STATE OF FLORIDA
STATE BOARD OF CONSERVATION
DIVISION OF GEOLOGY

FLORIDA GEOLOGICAL SURVEY
Robert O. Vernon, *Director*

REPORT OF INVESTIGATIONS NO. 40

WATER RESOURCES OF ESCAMBIA AND SANTA ROSA COUNTIES, FLORIDA

By

Rufus H. Musgrove, Jack T. Barraclough, and
Rodney G. Grantham

Prepared by the
UNITED STATES GEOLOGICAL SURVEY
in cooperation with the
FLORIDA GEOLOGICAL SURVEY,
ESCAMBIA COUNTY, SANTA ROSA COUNTY,
and the
CITY OF PENSACOLA

Tallahassee
1965

FLORIDA STATE BOARD
OF
CONSERVATION

LETTER OF TRANSMITTAL

Florida Geological Survey

TALLAHASSEE

January 28, 1965

Governor Haydon Burns, *Chairman*
State Board of Conservation
Tallahassee, Florida

Dear Governor Burns:

The Florida Geological Survey is publishing the "Water Resources of Escambia and Santa Rosa Counties, Florida," as its Report of Investigations No. 40. This report was prepared from a cooperative program between the U. S. Geological Survey, the Florida Geological Survey, Escambia County, Santa Rosa County, and the City of Pensacola.

As you know, Escambia and Santa Rosa counties are the westernmost counties in Florida. Much of the recent industrial growth of this section of Florida has been placed in this area. The impact and demand for water resources have been greatly accelerated, and this study was undertaken by this department, the counties, and the City of Pensacola, through the cooperative program to monitor the salt-water-fresh-water contact, to determine the total demand for water at the moment, and to try to meet the future needs of the area. I believe that the details presented in the report will meet the intended purpose.

Respectfully yours,
Robert O. Vernon
Director and State Geologist

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PREFACE

This report is the result of a 4-year investigation dealing with the water resources of Escambia and Santa Rosa counties, Florida. The mild climate and excellent water supplies are prime reasons for industrial development in this section of Florida. Information on the water resources of the area prior to this investigation was sketchy and based on a minimum of documented data. The purpose of this project was to collect water data to combine with data previously collected into an interpretative report that will be beneficial to water users.

In 1958, the U.S. Geological Survey in cooperation with the Florida Geological Survey began a detailed investigation of the surface-water and ground-water resources of Escambia and Santa Rosa counties, Florida. The investigation was financed by the U.S. Geological Survey, the Florida Geological Survey, Escambia and Santa Rosa counties, and the city of Pensacola.

The investigation was made by the following personnel of the Water Resources Division of the U.S. Geological Survey: Rufus H. Musgrove, hydraulic engineer, Surface Water Branch; Jack T. Barraclough, hydraulic engineer, Ground Water Branch; and Rodney G. Grantham, chemist, Quality of Water Branch. Owen T. Marsh, geologist, Ground Water Branch, did the basic geologic study and was transferred before the completion of the investigation. The work was supervised by A. O. Patterson, district engineer, Surface Water Branch; M. I. Rorabaugh, succeeded by C. S. Conover, district engineers, Ground Water Branch; and J. W. Guerin, district chemist, succeeded by K. A. Mac Kichan, district engineer, Quality of Water Branch.

Appreciation is expressed to the many individuals who furnished information and in particular to the following persons for providing information and extending courtesies which greatly facilitated the investigation:

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WATER RESOURCES OF ESCAMBIA AND SANTA ROSA COUNTIES, FLORIDA

By

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and Rodney G. Grantham

ABSTRACT

Escambia and Santa Rosa counties, the westernmost counties in Florida, have an abundant supply of both ground and surface water of excellent quality. A 4-year study was made to determine the quantity and quality of the water and the possible effect of municipal and industrial expansion on the water.

Over 8.5 bgd (billion gallons per day) of fresh water flow into the 200 square miles of estuarine bays from four major rivers. Only about 5 per cent of this water is used. The Escambia River, the fifth largest in the state, has an average flow of over 4.5 bgd. Many smaller streams within the area produce large quantities of water.

Most of the 87 mgd (million gallons per day) of water taken from the ground comes from the sand-and-gravel aquifer. This aquifer extends from the water table down to various depths ranging from 200 to 1,000 feet. In parts of this aquifer the water is confined under artesian pressure by numerous layers of clay and hardpan. The sand-and-gravel aquifer contains a large supply of exceptionally soft and unmineralized water.

The Floridan aquifer, consisting of limestones which underlie the sand-and-gravel aquifer, contains a large supply of harder, more mineralized artesian water, and is virtually untapped.

Recharge of the sand-and-gravel aquifer is by local rainfall. The Floridan aquifer is recharged by rain falling in southern Alabama, 10 to 35 miles north of the area, and by downward leakage from the sand-and-gravel aquifer.

Factors such as decline of the water table, salt-water encroachment, and contamination of surface and ground water can greatly affect the availability of water of good quality. Decline in the water table may be caused by below-normal rainfall or heavy pumping of closely spaced wells. Salt-water encroachment is likely to occur where heavy pumping

of wells near salty bays or estuaries lowers the water table below sea level. Contamination can be brought about by disposing of wastes directly into rivers and bays, or by seepage from waste basins to the water table.

Industries use about 60 percent of the ground water withdrawn from the area: St. Regis Paper Company, the largest user in the area, pumps 31 mgd. Chemstrand, using 31.5 mgd, is the largest user of surface water in the area. The large amount of surface and ground water being used by industries and municipalities is only a small part of the usable supply of the area.

INTRODUCTION

PURPOSE AND SCOPE

An immediate need of community and industrial planners in Escambia and Santa Rosa counties is information on the water resources of the area. It is presently known that the area has a large supply of surface and ground water that is low in mineral content. However, because the water needs of this fast growing section of Florida are becoming greater, information about other characteristics of the water must be made available so that the area may realize its full industrial potential without creating problems caused by permanently lowered water levels, salt-water encroachment, and pollution.

An investigation of the water resources of Escambia and Santa Rosa counties was started in January 1958 by the U.S. Geological Survey in cooperation with the Florida Geological Survey, Escambia and Santa Rosa counties, and the city of Pensacola. This investigation was designed to obtain, over a 4-year period, data on the occurrence, quality, and quantity of surface and ground water. The information collected during the investigation will serve two major purposes: (1) it will provide an inventory of the water of the area; and (2) it will provide a sound basis for planning development and use of the water resources of the area.

The purpose of this report is to make available information on the quantity and quality of water in the area collected prior to 1962. It contains a brief discussion of climate, a geologic description of the area, information on streamflow and streamflow characteristics, principles of the occurrence and movement of ground water, properties of the ground-water aquifers, and chemical characteristics of the water resources of the area. It discusses present use of water, some existing problems associated with water, and potential water supplies of the area.

PREVIOUS WORK

The earliest published report that describes the water resources of Escambia and Santa Rosa counties was by Sellards and Gunter (1912); it discusses the water supply of west-central and west Florida. This report describes the physiography, drainage, water wells, and soils of Escambia and Santa Rosa counties. It contains information on wells in Santa Rosa County at Bagdad, Blackman, Cobb, Milligan, Milton, Mulat, Pace, and Robinson Point. Data are supplied for wells in Escambia County at Cantonment, Bohemia, Molino, Muscogee, Pine Barren, McDavid and Pensacola, including chemical analyses of water from several of these wells. The report also contains a map (p. 95) showing areas of artesian flow in the two counties.

The following year (1913) Matson and Sanford published a report on the geology and ground water of the entire State. They briefly describe the physiography, geology, and water supply of Escambia and Santa Rosa counties (p. 301-304; 401-403). Data on typical wells and general information on water resources of selected towns are tabulated for each of the two counties.

Streamflow records have been collected on the Escambia River since 1934, on Big Coldwater Creek since 1938, and on the Perdido River since 1941. Daily records of flow for these rivers are published by the U.S. Geological Survey in the annual series of water-supply papers.

The first detailed investigation of ground water in the area was made by Jacob and Cooper (1940). The report contained a section on geology by Sidney A. Stubbs. The study included pumping tests of both the drawdown type and the recovery type to obtain coefficients of transmissibility and storage for the aquifer in the vicinity of Pensacola. Since 1940, continuous and periodic measurements have been made of the water levels in wells as far north as Cantonment to determine the effect of rainfall, pumping, barometric pressure, and tides. Jacob and Cooper also had chemical analyses made of water from several wells and studied the encroachment of salt water from Bayou Chico into wells of the Newport Industries and of the U.S. Navy.

The mineral spring at Chumuckla in Santa Rosa County is briefly described by Ferguson, Lingham, Love, and Vernon (1947) in their report on the springs of Florida.

Heath and Clark (1951) made a detailed investigation of the potential yield of ground water in the vicinity of Gulf Breeze on Fair Point Peninsula, Santa Rosa County. Twenty test wells were drilled across the peninsula, and periodic water-level measurements were made to obtain profiles of the water table. Heath and Clark conducted quantitative studies to determine the effect of pumping in relation to salt-water encroachment and to determine how much ground water could be pumped from wells. They give a brief but adequate discussion on the geology and cover such topics as use and quality of ground water.

Chemical analyses of ground water in the two counties have been published by the U.S. Geological Survey (Collins and Howard, 1928) and by the Florida State Board of Conservation (Black and Brown, 1951). Black, Brown, and Pearce (1953) give a short description of the intrusion of salt water into wells of the Newport Industries and of the U.S. Navy near Pensacola. Chemical analysis of water from Pensacola city wells was published in a report by Collins (1923, p. 33). Another analysis of water from these wells was published by the U.S. Geological Survey (Lohr and Love, 1954, p. 111).

Stubbs (in Jacob and Cooper, 1940, p. 5-12) describes the upper 300 feet of geologic deposits in the southern half of Escambia County. Heath and Clark (1951, p. 12-15) describe the same interval on Gulf Breeze Peninsula. Cooke (1945, p. 232-233) describes a short measured section exposed in the bluffs on the west side of Escambia Bay. He also noted the presence of several Pleistocene marine terraces in Escambia and Santa Rosa counties. MacNeil (1949) and Carlston (1950) likewise recognize the existence of several marine terraces in the area. Calver's report on Florida kaolins and clays (1949, p. 24-28, 41-42) gives information on clays in Escambia and Santa Rosa counties and indicates which clays he believes have commercial value. The first detailed geologic study of Escambia and Santa Rosa counties was made by Marsh (1962) in connection with the comprehensive investigation of the water resources of the area. An interim report of that investigation (Musgrove, Barraclough, and Marsh, 1961) summarizes the geology and water resources of the two counties. Barraclough and Marsh (1962) describe the geology and water resources of the southern half of Escambia, Santa Rosa, Okaloosa, and Walton counties.

DESCRIPTION OF THE AREA

Escambia and Santa Rosa counties are in the extreme northwest corner of Florida (fig. 1). Escambia County is the westernmost county in the State and is bordered by Alabama on the west. Both counties border on Alabama to the north and on the Gulf of Mexico to the south. Water courses serve as boundary lines on three sides of Escambia County and two sides of Santa Rosa County. The Perdido River is the boundary line between Florida and Alabama on the west and the Escambia River separates the two counties. Santa Rosa is the larger, but less populous county, with 1,151 square miles and a 1960 population density of 25.6 persons per square mile. Escambia County covers 759 square miles and had a 1960 population density of 229 persons per square mile.

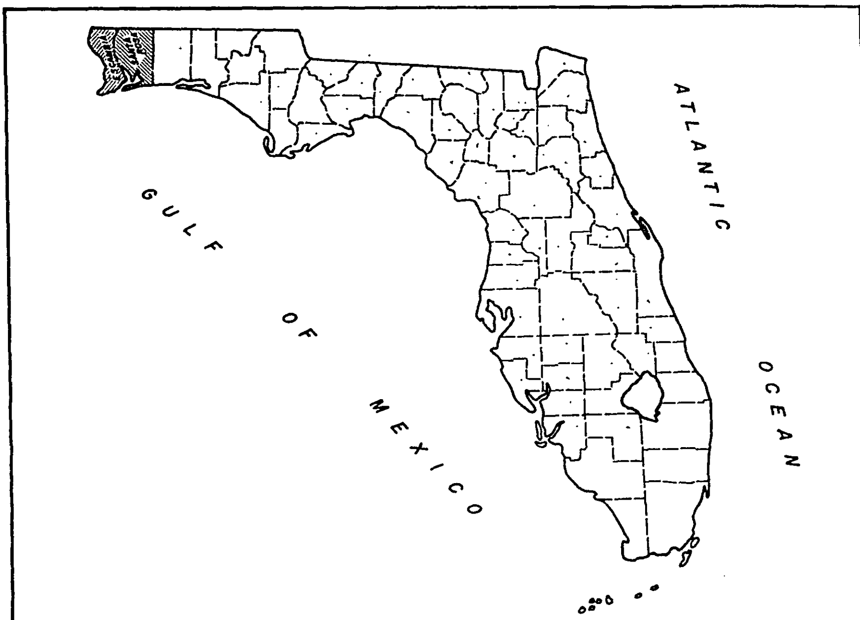

Figure 1. Map of Florida showing location of Escambia and Santa Rosa counties.

The two major cities in the area are Pensacola and Milton. Pensacola, located in southern Escambia County on Pensacola Bay, had a population of 56,752 in 1960. Greater Pensacola includes several small suburban communities and thus has a much greater population than Pensacola proper. Milton is the largest town in Santa Rosa County, with a population of 4,108 in 1960.

Much of the land in the southern part of the area is less than 30 feet above sea level. Bays, low marshy areas, peninsulas, and islands with long shorelines characterize this section. Estuarine bays extend inland some 20 miles and cover over 200 square miles. Santa Rosa Island is about half a mile wide and 55 miles long and extends from the mouth of the Pensacola Bay eastward. Sand dunes on the island are as high as 55 feet above sea level. North of Pensacola the land is hilly and well dissected with streams that drain toward the Pensacola area. The elevations of the streambeds are sea level for distances of 30 to 40 miles inland from the coast. The hills 20 miles inland are about 150 feet above sea level, becoming higher to the north. The highest land elevations, 290 feet, are along the northern boundary of the counties.

Agriculture is the principal industry of the northern half of the area. Much of the area is devoted to forest. The Blackwater River State Forest occupies the northeastern quarter of the Santa Rosa County. Row-crop farming is prevalent throughout the northern half of the area. Industrial operations predominate in the section south of Cantonment and Milton. Chemicals, synthetic fibers, and paper are the major products of the local industries. Raw materials from many parts of the State are shipped to the industrial area around Pensacola for processing and manufacturing. Military operations, tourists, shipping, and fishing also contribute to the economy of the area.

RAINFALL

To evaluate the effect of rainfall on the water resources of the area, a study was made of records collected by the U.S. Weather Bureau at two stations for a 36-year period, 1926-61. Data for these two stations are presented in graphical form in figure 2. The rainfall data at Pensacola were selected to represent the rainfall in the southern part of the area along the coast. Data from the Brewton station, located in Alabama about 10 miles north of the State line, were selected to represent the rainfall farther inland.

Within the two-county area there seems to be only minor long-term variations in amounts of rainfall. The difference between the Pensacola and Brewton averages for the 36-year period is only 0.46 inch. The shorter the period of time for which rainfall is measured at any two points, the greater the difference may be. A 1-year period can show uneven distributions. For example, in 1953 Pensacola received one-third more rainfall than Brewton. The pattern was reversed in 1929 when Brewton had 87.18 inches and Pensacola had a below-average rainfall of 60.79 inches. The average rainfall, based on the 36 years of record at the Brewton and Pensacola stations, is about 63 inches per year. The year-to-year variation can be great at any one point. For example, the highest and lowest annual rainfall occurred in successive years at Pensacola—90.41 inches in 1953 and 28.66 inches in 1954.

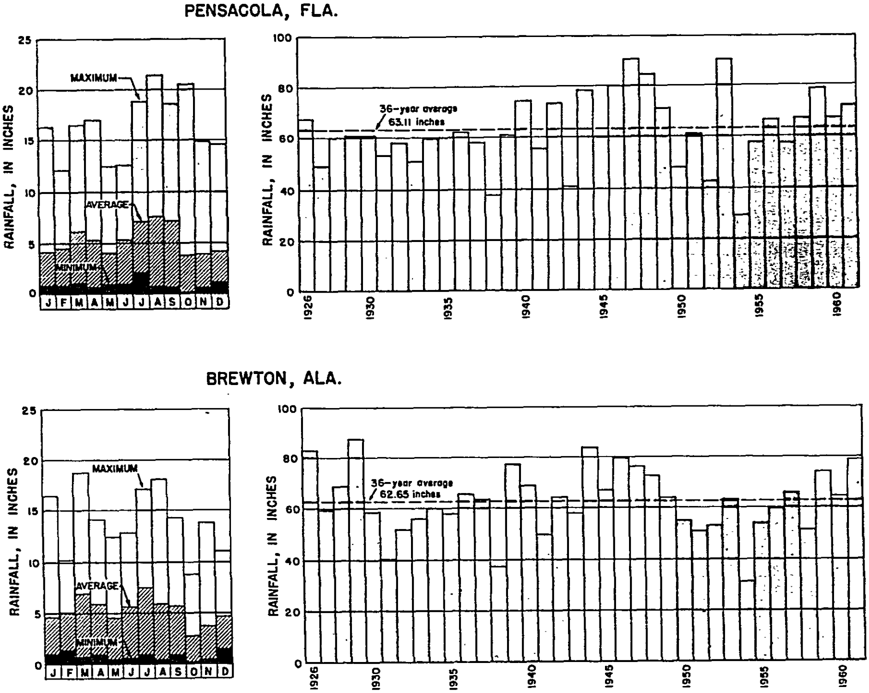

Figure 2. Graph of rainfall at Pensacola, Fla., and Brewton, Ala., showing monthly averages, maximums and minimums, and yearly rainfall for the period 1926-61.

The pattern of seasonal distribution is the same over the entire area, the wettest periods occurring in early spring and late summer and the driest in October and November. Except during October and November, an average rainfall of at least 4 inches each month can be expected. October and November have an average rainfall of about 2.9 inches and 3.8 inches, respectively. An average rainfall of over 6.0 inches occurs during March, July, August, and September. July has the highest average, with 7.4 inches. There is always the possibility, however, of having a dry month during normally wet seasons or a wet month during seasons which are usually dry. For example rainfall in October has varied from near zero to a maximum of 20.5 inches at Pensacola, and March, normally a wet month, has experienced as little as 0.9 inch of rainfall.

Another interesting aspect of the rainfall of the area is the high intensity—as much as 0.6 inch has been measured during a 5-minute period. Rainfalls of 3.5 inches during a 1-hour period and daily rainfalls in excess of 6.0 inches are not uncommon.

TEMPERATURE

Temperatures in the area are mild. The average annual temperature at Pensacola is 68°F. Average monthly temperatures vary from a high of 81°F in July and August to a low of 54°F in December and January. The extreme temperatures recorded at Pensacola have been as high as 103°F and as low as 7°F; however, they seldom rise above 100°F or drop below 20°F. On the average, 275 frost-free days occur annually. Winter temperatures may be as much as 10°F higher along the coast than in the northern part of the area.

WELL-NUMBERING SYSTEM

The well-numbering system that is derived from latitude and longitude coordinates is based on a state-wide grid of 1-minute parallels

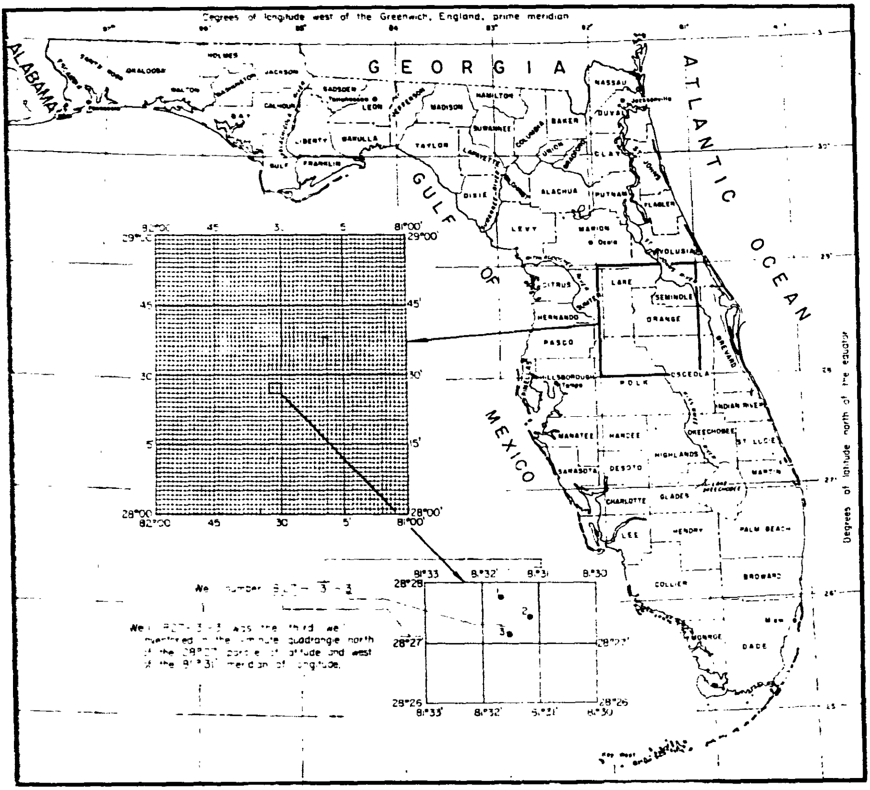

Figure 3. Map of Florida showing the well-numbering system.

of latitude and 1-minute meridians of longitude. The wells in a 1-minute quadrangle are numbered consecutively in the order inventoried. In Florida, the latitude and longitude prefix north and west and the first digit of the degree are not included in the well number.

The well number is a composite of three numbers separated by hyphens: the first number is composed of the last digit of the degree and the two digits of the minutes that define the latitude on the south side of a 1-minute quadrangle; the second number is composed of the last digit of the degree and the two digits of the minutes that define the longitude on the east side of a 1-minute quadrangle; and the third number gives the numerical order in which the well was inventoried in the 1-minute quadrangle (fig. 3).

GEOLOGY

GENERAL STATEMENT

In Escambia and Santa Rosa counties, a thick sequence of sand, gravel, and clay extends from the surface to as much as 1,000 feet (fig. 4). Nearly all the wells in this area tap permeable sediments within this sequence—referred to as the sand-and-gravel aquifer (Musgrove, Barraclough, and Marsh, 1961). In the northern half of the area, the sand-and-gravel aquifer lies on the upper limestone of the Floridan aquifer, but in the southern part, the two aquifers are separated by a thick clay unit of Miocene age which serves to confine the water that is present in the upper limestone of the Floridan aquifer. An extensive clay bed, the Bucatunna Clay Member of the Byram Formation, underlies the upper limestone of the Floridan aquifer and forms an aquiclude throughout the area (Marsh, 1962). The lower limestone of the Floridan aquifer underlies the Bucatunna and rests upon relatively impermeable clay and shale. Within the area, no fresh-water aquifers occur below the lower limestone of the Floridan aquifer. A more detailed report of the geology of the Florida Panhandle was prepared by Marsh.

COLLECTION OF DATA

Information has been collected on about 600 water wells in this area. Figure 5 shows the location of the wells in Escambia and Santa Rosa counties. They range in depth from about 15 feet to over 1,800 feet but most of them are between 30 and 300 feet deep. They range in diameter from 1¼ inches to 30 inches. Most of the domestic-supply wells are 1¼ to 4 inches in diameter and most of the industrial supply wells are

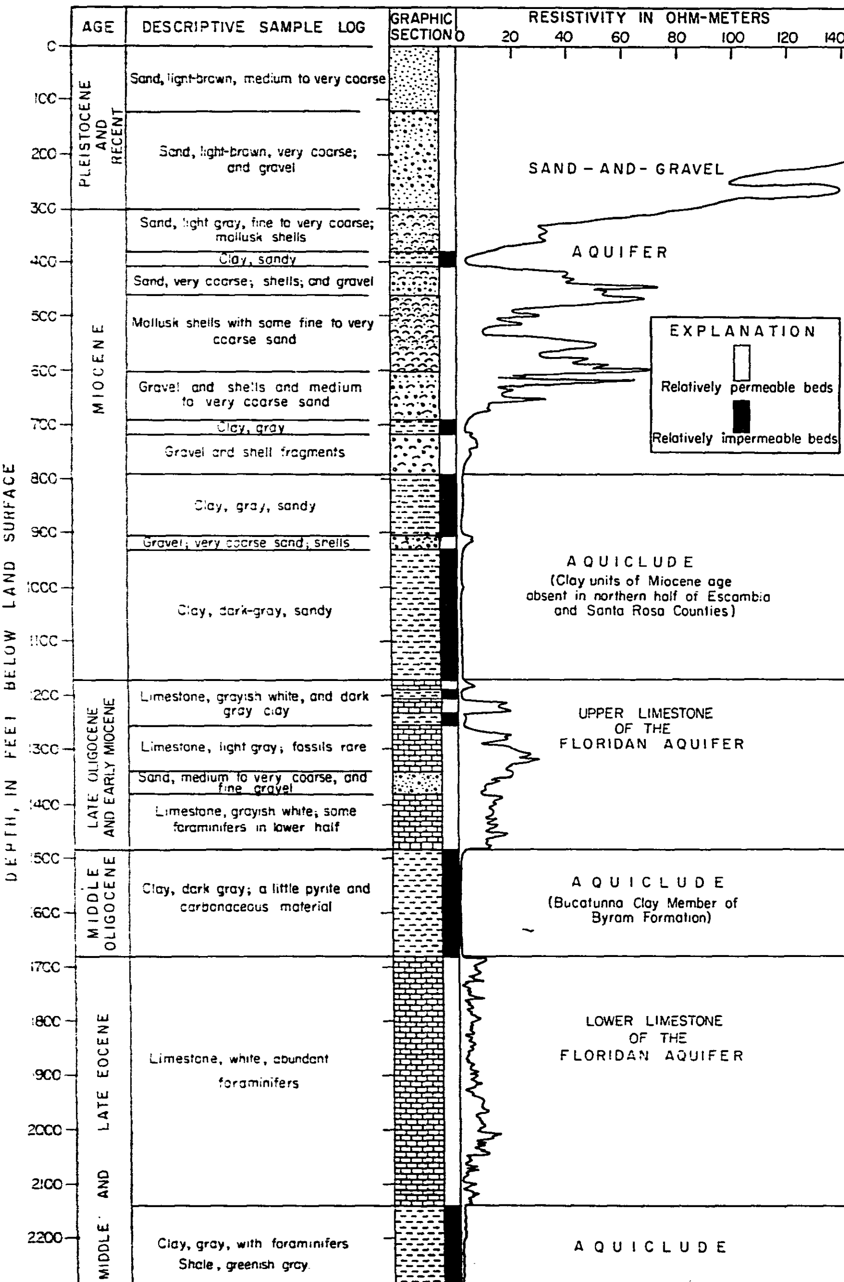

Figure 4. Geologic sequence in Escambia and Santa Rosa counties as shown by representative log of oil test well near Pensacola.

