Report 320

Evaluation of Water Resources of Orange and Eastern Jefferson Counties, Texas

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Texas Water Development Board

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by

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ABSTRACT

This evaluation of water resources in Orange and eastern Jefferson Counties is in response to the 1985 passage of House Bill 2 by the Sixty-ninth Texas Legislature, which called for the identification of study areas in the state that are experiencing, or expected to experience within the next 20 years, critical underground-water problems. The study area is located on the Gulf Coastal Plain in the extreme southeastern part of Texas. Climatic conditions are subtropical-humid, characterized by high rainfall. Petrochemical and other heavy industries dominate the economy with agribusiness contributing to a smaller degree.

Surface water supplies the majority of municipal and industrial demands, which make up the largest portion of total water use in the study area. Ground-water needs, including all municipal requirements in Orange County, are met almost entirely from the lower Chicot aquifer. Annual effective recharge (availability) to the Chicot aquifer is approximately 19,600 acre-feet; however, an estimated 18 million acre-feet of water is held in storage within the aquifer system.

Historically, large ground-water withdrawals have caused water-level declines of as much as 40 feet, which have resulted in a slight amount of land-surface subsidence (generally less than 0.5 foot). Since the late 1970's and 80's pumpage has decreased, resulting in water-level rises over most of the study area. With surface-water supplies expected to meet most future large-scale needs, additional regional subsidence will most likely be insignificant. The main ground-water quality problem is elevated chloride concentrations caused by saline-water encroachment in areas of concentrated pumpage, although from the late 1970's to 1988, chloride concentrations have not changed significantly due to decreased ground-water withdrawals.

In 1985, total water use in the study area was about 243,643 acre-feet, of which 92 percent was for municipal and industrial purposes. Projected demands are expected to reach 325,713 acre-feet per year by 2010. Available surface-water supplies (1,570,000 acre-feet per year) are adequate to meet all surface-water needs through the planning period; however, ground-water demand is likely to exceed the annual effective recharge by 1990. Although ground water in storage within the aquifer is sufficient to meet future demands, heavy pumpage in concentrated areas would result in significant water-level declines, which could cause saline-water encroachment and possible subsidence problems. Therefore, future ground-water development programs will require careful planning in order to avoid a recurrence of historical ground-water problems.

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INTRODUCTION

Purpose

In 1985, the Sixty-ninth Texas Legislature recognized that certain areas of the State were experiencing or were expected to experience, within the next 20 years, critical ground-water problems. House Bill 2 was enacted which, in part, directed the Texas Department of Water Resources to identify the critical ground-water areas, conduct studies in those areas, and submit its findings and recommendations on whether a ground-water conservation district should be established in the respective areas to address the ground-water problems (Subchapter C, Chapter 52, Texas Water Code).

This study focuses on the areas of Orange and eastern Jefferson Counties. It was conducted to identify and address any problems of overdraft, quality deterioration, or land-surface subsidence with respect to the Chicot and Evangeline aquifers, which are the primary aquifers in the area.

Location and Extent

The study area is located on the Gulf Coastal Plain in the extreme southeastern part of Texas (Figure 1). It has an area of approximately 616 square miles. The area is bordered on the east and southeast by the Sabine River, which is also the boundary between Texas and Louisiana, on the north by Jasper and Newton Counties, on the northwest by Hardin County, and on the south by Sabine Lake, which is formed at the confluence of the Neches and Sabine Rivers. The western and southwestern borders of the study area are located in Jefferson County, just west of the cities of Beaumont and Port Arthur. Larger cities in the area include Orange, Bridge City, Pinehurst, and Vidor in Orange County and Beaumont and Port Arthur in Jefferson County.

Geographic Setting

Orange and Jefferson Counties are on the seaward margin of the southeastern Gulf Coastal Plain of Texas and are drained by the Sabine and Neches Rivers. Topography is typically flat to gently rolling. Broad flat valleys of the Neches and Sabine Rivers are covered with coastal-type marsh vegetation and are subject to flooding during periods of high tides caused by storms. Along the rivers and waterways, some natural levees and spoil banks, which rise above the flat marshes, support tree growth. Between the river valleys, the land surface is a slightly dissected plain characterized by grass surfaces and some dense tree growth.

Climatic conditions are classified as subtropical-humid with warm summers and mild winters. Average annual precipitation as recorded by the National Weather Service ranges from 52 to 56 inches. The normal temperature ranges from the low to mid-40's (degrees F) in the winter and the low 90's in summer (Larkin and Bomar, 1983).

Historically, the petrochemical and related industries have played a dominant role in the economy of Orange and Jefferson Counties. Within the study area, the cities of Orange, Beaumont, and Port Arthur form a large industrial complex often referred to as the "Golden Triangle." Other heavy industries in the area include steel, rubber, shipbuilding, and timber, as well as numerous smaller operations, which produce a variety of fabricated metal products and non-electrical machinery. Agribusiness such as rice and soybean farming, raising beef cattle, and crawfish production also contribute to the overall economy.

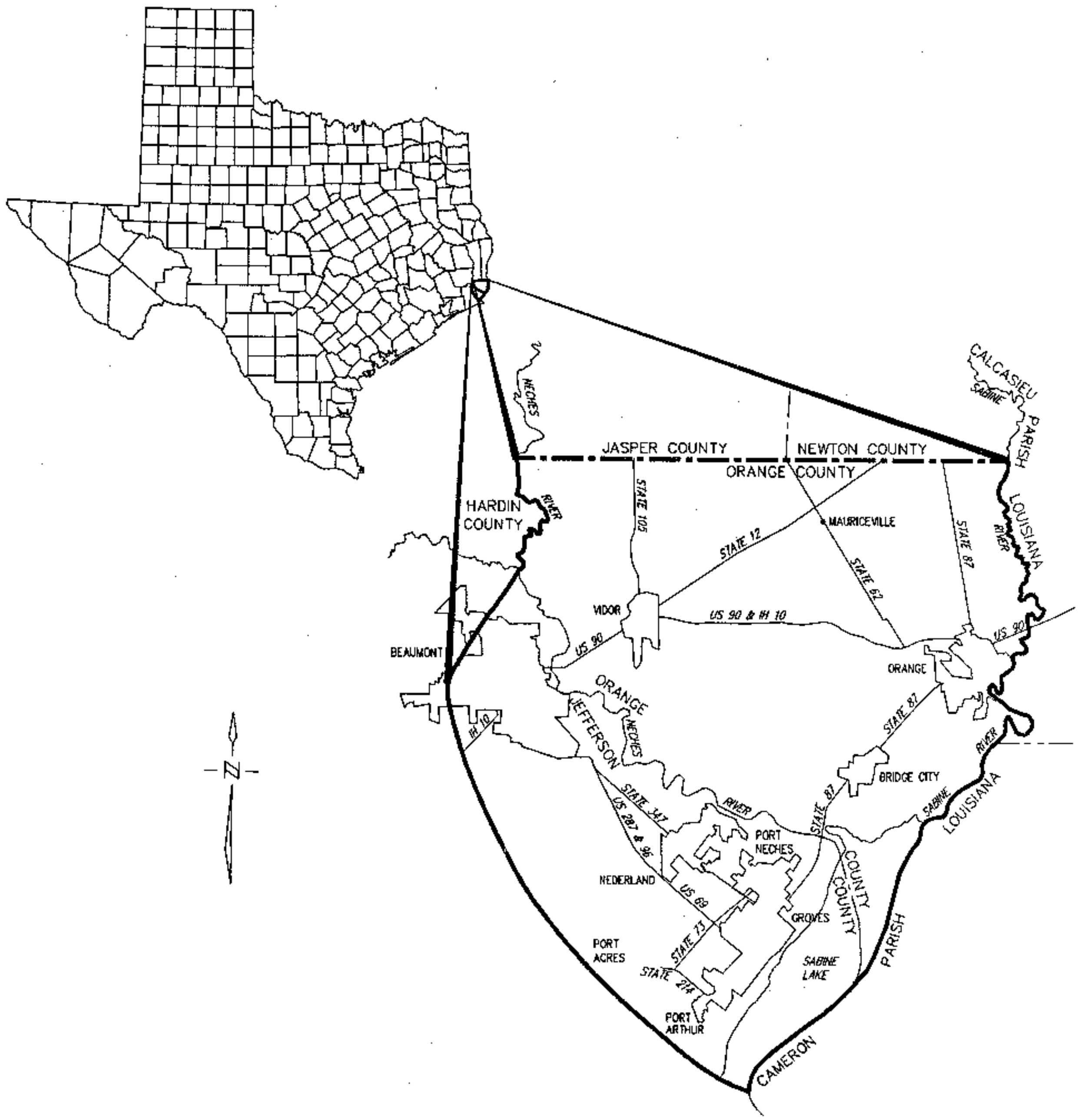


Figure 1
LOCATION OF STUDY AREA

Previous and Current Investigations

Numerous ground-water investigations have been conducted in the Orange and Jefferson County area. The principal investigator for most of these studies has been the U.S. Geological Survey in cooperation with the Texas Water Development Board and its predecessor agencies. Some studies are regional in nature, while others were made on a county scale. Publications relating to the geohydrology of the aquifer system in the study area and surrounding counties are listed in the selected references of this report.

Geologic mapping in the area is best presented on the Beaumont and Houston Geologic Atlas Sheets published by the University of Texas, Bureau of Economic Geology. The base map for this work was adapted from these sheets.

Currently, the U.S. Geological Survey maintains a system of water-level and water-quality monitoring wells in Orange and other counties, which surround the Harris-Galveston Coastal Subsidence District. The data collected through this network is used to publish basic-data reports and periodic reports addressing the most current status of water-level and water-quality changes in the aquifers and land-surface subsidence throughout the area. Orange and Jefferson Counties are also included in the Survey's Gulf Coast regional aquifer system analysis (RASA) project designed to define the hydrogeologic framework of the Gulf Coast aquifer system, and simulate regional flow patterns using a computer model.

Acknowledgements

The authors wish to thank numerous individuals for their cooperation in providing information on the aquifer in their area. More specifically, appreciation is extended to city, county, and water supply district officials who furnished information concerning their municipal water-supply systems, and to the many property owners who allowed access to their wells to measure water levels and sample for chemical quality.

Additionally, special thanks are given to the staff of the U.S. Geological Survey who provided current water-level and water-quality data for the study area.

GEOHYDROLOGY

Geology as Related to Ground Water

Stratigraphy

The geologic units composing the aquifers within the study area range in age from Miocene to Holocene. They are, from oldest to youngest, Fleming Formation, Willis Sand, Bently Formation, Montgomery Formation, Beaumont Clay, Deweyville Formation, and Quaternary alluvium. These units generally consist of alternating beds of sand, gravel, clay, and silt.

Outcrops of the Beaumont Clay, the Deweyville Formation, and Quaternary alluvium occur in the study area (Figure 2). The older formations crop out in the counties north of Orange and Jefferson Counties. One or more of the formations may be absent at any specific location due to nondeposition or erosion, and the sand-clay ratio of the formations varies considerably from location to location. Sand occurs in bands which may be either parallel or perpendicular to the coastline. Regionally, all of the formations dip toward the gulf at an angle greater than the slope of the land surface and generally thicken with depth in the downdip gulfward direction.

Earlier investigators in the Gulf Coast region of Texas attempted to delineate aquifer units on the basis of geologic formations. This has proven difficult because in the younger sediments the aquifers generally consist of parts of more than one geologic formation. Because of the difficulty in differentiating the formations in the subsurface, they are commonly grouped together and collectively referred to as the Gulf Coast aquifer.

Wesselman (1965) subdivided the Gulf Coast aquifer into three hydrologic units in Orange County. They were simply the "Lower," "Middle," and "Upper" aquifers. He further refined these units in Jasper and Newton Counties and applied the terms Jasper aquifer, Burkeville aquiclude, Evangeline aquifer, and Chicot aquifer (Wesselman, 1967). Baker (1979) used these subdivisions and correlated the aquifers across the entire coastal plain of Texas. This correlation of the Evangeline and Chicot aquifers is also adopted for this report (Table 1).

Figures 3, 4, and 5 are geologic cross sections which illustrate the stratigraphic relationship between the different aquifers within the study area.

Evangeline Aquifer

The Evangeline aquifer, which underlies the Chicot aquifer, is composed of sediments of the Fleming Formation. Depths to the top of the aquifer range from about 425 feet in the northwest part of the study area to more than 1,000 feet in the southeast part. Within the study area, the Evangeline does not contain fresh water with the possible exception of the extreme northwest part. Because ground water of superior quality can be obtained from shallower zones, there is no development of the Evangeline aquifer within the study area.

Chicot Aquifer

The Chicot aquifer is a sequence of sand and clay beds which overlie the Evangeline aquifer. Stratigraphic units which make up the Chicot aquifer are the Willis Sand, Bently Formation, Montgomery Formation, Beaumont Clay of Pleistocene age, the Deweyville Formation of Pleistocene and Holocene age, and any overlying Holocene alluvium.

