Chapter 6

Stratigraphy, Lithology, and Hydraulic Properties of the Chicot and Evangeline Aquifers in the LSWP Study Area, Central Texas Coast

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Introduction

A numerical groundwater model of the Chicot and Evangeline aquifers is under construction for the Lower Colorado River Authority-San Antonio Water System Water Project (LSWP) in Colorado, Wharton, and Matagorda counties along the Texas Gulf Coast, south of Houston. Because the hydraulic properties of the aquifer should correlate with lithology and depositional origin, a study defining the comprising formations, their juxtapositional relationships, dominant lithologies, and depositional environments was undertaken.

Previous geologic and hydrogeologic studies and numerical models of the Gulf Coast aquifer in the study area are summarized by Young and Kelley (2005). These studies, though of varying scope and differing geographic area and stratigraphic interval, have established a general framework for the Gulf Coast aquifer, but they can differ appreciably in their details. Our study uses the Chicot formations established by Baker (1979) and the formation ages established by BEG (1992). This Gulf Coast aquifer framework includes the shallower Chicot aquifer, which is composed of the Pleistocene-age Lissie Formation and Pliocene-age Willis Formation, and the deeper Evangeline aquifer, which includes the upper and lower Goliad (Miocene-age) formations. The goal of this study (Young and Kelly, 2005) is to create a unified and well-documented geologic and hydrogeologic framework for the Chicot and Evangeline aquifers defined at the scale of the geologic formations that compose them.

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Methods

Formation-level stratigraphic correlations were tied to outcrop formations from the Geologic Map of Texas (BEG, 1992). Subsurface stratigraphic, lithologic, and depositional facies interpretations relied upon geophysical logs from a total of 622 wells (Figure 6-1), which include 300 logs analyzed by Dutton and Richter (1990). A series of six cross-sections through selected wells, along with additional wells between sections (140 wells total), were used to establish the subsurface stratigraphic framework and interpret depositional facies. Micropaleontology-based geologic age boundaries from previous cross-section studies (Dodge and Posey, 1981; Morton and others, 1985) were correlated to study wells in order to establish subsurface formational boundaries for Miocene-age formations, including the contact of the top of the Miocene and the base of Pliocene-age strata. A depth to the base of Pleistocene-age sediments in the subsurface was estimated from work by Guevara-Sanchez (1974), also supported by micropaleontology. A series of 11 geologic "timelines" from the top of the Lissie Formation to the base of the Goliad Formation were correlated throughout the 140 logs by recognition of laterally persistent changes in vertical lithology and facies profiles in logs.

