Investigation of Declining Water Levels in Shallow Wells Located Near Lissie, Texas

Prepared for:

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Geoscientist Seal

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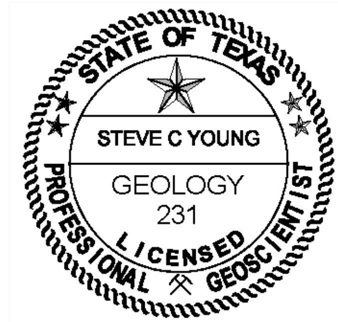


Steve C. Young, P.G. ____________________________

Dr. Steven Young is responsible for the writing of the report and the predicted drawdowns from the numerical groundwater flow models.

Executive Summary

During the summer of 2014, approximately twenty exempt well owners living near the town of Lissie (see Figure 1-1) contacted the Coastal Bend Groundwater Conservation District (CBGCD) regarding problems with declining water levels and associated pumping problems in their wells. The wells were all considered shallow and had total depths of 100 feet or less. Because of the poor performance of many of these wells, several of the well owners abandoned their shallow wells and drilled new deeper, replacement wells. The reported problems with the low water table conditions in shallow wells are primarily attributed to the contributing factors discussed below.

1. Significant Increases in Irrigation Pumping in the Vicinity of the Lakeside Irrigation District – Since 2011, the reported pumping in the vicinity of the town of Lissie has increased significantly. Within a circular area contained by a five-mile radius around the town of Lissie, the reported pumping has steadily increased (see Table 4-2) during the last few years. In 2013, the average production rate per arce is about 0.37 AFY/acre substantially higher the average production rate per acre of 0.24 AFY/acre for Wharton County.
2. Absence of Beaumont Formation near the town of Lissie– Across most of Wharton County, shallow wells are screened in the Beaumont Formation. The Beaumont Formation is the most clayey of the three formation that comprise the Chicot Aquifer and is the least pumped. As a result, the water levels in the shallow wells in the Beaumont Formation are somewhat protected from drawdowns caused by pumping in the two other formations in the Chicot Aquifer: the Lissie and the Willis Formations. In Wharton County, approximately 85% of the total pumping occurs in the Lissie and Willis Formations. Because the Beaumont Formation is absent in the area around the town of Lissie, the shallow wells near the town of Lissie are screened in deposits that in good hydraulic communication with the formations being pumped by irrigation wells. As a result, the shallow wells near the town of Lissie are more vulnerable and at a higher risk of experiencing drawdown impacts from irrigation pumping than most of the shallow wells in Wharton County.
3. Relatively Low Historical Drawdowns for Shallow Wells – Based on simulations using the LCRB model to estimate historical drawdowns that occurred from 1900 to 2000, the wells with depths of less than 250 feet near the town of Lissie are among the group of wells in Wharton County with the lowest historical declines in water table elevation. Whereas the majority of the shallower wells in western Wharton County (see Figure 5-1) have historical drawdowns between 40 and 90 feet, the majority of wells in eastern Wharton County have historical drawdowns that are less than 40 feet. Furthermore in the town of Lissie, wells with depths less than 250 feet typically have historical drawdowns less than 20 feet. The relatively low historical drawdowns in the area around the town of Lissie has likely contributed to the pre-2014 practice of installing domestic wells with depths of about 100 feet below ground surface. As a result of similar well

designs and depths, the opportunity exists for a relatively high percentage of the shallow wells to have pumping problems during a period of high irrigation pumping like 2013.

4. Reduction of Surface Water Diversion in the Lakeside Irrigation District – A primary cause for the sudden and rapid increase in pumping near the town of Lissie is the forced reduction in the surface water diversion across the Lakeside Irrigation District by the LCRA. In 2012 and 2013, the LCRA reported the annual surface water diversions for the Lakeside Irrigation District were 649 acre-feet and 0 acre-feet, respectively. Between 1989 and 2012, the least amount of surface water diversion was 95,390 acre-feet which occurred in 1997. For comparison, the surface water diversion for the Garwood Irrigation District for 2012 and 2013 was 85,478 acre-feet and 90,474 acre-feet, respectively. The average of these two values is greater than the surface water diversion that occurred over the nine years between 1989 and 2012. As a result of the very large reduction of surface water diversion across the Lakeside Irrigation District, the greatest increases in pumping occurred near the town of Lissie.

A potentially important question is what depth should replacement wells be drilled based on the desired to operate the well at least thirty-years so that problems with pumping will not occur. A very conservative approach to replace a shallow well by drilling the deepest well possible that would meet the desired water quality and quantity. Near the town of Lissie there are productive sand units containing fresh water to a depths below 600 feet . Based on our analysis of the data, there is no need to drill such a deep well. After a review of the LCRB model results and the field data, we recommend that new wells be drilled to a depth of 250 feet. Locations where this depth may not be acceptable are where several permitted well are pumping large amounts of groundwater from the Lissie Formation and/or the upper Willis Formation. The recommended depth of 250 feet is based on analyses provided Section 7. A key assumption of this analysis is the production permitted by CCGCD and CBGCD is fully implemented in the vicinity of the town of Lissie.

1.0 Introduction

During the summer of 2014, approximately twenty owners of shallow wells (with total depths of about 100 feet or less) living near the town of Lissie (see Figure 1-1) contacted the Coastal Bend Groundwater Conservation District (CBGCD) regarding problems with pumping because of declining groundwater levels in their wells. Because of the poor performance of many of these wells, including under producing and non-producing wells, several of the well owners abandoned their shallow wells and drilled new, replacement wells. To better understand the cause of the declining water levels and associated well problems and to help manage and mitigate the problems, the CBGCD contacted INTERA to perform an investigation and those results are provided herein.

1.1 Objectives

The investigation had two main project objectives. The first objective was to identify probable causes and conditions that are responsible for the declining water levels and associated pumping problems in the area. The second objective was to develop guidelines for installing shallow exempt wells near the town of Lissie to help avoid the pumping issues.

1.2 Report Outline

This report discusses the historical pumping, measured water levels in monitoring wells, and the hydrogeology of Wharton County. This information was evaluated with the purpose of identifying the factors responsible for the declining water levels in the shallow wells near the town of Lissie and the resulting lack of production in the wells. Based on the evaluation of these factors, recommendations are made herein to help improve and expand on the findings presented herein and to help manage and mitigate the problem.

This report is organized into seven sections included as follows:

- Section 1 introduces the objectives of the report
- Section 2 provides a summary of the geology of Wharton County with an emphasis on the northeast portion of the county near the town of Lissie
- Section 3 provides a summary of the locations of the approximately 4,800 exempt wells registered with the CBGCD
- Section 4 presents maps and tables describing the spatial and temporal distribution of pumping in Wharton County
- Section 5 discusses measured water levels and simulations included in the Lower Colorado River Basin (LCRB) model during its calibration period from 1900 to 2006
- Section 6 provides a sensitivity analysis of water levels in the subject wells to changes in localized pumping based on LCRB model simulations
- Section 7 provides a summary of the data analysis

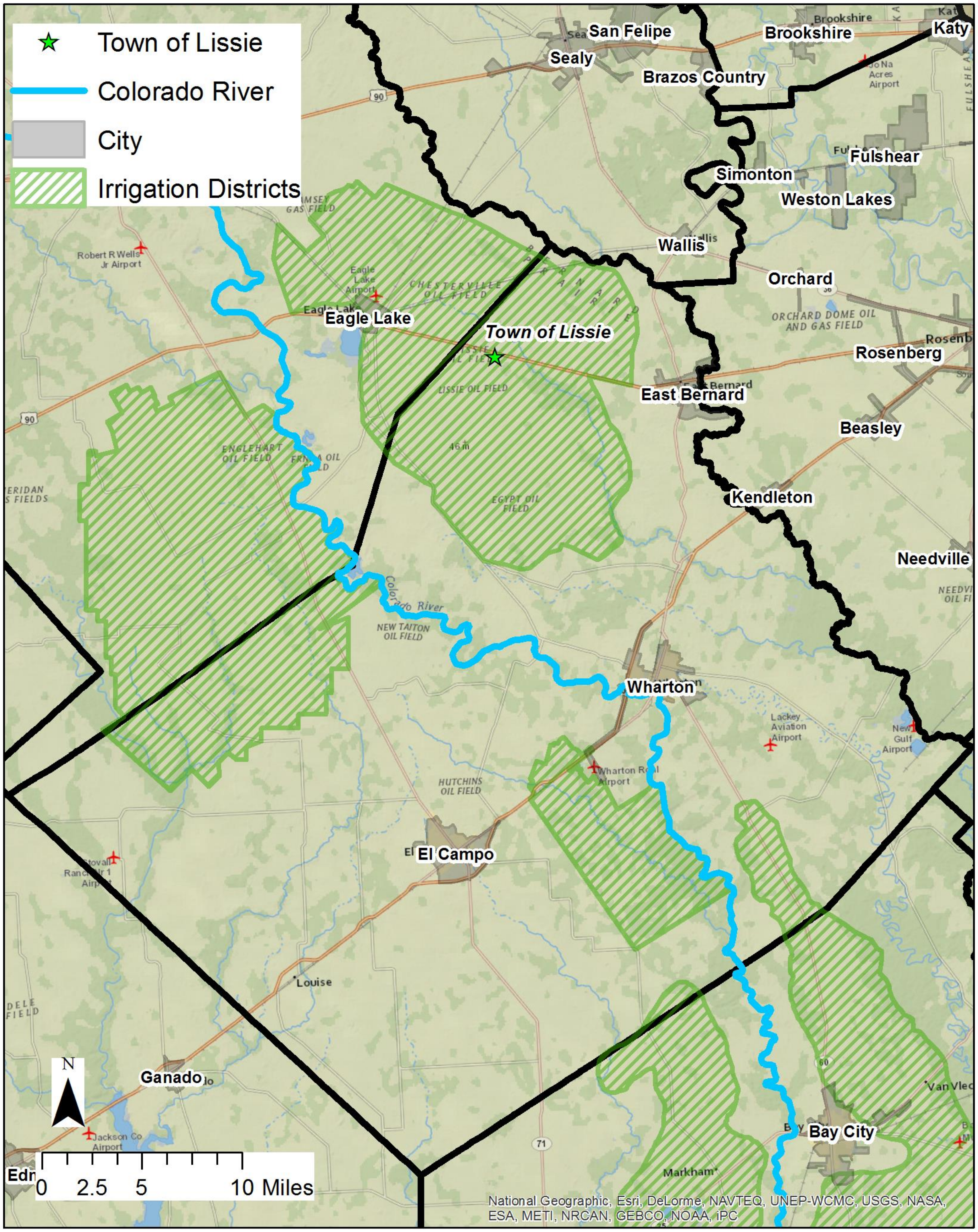


Figure 1-1 A regional map showing the location of the town of Lissie.

2.0 Geology

In order for an exempt well located in the shallow subsurface to be protected from adverse impacts from pumping permitted wells, the shallow well should be hydraulically isolated from geological units experiencing significant pumping. Factors promoting hydraulic isolation between shallow exempt wells and permitted wells include large vertical and horizontal distances between the wells, thick clay beds between the wells, and the absence of interconnected sandy deposits between the wells. This section describes the geologic formations in Wharton County with respect to properties and characteristics that influence how the water levels and groundwater discharge respond to pumping from wells.

2.1 Geological Formations that Comprise Gulf Coast Aquifer System

The aquifers that underlie Wharton County are part of the Gulf Coast Aquifer System. The Gulf Coast sediments are comprised of sequences of interbedded sandstones and shales that have been grouped into geological formations and aquifers based on regional-scale correlations of the lithologic units and the depositional environments responsible for the spatial variability in the patterns and thickness of these lithologic units. Among the factors that cause the depositional environments and lithology variability are changes in sedimentary processes, sediment supply, climate, tectonics (earth movements), sea level changes, biological activity, water chemistry, and volcanic activity. Figure 2-1 shows the geological formations and the hydrogeological units that comprise the Gulf Coast Aquifer System. The Gulf Coast Aquifer System encompasses all geological units above the Vicksburg Formation (George and others, 2011, Young and others 2010).

The most recent studies funded by the Texas Water Development Board (TWDB) that delineate the structure and stratigraphy of the Gulf Coast Aquifer are by Young and others (2010; 2012). These studies subdivided the aquifer units into geological formations based on chronostratigraphic correlations. Figure 2-2 is a vertical cross-section through the Gulf Coast Aquifer System that crosses through the middle of Wharton County. All of the District's registered wells are located in either the Chicot Aquifer or the Evangeline Aquifer. As shown in Figure 2-2, these two aquifers comprise the majority of the upper 2,000 feet of the Gulf Coast Aquifer System in Wharton County and are described below.

Chicot Aquifer – The Chicot Aquifer includes, from the shallowest to deepest, the Beaumont and Lissie Formations of Pleistocene-age and the Pliocene-age Willis Formation. The Beaumont outcrop covers a large part of the lower coastal plain except where cut by modern river valleys or covered by Holocene wind-blown sand in south Texas. The Beaumont Formation is often composed of clay-rich sediments transected by sandy fluvial and deltaic-distributary channels. At outcrop, the Lissie Formation is composed of fine-grained sand and sandy clay and unconformably overlies and onlaps the Willis Formation (Morton and Galloway, 1991). The Lissie Formation is dominated by nonmarine depositional systems in the onshore part across most of the Texas Gulf Coast, although some shore-zone facies occur in Matagorda County as well as other coastal counties. At outcrop, the Willis Formation is composed of gravelly coarse sand in several upward-fining successions that are interpreted as incised valley fills overlain by transgressive deposits (Morton and Galloway, 1991). Near the modern shoreline and offshore, Willis Formation deltaic and marine systems record four cyclic depositional episodes bounded by transgressive shales (Galloway and others, 2000). Willis Formation fluvial systems include dip-oriented sand-rich channel-fill facies and sand-poor interchannel areas, which grade toward the coast into shore-parallel deltaic and shore-zone sands and interdeltaic muddy bay deposits. Individual Willis Formation sands vary widely in thickness from about 20 to 200 feet and are separated by muds of similar thickness (Knox and others, 2006).

Evangeline Aquifer – The Evangeline Aquifer includes the upper Goliad Formation of earliest Pliocene and late Miocene age, the lower Goliad Formation of middle Miocene age, and the upper unit of the Lagarto Formation (a member of the Fleming Group) of middle Miocene age. The Goliad Formation in Matagorda County was formed as part of the Eagle Lake Extrabasinal fluvial system. In this system the Goliad Formation fluvial depositional systems consist of channel-fill and interchannel deposits (Young and others, 2012). Channel belts typically are 10 to 30 miles wide and consist of about 50% sands while the interchannel deposits typically are less than 20 percent sand. The Upper Lagarto Formation is comprised of deposits from the Fleming Group. The Fleming Group comprises several large fluvial systems that grade downdip into equally large delta and shore-zone systems (Rainwater, 1964; Doyle, 1979; Spradlin, 1980; DuBar, 1983; Galloway and others, 1982, 1991). In Matagorda County, the Fleming sands tend to align parallel to the shoreline and to have sand contents between 10 and 40 percent (Young and others, 2012).

Burkeville – The Burkeville Confining Unit is represented by the middle unit of the Lagarto Formation of middle and early Miocene age, which is the chronostratigraphic layer with the most widespread clayey interval between the Evangeline and Jasper Aquifers.

Jasper Aquifer – The Jasper Aquifer includes the lower Lagarto unit of early Miocene-age, the early Miocene Oakville sandstone member of the Fleming Group, and the sandy intervals of the Oligocene-age Catahoula Formation.

2.2 Surface Geology

Figure 2-3 shows the surface geology for Wharton County and nearby counties. The surface geology consists of outcrops of the geologic formations listed in Figure 2-1 and alluvial sediments that compose the Gulf Coast Aquifer System. Figure 2-3 shows that for the majority of Wharton County, the shallowest deposits are composed of the Beaumont Formation with exceptions occurring near the Colorado River and in an area near Colorado County. Near the Colorado River, the surface deposits consist of alluvium, which is typically less than fifty feet thick and underlain by the Beaumont Formation. Near Colorado County, the Beaumont Formation pinches out and the shallow deposits are comprised of the Lissie Formation, which outcrops in the area around the town of Lissie.

2.3 Sand and Clay Composition of the Geological Formations

Figure 2-4 shows a distribution of the sand and clay bed thicknesses for the geological formations that comprise the Chicot and Evangeline Aquifers. The values are based on an analysis of approximately 350 geophysical logs over a 10-county area that is centered on Wharton County and included in the spatial extent of the LCRB model.

Figure 2-4 shows that the Lissie Formation has the most sand and the thickest sand beds as well as the formation with the least clay and the thinnest clay beds. Numerous studies within the geologic literature (Folk, 1980; Carmen, 1939; Lame, 1969; Masch and Denny, 1966) show that lithology can be a useful and reliable estimator of hydraulic conductivity and other aquifer hydraulic properties. With other factors being equal in a mixture of sands and clays, the hydraulic conductivity of the deposit will increase with increases in the percentage of sand, in the average size of the sand grains, and in the sorting of the deposits. In addition, with all other factors being equal, a formation with a few thick sand beds will have a higher effective hydraulic conductivity than a formation with more numerous but thinner sand beds.

Based on the information in Figure 2-4 and proven relationships between physical and hydraulic properties of the aquifer, the most permeable formation in Wharton County is the Lissie Formation. Because of the similar percentages for total sands and sand bed with thicknesses greater than 80 feet, the Willis Formation is expected to be nearly as permeable as the Lissie Formation. Across most of the domain of the LCRB model, the lower portion of the Chicot Aquifer, composed of the Lissie and Willis Formations, should be significantly more permeable than the deposits that comprise the upper Chicot Aquifer and the Evangeline Aquifer.

2.4 Sand and Thickness Maps

Among the important hydrogeological factors that affect how water levels respond to pumping from a well is the thickness and sand content of the geological formation at the location of the well. To help establish a hydrogeological framework for assessing the impact of pumping from permitted wells on shallow wells, maps of sand fraction and formation thickness were developed based on the information provided by Young and others (2010, 2012).

The Beaumont Formation plays a potentially important role in protecting shallow wells from changes in water levels in the lower formations. Being a different formation and one with less sand and considerably thinner sand beds, the Beaumont Formation provides a measureable amount of protection to water level change when it serves to help hydraulically isolate shallow wells from the underlying Lissie Formation, which is heavily pumped in Wharton County. Thus, the thickness and sand distribution of the Beaumont Formation is important to understanding the hydraulic connection between change in water levels in shallow wells and water levels in the permitted irrigation wells screened below the Beaumont Formation.

Figure 2-5 presents the sand fraction and thickness maps for the Beaumont Formation. As is shown on the figure, the Beaumont Formation the thickest in southern Wharton County and in Matagorda County.

Because of its variable thickness and sand content, the Beaumont Formation provides varying amounts of protection to water levels in shallow wells from pumping occurring in the geological units that are older and underlie the Beaumont Formation. Along most of the northern county line for Wharton County and at the town of Lissie, the Lissie Formation is the uppermost formation and the Beaumont does not exist. Along most of the southern county line for Wharton County, the Beaumont is the uppermost formation and overlies the Lissie Formation. In the southern region of Wharton County where the Beaumont Formation is greater than 200 feet thick, the Beaumont Formation would serve as an effective hydraulic barrier that would help protect the water levels in the shallow wells from the effects of pumping in the underlying Lissie Formation. However, in the northern region of Wharton County where the Beaumont is absence or less than 100 fee thick, the Beaumont Formation would not help protect the water levels in the shallow wells from the effects of pumping in the underlying Lissie Formation.

Figure 2-6 shows the sand fraction and thickness maps for the Lissie Formation. Near the town of Lissie, the Lissie Formation is about 200 feet thick. Thus, for a 100-foot deep well located near the town of Lissie, there is about 100 feet of Lissie deposits between the bottom of the well and the Willis Formation, which is the geological unit that underlies the Lissie Formation.