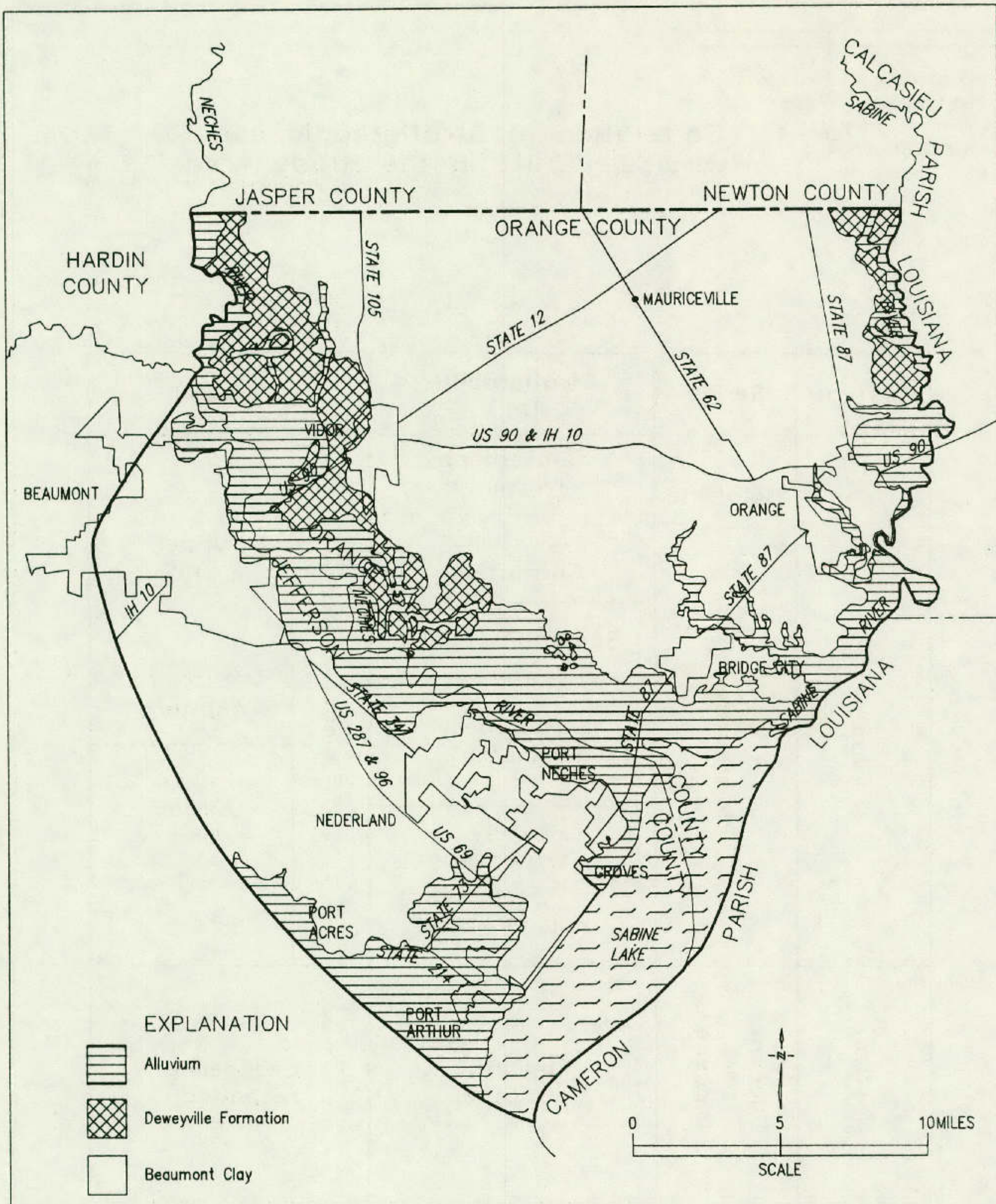


Figure 2

GEOLOGIC MAP OF STUDY AREA

Table 1. Correlation of Stratigraphic and Hydrologic Units in the Study Area

<table>
<tr><th>System</th><th>Series</th><th>Stratigraphic Unit</th><th colspan="2">Aquifer</th></tr>
<tr><td rowspan="6">Quaternary</td><td>Holocene</td><td>Quaternary Alluvium</td><td rowspan="6">Chicot Aquifer</td><td rowspan="3">Upper Unit</td></tr>
<tr><td rowspan="5">Pleistocene</td><td>Deweyville Formation</td></tr>
<tr><td>Beaumont Clay</td></tr>
<tr><td>Montgomery Formation</td><td>? — ? Aquitard ? — ?</td></tr>
<tr><td>Bentley Formation</td><td rowspan="2">Lower Unit</td></tr>
<tr><td>Willis Sand</td></tr>
<tr><td>Tertiary</td><td>Pliocene and Miocene</td><td>Fleming Formation</td><td colspan="2">Evangeline Aquifer</td></tr>
</table>

(Modified from Wesselman, 1965 and Baker, 1979)

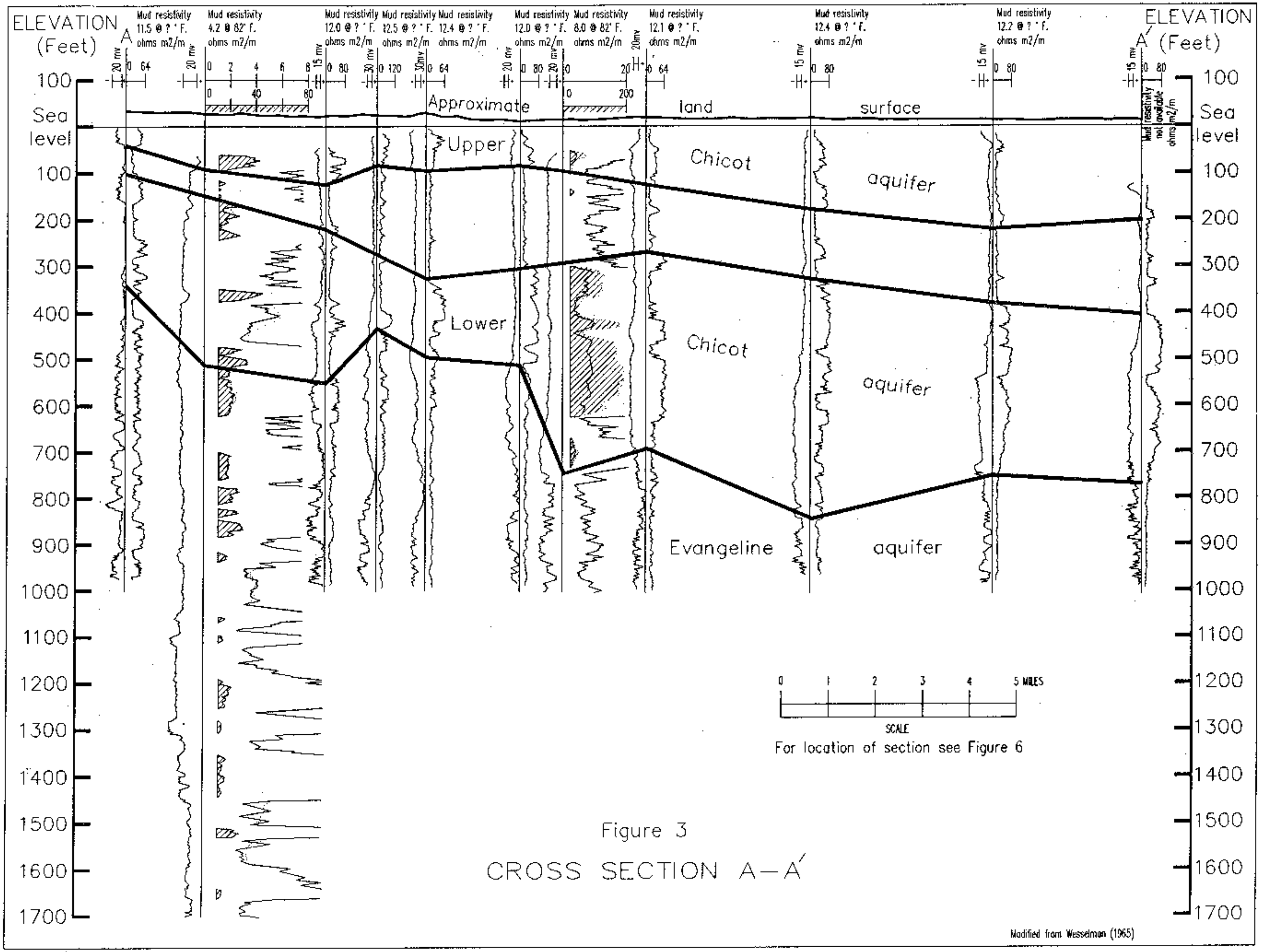
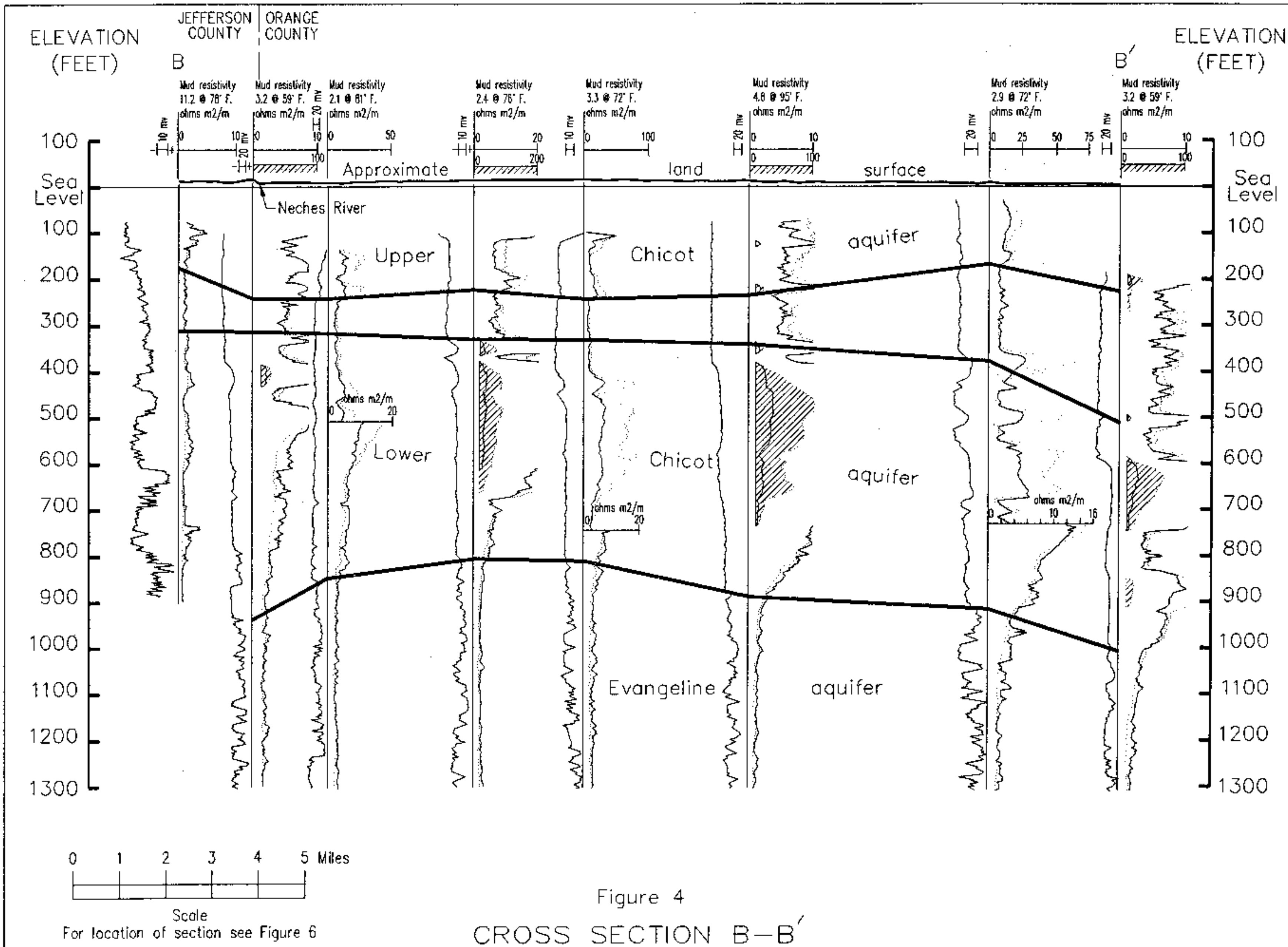