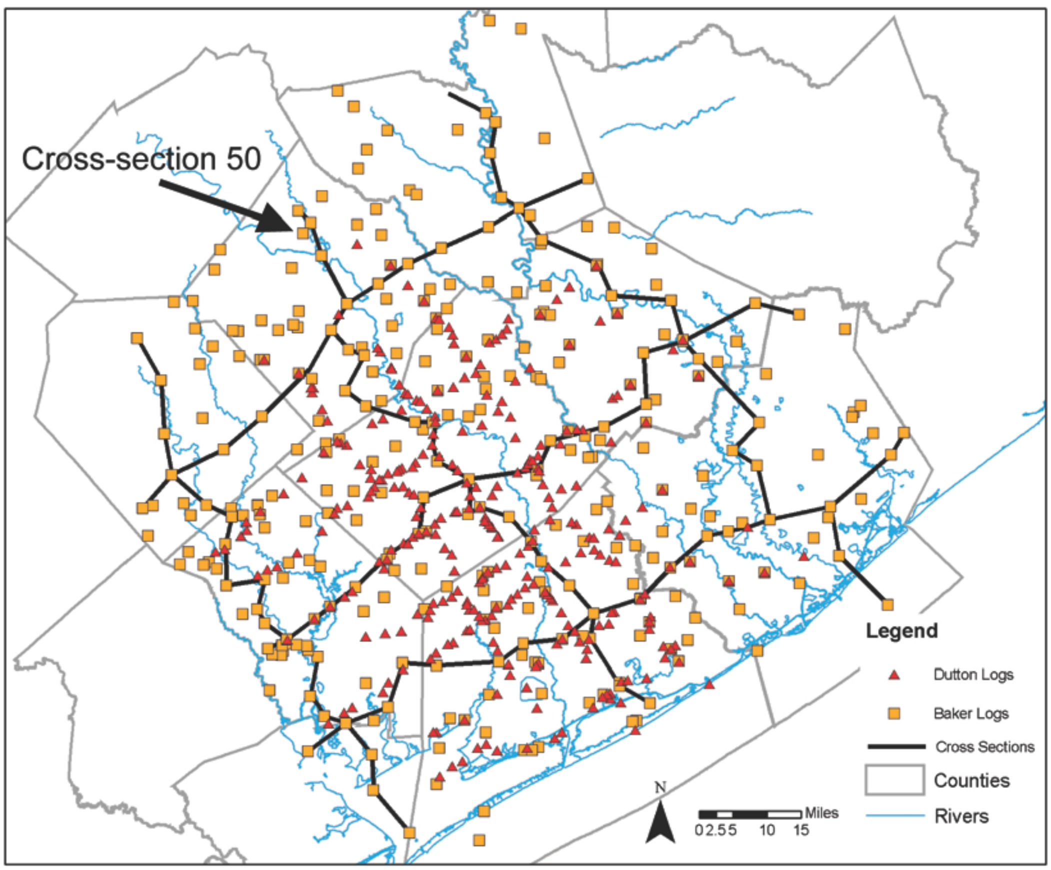


Figure 6-1. Location of geophysical logs and the six cross-sections.

Stratigraphy, Lithology, and Depositional Facies

The four major formations studied descend from the surface outcrop at the northern fringe of the study area into the subsurface to the southeast (toward the coast), as exhibited by cross-section 50 in Figure 6-2. An area of increased dip occurs along a zone in the northwest part of the study area, in central Colorado County, and is sub-parallel to the coast. Updip (northwest) of this zone, both the Lissie and Willis formations thin abruptly as they come up to the surface, each exhibiting mild erosional truncation of the respectively underlying formation. At outcrop, these two formations exist over large areas, most likely as a thin veneer of gravel as little as ten feet thick. The boundary between the upper and lower Goliad formations appears to be mildly erosional over much of the subsurface area and an abrupt increase in sand content occurs above this boundary. The aquifer boundaries as interpreted in the Source Water Assessment and Protection (SWAP) Program are also plotted and show the base of the SWAP Chicot aquifer to be significantly above the base of the Willis Formation (LSWP base Chicot), by as much as 500 feet in many areas. Across much the study area the SWAP data places the bottom of the Chicot aquifer much closer to the bottom of the Lissie Formation than the Willis Formation.

