STATE OF LOUISIANA

DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT

PUBLIC WORKS AND FLOOD CONTROL DIRECTORATE

WATER RESOURCES SECTION

WATER RESOURCES

TECHNICAL REPORT

NO. 62

DISTRIBUTION OF SALTWATER IN THE CHICOT AQUIFER SYSTEM IN THE CALCASIEU PARISH AREA, LOUISIANA, 1995-96

USGS
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Prepared by the
U.S. DEPARTMENT OF THE INTERIOR
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1998

STATE OF LOUISIANA

CALCASIEU PARISH

Cooperative project with the

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per mile (ft/mi)	0.3048	meter per mile (m/mi)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
mile (mi)	1.609	kilometer
square mile (mi^2)	2.590	square kilometer
million gallons per day (Mgal/d)	3,785	cubic meter per day

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows: °F = 1.8 X °C + 32

Sea level: In this report,"sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units:

microsiemens per centimeter at 25 degrees Celsius (µS/cm)
milligrams per liter (mg/L)
milligrams per liter per year [(mg/L)/yr]

DISTRIBUTION OF SALTWATER IN THE CHICOT AQUIFER SYSTEM IN THE CALCASIEU PARISH AREA, LOUISIANA, 1995-96

By John K. Lovelace

ABSTRACT

Intense pumping in the Lake Charles area of Calcasieu Parish has lowered water levels and altered flow patterns from pre-development conditions in the Chicot aquifer system in Calcasieu Parish, Louisiana. In Calcasieu Parish, the Chicot aquifer system includes many sands, referred to as the shallow, massive, upper, lower, "200-foot," "500-foot," and "700-foot" sands. In 1995, 10 Mgal/d (million gallons per day) of water were withdrawn from the upper and "200-foot" sands, 90 Mgal/d were withdrawn from the "500-foot" sand, and 10 Mgal/d were withdrawn from the lower and "700-foot" sands. Water levels in the upper and "200-foot" sands in Calcasieu Parish during fall 1995 and spring 1996 ranged from approximately sea level to 60 ft below sea level. In the southeastern part of the parish, water levels in the upper and "200-foot" sands have large seasonal fluctuations (30 ft or more) in response to pumping for rice irrigation. Water levels in the "500-foot" sand ranged from less than 20 feet below sea level to more than 100 feet below sea level during fall 1995. A large cone of depression, centered beneath the Lake Charles industrial district, is the result of intense pumping. Water levels in the lower and "700-foot" sands ranged from less than 20 feet below sea level to more than 80 feet below sea level during fall 1995. Vertical leakage of water from the "700-foot" sand to the "500-foot" sand has resulted in much lower water levels in the "700-foot" sand than could be attributed to pumping from the "700-foot" sand.

Pumping in Calcasieu Parish could cause saltwater, present in the upper, "200-foot," "500-foot," and "700-foot" sands, to migrate toward pumping centers. However, there is little evidence to indicate substantial movement of saltwater in the upper sand. Chloride concentrations have increased at low rates (less than 3 milligrams per liter per year) in water samples from three wells completed along the freshwater-saltwater interface in the "500-foot" sand near the Calcasieu-Cameron Parish line. This may indicate slow northward movement of the saltwater interface in this area.

Three small chloride bodies also occur in the "500-foot" sand in the Lake Charles industrial district, partially due to upconing of saltwater from the "700-foot" sand into the "500-foot" sand in response to intense pumping. In general, chloride concentrations in the central and northern chloride bodies are relatively stable at this time. However, chloride concentrations have increased, as much as 10 milligrams per liter per year, at the southern chloride body; additional upconing of saltwater from the "700-foot" sand into the "500-foot" sand is probably occurring just west of the southern chloride body as a result of the lowered heads in the cone of depression.

Few facilities in Calcasieu Parish have continued to use water from the "700-foot" sand. In general, chloride concentrations in samples from pumped wells or wells located near wells pumping from the "700-foot" sand slightly increased, and concentrations in samples from wells located more distant from pumped wells have shown no trends or slight to moderate decreases. However, chloride concentrations in samples from one well, near a pumped public-supply well in Lake Charles, have increased at a rate of about 30 milligrams per liter per year since 1991. This rate of increase is similar to the rate of increase during the 1970's, indicating that the sharp rise in water levels after the completion of the Sabine River Diversion Canal in 1982 only temporarily relieved the stresses causing saltwater encroachment in the area.

Hourly water-level data were collected from four nested wells completed in the Chicot shallow sand, the "200-," "500-," and "700-foot" sands and compared with data from two gaging stations on the Calcasieu River. Water levels in all four sands exhibit signs of external loading in response to tidal variations in stage of the Calcasieu River. Water-level fluctuations in the shallow sand do not indicate a direct hydraulic connection between the shallow sand and the Calcasieu River in the vicinity of the well site.

INTRODUCTION

The Chicot aquifer system is the principal source of fresh ground water in southwestern Louisiana, including Calcasieu Parish. In Calcasieu Parish, the Chicot aquifer system includes many sands, referred to as the shallow, massive, upper, lower, "200-foot," "500-foot," and "700-foot" sands. In 1995, approximately 550 Mgal/d of water were withdrawn from the Chicot aquifer system in southwestern Louisiana (Lovelace and Johnson, 1996). More than one-half of the withdrawals were for rice irrigation. Withdrawals for rice irrigation, which began around the turn of the century (Harris, 1904), have lowered water levels in the aquifer, creating an elongated cone of depression in the potentiometric surface that extends over much of the region (Harder and others, 1967, p. 16-17, pl. 4).

During 1995, approximately 110 Mgal/d of water were withdrawn from the Chicot aquifer system in Calcasieu Parish (fig. 1) (Lovelace and Johnson, 1996, p. 90). Of this total, 10 Mgal/d were withdrawn from the "200-foot" sand and upper sand, 90 Mgal/d were withdrawn from the "500-foot" sand, and 10 Mgal/d were withdrawn from the "700-foot" sand and lower sand. The "500-foot" sand is the primary source of ground water for industry and public supply in Calcasieu Parish and sixty-seven percent of the withdrawals from the "500-foot" sand were for industrial use, primarily in the Lake Charles industrial district. Water withdrawal rates from the Chicot aquifer system in Calcasieu Parish in 1995 for various categories of use were as follows: public supply, 21 Mgal/d; industry, 68 Mgal/d; power generation, 7.8 Mgal/d; rural domestic, 2.0 Mgal/d; livestock, 0.13 Mgal/d; rice irrigation, 11 Mgal/d; and aquaculture, 2.6 Mgal/d.

Pumping in Calcasieu Parish may induce movement of saltwater laterally northward from coastal areas and upward from underlying aquifers into the freshwater-bearing sands underlying Calcasieu Parish (Nyman, 1984, p. 32, 37). Saltwater is present in the upper sand in the extreme southeast corner of the parish (Nyman, 1984, pl. 2). Saltwater is present in the "500-foot" sand near the Calcasieu-Cameron Parish border and in the Lake Charles industrial district (Nyman, 1984, pl. 4, 5). Saltwater also is present in the "700-foot" sand in the southern two-thirds of Calcasieu Parish (Nyman, 1984, pl. 7).

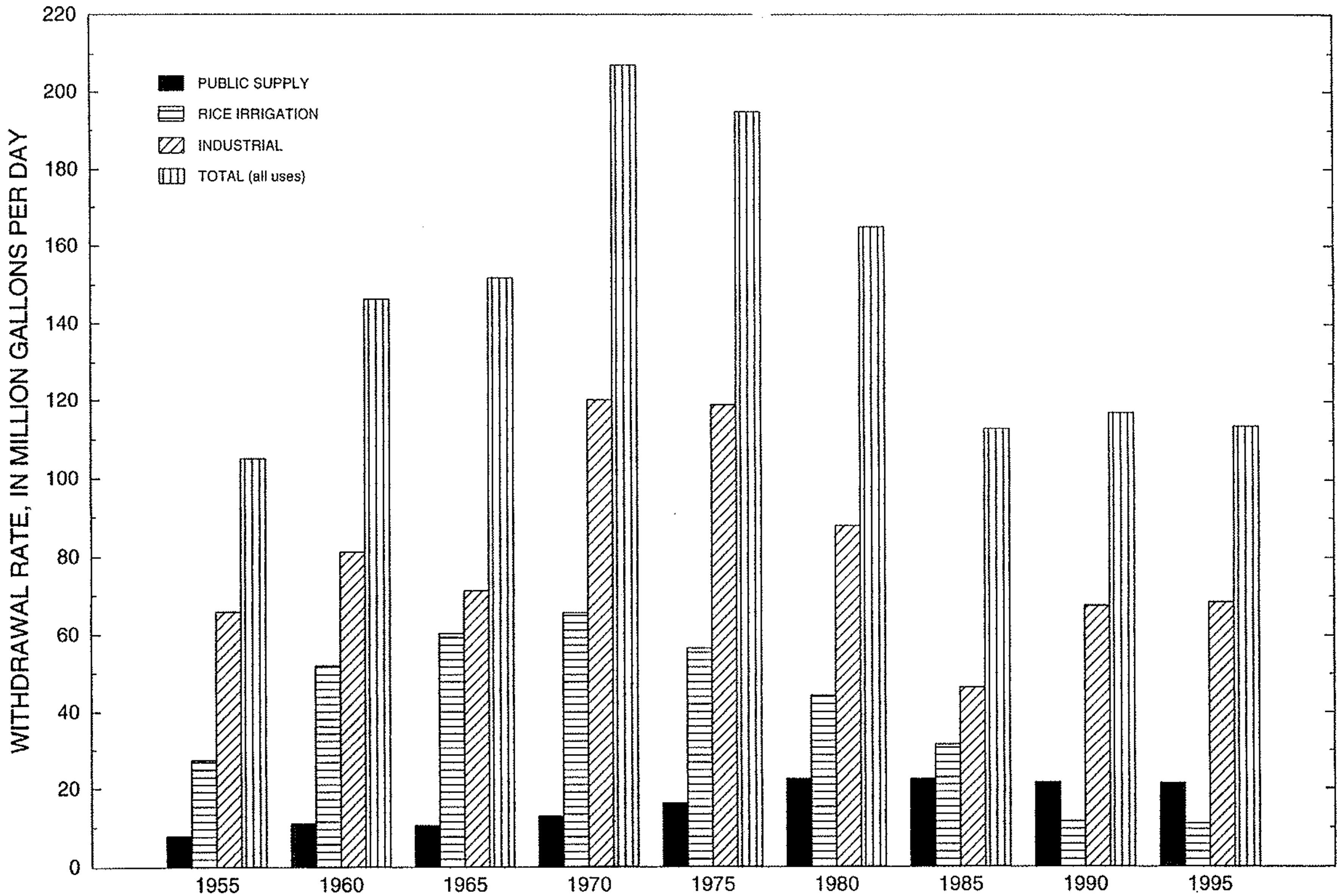

Figure 1. Ground-water withdrawal rates in Calcasieu Parish, 1955-95 (Bieber and Forbes, 1966; Cardwell and Walter, 1979; Dial, 1970; Louisiana Department of Public Works, 1956; Lovelace, 1991; Lovelace and Johnson, 1996; Lurry, 1987; Snider and Forbes, 1961; Walter, 1982).

Intense pumping in the Lake Charles area has caused a deep cone of depression in the potentiometric surface of the Chicot aquifer system in Calcasieu Parish (Zack, 1971, p. 12). In 1982, the Sabine River Diversion Canal was completed and began supplying fresh surface water to industries and other water users in the Lake Charles area. Subsequently, ground-water withdrawal rates in Calcasieu Parish decreased from more than 160 Mgal/d in 1980 to about 110 Mgal/d in 1985 (fig. 1) (Walter, 1982; Lurry, 1987). The reduced pumping of ground water caused water levels in the area to rise sharply. Chloride concentrations have continued to increase in water samples from some wells in the Lake Charles industrial district and near the Calcasieu-Cameron Parish border despite the rise in water levels that occurred after 1982.

Since 1963, the Louisiana Department of Transportation and Development (DOTD) and the U.S. Geological Survey (USGS) have maintained a cooperative agreement to monitor movement of saltwater in the Chicot aquifer system in southwestern Louisiana. Although chloride concentrations at the monitor wells indicate that saltwater encroachment may be occurring, the extent and rate of encroachment are unknown. In 1995, the USGS, in cooperation with Calcasieu Parish, began a 2-year study to define current (1995-96) hydrologic conditions of the aquifers underlying and used in Calcasieu Parish. Because saltwater encroachment has occurred to some extent in many developed coastal areas of the United States, results of this study also may help improve understanding of conditions in similar coastal settings.

Purpose and Scope

This report describes the distribution of saltwater in the Chicot aquifer system which includes many sands, referred to as the shallow, massive, upper and "200-foot" sands, "500-foot" sand, and the lower and "700-foot" sands, in the Calcasieu Parish area, Louisiana, during 1995-96, and the hydraulic connection between sands of the Chicot aquifer system and the Calcasieu River. Water levels, trends in chloride concentrations, and movement of saltwater also are discussed.

Maps are presented that show the potentiometric surface for the upper and "200-foot" sands, the "500-foot" sand, and the lower and "700-foot" sands during fall 1995. A map also shows the potentiometric surface for the upper and "200-foot" sand during spring 1996. A discussion of water-level trends is included.

The report presents comparisons of hourly water-level data collected at four nested wells with the stage of the Calcasieu River. One well is completed in each of the three Lake Charles sands, and one is completed in the overlying Chicot shallow sand. The wells are located along the banks of the Calcasieu River near pumping centers in the Lake Charles industrial district. The purpose of the comparisons is to examine the effect of river stage and pumping on water levels in the four sands.

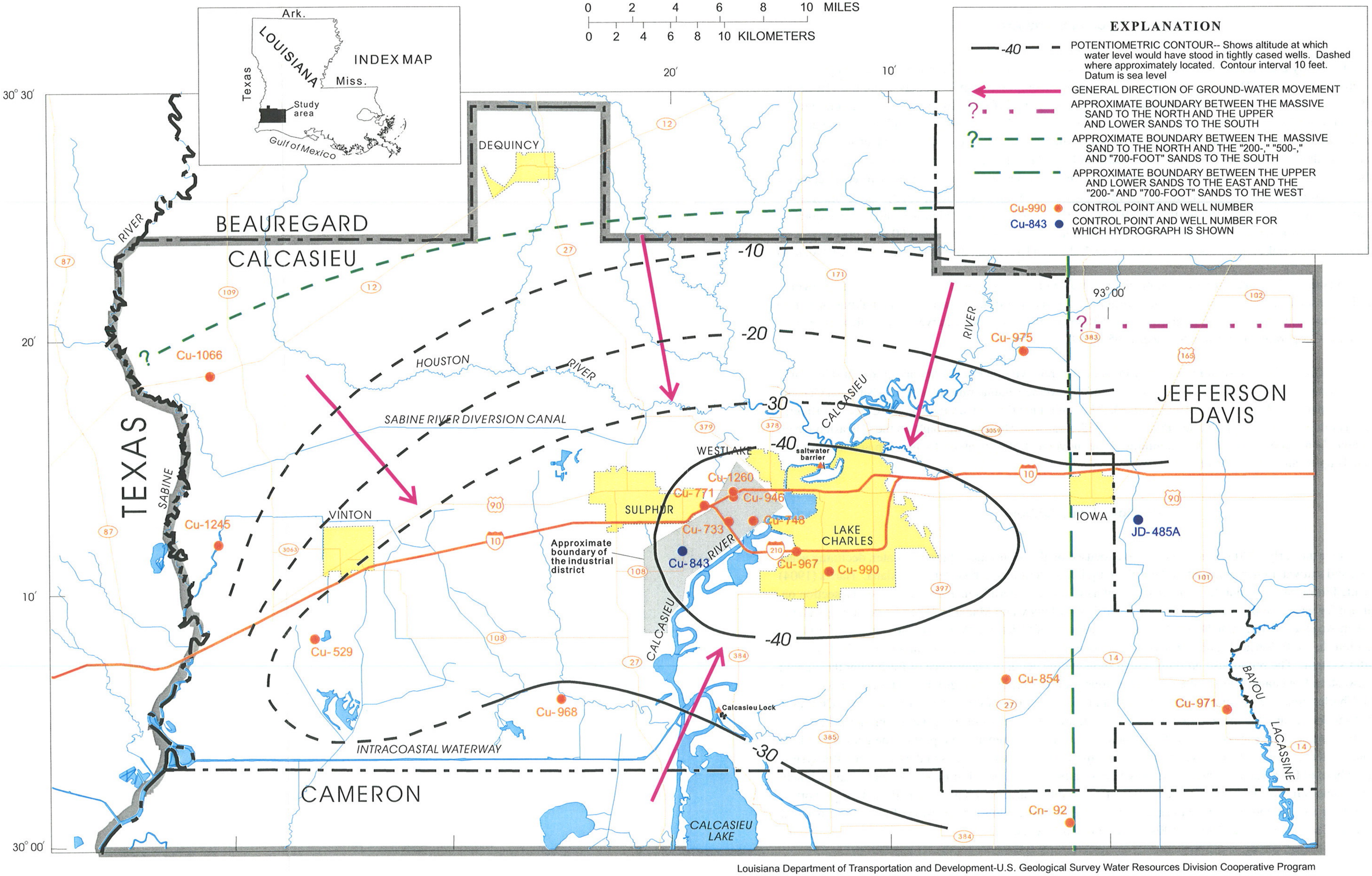

Figure 2. Location of study area and potentiometric surface of the upper and "200-foot" sands in the Calcasieu Parish area, southwestern Louisiana, fall 1995.

Description of Study Area

The study area, located in southwestern Louisiana (fig. 2), includes Calcasieu Parish and parts of Cameron and Jefferson Davis Parishes. Calcasieu Parish encompasses approximately 1,100 mi^2 (Hoffman, 1989, p. 578) and had an estimated population of 174,000 in 1994 (Center for Business and Economic Research, Louisiana Tech University, written commun., 1995). The seat of Calcasieu Parish is Lake Charles, which is located along the Calcasieu River about 12 mi north of the Intracoastal Waterway. Lake Charles, with a 1994 population of about 72,000 people, is the fifth largest city in Louisiana and home to numerous manufacturing industries, including petroleum refineries and chemical manufacturers (Center for Business and Economic Research, Louisiana Tech University, written commun., 1995). Lake Charles became a major industrial center during the 1940's when several plants moved into the area to manufacture petrochemicals for World War II. The Lake Charles industrial district covers about 60 mi^2, primarily west and southwest of Lake Charles near the banks of the Calcasieu River (fig. 2) (Nyman and others, 1990, p. 4).

Outside of the Lake Charles area, much of Calcasieu Parish is agricultural and is used for growing rice. Dense surficial clays throughout southwestern Louisiana retard surface infiltration, making the region ideal for rice cultivation. In 1994, approximately 30,000 acres of rice were harvested in Calcasieu Parish (Louisiana Cooperative Extension Service, 1995, p. 69).

The climate in Calcasieu Parish is warm and temperate with high humidity and frequent rain. The average annual temperature in the parish is 20°C and the average annual rainfall is 55 in. (National Oceanic and Atmospheric Administration, 1995, p. 7, 9). The region is primarily drained by the Calcasieu River, which is tidally affected in Calcasieu Parish. In 1968, a saltwater barrier was built on the Calcasieu River, immediately north of Lake Charles, to minimize the movement of saltwater into the deep and numerous channels upstream (Forbes, 1988).

Previous Investigations

Since the early 1900's, many studies have focused on the occurrence of ground water, declining water levels, and saltwater encroachment in the Chicot aquifer system of southwestern Louisiana. Harris (1904) presented information about the underground waters of southwestern Louisiana and included a section on their use for water supplies and rice irrigation. In 1944, Stanley and Maher reported on declining water levels in Acadia and Jefferson Davis Parishes, located east of Calcasieu Parish, due to pumpage for rice irrigation. In 1950, Jones (1950b) discussed water quality and the occurrence of saltwater in the Chicot aquifer system. The report also presents a map showing the depth of occurrence of freshwater throughout southwestern Louisiana. During the same year, Jones (1950a) reported on ground-water conditions in the Lake Charles area, mentioning the rapid growth and increasing use of ground water in the Lake Charles industrial district and the increasing chloride concentration in water from some wells completed in the "700-foot" sand. Jones and others (1954) presented the first comprehensive report on the geology and ground-water resources of southwestern Louisiana; the authors presented maps of the Chicot aquifer system and the base of freshwater, discussed the presence of saltwater, and possibilities of saltwater encroachment in basal sands and coastal areas of the Chicot aquifer system. Harder (1960a) presented a detailed report on the geology and ground-water resources of Calcasieu Parish, including a discussion of the occurrence and mobility of saltwater in the "200-," "500-," and "700-foot" sands.

Reports summarizing ground-water conditions in southwestern Louisiana were published regularly during 1948-71. These reports document long-term water-level declines in the upper sand and the "500-foot" and "700-foot" sands with hydrographs and potentiometric surface maps. Most of the reports include an additional discussion of some related aspect of the Chicot aquifer system. For example, the occurrence of saltwater in the "700-foot" sand and the subsequent abandonment of a well is mentioned in Fader (1954). Fader (1957) updated the Jones and others (1954) base-of-freshwater map and discussed possible sources of the saltwater, including incomplete flushing, lateral movement, recharge from surface sources, vertical movement, and upward movement near salt domes. Harder (1960b) mentioned the abandonment of several wells in the "700-foot" sand located in the Lake Charles industrial district due to the occurrence of brackish water in a nearby well. Whitman and Kilburn (1963) discussed the occurrence and inland movement of saltwater in coastal areas of the upper sand due to intense ground-water pumpage. Hodges and others (1963) discussed the occurrence of brackish water and methane in the "700-foot" sand at the Lockport oil field in the Lake Charles industrial district. Harder and others (1967) presented maps of freshwater-saltwater interfaces in the upper sand, the "500-foot" sand, and the "700-foot" sand and discussed the rates of encroachment in each.

Zack (1971) summarized the results of 10 years of monitoring chloride concentrations at 30 wells of a network established to monitor saltwater encroachment in the Chicot aquifer system. Nyman (1984) summarized chloride and specific-conductance data collected by the USGS for wells in the Chicot aquifer system since 1937, focusing on data from the network monitoring chloride concentrations. Nyman also used electric and drillers' log data to create geologic and hydrologic maps showing thicknesses of sections with freshwater and locations of saltwater in the Chicot aquifer system. In another study, Nyman and others (1990) presented the results of a digital ground-water flow model, which indicated that the largest component of recharge to the Chicot aquifer system during 1981 conditions was vertical leakage. Potentiometric surface maps of water levels in the Chicot aquifer system for 1984 and 1991 conditions have also been published (Fendick and Nyman, 1987; Walters, 1996).

