Report 295

Hydrology of the Jasper Aquifer in the Southeast Texas Coastal Plain

October 1986

Texas Water Development Board

TEXAS WATER DEVELOPMENT BOARD

REPORT 295

HYDROLOGY OF THE JASPER AQUIFER IN THE SOUTHEAST TEXAS COASTAL PLAIN

By

E. T. Baker, Jr.
U.S. Geological Survey

This report was prepared by the U.S. Geological Survey under cooperative agreement with the Texas Water Development Board

October 1986

Published and distributed
by the
Texas Water Development Board
Post Office Box 13231
Austin, Texas 78711

FOREWORD

Effective September 1, 1985, the Texas Department of Water Resources was divided to form the Texas Water Commission and the Texas Water Development Board. A number of publications prepared under the auspices of the Department are being published by the Texas Water Development Board. To minimize delays in producing these publications, references to the Department will not be altered except on their covers and title pages.

ABSTRACT

The Jasper (Miocene) aquifer is one of several important hydrologic units in the Gulf Coastal Plain. Because the Jasper aquifer underlies shallower aquifers in many areas, regional water withdrawals from the Jasper are not significant; however, it is capable of yielding 3,000 gallons per minute or more of water to wells in certain areas. The Jasper is underlain by the Catahoula confining system (restricted) and overlain by the Burkeville confining system. The Evangeline and Chicot aquifers, in turn, overlie the Burkeville and also are prolific water-yielding aquifers.

The ground-water hydrology of the Jasper aquifer in an area of about 20,000 square miles, was simulated by a two-dimensional digital model using a steady-state approach. The model represents hydrologic conditions prior to development by wells, when natural recharge equaled natural discharge. The model's grid pattern of 15 x 24 nodes varies from a dimension of 5 by 10 miles in the outcrop to 10 by 10 miles in the artesian section downdip from the outcrop.

The model was calibrated by simulating the predevelopment potentiometric surface of the Jasper aquifer. Results of the calibration showed that the simulation closely agrees with historical records of water levels in most areas Sensitivity analysis showed that the model is very sensitive to changes in recharge on the outcrop of the Jasper. The shape of the potentiometric surface is affected more by changes in transmissivity than by changes in vertical-hydraulic conductivity. The sensitivity of most of the modeled part of the aquifer to a 60-mile extension of its downdip boundary into highly saline water was about equal to a 25-percent reduction in transmissivity or a 25-percent increase in vertical-hydraulic conductivity.

TABLE OF CONTENTS

TABLE OF CONTENTS—Continued

TABLE

FIGURES

TABLE OF CONTENTS—Continued

TABLE OF CONTENTS—Continued

HYDROLOGY OF THE JASPER AQUIFER IN THE SOUTHEAST TEXAS COASTAL PLAIN

By

E.T. Baker, Jr.
U.S. Geological Survey

INTRODUCTION

This report has been prepared to document the construction and calibration of a digital-computer model that simulates water flow in the Jasper aquifer of Miocene age in southeast Texas, and to present an account of the improvement in our understanding of the hydrology of interconnected aquifers and confining layers. It is in this area of Texas that the Jasper has its greatest ground-water potential. For this reason, only this segment of the aquifer, which extends statewide across the coastal plain of the State, has been modeled. The ground-water flow model of the Jasper is designed to quantify certain hydraulic properties of the hydrologic system such as vertical-hydraulic conductivity and to a lesser extent, recharge and transmissivity, and to be used as a tool to aid water planners in the regional development of the Jasper aquifer and in the protection of its water supplies.

This report on the model also serves to improve our understanding of the hydrology of the interrelationship of adjoining aquifer systems and confining systems. The improvement is achieved by the development of the digital model of the hydrologic system prior to significant ground-water development.

The scope of this report directed primarily to a discussion of: (1) the geohydrology of the ground-water system including the frame work of the southeastern Coastal Plain; (2) a discussion of the hydrologic and hydraulic parameters that are built into the model; and (3) a discussion of the calibration and various sensitivity analyses of the model including a steady-state simulation prior to development of the aquifer by wells.

This report constitutes the ultimate objective of a project to evaluate the ground-water resources of the Miocene aquifer(s) in the Gulf Coastal Region of Texas. As an interim part of the project, a report (Baker, 1979) was prepared to illustrate the stratigraphic and hydrogeologic framework of the Jasper aquifer as well as other hydrogeologic units from the Sabine River to the Rio Grande (Louisiana to Mexico). This was shown by a series of 11 dip sections that are about 50 miles apart and 100 miles long and 1 strike section 500 miles long. Ground water having concentrations of less than 3,000 mg/l (milligrams per liter) of dissolved solids (fresh to slightly saline water) is shown on the sections and serves as an index to the availability of freshwater.

Description of the Study Area

The study area, which extends slightly beyond the modeled area, is about 25,000 square miles and is predominantly within the southeast Texas Coastal Plain (Figure 1). The eastern limit of the area, however, extends into western Louisiana from 20 to 50 miles. The western boundary of the area is slightly west of the Brazos River and is about 170 miles west of the Texas-Louisiana border. The northern boundary is the most inland extent of the Miocene-age formations (Catahoula Sandstone), which is about 100 miles inland from the coastline. The southern boundary of the described area approximates the coastline, although the model's southern boundary is from 30 to 50 miles inland from the Gulf of Mexico.

The land surface is mostly a smooth depositional plain in the southern two-thirds of the area and a slightly rolling dissected terrain in the northern one-third. Altitudes range from sea level to more than 600 feet in places on the outcrop of the Jasper aquifer.

Precipitation ranges from 40 to almost 60 inches, becoming progressively greater from west to east. The southeast Texas Coastal Plain is the area of greatest precipitation in the State, and for this reason, the water tables of the aquifers are near the land surface.

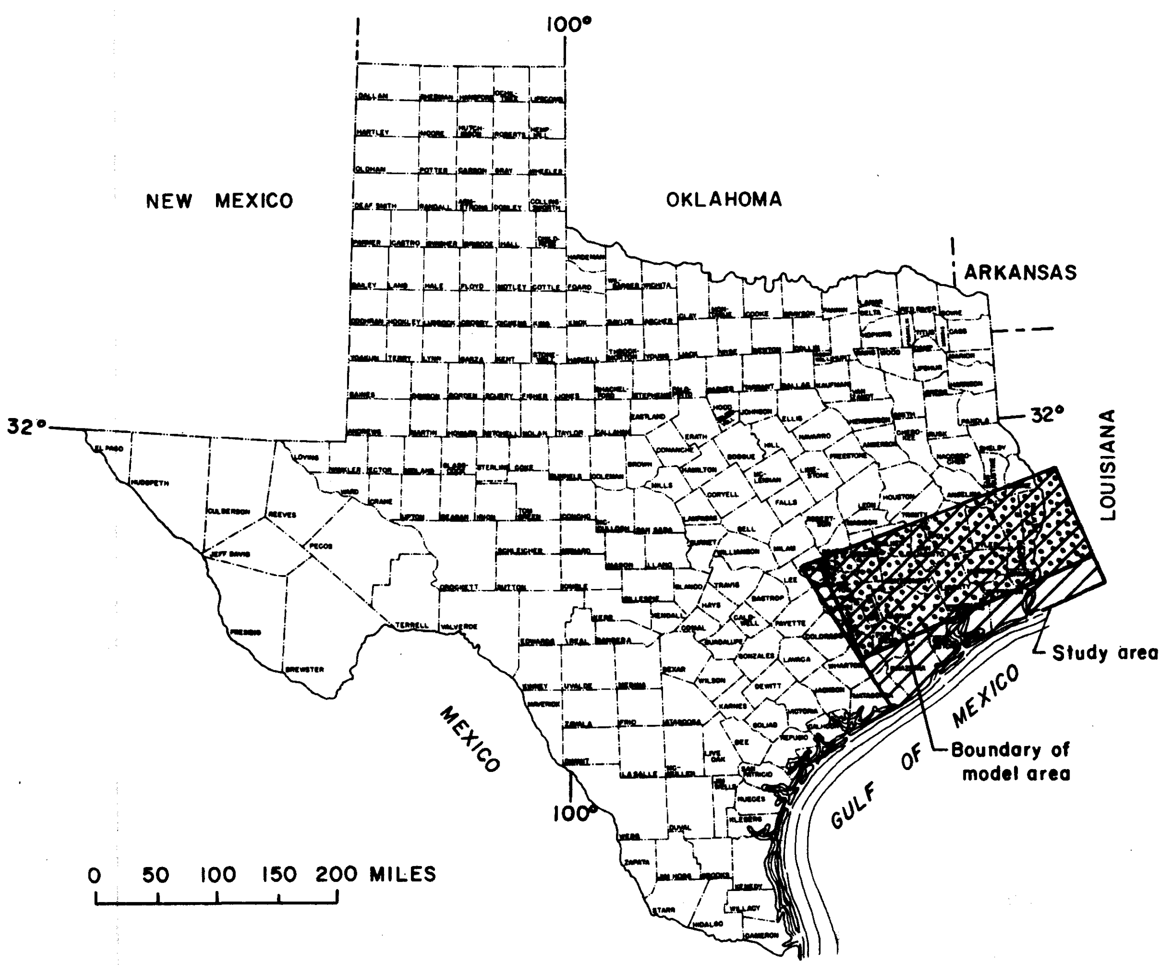

Figure 1.—Location and Extent of the Study Area

Several major streams cross the area in a southward direction and flow into the Gulf of Mexico. These include, from east to west, the Sabine, Neches, Trinity, San Jacinto, Brazos, and Colorado Rivers. About 55 percent of the average annual runoff in Texas is transported by these rivers, their base flows being sustained by large volumes of seepage from the aquifers.