Figure 2-7 shows the sand fraction and thickness maps for the Willis Formation. Across Wharton County, the thickness of the Willis Formation varies between 200 and 400 feet. Near the town of Lissie, the Willis Formation is more than 80% sand. This high sand fraction would help facilitate a good hydraulic connection in the vertical direction between the Willis and the Lissie Formations.

Figure 2-8 shows the sand fraction and thickness maps for the Upper Goliad Formation. The figure shows that the formation is between 100 and 200 feet thick beneath the town of Lissie and that the formation thins toward Colorado County and thickens toward Matagorda County. The sand fraction in beneath the town of Lissie is between 0.2 and 0.6, which is very similar to the rest of Wharton County.

ERA	Epoch		Est. Age (M.Y)	Geologic Unit	Hydrogeologic Unit
Cenozoic	Pleistocene		0.7	Beaumont	CHICOT AQUIFER
			1.6	Lissie	
	Pliocene		3.8	Willis	
	Miocene	Late	11.2	Upper Goliad	EVANGELINE AQUIFER
			14.5	Lower Goliad	
			17.8	Upper Lagarto	
		Middle		Middle Lagarto	BURKEVILLE
		Early		Lower Lagarto	JASPER AQUIFER
			24.2	Oakville	
	Oligocene		32	Frio	CATAHOULA
			34	Vicksburg	

Figure 2-1 **Geologic and Hydrogeologic Units of the Gulf Coast Aquifer System in Matagorda County, Modified from (Young and others (2010; 2012) and LGB Guyton and INTERA (2012)).**

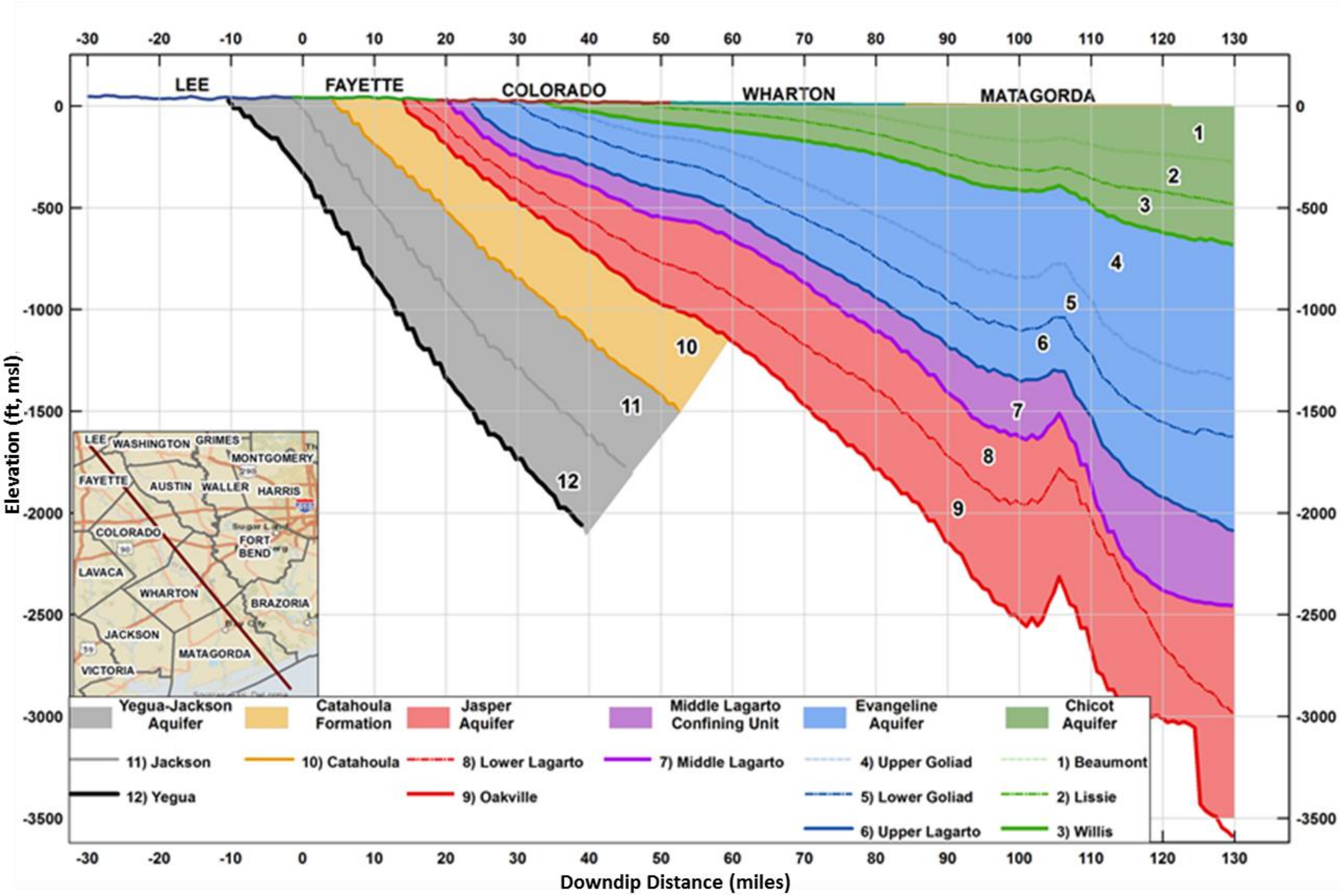


Figure 2-2 **Cross-Section along a Dip through the Gulf Coast Aquifer System showing the Aquifers and Geological Formations in Fayette, Colorado, Wharton, and Matagorda Counties.**

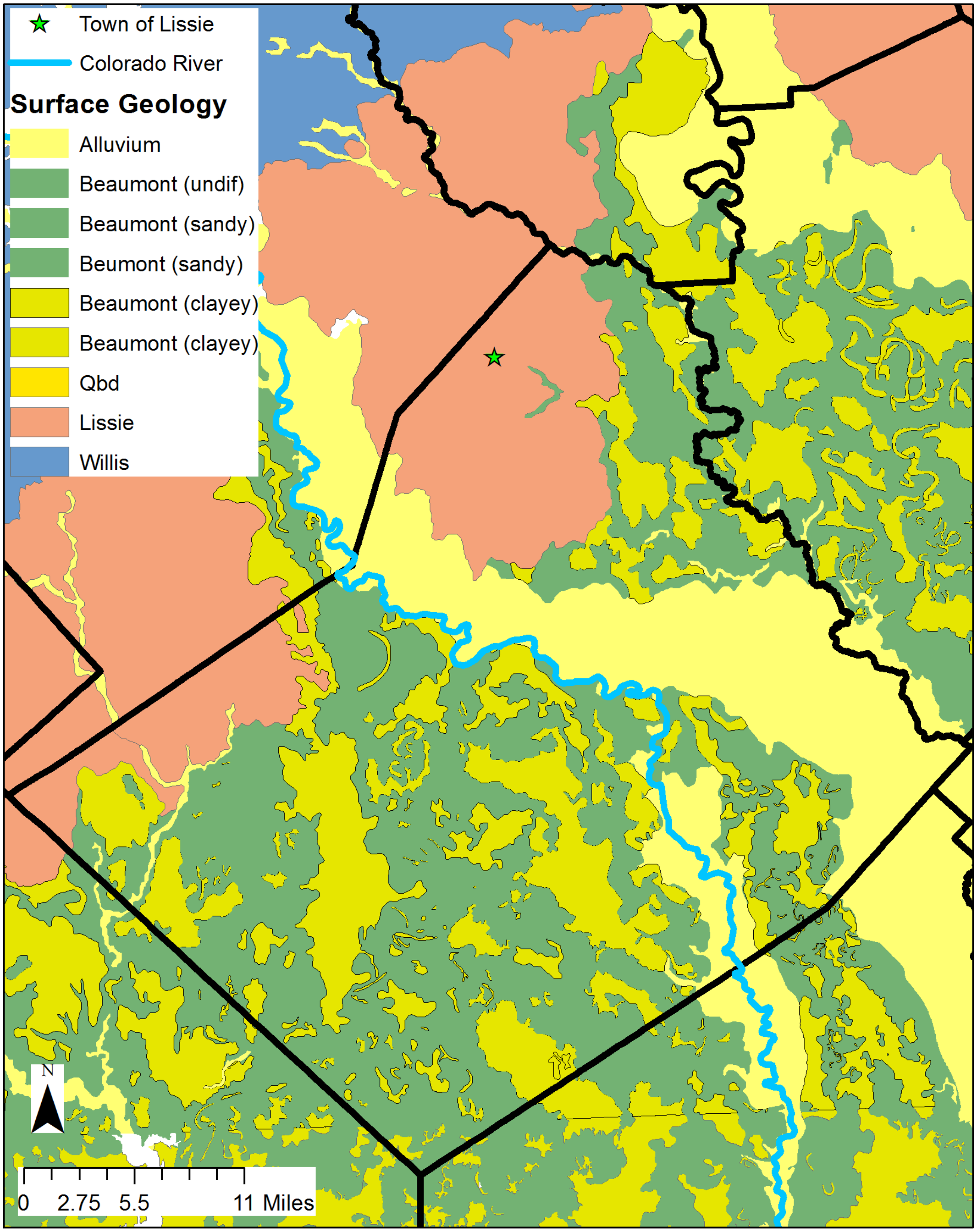


Figure 2-3 Surface Geology for Wharton County (from Barnes, 1974).

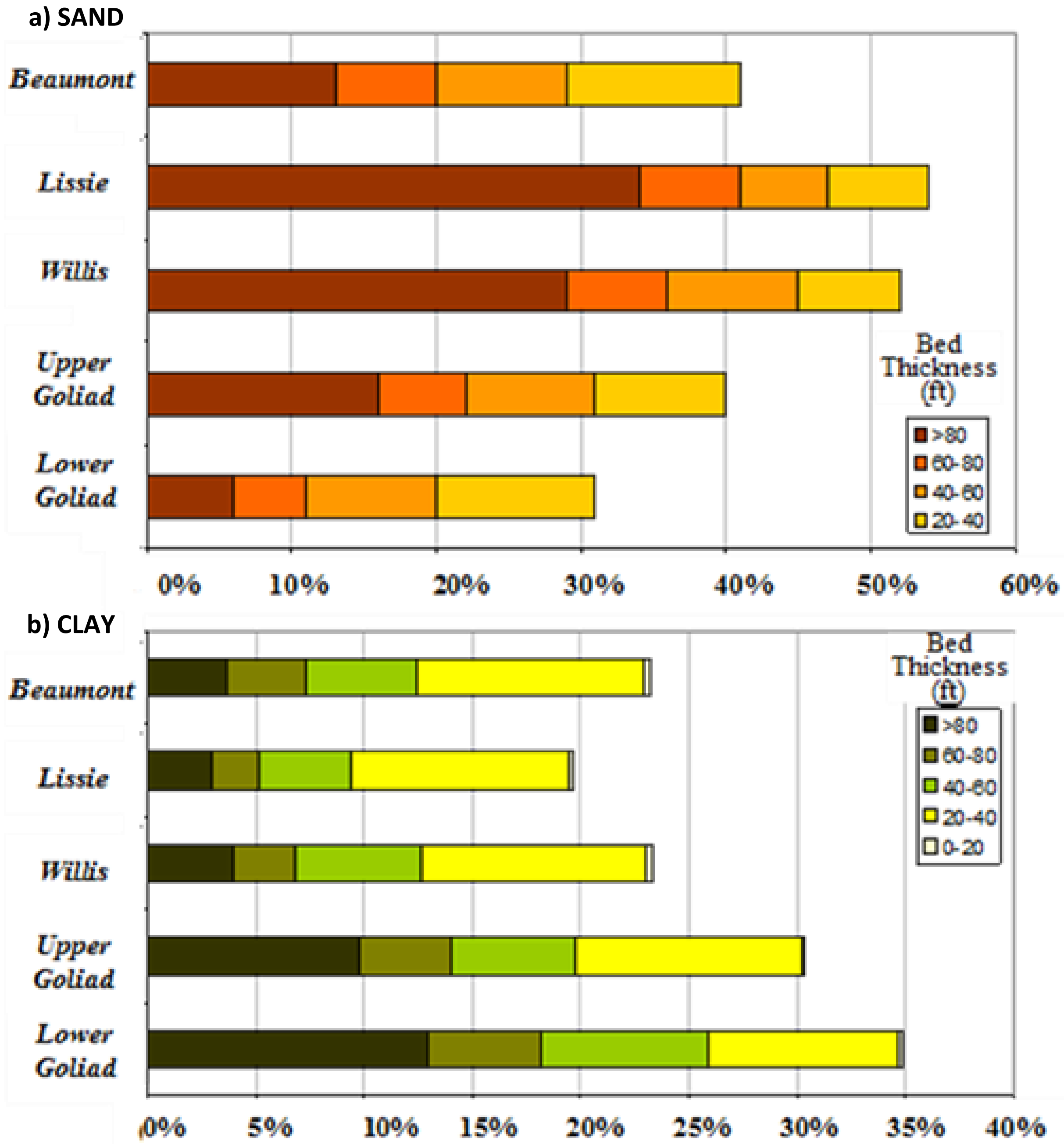


Figure 2-4 **Thicknesses of the Sand (a) and Clay (b) Beds that Comprise the Geological Formations of the Chicot and Evangeline Aquifers in the the 10-County Area Centered on Wharton County (from Young and Kelley, 2006).**

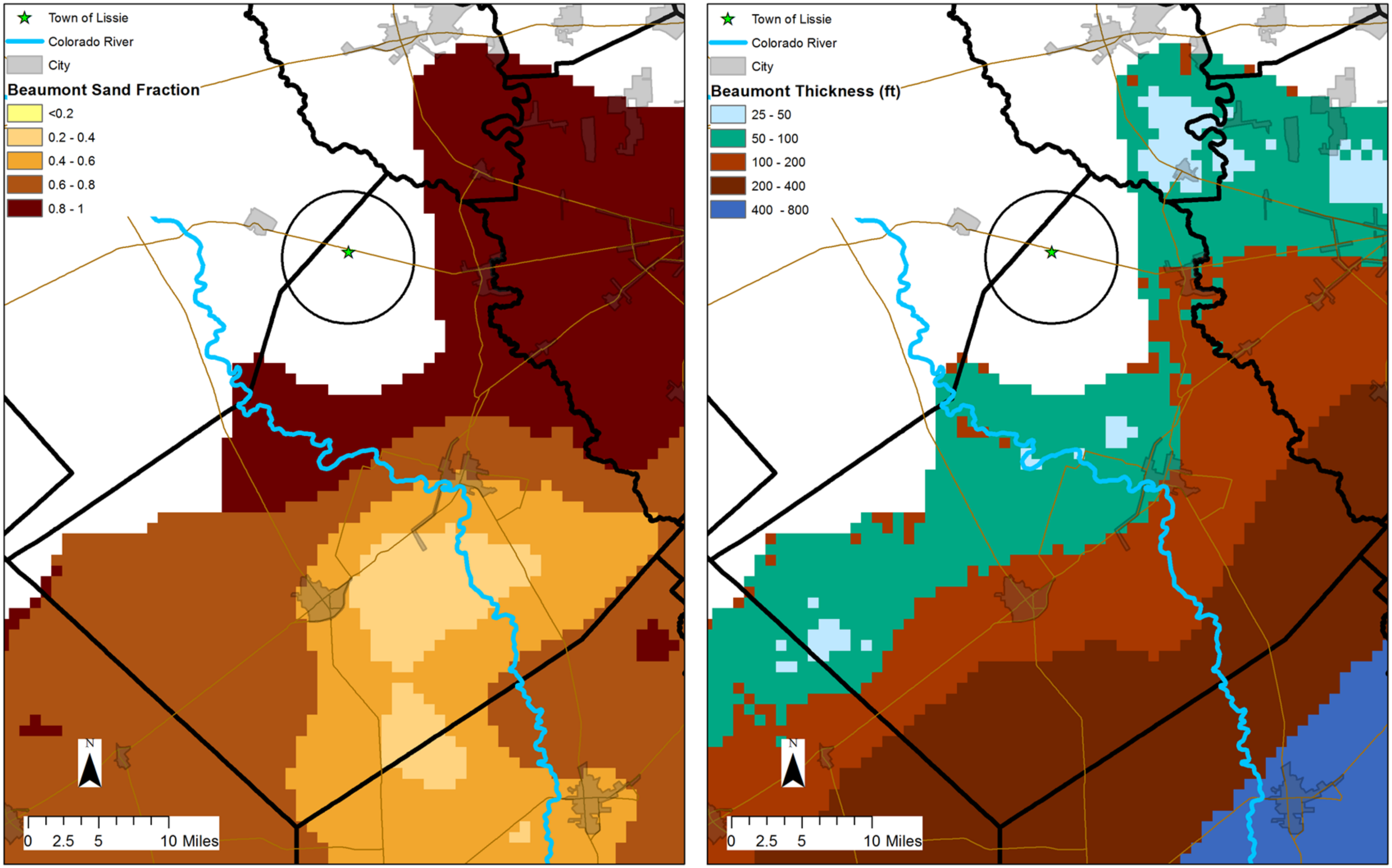


Figure 2-5 Sand Fraction and Thickness for the Beaumont Formation.

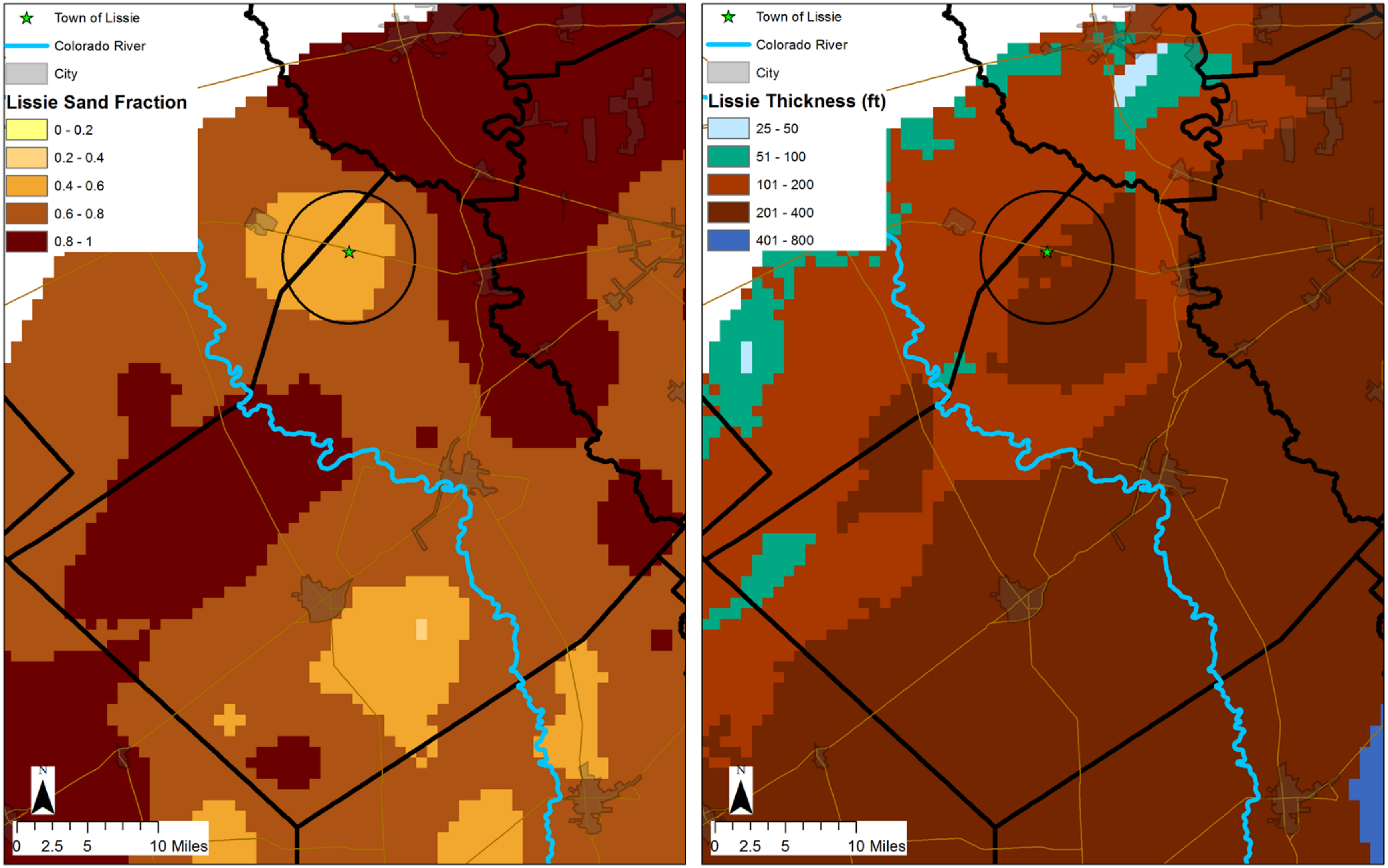


Figure 2-6 Sand Fraction and Thickness for the Lissie Formation.