Figure 3

CROSS SECTION A–A′

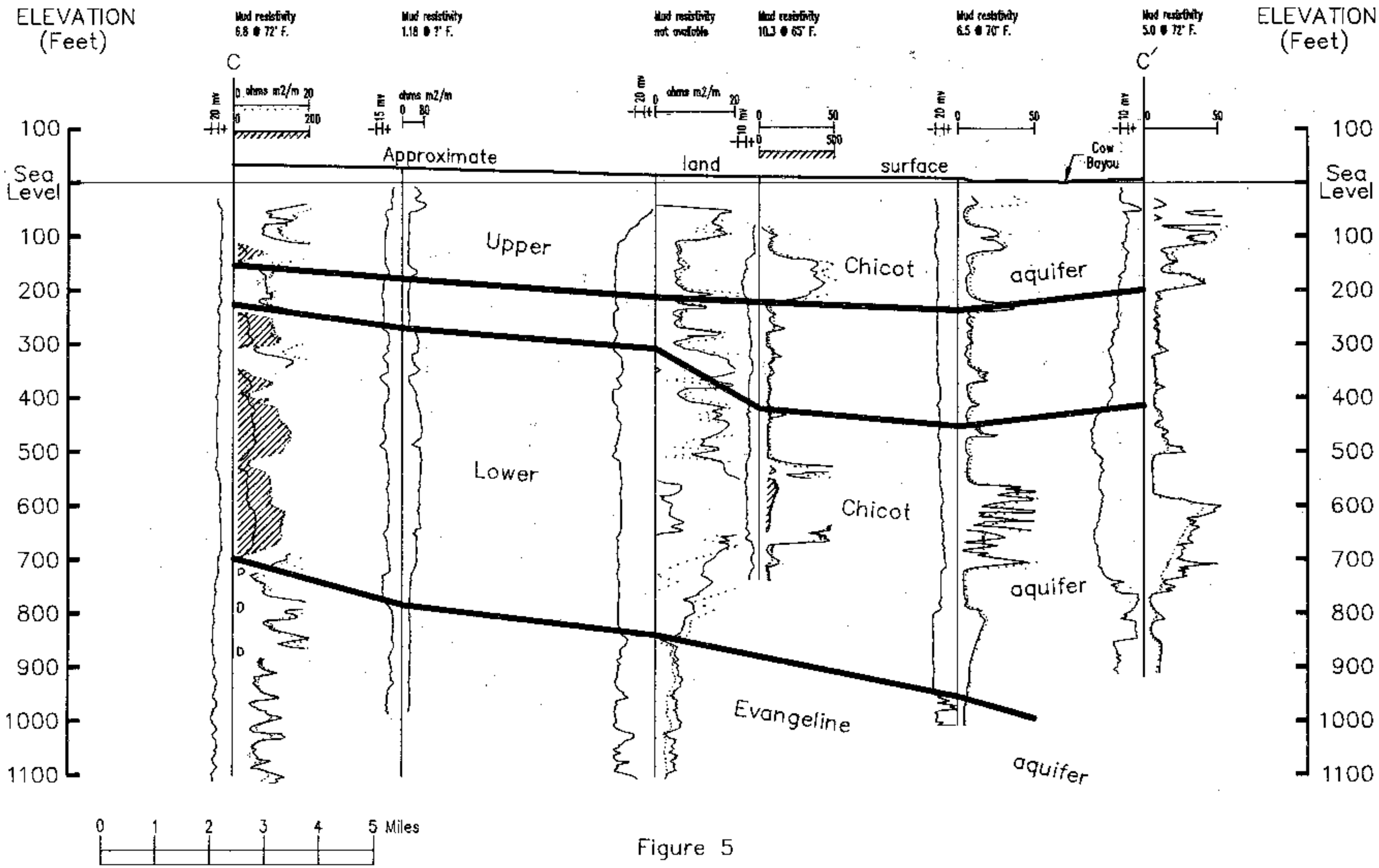


For location of section see Figure 6

Figure 4

CROSS SECTION B–B′

Modified from Wesselman (1965)



For location of section see Figure 6

Figure 5

CROSS SECTION C–C′

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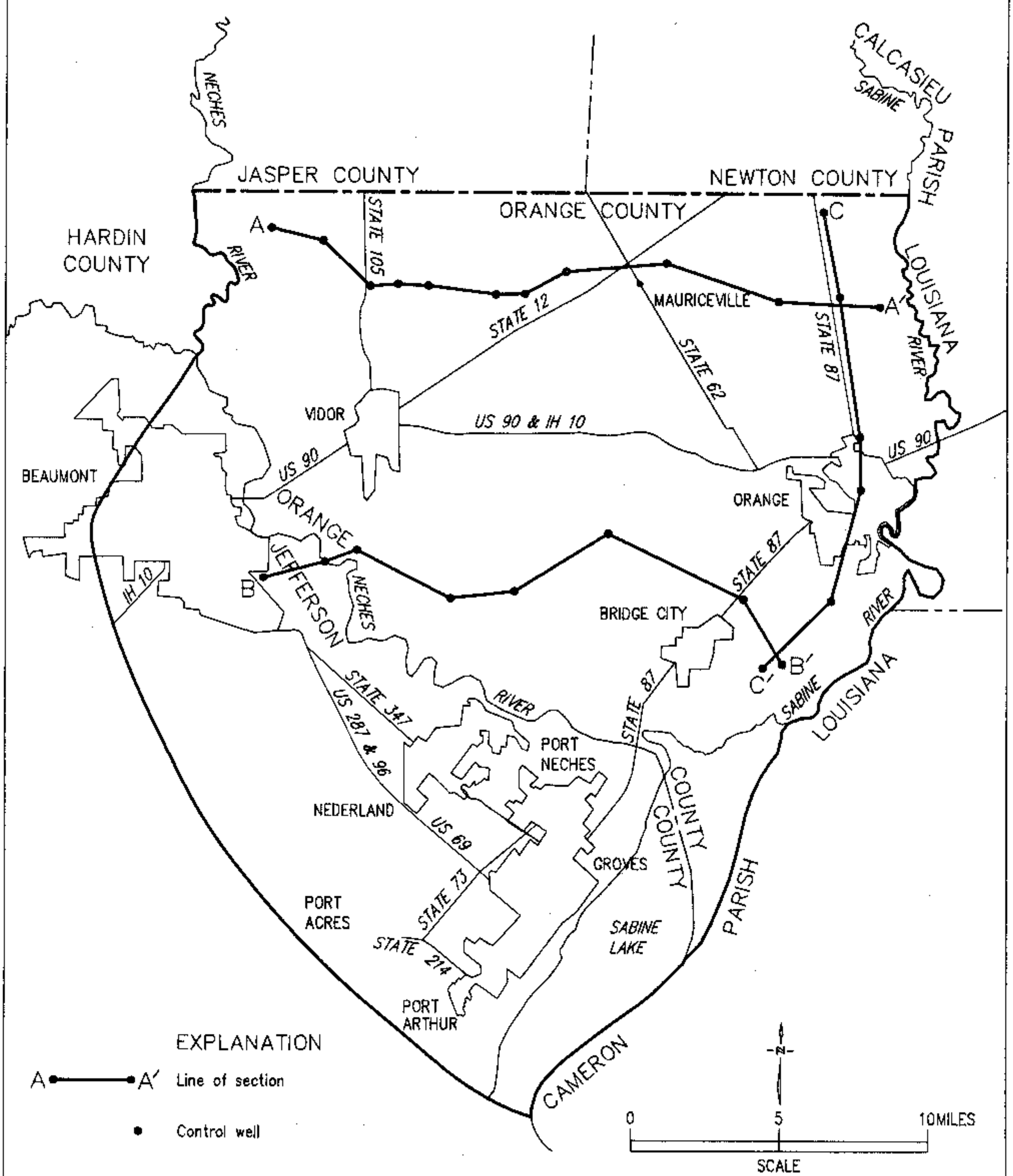


Figure 6

CROSS SECTION LOCATIONS

Total aquifer thickness in the study area ranges from about 425 feet in the northwest to about 1,000 feet in the southeast. The Chicot is divided into upper and lower units over most of the study area by clay beds that are as much as 200 feet thick.

Both the upper and lower Chicot are capable of yielding large quantities of fresh to slightly saline water (less than 3,000 milligrams per liter dissolved solids) to wells. The lower Chicot, however, is the principal source of water within the study area.

Source and Occurrence

There are several sources of ground water in the Chicot and Evangeline aquifers in the study area. The primary source is precipitation on the outcrop, which is abundant. A large amount of precipitation is lost to surface evaporation or becomes runoff to local streams and lakes. Also, a large portion which does infiltrate the soil is lost by transpiration through plants. There is a small amount, however, of the original precipitation which does slowly percolate downward, by gravity, and becomes part of the saturated zone below the water table. Other sources include seepage from streams and lakes, vertical leakage of ground water from one aquifer to another, and lateral movement through the aquifer from areas outside the study area.

All ground water occurs under either water-table or artesian conditions. In the Chicot aquifer, water-table conditions exist in the outcrop area where there is sufficient sand to allow infiltration, including major steam valleys where the upper unit of the aquifer is in hydraulic continuity with surficial sand deposits. Here, the top of the zone of saturation is under direct atmospheric pressure. Wells in this area are filled with water to the level of the water table, and water levels fluctuate in response to the volume of water in storage. At locations in the study area where the Beaumont Formation is composed of clay, water in the underlying lower Chicot aquifer occurs under artesian conditions. The Evangeline aquifer is also under artesian conditions throughout the area. Where this condition exists, when the aquifer is tapped by wells, hydrostatic pressure will cause water levels to rise above the top of the aquifer and, in some cases, actually flow at the surface.

Recharge, Movement, and Discharge

Recharge to the Chicot and Evangeline aquifers in the study area occurs primarily from precipitation on the aquifer outcrops in Orange and Jefferson Counties and in outcrop areas to the north. With the exception of parts of the upper unit of the Chicot, water also moves into the aquifers by lateral flow. Locally, recharge may also occur as vertical flow between the aquifers where sands of one are in contact with those of another.

Ground water moves under the influence of decreasing head or pressure from areas of recharge to areas of discharge. The general direction of movement of fresh water, before pumping began, was down gradient toward the coast, and toward areas in the major river systems where the aquifers are connected vertically.

A recent map of the piezometric surface (Figure 7) indicates that horizontal movement in the northern part of the study area is generally in a southern direction and elsewhere to the east and southeast toward major pumpage centers.

Ground-water discharge from the aquifer system occurs through both natural and artificial means. Natural discharge occurs as flow to seeps and springs, transpiration by plants, and by evaporation. Some discharge also takes place as vertical leakage between aquifers, usually from deeper artesian zones upward to shallower zones. The amount of water moving vertically is variable and depends on the

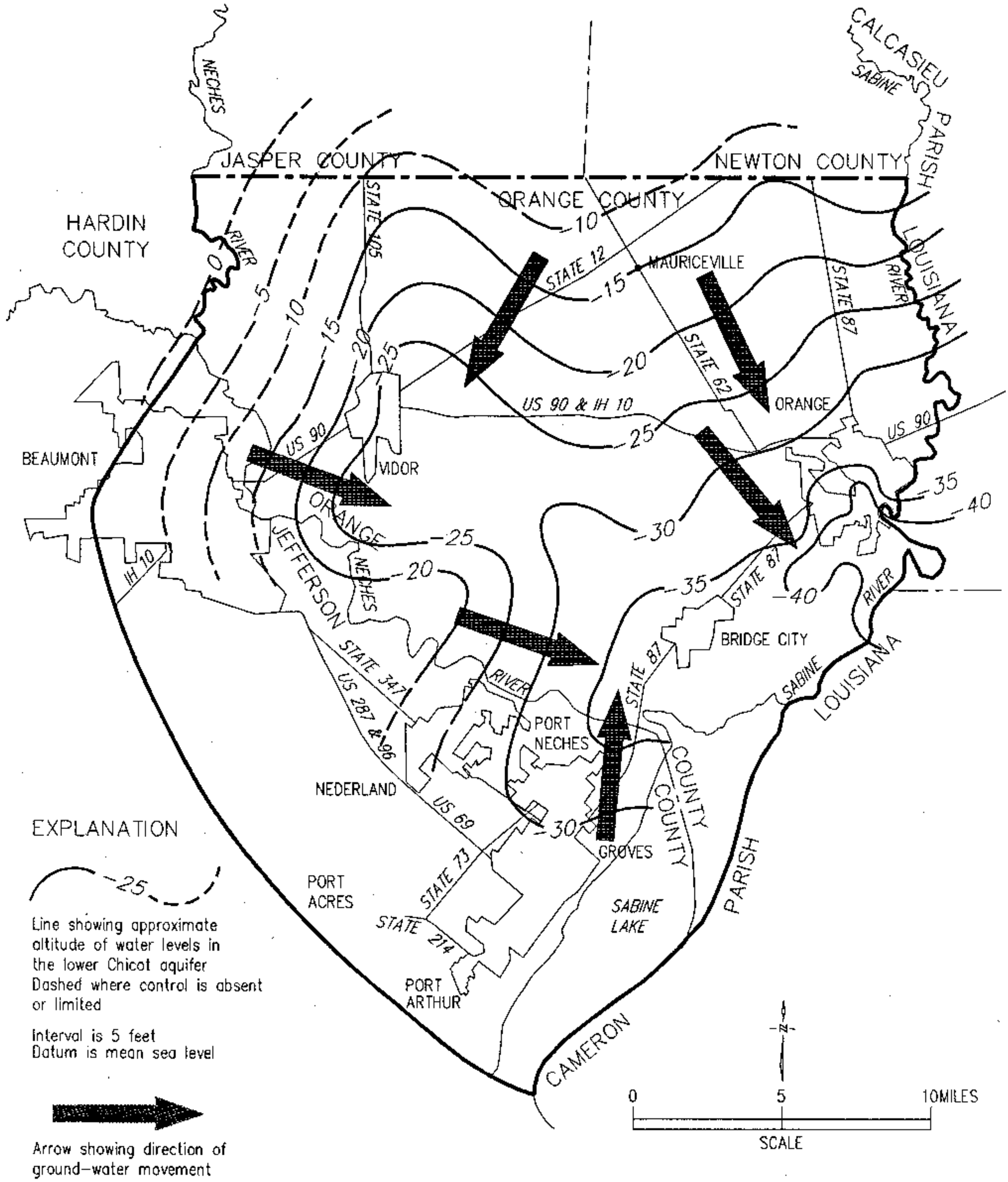


Figure 7

APPROXIMATE ALTITUDE OF WATER LEVELS IN THE LOWER CHICOT AQUIFER, SPRING 1987 vertical hydraulic conductivity of intervening beds and head differential between the aquifers. Ground water is discharged artificially through wells by pumping. In 1985, approximately 19,400 acre-feet of ground water was pumped from wells in the study area (Texas Water Development Board, 1988).