The economic development of the study area varies widely. The urbanized sections in the south part of the area have a large and diversified industrial base. Houston, the Beaumont-Port Arthur-Orange complex, and Lake Charles are densely populated centers to the south with large petrochemical industries. Extensive rice irrigation also is practiced in the south. The northern sections are largely rural with only a relatively small scattering of industry and less irrigated farming. Large volumes of surface and ground water are used by industry for cooling and processing purposes and by rice and cotton growers for irrigation. The rapid growth and development of much of the area is due to the accessibility and abundance of surface and ground water. Not withstanding the fact that large volumes of water are pumped from various aquifers underlying the Coastal Plain, the Jasper aquifer remains relatively undeveloped. This is primarily because it lies beneath two prolific aquifers -the Chicot and Evangeline-that because of their shallower positions, are the more extensively pumped aquifers in the southern part of the area.

History of Hydrologic Modeling in the Texas Coastal Plain

The first attempt at modeling the ground-water system in the Texas Coastal Plain resulted in the construction of an electrical-analog model of the Chicot and Evangeline aquifers in the Houston district (Wood and Gabrysch, 1965). This model covered an area of 5,000 square miles in all or parts of Harris, Galveston, Brazoria, Fort Bend, Austin, Waller, Montgomery, Liberty, and Chambers Counties. It was used to predict water-level responses under various conditions of pumping, but had only limited success because the Chicot and Evangeline were simulated independently, and agricultural pumping in the western part of the area could not be represented. The model indicated a need for improvement in aquifer delineation and a more adequate modeling of the aquifers' transmissivities and the vertical leakage between them.

Ten years later, a second electrical-analog model was constructed incorporating additional hydrologic data and more advanced concepts of the hydrologic system (Jorgensen, 1975). This model, also of the Chicot and Evangeline aquifers, was larger than the first one and included an area of about 9,000 square miles, with the Houston district as its center. The larger area minimized the boundary effects within the Houston district, which were a problem with the first model. The effects of the withdrawals of water from well fields for a year or longer were simulated by this second electrical-analog model.

A third model, also of the Chicot and Evangeline aquifers and centering on the Houston district, was constructed several years later (Meyer and Carr, 1979). The five-layer, finite-difference model used a digital computer for simulation of three-dimensional ground-water flow in an area of 27,000 square miles. This model simulated water-level responses to pumping, changes in storage in the clay layers, and land-surface subsidence.

The most recent hydrologic modeling of ground-water flow in the Chicot and Evangeline aquifers refined much of the previous work and extended coverage of these aquifers throughout the Coastal Plain of Texas (Carr and others, 1985). This work resulted in a series of multilayered, three-dimensional models that also simulate the response of water levels to pumping, changes in storage in the clay layers, and land-surface subsidence.

Metric Conversions

For those readers interested in using the metric system, the metric equivalents of inch-pound units of measurements are given in parentheses. The inch-pound units used in this report have been converted to metric units by the following factors:

From	Multiply by	To obtain
feet	0.3048	meters (m)
feet per day (ft/d)	0.3048	meters per day (m/d)
feet per mile (ft/mi)	0.189	meters per kilometer (m/km)
feet per second (ft/s)	0.3048	meters per second (m/s)
square feet per day (ft^2/d)	0.0929	square meters per day (m^2/d)
gallons per minute (gal/min)	0.06309	liters per second (l/s)
inches	25.4	millimeters (mm)
miles	1.609	kilometers (km)
million gallons per day (Mgal/d)	0.04381	cubic meters per second (m^3/s)
square miles	2.590	square kilometers (km^2)

National Geodetic Vertical Datum of 1929 (NGVD 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 mean sea level. NGVD of 1929 is referred to as sea level in the text of this report.

GEOHYDROLOGIC FRAMEWORK OF THE SOUTHEAST TEXAS COASTAL PLAIN

Miocene and younger sediments that underlie the southeast Texas Coastal Plain and that form important hydrologic units are thousands of feet thick at the coastline. These clastic sediments constitute geologic formations, which collectively or in part, form important hydrologic units. The geologic formations and hydrologic units are composed of varying proportions of gravel, sand, silt, and clay. They thicken toward the Gulf of Mexico and are inclined in that direction. The younger geologic formations and hydrologic units crop out nearer the Gulf and the older ones farther inland. All of them have outcrops or subcrops that are virtually parallel to the shoreline.

In the following discussion, emphasis is placed on the geologic and hydrologic units of Miocene age. It is necessary, however, to discuss the older and younger units in order to understand their relationship, both stratigraphically and hydrologically, to the Miocene. (Stratigraphic and geologic units that are pertinent to the discussion are described in Table 1. The units were determined from several sources and may not necessarily follow the usage of the U.S. Geological Survey.) Four dip sections and one strike section are located in Figure 2 and are presented in Figures 3-7 to visualize the interrelationships and to show the presence of water having concentrations of less than about 3,000 mg/l of dissolved solids within the units.

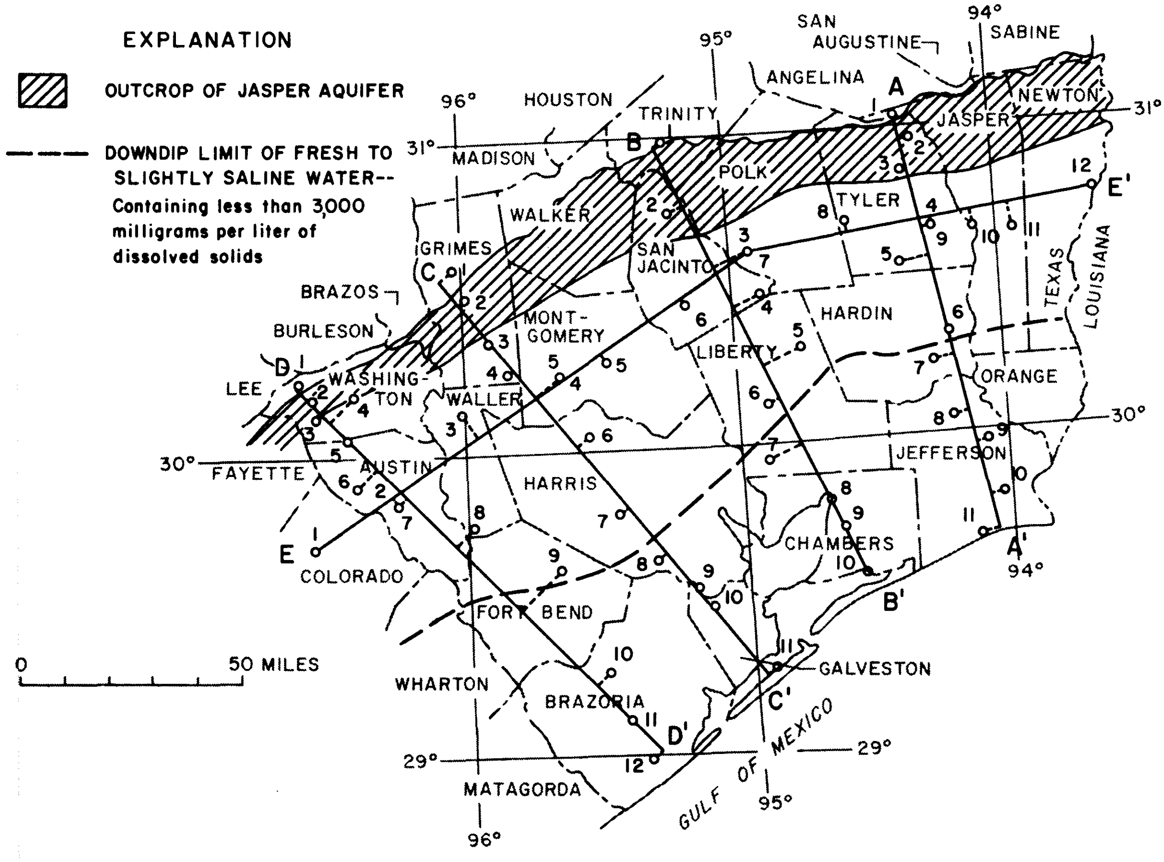

Figure 2.—Location of Stratigraphic and Hydrologic Sections

Stratigraphic Units

Pre-Miocene

Pre-Miocene rocks are composed of beds of sand, clay, carbonate rocks, and other rock types that are tens of thousands of feet thick. Within this thick section of rocks that underlie the Jasper

Table 1.--Stratigraphic and Hydrologic Framework of the Southeast Texas Coastal Plain [1/]

Era-them	System	Series	Stratigraphic Units	Hydrogeologic Units	Selected Faunal Markers	Remarks
CENOZOIC	Quater-nary	Holocene	Alluvium	Chicot aquifer		Quaternary System undifferentiated on sections.
		Pleistocene	Beaumont Clay			
			Montgomery Formation			
			Bentley Formation			
			Willis Sand			
	Tertiary	Pliocene	Goliad Sand	Evangeline aquifer		
		Miocene	Fleming Formation	Burkeville confining system	*Potamides matsoni* *Bigenerina nodosaria var. directa* *Bigenerina humblei* *Amphistegina sp.*	
			Oakville Sandstone			Oakville Sandstone included in Fleming Formation east of Washington County.
			Surface: Catahoula Sandstone / Subsurface: Upper part of Catahoula Sandstone	Jasper aquifer		
		?	Subsurface: Anahuac Formation	Cata-houla confining system (restricted)	*Discorbis nomada* *Discorbis gravelli* *Heterostegina sp.* *Marginulina idiomorpha*	Anahuac and "Frio" Formations may be Oligocene in age.
		?	Subsurface: "Frio" Formation		*Textularia mississippiensis*	
		Pre-Miocene rocks				

1/ Modified from Baker (1979, p. 4).

aquifer are identifiable stratigraphic units. These units are not delineated on the sections included with this report; however, a discussion of these units and their identity in the subsurface to a depth of about 8,000 feet are presented by Baker (1979).