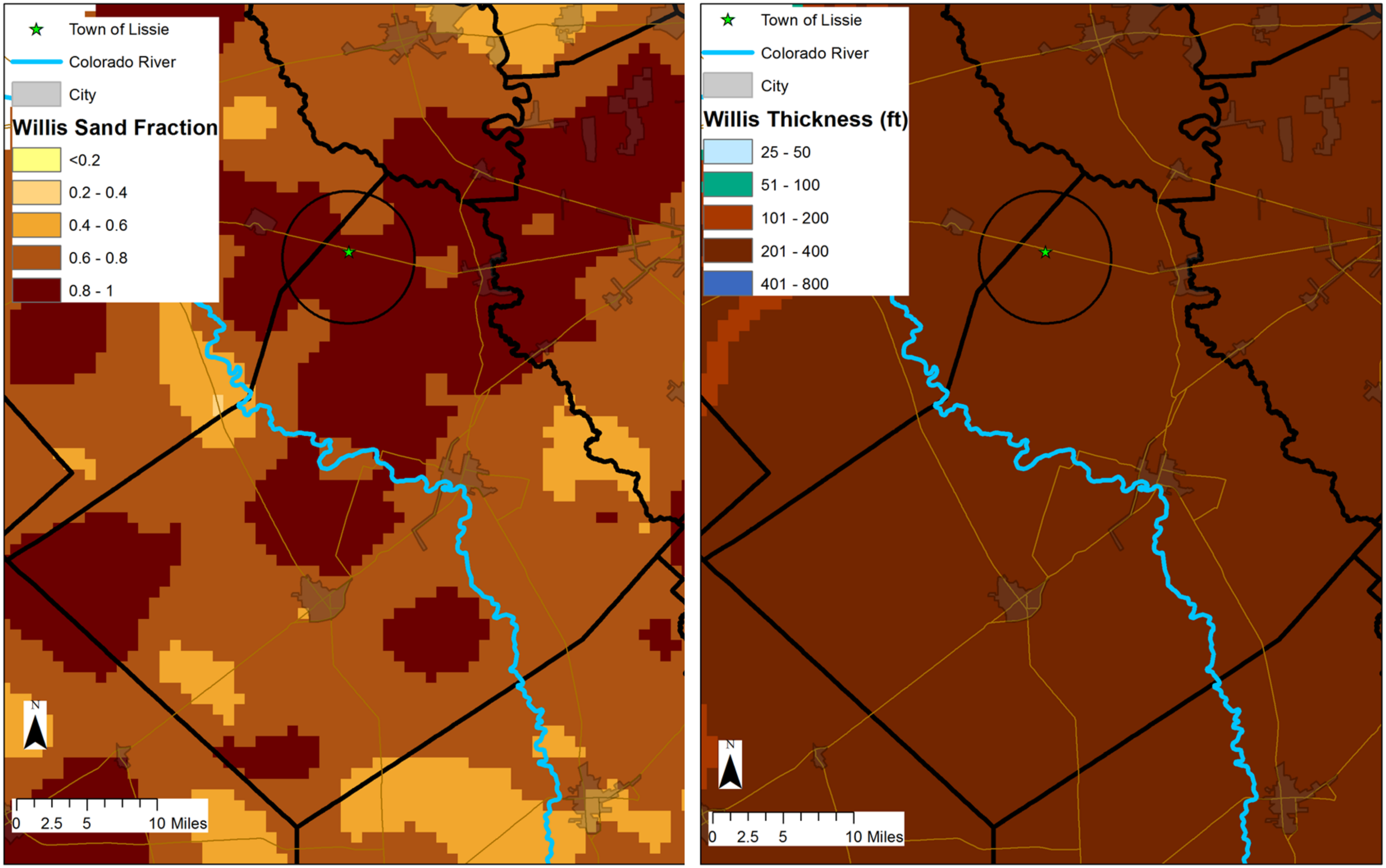


Figure 2-7 Sand Fraction and Thickness for the Willis Formation.

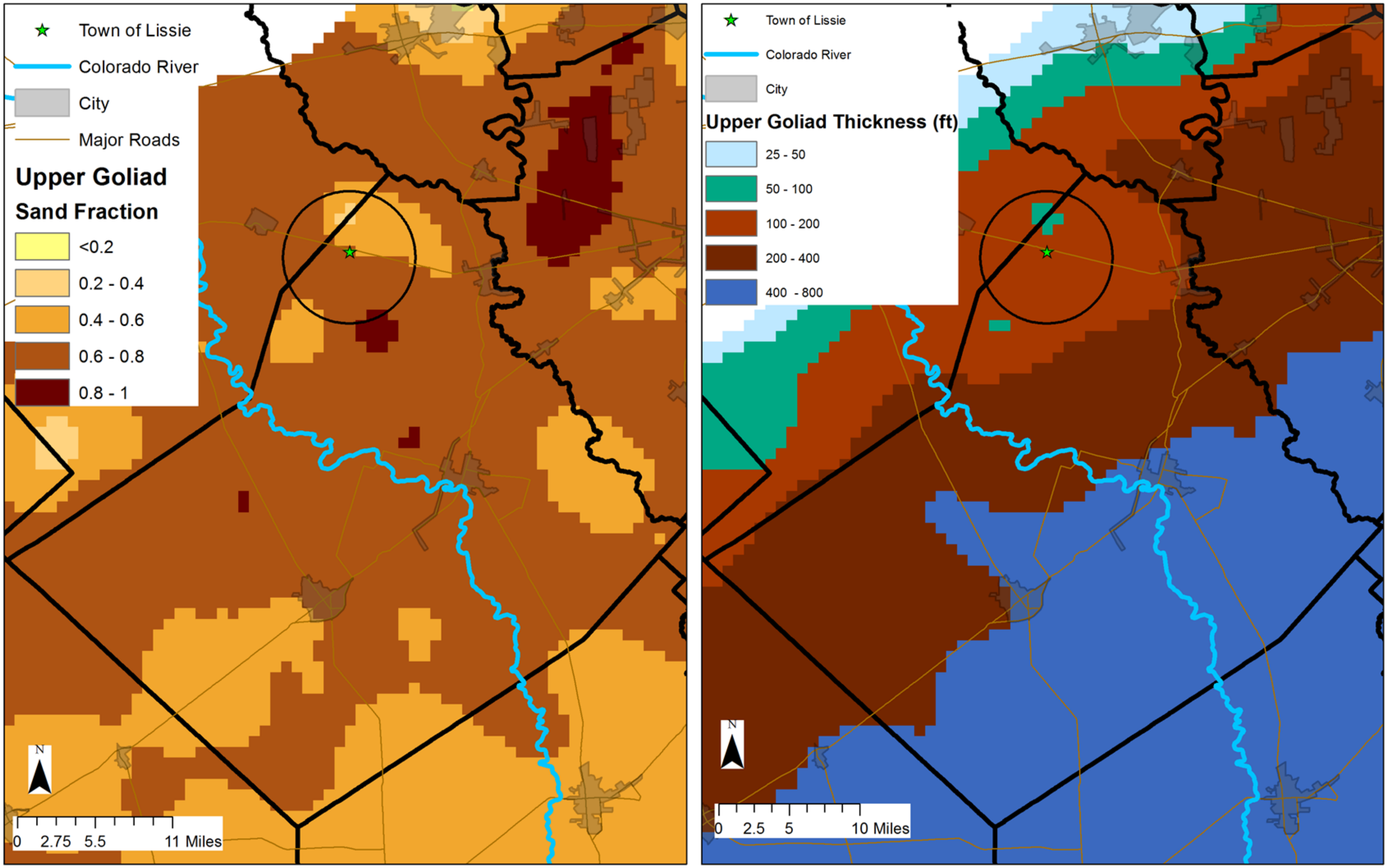


Figure 2-8 **Sand Fraction and Thickness for the Upper Goliad Formation.**

3.0 Exempt Wells

At the time of the writing of this report, the CBGCD well database for Wharton County contains 4,756 exempt wells. Figure 3-1 shows approximately 3,150 of these wells that have a total depth equal to or less than 150 feet. Of these wells, approximately 2,300 of them have a total depth equal to or less than 100 feet. As shown in Figure 3-1 there are relatively few shallow wells shown in the vicinity of the town of Lissie. Based on information provided to INTERA by CBGCD, the majority of well owners that expressed concerns to the CBGCD about the performance of their shallow wells during the summer of 2014 did not have their well registered. Thus, the reader should be aware that the true distribution of exempt wells shown in Figure 3-1 is different from the distribution of registered exempt wells shown in Figure 3-1.

Figure 3-1 shows five circles with radii that are approximately 5 miles. One circle circumscribes the town of Lissie and the four other circles cover areas where the density of shallow wells is relatively high. Table 3-1 shows the number of shallow wells contained by the five circles. On average, there are approximately ten times more shallow wells in the four circles numbered 1 through 4 than in the circle surrounding the town of Lissie. Table 3-2 shows the distribution of geological formations in which the shallow wells terminate. The table shows that the farther north the circle, the lower the percentage of shallow wells that terminate in Beaumont Formation and the greater the percentage of shallow wells that terminate in the Lissie Formation.

Table 3-1 Number of Exempt Wells with Shallow Total Depths in Five Areas of Interest.

Circular Area of Interest	Maximum Depth of Exempt Well	
	<100 ft	<150 ft*
Lissie	20	45
1	297	368
2	273	396
3	418	582
4	224	384

Table 3-2 Placement of Exempt Wells with Depths less than 150 feet Among the Geological Formations.

Circular Area of Interest	Geological Formation	
	Beaumont	Lissie
Lissie	0	45
1	368	0
2	396	0
3	558	24
4	228	156

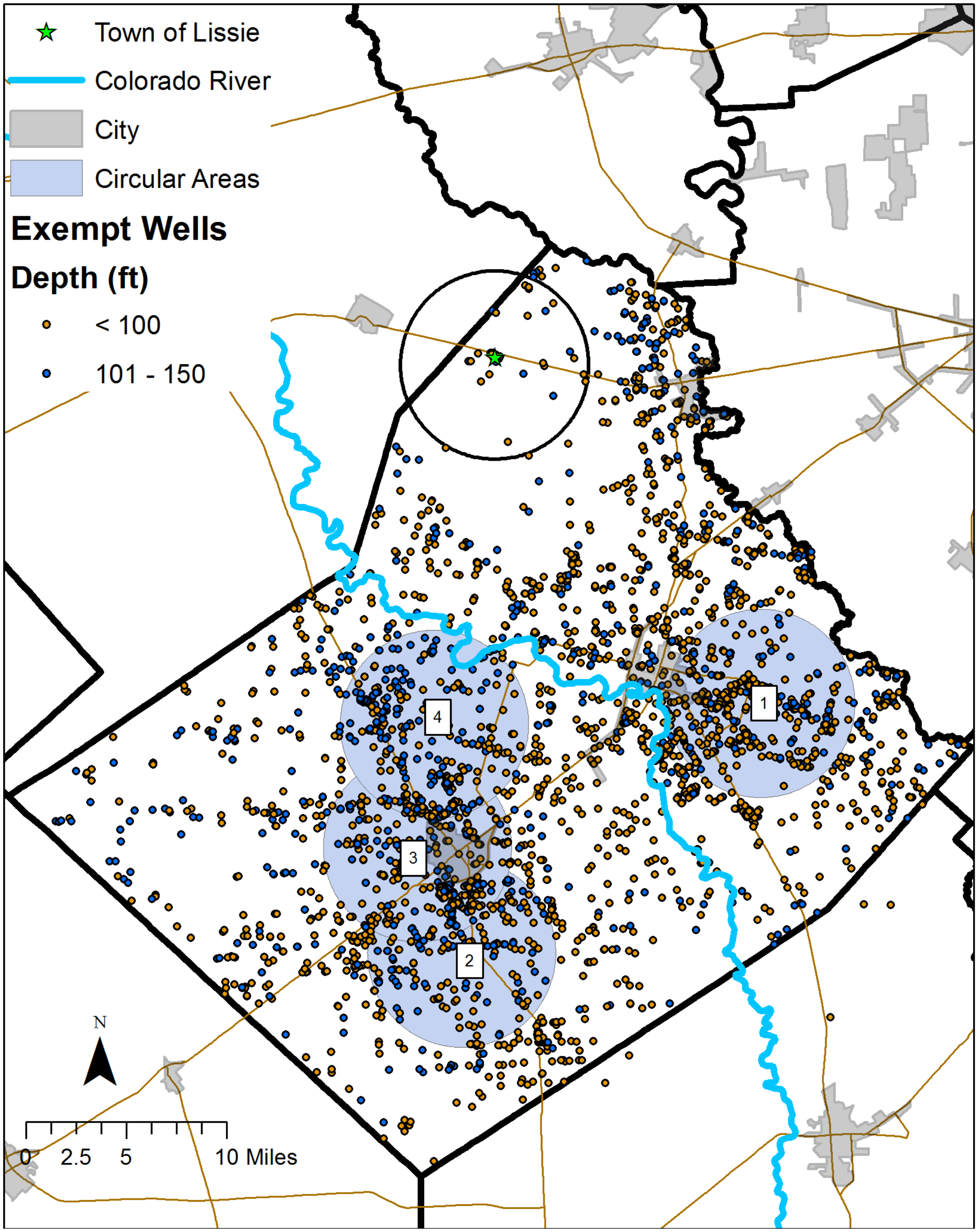


Figure 3-1 Location of Shallow Wells Registered with the Coast Bend GCD in Wharton County and of Five Circular Areas of Interest.

4.0 Recent Pumping

The primary cause for declining water levels in an aquifer is pumping. As such, an important aspect to understanding the causes for the water level declines in shallow wells is the understanding of temporal and spatial variability in pumping.

4.1 Reported Pumping for 2011, 2012, and 2013

Figure 4-1 shows the location of wells in the CBGCD database that are permitted to pump groundwater. In addition, Figure 4-1 shows the permitted wells from the CCGCD well database that are located near the town of Lissie. The wells are color-coded to show the formation from which the well pumps most of its groundwater. Across most of Wharton the majority of the pumping occurs from the Lissie Formation. Near the town of Lissie, however, most of the pumping is occurring from the Willis Formation. Figure 4-2 shows the same well locations in Figure 4-1 but the well locations are color-coded based on the reported production rate for 2013. The figures shows that some of the wells with the highest production rates are near the town of Lissie.

Table 4-1 shows the reported pumping, in acre-feet/year (AFY), from permitted wells for years 2011, 2012, and 2013 by geological formation in Wharton County. For all three years, more than 60% of the total pumping is from the Lissie Formation. Less than 5% of the total pumping is from the Beaumont Formation. Most of the pumping is from the Lissie Formation because it is the geological formation with the highest transmissivity, thickest sand beds, and the highest percentage of sand (Young and Kelley, 2006, Young and others, 2009). Also in Wharton County, approximately 95% of the permitted pumping is for irrigation.

In order to help quantify the spatial and temporal variations in pumping among the five circular areas identified in Figure 3-1, Tables 4-2, through 4-6 were created. Table 4-2 shows the reported pumping in the five circular areas for 2011, 2012, and 2013. The variation in the pumping is caused primarily because of varying climate conditions and the additions of new irrigation wells in response to the LCRA reduction in surface water diversions for irrigation. Tables 4-3 and 4-4 distribute the pumping in 2011 and 2013 by well depth interval and geological formation, respectively. Tables 4-5 and 4-6 show the change in reported production for the five circular areas from 2011 to 2013 by well depth interval and by geological formation.

The production amounts in these tables are based on reported production extracted from the CBGCD well database for 2011, 2012, and 2013 and production estimates provided to INTERA by CCGCD. CCGCD provided INTERA reported production for the wells in Colorado County shown in Figure 3-1 for 2012 and 2103 and anticipated production for 2014 and 2015. For the CCGCD wells in shown in Figure 3-1, the productions estimates provided by CCGCD are 5600 AF, 7200 AF, 12500 AF, and 16100 AF for 2012, 2013, 2014, and 2015, respectively. Based on available data, the estimate for the 2011 production was 4000 AF, which includes 3700 AF of production in the portion of the Lissie Circle in Colorado County.

Table 4-1 Reported Production in Wharton County by Geological Formation in AFY.

Formation	Number of Wells in 2013	Year			Average	
		2011	2012	2013	Total	Percent
Shallow	12	869	29	703	534	0.3%
Beaumont	167	10,268	5,479	7,233	7,660	4.7%
Lissie	608	118,986	92,880	102,553	104,806	63.8%
Willis	132	31,589	35,890	43,358	36,946	22.5%
Upper Goliad	35	14,596	12,620	15,929	14,382	8.8%
Total	**954**	**176,308**	**146,898**	**169,777**	**164,328**	**100%**

Table 4-2 Reported Production for the Five Circular Areas of Interest (see Figure 3-1).

Circular Area of Interest	Number of Wells in 2013	Reported Production (AFY)		
		2011	2012	2013
Lissie	55	12,025*	14,533	16,542
1	80	10,075	6,661	7,922
2	105	13,552	10,586	11,293
3	110	9,412	6,369	7,546
4	100	13,360	7,158	10,218

*2011 data not available for CCGCD, estimated to approximately 3,700 AF based on the CBGCD and CCGCD production estimates discussed in text

Table 4-3 Reported Production (AFY) for the Five Circular Areas in 2011 and 2013 by Depth Interval.

Year	Circular Area of Interest	Depth Interval (ft)					
		0-200	200-400	400-600	600-800	800-1000	Total
2011	Lissie	1,737*	211*	39*	4,111*	5,927*	12,025
	1	1,336	4,175	1,654	0	2,910	10,075
	2	170	2,723	4,297	3,296	3,066	13,552
	3	88	5,361	1,178	281	2,504	9,412
	4	2,132	8,497	2,732	0	0	13,360
2013	Lissie	1,146	551	2,849	5,049	6,947	16,542
	1	1,187	2,876	1,536	0	2,324	7,922
	2	204	1,962	4,233	3,648	1,247	11,293
	3	96	3,942	962	553	1,993	7,546
	4	1,932	5,846	2,441	0	0	10,218

*17% of CCGCD is assumed for 600-800 feet and 83% is assumed from 800-1000 feet for 2011

Table 4-4 Reported Production (AFY) for the Five Circular Areas of Interest in 2011 and 2013 by Geological Formation.