Hydraulic Characteristics

Hydraulic characteristics of an aquifer are generally expressed in terms of its transmissivity and coefficient of storage. These parameters are controlled by the porosities and hydraulic conductivities of the sediments which make up the aquifer, and control its capacity to yield water to wells. Through pumping of a test well and the use of repeated measurements of the water levels in the pumping well and nearby observation wells, the transmissivity and the coefficient of storage can be determined. Since these values are a measure of the aquifer's ability to transmit and store water, they can be used to determine the effects that a pumping well may have on another well, and to predict water-level drawdowns at various distances from a pumping well for a specified time and at a given pumping rate. This information is important when calculating proper well spacing.

Wesselman (1965 and 1971) discusses hydraulic characteristics of the aquifers in Chambers, Jefferson, and Orange Counties. He reports that results of aquifer tests indicate that the transmissivity for the lower Chicot aquifer ranges from 700 to 53,700 square feet per day. In Orange County alone, the average value is approximately 41,500 square feet per day based on an average value of saturated thickness and hydraulic conductivity for the unit. Coefficients of storage for the lower Chicot range from 0.0004 to 0.063. Well yields as large as 3,500 gallons per minute have been obtained from the lower Chicot with specific capacities ranging from 3.4 to 29.6 gallons per minute per foot of drawdown.

In Orange County, hydraulic characteristics for the upper Chicot aquifer are not well known. Sands which are thought to be equivalent to the upper Chicot in Calcasieu Parish, Louisiana have hydraulic conductivities ranging from 100 to 200 feet per day (Harder, 1960). Wesselman (1965) reports that conductivities of the upper Chicot in Orange County are probably similar. In Chambers and Jefferson Counties, transmissivities based on aquifer tests of the upper Chicot range from 1,400 to 4,000 square feet per day. Specific capacities ranged from 1.7 to 11 gallons per minute per foot of drawdown. Coefficients of storage for two wells were 0.0007 and 0.0002.

Due to the lack of development, very little is known about the values of transmissivity and storage for the Evangeline aquifer in Orange County. In Hardin and Jasper Counties, equivalent zones have average hydraulic conductivities of about 40 feet per day (Baker, 1964). The Evangeline is more extensively development in Chambers and Jefferson Counties where aquifer test results of two wells indicate transmissivities that range from 4,300 to 4,800 square feet per day. The coefficient of storage was 0.00003 and the specific capacity in one well was 16.2 gallons per minute per foot of drawdown.

GROUND-WATER PROBLEMS

Water-Level Decline

Historically, declining water levels have been of concern within the study area because of the affect they have on water quality and land-surface subsidence. Water levels in an aquifer are influenced primarily by the amount of recharge to and discharge from the system. Other controlling factors include topography, geologic structure, and hydraulic conductivities of the units.

Prior to large-scale withdrawals of ground water, the aquifers were essentially full and in a state of natural hydraulic equilibrium. The natural equilibrium for an aquifer system is disturbed by pumping of the ground water. As water is withdrawn, a slope in the piezometric surface is established toward the pumped well from all directions. This sloping surface assumes the shape of an inverted cone that is called the cone of depression. As pumping continues, the cone of depression becomes larger until equilibrium is reached, that is, until the hydraulic gradient is sufficient to force water through the aquifer at a rate equal to the discharge. Withdrawal from wells drilled close together creates cones of depression that may intersect and cause additional lowering of water levels. Figure 8 illustrates an idealized cross section showing drawdown interference between two pumping wells.

Steady increases in pumpage in eastern Orange County and neighboring Calcasieu Parish, Louisiana caused wells which had strong artesian flows during the early 1900's to cease flowing by the early 1950's. This translates to a water-level decline on the order of 25 to 30 feet or more.

During the period from 1941 to 1963, increased industrial pumpage in the vicinity of the Cities of Orange and West Orange resulted in net declines of as much as 40 feet.

As part of this study, U.S. Geological Survey water-level monitoring records were used to construct water-level change maps for the lower Chicot aquifer in order to establish recent water-level trends. With the exception of the most southwest part, data was sufficient to cover all of the study area for the periods 1977 to 1987 and 1982 to 1987.

Records indicate that between 1977 and 1987 water levels in the lower Chicot have risen from less than 5 feet to more than 10 feet over practically the entire study area (Figure 9). Due to decreases in ground-water pumpage in recent years, areas in the vicinity of the City of Orange which have historically had large water-level declines now show significant water-level rises. Declines which did occur were minor (less than five feet) and relatively isolated.

Water-level changes between 1982 and 1987 continue to show rises throughout the study area with amounts generally ranging from less than 5 to 10 feet (Figure 10). Three small areas show rises in excess of 10 feet for the time period. Only two monitor wells indicate any decline at all (1 foot and 3 feet, respectively). Both wells are located in close proximity to wells exhibiting water-level rises and are probably not indicative of overall trends.

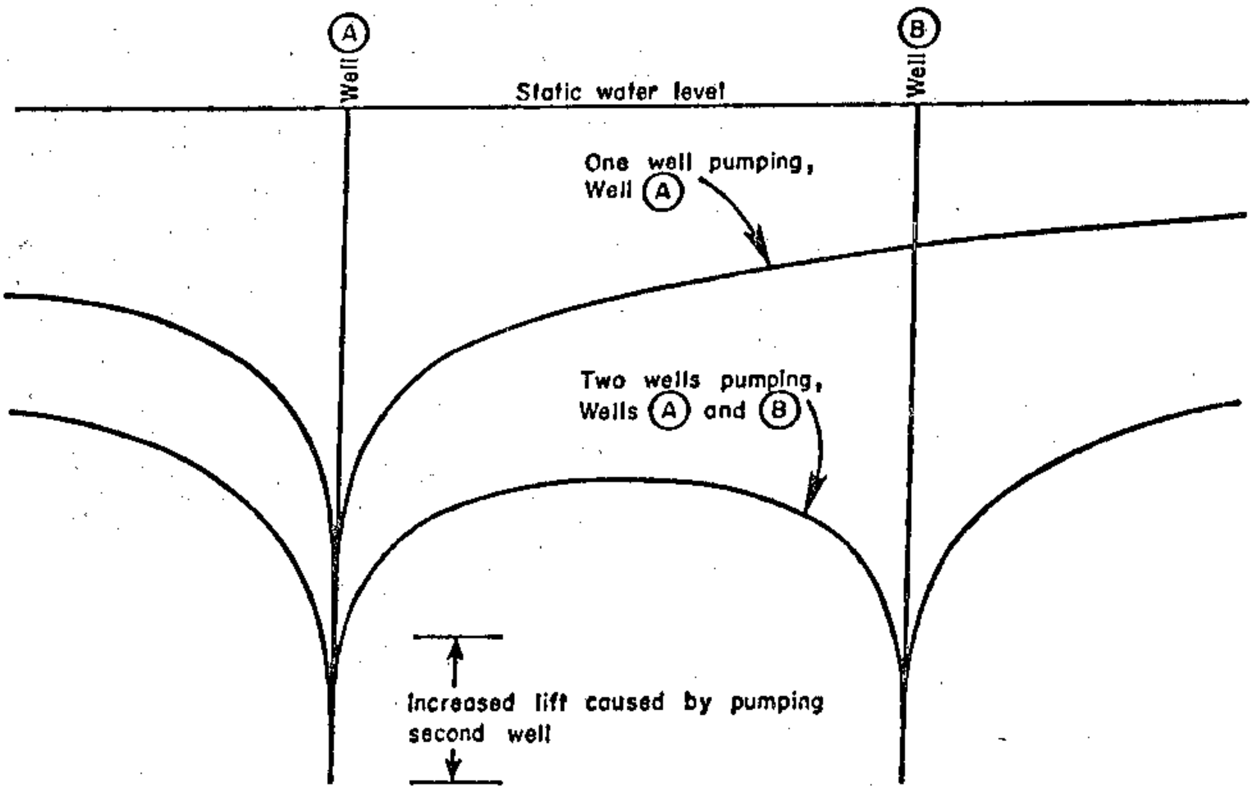


Figure 8 - Idealized Cross Section Showing Drawdown Interference Between Two Pumping Wells

