section 3) gives details on water-quantity and water-quality requirements. Section 4 endeavors to explain the use of small ponds by the industry by examining pond supply through time and under different climatic conditions (wet year, dry year). This information may suggest new approaches to the industry for coping with the lack of easily accessible groundwater.

Section 5 investigates availability of groundwater outside the Trinity aquifer, particularly in terms of volume, water volume, and well yield. Lastly, Section 6 describes options for the use of nonconventional sources of water and the availability of this water for future completions in the Barnett Shale.

As the population within the Barnett Shale footprint continues to grow and as demands for fresh water intensify, it may be strategically important in the long term for the industry to develop fewer water-intensive fracs. In the midterm, the ability of the industry to process its flowback and produced water for reuse in frac jobs will be of tactical significance as a means of reducing fresh-water demand in the shale-gas industry. Further improvement in industry fresh-water demand could be achieved through improved additives and treatment technologies to use with saline water produced from deeper saline aquifers (e.g., Ferguson and Johnson, 2009). Auxiliary water use such as drilling could also move from water-based mud to air drilling as much as possible. In the interval, alternate sources such as (nonpotable) brackish aquifers could help in the transition.

Table 1. Summary of water sources and assessment of use in the Barnett play.

Source	Water Quality			Water Use***
	Fresh*	**Brackish**	**Saline****	
Surface Water				
Lakes, rivers	√			**++++**
		√		**++**
Ponds	√			**+++**
Groundwater				
Shallow depth	√			**++++**
Shallow to intermediate depth		√		**++**
Deep aquifer and produced water			√	**+**
Unconventional / Reuse				
Municipal WS	√			**+++**
Industrial WW	√			**+**
Municipal WW	√			**++**
Minimally treated flowback	√	√		**++**
Recycled flowback	√			**++**
Mining impoundments or ponds				**–**

* defined as <1,000 mg/L

** defined as >20,000 mg/L (see Section 3)

*** qualitatively defined as heavy (++++), significant (+++), marginal (++), emerging (+), or very minor (–) use

WS= water supply; WW= wastewater

3 Water-Quantity and Water-Quality Requirements

3.1 Water-Quantity Requirements

Fracing needed to open up flow pathways to produce gas requires large amounts of water, and those details will not be discussed here. The Barnett Shale play has used ~100,000 AF of fresh water (1 AF = 325,851 gal = 7,758 bbl) (Figure 5) and is currently using ~25,000 AF/yr, with a dip in 2009–2010 because of economic circumstances and low gas prices. As described in Bené et al. (2007) and Nicot and Potter (2007), this amount of water is small compared with the volumes needed for municipal and other uses. The State of Texas as a whole uses 18+ million AF/yr of fresh water (TWDB, 2007). Initially in the 1990's and early 2000's, most fraced wells were vertical, but, beginning in 2003–04, drilling of horizontal wells grew fast and now dominates the play (Figure 6). Vertical wells were used mostly in the core area, close to Fort Worth, in Denton, Johnson, Tarrant, and Wise Counties. This comment is important because horizontal wells consume more water than vertical wells on average and, thus, require more plentiful water sources. Vertical wells use ~1 to 1.5 million gal per frac job (Figure 7a and Figure 8a), whereas horizontal wells consume 3+ million gal (Figure 7b and Figure 8b). In general, water must be delivered during fracing in a short amount of time (~1 day), and water is stored onsite while the well is being drilled (~3 weeks). This requirement translates into a constraint for water sources to be able to provide this volume in the allotted time. Of course, water demands for completions become larger in magnitude and more complex (with regard to timing of delivery) as the industry moves toward the use of multiple-well pads (Figure 9). Three million gal in 3 weeks requires a pumping rate of ~100 gal per minute (gpm) or 0.14 MGD (*gpm* and *MGD* are customary units for well pumpage and treatment plants, respectively). Bené et al. (2007) suggested that the groundwater–surface water split was ~50-50%, but the data are not easy to access and the issue has become more complicated by the use of recycling. The split most likely varies in space and time because operators are opportunistic.

3.2 Water-Quality Requirements

A report was obtained from a Hydraulic Fracturing Expert Panel conducted by the BSWCMC that described the minimum quality of water needed to conduct hydraulic fracturing without compromising the quality of shale-gas well completions (Hayes, 2007). The report discusses critical parameters on total dissolved solids (TDS), ionic make-up, and other requirements of fracing fluids. Some of the key elements are:

- Consistency in fluid composition, which relates to water amount—that is, a source large enough to provide water for at least a significant fraction of the job,
- Circum-neutral pH (6–8) for optimal biocide use,
- Low hardness (Ca <350 mg/L) to limit polyacrylamide friction reducer demand,
- TDS as measured by chloride; use of water with a chlorinity of 10 g/L(~16–17 g/L TDS) is still appropriate according to all panel members; high TDS (Cl>35,000 mg/L) is detrimental to friction reducers,
- Total suspended solids (TSS) <50–100 mg/L, and
- Sulfate that must be watched closely because of the impact of sulfate-reducing bacteria and because of scale-forming $BaSO_4$ with a very low solubility product.

Other parameters to be considered include iron, boron (premature cross-linkage), and dissolved O_2 (bacteria). These observations are confirmed by other statements available online. However, note that the Hydraulic Fracturing Expert Panel was conducted more than 3 yr ago and that the technology is quickly advancing. Another issue becoming more prevalent is the increase in the number of stages and total water volume requirements. A related concern involves the management of the chemical compatibility of waters that are more and more likely to be of from different origins (blending) as the required amount increases.

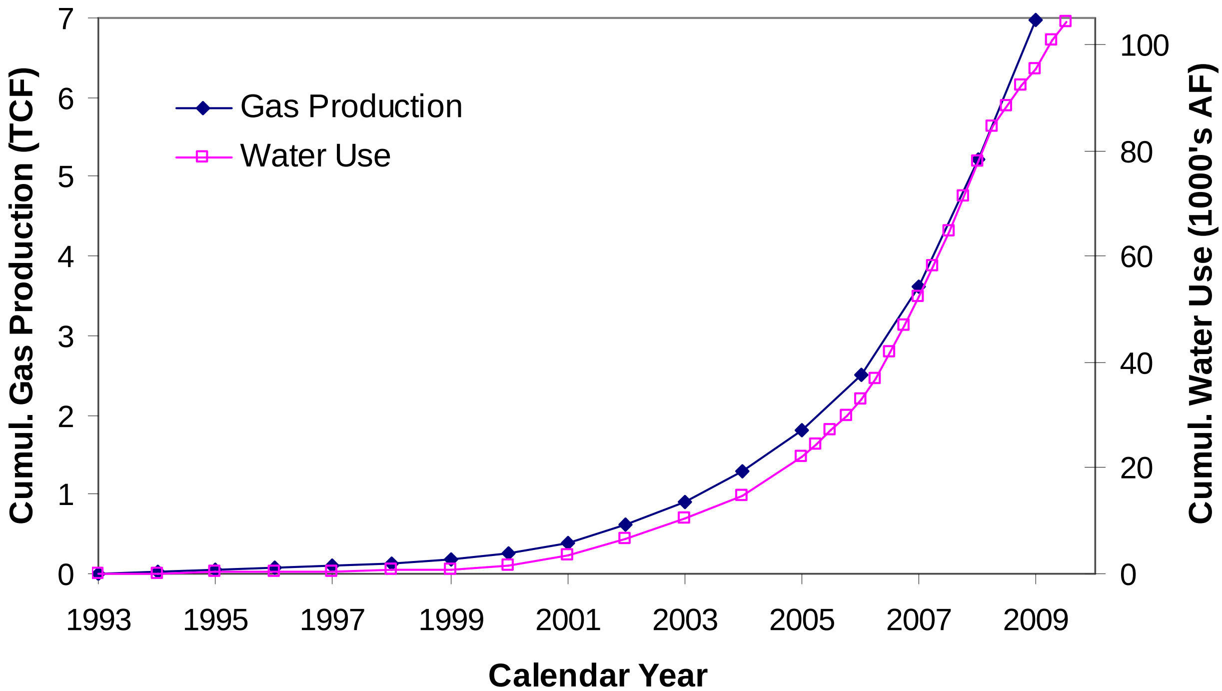


Figure 5. Cumulative gas production and water use in Barnett Shale play from origins.

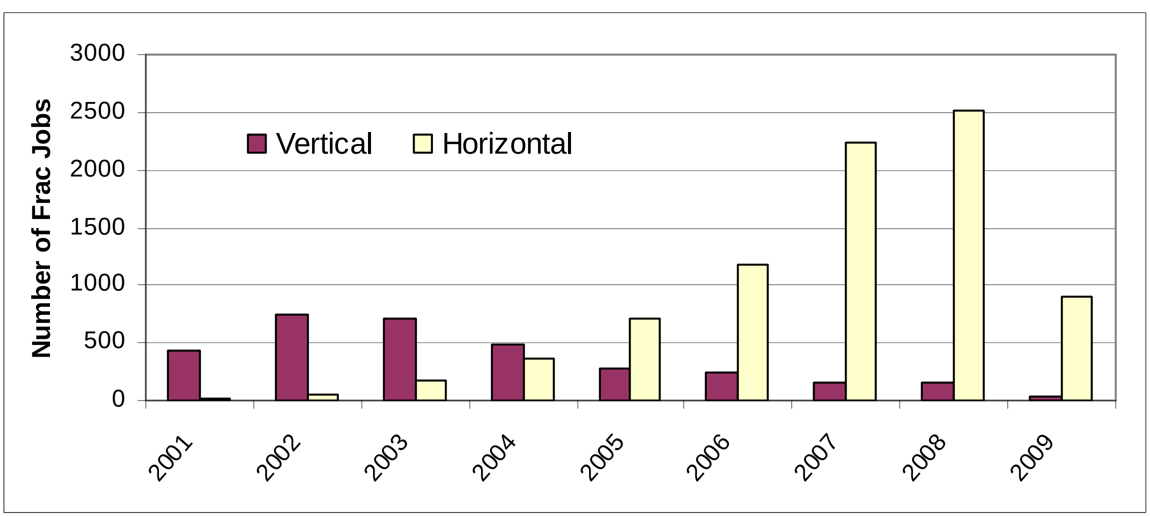
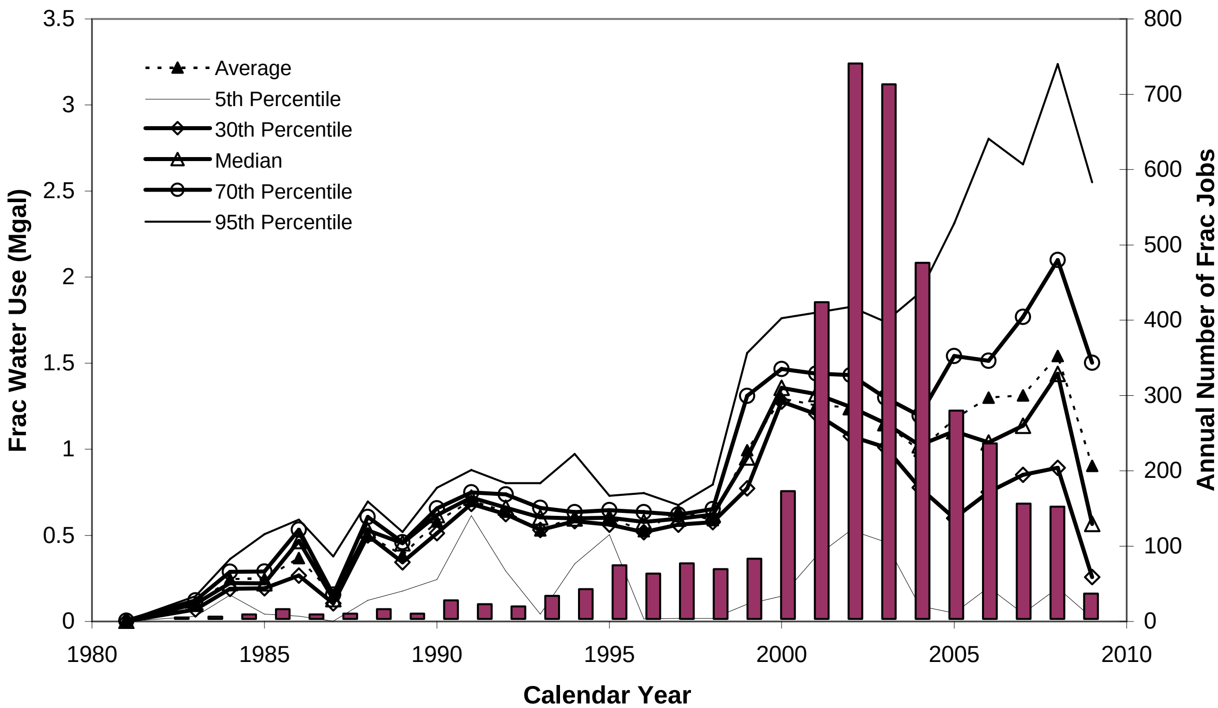
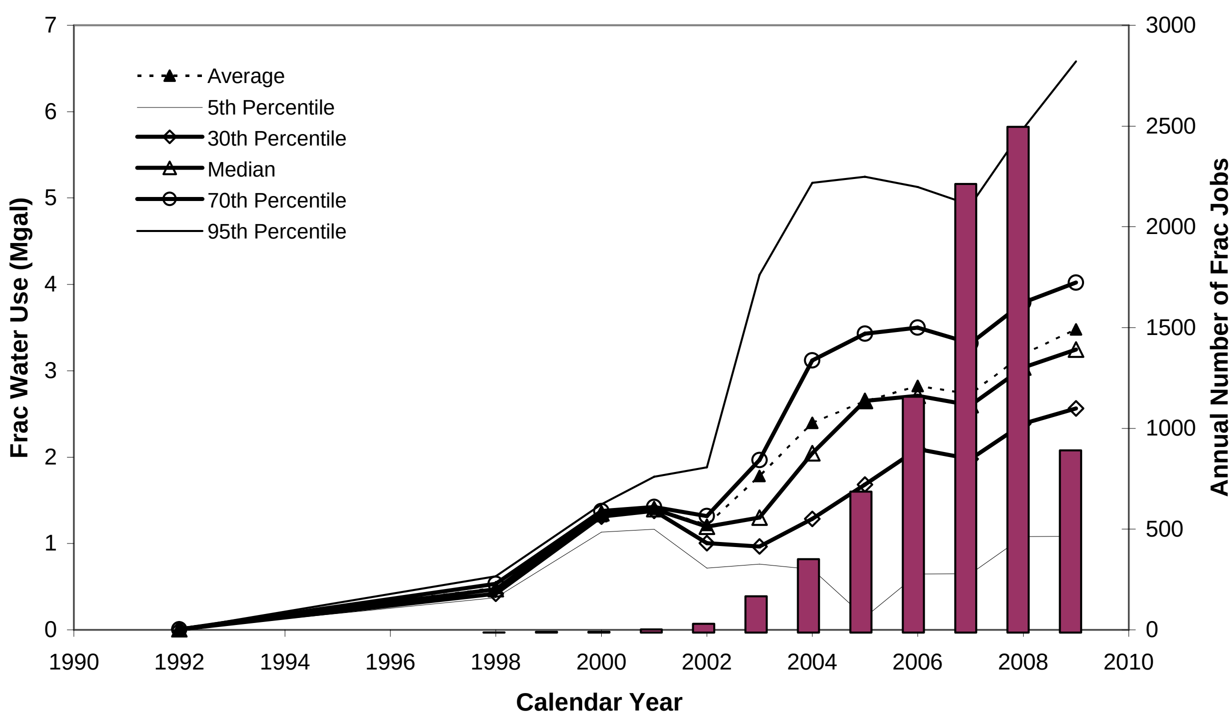


Figure 6. Barnett Shale—vertical vs. horizontal and directional wells through time.

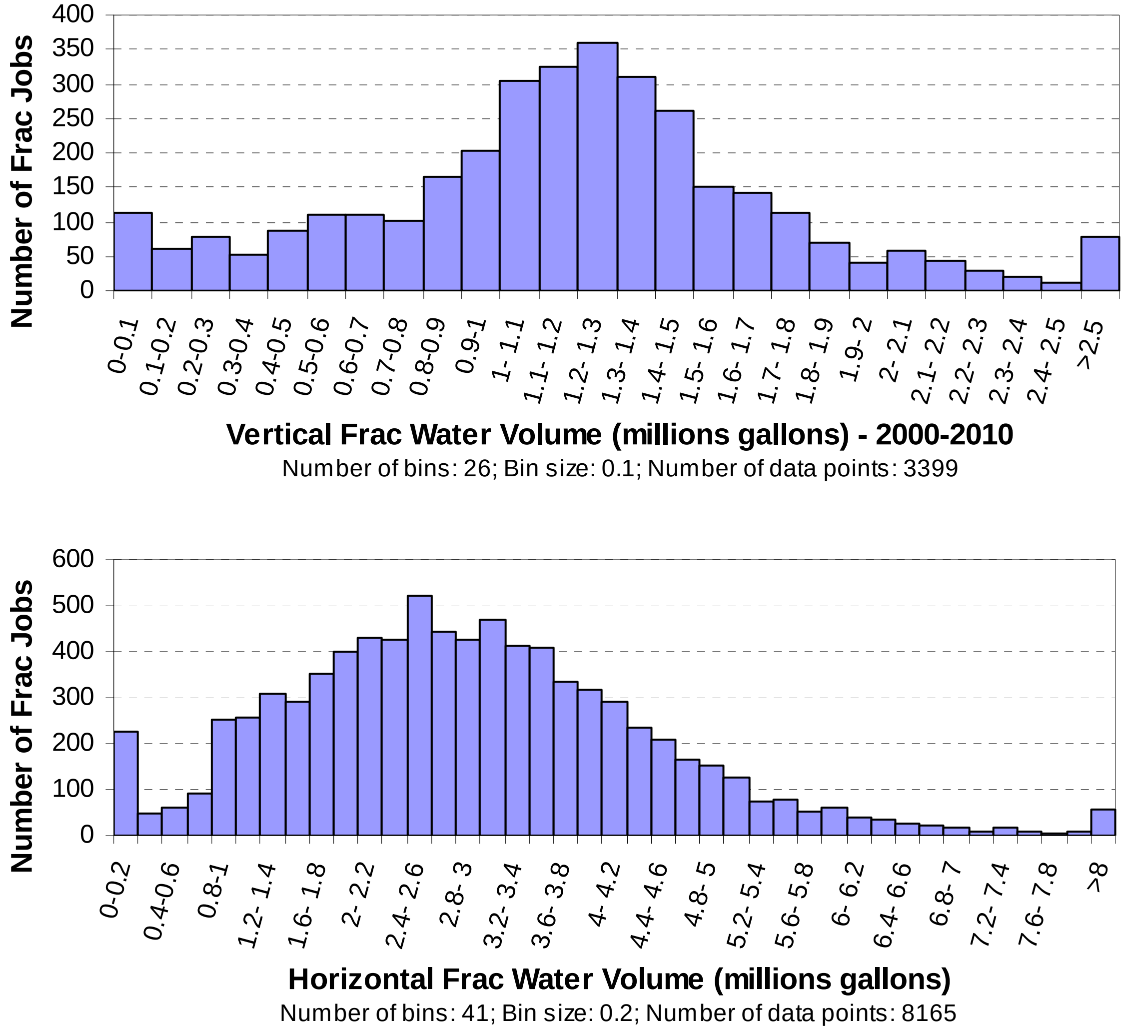


(a)



(b)

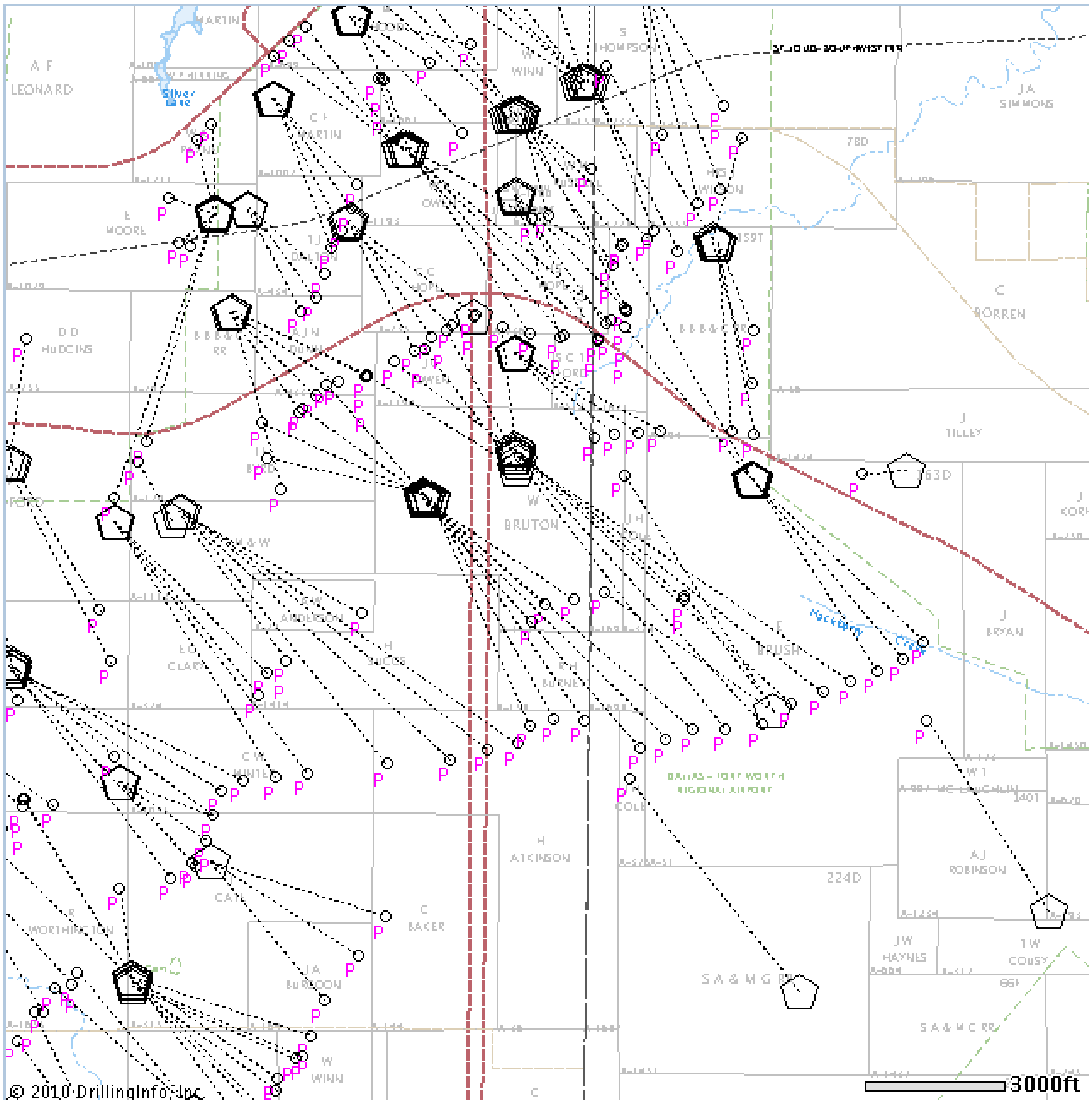
Figure 7. Barnett Shale—annual number of frac jobs superimposed on annual average, median, and other percentiles of individual-well frac-water use for (a) vertical wells and (b) horizontal wells.



(a)

(b)

Figure 8. Barnett Shale—histograms of frac-water use for 2000–2010 (a) vertical wells and (b) horizontal wells.



Source Courtesy of DrillingInfo

Note: map displays an average drainage area of ~80 acres/well (laterals not pads) where laterals are dense. Pentagons depict locations of multilateral well pads, whereas dotted lines depict different laterals originating from the same well pad. Laterals are more or less parallel because they are oriented perpendicular to the local minimum horizontal stress. Underlying gray boundaries denote property lines (not relevant to the discussion).

Figure 9. Example of Barnett Shale density of laterals (Dallas-Tarrant County line).

4 Surface-Water Bodies

Surface water in Texas, such as rivers and lakes (Figure 3), is owned by the State, which grants the right to use it to different entities. Typically a permit is needed to retrieve the water unless it falls under an "exempt use." Exempt uses include "domestic and livestock use," for which impounding and storing of water are allowed on properties adjoining a stream but not greater than 200 AF (65 million gal) on average in any consecutive 12 months. This water cannot be sold, however. For the water to be used for that purpose, the landowner would need to ensure that the potential buyer (gas operator) obtained a temporary permit from TCEQ. If a surplus of water is not appropriated, temporary permits can be granted relatively easily. Clearly, during drought, when junior water rights might not be fulfilled, temporary permit requests will not be approved. Processing in regional TCEQ offices is generally quick, provided the volume requested is, at most, less than 10 AF (3.26 million gal) in a calendar year. In addition, surface runoff, as long as it has not entered a natural water course, belongs to the landowner, not the State.

As detailed next, orthoimagery coverage (publicly available from Texas Natural Resources Information System, or TNRIS) was used to inventory surface-water bodies. In addition, the TCEQ Central Registry (see Section 6) was also used to examine and evaluate other program-related datasets for further water-availability potential. These included water rights, utilities, and public water system/supply programs. Water-rights permit holders are authorized to withdraw a designated amount of water from surface-water sources for industrial, agricultural, municipal, and other uses. Approximately 570 entities hold water-rights permits in the initial 10-county study area. Utilities are established entities approved by the TCEQ to provide water and wastewater services to specified geographic areas of the state. Approximately 250 utilities are authorized in the 10-county area. Public water systems (PWS) cover a broad spectrum of public or privately owned facilities, ranging from cities to neighborhood water-supply systems to individual businesses that provide potable water to customers. Approximately 530 PWSs exist in the study area. Because all of these entities are already committed to providing existing or future uses of water in the area, they were determined to be unlikely sources of available water for fracing operations.

4.1 Water-Body Statistics—Satellite-Imagery Study

The inventory of non-State-regulated surface-water features in the footprint of the Barnett Shale in Montague, Wise, Parker, Hood, Somervell, Jack, Palo Pinto, Erath, Bosque, and Hill Counties is nearing completion (Figure 10). Previously, the wettest and driest months from 1995 through 2000 (that is, before gas-drilling activities) were identified. Within the counties of interest, greatest departures from normal mean precipitation for 1971 through 2000, both wet and dry, occurred in the month of February (Figure 11). The wettest month was February 1997 in which a mean monthly precipitation of 7.7 inches was recorded. The driest month occurred 2 years later. For the 10-county area, the driest year in the region of interest occurred in 1999; 1997 was the wettest year.

Two Landsat satellite passes, typically called *paths*, are required to cover the area of interest. These are Path 28 to the west and Path 27 to the east (Figure 12). Two Landsat images per path are required to cover the area of interest. Previously all potential Landsat images for the period of interest (1995 through the present) were prescreened. In total 60 cloud-free candidates and 20 additional candidates were potentially useful in some capacity. Table 2 shows the image candidates chosen for time-series analysis and a brief synopsis of collection conditions in relation to monthly mean precipitation. The image candidates for 2010 were updated when cloud-free observations were made in November of that year. Preference was given to single date collections by path and near-date collections for adjacent paths. For example, the dry baseline image for Path 27 uses data collected on February 14, 1999, for the east half of the area of interest. A near-date image collected on February 21, 1999, was chosen for Path 28. Although the latter image was collected during the month ranked as third-driest, the mean monthly precipitation and the 7-day time proximity made it the best match. Images representing the wettest baseline dataset were chosen in a similar manner. For 2003 through 2010, preference was given to same-date images collected along each path. The final choice was based on date proximity of adjacent path collections.

Landsat 5 Thematic Mapper data were preprocessed and mosaicked by path. Alternative methods for preprocessing and classification were tested. In the final processing for identification of non-State-regulated water features from Landsat satellite data currently under way, each image mosaic is processed to remove most atmospheric noise. Vegetation indices, water indices, and a texture measure are calculated. The preprocessed data are subdivided into tiles. Next the multiband tiles are entered into a geographic, object-based, image-analysis program in which each tile is segmented into objects of varying size and classified using an iterative process that first identifies and flags large reservoirs and then identifies water bodies of increasingly smaller sizes. Some features as small as a quarter acre are identified, but the most reliably identified features are 1 acre in size or larger.

Following image classification, results were exported into a common raster data format. Included in the results were objects classified as medium and large reservoirs, rivers, and other surface-water features classed by area extent. The latter water features were exported as unified objects and, in parallel, as objects classified according to water content: 100% water, 75–99 % water content, and 50–74% water content. All tiled results were exported to a conventional image-processing application to reconstruct complete image mosaics. The reconstructed classified image data were exported into a vector GIS format. Within a GIS environment, classification results were compared with source Landsat images. GIS tools were used to eliminate most false-positive objects, including mosaic seam lines, cloud shadow, shadow in terrain, wet soil in fallow fields, water pooling in streambeds, river water not classified as such, and large pools of water in riverine floodplains. The data review also revealed some missed opportunities, but it was not feasible to correct omissions in a timely manner. The area of image overlap was scrutinized. For 6 of the 10 yr analyzed, <9 days elapsed between collection periods. For three of the remaining years, the gap was more than 3 weeks. The largest gap was 39 days in 2004. Consequently, it was decided to merge data collected during a single year to create 10 datasets. Appendix B contains summary statistics describing results, which are arranged by county geography, from north to south and west to east. Results are analyzed in Section 4.2.

Figure 13 and Figure 14 show representative results using Path 27 data from multiple years: 1997, 1999, 2005, and 2010. The area depicted shows the intersection of three counties of interest: Hood, Erath, and Somervell. The smallest identified features are 0.22 acres in size (30-×30-m pixels) but might be slightly larger or smaller in actuality. Graphics are displayed at a slightly greater resolution than is appropriate for 30-m Landsat data, so the reader can see changes in smaller features over time. Some change in feature size is evident in the time-series sample. Note that the number of the smallest water features fluctuates over time.

Note also that some features might be missing in the final classifications and that some features identified as water might not be water in actuality. Several factors determine which features are properly classified. In general, filtering out features represented by 1 to 3 pixels is preferable because of uncertainties in the classifications. However, these smallest features are retained at this time. A review of selected features in comparison with recent high-resolution aerial images indicates that many correspond to water features. Note that feature areas as presented in the tables of Appendix B necessarily represent metrics based on pixel size.

4.2 Surface-Water-Body Analysis

The objective of this part of Section 4 is to assess how much water is potentially available from small private ponds and whether impact of well-completion activities can be seen in a history of pond count and surface area. Note that satellite imagery provides access to the area covered by a water body not to its depth, although it makes sense to positively correlate area and depth. We plan to further investigate this relationship to better constrain the amount of water available. Figure 15 displays examples of plots prepared for all counties in Appendix C. Type 1 plots (Figure 15) display cumulative area at selected times (as discussed in the previous section). In a given county, the area varies by a factor of 3 as a function of precipitation. Type 2 plots, illustrating variations in pond count of different sizes at selected times, consistently show that small ponds are numerous, which is not only an advantage for servicing well pads distributed across the county, but also they are sensitive to weather variations (wet/dry periods). Type 3 plots display completion counts (extracted from the IHS Energy database and calculated on a 1/10 of a year basis) and pond intensity and try to discern impact of fracing on amount of water stored in ponds.

Typical surface area values ranges from <1,000 to <10,000 acres, depending on the county and time. Another way to present the information is to normalize the cumulative pond area by the county area (Figure 16) or to normalize the pond count (all sizes) by the county area (Figure 17). A representative value is 4 acres of (non-State) surface water per square mile, or 0.25 acre per 40 acres. Assuming a depth of 5 ft on average, this is a water volume of ~0.4 Mgal/40 acres. Adding the time dimension shows that this amount of water is more than sufficient to meet all fracing needs. If the play is active for several decades and the pond can be naturally replenished (that is, with precipitation and runoff, not through groundwater pumping or owner intervention) several times a year, the amount of water available is beyond what is needed for a generic well. Another way to present the information that may be simpler is to compare projections for annual needs at the county level to approximate pond volume. Annual needs are estimated to be close to an average of 2,000 AF/yr/county (Nicot et al., 2011), which is covered by the 1,000- to 10,000-acre range with a 5-ft nominal depth.

Comparison with National Weather Service data (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?WWDI~getstate~USA) shows that pond area is correlated with precipitation (Figure 18 and Figure 19) but requires more analysis. Gaining a better understanding of the split between stored groundwater and surface-water runoff (still unknown) is also important in fully accessing the true amount of water available in ponds and other surface-water bodies.

Table 2. Precipitation extremes and Landsat data availability.