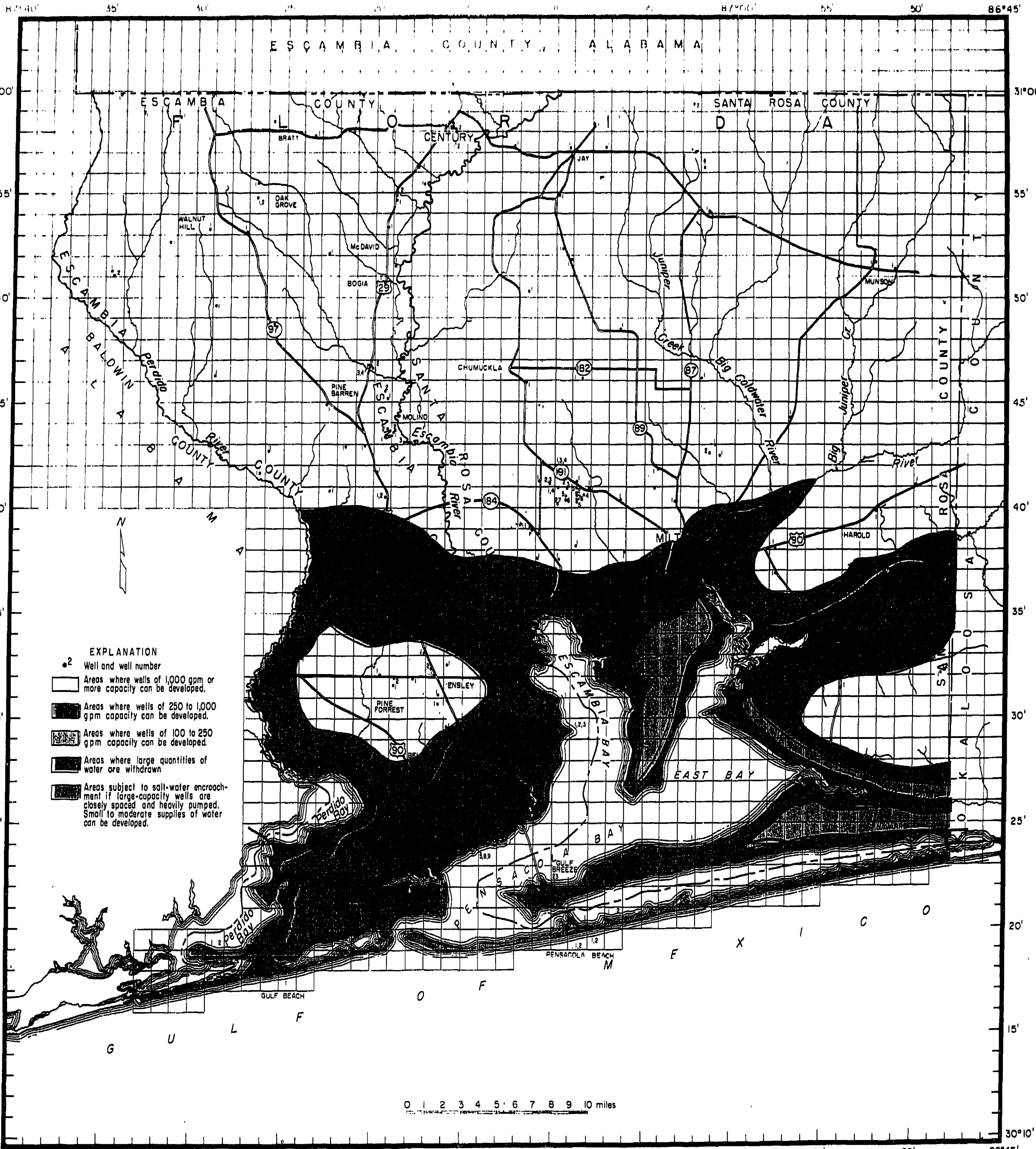

Figure 5. Map of Escambia and Santa Rosa counties showing locations of selected wells from which information was obtained and the water supplies that can be developed from wells in the sand-and-gravel aquifer.

10 to 24 inches in diameter. About 99 percent of the wells draw water from the sand-and-gravel aquifer and the rest draw water from the Floridan aquifer.

The larger-diameter wells tapping the sand-and-gravel aquifer are constructed by drilling an open hole until permeable strata (generally coarse sand or gravel) are encountered. Screens are then set in these permeable zones. Almost all of these wells are equipped with screens.

The wells obtaining water from the Floridan aquifer are constructed by drilling an open hole into the limestone, then casing the well to the top of the limestone. The water is obtained from the uncased limestone section. Sometimes an open hole is drilled to the top of the limestone, the casing is firmly seated into the limestone, and drilling is continued into the limestone below the bottom of the casing.

In 1959 and 1960, the U.S. Geological Survey contracted to have 31 test wells drilled, by the rotary method, in Escambia and Santa Rosa counties. There were three main purposes for these test wells. First, they helped to delineate aquifers and aquicludes in parts of the area where little or no geologic information was available. Geologic logs of wells were compiled from an examination of rock cuttings that were collected at intervals of 5 or 10 feet. Fossils were picked from the rock cuttings and were identified to determine the ages of the geologic formations. Electric logs of the two deepest wells were made to determine accurately the position of the clay layers and permeable zones. Second, these test wells were used to establish a grid of water-level observation wells in areas where information on water levels was needed. Third, 20 of the wells in Santa Rosa County were used to determine the water budget (water gains and losses) for a small topographic drainage basin. A total footage of 5,175 feet was drilled, and the depths of the wells ranged from 32 to 750 feet.

STRATIGRAPHY

AQUIFERS

Sand-and-gravel aquifer.—Virtually all of the wells in Escambia and Santa Rosa counties draw their water from the sand-and-gravel aquifer. This aquifer extends from the surface to various depths, ranging from 200 feet in the area 7 miles northwest of Milton to 1,000 feet in the area 14 miles northwest of Milton (fig. 6). In the northern half of the area, the sand-and-gravel aquifer overlies a thin limestone of late Oligocene age (the upper limestone of the Floridan aquifer), but in the southern

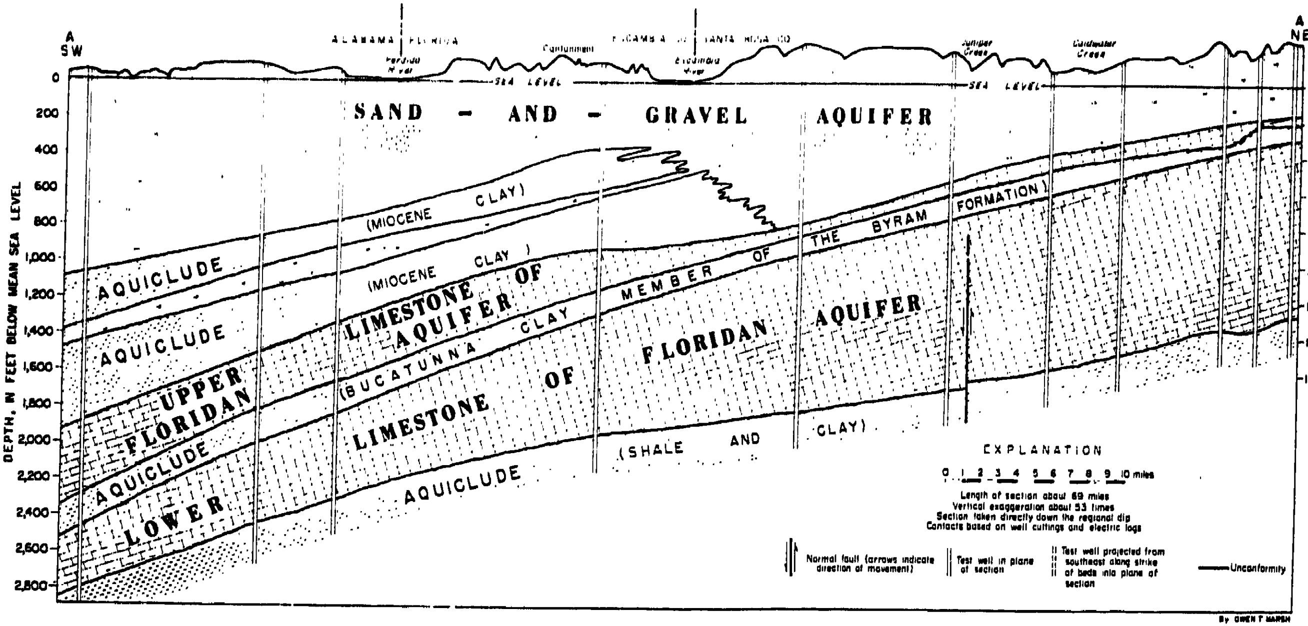

Figure 6. Geologic section across Escambia and Santa Rosa counties showing aquifers and aquicludes along section A-A′ in figure 11.

half of the area the sand-and-gravel aquifer rests upon a thick clay unit of Miocene age (fig. 7). The aquifer ranges in age from Miocene to Recent.

Abrupt facies changes are characteristic of the sand-and-gravel aquifer. Although composed predominantly of sand, the aquifer contains numerous lenses and layers of clay and gravel that are as much as 60 feet thick. The discontinuity of the sediments in the sand-and-gravel aquifer is shown in figure 8. This is a detailed geologic section of the uppermost 100 feet of the aquifer along the Perdido River in west-central Escambia County. The cross section is based on rock cuttings and electric logs of 20 test wells. These wells were drilled for the St. Regis Paper Co. to test the infiltration characteristics of the ground along the Perdido River. The logs were made by the firm of Leggette, Brashears, and Graham, consulting ground-water geologists. As can be seen from the cross section, irregular lenses of gravel and clay extend for short horizontal distances. For example, one gravel lens that is 20 feet thick is only about 200 feet long. Well logs of the sand-and-gravel aquifer elsewhere indicate that this cross section is fairly representative of the aquifer throughout the area.

The uppermost 5-20 feet of the sand-and-gravel aquifer differs markedly from the underlying beds. This upper part consists of light tan, fine to coarse sand that is soft and loose in contrast to the hard, reddish brown, pebbly sand that underlies it. In many places, the light tan sand has been removed by erosion, leaving the hard reddish brown sand exposed as a flat surface.

The sand-and-gravel aquifer consists predominantly of quartz sand, ranging from white to light brown or reddish brown. Although some beds of sand are moderately well sorted, the unit as a whole is generally rather poorly sorted. The grains range from very fine to very coarse and are commonly mixed with granules and small pebbles of quartz and chert. The sand grades laterally into stringers and lenses of gravel which are made up chiefly of pea-sized pebbles. In addition to the large lenses of clay within the aquifer, small stringers of white to gray clay are scattered throughout. Fragments and layers of black lignite are found occasionally and at many places throughout both counties layers of black carbonaceous sand and gravel, containing twigs and bits of coal, are exposed at the surface. These layers range in thickness from a few inches to more than 2 feet.

It seems likely that the materials in the upper part of the sand-and-gravel aquifer were deposited in an environment similar to that of the present-day Mississippi River delta. This is suggested by the rapid facies

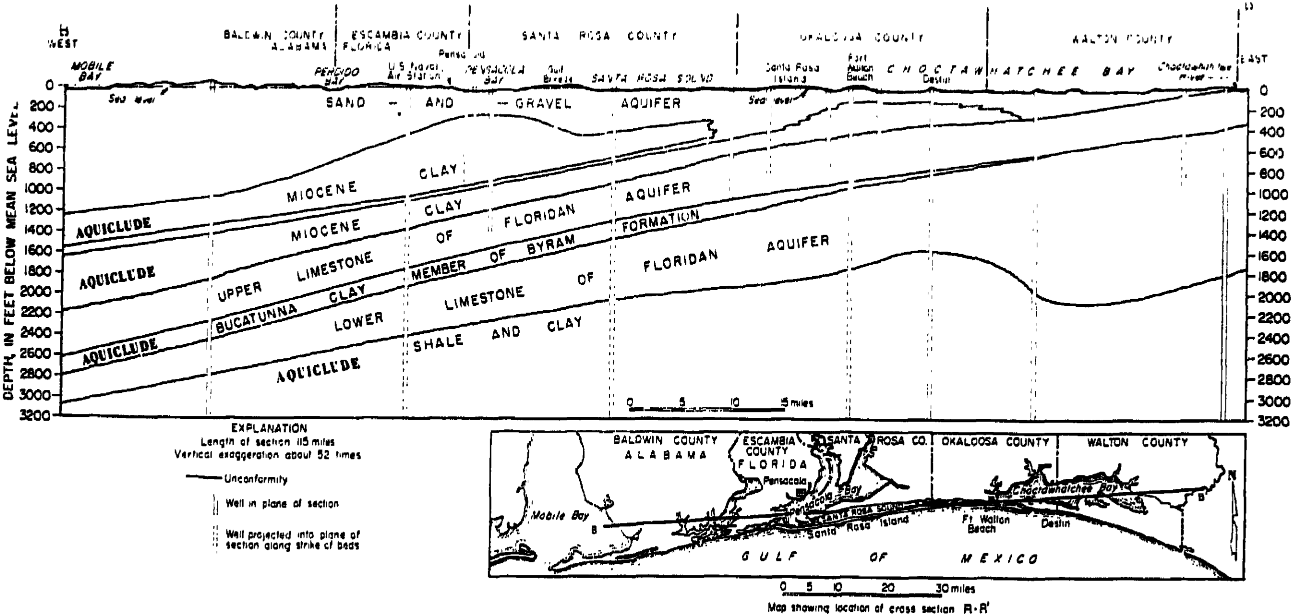

Figure 7. Geologic section along the Gulf Coast from Mobile Bay to the Choctaw-hatchee River showing aquifers and aquicludes.

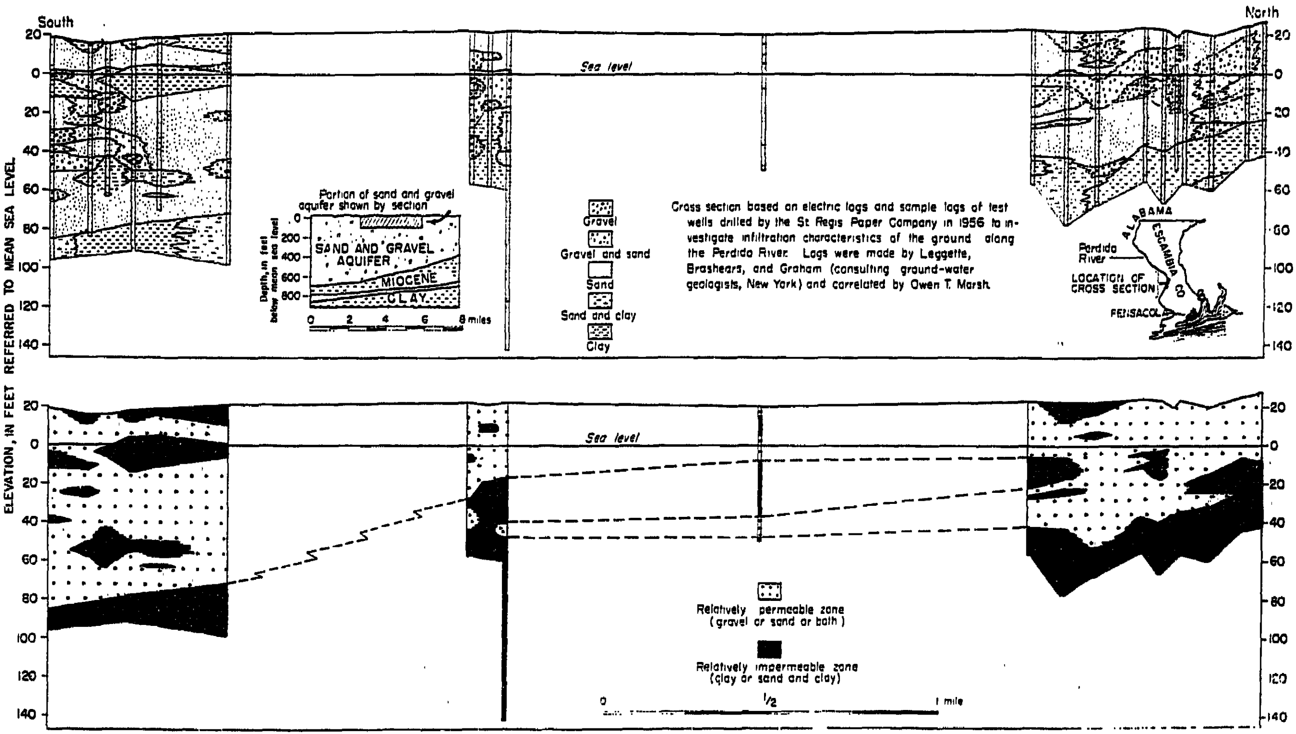

Figure 8. Geologic section showing facies changes and zones of relative permeability and impermeability in the upper part of the sand-and-gravel aquifer along the Perdido River, Escambia County.

changes, the absence of fossils, and the abundance of sand and gravel. These sediments were probably deposited by a network of streams whose channels were constantly shifting back and forth across the surface of the delta. In this environment, clay was deposited in quiet pools or abandoned channels while gravel was being laid down by swiftly flowing streams nearby.

Parts of the sand-and-gravel aquifer have a rather high average porosity and permeability and are thus excellent reservoirs for ground water. The aquifer consists principally of relatively insoluble quartz grains which accounts for the remarkably low mineral content and softness of this water. In contrast to the rest of Florida, the ground-water conditions in Escambia and Santa Rosa counties are complicated by the great lithologic variability of the aquifer. Ground water is under artesian pressure where lenses and layers of clay, sandy clay, or hardpan overlie a saturated, permeable bed. Ground water is under non-artesian conditions where such clays and hardpan are absent or where the permeable bed is not completely saturated. It is not uncommon for a well to tap both artesian and non-artesian water. Ground water in the sand-and-gravel aquifer is derived almost entirely from rain falling in the area.

Floridan aquifer.—In the northern half of the area, the sand-and-gravel aquifer is underlain by a thick sequence of limestones known collectively as the Floridan aquifer. In the southern half of the area the two aquifers are separated by a thick clay unit of Miocene age (fig. 4). The Floridan aquifer in Escambia and Santa Rosa counties is divided into two parts by an extensive clay bed (Bucatunna Clay Member of the Byram Formation) near the top of the aquifer. The part that lies above this clay bed was named the upper limestone of the Floridan aquifer and the part below the clay was named the lower limestone of the Floridan aquifer (Musgrove, Barraclough, and Marsh, 1961).

The upper limestone of the Floridan aquifer is chiefly the Chickasawhay Limestone of late Oligocene age. Within the area, this formation ranges in thickness from about 30 to 130 feet. Its upper surface is an erosional unconformity of low relief which dips gently toward the southwest at about 23 feet per mile. The Chickasawhay is typically a brown to light-gray hard dolomitic limestone or dolomite with a distinctive spongy-looking texture. It contains abundant shell fragments. Several wells in the area obtain water from this limestone.

In the southern part of the area, the Chickasawhay Limestone is overlain unconformably by a remnant of the Tampa Limestone of early Miocene age. This is a cream-colored to light-gray, soft to hard, sandy limestone which contains shell fragments and abundant foraminifers. The Tampa reaches a maximum thickness of 270 feet in southern Escambia County. The Tampa contains several beds of clay which would reduce the effective porosity and permeability of the limestone. A few wells in the southern part of the area obtain water from this limestone.

The upper limestone is recharged mainly by rain that falls in Conecuh, Escambia, and Monroe counties, Alabama. This is the area where the upper limestone comes to the surface. Additional recharge comes from downward leakage of water from the sand-and-gravel aquifer in northern Escambia and Santa Rosa counties, Florida. The movement of the water in the upper limestone is generally southward and southeastward.

The lower limestone of the Floridan aquifer in this area consists of the Ocala Limestone and other limestones of Eocene age. The top of the lower limestone, although an erosional unconformity, is a relatively flat surface that dips gently toward the southwest (fig. 9). The lower limestone rests unconformably upon shale and clay of middle Eocene age. The lower limestone ranges in thickness from about 360 feet in central Escambia County to as much as 1,200 feet in the northern part of Santa Rosa County (fig. 6). Thus, unlike most sedimentary units along the Gulf Coast, these limestones thin rather than thicken downdip. The lower limestone is white to grayish cream and is rather soft and chalky. Well samples contain as much as 30 percent very fine to very coarse sand, but some of this probably caved from above during drilling. Samples also contain some gray clay. Lenses of hard light-gray shale occur within the limestone, but these appear to be randomly distributed and cannot be correlated from well to well over any great distance. Much of this limestone consists of foraminifers, corals, bryozoans, ostracods, fragments of echinoids and mollusks, and other fossils. Black phosphatic grains are locally plentiful.

Much of the Floridan aquifer in Escambia and Santa Rosa counties is composed of a porous and permeable coquina consisting of fossil fragments. This aquifer contains substantial quantities of ground water. Most of the water in both the upper and lower limestones of the Floridan aquifer is confined above and below by beds of relatively impermeable clay. Ground water in the lower limestone is also derived mainly from precipitation that occurs 10 to 35 miles north of the area in Conecuh, Escambia, and Monroe counties, Alabama, where the limestone crops-out. The movement of water in the lower limestone is generally to the south and southeast.

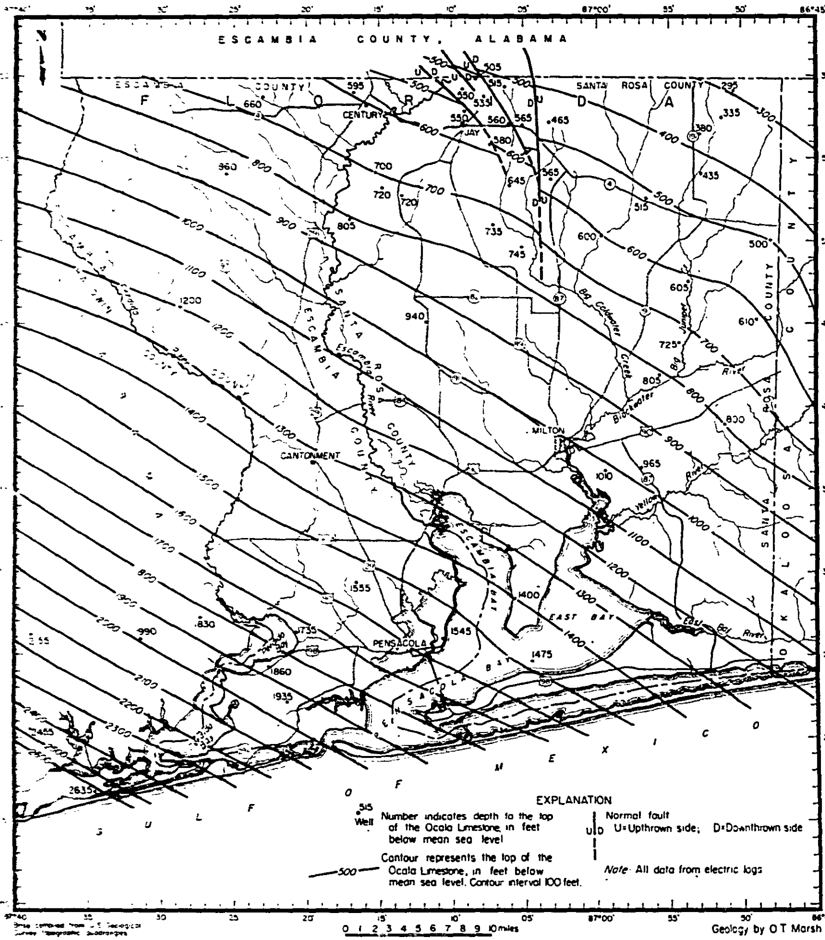

Figure 9. Map of Escambia and Santa Rosa counties showing contours on top of the lower limestone of the Floridan aquifer.