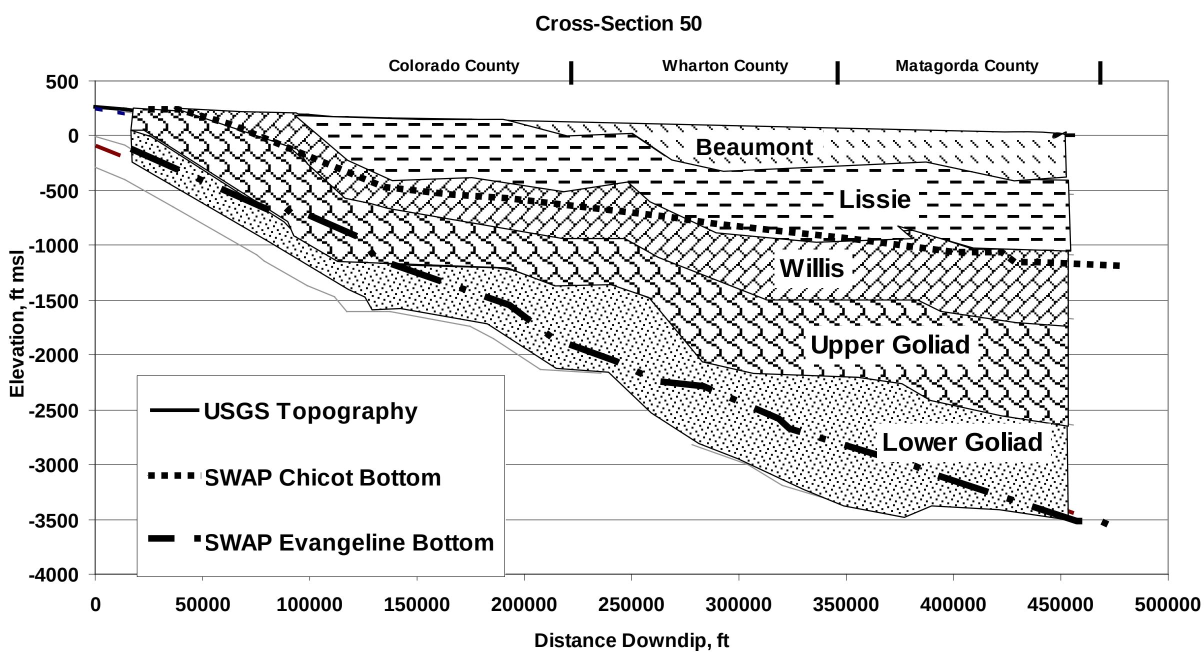


Figure 6-2. Surfaces for five geological formations along cross-section 50.

Data from the lithologic analyses performed by Dutton and Richter (1990) were significantly lower in percent sand class, and absolute values were not used in the mapping process. Instead, their relative values were used to guide sand trends in areas where four-fold data were sparse. The Lissie and Willis formations contain the highest sand-class percent material (each averaging about 65 percent) across the study area, with the greatest sand content in the northeast part of the study area. The upper Goliad Formation is approximately ten percent lower in sand-class material (average across the study area) than the Lissie and Willis formations, with sand dominating the north and east parts of the area. Calculated sand-class values for the lower Goliad

Formation are about seven percent lower than those for the upper Goliad Formation, with a series of distinctly sandier areas trending northwest to southeast across the study area. The differences in the sand-class distributions produced for the Willis and upper Goliad formations are shown in Figure 6-3. The sand-class data provide potentially pertinent information regarding the discrepancy between the base of the Chicot aquifer in this study and that in the SWAP dataset. Sand-class values were tabulated for the Chicot and Evangeline aquifers using the aquifer boundaries from the SWAP dataset and those from this study (Table 6-1). As noted by Baker (1979), Jorgensen (1975), and Carr and others (1985), the Chicot aquifer is conceptually distinguished from the Evangeline aquifer by its distinctly greater hydraulic conductivity, which equates to greater sand percent. Table 6-1 was created to help quantify the difference in the sand-class distributions between the Chicot and Evangeline aquifers in order to provide a framework for deciding whether or not our representation of the boundary of the base of the Chicot aquifer is reasonable. In Table 6-1, the "LSWP-SWAP" interval is the aquifer volume sandwiched between the two approximations of the base of the Chicot aquifer across the study area. Logs used by Dutton and Richter (1990) the "LSWP-SWAP" interval have nearly the same sand-class distribution as the Chicot aquifer for both sets of boundaries. For the LSWP logs, the "LSWP-SWAP" interval's sand-class distribution is intermediate to the distributions for the two aquifers but is significantly closer to the distributions for the Chicot aquifer than for the Evangeline aquifer. Hence, it would appear that, if the two aquifers are differentiated based on permeability, our base for Chicot aquifer is justified and defensible.

Geophysical log profiles for each of the formations were interpreted as reflecting a regional depositional transition from fluvial channel and intervening floodplain facies updip (northwestward) to a mixture of bayfill, coastal, incised valley, and shelf facies downdip (toward the current shoreline). Fluvial channel facies vary from broad, sand-dominated regions, such as in the northwest area of the Lissie Formation (Figure 6-4a), to a series of narrow northwest-southeast trending areas, such as in the northwest part of the Willis Formation (Figure 6-3a).