Acknowledgments

The author gratefully acknowledges the assistance of numerous industries, public suppliers, and private well owners in Calcasieu Parish who allowed their wells to be sampled. A special thanks is given to Don Starkovich and the Olin Corporation for allowing an additional well to be drilled and granting regular access to existing wells located on Olin Corporation property. Thanks also to Zahir "Bo" Bolourchi, Chief, Water Resources Section, Louisiana Department of Transportation and Development, for his assistance in the publication of this report.

HYDROGEOLOGY

Description of Hydrogeologic Units

The Chicot aquifer system consists of alternating beds of unconsolidated sand, gravel, silt, and clay and underlies most of southwestern Louisiana and parts of eastern Texas. The sediments, deposited in deltaic and near-shore marine environments during the Pleistocene Epoch, form beds that dip and thicken southward, beneath the Gulf of Mexico (fig. 3). The sand units grade southward from coarse sand and gravel to finer sediments and become increasingly subdivided by clay units. The aquifer system also thickens eastward, toward the Atchafalaya River basin, and is hydraulically connected to alluviums of the Atchafalaya and Mississippi Rivers. Recharge to the Chicot aquifer system occurs as downward percolation from the land surface in the outcrop area of the sand part of the aquifer north of the study area, through the Mississippi River alluvial aquifer from the Atchafalaya River east of the study area (fig. 4), from vertical leakage through surficial clay units, and, to a lesser extent, upward leakage from the underlying Evangeline aquifer.

The Chicot aquifer system has been divided into three subregions in Louisiana based on the occurrence of major clay units. In the northern part of the study area, the aquifer system is comprised mainly of a single massive sand, referred to in this report as the massive sand (fig. 4). South of the massive sand, in the extreme eastern part of Calcasieu Parish, and in parishes east to the Atchafalaya River, the Chicot aquifer system includes an upper sand and a lower sand (Whitman and Kilburn, 1963, p. 10). In most of Calcasieu Parish and in the central and western parts of Cameron Parish, the aquifer system includes the "200-," "500-," and "700-foot" sands, named after their depth of occurrence in the Lake Charles area (Jones, 1950b, p. 2). The "200-foot" sand is stratigraphically equivalent to, and continuous with, the upper sand. The "700-foot" sand is stratigraphically equivalent to, and continuous with, the lower sand. The "500-foot" sand pinches out to the east near the Calcasieu-Jefferson Davis Parish border. In addition, several relatively thin sands that occur locally within a surficial confining unit are collectively termed the shallow sands. The hydrogeologic column of aquifers and aquifer systems in southwestern Louisiana is shown in figure 5.

At the top of the Chicot aquifer system is a thick layer of clay that is a surficial confining unit and is areally extensive throughout most of southwestern Louisiana. Rice cultivation during the past 100 years has caused salts and fine clays to leach downward forming a low-permeability horizon in the surficial clay, called the "hard pan" by local farmers (Dale Nyman, formerly of the U.S. Geological Survey, written commun., 1997). The surficial confining unit generally ranges from 100 to 200 ft in thickness in Calcasieu Parish, but locally contains sand lenses that occur at varying depths (Harder, 1960a, plate 4). Surficial clays in southern Louisiana were once thought an impermeable barrier to downward movement of water from the surface (Stanley and Maher, 1944, p. 13; Meyer, 1953, p. 2). However, faulting and fracturing associated with salt domes and secondary porosity created by subaerial weathering after deposition have resulted in vertical hydraulic conductivities of the clays that may be several orders of magnitude higher than those measured from core samples in a laboratory (Hanor, 1993). Results of a computer simulation of ground-water flow in the Chicot aquifer system, conducted in the 1980's, indicate that vertical leakage, primarily from the surface, currently (1996) is the largest component of recharge to the aquifer and is occurring throughout southwestern Louisiana (Nyman and others, 1990, p. 33).

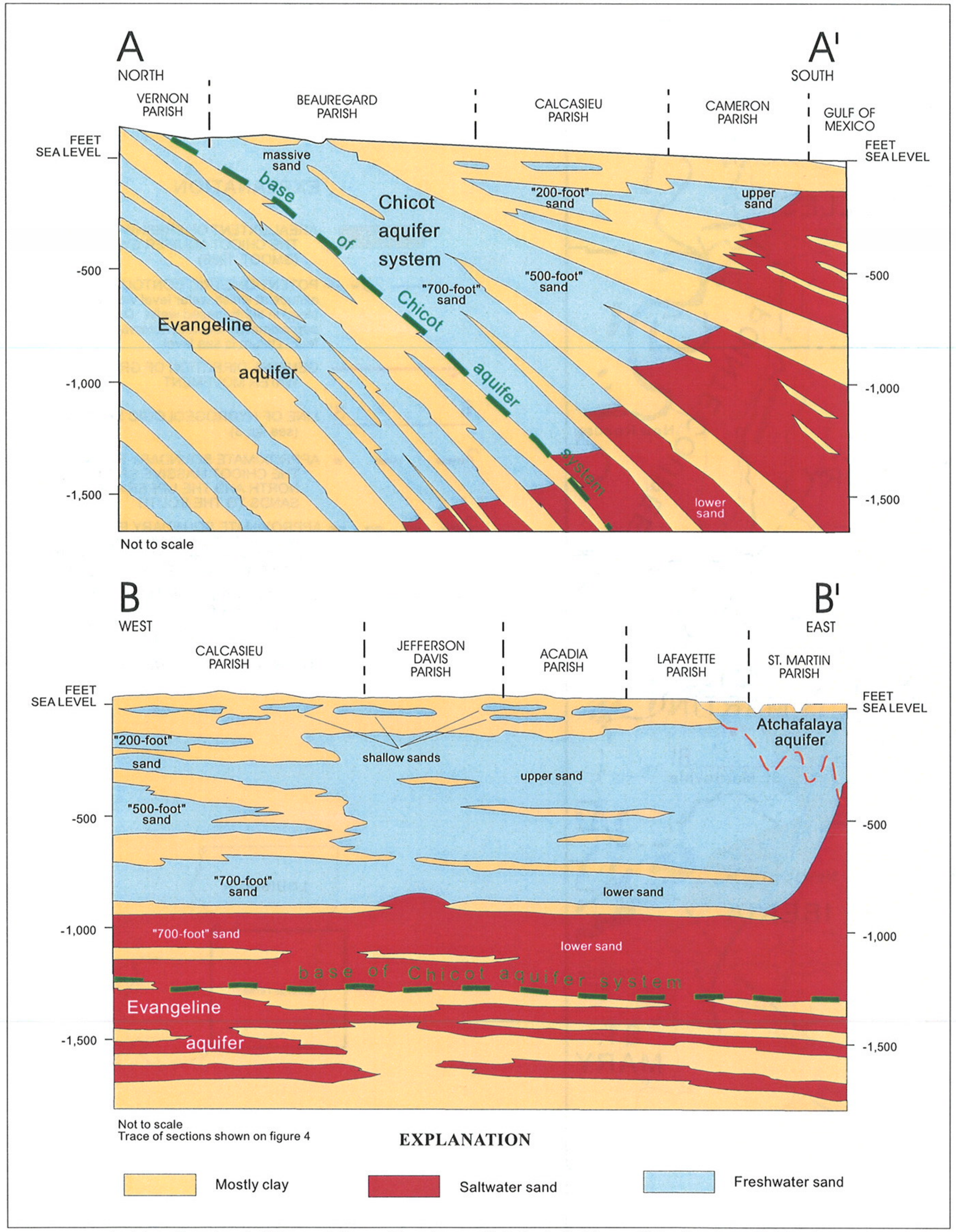

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Figure 3. Idealized hydrogeologic sections through southwestern Louisiana (modified from Nyman, 1984, p.5).

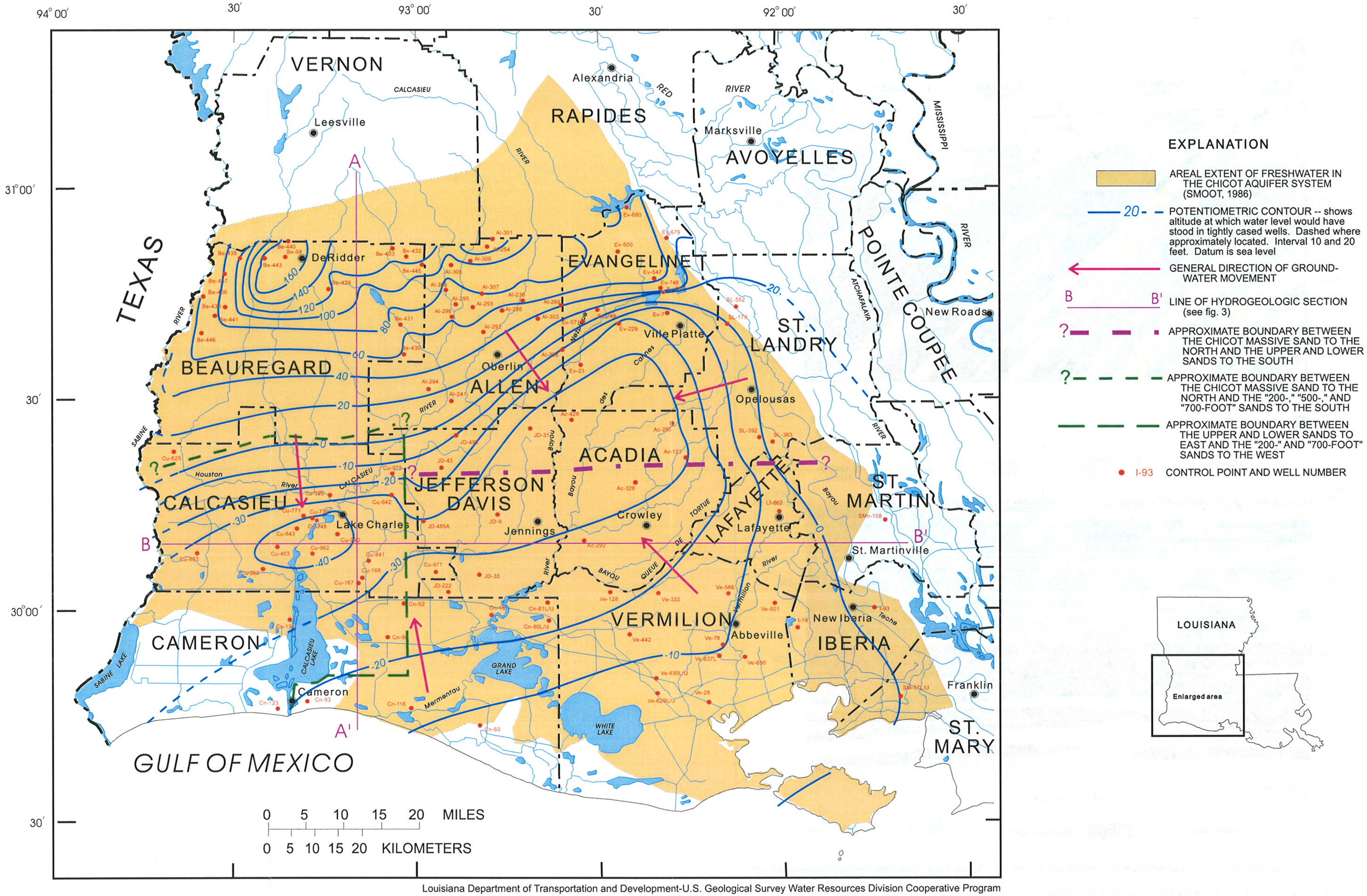

Figure 4. Potentiometric surface of the massive, upper, and "200-foot" sands of the Chicot aquifer system, spring 1991 (Modified from Walters, 1996, sheet 1).

<table>
<tr><th rowspan="2">System</th><th rowspan="2">Series</th><th rowspan="2">Aquifer system</th><th colspan="2">Aquifer</th></tr>
<tr><th>Lake Charles area</th><th>Rice growing area</th></tr>
<tr><td rowspan="3">Quaternary</td><td rowspan="3">Pleistocene</td><td rowspan="3">Chicot aquifer system</td><td>Shallow sands</td><td>Shallow sands</td></tr>
<tr><td>"200-foot" sand</td><td>Upper sand</td></tr>
<tr><td>"500-foot" sand
"700-foot" sand</td><td>Lower sand</td></tr>
<tr><td rowspan="2">Tertiary</td><td>Pliocene</td><td rowspan="2" colspan="3">Evangeline aquifer</td></tr>
<tr><td>? Miocene</td></tr>
</table>

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Figure 5. Partial hydrogeologic column of an aquifer system and aquifers in southwestern Louisiana (modified from Lovelace and Lovelace, 1995).

Water Levels and Movement

Prior to development, water entered the Chicot aquifer system at recharge areas in southern Rapides and Vernon Parishes and northern Allen, Beauregard, and Evangeline Parishes and moved down-dip to discharge areas in the Atchafalaya, Sabine, and lower Vermilion River basins (fig. 4) and in the coastal marshes (Nyman and others, 1990, p. 11-12). Springs and flowing wells completed in the Chicot aquifer system were common in parts of Calcasieu Parish and coastal areas from Cameron Parish to St. Mary Parish (Harris, 1904, p. 28).

By 1946, large withdrawals for rice farming and, in the Lake Charles area, for manufacturing purposes during World War II, had substantially altered the pattern of flow in the Chicot aquifer system (Jones and others, 1954). Water from all areas of the aquifer then flowed towards rice-growing areas in Acadia, Evangeline, and Jefferson Davis Parishes and towards the Lake Charles industrial district in Calcasieu Parish. This pattern of flow has continued to the present; water levels in the upper and "200-foot" sands are lower than 30 ft below sea level in much of Calcasieu, Jefferson Davis, and Acadia Parishes (fig. 4) (Fendick and Nyman, 1987; Walters, 1996).

The completion of the Sabine River Diversion Canal in 1982, and the subsequent decreased use of ground water by industries in the Lake Charles industrial district, caused water levels in the "500-foot" sand, the most intensely pumped of the three Lake Charles sands, to rise from a low of more than 150 ft below sea level to about 100 ft below sea level in the deepest part of the cone of depression beneath the industrial district. Water levels in wells in the "200-foot" sand and "700-foot" sand also rose in the industrial district by as much as 20 ft and 30 ft respectively.

Water levels in the upper and "200-foot" sands in Calcasieu Parish during fall 1995 and spring 1996 ranged from approximately sea level to 60 ft below sea level (figs. 2, 6). Lowered water levels in the "200-foot" sand in the Lake Charles area are partially due to vertical leakage of water from the "200-foot" sand into the "500-foot" sand, caused by intense pumping from the "500-foot" sand (Nyman, 1984, p. 8). Water-level data for all wells measured are included in the appendix. Variations in density caused by the presence of saltwater in wells in some areas were not great enough to require adjustment of water levels to freshwater equivalents.

In the southeastern part of the parish, water levels in the upper and "200-foot" sands have large seasonal fluctuations (30 ft or more) in response to pumping for rice irrigation, as illustrated by the hydrograph for well JD-485A (figs. 6, 7), near the Calcasieu-Jefferson Davis Parish border. In the industrial district, water levels in the "200-foot" sand primarily are affected by intense pumping from the "500-foot" sand, and the seasonal fluctuations typically are less than 5 ft, as illustrated by the hydrograph for well Cu-843 (figs. 6, 7), located near the center of the industrial district. Water levels in well Cu-843 rose about 12 ft during the early 1980's in response to decreased ground-water withdrawal rates due to industrial use of surface water after the completion of the Sabine River Diversion Canal.

During the fall and winter months, lateral movement of water through the upper and "200-foot" sands generally are toward the Lake Charles industrial district (fig. 2). During spring and summer months, as water levels decline due to pumping for rice irrigation, the lateral movement of water shifts toward the southeast corner of the parish (fig. 6). However, figures 2 and 6 do not present the seasonal extremes of recovery or drawdown in the upper and "200-foot" sands. The amplitude of fluctuation indicated for the 1995 rice-growing season in well JD-485A is 40 ft (fig. 7). Seasonal extremes would be mid-February (recovery) and mid-July (drawdown) in the rice-growing area.

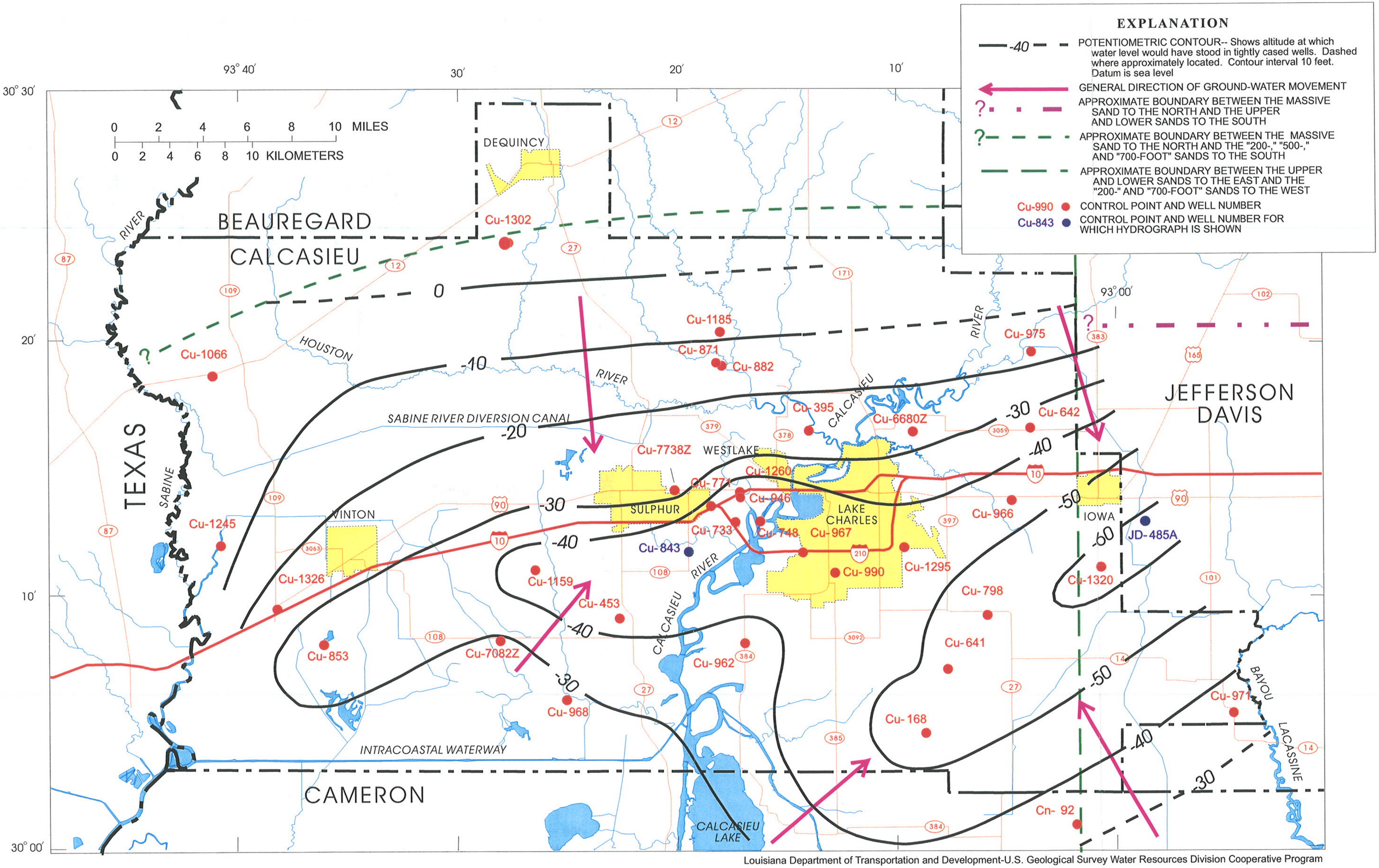

Figure 6. Potentiometric surface of the upper and "200-foot" sands in the Calcasieu Parish area, southwestern Louisiana, spring 1996.

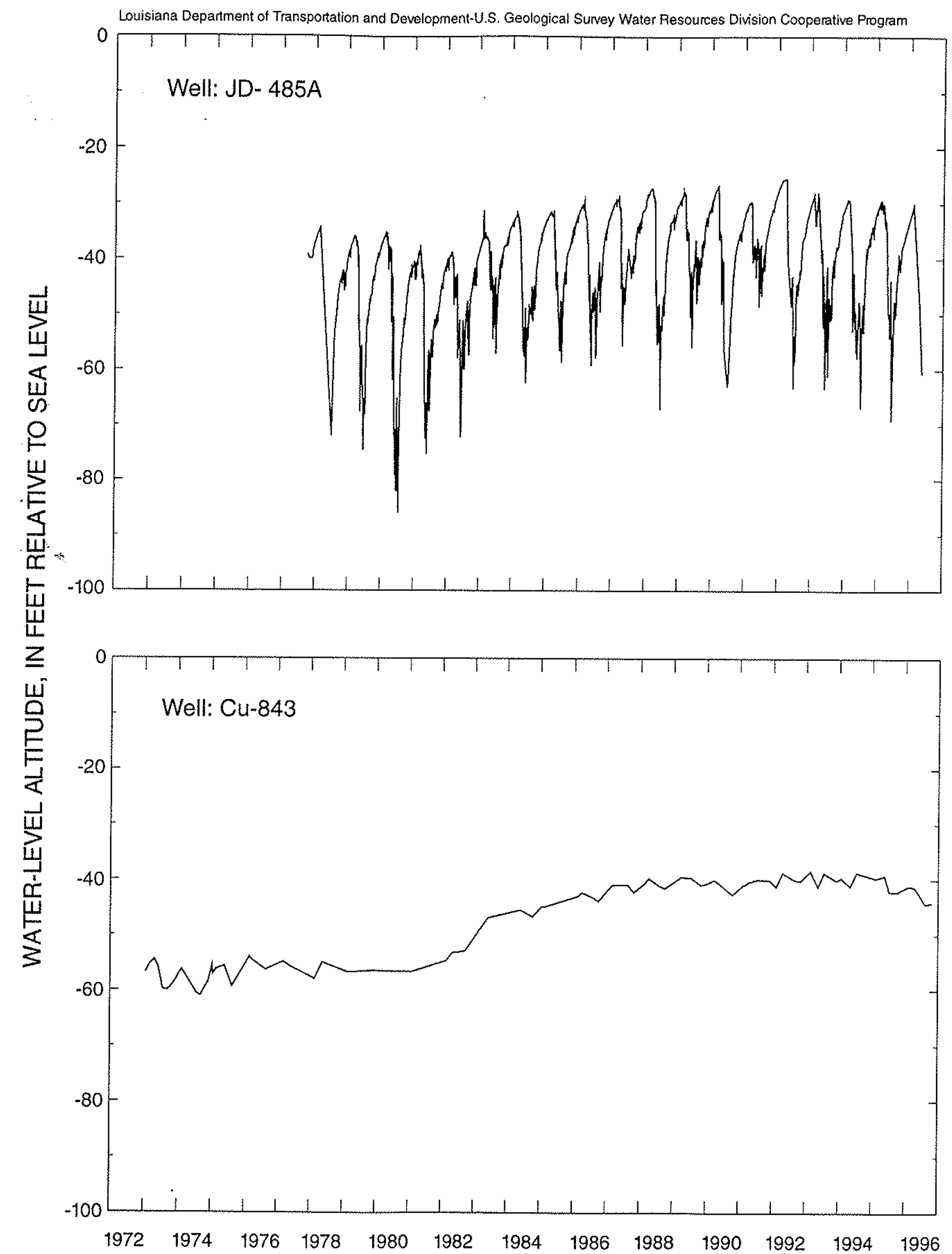

Figure 7. Water levels in the upper sand for well JD-485A and in the "200-foot" sand well Cu-843.