The stratigraphic units of pre-Miocene age are hydrologically significant. Some are aquifers and others are confining layers. The hydrologic relationship of the Jasper aquifer to the underlying contiguous units is of primary importance from the standpoint of boundary effects on the digital model. Stratigraphic examination of geophysical logs indicates, however, that freshwater in the stratigraphic units of pre-Miocene age is separated from water in the Jasper by confining layers.

Miocene

The outcropping stratigraphic units that are designated as Miocene in age are, from oldest to youngest, the Catahoula Sandstone, Oakville Sandstone, and Fleming Formation. The "Frio" Formation, Anahuac Formation, and a unit, that is referred to in this report as the upper part of the Catahoula Sandstone, are assigned by the author as possible downdip equivalents of the surface Catahoula although the Anahuac and "Frio" Formations may be Oligocene in age. The data in Table 1 and the dip sections (Figures 3-6) illustrate this relationship.

The Catahoula Sandstone is a pyroclastic unit that has been independently mapped on the outcrop by various geologists with little modification. Within the report area, it is composed of interbedded and interlensing sand and clay. The dip sections show that the thickness of the Catahoula increases downdip at a large rate. It eventually includes, when the Anahuac Formation is reached at depths of about 2,800 to 3,600 feet below sea level, the "Frio" Formation, the Anahuac Formation, and the upper Catahoula unit.

The Oakville Sandstone and Fleming Formation are composed almost entirely of terrigenous clastic sediments that form sand and clay interbeds. Their boundaries are discernible contacts in some areas and arbitrary ones within zones of lithologic gradation in other areas.

Within the limits of the report area, the Oakville Sandstone on the surface is recognized and mapped as a formation only west of the Brazos River in Washington County. Here its predominantly sandy character is barely distinguished from the overlying Fleming Formation, which is only slightly less sandy. Eastward from the vicinity of the Brazos River, the Oakville grades into the base of the Fleming. The position of the base of the Oakville in the deeper parts of the subsurface has been delineated on section D-D' (Figure 6) merely as an approximation.

The Fleming Formation, which is the uppermost unit of Miocene age, is lithologically similar to the Oakville Sandstone. Where the Fleming is not separated from the Oakville and directly overlies the Catahoula Sandstone from about Grimes County to the Sabine River, the percentage of sand in the formation increases eastward. In the far eastern part of the study area, the quantity of sand in the formation greatly exceeds the quantity of clay. This can be seen in strike section E-E' (Figure 7).

Post-Miocene

The stratigraphic units of post-Miocene age consist chiefly of interbedded sand and clay and subordinate beds of silt and gravel. Collectively, they are estimated to be in excess of 2,000 feet thick at the coastline in southeast Texas. This wedge of clastic sediment rapidly thins inland from the coastline to extinction along an irregular line from 70 to 100 miles inland from the coastline.

The Goliad Sand of Pliocene age; Willis Sand, Bentley Formation, Montgomery Formation, and Beaumont Clay of Pleistocene age; and alluvium of Holocene age comprise the post-Miocene sediments. All of these units are similar in lithology, and for this reason, delineation using electrical logs has not been attempted on the stratigraphic and hydrologic sections. Notwithstanding, the difficulty in identifying these stratigraphic units individually in the subsurface, as a group they constitute significant aquifers in the southeast Texas Coastal Plain.

Hydrologic Units

The fallowing discussion will emphasize five hydrologic units-the Catahoula confining system (restricted), which underlies the Jasper aquifer; the Jasper aquifer; and the Burkeville confining system and the Evangeline and Chicot aquifers, which overlie the Jasper. The hydrology of the units underlying and overlying the Jasper is important for understanding the water flow system in the Jasper and for modeling the aquifer.

Catahoula Confining System (Restricted)

The Catahoula confining system (restricted), which was named by Baker (1979) after the Catahoula Sandstone, is treated in this report as a quasi-hydrologic unit. In most of southeast Texas, this confining system has different boundaries than the stratigraphic Catahoula. Its top (base of the Jasper aquifer) is delineated along lithologic boundaries that are time-stratigraphic in some places, but transgress time lines in other places. Its base, which coincides with the base of the stratigraphic unit, is delineated everywhere in the report area along time-stratigaphic boundaries that are independent of lithology. No attempt was made to establish a lithologic (hydrologic) base for the unit, which would have created a distinct hydrologic unit. Such an effect would have involved a thorough hydrologic evaluation of pre-Miocene formations, which was beyond the scope of this study.

In some places, the Catahoula confining system (restricted) is identical to the stratigraphic unit, but there are notable exceptions. These departures of the hydrologic boundaries from the stratigraphic boundaries are most prominent in the eastern part of the study area near the Sabine River (Figure 7) and in numerous places at the outcrop and in the shallow subsurface (Figures 3-6). In these places, the very sandy parts of the Catahoula Sandstone (stratigraphic unit) that lie immediately below the Oakville Sandstone or Fleming Formation are included in the overlying Jasper aquifer. This leaves a lower section from 0 to 2,000 feet or more in thickness that consists predominantly of clay or tuff with some interbedded sand to compose the Catahoula confining system (restricted). In most places, this delineation creates a unit that generally is deficient in sand so as to preclude its classification in these areas as an aquifer. For this reason, in most of its shallow to moderately deep subsurface extent, the Catahoula confining system (restricted) functions hydrologically as a confining layer that greatly restricts interchange of water between the overlying Jasper aquifer and the underlying aquifers.

The quantity of clay and other fine-grained clastic material in the Catahoula confining system (restricted) generally increases downdip, until the Anahuac Formation is encountered at depths of 2,800 to 3,600 feet below sea level. Below this level, the "Frio" Formation becomes characteristically sandy and contains moderately saline water to brine (3,000 to more than 35,000 mg/l of dissolved solids) that extends to depths of many thousands of feet.

Jasper Aquifer

The Jasper aquifer, which was named by Wesselman (1967) for the town of Jasper in Jasper County, Texas, until recently had not been delineated farther west than Washington, Austin, and Fort Bend Counties in southeast Texas. Recently, delineations of the Jasper, as well as other related hydrogeologic units, were made by Baker (1979) across the Coastal Plain of Texas from the Sabine River to the Rio Grande.

The configuration of the Jasper aquifer in the subsurface, as shown in the sections, is geometrically irregular because the delineation was made on the basis of the aquifer being a rock-stratigraphic unit. The hydrologic boundaries were defined from observable physical (lithologic) features rather than from inferred geologic time lines, which do not necessarily correspond to lithologic features.

The position of the base and top of the Jasper aquifer in southeast Texas transgresses stratigraphic boundaries along strike and downdip. The base of the aquifer coincides with the stratigraphic lower boundary of the Oakville Sandstone or Fleming Formation in some places. In other places, the base of the Jasper lies within the Catahoula Sandstone or coincides with the base of that unit. The top of the aquifer is within the Fleming in places and is within the Oakville in other places. The dip of the top of the Jasper is fairly uniform in rate within the zone of fresh to slightly saline water. Within this zone, which is about 50 to 75 miles in width, the dip averages about 55 ft/mi to the south-southeast (Figure 8).

The Jasper aquifer ranges in thickness, where it is not eroded, from as little as 200 feet to about 3,200 feet within the area of its delineation. The maximum thickness occurs in the region where the aquifer contains moderately saline water to brine. An average range in thickness of the aquifer within the zone of water having concentrations of less than 3,000 mg/l of dissolved solids is from about 1,000 to 1,500 feet. At the Sabine River, the Jasper attains a thicknessof 2,400 feet in well 12 in section E-E' (Figure 7), where the aquifer is composed predominantly of sand. This predominance of sand in the Jasper in the eastern part of the study area, however, diminishes in a westward direction.