Mean Monthly Precip. (inches)	Mo	Yr	Path	Location of AOI	Date Landsat Collection	Rank (1995–1999) or Departure from Normal (2003–2010)	Precipitation Comparison Status	Mean Monthly Normal Precip. (inches)
0.13	Feb	1999	27	East	2/14/1999	Driest	Baseline	1.9
0.15	Feb	1999	28	West	2/21/1999	3rd driest	Baseline	1.8
7.8	Feb	1997	27	East	3/3/1997	Wettest	Baseline	2.0
5.5	Mar	1997	28	West	3/28/1997	4th wettest	Baseline	2.5
2.3	Oct	2003	27	East	10/23/2003	Drier than normal	Oct mean	3.9
2.9	Oct	2003	28	West	10/14/2003	Drier than normal	Sep/Oct mean	3.4
3.1	Sep	2004	27	East	9/7/2004	Near normal	Aug/Sep mean	2.7
2.5	Oct	2004	28	West	10/16/2004	Drier than normal	Sep/Oct mean	3.4
2.3	Feb	2005	27	East	2/14/2005	Near normal	Jan/Feb mean	1.9
2.2	Feb	2005	28	West	2/21/2005	Near normal	Feb mean	2.0
2.5	Nov	2006	27	East	11/16/2006	Drier than normal	Oct/Nov mean	3.1
1.6	Nov	2006	28	West	11/23/2006	Drier than normal	Nov mean	2.1
4.0	Mar	2007	27	East	3/8/2007	Wetter than normal	Feb/Mar mean	2.5
6.5	Mar	2007	28	West	3/31/2007	Wetter than normal	Mar mean	2.5
4.8	Apr	2008	27	East	4/11/2008	Wetter than normal	Mar/Apr mean	2.8
4.8	Apr	2008	28	West	4/18/2008	Wetter than normal	Mar/Apr mean	2.6
8.4	Oct	2009	27	East	10/23/2009	Wetter than normal	Oct mean	3.9
5.9	Sep	2009	28	West	9/28/2009	Wetter than normal	Sep mean	3.0
n/a	Jun	2010	27	East	11/27/2010	n/a	n/a	n/a
n/a	Apr	2010	28	West	11/18/2010	n/a	n/a	n/a

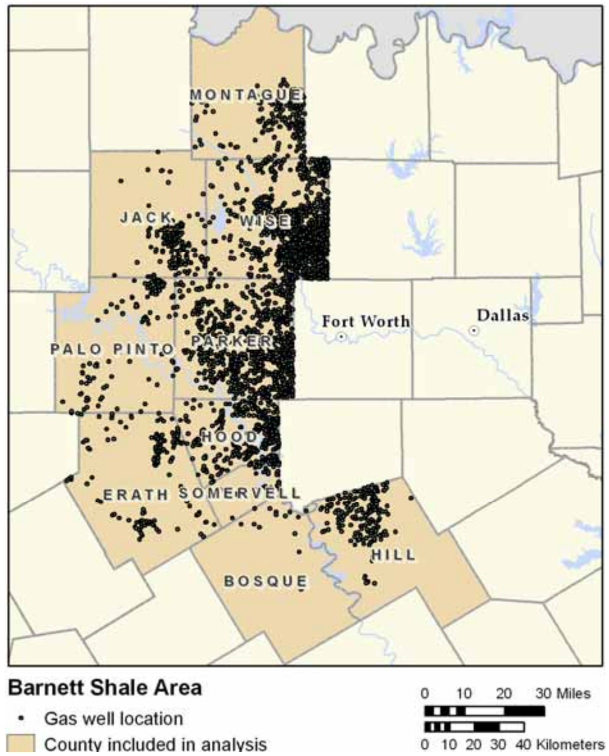


Figure 10. Project area counties and distribution of Barnett Shale wells.

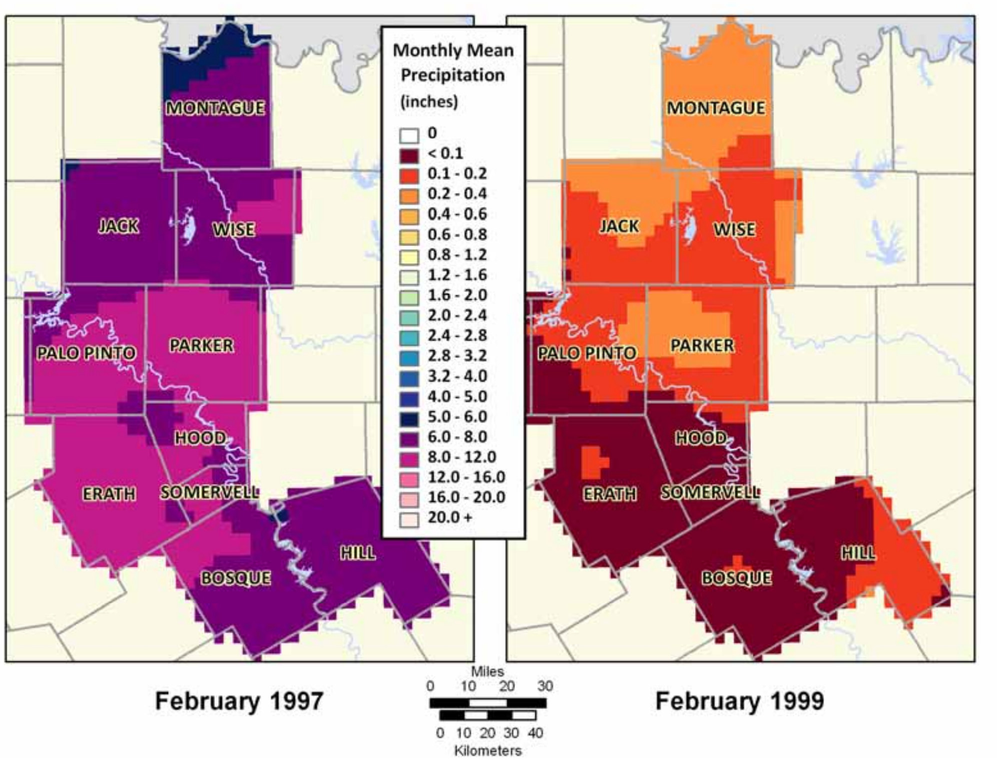


Figure 11. Wettest and driest months, 1995–2000.

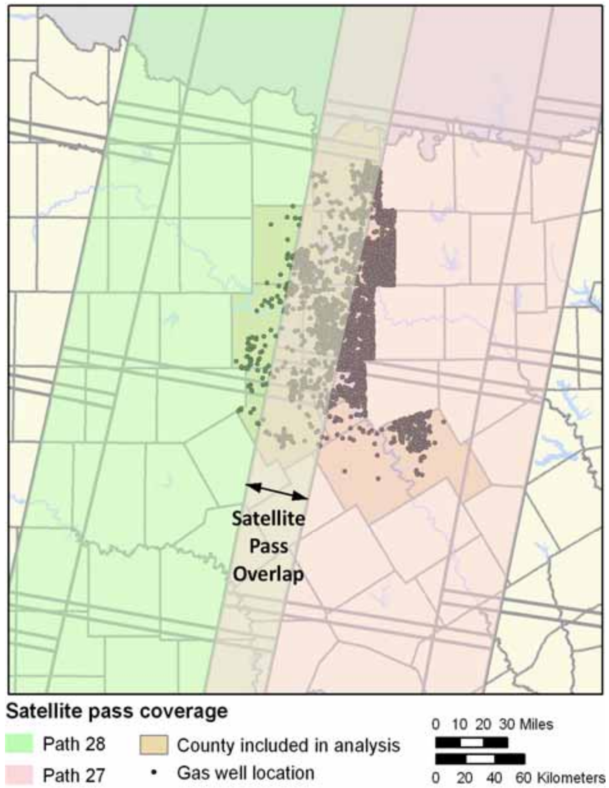


Figure 12. Landsat Paths 28 and 27 in relation to the study area.

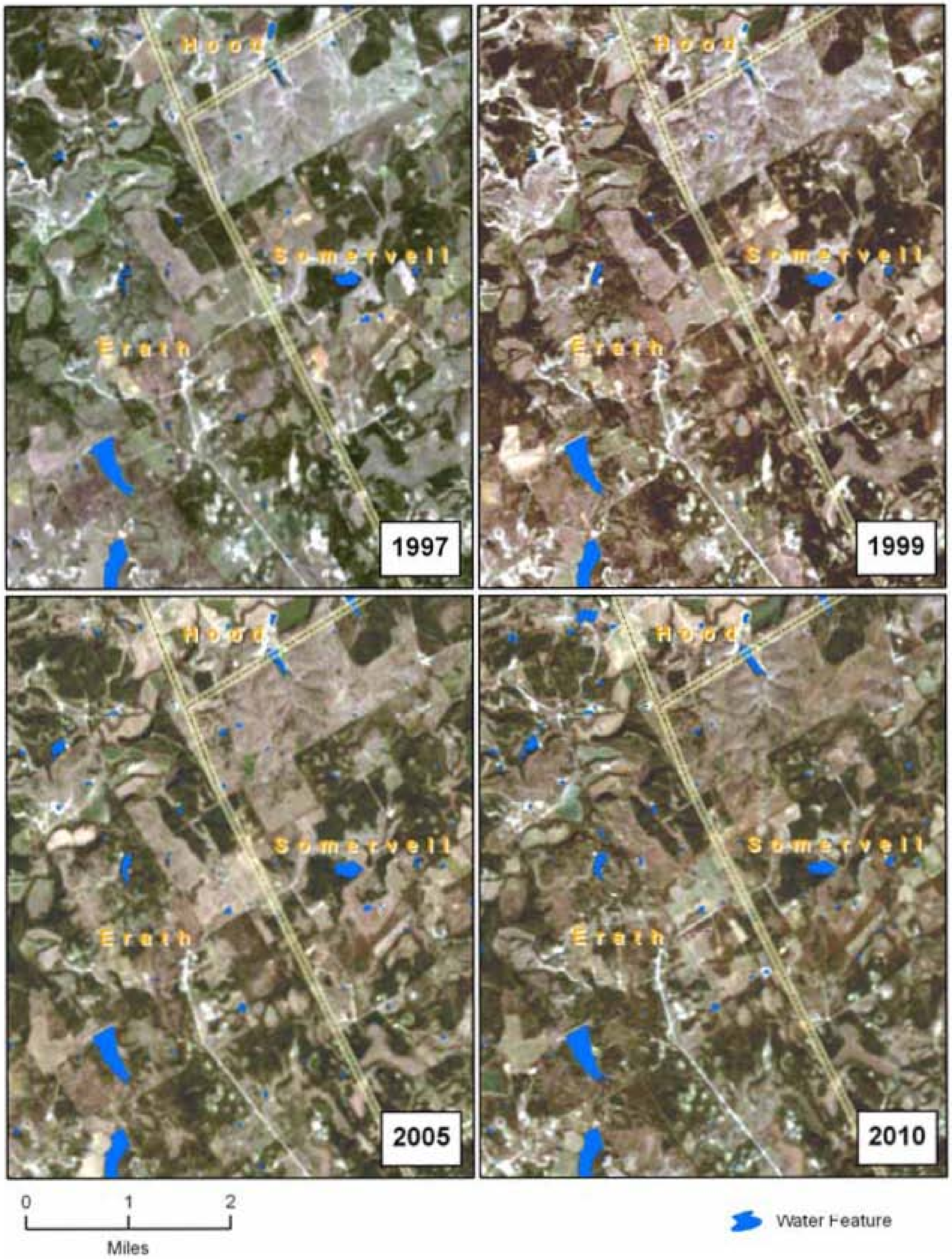


Figure 13. Surface-water features identified during multiple years and shown with source Landsat images.

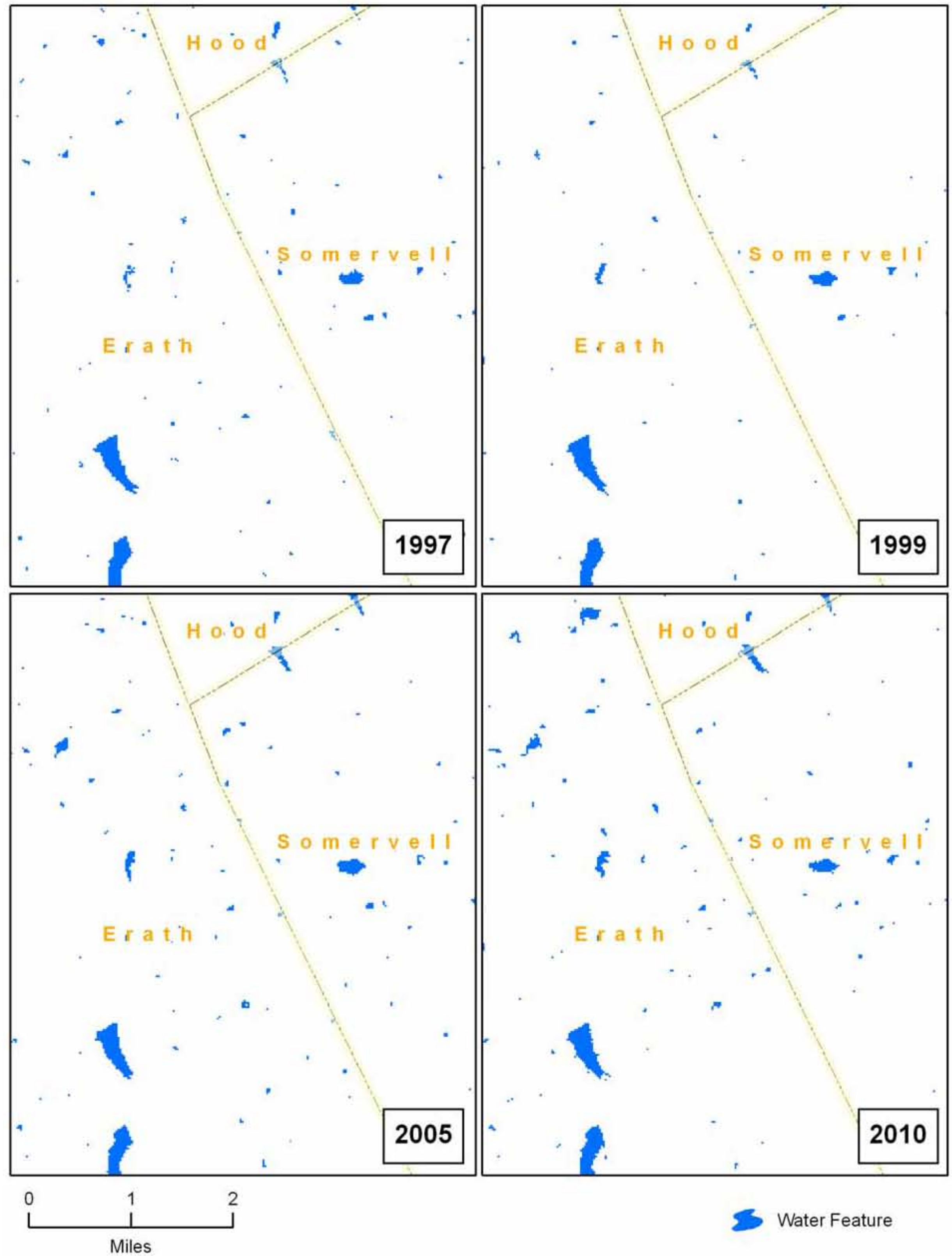
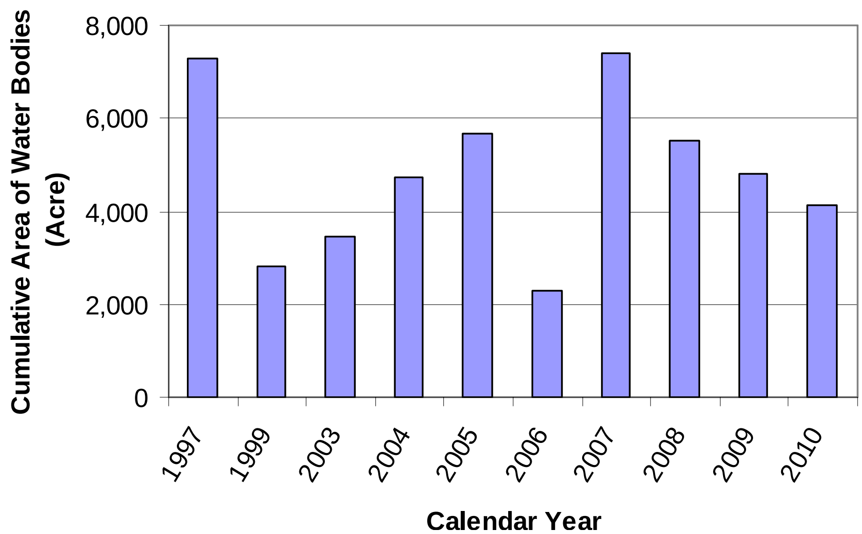
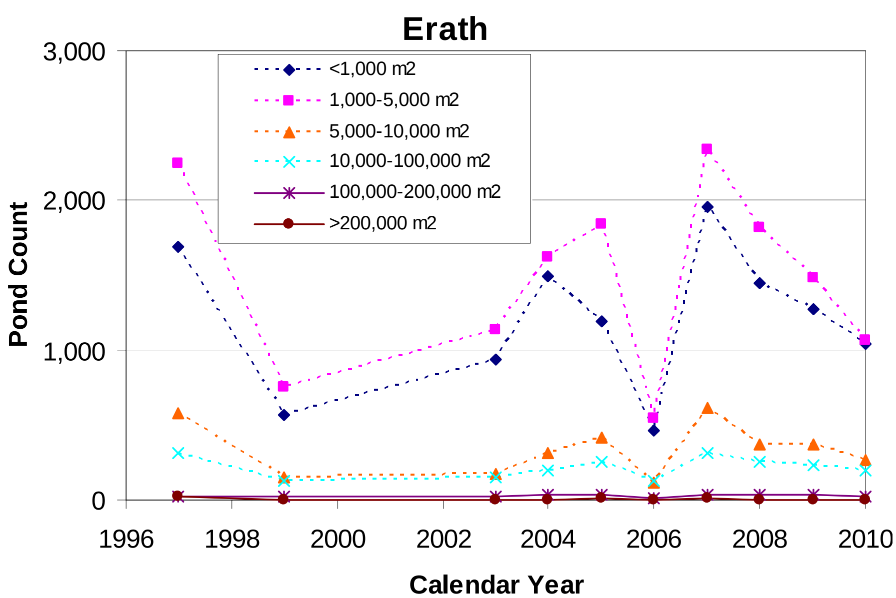


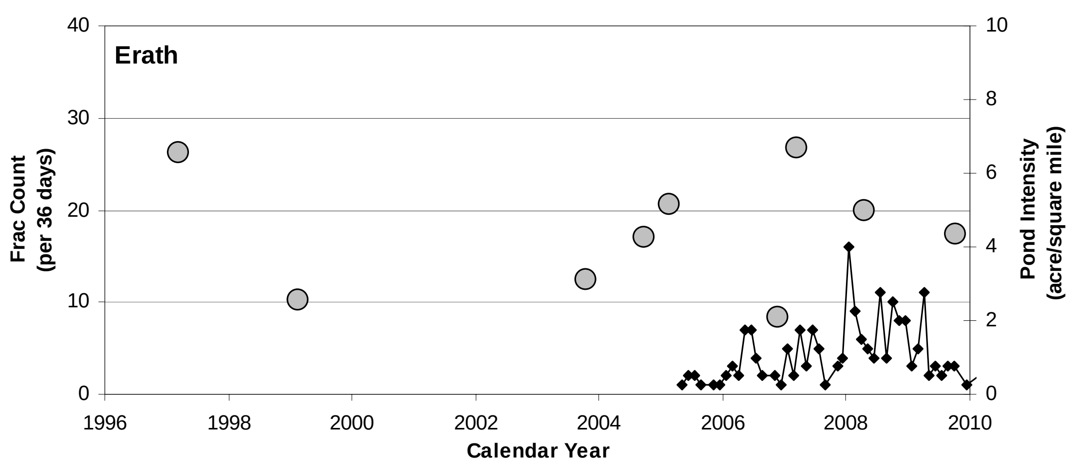
Figure 14. Surface-water features identified during multiple years without image backdrops.



Type 1 plot



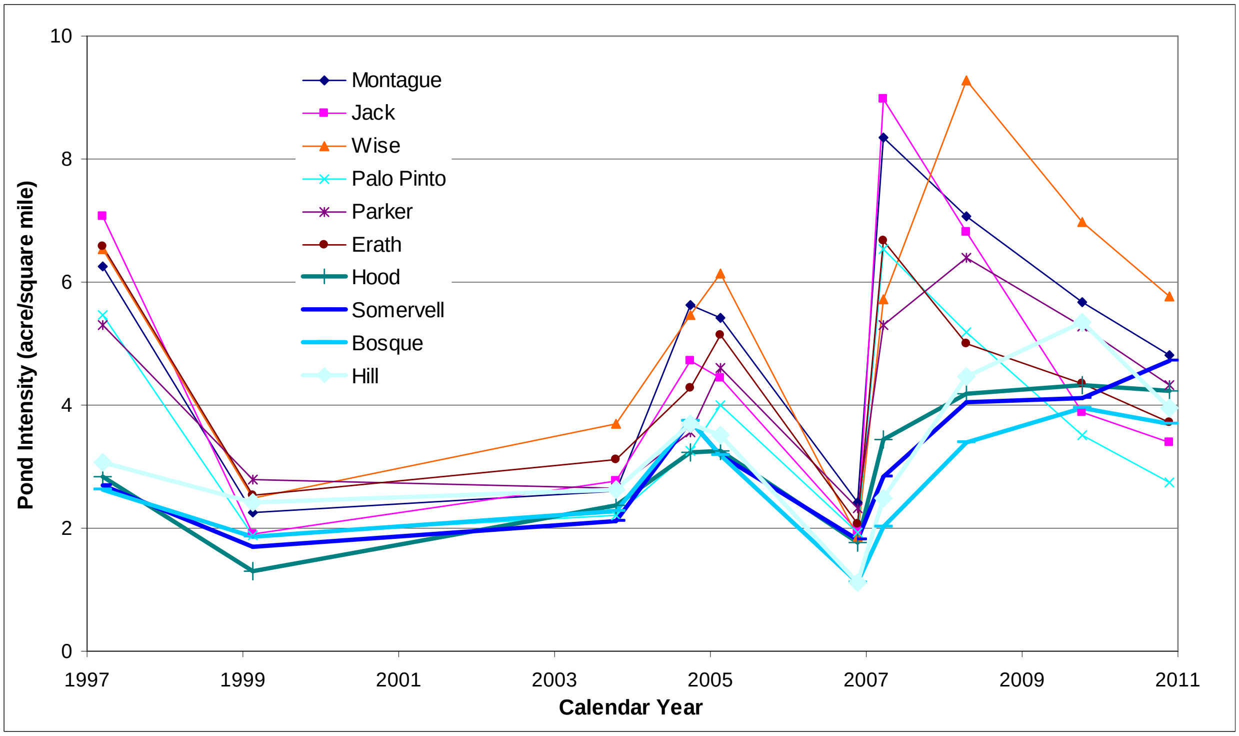
Type 2 plot



Type 3 plot

Note: 1997: preactivity wettest month; 1999 preactivity driest month

Figure 15. Example (Erath County) of plots presented in Appendix C.



Note: straight line segments are not meant to infer that interpolation is linear between data points (actually it is very likely that is not) but for ease of reading.

Figure 16. Pond intensity (acre per square mile) for selected times.

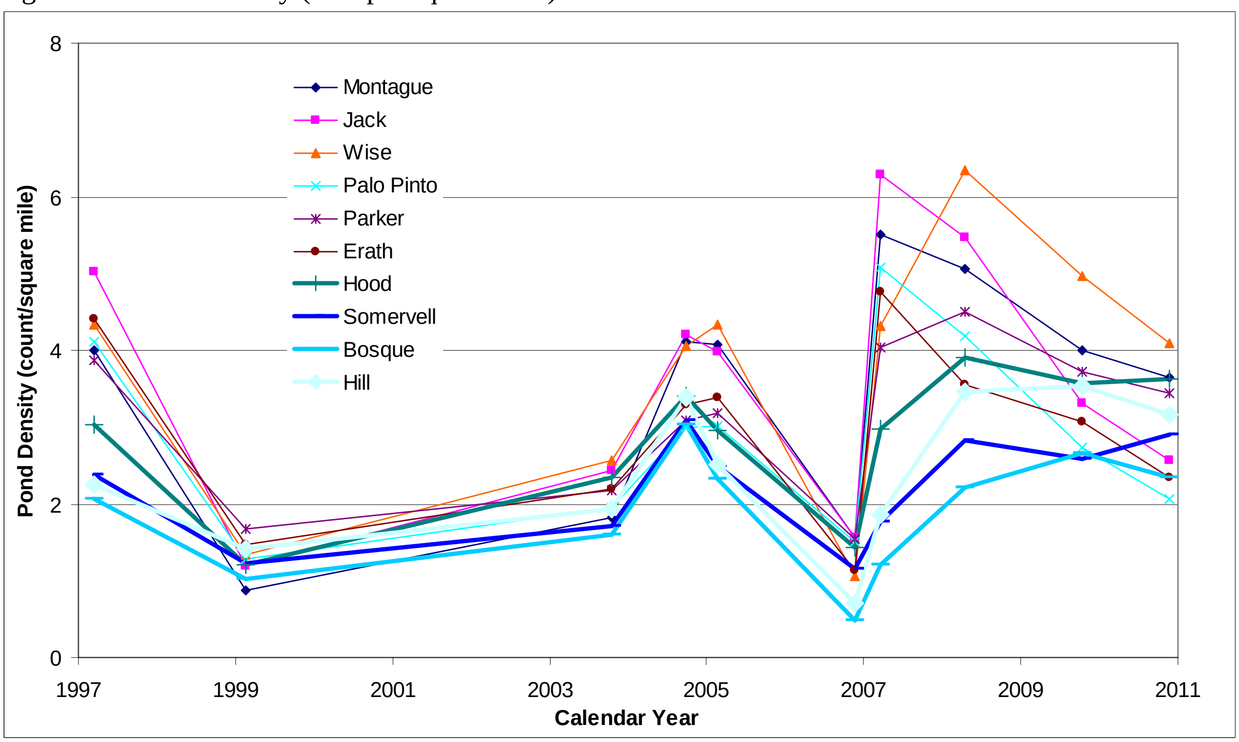
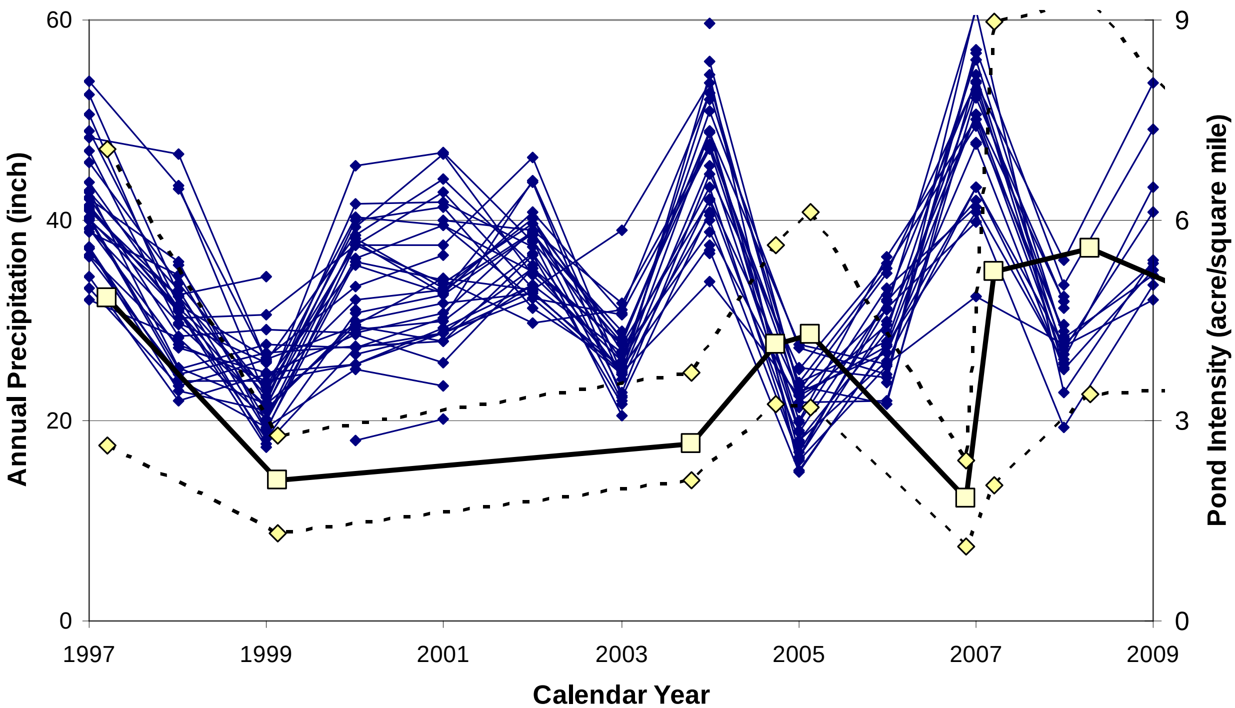


Figure 17. Pond density (pond count per square mile) for selected times.



Note: solid lines: 43 weather stations covering the 10-county area of interest; open symbols: pond intensity.

Figure 18. Comparison of annual precipitation (and minimum, average, and maximum pond intensity).

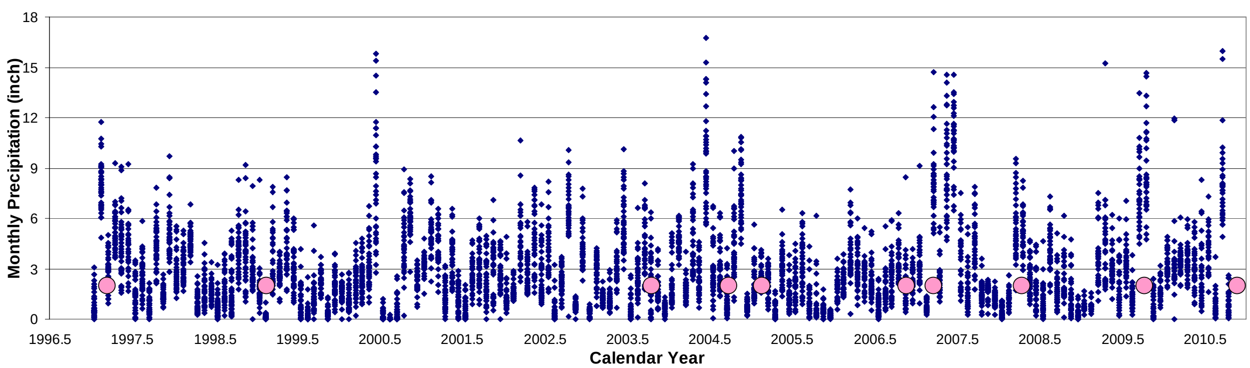


Figure 19. Monthly precipitation (small dots) and time location of orthoimagery results (large circles).

5 Groundwater

Generally groundwater belongs to the landowner under the rule of capture. Groundwater is managed by pseudo-governmental entities called Groundwater Conservation Districts (GCDs), often corresponding to a single county. If the property is not part of any GCD, the rule of capture fully applies, and the landowner is free to first pump and then sell as much water as he/she wishes. Within the confines of a GCD, some rules apply. Most of the area of interest is part of a GCD, except for Palo Pinto and Jack Counties (Figure 20). Not coincidentally these two counties also have a limited amount of good-quality groundwater.

A literature survey of aquifers existing in the footprint of the study area was performed and other information on them was gathered as well. The major aquifer in the area is the Trinity aquifer (Figure 1), but several counties also include smaller aquifers in Paleozoic formations in Palo Pinto and Jack Counties, as well as bits of Montague, Wise, Parker, and Erath. These smaller aquifers contain significant amounts of brackish water; in this analysis, both fresh-and brackish-water aquifers are of interest.

Overall, groundwater resources in the study area can be categorized into two groups: Trinity aquifer resources and all others (Figure 21). The Trinity aquifer outcrop is elongated north-south and covers, from north to south, most of or a sizable fraction of Montague, Wise, Parker, Hood, and Erath Counties. East of these counties the Trinity aquifer is confined (from north to south, Cooke, Denton, Tarrant, Johnson, Hill, and Bosque Counties), and water is more plentiful. Farther east, the Woodbine aquifer (a minor aquifer) crops out in the east section of Cooke, Denton, Tarrant, and Johnson Counties. No TWDB-defined major or minor aquifer lies west of the Trinity aquifer, only relatively limited sand lenses. Jack and Palo Pinto Counties are entirely outside the Trinity footprint. Montague, Wise, Parker, Hood, and Erath Counties are on the Trinity outcrop, which is thin in much of or in the west half of the counties. The Trinity aquifer, whose sediments are of Cretaceous age, is contained in the first formation deposited on top of older Paleozoic formations. They dip toward the southeast toward the Gulf, whereas Paleozoic formations dip toward the center of the basin, currently located in the Midland area (Figure 22). The Trinity aquifer outcrop is particularly thin in parts of Montague and Wise Counties, where wells are drilled through it to reach underlying Paleozoic aquifers. Figure 23 depicts the distribution of PWS wells (not domestic wells). Apparently when available, the Trinity aquifer is used heavily (although the Dallas-Fort Worth metroplex uses mostly surface water for municipal purposes). Some Paleozoic aquifers are also a good source of fresh water, with rates as high as 150 gpm in Montague County.