AQUICLUDES

Aquicludes within the sand-and-gravel aquifer.—As shown by the geologic section along the Perdido River in Escambia County (fig. 8), the sand-and-gravel aquifer contains discontinuous layers and lenses of clay and sandy clay. The clay strata range in thickness from a few inches to several tens of feet. For example, the clay bed mined by the Taylor Brick and Tile Co., Inc., of Molino in Escambia County is about 50 feet thick. The available data suggest that the clay and sandy clay strata may range in length from a few feet to several miles.

Another type of relatively impermeable layer within the sand-and-gravel aquifer is hardpan. This rock, formed by cementation of sand by iron oxides precipitated from ground water, occurs extensively throughout westernmost Florida and southern Alabama. This rock ranges in thickness from a fraction of an inch to 4 feet. Little is known concerning the lateral extent of these hardpan layers, but it is unlikely that any layer extends for more than a few thousand yards. Although the rock is dense, these layers are sometimes filled with many curiously shaped cavities of uncertain origin. The rock is rust brown and is generally hard, although some of it is soft. It is composed of iron oxides in the form of limonite and goethite. Most "rock" on local drillers' logs is hardpan. It is the only consolidated rock near the surface in westernmost Florida, and it is occasionally used in the construction of stone walls and buildings.

The relatively impermeable layers of clay and hardpan affect ground water in several ways. First, they reduce the average permeability of the aquifer. Second, although ground water in the sand-and-gravel aquifer probably is more or less hydraulically connected, owing to the discontinuity of the impermeable beds, these layers (assisted by the hydraulic gradient) cause the water beneath them to be under artesian pressure. Third, where these layers lie at or near the ground surface, they decrease recharge to the aquifer by reducing infiltration rates and cause water to be retained in depressions, where it is evaporated. Several hundred ponds, large enough to be shown on topographic maps, dot Escambia and Santa Rosa counties. Considerable inconvenience and damage is caused in some residential areas by ponding of water above clay or hardpan layers after heavy rains. In some areas these layers underlie perched water bodies and thus make small or moderate supplies of ground water available at relatively shallow depths. Finally, these layers are responsible for countless springs, which are typically found at the heads of gullies and small box canyons called steepheads. These canyons are notched into the plateau-like areas that are remnants of marine terraces of Pleistocene age. Excellent examples of such steepheads are found on the Eglin Air Force Base, south of the Yellow River. Here numerous small streams originate as springs that discharge along clay or hardpan layers at the steepheads of the gullies. As most of these springs occur at about the same elevation, 50 feet or so above sea level, it seems likely that they are emerging along the same relatively impermeable layer. The gullies were formed by headward erosion from the edges of the terraces.

Aquiclude below the sand-and-gravel aquifer.—Two thick clay units of Miocene age lie between the sand-and-gravel aquifer and the upper limestone of the Floridan aquifer in the southern part of the area (figs. 6, 10). The observed thickness of this clay ranges from about 150 feet on Santa Rosa Island near the Santa Rosa-Okaloosa county line to about 980 feet at a location 4 miles west of Pensacola. As shown by the structure-contour map in figure 10, the upper surface of the thick clay units generally dips to the southwest. The top of the clay units is only

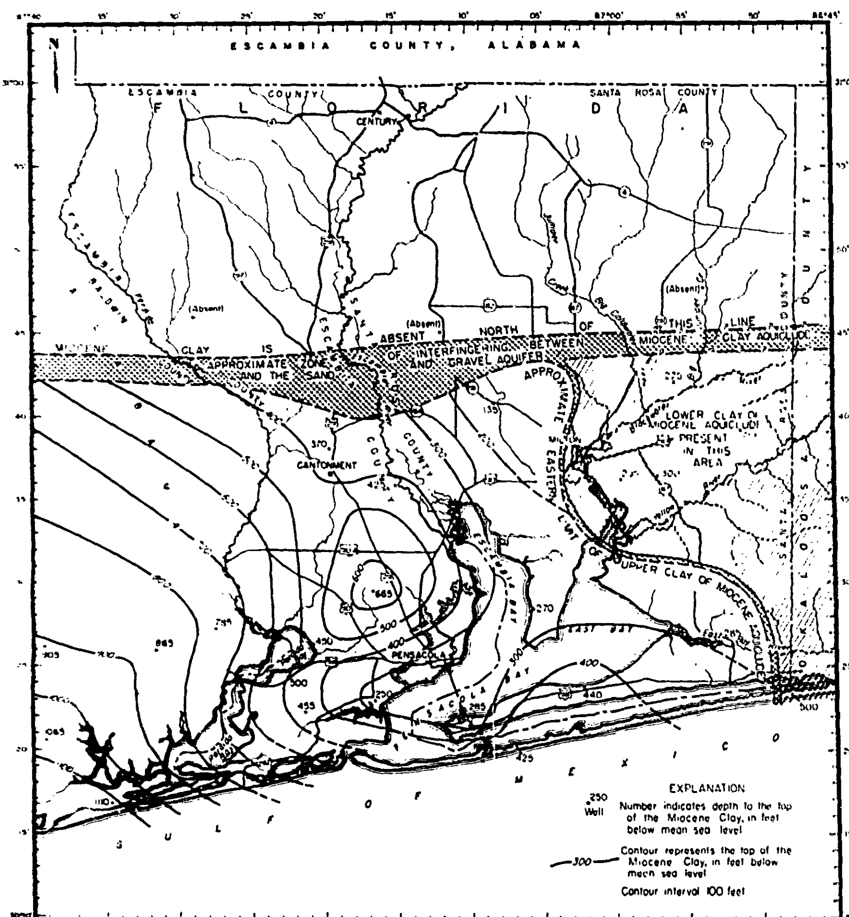

Figure 10. Map of Escambia and Santa Rosa counties showing contours on top of the Miocene clay units.

135 feet below sea level in the area 6 miles northwest of Milton and 1,000 feet below sea level in the southwest corner of Escambia County.

A few miles north of Cantonment, the clay interfingers with the sand-and-gravel aquifer (fig. 6). The two clay units are separated by a bed of sand that ranges from 20 to 160 feet thick.

The clay is gray to dark gray and contains much silt, very fine to coarse sand, and some gravel. It is dated as Miocene on the basis of mollusks and foraminifers. Apparently, this is one of the units that local drillers sometimes call the "Blue Marl."

Aquicludes within the Floridan aquifer.—The Bucatunna Clay Member of the Byram Formation of middle Oligocene age (Marsh, 1962) separates the upper and lower limestones of the Floridan aquifer and underlies all of westernmost Florida and parts of Louisiana, Mississippi, and Alabama. Within the area, the Bucatunna ranges in thickness from about 45 feet in the northwest corner of Santa Rosa County to 215 feet just north of Escambia Bay. The Bucatunna rests uncomformably upon the eroded surface of the lower limestone of the Floridan aquifer and is overlain conformably by the flat, even base of the upper limestone. The Bucatunna consists of gray, soft, silty to sand clay containing foraminifers, ostracods, and a few mollusks. The unit crops out along a belt that lies about 10 to 35 miles north of the area in Alabama.

Although much of the Floridan aquifer is porous, it contains zones of dense rock which may have been caused by solution and re-precipitation calcite. These dense layers serve to prevent or retard movement of water and thus may be classed as aquicludes.

The lower part of the lower limestone of the Floridan aquifer contains thick but irregular zones of gray, hard, slightly calcareous, silty clay-shale as much as 300 feet thick. As these zones are near the base of the aquifer and seem to be continuous, they have relatively little effect on the water in the limestone. However, they reduce the average transmissibility of the aquifer (see p. 160).

Aquiclude below the Floridan aquifer.—The lower limestone of the Floridan aquifer is underlain everywhere in the area by gray shale and clay of middle Eocene age. The top of this shale and clay, although sloping generally southwestward, undulates broadly implying that these rocks were eroded before deposition of the overlying limestone (fig. 4).

REGIONAL DIP

The lack of exposures and observable bedding within the sand-and-gravel aquifer makes it impossible to obtain the strike and dip of this unit. However, the top of the Bucatunna Clay Member presents a generally uniform, easily identifiable surface whose attitude can be computed readily (fig. 11). This surface strikes about N. 65° W. and dips about 30 feet per mile toward the southwest. The top of the lower limestone of the Floridan aquifer also dips southwestward at 30 feet per mile and has a strike of N. 60° W. Probably the sand-and-gravel aquifer has a gentler dip.

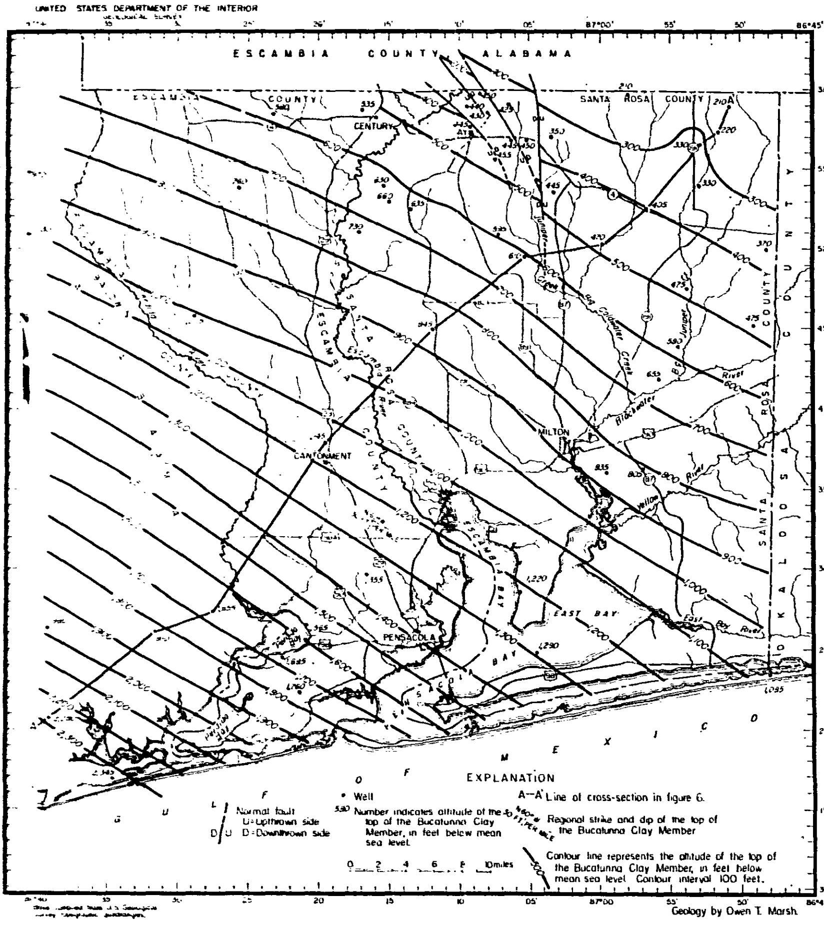

Figure 11. Map of Escambia and Santa Rosa counties showing contours on top of the Bucatunna Clay Member of Byram Formation.

RELATION OF GEOLOGY TO GROUND WATER

MOVEMENT OF WATER

The direction of ground-water flow is determined by the pressure head from point to point. The head, in turn, is determined by the hydrologic, geologic, and topographic conditions between the recharge and discharge areas. The relative position of rock layers of greatly differing permeabilities may have an important influence on the direction of ground-water flow. Owing to the relative impermeable clay unit and the Bucatunna Clay Member, which dip gently toward the southwest, one might expect ground water in the Floridan aquifer to move southwestward in the area. However, the movement of water in the Floridan aquifer is to the south and southeast. The dip of strata in the sand-and-gravel aquifer is so slight that ground-water flow in this aquifer is controlled principally by differences in head resulting from local topographic irregularities.

The location of four normal faults in the Jay area is shown on figures 9 and 11. These faults are extensions of the fault system around Pollard, Alabama, where the Pollard oil field is located. Oil is produced in this field from structural traps along the faults and comes from sands in the Tuscaloosa Formation of Late Cretaceous age at a depth of approximately 5,400 to 6,000 feet below sea level.

Just how faults affect flow of the ground water is not known but different resistivity readings on opposite sides of faults, shown by electric logs, suggest that some salty water may move upwards along faults in the lower part of the lower limestone of the Floridan aquifer. However, water wells near the faults are not nearly deep enough to verify this.

RELATION OF GEOLOGY TO QUALITY OF WATER

Zones of fresh and salty water.—Most of the water in the sand-and-gravel aquifer is fresh. The Floridan aquifer, however, contains substantial quantities of both fresh and salt water. In the northern part of the area, the uppermost few hundred feet of the lower limestone of the Floridan aquifer contains fresh water. At depths greater than about 1,200 feet, the water from this limestone is very salty. In the southern part of the area, the lower limestone contains only very salty water. Here the relatively impermeable Bucatunna Clay Member serves to retard the vertical movement of water and thus to prevent salt water in the lower limestone from moving upward and contaminating the fresher water in the upper limestone. The water in the upper limestone becomes salty downdip. Although few samples of water from these salt-water zones are available for analysis, the zones of relatively fresh and salty water may be distinguished on electric logs. An analysis of more than 60 electric logs was made for this purpose during the present study.

Mineralization and hardness of ground water.—In addition to differences in salinity, ground water in the sand-and-gravel aquifer and in the Floridan aquifer differs in amount of dissolved solids and hardness because of differences in lithology of the two aquifers. As might be expected, water in the Floridan aquifer (composed mostly of limestone) is generally harder and more mineralized than water in the sand-and-gravel aquifer, which is composed principally of relatively insoluble quartz sand. As ground water percolates through the upper part of the sand-and-gravel aquifer, it encounters very little soluble material and remains soft and virtually unmineralized. However, harder and more mineralized water comes from deeper wells in the sand-and-gravel aquifer that penetrate sediments containing abundant sea shells. The abundance of ground water remarkably low in mineral content has influenced several large industries to locate in Escambia and Santa Rosa counties.

Relation of quality of water to geologic history of the Gulf Coast.—For millions of years the Gulf coastal area has been slowly subsiding, forming a vast sinking trough, or geosyncline. As the trough sank, streams emptying into the Gulf of Mexico kept the trough nearly full by dumping into it huge quantities of mud, sand, and gravel. According to Howe (1936, p. 82), "These sediments have been concentrated along a narrow zone paralleling the present shore, and, since the beginning of the Eocene, have accumulated to a thickness which probably exceeds 30,000 feet [south of the Mississippi River] . . . the region of the present coastline has been depressed under the weight of these deposits to almost three times the present maximum depth of the Gulf of Mexico. The major axis of the Gulf Coast geosyncline approximately parallels the Louisiana coastline. . . ."

Ground water in the Floridan aquifer in the Florida Peninsula becomes mineralized as it moves through soluble limestones. In Escambia and Santa Rosa counties, however, these limestones have been depressed hundreds of feet by the sinking of the Gulf Coast geosyncline. This circumstance made it possible for rivers and streams to deposit the deltaic sand and gravel which make up the principal ground-water aquifer in westernmost Florida. The main area of subsidence did not extend far enough to the east to depress the limestones of peninsular Florida.

SURFACE WATER

Escambia and Santa Rosa counties have an abundant supply of surface water of excellent quality flowing in the streams and additional supplies are found in small natural ponds and a few man-made ponds. Streams are the main source of fresh surface water, discharging an average of 8.5 bgd into the bays along the southern boundary of the counties. Small reservoirs created by dams are few in number at present. However, much of the terrain lends itself well to the development of small reservoirs, and more will probably be built as the economy of the area expands. The bays along the coast cover more than 230 square miles and provide excellent facilities for boating, fishing, swimming, and shipping.

The streams that flow into Escambia and Santa Rosa counties or along their boundaries drain about 6,000 square miles before reaching the counties. An average of slightly more than 10,000 cfs (cubic feet per second), or 6.5 bgd, is brought into the counties by the surface streams. Streams within the two counties pick up an average flow of 3,100 cfs, or 2.0 bgd, from the 1,700 square miles of land of the area.

The flow of 2.0 bgd that is derived from within the two counties is equivalent to 25 inches, or 40 percent, of the 63-inch annual rainfall of the area. The combined losses by evaporation, transpiration, and underground flow averages about 38 inches per year.

Average unit runoff varies from basin to basin from 14 inches to 50 inches. The map in figure 12 shows approximate average annual runoff in inches from stream basins within the two counties.

Runoff during an extremely wet year is about 2½ times that for a dry year. Figure 13 shows runoff in inches for 1956, a year of low runoff, and for 1961, a year of high runoff. The 1956 rainfall was near normal but the low runoff for that year reflected the rainfall conditions during the two previous years, which were well below normal. The cumulative deficiency of rainfall for the 3-year period 1954-56 was about 40 inches. This 3-year deficiency in rainfall reduced the amount of direct surface runoff and caused a decline in ground-water levels which in turn caused a decline in the base flow of streams. Streams in this area have a high rate of base flow that comes as seepage from the ground.

The surface waters of Escambia and Santa Rosa counties are of excellent quality, except in the coastal reaches where tides bring salt water up the streams. The Escambia River coming out of Alabama brings water of higher mineral content (about 100 ppm, parts per million); however, this mineralization is diluted somewhat by the lower mineral-content waters of the Florida tributaries.

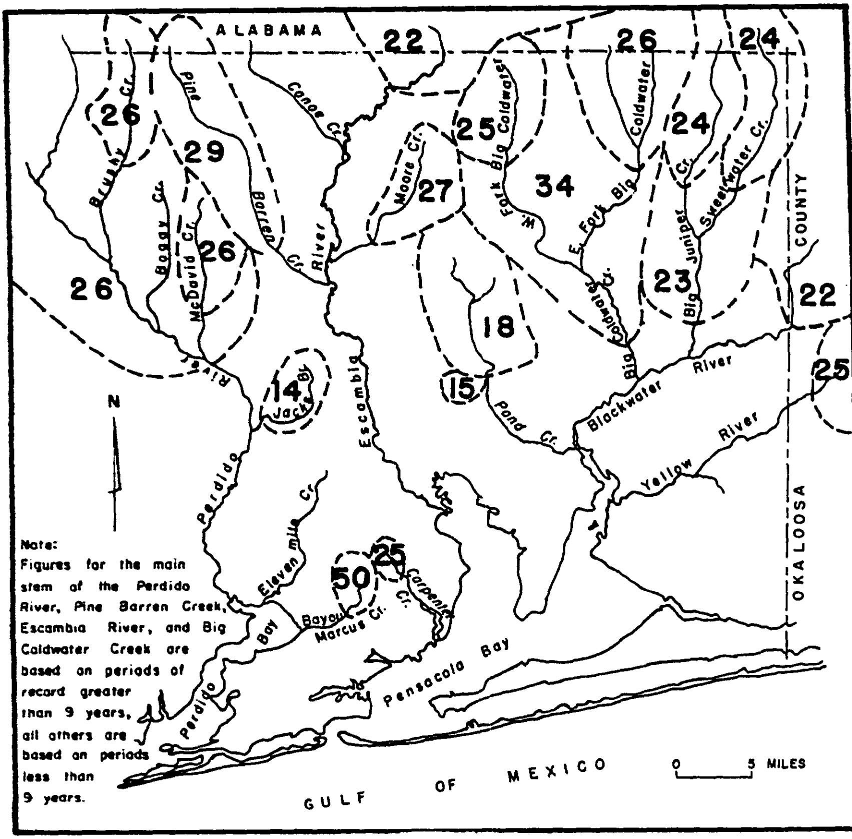

Figure 12. Approximate average annual runoff, in inches, from areas within Escambia and Santa Rosa counties.

Most of the streams of the two counties originate in the highlands and flow in sand and gravel-lined streambeds. The low solubility of the sand and gravel results in water of very low mineral content, generally less than 30 ppm. The mineral content varies seasonally. During the rainy season the minerals in the water are diluted, but the color generally increases because of surface runoff. In the dry season the water has a slightly higher mineral content, but very little color.

The quality of available surface water in the area varies from place to place and from time to time. The seasonal fluctuations follow very closely the pattern of rainfall. The discussion that follows is concerned with the availability of surface water with respect to quantity and quality within the two-county area. Where possible, short-term records were extended to long-term periods to obtain average flow figures and flow-duration curves. Streamflow characteristics are discussed by basins as outlined in figure 14.

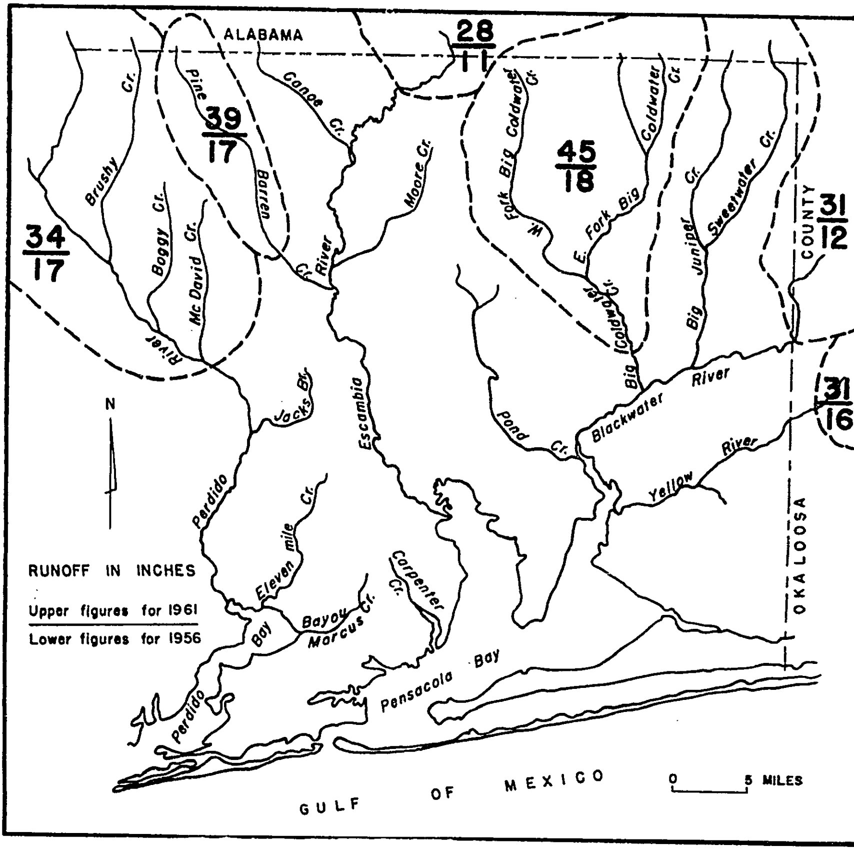

Figure 13. Runoff in inches for 1961, a year of high runoff, and for 1956, a year of low runoff, from areas within Escambia and Santa Rosa counties.

COLLECTION OF DATA

Streamflow data were collected at only four sites in Escambia and Santa Rosa counties prior to 1958. The first stream gaging station was started on the Escambia River at Century in 1934. In 1938 a station was established on Big Coldwater Creek near Milton, and in 1941 one was

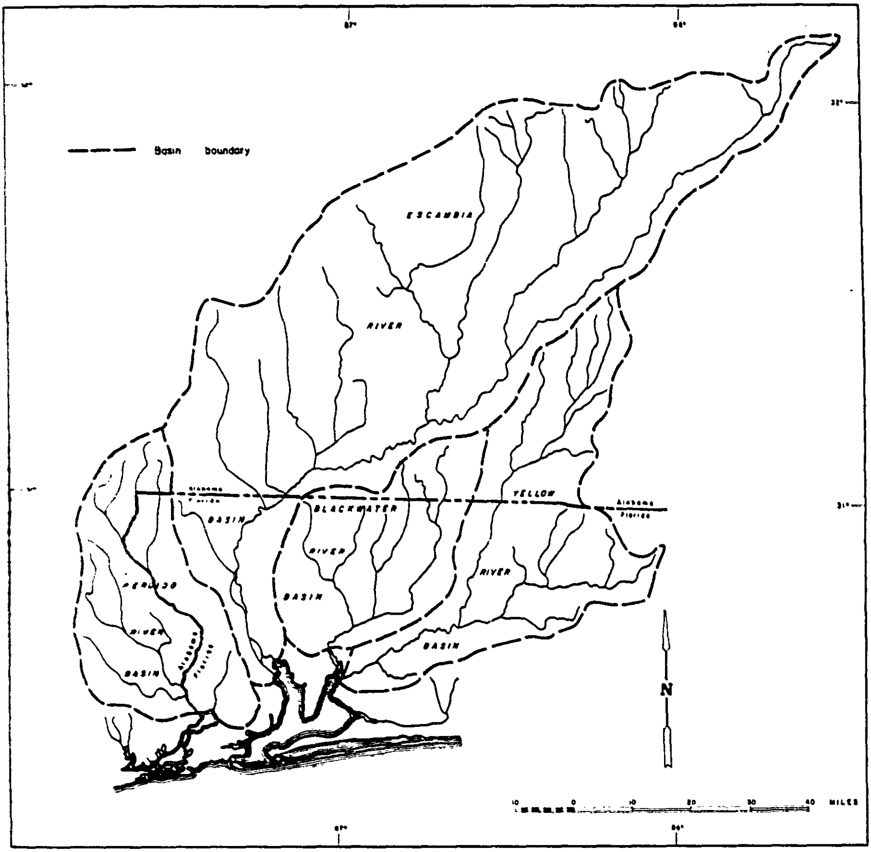

Figure 14. Basin map of Perdido, Escambia, Blackwater, and Yellow rivers.

started on Perdido River at Barrineau Park. The collection of river stages on the Escambia River near Gonzalez was started in 1951 and streamflow records on Pine Barren Creek near Barth were started in 1952. Streamflow data were also collected at two nearby sites, Yellow River near Holt (1934-1940) and Escambia Creek at Flomaton, Alabama (1939-1951).