The Jasper aquifer contains water having concentrations of less than 3,000 mg/l of dissolved solids from its outcrop to about 50 to 75 miles downdip from its outcrop. This downdip limit approximately parallels the coastline passing a few miles north of Beaumont and near the center of Houston. Water having concentrations of less than 3,000 mg/l of dissolved solids occurs in the Jasper as deep as 3,000 feet below sea level in section D-D' (Figure 6). Although pumpage from the Jasper is not significant, it is capable of yielding 3,000 gal/min or more of water to wells in certain areas.

Burkeville Confining System

The Burkeville confining system was named by Wesselman (1967) for outcrops near the town of Burkeville in Newton County, Texas. It separates the Jasper and Evangeline aquifers and retards the interchange of water between the two aquifers.

The Burkeville confining system is a rock-stratigraphic unit predominantly consisting of silt and clay. Upper and lower boundaries of the unit do not strictly correspond to geologic time boundaries, although in some places the unit appears to possess approximately isochronous boundaries. The configuration of the top and bottom of the unit is irregular. Boundaries are not restricted to a single stratigraphic unit, but are included within the Fleming Formation and Oakville Sandstone in some places. This is shown in section D-D' (Figure 6).

The thickness of the Burkeville confining system ranges from about 100 to 1,000 feet. In general, the greatest variations occur in the relatively deep subsurface within the zone of moderately saline water to brine. A typical thickness of the Burkeville is about 300 feet.

The Burkeville confining system is predominantly composed of fine-grsined materials, such as silt and clay, as shown in numerous geophysical logs. In most places, these fine-grained sediments are interbedded with sand lenses, which contain fresh to slightly saline water. Some of these sand lenses yield water to small-capacity wells. Because of its relatively large percentage of silt and clay when compared to the underlying Jasper aquifer and overlying Evangeline aquifer, the Burkeville is a confining unit. The effectivenessof the unit as a confining layer is further borne out by the fact that hydro-static pressures in the Jasper and Evangeline are notably different immediately above and below the Burkeville where detailed testing by well drillers has been done.

Evangeline and Chicot Aquifers

The Evangeline and Chicot aquifers were named and defined by Jones (Jones, Turcan, and Skibitzke, 1954) for ground-water reservoirs in southwestern Louisiana. They also have been mapped in Texas, but until recently, had not been delineated farther west than Washington, Austin, and Fort Bend Counties in southeast Texas. Their positions in the Coastal Plain of Texas westward to the Rio Grande are now known from mapping by D. G. Jorgensen, W. R. Meyer, and W. H. Sandeen of the U.S. Geological Survey (Baker, 1979).

The Evangeline aquifer primarily has been delineated as a rock-stratigraphic unit. Although the aquifer is composed of at least Pliocene-age sediments, its lower boundary crosses time lines to include sections of sand in the Fleming Formation. Within most of the study area, the Evangeline at the surface includes about the upper one-third of the Fleming outcrop as seen in sections A-A', B-B', and C-C' (Figures 3-5). In the western part of the area where the Oakville Sandstone is recognized, the Evangeline includes more than three-fourths of the Fleming outcrop as seen in section D-D' (Figure 6). The upper boundary of the aquifer probably closely follows the top of the Pliocene-age sediments or the Goliad Sand, which is not exposed, except perhaps in a few isolated places, in the report area. This stratigraphic relationship of the top of the Evangeline is somewhat speculative.

The Chicot aquifer has been defined to exclusively include the Quaternary age sediments. Its delineation in the subsurface on this stratigraphic basis is problematical due to the difficulty in identifying the base of the Quaternary deposits on electrical logs. This subsurface delineation in southeast Texas has been based largely on the presence of a greater sand-to-clay ratio in the Chicot than in the underlying Evangeline aquifer. In some places, a prominent clay layer has been used as the boundary. Differences in hydraulic conductivity or water levels in some areas also have been used to differentiate the Chicot from the Evangeline. At the surface, the base of the Chicot on the sections has been picked at the most landward edge of the oldest, undissected coastwise terrace of Quaternary age.

The Evangeline and Chicot aquifers are typically wedge-shaped and have a large sand-to-clay ratio. Individual sand beds are characteristically tens of feet thick. Near the outcrop, the Evangeline ranges in thickness from about 400 to 600 feet but near the coastline, where the aquifer's top is about 1,200 feet deep, its thickness averages about 2,300 feet. Water having concentrations of less than 3,009 mg/l of dissolved solids is not present in the aquifer, at the coastline. The Chicot attains a thickness of about 1,200 feet at the coastline, where, in places, it still contains water having concentrations of less than 3,000 mg/l of dissolved solids in most of its full thickness (Figures 5 and 6).

Huge quantities of water are pumped from the Chicot and Evangeline aquifers for municipal supply, industrial use, and irrigation. The most extensive and concentrated development is in the Houston area, where large-capacity wells yield from 1,000 to more than 3,000 gal/min and average about 2,000 gal/min.

GROUND-WATER DEVELOPMENT

The Jasper aquifer regionally is relatively undeveloped. This primarily is because it underlies the Evangeline and Chicot aquifers, which are capable of supplying large volumes of adequate-quality water for most needs. Most of the wells that produce water from the Jasper are located on its outcrop and short distances downdip where the Burkeville confining system is exposed, or where the Chicot and Evangeline are not thick enough to provide sufficient water to large capacity wells.

Moderate to large volumes of water are pumped locally from the Jasper aquifer only in a few widely spaced localities (Figure 9). These centers of pumpage are mostly towns and industrial sites, where one or more public-supply or industrial wells are usually within the confines of the city limits or at individual industrial sites. By far, the largest withdrawal of water within the modeled area is in Beauregard Parish near De Ridder, Louisiana, where industrial usage exceeded 20 Mgal/d during 1979. This site is about 10 miles east of the Sabine River. Elsewhere (Figure 9), municipal or industrial pumpage at any one site is many orders of magnitude smaller than the pumpage near De Ridder and ranges from 0.10 to 4.0 Mgal/d.

As a result of the relatively limited development in the Jasper aquifer in southeast Texas, water levels have remained near the land surface, and only slight water-level declines have occurred regionally. Water-level trends in the Jasper aquifer for several representative wells are shown in Figure 10. Some of these wells are in pumping centers, whereas others are away from such centers. The hydrographs show that there have been, for the most part, only slight declines of 10-l5 feet in 20 years in the potentiometric surface at those sites.

The potentiometric surface of the Jasper aquifer prior to well development has been approximated on the basis of the earliest available water levels. To approximate predevelopment conditions, the hydraulic heads have been adjusted upward in varying amounts by backward projection of hydrographs and, in some areas, by considering heads measured in nearby wells that represented pressures little affected by pumping stresses. The potentiometric contours reflect these adjustments, while the well data indicate actual measured water levels prior to any adjustment (Figure 11).

DESCRIPTION OF THE DIGITAL MODEL

The digital model that was developed to simulate the ground-water hydrology of the Jasper aquifer is a mathematical, two-dimensional, finite-difference program that was documented by Trescott, Pinder, and Larson (1976). The iterative-numerical technique used to solve the simultaneous equations is the strongly implicit procedure (SIP). This procedure was originally described by Stone (1968) for problems in two dimensions.

The steady-state approach was used to simulate the hydrologic conditions in the aquifer. This approach was taken because, on a regional basis, the aquifer is only slightly stressed from pumping, and in many places, groundwater levels are virtually static, which indicates a nearly steady-state condition. For this reason, no attempt was made to develop a transient model to simulate the small regional water-level changes that have occurred since pumping began. The steady-state model developed for the project area, therefore, represents hydrologic conditions prior to development by wells, when natural recharge equaled natural discharge and water levels varied little during long periods.

The Jasper aquifer is part of an extensive and continuous hydrologic system in the Gulf Coastal Plain; its lateral boundaries are far beyond the modeled area. The aquifer contains freshwater for varying distances downdip beyond which the aquifer contains saltwater. For modeling purposes, however, only the part of the aquifer containing fresh to slightly saline water was considered. Under steady-state conditions, the interface between the fresh to slightly saline water and saltwater is assumed to be static and is considered to be a no-flow boundary. Beyond the interface on the downdip side, the saltwater is virtually motionless, whereas on the updip side, the fresh to slightly saline water is circulating throughout the aquifer. From the outcrop, water as recharge (a finite flux or constant recharge boundary in the model) moves downdip beneath the Burkeville confining system. Here two components of movement are in effect. One is a downdip component, and the other is an upward component. Where the Jasper is overlain by the Burkeville, water is being discharged through the Burkeville as steady leakage, with the sum of the leakage equal to the sum of the net recharge. The contact of the base of the Jasper with the underlying Catahoula confining system (restricted) is treated as a no-flow or zero-flux boundary, as the Catahoula functions in the hydrologic system as a confining layer of mostlyclayor tuff that for all practical purposes prevents any significant interchange of water between the Jasper and underlying aquifers. (See Figure 12.)

The model has a grid pattern of 15 x 24 nodes representing an area of about 20,000 square miles as shown in Figure 13. In the outcrop of the Jasper aquifer, the grids have dimensions of 5 x 10 miles and are the smallest in the model. The purpose of using the smaller grids is to provide a better distribution of net recharge on the relatively narrow outcrop of the aquifer. Downdip from the outcrop, where the aquifer is beneath the Burkeville confining system, the model has grid dimensions of 10 x 10 miles. Within any one grid, the aquifer properties are assumed to be uniform.