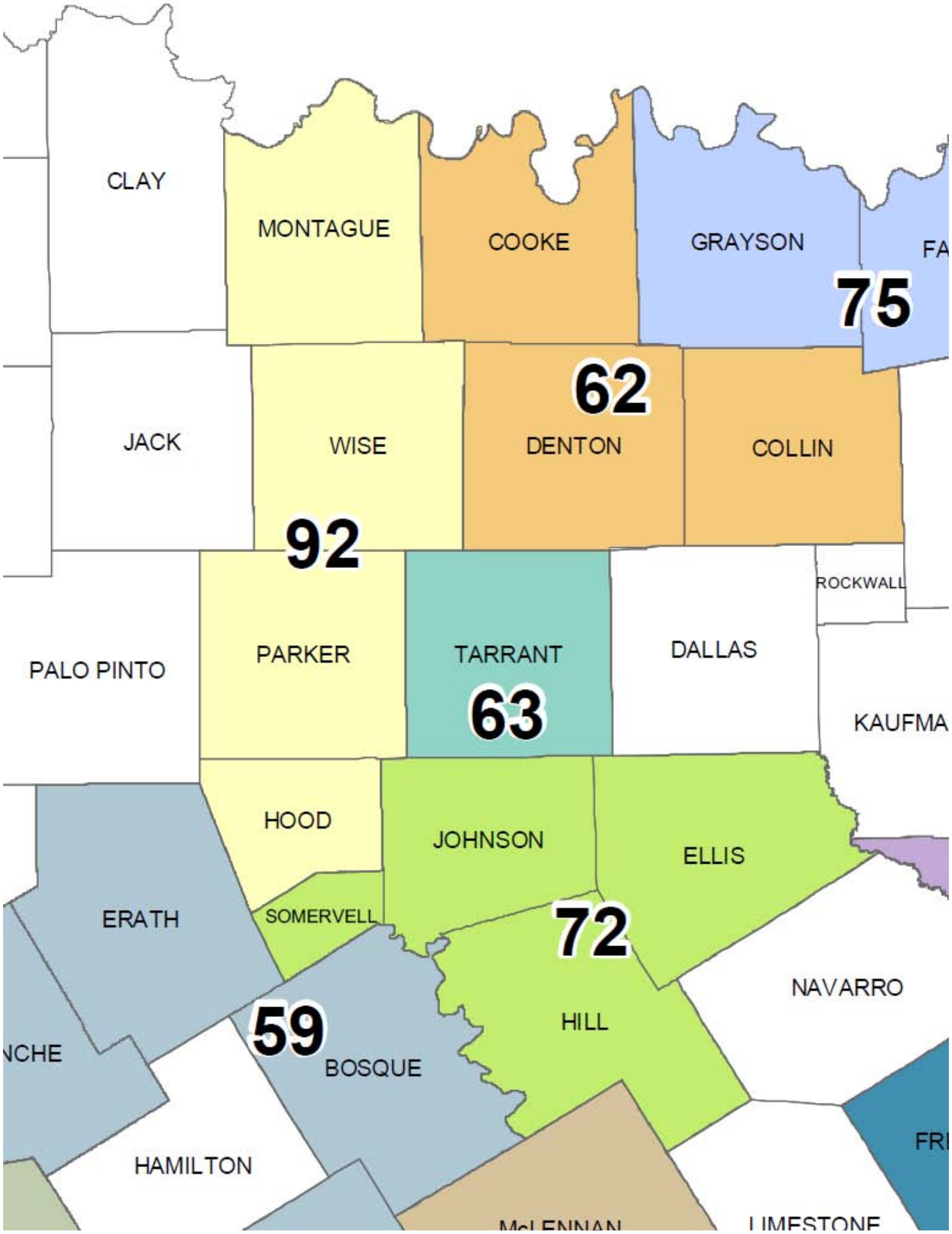
The TCEQ PWS database provides mostly flow-rate information about municipal wells and other regulated entities; water-quality information is not as complete. The TWDB Driller database (http://www.twdb.state.tx.us/GwRD/waterwell/well_info.asp) contains data about domestic wells and provides more information on both well and aquifer characteristics. Note that any water well drilled in Texas needs to be reported to TCEQ. Some drillers do so electronically, and their applications are available through the TWDB website. Others file their applications in a paper format, and extracting the information would require much more time to sift through the files. Data to be extracted are yield (Q or flow rate) sustained by wells and drawdown (s). Most well files provide that information; however, most wells are domestic and do not pump as much water as the well can provide. This information is available through computation of specific discharge (*Q*/*s* or flow rate over drawdown), although it is harder to obtain because many drillers do not report drawdowns.

Clearly a better understanding of Paleozoic aquifers is needed, particularly their recharge processes and flow systems. TWDB has understandably been focusing on much larger, more heavily used aquifers across the state, although these Paleozoic aquifers are locally important. Typically in a period of drought, water users rely more on groundwater than on surface water, but how resilient to drought is groundwater if most of the flow system has short pathways and quickly discharges into streams and rivers? Further work is needed to compare water level as a function of time and precipitation. Paleozoic aquifers are typically small, with a footprint of less than a county in area. Limited information about one of them is provided next.

Avakian and Wermund (1994) studied the Mineral Wells aquifer in Palo Pinto County. The Mineral Wells Formation generally consists of thin sandstones and limestones embedded within mostly shaly sediments. Near the city of Mineral Wells in Palo Pinto County, where the formation is 700 ft thick (Avakian and Wermund, 1994, p. 21), seven nonshale units can be counted with the following thicknesses: 25 ft (Hog Mountain Sandstone); 10 ft (unknown); <50 ft (Lake Pinto Sandstone); and 5 ft, 12 ft, and <50 ft (Turkey Creek Sandstone), from oldest to youngest (note that names vary in different publications). Avakian and Wermund (1994) found that the Hog Mountain Sandstone (IPhm in Brown et al., 1972) can be followed ~5 or 6 miles east of the city of Mineral Wells. The Turkey Creek Sandstone (IPtc in Brown et al., 1972) can be followed 25+ miles until it disappears under the Cretaceous; it is probably hydraulically connected to the sands of the Twin Mountains Formation and possibly recharged through them. TDSs are close to the 1,000 mg/L threshold and frequently above it. Formations seem unconnected, and water levels in wells seem to reflect local precipitation (Avakian and Wermund, 1994, p. 57). Many low-yield wells tap (or at least used to tap) these formations (Fisher et al., 1996, p. 7). Water drillers go down 500 ft to reach these formations, and they report that traces of oil or gas are currently encountered below ~250 ft (p. 7) [see Parker County recent incident]. Fisher et al. (1996, p. 17) also noted that wells are constructed deep to increase well storage and ensure steady water supply. Fisher et al. (1996) performed well testing and extensive sampling.

Table 3. Characteristics of small aquifers outside Trinity aquifer footprint.

Percentile	Bicarb (mgl)	Sulfate (mgl)	Chloride (mgl)	pH	TDS	Alkalinity	Specific Capacity (gpm/ft drawdown)	Transmissivity (ft^2/day)	Well Depth (ft)
95th	749	593	1,700	8.8	3,796	638	5.01	964.2	499
70th	518	151	235	8.3	1170	434	1.70	327.6	245
50th	425	78	120	8.1	758	357	1.00	192.6	190
30th	353	45	52	7.7	545	296	0.50	96.3	113
5th	213	15	14	7.2	334	182	0.10	19.3	29
Max	2,026	4530	9,572	11.5	14,189	1,660	40.1	7,722.5	1,010



Source: TWDB website
Note: 75: Red River GCD; 62: North Texas GCD; 92: Upper Trinity GCD; 63: Northern Trinity GCD; 72: Prairielands GCD; 59: Middle Trinity GCD.

Figure 20. Map of groundwater conservation districts.

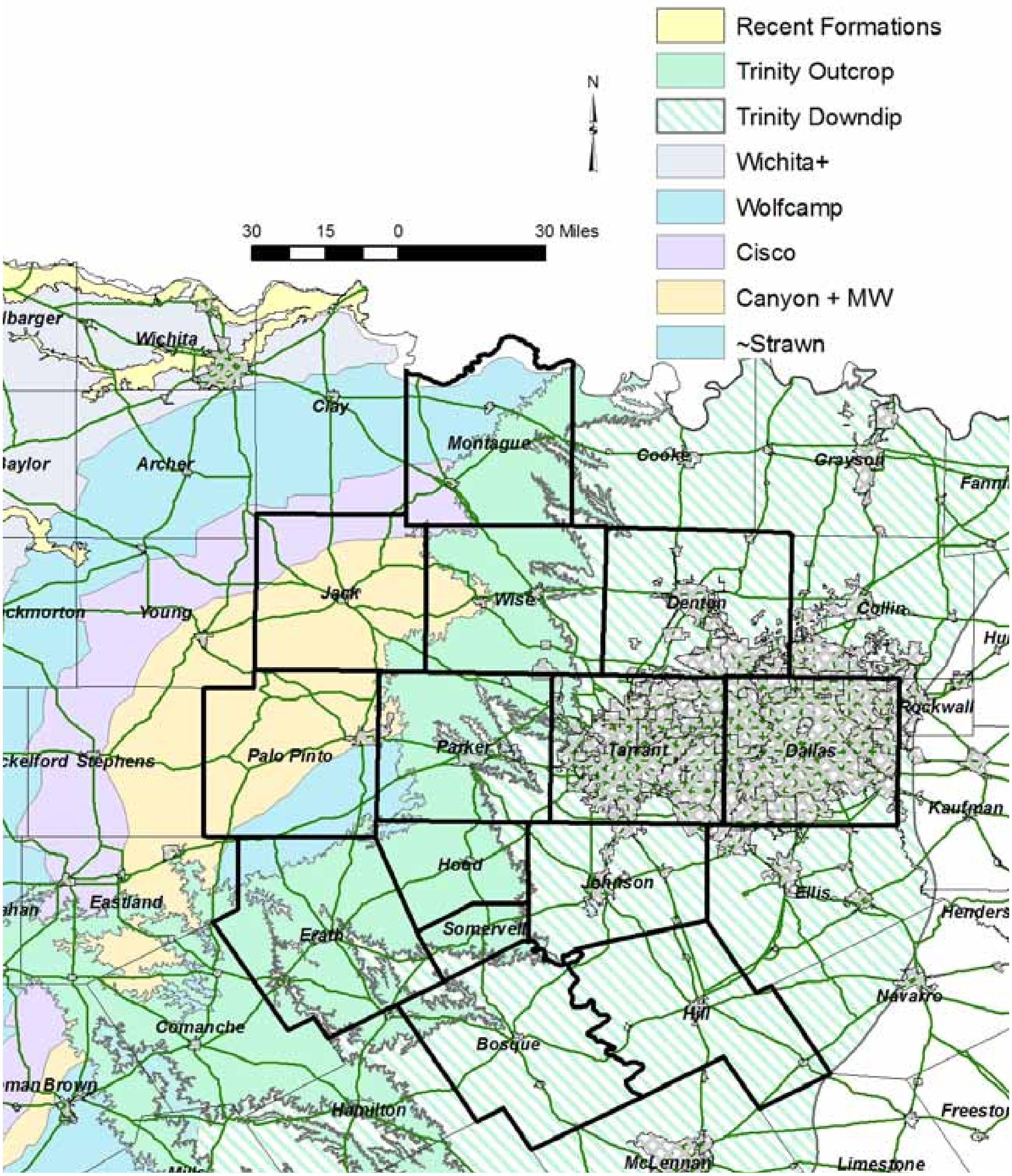
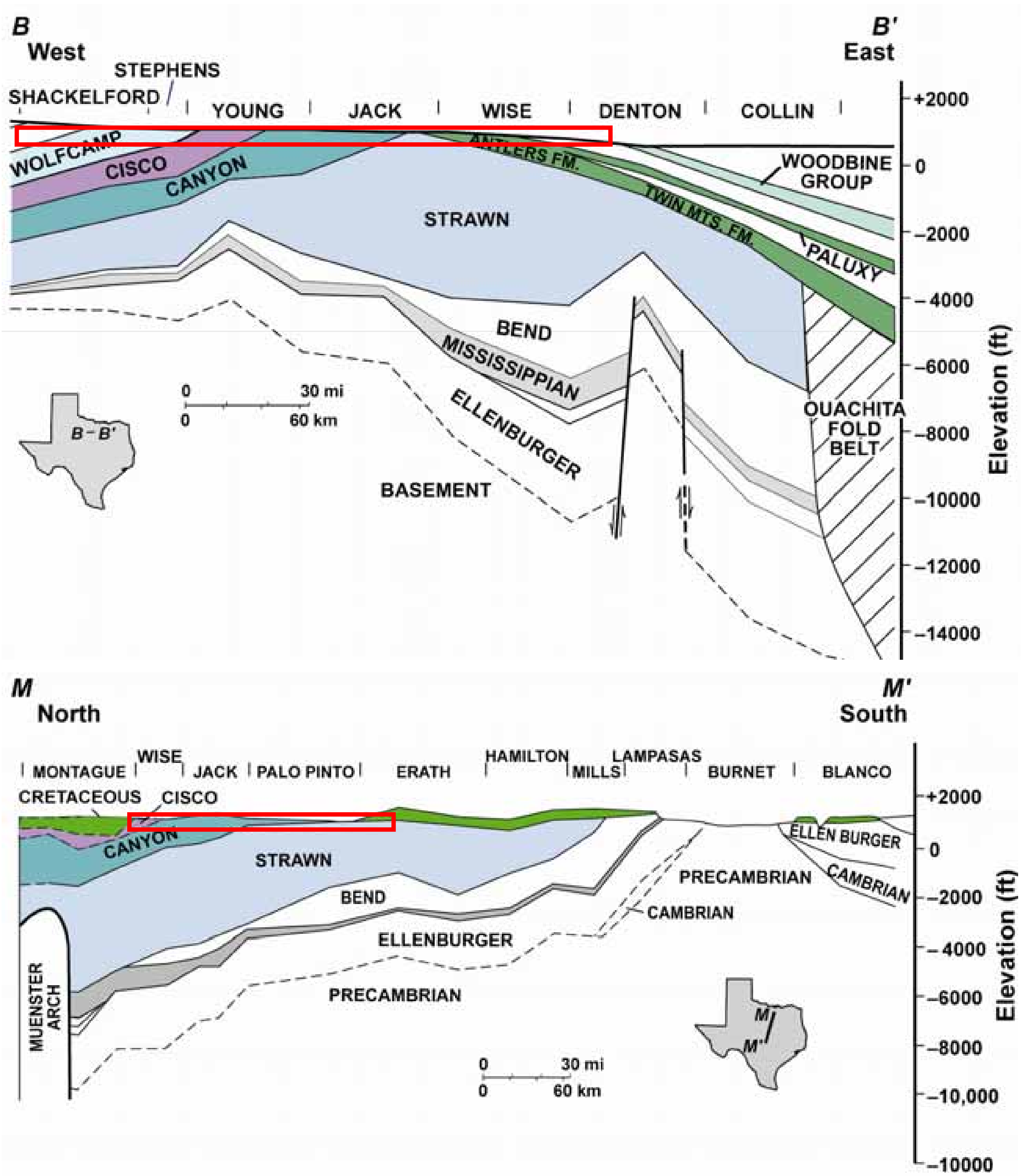
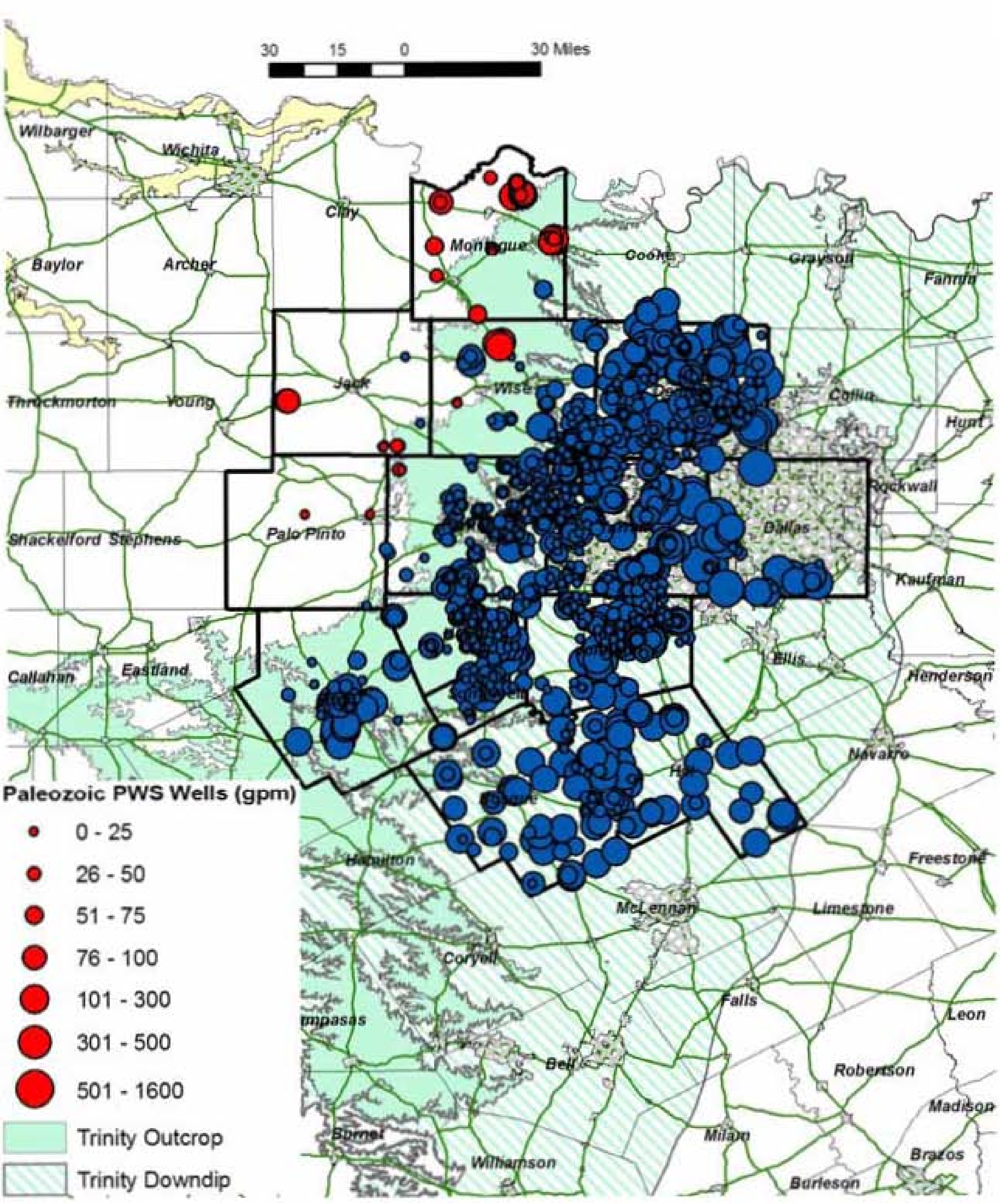


Figure 21. Tentative map of Paleozoic formations in north-central Texas.



Note: Barnett Shale of Mississippian age included in gray-colored horizon.

Figure 22. West-east and north-south geologic cross sections of study area.



Note: highest Paleozoic well rate is 150 gpm.

Figure 23. Public water-supply wells tapping Paleozoic aquifers (red) and all others (blue), mostly Trinity but also Woodbine and alluvium.

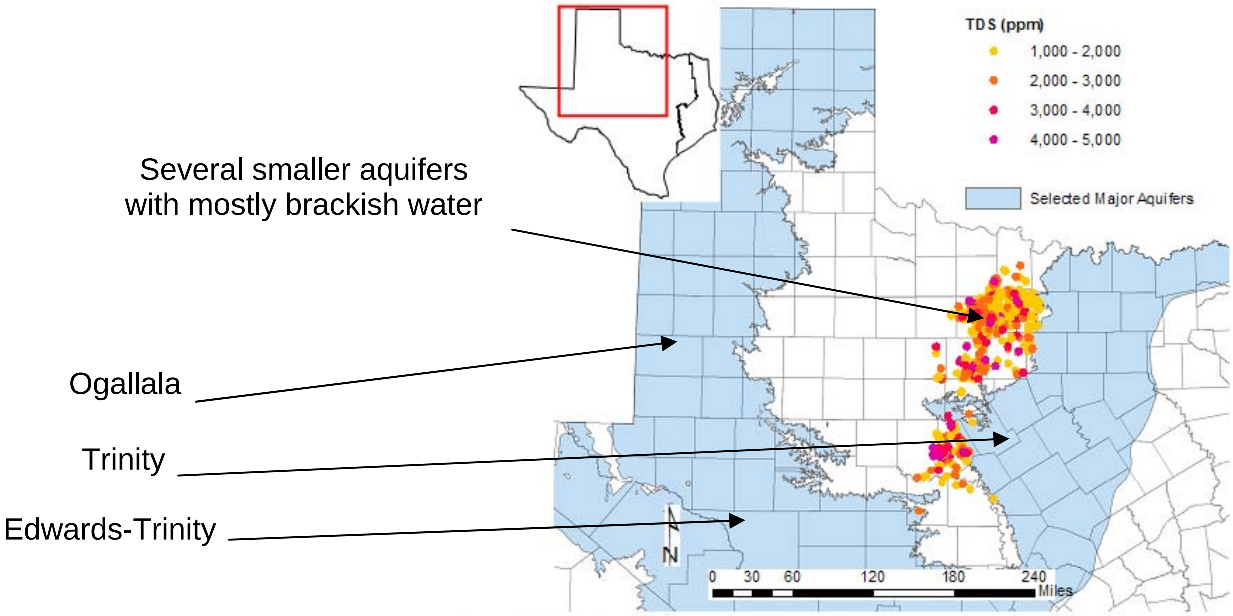


Figure 24. Brackish water is common in Paleozoic aquifers.

6 Nonconventional Water Sources

6.1 What are they?

This task consists of an inventory of all nonconventional water sources, such as desalination plants, mines with dewatering operations, produced water from conventional oil and gas operations, and, most likely with the highest potential, WWTP outfalls.

6.2 WWTP Data Source

This project was initiated to research available data on potential sources of water of sufficient quantity and quality in the large Barnett Shale natural gas field in north-central Texas west of the Dallas-Fort Worth metropolitan area. The study focused on identifying available water sources in a 10-county area, including Bosque, Erath, Hood, Hill, Jack, Montague, Palo Pinto, Parker, Somervell, and Wise Counties. Examinations were later expanded to Tarrant and Johnson Counties and parts of Denton County (west of IH 35) as well (Figure 4).

TCEQ maintains an electronic Central Registry database of information on all companies and facilities regulated by the various rules and programs of the agency. The database (http://www12.tceq.state.tx.us/crpub/index.cfm?fuseaction=regent.RNSearch), accessible through the TCEQ website, was initially queried to identify all large industrial or municipal operations in the area by examining data for various TCEQ program areas, including air, water-rights, stormwater, and wastewater permits.

Because the intent of the project was to identify sources of water that were not committed to other uses, we decided to examine only wastewater dischargers in greater detail. A methodical search was conducted for every active wastewater discharge permit by county to obtain facility identification, ownership, and other registration information. Research was also conducted on the TCEQ Central Records to obtain hardcopies of critical portions of permit documents. Specific information regarding the regulated entity, contact information, description of type of source and discharges at the facilities, effluent flow and parameter discharge limitations, sampling and reporting requirements, and geographic coordinates are recorded in the permits. Information on ~143 individual permits was retrieved.

To ensure completeness, a listing of all cities and towns within the Barnett Shale study area was obtained from Texas Home Locators (http://texas.hometownlocator.com/index.cfm). A comparison was made to determine whether the incorporated areas were included in the wastewater discharger data obtained from TCEQ and EPA. Most incorporated cities appeared to have wastewater treatment systems included in the datasets, whereas others may have been served by county or regional systems or depended to a large extent on onsite sewage treatment. The greatest gaps appeared to be in Denton, Tarrant, and Parker Counties, and additional investigation may be necessary to obtain more data on the wastewater systems in these areas. However, most missing treatment facilities are associated with communities that are small and may not represent significant potential water sources.

Most wastewater dischargers permitted by TCEQ (http://www.tceq.state.tx.us/gis/sites.html) under the Texas Pollutant Discharge Elimination System (TPDES) must file quarterly effluent monitoring reports with EPA into the Permit Compliance System (PCS) and the Integrated Compliance Information System—National Pollutant Discharge Elimination System (ICIS-

NPDES), which is gradually replacing PCS. This reporting data may be accessed through EPA's Enforcement and Compliance History On-Line (ECHO) system (http://www.epa-echo.gov/cgi-bin/effluentsquery.cgi). From this site, data were obtained regarding average and maximum flow rates (MGD) through the treatment plant, as well as average concentrations of dissolved oxygen (DO), biochemical oxygen demand (BOD), total suspended solids (TSS), nitrogen, sulfate, and chlorine (in milligrams per liter, mg/L). Maximum and minimum pH and chlorine levels were also retrieved. Available information was analyzed for the 3-yr period from October 2006 through September 2009 and recorded on a comprehensive spreadsheet for each permitted discharge by county. The number of facilities examined in each county is as follows:

- Bosque County—11
- Erath County—3
- Hill County—14
- Hood County—15
- Jack County—2
- Montague County—4
- Palo Pinto County—11
- Parker County—11
- Somervell County—5
- Wise County—14
- Denton County—16
- Johnson County—17
- Tarrant County—20

In most counties, several TCEQ permits were identified for wastewater dischargers for which no corresponding EPA data were available. In some cases, it was determined that the permits had been terminated or were inactive.

Geographic coordinates were obtained from TCEQ permit files and from a TCEQ database of wastewater outfalls. These data were compared to determine similarities and significant differences. Whereas most of the coordinates for the same identified facilities were similar, permit files seemed to be the most accurate and up to date. During examination of the two coordinate datasets, it was observed that a small number of dischargers were not included in either database and/or had no current effluent reporting information. Additional effort was made to obtain information regarding these dischargers. But, in most cases, the wastewater permits had been either terminated or were inactive. Most also appeared to be sources that would not be expected to generate significant flows, such as small commercial sites, private resorts or camps, schools, or community systems.

6.3 Results

6.3.1 Wastewater Flow

Assuming that ~3.5 million gal of fresh water must be used for a single fracing operation, it is useful to further categorized wastewater dischargers in each county according to their daily volume of effluent to determine the sources with the greatest potential to provide sufficient water to meet that demand. If a wastewater discharger produces >0.1 MGD, sufficient water could be obtained within ~1 month from that single source to support one hydraulic fracturing completion of a horizontal shale gas well. Smaller dischargers could also be used if more time were allocated to accumulating water or if water were obtained from multiple sources. Figure 26 shows wastewater dischargers in each county in the study area with a distribution of the approximate daily volume of effluent that may be available for acquisition and use. Figure 26a shows that flow rates are dominated by the Fort Worth WWTP in Tarrant County, followed by many large and medium-sized facilities in Denton County, whose grand total is ~52 MGD. Because these two counties are different in their plant count or volume from those of the remaining 11 counties, Figure 26b displays outfall flow rate for all facilities but the Fort Worth WWTP and facilities with a capacity of >1 MGD in Denton County; they are included in Figure 26c, which shows these >1-MGD facilities. Most counties have a larger facility (county seat) and several other smaller dischargers.

The largest wastewater discharger in the study area by far is the Comanche Peak Steam Electric Station (SES) (Somervell County), with a reported effluent flow of 2,844 MGD. Other large dischargers include Decordova SES (Hood County) with 441 MGD, Randle W. Miller SES (Palo Pinto County) with 119 MGD, Handley SES (Tarrant County) with 219 MGD, and the City of Fort Worth Village Creek WWTP (Tarrant County) with 116 MGD. The four SES facilities' outfalls are once-through cooling outfalls and cannot be considered available. Some of the same SES facilities do have a regular wastewater outfall, whose rates are more on par with those of other facilities.

Other dischargers that reported >1.0 MGD include City of Lewisville (Denton County), Stewart Creek WWTP (Denton County), City of Stephenville (Erath County), Hillsboro WWTP (Hill County), Southeast Plan WWTP (Hood County), City of Cleburne (Johnson County), Randle W. Miller WWTP #2 (Palo Pinto County), City of Weatherford (Parker County), City of Grapevine (Tarrant County), and Hanson Aggregates, Inc. (Wise County). Large cities and power plants dominate these larger sources. A relatively wide gap exists in most counties between larger dischargers (>0.1 MGD) and much smaller dischargers (<0.05 MGD), reflecting the differences in wastewater plants that serve concentrated population centers and those that serve small communities and dispersed commercial operations (Figure 27a–c). A large percentage of wastewater dischargers in the study area have reported average effluent flows less than 0.025 MGD. Unless several of these small dischargers were in the immediate area of a proposed gas well and could be combined, it may be difficult to utilize them as practical sources of fracing water.

Combined, nonpower sources total 224 MGD, half of which comes from the Fort Worth Village Creek WWTP (Tarrant County). The remaining 108 MGD, or 121,000 AF/yr, is the equivalent of two to three times the anticipated maximum annual consumption in the Barnett play (Nicot et al., 2011).

6.3.2 Wastewater Quality

Water quality from wastewater-treatment facilities is generally good and is closely regulated by TCEQ to prevent violations of surface-water-quality standards in rivers, streams, and lakes. Specific effluent standards in the permits of individual plants can vary, depending on the type of wastewater being treated (municipal, commercial, industrial), the designated use of the receiving water body, and the current degree of water-quality impairment. However, most effluent limitations for the parameters evaluated in this report include

- Biochemical oxygen demand (5-day) (BOD5)—30-day average of no more than 10 mg/L and a daily maximum of no more than 45 mg/L;
- Total suspended solids (TSS)—30-day average of no more than 15 mg/L and a daily maximum of no more than 40 mg/L;
- Residual chlorine—minimum of at least 2.0 mg/L and a maximum of 4.0 mg/L at all times;
- pH—minimum of 6.0 (standard units) and a maximum of 9.0 at all times;

- Dissolved oxygen (DO)—minimum of between 2.0 and 5.0 mg/L, depending on aquatic life use of the receiving stream; and
- Effluent limits on certain nutrients and other compounds, such as nitrogen, phosphate, sulfate, and chlorine, which are also placed on some permits.

With a few exceptions, the actual average and maximum values for these parameters reported by dischargers are generally well within established standards, with fluctuations occurring only during rare instances of noncompliance. The data provided in this report were obtained from monthly self-monitoring reports to the EPA recorded on the automated ECHO system. BOD5 and TSS values are averages of all available data from the reported 30-day averages over the 3-yr period from October 2006 through September 2009. Chlorine residual and pH maximums and minimums and minimum DO values are also averages over that same period of time. Overall, 25th and 75th percentiles are: BOD5: 3–7.5 mg/L; TSS: 3.5–14.0 mg/L; chlorine: 1–3.5 mg/L; pH: 6.9–7.9; DO: 5–7 mg/L. There is little information on the TDS, but, by law, it has to be less than 1,000 mg/L. The high O_2 concentration is an impediment for use in fracing operations, but one that can be overcome easily.