At the start of the present investigation in 1958, additional data-collection sites were established to define streamflow conditions and to determine in more detail the quantity and quality of the water supply in the area. A list of data-collection sites and the length of record at each site are given in figure 15. The map in figure 16 shows the location of these sites.

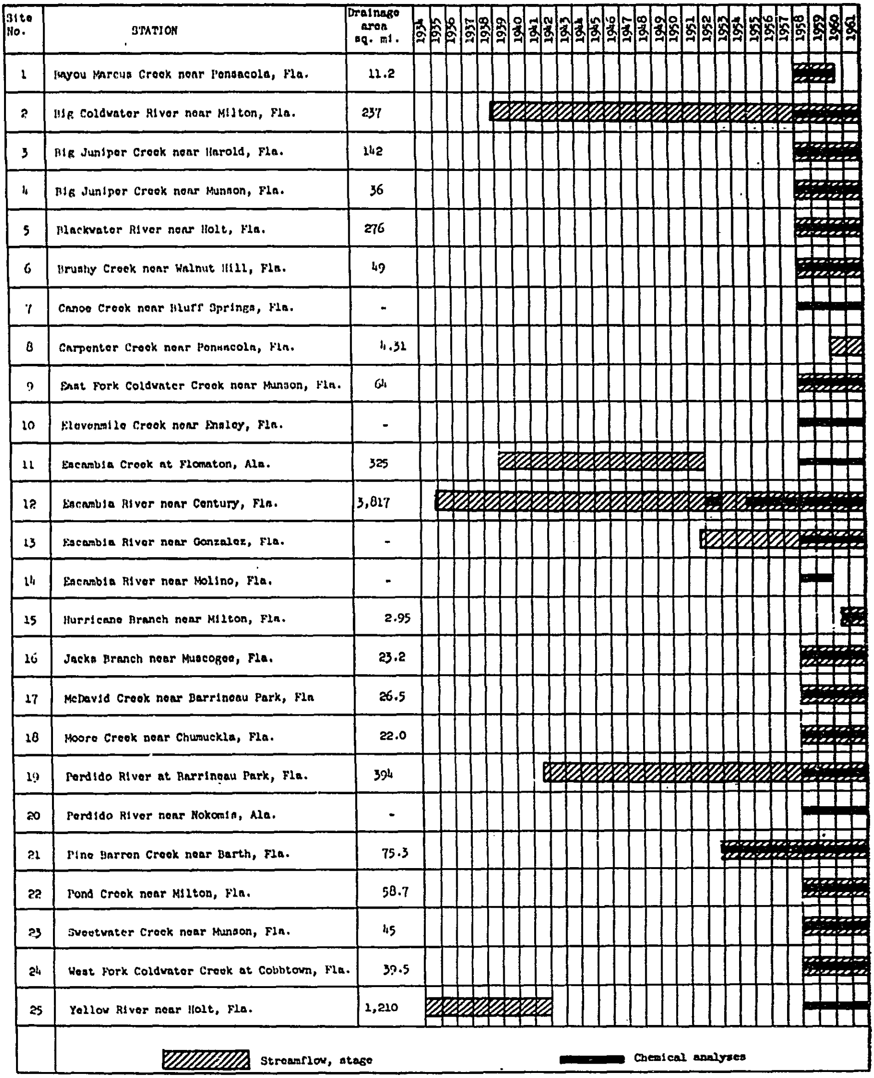

Figure 15. Graph showing periods and types of surface-water records in and near Escambia and Santa Rosa counties.

FLOW-DURATION CURVES

Daily streamflow data are available at 10 sites with 4 to 27 years of record. Escambia River near Century has the longest record. Records from 9 of these stations were extended to the 27-year period, and figures of average flow and flow-duration curves were obtained from these extensions. The flow-duration curves and average flows for the 10 stations are given in figures 17 and 18.

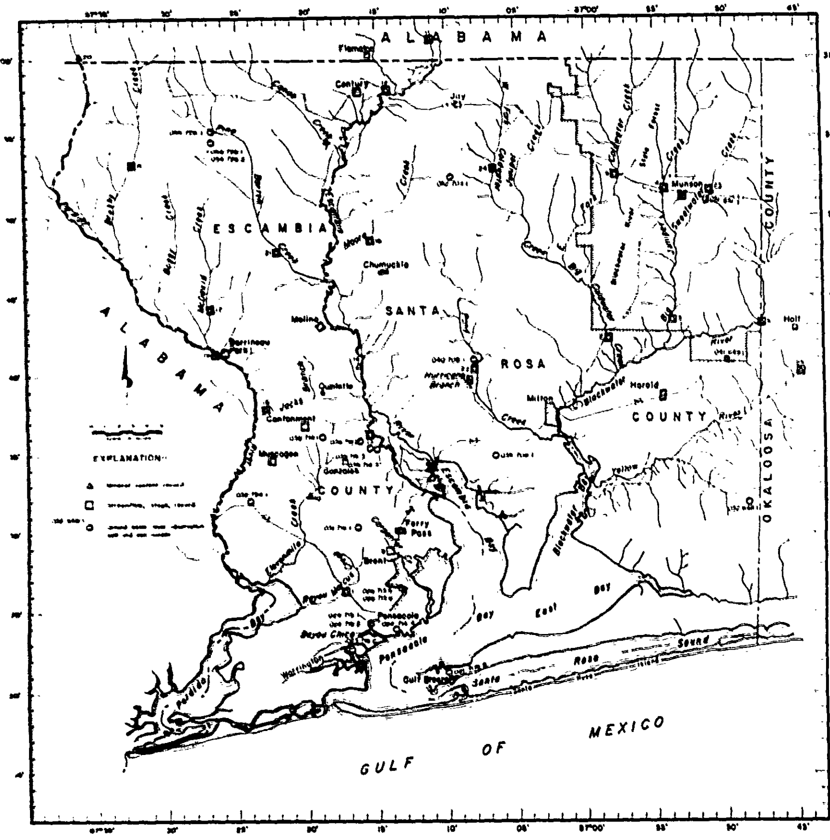

Figure 16. Map of Escambia and Santa Rosa counties showing surface drainage and data-collection points.

PERDIDO RIVER BASIN

OCCURRENCE OF WATER

The Perdido River, the westernmost stream in Florida, forms the part of the boundary line between Florida and Alabama. The part of the basin in Florida lies in a narrow band, 5 to 10 miles wide, along the eastern side of the main channel in Escambia County. The four major tributary streams on the Florida side of the river are Brushy Creek, Boggy Creek, McDavid Creek, and Jacks Branch. Elevenmile Creek and

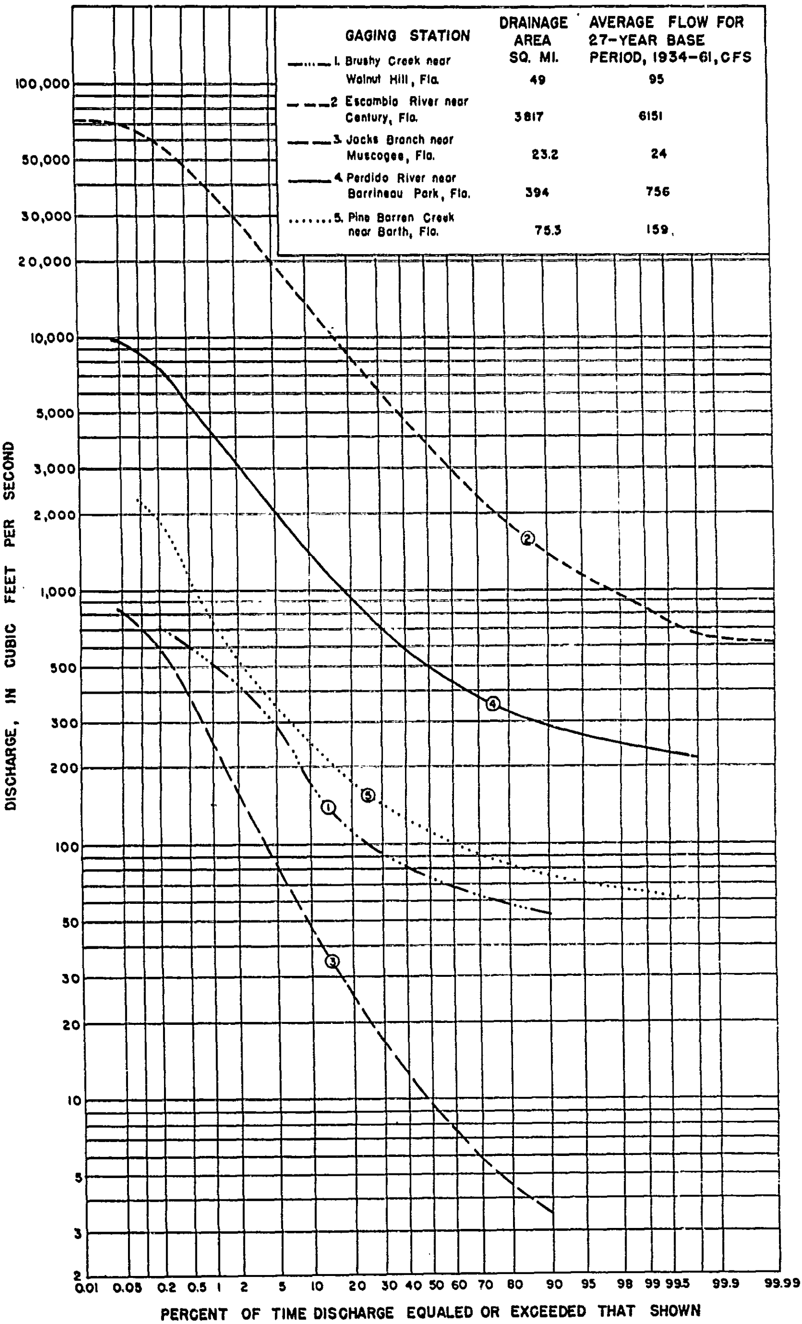

Figure 17. Flow-duration curves for 5 streams in Escambia County.

Bayou Marcus Creek flow into Perdido Bay and are included in the discussion of the Perdido River basin.

The basin, outlined on the map in figure 14, covers 925 square miles. Of this area, 236 square miles are in Escambia County, Florida. Streams

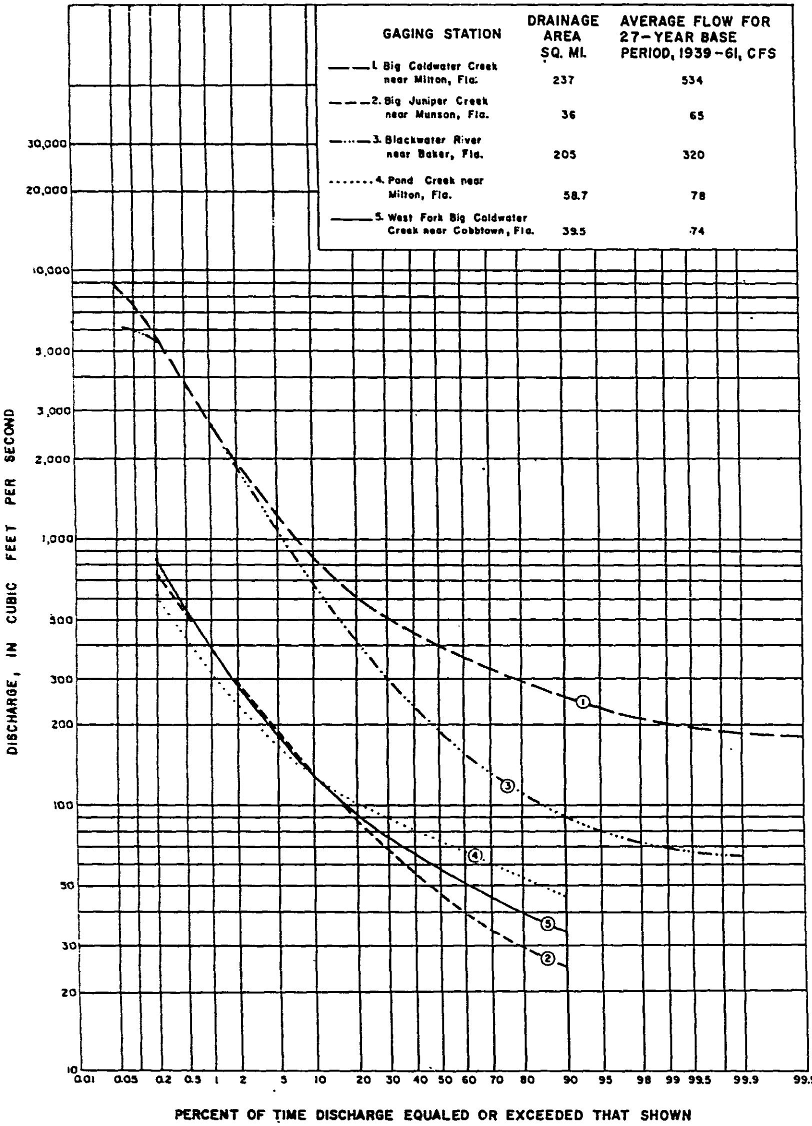

Figure 18. Flow-duration curves for 5 streams in Santa Rosa County.

in the basin drain very hilly country. The hills are from 100 to 150 feet above the stream valleys. The fall of the Perdido River streambed from the Alabama-Florida State line to Muscogee is 150 feet for a channel length of about 40 miles. The fall from Muscogee to Perdido Bay is 15 feet for a channel length of about 20 miles (taken from U.S.G.S. topographic maps).

Tidal fluctuations occur in the lower reach of the river. During periods of low flow, tidal effects extend about 15 miles upstream from Perdido Bay nearly to Muscogee. Tidal effect will extend the greatest distance upstream during periods when the river is low and the tides are at seasonal highs. The salt front, however, does not extend as far upstream as the tidal effect.

The downstream, 10-mile reach of the main channel is generally more than 10 feet deep, with holes extending to 45-feet depths. A depth-profile graph of the lower 10 miles of the river is given in figure 19.

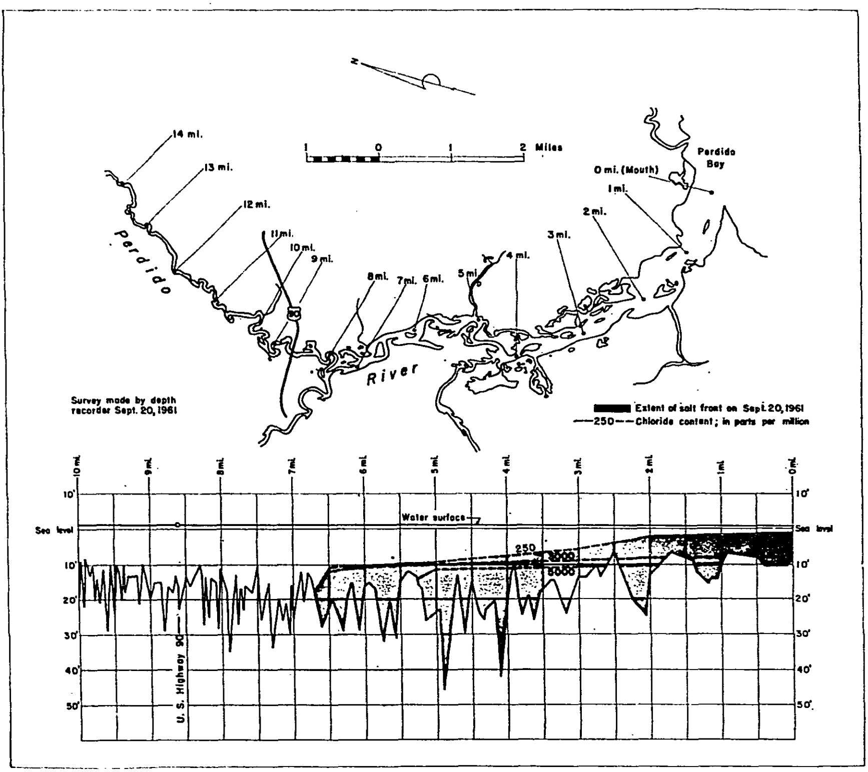

Figure 19. Channel-bottom profile of lower Perdido River.

This depth-profile graph was obtained from a sonic depth-recorder moving along the centerline of the channel. The water-surface elevation in the lower reach of the river during low stages fluctuates with tide from about 0.5 to 1.5 feet above mean sea level.

Throughout its length the Perdido River channel is tortuous. The low-water channel in the vicinity of Barrineau Park is about 150 feet wide and winds through a thickly wooded flood plain that is half a mile wide. The streambed is composed of sand and gravel and characterized by alternate sandbars and holes.

The steep slope of the drainage basin causes high rates of direct runoff. Consequently, floods in this basin are usually of short duration. A rise in water level of 15 feet is not uncommon at Barrineau Park. The highest flood of record reached an elevation of 51.5 feet above sea level in March 1929. The usual low-water stage is 28 feet above sea level. During the flood of April 1955, which was the highest in the 20-year period ending in 1961, the river reached a peak flow of 39,000 cfs at an elevation of 49.7 feet above sea level at the Barrineau Park gaging station. Three days after this flood peak the stage had receded 17 feet and the river was within its banks.

The consideration of floods and their effects on the area is an essential item in planning developments adjacent to the stream channel. The probability of future floods can be predicted on the basis of floods that have occurred in the past. From a study of the magnitude and frequency of past floods, a means of estimating the frequency of floods has been developed for Florida (Pride, 1958). Regional flood-frequency curves applicable to this area have been developed from this report and are presented in figure 20.

The sustained low-flow yield of the streams should be examined in considering an area for development. If the minimum flow of a stream during a reasonably long period of time is known to be above the anticipated demand, the supply is adequate without storage. However, if the minimum flow falls below the anticipated demand, either of two measures can be undertaken. Storage reservoirs can be built to store water during periods of excess flow for use during periods of deficient flow; or, if the deficient flow is of short duration and occurs infrequently, the use of water might be geared to the available supply.

The low-flow frequency curves given in figure 21 for Perdido River at Barrineau Park, Florida, show the frequency of average flows for the indicated periods. For example, a discharge of 250 cfs will occur as a 1-day average once in 2.4 years, or as a 30-day average once in 6.5 years.

The Perdido River basin yields copious quantities of water. The average runoff at Barrineau Park is 26.0 inches per year. That is, the average flow of 756 cfs for 1 year would cover the drainage area of 394 square miles to a depth of 26.0 inches. This is in comparison with the State average runoff estimated to be 14 inches per year (Patterson, 1955). The high yield of the Perdido River basin can be attributed to two factors: (1) a high annual rainfall—this area receives about 63 inches per year; and (2) the coarse sand and gravel surficial covering that releases water to the streams as seepage from the water table or as artesian flow from local aquifers.

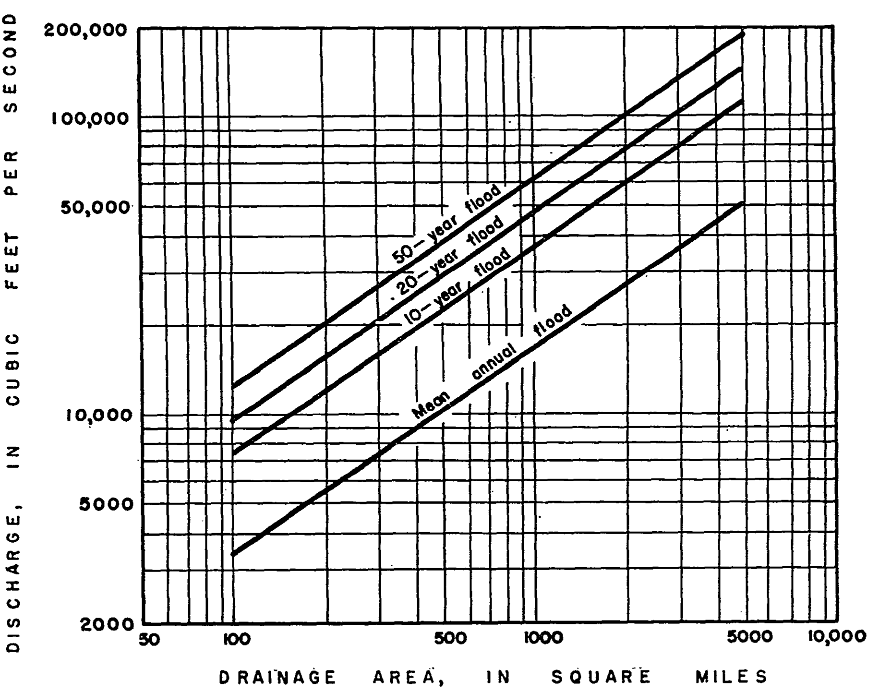

Figure 20. Regional flood-frequency curves for the Perdido, Escambia, Blackwater, and Yellow rivers.

The pattern of flow with respect to time is similar to that of rainfall. March and April are by far the months of highest runoff, and October is the month of lowest runoff. The bar graphs in figure 22 show the average, maximum, and minimum monthly discharges for the Perdido River at Barrineau Park for the 20-year period 1941-61.

The flow-duration curve for Perdido River is given in figure 17. The slope of this curve indicates the variability of flow. This stream has high flood flows, and relatively stable flows during medium and low-water periods.

The average flow from the entire Perdido River basin is estimated to be 1,730 cfs. About one-fourth of this, or 440 cfs, is derived from the area lying within Escambia County.

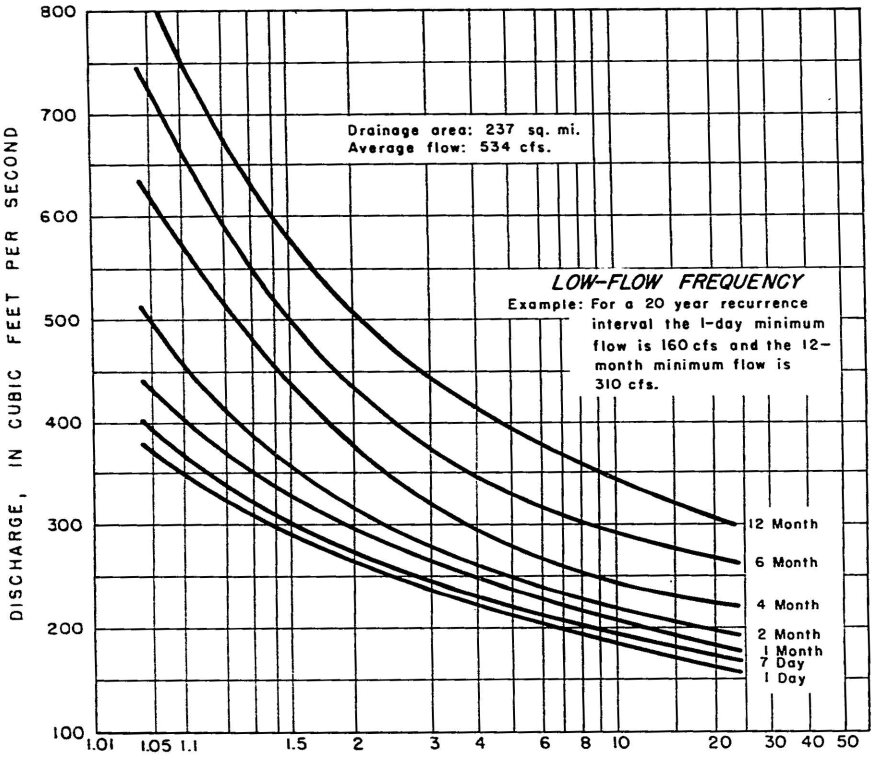

Figure 21. Low-flow frequency curves for Perdido River at Barrineau Park, 1941-61.