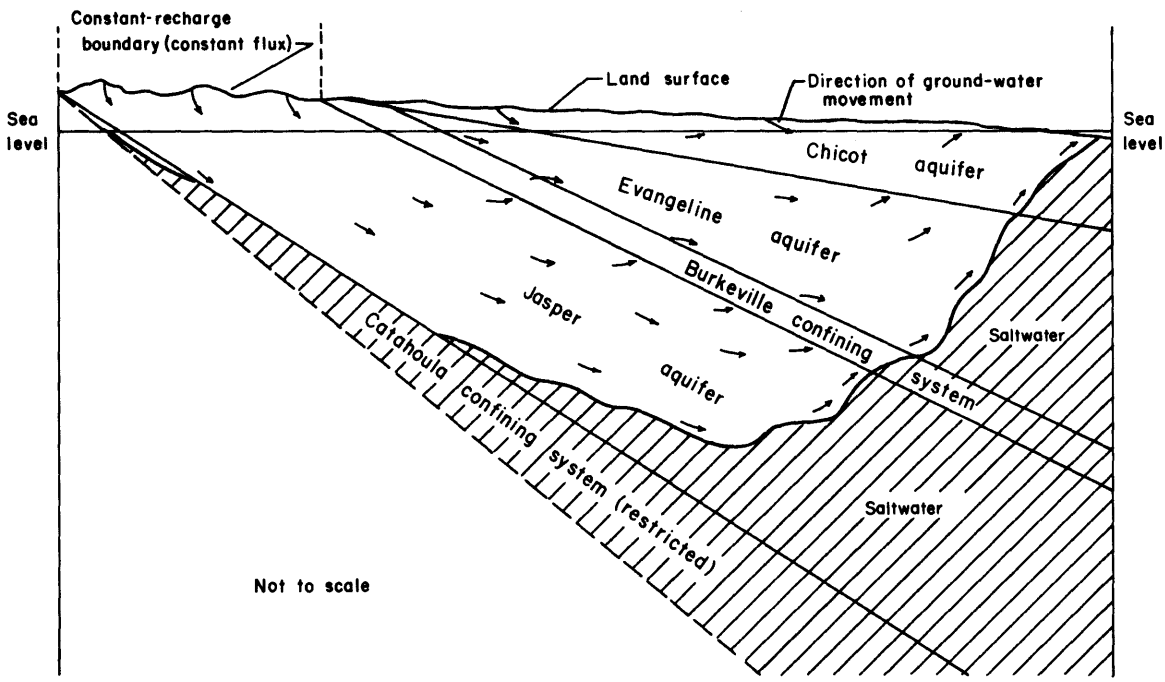

Figure 12.—Conceptual Model of the Ground-Water Hydrology of the Texas Coastal Plain Prior to Development by Wells

Impermeable (no-flow) boundaries were placed at the two lateral extremities of the model sufficiently far beyond the main study area to decrease any boundary effects in the area of interest. At the downdip edge of the model, a no-flow boundary also was placed sufficiently far enough into the part of the aquifer containing saltwater so that the boundary would have negligible effect on the part of the aquifer containing fresh to slightly saline water. The updip edge of the outcrop was a natural physical boundary having zero flow.

The boundary effects in the model were tested by substituting constant-head boundaries for the no-flow boundaries at the two lateral extremities on the east and west and on the downdip extremity on the south. Hydraulic heads representing the approximate potentiometric surface of the Jasper aquifer prior to development by wells (Figure 11) constituted the starting-head matrix. The results showed very little difference (less than 2 feet) even within 10 miles of the adjacent constant-head boundaries. Most nodes showed no differences, and where differences did occur, they were rises of no more than 1 foot.

Aquifer Properties and Parameters Modeled

Transmissivity of the Aquifer

All known aquifer tests conducted in wells completed in the Jasper aquifer within the modeled area were examined. From these tests, horizontal hydraulic conductivities were computed, and horizontal hydraulic-conductivity maps and sand-thickness maps were prepared. The areal distribution of transmissivity of the Jasper was then determined (Figure 14).

The transmissivity of the Jasper aquifer ranges from less than 2,500 ft^2/d in places in the outcrop and near the downdip limit of fresh to slightly saline water to about 35,000 ft^2/d east of the Sabine River. Outcrop transmissivities increase eastward as do transmissivities in the artesian part beneath the Burkeville confining system. These increases are attributed primarily to eastward increases in sand thicknesses. Conversely, the decreases in transmissivities near the downdip limit of fresh to slightly saline water are due to the fact that the thickness of sand with this quality water decreases to zero at this southern interface.

Recharge to the Aquifer

Precipitation on the outcrop of the Jasper aquifer is the source of recharge to the aquifer. Only a small part of the total precipitation, however, does not run off directly or is not evapotranspired, and a large part of the precipitation that reaches the zone of saturation in the outcrop moves to streams where it is discharged as seepage and springflow. Therefore, only a small quantity of water from precipitation becomes net recharge, or that quantity of water that moves into the downdip part of the aquifer south of the outcrop. Under steady-state conditions in the Jasper as conceptualized prior to development by wells, this net quantity of recharge is equal to the quantity of discharge by vertical leakage through the Burkeville confining system.

In the model, the outcrop was treated as a constant-recharge (constant-flux) boundary with each node constantly recharging a given volume of water. The total net recharge was determined incrementally for each 10-mile length of the Jasper aquifer's outcrop using the Darcy flow equation in the following form:

$$Q = TIL, \tag{1}$$

where Q = flow rate, in cubic feet per day;

T = transmissivity, in square feet per day;

I = hydraulic gradient, in feet per mile; and

L = length of aquifer (in miles) across which the flow moves.

The 10-mile cross-sectional length of the outcrop, which the flow moves across, was chosen at the outcrop's contact with the overlying Burkeville confining system. The flow thus determined to be moving into the downdip artesian parts of the aquifer can be equated with the total net recharge for the incremental area of the outcrop. This volume of recharge was then apportioned to the nodes within that part of the outcrop. The distribution of total net recharge as equivalent precipitation on the outcrop of the Jasper is shown in Figure 15.

The quantity of water as net recharge to the Jasper aquifer is equivalent to 0.9 inch of precipitation on the sandy part of the outcrop, about 2 percent of the average precipitation. In addition to this quantity, according to Wood (1956, p. 30-33), about 1 inch or more of precipitation enters the outcrop but is discharged to streams crossing the outcrop as base flow or rejected recharge.

Leakage Through the Burkeville Confining System

Water in the Jasper aquifer downdip from the outcrop is discharged upward through the Burkeville confining system. This process is simulated in the model by considering the vertical-hydraulic conductivity of the Burkeville, the thickness of the Burkeville, and the hydraulic head on the upper side of the Burkeville which is the predevelopment potentiometric surface of water in the Evangeline aquifer.

Vertical-Hydraulic Conductivity of the Burkeville Confining System

The effective vertical-hydraulic conductivity of the Burkeville confining system is a function of the composite intergranular flow characteristics of the predominantly silt and clay beds that compose this hydrologic unit. Hydraulic-conductivity values, which were determined by calibration of the model, range from 1.0×10^{-5} to 2.5×10^{-3} ft/d. These values are similar to those determined for the clay beds in the Chicot and Evangeline aquifers by previous model studies in the Houston area and in other areas along the Gulf Coast of Texas (Jorgensen, 1975, p. 54; Meyer and Carr, 1979, p. 17; and Carr and others, 1985). In these areas, the vertical-hydraulic conductivity of the Chicot and Evangeline, which is controlled primarily by the clay beds that occur within the vertical sequence of sand beds, ranges from 9.2×10^{-5} to 2.3×10^{-4} ft/d.

The larger values of vertical-hydraulic conductivity of the Burkeville confining system are associated with the outcrop and updip parts of the hydrologic unit, and the smaller values are associated with the downdip parts. This pattern of differing vertical hydraulic conductivities is shown in Figure 16. Sedimentation features of the Burkeville support this pattern as increasingly finer grained sediments were deposited in the downdip direction (Baker, 1979, p. 40).

Thickness of the Burkeville Confining System

Large variations in the thickness of the Burkeville confining system affect the leakage at each node in the model where the confining system overlies the Jasper aquifer. All areas of the Jasper south of its outcrop are overlain by the Burkeville, and in no place are the Evangeline or Chicot aquifers, which overlie the Burkeville, in contact with the Jasper.

Large thicknesses of the Burkeville confining system of more than 600 feet are present in several grids near the southeastern boundary of the model, and even larger thicknesses of more than 900 feet are present in a few grids along the western boundary near the downdip limit of fresh to slightly saline water in the Jasper aquifer. In other places between these two areas-chiefly in the outcrop of the Burkeville where it thins to extinction-the thickness of the confining system, is less than 100 feet as shown in Figure 17. Leakage is facilitated along the outcrop where the vertical-hydraulic conductivity generally is greater than elsewhere and where the confining layers are relatively thin.