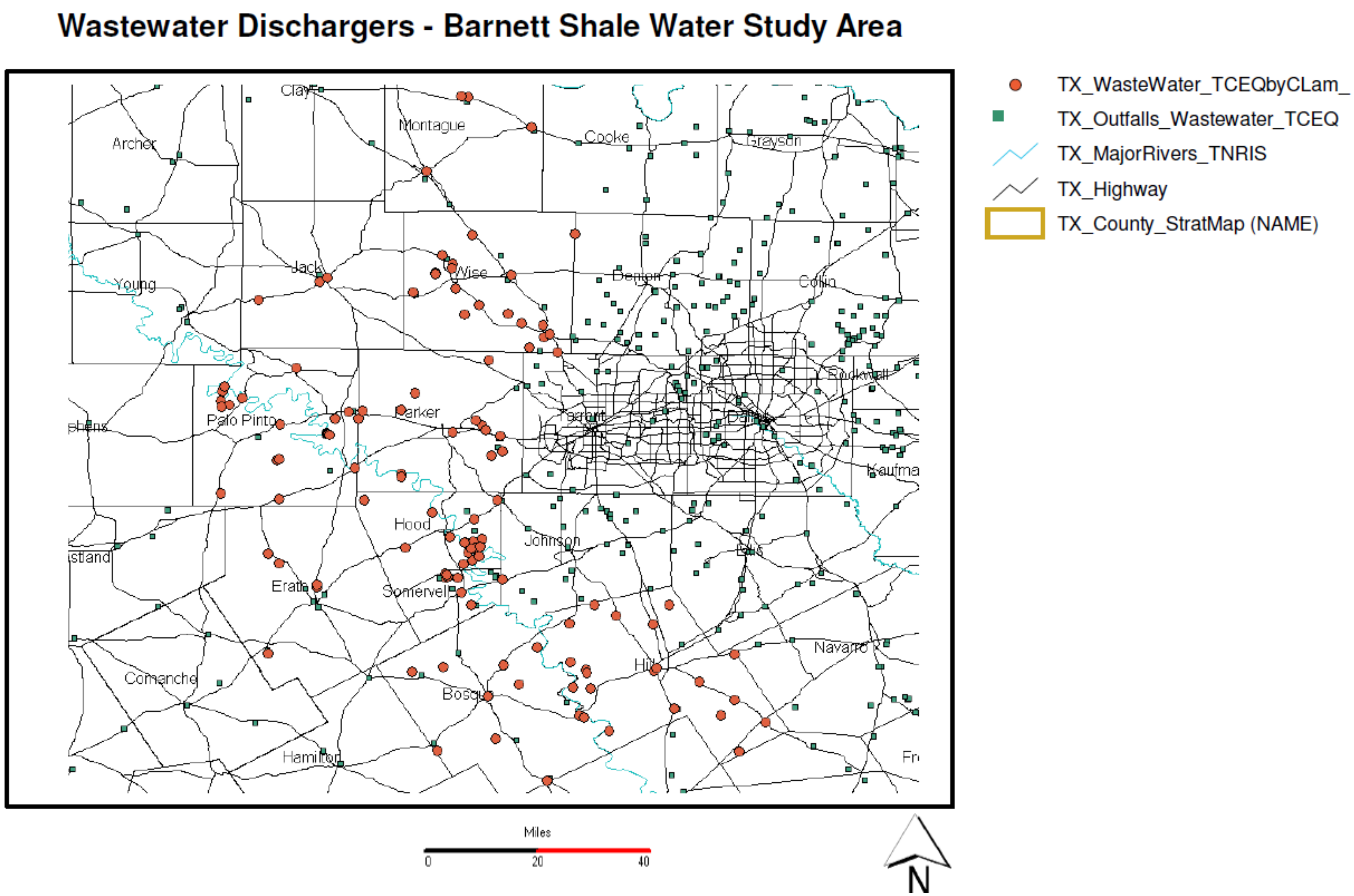
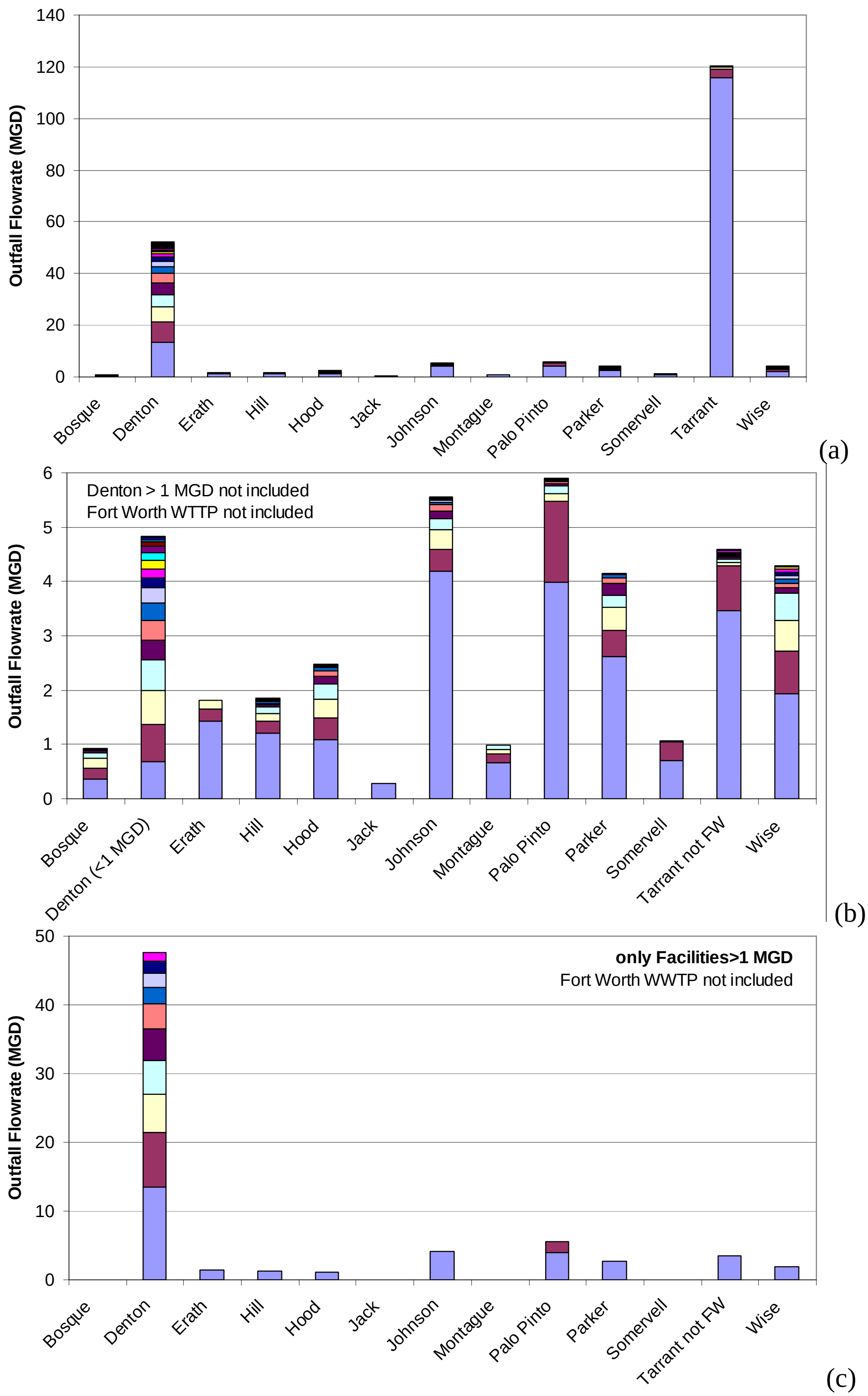


Figure 25. Map showing municipal and industrial wastewater facilities listed in the TCEQ Wastewater Outfall database (green dots) vs. those facilities for which we have chemical and flow-rate information (red dots—most masking green dots).



Note: colors represent different facilities in each county

Figure 26. Distribution of wastewater facilities sorted by county according to their discharge rates.

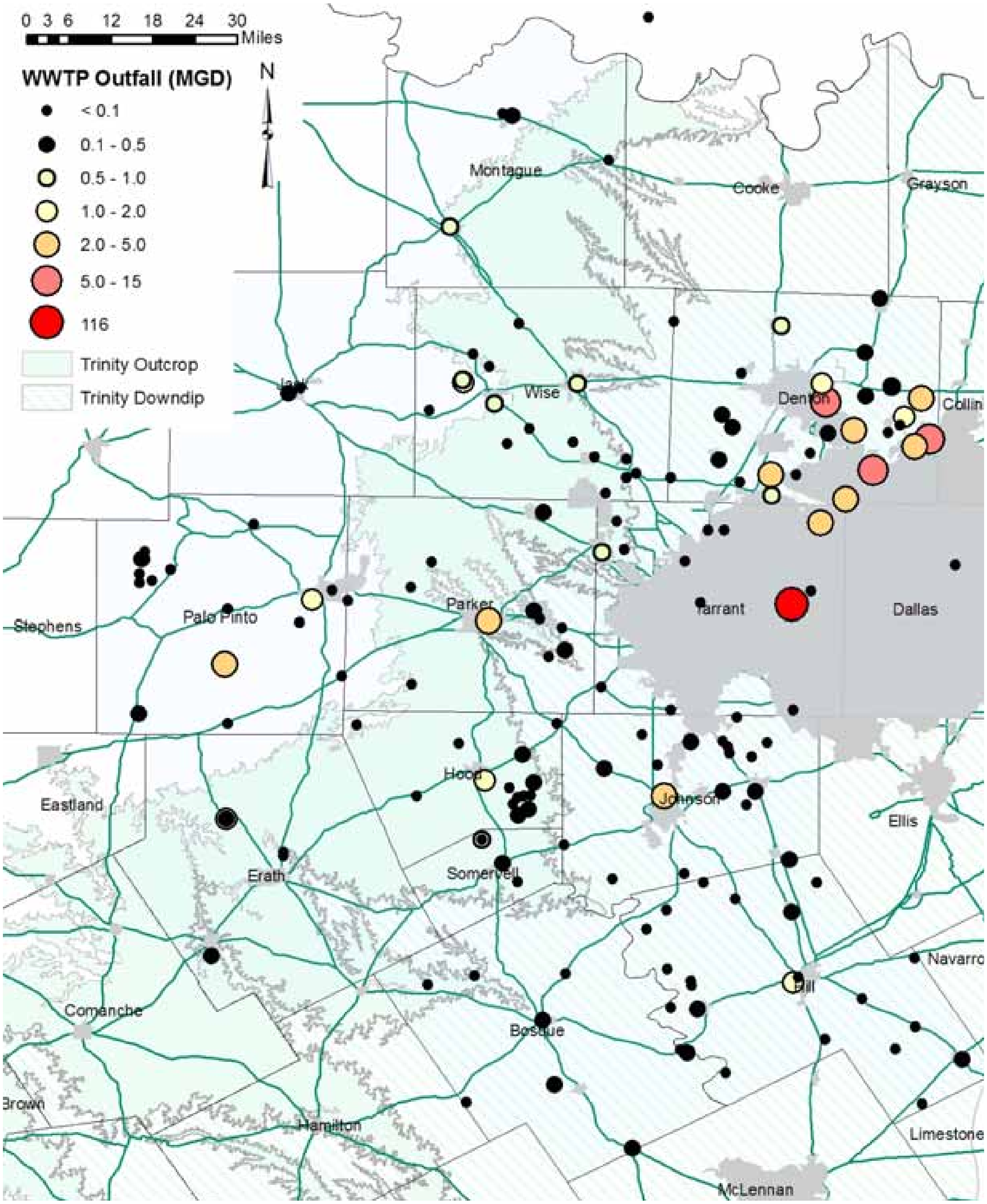


Figure 27. All dischargers within the study area separated into groups on the basis of various flow rates (<0.05 MGD; 0.05–0.1 MGD; 0.1–1.0 MGD; >1.0 MGD).

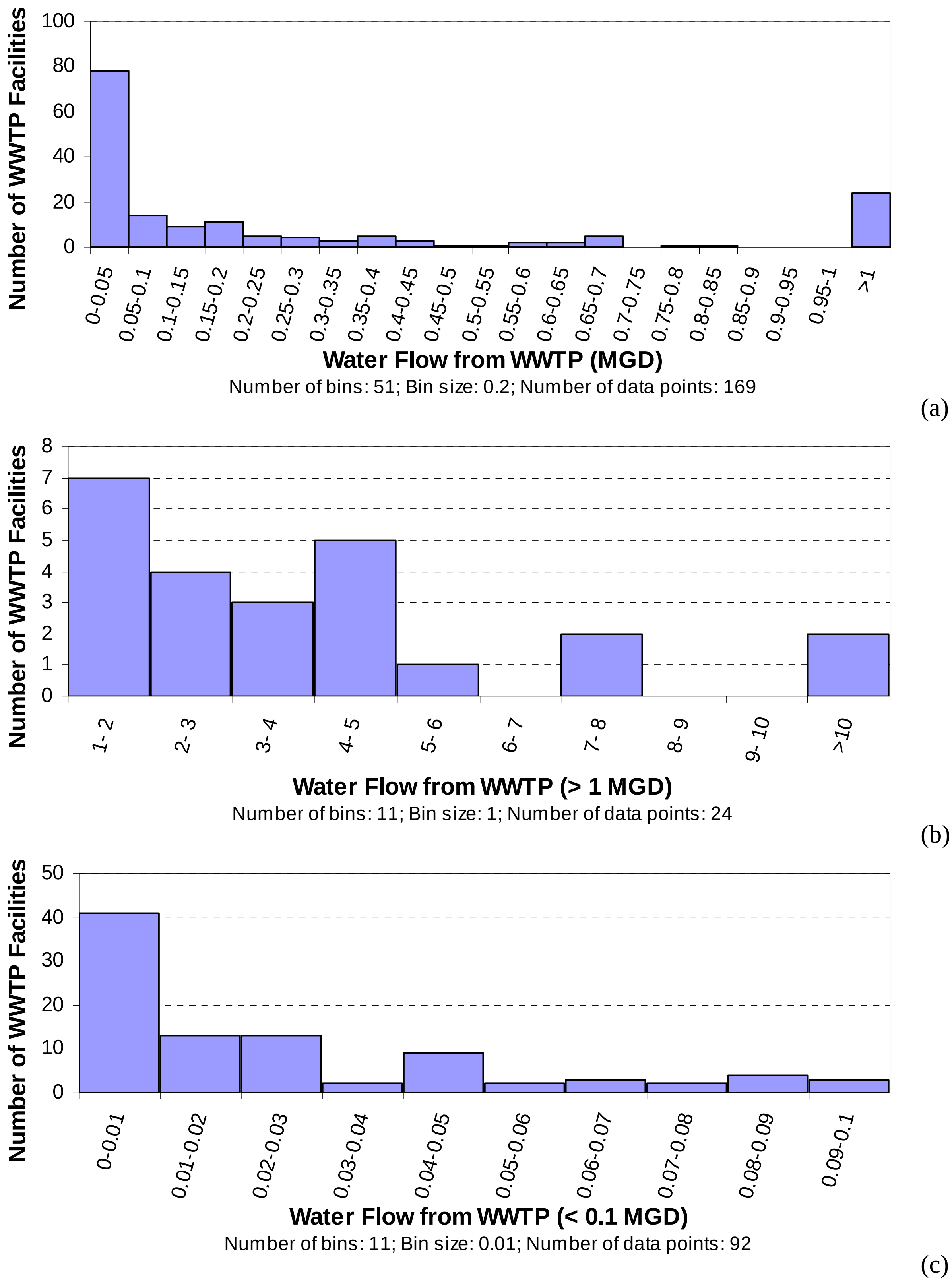


Figure 28. Flow-rate distribution of WWTP: (a) all plants, (b) plants with average flow >1 MGD, and (c) plants with average flow <0.1 MGD.

7 Summary and Conclusions

This preliminary report documents the current but fast-changing practices of the gas industry to access water in the Barnett Shale footprint and analyzes potential sources of water alternative to large surface water bodies and the local major aquifer (the Trinity Aquifer). They include treated water from wastewater treatment plants, groundwater from smallish possibly slightly brackish aquifers, and farmer ponds and other non-state surface water bodies. A first-order estimate of the amount of water available consists of more than 100,000 AF at any given time in non-State-surface-water bodies, more than 25,000 AF available per year from groundwater, and more than 100,000 AF available per year from wastewater outfalls. Those figures compare well with the maximum projected annual water use of 40,000 AF. However, spatial match between water sources and points of use remain an issue and is the subject of an analysis being currently conducted.

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9 Appendix A: Characteristics of WWTP Outfalls

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	BOD (mg/L)	TSS (mg/L)	Cl min (mg/L)	Cl max (mg/L)	pH Min	pH Max	DO (mg/L)	N (mg/L)
Bosque										
WQ0010043001	CITY OF CLIFTON WWTF	0.357	4.24	3.24	0.99	2.50	6.86	7.07	5.15	
WQ0010113001	CITY OF MERIDIAN	0.201	3.56	6.71	1.29	3.25	7.23	7.80	6.36	
WQ0004167000	BOSQUE COUNTY POWER PLANT	0.183			0.03	0.04	6.91	8.07		
WQ0010307001	CITY OF VALLEY MILLS WWTP	0.112	3.91	6.26	1.13	1.91	7.45	7.79	5.19	
WQ0012217001	CITY OF MORGAN	0.027	19.71	54.23			8.16	8.77	6.16	
WQ0014169001	CITY OF CRANFILLS GAP WWTP	0.022	4.77	13.16	1.42	2.95	7.32	7.67	5.73	
WQ0011565001	CITY OF IREDELL WWTP	0.013	8.03	8.03	1.62	2.47	7.44	7.77	5.55	
WQ0013536001	CAMP JOHN MARC WWTF	0.011	5.28	11.53	1.19	1.98	7.72	8.30		
WQ0013436001	WALNUT SPRINGS CITY OF WWTP	0.001	23.06	68.15			8.43	9.00	5.99	
WQ0013982001	KOPPERL ISD WWTP	0.001	6.89	11.53	1.09	2.53	7.35	7.93	4.33	
WQ0012087001	WHITNEY POWERHOUSE WWTP	0.000	5.70	19.23	1.38	3.61	7.15	8.03	6.68	
Denton										
WQ0010027003	PECAN CREEK WATER RECLAMATION PLANT	13.457	2.21	3.05			6.98	7.35	6.60	0.23
WQ0010662001	CITY OF LEWISVILLE	7.986	4.58	1.57	1.16		6.45	7.10	7.31	
WQ0010172003	STEWART CREEK WEST PLANT	5.529	2.94	1.92			6.77	7.35	6.63	2.44
WQ0013457001	DENTON CREEK REGIONAL WWTP	4.976	1.95	3.54			6.81	7.39	6.84	0.79
WQ0011321001	TOWN OF FLOWER MOUND WWTF	4.541	5.07	3.09			6.86	7.48	7.45	0.84
WQ0010698001	UTRWD LAKEVIEW REGIONAL WATER RECLAMATION PLANT	3.739	2.31	1.55			6.76	7.26	5.48	
WQ0011570001	STEWART CREEK WWTP	2.290	2.46	2.72			6.93	7.26	6.86	1.34
WQ0014245001	PANTHER CREEK WWTP	2.062	3.07	0.82			6.71	7.34	6.29	0.15
WQ0011600001	TOWN OF LITTLE ELM	1.731	3.19	2.44			7.09	7.49	7.48	0.38

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	BOD (mg/L)	TSS (mg/L)	Cl min (mg/L)	Cl max (mg/L)	pH Min	pH Max	DO (mg/L)	N (mg/L)
WQ0004336000	DENTON RECYCLE CENTER	1.291					7.03	8.21		
WQ0010271001	CITY OF SANGER	0.683	2.31	4.69	1.31	2.13	7.45	7.68	8.81	1.26
WQ0014372001	SANGER WWTP	0.683	2.31	4.69	1.31	2.13	7.45	7.68	8.81	1.26
WQ0011593001	TROPHY CLUB MUD	0.624	3.64	3.09			7.44	7.83	6.50	0.19
WQ0010698002	UTRWD RIVERBEND REGIONAL WATER RECLAMATION PLANT	0.569	2.16	1.77			6.94	7.70	6.53	0.39
WQ0010361001	CITY OF PILOT POINT	0.366	2.27	4.45	1.12	3.51	7.00	7.66	6.94	0.42
WQ0003840000	SEWELL CLAY MINE	0.365		6.00			6.77	6.77		
WQ0010698002	UTRWD RIVERBEND REGIONAL WATER RECLAMATION PLANT	0.305	2.16	1.79			6.94	7.71	6.54	0.40
WQ0011312001	CITY OF JUSTIN	0.296	7.05	15.33	1.01	2.69	7.24	7.59	5.97	2.32
WQ0010027004	ROBSON RANCH TREATMENT PLANT	0.179	7.47	1.06			8.04	8.04	5.92	0.41
WQ0013647001	AUBREY WWTP	0.159	2.44	4.59	1.26	3.39	7.37	7.86	4.61	0.79
WQ0010064001	CITY OF AUBREY	0.159	2.44	4.59	1.26	3.39	7.37	7.86	4.61	0.79
WQ0014323001	UTRWD PENINSILA REGIONAL WATER RECLAMATION PLANT	0.152	2.06	1.14			6.77	7.47	5.80	0.21
WQ0011287003	PONDER WWTP	0.103	5.44	8.57	1.14	3.62	7.38	7.80	7.66	0.63
WQ0010729001	CITY OF KRUM	0.087	26.39	28.86			7.94	7.94		
WQ0013434001	CITY OF HACKBERRY	0.043	11.94	14.69	0.70	2.98	7.07	7.12	5.45	15.70
WQ0014186001	SHALE CREEK WWTP	0.033	4.29	11.31	1.36	3.42	7.28	7.73	7.47	1.47
WQ0013732001	ROCKY POINT MHP FLOWER MOUND	0.015	5.46	8.42	1.17	3.65	6.75	7.22	4.74	4.50
WQ0014139001	NORTHLAKE VILLAGE MHP	0.007	2.67	3.09	1.36	3.26	6.92	6.92	7.24	
WQ0013785001	HIDDEN COVE PARK WWTP	0.003	3.17	7.34	1.06	2.92	7.86	8.03	6.55	
WQ0012605002	BRIARWOOD RETREAT	0.002	4.53	8.02	1.03	3.20	7.99	8.28	7.75	
Denton -West										
WQ0010662001	CITY OF LEWISVILLE	7.986	4.58	1.57	1.16		6.45	7.10	7.31	
WQ0013457001	DENTON CREEK REGIONAL WWTP	4.976	1.95	3.54			6.81	7.39	6.84	0.79

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	BOD (mg/L)	TSS (mg/L)	Cl min (mg/L)	Cl max (mg/L)	pH Min	pH Max	DO (mg/L)	N (mg/L)
WQ0011321001	TOWN OF FLOWER MOUND WWTF	4.541	5.07	3.09			6.86	7.48	7.45	0.84
WQ0011570001	STEWART CREEK WWTP	2.290	2.46	2.72			6.93	7.26	6.86	1.34
WQ0010271001	CITY OF SANGER	0.683	2.31	4.69	1.31	2.13	7.45	7.68	8.81	1.26
WQ0011593001	TROPHY CLUB MUD	0.624	3.64	3.09			7.44	7.83	6.50	0.19
WQ0003840000	SEWELL CLAY MINE	0.365		6.00			6.77	6.77		
WQ0011312001	CITY OF JUSTIN	0.296	7.05	15.33	1.01	2.69	7.24	7.59	5.97	2.32
WQ0010027004	ROBSON RANCH TREATMENT PLANT	0.179	7.47	1.06			8.04	8.04	5.92	0.41
WQ0010064001	CITY OF AUBREY	0.159	2.44	4.59	1.26	3.39	7.37	7.86	4.61	0.79
WQ0011287003	PONDER WWTP	0.103	5.44	8.57	1.14	3.62	7.38	7.80	7.66	0.63
WQ0010729001	CITY OF KRUM	0.087	26.39	28.86			7.94	7.94		
WQ0014186001	SHALE CREEK WWTP	0.033	4.29	11.31	1.36	3.42	7.28	7.73	7.47	1.47
WQ0013732001	ROCKY POINT MHP FLOWER MOUND	0.015	5.46	8.42	1.17	3.65	6.75	7.22	4.74	4.50
WQ0014139001	NORTHLAKE VILLAGE MHP	0.007	2.67	3.09	1.36	3.26	6.92	6.92	7.24	
WQ0012605002	BRIARWOOD RETREAT	0.002	4.53	8.02	1.03	3.20	7.99	8.28	7.75	
Erath										
WQ0010290001	CITY OF STEPHENVILLE	1.432								
WQ0010405001	DUBLIN WWTF	0.210	18.51	34.85			8.12	8.99	7.61	3.65
WQ0010290001	CITY OF STEPHENVILLE	0.178								
WQ0004314000	MILK TRANSPORT SERVICES									
WQ0003074000	SCHREIBER FOODS									
Hill										
WQ0010630001	HILLSBORO WWTP	1.215	2.35	2.21		0.07	6.48	7.16	6.30	0.29
WQ0011408002	POLK STREET WWTP	0.212	10.95	18.03			8.50	9.21	4.85	0.86
WQ0010534001	CITY OF HUBBARD WWTP	0.136	3.76	6.23	0.98	2.75	7.30	8.09	5.86	0.54
WQ0010423001	CITY OF ITASCA WWTP	0.134	5.36	14.60	1.15	3.26	7.34	7.72	6.94	

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	**BOD (mg/L)**	**TSS (mg/L)**	**Cl min (mg/L)**	**Cl max (mg/L)**	**pH Min**	**pH Max**	**DO (mg/L)**	**N (mg/L)**
WQ0013786002	WHITE BLUFF WWTP	0.041	7.74	14.33	1.32	3.03	7.26	7.62	5.36	
WQ0010820001	CITY OF BLUM WWTP	0.023	4.57	7.36	1.25	3.05	7.38	7.73	4.34	
WQ0011544001	CITY OF ABBOTT WWTP	0.022	18.50	39.95			8.14	8.71	5.31	
WQ0010514001	CITY OF MALONE WWTF	0.019	5.93	6.93	1.31	2.35	7.32	7.42	4.16	
WQ0011542001	CITY OF BYNUM WWTP	0.014	7.42	10.99	1.41	2.53	6.74	7.28	4.47	
WQ0012279001	CITY OF COVINGTON WWTP	0.013	24.64	77.92			8.48	9.66	6.23	
WQ0013621001	PENELOPE SANITATION DEPT.-WWTP	0.011	34.35	152.77			8.66	8.67	7.93	
WQ0011464001	CITY OF MOUNT CALM WWTP	0.009	32.57	121.61			8.76	9.04	7.55	
WQ0013075001	MHC TT LAKE WHITNEY PRESERVE	0.008	4.71	7.08	1.44	2.01	7.27	7.62	4.23	
WQ0013271001	CITY OF MERTENS WWTF	0.006	31.00	187.67			8.30	8.30	10.50	
WQ0014883001	LAKE WHITNEY RESORTS, LLC									
WQ0013891001	LAKE WHITNEY RESORTS, LLC									
WQ0002726000	VLASIC FARMS									
WQ0004497000	OWL LIVESTOCK									
WQ0011276001	PRESBYTERIAN CHILDERN'S HOME									
WQ0013820001	LATHAM SPRINGS BAPTIST ENCAMPMENT									
Hood										
WQ0001481000	DECORDOVA SES	441.316				0.06				
WQ0010178002	SOUTHEAST PLANT WWTP	1.078	2.90	3.13			7.32	7.51	5.62	0.40
WQ0002889000	LAKE GRANBURY SURFACE WATER	0.421					7.39	7.78		
WQ0004288000	WOLF HOLLOW I, L.P.-POWER PLT.	0.341	5.29			0.12	7.36	8.28		0.23
WQ0014211001	DECORDOVA BEND ESTATES WWTP	0.272	2.76	3.58	7.23	7.49	1.03	3.55	7.00	0.25
WQ0014212001	ACTON MUD- PECAN PLANTATION	0.150	3.70	4.83	1.03	3.54	7.18	7.40	5.76	
WQ0002678000	OAK TRAIL SHORES-EDR - WWTP	0.084					7.37	7.78		
WQ0014233001	CITY OF TOLAR	0.059	3.49	5.97	1.80	3.36	7.32	7.68	5.92	

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	BOD (mg/L)	TSS (mg/L)	Cl min (mg/L)	Cl max (mg/L)	pH Min	pH Max	DO (mg/L)	N (mg/L)
WQ0013022001	BLUE WATER SHORES	0.022	9.25	15.18	1.26	3.50	7.40	7.85	5.84	
WQ0013786001	CANYON CREEK WWTP	0.015	7.92	13.73	0.93	3.27	7.96	8.33	7.14	
WQ0014147001	TREATY OAKS WWTF	0.009	4.50	7.85	1.15	3.57	7.44	7.97	8.05	0.15
WQ0013025001	RIDGE UTILITIES WWTF	0.007	7.09	11.69	1.00	3.70	7.67	8.12	6.75	
WQ0014805001	CITY OF CRESSON WWTP 1	0.005	2.68	3.84	1.44	3.41	7.03	7.23	4.55	0.23
WQ0013590001	CITY OF LIPAN WWTP	0.004	22.08	57.88			8.48	9.16	8.07	
WQ0013809001	FALL CREEK UTILITY CO, INC.	0.003	7.71	13.48	1.01	2.90	7.19	7.83	4.61	
WQ0001481000	DECORDOVA SES									
WQ0004288000	WOLF HOLLOW I, L.P.-POWER PLT.									
Jack										
WQ0010994001	CITY OF JACKSBORO WWTF	0.278	4.05	5.39	1.15	2.07	7.40	7.86	7.21	0.14
WQ0010994002	CITY OF JACKSBORO WWTF	0.005		3.66			7.57	7.75		
WQ0010135001	CITY OF BRYSON									
Johnson										
WQ0010006001	CITY OF CLEBURNE WWTP	4.184	2.24	3.15			6.61	7.29	5.66	0.25
WQ0014350001	JOHNSON COUNTY SUD WWTF	0.402	3.96	6.33	1.19	3.71	6.49	6.91	6.95	0.84
WQ0010611002	CITY OF KEENE	0.369	2.29	2.97	1.06	3.44	7.10	7.51	7.61	1.82
WQ0010567001	CITY OF ALVARADO	0.191	23.61	55.10			7.74	8.14	5.22	23.22
WQ0010180001	CITY OF GRANDVIEW	0.157	2.72	5.07	1.27	3.73	7.41	7.76	5.17	0.42
WQ0010542001	CITY OF GODLEY	0.114	10.33	15.49	1.83	2.36	7.38	7.57	5.91	6.96
WQ0013546001	CITY OF RIO VISTA	0.048	2.98	4.83	1.01	3.39	7.37	7.76	5.03	0.54
WQ0013769001	COUNTRY VISTA PLANT	0.028	5.37	7.98	1.12	2.70	7.30	7.56	4.85	
WQ0013846001	GRAND RANCH PHASE 2	0.016	4.93	10.07	1.06	2.63	7.34	7.69	6.83	
WQ0014411001	BLUE WATER OAKS POA	0.013	4.51	9.54	1.07	2.64	7.47	7.83	4.49	0.46
WQ0014680001	RV RANCH WWTP	0.009	15.56	31.15	0.96	1.64	7.35	7.72	4.15	

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	BOD (mg/L)	TSS (mg/L)	Cl min (mg/L)	Cl max (mg/L)	pH Min	pH Max	DO (mg/L)	N (mg/L)
WQ0013868001	WALNUT CREEK MHP	0.008	9.83	13.94	1.82	3.08	7.25	7.81	5.11	
WQ0013376001	OAK RIDGE SQUARE MHP	0.006	19.51	26.99	1.48	2.89	7.06	7.08	3.01	
WQ0014373001	THE RETREAT WWTP	0.005	2.89	5.52	1.23	2.82	7.54	8.11	4.62	
WQ0014101001	ALVARADO ISD	0.004	3.63	7.29	1.26	3.32	7.48	7.81	6.82	
WQ0014556001	PLEASANT OAKS MHP	0.003	13.84	18.19	1.58	2.36	7.20	7.78	4.72	
WQ0014790001	JOHNSON CO NORTHBOUND REST AREA WWTP	0.003	7.11	12.46	1.15	3.54	7.05	7.65	7.93	
Montague										
WQ0010071003	CITY OF BOWIE WWTF	0.658	2.09	2.59			7.44	7.67	7.54	0.11
WQ0010355003	CITY OF NOCONA SOUTH WWTP	0.168	2.38	5.07	1.41	3.33	7.02	7.47	5.01	
WQ0010355002	CITY OF NOCONA WWTF	0.088	2.17	4.31	1.33	3.21	6.93	7.36	4.53	
WQ0014496001	CITY OF SAINT JO WWTP	0.077	2.71	6.48	1.12	2.05	7.16	7.96	4.30	0.60
Palo Pinto										
WQ0001903000	RANDLE W. MILLER SEGS - WWTP	118.864								
WQ0001903000	RANDLE W. MILLER SEGS - WWTP	3.978		29.21			7.85	8.17		
WQ0010585001	POLLARD CREEK WWTP	1.503	3.45	1.75	1.00	0.08	6.91	7.49	7.08	0.75
WQ0004325000	GEORGE N. BAILEY, JR. - WWTP	0.145		24.81			7.57	7.82		
WQ0010326001	CITY OF STRAWN - WWTP	0.127	21.55	31.21			7.73	8.12	4.24	
WQ0002461000	SPORTMAN'S WORLD MUD	0.044					7.39	7.88		
WQ0002789000	DOUBLE DIAMOND UTILITIES CO	0.043	15.00	13.00			7.34	8.00		
WQ0011698001	PALO PINTO COUNTY WWTF	0.022	7.42	5.01	1.11	3.64	7.01	7.01	6.68	
WQ0010722001	CITY OF GRAFORD WWTP	0.020	22.81	55.84			8.09	8.86	6.17	
WQ0011311001	PALO PINTO COUNTY RA - WWTP	0.005	9.62	15.00	1.25	5.12	6.51	7.24	7.86	
WQ0014173001	HILL COUNTY HARBOR WWTF	0.002	3.80	7.90	1.15	4.03	6.95	7.42	7.06	1.98
WQ0004891000	BAR-B TRAVEL PLAZA									