Water levels in the "500-foot" sand ranged from less than 20 ft below sea level to more than 100 ft below sea level in Calcasieu Parish during fall 1995 (fig. 8). The cone of depression, centered over the Lake Charles industrial district (fig. 9), is the result of intense local pumping. The hydrograph for well Cu-445 (former location shown on fig. 9; destroyed in 1994) shows a 50-ft rise in water level during 1982 after completion of the Sabine River Diversion Canal (fig. 10). Typically water levels in the aquifer fluctuate seasonally between 5 and 10 ft, which can be attributed to increased withdrawal rates by industries and public supplies during summer months, as well as some withdrawals for rice irrigation. The general lateral movement of water in the "500-foot" sand in all areas of Calcasieu Parish is toward the Lake Charles industrial district (fig. 8).

Water levels in the lower and "700-foot" sands ranged from less than 20 ft below sea level to more than 80 ft below sea level during fall 1995 (fig. 11). A cone of depression, centered beneath the Lake Charles industrial district, is primarily the result of pumping from the "500-foot" sand. The "500-foot" sand and the "700-foot" sand are hydraulically connected in numerous areas throughout the parish where the confining unit between the two sands is thin or missing. Vertical leakage of water from the "700-foot" sand to the "500-foot" sand has resulted in much lower water levels in the "700-foot" sand than could be attributed to pumping from the "700-foot" sand. Water levels rose about 30 ft in well Cu-446 (former location shown on fig. 11; destroyed in 1994) due to decreased withdrawal rates from the "500-foot" sand after the completion of the Sabine River Diversion Canal (fig. 10).

DISTRIBUTION OF SALTWATER IN THE CHICOT AQUIFER SYSTEM

The occurrence of saltwater in the Chicot aquifer system in Calcasieu Parish primarily has been attributed to encroachment (lateral movement inland from coastal areas and upward movement from underlying aquifers). For this report, saltwater is defined as water containing greater than 250 mg/L of chloride[1]. Chloride concentrations in water from the Chicot aquifer system in Calcasieu Parish generally range from 15 to 70 mg/L (background concentrations). Water with higher chloride concentrations (>70 mg/L) occurs in the Chicot aquifer system in small areas of Calcasieu Parish where it is not associated with saltwater encroachment, such as in very shallow sands and locally near salt domes.

Because highly saline water is denser than freshwater, two distinct layers may be formed because of the density difference, and the contact between a freshwater body and a saltwater body within an aquifer may form a mixing zone or interface. In Louisiana's coastal areas, the freshwater-saltwater interface typically resembles a low-angle wedge. The leading edge of the saltwater wedge, known as the "toe," lies at the base of each sand and generally extends many miles inland from the main body of saltwater (Nyman, 1984, p. 10).

Hydrogeologic factors and the effects of pumping on hydraulic and salinity gradients determine the rate and direction of saltwater encroachment in the Chicot aquifer system. Hydraulic properties of the individual sands, such as permeability and porosity, affect the rate of flow through the aquifer. Hydrogeologic factors, such as the configuration of the base of the aquifer and faulting, can affect the direction of movement of saltwater. Pumped wells affect hydraulic gradients and the rate and direction of saltwater movement.

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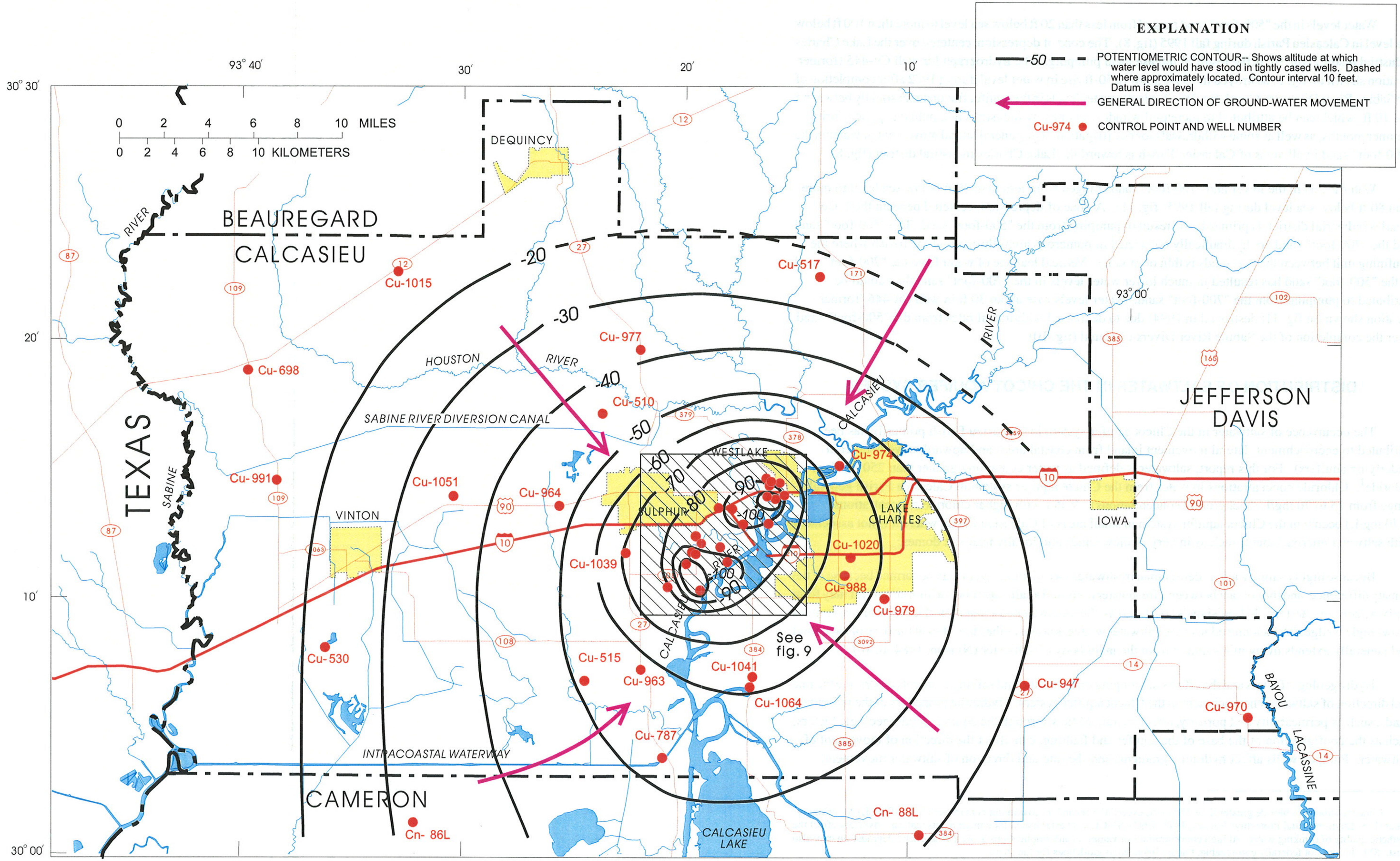
[1]Concentrations of chloride greater than 250 mg/L exceed the secondary maximum contaminant level (SMCL) for drinking water (U.S. Environmental Protection Agency, 1977, 1992). SMCL's are established for contaminants that can adversely affect the aesthetic quality of drinking water. At high concentrations or values, health implications as well as aesthetic degradation may also exist. SMCL's are not federally enforceable, but are intended as guidelines for the states.



Louisiana Department of Transportation and Development-U.S. Geological Survey Water Resources Division Cooperative Program

Figure 8. Potentiometric surface of the "500-foot" sand in the Calcasieu Parish area, southwestern Louisiana, fall 1995.

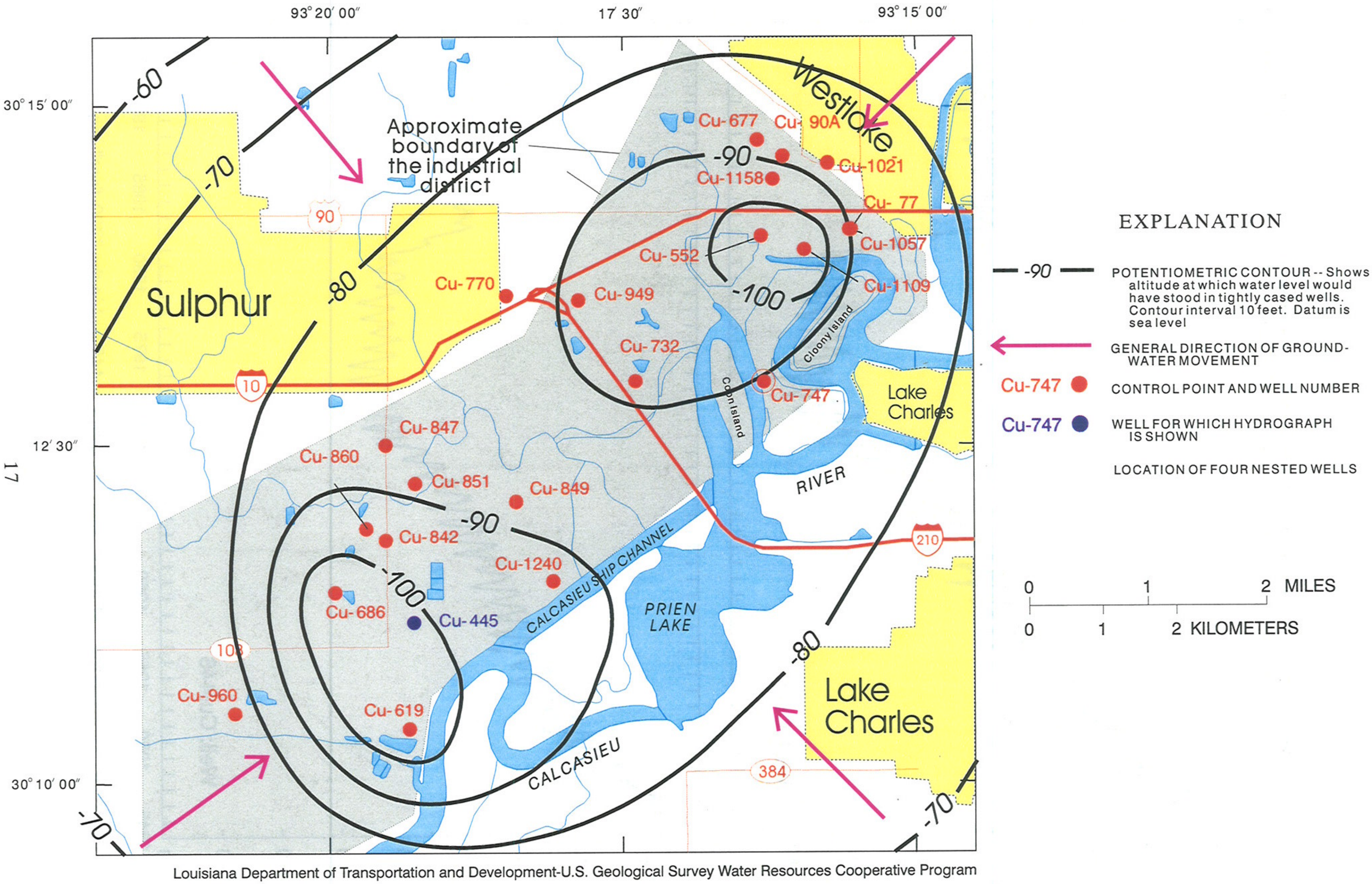


Figure 9. Potentiometric surface of the "500-foot" sand in the Lake Charles industrial district, Calcasieu Parish, Louisiana, fall 1995.

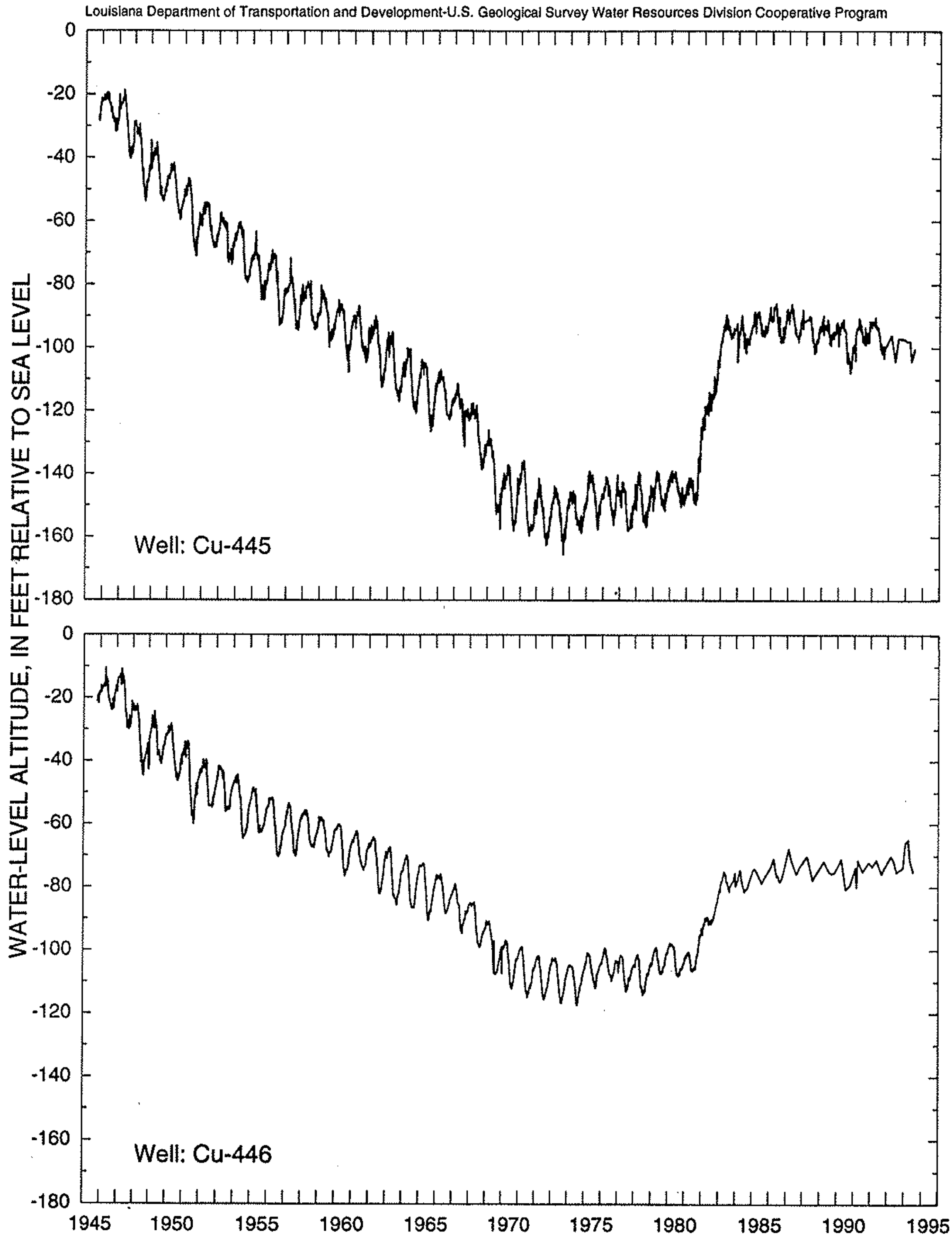


Figure 10. Water levels in the "500-foot" sand for well Cu-445 and in the "700-foot" sand for well Cu-446.

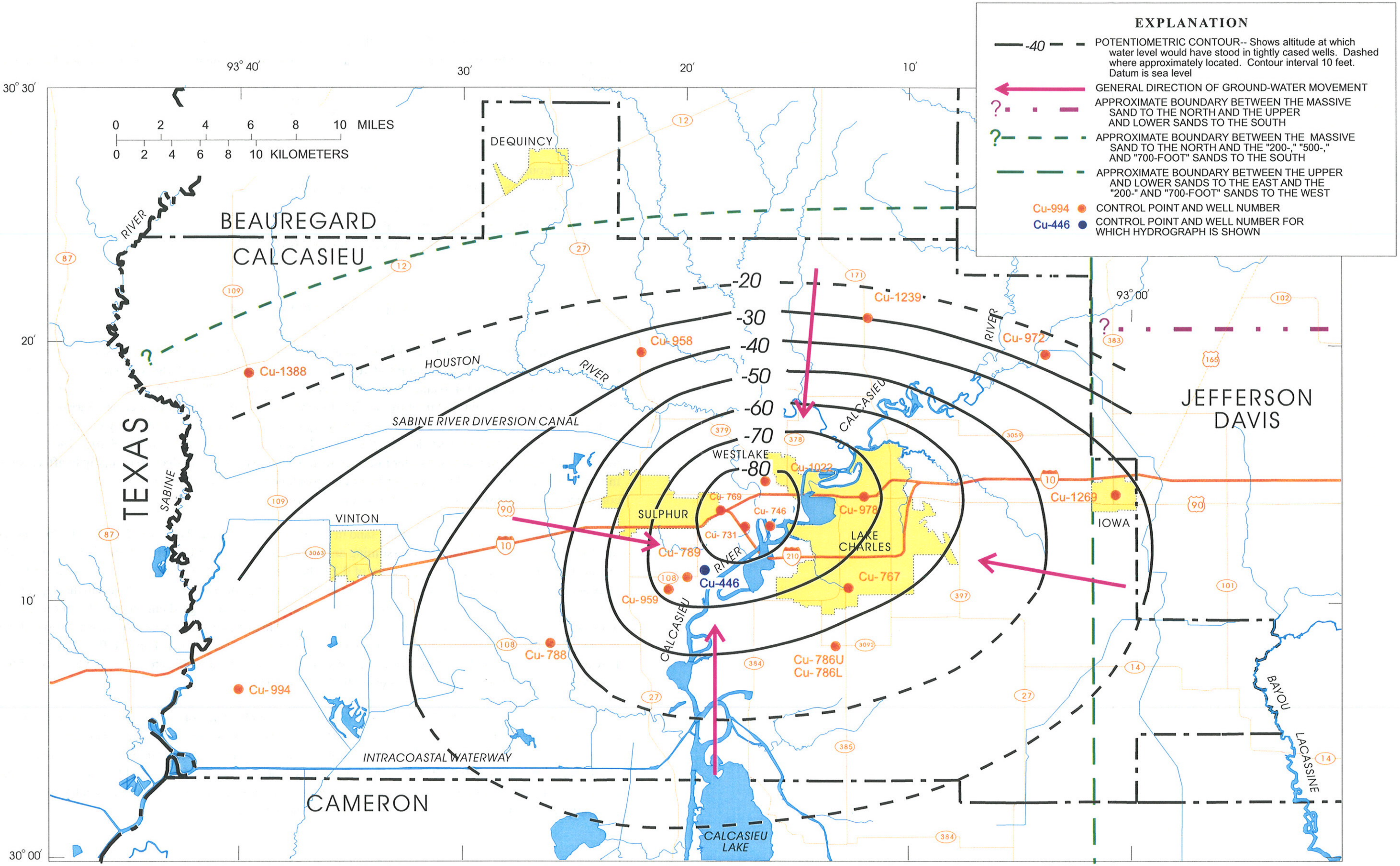


Figure 11. Potentiometric surface of the lower and "700-foot" sands in the Calcasieu Parish area, southwestern Louisiana, fall 1995.

The rate of ground-water flow and, therefore, the potential rate of saltwater movement, can be estimated based on hydraulic properties of an aquifer, hydraulic gradient, and the following application of Darcy's law:

$$V = \frac{KI}{\Theta}, \qquad \text{(Eq. 1)}$$

where

V is ground-water velocity, in feet per day;
K is aquifer hydraulic conductivity, in feet per day;
I is hydraulic gradient, in feet per foot; and
Θ is aquifer porosity, as a decimal fraction.
Use of Darcy's Law for this estimate assumes no dispersion or density effects.

Upper and "200-Foot" Sands

Saltwater in the upper and "200-foot" sands has been documented in the extreme southeastern corner of Calcasieu Parish, near Hayes and Bell City, and eastward into southern Jefferson Davis Parish (fig. 12) between altitudes of about 400 and 500 ft below sea level (Nyman, 1984, p. 13-20, pl. 2). The base of the upper sand occurs at about 500 ft below sea level in the southeastern corner of Calcasieu Parish (Nyman, 1984, p. 15, 41). The base of the stratigraphically equivalent "200-foot" sand generally occurs at altitudes between 200 and 300 ft below sea level in the Lake Charles area (Nyman, 1984, p. 41; Harder, 1960a, pl. 4), indicating that the freshwater-saltwater interface would have to move more than 10 mi updip to affect wells in the Lake Charles area. However, northward encroachment of saltwater towards rice-farming regions could occur in response to intense pumping for irrigation.