Brushy Creek, entering the Perdido River 13 miles above Barrineau Park, drains 75 square miles—53 square miles in the extreme northwest corner of Florida and 22 square miles in southern Alabama. At the gaging station near Walnut Hill, the long-term computed average flow was 95 cfs from the drainage area of 49 square miles. The average flow from the entire basin is estimated to be 140 cfs, of which about 100 cfs comes from Escambia County and about 40 cfs from southern Alabama. The 4 years of streamflow records on Brushy Creek were adjusted to long-term

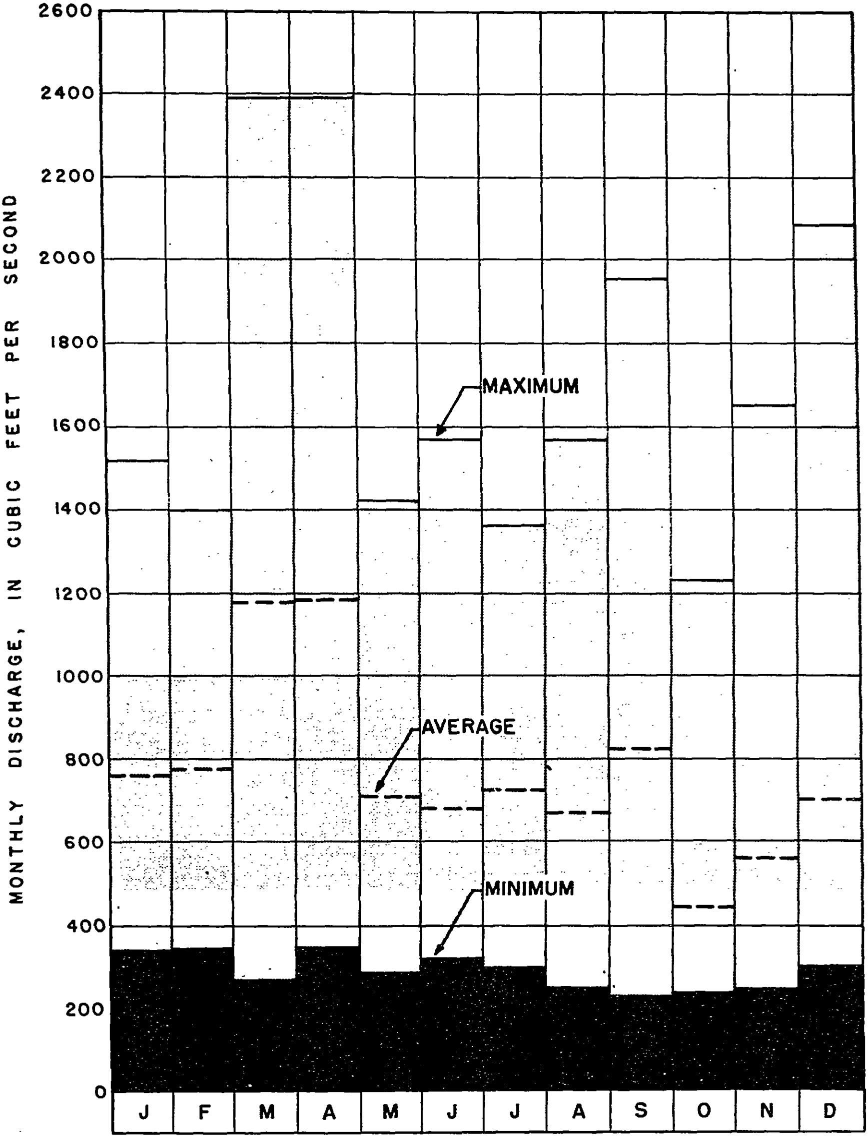

Figure 22. Graph of the minimum, average, and maximum monthly discharge of the Perdido River at Barrineau Park, 1941-61.

records on the basis of 27 years of records for Escambia River near Century. The flow-duration curve given in figure 8 was also adjusted on the basis of this long-term station.

Boggy Creek drains an area of 27 square miles. Based on unit runoff per square mile of nearby streams, the average flow of Boggy Creek is estimated to be 50 cfs.

McDavid Creek drains 34 square miles in Escambia County and flows into the Perdido River a mile above Barrineau Park. The average unit runoff from this basin is estimated, on the basis of discharge measurements and correlation with records of nearby basins, to be 1.9 cfs per square mile, giving a total flow from the basin of 65 cfs.

Jacks Branch, a tributary entering the Perdido River west of Cantonment, has the lowest runoff of any stream gaged in the Perdido River basin. The average unit runoff was computed to be 1.0 cfs per square mile. The Jacks Branch basin covers 24 square miles and produces an average flow of 24 cfs. The minimum daily flow measured at the gaging station is 3.0 cfs, or 0.13 cfs per square mile. The flow-duration curve given in figure 17 has a greater slope than that for other streams in the area and shows the flow of Jacks Branch to be more variable.

The low yield of Jacks Branch, as compared with other streams in the area, is a result of unusually low base flow or seepage to the stream. Only about 30 percent of the total runoff is base flow, whereas the base flows of other streams comprise from 55 to 75 percent of the total. Direct surface flow, or overland flow, of Jacks Branch is about the same as other streams, based on a unit area comparison. The average annual runoff of Jacks Branch is 14 inches.

Elevenmile Creek drains into the north end of Perdido Bay and is used for industrial waste disposal.

Bayou Marcus Creek drains 25.9 square miles along the northwestern outskirts of Pensacola and empties into the northeast corner of Perdido Bay. Two years of records were collected at a gaging station located at U.S. Highway 90 prior to construction of a dam in February 1960. The dam created a reservoir of about 60 acres above State Road 296, about two miles upstream from the gaging station.

An average annual flow of 43 cfs was measured at the gaging station from a drainage area of 11.2 square miles. This unit runoff of 3.8 cfs per square mile is the highest unit runoff within the two counties. The average runoff from this small area is about 50 inches per year, or 80 percent of the average annual rainfall. This high runoff is probably derived from large rates of ground-water inflow from areas outside the surface drainage divide.

MINERAL CONTENT

The Perdido River and tributaries contain water of very good quality. The highest mineral content of 52 ppm was recorded at Barrineau Park where daily water samples were collected for one year. The mineral content varies with streamflow. During high flows the mineral content is lower because of dilution; however, during this same period the color increases because of surface runoff. The color is the most objectionable characteristic to potential industry because it is harmful to many processes and difficult to remove.

Elevenmile Creek contains the water of poorest quality in the two-county area. Samples collected from Elevenmile Creek on a semiannual basis have shown the mineral content to range from 392 to 914 ppm and color from 500 to 1,250 units. This stream has been contaminated by industrial wastes; however, recent corrective measures have been taken to clean it up.

On September 20, 1961, a chloride profile was made on Perdido River. The salt front was followed with a specific conductance meter to the point of furthest intrusion (see fig. 19). When the movement upstream of salt water halted a top to bottom profile was made at 2-foot intervals. This was quickly followed by a series of profiles at various points downstream.

On this particular day the salt extended a little over 6½ miles upstream from the mouth. The flow of the river on this day is exceeded about 50 percent of the time indicating the salt would probably extend further upstream about 50 percent of the time.

ESCAMBIA RIVER BASIN

OCCURRENCE OF WATER

The Escambia River is the largest single source of surface water within the study area and is the fifth largest source in the State. The basin as outlined in figure 8 covers 4,233 square miles, of which 410 square miles are in Florida. The main channel starts near Union Springs, Alabama, as the Conecuh River, and flows southwestward to the Florida-Alabama line near Century, Florida. Near the State line the name changes to Escambia River. The Escambia River flows southward and empties into Escambia Bay north of Pensacola.

The average flow from the Escambia River basin is estimated to be 7,000 cfs. The average flow from the 410 square miles of the basin in Florida is estimated to be 860 cfs. The average unit runoff at the Century gaging station, drainage area 3,817 square miles, is 1.6 cfs per square mile. The average unit runoff from gaged tributaries in Florida (Pine Barren Creek and Moore Creek) is 2.1 cfs per square mile.

The lower part of the Escambia River exerts a major influence on the two-county area, not only because it serves as a source of water supply but also because of its size and location with respect to the fast developing industrial area around Pensacola. The lower basin is about 9 miles wide. The river channel is tortuous and winds through a low, swampy flood plain about 3 miles wide. Several estuarine channels extend into the flood plain from Escambia Bay. Farther upstream two islands within the flood plain are exposed during periods of low river stages.

Flow in the lower river basin is affected by tide to a point north of Brosnaham Island. The change in stage due to tide effect at the north end of the island was 1.8 feet during a series of flow measurements made on August 24, 1954, but the direction of flow does not reverse at that point. A tide range of 2.5 feet is not uncommon near the nylon plant of the Chemstrand Corporation. An observation of flow conditions made near the Chemstrand plant on October 22, 1952, showed the flow to reverse at that point.

Soundings along the centerline of the lower channel, made by use of a sonic depth-recorder, showed the deepest part of the channel to be about 50 feet at a point 5 miles upstream from Escambia Bay. A depth-profile graph made from these soundings is given in figure 23. Deep holes in the channel, such as that 5 miles upstream from the river mouth, trap salt water that can be a source of contamination of surrounding ground-water supplies if heavy pumping from wells near the river is carried on for long periods of time.

The tributaries below Pine Barren Creek are short and drain small areas. The ridges forming the drainage divides vary in elevation from 150 to 200 feet above sea level. The Escambia River flood plain slopes from about 15 feet above sea level near the mouth of Pine Barren Creek to sea level at Escambia Bay.

The larger streams in the Escambia River basin with watersheds in Florida are Pine Barren Creek, Canoe Creek, and Moore Creek.

Pine Barren Creek drains an area of 98.1 square miles, 85 square miles of which is in Escambia County, Florida. The headwaters of the creek are near the town of Atmore, Alabama, 2 miles north of the state line. The average yield of Pine Barren Creek is 28.6 inches per year, which is about 45 percent of the rainfall on the basin. A very substantial base flow of 60 cfs (38.8 mgd) has been measured from the area of 75.3 square miles above the gaging station. The magnitude of flow will be different at any other point in the basin. Based on a flow measurement of a tributary entering just below the gaging station, it is assumed that the magnitude of flow at any point in the basin is proportional to the size of the area drained above that point.

The average flow from the Pine Barren Creek basin is estimated to be 207 cfs, of which about 28 cfs comes from Alabama and 179 cfs from the drainage area within Escambia County, Florida. About two-thirds of the total streamflow is base flow or seepage, and one-third is direct runoff from overland flow.

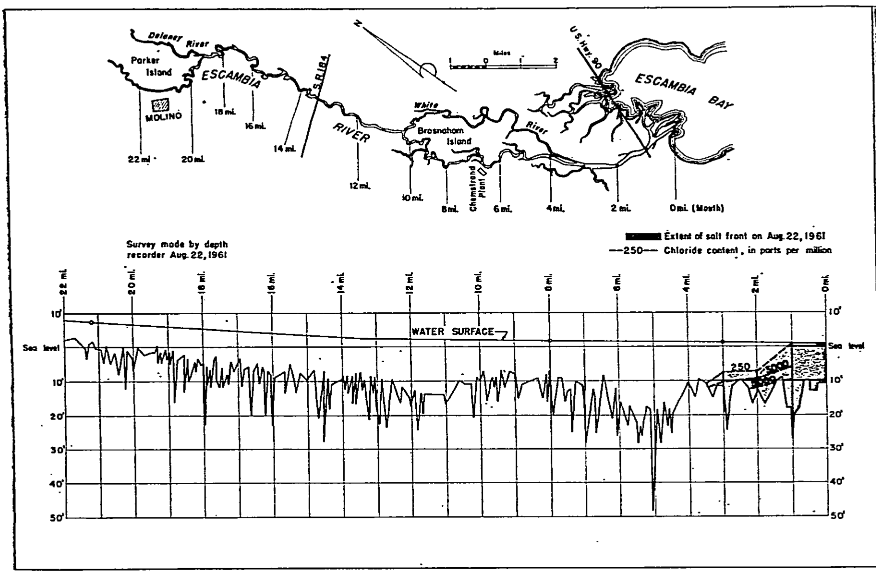

Figure 23. Channel-bottom profile for lower Escambia River.

The length of the Perdido River basin is about six times the width. This elongated shape and the steep topography of the basin produce a short time of concentration of runoff. Rain anywhere on the basin has to move only a short distance before reaching the main channel. The steep valley slope of the main channel allows this water to flow at high velocities to the Escambia River. The channel-bottom profile of Pine Barren Creek is given in figure 24. This channel has an average slope of more than 10 feet per mile.

The fast-changing rates of flow during floods in this basin can be visualized more clearly by comparing an average flow for a day with the momentary peak flow. The mean daily flow for April 14, 1955, was 9,460 cfs and the peak flow on the same day was 24,800 cfs—over 2½ times greater.

The flow-duration curve for Pine Barren Creek given in figure 15 shows the percent of time a specified discharge has been equaled or exceeded. For example, the mean daily flows at the gaging station were

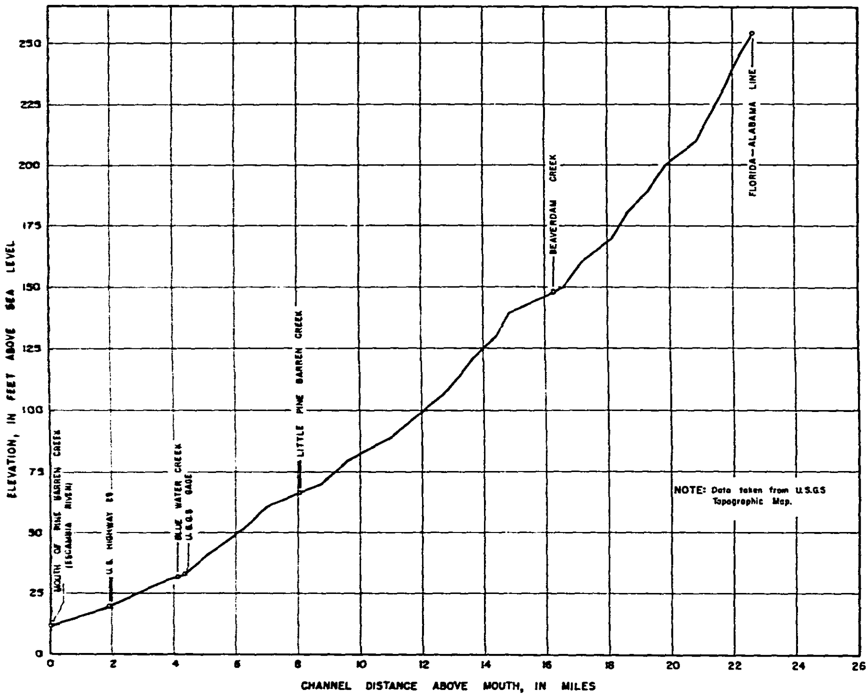

Figure 24. Channel-bottom profile of Pine Barren Creek.

greater than 67 cfs (43 mgd) for 98 percent of the time. If an industry needs a water supply of 43 mgd, a deficiency 2 percent of the time might be tolerated if it were uniformly distributed, with only a few days of deficient flow in any continuous period. A deficient flow of 2 percent of the time, on the other hand, could prove disastrous if it came in a continuous period of several months duration.

The data given in figure 25 are helpful in determining probability of length of periods of deficient flow. The lowest average flow for a specified period can be determined from the lower curve in figure 25.

For example, the lowest average flow for a 1-month period was 60 cfs (38.8 mgd). The upper curve shows the longest period of time that a specified flow was deficient. The curve shows, for example, the longest period that the flow was 60 cfs or less was 10 consecutive days.

The curves shown in figure 25 can be used to determine if the flow

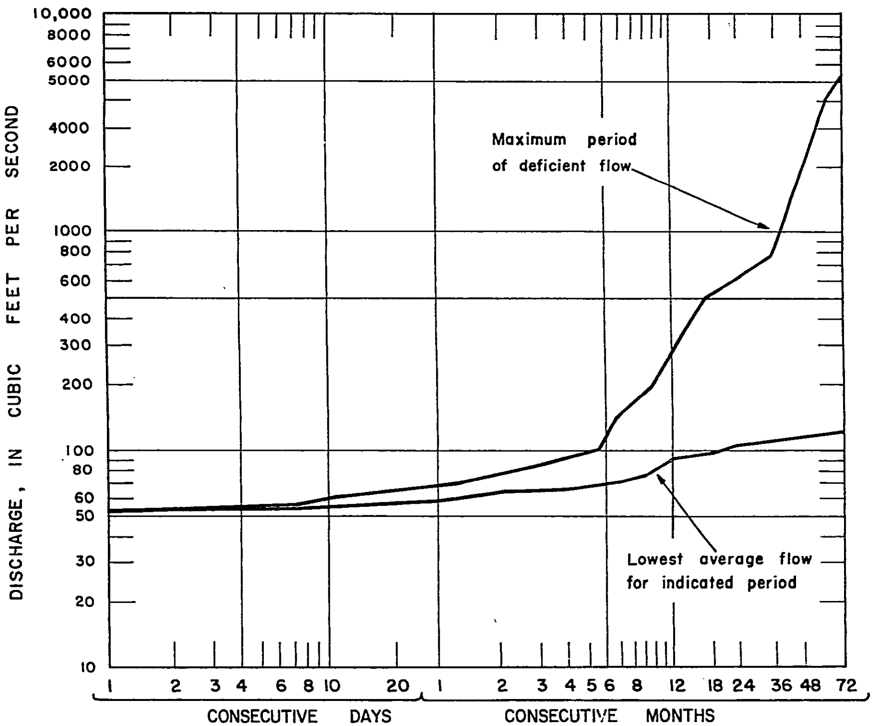

Figure 25. Discharge available without storage, Pine Barren Creek near Barth, 1952-61.

is sufficient for a particular use without storage. If storage is needed, the amount of storage required can be determined from the mass-flow curve given in figure 26. The volume of water required in a reservoir can be determined by superimposing a line representing the required rate onto the mass curve at such a position as to give the maximum distance between mass curve and the flow-required line. The maximum distance represents the amount of storage required, excluding losses by evaporation and seepage.

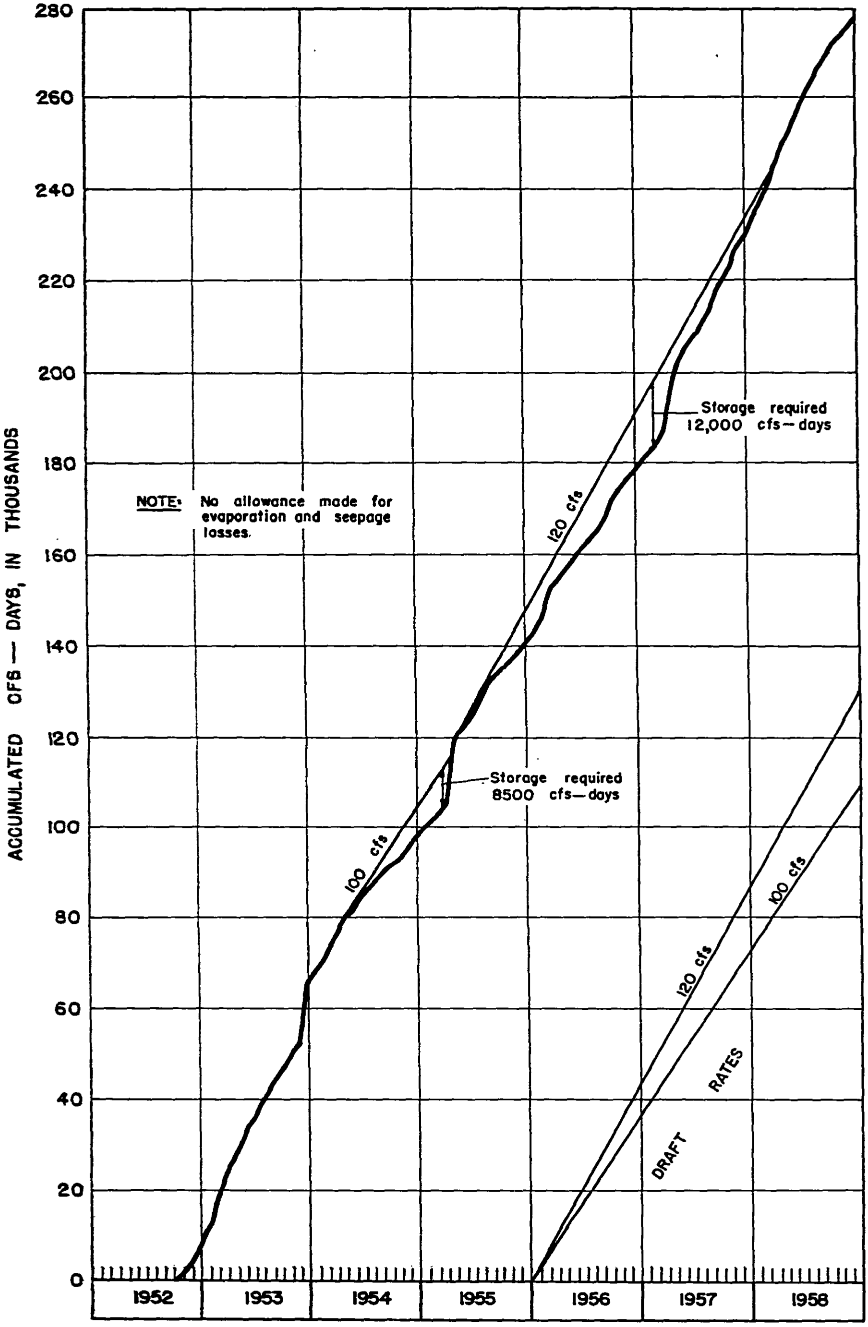

Figure 26. Mass-flow curve for Pine Barren Creek near Barth, 1952-58.

The Moore Creek watershed covers 32 square miles in Santa Rosa County. The flow from this creek enters the Escambia River just upstream from Pine Barren Creek. The yield from this basin is estimated to be approximately the same as Pine Barren Creek basin, about 29 inches per year. Average flow from the basin is estimated to be 67 cfs.

Canoe Creek lies mostly within Escambia County, Florida, with its headwaters in Alabama—24 square miles in Florida and 13 square miles in Alabama. The channel bed is lined with sand and gravel, and the banks are steep and heavily wooded. Based on a field observation of the physical characteristics of Canoe Creek basin, it appears that the flow characteristics are similar to those of Pine Barren Creek. An average flow of 78 cfs for Canoe Creek is obtained by multiplying the drainage area by the unit runoff of 2.1 cfs per square mile for Pine Barren Creek.

The drainage area of the Escambia River at the Century gaging station is 3,817 square miles. The river above the Century gaging station is called the Conecuh River in Alabama. Its basin is slightly elongated in shape, with the longer axis lying in a northeast-southwest direction. The Conecuh River is located along the southern edge of the basin. All of its large tributaries have their headwaters along the northern edge of the basin and flow southward to the Conecuh River.

The seasonal distribution of flow at the Century gaging station, although from a large area located in Alabama, follows a pattern similar to that of the smaller nearby streams in Florida. The bar graph in figure 27 shows the seasonal distribution of flows for a 27-year period at the gaging station at State Highway 4 near Century. The highest average flows occur in March and April and the lowest flows occur in September, October, and November. The variation of flows for any month can be great. January has the greatest variation of monthly mean flows, varying from a low of 1,900 cfs to a maximum of 31,500 cfs. October has the lowest variation of monthly mean flows ranging from 666 cfs to 7,530 cfs.

Some streamflow characteristics for the 27-year period of record at the Century gaging station are indicated by the flow-duration curve in figure 17. Based on the flow-duration curve, the flow has been below 1,000 cfs (646 mgd) for only 3 percent of the time. The maximum flow during the 27-year period ending in 1961 was 77,200 cfs, and the minimum flow recorded was 600 cfs (388 mgd). The computed peak discharge for the flood of March 1929 was 315,000 cfs. The elevation of this flood peak was 66.1 feet above sea level which was 4.5 feet above the floor of the bridge. Regional flood-frequency curves for the Escambia River basin are given in figure 20.