Head Differences Across the Burkeville Confining System

The flux across the Burkeville confining system in the model is controlled in part by the hydraulic head differences in the Evangeline and Jasper aquifers. In the steady-state model, the predevelopment potentiometric surfaces were approximated for the two aquifers using available water-level data, and the hydraulic head differences were determined. The approximate predevelopment potentiometric surface of the Evangeline aquifer is shown in Figure 18. The map is based on the oldest available water levels adjusted upward by varying amounts for some sites to account for the effects of development. The predevelopment potentiometric surface of the Jasper aquifer is shown in Figure 11.

Hydraulic-head differences between the Evangeline and Jasper aquifers varied significantly prior to well development. As simulated in the model, these differences were less than 15 feet for most nodes near the updip reaches of the overlying Evangeline aquifer, and gradually increased downdip ranging from 70 to 130 feet at nodes along the southern limit of fresh to slightly saline water in the Jasper. At all nodes, the predevelopment head in the Jasper was greater than the predevelopment hydraulic head in the Evangeline. It should be noted that postdevelopment hydraulic head changes in the Evangeline as well as in the Jasper could alter the magnitude of the hydraulic head differences across the Burkeville confining system or possibly even reverse the direction of water movement. These changes would have to be considered in any leakage determinations for a transient model.

Calibration of the Model

The model was calibrated by simulating the predevelopment hydrologic conditions of the Jasper aquifer and comparing the computed potentiometric surface with the predevelopment surface that was based on historical water-level measurements. Where the computed surface differed significantly from the measured surface, vertical-hydraulic conductivity of the Burkeville confining system was modified, and the model was tested again. Transmissivity of the Jasper aquifer was modified in some areas, but to a much lesser extent than vertical-hydraulic conductivity of the Burkeville, because aquifer-test results were available for computing transmissivity. This trial and error procedure was continued using reasonable modifications until a satisfactory match with the approximate potentiometric surface shown in Figure 11 was obtained (Figure 19).

Results of the calibration show that the simulation basically agrees in most areas with the historical records of water levels. A good match was achieved in the artesian part of the aquifer south of the outcrop. In the outcrop, the influence of semiartesian conditions in combination with rolling topography and associated variable transmissivity in short distances creates an irregular potentiometric surface. For these reasons, simulations of the potentiometric surface are less exact in the outcrop than elsewhere.

The water-level data in Figure 19 are the oldest available data that represent approximate predevelopment conditions. Actual predevelopment water levels were greater in some areas, but the data presented give a basis for comparison with the simulated water-level contours.

Sensitivity Analysis

Sensitivity of the model was demonstrated by hydrologic analysis primarily using a single model column or cross section. This procedure simulated a one-dimensional flow tube along a line of ground-water flow from the outcrop of the Jasper aquifer into the part of the aquifer that contains saltwater. The position of this cross section and arrangement of cells from node 2 on the outcrop to node 27, which is about 60 miles downdip from the limit of the fresh to slightly saline water, are shown in Figure 20. The calibrated values of transmissivity of the Jasper aquifer, of vertical-hydraulic conductivity and thickness of the Burkeville confining system, and of potentiometric heads within the Jasper and Evangeline aquifers for appropriate nodes along the cross section are illustrated in Figure 21. Using these calibrated data and by varying the data values, as well as extending them beyond the model's downdip no-flow boundary at node 16, head values were simulated to show the changes in water levels that resulted from such modifications. Although the resulting changes in water levels pertain to the line of section represented by the flow tube, similar effects are expected to apply elsewhere in the model.

The sensitivity analysis for transmissivity showed that a uniform 25-percent increase in this parameter from that of the calibrated model resulted in a maximum decrease in head of 11 feet in the updip limit of the aquifer's outcrop at node 2 and a maximum increase in head of 10 feet at the downdip limit of water containing less than 3,000 mg/l of dissolved solids at node 16. A uniform decrease of 25 percent in transmissivity resulted in a maximum increase in head of 18 feet at the updip limit of the aquifer's outcrop to a maximum decrease in head of 13 feet at the downdip limit of 3,000 mg/l water. If the calibrated values of transmissivity that are uniformly decreasing from node 6 to 12 are extended as a straight-line projection to node 16, then this results in an increase in transmissivity of as much as about 7,500 ft^2/d over the calibrated model, which, in turn, causes a maximum increase in head of 4 feet. (See Figure 22.) The projected increase in transmissivity from nodes 12 to 16 negates the gradual decrease in transmissivity of the calibrated model as the downdip limit of fresh to slightly saline water, which serves as a no-flow boundary, is approached. This procedure compares the sensitivity of the no-flow boundary as an interface of fresh to slightly saline water with more highly saline water.

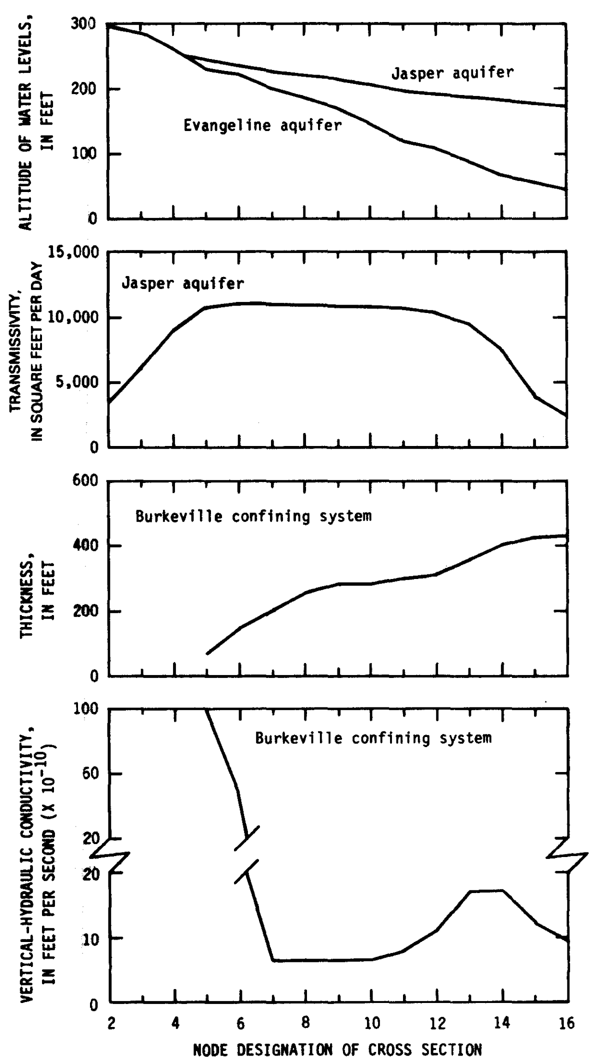

Figure 21.—Hydrologic Parameters and Hydraulic Heads of the Calibrated Model for the Cross Section Used for Sensitivity Analysis

The changes in hydraulic head represent the result of new equilibriums being established in the aquifer from the uniform increases and decreases in transmissivity. A uniform 25-percent increase in transmissivity caused a decrease in the hydraulic gradient (a flattening of the potentiometric surface),

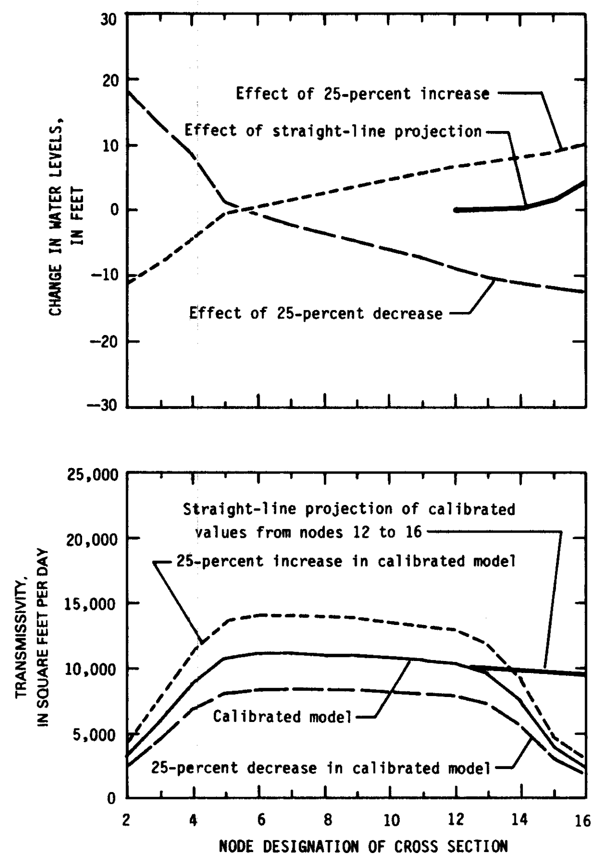

Figure 22.—Sensitivity of Calibrated Model to Variations in Transmissivity of the Jasper Aquifer