The hydraulic gradient in the upper sand in southeastern Calcasieu Parish was less than 1 ft/mi during fall 1995 (fig. 2). Using equation 1, assuming an average hydraulic conductivity of 200 ft/d (Harder and others, 1967, p. 7) and an average porosity of 0.25, the average velocity of ground-water flow along the interface was less than 55 ft/yr (0.15 ft/d) during the fall. During spring 1996, water levels in the upper sand declined due to pumping for rice irrigation and the northward hydraulic gradient increased to more than 3.3 ft/mi in the southeastern corner of the parish (fig. 6). The average velocity of ground-water flow along the interface, and the potential rate of saltwater movement, increased to more than 180 ft/yr (0.5 ft/d). However, there is no evidence that further encroachment has occurred in this area since the location of the freshwater-saltwater interface was delineated by Nyman (1984).

Chlorographs for wells Cn-92 and Cu-971 indicate that chloride concentrations at these wells have not changed substantially since the early 1970's (fig. 13). These wells were designed to enable identification of changes in chloride concentrations at the freshwater-saltwater interface in this area. Well Cn-92 is completed immediately below the base of freshwater at the interface. Well Cu-971 is completed at the base of the upper sand. Chloride concentrations in water samples from other wells in the area, generally located north of the interface, also showed little change.

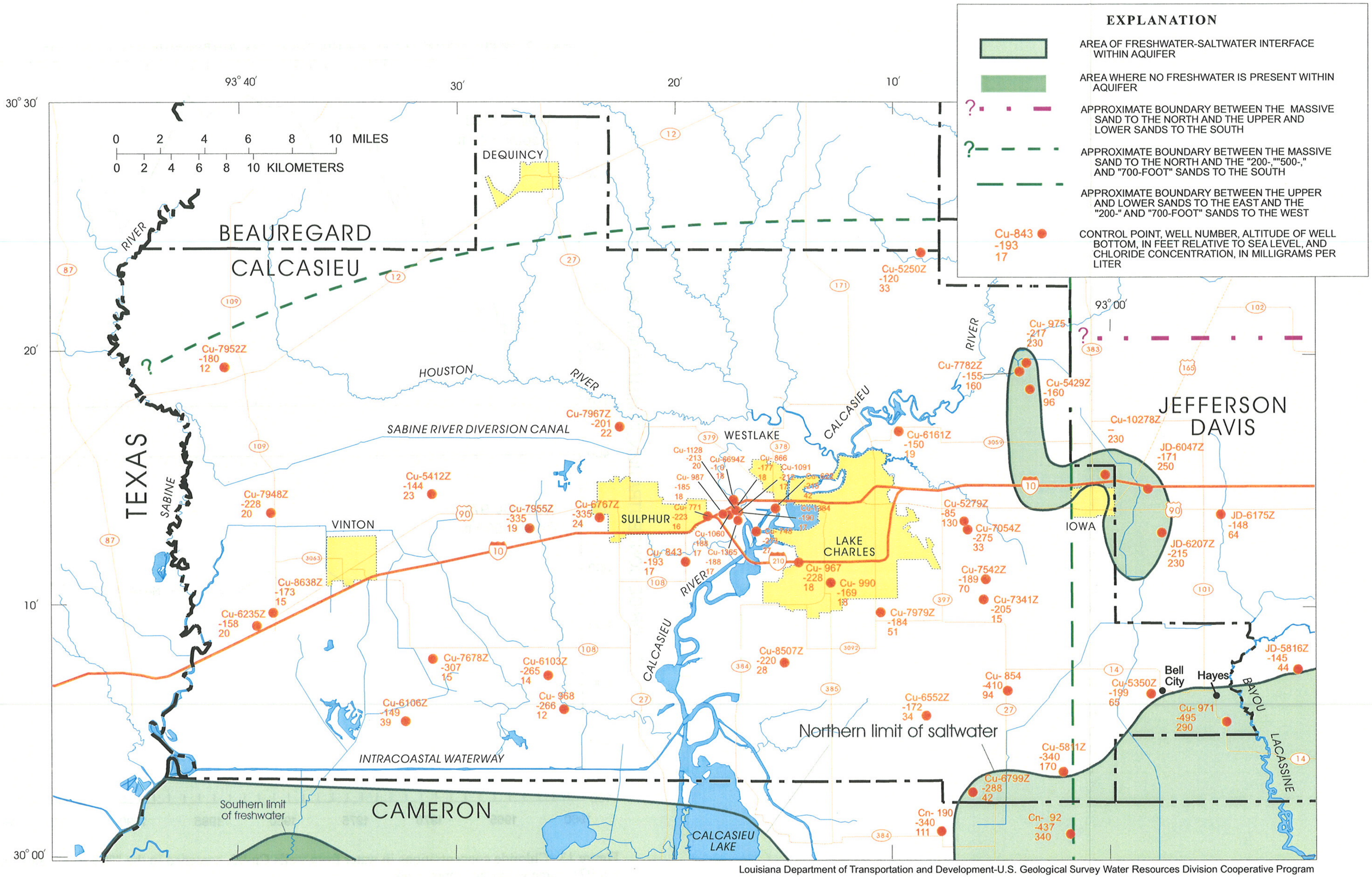


Figure 12. Distribution of chloride in the upper and "200-foot" sands in the Calcasieu Parish area, southwestern Louisiana, 1996 (modified from Nyman, 1984 and 1989).

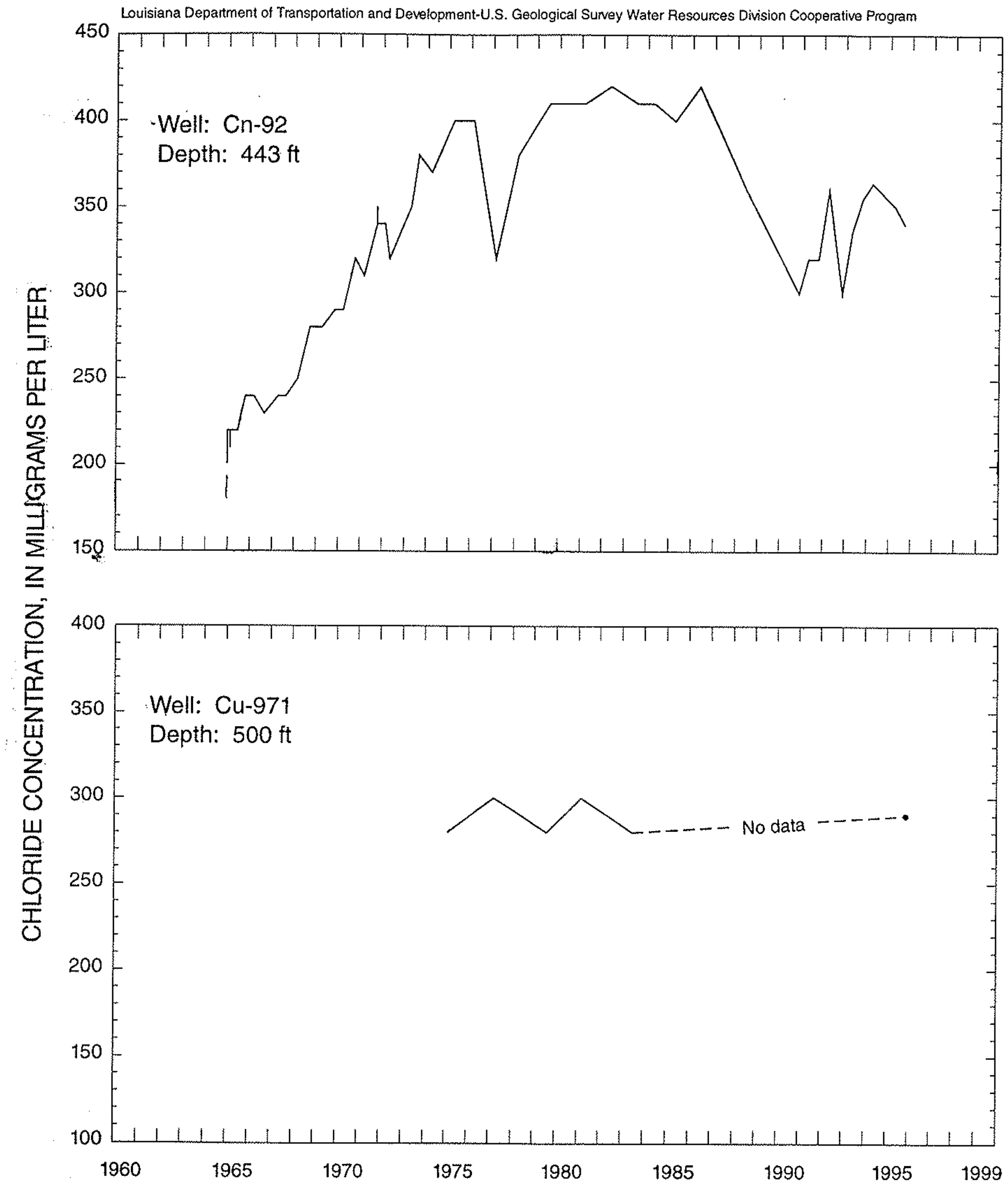


Figure 13. Chloride concentrations in water from wells Cn-92, screened in the "200-foot" sand, and Cu-971, screened in the upper sand.

Saltwater also is present in the "200-foot" sand in western Cameron Parish, where the freshwater-saltwater interface is a relatively thin band near the Calcasieu-Cameron Parish border (fig. 12) (Nyman, 1989, pl. 9). In this area, the aquifer thins to less than 50 ft and splits into two or three separate sands (Harder, 1960a, p. 27). Because the "200-foot" sand is relatively thin throughout southwestern Calcasieu Parish, water from this unit generally is used only for domestic purposes, and there has been no evidence of saltwater encroachment in this area since the location of the freshwater-saltwater interface was delineated by Nyman (1984).

A saltwater body is present in the upper sand over a 90 mi^2 area in the vicinity of Iowa, in eastern Calcasieu Parish (fig. 12). Nyman (1984, p. 26-30) determined that this saltwater body was static, neither spreading nor increasing in salinity, since the early 1960's. Water samples from wells in the area confirm the presence of the high chloride concentrations. However, because none of the wells available for sampling during this study had been previously sampled, it is not known whether chloride concentrations have increased or decreased, or whether the saltwater body has moved substantially since the early 1980's. However, any saltwater movement in the area probably would be toward the south. The base of the upper sand dips to the south at a rate of about 20 ft/mi in this area (Nyman, 1984, pl. 3), and the potentiometric surface maps (figs. 2, 6) indicate a southward hydraulic gradient averaging about 3.5 ft/mi in the Iowa area. Using equation 1 and assuming the same hydraulic conductivity and porosity values as used previously, the average velocity of ground-water flow along the freshwater-saltwater interface in the Iowa area is about 190 ft/yr (0.53 ft/d) toward the south.

"500-Foot" Sand

Saltwater is present in the "500-foot" sand near the Calcasieu-Cameron Parish border between altitudes of about 500 and 600 ft below sea level (Nyman, 1984, pl. 4) and may be moving slowly northward in response to pumping in Calcasieu Parish (fig. 14). Saltwater also occurs in the "500-foot" sand in the Lake Charles industrial district, where intense pumping has caused saltwater to migrate vertically upward from the saltier "700-foot" sand in areas where the aquifers are interconnected.

Coastal Area

Chloride concentrations in wells Cn-86L, Cn-88L, and Cu-787 indicate that saltwater encroachment in the "500-foot" sand may be occurring at an extremely low rate near the Calcasieu-Cameron Parish border. These wells have been sampled semi-annually since 1964 to track the northward progress of saltwater in this area, and chlorographs for all three wells indicate long-term increases in chloride concentrations (fig. 15). Chloride concentrations in wells Cn-86L and Cn-88L, completed below the base of freshwater at the freshwater-saltwater interface, increased at rates of about 3 (mg/L)/yr and 2 (mg/L)/yr. These rates are relatively low, but could increase in response to increased pumping and lowered water levels in the Lake Charles area. Well Cu-787, which is located north of the leading edge of saltwater and completed about 35 ft above the base of the aquifer, experienced an extremely low rate of increase of 0.7 mg/L per year (fig. 15). Chloride trends at other wells completed in the "500-foot" sand near the freshwater-saltwater interface generally have shown no substantial long-term changes.

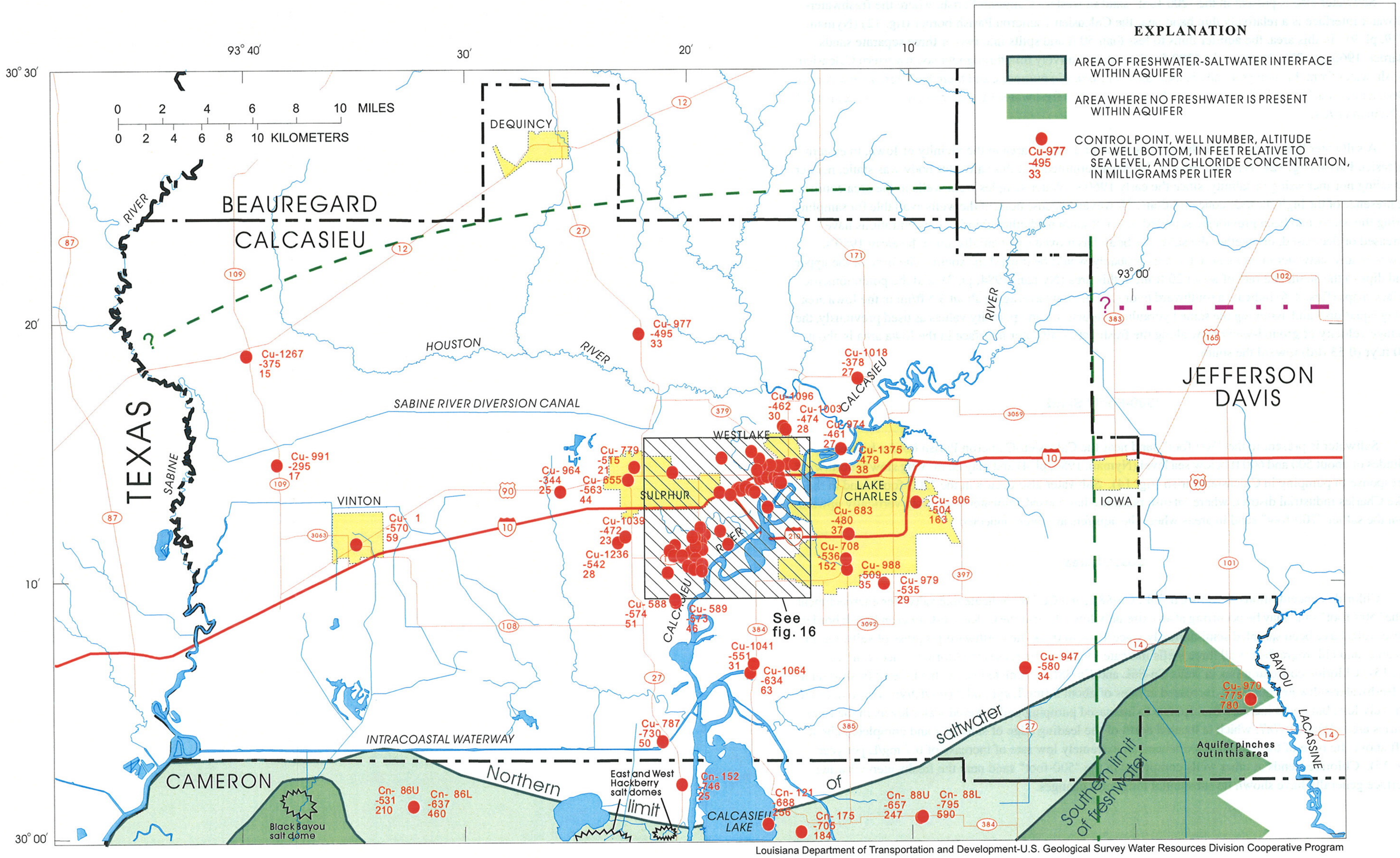


Figure 14. Distribution of chloride in the "500-foot" sand in the Calcasieu Parish area, southwestern Louisiana, 1996 (modified from Nyman, 1984).

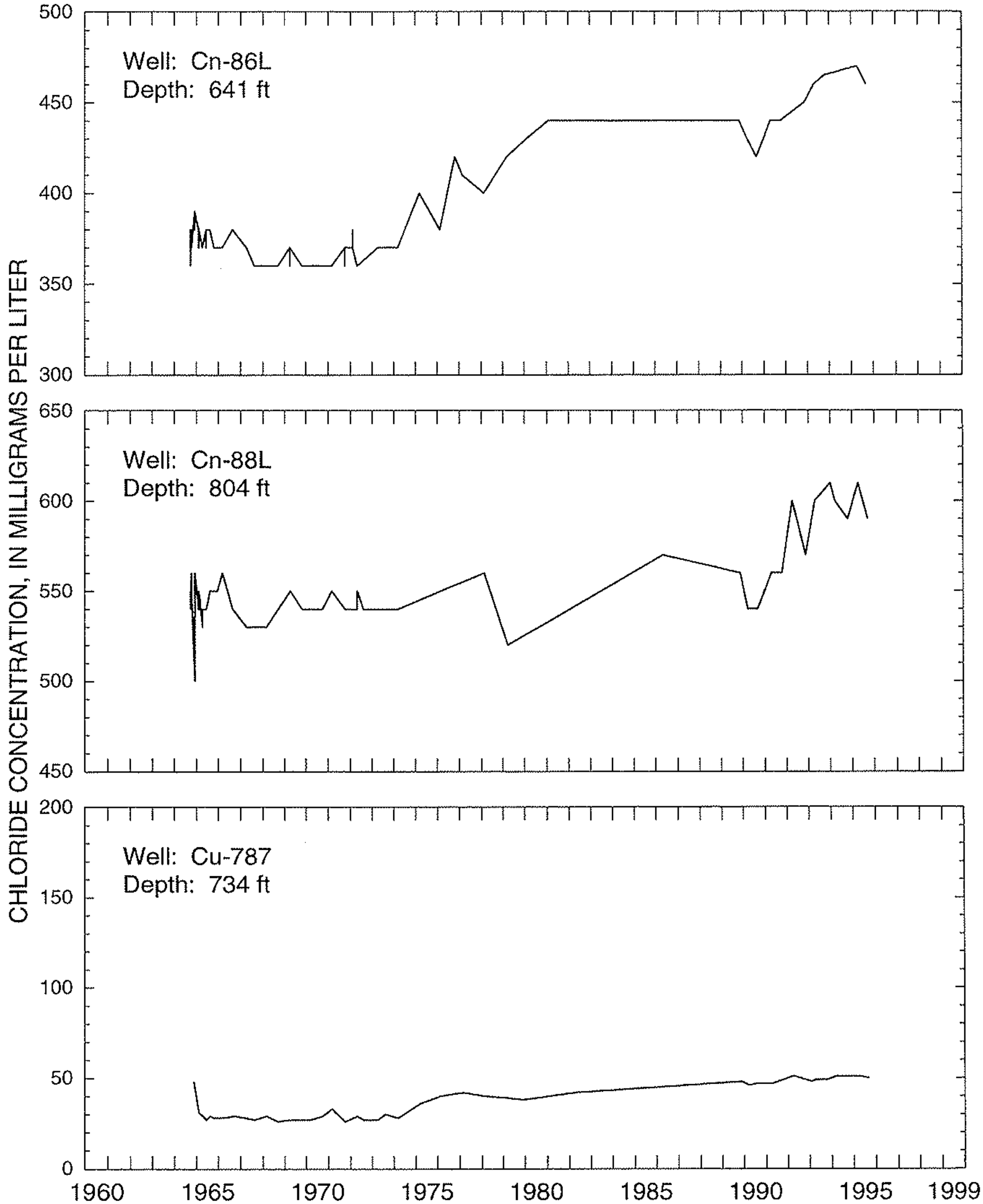


Figure 15. Chloride concentrations in water from wells Cn-86L, Cn-88L, and Cu-787, screened in the "500-foot" sand.

Flow in the "500-foot" sand is radially inward toward the Lake Charles area, and the hydraulic gradient averages about 2 ft/mi along the Calcasieu-Cameron Parish border (fig. 8). Using equation 1, assuming an average porosity of 0.25 and using an average hydraulic conductivity of 130 ft/d for the "500-foot" sand (Harder, 1960a, p. 32), the average velocity of ground-water flow along the freshwater-saltwater interface is about 70 ft/yr (0.2 ft/d) along the Calcasieu-Cameron Parish border.

The base of the "500-foot" sand occurs at altitudes between 500 and 600 ft below sea level in the Lake Charles area and ranges from about 600 ft below sea level at the western end of the Calcasieu-Cameron Parish border to about 800 ft below sea level at the center and the eastern end of the border (Nyman, 1984, pl. 6; Nyman, 1989, pl. 11). Because the altitude of the base of the "500-foot" sand is similar at Lake Charles and the western end of the Calcasieu-Cameron Parish border, saltwater could move laterally northeastward toward Lake Charles, controlled by hydraulic gradients. Saltwater along the center of the Calcasieu-Cameron Parish border also could move northwards updip toward pumping centers in the Lake Charles area. However, northward movement of the saltwater in western and central parts of the interface is somewhat diminished by decreased transmissivity in the "500-foot" sand in areas where it thins near the East and West Hackberry and Black Bayou salt domes (fig. 14) (Nyman, 1984, p. 33).

Lake Charles Area

In the Lake Charles area, saltwater probably is entering the "500-foot" sand through aquifer interconnections with the underlying, saltier "700-foot" sand. Because water levels in the "700-foot" sand are higher than those in the "500-foot" sand, salty water from the "700-foot" sand can move into the "500-foot" sand in areas where the confining unit between the two sands is thin or missing. Intense pumping may also create a situation referred to as upconing, in which saltwater is drawn upward from the "700-foot" sand or the base of the "500-foot" sand toward pumped wells.