The average yield per unit area from the Escambia River basin ap-

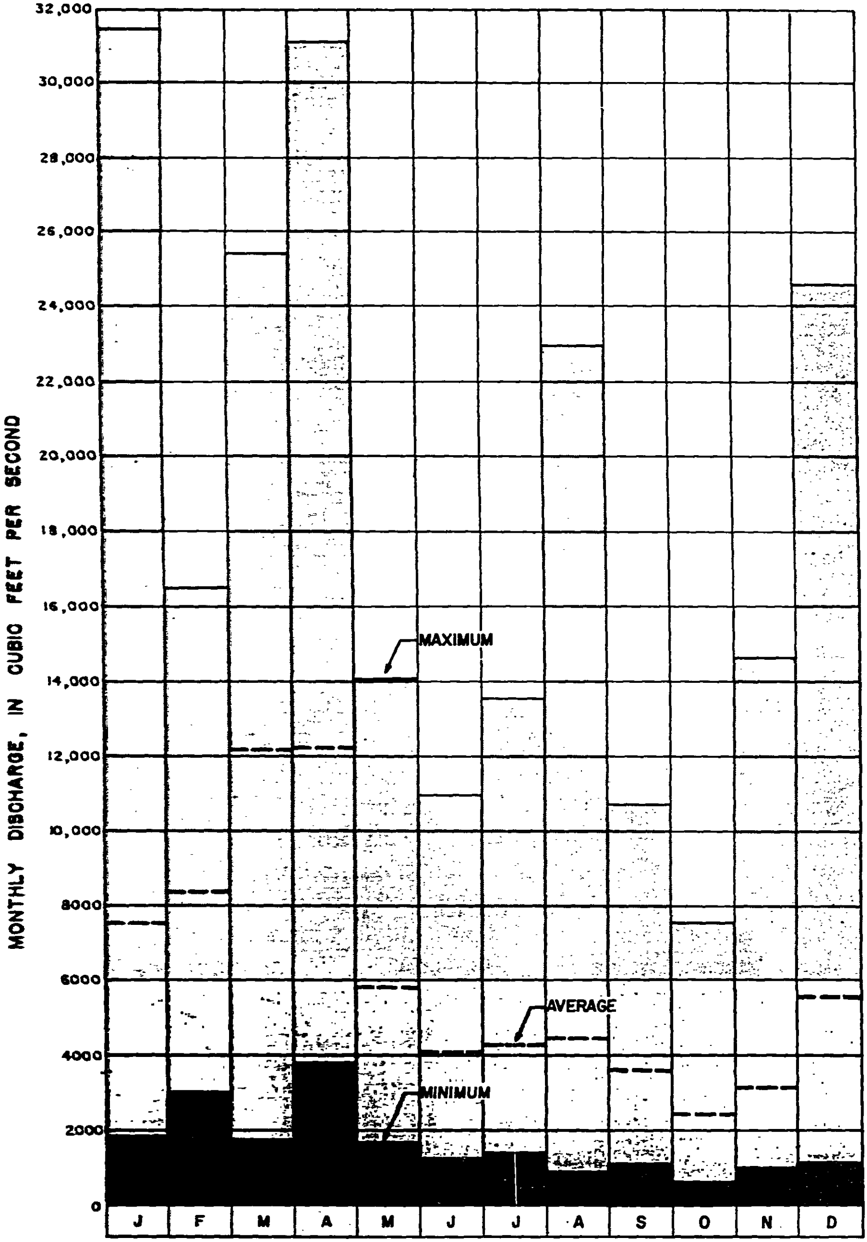

Figure 27. Graph of the minimum, average, and maximum monthly discharge of the Escambia River near Century, 1935-61.

pears to be about the same throughout the basin. Based on records of the eight gaging stations that are located throughout the basin, the average yield is about 21 inches per year, ranging from a low of 18.3 inches to a high of 28.7 inches. The flows measured at these stations came from drainage areas ranging in size from 75.3 to 3,817 square miles. The average yield at the Century gaging station was 21.9 inches per year.

MINERAL CONTENT

The Escambia River passes through the outcrop area of the Floridan aquifer in southern Alabama and dissolves minerals from these limestones. The water of the Escambia River near Century has a mineral content ranging from 47 to 101 ppm. This is generally considered to be low mineralization, but compared to the waters of other streams in Escambia-Santa Rosa counties, it is high. This mineralization is diluted by the flow from the tributaries that empty into the Escambia River. A semiannual station located on the Escambia River near Quintette shows a maximum dissolved solids of 60 ppm. The extent of the salt water wedge in the tidal reach of the river is dependent on the flow of the river and the height of the tide in Pensacola Bay. During periods of high tides and low flows, the salt water extends upstream just beyond the Chemstrand plant (see figs. 23, 28).

In the last 3 months of 1959 the flow in the Escambia River at Century was high and as shown by the graph in figure 28 the chloride at the Chemstrand plant was low. During the last 3 months of 1960 the situation was entirely different. The flow at Century was low and the chloride at the Chemstrand plant was high. On November 22, 1960, the flow at Century was 1,550 cfs (equaled or exceeded 90 percent of the time) and the chloride at Chemstrand was 1,454 ppm. On August 22, 1961, a chloride-profile run on the Escambia River (fig. 23) showed that the salt front extended about 3½ miles upstream. On this day the flow at the Century gaging station was 2,380 cfs, (equaled or exceeded 70 percent of the time).

The tributaries of the Escambia River originate in highland regions, the major recharge areas for the sand-and-gravel aquifer. Surface water in these tributaries is very low in mineral content and generally is very clear. However, color increases due to contact with organic material during periods of high flow.

Silica and color could be the two objectionable constituents in the Escambia River. Silica ranges from 5 to 21 ppm and color ranges from 4 to 120 platinum-cobalt units. The quantity and quality of the waters of the Escambia River basin make it a good potential source.

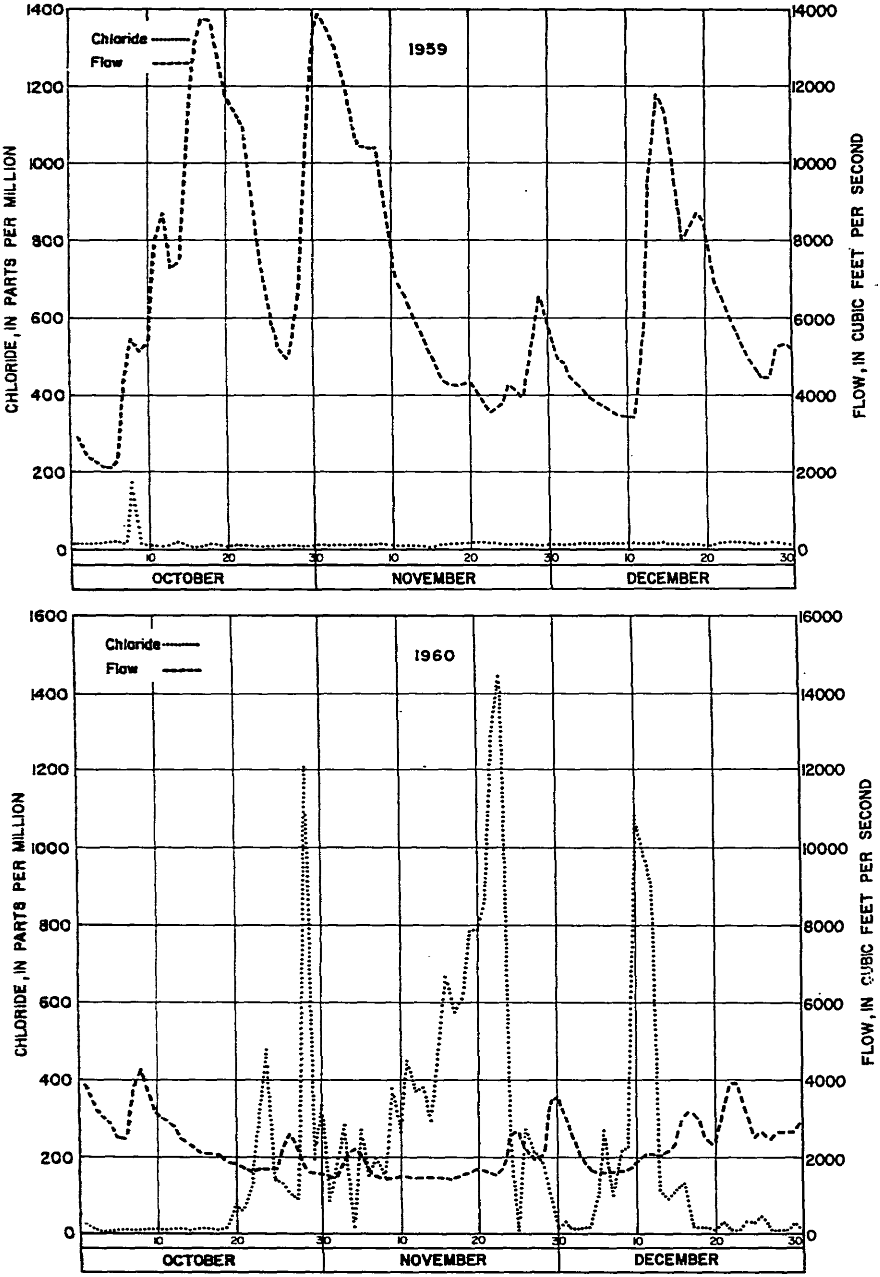

Figure 28. Relation of daily chloride content in water in Escambia River at Chemstrand plant to streamflow at State Highway 4 near Century, October-December 1959 and October-December 1960.

BLACKWATER RIVER BASIN

OCCURRENCE OF WATER

Blackwater River heads in southern Alabama, north of Bradley. The river enters Florida north of Baker, flows across the northwestern corner of Okaloosa County, and winds southward along the Santa Rosa-Okaloosa county line for a distance of about 4 miles. At Bryant Bridge at the county line, the river turns to the southwest and is joined by Big Juniper Creek and Big Coldwater Creek, and then continues toward Milton. At Milton it turns southward and flows into Blackwater Bay.

The shape of the Blackwater River basin and the pattern of drainage are similar to those of the Escambia River basin, in that the main channel parallels the eastern and southern edge of the basin and all major tributaries enter from the north. The basin is well dissected by tortuous stream channels that wind their way through a thick forest of pine and juniper trees. Except during floods, the water is clear and flows in clean channels of sand and gravel.

The following discussion of streamflow is by tributary basins, proceeding upstream in the following order: Pond Creek, Big Coldwater Creek, Big Juniper Creek, and upper Blackwater River.

Pond Creek drains an area of 88 square miles, all within Santa Rosa County. The creek flows southward and empties into the Blackwater River just south of Milton. The basin has an elongated shape with relatively short tributaries that drain directly from the steep hills. The land along the basin divide is flat and is from 1 to 2 miles wide. From the flat divide, however, the land slopes steeply to the stream channel.

Pond Creek has two channels within the lower three-fourths of its flood plain. One of these is the natural channel which is very crooked while the other is a straight channel dug many years ago for transporting logs. The valley slope is steep (fig. 29) with a total fall of about 200 feet from the headwaters to the mouth, a distance of 24 miles.

The estimated unit runoff from Pond Creek is 1.4 cfs per square mile, which is equivalent to an average flow of 123 cfs from the basin. The minimum daily flow measured at the gaging station during a 4-year period ending 1961 was 43 cfs, or 0.7 cfs per square mile. About 75 percent of the total flow is derived from the ground as base flow and 25 percent is direct runoff by overland flow.

Big Coldwater Creek is the largest tributary feeding the Blackwater River. The total area drained by this tributary is 241 square miles, of which 228 square miles are in Santa Rosa County. All except the smallest streams in the Big Coldwater Creek basin have perennial flows. The average flow from the basin is estimated to be 542 cfs, of which 517 cfs come from the drainage area within Santa Rosa County.

The unit runoff of East Fork and West Fork, the two main tributaries of Big Coldwater Creek, is slightly lower than that of the main creek. The unit runoff from the upper 64 square miles of East Fork is 2.0 cfs per square mile; that from the upper 39.5 square miles of West Fork is 1.9 cfs per square mile; and that from the 237 square miles above State

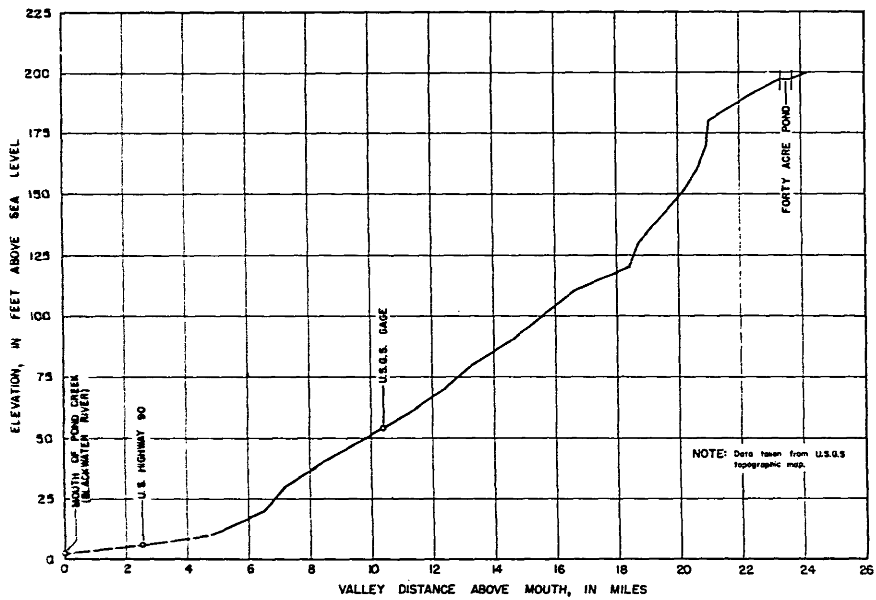

Figure 29. Channel-bottom profile of Pond Creek.

Highway 191, below the confluence of the two forks, is 2.2 cfs per square mile. The intervening drainage area of 133.5 square miles between the two gaging stations on the forks and the gaging station on State Highway 191 has a unit runoff of 2.5 cfs per square mile. About 60 percent of the flow of West Fork Coldwater Creek is base flow and 40 percent is direct runoff from overland flow.

Streamflow records have been collected for 23 years (1938-61) on Big Coldwater Creek. The gaging station near Milton is located on State Highway 191 and measures flow from 237 square miles. The flow-duration curve for Big Coldwater Creek in figure 16 shows some streamflow characteristics at this point. Because of the rolling topography and steep slope of the basin, flood waters drain rapidly. Ground-water seepage sustains the base flows at rather high rates during dry weather.

A useful arrangement of data is the group of low-flow frequency curves given in figure 30. They show what the lowest daily flow is likely to be and how often it is likely to occur. For example, the 1-day average flow of 200 cfs (129 mgd) for Big Coldwater Creek has an average recurrence interval of about 7 years.

The seasonal distribution of runoff in Big Coldwater Creek basin follows very closely the pattern of rainfall. The distribution of monthly flows is given in figure 31. Heavy spring rains cause high runoff, thus March and April have the highest average flows. High-intensity rainstorms in July and August cause high peak flows. October is the month of lowest flow.

Big Juniper Creek, which joins the Blackwater River 5 miles upstream from Big Coldwater Creek, drains 146 square miles, of which 134 square miles are in Florida. The streambeds in this basin are composed of loosely packed sand and gravel, and the banks are steep and heavily wooded.

The average flow from the Big Juniper Creek basin is estimated to be 260 cfs, or 1.8 cfs per square mile, of which about 240 cfs comes from the area within Florida. Flow was measured at the three sites within the basin: Big Juniper Creek at State Highway 4, near Munson; Sweetwater Creek at State Highway 4, near Munson; and Big Juniper Creek near Harold. Runoff characteristics are similar at these three sites. Slightly over one-half of the flow is base flow; the remaining is direct runoff from overland flow.

The Blackwater River drains 580 square miles in Santa Rosa County and 280 square miles in surrounding areas. The streams in this basin bring 390 cfs into the county from surrounding areas, pick up 1,100 cfs within the county, and discharge an average of 1,490 cfs into Blackwater Bay.

The main stem of Blackwater River brings in most of the flow from outside the county. The average flow at the Santa Rosa-Okaloosa county line near Holt is estimated to be 440 cfs. The flow-duration curve given in figure 16 is based on records collected at State Highway 4 near Baker in Okaloosa County. The drainage area above this point is 205 square miles. The daily flow has varied at this site from a low of 61 cfs to a high of 10,300 cfs. The average flow is 320 cfs. The flood of December

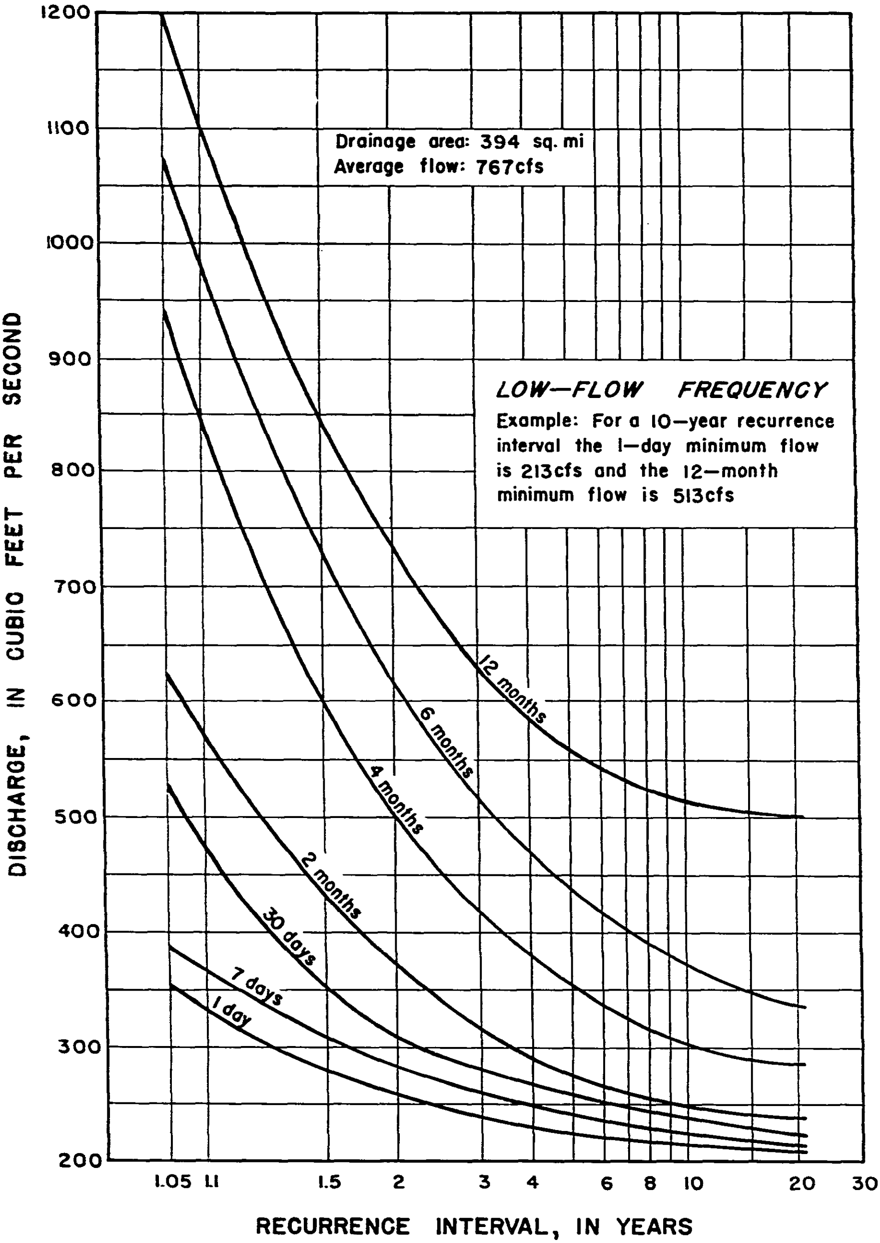

Figure 30. Low-flow frequency curves for Big Coldwater Creek near Milton, 1938-61.

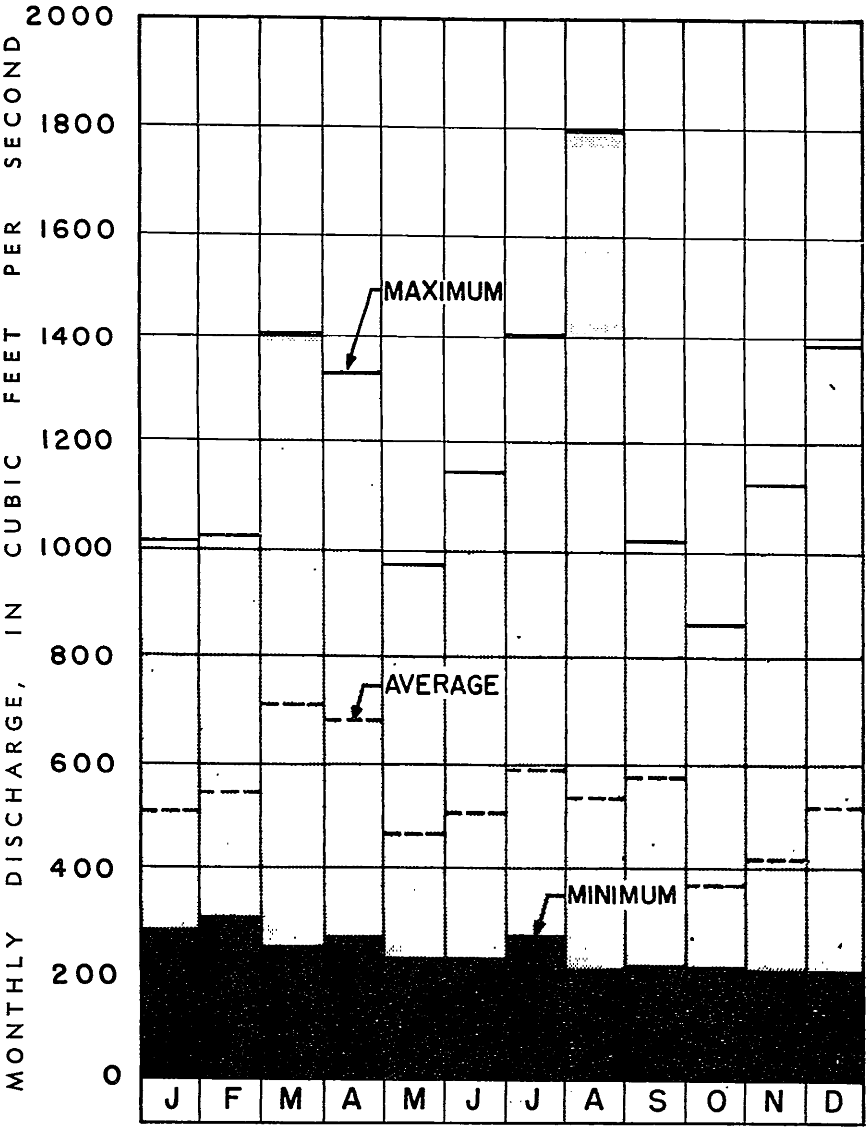

Figure 31. Graph of minimum, average, and maximum monthly discharge of Big Coldwater Creek near Milton, 1938-61.

4, 1953, reached a crest elevation of 81.3 feet above sea level at State Highway 4 and a peak flow of 17,200 cfs.

The lower 6 miles of the Blackwater River channel varies in depth from 10 feet to as much as 60 feet in holes. A depth-profile graph is given in figure 32. At least 6 holes in the lower river are 35 to 60 feet deep. These deep holes trap salt water moving in from the Gulf and could be a source of contamination of the surrounding ground water if large capacity wells are located nearby and pumped heavily enough to cause major drawdowns. The salt front during extreme high tides extends upstream about 6 miles from Blackwater Bay.

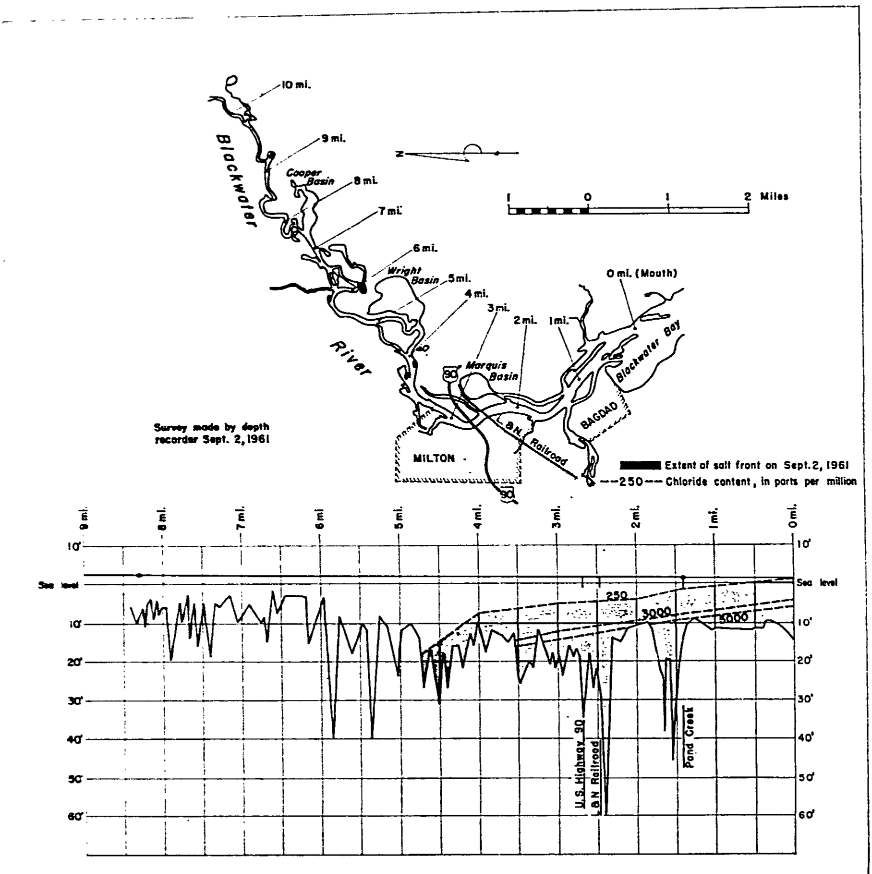

Figure 32. Channel bottom profile of lower Blackwater River.

MINERAL CONTENT

The surface waters of this basin are of exceptionally good quality, with a mineral content ranging from 11 to 33 ppm, and the water is slightly acid (pH 5.5 to 5.9). The low mineralization of this water can be attributed to its flowing through an area of practically insoluble sands and gravels.

On September 2, 1961, a chloride-profile run on the Blackwater River (fig. 32) showed that salt water extended about 5½ miles upstream. Apparently, the downstream flow of the river causes the salt water to be funneled in to Wright Basin, this being a course of least resistance. Unless there was a very high tide accompanied by a low flow, the salt water would probably not extend much farther upstream than Wright Basin.