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	BOD (mg/L)	TSS (mg/L)	Cl min (mg/L)	Cl max (mg/L)	pH Min	pH Max	DO (mg/L)	N (mg/L)
WQ0004820000	METROPLEX QUARRY									
WQ0004820000	METROPLEX QUARRY									
WQ0004820000	METROPLEX QUARRY									
WQ0004820000	METROPLEX QUARRY									
WQ0004820000	METROPLEX QUARRY									
WQ0004820000	METROPLEX QUARRY									
WQ0004820000	METROPLEX QUARRY									
WQ0004894000	BUCKLEY OIL COMPANY									
WQ0014511001	GAINES BEND UTILTIES, INC									
WQ0012330001	SPORTSMAN'S WORLD MUNICIPAL									
Parker										
WQ0010380002	CITY OF WEATHERFORD WWTP	2.622	1.98	1.07			7.17	7.60	6.48	0.83
WQ0010585004	WILLOW CREEK WWTP	0.473	3.28	2.78		0.08	6.76	7.45	7.20	0.37
WQ0014198001	WEATHERFORD WATER PURIFICATION	0.422		11.58			7.58	7.89		
WQ0010847001	CITY OF ALEDO WWTP	0.231	6.40	7.75	1.06	2.69	7.47	7.48	6.45	2.65
WQ0010649001	CITY OF SPRINGTOWN - WWTP	0.226	6.26	13.37	1.08	3.49	6.93	7.26	6.10	0.93
WQ0013834001	CITY OF WILLOW PARK - WWTP	0.095	5.20	11.18	1.01	3.20	7.74	8.15	7.82	2.81
WQ0001904000	NORTH TEXAS SES - WWTP	0.060		2.96			7.55	8.07		
WQ0014003001	COWTOWN RV PARK WWTF	0.009	7.02	8.13	1.42	2.22	7.37	7.40	4.41	
WQ0014163001	SUGARTREE WWTF	0.006	6.25	9.57	1.01	3.46	7.13	7.53	6.61	
WQ0013589001	PEASTER I.S.D. WWTP	0.006	6.97	22.10	1.32	2.75	7.36	7.56	5.37	1.14
WQ0003835000	PHILIPS ELECTRONICS	0.001					7.28	7.52		
WQ0001904000	NORTH TEXAS SES - WWTP			4.84			7.55	8.06		
WQ0004852000	PARKER COUNTY SPECIAL UTILITY DISTRICT									
WQ0013798002	BROCK INDEPENDENT SCHOOL DISTRICT									

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	BOD (mg/L)	TSS (mg/L)	Cl min (mg/L)	Cl max (mg/L)	pH Min	pH Max	DO (mg/L)	N (mg/L)
WQ0013759001	CITY OF WILLOW PARK									
Somervell										
WQ0001854000	COMANCHE PEAK SES	2843.694								
WQ0001854000	COMANCHE PEAK SES	0.695		8.56			7.35	7.99		
WQ0010177001	CITY OF GLEN ROSE WWTP	0.344	3.23	3.01	2.45	3.33	7.29	7.84	7.81	0.81
WQ0001854000	COMANCHE PEAK SES	0.021	3.67	5.34			6.72	6.95		
WQ0010895001	RIVERBEND RETREAT CENTER -WWTP	0.007	5.43	6.84	1.35	2.89	7.12	7.75	4.31	
WQ0001854000	COMANCHE PEAK SES									
WQ0001854000	COMANCHE PEAK SES									
WQ0001854000	COMANCHE PEAK SES									
WQ0001401000	UNIMIN CORP - CLEBURNE PLANT									
Tarrant										
WQ0000552000	HANDLEY STEAM ELECTRIC STATION	218.514								
WQ0010494013	CITY OF FORTH WORTH VILLAGE CREEK WWTP	115.831	2.02	2.28			6.92	7.39	6.48	0.19
WQ0010486002	CITY OF GRAPEVINE	3.458	2.44	1.30			6.76	7.64	6.83	0.39
WQ0011183003	ASH CREEK PLANT	0.833	3.17	2.05	1.05	2.38	7.05	7.52	6.98	0.91
WQ0013036001	PINE TREE MHP	0.065	3.15	3.80	1.40	2.20	7.05	7.05	4.70	
WQ0010486003	SOUTHWEST PLANT	0.046	4.22	8.34	1.18	4.20	7.82	7.83	7.50	
WQ0013518001	MAYFAIR ADDITION	0.046	5.76	9.20	1.05	2.90	7.43	7.71	4.92	9.02
WQ0012536002	NORTH PLANT	0.023	3.28	3.30	1.25	1.90	7.05	7.05	5.85	
WQ0013831001	PINE TREE	0.023	3.28	3.30	1.25	1.90	7.05	7.05	5.85	
WQ0012536001	SOUTH PLANT	0.023	3.28	3.30	1.25	1.90	7.05	7.05	5.85	
WQ0012723001	BENBROOK VILLAGE MHP	0.023	7.74	14.92	1.20	3.73	7.56	7.60	5.36	
WQ0003993000	ARLINGTON PUMPING STATION PIPELINE BREAKOUT STATION	0.021			6.49	7.03				

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	BOD (mg/L)	TSS (mg/L)	Cl min (mg/L)	Cl max (mg/L)	pH Min	pH Max	DO (mg/L)	N (mg/L)
WQ0010791001	OAK GROVE AIRPORT	0.007	7.68	8.26	1.27	2.70	6.99	7.48	3.75	3.96
WQ0003730000	CHEVRON FORTH WORTH TERMINAL	0.006					8.49	8.44		
WQ0012807001	GOLDEN TRIANGLE ESTATES	0.006	8.84	13.82	0.92	2.95	7.05	7.07	3.96	
WQ0011032001	ALTA VISTA MOBILE HOME PARK	0.006	4.29	6.71	1.52	2.71	6.93	6.93	4.54	
WQ0011123001	FORTH WORTH BOAT CLUB	0.005	3.60	4.55	1.29	3.54	7.42	7.42	4.51	
WQ0012982001	REGENCY CONVERSIONS	0.002	2.86	4.45	1.11	3.67	7.54	7.56	4.88	
WQ0002831000	REAGENT CHEMICAL & RESEARCH	0.002	38.12				6.67	6.81		3.17
WQ0012909001	EAGLE MOUNTAIN RV PARK	0.001	4.44	4.87	1.30	3.65	7.33	7.33	4.99	
Wise										
WQ0001406001	HANSON AGGREGATES, INC.	1.937		9.67			8.05	8.15		
WQ0010009001	CITY OF DECATUR WWTP	0.790	3.15	2.33			7.07	7.82	6.96	0.24
WQ0010389002	CITY OF BRIDGEPORT WWTF	0.553	3.17	3.94	0.98	3.46	6.87	7.26	5.96	2.18
WQ0001406000	HANSON AGGREGATES, INC.	0.504		26.40			7.92	8.08		
WQ0010131001	CITY OF BOYD WWTP	0.097	4.57	15.92	0.94	2.70	7.51	7.62	7.29	
WQ0010862001	CITY OF RUNAWAY BAY WWTP	0.096	3.47	3.17	1.15	3.06	6.94	7.51	6.97	2.61
WQ0010701002	WESTSIDE WWTF	0.071	4.21	7.51	1.00	2.90	7.11	7.73	6.65	1.67
WQ0010023001	CITY OF CHICO	0.066	28.53	28.73	0.89	4.06	7.41	7.73	5.69	15.24
WQ0014339001	CITY OF ALVORD WWTP	0.060	4.84	8.76	0.99	3.98	7.36	7.75	5.69	0.67
WQ0011626001	CITY OF NEWARK WWTF	0.049	4.67	13.89	1.01	4.67	7.43	7.80	6.67	0.64
WQ0010701001	CITY OF RHOME	0.044	36.25	63.88			7.97	9.05	7.99	
WQ0013439001	PARADISE ISD WWTF	0.017	8.16	9.43	1.35	3.00	7.13	7.13	4.85	
WQ0014306001	SLIDELL I.S.D. - WWTP	0.007	2.60	5.53	1.54	3.30	7.42	7.42	7.52	
WQ0013427001	GARRETT CREEK RANCH WWTP	0.001	6.91	9.16	1.34	2.75	7.57	7.80	3.67	
WQ0001214000	LIMESTONE MINING AND PROCESSIN									
WQ0000679000	HANSON AGGREGATES, INC.									

TPDES #	Regulated Entity	Average Monthly Discharge Conditions (PCS database)								
		Flow (MGD)	BOD (mg/L)	TSS (mg/L)	Cl min (mg/L)	Cl max (mg/L)	pH Min	pH Max	DO (mg/L)	N (mg/L)
WQ0014841001	IVY VALLEY UTILITIES, LP									
WQ0011382001	FORTH WORTH INDEPENDENT SCHOOL DISTRICT									
WQ0014910001	CHISOLM SPRINGS									

10 Appendix B: Summary Statistics for Water Features

Water-feature statistics for the following counties:

Montague, Jack, Wise, Palo Pinto, Parker, Erath, Hood, Somervell, Bosque, and Hill

Montague County

Summary Statistics for Water Features in Acres

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	1118	248.24	0.22	0.01	0.22	0.01	0.21
Date 1	Mar 3	0.1 - 0.5 ha	1714	1189.07	0.69	0.25	1.20	0.25	0.95
Date 2	Mar 28	0.5 - 1 ha	522	898.21	1.72	1.29	2.47	0.35	1.18
		1 - 10 ha	404	2441.15	6.04	2.47	24.32	4.53	21.85
		10 - 20 ha	20	693.91	34.70	24.82	47.96	7.22	23.15
		> 20 ha	4	452.36	113.09	64.50	218.17	71.45	153.67
Baseline Wet		**Total**	**3782**	**5922.95**	**26.08**	**0.01**	**218.17**		**218.16**
Year	**1999**	< 0.1 ha	263	58.49	0.22	0.22	0.22	0	0
Date 1	Feb 14	0.1 - 0.5 ha	360	206.90	0.57	0.25	1.19	0.27	0.94
Date 2	Feb 21	0.5 - 1 ha	71	123.17	1.73	1.32	2.45	0.35	1.13
		1 - 10 ha	118	788.69	6.68	2.49	22.55	4.44	20.06
		10 - 20 ha	6	165.33	27.55	24.91	35.48	4.09	10.57
		> 20 ha	4	786.85	196.71	52.93	517.98	219.07	465.05
Baseline Dry		**Total**	**822**	**2129.43**	**38.91**	**0.22**	**517.98**		**517.76**
Year	**2003**	< 0.1 ha	598	132.97	0.22	0.20	0.22	0	0.02
Date 1	Oct 14	0.1 - 0.5 ha	775	478.28	0.62	0.25	1.20	0.26	0.95
Date 2	Oct 23	0.5 - 1 ha	182	304.92	1.68	1.29	2.45	0.32	1.15
		1 - 10 ha	161	997.15	6.19	2.50	23.96	3.95	21.45
		10 - 20 ha	9	283.77	31.53	26.91	38.03	4.15	11.12
		> 20 ha	3	261.54	87.18	54.49	151.01	55.28	96.52
		Total	**1728**	**2458.63**	**21.24**	**0.20**	**151.01**		**150.80**
Year	**2004**	< 0.1 ha	1296	288.22	0.22	0.22	0.22	0	0
Date 1	Sep 7	0.1 - 0.5 ha	1749	1127.17	0.64	0.25	1.20	0.26	0.95
Date 2	Oct 16	0.5 - 1 ha	472	807.28	1.71	1.31	2.46	0.35	1.15
		1 - 10 ha	353	2206.49	6.25	2.48	23.83	4.50	21.35
		10 - 20 ha	15	539.64	35.98	25.44	46.67	6.75	21.22
		> 20 ha	3	354.05	118.02	62.49	218.39	87.09	155.90
		Total	**3888**	**5322.85**	**27.14**	**0.22**	**218.39**		**218.17**
Year	**2005**	< 0.1 ha	1184	262.80	0.22	0.00	0.22	0.01	0.22
Date 1	Feb 14	0.1 - 0.5 ha	1894	1221.45	0.64	0.25	1.21	0.27	0.96
Date 2	Feb 21	0.5 - 1 ha	435	746.98	1.72	1.25	2.47	0.34	1.22
		1 - 10 ha	337	1988.81	5.90	2.47	22.67	4.07	20.20
		10 - 20 ha	16	554.69	34.67	25.07	45.21	6.30	20.13
		> 20 ha	3	366.28	122.09	69.83	207.05	74.22	137.22
		Total	**3869**	**5141.02**	**27.54**	**0.00**	**207.05**		**207.05**

Montague County **Summary Statistics for Water Features in Acres**

Year	**2006**	< 0.1 ha	545	121.09	0.22	0.15	0.22	0	0.08
Date 1	Nov 16	0.1 - 0.5 ha	660	409.29	0.62	0.25	1.21	0.26	0.96
Date 2	Nov 23	0.5 - 1 ha	115	193.38	1.68	1.33	2.47	0.32	1.14
		1 - 10 ha	146	850.12	5.82	2.48	20.24	3.67	17.75
		10 - 20 ha	8	244.18	30.52	25.09	43.14	7.68	18.06
		> 20 ha	3	466.14	155.38	51.37	252.20	100.60	200.82
		Total	**1477**	**2284.20**	**32.37**	**0.15**	**252.20**		**252.05**
Year	**2007**	< 0.1 ha	1797	399.13	0.22	0.01	0.22	0.01	0.21
Date 1	Mar 8	0.1 - 0.5 ha	2268	1469.74	0.65	0.25	1.23	0.25	0.97
Date 2	Mar 31	0.5 - 1 ha	628	1089.41	1.73	1.29	2.47	0.34	1.18
		1 - 10 ha	477	2905.78	6.09	2.47	23.14	4.28	20.67
		10 - 20 ha	30	958.12	31.94	25.38	47.33	5.38	21.96
		> 20 ha	12	1092.83	91.07	52.07	228.62	57.07	176.55
		Total	**5212**	**7915.02**	**21.95**	**0.01**	**228.62**		**228.61**
Year	**2008**	< 0.1 ha	1427	316.81	0.22	0.06	0.22	0.01	0.16
Date 1	Apr 11	0.1 - 0.5 ha	2253	1465.01	0.65	0.25	1.23	0.27	0.97
Date 2	Apr 18	0.5 - 1 ha	621	1068.28	1.72	1.30	2.45	0.35	1.14
		1 - 10 ha	479	2869.63	5.99	2.47	24.64	4.58	22.16
		10 - 20 ha	15	552.81	36.85	25.35	48.96	8.28	23.61
		> 20 ha	4	419.92	104.98	52.74	213.28	73.21	160.53
		Total	**4799**	**6692.44**	**25.07**	**0.06**	**213.28**		**213.22**
Year	**2009**	< 0.1 ha	1237	275.08	0.22	0.20	0.22	0	0.02
Date 1	Sep 28	0.1 - 0.5 ha	1631	1084.57	0.66	0.30	1.23	0.25	0.93
Date 2	Oct 23	0.5 - 1 ha	519	883.89	1.70	1.24	2.47	0.36	1.23
		1 - 10 ha	377	2263.67	6.00	2.48	24.02	4.33	21.54
		10 - 20 ha	15	529.81	35.32	26.46	44.03	6.98	17.57
		> 20 ha	3	334.26	111.42	59.38	201.27	78.14	141.89
		Total	**3782**	**5371.28**	**25.89**	**0.20**	**201.27**		**201.06**
Year	**2010**	< 0.1 ha	1274	283.33	0.22	0.22	0.22	0	0
Date 1	Nov 18	0.1 - 0.5 ha	1477	968.45	0.66	0.41	1.11	0.23	0.70
Date 2	Nov 27	0.5 - 1 ha	400	686.27	1.72	1.33	2.45	0.36	1.11
		1 - 10 ha	291	1948.85	6.70	2.67	24.24	4.46	21.57
		10 - 20 ha	12	415.21	34.60	26.02	44.26	6.53	18.24
		> 20 ha	2	261.09	130.55	72.95	188.15	81.46	115.20
		Total	**3456**	**4563.19**	**29.07**	**0.22**	**188.15**		**187.92**

Jack County

Summary Statistics for Water Features in Acres

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	1238	274.43	0.22	0.00	0.22	0.01	0.22
Date 1	Mar 3	0.1 - 0.5 ha	2301	1598.48	0.69	0.25	1.20	0.24	0.95
Date 2	Mar 28	0.5 - 1 ha	722	1229.36	1.70	1.33	2.47	0.35	1.15
		1 - 10 ha	343	1776.17	5.18	2.48	23.80	3.78	21.32
		10 - 20 ha	9	294.01	32.67	26.02	40.11	4.83	14.09
		> 20 ha	12	1341.32	111.78	53.17	558.66	141.58	505.49
Baseline Wet		**Total**	**4625**	**6513.77**	**25.37**	**0.00**	**558.66**		**558.65**
Year	**1999**	< 0.1 ha	503	111.72	0.22	0.07	0.22	0	0
Date 1	Feb 14	0.1 - 0.5 ha	433	270.28	0.62	0.25	1.20	0.23	0.95
Date 2	Feb 21	0.5 - 1 ha	87	147.25	1.69	1.32	2.45	0.35	1.13
		1 - 10 ha	67	421.38	6.29	2.50	23.00	4.29	20.50
		10 - 20 ha	5	171.80	34.36	27.58	41.37	5.94	13.79
		> 20 ha	5	627.82	125.56	51.37	338.26	122.82	286.89
Baseline Dry		**Total**	**1100**	**1750.25**	**28.13**	**0.07**	**338.26**		**338.19**
Year	**2003**	< 0.1 ha	941	208.75	0.22	0.01	0.22	0	0.21
Date 1	Oct 14	0.1 - 0.5 ha	1007	625.47	0.62	0.25	1.19	0.24	0.93
Date 2	Oct 23	0.5 - 1 ha	192	322.13	1.68	1.33	2.45	0.35	1.11
		1 - 10 ha	95	561.87	5.91	2.56	20.46	4.14	17.89
		10 - 20 ha	5	198.22	39.64	35.36	44.92	3.58	9.56
		> 20 ha	3	641.83	213.94	57.60	497.50	246.00	439.90
		Total	**2243**	**2558.27**	**43.67**	**0.01**	**497.50**		**497.49**
Year	**2004**	< 0.1 ha	1427	316.97	0.22	0.02	0.22	0	0
Date 1	Sep 7	0.1 - 0.5 ha	1817	1200.44	0.66	0.25	1.19	0.24	0.93
Date 2	Oct 16	0.5 - 1 ha	435	737.72	1.70	1.33	2.46	0.36	1.13
		1 - 10 ha	190	1037.61	5.46	2.50	22.24	4.12	19.74
		10 - 20 ha	8	297.84	37.23	26.02	46.70	7.18	20.68
		> 20 ha	4	758.59	189.65	54.04	545.53	238.00	491.49
		Total	**3881**	**4349.17**	**39.15**	**0.02**	**545.53**		**545.52**
Year	**2005**	< 0.1 ha	1342	297.74	0.22	0.02	0.23	0.01	0.21
Date 1	Feb 14	0.1 - 0.5 ha	1769	1158.99	0.66	0.25	1.20	0.24	0.95
Date 2	Feb 21	0.5 - 1 ha	374	626.45	1.67	1.31	2.45	0.33	1.14
		1 - 10 ha	177	1029.67	5.82	2.52	23.57	4.49	21.05
		10 - 20 ha	7	264.23	37.75	26.99	45.12	6.57	18.13
		> 20 ha	5	726.34	145.27	52.93	400.31	145.75	347.38
		Total	**3674**	**4103.41**	**31.90**	**0.02**	**400.31**		**400.29**
Year	**2006**	< 0.1 ha	656	145.65	0.22	0.01	0.22	0	0.21
Date 1	Nov 16	0.1 - 0.5 ha	614	375.38	0.61	0.25	1.20	0.23	0.95
Date 2	Nov 23	0.5 - 1 ha	87	151.32	1.74	1.33	2.47	0.35	1.14

Jack County

Summary Statistics for Water Features in Acres

		1 - 10 ha	68	434.30	6.39	2.53	20.76	4.49	18.23
		10 - 20 ha	3	94.68	31.56	29.07	33.58	2.29	4.51
		> 20 ha	4	605.36	151.34	49.59	362.50	143.44	312.91
		Total	**1432**	**1806.70**	**31.98**	**0.01**	**362.50**		**362.49**
Year	**2007**	< 0.1 ha	1949	432.65	0.22	0.00	0.22	0.01	0.22
Date 1	Mar 8	0.1 - 0.5 ha	2619	1750.44	0.67	0.25	1.21	0.24	0.95
Date 2	Mar 31	0.5 - 1 ha	760	1304.33	1.72	1.33	2.47	0.36	1.14
		1 - 10 ha	441	2385.64	5.41	2.47	24.69	3.91	22.21
		10 - 20 ha	10	361.17	36.12	27.35	48.04	6.80	20.68
		> 20 ha	16	2046.10	127.88	51.37	604.91	134.47	553.54
		Total	**5795**	**8280.34**	**28.67**	**0.00**	**604.91**		**604.91**
Year	**2008**	< 0.1 ha	1631	362.09	0.22	0.02	0.22	0.01	0.20
Date 1	Apr 11	0.1 - 0.5 ha	2372	1583.27	0.67	0.25	1.21	0.25	0.95
Date 2	Apr 18	0.5 - 1 ha	669	1140.64	1.70	1.32	2.46	0.35	1.14
		1 - 10 ha	350	1807.82	5.17	2.48	24.69	3.71	22.21
		10 - 20 ha	6	231.80	38.63	25.35	48.70	9.00	23.35
		> 20 ha	10	1164.72	116.47	49.43	567.33	159.60	517.90
		Total	**5038**	**6290.34**	**27.14**	**0.02**	**567.33**		**567.31**
Year	**2009**	< 0.1 ha	1189	263.84	0.22	0.02	0.22	0	0.21
Date 1	Sep 28	0.1 - 0.5 ha	1348	887.74	0.66	0.25	1.23	0.24	0.98
Date 2	Oct 23	0.5 - 1 ha	322	548.29	1.70	1.24	2.46	0.36	1.22
		1 - 10 ha	177	931.75	5.26	2.49	22.68	3.78	20.20
		10 - 20 ha	9	304.63	33.85	24.91	48.99	9.82	24.08
		> 20 ha	4	640.81	160.20	56.13	435.45	184.29	379.32
		Total	**3049**	**3577.05**	**33.65**	**0.02**	**435.45**		**435.43**
Year	**2010**	< 0.1 ha	908	201.51	0.22	0.03	0.22	0	0
Date 1	Nov 18	0.1 - 0.5 ha	1085	718.93	0.66	0.44	1.11	0.23	0.67
Date 2	Nov 27	0.5 - 1 ha	236	398.31	1.69	1.33	2.45	0.35	1.11
		1 - 10 ha	129	790.17	6.13	2.67	23.13	4.25	20.46
		10 - 20 ha	10	334.70	33.47	27.58	43.14	6.46	15.57
		> 20 ha	4	692.09	173.02	49.59	496.61	216.48	447.01
		Total	**2372**	**3135.72**	**35.87**	**0.03**	**496.61**		**496.58**

Wise County

Summary Statistics for Water Features in Acres

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	1389	308.30	0.22	0.00	0.22	0.01	0.22
Date 1	Mar 3	0.1 - 0.5 ha	1828	1225.04	0.67	0.25	1.19	0.24	0.93
Date 2	Mar 28	0.5 - 1 ha	486	828.27	1.70	1.32	2.45	0.35	1.13
		1 - 10 ha	285	2053.08	7.20	2.47	23.80	5.46	21.32
		10 - 20 ha	28	926.77	33.10	24.91	47.37	6.50	22.46
		> 20 ha	8	725.97	90.75	51.81	129.43	32.33	77.62
Baseline Wet		**Total**	**4024**	**6067.43**	**22.27**	**0.00**	**129.43**		**129.43**
Year	**1999**	< 0.1 ha	468	104.08	0.22	0.22	0.22	0	0
Date 1	Feb 14	0.1 - 0.5 ha	540	337.42	0.62	0.25	1.20	0.26	0.95
Date 2	Feb 21	0.5 - 1 ha	89	154.72	1.74	1.33	2.45	0.36	1.11
		1 - 10 ha	139	1119.62	8.05	2.50	24.69	5.36	22.19
		10 - 20 ha	10	343.98	34.40	25.35	48.17	8.37	22.81
		> 20 ha	4	256.55	64.14	52.11	76.28	9.90	24.17
Baseline Dry		**Total**	**1250**	**2316.37**	**18.20**	**0.22**	**76.28**		**76.06**
Year	**2003**	< 0.1 ha	887	197.08	0.22	0.02	0.24	0	0.23
Date 1	Oct 14	0.1 - 0.5 ha	1061	669.98	0.63	0.25	1.20	0.25	0.95
Date 2	Oct 23	0.5 - 1 ha	214	363.32	1.70	1.31	2.45	0.34	1.14
		1 - 10 ha	197	1538.95	7.81	2.49	24.69	5.21	22.20
		10 - 20 ha	15	439.22	29.28	25.13	39.14	4.55	14.01
		> 20 ha	3	228.59	76.20	69.74	82.60	6.43	12.87
		Total	**2377**	**3437.12**	**19.31**	**0.02**	**82.60**		**82.59**
Year	**2004**	< 0.1 ha	1500	333.18	0.22	0.04	0.22	0	0
Date 1	Sep 7	0.1 - 0.5 ha	1612	1035.87	0.64	0.25	1.20	0.25	0.95
Date 2	Oct 16	0.5 - 1 ha	367	620.76	1.69	1.29	2.46	0.33	1.17
		1 - 10 ha	253	2023.20	8.00	2.49	24.46	5.59	21.97
		10 - 20 ha	20	629.53	31.48	24.91	38.47	4.56	13.57
		> 20 ha	5	418.79	83.76	69.39	108.75	14.77	39.36
		Total	**3757**	**5061.32**	**20.96**	**0.04**	**108.75**		**108.70**
Year	**2005**	< 0.1 ha	1386	307.53	0.22	0.00	0.24	0.01	0.24
Date 1	Feb 14	0.1 - 0.5 ha	1914	1252.04	0.65	0.25	1.21	0.25	0.95
Date 2	Feb 21	0.5 - 1 ha	394	664.15	1.69	1.33	2.47	0.32	1.14
		1 - 10 ha	304	2210.06	7.27	2.48	24.69	5.08	22.21
		10 - 20 ha	20	653.50	32.68	26.24	46.29	5.90	20.04
		> 20 ha	7	599.81	85.69	51.82	133.44	27.74	81.62
		Total	**4025**	**5687.11**	**21.37**	**0.00**	**133.44**		**133.44**
Year	**2006**	< 0.1 ha	356	78.98	0.22	0.04	0.22	0	0.18
Date 1	Nov 16	0.1 - 0.5 ha	417	267.67	0.64	0.25	1.20	0.27	0.95
Date 2	Nov 23	0.5 - 1 ha	76	134.76	1.77	1.33	2.45	0.36	1.12
		1 - 10 ha	121	917.70	7.58	2.50	24.51	4.85	22.00

Wise County

Summary Statistics for Water Features in Acres

		10 - 20 ha	4	117.44	29.36	26.05	35.42	4.25	9.37
		> 20 ha	3	216.69	72.23	58.72	92.60	17.95	33.88
		Total	**977**	**1733.24**	**18.64**	**0.04**	**92.60**		**92.55**
Year	**2007**	< 0.1 ha	1574	349.49	0.22	0.00	0.22	0.01	0.22
Date 1	Mar 8	0.1 - 0.5 ha	1712	1123.94	0.66	0.25	1.19	0.24	0.93
Date 2	Mar 31	0.5 - 1 ha	418	717.24	1.72	1.31	2.46	0.34	1.15
		1 - 10 ha	271	1866.33	6.89	2.48	23.72	5.06	21.24
		10 - 20 ha	15	528.81	35.25	26.46	45.64	6.19	19.17
		> 20 ha	7	713.89	101.98	55.21	171.81	51.58	116.60
		Total	**3997**	**5299.69**	**24.45**	**0.00**	**171.81**		**171.81**
Year	**2008**	< 0.1 ha	2063	457.93	0.22	0.00	0.22	0.01	0.22
Date 1	Apr 11	0.1 - 0.5 ha	2612	1710.45	0.65	0.25	1.22	0.26	0.97
Date 2	Apr 18	0.5 - 1 ha	698	1204.65	1.73	1.32	2.47	0.34	1.15
		1 - 10 ha	462	3212.24	6.95	2.48	24.46	5.23	21.99
		10 - 20 ha	37	1227.36	33.17	24.91	48.62	7.33	23.72
		> 20 ha	9	782.16	86.91	54.49	123.65	25.03	69.16
		Total	**5881**	**8594.79**	**21.61**	**0.00**	**123.65**		**123.65**
Year	**2009**	< 0.1 ha	1739	386.47	0.22	0.00	0.24	0	0.24
Date 1	Sep 28	0.1 - 0.5 ha	1951	1287.79	0.66	0.27	1.23	0.24	0.95
Date 2	Oct 23	0.5 - 1 ha	512	867.58	1.69	1.24	2.45	0.33	1.20
		1 - 10 ha	369	2601.05	7.05	2.49	24.43	5.07	21.95
		10 - 20 ha	24	778.65	32.44	25.13	48.51	6.34	23.38
		> 20 ha	7	537.58	76.80	54.49	95.87	19.08	41.39
		Total	**4602**	**6459.12**	**19.81**	**0.00**	**95.87**		**95.87**
Year	**2010**	< 0.1 ha	1477	327.89	0.22	0.01	0.22	0	0
Date 1	Nov 18	0.1 - 0.5 ha	1668	1101.16	0.66	0.44	1.11	0.23	0.67
Date 2	Nov 27	0.5 - 1 ha	351	612.41	1.74	1.33	2.45	0.37	1.11
		1 - 10 ha	272	2060.07	7.57	2.67	24.69	5.22	22.02
		10 - 20 ha	24	746.80	31.12	25.35	43.81	5.59	18.46
		> 20 ha	6	491.27	81.88	57.60	111.86	18.85	54.26
		Total	**3798**	**5339.60**	**20.53**	**0.01**	**111.86**		**111.86**

Palo Pinto County **Summary Statistics for Water Features in Acres**

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	1278	283.83	0.22	0.08	0.22	0.01	0.14
Date 1	Mar 3	0.1 - 0.5 ha	1844	1259.64	0.68	0.25	1.19	0.25	0.93
Date 2	Mar 28	0.5 - 1 ha	562	961.55	1.71	1.33	2.45	0.35	1.11
		1 - 10 ha	335	1959.97	5.85	2.49	24.69	4.59	22.20
		10 - 20 ha	9	280.58	31.18	25.35	45.50	7.26	20.15
		> 20 ha	5	620.60	124.12	73.84	182.59	42.89	108.75
Baseline Wet		**Total**	**4033**	**5366.16**	**27.29**	**0.08**	**182.59**		**182.51**
Year	**1999**	< 0.1 ha	448	99.49	0.22	0.13	0.23	0	0
Date 1	Feb 14	0.1 - 0.5 ha	576	376.15	0.65	0.25	1.19	0.24	0.93
Date 2	Feb 21	0.5 - 1 ha	127	220.82	1.74	1.31	2.45	0.38	1.14
		1 - 10 ha	106	789.29	7.45	2.49	23.76	5.30	21.27
		10 - 20 ha							
		> 20 ha	4	369.77	92.44	59.82	126.91	27.74	67.09
Baseline Dry		**Total**	**1261**	**1855.51**	**20.50**	**0.13**	**126.91**		**126.78**
Year	**2003**	< 0.1 ha	856	190.37	0.22	0.22	0.22	0	0.00
Date 1	Oct 14	0.1 - 0.5 ha	813	517.77	0.64	0.25	1.20	0.25	0.95
Date 2	Oct 23	0.5 - 1 ha	136	232.69	1.71	1.33	2.45	0.36	1.11
		1 - 10 ha	111	756.48	6.82	2.49	24.69	4.99	22.20
		10 - 20 ha	1	30.25	30.25	30.25	30.25	0.00	0.00
		> 20 ha	5	447.93	89.59	57.16	124.12	30.22	66.96
		Total	**1922**	**2175.48**	**21.54**	**0.22**	**124.12**		**123.90**
Year	**2004**	< 0.1 ha	1312	291.61	0.22	0.12	0.22	0	0
Date 1	Sep 7	0.1 - 0.5 ha	1223	778.49	0.64	0.25	1.20	0.25	0.95
Date 2	Oct 16	0.5 - 1 ha	226	384.97	1.70	1.31	2.45	0.36	1.14
		1 - 10 ha	165	1072.74	6.50	2.47	23.80	4.94	21.32
		10 - 20 ha	3	113.09	37.70	32.81	42.26	4.73	9.45
		> 20 ha	5	544.45	108.89	66.94	129.01	25.35	62.07
		Total	**2934**	**3185.35**	**25.94**	**0.12**	**129.01**		**128.89**
Year	**2005**	< 0.1 ha	1003	222.89	0.22	0.14	0.22	0.00	0.09
Date 1	Feb 14	0.1 - 0.5 ha	1355	924.93	0.68	0.25	1.20	0.25	0.95
Date 2	Feb 21	0.5 - 1 ha	356	603.87	1.70	1.33	2.46	0.35	1.14
		1 - 10 ha	223	1384.78	6.21	2.47	24.24	4.47	21.77
		10 - 20 ha	6	175.68	29.28	24.78	35.69	4.90	10.91
		> 20 ha	6	602.14	100.36	51.15	130.89	33.68	79.74
		Total	**2949**	**3914.30**	**23.07**	**0.14**	**130.89**		**130.75**
Year	**2006**	< 0.1 ha	674	149.89	0.22	0.22	0.22	0	0.00
Date 1	Nov 16	0.1 - 0.5 ha	567	359.11	0.63	0.25	1.21	0.25	0.96
Date 2	Nov 23	0.5 - 1 ha	108	185.68	1.72	1.32	2.45	0.36	1.13
		1 - 10 ha	116	715.19	6.17	2.54	20.91	4.74	18.37