Year	Circular Area of Interest	Geological Formation				
		Beaumont	Lissie	Willis	Upper Goliad	Total
2011	Lissie *	0	1,987	4490	5047	12,025
	1	2,133	4,438	2,493	1,011	10,075
	2	451	10,057	3,045	0	13,552
	3	49	6,859	2,504	0	9,412
	4	67	13,293	0	0	13,360
2013	Lissie	0	1,186	7,382	7,975	16,542
	1	1,706	3,532	1,627	1,058	7,922
	2	574	7,513	3,206	0	11,293
	3	81	5,472	1,993	0	7,546
	4	45	10,173	0	0	10,218

*83% of CCGCD assumed to be from Willis and 17% from Upper Goliad in 2011

Table 4-5 Changes in Reported Production from 2011 to 2013 for the Five Circular Areas of Interest by Depth.

Circular Area of Interest	Depth Interval (ft)					
	0-200	200-400	400-600	600-800	800-1000	Total
Lissie	-592	340	2810	938	1020	4,517
1	-149	-1299	-118	0	-586	-2153
2	33	-761	-64	352	-1820	-2259
3	8	-1419	-215	272	-512	-1866
4	-200	-2651	-291	0	0	-3142

note: negative values indicate less pumping in 2013 than in 2011

Table 4-6 Changes in Reported Production from 2011 to 2013 for the Five Circular Areas of Interest by Geological Formation.

Circular Area of Interest	Geological Formation				
	Beaumont	Lissie	Willis	Upper Goliad	Total
Lissie	0	-801	2892	2928	4517
1	-427	-906	-866	46	-2153
2	123	-2544	162	0	-2259
3	33	-1387	-512	0	-1866
4	-22	-3120	0	0	-3142

note: negative values indicate less pumping in 2013 than in 2011

4.2 Noteable Observations in the Reported Pumping Across Wharton County for Five Selected Areas of Interest

Among the notable results in Tables 4-1 through 4-6 and Figures 4-1 and 4-2 are the following:

- The highest amount of pumping in 2013 among the five circular areas is for the Lissie circle.
- The Lissie circle has the highest average pumping rate per permitted well in 2013 among the five circles. This rate is 300 AFY/well and is calculated from information in Table 4-2 (a.k.a 16,542 AFY divided by 55 wells)
- In 2013, the production per acre was 0.37 AF/acre and 0.24 AF/acre for the Lissie Circle (which has an area of 44,414 acres) and for Wharton County (which has an area of 697,600 acres). Thus, the production rate per acre near Lissie is about 50% greater than the average production rate per acre for Wharton County
- Using the average permitted pumping per year, the permitted pumping per acre per year in acre feet for the Lissie Circle and Wharton county is approximately 40,397 AF/(acre-yr) and 326,305 AF/(acre-yr). Based the same areas cite in paragraph above the maximum production that could occur based on current permits is 0.91 AF/(acre-yr) and 0.46 AF/(acre-yr) for the area near the town of Lissie and for the Wharton County. Thus, the permitted production rate per acre near Lissie is about double the average permitted production rate per acre for Wharton County
- Out of the five circles shown Figure 3-1, only the Lissie circle shows an increase in production from 2011 to 2012 and from 2012 to 2013. This trend would hold even if the pumping reported by the CCGCD for the Lissie circle, which is 5638 AF, is used instead of our best estimate of 3700 AF.
- From 2011 to 2013, Table 4-1 indicates that of the total average pumping, the Lissie Formation represents approximately 64% of the reported production for Wharton County. In the Lissie Circle, all of the shallow wells are screened in the Lissie Formation. The majority of the shallow wells in Wharton County are screened in the Beaumont, which contributes less than 4% of the total production

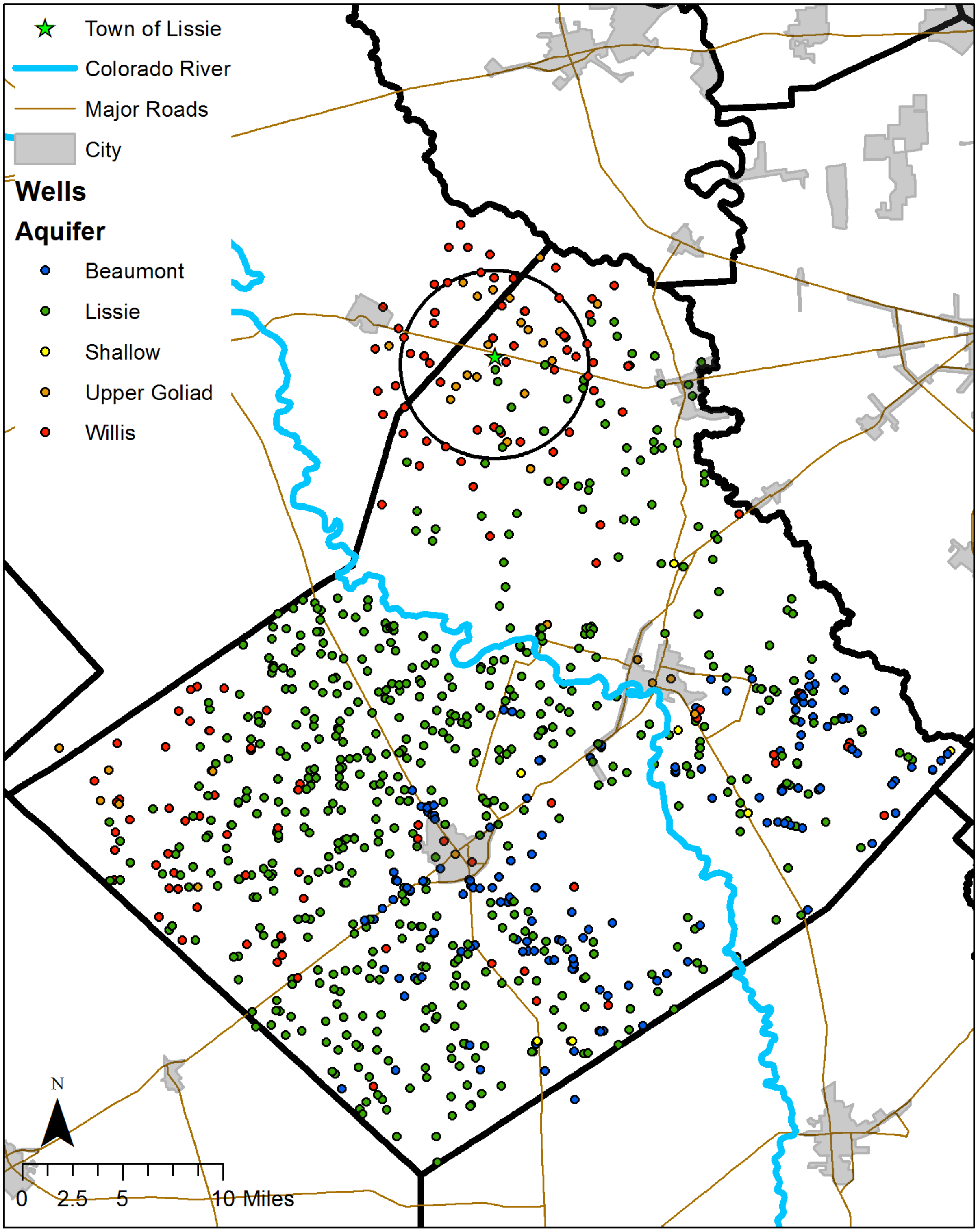


Figure 4-1 **Location of 2013 Permitted Wells in the Coastal Bend GCD and the Colorado County GCD Well Databases for Wharton County and the Lissie Area.** ***(Permitted wells are assigned to Geological Formation based on the Model Layers in the Lower Colorado River Basin Model (Young and Kelley, 2006))***

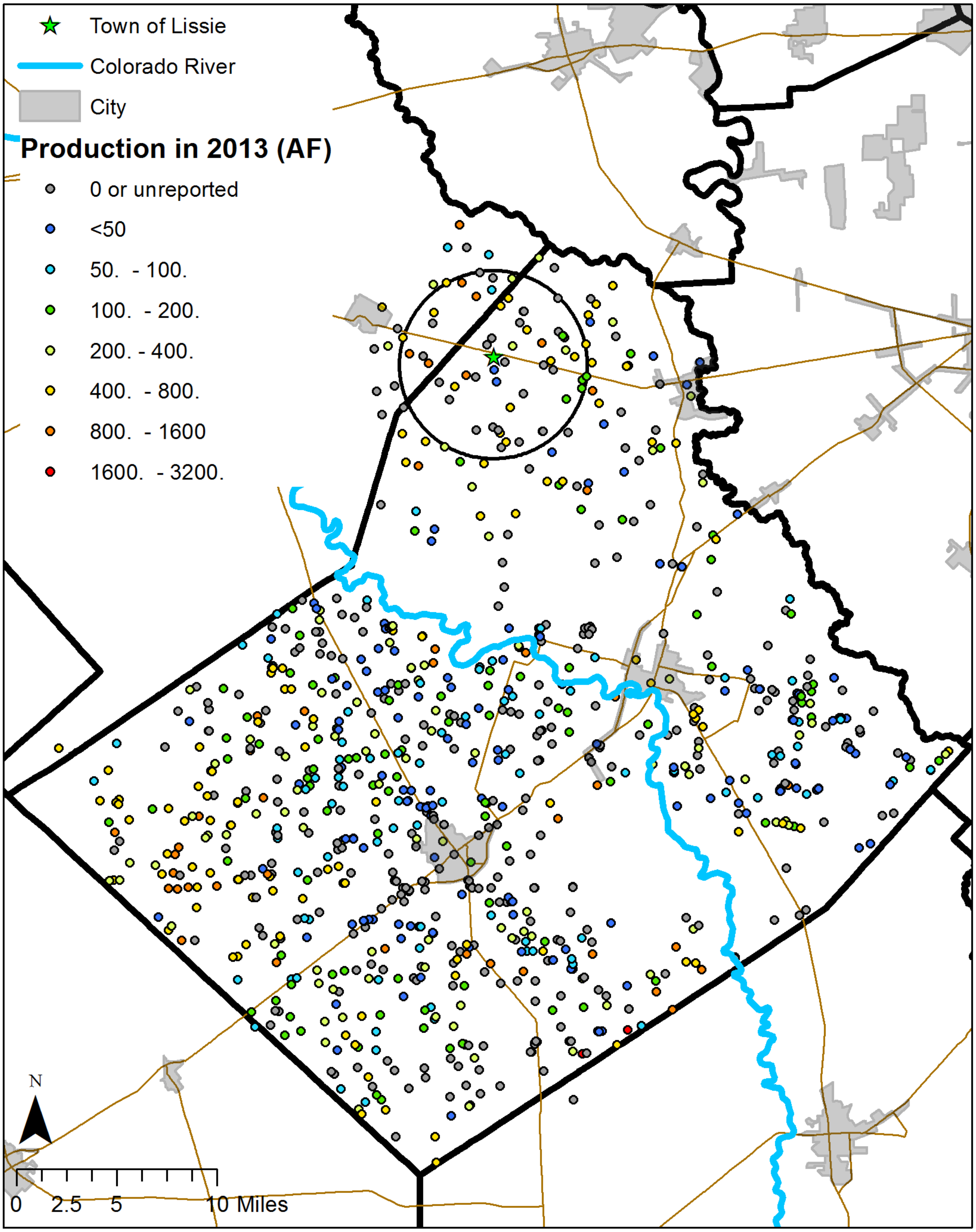


Figure 4-2 **Location of 2013 Permitted Wells in the Coastal Bend GCD and Colorado County GCD Well Databases for Wharton County and the Lissie Area.*(Production Rates are based on reported values from the CBGCD and the CCGCD well databases)***

5.0 Water Levels

This section discusses numerically simulated and measured values for historical water levels for Wharton County.

5.1 Simulated Water Levels

Simulated water levels produced by the LCRB model calibration (Young and others, 2009) were used to estimate the changes in water levels that have occurred at well locations in Wharton County. The LCRB model consists of six model layers representing the shallow groundwater system, the Beaumont Formation, the Lissie Formation, the Willis Formation, the Upper Goliad Formation, and the Lower Goliad Formation. Because of manner in which the model is divided into layers, there are limitations to how shallow wells can be defined. For the LCRB model runs, the shallow wells are represented by wells with depths between 50 and 250 feet.

In order to evaluate the vulnerability of shallow wells to drawdowns, two sets of simulated drawdowns are presented. One set of drawdowns is referred to as historical drawdowns, shown in Figure 5-1, and represent drawdowns that would have occurred at the shallow well locations from 1900 to 2000. The other set of drawdowns is referred to as seasonal drawdowns. These drawdowns are shown in Figure 5-2 and represent the difference in the water levels in the winter and summer months as a result of seasonal pumping associated with irrigation. In Wharton County, approximately 95% of the total pumping is associated with irrigation and occurs over a 6-month period. In general, fields are cyclically flooded, often in March or April, to prepare for the growing season. By September or October the growing season is complete and irrigation ceases. During the non-irrigation period (a.k.a. winter months) the water levels are much higher and continue to rise until irrigation occurs for the subsequent growing season. As a result, the average water level in the aquifers is much higher during the non-irrigation period (a.k.a. winter months) than the irrigation period (a.k.a. summer months).

A potentially important characteristic of the groundwater system in Wharton County is that the pumping during irrigation time periods produces seasonal fluctuations in the water levels that are typically much greater than the annual net change in water levels. The potential importance of seasonal fluctuations is illustrated by the simulated water levels in Figure 5-3. In Figure 5-3, hydrographs are shown for select wells with an abundant number of water level measurements for comparison to the simulated water level values. Prior to 1950, only one winter water level is simulated. After 1950, winter, spring, and fall water levels were simulated. For many of the hydrographs, the seasonal water level fluctuations are greater than 30 feet, although the net change in water level over a year is less than a foot.

Visual comparison of Figures 5-1 and 5-2 show that the areas of greatest and least drawdown occur in the west and east quadrants of Wharton County, respectively. For the discussion of drawdown, it is useful to divide Wharton County into quadrants based on the intersection of the 100 ft thickness contour of the Beaumont Formation that trends southwest to northeast and the Colorado River that trends northwest to southeast as shown in Figure 5-1 and 5-2. The primary factor affecting the amount of historical and seasonal simulated drawdowns is the spatial distribution of the pumping for irrigation purposes in the county. Consistent with that, a primary reason for the low seasonal and historical drawdowns near the town of Lissie is the relatively low amount of historical irrigation pumping that occurred from 1900 to 2006, which is the simulation period for the LCRB model.

In Figure 5-1, the majority of shallow wells in the north quadrant and near the town of Lissie have historical drawdowns less than 20 feet and no shallow wells have simulated drawdowns greater than 40 feet. These drawdowns are considerably lower than the historical drawdowns of greater than 60 feet that are associated with the majority of the shallow wells in the west quadrant. In Figure 5-2, the majority of shallow wells in the north quadrant and near the town of Lissie have seasonal drawdowns less than 10 feet and no shallow wells have simulated drawdowns greater than 20 feet. These drawdowns are considerably less than the seasonal drawdowns of greater than 50 feet that are associated with the majority of the shallow wells in the west quadrant.

The results in Figures 5-1 and 5-2 indicate that the locations where drawdowns in shallow wells have historically been the lowest in Wharton County are near the town of Lissie. This has occurred despite the fact that the Beaumont Formation does not underlie the town of Lissie, because irrigation pumping has been considerably lower in this area compared to the rest of Wharton County. Among the contributing factors to the low historical pumping in the Lissie area is the presence of the Lakeside Irrigation District, which up until 2011 had historically provided surface water for irrigation to much of the rice fields in the east quadrant of Wharton County.

5.2 Measured Water Levels from Monitoring Wells

Figures 5-4, 5-5, and 5-6 show hydrographs of water levels measured by the CCGCD and the CBGCD. Each hydrograph contains a Well ID and the depth of the well shown in parentheses, unless the well depth is unknown in which case a "?" was entered. For wells where the total depth is less than 150 feet, a label of "Shallow" is included in the hydrograph. At some of the wells, the seasonal water level fluctuations evident in the numerical simulations are evident in the measured well hydrographs. For instance, at Well W12 in Figure 5-5 and Well W16 in Figure 5-6, there are differences between summer and winter water levels that are greater than 40 feet in a given year.

The only shallow well in the Lissie circle is Well C6 that is shown in Figure 5-6. The three shallow wells in Wharton County with monitoring data are shown on Figure 5-5. All three of these wells are located in the region of the county where the Beaumont Formation is greater than 100 feet thick. At these three shallow wells, the measured water levels show that less than two feet of net drawdown has occurred since 2006.

Figure 5-6 shows that out of the non-shallow wells presented, the three CBGCD wells with the largest periods of measured drawdown (based on winter water levels) since 2011, including W4, W14, and W16, are close to the town of Lissie. From 2012 to 2013, W16 shows a net drawdown of about 50 feet between Winter of 2011 and Summer of 2013. For that same time period, Well W14 shows drawdowns of about 10 feet and W4 shows a drawdown of about 35 feet.

The shallow well that is closest to the town of Lissie is CCGCD Well C6, which has a total depth of 116 feet. From 2012 to 2014 the drawdown (based on winter water levels) was about 5 feet. However, the well is showing a steady increase in seasonal drawdown. From 2011 to 2014, the seasonal drawdown has increased from approximately 15 feet to about 38 feet. As can be readily gleaned from the hydrograph in Figure 5-7, the water level in Well C6 was approximately 25 feet lower in the summer of 2014 than it was during the summer of 2011. This rate of decline can be expressed as about 8 ft/year over the three year period . The water level for Well C-6 shows two important trends. The first trend is that each year the water level measured around March is approximately one foot lower than it was the previous March. The second trend is that each year during the irrigation season, the drawdown in the well as a result of irrigation pumping is increasing by about 4 to 6 feet a year. The combined impact of these two trends are what causes the approximately 25 feet decline in water levels between from the summer of 2011 to the summer of 2014.

The quick seasonal response in Well C6 is attributed to the absence of the Beaumont Formation in the north quadrant of Wharton County. The absence of the Beaumont Formations means that all shallow near the town of Lissie are screened in the more sandier and more heavily pumped formations than the Beaumont Formation such as the Lissie and Willis formations. As a result of being screened in the Lissie and Willis formations, shallow wells near the town of Lissie are more vulnerable to drawdown impacts caused by permitted pumping than are the shallow wells in the southern regions of Wharton County where the Beaumont Formation can serve has a hydraulic barrier between the bottom of the well and the zone of high pumping.

5.2.1 Installation of Pressure Transducers

Pressure transducers are device than can be used to continuously record temporal changes in water levels in a well On August 14 2014, INTERA installed pressure transducers at the three wells listed in Table 5-1. Two of the wells are located approximately 30 feet from each other in the town of Lissie and the remaining well is located approximately two miles away along County Line Road (see Figure 5-8).

In the summer of 2014, the Dale Road Well #1 was drilled as a replacement well for Dale Road Well #2. During late spring/summer 2014, Dale Road Well #2 experienced problems with consistently pumping groundwater because the water level would occasionally drop below the elevation of the pump. To overcome this problem Well #1 was drilled approximately 50 feet deeper.

On September 22 2014, INTERA visited the three wells to download the data from the transducers and to replace the transducers. Data was successfully downloaded from two of the transducers and these data are plotted in Figure 5-9. No transducer data were obtained from Well #1, because the transducer cable became caught with the piping and wiring associated with the pump and could not be removed from the well. However, manual water level measurements were made in Well #1 so the water levels could be check with Well #2, which is adjacent to Well #1 and approximately fifty feet deeper than Well

Table 5-1 Wells Selected for using Pressure Transducers to Monitor Water Levels.