YELLOW RIVER BASIN

OCCURRENCE OF WATER

Yellow River heads in southern Alabama, north of Andalusia and Opp. The river flows in a southerly direction, entering Okaloosa County north of Crestview. South of Crestview, it is joined by Shoal River, its largest tributary. The river then turns southwestward, enters Santa Rosa County, and flows southwestward into Blackwater Bay.

The Yellow River drains 1,365 square miles, of which only 115 are in Santa Rosa County. Although only a small percentage of the basin is in Santa Rosa County, the entire flow of the river is available to the county. The average flow entering Blackwater Bay from the Yellow River basin is about 2,500 cfs. This is the second largest flow in the two-county area; the flow of Escambia River is the largest. Tides from the Gulf of Mexico affect the flow in a large part of the 19-mile reach of channel in Santa Rosa County. The main channel winds through a heavily wooded, swampy flood plain about 2 miles wide. Several estuarine channels extend into the flood plain from Blackwater Bay. From the Okaloosa County line to the mouth, there are several cutoff channels that leave the main channel and re-enter farther downstream.

MINERAL CONTENT

The water of this basin is low in mineral content (23 to 32 ppm), but has color ranging from 10 to 30 units. This color, owing to the river flowing through a swampy area, makes the water objectionable for many uses. Other than the color, the water is of very good quality.

GROUND WATER

PRINCIPLES OF OCCURRENCE

Ground water is the subsurface water in the zone of saturation, the zone in which all pore spaces are filled with water under pressure greater than atmospheric. Potable ground water in Escambia and Santa Rosa counties is derived from precipitation. Part of the precipitation reaches the zone of saturation to become ground water. Ground water in Escambia and Santa Rosa counties moves laterally under the influence of gravity from places of recharge toward places of discharge, such as wells, springs, and surface-water bodies.

Ground water in Escambia and Santa Rosa counties occurs under both nonartesian and artesian conditions. Where it is not confined, its surface is free to rise and fall, and the water is under nonartesian conditions. The upper water surface is called the water table. Where the water is confined in a permeable bed that is overlain by a less permeable bed, so that its water surface is not free to rise and fall, it is under artesian conditions and the upper water surface in wells is called the artesian pressure surface. The term "artesian" is applied to ground water that is confined and under sufficient pressure to rise above the top of the permeable bed that contains it, though not necessarily to or above the land surface. The height to which water will rise in an artesian well is called the artesian pressure head.

An aquifer is a formation, group of formations, or part of a formation —in the zone of saturation—that is permeable enough to transmit usable quantities of water. Places where aquifers are replenished are called recharge areas, and places where water is lost from aquifers are called discharge areas.

HYDROLOGIC PROPERTIES OF THE AQUIFERS

Ground water in Escambia and Santa Rosa counties occurs in three major aquifers: a shallow aquifer which is both artesian and nonartesian (the sand-and-gravel aquifer), and two deep artesian aquifers (the upper and lower limestones of the Floridan aquifer). In the southern half of the area, the sand-and-gravel aquifer and the upper limestone of the Floridan aquifer are separated by a thick section of relatively impermeable clay; but in the northern half the sand-and-gravel aquifer and the upper limestone of the Floridan aquifer are in contact with one another. The upper limestone of the Floridan aquifer is separated from the lower limestone by a thick clay bed.

SAND-AND-GRAVEL AQUIFER

The sand-and-gravel aquifer is composed of sand but has numerous lenses and layers of clay and gravel. In the northeast corner of Santa Rosa County, the aquifer extends from the first saturated beds (near land surface) to a depth of about 350 feet. In the center of the area, however, it extends to a depth of about 1,000 feet. This aquifer lies at the surface throughout Escambia and Santa Rosa counties.

The shallow saturated permeable beds in the sand-and-gravel aquifer contain ground water under nonartesian conditions, and the deep permeable beds contain ground water under artesian pressure. The artesian water is confined by lenses of clay and sandy clay. Most of the water in the sand-and-gravel aquifer is under artesian pressure.

The gradient of the water table in the shallow beds of the sand-and-gravel aquifer generally indicates movement of ground water toward the nearby streams. The seepage of this ground water supplies more than half of the entire flow of the smaller streams in Escambia and Santa Rosa counties. The water table is the highest under the broad, relatively level lands that are at a higher elevation than surrounding lands. Examples of places where the water table is high include the lands between Jay and Milton, the lands between Pensacola and Cantonment, and the land east of Milton.

The artesian pressure head of water in the lower permeable beds of the sand-and-gravel aquifer does not conform to the topography of the land as much as the water table. The artesian pressure head of water from the lower beds indicates a general movement of water to the south. The head of water in the northern part of both counties is usually more than 100 feet above sea level and at some places is more than 150 feet above sea level. In the central part of the counties, the artesian pressure head is about 30 to 80 feet above sea level except near the larger rivers. Upward leakage of ground water probably occurs which lowers the pressure head of the ground water. The artesian pressure head of water under the lands adjacent to the bays is usually less than 20 feet above sea level and often less than 10 feet above sea level.

FLORIDAN AQUIFER

In Escambia and Santa Rosa counties, the Floridan aquifer is composed of two sections of limestone separated by a thick clay bed. In the northeast corner of Santa Rosa County, the upper surface of the Floridan aquifer is only about 350 feet below the land surface; whereas in the southwest corner of Escambia County the upper surface is more than

1,800 feet below the land surface, owing to the southwestward dip of the aquifer.

The Floridan aquifer is thickest, 1,300 feet, in north-central Santa Rosa County and thinnest, 800 feet, at the Perdido River near Perdido Bay. The thickness of the Bucatunna Clay Member has not been included in the above figures.

The water in the Floridan aquifer is under high artesian pressure. The artesian pressure head in wells drilled into the upper limestone of the Floridan aquifer in southeastern Santa Rosa County is about 50 to 70 feet above sea level (fig. 33). At low land-surface elevations, 50 to several hundred gallons per minute by natural flow are obtained from this aquifer; but the water is more mineralized than that from the sand-and-gravel aquifer. Because suitable water of low mineral content usually is available near the surface, little use is made of the water from the upper limestone in this area.

MOVEMENT OF WATER

Ground water in the sand-and-gravel aquifer moves from high to low elevations. Ground-water levels usually correlate with land-surface elevations. Thus, in the two counties, the general areas of ground-water recharge can be delineated on topographic maps. Recharge is greatest where the land is relatively flat. Water percolates downward to the water table and then moves laterally toward the places of discharge.

The lower permeable beds in the sand-and-gravel aquifer are recharged by percolation of water from upper permeable beds through and around beds of clay or sandy clay. The percolation results from differences in the hydrostatic heads within the permeable beds.

The sand-and-gravel aquifer is recharged by local rainfall, which infiltrates to the water table. The aquifer is discharged by pumping; evapotranspiration; and seepage into streams, swamps, bays, and the Gulf of Mexico.

Data at Gulf Breeze were used to calculate the amount of recharge received by the upper part of the sand-and-gravel aquifer for different periods of time. Gulf Breeze was selected because the surface material contains little clay, the water table is near the surface, and the direct overland runoff is slight. In addition, no lateral movement of fresh ground water to or from other areas is possible because Gulf Breeze is on a peninsula. Thus, recharge from rainfall at Gulf Breeze would be as great as anywhere in the area.

The highest percentage of recharge from rainfall, about 92 percent, occurred from a one-day rain on October 10, 1959. The 7.5-inch rainfall on this day (at Pensacola Beach) caused a rise in the water table of 2.54 feet by the next day, equivalent to 7.0 inches of water computed by using a coefficient of storage of 0.23. The loss by evapotranspiration in one day was estimated as 8 percent. Later that month on the 28th, a rain of 4.15 inches caused a rise in the water table of 0.92 foot. On the assumption that the coefficient of storage remains a uniform 0.23, this rise accounts for about 61 percent of the rain. These short-term recharge values were obtained by comparing the amount of ground water taken into storage if all the rain percolated to the water table to the amount of water actually taken into storage.

The average annual amount of recharge from rain may be computed by determining the amount of rain that falls on an area and computing the amount of seepage from that area. The average water level near the center of the peninsula at Gulf Breeze is 4.5 feet above sea level. This gives a hydraulic gradient of about 9 feet per mile toward Pensacola Bay and toward Santa Rosa Sound. Using this gradient and the rate of movement of water through the sand, the average ground-water seepage into either Pensacola Bay or Santa Rosa Sound would be about 305,000 gpd per mile length of the peninsula. The total seepage into Pensacola Bay and Santa Rosa Sound would be about 610,000 gpd per mile length of the peninsula. The average rainfall at Pensacola from 1950 through 1961 was 61.6 inches. The average rain falling on a one-mile length of the peninsula (which is about 0.95 square mile) was about 2,770,000 gpd. The average daily seepage of fresh ground water represents the annual amount of recharge from rainfall and is about 22 percent of the total rain or 13.6 inches of rain. The figures do not take into account the loss by pumpage of ground water and the loss by evapotranspiration after the water reaches the water table. The amount of water removed by these processes would increase the recharge to possibly 25 to 28 percent or about 15 to 17 inches of rain.

A graph of monthly rainfall at Pensacola and graphs of the water levels in an artesian well and in two nonartesian wells, drilled into the sand-and-gravel aquifer, are illustrated by figure 33. Wells 054-726-1 and 054-726-2 are at Oak Grove in northern Escambia County, and are about 6 feet apart. Well 055-726-1 is 0.6 mile north of these two wells. Relatively permeable and impermeable beds and changes in water levels caused by rainfall are shown in figure 33.

Well 054-726-1 was drilled to a depth of 206 feet and is screened from 201 to 206 feet in a permeable sand bed. Although the top of the bed is 190 feet below the surface, the water in the well rose to within 83 to 90 feet of the surface. The artesian pressure head ranged from 170 to 177 feet above sea level during the period of record. The artesian pressure head rose about 3 feet from May 1959 to July 1960, then declined about 2 feet until February 1961. High rainfall periods in 1961 and 1962 caused the head to rise more than 5 feet until April 1962. From April until

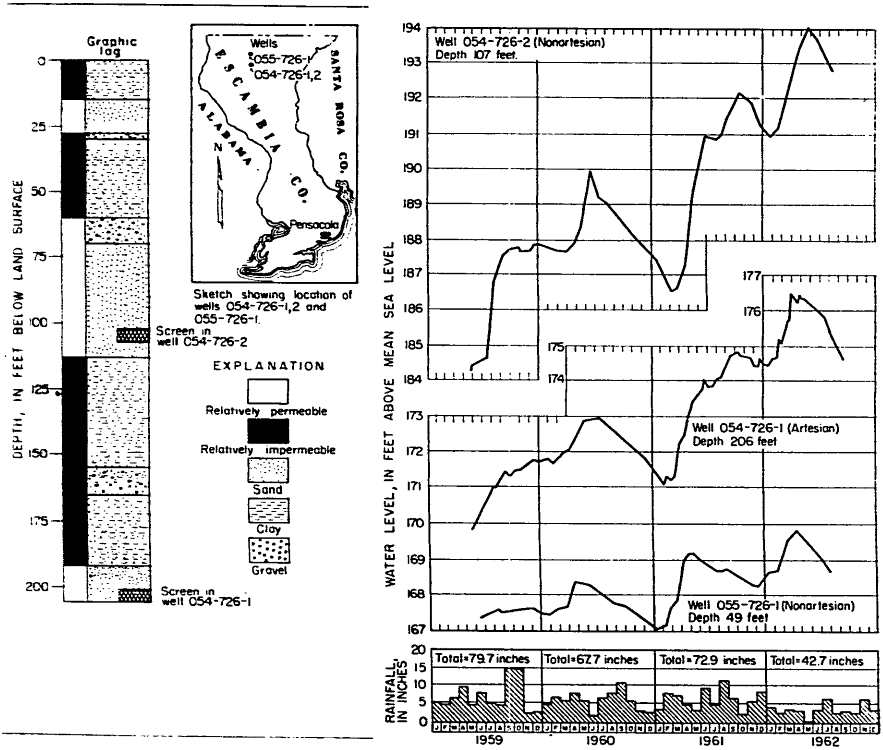

Figure 33. Water levels in an artesian well and two nonartesian wells drilled into the sand-and-gravel aquifer in northern Escambia County, and graph of monthly rainfall at Pensacola.

September 1962, the artesian pressure head declined about 2 feet because of below normal rainfall.

Well 054-726-2 was drilled to a depth of 107 feet and is screened from 102-107 feet in a permeable sand bed. The water in this bed is not under artesian pressure, and its upper surface is free to rise and fall. The water level ranged from 184 to 194 feet above sea level during the period of record. The water level rose several feet every spring or summer. Because the land around Oak Grove is cultivated, tilling the soil may increase the amount of recharge from rainfall.

Well 055-726-1 was drilled to a depth of 80 feet and screened from 44 to 49 feet in a permeable sand bed (fig. 34). This sand bed is believed to be a continuation of the bed tapped by well 054-726-2. The

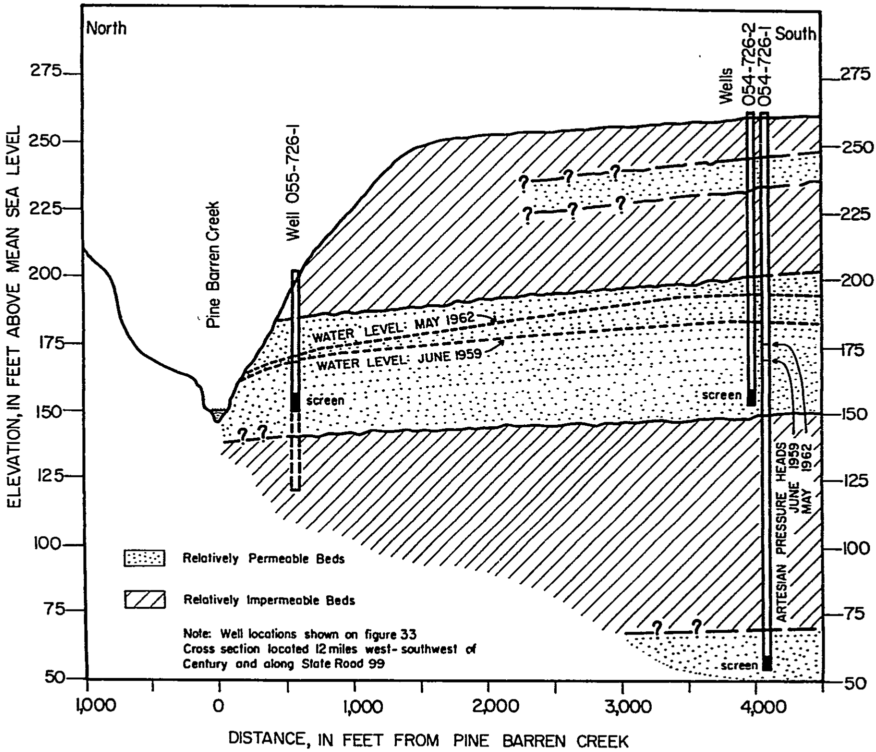

Figure 34. Cross section showing geology and hydrology in northern Escambia County.

water in this bed is not under artesian pressure. The water level ranged from 167 to 170 feet above sea level during the period of record. The water level fluctuation in well 055-726-1 was similar to the fluctuation in well 054-726-2, but much less. Well 054-726-2 is near the center of a recharge area at Oak Grove and the water level in this well changed about 10 feet. Well 055-726-1 is about 600 feet south of a discharge area, Pine Barren Creek, and the water level in this well changed only about 3 feet. Water-level changes are usually much greater near areas of recharge than those near areas of discharge.

Figure 34 shows some geologic and hydrologic conditions in the Oak Grove area. The beds of clay and sandy clay have been classed as relatively impermeable beds. The beds of sand, sand and gravel, and gravel have been classed as relatively permeable beds. In the vicinity of wells 054-726-1 and 2, ground water is recharged from local rainfall. Most of this recharge moves northward and seeps into Pine Barren Creek. Some of the recharge percolates downward to the lower permeable zone. Ground water in this lower permeable zone may also seep into Pine Barren Creek or move southward and discharge into other streams.

The water level in well 054-726-2 is generally from 14 to 18 feet higher than the level in well 054-726-1. Thus, water in the upper permeable sands has the head potential to recharge the lower permeable sands. The water level in the upper sands shows more response to high rainfall than that in the lower sands.

The Floridan aquifer is recharged by rain in areas where the limestones outcrop in Conecuh, Escambia, and Monroe counties, Alabama, 10 to 35 miles north of the area. The upper limestone of the Floridan aquifer probably is recharged also by percolation from the sand-and-gravel aquifer in the northern half of the area. The aquifer is discharged by seepage into the Gulf, upward and downward leakage, and pumping.

GROUND-WATER VELOCITIES

The rate of ground-water flow depends upon the slope of the water surface, the permeability of the aquifer, and the temperature of the water. A knowledge of the rate of ground-water flow is useful to determine how fast and how far contaminated ground water will move, to predict future areas of salt-water encroachment, and to evaluate the effectiveness of clay beds as aquicludes.

Using the earliest water-level data available, Jacob and Cooper (1940, p. 50-51) computed the average ground-water velocity in the sands near Pensacola Bay to be 0.37 foot per day, or 135 feet per year. The figure given represents the velocity under natural, undisturbed conditions. In the vicinity of discharging wells, the velocities would, of course, be higher.

The average velocity of ground water moving through an aquifer may be computed by the following formula:

$$V = \frac{Tg}{7.48\ mp}$$

Where: V is the velocity in feet per day; T is the coefficient of transmissibility in gpd (gallons per day) per foot; g is the gradient of the water table in feet per mile; m is the thickness of the aquifer in feet; and p is the porosity of the aquifer in percent.

Data from Gulf Breeze was used to compute the highest, average, and lowest velocities of the water in the upper part of the sand-and-gravel aquifer. In 1959, the water level at Gulf Breeze was 9.8 feet above sea level, the highest level during the last 13 years. This level would give an average gradient of 23 feet per mile (or 0.0044) toward Pensacola Bay. The coefficient of transmissibility averages about 34,000 gpd per foot and the aquifer is 80 feet thick. The porosity is assumed to be about 30 percent. These figures give the highest velocity of ground water in Gulf Breeze from the center of the peninsula toward Pensacola Bay of:

$$V = \frac{(34{,}000)\ (0.0044)}{(7.48)(80)(0.30)} = 0.83 \text{ foot per day,}$$

or about 300 feet per year.

An inspection of the hydrograph at Gulf Breeze (fig. 38) gives an average water level of 4.5 feet above sea level. Using this level, the average velocity of ground water is computed to be 0.38 foot per day or about 140 feet per year. The lowest water level, 2.8 feet above sea level (except when the water level was lowered by nearby pumping), occurred in 1951. Using these data, the lowest velocity of ground water is computed to be 0.24 foot per day or about 90 feet per year.

AREAS OF ARTESIAN FLOW

Water will flow from artesian wells when the artesian pressure head is higher than the land surface. The water from rainfall percolates into the ground in the higher, relatively level land and moves downward and laterally toward places of discharge. Some of this water is confined by impermeable beds below which the water is under artesian pressure.

The areas of flow of water from the sand-and-gravel aquifer in the two counties are usually low lands along streams. One area of artesian flow is at Molino, near the Escambia River, where the artesian pressure head is more than 20 feet above the land surface in places. At Pine Barren, the artesian pressure head is as much as 30 feet above the land surface.

Water from the upper limestone of the Floridan aquifer is under sufficient artesian pressure to rise to more than 50 feet above sea level in the southeastern part of the area. Thus, the areas of flow from wells that tap the Floridan aquifer are generally at elevations less than 50 feet above sea level. Examples of areas of artesian flow of water from the Floridan aquifer are at Gulf Breeze Peninsula, Holley, Navarre, Navarre

Beach, Pensacola Beach, and the western two-thirds of Santa Rosa Island.

The artesian pressure head of water from the Floridan aquifer ranges from about 140 feet above sea level in northern Santa Rosa County (well 059-658-1) to about 55 feet above sea level in southern Santa Rosa County (well 022-652-1). Therefore, the artesian pressure head in the Floridan aquifer would be greater than the water table in the sand-and-gravel aquifer at most of the low to moderate land elevations in the two counties. The water in the Floridan aquifer would have a potential upward flow. The water level in the sand-and-gravel aquifer would stand above the artesian pressure head of the Floridan aquifer in the higher land elevations of the area and would have a potential downward flow.

FLUCTUATION OF THE WATER LEVEL

Water-level records show that the water surface is not stationary but fluctuates almost continuously. Water-level fluctuations result from variations in recharge and discharge. Discharge is from evaporation and transpiration, seepage, and pumping. Recharge is from rainfall and seepage from other aquifers. Long-term periodic measurements of water levels are used to determine significant changes in the water in storage, to correlate water levels and rainfall, and to show the influence of pumping on the water level. Long-term records are needed to distinguish between short-term fluctuations and progressive trends.

Over most of the area, changes in the water level correlate in general with rainfall. In the heavily pumped areas, water levels reflect both the influence of the pumping and the rainfall.

Figure 35 compares changes in the artesian pressure head in a well drilled into the Floridan aquifer with changes of the water level in a well drilled into the sand-and-gravel aquifer. Well 037-645-1 is at Auxiliary Field 6, located 18 miles east of Milton, in Okaloosa County. This well is 690 feet deep and obtains water from the upper limestone of the Floridan aquifer from 527 to 690 feet below land surface. Well 032-648-1, 15 miles southeast of Milton, is 197 feet deep and obtains water from the sand-and gravel aquifer from about 140 to 197 feet below land surface.

Well 037-645-1 is a representative well for this area. It taps the upper limestone of the Floridan aquifer and has a long-term record. The hydrograph is included to show the relation between artesian pressure changes and the use of water, to illustrate the fluctuations in artesian pressure in the upper limestone of the Floridan aquifer, and to compare these fluctuations with those in the sand-and-gravel aquifer.

The hydrograph for the shallow well shows the water-level changes during the last 15 years in an area where there is not much withdrawal of ground water. When compared to rainfall records, the graph shows a general correlation with rainfall and reflects a very wet period from 1944-49, a relatively dry period from 1950-55, a wet period from

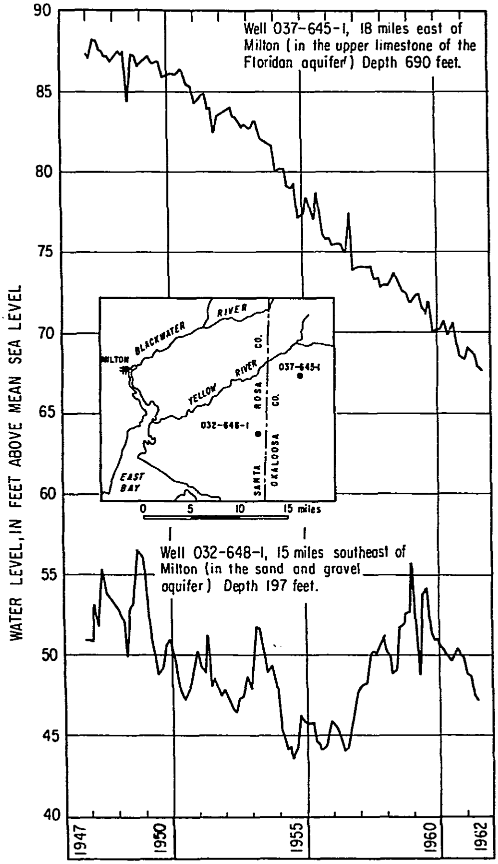

Figure 35. Hydrographs of wells 037-645-1 and 032-648-1.

1956-61, and another dry year in 1962. The effect of 90.41 inches of rainfall in 1953, the highest recorded in 83 years at Pensacola, is shown by the rise in water levels during 1953 and the first part of 1954. However, this trend in the water level was reversed by the effect of the lowest rainfall on record, 28.68 inches, in 1954. Declining water levels during 1954 and the first half of 1955 reflect this low rainfall. The maximum change observed during the period of record was 13 feet. The water level was highest, 56 feet above sea level, in 1949, and lowest, 43 feet above sea level in 1955.

The hydrograph for well 037-645-1, which penetrates the upper limestone of the Floridan aquifer, shows very different fluctuations. The hydrograph shows a progressive decline in the artesian pressure head of 21 feet during the period of record. Artesian pressure was highest, 88 feet above sea level, in 1948 and lowest, 67 feet above sea level, in 1962. The artesian pressure head stood above the water level in the sand-and-gravel aquifer during the entire period of record.

The hydrograph for well 037-645-1 shows the decline of the artesian pressure head that has occurred in the upper limestone of the Floridan aquifer, in the Fort Walton Beach area. Barraclough and Marsh (1962) found this decline to be greatest at Fort Walton Beach, about 17 miles to the southeast, where one well had a decline of about 56 feet between 1948 and 1960, and a net decline of 125 feet between 1936 and 1962. The amount of decline increases toward Fort Walton Beach and results from use of water by Fort Walton Beach, Eglin Air Force Base, and others. In addition, the decline relates to thinning of the upper limestone northward from about 400 to about 40 to 60 feet thick. This thinning has a restricting effect on the amount of water moving through the aquifer. Barraclough and Marsh (1962) noted the large amount of clay in the aquifer, both in beds and clay-filled voids, and suggested that the clay within the aquifer reduces both the permeability and effective porosity of the aquifer, resulting in the large drawdowns.