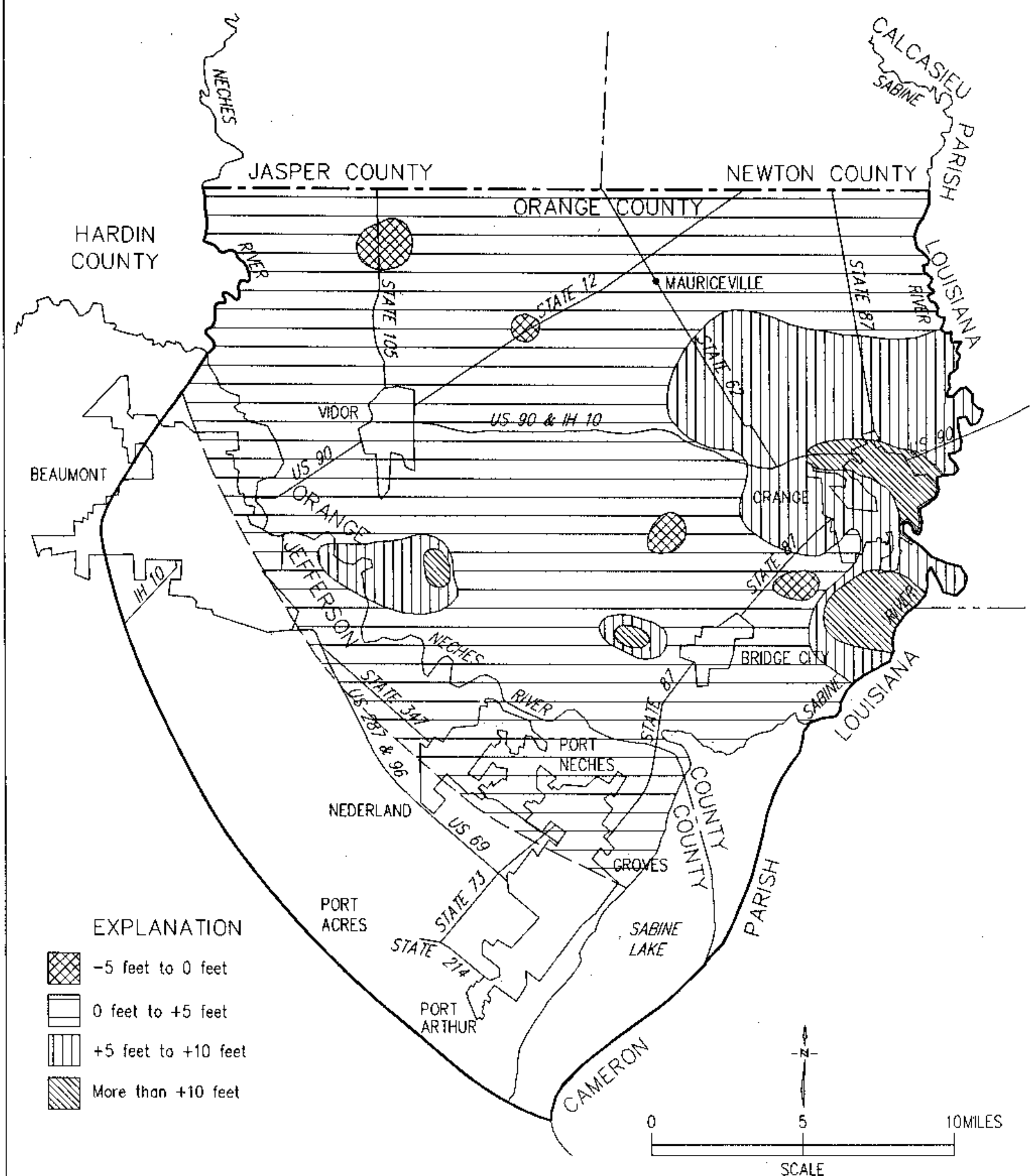


Figure 9

AREAS OF WATER-LEVEL CHANGE IN THE LOWER CHICOT AQUIFER, 1977 TO 1987

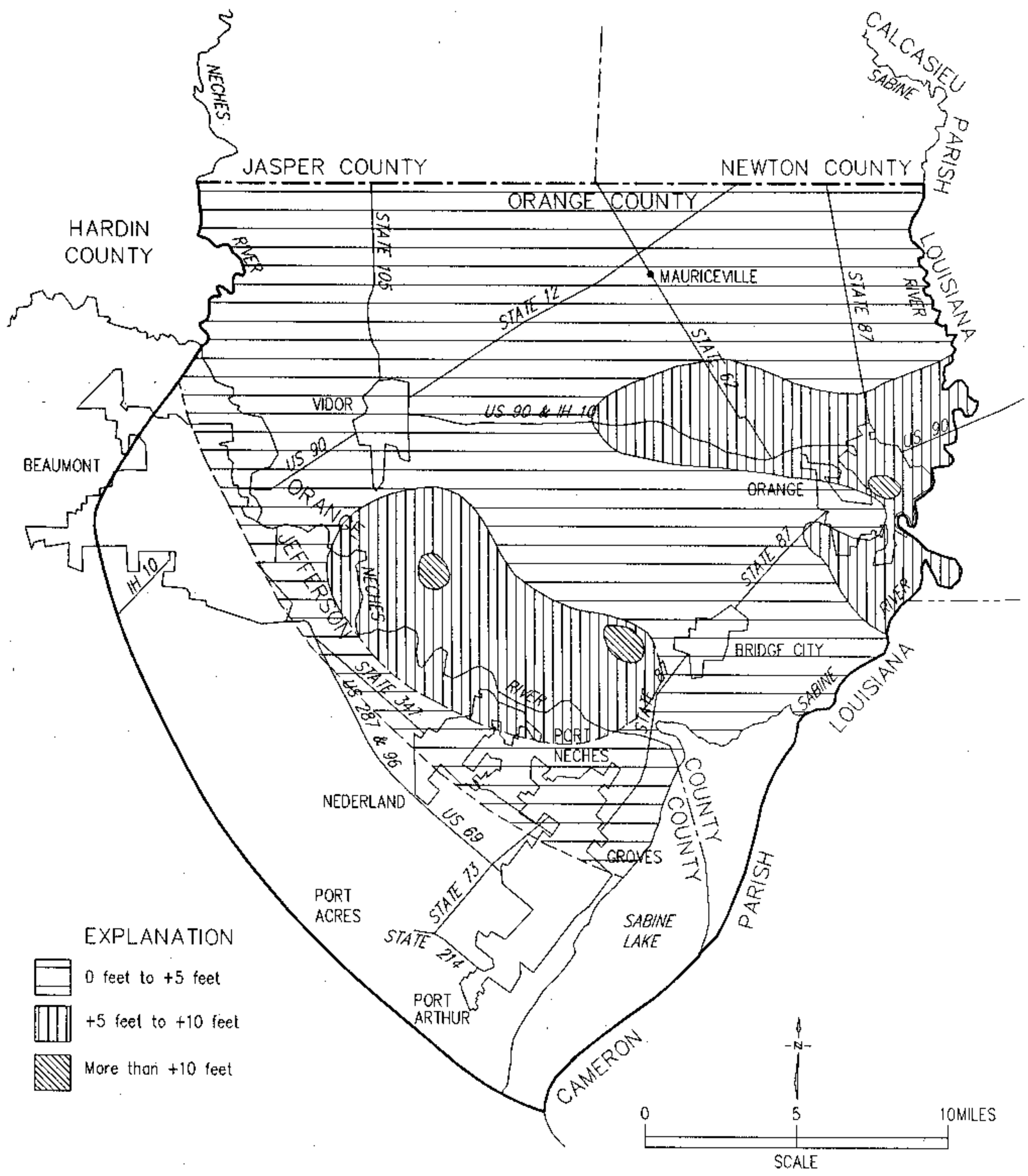


Figure 10

AREAS OF WATER-LEVEL CHANGE IN THE LOWER CHICOT AQUIFER, 1982 TO 1987

Water Quality

In this discussion of water quality, the chemical quality of ground water is classified according to the following:

Description	Dissolved Solids (Milligrams per liter)
Fresh	Less than 1,000
Slightly Saline	1,000 to 3,000
Saline	More than 3,000

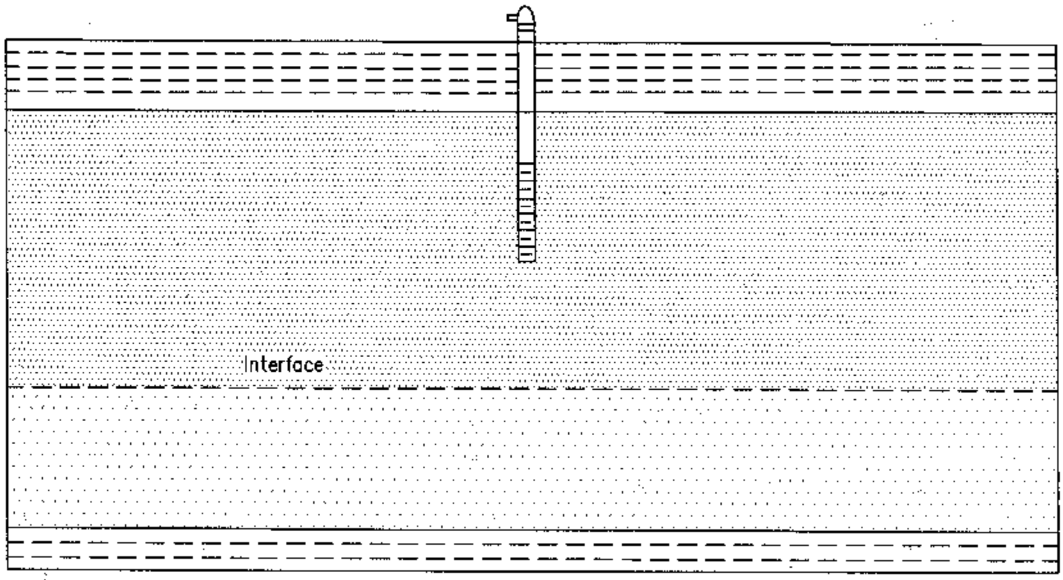
Presently, there are no large-scale ground-water quality problems within the study area. The most serious quality concern deals with the presence of naturally occurring saline water and its relationship to ground-water development. In the study area, the Chicot and Evangeline aquifers contain both fresh and saline ground water under natural conditions. Less dense fresh-water zones commonly lie on top of more dense saline-water zones. Prior to large-scale withdrawals of ground water the aquifer system was in dynamic equilibrium and the interface between fresh and saline waters was nearly stationary. When the interface was disturbed by pumping, saline water moved both vertically and horizontally into fresh water zones, causing quality deterioration most notably in the form of elevated chloride concentrations.

Vertical movement, or upward "coning", occurs when salt water is drawn upward into the fresh-water zone. It is fairly localized and evident when a well, or wells, producing water with unusually high chloride concentration is found associated with wells producing much lower concentrations. A graphic representation of saline-water coning is shown in Figure 11. Lateral saline-water encroachment, generally found in the southern part of the study area, occurs when water-level declines caused by large ground-water withdrawals reverse the hydraulic gradient and allow saline waters to move updip into the areas normally producing fresh water. Saline-water coning and horizontal encroachment have occurred in the study area, most notably in association with areas of concentrated municipal and industrial pumpage during the 1970's.

Figure 12 shows the general chloride concentration within the study area for the lower Chicot aquifer for the year 1988. The overall configuration of chloride concentration has changed very little in recent years due to a general decrease in ground-water withdrawals since the late 1970's. Concentrations in Orange County are less than 300 milligrams per liter (mg/l) except for two areas of industrial pumpage in the vicinity of the Cities of Orange and Vidor. In the southwest part of the study area, the interface between fresh and saline waters is very high in the stratigraphic section and there is virtually no fresh water in the aquifers southwest of the Neches River. Chloride concentrations exceed 300 mg/l in this area.

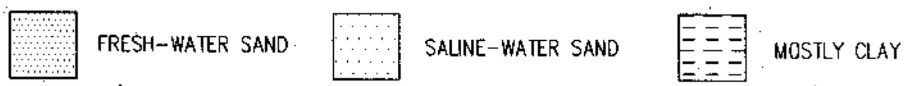
Chloride concentrations in waters from the lower Chicot seem to have stabilized regionally; however, the potential for additional encroachment and coning of saline water exists. In areas of concentrated ground-water development, chloride concentrations may increase with increased pumpage. For this reason, proper management of pumpage and future development is essential for this area.

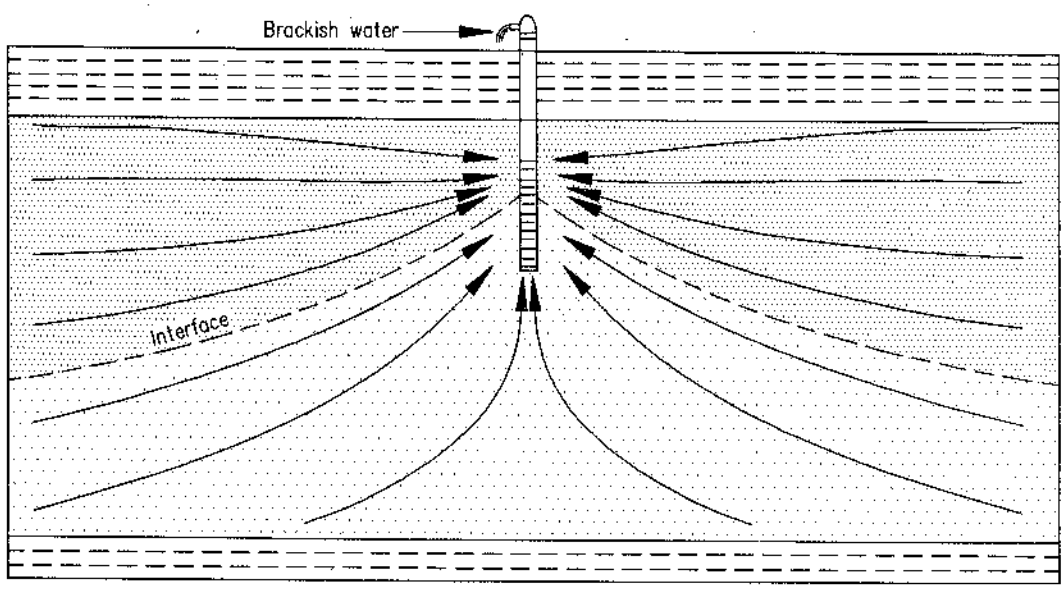
Another potential source of ground-water contamination within the study area is from the improper disposal of municipal and industrial wastes. Wesselman (1965) states that potential for harmful contamination is greatest in the northern part of the study area where the soil is sandy and shallow ground water is fresh to slightly saline. In the past, some shallow contamination occurred in this area due to improper disposal of oil field brines. Currently, two U.S.