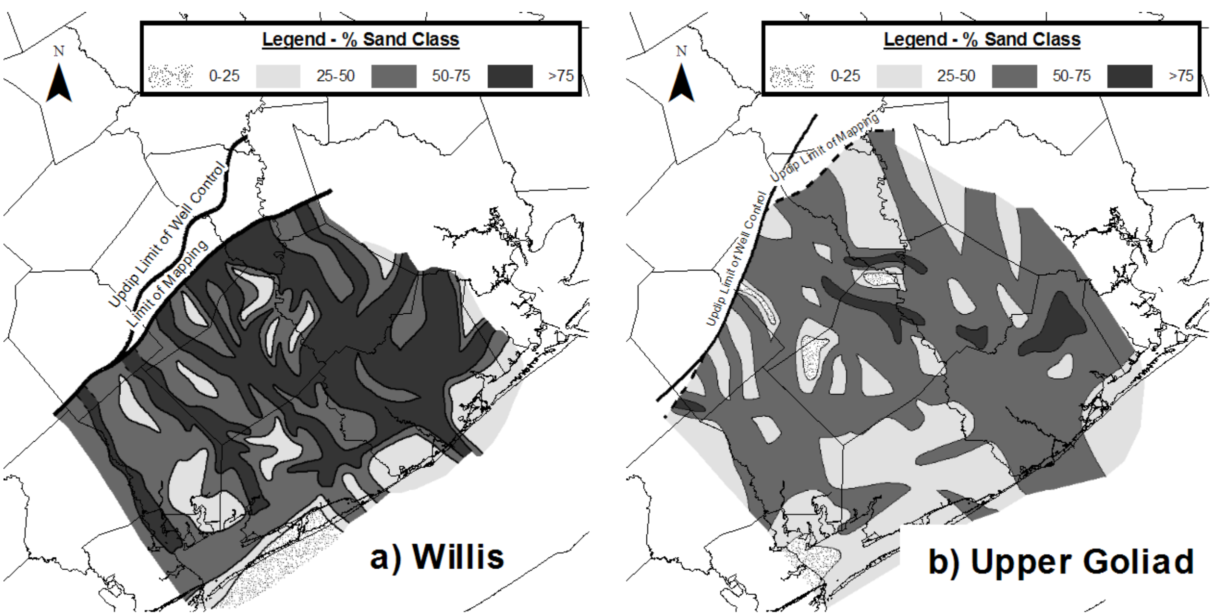


Figure 6-3. Sand-class distribution maps for the Willis and upper Goliad formations.

Table 6-1. Differences in the fraction of sand classes for the Chicot aquifer, the Evangeline aquifer, and a volume difference defined by the differences in how the LSWP and SWAP define the base of the Chicot aquifer.

		Minimum thickness of sand class interval (feet)									
		LSWP Logs					Dutton Logs				
		0	**20**	**40**	**60**	**80**	**0**	**20**	**40**	**60**	**80**
SWAP boundaries	Chicot aquifer	0.69	0.56	0.49	0.40	0.28	0.49	0.42	0.30	0.20	0.15
	LSWP-SWAP interval	0.63	0.49	0.41	0.33	0.33	0.49	0.43	0.30	0.24	0.17
	Evangeline aquifer	0.54	0.39	0.29	0.20	0.14	0.35	0.29	0.18	0.08	0.05
LSWP boundaries	Chicot aquifer	0.68	0.55	0.47	0.39	0.32	0.50	0.43	0.31	0.22	0.15
	LSWP-SWAP interval	0.63	0.49	0.41	0.33	0.33	0.49	0.43	0.30	0.24	0.17
	Evangeline aquifer	0.52	0.37	0.27	0.17	0.12	0.31	0.25	0.13	0.06	0.03

Bayfill facies include river-fed deltas (bayhead deltas) that filled bays with sandy sediments, as well as more clay-dominated quiet-water bay settings. Broad sandy areas downdip of fluvial facies and containing some upward-coarsening log profiles represent bayhead delta facies, such as across the middip areas of the Lissie, Willis, and upper Goliad formations. Narrow sandy areas in the downdip part of the study area that are parallel to and just landward of the current coastline often contain blocky or slightly upward-coarsening log profiles and are interpreted as a mix of coastal facies, including barrier island, shoreline, and delta front settings. Large regions of clay-dominated sediment in downdip areas that are crossed by northwest-southeast-trending sandy regions are interpreted as shelf settings during periods when sea level is high and as a broad area of dry land across which entrenched rivers (incised valleys) flow southeastward to the coast when sea level is low (a cycle that repeats every several hundred thousand years). Examples of this setting occur near the present shoreline in each of the formations. It is important to note that these incised valleys, such as those interpreted near the shore in the lower Goliad Formation (Figure 6-4b), provide a focused flow path for brine waters moving upward into the aquifers from deeper in the Gulf Coast basin.