Palo Pinto County

Summary Statistics for Water Features in Acres

		10 - 20 ha	2	58.93	29.47	27.13	31.80	3.30	4.67
		> 20 ha	5	417.76	83.55	56.93	108.86	23.12	51.92
		Total	**1472**	**1886.58**	**20.29**	**0.22**	**108.86**		**108.63**
Year	**2007**	< 0.1 ha	1784	396.04	0.22	0.05	0.22	0.01	0.17
Date 1	Mar 8	0.1 - 0.5 ha	2174	1432.12	0.66	0.25	1.23	0.23	0.97
Date 2	Mar 31	0.5 - 1 ha	631	1083.95	1.72	1.33	2.46	0.35	1.13
		1 - 10 ha	375	2197.36	5.86	2.47	24.69	4.24	22.21
		10 - 20 ha	12	375.18	31.27	26.24	42.70	5.44	16.46
		> 20 ha	10	919.36	91.94	49.82	134.85	33.04	85.03
		Total	**4986**	**6404.01**	**21.94**	**0.05**	**134.85**		**134.80**
Year	**2008**	< 0.1 ha	1419	315.08	0.22	0.10	0.22	0.01	0.12
Date 1	Apr 11	0.1 - 0.5 ha	1889	1266.92	0.67	0.25	1.20	0.26	0.95
Date 2	Apr 18	0.5 - 1 ha	484	836.11	1.73	1.33	2.46	0.36	1.13
		1 - 10 ha	294	1736.80	5.91	2.51	24.46	4.24	21.95
		10 - 20 ha	10	354.92	35.49	26.24	49.15	7.30	22.91
		> 20 ha	5	583.51	116.70	72.28	146.34	29.52	74.06
		Total	**4101**	**5093.35**	**26.79**	**0.10**	**146.34**		**146.24**
Year	**2009**	< 0.1 ha	1009	223.79	0.22	0.04	0.24	0	0.21
Date 1	Sep 28	0.1 - 0.5 ha	1169	756.88	0.65	0.37	1.23	0.24	0.86
Date 2	Oct 23	0.5 - 1 ha	278	480.61	1.73	1.25	2.45	0.36	1.20
		1 - 10 ha	205	1268.74	6.19	2.49	24.69	4.47	22.20
		10 - 20 ha	8	281.97	35.25	25.82	47.81	7.97	21.99
		> 20 ha	4	422.67	105.67	80.06	124.88	18.67	44.82
		Total	**2673**	**3434.66**	**24.95**	**0.04**	**124.88**		**124.85**
Year	**2010**	< 0.1 ha	827	183.65	0.22	0.06	0.22	0	0
Date 1	Nov 18	0.1 - 0.5 ha	841	550.32	0.65	0.36	1.11	0.24	0.76
Date 2	Nov 27	0.5 - 1 ha	189	334.38	1.77	1.25	2.45	0.38	1.20
		1 - 10 ha	153	949.82	6.21	2.67	22.24	4.24	19.57
		10 - 20 ha	5	159.15	31.83	26.46	38.92	4.51	12.45
		> 20 ha	5	501.50	100.30	55.38	126.54	28.17	71.17
		Total	**2020**	**2678.83**	**23.50**	**0.06**	**126.54**		**126.48**

Parker County — **Summary Statistics for Water Features in Acres**

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	1288	285.92	0.22	0.05	0.22	0.01	0.17
Date 1	Mar 3	0.1 - 0.5 ha	1575	1048.19	0.67	0.25	1.21	0.26	0.96
Date 2	Mar 28	0.5 - 1 ha	393	676.39	1.72	1.33	2.47	0.35	1.13
		1 - 10 ha	295	1779.93	6.03	2.47	22.08	4.24	19.61
		10 - 20 ha	10	350.51	35.05	25.70	48.69	6.70	23.00
		> 20 ha	6	753.82	125.64	50.11	398.98	136.52	348.87
Baseline Wet		**Total**	**3567**	**4894.76**	**28.22**	**0.05**	**398.98**		**398.92**
Year	**1999**	< 0.1 ha	511	113.27	0.22	0.06	0.22	0	0
Date 1	Feb 14	0.1 - 0.5 ha	705	452.14	0.64	0.25	1.22	0.25	0.97
Date 2	Feb 21	0.5 - 1 ha	164	288.26	1.76	1.31	2.47	0.37	1.16
		1 - 10 ha	141	963.41	6.83	2.47	24.43	4.83	21.96
		10 - 20 ha	10	316.62	31.66	25.92	44.22	5.99	18.29
		> 20 ha	4	434.11	108.53	65.16	135.88	30.32	70.72
Baseline Dry		**Total**	**1535**	**2567.82**	**24.94**	**0.06**	**135.88**		**135.82**
Year	**2003**	< 0.1 ha	779	172.66	0.22	0.03	0.22	0	0.20
Date 1	Oct 14	0.1 - 0.5 ha	905	549.97	0.61	0.25	1.21	0.26	0.95
Date 2	Oct 23	0.5 - 1 ha	153	261.44	1.71	1.33	2.46	0.32	1.13
		1 - 10 ha	158	1043.89	6.61	2.48	24.02	4.77	21.54
		10 - 20 ha	8	259.74	32.47	24.85	43.81	7.34	18.97
		> 20 ha	2	158.12	79.06	64.72	93.41	20.29	28.69
		Total	**2005**	**2445.81**	**20.11**	**0.03**	**93.41**		**93.38**
Year	**2004**	< 0.1 ha	1137	252.28	0.22	0.05	0.22	0	0
Date 1	Sep 7	0.1 - 0.5 ha	1246	761.80	0.61	0.25	1.20	0.25	0.95
Date 2	Oct 16	0.5 - 1 ha	252	430.06	1.71	1.30	2.45	0.33	1.14
		1 - 10 ha	197	1251.09	6.35	2.48	24.63	4.19	22.15
		10 - 20 ha	12	396.79	33.07	25.45	44.92	6.89	19.47
		> 20 ha	2	195.49	97.74	71.61	123.87	36.96	52.26
		Total	**2846**	**3287.51**	**23.28**	**0.05**	**123.87**		**123.82**
Year	**2005**	< 0.1 ha	886	196.22	0.22	0.00	0.22	0.01	0.22
Date 1	Feb 14	0.1 - 0.5 ha	1423	945.80	0.66	0.25	1.24	0.26	0.98
Date 2	Feb 21	0.5 - 1 ha	363	618.07	1.70	1.33	2.45	0.34	1.12
		1 - 10 ha	248	1442.75	5.82	2.49	22.19	3.88	19.71
		10 - 20 ha	13	437.36	33.64	27.04	44.48	5.82	17.44
		> 20 ha	6	602.24	100.37	56.84	153.67	36.32	96.83
		Total	**2939**	**4242.44**	**23.74**	**0.00**	**153.67**		**153.67**
Year	**2006**	< 0.1 ha	459	101.69	0.22	0.05	0.24	0	0.19
Date 1	Nov 16	0.1 - 0.5 ha	634	408.74	0.64	0.25	1.22	0.27	0.97
Date 2	Nov 23	0.5 - 1 ha	176	306.13	1.74	1.33	2.45	0.34	1.11
		1 - 10 ha	140	909.71	6.50	2.55	21.82	4.68	19.26

Summary Statistics for Water Features in Acres

		10 - 20 ha	5	153.22	30.64	25.13	38.18	4.87	13.05
		> 20 ha	3	260.42	86.81	58.71	121.21	31.72	62.49
		Total	**1417**	**2139.93**	**21.09**	**0.05**	**121.21**		**121.15**
Year	**2007**	< 0.1 ha	1267	280.88	0.22	0.03	0.22	0.01	0.20
Date 1	Mar 8	0.1 - 0.5 ha	1682	1122.87	0.67	0.25	1.20	0.24	0.95
Date 2	Mar 31	0.5 - 1 ha	425	723.17	1.70	1.30	2.46	0.34	1.16
		1 - 10 ha	322	1757.61	5.46	2.48	23.40	3.84	20.92
		10 - 20 ha	13	414.48	31.88	25.13	40.92	4.82	15.79
		> 20 ha	5	591.22	118.24	66.50	225.59	66.14	159.10
		Total	**3714**	**4890.24**	**26.36**	**0.03**	**225.59**		**225.57**
Year	**2008**	< 0.1 ha	1358	301.10	0.22	0.01	0.22	0.01	0.22
Date 1	Apr 11	0.1 - 0.5 ha	1914	1225.84	0.64	0.25	1.20	0.27	0.95
Date 2	Apr 18	0.5 - 1 ha	488	839.97	1.72	1.31	2.46	0.33	1.15
		1 - 10 ha	369	2113.32	5.73	2.49	23.63	4.19	21.14
		10 - 20 ha	13	501.91	38.61	26.78	48.03	7.54	21.25
		> 20 ha	4	913.60	228.40	80.06	407.87	150.66	327.81
		Total	**4146**	**5895.73**	**45.89**	**0.01**	**407.87**		**407.87**
Year	**2009**	< 0.1 ha	1213	269.06	0.22	0.03	0.24	0	0.21
Date 1	Sep 28	0.1 - 0.5 ha	1446	943.63	0.65	0.37	1.23	0.24	0.86
Date 2	Oct 23	0.5 - 1 ha	435	758.55	1.74	1.24	2.47	0.36	1.23
		1 - 10 ha	316	1926.38	6.10	2.48	24.45	4.58	21.98
		10 - 20 ha	8	273.32	34.16	26.24	47.87	7.82	21.63
		> 20 ha	5	702.44	140.49	74.50	284.67	85.77	210.16
		Total	**3423**	**4873.39**	**30.56**	**0.03**	**284.67**		**284.63**
Year	**2010**	< 0.1 ha	1205	267.06	0.22	0.01	0.22	0	0
Date 1	Nov 18	0.1 - 0.5 ha	1344	881.65	0.66	0.29	1.19	0.23	0.90
Date 2	Nov 27	0.5 - 1 ha	383	665.81	1.74	1.33	2.45	0.36	1.11
		1 - 10 ha	235	1638.70	6.97	2.67	24.24	4.93	21.57
		10 - 20 ha	9	302.90	33.66	26.02	46.26	6.35	20.24
		> 20 ha	2	232.63	116.31	69.39	163.24	66.36	93.85
		Total	**3178**	**3988.74**	**26.59**	**0.01**	**163.24**		**163.23**

Erath County

Summary Statistics for Water Features in Acres

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	1696	376.85	0.22	0.01	0.22	0.01	0.21
Date 1	Mar 3	0.1 - 0.5 ha	2252	1498.17	0.67	0.25	1.20	0.25	0.95
Date 2	Mar 28	0.5 - 1 ha	575	978.62	1.70	1.30	2.47	0.34	1.17
		1 - 10 ha	309	2096.65	6.79	2.47	24.40	5.36	21.93
		10 - 20 ha	25	893.25	35.73	24.91	49.25	7.70	24.34
		> 20 ha	21	1436.14	68.39	49.44	138.55	26.14	89.11
Baseline Wet		**Total**	**4878**	**7279.67**	**18.92**	**0.01**	**138.55**		**138.54**
Year	**1999**	< 0.1 ha	572	127.09	0.22	0.10	0.22	0	0
Date 1	Feb 14	0.1 - 0.5 ha	751	460.35	0.61	0.25	1.19	0.25	0.94
Date 2	Feb 21	0.5 - 1 ha	147	255.33	1.74	1.33	2.45	0.36	1.12
		1 - 10 ha	133	1110.94	8.35	2.48	23.96	5.57	21.48
		10 - 20 ha	19	573.74	30.20	25.13	41.81	4.45	16.68
		> 20 ha	4	279.55	69.89	51.15	89.85	21.17	38.70
Baseline Dry		**Total**	**1626**	**2807.00**	**18.50**	**0.10**	**89.85**		**89.75**
Year	**2003**	< 0.1 ha	939	208.59	0.22	0.10	0.22	0	0.12
Date 1	Oct 14	0.1 - 0.5 ha	1133	690.35	0.61	0.25	1.20	0.25	0.95
Date 2	Oct 23	0.5 - 1 ha	177	295.63	1.67	1.33	2.46	0.34	1.13
		1 - 10 ha	152	1136.16	7.47	2.49	23.37	5.43	20.89
		10 - 20 ha	26	835.59	32.14	24.91	40.92	4.90	16.01
		> 20 ha	4	298.66	74.66	53.82	114.51	28.30	60.69
		Total	**2431**	**3464.98**	**19.46**	**0.10**	**114.51**		**114.41**
Year	**2004**	< 0.1 ha	1491	331.18	0.22	0.01	0.22	0	0
Date 1	Sep 7	0.1 - 0.5 ha	1617	1015.93	0.63	0.25	1.21	0.25	0.95
Date 2	Oct 16	0.5 - 1 ha	308	526.20	1.71	1.32	2.47	0.34	1.15
		1 - 10 ha	196	1432.02	7.31	2.49	22.98	5.53	20.50
		10 - 20 ha	33	1117.83	33.87	25.15	43.68	5.62	18.54
		> 20 ha	4	306.83	76.71	52.26	117.12	29.31	64.86
		Total	**3649**	**4729.99**	**20.07**	**0.01**	**117.12**		**117.11**
Year	**2005**	< 0.1 ha	1189	264.23	0.22	0.12	0.22	0	0.10
Date 1	Feb 14	0.1 - 0.5 ha	1846	1200.60	0.65	0.25	1.20	0.25	0.95
Date 2	Feb 21	0.5 - 1 ha	418	704.37	1.69	1.30	2.46	0.33	1.16
		1 - 10 ha	258	1774.08	6.88	2.48	24.41	5.52	21.93
		10 - 20 ha	34	1213.59	35.69	24.91	48.26	6.21	23.35
		> 20 ha	7	528.19	75.46	50.71	123.47	27.78	72.77

Erath County **Summary Statistics for Water Features in Acres**

		Total	**3752**	**5685.07**	**20.10**	**0.12**	**123.47**		**123.35**
Year	**2006**	< 0.1 ha	464	103.19	0.22	0.22	0.22	0	0
Date 1	Nov 16	0.1 - 0.5 ha	539	341.55	0.63	0.25	1.22	0.26	0.96
Date 2	Nov 23	0.5 - 1 ha	112	188.36	1.68	1.33	2.45	0.37	1.12
		1 - 10 ha	129	1088.17	8.44	2.54	24.68	5.98	22.14
		10 - 20 ha	13	427.35	32.87	25.87	42.48	5.65	16.61
		> 20 ha	2	138.80	69.40	58.93	79.87	14.80	20.93
		Total	**1259**	**2287.43**	**18.87**	**0.22**	**79.87**		**79.64**
Year	**2007**	< 0.1 ha	1955	434.28	0.22	0.01	0.22	0.01	0.21
Date 1	Mar 8	0.1 - 0.5 ha	2337	1529.98	0.65	0.25	1.21	0.23	0.96
Date 2	Mar 31	0.5 - 1 ha	609	1028.49	1.69	1.29	2.47	0.35	1.18
		1 - 10 ha	318	2033.47	6.39	2.48	23.57	5.10	21.10
		10 - 20 ha	37	1322.46	35.74	25.35	48.93	7.41	23.57
		> 20 ha	15	1034.08	68.94	50.26	154.69	27.80	104.43
		Total	**5271**	**7382.75**	**18.94**	**0.01**	**154.69**		**154.69**
Year	**2008**	< 0.1 ha	1452	322.51	0.22	0.03	0.22	0.01	0.19
Date 1	Apr 11	0.1 - 0.5 ha	1822	1157.43	0.64	0.25	1.20	0.25	0.95
Date 2	Apr 18	0.5 - 1 ha	368	635.36	1.73	1.33	2.45	0.34	1.12
		1 - 10 ha	257	1853.24	7.21	2.49	23.67	5.52	21.18
		10 - 20 ha	34	1170.03	34.41	25.13	48.93	5.89	23.80
		> 20 ha	5	398.97	79.79	52.03	116.76	32.77	64.72
		Total	**3938**	**5537.54**	**20.67**	**0.03**	**116.76**		**116.72**
Year	**2009**	< 0.1 ha	1272	282.47	0.22	0.01	0.22	0	0.21
Date 1	Sep 28	0.1 - 0.5 ha	1488	985.34	0.66	0.27	1.23	0.25	0.95
Date 2	Oct 23	0.5 - 1 ha	375	649.17	1.73	1.24	2.47	0.36	1.23
		1 - 10 ha	235	1694.22	7.21	2.49	24.24	5.40	21.75
		10 - 20 ha	29	996.50	34.36	25.22	48.93	7.43	23.71
		> 20 ha	3	218.49	72.83	64.36	78.73	7.52	14.37
		Total	**3402**	**4826.19**	**19.50**	**0.01**	**78.73**		**78.72**
Year	**2010**	< 0.1 ha	1045	231.45	0.22	0.02	0.22	0	0
Date 1	Nov 18	0.1 - 0.5 ha	1066	704.99	0.66	0.44	1.11	0.23	0.67
Date 2	Nov 27	0.5 - 1 ha	263	440.12	1.67	1.33	2.45	0.33	1.11
		1 - 10 ha	195	1517.00	7.78	2.67	24.46	5.60	21.79
		10 - 20 ha	28	932.50	33.30	26.24	42.48	5.06	16.23
		> 20 ha	4	304.01	76.00	53.60	113.20	27.31	59.60

Erath County

Summary Statistics for Water Features in Acres

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
		Total	**2601**	**4130.07**	**19.94**	**0.02**	**113.20**		**113.18**

Hood County

Summary Statistics for Water Features in Acres

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	571	126.35	0.22	0.00	0.22	0.01	0.22
Date 1	Mar 3	0.1 - 0.5 ha	522	340.24	0.65	0.25	1.20	0.24	0.94
Date 2	Mar 28	0.5 - 1 ha	141	242.95	1.72	1.33	2.46	0.34	1.13
		1 - 10 ha	76	409.09	5.38	2.48	21.35	4.47	18.87
		10 - 20 ha	1	28.62	28.62	28.62	28.62	0	0
		> 20 ha	1	73.28	73.28	73.28	73.28	0	0
Baseline Wet		**Total**	**1312**	**1220.52**	**18.31**	**0.00**	**73.28**		**73.28**
Year	**1999**	< 0.1 ha	221	49.05	0.22	0.12	0.22	0	0
Date 1	Feb 14	0.1 - 0.5 ha	219	146.37	0.67	0.25	1.19	0.26	0.93
Date 2	Feb 21	0.5 - 1 ha	41	69.44	1.69	1.33	2.45	0.30	1.11
		1 - 10 ha	41	240.06	5.86	2.49	24.54	4.34	22.06
		10 - 20 ha							
		> 20 ha	1	59.23	59.23	59.23	59.23	0	0
Baseline Dry		**Total**	**523**	**564.16**	**13.53**	**0.12**	**59.23**		**59.11**
Year	**2003**	< 0.1 ha	466	103.61	0.22	0.20	0.22	0	0.03
Date 1	Oct 14	0.1 - 0.5 ha	397	261.25	0.66	0.25	1.20	0.26	0.95
Date 2	Oct 23	0.5 - 1 ha	83	145.52	1.75	1.31	2.45	0.38	1.14
		1 - 10 ha	61	387.62	6.35	2.56	21.49	4.85	18.93
		10 - 20 ha	2	59.96	29.98	25.05	34.92	6.98	9.87
		> 20 ha	1	68.32	68.32	68.32	68.32	0	0
		Total	**1010**	**1026.28**	**17.88**	**0.20**	**68.32**		**68.12**
Year	**2004**	< 0.1 ha	723	160.46	0.22	0.05	0.22	0	0
Date 1	Sep 7	0.1 - 0.5 ha	529	340.15	0.64	0.25	1.20	0.24	0.95
Date 2	Oct 16	0.5 - 1 ha	127	218.56	1.72	1.32	2.45	0.36	1.13
		1 - 10 ha	85	521.12	6.13	2.47	24.46	5.14	21.99
		10 - 20 ha	3	89.33	29.78	25.80	35.58	5.14	9.79
		> 20 ha	1	69.04	69.04	69.04	69.04	0.00	0.00
		Total	**1468**	**1398.66**	**17.92**	**0.05**	**69.04**		**68.98**
Year	**2005**	< 0.1 ha	439	97.63	0.22	0.22	0.22	0	0
Date 1	Feb 14	0.1 - 0.5 ha	607	405.53	0.67	0.25	1.20	0.25	0.95
Date 2	Feb 21	0.5 - 1 ha	144	245.36	1.70	1.33	2.46	0.34	1.13
		1 - 10 ha	86	487.74	5.67	2.52	23.80	4.57	21.28

		10 - 20 ha	3	91.01	30.34	28.02	34.47	3.59	6.45
		> 20 ha	1	75.66	75.66	75.66	75.66	0.00	0.00
		Total	**1280**	**1402.92**	**19.04**	**0.22**	**75.66**		**75.43**
Year	**2006**	< 0.1 ha	229	50.91	0.22	0.20	0.22	0	0.02
Date 1	Nov 16	0.1 - 0.5 ha	258	181.08	0.70	0.25	1.18	0.26	0.93
Date 2	Nov 23	0.5 - 1 ha	77	133.54	1.73	1.33	2.45	0.35	1.11
		1 - 10 ha	50	302.73	6.05	2.67	18.46	3.82	15.79
		10 - 20 ha	1	33.14	33.14	33.14	33.14	0.00	0.00
		> 20 ha	1	64.77	64.77	64.77	64.77	0.00	0.00
		Total	**616**	**766.17**	**17.77**	**0.20**	**64.77**		**64.57**
Year	**2007**	< 0.1 ha	441	97.85	0.22	0.09	0.22	0.01	0.13
Date 1	Mar 8	0.1 - 0.5 ha	577	391.78	0.68	0.25	1.20	0.25	0.94
Date 2	Mar 31	0.5 - 1 ha	156	267.50	1.71	1.31	2.46	0.35	1.15
		1 - 10 ha	104	534.83	5.14	2.48	21.00	3.40	18.53
		10 - 20 ha	4	125.85	31.46	26.02	36.92	4.50	10.90
		> 20 ha	1	73.72	73.72	73.72	73.72	0.00	0.00
		Total	**1283**	**1491.53**	**18.82**	**0.09**	**73.72**		**73.63**
Year	**2008**	< 0.1 ha	673	149.46	0.22	0.08	0.22	0.01	0.14
Date 1	Apr 11	0.1 - 0.5 ha	682	443.40	0.65	0.25	1.19	0.24	0.93
Date 2	Apr 18	0.5 - 1 ha	209	355.47	1.70	1.31	2.45	0.36	1.14
		1 - 10 ha	118	661.75	5.61	2.48	22.02	3.73	19.54
		10 - 20 ha	4	133.29	33.32	29.13	37.81	4.24	8.67
		> 20 ha	1	68.02	68.02	68.02	68.02	0.00	0.00
		Total	**1687**	**1811.39**	**18.25**	**0.08**	**68.02**		**67.94**
Year	**2009**	< 0.1 ha	609	135.33	0.22	0.17	0.22	0	0.05
Date 1	Sep 28	0.1 - 0.5 ha	609	404.29	0.66	0.31	1.23	0.24	0.92
Date 2	Oct 23	0.5 - 1 ha	168	286.49	1.71	1.33	2.45	0.34	1.11
		1 - 10 ha	156	924.38	5.93	2.53	24.24	4.71	21.71
		10 - 20 ha	1	36.92	36.92	36.92	36.92	0.00	0.00
		> 20 ha	1	76.85	76.85	76.85	76.85	0.00	0.00
		Total	**1544**	**1864.27**	**20.38**	**0.17**	**76.85**		**76.68**
Year	**2010**	< 0.1 ha	556	123.61	0.22	0.16	0.24	0	0
Date 1	Nov 18	0.1 - 0.5 ha	699	451.53	0.65	0.37	1.11	0.23	0.74
Date 2	Nov 27	0.5 - 1 ha	181	309.35	1.71	1.33	2.45	0.37	1.11
		1 - 10 ha	127	748.84	5.90	2.67	23.35	4.24	20.68
		10 - 20 ha	4	128.10	32.02	27.13	37.58	5.33	10.45
		> 20 ha	1	70.05	70.05	70.05	70.05	0.00	0.00
		Total	**1568**	**1831.48**	**18.43**	**0.16**	**70.05**		**69.89**

Somervell County — **Summary Statistics for Water Features in Acres**

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	1118	248.24	0.22	0.01	0.22	0.01	0.21
Date 1	Mar 3	0.1 - 0.5 ha	1714	1189.07	0.69	0.25	1.20	0.25	0.95
Date 2	Mar 28	0.5 - 1 ha	522	898.21	1.72	1.29	2.47	0.35	1.18
		1 - 10 ha	404	2441.15	6.04	2.47	24.32	4.53	21.85
		10 - 20 ha	20	693.91	34.70	24.82	47.96	7.22	23.15
		> 20 ha	4	452.36	113.09	64.50	218.17	71.45	153.67
Baseline Wet		**Total**	**3782**	**5922.95**	**26.08**	**0.01**	**218.17**		**218.16**
Year	**1999**	< 0.1 ha	263	58.49	0.22	0.22	0.22	0	0
Date 1	Feb 14	0.1 - 0.5 ha	360	206.90	0.57	0.25	1.19	0.27	0.94
Date 2	Feb 21	0.5 - 1 ha	71	123.17	1.73	1.32	2.45	0.35	1.13
		1 - 10 ha	118	788.69	6.68	2.49	22.55	4.44	20.06
		10 - 20 ha	6	165.33	27.55	24.91	35.48	4.09	10.57
		> 20 ha	4	786.85	196.71	52.93	517.98	219.07	465.05
Baseline Dry		**Total**	**822**	**2129.43**	**38.91**	**0.22**	**517.98**		**517.76**
Year	**2003**	< 0.1 ha	598	132.97	0.22	0.20	0.22	0	0.02
Date 1	Oct 14	0.1 - 0.5 ha	775	478.28	0.62	0.25	1.20	0.26	0.95
Date 2	Oct 23	0.5 - 1 ha	182	304.92	1.68	1.29	2.45	0.32	1.15
		1 - 10 ha	161	997.15	6.19	2.50	23.96	3.95	21.45
		10 - 20 ha	9	283.77	31.53	26.91	38.03	4.15	11.12
		> 20 ha	3	261.54	87.18	54.49	151.01	55.28	96.52
		Total	**1728**	**2458.63**	**21.24**	**0.20**	**151.01**		**150.80**
Year	**2004**	< 0.1 ha	1296	288.22	0.22	0.22	0.22	0	0
Date 1	Sep 7	0.1 - 0.5 ha	1749	1127.17	0.64	0.25	1.20	0.26	0.95
Date 2	Oct 16	0.5 - 1 ha	472	807.28	1.71	1.31	2.46	0.35	1.15
		1 - 10 ha	353	2206.49	6.25	2.48	23.83	4.50	21.35
		10 - 20 ha	15	539.64	35.98	25.44	46.67	6.75	21.22
		> 20 ha	3	354.05	118.02	62.49	218.39	87.09	155.90
		Total	**3888**	**5322.85**	**27.14**	**0.22**	**218.39**		**218.17**
Year	**2005**	< 0.1 ha	1184	262.80	0.22	0.00	0.22	0.01	0.22
Date 1	Feb 14	0.1 - 0.5 ha	1894	1221.45	0.64	0.25	1.21	0.27	0.96
Date 2	Feb 21	0.5 - 1 ha	435	746.98	1.72	1.25	2.47	0.34	1.22
		1 - 10 ha	337	1988.81	5.90	2.47	22.67	4.07	20.20
		10 - 20 ha	16	554.69	34.67	25.07	45.21	6.30	20.13
		> 20 ha	3	366.28	122.09	69.83	207.05	74.22	137.22
		Total	**3869**	**5141.02**	**27.54**	**0.00**	**207.05**		**207.05**
Year	**2006**	< 0.1 ha	545	121.09	0.22	0.15	0.22	0	0.08

Somervell County **Summary Statistics for Water Features in Acres**

Date 1	Nov 16	0.1 - 0.5 ha	660	409.29	0.62	0.25	1.21	0.26	0.96
Date 2	Nov 23	0.5 - 1 ha	115	193.38	1.68	1.33	2.47	0.32	1.14
		1 - 10 ha	146	850.12	5.82	2.48	20.24	3.67	17.75
		10 - 20 ha	8	244.18	30.52	25.09	43.14	7.68	18.06
		> 20 ha	3	466.14	155.38	51.37	252.20	100.60	200.82
		Total	**1477**	**2284.20**	**32.37**	**0.15**	**252.20**		**252.05**
Year	**2007**	< 0.1 ha	1797	399.13	0.22	0.01	0.22	0.01	0.21
Date 1	Mar 8	0.1 - 0.5 ha	2268	1469.74	0.65	0.25	1.23	0.25	0.97
Date 2	Mar 31	0.5 - 1 ha	628	1089.41	1.73	1.29	2.47	0.34	1.18
		1 - 10 ha	477	2905.78	6.09	2.47	23.14	4.28	20.67
		10 - 20 ha	30	958.12	31.94	25.38	47.33	5.38	21.96
		> 20 ha	12	1092.83	91.07	52.07	228.62	57.07	176.55
		Total	**5212**	**7915.02**	**21.95**	**0.01**	**228.62**		**228.61**
Year	**2008**	< 0.1 ha	1427	316.81	0.22	0.06	0.22	0.01	0.16
Date 1	Apr 11	0.1 - 0.5 ha	2253	1465.01	0.65	0.25	1.23	0.27	0.97
Date 2	Apr 18	0.5 - 1 ha	621	1068.28	1.72	1.30	2.45	0.35	1.14
		1 - 10 ha	479	2869.63	5.99	2.47	24.64	4.58	22.16
		10 - 20 ha	15	552.81	36.85	25.35	48.96	8.28	23.61
		> 20 ha	4	419.92	104.98	52.74	213.28	73.21	160.53
		Total	**4799**	**6692.44**	**25.07**	**0.06**	**213.28**		**213.22**
Year	**2009**	< 0.1 ha	1237	275.08	0.22	0.20	0.22	0	0.02
Date 1	Sep 28	0.1 - 0.5 ha	1631	1084.57	0.66	0.30	1.23	0.25	0.93
Date 2	Oct 23	0.5 - 1 ha	519	883.89	1.70	1.24	2.47	0.36	1.23
		1 - 10 ha	377	2263.67	6.00	2.48	24.02	4.33	21.54
		10 - 20 ha	15	529.81	35.32	26.46	44.03	6.98	17.57
		> 20 ha	3	334.26	111.42	59.38	201.27	78.14	141.89
		Total	**3782**	**5371.28**	**25.89**	**0.20**	**201.27**		**201.06**
Year	**2010**	< 0.1 ha	1274	283.33	0.22	0.22	0.22	0	0
Date 1	Nov 18	0.1 - 0.5 ha	1477	968.45	0.66	0.41	1.11	0.23	0.70
Date 2	Nov 27	0.5 - 1 ha	400	686.27	1.72	1.33	2.45	0.36	1.11
		1 - 10 ha	291	1948.85	6.70	2.67	24.24	4.46	21.57
		10 - 20 ha	12	415.21	34.60	26.02	44.26	6.53	18.24
		> 20 ha	2	261.09	130.55	72.95	188.15	81.46	115.20
		Total	**3456**	**4563.19**	**29.07**	**0.22**	**188.15**		**187.92**