a. Relationship between fresh water and saline water before pumping begins

EXPLANATION





b. The development of a saline-water cone during pumping

Modified from Nyman, 1984

Figure 11

DEVELOPMENT OF SALINE-WATER CONING

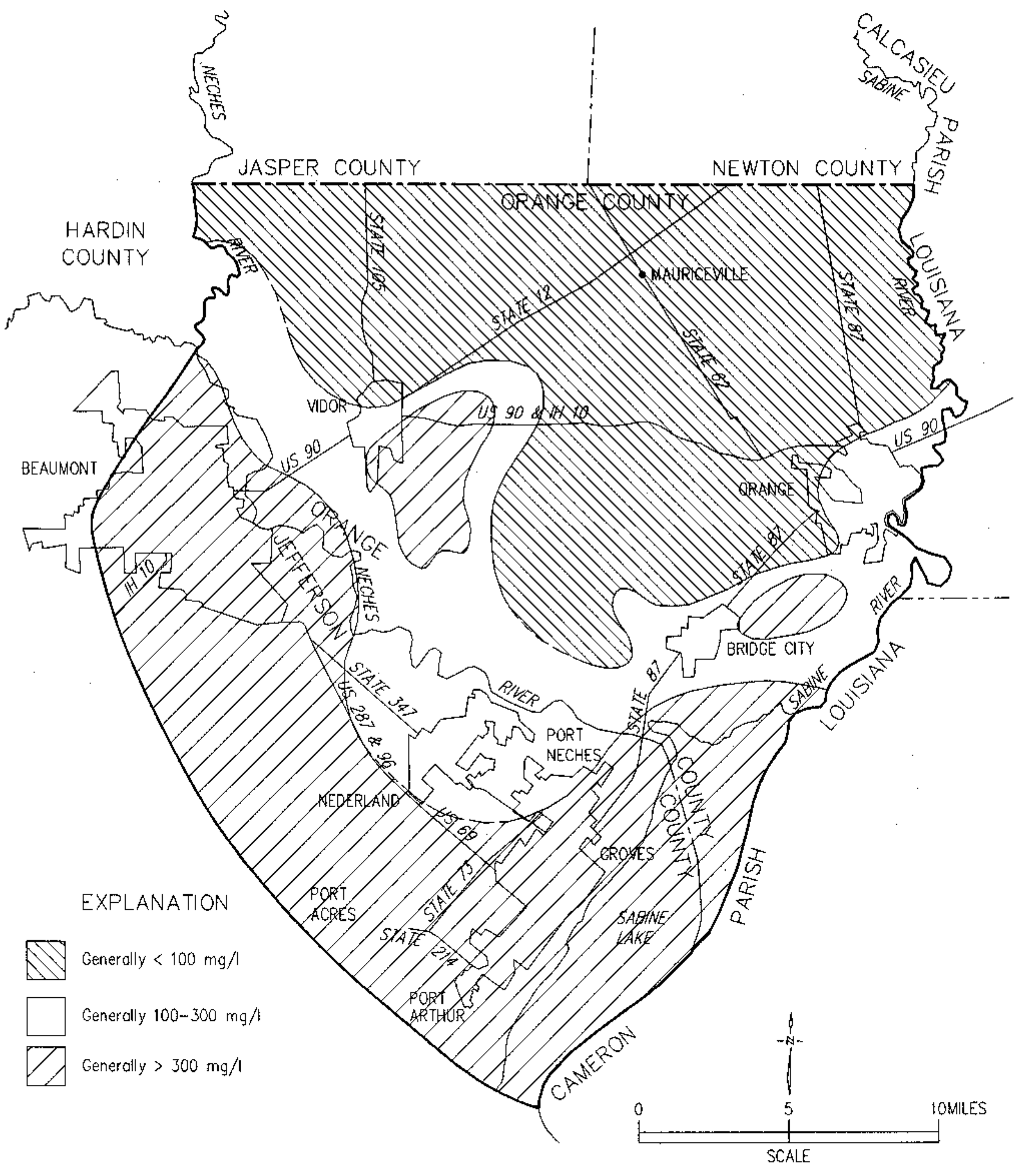


Figure 12

RANGE OF CHLORIDE CONCENTRATIONS
IN THE LOWER CHICOT AQUIFER, 1988

Data Source: U.S.G.S. Water-Quality Data
and Texas Water Commission Rept. 89-01 Figure 15

Environmental Protection Agency Superfund sites are located in southern Orange County (Bailey Waste Disposal, and Triangle Chemical Company). Contamination at both sites is very shallow (20 feet or less) and localized. In both cases, fresh-water zones which occur at greater depth and are undeveloped, have not been affected.

Land-Surface Subsidence

The main cause of land-surface subsidence in the Gulf Coast Region of Texas is the production of ground water, oil, and gas, and the withdrawal of ground water associated with oil and gas production (Ratzlaff, 1982). Some local subsidence has also occurred due to sulfur mining operations. Areas of concentrated municipal, industrial, and irrigation pumpage have experienced significant subsidence.

As water is withdrawn from an aquifer under artesian pressure, there is a corresponding decrease in pore pressure. The result is an increase in pressure on the aquifer skeleton in order to support the weight of overburden. Differential pressure between the sands and clays causes water to move from the clays into the sands. With the loss of water, the clays become compacted and subsidence of the land surface follows.

Regional land-surface subsidence in the study area has been small and is generally the result of water-level declines caused by municipal and industrial pumpage. Figure 13 illustrates subsidence in the study area from 1953-55 to 1973. Subsidence is determined by comparison of bench mark elevations as determined by the National Geodetic Survey. Ratzlaff (1982) states that land-surface subsidence from 1953-55 to 1973 in Orange County generally was less than 0.5 foot. More than 0.5 foot of subsidence occurred in the east-central area near the City of Orange and the western area near the City of Beaumont. Subsidence in these areas is generally attributed to municipal and industrial ground-water development and ranged between 0.55 to 0.80 foot. With ground-water pumpage having moderated in recent years, and surface-water supplies expected to meet most future large-scale needs, additional regional subsidence will most likely be insignificant.

Two areas of local subsidence caused by the production of oil, gas, saltwater, and sulfur can be seen in the Spindletop Dome and Port Acres gas field areas in the western part of the study area. Figure 14 shows the estimated subsidence in the Spindletop Dome area from 1925 to 1977. In this area, as much as 10 feet of the total subsidence may be due solely to sulfur mining (Ratzlaff, 1982). Subsidence in the Port Acres area for the years 1959-1977 is illustrated on Figure 15 and is the result of oil, gas, and associated saltwater production.

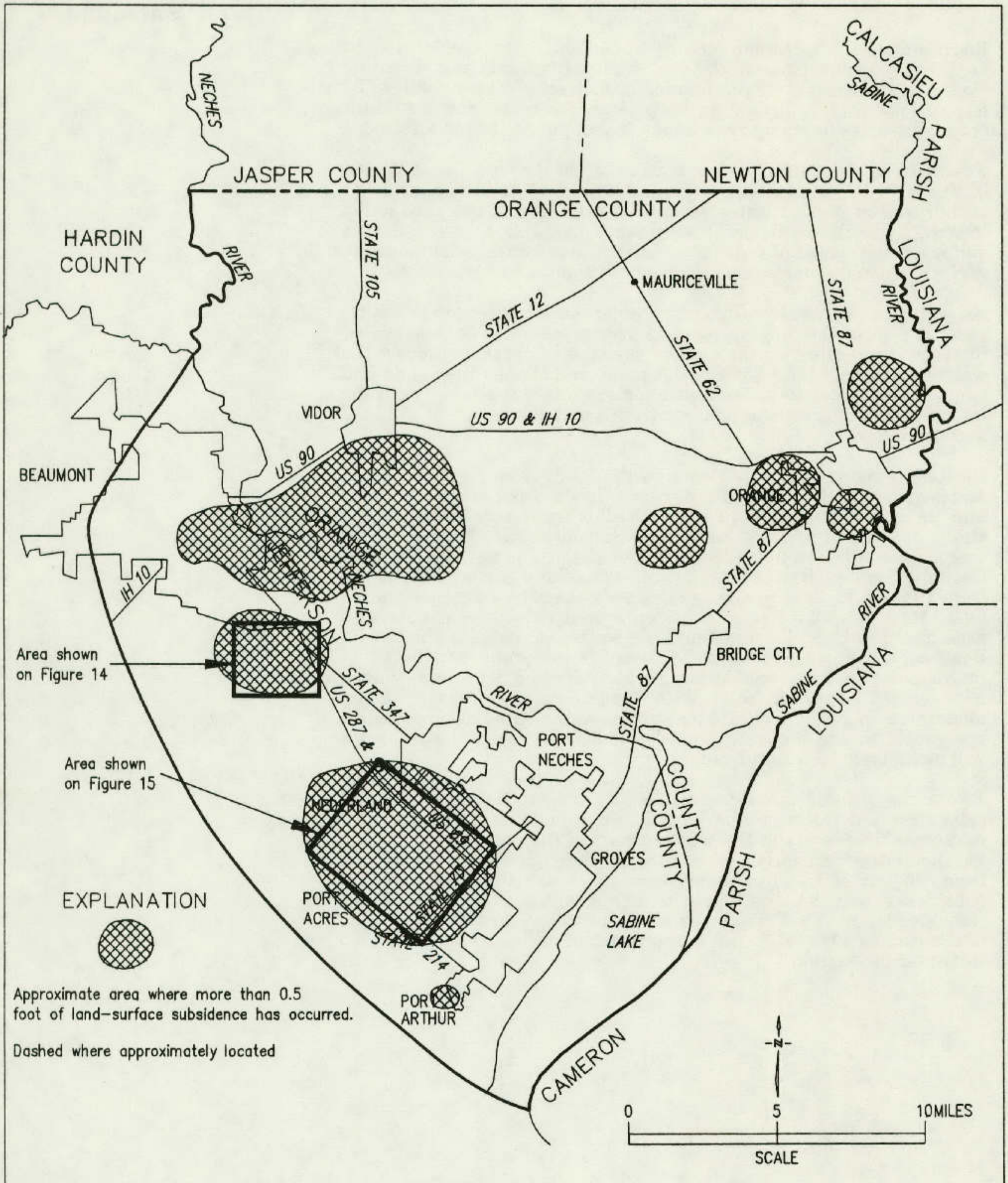


Figure 13

LAND–SURFACE SUBSIDENCE
IN THE STUDY AREA, 1953–55 TO 1973

Modified from Ratzlaff (1982)