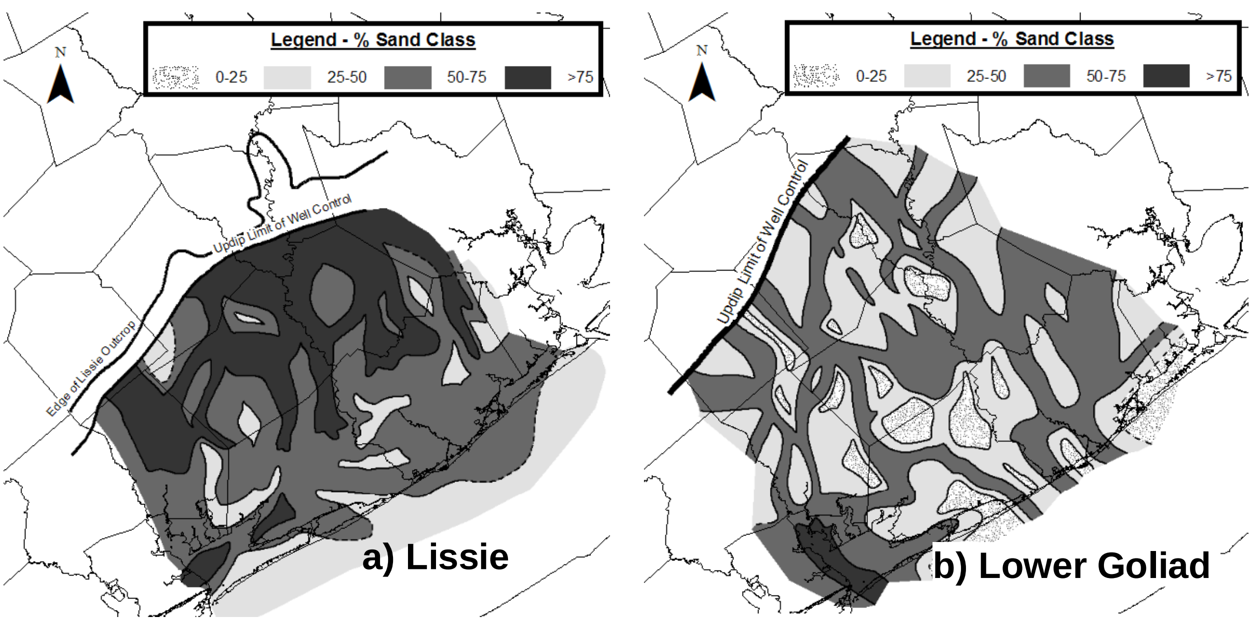


Figure 6-4. Sand-class distribution maps for the Lissie and lower Goliad formations.

Aquifer Summary

The Chicot and Evangeline aquifers in the LSWP study area have been subdivided into the upper Chicot (Lissie Formation), lower Chicot (Willis Formation), upper Evangeline (upper Goliad Formation), and lower Evangeline (lower Goliad Formation), using formation boundaries and geologic timelines established by outcrop geology and micropaleontologic evidence from the subsurface. The upper and lower Chicot aquifers are distinctly sandier than the upper Evangeline aquifer, which in turn is sandier than the lower Evangeline aquifer. Sand content of the Chicot and upper Evangeline aquifers is greatest in the updip half of the study area, whereas no specific area of sandiness is seen in the lower Evangeline aquifer. The sandiest areas in both aquifers may be narrow, on the order of ten miles wide, and strongly northeast-southwest trending. This trend reflects a series of sedimentary depositional settings from fluvial in the updip (northwest) area to bayfill in the middip, and a mix of coastal, incised valley, and shelf in the downdip (southeast) area.