Well		County	Estimated Depth (ft), Below Ground Surface		Measured Depth (ft) of Water Level Below Ground Surface	
Name	Location		Well	Transducer	Aug 14, 2014	Sept 22, 2014
Kelley Well	County Line Road	Colorado	116	110.3	76.2	74.6
Guthman – Shallow (Well # 2) – Dale Road Well #2	Corner of Dale Street and Kansas	Wharton	105	100	83.3	82.9
Guthman – Deep (Well #1) – Dale Road Well #1		Wharton	150	130	83.12	83.3

#1. The manually measured water levels recorded in August and September 2014 indicate that the water level elevation at these two wells (Dale Road Well #1 and Dale Road Well #2) were within about 1 foot of each other. This indicates that despite having well screens that are offset by fifty feet, the two wells screens intersect sandy deposits in the Lissie Formation and have nearly identical hydraulic heads because of good hydraulic communication among the sand beds in the Lissie Formation.

Figure 5-9 shows the measured water levels for the Kelley Well (County Line Road Well and Well C6 in Figures 5-4 and 5-6) and Dale Road Well #2, that terminate at depths of approximately 116 and 105 feet below ground surface, respectively. As previously discussed, both wells were not pumped during the monitoring period but the Dale Road Well #2 is approximately 50 feet from Dale Road Well #1, which is pumped for domestic use. From August 14 to September 8, the two sets of measurements have very similar changes. On September 8, there is a 2 feet drop in the water level at Dale Road Well #2 which does not occur in the County Line Road. If the differences that occur between the two sets of water level measurements on September 8 was caused by pumping at Dale Road Well #1 then the data suggests that the major sand deposits in the upper Lissie Formation may be hydraulically connected over several miles between Dale Road Well #2 and the County Line Road Well.

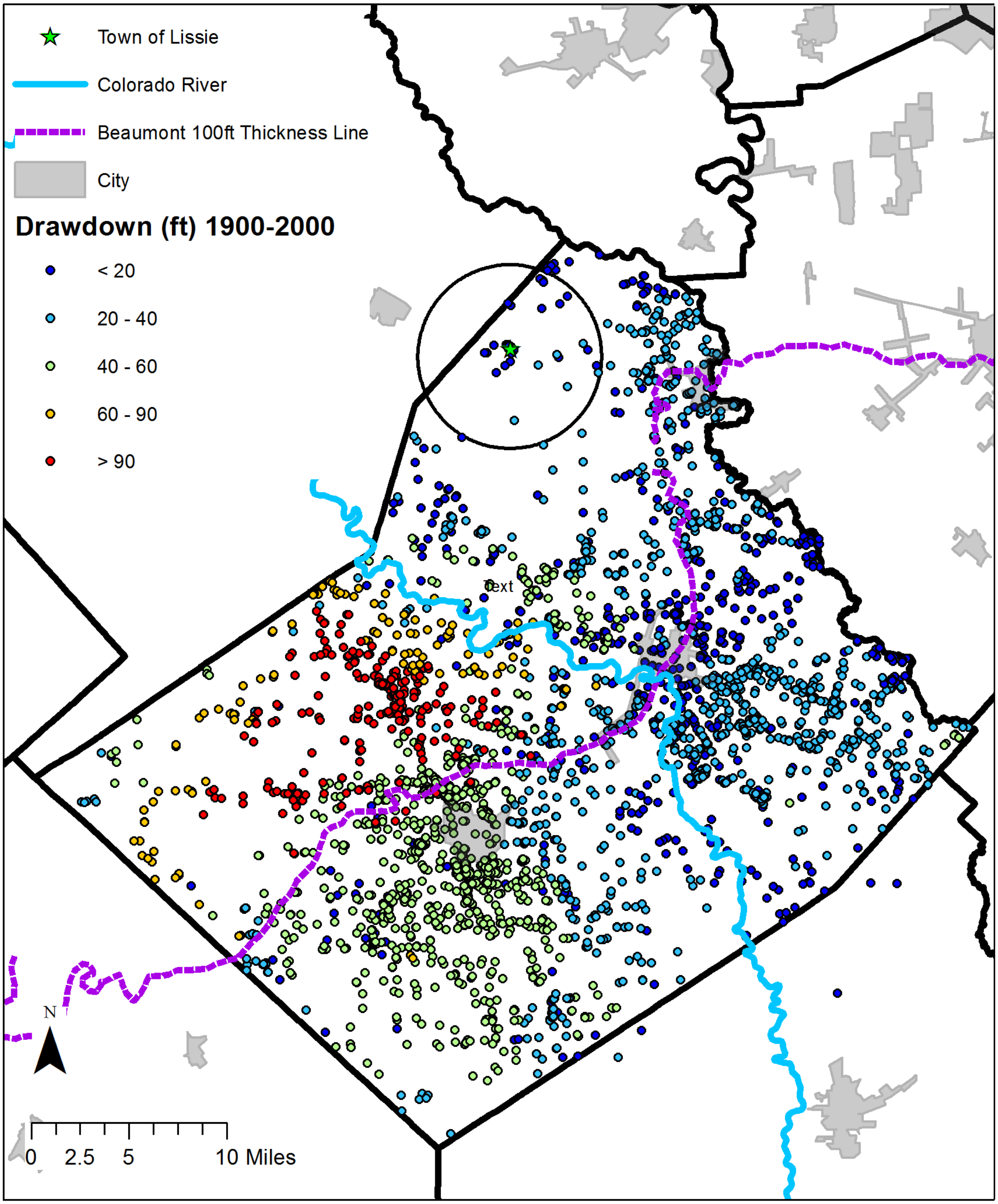


Figure 5-1 **Estimated Historical Drawdown from 1900 to 2000 for Wells with Depths Between 50 and 250 Feet Based on LCRB Model Runs Performed by Young and Others (2009). (Northwest of the purple line, the Beaumont Formation is absent or less than 100 feet thick).**

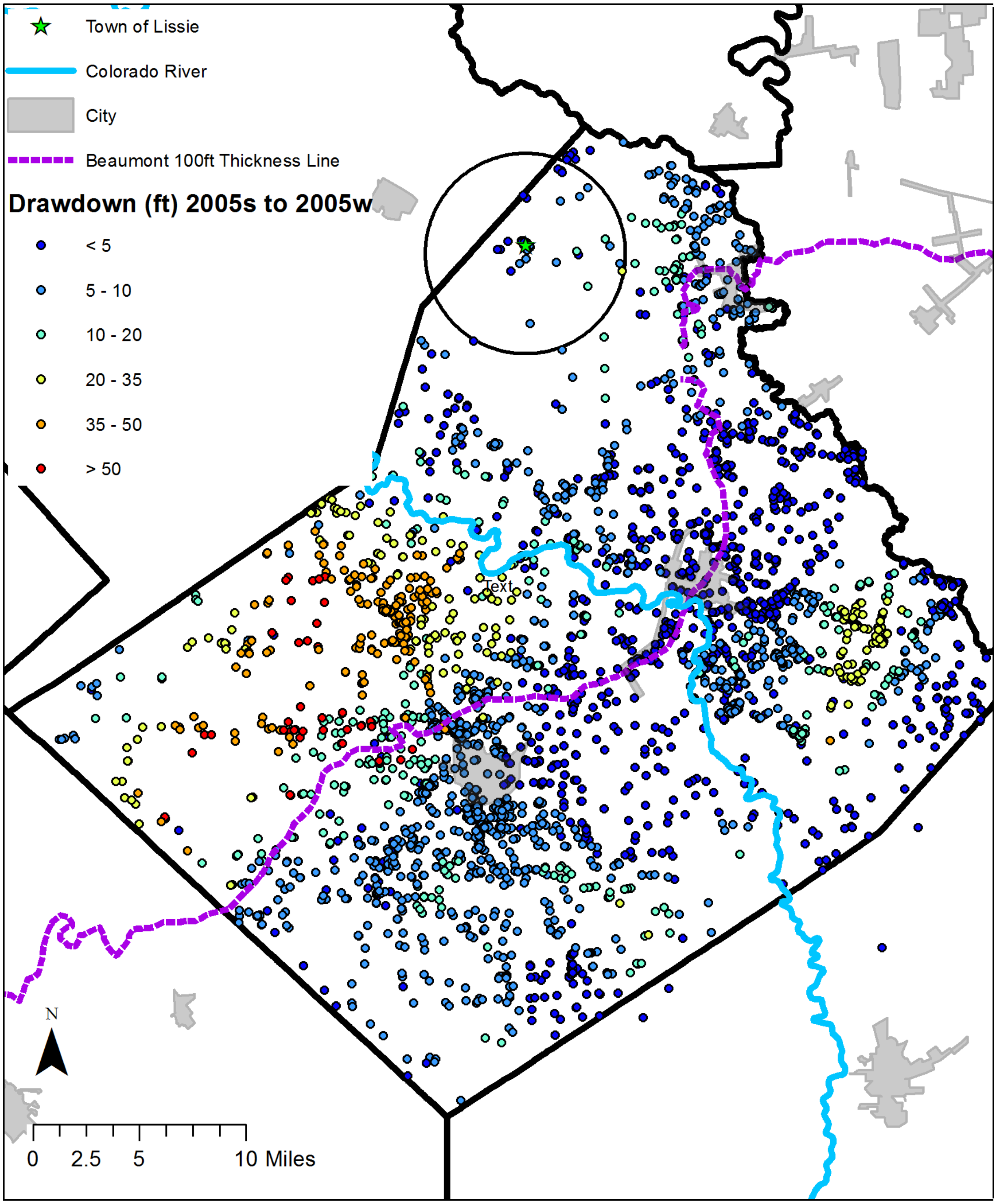


Figure 5-2 **Simulated seasonal dradown that occurred in wells with depths between 50 and 250 feet during 2005 based on LCRB model runs performed by Young and others (2009). (North of the blue line, the Beaumont Formation is absent or less than 100 feet thick).**

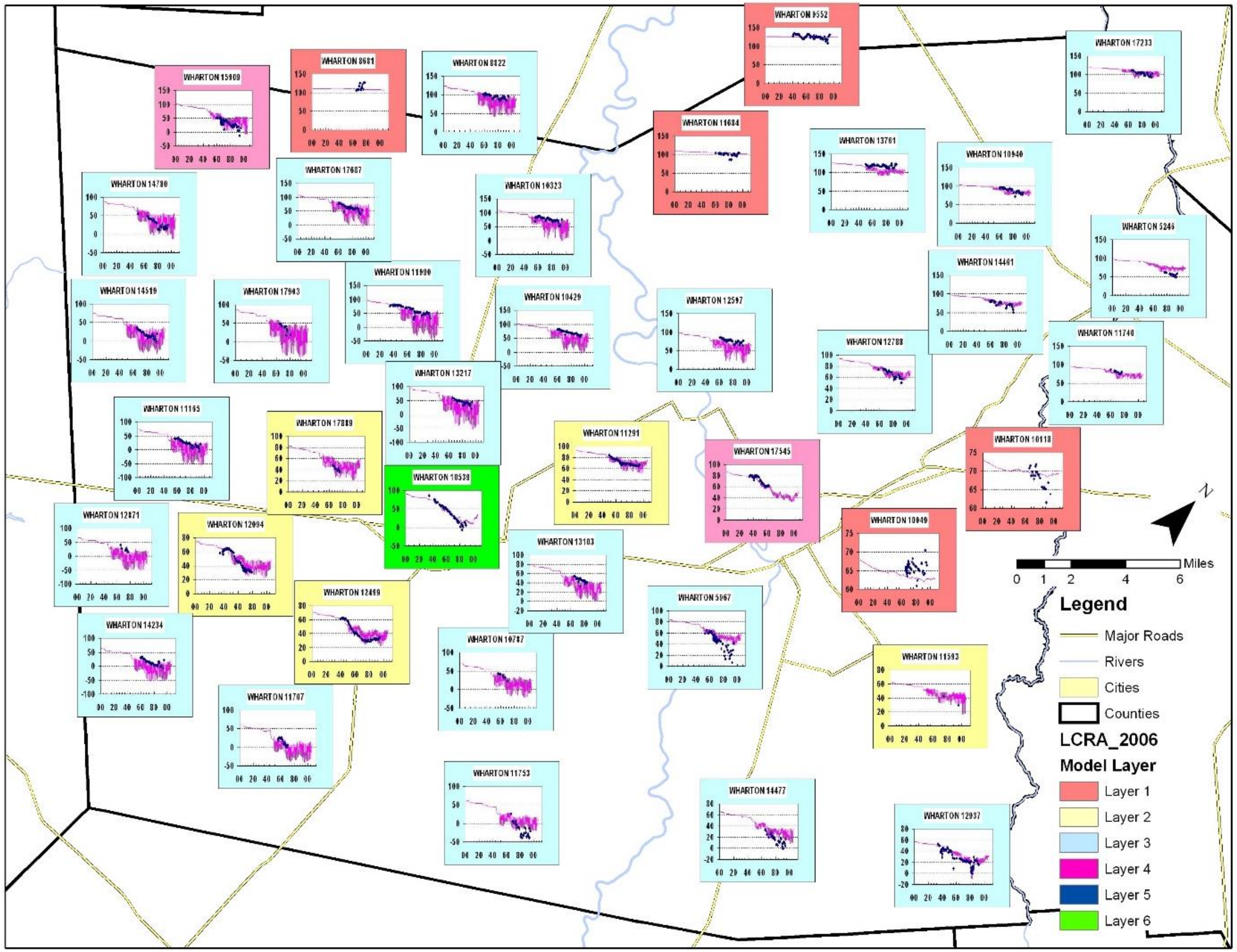


Figure 5-3 **Comparison of Measured (blue symbols) Versus Simulated (magenta line) Hydraulic Head from 1900 to 1997 in Wharton County for Selected Hydrographs (from Figure 9-18 in Young and others, 2009). (The measured hydraulic head values were taken during the winter months. Model layers 1, 2, 3, 4, 5, and 6 reprsent the shallow flow zone, the Beaumont, the Lissie, the Willis, the Upper Goliad and the Lower Goliad formations).**

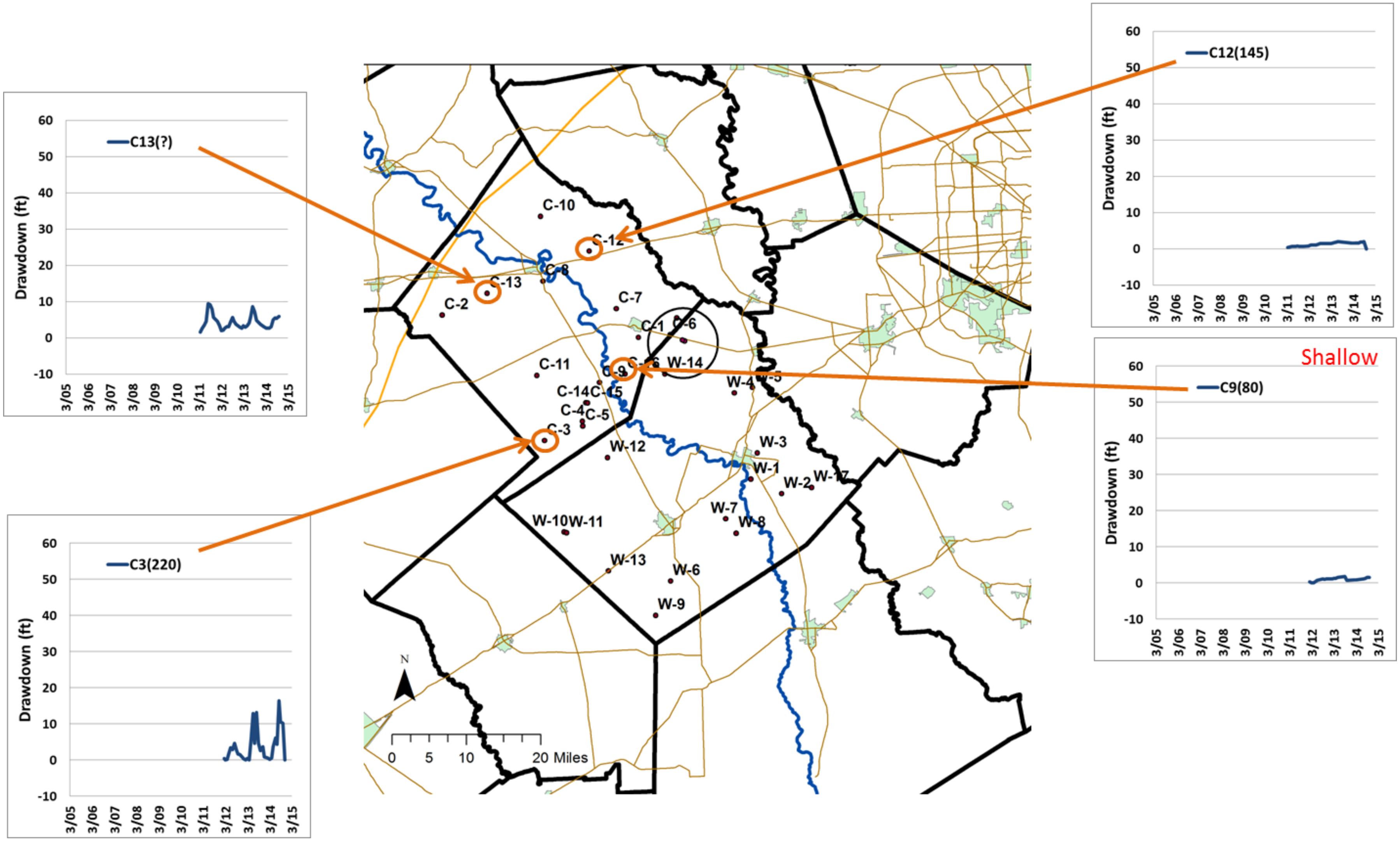


Figure 5-4 **Four CCGCD Monitoring Locations where water levels indicate small declines in the winter water level during the last several years (note: value in parentheses is the depth of the well – a "?" indicates that the depth is unknown).**

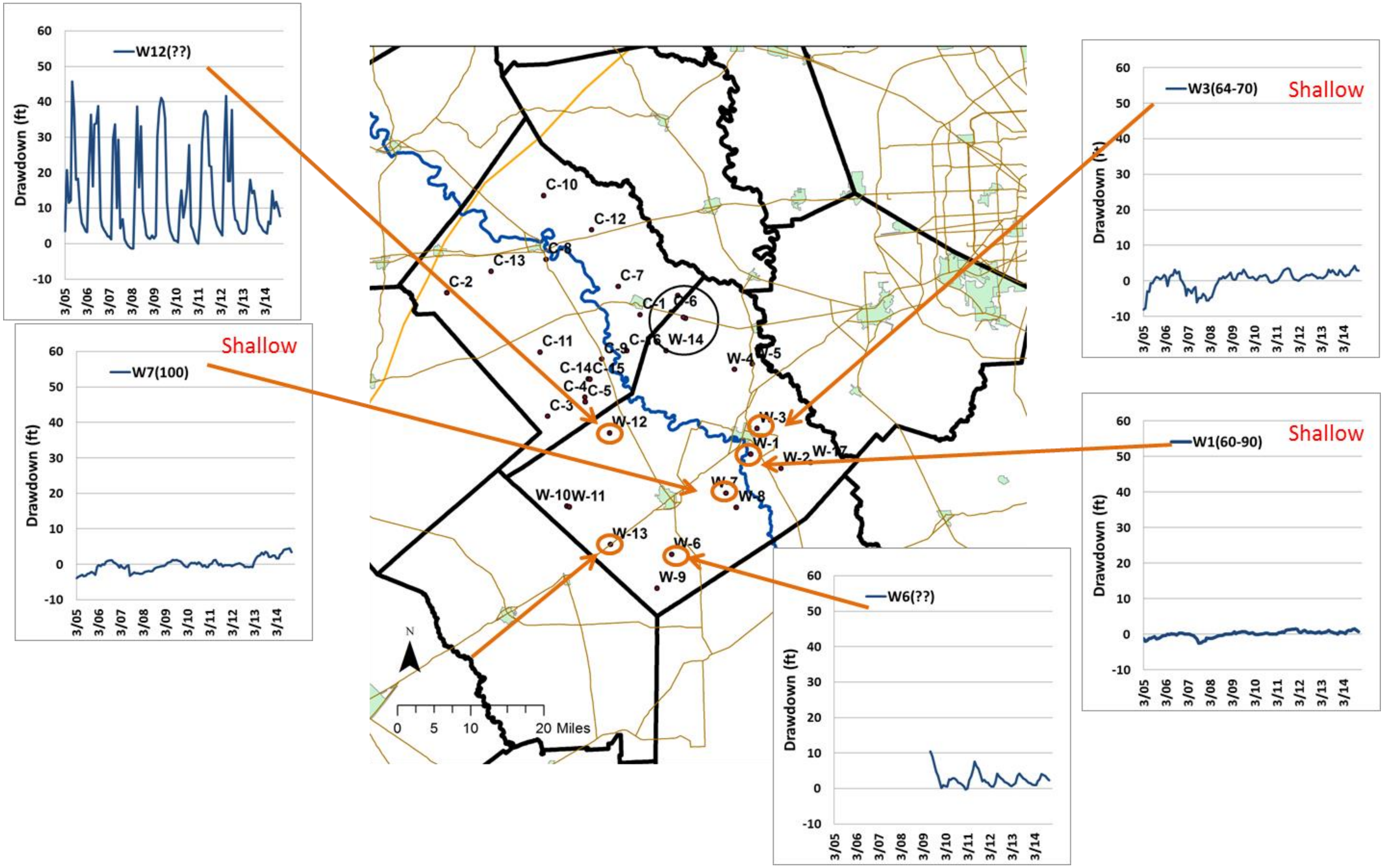


Figure 5-5 **Five CBGCD Monitoring Locations where water levels indicate small declines in the winter water level during the last several years (note: value in parentheses is the depth of the well – a "?" indicates that the depth is unknown).**