Bosque County | **Summary Statistics for Water Features in Acres**

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	1025	227.71	0.22	0.01	0.22	0.01	0.22
Date 1	Mar 3	0.1 - 0.5 ha	705	456.70	0.65	0.44	1.11	0.23	0.67
Date 2	Mar 28	0.5 - 1 ha	163	280.88	1.72	1.33	2.45	0.39	1.11
		1 - 10 ha	167	1157.90	6.93	2.67	22.91	5.11	20.24
		10 - 20 ha	6	204.60	34.10	27.13	43.81	6.36	16.68
		> 20 ha	4	299.56	74.89	51.37	128.18	35.76	76.80
Baseline Wet		**Total**	**2070**	**2627.36**	**19.75**	**0.01**	**128.18**		**128.17**
Year	**1999**	< 0.1 ha	422	93.74	0.22	0.11	0.22	0	0
Date 1	Feb 14	0.1 - 0.5 ha	367	244.22	0.67	0.25	1.11	0.23	0.86
Date 2	Feb 21	0.5 - 1 ha	103	184.64	1.79	1.33	2.45	0.38	1.11
		1 - 10 ha	125	940.25	7.52	2.67	24.24	5.41	21.57
		10 - 20 ha	3	82.95	27.65	25.58	30.47	2.53	4.89
		> 20 ha	5	327.09	65.42	49.82	113.87	27.21	64.05
Baseline Dry		**Total**	**1025**	**1872.90**	**17.21**	**0.11**	**113.87**		**113.76**
Year	**2003**	< 0.1 ha	747	165.93	0.22	0.03	0.22	0	0.19
Date 1	Oct 14	0.1 - 0.5 ha	576	370.62	0.64	0.25	1.11	0.23	0.86
Date 2	Oct 23	0.5 - 1 ha	135	237.74	1.76	1.33	2.45	0.36	1.11
		1 - 10 ha	143	1059.49	7.41	2.67	24.24	5.54	21.57
		10 - 20 ha	4	110.09	27.52	24.91	29.58	1.97	4.67
		> 20 ha	5	338.83	67.77	51.37	108.53	24.18	57.16
		Total	**1610**	**2282.70**	**17.55**	**0.03**	**108.53**		**108.50**
Year	**2004**	< 0.1 ha	1582	351.41	0.22	0.00	0.22	0	0
Date 1	Sep 7	0.1 - 0.5 ha	988	629.94	0.64	0.25	1.11	0.22	0.86
Date 2	Oct 16	0.5 - 1 ha	212	365.39	1.72	1.33	2.45	0.38	1.11
		1 - 10 ha	246	1747.44	7.10	2.67	24.69	5.11	22.02
		10 - 20 ha	12	368.95	30.75	25.35	45.81	6.03	20.46
		> 20 ha	4	287.06	71.77	50.48	112.31	28.33	61.83
		Total	**3044**	**3750.20**	**18.70**	**0.00**	**112.31**		**112.31**
Year	**2005**	< 0.1 ha	981	217.58	0.22	0.00	0.22	0.01	0.22
Date 1	Feb 14	0.1 - 0.5 ha	921	603.54	0.66	0.28	1.11	0.23	0.83
Date 2	Feb 21	0.5 - 1 ha	206	358.06	1.74	1.33	2.45	0.38	1.11
		1 - 10 ha	209	1462.91	7.00	2.67	23.80	5.07	21.13
		10 - 20 ha	10	322.92	32.29	26.02	41.59	5.29	15.57

Bosque County **Summary Statistics for Water Features in Acres**

		> 20 ha	3	232.21	77.40	61.56	106.38	25.13	44.83
		Total	**2330**	**3197.22**	**19.88**	**0.00**	**106.38**		**106.38**
Year	**2006**	< 0.1 ha	153	33.65	0.22	0.01	0.22	0	0.22
Date 1	Nov 16	0.1 - 0.5 ha	169	107.86	0.64	0.44	1.11	0.23	0.67
Date 2	Nov 23	0.5 - 1 ha	73	132.77	1.82	1.33	2.45	0.39	1.11
		1 - 10 ha	89	647.17	7.27	2.67	23.35	4.97	20.68
		10 - 20 ha	4	136.11	34.03	25.13	39.36	6.67	14.23
		> 20 ha	1	73.84	73.84	73.84	73.84	0.00	0.00
		Total	**489**	**1131.39**	**19.63**	**0.01**	**73.84**		**73.83**
Year	**2007**	< 0.1 ha	427	94.96	0.22	0.22	0.22	0	0
Date 1	Mar 8	0.1 - 0.5 ha	492	328.29	0.67	0.25	1.11	0.23	0.86
Date 2	Mar 31	0.5 - 1 ha	130	234.63	1.80	1.33	2.45	0.38	1.11
		1 - 10 ha	149	1009.23	6.77	2.67	21.79	4.79	19.13
		10 - 20 ha	8	243.74	30.47	24.91	41.59	5.86	16.68
		> 20 ha	2	128.32	64.16	51.37	76.95	18.09	25.58
		Total	**1208**	**2039.17**	**17.35**	**0.22**	**76.95**		**76.73**
Year	**2008**	< 0.1 ha	1046	232.46	0.22	0.06	0.22	0.01	0.16
Date 1	Apr 11	0.1 - 0.5 ha	754	496.20	0.66	0.33	1.11	0.24	0.78
Date 2	Apr 18	0.5 - 1 ha	191	325.14	1.70	1.33	2.45	0.38	1.11
		1 - 10 ha	219	1572.78	7.18	2.67	24.69	5.21	22.02
		10 - 20 ha	15	477.04	31.80	25.80	47.59	5.70	21.79
		> 20 ha	4	312.84	78.21	54.71	129.41	34.60	74.71
		Total	**2229**	**3416.46**	**19.96**	**0.06**	**129.41**		**129.36**
Year	**2009**	< 0.1 ha	1127	250.63	0.22	0.21	0.22	0	0.01
Date 1	Sep 28	0.1 - 0.5 ha	978	647.61	0.66	0.25	1.11	0.24	0.86
Date 2	Oct 23	0.5 - 1 ha	269	468.36	1.74	1.33	2.45	0.38	1.11
		1 - 10 ha	283	1898.58	6.71	2.67	23.13	4.76	20.46
		10 - 20 ha	8	228.84	28.61	25.35	33.14	3.10	7.78
		> 20 ha	6	483.04	80.51	53.15	108.53	21.46	55.38
		Total	**2671**	**3977.07**	**19.74**	**0.21**	**108.53**		**108.31**
Year	**2010**	< 0.1 ha	902	200.30	0.22	0.03	0.22	0	0
Date 1	Nov 18	0.1 - 0.5 ha	949	612.71	0.65	0.26	1.11	0.23	0.85
Date 2	Nov 27	0.5 - 1 ha	238	413.21	1.74	1.33	2.45	0.35	1.11
		1 - 10 ha	244	1712.44	7.02	2.67	24.69	5.24	22.02
		10 - 20 ha	13	376.29	28.95	25.35	36.70	3.20	11.34

Bosque County — Summary Statistics for Water Features in Acres

	> 20 ha	5	386.95	77.39	54.26	131.68	30.97	77.41
	Total	**2351**	**3701.90**	**19.33**	**0.03**	**131.68**		**131.65**

Hill County — Summary Statistics for Water Features in Acres

		Category	Count	Sum	Mean	Minimum	Maximum	Std Dev	Range
Year	**1997**	< 0.1 ha	1016	225.953	0.222	0.222	0.222	0	0
Date 1	Mar 3	0.1 - 0.5 ha	799	524.185	0.656	0.445	1.112	0.233	0.667
Date 2	Mar 28	0.5 - 1 ha	189	329.589	1.744	1.334	2.446	0.370	1.112
		1 - 10 ha	184	1310.795	7.124	2.669	23.129	5.148	20.460
		10 - 20 ha	19	630.045	33.160	25.131	47.815	6.862	22.684
		> 20 ha							
Baseline Wet		**Total**	**2207**	**3020.567**	**8.581**	**0.222**	**47.815**		**47.592**
Year	**1999**	< 0.1 ha	620	137.885	0.222	0.222	0.222	0	0
Date 1	Feb 14	0.1 - 0.5 ha	471	309.351	0.657	0.445	1.112	0.239	0.667
Date 2	Feb 21	0.5 - 1 ha	126	214.833	1.705	1.334	2.446	0.383	1.112
		1 - 10 ha	158	1226.063	7.760	2.669	24.463	5.581	21.795
		10 - 20 ha	15	497.720	33.181	25.575	44.924	6.845	19.348
		> 20 ha							
Baseline Dry		**Total**	**1390**	**2385.852**	**8.705**	**0.222**	**44.924**		**44.701**
Year	**2003**	< 0.1 ha	885	196.819	0.222	0.222	0.222	0	0
Date 1	Oct 14	0.1 - 0.5 ha	665	435.227	0.654	0.445	1.112	0.241	0.667
Date 2	Oct 23	0.5 - 1 ha	176	303.124	1.722	1.334	2.446	0.344	1.112
		1 - 10 ha	160	1130.211	7.064	2.669	24.019	4.917	21.350
		10 - 20 ha	16	518.402	32.400	25.131	46.481	7.051	21.350
		> 20 ha							
		Total	**1902**	**2583.783**	**8.413**	**0.222**	**46.481**		**46.258**
Year	**2004**	< 0.1 ha	1635	363.616	0.222	0.222	0.222	0	0
Date 1	Sep 7	0.1 - 0.5 ha	1198	765.483	0.639	0.445	1.112	0.227	0.667
Date 2	Oct 16	0.5 - 1 ha	255	436.339	1.711	1.334	2.446	0.356	1.112
		1 - 10 ha	222	1505.613	6.782	2.669	21.795	4.887	19.126
		10 - 20 ha	17	565.105	33.241	26.243	48.260	6.961	22.017
		> 20 ha							
		Total	**3327**	**3636.156**	**8.519**	**0.222**	**48.260**		**48.037**
Year	**2005**	< 0.1 ha	974	216.613	0.222	0.222	0.222	0	0
Date 1	Feb 14	0.1 - 0.5 ha	991	644.945	0.651	0.445	1.112	0.226	0.667
Date 2	Feb 21	0.5 - 1 ha	277	485.266	1.752	1.334	2.446	0.384	1.112

Hill County				Summary Statistics for Water Features in Acres					
		1 - 10 ha	212	1446.678	6.824	2.669	24.241	4.824	21.572
		10 - 20 ha	20	661.180	33.059	25.131	48.037	6.540	22.907
		> 20 ha							
		Total	**2474**	**3454.681**	**8.502**	**0.222**	**48.037**		**47.815**
Year	**2006**	< 0.1 ha	241	53.597	0.222	0.222	0.222	0	0
Date 1	Nov 16	0.1 - 0.5 ha	271	181.919	0.671	0.445	1.112	0.236	0.667
Date 2	Nov 23	0.5 - 1 ha	84	147.448	1.755	1.334	2.446	0.370	1.112
		1 - 10 ha	94	657.844	6.998	2.669	22.017	4.861	19.348
		10 - 20 ha	2	64.050	32.025	31.135	32.914	1.258	1.779
		> 20 ha							
		Total	**692**	**1104.858**	**8.334**	**0.222**	**32.914**		**32.692**
Year	**2007**	< 0.1 ha	744	165.462	0.222	0.222	0.222	0	0
Date 1	Mar 8	0.1 - 0.5 ha	702	455.909	0.649	0.445	1.112	0.230	0.667
Date 2	Mar 31	0.5 - 1 ha	200	350.717	1.754	1.334	2.446	0.380	1.112
		1 - 10 ha	169	1154.007	6.828	2.669	23.351	4.791	20.683
		10 - 20 ha	10	321.583	32.158	25.353	46.481	6.604	21.128
		> 20 ha							
		Total	**1825**	**2447.678**	**8.322**	**0.222**	**46.481**		**46.258**
Year	**2008**	< 0.1 ha	1468	326.476	0.222	0.222	0.222	0	0
Date 1	Apr 11	0.1 - 0.5 ha	1286	831.806	0.647	0.445	1.112	0.233	0.667
Date 2	Apr 18	0.5 - 1 ha	345	605.804	1.756	1.334	2.446	0.384	1.112
		1 - 10 ha	287	1850.833	6.449	2.509	22.907	4.594	20.398
		10 - 20 ha	22	771.933	35.088	25.575	49.149	7.476	23.574
		> 20 ha							
		Total	**3408**	**4386.850**	**8.832**	**0.222**	**49.149**		**48.927**
Year	**2009**	< 0.1 ha	1380	306.905	0.222	0.222	0.222	0	0
Date 1	Sep 28	0.1 - 0.5 ha	1318	874.679	0.664	0.445	1.112	0.234	0.667
Date 2	Oct 23	0.5 - 1 ha	404	712.331	1.763	1.334	2.446	0.371	1.112
		1 - 10 ha	345	2194.148	6.360	2.669	23.796	4.534	21.128
		10 - 20 ha	23	802.623	34.897	25.353	49.372	6.935	24.019
		> 20 ha	5	384.298	76.860	50.261	95.852	17.578	45.591
		Total	**3475**	**5274.983**	**20.128**	**0.222**	**95.852**		**95.630**
Year	**2010**	< 0.1 ha	1300	289.113	0.222	0.222	0.222	0	0
Date 1	Nov 18	0.1 - 0.5 ha	1244	819.525	0.659	0.445	1.112	0.234	0.667
Date 2	Nov 27	0.5 - 1 ha	285	490.825	1.722	1.334	2.446	0.364	1.112
		1 - 10 ha	272	1809.182	6.651	2.669	24.019	4.855	21.350
		10 - 20 ha	15	491.270	32.751	25.131	46.925	6.914	21.795

Hill County **Summary Statistics for Water Features in Acres**

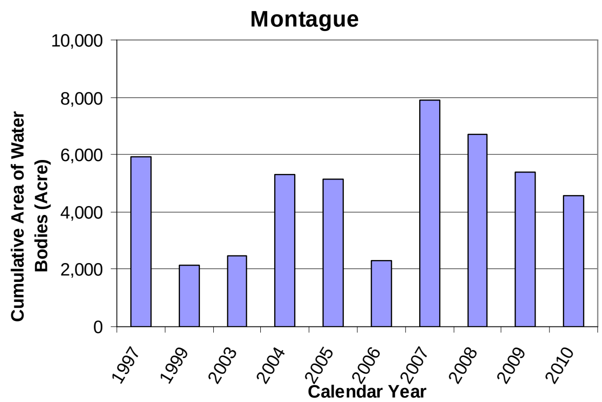
> 20 ha						
Total	**3116**	**3899.916**	**8.401**	**0.222**	**46.925**	**46.703**

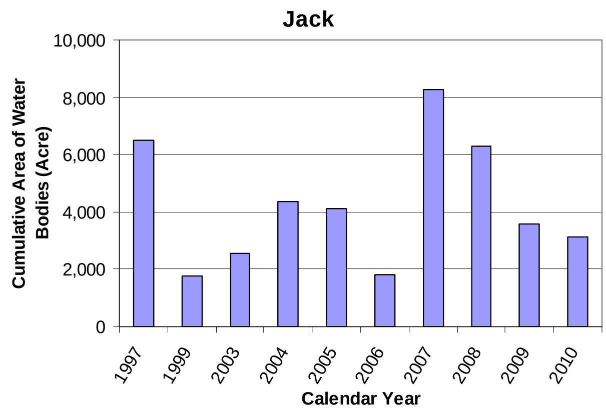
11 Appendix C: Plotting Results of Surface-Water-Body Study

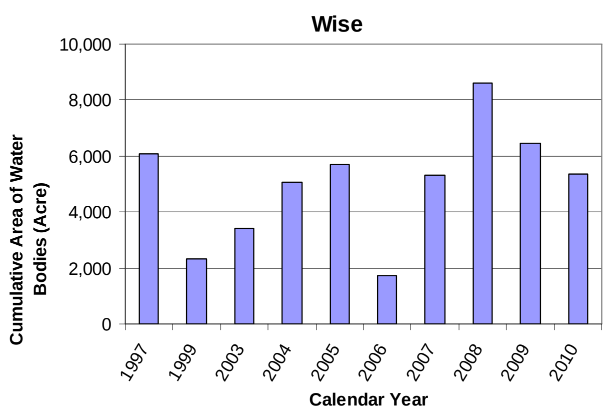
This appendix presents three sets of plots:

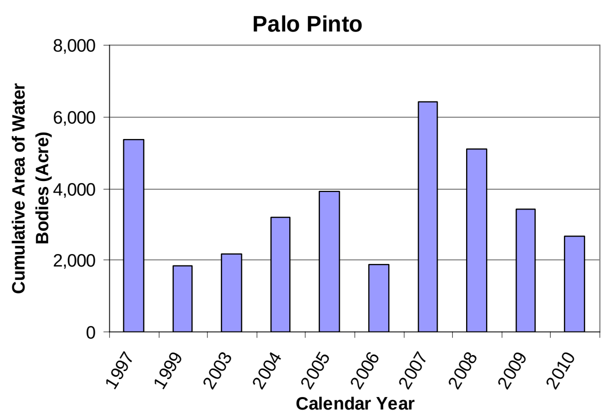
- Water-body cumulative surface area per county for selected times
- Water-body count per county for selected times
- Comparison of pond intensity (acre per square mile for each county) and drilling activity

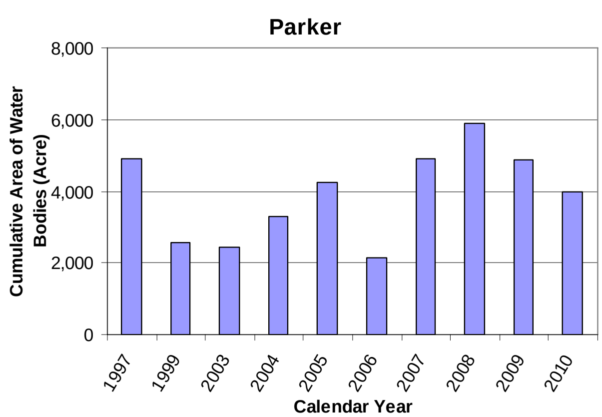
1- Plots displaying for each county (Montague, Jack, Wise, Palo Pinto, Parker, Erath, Hood, Somervell, Bosque, and Hill) the cumulative surface area of non-state waters for selected times, as described in the main text.

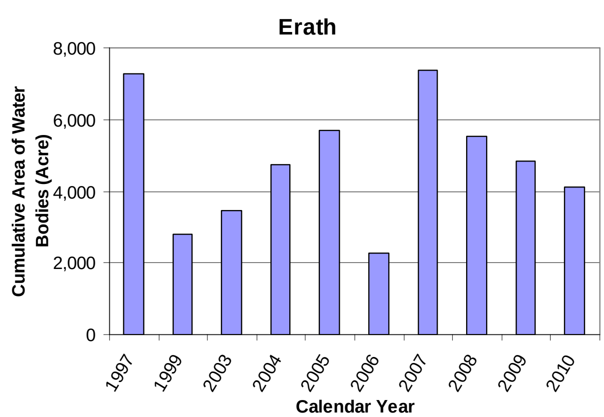


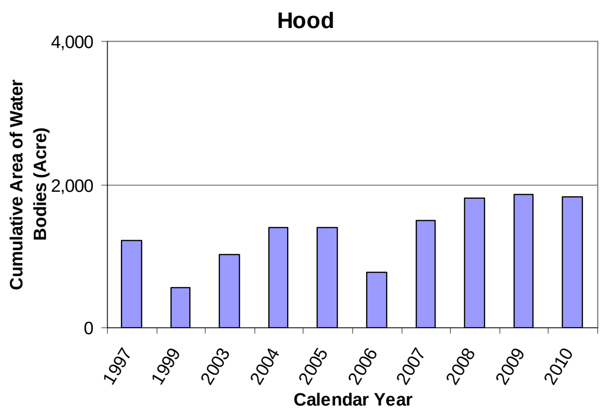


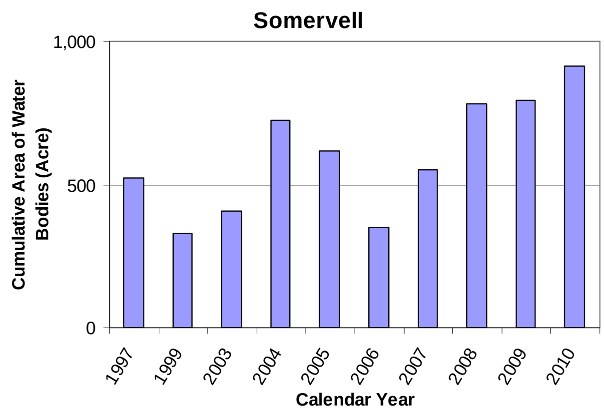


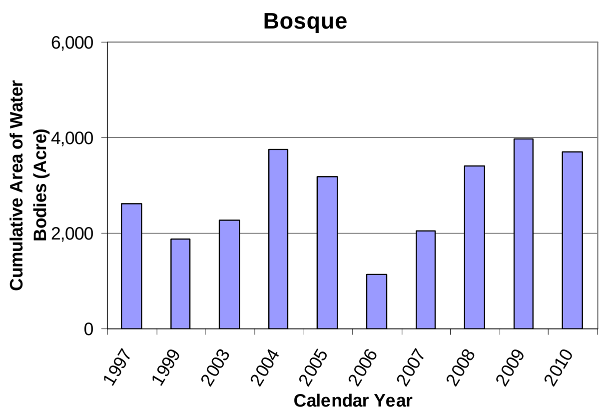


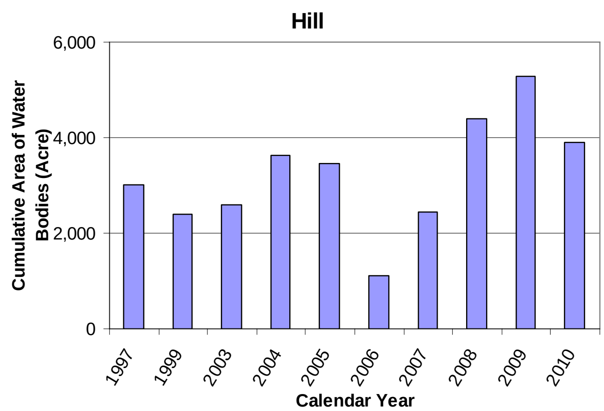




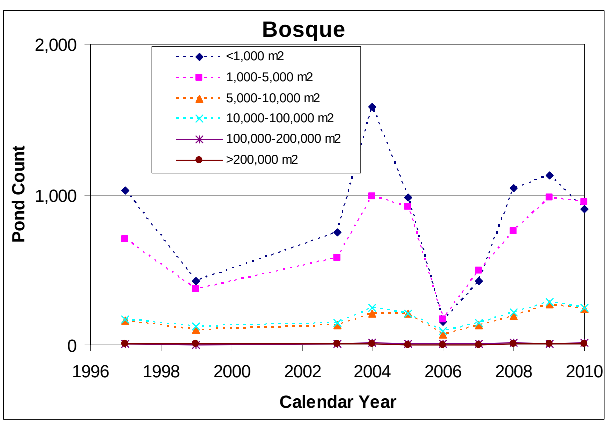


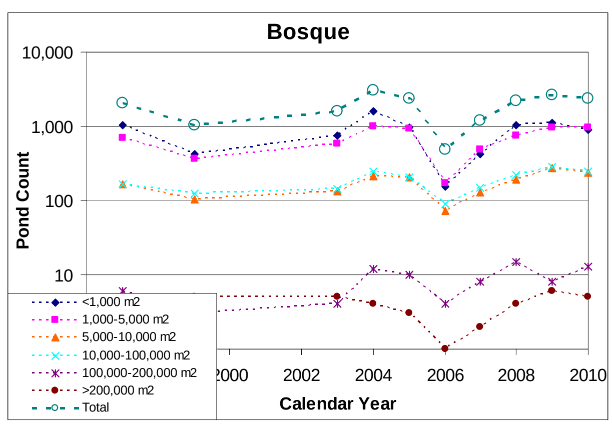


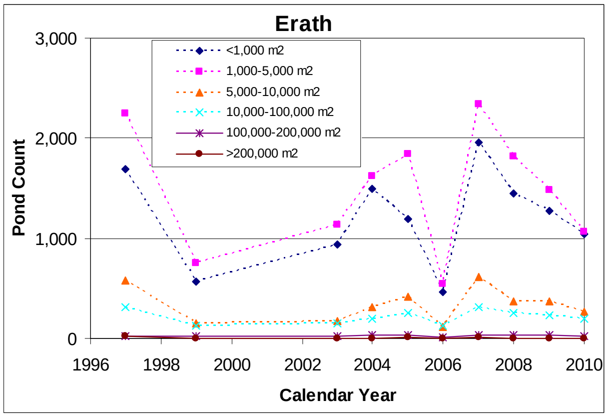


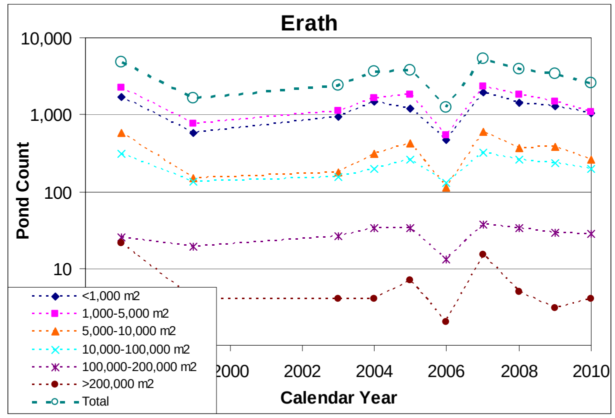


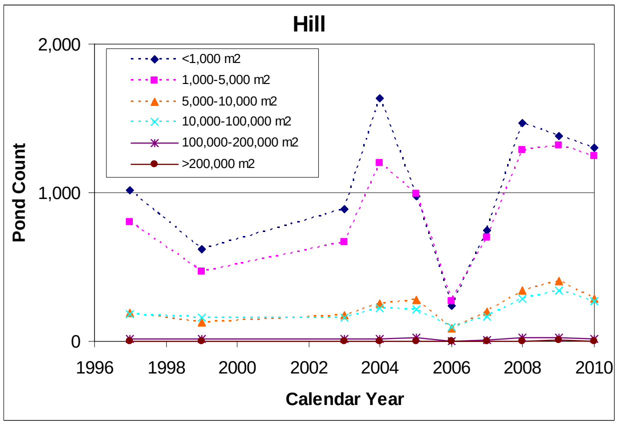
2- Plots (linear scale and log scale on left-hand and right-hand sides, respectively) displaying number of ponds in each category (<1,000 m^2, between 1,000 and 5,000 m^2, between 5,000 and 10,000 m^2, between 10,000 and 100,000 m^2, between 100,000 and 200,000 m^2, and >200,000 m^2) for each county (Montague, Jack, Wise, Palo Pinto, Parker, Erath, Hood, Somervell, Bosque, and Hill) for selected times, as described in the main text.

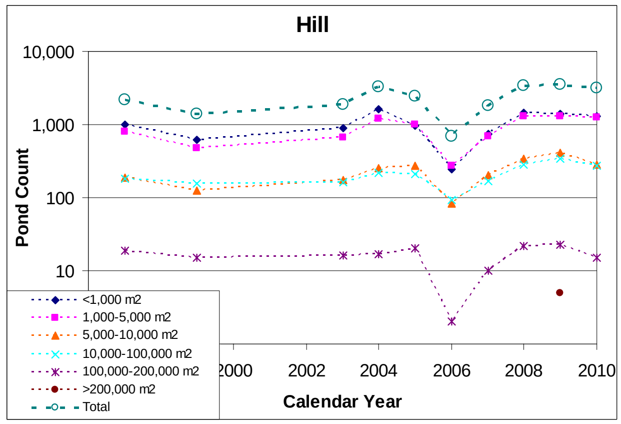


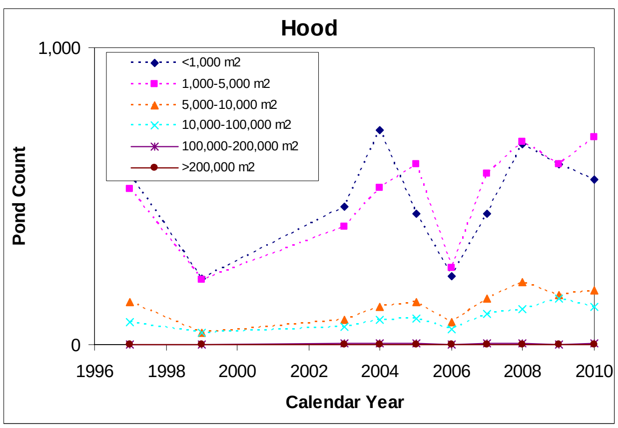


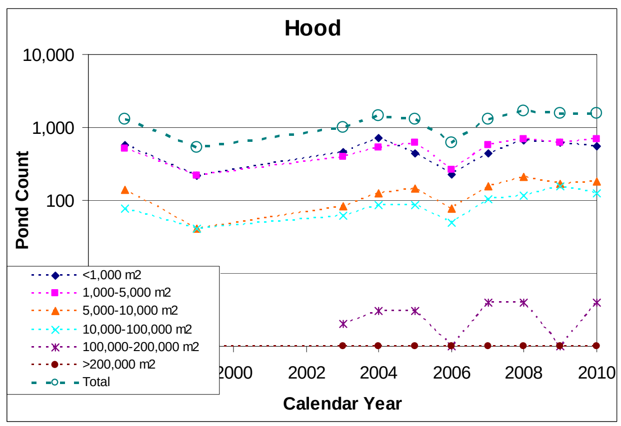

Erath
Pond Count
Calendar Year
3,000
2,000
1,000
0
1996
1998
2000
2002
2004
2006
2008
2010
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2

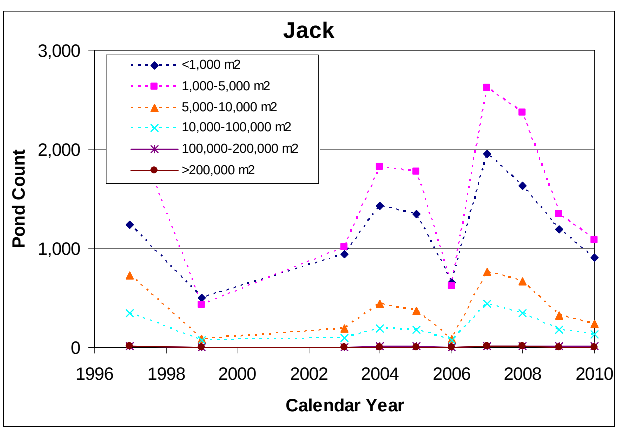

Erath
Pond Count
Calendar Year
10,000
1,000
100
10
2000
2002
2004
2006
2008
2010
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2
Total

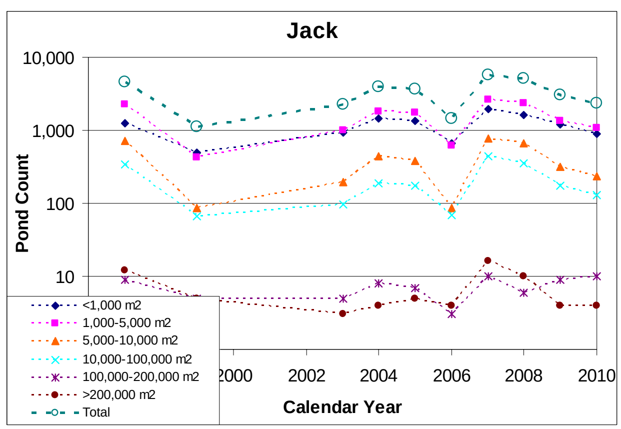

Hill
Pond Count
Calendar Year
2,000
1,000
0
1996
1998
2000
2002
2004
2006
2008
2010
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2

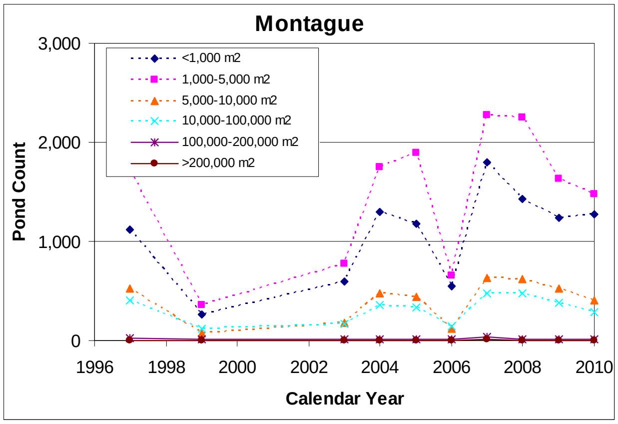

Hill
Pond Count
Calendar Year
10,000
1,000
100
10
2000
2002
2004
2006
2008
2010
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2
Total