The Chicot-Evangeline aquifer boundary interpreted here is above that established in the SWAP dataset over much of the study area by amounts up to 500 feet. Although analysis of lithologic data tends to support the LSWP boundary, more study may be needed to understand this discrepancy and to evaluate it in a broader geographic context.

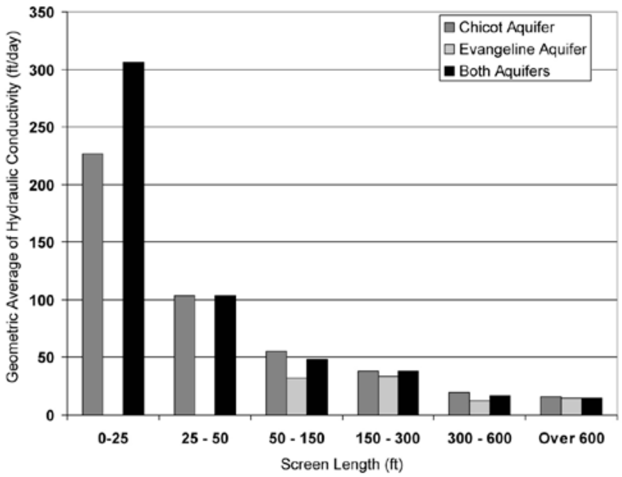
Data Sources Related to Hydraulic Conductivity Values

To estimate the spatial variability in the hydraulic conductivity field across the study area, we used transmissivity values, specific capacity values, sand distribution maps, and depositional facies maps. Transmissivity values were collected from two sources. One source consisted of tabulated transmissivity values from U.S. Geological Survey and Texas Water Development Board reports. The other source consisted of transmissivity values calculated from pumping test data obtained from the Texas Commission on Environmental Quality's Division of Water Supply. The specific capacity values were calculated from information collected from water driller logs at the Texas Ccommission on Environmental Quality. The sand distribution and facies maps were developed from analyses of geophysical logs.

Screen Length Effect on Hydraulic Conductivity Estimates

The method of Meyers (1969) was used to calculate hydraulic conductivity from approximately 400 pumping tests. Figure 6-5 shows how the mean calculated hydraulic conductivity values change as a function of screen length. The figure shows a nearly exponential decrease of hydraulic conductivity with increases in screen length. Relative changes in normalized specific capacity values (specific capacity divided by screen length) can be used to approximate relative changes in hydraulic conductivity values. Figure 6-6 shows the average normalized specific capacity as a function of well screen length. In general, the trends are consistent with the trends obtained with the hydraulic conductivity data set shown in Figure 6-5.

We attribute the observed trends in Figures 6-5 and 6-6 to three causes. The first cause is that the process involved with locating a well screen is not a random process, but rather a very biased and



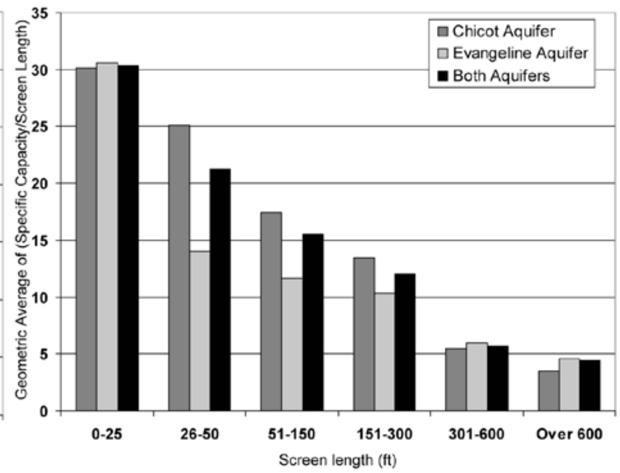


Figure 6-5. Relationship between hydraulic conductivity and well screen length.