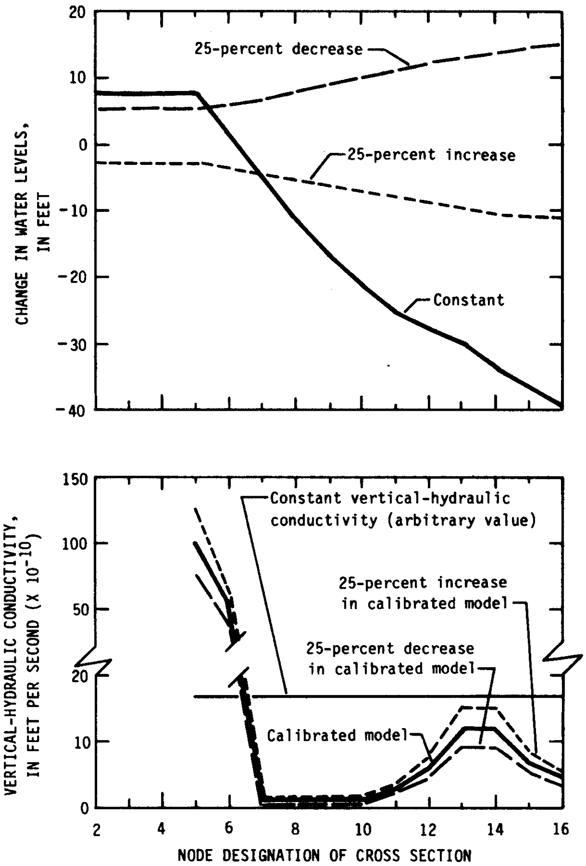

Figure 23.—Sensitivity of Calibrated Model to Variations in Vertical-Hydraulic Conductivity of the Burkeville Confining System

whereas a 25-percent decrease in transmissivity caused an increase in the hydraulic gradient (a steepening of the potentiometric surface). This is in accordance with the Darcy flow equation (equation 1) where the hydraulic gradient is inversely proportional to the transmissivity. The decrease in hydraulic head in the outcrop (with a uniform 25-percent increase in transmissivity) necessitates a rise in hydraulic head downdip, and conversely, with a 25-percent decrease in transmissivity, the increase in hydraulic head in the outcrop requires a decrease in hydraulic head downdip—the flow rate or recharge being held constant.

A uniform 25-percent increase in the vertical-hydraulic conductivity of the Burkeville confining system from that of the calibrated model resulted in a decrease in water levels from 3 feet in the outcrop of the aquifer to 11 feet near the downdip limit of 3,000 mg/l water at node 16. A uniform 25-percent decrease in the vertical-hydraulic conductivity resulted in an increase in water levels that ranged from 5 feet in the aquifer's outcrop to 15 feet at node 16. If the vertical-hydraulic conductivity remains constant throughout the model at 16.7×10^{-10} ft/s, the water levels show a rise of as much as 8 feet above the calibrated amount in the aquifer's outcrop, and show a steady decrease from the 8-foot rise near the outcrop to as much as 40 feet below the calibrated amount at the downdip limit of 3,000 mg/l water at node 16. (See Figure 23.)

The changes in water levels that resulted from the uniform changes in vertical-hydraulic conductivity of the Burkeville confining system constitute the response of the Jasper aquifer to changes in one of the three leakage parameters in this case, vertical-hydraulic conductivity. With the other two leakage parameters-thickness of the Burkeville and hydraulic head on the upper side of the Burkeville (base of Evangeline aquifer) not changing in value, the 25-percent increase in vertical-hydraulic conductivity over the calibrated value of each node necessitated a decrease in hydraulic head (water-level decrease) in the Jasper in order to maintain steady-state conditions. Conversely, the 25-percent decrease in vertical-hydraulic conductivity necessitated an increase in hydraulic head in the Jasper.

The application of a constant value of 16.7×10^{-10} ft/s for vertical-hydraulic conductivity caused the aquifer to adjust its hydraulic head at each node by increasing or decreasing the head so as to keep the volumes of recharge and discharge equal in the steady-state simulation. The constant value utilized in the sensitivity analysis was between the two extreme calibrated values of 100×10^{-10} ft/s and 1.5×10^{-10} ft/s. The 8-foot rise in hydraulic head in the outcrop of the Jasper aquifer was due to the constant value of vertical-hydraulic conductivity being six times smaller than the calibrated vertical-hydraulic conductivity of the Burkeville at node 5 adjacent to the outcrop of the aquifer. The steady decline in hydraulic head downdip from the 8-foot rise in the outcrop of the aquifer to 40 feet below the calibrated value at the downdip limit of 3,000 mg/l water at node 16 was due to the constant vertical-hydraulic conductivity being about 1.5 to 11 times greater than the calibrated vertical-hydraulic conductivities of most of the Burkeville nodes downdip from its outcrop.

The distribution of leakage and sensitivity of water levels to a reduction in recharge on the Jasper outcrop and a reduction in vertical-hydraulic conductivity on and near the outcrop of the Burkeville confining system are shown in Figure 24. A large reduction in vertical-hydraulic conductivity on and near the outcrop of the Burkeville from calibrated values of 100×10^{-10} and 50×10^{-10} ft/s for nodes 5 and 6, respectively, to a uniform value of 1.2×10^{-10} ft/s for those nodes, which coupled with a decrease in recharge of 58 percent from an average calibrated value of 10.5×10^{-10} ft/s resulted in leakage being reduced from 30 to 100 times as much as that which would result from the calibrated model. The leakage reduction affected only nodes 5 and 6 on and near the outcrop of the Burkeville.

Figure 24 also demonstrates that hydraulic head losses occurred when large reductions in vertical-hydraulic conductivity of the Burkeville on and near its outcrop were coupled with a recharge reduction of 58 percent from the calibrated value. The losses in hydraulic head varied from 0 to 30 feet and only affected water levels on the outcrop of the Jasper aquifer at nodes 2-4. Water levels at nodes 5-16 from the downdip edge of the aquifer's outcrop to the limit of 3,000 mg/l water were unchanged from those of the calibrated model. It is significant to note that the normal effect of water levels rising in the Jasper from a decrease in vertical-hydraulic conductivity of the Burkeville (in this case a large decrease of several orders of magnitude) was reversed by the greater effect of a decrease in recharge (in this case a 58 percent decrease), and the net result was that water levels declined.

The sensitivity of the calibrated model to an experimental 60-mile extension further downdip of the actual downdip limit of fresh to slightly saline water (the no-flow boundary) into the part of the Jasper aquifer that contains moderately saline water to brine is illustrated in Figure 25. The hydrologic parameters that were extended beyond the calibrated model's no-flow boundary at the downdip limit of fresh to slightly saline water included the transmissivity of the Jasper aquifer, vertical-hydraulic conductivity of the Burkeville confining system, thickness of the Burkeville, and

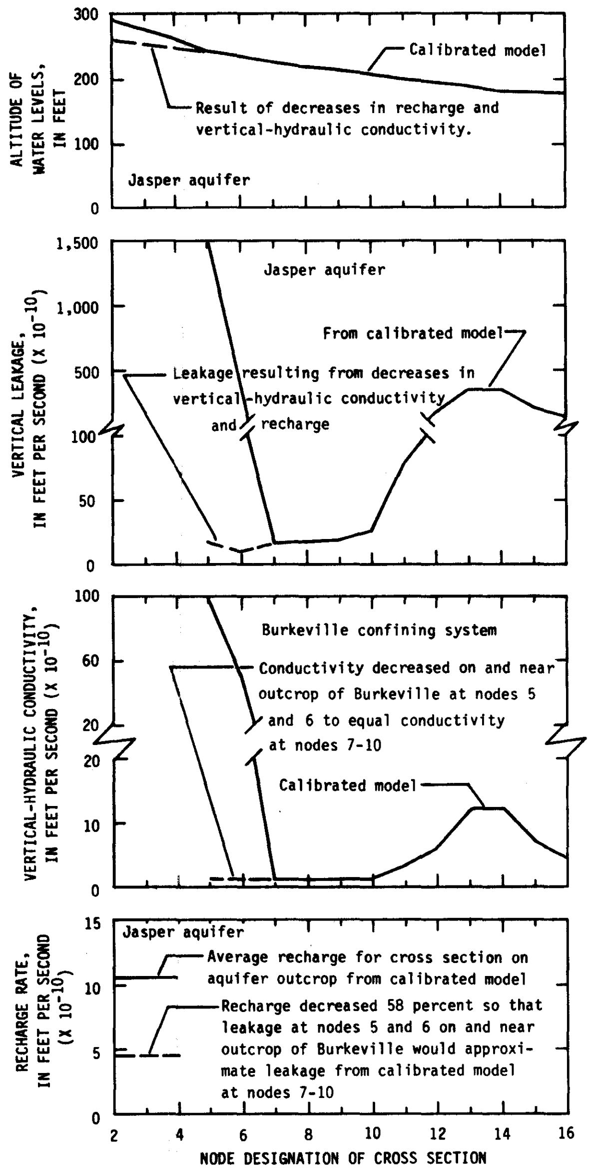

Figure 24.—Distribution of Leakage and Sensitivity of Water Levels to Reductions in Recharge and Vertical-Hydraulic Conductivity on and Near the Outcrop of the Jasper Aquifer and Burkeville Confining System