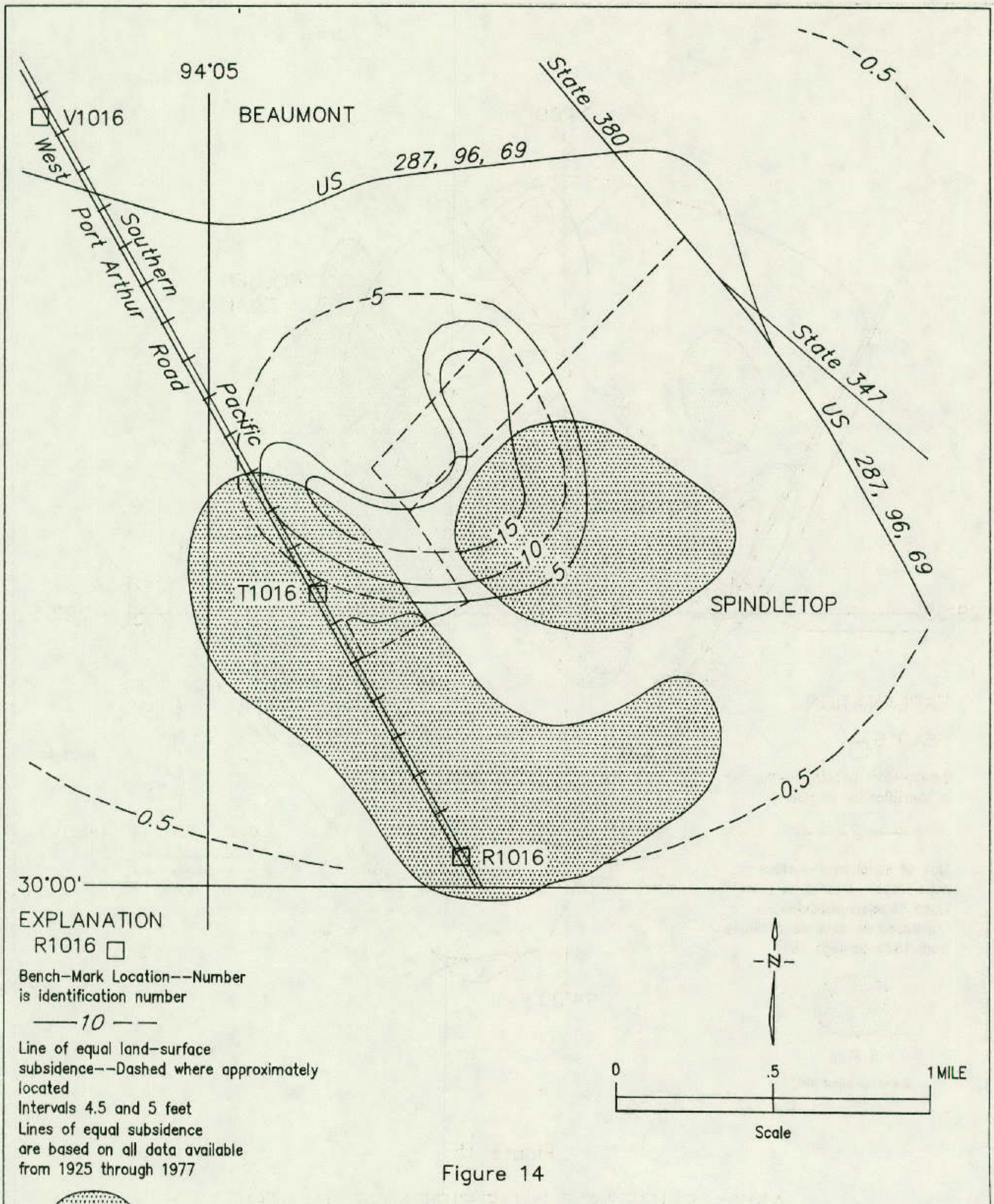


Figure 14

LAND-SURFACE SUBSIDENCE IN THE SPINDLETOP DOME AREA, 1925 TO 1977

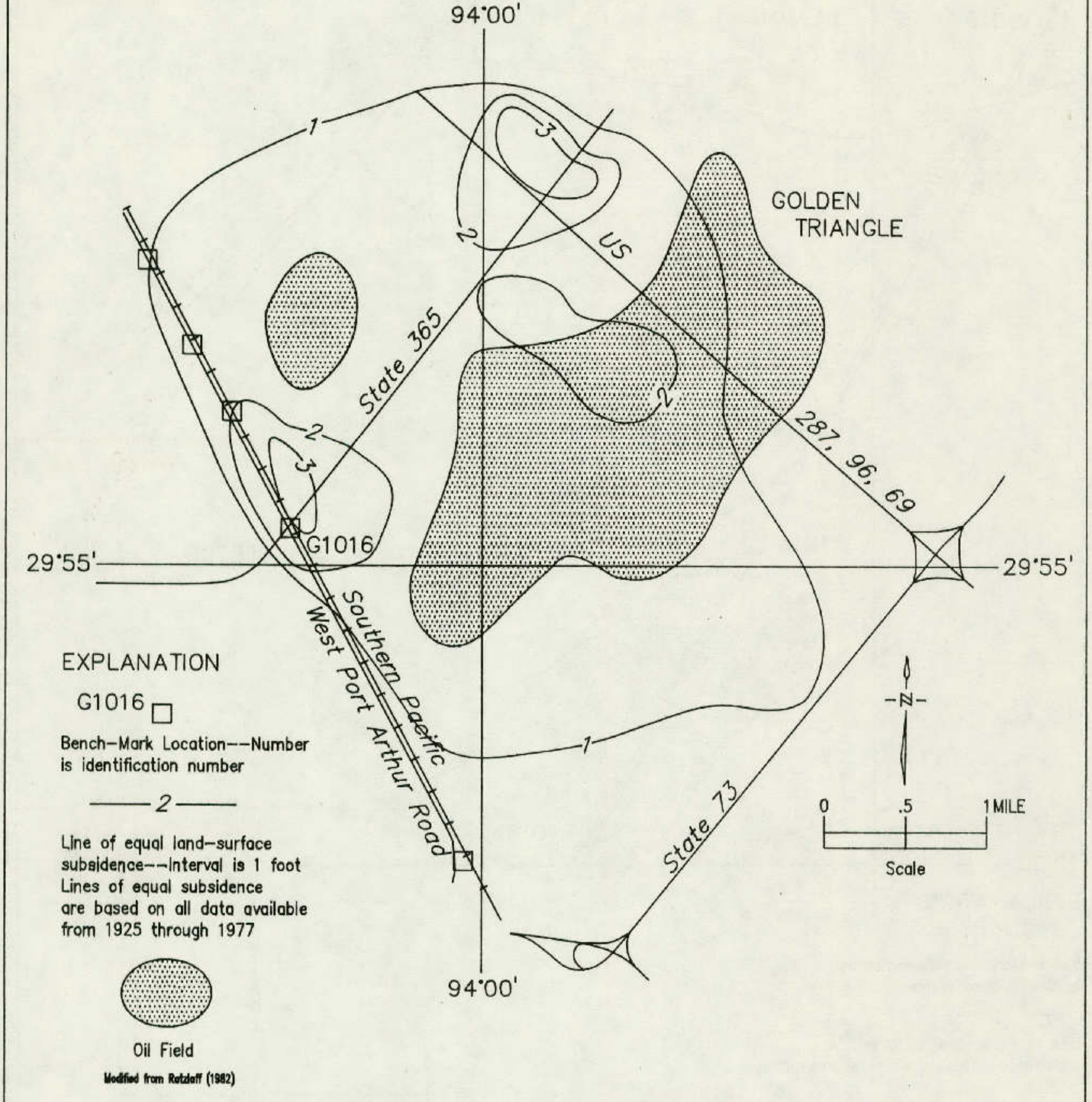


Figure 15

LAND-SURFACE SUBSIDENCE IN THE PORT ACRES AREA, 1959 TO 1977

PROJECTED WATER DEMANDS

Population

Due to the region's heavy economic dependence on the depressed petroleum industry, population growth from 1980 to 1985 was slow with an increase of only 1 percent for the period. The population of the study area is generally concentrated in the industrialized metropolitan areas. In 1985, the major cities of Beaumont, Port Arthur, and Orange had a combined population of 208,865 or approximately 64 percent of the total for the study area. The population for these cities is expected to increase to 233,078 by the year 2010 (Texas Water Development Board, 1988).

Population for the rural area in 1985 was 40,311, which is a 2 percent decrease since 1980. Rural population is projected to increase to 54,047 by the year 2010. The 1980 and 1985 population for cities and rural areas along with projected estimates for the years 1990, 2000, and 2010 are shown in Table 2. Population projections for the study area were estimated using the revised Texas Water Plan High Series population projection methodology (Texas Water Development Board, 1988).

Water Use

In 1985, total use of ground water and surface water was 243,643 acre-feet in the study area. Of this amount, 92 percent (223,437 acre-feet) was for municipal and industrial purposes. The amount of water used for all purposes in 1980 and 1985 is shown on Table 3.

Surface water makes up the largest portion of water used in the study area. The bulk of surface-water supplies is provided by the Lower Neches Valley Authority and the Sabine River Authority. Used for all purposes in 1985, surface water accounted for approximately 88 percent (213,675 acre-feet) of all water use. One exception is in Orange County where all municipal demand was met from ground-water sources. This amount (7,367 acre-feet), however, is only 3 percent of total water use.

Projected Water Demands, 1990-2010

Current and projected water demands by use category are shown in Table 3. Projections of future municipal and rural requirements are based on 1988 Texas Water Development Board Revised Data Series population projections and projected high series per capita water use. Future projections of irrigation, industrial, and livestock use are based upon high series projected demands and the apportioned share of total county demands. High series projections take into account the demands that are likely to occur during drought conditions. The great majority of future requirements are expected to be met from surface- water sources. Only a small portion of future requirements will be met from ground-water sources, mainly for municipal needs in Orange County.

Under high series projection conditions, the total annual water requirement for the study area is expected to increase by 34 percent from 1985 to the year 2010, at which time the annual demand is estimated to be 325,713 acre-feet. Municipal and rural requirements are projected to increase to 56,196 acre-feet annually during this period. The major projected increase under these conditions is with industrial use, which will increase 46 percent by 2010 to 260,850 acre-feet annually.

Table 2
Current and Projected Population of Study Area[1]

County[2]	Year	Cities[3]	Rural[4]	Total
ORANGE	1980	51,077	32,205	83,282
	1985	51,270	31,184	82,454
	1990	53,014	35,640	88,654
	2000	60,210	39,673	99,883
	2010	67,728	43,922	111,650
JEFFERSON	1980	229,044	8,967	238,011
	1985	232,265	9,127	241,392
	1990	233,084	9,301	242,385
	2000	234,694	9,327	244,021
	2010	254,838	10,125	264,963
TOTAL	1980	280,121	41,172	321,293
	1985	283,535	40,311	323,846
	1990	286,098	44,941	331,039
	2000	294,904	49,000	343,904
	2010	322,566	54,047	376,613

1 1980 and 1985 population is based on Bureau of Census statistics. 1990, 2000, and 2010 population is based on 1988 Texas Water Development Board Revised High Series population projection.

2 Population estimates are for the area of each county that falls within the study area (Figure 1).

3 The term "Cities" includes Bridge City, Orange, Pinehurst, Vidor, and West Orange in Orange County; and Beaumont, Groves, Nederland, Port Arthur, and Port Neches in Jefferson County.

4 The term "Rural" includes cities and unincorporated areas with a 1980 population of less than 1,000 and all rural population.

Table 3
Current and Projected Water Demand by Use in the Study Area[1]
(Units in Acre-Feet)

County[2]	Year	Municipal[3]	Industrial[4]	Irrigation	Domestic[5]	Livestock	Total
Orange	1980	7,950	53,522	9,990	3,804	106	75,282
	1985	7,367	47,694	7,854	3,654	53	66,622
	1990	9,296	55,130	5,546	5,181	125	75,278
	2000	9,993	65,943	4,320	5,470	146	85,872
	2010	10,634	77,187	4,320	5,730	146	98,017
Jefferson	1980	35,792	166,122	10,494	1,054	9	213,471
	1985	37,601	130,775	7,544	1,094	7	177,021
	1990	39,304	141,439	5,388	1,352	4	187,487
	2000	37,495	173,713	4,197	1,286	4	216,695
	2010	38,511	183,663	4,197	1,321	4	227,696
Total	1980	43,742	219,644	20,394	4,858	115	288,753
	1985	44,968	178,469	15,398	4,748	60	243,643
	1990	48,600	196,569	10,934	6,533	129	262,765
	2000	47,488	239,656	8,517	6,756	150	302,567
	2010	49,145	260,850	8,517	7,051	150	325,713

[1] 1980 and 1985 water demands are based on reported and site-specific computed use; 1990, 2000 and 2010 water demands are based on Texas Water Development Board High Series Preliminary Draft dated September 1988. Amounts include both surface- and ground-water sources.
[2] Water-demand estimates are for the study area only and do not include parts of Jefferson County outside the study area.
[3] Public-supply demand in Jefferson County includes ground water imported to Beaumont from outside the study area.
[4] Industrial demand includes water used for manufacturing, power and mining uses.
[5] Domestic includes cities and unincorporated areas with a 1980 population of less than 1,000 and all rural population.

AVAILABILITY OF WATER

Current Ground-Water Availability

Annual ground-water availability in the study area, as derived from the Texas Department of Water Resources's reports, "Water For Texas" (Texas Department of Water Resources, 1984) and "Ground-Water Availability in Texas" (Muller and Price, 1979), is approximately 19,600 acre-feet per year. This estimate is based on the results of a digital computer model used to evaluate the long-term regional water-supply capabilities of the Gulf Coast aquifer (Muller and Price, 1979). This amount is referred to as the annual effective recharge and represents the volume of ground water which can be developed on an annual basis without causing large-scale water-level declines, land-surface subsidence, or saline-water encroachment.

Nearly all of the study area is underlain by sands containing fresh and slightly saline water extending to various depths. The volume of water stored in these sands is considerably more than the annual effective recharge. Wesselman (1965) estimates that the volume of fresh water stored in the Chicot aquifer in Orange County alone is approximately 18 million acre-feet. Only a small percentage of this total, however, is economically recoverable. The amount of water available to wells in the study area depends upon several factors. In addition to the amount of water in storage, these include the amount of recharge, the ability of the aquifer to transmit water, and the effects that water withdrawals have on water levels and water quality. Factors limiting the development of ground water in the study area are land-surface subsidence and saline-water encroachment, which result from excessive water-level declines. In recent years annual effective recharge has exceeded ground-water demands, resulting in water-level rises as shown in Figures 9 and 10.

Current Surface-Water Availability

The study area is in two major river basins. The Sabine River basin is located on the east side of the study area and the Neches River basin comprises the west side of the study area.

Toledo Bend Reservoir supplies the largest amount of water to the area in the Sabine River basin. The Texas share of Toledo Bend, owned and operated by the Sabine River Authority of Texas, is permitted for the appropriation of 750,000 acre-feet of water annually. The permitted usage of the water is as follows:

Municipal	100,000 acre-feet
Industrial	600,000 acre-feet
Irrigation	50,000 acre-feet

At full conservation storage, the Lake contains 4,477,000 acre-feet of water and covers a surface area of 181,600 acres.

In 1986, the Sabine River Authority sold 1,046 acre-feet of water from the project. In addition, the San Jacinto River Authority has an option to take up to 600 million gallons per day from the project. The Sabine River Authority also uses water from Toledo Bend to supply run of river sales made by the authority.

In the Neches River basin, the major project that supplies parts of the study area is the Sam Rayburn Reservoir. The project was built by the U.S. Army Corps of Engineers and is operated by the Lower Neches Valley Authority. The Authority has the right to appropriate 820,000 acre-feet annually. The permitted usage is as follows:

Municipal	50,000 acre-feet
Industrial	660,000 acre-feet
Irrigation	110,000 acre-feet

In 1986, water sales totaled 145,540 acre-feet to municipal and industrial users in the study area.

Potential for Additional Ground-Water Development

Ground-water resources in the study area are only partly developed. Since ground-water quality in the Beaumont-Port Arthur area of eastern Jefferson County is questionable and the majority of demands there are currently met with surface-water supplies, areas most favorable for future ground-water development are in Orange County.