Figure 6-6. Relationship between normalized specific capacity and well screen length.

systematic process aimed at placing the well screen into one of the aquifer's more permeable intervals. Typically, drillers install well screens across the first reliable producing zone that will meet the needs of a client. As the well screen length becomes large with respect to the average thickness of the aquifer, the opportunity for the well screen to intersect moderate to low permeability deposits increases. Consequently, hydraulic conductivity values calculated from pumping wells with small well screens will likely be higher than the average hydraulic conductivity of the aquifer. In addition, the calculated hydraulic conductivity is likely to be more representative of the aquifer as a whole as the length of the well screen approaches the thickness of the aquifer. The second cause for the observed trends in Figures 6-5 and 6-6 is that smaller well screens tend to promote non-lateral flow toward a well, which violates the assumption of the Meyers (1969) method and thereby leads to overestimation of the hydraulic conductivity. The third cause is that a decreasing trend in hydraulic conductivity with depth may be contributing to the asymptotic behavior at large screen lengths. One of the factors that could lead to a decrease trend in hydraulic conductivity with depth is increased compaction of sediments with depth.

Hydraulic Conductivity Values

Hydraulic conductivity values used to constrain a model's calibration should be representative of a scale that is consistent with the volume and size of the numerical model's grid. Most of the model grids in the LSWP groundwater model will be greater than 300 feet thick. In order to account for the well screen length bias shown in Figures 6-5 and 6-6, we used a minimum cut-off well screen length of 150 feet to develop a set of values for the model calibration (Table 6-2). The results in the table demonstrate that the selection criteria have a significant impact on both the magnitudes of the averages as well as the relative differences in the averages among the different counties. One of the effects of the filtering is to change the location of the highest averages from Brazoria and Galveston counties to Wharton and Fort Bend counties.

Table 6-2. Arithmetic and geometric means for hydraulic conductivity values for the Chicot aquifer, calculated from transmissivity values.

County	All qualifying tests			Well screens greater than 150 feet		
	Count	Arithmetic average (feet per day)	Geometric average (feet per day)	Count	Arithmetic average (feet per day)	Geometric average (feet per day)
Brazoria	27	154	98	3	20	10
Colorado	8	18	12	7	15	9
Fort Bend	14	64	48	6	32	16
Galveston	6	74	53	1	NA	NA
Harris	32	35	27	26	24	14
Jackson	87	31	23	74	26	20
Lavaca	9	13	11	6	10	9
Matagorda	31	50	29	22	21	14
Wharton	23	62	42	18	48	20

Specific Capacity Values

Figure 6-7 shows the spatial distribution of normalized specific capacity values calculated from approximately 300 short-term pumping tests performed in the Chicot aquifer with well screens over 100 feet. The results in Figure 6-7, as well as those in plots of the hydraulic conductivity values (which are also reflected in Table 6-2), suggest that the highest values in the Chicot aquifer occur in the up-dip region of Wharton and Fort Bend counties.