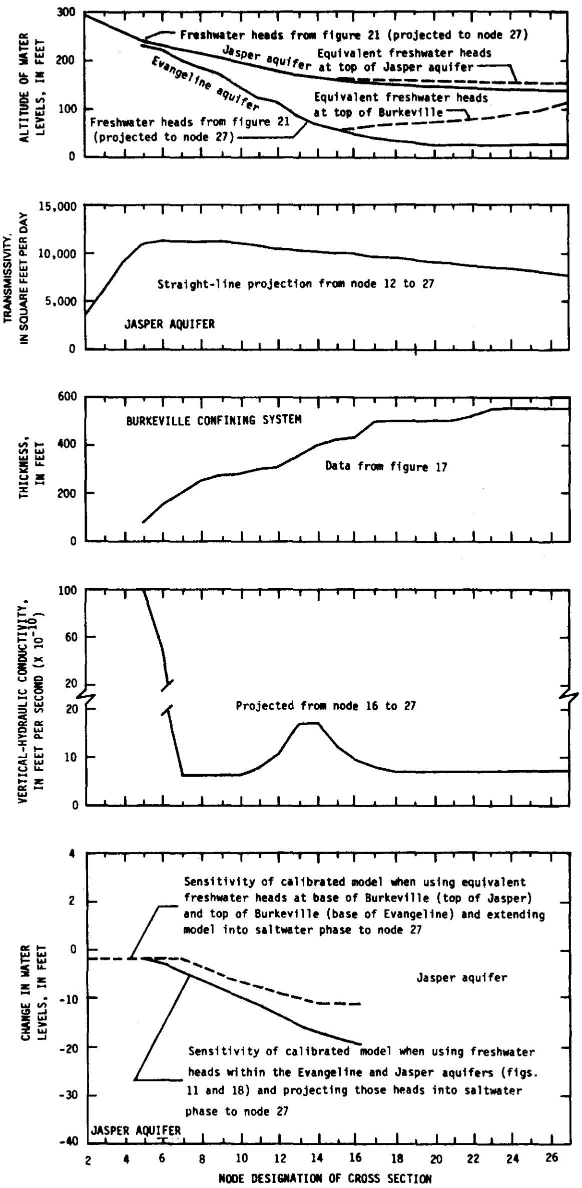

Figure 25.—Hydrologic Parameters for the Cross Section of the Model Extended Into the Part of the Aquifer Containing Saltwater and Sensitivity of the Calibrated Model to the Downdip Extension

freshwater hydraulic heads of the Jasper and Evangeline aquifers. The available freshwater hydraulic heads within the Jasper and Evangeline aquifers were projected to node 27 in the cross section using the aquifer's established hydraulic gradients from Figures 11 and 18. Equivalent freshwater hydraulic heads at the base of the Evangeline aquifer (top of the Burkeville confining system) were computed as well as the equivalent freshwater hydraulic heads at the top of the Jasper aquifer (base of Burkeville). These computations of equivalent freshwater hydraulic heads were necessary due to the presence of saltwater at the base of the Evangeline and top of the Jasper in the downdip extension of the calibrated model's boundary. The equivalent freshwater hydraulic heads were approximated using the Ghyben-Herzberg principle, which states that freshwater will extend 40 feet below sea level for every foot of freshwater above sea level provided that an environment where seawater, with a specific gravity of 1.025, is in good hydraulic connection with freshwater in the aquifer (Winslow and others, 1957, p. 381-383).

The effect of the calibrated model's no-flow boundary at the downdip limit of fresh to slightly saline water if the model is extended 60 miles into the part of the Jasper aquifer that contains saltwater is shown in Figure 25. The change in water levels of the calibrated model (if saltwater effects were not a factor in the downdip extension of the model) ranged from a decrease of 2 feet on the outcrop of the Jasper aquifer to a decrease of 11 feet at the no-flow boundary at node 16, when considering equivalent freshwater hydraulic heads in the top of the Jasper and base of the Evangeline aquifers. When considering the projections of the freshwater potentiometric surfaces within the Jasper and Evangeline aquifers (from Figures 11 and 18) downdip beyond the limit of fresh to slightly saline water in the Jasper to node 27 of the cross section, the net change in water levels in the calibrated model also decreased 2 feet in the Jasper's outcrop and decreased to 19 feet at the model's no-flow boundary at node 16.

In conclusion, the sensitivity analysis indicated that the calibrated model of the Jasper aquifer was more sensitive to certain hydrologic properties than to others, but was similar in sensitivity to various other modifications.

The shape of the potentiometric surface in the outcrop and downdip was affected to a greater degree by increasing and decreasing the value of transmissivity a specified percentage than by increasing and decreasing vertical-hydraulic conductivity the same percentage. By modifying transmissivity, either by 25-percent increases or decreases, the water level changed 20 to 30 feet, which flattened or steepened the slope of the potentiometric surface considerably. An increase and decrease of vertical-hydraulic conductivity by 25 percent, which lowered and raised the potentiometric surface less than the same percentage changes in transmissivity, did not alter the shape or slope of the potentiometric surface significantly.

The experimentation with leakage showed that modifications in the volume of recharge affected the water levels substantially when compared to effects from modifications in vertical-hydraulic conductivity of the Burkeville confining system. Only relatively slight changes in recharge are required to equal the effect on water levels from very large changes in vertical-hydraulic conductivity.

The sensitivity of most of the calibrated model to an extension of the downdip limit of water containing 3,000 mg/l of dissolved solids into more highly saline water was about the same as a reduction of 25 percent in transmissivity and an increase of 25 percent in vertical-hydraulic conductivity. All three experimentations caused water-level decreases of similar magnitude in the downdip part of the aquifer.

IMPROVEMENT OF THE MODEL AND FUTURE MODELING STUDIES

Rational values of hydraulic and hydrologic properties were built into the model of the aquifer system. Nevertheless, as additional data become available more accurate values can be used.

An extensive network of observation wells will be required to provide long-term responses of the aquifer to pumping stresses. At present (1983), the aquifer is only slightly to moderately developed by mostly small-capacity wells, and consequently, it is stressed only slightly. Larger withdrawals of water are anticipated from an increasing number of large-capacity wells, which are expected to be drilled to the aquifer. This is predicated on the economic advantage offered by the relatively high artesian pressure in the aquifer. Such well development, coupled with adequate records of aquifer responses and of pumpage, will allow for development of a transient flow model and for verification of the model by simulating different pumping periods. A transient model will provide a means of determining or verifying the aquifer's storage coefficient and will permit predictions of the potentiometric surface from proposed pumping.

It is important to remember that the Texas Coastal Plain sediments constitute a stacked series of hydrologic units including aquifers and confining systems. Future modeling efforts should not simply consider the effects of pumping stresses on individual aquifers, but should make provision to simulate the net effect of multiple stresses acting within a group of hydrologic units that mutually interact. Three-dimensional flow models will be required, and they should have the capability of considering the influence of different salinities within the hydrologic system.

REFERENCES CITED

Baker, E. T., Jr., 1979, Stratigraphic and hydrogeologic framework of part of the Coastal Plain of Texas: Texas Dept. Water Resources Rept. 236, 43 p.

Barnes, V. E., 1968a, Geologic atlas of Texas, Beaumont sheet: Univ. Texas, Austin, Bur. Econ. Geology map, scale 1:250,000.

______ 1968b, Geologic atlas of Texas, Palestine sheet: Univ. Texas, Austin, Bur. Econ. Geology map, scale 1:250,000.

______ 1974a, Geologic atlas of Texas, Austin sheet: Univ. Texas, Austin, Bur. Econ. Geology map, scale 1:250,000.

______ 1974b, Geologic atlas of Texas, Seguin sheet: Univ. Texas, Austin, Bur. Econ. Geology map, scale 1:250,000.

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, 110 p.

Jones, P. H., Turcan, A. N., Jr., and Skibitzke, H. E., 1954, Geology and ground-water resources of southwestern Louisiana: Louisiana Geol. Survey Bull. 30, 285 p.

Jorgensen, D. G., 1975, Analog-model studies of ground-water hydrology in the Houston district, Texas: Texas Water Devel. Board Rept. 190, 84 p.

Meyer, W. R., and Carr, J. E., 1979, A digital model for simulation of ground-water hydrology in the Houston area, Texas: U.S. Geol. Survey open-file rept. 79-677 (duplicated as Texas Dept. Water Resources LP-103, 27 p., 3 apps.).

Stone, H. L., 1968, Iterative solution of implicit approximations of multidimensional partial differential equations: Soc. for Industrial and Applied Mathematics, Jour. for Numerical Analysis, v. 5, no. 3, p. 530-558.

Trescott, P. C., Pinder, G. F., and Larson, S. P., 1976, Finite-difference model for aquifer simulation in two dimensions with results of numerical experiments: U.S. Geol. Survey Techniques of Water-Resources Investigations, Book 7, Chapter C1, 116 p.

Wesselman, J. B., 1967, Ground-water resources of Jasper and Newton Counties, Texas: Texas Water Devel. Board Rept. 59, 167 p.

Winslow, A. G., Doyel, W. W., and Wood, L. A., 1957, Salt water and its relation to fresh ground water in Harris County, Texas: U.S. Geol. Survey Water-Supply Paper 1360-F, p. 375-407.

Wood, L. A., 1956, Availability of ground water in the Gulf Coast Region of Texas: U.S. Geol. Survey open-file rept., 55 p.

Wood, L. A., and Gabrysch, R. K., 1965, Analog-model study of ground water in the Houston district, Texas, with a section on Design, construction, and use of electric analog models, by E. P. Patten: Texas Water Comm. Bull. 6508,103 p.