Three high-chloride bodies of water have been defined in the "500-foot" sand in the Lake Charles industrial area (fig. 16) (Nyman, 1984, p. 33-37). In the northern and southern chloride bodies, saltwater probably is moving into the "500-foot" sand from the "700-foot" sand and then upconing due to intense localized pumping from the "500-foot" sand in these areas. In the central chloride body, little pumping occurs and the source of the salty water is unknown, but could be associated with oil and gas exploration that occurred in the early 1900's at the Lockport oil field near the Lockport salt dome. The base of the "500-foot" sand occurs at an average altitude of 500 ft below sea level in the northern part of the industrial district and generally dips southward to an altitude of about 600 ft below sea level at the southern edge of the industrial district (Nyman, 1984, pl. 6). However, the base of the aquifer is uneven and local highs and lows occur throughout the area and affect the movement and distribution of saltwater.

The potentiometric surface of the "500-foot" sand in the Lake Charles industrial district during the fall of 1995 indicates that water in the aquifer flows radially inward toward two separate cones of depression that approximately overlay the northern and southern chloride bodies (figs. 9 and 16). The hydraulic gradient ranges from about 5 ft/mi at the edges of the industrial district to 50 ft/mi near the deepest water levels. Using equation 1, assuming an average porosity of 0.25, and using an average hydraulic conductivity of 130 ft/d for the "500-foot" sand (Harder, 1960a, p. 32), the average velocity of ground-water flow along the freshwater-saltwater interface in the Lake Charles industrial district ranges from about 180 to 1,800 ft/yr (0.5 to 5 ft/d). Considering that the high chloride concentrations occur near the pumping centers, the strong hydraulic gradient toward the pumping centers probably prevents the saltwater from moving away from the industrial district.

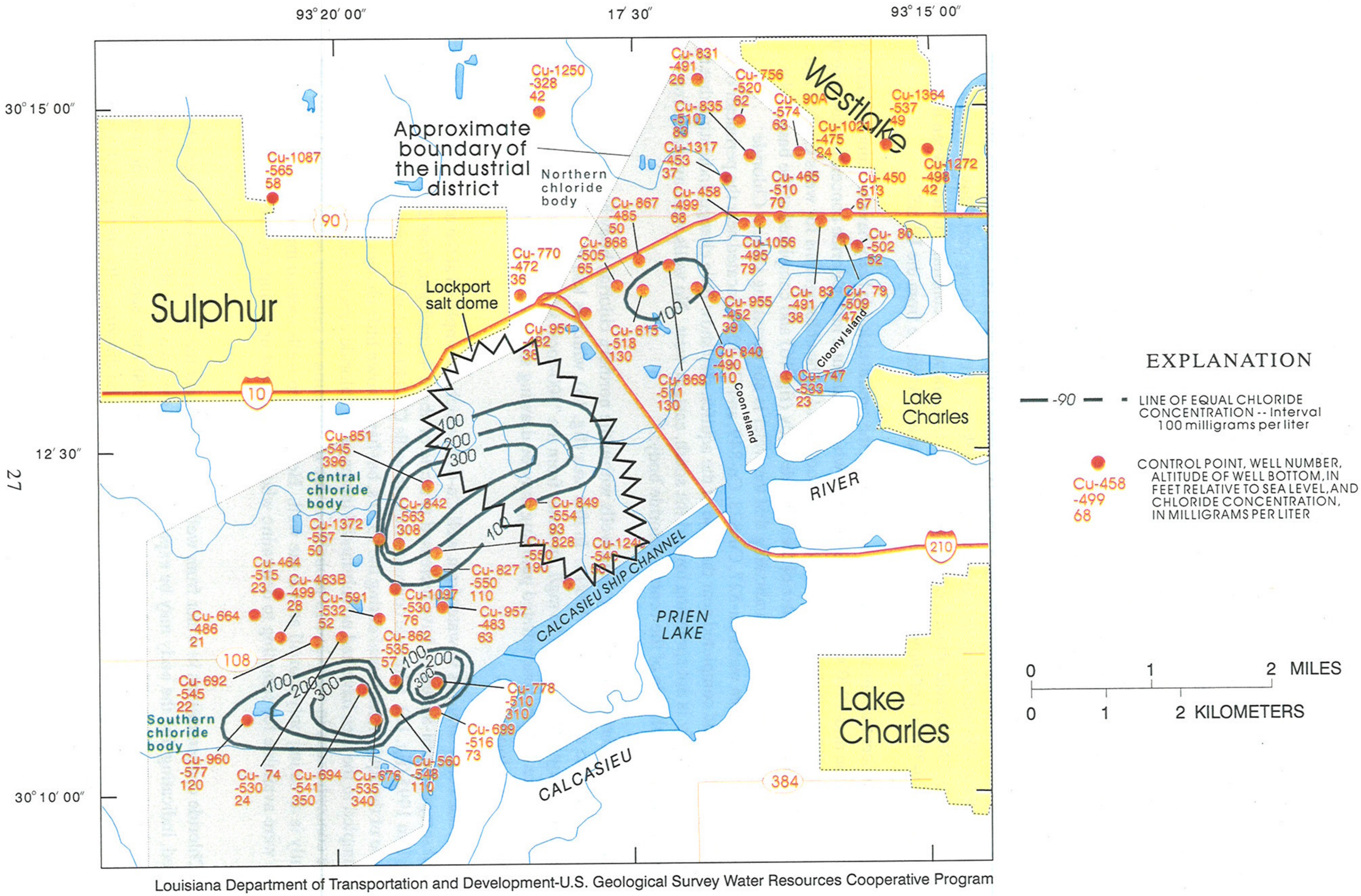


Figure 16. Chloride concentrations in water in the "500-foot" sand in the Lake Charles industrial district, Calcasieu Parish, Louisiana, 1996 (modified from Nyman, 1984).

Chloride concentrations greater than 100 mg/L also are present in the "500-foot" sand in wells in the Lake Charles area. Water from public-supply well Cu-708 (fig. 14), located in the southern part of Lake Charles, had a chloride concentration of 152 mg/L. Water from public-supply well Cu-806, located in the eastern part of the city, had a chloride concentration of 163 mg/L. Each of these wells is pumped alternately with another well located within 300 ft and completed at the same depth. Monthly analyses of the water from the four wells (Russell Buckels, City of Lake Charles, written commun., 1996) indicate that chloride concentrations at each pair of wells are similar, but vary considerably from month to month. Localized upconing through aquifer interconnections between the "500-foot" and "700-foot" sands is probably the reason for the higher concentrations of chloride (Nyman, 1984, p. 35-37, pl. 5). The alternating pumping schedule helps to decrease the intensity of upconing and could account, at least partly, for the variations in chloride concentrations observed. Several electric logs from wells near well Cu-708 indicate that the confining unit between the aquifers averages about 70 ft thick in this area. No available electric logs for wells near well Cu-806 were deep enough to show the thickness of the confining unit. However, an electric log for a well Cu-796, located about 2 mi east of well Cu-806, shows no confining unit between the two aquifers. Well Cu-796 is not shown on figure 14, but data are available from the USGS.

Chloride concentrations in water from wells within the central chloride body have remained relatively unchanged since the mid-1970's. In this area (fig. 16), which is about 2 mi^2, chloride concentrations ranged from 50 to almost 400 mg/L in water from the "500-foot" sand. The chlorographs for wells Cu-842 and Cu-851 (fig. 17), located near the center of the chloride body (fig. 16) and completed at the base of the "500-foot" sand, show little change, indicating that the water is not becoming saltier. Chloride concentrations in water from wells Cu-827, Cu-828, Cu-849, and Cu-1372, located near the perimeter of the central chloride body and completed near the base of the aquifer, also show little change, indicating that the saltwater body probably is not spreading toward the south, east, or west. No wells were available for sampling along the north side of the central chloride body.

Chloride concentrations in water from wells within the northern chloride body have remained relatively unchanged since the early 1980's. In this area (fig. 16), which is less than 1 mi^2, chloride concentrations ranged from 50 to 150 mg/L in water from the "500-foot" sand. The northern chloride body is located in an area where concentrated pumping may be drawing saltwater upward from the "700-foot" sand into the "500-foot" sand.

Chloride concentrations in water from well Cu-615, which is completed at the base of the "500-foot" sand and sampled semi-annually, have increased at a rate of about 4 (mg/L)/yr, from 25 mg/L in 1966 to 140 mg/L in 1995 (fig. 18). Chloride concentrations in wells Cu-840 and Cu-869, which are also completed at the base of the aquifer, increased during the 1970's, but have shown little change since about 1980. Other wells sampled in the area have had no substantial increases in chloride concentrations. The increase in chloride concentrations in well Cu-615 probably is due to upconing of saltwater at the pumped well and apparently is affecting only a small area at the well. However, no wells located immediately south of well Cu-615 were available for sampling to determine whether additional upconing could be occurring in this area.

Chloride concentrations in water from wells within and near the southern chloride body have increased, indicating that the body may be expanding. In this area, which is about 1.5 mi^2, chloride concentrations ranged from 57 to 350 mg/L in water from the "500-foot" sand (fig. 16). The southern chloride body is located in an area where intense pumping may be drawing saltwater upward from the "700-foot" sand into the "500-foot" sand.

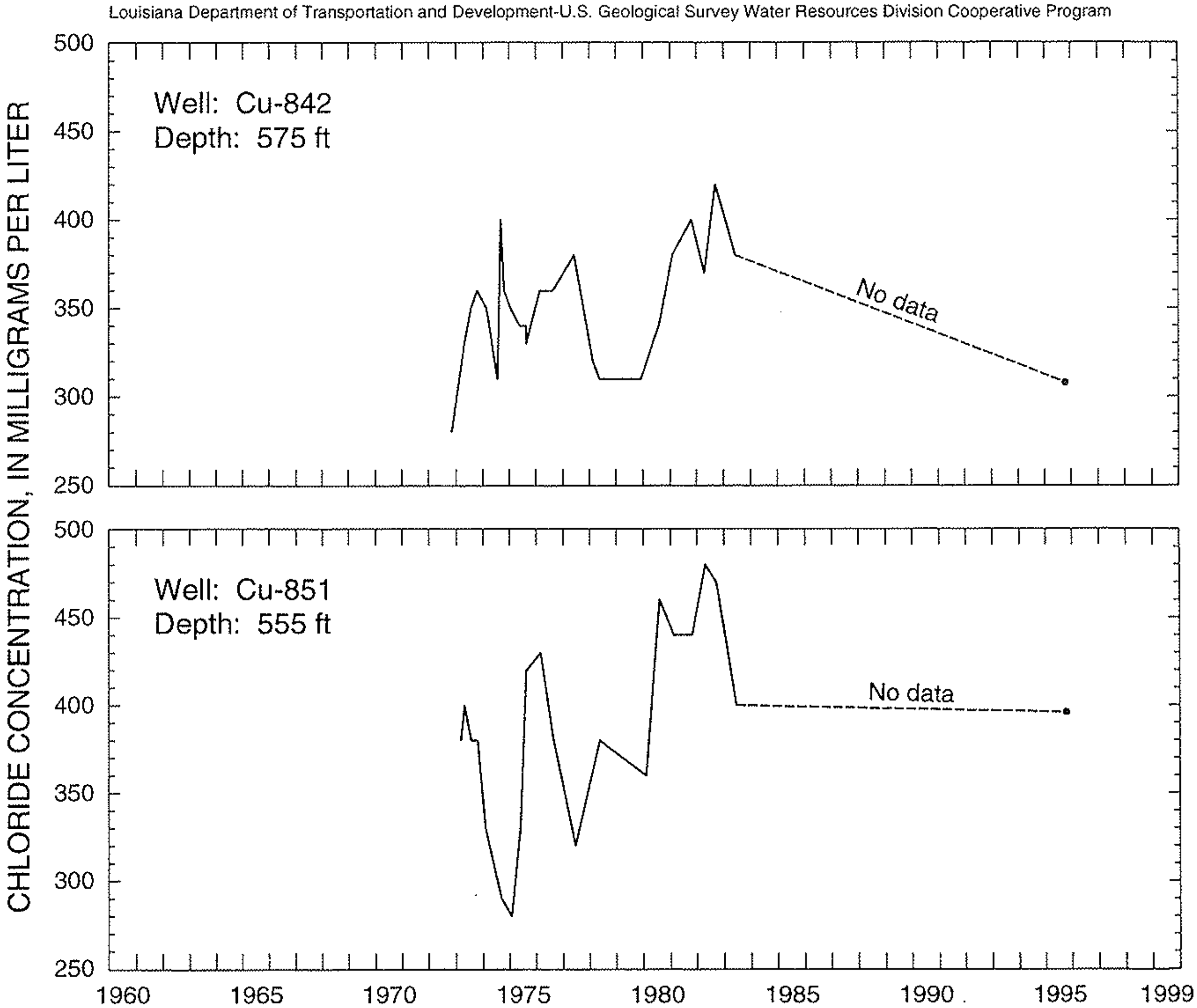


Figure 17. Chloride concentrations in water from wells Cu-842 and Cu-851, screened in the central chloride body of the "500-foot" sand.

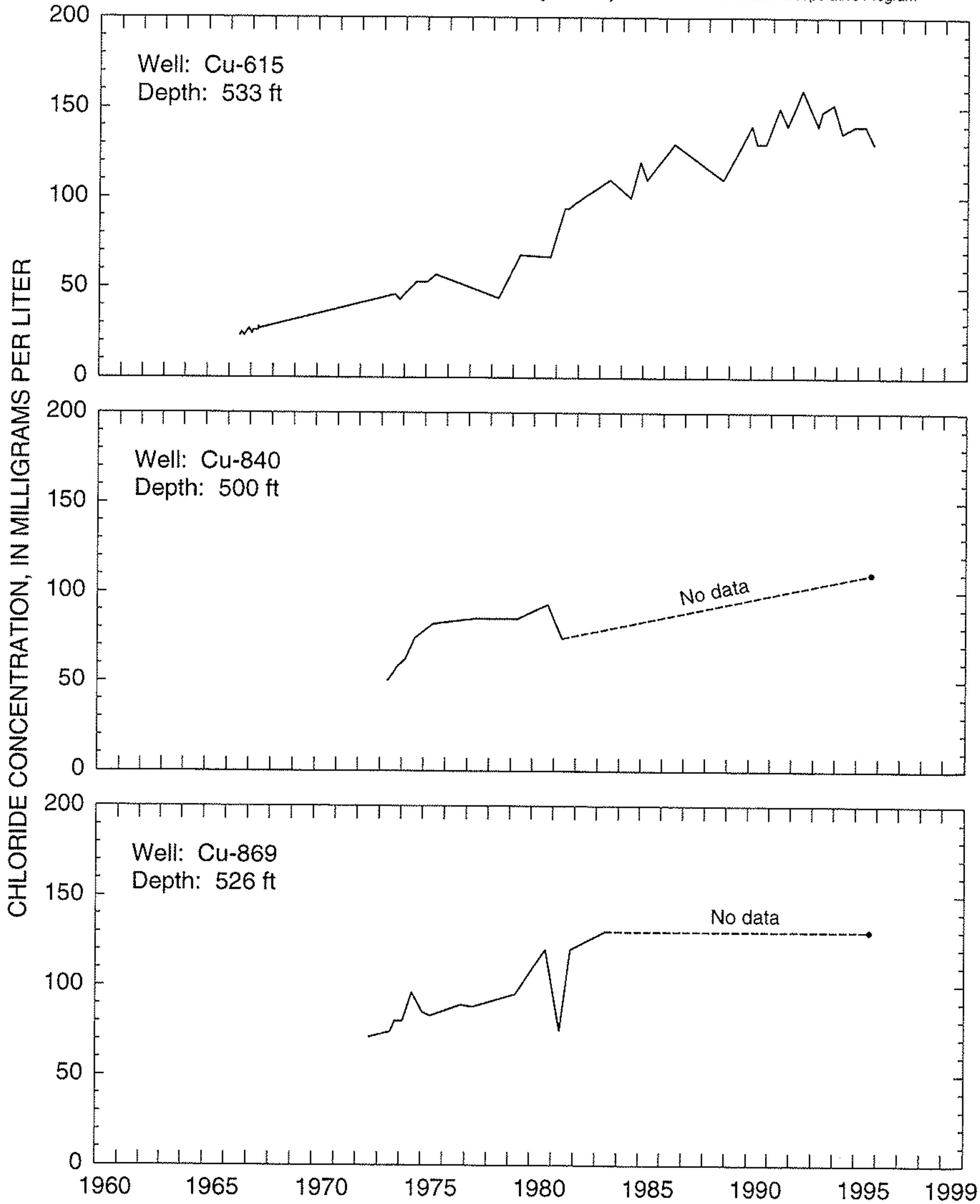


Figure 18. Chloride concentrations in water from wells Cu-615, Cu-840, and Cu-869, screened in the northern chloride body of the "500-foot" sand.

Well Cu-694 is located near the center of the southern chloride body and is completed about 30 ft above the base of the "500-foot" sand. Chloride concentrations in water from well Cu-694 increased rapidly from about 230 to about 350 mg/L during the early 1970's, but have shown little net change since the late 1970's (fig. 19). Well Cu-694 has been sampled semi-annually since 1972.

Chloride concentrations in water samples from wells located east, west, and south of well Cu-694 have increased substantially since the wells were last sampled in the 1970's or early 1980's. The concentration of chloride in water from well Cu-778, located about 0.7 mi east of well Cu-694 and also completed about 30 ft above the base of the aquifer, increased from 180 to 310 mg/L during 1982-95 (fig. 19). However, chloride concentrations in water from well Cu-862, which is located between wells Cu-694 and Cu-778 and completed at the base of the aquifer, decreased from 130 to 57 mg/L during the same period. The chloride concentration in water from well Cu-676, located along the south side of the southern chloride body and completed at the base of the aquifer, increased from 130 mg/L in 1972 to 340 mg/L in 1995 (fig. 19). Because interim data are not available, it is not possible to determine whether the increase has been continuous or occurred during the early and mid-1970's, when chloride concentrations increased rapidly in well Cu-694.

On the western side of the southern chloride body, chloride concentrations in water from well Cu-960 increased from 66 mg/L in 1983 to 120 mg/L in 1995 (fig. 19). Well Cu-960 is completed at the base of the aquifer and saltwater movement in that area would be detected in water samples from this well. Chloride concentrations in samples from wells located immediately northeast of the southern chloride body have remained at background concentrations.

Increased chloride concentrations in water from wells Cu-778 and Cu-676 probably are the result of upconing in the vicinity of the wells and are apparently localized. The lack of change in chloride concentrations in water from well Cu-694 is an indication that water in the body is not becoming saltier. However, the increase in chloride concentrations in water from well Cu-960, which is located west of the pumping center, indicates that additional upconing of saltwater from the "700-foot" sand to the "500-foot" sand is probably occurring near well Cu-960 as a result of the lowered heads in the cone of depression.

Lower and "700-Foot" Sands

The saltwater wedge is between altitudes of about 600 to 800 ft below sea level in the "700-foot" sand and the stratigraphically equivalent lower sand in the southern two-thirds of Calcasieu Parish (fig. 20). The base of the "700-foot" sand occurs at an altitude of about 500 ft below sea level at the northern border of Calcasieu Parish (Nyman, 1984, p. 40). The aquifer dips southward and slightly eastward so that the base of the aquifer ranges from 800 ft below sea level at the western end of the Calcasieu-Cameron Parish border to 1,200 ft below sea level at the eastern end of the border. In the Lake Charles area, the base of the aquifer occurs at an average altitude of 800 ft below sea level. No substantial amounts of freshwater occur in the "700-foot" sand south of the Calcasieu-Cameron Parish border.

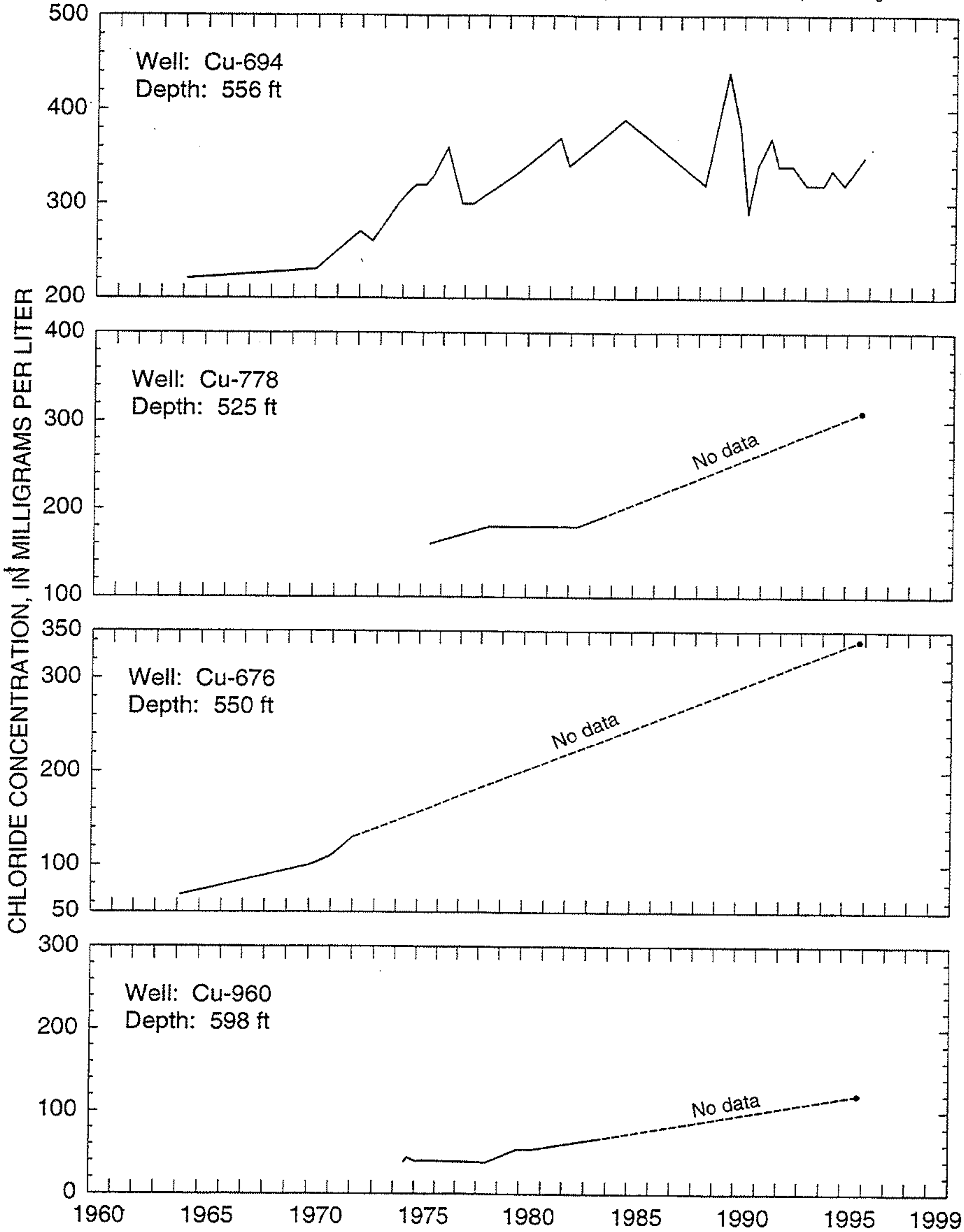


Figure 19. Chloride concentrations in water from wells Cu-694, Cu-778, Cu-676, and Cu-960, screened in the southern chloride body of the "500-foot" sand.