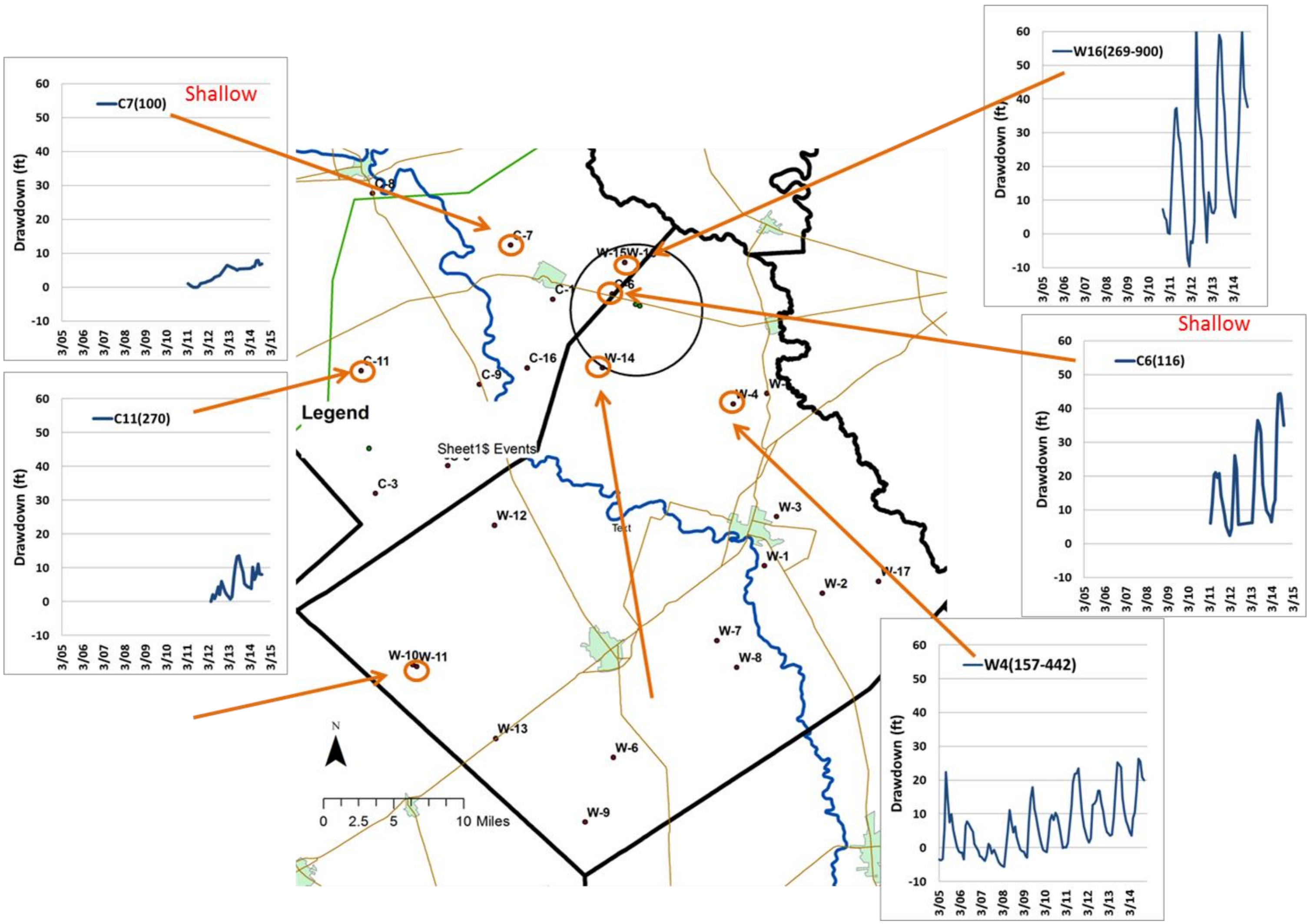


Figure 5-6 **Seven CBGCD Monitoring Locations where water levels indicate several feet of decline in the winter water level during the last several years (note: value in parathesis is the depth of the well – a "?" indicates that the depth is unknown).**

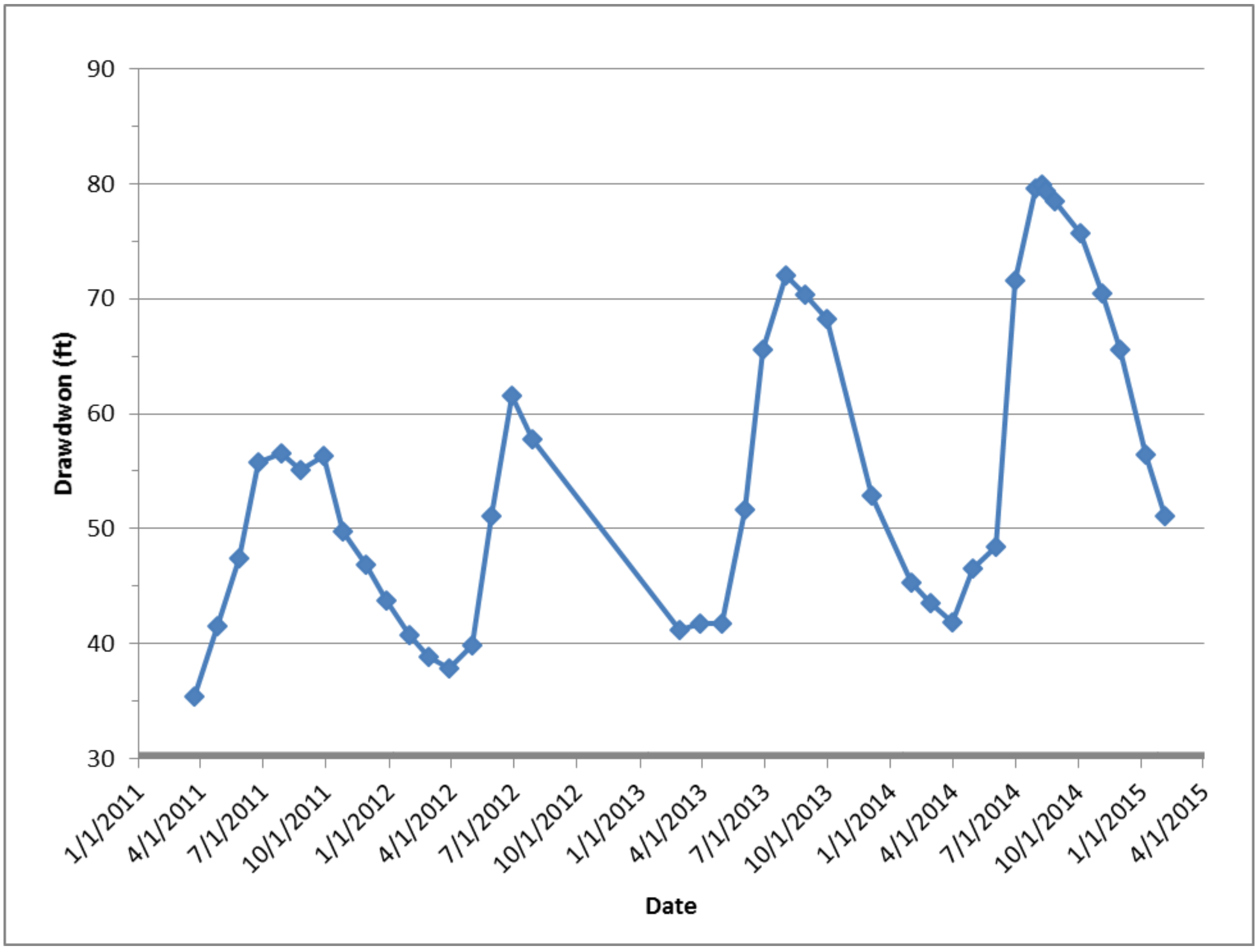


Figure 5-7 **Water Monitoring Data from CCGCD Well C-6 near the County Line Road in Colorado County.**

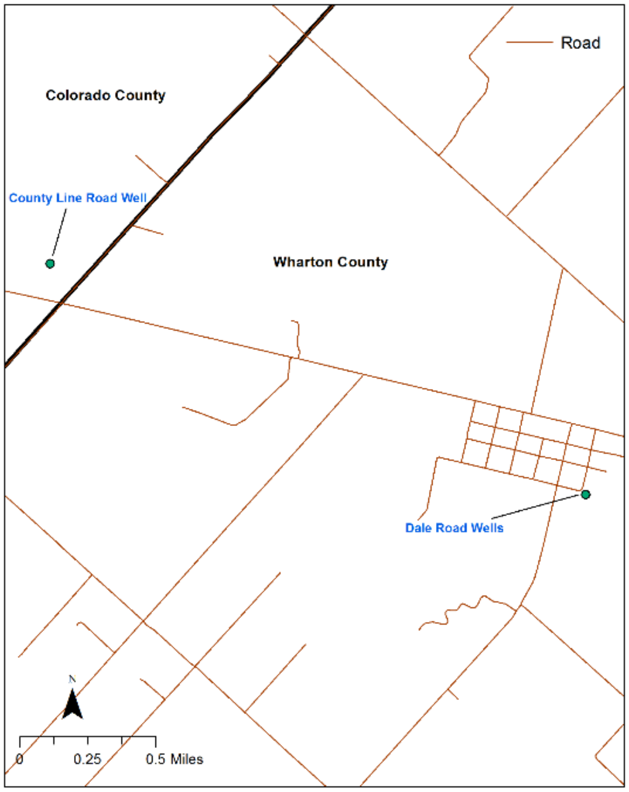


Figure 5-8 **Location of the CCGCD Monitoring Well near the County Line Road in Colorado County (Well C6 in Figure 5-6) and of Wells #1 and #2 at Dale Road in Wharton County.**

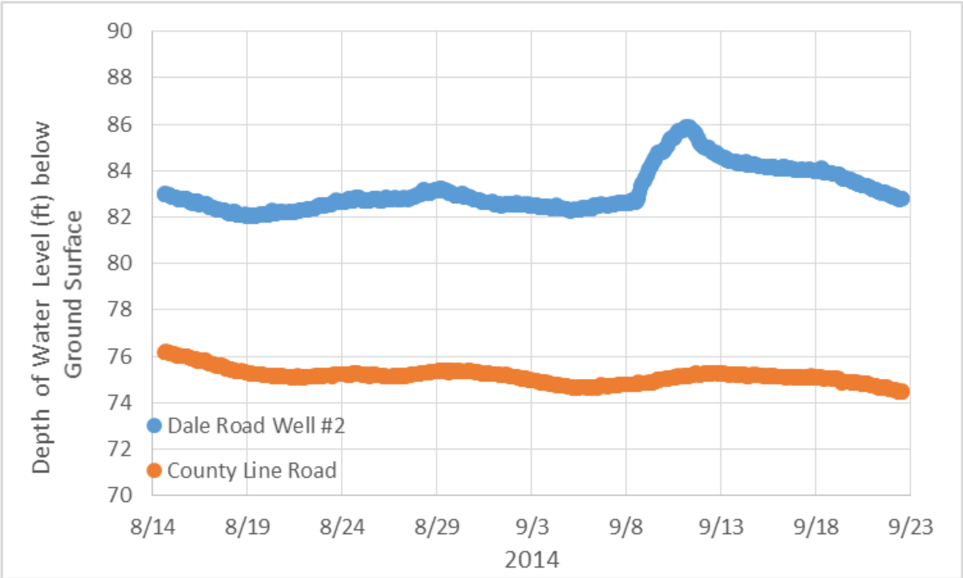


Figure 5-9 **Comparison of Measured Water Levels in CCGCD Monitoring Well near the County Line Road in Colorado County and Well #2 at Dale Road in Wharton County.**

6.0 Model Simulations

A groundwater model was used to investigate the sensitivity of water levels to pumping near the town of Lissie. The objective of the model simulations is to evaluate the relative importance of hydrogeological factors that have contributed to the recent decline in the water levels in the shallow wells with total depths less than 150 feet.

6.1 Application of Groundwater Model

The LCRB model (Young and Kelley, 2009) was used to simulate the impacts of pumping on water levels in the Lissie Circle. The LCRB model was calibrated to 2006, which is the last year for which the model contains groundwater pumping. Table 6-1 lists the pumping associated with the three stress periods used in the LCRB model to simulate pumping in the Lissie Circle for 2006. The model simulations began in 2007 and lasted either 5-year or 20-year periods. Our analysis between the twenty-year and five-year runs did not produce any notable changes in conclusions, so only results from the five-year runs are discussed.

Table 6-1 Pumping Rates in 2006 by Layer in the LCRB Model for the Lissie Five-Mile Circle

Formation	Pumping Rate (AFY)		
	Jan. - Mar.	Apr.- Sept	Oct- Dec.
Shallow	5	5	5
Lissie	728	728	728
Willis	1086	2471	1086
Upper Goliad	595	311	595
Lower Goliad	0	0	0
Total Amount	2414	3515	2414

During the modeling period, the recharge rate and pumping rate were constant. The constant recharge rate was set to either the 2006 recharge rate or to zero. Zero recharge represents the case of extreme drought. Twelve model simulations plus a baseline simulation were performed with different pumping rates for the assumption of recharge or no recharge. Table 6-2 lists the pumping assumptions for the thirteen pumping simulation. For simulation purposes, the pumping period was modeled as 153 days and was only added to the irrigation season. Therefore, the constant pumping used for the baseline consists of the spatial and temporal pumping distributions provided in Table 6-1. For Pumping Scenario 1 , the pumping rates of 2414 AFY, 8515 AFY, and 2414 AFY are used for stress periods associated with the periods "January through March; April through September, and October through December. The pumping rates for Scenario 1 different from the Baseline Scenario 0 by the addition of 3500 AFY pumping for the time period of April through September.

Table 6-2 Pumping Rates that were added to the "Apr-Sept" Pumping Values 2006 to Create 12 Pumping Scenarios with Constant Pumping from 2007 to 2012 for the Lissie Circle

Formation	Additional Pumping (AFY) Included in LCRB Model Simulation												
	Base-line	Single-Formations Runs						Dual-Formations Runs				Tri-Formations Runs	
		1	2	3	4	5	6	7	8	9	10	11	12
Lissie	0	3500	0	0	7000	0	0	3500	0	7000	0	3500	7000
Willis	0	0	3500	0	0	7000	0	3500	3500	7000	7000	3500	7000
Upper Goliad	0	0	0	3500	0	0	7000	0	3500	0	7000	3500	7000

6.2 Discussion of the Groundwater Model Predictions

The model predictions are expressed as average drawdown across the area of the Lissie circle. A positive drawdown values represents a decline in the hydraulic heads. A negative drawdown values represents a rise in the hydraulic heads. The average drawdown is calculated for each model layer by averaging the simulated drawdown in the 1040 grid cells contained in the Lissie Circle.

Tables 6-3 and 6-4 provide the average drawdown for the thirteen model scenarios for the recharge and no recharge assumptions, respectively. Figures 6-1, 6-2, and 6-3 provide the simulated drawdowns in the Lissie, Willis, and Upper Goliad, respectively. In the tables and the figures, three drawdown values are provided for each year. The drawdown for March represents the drawdown prior to irrigation season. The drawdown for September represents the drawdown at the end of the irrigation season. The drawdown for December represents the drawdown at the end of the calendar year.

Prior to presenting the model results, it should be understood that the application of the LCRB model to estimate future drawdowns in shallow wells near the town of Lissie is limited for two major reasons. First, the LCRB Model was not designed to accurately predict water level changes for a small area such as the town of Lissie. For a model like the LCRB model to accurately predict water levels near the town of Lissie, the groundwater model would need to be developed and calibrated using significantly more site-specific hydrological data for the town of Lissie than used to develop and calibrate the LCRB model. For instance, the LCRB model predictions of water level change to pumping for the Lissie Circle would be improved if the results from several aquifer pumping tests with multiple observation wells were used to calibrate the model. Without such site specific data, the biases and errors in the model cannot be identified nor quantified. The second reason is the LCRB model's latest set of pumping values is for 2006 and over the last eight years, the spatial distribution of pumping has substantially changed in northern Wharton County and Southern Colorado County. Despite these two caveats the LCRB model will provide useful information, because it has simulates the major hydrogeologic factors controlling groundwater flow and it has proven to be a relatively reliable predictor of changes in water levels to pumping at a regional scale . Moreover, the LCRB model has been demonstrated (Young and others, 2009) to be a significantly better predictor of groundwater flow than previous regional groundwater models for Wharton County. The potentially important findings from the model results include the following:

- For the baseline run where no additional pumping is occurring, the predicted water level is rising in all three formations over time. The hydraulic head levels rise between 1 and 4.5 feet for the three formations after five years. The rise in water levels indicates that for the baseline run, the aquifer is recovering as a result of future pumping being less than historical pumping.
- Figures 6-1, 6-2, and 6-3 show that the difference between recharging conditions and zero recharge is relatively small. Over a five-year period, the total lack of recharge increases drawdown only by about a foot. As a result, the reduction of recharge due to drought conditions or reduced irrigation near the town of Lissie is not a credible reason for significant declines in shallow well water levels in the Lissie formation.
- The vast majority of the pumping simulations indicate that the aquifer is not fully rebounding during the non-irrigation season, so there is a small component of drawdown from irrigation pumping that is carried-forward every year.
- The relationship between pumping rate and drawdown in the Lissie, Willis, and Upper Goliad Formations is nearly a linear relationship meaning that if the pumping rate is doubled, then the drawdown will nearly be double.
- Pumping in the Willis Formation causes drawdown in the Lissie Formation. Based on the results presented in Table 6-3, for every foot of drawdown that occurs in the Willis Formation as a result of pumping in the Willis Formation about 0.5 feet of drawdown occurs in the Lissie Formation.
- Pumping in the Upper Goliad Formation causes drawdown in the Lissie Formation when the pumping rate exceeds a value of about 3,000 AFY. Based on results presented in Table 6-3, for every foot of drawdown that occurs in the Upper Goliad Formation as a result of pumping in the Upper Goliad Formation, about 0.3 feet of drawdown occurs in the Lissie Formation.
- The difference in the predicted drawdown in the Lissie Circle for the 5-year run and 20-year run is relatively small for the Lissie Formatoin. For Scenario 12, for example, the maximum seasonal drawdown is 21 feet and 26 feet in the Lissie Formation for the 5-year run and 20-year run, respectively; and the average seasonal low drawdown at the is 18 feet and 21 feet for the 5-year run and 20-year run, respectively. However, for both the Willis and the Upper Goliad Formation difference between the 5-year and 20-year run is significant The importance of time period for these simulations is evident from a review of Figures 6-2 and 6-3.