Although current ground-water demands (19,400 acre-feet in 1985) are nearly equal to the annual effective recharge, there still remains a large volume of water held in storage which could be utilized. Wesselman (1965) estimates that as much as 90,000 acre-feet per year could be developed from the lower Chicot in Orange County without creating ground-water problems. However, care must be taken when planning locations and development scenarios for future well fields. Improper locations and concentrated pumpage will cause lateral encroachment and vertical "coning" of highly saline water into fresh-water zones. This is the principal problem with additional development in the study area. If withdrawals are moderate or decreased, as needed to control water salinity, substantial quantities of fresh ground water can be pumped, even near the coast (Bonnet and Gabrysch, 1983).

In northern Orange County, the possibility of developing the Evangeline aquifer as an alternate or supplemental water supply should also be investigated.

Potential Methods of Increasing Aquifer Recharge

There are several factors which influence the amount of recharge to an aquifer. In an unconfined aquifer, one of the most important factors is the amount of precipitation that is not lost by evapotranspiration or runoff and, therefore, is available for recharge. Other factors include the vertical hydraulic conductivity of surficial deposits and the ability of the aquifer to transmit water away from the recharge area.

Recharge to a confined aquifer is also controlled primarily by the amount of precipitation at its outcrop that is available to move into the confined section. Vertical recharge to a confined aquifer is controlled by the hydraulic conductivity and thickness of the confining layer. There must also be a sufficient hydraulic gradient across the confining layer to promote flow into the aquifer.

In areas of severely deficient natural recharge, methods of artificial recharge are often utilized to increase the amount of available water. Some common methods are water spreading, recharge basins, and injection wells.

Water spreading commonly involves the use of control structures such as check dams, pits, furrows, ditches, and field terracing to control streamflow and runoff in order to increase infiltration time over a large area. Wastewater from municipal water systems is a potential source for water-spreading projects in some areas. Recharge basins are similar, but generally cover a smaller area. They are advantageous because a substantial hydraulic head can be created to increase infiltration rates. Injection wells are used where water spreading or recharge basins are not applicable.

Within the study area there are several factors which make the feasibility and necessity of artificial recharge methods questionable. One is the fact that the area receives a substantial amount of annual precipitation (52 to 56 inches). In recent years, natural recharge has exceeded ground-water withdrawals, and has resulted in significant water-level rises over much of the study area (Figures 9 and 10).

Also, surface deposits (upper Chicot) generally contain a high percentage of clay. This tends to render surface spreading and recharge basin methods ineffective due to low infiltration rates caused by low vertical hydraulic conductivities. For water spreading to be an effective method of artificial recharge, the water table should not be close to the surface (Fetter, 1980). Water-level data from the U.S. Geological Survey indicates that the water table is shallow (less than 10 feet) in the upper Chicot, which further decreases the feasibility for artificial recharge to shallow water zones.

To supply artificial recharge to deeper confined zones of the lower Chicot and Evangeline would require the use of injection wells. This method requires the availability of a source of water for injection to the aquifer. A major problem with injection wells is that they are prone to clogging due to a number of factors including filtration of suspended sediment and organic matter, formation precipitates caused by chemical reactions between recharge water and native ground water, and mechanical compaction of aquifer materials due to high injection pressures (Fetter, 1980). Initial capitol costs may be high as well as annual operation and maintenance costs, which must be considered when determining the feasibility of such a program.

Projected Availability Through the Year 2010

Water demand in the study area is expected to reach 325,713 acre-feet annually by the year 2010 (see Table 3). Figure 16 illustrates the current and projected total water demand through 2010, as well as the projected amount of ground water and surface water available to meet those demands.

Surface-water sources have historically supplied the large majority of total demand. This trend is expected to continue in the future. Available surface-water supplies (1,570,000 acre-feet annually) are adequate to meet surface-water needs in the study area through the 2010 planning period.

Ground water, on the other hand, supplies only a small percentage of total demand. The majority of ground-water development is in Orange County, primarily for municipal supply. In 1985, annual effective recharge (ground-water availability) was sufficient to meet all ground-water pumpage in the study area. Projections indicate that ground-water demands will exceed the effective recharge by 1990. Estimates by Wesselman (1965) of the amount of ground water in storage that can be safely developed (90,000 acre-feet/yr) suggest that there are adequate supplies to meet future ground-water requirements. However, heavy pumpage in concentrated areas will result in significant water-level declines which may cause saline-water encroachment and possible subsidence problems. For this reason, careful planning of well field locations and pumpage schemes is critical for any future ground-water development program.

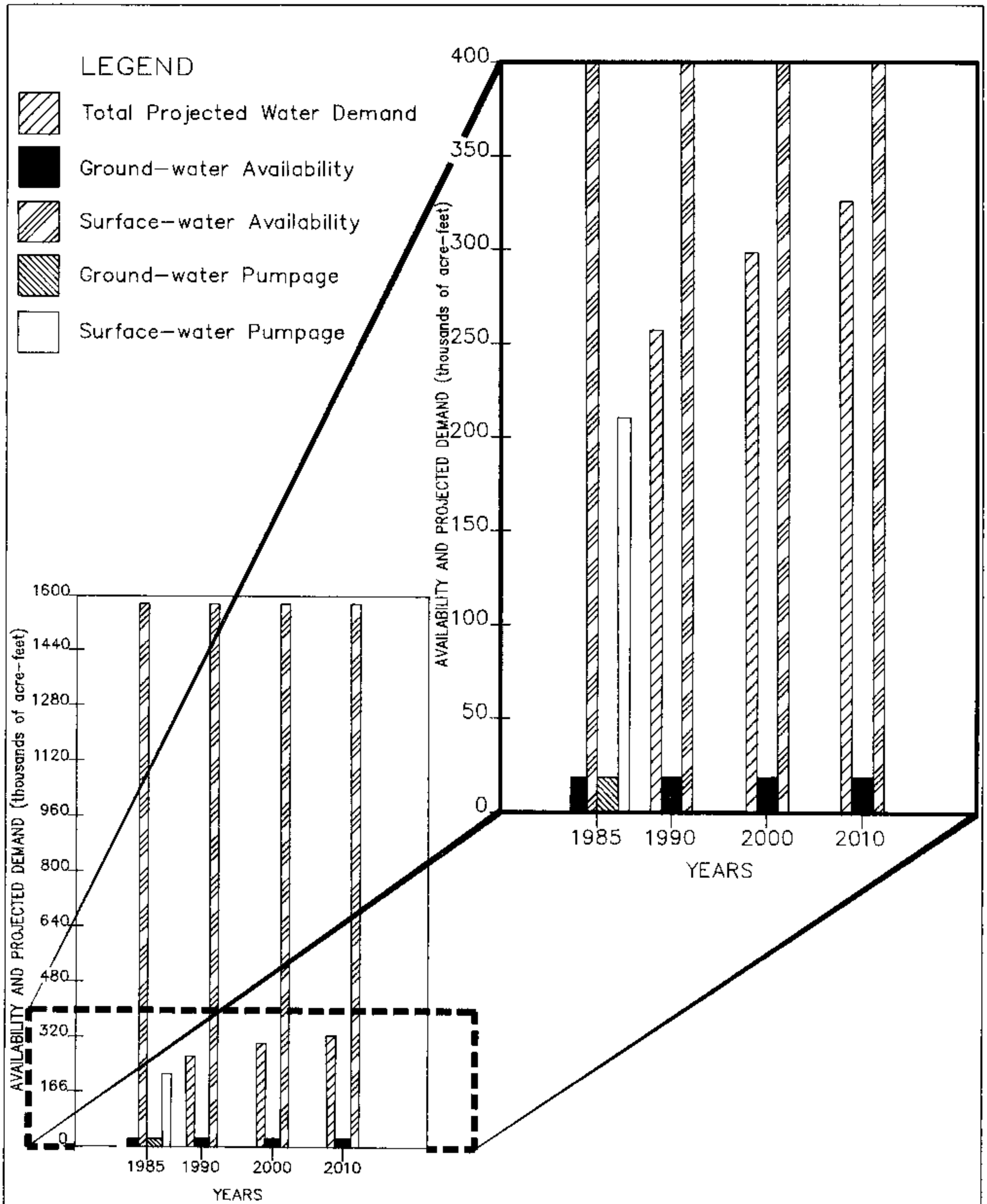


Figure 16

WATER AVAILABILITY VERSUS PROJECTED DEMAND

SUMMARY

Surface water supplies the majority of water demands in the study area. Ground-water needs, including all municipal requirements in Orange County, are met almost entirely from the lower Chicot aquifer. Historical ground-water problems including water-level declines, saline-water encroachment, and land-surface subsidence have not been serious in recent years due to a decrease in pumpage. Surface-water and ground-water supplies are adequate to meet projected water demands through the year 2010; however, future ground-water development will most likely exceed annual effective recharge (availability). Ground water in storage is sufficient to meet future demands, but planning development programs must consider well field locations and pumpage schemes in order to avoid a recurrence of historical problems.

SELECTED REFERENCES

Baker, B.B., Dillard, J.W., Souders, V.L., and Peckham, R.C., 1963, Reconnaissance investigation of the ground-water resources of the Sabine River basin, Texas: Texas Water Comm. Bull. 6307, 57 p.

Baker, E.T., 1964, Geology and ground-water resources of Hardin County, Texas: Texas Water Comm. Bull. 6406, 179 p.

______1979, Stratigraphic and hydrogeologic framework of part of the Coastal Plain of Texas: Texas Dept. Water Resources Rept. 236, 43 p.

Bonnet, C.W., 1975, Ground-water data for Orange County and vicinity, Texas and Louisiana, 1971-1974: Texas Water Devel. Board Rept. 197, 24 p.

Bonnet, C.W., and Gabrysch, R.K., 1983, Development of ground-water resources in Orange County, Texas and adjacent areas, 1971-1980: Texas Dept. Water Resources Rept. 283, 49 p.

Bonnet, C.W., and Williams, J.F., III, 1987, Development of ground-water resources in the Orange County area, Texas and Louisiana, 1980-Spring 1985: U.S. Geological Survey Water-Resources Investigations Rept. 87-4158, 50 p.

Bureau of Economic Geology, 1968a, Geologic atlas of Texas, Beaumont sheet: Univ. Texas, Bur. Econ. Geology map.

______1968b, Geologic atlas of Texas, Houston sheet: Univ. Texas, Bur. Econ. Geology map.

Carr, J.E., Meyer, W.R., Sandeen, W.M., and McLane, I.R., 1985, Digital models for simulation of ground-water hydrology of the Chicot and Evangeline aquifers along the Gulf Coast of Texas: Texas Dept. Water Resources Rept. 289, 101 p.

Fetter, C.W., Jr., 1980, Applied hydrogeology: Columbus, Merril Puhing Company.

Gabrysch, R.K., and McAdoo, G.D., 1972, Development of ground-water resources in the Orange County area, Texas and Louisiana, 1963-1971: Texas Water Devel. Board Rept. 156, 47 p.

Harder, A.H., 1960, Geology and ground-water resources of Calcasieu Parish, Louisiana: U.S. Geological Survey Water-Supply Paper 1549, 102 p.

Hogan and Rasor, Inc., 1984, Report on water supply for the City of Orange, Texas: Prepared for the City of Orange.

Knape, B.K., 1984, Underground injection operations in Texas: Texas Dept. Water Resources Rept. 291.

Larkin, T.J., and Bomar, G.W., 1983, Climatic atlas of Texas: Texas Dept. Water Resources Rept. LP-192, 151 p.

Müller, D.A., and Price, R.D., 1979, Ground-water availability in Texas, estimates and projections through 2030: Texas Dept. Water Resources Rept. 238, 77 p.

Nyman, D.J., 1984, The occurrence of high concentrations of chloride in the Chicot aquifer system of southwestern Louisiana: Louisiana Department of Transportation and Development, Water Resources Technical Report No. 33, 75 p.

Ratzlaff, K.W., 1982, Land-surface subsidence in the Texas coastal region: Texas Dept. Water Resources Rept. 272, 26 p.

Texas Water Commission, 1989, Ground-water quality of Texas - an overview of natural and man-affected conditions: Texas Water Comm. Rept. 89-01, 197 p.

Texas Department of Water Resources, 1984, Water for Texas - A comprehensive plan for the future, v. 1 and v. 2.

______1988, Revised data series, preliminary draft: unpublished.

Turcan, A.N., Jr., Wesselman, J.B., and Kilburn, Chabot, 1966, Interstate correlation of aquifers, southwestern Louisiana and southeastern Texas: U.S. Geological Survey Ppssional Paper 550-D, pp. D-231-236.

Wesselman, J.B., 1965, Geology and ground-water resources of Orange County, Texas: Texas Water Comm. Bull. 6516, 112 p.

______1967, Ground-water resources of Jasper and Newton Counties, Texas: Texas Water Devel. Board Rept. 59, 167 p.

______1971, Ground-water resources of Chambers and Jefferson Counties, Texas: Texas Water Devel. Board Rept. 133, 183 p.