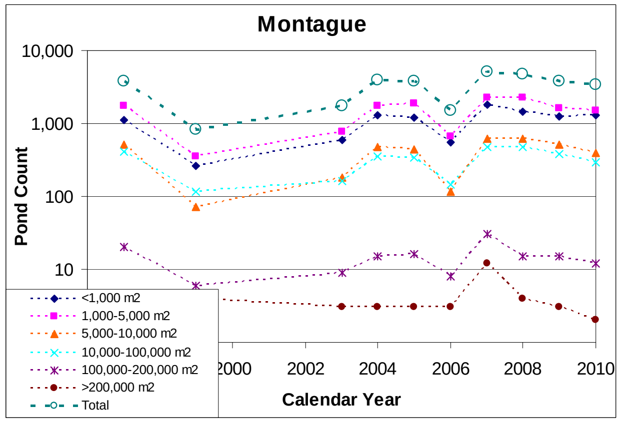

Hood
Pond Count
Calendar Year
1,000
0
1996
1998
2000
2002
2004
2006
2008
2010
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2

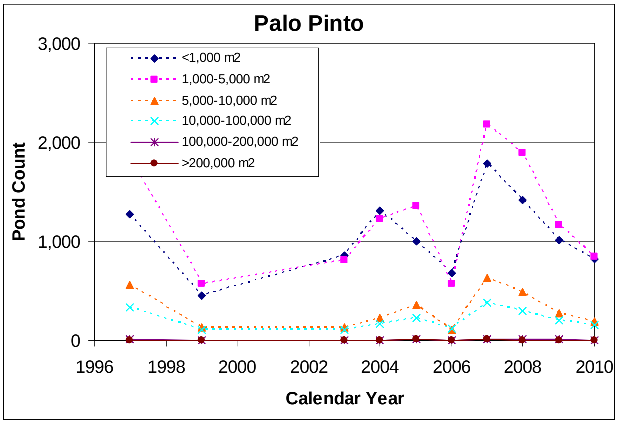

Hood
Pond Count
Calendar Year
10,000
1,000
100
2000
2002
2004
2006
2008
2010
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2
Total

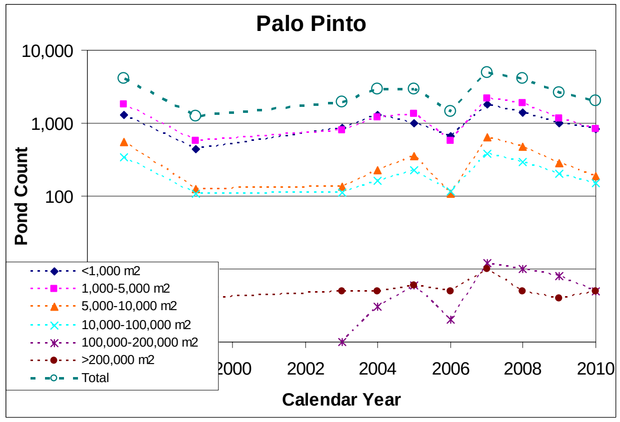

Jack
Pond Count
Calendar Year
3,000
2,000
1,000
0
1996
1998
2000
2002
2004
2006
2008
2010
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2

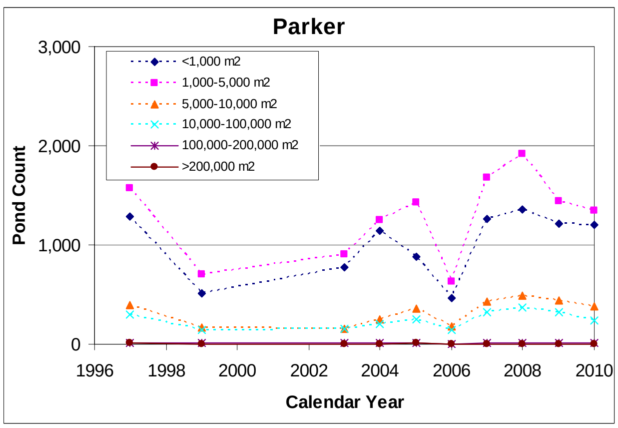

Jack
Pond Count
Calendar Year
10,000
1,000
100
10
2000
2002
2004
2006
2008
2010
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2
Total

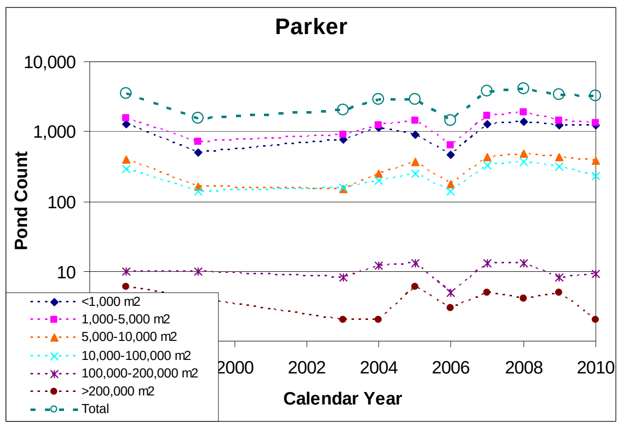

Montague
Pond Count
Calendar Year
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2

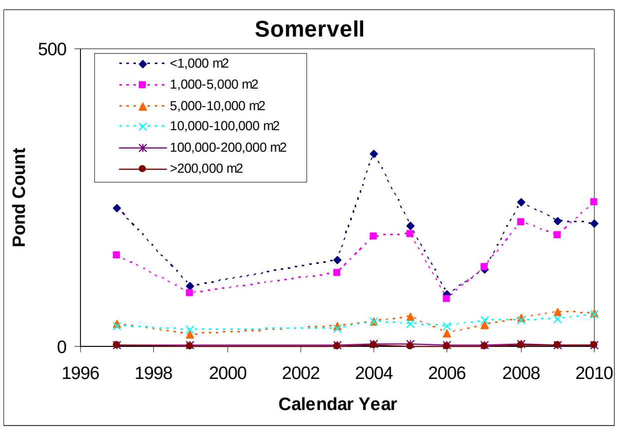

Montague
Pond Count
Calendar Year
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2
Total

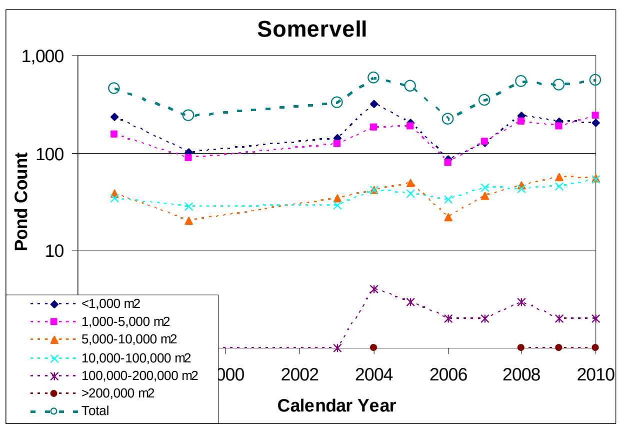

Palo Pinto
Pond Count
Calendar Year
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2

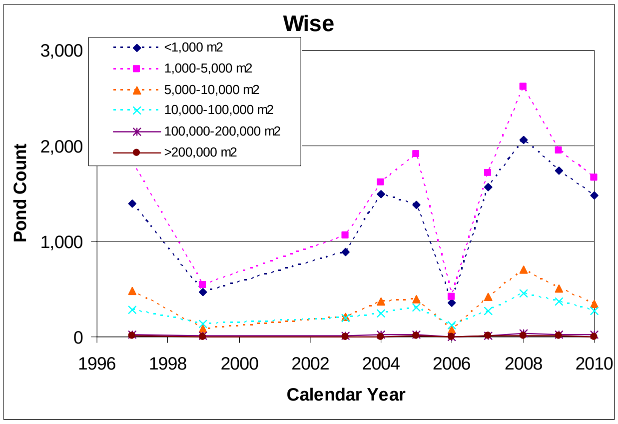

Palo Pinto
Pond Count
Calendar Year
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2
Total

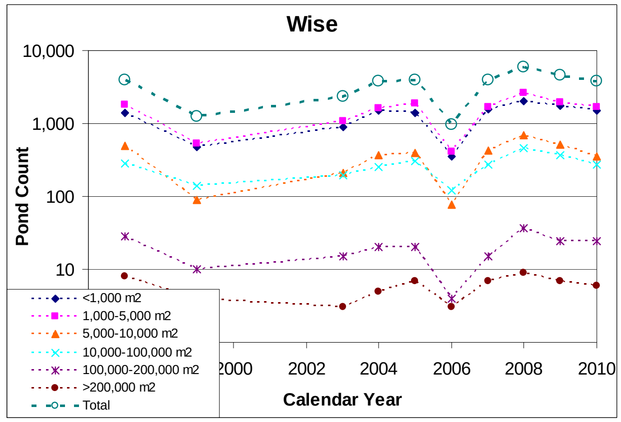

Parker
Pond Count
Calendar Year
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2


Parker
Pond Count
Calendar Year
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2
Total

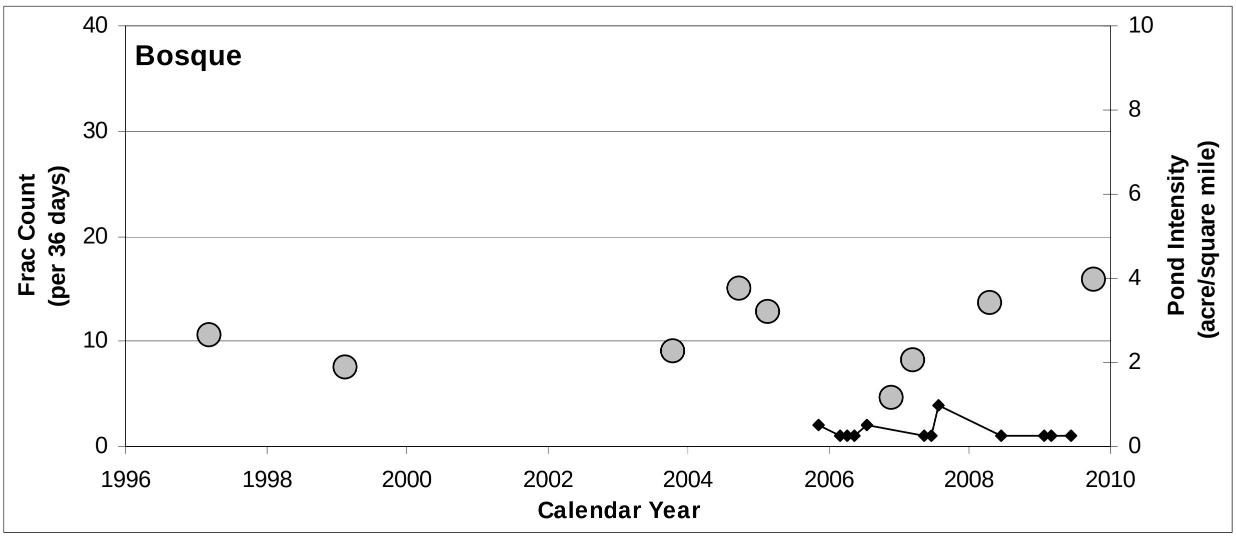

Somervell
Pond Count
Calendar Year
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2

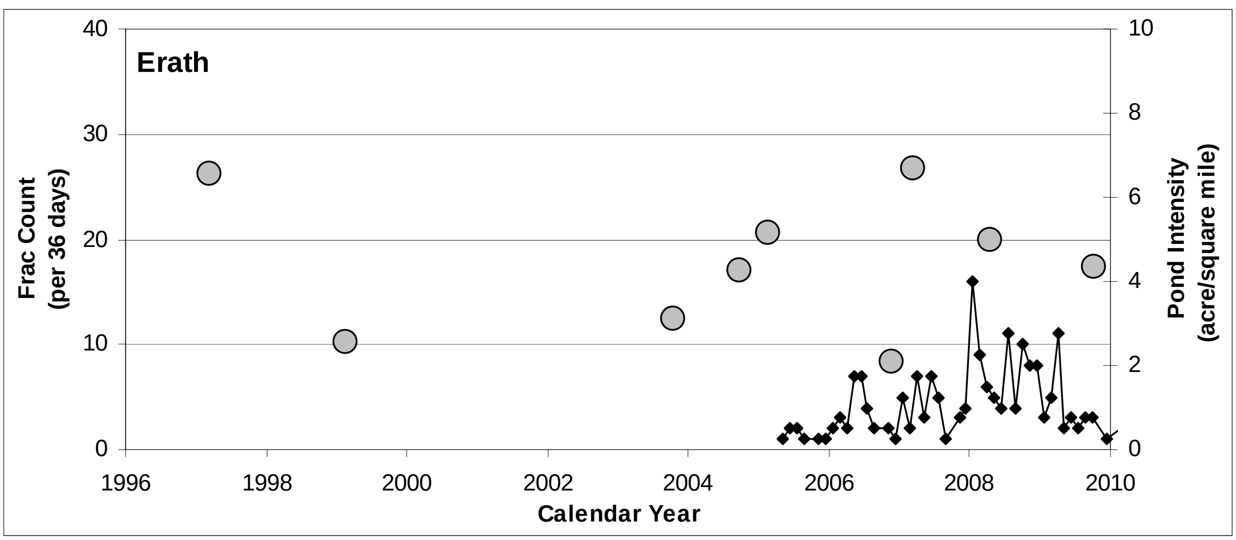

Somervell
Pond Count
Calendar Year
<1,000 m2
1,000-5,000 m2
5,000-10,000 m2
10,000-100,000 m2
100,000-200,000 m2
>200,000 m2
Total

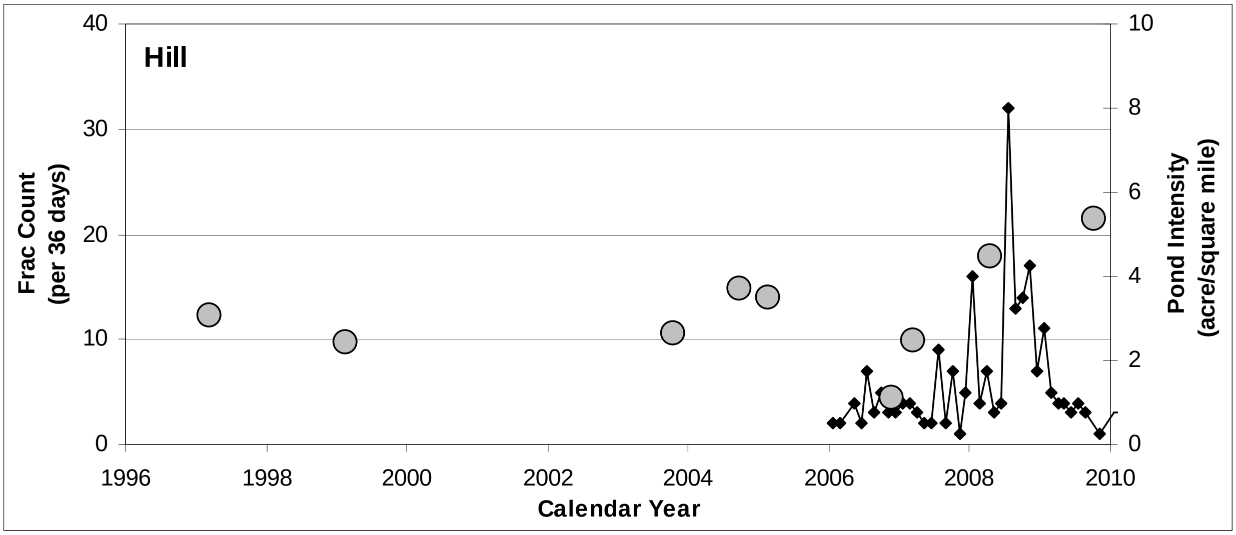


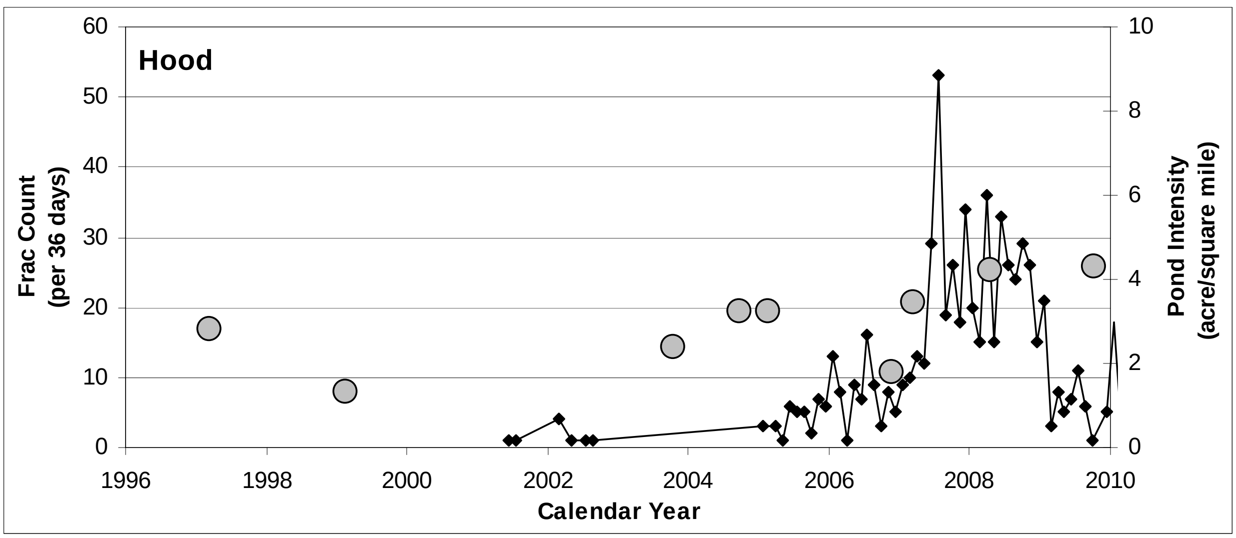


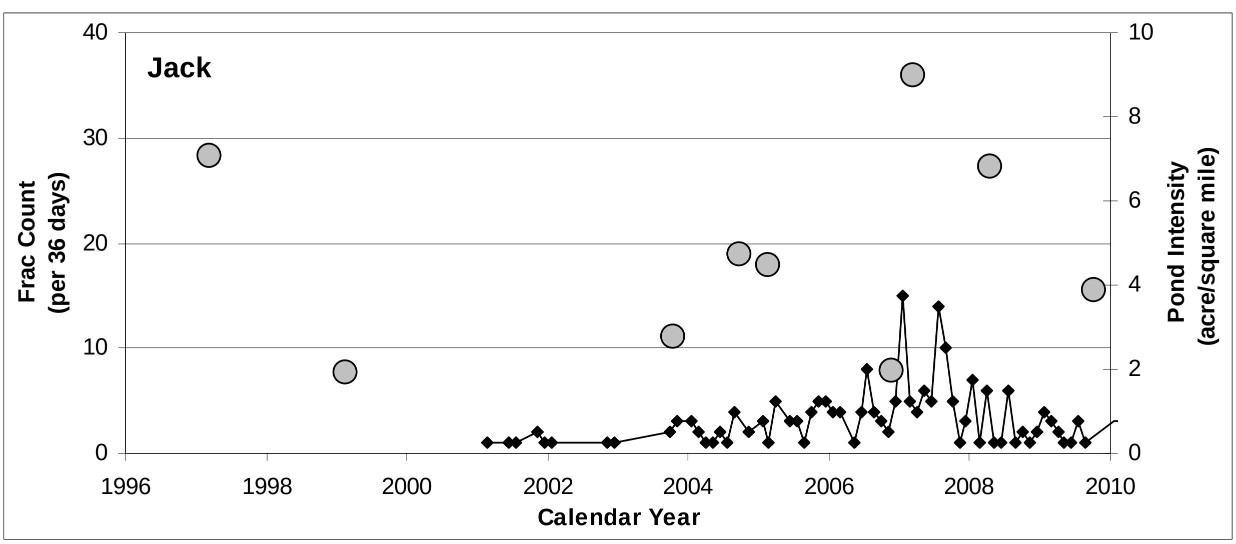
3- Plots contrasting completion count (extracted from IHS Energy database and calculated on a 1/10 of a year basis) and pond intensity (acre per square mile) per county (Montague, Jack, Wise, Palo Pinto, Parker, Erath, Hood, Somervell, Bosque, and Hill).

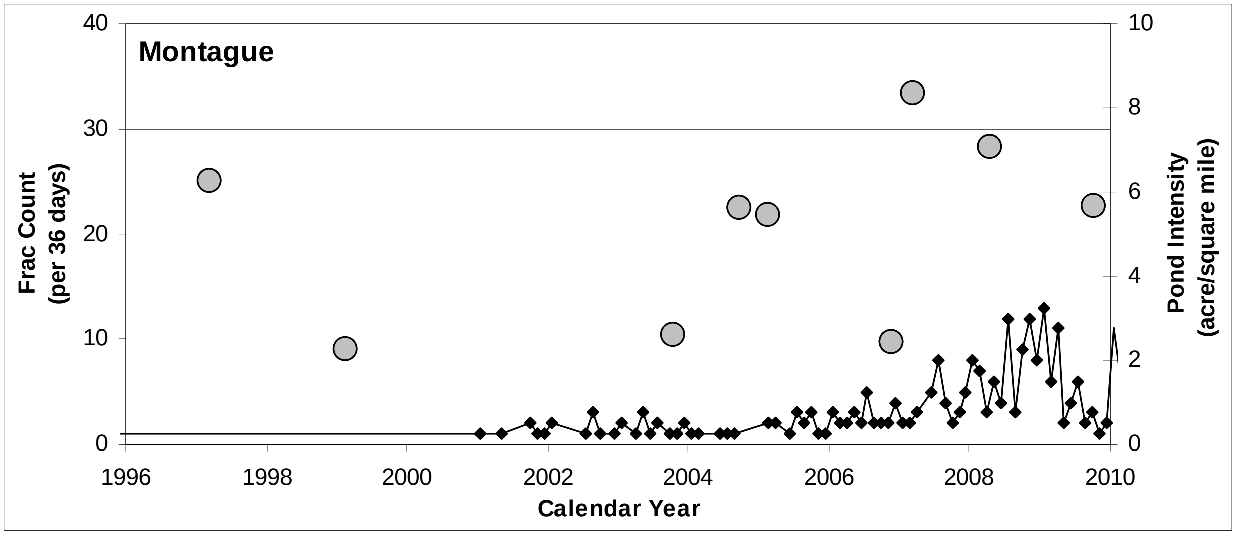


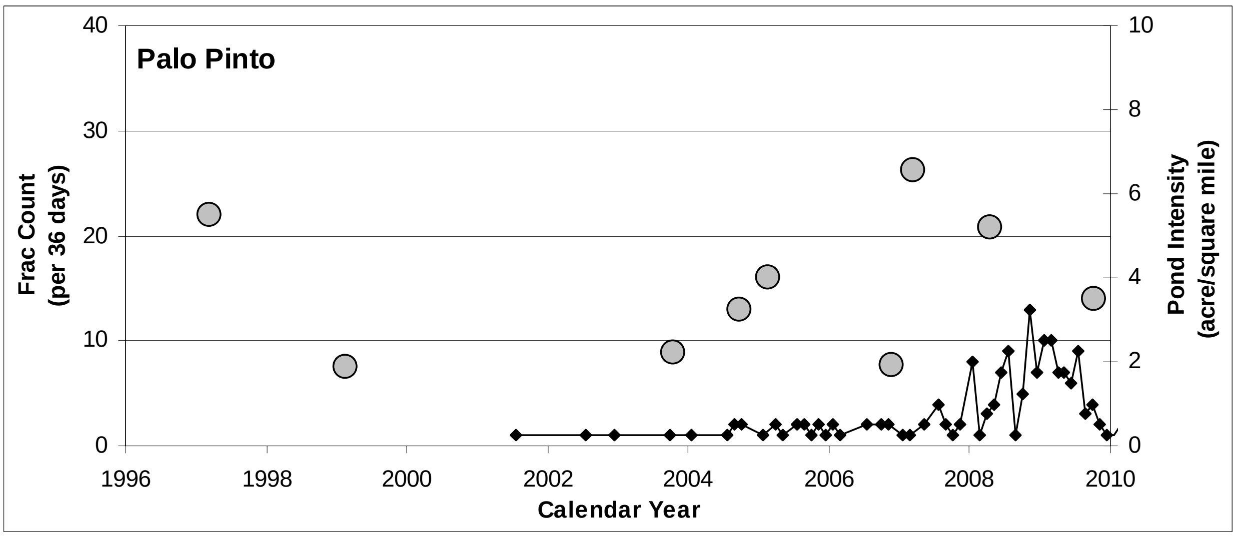


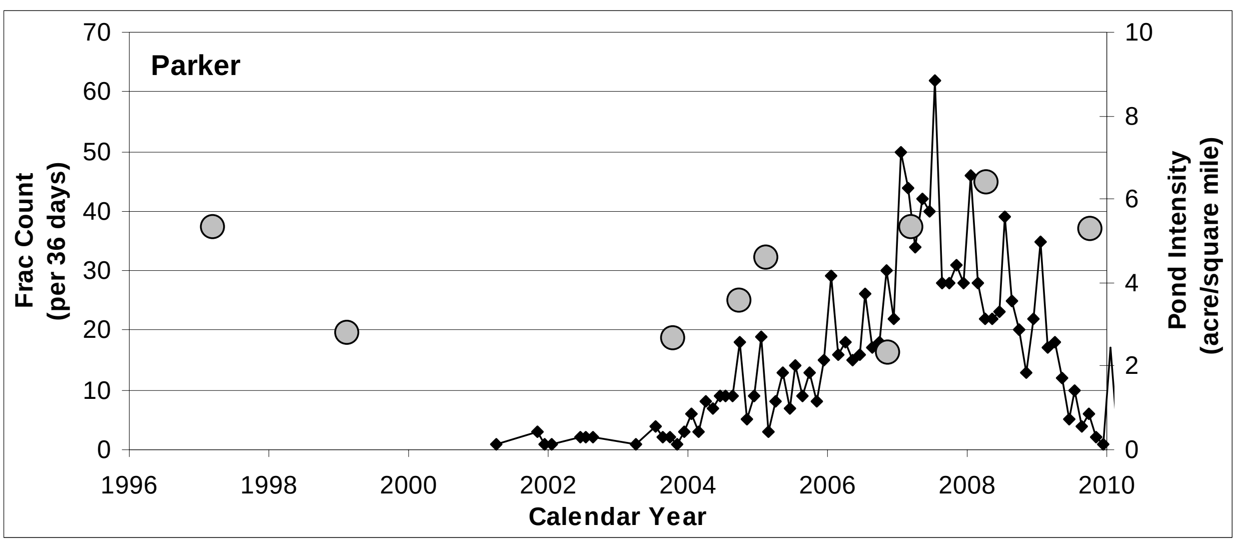

Hill
Frac Count
(per 36 days)
Pond Intensity
(acre/square mile)
Calendar Year
0
10
20
30
40
0
2
4
6
8
10
1996
1998
2000
2002
2004
2006
2008
2010

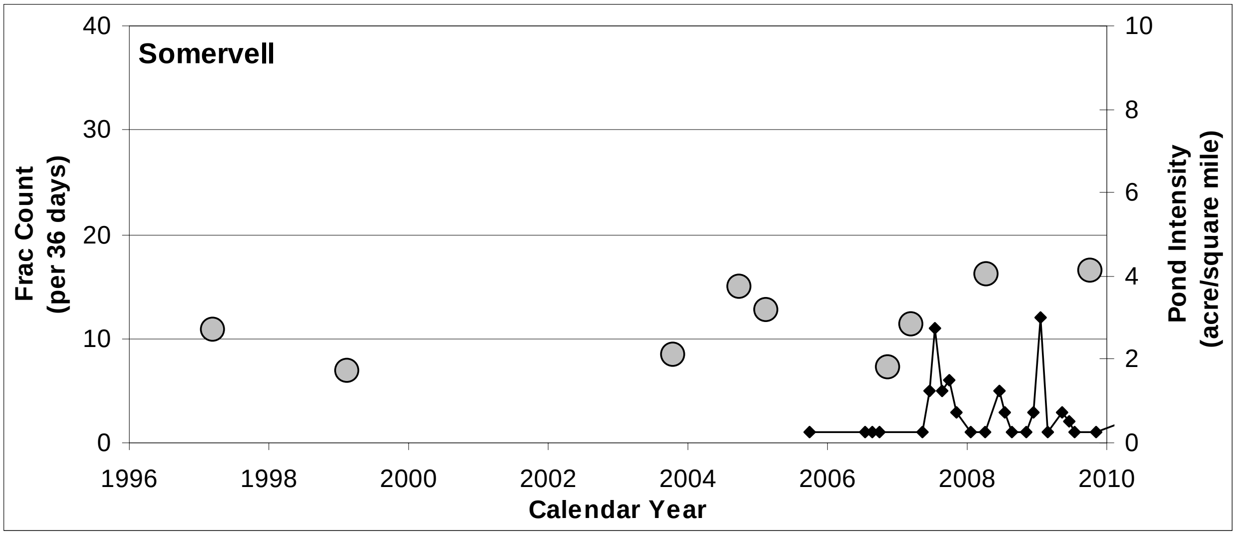

Hood
Frac Count
(per 36 days)
Pond Intensity
(acre/square mile)
Calendar Year
0
10
20
30
40
50
60
0
2
4
6
8
10
1996
1998
2000
2002
2004
2006
2008
2010

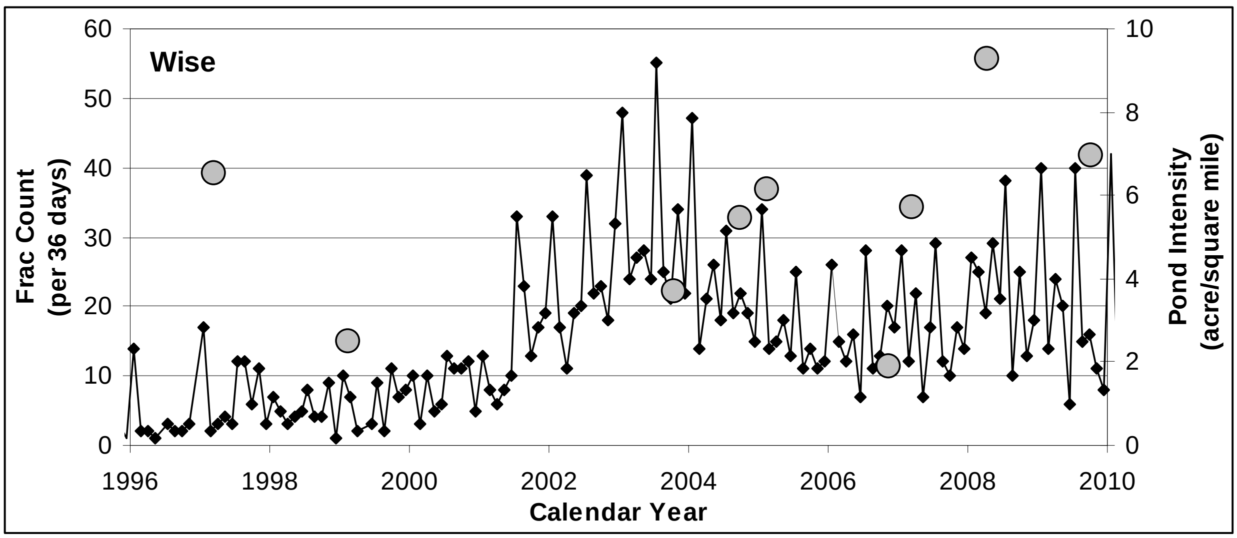

Jack
Frac Count
(per 36 days)
Pond Intensity
(acre/square mile)
Calendar Year
0
10
20
30
40
0
2
4
6
8
10
1996
1998
2000
2002
2004
2006
2008
2010


Montague
Frac Count
(per 36 days)
Pond Intensity
(acre/square mile)
Calendar Year
0
10
20
30
40
0
2
4
6
8
10
1996
1998
2000
2002
2004
2006
2008
2010


Palo Pinto
Frac Count
(per 36 days)
Pond Intensity
(acre/square mile)
Calendar Year
0
10
20
30
40
0
2
4
6
8
10
1996
1998
2000
2002
2004
2006
2008
2010


Parker
Frac Count
(per 36 days)
Pond Intensity
(acre/square mile)
Calendar Year
0
10
20
30
40
50
60
70
0
2
4
6
8
10
1996
1998
2000
2002
2004
2006
2008
2010


Somervell
Frac Count (per 36 days)
Pond Intensity (acre/square mile)
Calendar Year
0
10
20
30
40
0
2
4
6
8
10
1996
1998
2000
2002
2004
2006
2008
2010


Wise
Frac Count (per 36 days)
Pond Intensity (acre/square mile)
Calendar Year
0
10
20
30
40
50
60
0
2
4
6
8
10
1996
1998
2000
2002
2004
2006
2008
2010