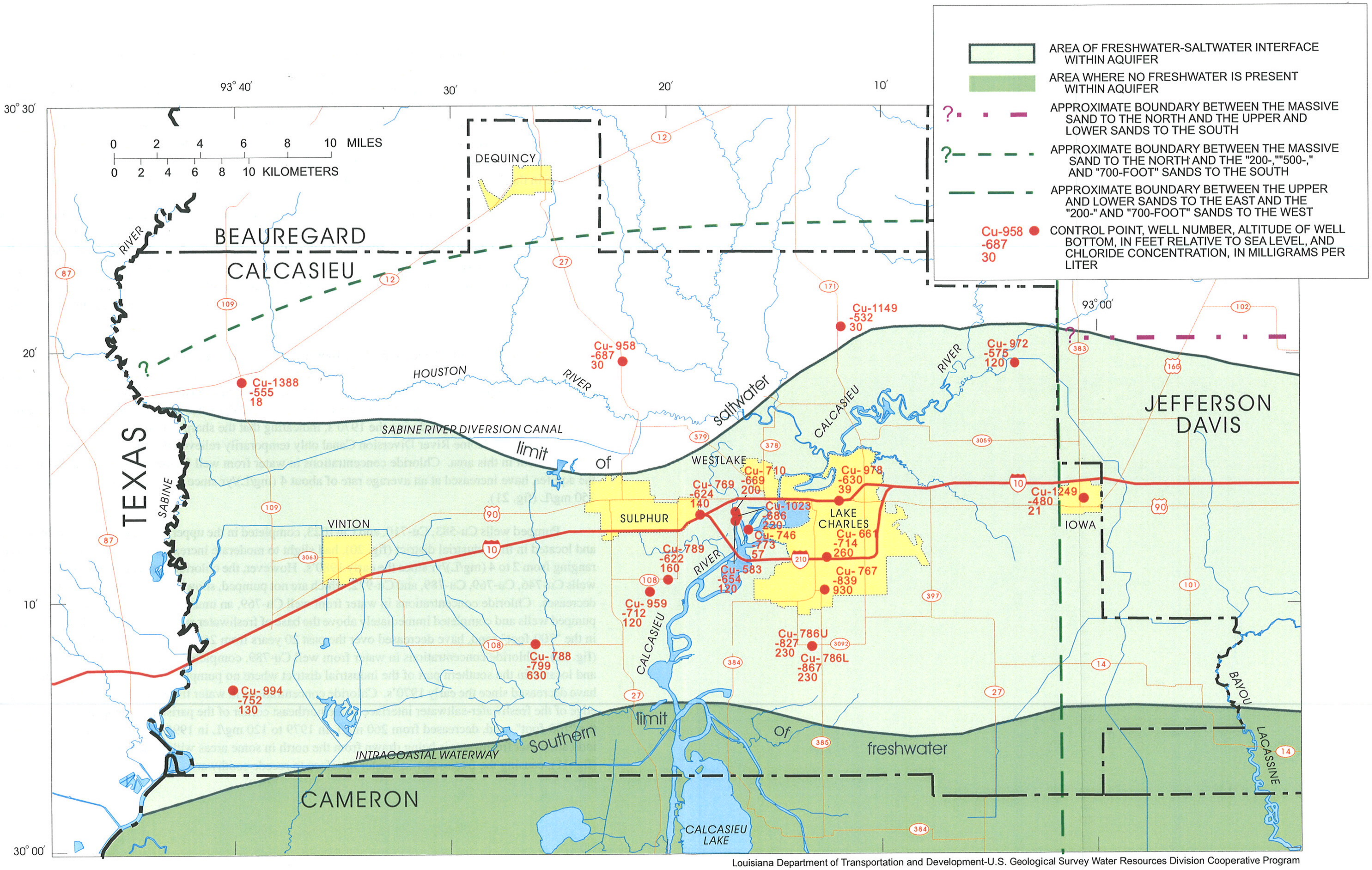


Figure 20. Distribution of chloride in the lower and "700-foot" sands in the Calcasieu Parish area, southwestern Louisiana, 1996 (modified from Nyman, 1984).

Hydraulic gradients in the "700-foot" sand during the fall of 1995 ranged from about 1.5 ft/mi in southern and western areas to 7.5 ft/mi in north-central and northeastern areas of Calcasieu Parish (fig. 11). Using equation 1, assuming an average porosity of 0.25 and an average hydraulic conductivity of 160 ft/d (Harder, 1960a, p. 35), the average velocity of ground-water flow towards the Lake Charles industrial district along the freshwater-saltwater interface in the "700-foot" sand ranged from 66 ft/yr (0.18 ft/d) in southern and western areas to 330 ft/yr (0.9 ft/d) in north-central and northeastern areas of Calcasieu Parish. The southward hydraulic gradient and southerly dip of the aquifer along the toe of the freshwater-saltwater interface in the "700-foot" sand probably hinders northward movement of the toe.

Few facilities in Calcasieu Parish have continued to use water from the "700-foot" sand since chloride concentrations in samples from wells completed in the aquifer in the Lake Charles industrial district began to increase in the late 1940's (Jones, 1950a). Wells still pumping water from the "700-foot" sand usually are completed near the top of the aquifer. In general, chloride concentrations in samples from pumped wells or wells located near wells pumping from the "700-foot" sand slightly increased, and concentrations in samples from wells located more distant from pumped wells have shown no trends or slight to moderate decreases.

Well Cu-767 is completed in the "700-foot" sand and located south of the Lake Charles area, approximately 1.5 mi south of public-supply well Cu-661 (fig. 20). Chloride concentrations in water from well Cu-767, completed near the middle of aquifer, have increased at an average rate of about 16 (mg/L)/yr since 1962. However, the rate has almost doubled to 30 (mg/L)/yr since 1991. This rate of increase is similar to the rate of increase during the 1970's, indicating that the sharp rise in water levels after the completion of the Sabine River Diversion Canal only temporarily relieved the stresses causing saltwater encroachment in this area. Chloride concentrations in water from well Cu-661, completed near the top of the aquifer, have increased at an average rate of about 4 (mg/L)/yr since the mid-1950's and are now near 250 mg/L (fig. 21).

Pumped wells Cu-583, Cu-710, and Cu-1023, completed in the upper one-half of the "700-foot" sand and located in the industrial district (fig. 20), had slight to moderate increases in chloride concentrations ranging from 2 to 4 (mg/L)/yr since the early 1980's. However, the chloride concentrations in samples from wells Cu-746, Cu-769, Cu-789, and Cu-972, which are not pumped, showed no change or slight to moderate decreases. Chloride concentrations in water from well Cu-769, an unused well about 1.5 mi west of the pumped wells and completed immediately above the base of freshwater at the freshwater-saltwater interface in the "700-foot" sand, have decreased over the past 20 years from 260 mg/L in 1975 to 140 mg/L in 1996 (fig. 22). Chloride concentrations in water from well Cu-789, completed at the top of the "700-foot" sand and located in the southern part of the industrial district where no pumping from the aquifer occurs, also have decreased since the early 1970's. Chloride concentrations in water from well Cu-972, near the leading edge of the freshwater-saltwater interface in the northeast corner of the parish and completed at the base of the "700-foot" sand, decreased from 260 mg/L in 1979 to 120 mg/L in 1995 (fig. 22). This may be an indication that freshwater is being drawn from the north in some areas within the cone of depression (fig. 11), causing the freshwater-saltwater interface to recede southward.

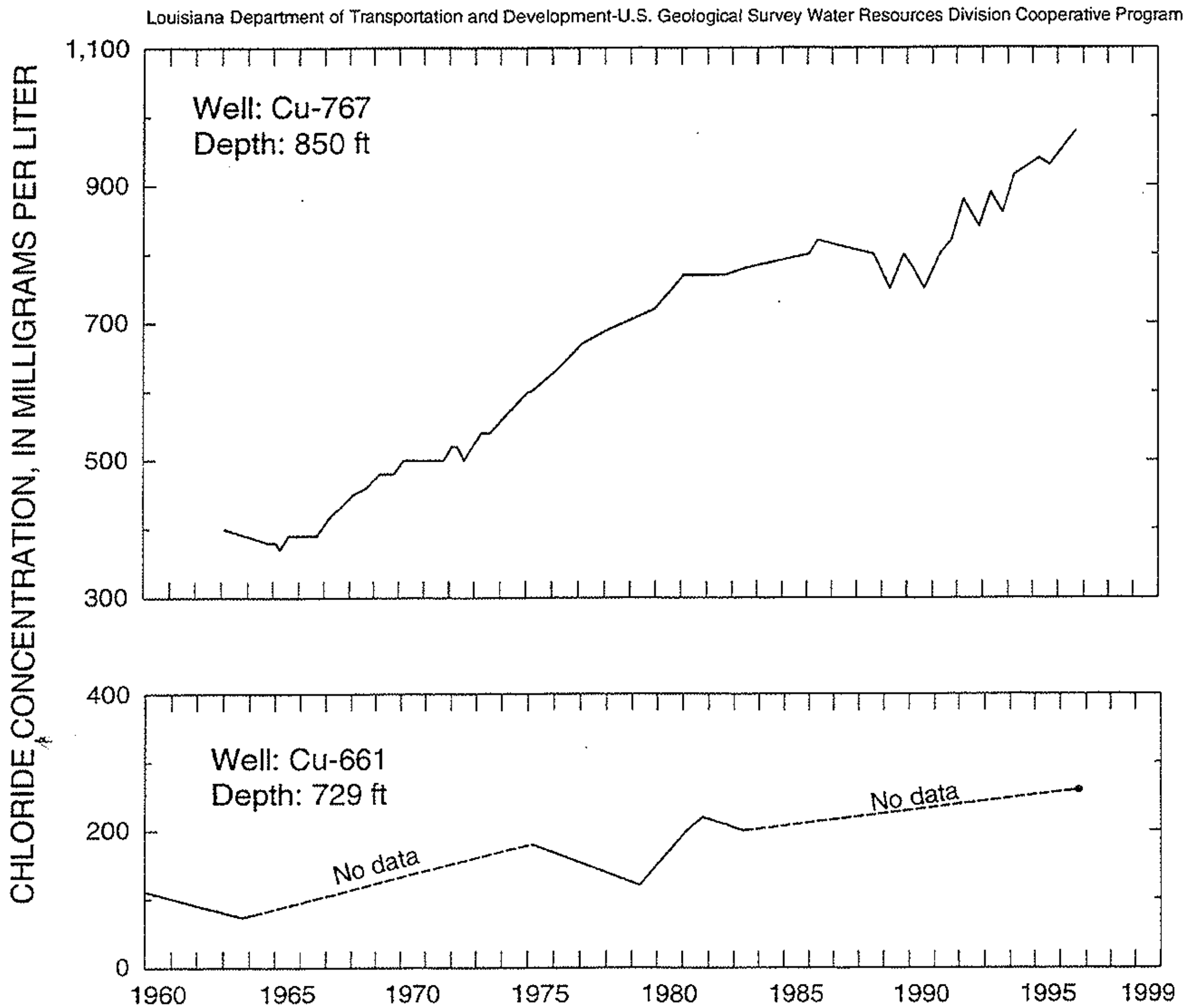


Figure 21. Chloride concentrations in water from wells Cu-767 and Cu-661, screened in the "700-foot" sand.

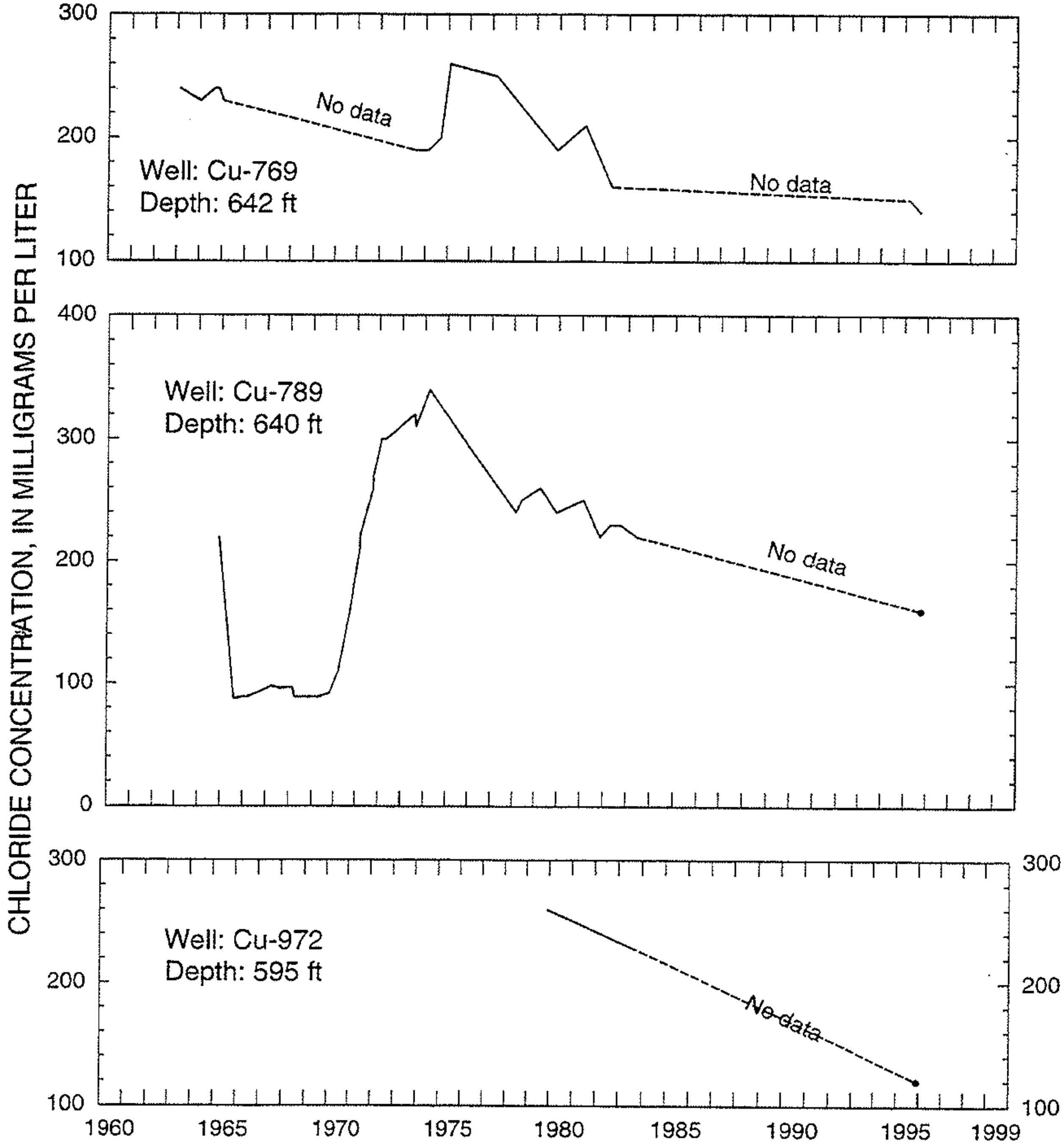


Figure 22. Chloride concentrations in water from wells Cu-769, Cu-789, and Cu-972, screened in the "700-foot" sand.

HYDRAULIC CONNECTION BETWEEN SANDS OF THE CHICOT AQUIFER SYSTEM AND THE CALCASIEU RIVER

Local shallow sand lenses occur within the surficial confining unit throughout Calcasieu Parish. Water from shallow wells adjacent to streams containing saltwater may become contaminated when the stream levels are higher than the ground-water levels (Harder, 1960a, p.26).

Water-level recorders were installed in four nested wells, located in the Lake Charles industrial district, about 20 ft from the Calcasieu River to study the effects of pumping and the stage of the Calcasieu River on water levels in the sands. The wells are within about 50 ft of each other along a levee that separates the Coon Island reach of the Calcasieu River from an area formerly used as a non-hazardous wastewater impoundment (fig. 9). Well Cu-1395 is completed from 30 to 50 ft below land surface in a shallow sand within the surficial confining unit; well Cu-748 is completed in the "200-foot" sand; well Cu-747 is completed in the "500-foot" sand; and well Cu-746 is completed in the "700-foot" sand. Water levels in wells Cu-746, Cu-747, and Cu-748 were recorded hourly during February 1996 through February 1997. Water levels in well Cu-1395 were recorded hourly during May 1996 through February 1997. Hourly Calcasieu River stage data were obtained from the U.S. Army Corps of Engineers for a gage at the saltwater barrier, located about 5 mi upstream from the wells, and a gage at the Calcasieu Lock, located about 10 mi downstream from the wells (fig. 2).

Effects of Pumping in the "500-Foot" Sand on Water Levels in the "200-," "500-," and "700-Foot" Sands

Pumping from the "500-foot" sand affects water levels in the "200-foot" and "700-foot" sands. Hydrographs for wells Cu-746, Cu-747, and Cu-748 during February 1996 through February 1997 are shown in figure 23. Water levels ranged from 43 to 48 ft below sea level in the "200-foot" sand, 86 to 99 ft below sea level in the "500-foot" sand, and 82 to 93 ft below sea level in the "700-foot" sand. Because water levels are deepest in the "500-foot" sand, water moves vertically through confining units from the "200-foot" sand and the "700-foot" sand toward the "500-foot" sand.

Water levels in the "500-foot" sand in the Lake Charles area vary due to seasonal variations in pumping. The hydrograph for well Cu-747 shows water levels declined in response to increased pumpage during spring and summer months (fig. 23). The seasonal variation in the total monthly ground-water pumpage for industrial, power-generation, and public-supply uses in Calcasieu Parish during 1995 is shown in figure 24. These uses accounted for 86 percent of the total withdrawals from the Chicot aquifer system in Calcasieu Parish in 1995. These data were derived from a complete inventory of ground-water withdrawals from the Chicot aquifer system in Calcasieu Parish; the inventory was conducted in 1995 by the USGS, in cooperation with the Louisiana Department of Transportation and Development.

Because of the hydraulic interconnection between the "500-foot" sand and the "700-foot" sand, water levels in the "700-foot" sand are strongly affected, as indicated in the hydrograph for well Cu-746. Water levels in the "200-foot" sand also show declines during spring and summer months, as indicated by the hydrograph for well Cu-748. These declines are caused by both seasonal irrigation withdrawals from the "200-foot" sand and pumping from the "500-foot" sand in the Lake Charles area. The effects of the pumping from the "500-foot" sand are not as pronounced in the "200-foot" sand as in the "700-foot" sand because of poorer hydraulic connection between the "200-foot" sand and the "500-foot" sand. Water levels in well Cu-1395, completed in the shallow sand, were not substantially affected by pumping and remained slightly above sea level.

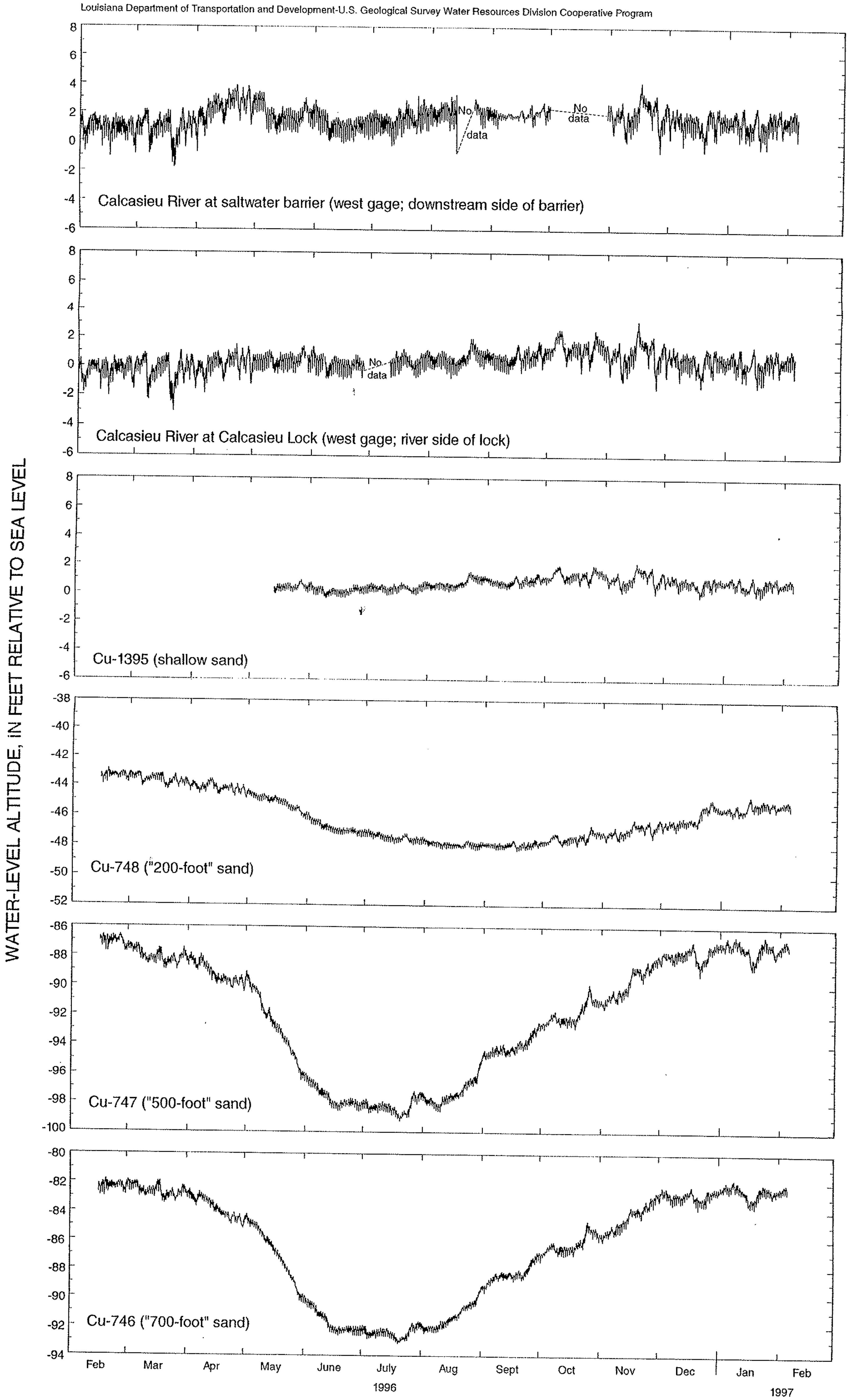


Figure 23. River stage for the Calcasieu River at the saltwater barrier and the Calcasieu Lock and water levels in the Chicot aquifer system for wells Cu-1395, Cu-748, Cu-747, and Cu-746 during February 1996 through February 1997.