Table 6-3 Simulated Average Drawdown for the Five-mile Lissie Circle for 12 Model Scenarios with Recharge

LCRB Model Runs				Simulated Average Drawdown In Lissie														
				YR 1			YR 2			YR 3			YR 4			YR 5		
Formations		AFY	Run #	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.
NA	NA	0	0	-1.16	0.06	-0.62	-1.58	-0.22	-0.84	-1.66	-0.3	-0.91	-1.7	-0.37	-0.98	-1.81	-0.42	-1.02
Single	L	3500	1	-1.16	6.39	0.83	-1.26	6.22	0.68	-1.15	6.2	0.64	-1.2	6.15	0.6	-1.25	6.11	0.57
	W	3500	2	-1.16	1.95	0.38	-1.19	1.83	0.26	-1.12	1.81	0.23	-1.2	1.77	0.19	-1.21	1.73	0.15
	UG	3500	3	-1.16	0.39	-0.27	-1.3	0.29	-0.35	-1.28	0.29	-0.37	-1.3	0.26	-0.39	-1.34	0.23	-0.42
	L	7000	4	-1.16	12.7	2.28	-0.95	12.7	2.2	-0.64	12.7	2.19	-0.7	12.7	2.17	-0.69	12.7	2.16
	W	7000	5	-1.16	3.77	1.35	-0.81	3.85	1.35	-0.58	3.92	1.37	-0.6	3.9	1.35	-0.62	3.88	1.33
	UG	7000	6	-1.16	0.66	0	-1.09	0.73	0.06	-0.96	0.82	0.12	-0.9	0.85	0.14	-0.92	0.86	0.15
Two	L,W	3500	7	-1.16	8.27	1.83	-0.87	8.26	1.78	-0.6	8.31	1.78	-0.6	8.29	1.76	-0.66	8.27	1.74
	W,UG	3500	8	-1.16	2.27	0.72	-0.92	2.33	0.74	-0.74	2.4	0.77	-0.7	2.4	0.76	-0.75	2.38	0.76
	L,W	7000	9	-1.16	16.3	4.2	-0.2	16.7	4.36	0.44	16.9	4.46	0.5	16.9	4.49	0.49	17	4.51
	W,UG	7000	10	-1.16	4.29	1.91	-0.36	4.73	2.18	0.09	4.98	2.35	0.2	5.07	2.43	0.24	5.12	2.48
Three	L,W,UG	3500	11	-1.16	8.6	2.17	-0.6	8.77	2.25	-0.23	8.89	2.32	-0.2	8.91	2.34	-0.2	8.92	2.34
	L,W,UG	7000	12	-1.16	16.8	4.75	0.24	17.6	5.18	1.09	17.9	5.43	1.27	18.1	5.56	1.34	18.2	5.64

LCRB Model Runs				Simulated Average Drawdown In Willis														
				YR 1			YR 2			YR 3			YR 4			YR 5		
Formations		AFY	Run #	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.
NA	NA	0	0	-2.45	1.72	-1.24	-3.38	1.06	-1.75	-3.63	0.81	-1.99	-3.9	0.62	-2.17	-4.03	0.46	-2.3
Single	L	3500	1	-2.45	3.6	-0.24	-2.99	3.1	-0.65	-3.08	2.93	-0.84	-3.3	2.75	-1	-3.43	2.61	-1.13
	W	3500	2	-2.45	11.6	1.24	-2.65	11.3	0.92	-2.53	11.2	0.78	-2.7	11	0.64	-2.84	10.9	0.52
	UG	3500	3	-2.45	3.4	0.01	-2.6	3.23	-0.15	-2.53	3.2	-0.22	-2.6	3.11	-0.31	-2.72	3.01	-0.39
	L	7000	4	-2.45	5.49	0.77	-2.6	5.15	0.44	-2.53	5.04	0.3	-2.7	4.89	0.16	-2.84	4.76	0.05
	W	7000	5	-2.45	21.1	3.64	-1.94	21.4	3.58	-1.44	21.5	3.53	-1.5	21.4	3.43	-1.66	21.3	3.34
	UG	7000	6	-2.45	4.74	0.98	-1.99	5.1	1.21	-1.6	5.35	1.36	-1.5	5.43	1.41	-1.52	5.45	1.42
Two	L,W	3500	7	-2.45	13.5	2.25	-2.26	13.3	2.02	-1.98	13.3	1.92	-2.1	13.1	1.8	-2.25	13	1.7
	W,UG	3500	8	-2.45	13.3	2.47	-1.88	13.4	2.5	-1.44	13.5	2.53	-1.5	13.5	2.48	-1.55	13.4	2.42
	L,W	7000	9	-2.45	24.3	5.51	-1.19	25.3	5.72	-0.36	25.6	5.79	-0.4	25.6	5.75	-0.47	25.6	5.7
	W,UG	7000	10	-2.45	23.6	5.65	-0.65	25	6.33	0.47	25.7	6.71	0.7	26	6.88	0.76	26.1	6.98
Three	L,W,UG	3500	11	-2.45	15.1	3.46	-1.49	15.4	3.59	-0.9	15.6	3.66	-0.9	15.6	3.64	-0.96	15.6	3.6
	L,W,UG	7000	12	-2.45	15.1	3.46	-1.49	15.4	3.59	-0.9	15.6	3.66	-0.9	15.6	3.64	-0.96	15.6	3.6

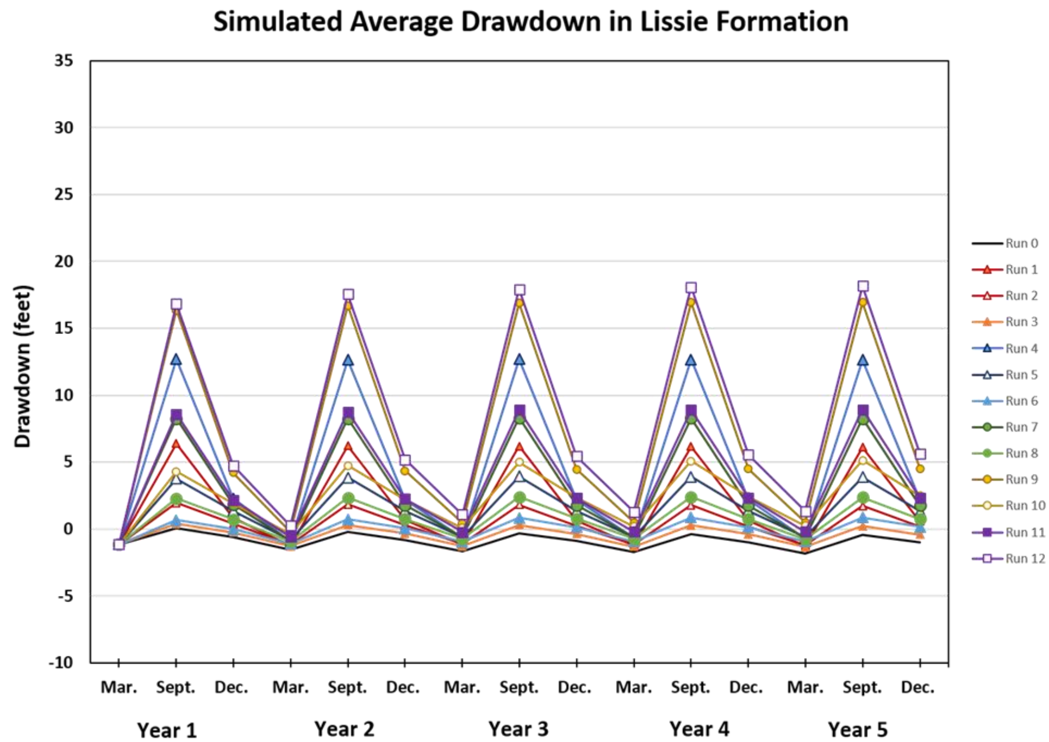
LCRB Model Runs				Simulated Average Drawdown In Upper Goliad														
				YR 1			YR 2			YR 3			YR 4			YR 5		
Formations		AFY	Run #	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.
NA	NA	0	0	-2.88	1.36	-2	-4.6	0.11	-3.02	-5.34	-0.51	-3.58	-5.9	-0.97	-3.99	-6.26	-1.32	-4.31
Single	L	3500	1	-2.88	1.7	-1.64	-4.32	0.63	-2.53	-4.96	0.08	-3.03	-5.4	-0.33	-3.4	-5.79	-0.66	-3.7
	W	3500	2	-2.88	3.08	-0.72	-3.8	2.31	-1.4	-4.23	1.89	-1.8	-4.6	1.54	-2.12	-4.94	1.24	-2.39
	UG	3500	3	-2.88	14.1	2.79	-2.51	14.3	2.68	-2.23	14.3	2.56	-2.4	14.2	2.38	-2.64	14	2.19
	L	7000	4	-2.88	2.04	-1.29	-4.04	1.15	-2.04	-4.57	0.68	-2.47	-5	0.3	-2.82	-5.32	0	-3.09
	W	7000	5	-2.88	4.75	0.52	-3.02	4.48	0.21	-3.12	4.28	-0.02	-3.4	4.03	-0.26	-3.64	3.79	-0.48
	UG	7000	6	-2.88	23.6	6.43	-0.89	26	7.43	0.37	27.4	7.98	0.64	28.1	8.25	0.69	28.5	8.36
Two	L,W	3500	7	-2.88	3.42	-0.36	-3.51	2.82	-0.91	-3.84	2.48	-1.24	-4.2	2.17	-1.54	-4.48	1.9	-1.79
	W,UG	3500	8	-2.88	15.6	3.97	-1.74	16.3	4.21	-1.17	16.6	4.27	-1.2	16.6	4.2	-1.35	16.5	4.08
	L,W	7000	9	-2.88	5.36	1.19	-2.48	5.47	1.15	-2.37	5.44	1.06	-2.5	5.28	0.9	-2.71	5.1	0.73
	W,UG	7000	10	-2.88	25.6	8.42	0.46	28.9	10.1	2.29	31	11.1	2.85	32.3	11.6	3.08	33	11.9
Three	L,W,UG	3500	11	-2.88	15.8	4.31	-1.47	16.7	4.67	-0.79	17.1	4.8	-0.8	17.2	4.77	-0.9	17.1	4.68
	L,W,UG	7000	12	-2.88	26	8.98	0.95	29.5	10.9	2.96	31.8	12	3.63	33.3	12.6	3.94	34.1	13

Table 6-4 Simulated Average Drawdown for the Five-mile Lissie Circle for 12 Model Scenarios with No Recharge

LCRB Model Runs				Simulated Average Drawdown In Lissie														
				YR 1			YR 2			YR 3			YR 4			YR 5		
Formations		AFY	Run #	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.
NA	NA	0	0	-1.16	0.06	-0.62	-1.58	-0.22	-0.84	-1.66	-0.3	-0.91	-1.7	-0.37	-0.98	-1.81	-0.42	-1.02
Single	L	3500	1	-1.16	6.39	0.83	-1.26	6.22	0.68	-1.15	6.2	0.64	-1.2	6.15	0.6	-1.25	6.11	0.57
	W	3500	2	-1.16	1.95	0.38	-1.19	1.83	0.26	-1.12	1.81	0.23	-1.2	1.77	0.19	-1.21	1.73	0.15
	UG	3500	3	-1.16	0.39	-0.27	-1.3	0.29	-0.35	-1.28	0.29	-0.37	-1.3	0.26	-0.39	-1.34	0.23	-0.42
	L	7000	4	-1.16	12.7	2.28	-0.95	12.7	2.2	-0.64	12.7	2.19	-0.7	12.7	2.17	-0.69	12.7	2.16
	W	7000	5	-1.16	3.77	1.35	-0.81	3.85	1.35	-0.58	3.92	1.37	-0.6	3.9	1.35	-0.62	3.88	1.33
	UG	7000	6	-1.16	0.66	0	-1.09	0.73	0.06	-0.96	0.82	0.12	-0.9	0.85	0.14	-0.92	0.86	0.15
Two	L,W	3500	7	-1.16	8.27	1.83	-0.87	8.26	1.78	-0.6	8.31	1.78	-0.6	8.29	1.76	-0.66	8.27	1.74
	W,UG	3500	8	-1.16	2.27	0.72	-0.92	2.33	0.74	-0.74	2.4	0.77	-0.7	2.4	0.76	-0.75	2.38	0.76
	L,W	7000	9	-1.16	16.3	4.2	-0.2	16.7	4.36	0.44	16.9	4.46	0.5	16.9	4.49	0.49	17	4.51
	W,UG	7000	10	-1.16	4.29	1.91	-0.36	4.73	2.18	0.09	4.98	2.35	0.2	5.07	2.43	0.24	5.12	2.48
Three	L,W,UG	3500	11	-1.16	8.6	2.17	-0.6	8.77	2.25	-0.23	8.89	2.32	-0.2	8.91	2.34	-0.2	8.92	2.34
	L,W,UG	7000	12	-1.16	16.8	4.75	0.24	17.6	5.18	1.09	17.9	5.43	1.27	18.1	5.56	1.34	18.2	5.64

LCRB Model Runs				Simulated Average Drawdown In Willis														
				YR 1			YR 2			YR 3			YR 4			YR 5		
Formations		AFY	Run #	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.
NA	NA	0	0	-2.45	1.72	-1.24	-3.38	1.06	-1.75	-3.63	0.81	-1.99	-3.9	0.62	-2.17	-4.03	0.46	-2.3
Single	L	3500	1	-2.45	3.6	-0.24	-2.99	3.1	-0.65	-3.08	2.93	-0.84	-3.3	2.75	-1	-3.43	2.61	-1.13
	W	3500	2	-2.45	11.6	1.24	-2.65	11.3	0.92	-2.53	11.2	0.78	-2.7	11	0.64	-2.84	10.9	0.52
	UG	3500	3	-2.45	3.4	0.01	-2.6	3.23	-0.15	-2.53	3.2	-0.22	-2.6	3.11	-0.31	-2.72	3.01	-0.39
	L	7000	4	-2.45	5.49	0.77	-2.6	5.15	0.44	-2.53	5.04	0.3	-2.7	4.89	0.16	-2.84	4.76	0.05
	W	7000	5	-2.45	21.1	3.64	-1.94	21.4	3.58	-1.44	21.5	3.53	-1.5	21.4	3.43	-1.66	21.3	3.34
	UG	7000	6	-2.45	4.74	0.98	-1.99	5.1	1.21	-1.6	5.35	1.36	-1.5	5.43	1.41	-1.52	5.45	1.42
Two	L,W	3500	7	-2.45	13.5	2.25	-2.26	13.3	2.02	-1.98	13.3	1.92	-2.1	13.1	1.8	-2.25	13	1.7
	W,UG	3500	8	-2.45	13.3	2.47	-1.88	13.4	2.5	-1.44	13.5	2.53	-1.5	13.5	2.48	-1.55	13.4	2.42
	L,W	7000	9	-2.45	24.3	5.51	-1.19	25.3	5.72	-0.36	25.6	5.79	-0.4	25.6	5.75	-0.47	25.6	5.7
	W,UG	7000	10	-2.45	23.6	5.65	-0.65	25	6.33	0.47	25.7	6.71	0.7	26	6.88	0.76	26.1	6.98
Three	L,W,UG	3500	11	-2.45	15.1	3.46	-1.49	15.4	3.59	-0.9	15.6	3.66	-0.9	15.6	3.64	-0.96	15.6	3.6
	L,W,UG	7000	12	-2.45	26.7	7.48	0.08	28.7	8.42	1.51	29.7	8.92	1.82	30.2	9.16	1.92	30.4	9.29

LCRB Model Runs				Simulated Average Drawdown In Upper Goliad														
				YR 1			YR 2			YR 3			YR 4			YR 5		
Formations		AFY	Run #	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.	Mar.	Sept.	Dec.
NA	NA	0	0	-2.88	1.36	-2	-4.6	0.11	-3.02	-5.34	-0.51	-3.58	-5.9	-0.97	-3.99	-6.26	-1.32	-4.31
Single	L	3500	1	-2.88	1.7	-1.64	-4.32	0.63	-2.53	-4.96	0.08	-3.03	-5.4	-0.33	-3.4	-5.79	-0.66	-3.7
	W	3500	2	-2.88	3.08	-0.72	-3.8	2.31	-1.4	-4.23	1.89	-1.8	-4.6	1.54	-2.12	-4.94	1.24	-2.39
	UG	3500	3	-2.88	14.1	2.79	-2.51	14.3	2.68	-2.23	14.3	2.56	-2.4	14.2	2.38	-2.64	14	2.19
	L	7000	4	-2.88	2.04	-1.29	-4.04	1.15	-2.04	-4.57	0.68	-2.47	-5	0.3	-2.82	-5.32	0	-3.09
	W	7000	5	-2.88	4.75	0.52	-3.02	4.48	0.21	-3.12	4.28	-0.02	-3.4	4.03	-0.26	-3.64	3.79	-0.48
	UG	7000	6	-2.88	23.6	6.43	-0.89	26	7.43	0.37	27.4	7.98	0.64	28.1	8.25	0.69	28.5	8.36
Two	L,W	3500	7	-2.88	3.42	-0.36	-3.51	2.82	-0.91	-3.84	2.48	-1.24	-4.2	2.17	-1.54	-4.48	1.9	-1.79
	W,UG	3500	8	-2.88	15.6	3.97	-1.74	16.3	4.21	-1.17	16.6	4.27	-1.2	16.6	4.2	-1.35	16.5	4.08
	L,W	7000	9	-2.88	5.36	1.19	-2.48	5.47	1.15	-2.37	5.44	1.06	-2.5	5.28	0.9	-2.71	5.1	0.73
	W,UG	7000	10	-2.88	25.6	8.42	0.46	28.9	10.1	2.29	31	11.1	2.85	32.3	11.6	3.08	33	11.9
Three	L,W,UG	3500	11	-2.88	15.8	4.31	-1.47	16.7	4.67	-0.79	17.1	4.8	-0.8	17.2	4.77	-0.9	17.1	4.68
	L,W,UG	7000	12	-2.88	26	8.98	0.95	29.5	10.9	2.96	31.8	12	3.63	33.3	12.6	3.94	34.1	13