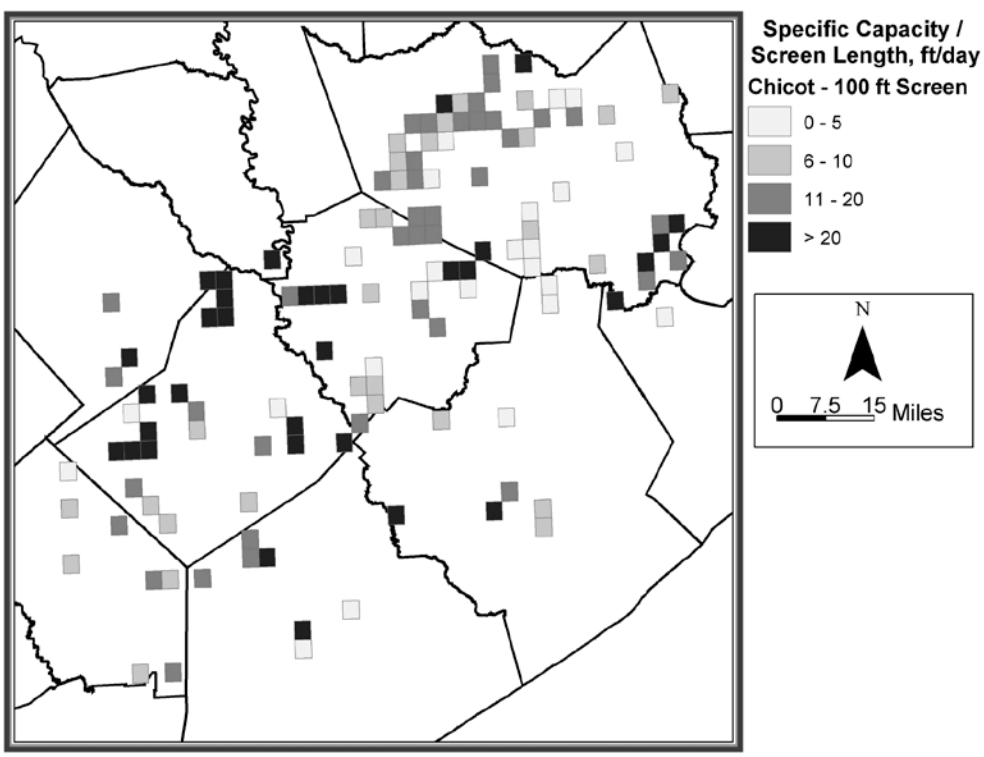


Figure 6-7. Spatial distribution of normalized specific capacity values for the Chicot aquifer.

Correlation between Lithology and Hydraulic Conductivity

To investigate correlations between lithology and hydraulic conductivity in the Chicot aquifer, we assembled data for 48 wells with reliable pumping test data and lithologic information. Using data from these 48 wells, we developed an equation for predicting average hydraulic conductivity based primarily on the percent sands in the deposit that the well screen intersects. Minor adjustments existed in the equation to account for the thicknesses of the clay and sand beds. Based on the lithologic logs of these wells, the average sand content in the Chicot aquifer is 53 percent and an approximate average hydraulic conductivity for sand is approximately 32 feet per day. As designed, the equation matches the average hydraulic conductivity of the 48 pumping tests, which is 19 feet per day. The regression analysis indicates that for most of the Chicot aquifer, the percent sand coverage is a reasonable indicator of average hydraulic conductivity.

The analysis of the geophysical logs for lithology involved categorizing the interpreted lithology into sand and clay classes. Our sand class, for instance, indicates that a deposit is composed of 50 to 100 percent sands. Figure 6-8 shows the distribution of the thicknesses associated with the sand class coverage by county. These results, in combination with results from our regression analysis, indicate the highest hydraulic conductivity values should occur within Wharton and Fort Bend counties.

Analysis of the geophysical logs also involved developing chronostratigraphy surfaces and maps of depositional facies. Within the Chicot aquifer, there are significant differences among the counties regarding the depositional facies associated with the Chicot aquifer. The two counties having a distribution of facies most conducive to producing permeable deposits are Wharton and Fort Bend counties.

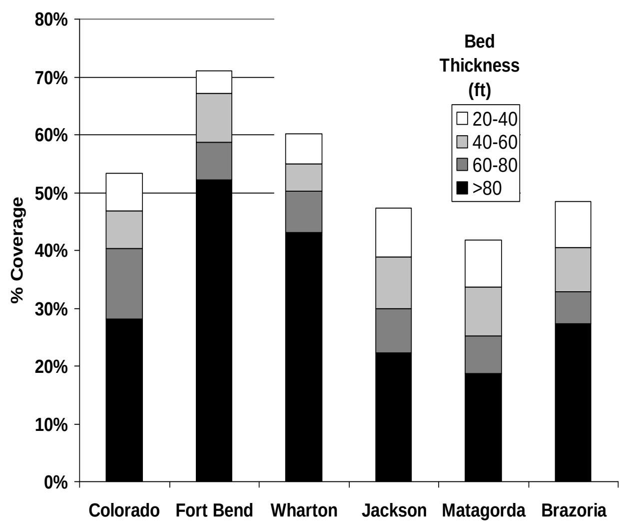


Figure 6-8. Distribution of the bed thicknesses of sand class beds in the Chicot aquifer.

Hydraulic Conductivity Summary

Multiple data sources and analysis approaches were investigated for developing estimates of spatial variability in the hydraulic conductivity field of the Chicot aquifer in the study area for the LSWP. All of the methods produced valuable information, most of which is consistent and useful for guiding the development of the groundwater flow model. All methods indicate that the highest average hydraulic conductivity values in the Chicot aquifer exist in Wharton and Fort Bend counties. Young and Kelley (2005) provide additional details regarding the results.

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