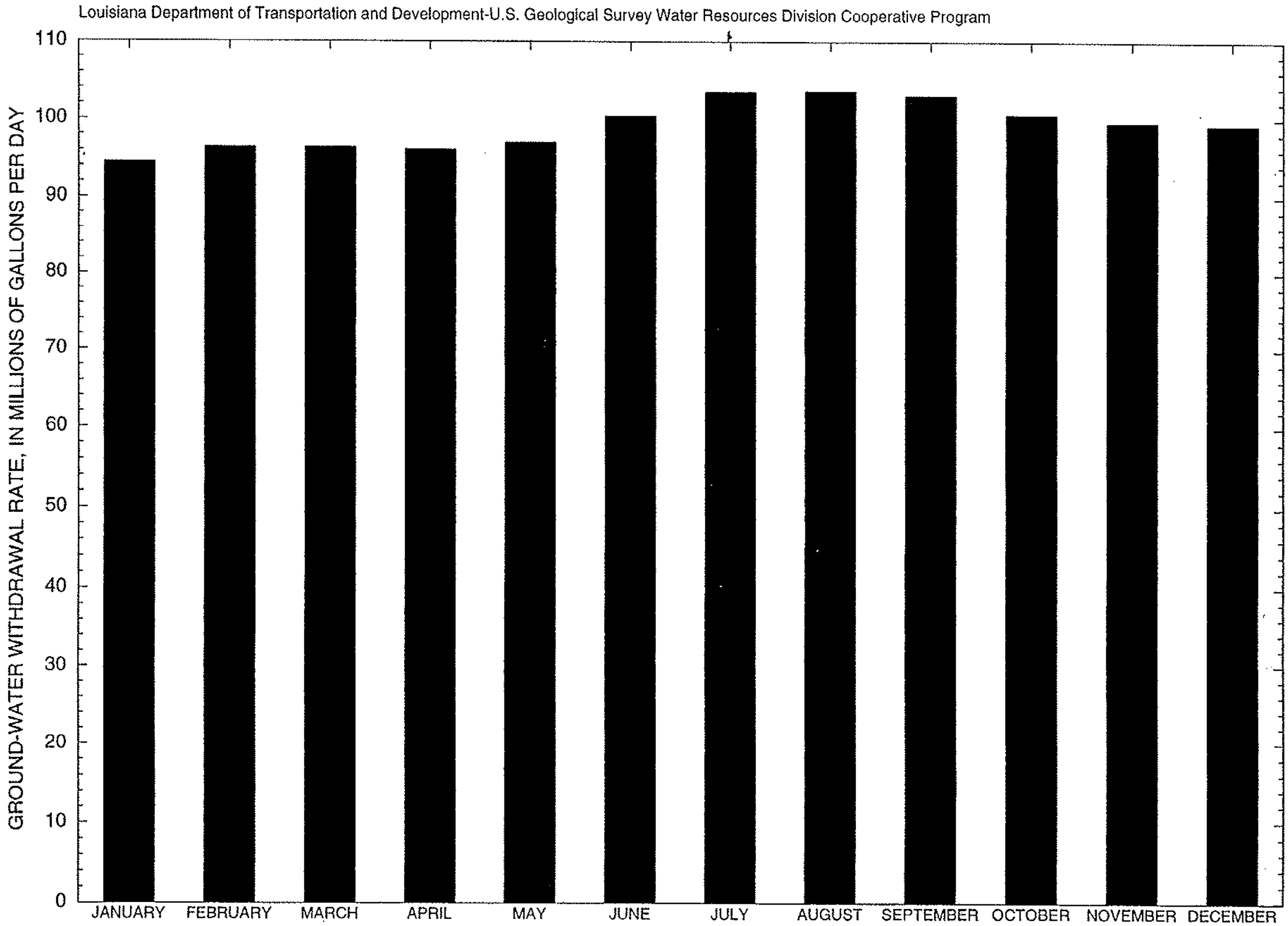


Figure 24. Monthly ground-water withdrawal rates by industrial, power-generation, and public-supply facilities in Calcasieu Parish, Louisiana, 1994.

Effects of the Calcasieu River on Water Levels in the Chicot Aquifer System

Well Cu-1395 is completed in a shallow sand that occurs locally beneath the Coon Island reach of the Calcasieu River between 35 and 50 ft below land surface, or 31 to 46 ft below sea level. According to the driller's log for well Cu-746, located within a few ft of well Cu-1395, the sand is overlain by 25 ft of clay and underlain by 70 ft of clay. However, additional shallow sands occurring at various depths within the areal extent of this sand also have been documented.

The water level in well Cu-1395 indicates that the shallow sand is confined in the vicinity of the well. The channel depth of the Calcasieu River is 35 ft or more below sea level along much of the river near the well site (Forbes, 1988), and the sand might appear to be in direct hydraulic connection with the river in the vicinity of the well site. A recent ground-water monitoring study for the area surrounding the well site concluded that the Calcasieu River and the shallow sand were in hydraulic connection, but the hydraulic gradient across the area was very flat and the primary direction of ground-water flow in the shallow sand is vertically downward at an extremely slow rate (Olin Corporation, 1996). A previous ground-water study also concluded that the primary direction of water movement in the shallow sands near the Coon Island reach of the Calcasieu River was vertically downward (International Technology Corporation, 1995).

A visual inspection of 15 days of data from the 2 gaging stations and the 4 wells shows that water levels in all 4 sands fluctuate in response to tidal changes in river stage (fig. 25). Tidal changes in the Calcasieu River affect water levels in the aquifers through a phenomenon known as external loading. External loading causes short-term variations in water levels in confined aquifers. Fluid pressure within the aquifers and, therefore, the water level in a cased well, varies as the total stress on the system varies due to changes in the load on the system. As the river stage rises, the total stress on the system increases and the water level in the aquifer rises. As the river stage declines, the total stress on the system decreases and the water level in the aquifer also declines. The effects of external loading would be expected to decrease away from the river and tidal effects. The response of an aquifer to tidal loading, or the tidal efficiency of an aquifer, is a function of the compressibility of the rock matrix in the aquifer (Domenico and Schwartz, 1990, p. 129). Because the water levels in all four sands show about the same response to the tidal variations and because the deeper wells are not in direct hydraulic connection with the river, almost all of the daily water-level variations observed in shallow sand could be assumed to be due to tidal loading, rather than a direct hydraulic connection. If the river was in direct hydraulic connection to the shallow sand, the amplitude of water level changes in well Cu-1395 would probably be closer to the amplitude of changes in river stage, due to the proximity of the well to the river. Water levels in all four sands typically vary 3 to 4 in. in response to a 1 ft change in river stage.

Based on figures 23 and 25, the river stage is almost always higher than the water level in the shallow sand at the well site, which would indicate that the river is a potential source of recharge to the shallow sand. However, because the altitudes of the gages and the wells were established during separate surveys, direct comparisons may not be reliable. A 1996 survey of the well site and the water surface in the river indicated that the water level in well CU-1395 and the stage of the Calcasieu River were within 0.2 ft at the time of the survey.

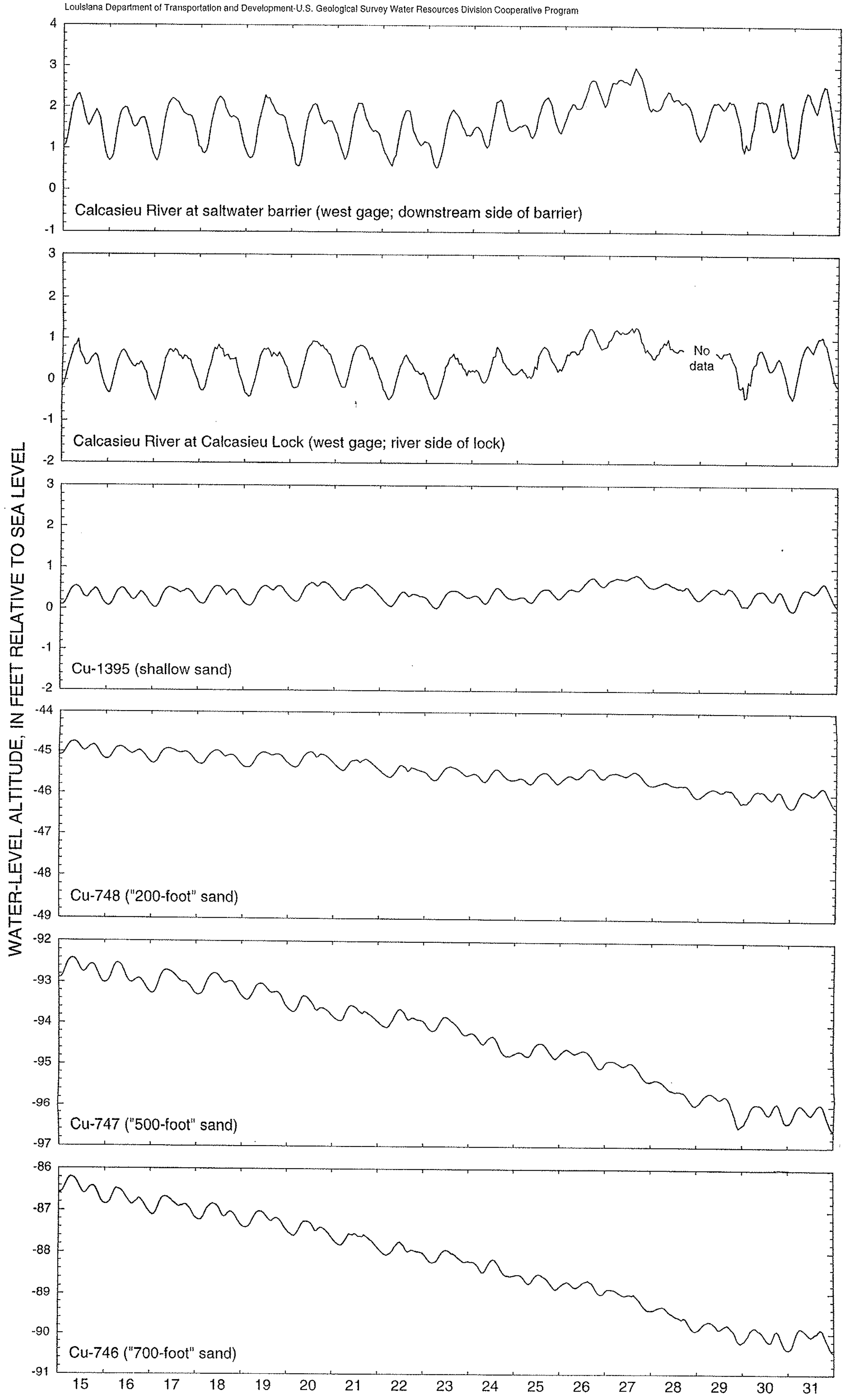


Figure 25. River stage for the Calcasieu River at the saltwater barrier and the Calcasieu Lock and water levels in the Chicot aquifer system for wells Cu-1395, Cu-748, Cu-747, and Cu-746 during May 15-31, 1996.

A sample of water from well Cu-1395, collected in May 1996, had a specific conductance of 56,600 µS/cm and the chloride concentration was 24,000 mg/L. These high values are the result of past waste-management practices at the wastewater impoundment (Olin Corporation, 1996, p. 2). This specific conductance is about double the highest specific conductances measured during a 1985 survey of water quality in the Calcasieu River downstream from the saltwater barrier at Lake Charles (Demas, 1989). Specific conductances and chloride concentrations in the Calcasieu River are high due to seawater intrusion from the Gulf of Mexico. The large difference in water quality of the Calcasieu River and water in the shallow sand in well Cu-1395 suggests that the Calcasieu River is not a major source of water to the shallow sand at the well site. The chloride concentrations in water from well Cu-1395 were also different from the chloride concentrations in water from well Cu-748 (27 mg/L), completed at the base of the "200-foot" sand, indicating that the high-chloride water has not migrated downward to the base of the "200-foot" sand at this time (1995).

SUMMARY AND CONCLUSIONS

The Chicot aquifer system is the principal source of fresh ground water in Calcasieu Parish, Louisiana. In Calcasieu Parish, the Chicot aquifer system includes many sands, referred to as the shallow, massive, upper, lower, "200-foot," "500-foot," and "700-foot" sands. In 1995, 10 Mgal/d (million gallons per day) of water were withdrawn from the upper and "200-foot" sands, 90 Mgal/d were withdrawn from the "500-foot" sand, and 10 Mgal/d were withdrawn from the lower and "700-foot" sands. Sixty percent of this water was withdrawn by industries, primarily located in the Lake Charles industrial district.

Water levels in the upper and "200-foot" sands in Calcasieu Parish during fall 1995 and spring 1996 ranged from approximately sea level to 60 ft below sea level. Lowered water levels in the "200-foot" sand in the Lake Charles area are partially due to vertical leakage of water from the "200-foot" sand into the "500-foot" sand, caused by intense pumping from the "500-foot" sand (Nyman, 1984, p. 8). In the southeastern part of the parish, water levels in the upper and "200-foot" sands have large seasonal fluctuations (30 ft or more) in response to pumping for rice irrigation. During the fall and winter months, lateral movement of water through the upper and "200-foot" sands are generally toward the Lake Charles industrial district. During spring and summer months, as water levels decline due to pumpage for rice irrigation, the lateral movement of water shifts toward the southeast corner of the parish.

Intense pumping from the "500-foot" sand has lowered water levels to more than 100 ft below sea level at pumping centers in the industrial district during fall 1995. Water levels in the "700-foot" sand are strongly affected by pumping from the "500-foot" sand and were more than 80 ft below sea level at pumping centers in the industrial district during fall 1995. The movement of water in the "500-foot" and "700-foot" sands in all parts of Calcasieu Parish is toward pumping centers in the Lake Charles industrial district. Because water levels in the "500-foot" sand are lower than those in the "200-foot" and "700-foot" sands, water also moves vertically through confining units from the "200-foot" and "700-foot" sands towards the "500-foot" sand. Water levels in all three Lake Charles sands have not changed substantially since the completion of the Sabine River Diversion Canal in 1982; the subsequent reduction in ground-water withdrawals caused water levels to rise.

Pumping from the Chicot aquifer system in Calcasieu Parish has created the potential for saltwater encroachment from coastal areas and from underlying aquifers. Saltwater is present in the upper and "200-foot" sands, near Hayes and Bell City, in the extreme southeastern part of Calcasieu Parish. However, chloride concentrations in samples from wells in this area have not changed substantially since the early 1970's, and there is no evidence that the saltwater has moved since the location of the freshwater-saltwater interface was defined in 1984. Saltwater, present in the "500-foot" sand along the Calcasieu-Cameron Parish border, may be moving slowly northward toward pumping centers in Calcasieu Parish. Chloride concentrations at three wells along the freshwater-saltwater interface have increased at low rates (< 3 [(mg/L)/yr] milligrams per liter per year). Northward movement of the saltwater in the "500-foot" sand is somewhat diminished by decreased transmissivity in the aquifer near salt domes near the Calcasieu-Cameron Parish border.

The central, northern, and southern chloride bodies have been defined in the "500-foot" sand in the Lake Charles industrial district. Saltwater from the "700-foot" sand may be moving upward into the "500-foot" sand through aquifer interconnections due to intense pumping in the industrial district. Chloride concentrations greater than 100 mg/L (milligrams per liter) also occur in the "500-foot" sand at public-supply wells in eastern and southern Lake Charles. Each of these wells is pumped alternately with another well located within 300 ft and completed at the same depth, which helps to decrease the intensity of upconing.

The central chloride body extends across an area of about 2 mi^2 (square miles) and contains water with concentrations of chloride of almost 400 mg/L. Chloride concentrations in samples from wells located within the central chloride body of the Lake Charles industrial district have remained relatively stable since the mid-1970's. Chloride concentrations in samples from wells along the perimeter of the body have not increased — an indication that the body is not spreading. Little pumping occurs in the central chloride body area and the presence of saltwater could be associated with oil and gas exploration activities during the early 1900's at the nearby Lockport oil field.

The northern chloride body extends across an area of about 1 mi^2 and contains water with chloride concentrations greater than 100 mg/L. Chloride concentrations in water from well Cu-615, completed in the "500-foot" sand at the northern chloride body, increased at an average annual rate of about 4 (mg/L)/yr from 1966 to 1995. This increase probably is due to upconing of saltwater at the pumped well and apparently is only affecting a small area at the well. Chloride concentrations in water from other wells completed in or near the northern chloride body have not changed substantially since the early 1980's.

The southern chloride body covers an area of about 1.5 mi^2 and contains water with chloride concentrations greater than 300 mg/L. Chloride concentrations in wells located east, west, and south of the southern chloride body have increased, although chloride concentrations in water from well Cu-694, located near the center of the body, have shown little net change since the late 1970's. Chloride concentrations in water from wells Cu-676 and Cu-778, located on the south and east sides of the chloride body, have increased at a rate of almost 10 (mg/L)/yr. The increase in chloride concentrations at these wells probably is due to upconing in the vicinity of the wells and is localized. However, the rise in chloride concentrations in water from well Cu-960, which is located west of the pumping center, indicates that additional upconing of saltwater from the "700-foot" sand to the "500-foot" sand is probably occurring near well Cu-960 as a result of the lowered heads in the cone of depression.

Saltwater occurs at altitudes between about 600 and 800 ft below sea level in the lower and "700-foot" sands in the southern two-thirds of Calcasieu Parish. Although few facilities continue to pump water from the aquifer, pumping from the "500-foot" sand strongly affects water levels in the "700-foot" sand, and the general lateral movement of water in the "700-foot" sand in all areas of Calcasieu Parish is toward the Lake Charles industrial district. In general, chloride concentrations in samples from pumped wells or wells located near wells pumping from the "700-foot" sand have slightly increased. However, chloride concentrations in samples from well Cu-767, which is not pumped, have increased at an average rate of about 16 (mg/L)/yr since 1962. This rate has almost doubled to 30 (mg/L)/yr since 1991. This rate of increase is similar to the rate of increase during the 1970's, indicating that the sharp rise in water levels after the completion of the Sabine River Diversion Canal in 1982 only temporarily relieved the stresses causing saltwater encroachment in the area. Well Cu-767 is located about 1.5 miles south of public-supply well Cu-661, which has experienced increases in chloride concentrations at an average rate of about 4 (mg/L)/yr. Chloride concentrations in samples from wells located away from pumping generally showed no trends or slight decreases. Chloride concentrations in samples from well Cu-972, located near the leading edge of the freshwater-saltwater interface in the northeastern corner of Calcasieu Parish, decreased from 260 mg/L in 1979 to 120 mg/L in 1995. This may be an indication that freshwater is being drawn from the north in some areas within the cone of depression, causing the freshwater-saltwater interface to recede southward.

Hourly water-level data collected from four nested wells completed in the shallow sand, the "200-foot" sand, the "500-foot" sand, and the "700-foot" sand were compared with data from two gaging stations on the Calcasieu River. Water-level data indicate that seasonal pumpage from the "500-foot" sand strongly affects water levels in the "700-foot" sand and may affect water levels in the "200-foot" sand to a lesser degree. Water levels ranged from 43 to 48 ft below sea level in the "200-foot" sand, 86 to 99 ft below sea level in the in the "500-foot" sand, and 82 to 93 ft below sea level in the "700-foot" sand. Because water levels in the "500-foot" sand are lowest, water moves vertically through confining units from the "200-foot" sand and the "700-foot" sand towards the "500-foot" sand. Water levels in the shallow sand remained slightly above sea level and were not substantially affected by pumping.

Water levels in all four sands are affected by the tidal variations in stage of the Calcasieu River due to external loading. The shallow sand might appear to be in direct hydraulic connection with the river, based on its depth of occurrence and the depth of the river channel. However, water levels in the shallow sand show the same response to the tidal variations in stage as the water levels in the deeper sands, which are not directly hydraulically connected to the river. This indicates that the river may not be in direct hydraulic connection with the shallow sand. Water levels in all four sands typically vary 3 to 4 inches in response to a 1 ft change in river stage. A May 1996 sample of water from the well completed in the shallow sand had a chloride concentration of 24,000 mg/L. The chloride concentration in the "200-foot" sand was 27 mg/L, indicating that the high-chloride water has not migrated downward to the base of the "200-foot" sand at this time.

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APPENDIX

Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations

[Aquifer code: 112CHCT, Chicot aquifer; 11202LC, "200-foot" Lake Charles sand; 11205LC, "500-foot" Lake Charles sand; 11207LC, "700-foot" Lake Charles sand; 112CHCTU, Chicot upper sand; 112CHCTL, Chicot lower sand.]