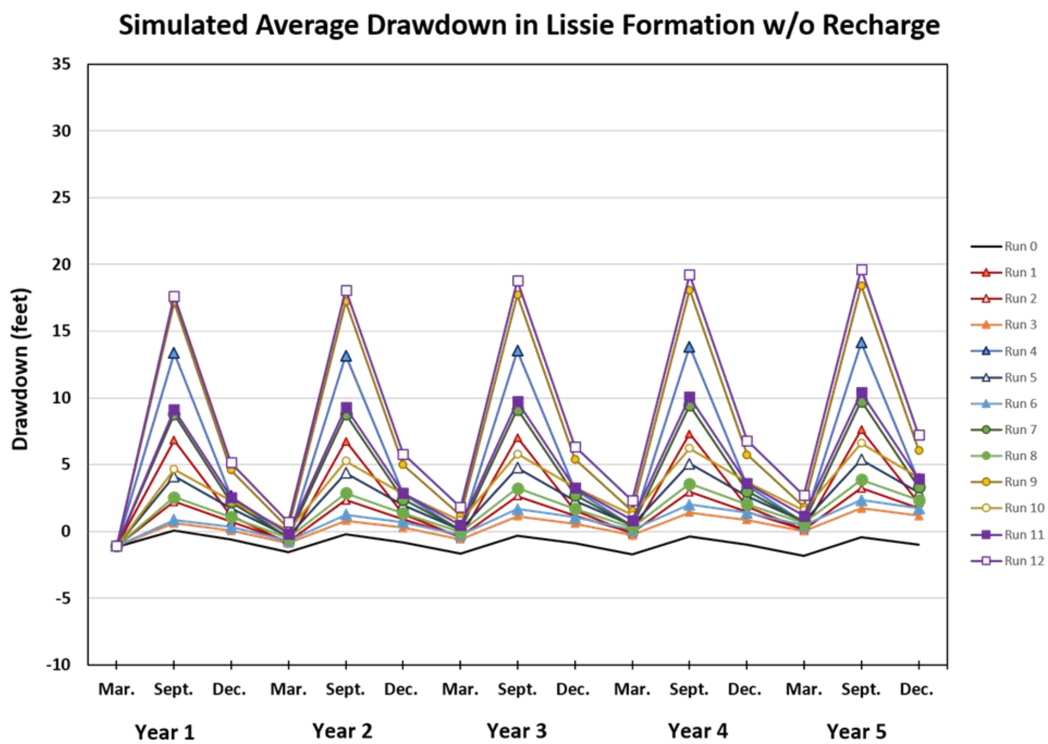
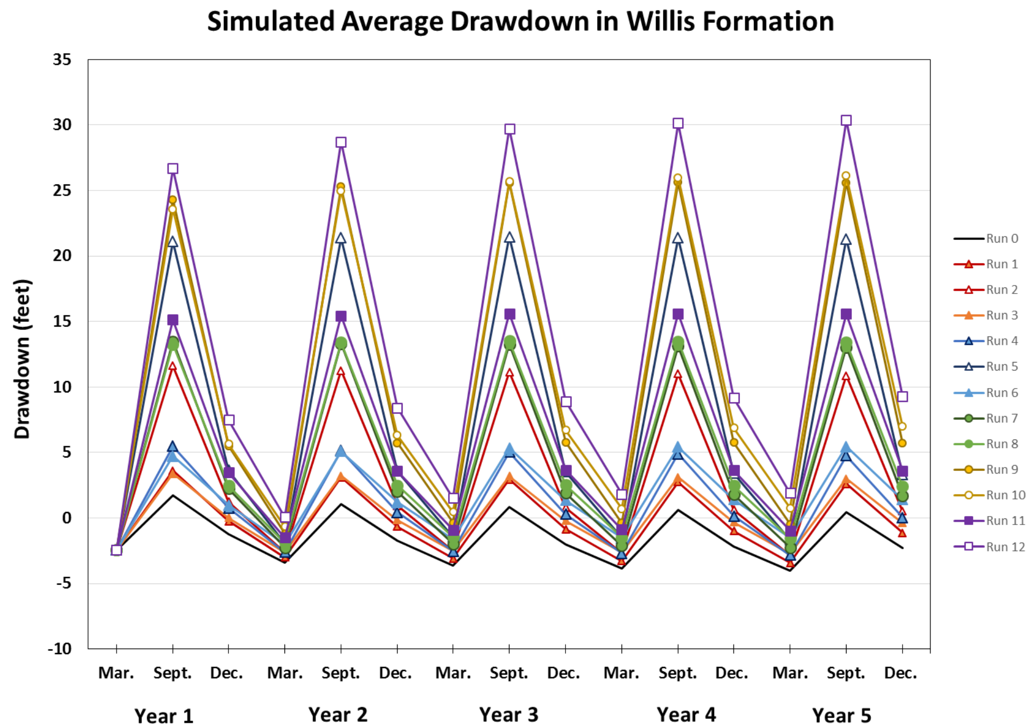


Figure 6-1 **Simulated Water Level Changes in the Lissie Formation for Twenty-Six Modeling Scenarios**



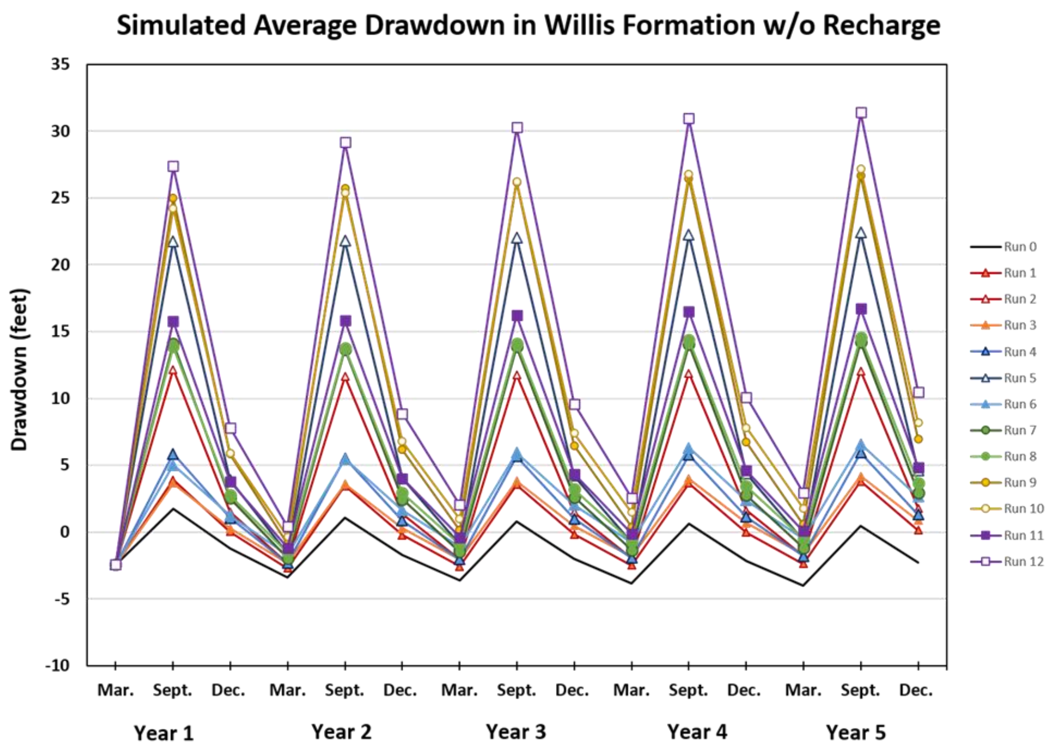
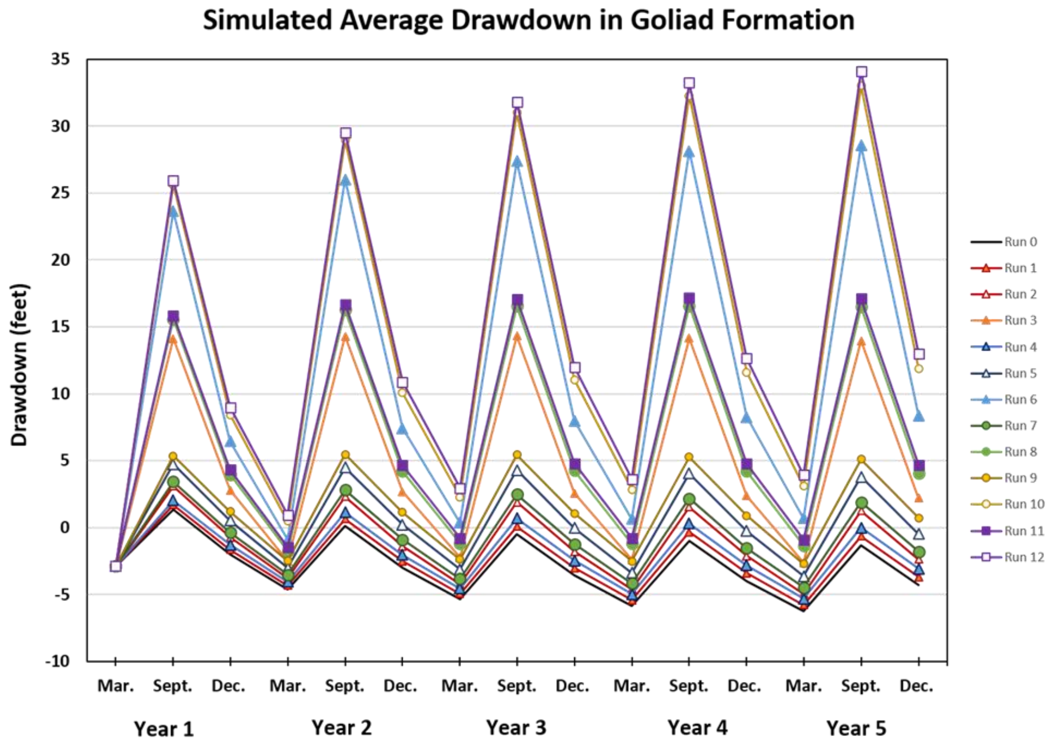


Figure 6-2 **Simulated Water Level Changes in the Willis Formation for Twenty-Six Modeling Scenarios**



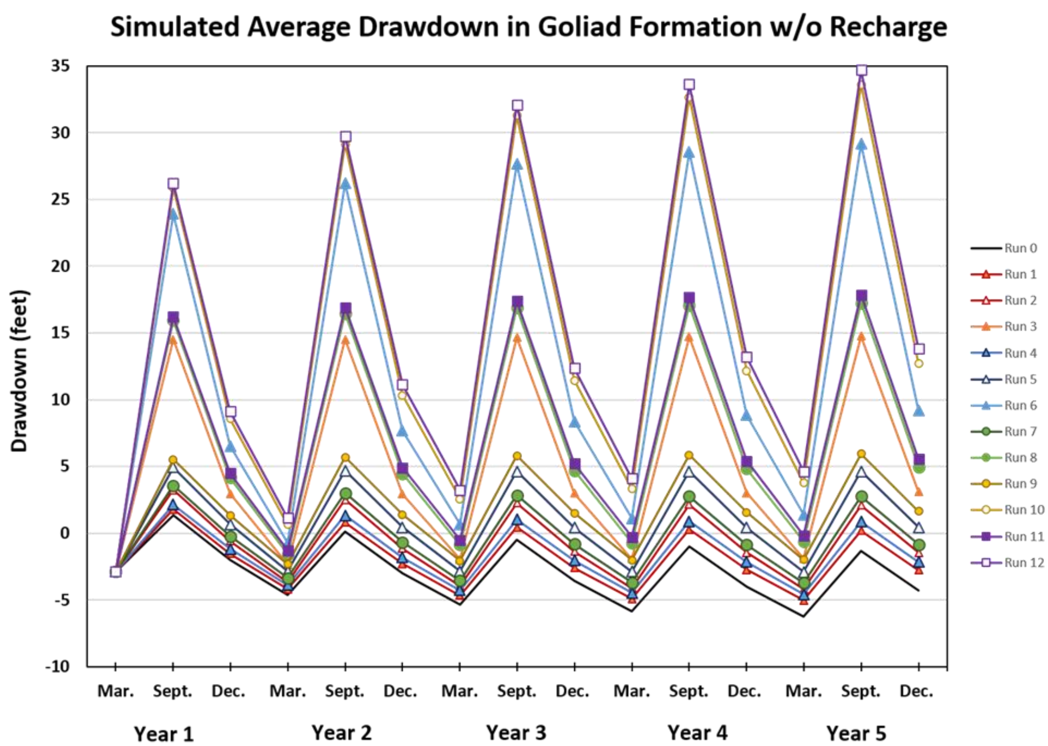


Figure 6-3 Simulated Water Level Changes in the Upper Goliad Formation for Twenty-Six Modeling Scenarios

7.0 Summary of the Data Analysis

This section provides an overview of the conditions and factors that contributed to the problems associated with low water table conditions in shallow wells located near the town of Lissie during the summer of 2014.

7.1 Assessment of the Problem with Pumping Shallow Wells Near the Town of Lissie

At the start of the project CBGCD general manager Neil Hudgins informed INTERA that approximately twenty people cited problems with pumping from shallow wells near the town of Lissie. The majority of the well owners who reported problems with groundwater levels dropping to near or below the elevation of their well pumps had not registered their wells. Most of the well owners said the affected wells were drilled to a depth of about 100 feet below the ground surface. Because the majority of the wells were not registered with the CBGCD, INTERA was not able to accurately map the location and total depths of the affected wells. Based on INTERA's assessment of the hydrogeologic data, it appears that the problem with many of the shallow wells was triggered when the elevation of the water table dropped below a depth of about 70 feet below the ground surface.

Based on information discussed in Sections 1 to 6, the reported problems with low water table conditions in shallow wells are primarily attributed to the contributing factors discussed below.

1. <u>Significant Increases in Irrigation Pumping in the Vicinity of the Lakeside Irrigation District</u> – Since 2011, the reported pumping in the vicinity of the town of Lissie has increased significantly. Within a circular area contained by a five-mile radius around the town of Lissie, the reported pumping has steadily increased (see Table 4-2) during the last few years. In 2013, the average production rate per arce is about 0.37 AFY/acre substantially higher the average production rate per acre of 0.24 AFY/acre for Wharton County.

2. <u>Absence of Beaumont Formation near the town of Lissie</u>– Across most of Wharton County, shallow wells are screened in the Beaumont Formation. The Beaumont Formation is the most clayey of the three formation that comprise the Chicot Aquifer and is the least pumped. As a result, the water levels in the shallow wells in the Beaumont Formation are somewhat protected from drawdowns caused by pumping in the two other formations in the Chicot Aquifer: the Lissie and the Willis Formations. In Wharton County, approximately 85% of the total pumping occurs in the Lissie and Willis Formations. Because the Beaumont Formation is absent in the area around the town of Lissie, the shallow wells near the town of Lissie are screened in deposits that in good hydraulic communication with the formations being pumped by irrigation wells. As a result, the shallow wells near the town of Lissie are more vulnerable and at a higher risk of experiencing drawdown impacts from irrigation pumping than most of the shallow wells in Wharton County.

3. Relatively Low Historical Drawdowns for Shallow Wells – Based on simulations using the LCRB model to estimate historical drawdowns that occurred from 1900 to 2000, the wells with depths of less than 250 feet near the town of Lissie are among the group of wells in Wharton County with the lowest historical declines in water table elevation. Whereas the majority of the shallower wells in western Wharton County (see Figure 5-1) have historical drawdowns between 40 and 90 feet, the majority of wells in eastern Wharton County have historical drawdowns that are less than 40 feet. Furthermore in the town of Lissie, wells with depths less than 250 feet typically have historical drawdowns less than 20 feet. The relatively low historical drawdowns in the area around the town of Lissie has likely contributed to the pre-2014 practice of installing domestic wells with depths of about 100 feet below ground surface. As a result of similar well designs and depths, the opportunity exists for a relatively high percentage of the shallow wells to have pumping problems during a period of high irrigation pumping like 2013.
4. Reduction of Surface Water Diversion in the Lakeside Irrigation District – A primary cause for the sudden and rapid increase in pumping near the town of Lissie is the forced reduction in the surface water diversion across the Lakeside Irrigation District by the LCRA. In 2012 and 2013, the LCRA reported the annual surface water diversions for the Lakeside Irrigation District were 649 acre-feet and 0 acre-feet, respectively. Between 1989 and 2012, the least amount of surface water diversion was 95,390 acre-feet which occurred in 1997. For comparison, the surface water diversion for the Garwood Irrigation District for 2012 and 2013 was 85,478 acre-feet and 90,474 acre-feet, respectively. The average of these two values is greater than the surface water diversion that occurred over the nine years between 1989 and 2012. As a result of the very large reduction of surface water diversion across the Lakeside Irrigation District, the greatest increases in pumping occurred near the town of Lissie.

7.2 Recommended Depths for Future Exempt Wells Near the Town of Lissie

A potentially important question is what depth should replacement wells be drilled based on the desired to operate the well at least thirty-years so that problems with pumping will not occur. A very conservative approach to replace a shallow well by drilling the deepest well possible that would meet the desired water quality and quantity. This report and referenced reports (Young and Kelley, 2006; Young and others, 2009) show that near the town of Lissie there are productive sand units containing fresh water to a depths below 600 feet. Based on our analysis of the data, there is no need to drill such a deep well. After a review of the LCRB model results and the field data, we recommend that new wells be drilled to a depth of 250 feet. Locations where this depth may not be acceptable are where several permitted well are pumping large amounts of groundwater from the Lissie Formation and/or the upper Willis Formation. The recommended depth of 250 feet is based on the measured water levels in Section 5 and results from the LCRB model in Section 6.

In Section 5, a very useful set of measured water levels are those shown in Figure 5-7 for Well C-6. This shallow water well is located in the Lissie Circle and it has been monitored about 10 times a year since 2011. Figure 5-7 shows that the seasonal low water level has declined approximately 8 ft/year for the last 3 years from Summer 2011 to Summer 2014. From Summer 2011 to Summer 2012 and from Summer 2013 and Summer 2014, the reported pumping has increased approximately 2,000 AFY in the Lissie Circle. For the purpose of estimating future water levels, a simple correlation is made between a 2,000 AFY increase in pumping in the Lissie Circle and a 8-ft drop in the seasonal low water level. It should noted that this correlation implicitly accounts for pumping both inside and outside of the Lissie Circle. In 2013, the estimated pumping in the Lissie Circle was approximately 16,000 AFY. For the 55 permitted wells located in the Lissie Circle, their average annual permitted production is about 40,000 AFY. Thus, if the permitted wells were to pump their current permitted amounts, the increase in total annual pumping in the Lissie Circle would be approximately 24,000 AFY. Assuming that for every 2,000 AFY increment of additional pumping the seasonal low water table will drop 8 ft, the estimated drop in seasonal low water level would be about 96 feet from 2013 conditions if wells in Wharton County and around the town of Lissie were fully permitted. Adding the 96 feet to well depth of 150 feet for the Dale Road Well #2 well, the recommend total well depth for new wells is 250 feet.

In Section 6, there is sufficient information to estimate a potential bias in the predicted drawdown. Seasonal differences in the high and low water levels for the basecase (with no additional pumping) is approximately 1.5 feet, 3 feet, and 6 feet in the Lissie, Willis, and Upper Goliad respectively. These difference are within the range of seasonal differences shown in hydrographs for wells near the Lissie Circle but they are on the low end of the range. At the higher end of the range, there is a shallow well with seasonal differences of 20 to 40 feet (see Well C6) and a deep well with seasonal difference of 40 to 60 feet (see Well W16). The likely reason for the under prediction of drawdown of the model is the overestimate of hydraulic conductivity values and storativity values near the town of Lissie, the large time steps over which temporal variations in water levels are averaged, and the relatively large grid blocks over which spatial variations in drawdown on average. Based on our analysis of the modeling and measured seasonal difference in water levels, it appears that the LCRB model is underestimating the maximum different in seasonal water table for the Lissie Circle by a factor or 3 to 4. Using these factors and a simulated difference of 20 feet difference between the winter and summer water levels for the 20-year run for Scenario 12, the adjusted maximum seasonal difference is about 60 to 80 feet. Scenario 12 was selected because adds 21,000 AFY to the basecase run. This 21,000 AFY is close to the 24,000 AFY which is the difference between the 2013 production and average permitted annual production in the Lissie Circle. The values of 60 to 80 feet is less than the 96 feet additional drawdown discussed above but it does not include any long-term increase in the drawdown due to regional effects, which appears to be about 1 ft per year. Thus, an upper estimate of additional drawdown caused by fully implementation of permitted pumping based on up-scaling the model results is about 100 feet. Based on this result, the recommend depth of 250 feet should be sufficient.

8.0 References

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