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (micro-siemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
CALCASIEU PARISH											
Cu-1	301133	933445	11205LC	15.00	585	535	585	12-08-95	--	470	59
Cu-74	301107	932001	11205LC	15.00	545	415	545	09-19-95	--	386	24
Cu-77	301405	931535	11205LC	9.61	512	448	512	10-20-95	-87.87	--	--
Cu-79	301356	931602	11205LC	10.00	519	399	519	09-06-95	--	437	47
Cu-80	301354	931552	11205LC	10.00	512	--	--	09-06-95	--	451	52
Cu-83	301406	931552	11205LC	10.00	501	421	501	09-06-95	--	375	38
Cu-90A	301438	931609	11205LC	10.00	584	464	584	09-20-95	-87.42	467	63
Cu-168	300440	930845	11202LC	7.81	375	--	--	04-30-96	-57.69	--	--
Cu-395	301634	931402	11202LC	12.00	200	--	--	04-22-96	-25.34	--	--
Cu-450	301423	931551	11205LC	10.00	523	393	523	09-06-95		476	67
Cu-453	300910	932240	11202LC	13.18	345	261	345	04-22-96	-43.61	--	--
Cu-458	301422	931606	11205LC	10.00	509	--	--	09-06-95	--	540	68
Cu-463B	301106	932032	11205LC	17.00	516	400	516	09-08-95	--	412	28
Cu-464	301129	932020	11205LC	15.00	530	406	530	09-08-95	--	370	23
Cu-465	301407	931617	11205LC	10.00	520	437	520	09-06-95	--	507	70
Cu-510	301714	932345	11205LC	19.75	450	370	450	12-01-95	-46.60	--	--
Cu-515	300641	932425	11205LC	11.15	573	554	573	12-07-95	-50.96	--	--
Cu-517	302228	931403	11205LC	38.80	439	357	439	12-13-95	-22.30	--	--
Cu-529	300818	933616	11202LC	18.00	276	--	--	12-07-95	-35.91	--	--
Cu-530	300806	933606	11205LC	9.32	595	515	595	12-07-95	-21.07	--	--
Cu-552	301359	931622	11205LC	10.00	517	--	--	09-06-95	-106.25	--	--
Cu-560	301035	931934	11205LC	15.00	563	433	563	09-19-95	--	703	110
Cu-583	301320	931657	11207LC	15.00	669	569	669	09-07-95	--	716	120
Cu-588	300922	932029	11205LC	12.00	586	506	586	09-16-96	--	485	51

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations—Continued

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (micro-siemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
				CALCASIEU PARISH -- continued							
Cu-589	300917	932029	11205LC	12.00	585	505	585	09-16-96	--	485	46
Cu-591	301118	931950	11205LC	15.00	547	427	547	09-19-95	--	464	52
Cu-615	301339	931725	11205LC	15.00	533	413	533	09-07-95	--	748	130
Cu-619	301035	931911	11205LC	15.00	586	--	--	09-19-95	-103.74	--	--
Cu-622	301355	931523	11202LC	4.00	219	187	219	09-20-95	--	433	42
Cu-641	300711	930745	11202LC	11.50	368	268	368	04-23-96	-51.32	--	--
Cu-642	301641	930359	11202LC	19.00	287	--	--	04-23-96	-38.59	--	--
Cu-655	301403	932246	11205LC	15.00	578	498	578	09-16-96	--	367	44
Cu-661	301154	931238	11207LC	15.00	729	649	729	09-17-96	--	1063	260
Cu-664	301115	932036	11205LC	15.00	501	--	--	09-08-95	--	387	21
Cu-676	301029	931944	11205LC	15.00	550	430	550	09-19-95	--	1430	340
Cu-677	301445	931622	11205LC	10.00	568	468	568	09-20-95	-89.69	--	--
Cu-683	301155	931238	11205LC	17.50	497	417	497	09-17-96	--	441	37
Cu-686	301125	931958	11205LC	15.00	530	430	530	09-19-95	-102.72	--	--
Cu-692	301112	932016	11205LC	15.00	560	435	560	09-08-95	--	384	22
Cu-694	301044	931951	11205LC	15.00	556	446	556	09-19-95	--	1520	350
Cu-698	301852	933940	11205LC	30.00	425	405	425	12-12-95	-15.36	--	--
Cu-699	301027	931915	11205LC	14.00	530	425	530	09-19-95	--	593	73
Cu-708	301036	931243	11205LC	13.00	549	489	549	09-17-96	--	784	152
Cu-710	301349	931652	11207LC	15.00	684	584	684	09-07-95	--	972	200
Cu-731	301258	931724	11207LC	11.79	660	650	659	09-07-95	-89.60	--	--
								05-13-96	-87.55	--	--
Cu-732	301258	931724	11205LC	12.08	492	480	492	09-07-95	-92.04	--	--
								05-13-96	-90.35	--	--

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations—Continued

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (micro-siemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
				CALCASIEU PARISH -- continued							
Cu-733	301258	931724	11202LC	12.16	201	191	201	09-07-95	-43.00	--	--
								05-13-96	-43.52	--	--
Cu-746	301300	931616	11207LC	7.22	780	770	780	10-20-95	-85.42	477	57
								04-30-96	-85.57	--	--
Cu-747	301300	931616	11205LC	7.17	540	530	540	10-20-95	-89.85	386	23
								04-30-96	-90.30	--	--
Cu-748	301300	931616	11202LC	7.15	280	270	280	10-20-96	-44.81	428	27
								04-30-96	-44.97	--	--
Cu-756	301452	931639	11205LC	10.00	530	430	530	09-20-95	--	465	62
Cu-767	301036	931244	11207LC	11.42	850	840	850	09-12-95	-66.61	3320	930
Cu-769	301336	931830	11207LC	17.62	642	632	642	10-12-95	-84.71	822	140
Cu-770	301336	931830	11205LC	17.54	490	480	490	10-12-95	-85.13	388	36
Cu-771	301336	931830	11202LC	17.76	241	231	241	09-13-95	-43.32	425	16
								04-16-96	-42.81	--	--
Cu-778	301047	931912	11205LC	15.00	525	415	525	09-19-95	--	1360	310
Cu-779	301438	932217	11205LC	15.00	530	450	530	09-16-96	--	273	21
Cu-786L	300820	931319	11207LC	13.25	880	870	880	12-07-95	55.70	1090	230
Cu-786U	300820	931319	11207LC	13.25	840	830	840	12-07-95	-55.78	1080	230
Cu-787	300353	932102	11205LC	4.33	734	729	734	09-12-95	-52.36	535	50
Cu-788	300825	932608	11207LC	6.11	805	800	805	11-22-95	-48.56	2530	630
Cu-789	301100	932000	11207LC	18.42	640	635	640	10-11-95	-73.28	848	160
Cu-798	300919	930556	11202LC	25.43	345	265	345	05-13-96	-57.42	--	--
Cu-806	301312	930941	11205LC	12.00	516	416	516	09-17-96	--	749	163
Cu-811	300812	931658	11207LC	11.00	923	912	923	04-22-96	-61.50	--	--
Cu-827	301134	931911	11205LC	10.00	560	480	560	09-27-95	--	680	110

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations—Continued

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
CALCASIEU PARISH -- continued											
Cu-828	301149	931908	11205LC	10.00	560	500	560	09-27-95	--	973	190
Cu-831	301510	931601	11205LC	6.00	497	397	497	09-28-95	--	331	26
Cu-835	301437	931634	11205LC	10.00	520	410	520	09-20-95	--	548	83
Cu-840	301339	931655	11205LC	10.00	500	380	500	09-07-95	--	685	110
Cu-842	301148	931932	11205LC	12.00	575	572	575	10-19-95	-96.62	1340	308
								04-30-96	-97.76	--	--
Cu-843	301148	931932	11202LC	12.00	205	200	205	10-19-95	-41.64	387	17
								04-30-96	-41.21	--	--
Cu-847	301230	931932	11205LC	13.00	522	517	522	10-12-95	-85.61	--	--
Cu-849	301205	931825	11205LC	10.00	564	559	564	10-11-95	-87.99	614	93
Cu-851	301213	931917	11205LC	10.00	555	550	555	10-19-95	-89.59	1630	396
Cu-853	300806	933603	11202LC	18.00	230	220	230	05-06-96	-39.27	--	--
Cu-854	300643	930447	11205LC	20.00	430	420	430	11-29-95	-32.37	1170	94
Cu-860	301052	931944	11205LC	12.00	566	446	566	09-27-95	-98.60	--	--
Cu-862	301048	931934	11205LC	15.00	550	420	550	09-19-95	--	516	57
Cu-866	301350	931712	11202LC	15.00	192	--	--	09-28-95	--	412	18
Cu-867	301350	931729	11205LC	15.00	500	380	500	09-07-95	--	437	50
Cu-868	301341	931740	11205LC	15.00	520	400	520	09-07-95	--	509	65
Cu-869	301348	931714	11205LC	15.00	526	406	526	09-07-95	--	755	130
Cu-871	301914	931816	11202LC	25.60	114	106	114	05-08-96	-10.24	--	--
Cu-882	301907	931801	11202LC	20.00	110	100	110	05-01-96	-10.65	--	--
Cu-946	301356	931710	11202LC	15.00	198	178	198	09-28-95	-46.68	--	--
								04-30-96	-46.39	--	--
Cu-947	300643	930447	11205LC	20.00	600	595	600	11-29-95	-38.89	481	34
Cu-949	301334	931753	11205LC	18.00	504	474	504	09-27-95	-91.56	--	--

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations—Continued

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (micro-siemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
CALCASIEU PARISH -- continued											
Cu-951	301328	931757	11205LC	18.00	500	430	500	09-27-95	--	420	38
Cu-955	301335	931651	11205LC	7.00	459	339	459	09-07-95	--	441	39
Cu-957	301120	931910	11205LC	17.00	500	440	500	09-27-95	--	536	63
Cu-958	301944	932204	11207LC	20.00	707	702	707	11-30-95	-32.55	296	30
Cu-959	301031	932049	11207LC	21.00	733	727	733	10-11-95	-71.01	737	120
Cu-960	301031	932049	11205LC	21.00	598	592	598	10-11-95	-74.82	689	120
Cu-962	300812	931658	11202LC	11.00	287	281	287	04-22-96	-38.26	--	--
Cu-963	300718	932200	11202LC	10.00	399	393	399	12-07-95	-57.06	--	--
Cu-964	301339	932539	11205LC	16.00	360	354	360	11-21-95	-47.94	373	25
Cu-966	301350	930450	11202LC	18.00	235	229	235	04-30-96	-47.90	--	--
Cu-967	301147	931419	11202LC	12.00	240	234	240	11-02-95	-44.19	435	18
								04-30-96	-43.73	--	--
Cu-968	300557	932504	11202LC	10.00	276	270	276	11-22-95	-29.68	433	12
								04-22-96	-29.53	--	--
Cu-970	300534	925644	11205LC	5.00	780	770	780	11-21-95	-35.39	2880	780
								04-30-96	-34.21	--	--
Cu-971	300534	925644	112CHCTU	5.00	500	490	500	11-21-95	-33.03	1410	290
								04-30-96	-35.51	--	--
Cu-972	301941	930356	11207LC	20.00	595	585	595	11-29-95	-22.38	696	120
								04-30-96	-24.18	--	--
Cu-974	301601	931306	11205LC	5.00	466	456	466	11-30-95	-61.39	331	27
Cu-975	301941	930356	11202LC	20.00	237	231	237	11-29-95	-17.20	1080	230
								04-30-96	-17.28	--	--
Cu-977	301944	932204	11205LC	20.00	515	510	515	11-22-95	-34.44	473	33
Cu-978	301409	931203	11207LC	15.00	645	640	645	11-01-95	-71.99	360	39

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations—Continued

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (micro-siemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
CALCASIEU PARISH -- continued											
Cu-979	301005	931104	11205LC	20.00	555	550	555	11-21-95	-56.40	435	29
Cu-987	301341	931748	11202LC	15.00	200	170	200	09-27-95	--	409	18
Cu-988	301059	931251	11205LC	14.00	523	518	523	11-02-95	-67.57	466	35
								04-22-96	-68.96	--	--
Cu-989	301059	931251	11205LC	14.00	335	330	335	11-02-95	-54.47	424	20
								04-22-96	-53.70	--	--
Cu-990	301059	931251	11202LC	14.00	183	178	183	11-02-95	-46.72	430	18
								04-22-96	-45.57	--	--
Cu-991	301436	933351	11205LC	20.00	315	310	315	12-08-95	-17.62	206	17
								05-02-96	-17.81	--	--
Cu-994	300634	934004	11207LC	5.00	757	752	757	12-08-95	-38.00	760	130
Cu-1003	301603	931530	11205LC	18.00	492	410	492	09-16-96	--	292	28
Cu-1015	302244	933257	11205LC	47.50	386	296	386	12-13-95	-17.41	--	--
Cu-1017	302719	932342	112CHCT	72.50	351	301	351	05-01-96	-0.62	--	--
Cu-1018	301800	931217	11205LC	20.00	398	318	398	11-30-95	--	316	27
Cu-1020	301141	931235	11205LC	18.00	375	367	375	11-02-95	-68.02	--	--
Cu-1021	301435	931546	11205LC	12.00	487	477	487	10-12-95	-81.43	311	24
Cu-1022	301444	931629	11207LC	11.00	618	608	618	09-28-95	-83.78	--	--
Cu-1023	301328	931647	11207LC	15.00	701	566	701	09-07-95	--	1060	220
Cu-1039	301150	932243	11205LC	11.50	484	464	484	09-28-95	-70.65	368	23
Cu-1041	300702	931658	11205LC	9.00	560	550	560	11-02-95	-60.72	445	31
Cu-1051	301401	933024	11205LC	20.00	410	380	410	12-13-95	-37.42	--	--
Cu-1056	301406	931552	11205LC	10.00	505	405	505	09-06-95	--	543	79
Cu-1057	301405	931552	11205LC	10.00	510	390	510	09-06-95	-94.68	--	--

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations—Continued

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (micro-siemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
				CALCASIEU PARISH -- continued							
Cu-1060	301339	931728	11202LC	12.00	200	180	200	09-07-95	--	377	17
Cu-1064	300638	931705	11205LC	6.00	640	568	640	11-21-95	-63.85	558	63
Cu-1066	301847	934057	11202LC	25.00	255	235	255	12-12-95	-7.29	--	--
								05-02-96	-7.92	--	--
Cu-1087	301419	932035	11205LC	15.00	580	344	580	09-16-96	--	423	58
Cu-1091	301347	931705	11202LC	10.00	222	202	222	09-27-95	--	413	17
Cu-1096	301607	931531	11205LC	17.50	480	400	480	09-16-96	--	302	30
Cu-1097	301133	931934	11205LC	15.00	545	425	545	09-19-95	--	550	76
Cu-1109	301356	931601	11205LC	10.00	500	--	--	09-06-95	-104.30	--	--
Cu-1128	301352	931714	11202LC	10.00	223	193	223	09-28-95	--	406	20
Cu-1149	302108	931157	11207LC	25.00	557	461	557	11-30-95	--	277	30
Cu-1158	301428	931614	11205LC	10.00	495	395	495	09-20-95	-95.71	--	--
Cu-1159	301025	932616	11202LC	11.00	280	270	280	05.06-96	-48.00	--	--
Cu-1185	302027	931805	11202LC	21.73	--	--	--	05-01-96	-9.94	--	--
Cu-1236	301135	932301	11205LC	12.00	554	451	554	09-17-96	--	374	28
Cu-1239	302106	931154	11207LC	25.00	502	389	502	11-30-95	-29.08	--	--
Cu-1240	301130	931806	11205LC	8.00	548	468	548	10-19-95	-92.10	494	50
Cu-1245	301200	934044	11202LC	11.00	136	116	136	12-13-95	-4.54	--	--
								05-02-96	-4.38	--	--
Cu-1249	301415	930045	112CHCTL	20.00	500	420	500	12-12-95	--	383	21
Cu-1250	301456	931820	11205LC	15.00	343	303	343	09-16-96		370	42
Cu-1260	301409	931711	11202LC	10.00	252	212	252	10-19-95	-46.18	--	--
								04-30-96	-46.19	--	--
Cu-1267	301852	933939	11205LC	30.00	405	--	--	12-12-95	--	261	15
Cu-1269	301414	930045	112CHCTL	22.00	503	423	503	12-12-95	-41.84	--	--

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations—Continued

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (microsiemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
				CALCASIEU PARISH -- continued							
Cu-1272	301439	931504	11205LC	13.00	511	440	511	09-16-96	--	356	42
Cu-1295	301159	930943	11202LC	14.00	180	160	180	05-01-96	-43.57	--	--
Cu-1302	302357	932742	11202LC	45.00	180	160	180	05-01-96	+3.96	--	--
Cu-1317	301427	931646	11205LC	7.00	460	430	460	09-27-95	--	410	37
Cu-1320	301112	930046	112CHCTU	24.00	345	265	345	05-13-96	-62.20	--	--
Cu-1326	300930	933810	11202LC	17.00	280	260	280	05-06-96	-27.18	--	--
Cu-1364	301441	931525	11205LC	15.00	552	450	552	09-16-96	--	380	49
Cu-1365	301326	931707	11202LC	14.92	203	180	200	09-07-95	--	418	17
Cu-1372	301151	931941	11205LC	10.00	567	--	--	09-27-95	--	447	50
Cu-1375	301424	931250	11205LC	16.00	500	394	495	09-17-96	--	392	38
Cu-1384	301344	931705	11202LC	10.00	200	--	--	09-27-95	--	411	17
Cu-1388	301852	933939	11205LC	30.00	585	555	585	12-12-95	-14.50	315	18
Cu-1395	301300	931616	112CHCTS	7.00	52	31	51	05-13-96	3.22	56,600	24,000
Cu-5250Z	302403	930846	11202LC	20.00	140	128	138	03-28-95	--	418	33
Cu-5279Z	301326	930646	11202LC	20.00	105	100	105	03-28-95	--	1180	130
Cu-5350Z	300636	925815	112CHCTU	20.00	219	--	--	03-28-95	--	739	65
Cu-5412Z	301426	933107	11202LC	21.00	165	160	165	03-29-95	--	316	23
Cu-5429Z	301838	930346	11202LC	20.00	180	175	180	03-28-95	--	636	96
Cu-5811Z	300331	930216	11202LC	10.00	350	340	350	07-26-94	--	944	170
Cu-6103Z	300717	932547	11202LC	20.00	285	279	285	03-29-95	--	388	14
Cu-6106Z	300527	933217	11202LC	10.00	159	154	159	03-29-95	--	761	39
Cu-6161Z	301658	930946	11202LC	15.00	165	160	165	03-28-95	--	408	19
Cu-6235Z	300912	933904	11202LC	12.00	170	160	170	03-29-95	--	419	20
Cu-6552Z	300544	930830	11202LC	8.00	180	40	180	03-28-95	--	578	34
Cu-6680Z	301632	930919	11202LC	11.00	170	160	170	05-08-96	-27.68	--	--

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations—Continued

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (micro-siemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
CALCASIEU PARISH -- continued											
Cu-6694Z	301415	931719	11202LC	15.00	155	150	155	03-27-95	--	434	18
Cu-6767Z	301332	932327	11202LC	15.00	350	340	350	03-29-95	--	324	24
Cu-6799Z	300243	930622	11202LC	12.00	300	40	300	03-28-95	--	619	42
Cu-7054Z	301306	930636	11202LC	20.00	295	285	295	07-27-94	--	692	33
Cu-7082Z	301816	932805	11202LC	13.00	260	240	260	05-06-96	--	--	--
Cu-7341Z	301020	930552	11202LC	20.00	225	40	225	03-28-95	--	362	15
Cu-7542Z	301108	930546	11202LC	21.00	210	200	210	07-26-95	--	837	70
Cu-7678Z	300755	933103	11202LC	8.00	315	310	315	03-29-95	--	407	15
Cu-7738Z	301413	932010	11202LC	19.00	201	186	201	05-06-96	-27.05	--	--
Cu-7782Z	301920	930415	11202LC	10.00	165	160	165	07-27-94	--	912	160
Cu-7948Z	301340	933826	11202LC	22.00	250	240	250	03-29-95	--	293	20
Cu-7952Z	301924	934035	11202LC	25.00	205	200	205	03-29-95	--	300	12
Cu-7955Z	301306	932639	11202LC	15.00	350	340	350	03-27-95	--	349	19
Cu-7967Z	301707	932232	11202LC	19.00	220	210	220	03-27-95	--	290	22
Cu-7979Z	300949	931035	11202LC	21.00	205	200	205	03-28-95	--	595	51
Cu-8507Z	300749	931458	11202LC	10.00	230	225	230	03-28-95	--	586	28
Cu-8638Z	300943	933819	11202LC	12.00	185	180	185	03-29-95	--	403	15
Cu-10278Z	301509	930052	112CHCTU	25.00	--	--	--	11-01-95	--	1130	230
CAMERON PARISH											
CN-86L	300120	933208	11205LC	3.66	641	631	641	09-13-95	-32.45	1910	460
CN-86U	300120	933208	11205LC	3.66	535	527	535	09-26-96	--	1067	210
CN-88L	300055	930930	11205LC	8.86	804	794	804	09-19-95	-41.24	2370	590
CN-88U	300055	930930	11205LC	8.86	666	656	666	08-28-96	--	1210	254
CN-90	295611	930448	11202LC	3.19	396	386	396	09-21-95	-26.49	987	170
								04-17-96	-25.97	--	--

Appendix. Selected data for wells in the Calcasieu Parish area, including water-level measurements, specific conductance, and chloride concentrations—Continued

Well number	Latitude (degrees)	Longitude (degrees)	Aquifer code	Altitude of land surface (feet relative to sea level)	Depth of well (feet)	Depth to top of screen (feet)	Depth to bottom of screen (feet)	Date sampled	Altitude of water level (feet relative to sea level)	Specific conductance (micro-siemens per centimeter at 25 degrees Celsius)	Chloride concentration (milligrams per liter)
CAMERON PARISH -- continued											
CN-92	300104	930156	11202LC	5.50	443	438	443	09-12-95	-32.12	1610	340
								04-17-96	-32.35	--	--
CN-121	300040	931618	11205LC	3.00	691	681	691	04-23-96	-42.88	--	--
CN-152	300213	932010	11205LC	4.00	750	710	750	06-13-96	--	456	25
CN-175	300022	931450	11205LC	5.00	709	649	709	06-14-96	--	1018	184
CN-190	300111	930748	11202LC	14.00	354	293	354	06-14-96	--	799	111
JEFFERSON DAVIS PARISH											
JD- 485A	301300	925845	112CHCTU	21.36	290	270	290	10-23-95	-36.94	--	--
								05-13-96	-60.70	--	--
JD-5816Z	300733	925131	112CHCTU	5.00	150	145	150	02-28-95	--	451	230
JD-6047Z	301442	925823	112CHCTU	29.00	200	190	200	02-28-95	--	1080	250
JD-6175Z	301341	925503	112CHCTU	17.00	165	160	165	02-28-95	--	503	64
JD-6207Z	301258	925744	112CHCTU	20.00	235	230	235	02-28-95	--	1040	230