The artesian pressure head in well 037-645-1 has declined at an average rate of 1.4 feet per year. Wells that tap the upper limestone of the Floridan aquifer in southeastern Santa Rosa County around Navarre probably have had a similar rate of decline which may continue. Farther away from the Fort Walton Beach, the artesian pressure heads have declined at a slower rate.

Figure 36 contrasts changes of the water level in an area affected slightly by pumping, as shown by well 031-716-1 at Ensley, with changes of the water level in areas of heavy pumping, as shown by well 036-719-1 at Cantonment and well 036-716-1, 3 miles east of Cantonment. All three wells are in the sand-and-gravel aquifer. From 1940 to 1962, the water level at Ensley varied a maximum of 26 feet; the water-level high of 75 feet above sea level was recorded in 1948, and the water-level low of 49 feet was recorded in 1956. Well 031-716-1 is 239 feet deep. The rise and fall of the water table in this area, as shown by the graph, closely follows variations in rainfall. In general, whenever the annual rainfall

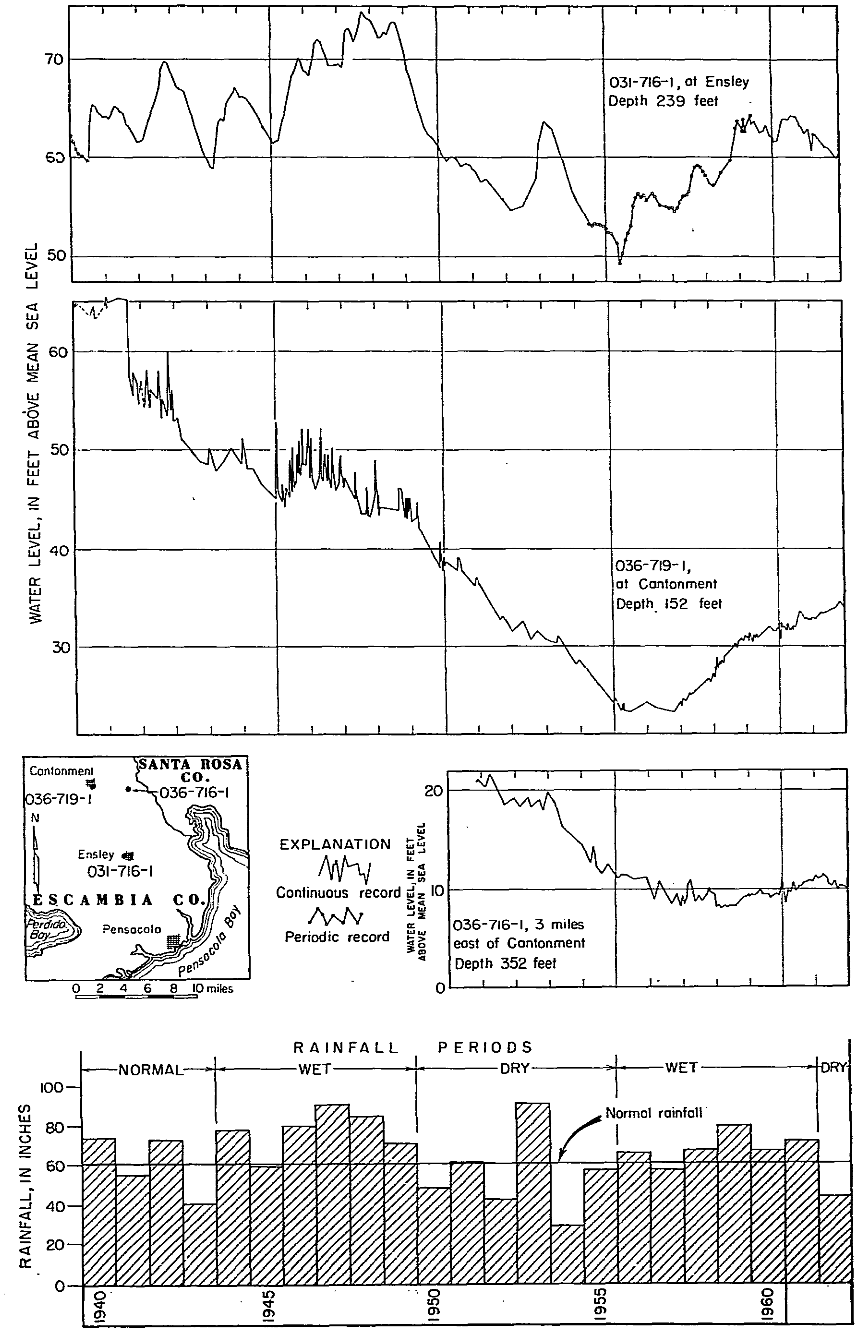

Figure 36. Hydrographs of wells 031-716-1, 036-719-1, and 036-716-1 and graph of yearly rainfall at Pensacola.

was less than 60 inches, the water level declined; and whenever the annual rainfall exceeded 60 inches, the water level rose.

The water level in well 031-716-1 was about 10 feet lower in 1959-60 than in 1948-49 (fig. 36). The graph of well 032-648-1 (fig. 35) shows a high water level in 1948-49 and a similar high water level in 1959-60. Industrial pumping at St. Regis, 7 miles north-northeast of well 031-716-1 is believed to be the principal factor limiting the rise of the water level in 1959-60.

Figure 36 shows the water level in well 036-719-1 (152 feet deep) at Cantonment. This hydrograph shows the decline usually associated with continued, concentrated pumping in an area. During 23 years of record, the water level fluctuated 42 feet. The highest water level was 65 feet above sea level in 1941 and the lowest was 23 feet above sea level in 1957. The slight rise and then gentle decline of water levels for 1946-49 shows the effect of abnormally high rainfall.

The sharp decline of the water level in well 036-719-1 stopped in 1956. Late in 1958 the water level started to recover. This recovery was the result of the following: (1) several nearby wells were taken out of service; (2) rainfall was above normal in 1956 and 1958-61; (3) a recharge experiment was conducted by St. Regis Paper Company; and (4) the use of cooling towers that began in 1961 lowered the pumping rate. During this recharge experiment cooling water was pumped into a nearby well at a rate of a million gallons per day for a year. The recharge well is located 2,170 feet from well 036-719-1 and the calculated time-distance-recovery curves indicate that this amount of recharge would cause the nonpumping water level in well 036-719-1 to rise from 1 to 2 feet.

The hydrograph of well 036-716-1, about 3 miles east of Cantonment and about 1 mile west-northwest of the Chemstrand Corporation plant, is shown in figure 34. This well is 352 feet deep and is screened from 260 to 270 feet and from 340 to 350 feet below the land surface. The water level is affected by pumping at two nearby industrial plants, the St. Regis Paper Company and the Chemstrand Corporation. The graph shows a maximum change of 16 feet during the 11 years of record, with the highest water level being 24 feet above sea level in 1951 and the lowest water level being 8 feet above sea level in 1959. The water level declined rapidly from 1951 to 1957 owing to pumping and below-normal rainfall. The water level was nearly stable during 1958 and recovered about 3 feet from 1959 to 1962 owing to above-normal rainfall, infiltration of water from the Escambia River into the well field of the Chemstrand Corporation, and reduced pumpage at St. Regis and Chemstrand.

Figure 37 shows the water levels southwest of Pensacola, as recorded in three wells. Two of the wells, 024-715-1 and 024-715-2, are near the Newport Industries plant at Pensacola. Well 023-716-2 is in Warrington, about 2 miles southwest of the plant. Well 024-715-1 is 142 feet deep and is at Pensacola, 450 feet from Bayou Chico. The range of water-level fluctuations in this well was 18.6 feet during the 23 years of record. The water level was highest, 7.8 feet above sea level, in 1949 and lowest, 10.8 feet below sea level, in 1955. The water level in well 024-715-1 is

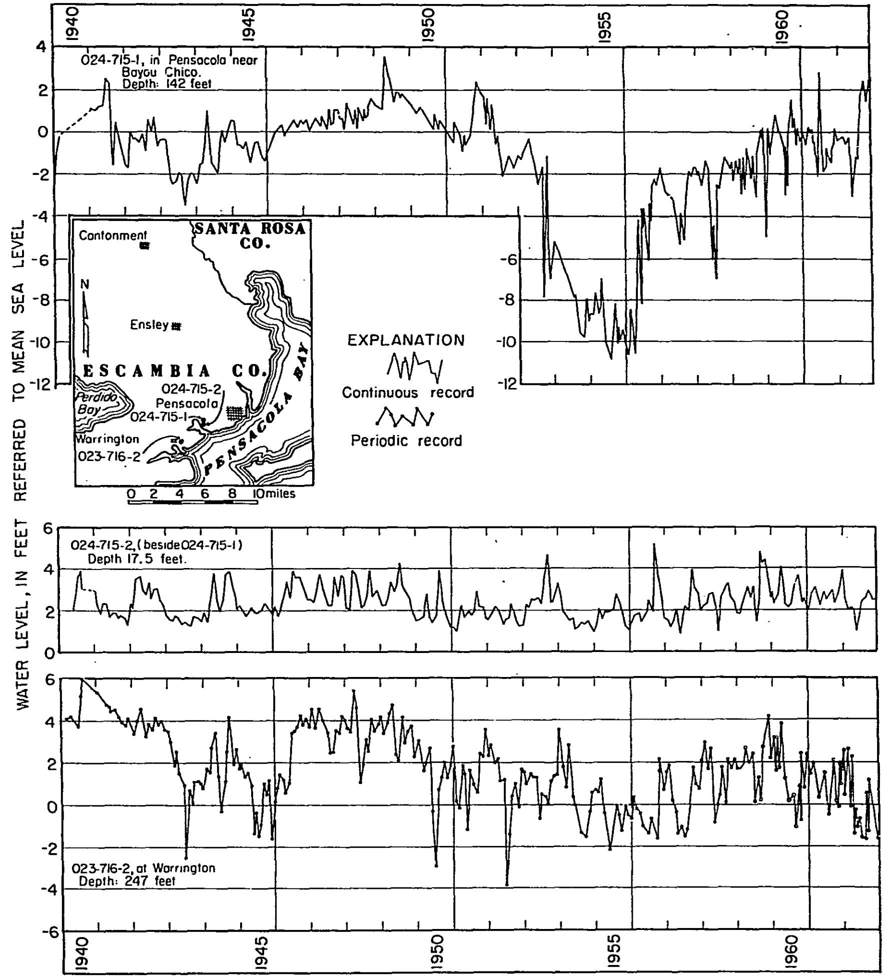

Figure 37. Hydrographs of wells 024-715-1, 024-715-2, and 023-716-2.

influenced by heavy pumping at Newport Industries and by changes in rainfall. The water level was lowered by pumping before water-level measurements were started in 1940.

Ground-water pumping at Newport Industries started in 1918 at an average rate of 2 mgd and increased to an average rate of 9 mgd in 1939. Cooling towers were installed in 1941, 1948, 1954, and 1962. Re-use of some of the water reduced the average pumping rate to 3.6 mgd in 1962.

The hydrograph of well 024-715-1 shows that the water level has been lowered by heavy pumping by Newport Industries and has been below sea level most of the time since the summer of 1952. As salt water in Bayou Chico is only 450 feet from the well, the lowered fresh-water levels could cause salty water from the bayou to percolate into the aquifer in this area and destroy its usefulness.

Well 024-715-2, which was drilled beside well 024-715-1, is 17.5 feet deep. The water level in well 024-715-2 had a range of only 4.4 feet during the 23-year period of record. The water level rose to 5.2 feet above sea level in 1956 and declined to 0.8 feet above sea level in 1951, 1955, 1957, 1958, and 1962.

The water level in shallow well 024-715-2 has been above the water level in deep well 024-715-1 for most of the 23 years of record. The greater head of water in the upper permeable beds permits some recharge to the lower permeable beds. However, some of the water from the shallow zone moves laterally into Bayou Chico.

The hydrograph of well 023-716-2 (247 feet deep) at Warrington shows that the highest water level was 6 feet above sea level in 1940, and the lowest was 4 feet below sea level in 1952. The graph shows a slight decline of the water level during the 23-year period, 1940-62, owing to increased use of ground water in the Warrington area. During the summers of 1943-45, 1950-58, and 1960-62, 15 of the 23 years of record, the water level declined below sea level. The lowering of the water during the summer is brought about by an increase in the use of ground water.

The water level in well 021-709-8, half a mile east of the Gulf Breeze post office, is shown in figure 38. This well was drilled to a depth of 41 feet and the lower 10 feet of the well was screened. During the 13-year period of record, the water level fluctuated 8.6 feet. The highest water level was 9.8 feet above sea level in 1959, and the lowest was 1.2 feet above sea level in 1955.

Fresh ground water on Gulf Breeze Peninsula is derived entirely from local rainfall. Some of the rain water percolates quickly through the

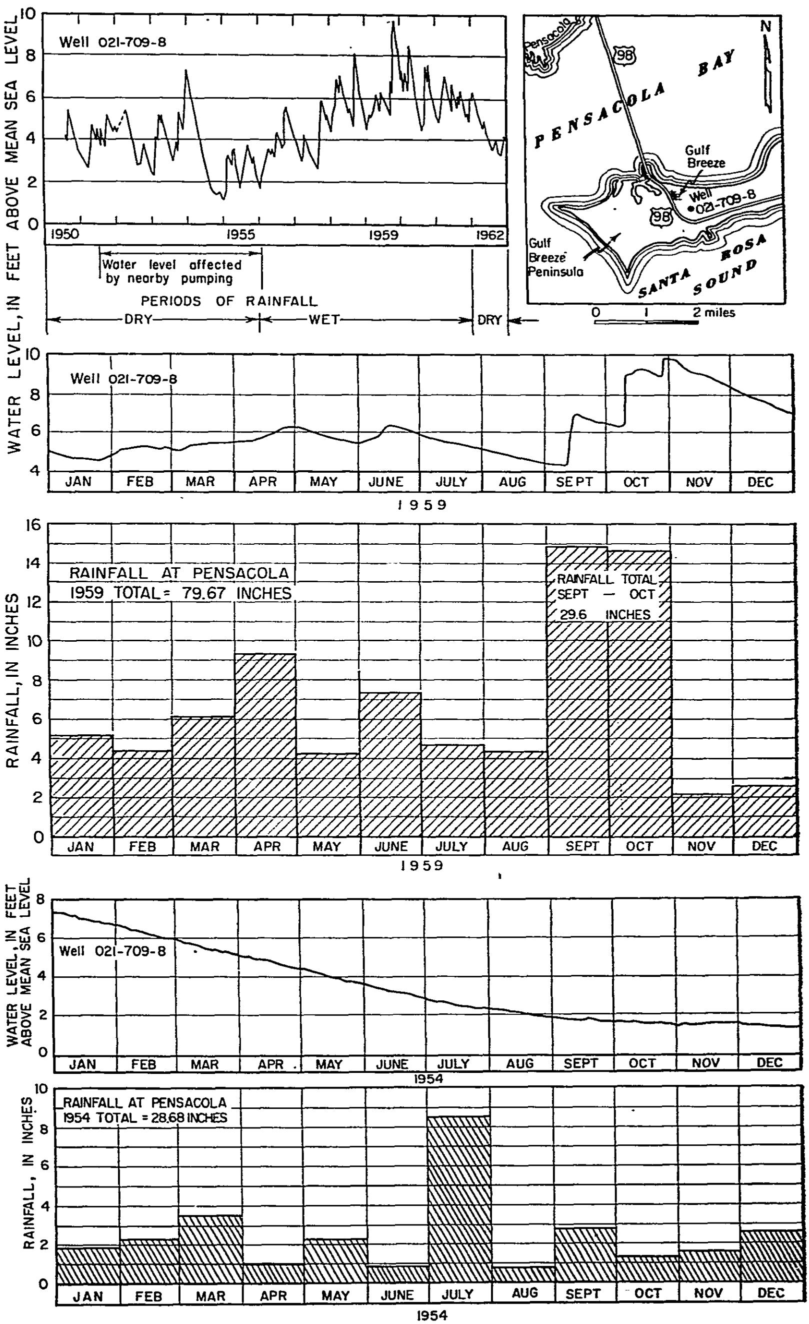

Figure 38. Hydrograph of well 021-709-8 and graph of the rainfall at Pensacola.

few feet of sand to the water table. Ground water then moves laterally and discharges into Pensacola Bay or Santa Rosa Sound. The water in the upper part of the sand-and-gravel aquifer is under nonartesian conditions, and the water level rises rapidly after intense rainfall and declines slowly during prolonged periods without rain. The hydrograph of well 021-709-8 shows the response of the water level to rainfall. Pumping from nearby wells also had an influence on the water level in this well. Wells owned by the Santa Rosa Island Authority were pumped at rates of about 60,000 gpd during the winter and about 120,000 gpd during the summer from 1951 to 1956. After 1956, when the pumping from these wells ceased and rainfall was above average, the water level rose gradually to a record high in 1959. From the high water level in late 1959 to mid 1962, the water level declined about 6 feet.

The hydrograph of water levels in well 021-709-8 and the monthly rainfall at Pensacola for 1959 shows the rapid rise of the water level that resulted from intense rainfall. The water level changed only slightly until heavy rains in September caused a rise of 2.5 feet. Additional heavy rains in October caused rises totaling about 4 feet. A total of almost 30 inches of rain fell in Pensacola in September and October 1959. These rises brought the water table near or above the land surface in some areas around Gulf Breeze, causing some damage and considerable inconvenience.

The 1954 hydrograph in figure 38 illustrates a decline of the water level during a year of low rainfall. In 1954, Pensacola had the lowest rainfall of record, 28.68 inches. The water level at Gulf Breeze declined 6.2 feet during this year. The water level declined 5.7 feet from January to September and remained less than 2 feet above sea level until the end of the year. The ground-water table received very little recharge from rainfall in 1954. Most of the rain was lost through evapotranspiraion.

TEMPERATURE OF GROUND WATER

The temperature of the earth's crust increases with depth at the rate of about 1°F. for each 50 to 100 feet. The temperature of ground water generally increases with depth at approximately the same rate.

Ground-water temperatures in Escambia and Santa Rosa counties from the sand-and-gravel aquifer 50 to 250 feet deep usually range from 66° to 73°F. These temperatures reflect the average annual air temperature (68°) at Pensacola and the geothermal gradient.

The temperature of water from the upper limestone of the Floridan aquifer in southern Escambia and Santa Rosa counties ranges from 84° to 92°F. The wells that tap this aquifer are from 900 to 1,500 feet deep.

The temperature of ground water in this area usually increases about 1°F. for each 52 to 85 feet of depth. For example, the geothermal gradient 9 miles southwest of Pensacola, as shown by measurements made in an oil test hole, is about 1°F. for each 81 feet of depth down to 12,500 feet. The temperature at the bottom of the hole was 222°F.

SPECIFIC CAPACITY

The specific capacity is used to indicate the amount of water, in gallons per minute, that can be obtained from a well for each foot of drawdown of water level in the well. The specific capacity is obtained by dividing the yield of the well in gallons per minute by the difference of the static water level and the pumping water level in feet. Factors that affect the yield of wells include: (1) the diameter of the well; (2) depth of aquifer penetrated; (3) transmissibility of the aquifer; (4) efficiency of the pump; (5) amount of well development; (6) amount and size of well screen (if any); and (7) the friction loss within the well.

An example of the specific capacity of wells drilled into the sand-and-gravel aquifer can be shown by data from 8 wells at the Chemstrand Corporation nylon plant. The wells are constructed similarly with 24-inch casing at the surface, 16-inch casing in the middle, and 12-inch screen at the bottom. The amount of well screen is usually 110 feet and the wells are pumped at 1,500 gpm for 24 hours. The specific capacity ranged from 39.5 to 76.8 gpm per foot of drawdown and the average specific capacity was 53 gpm per foot of drawdown.

Little information is known about the specific capacity of wells from the Floridan aquifer in the area of study. However, large-capacity wells, 10 to 16 inches in diameter, drilled into the Floridan aquifer in southern Okaloosa and Walton counties had a specific capacity ranging from 10 to 100 gpm per foot of drawdown. The average specific capacity was 38 gpm per foot of drawdown. Similar values could be expected from wells drilled into the Floridan aquifer in Escambia and Santa Rosa counties.

QUANTITATIVE STUDIES

The withdrawal of water from an aquifer creates a depression in the water table or artesian pressure surface around the point of withdrawal. This depression generally has the form of a cone with its apex down and is referred to as the cone of depression. The amount by which the water surface is lowered at any point within this cone is known as the drawdown. The size, shape, and rate of growth of the cone of depression depend on several factors: (1) the rate of pumping; (2) the duration of pumping; (3) the water-transmitting and storage capacities of the aquifer; (4) the increase in recharge resulting from the lowering of the water surface; (5) the decrease in natural discharge from the aquifer due to the lowering of that surface; and (6) the hydrologic boundaries of the aquifer.

A measure of the capacity of an aquifer to transmit water is the coefficient of transmissibility. This is the quantity of water in gpd (gallons per day), that will move through a vertical section of the aquifer 1 foot wide and extending the full saturated height of the aquifer, under a unit hydraulic gradient, at the prevailing temperature of the water.

The coefficient of storage is a measure of the capacity of an aquifer to store water. It is defined as the volume of water released from or taken into storage per unit surface area of the aquifer per unit change in the component of head normal to that surface.

The amount of water that may be stored in a rock or soil is limited by the porosity of the material. The amount of water that a saturated rock will yield when allowed to drain is somewhat less than the porosity because some of the stored water will be held by capillarity.

The amount of water stored by an aquifer also depends on whether the aquifer is artesian or nonartesian, for all aquifers serve as both conduits and reservoirs. An artesian aquifer functions primarily as a conduit, transmitting water from places of recharge to places of discharge; however, it is capable of storing water by expansion, or releasing water by compression. An artesian aquifer also stores water in the unconfined portion of the aquifer. A nonartesian aquifer functions primarily as a reservoir and can store a much larger quantity of water for a given rise in the water level than can be stored in an artesian aquifer.

The coefficient of transmissibility and coefficient of storage are generally determined by means of an aquifer test on wells. Although only a few aquifer tests have been made during the current investigation, many detailed tests have been made in parts of the area. The coefficients determined by these tests are still applicable to the test areas and may be used for hydrologically similar areas.

In the spring of 1940, Jacob and Cooper (1940, p. 33-49) made several aquifer tests on wells owned by the City of Pensacola, the U.S. Navy (at Corry Field), and Newport Industries. These wells were drilled about 240 feet into the sand-and-gravel aquifer, and the lower half was screened. The average coefficient of transmissibility, T, for 120 feet of aquifer, as determined by the tests is 75,000 gpd per foot. The coefficient ranged from 58,800 to 94,000 gpd per foot. This coefficient may be used to calculate the effects of pumping on the water level near Pensacola. The average coefficient of storage is 0.00055. This relatively low average coefficient of storage indicates that an effective confining layer overlies the sands from which the water is withdrawn. However, this confining layer does not extend over a large area.

The aquifer tests show that artesian conditions existed during the few days of the tests and perhaps artesian conditions would exist for as long as a few weeks after continuous pumping started. Later, local recharge by leakage from other parts of the sand-and-gravel aquifer would probably occur at the edges of and through the confining layers. This local recharge would lessen the drawdown. Because of the effect of this recharge, it has been found by trial and error that reasonably accurate drawdowns can be predicted using a storage coefficient of 0.15 in this area. This coefficient of storage would give more reasonable time-distance-drawdown figures than those calculated by using the average coefficient obtained from the relatively short pumping tests. Jacob and Cooper (1940, p. 48) calculated the "apparent coefficient of storage" to be 0.32 in the upper sands in the Pensacola area. This calculated coefficient of storage takes into consideration the effects of local recharge.

In the fall of 1950, Heath and Clark (1951, p. 31-34) made an aquifer test on the Gulf Breeze Peninsula in Santa Rosa County. The test area was about half a mile east of the Gulf Breeze post office. The wells penetrated the upper part of the sand-and-gravel aquifer and the coefficients that were determined apply to the upper 75 feet of the aquifer. This part of the aquifer was found to have a coefficient of transmissibility of 34,000 gpd per foot and a coefficient of storage of 0.23. This relatively high storage coefficient indicates nonartesian conditions. Several curves relating pumping rates and well spacing to the resultant drawdowns are given in the report.

Several aquifer tests have been made during 1951-55 on some of the Chemstrand Corporation's wells, about 13 miles north of Pensacola. Each supply well is equipped with 110 feet of well screen, usually made up in two sections. The screens are set in the most permeable zones in the sand-and-gravel aquifer, between 170 and 380 feet below the sand surface. The average value of the coefficients of transmissibility and storage determined from these tests were about 150,000 gpd per foot and about 0.001, respectively.

The coefficients of transmissibility and storage may differ considerably from place to place; therefore, drawdowns at one place cannot be predicted on the basis of data collected elsewhere. Figure 39 illustrates how water levels are affected in the vicinity of a pumped well near the Chemstrand plant. This figure shows theoretical drawdowns in the vicinity of a well pumped at the rate of 700 gpm (about 1 mgd) from an aquifer having a transmissibility coefficient of 150,000 gpd per foot and a storage coefficient of 0.15. As the drawdowns outside the pumped well vary directly with discharge, drawdowns for greater or

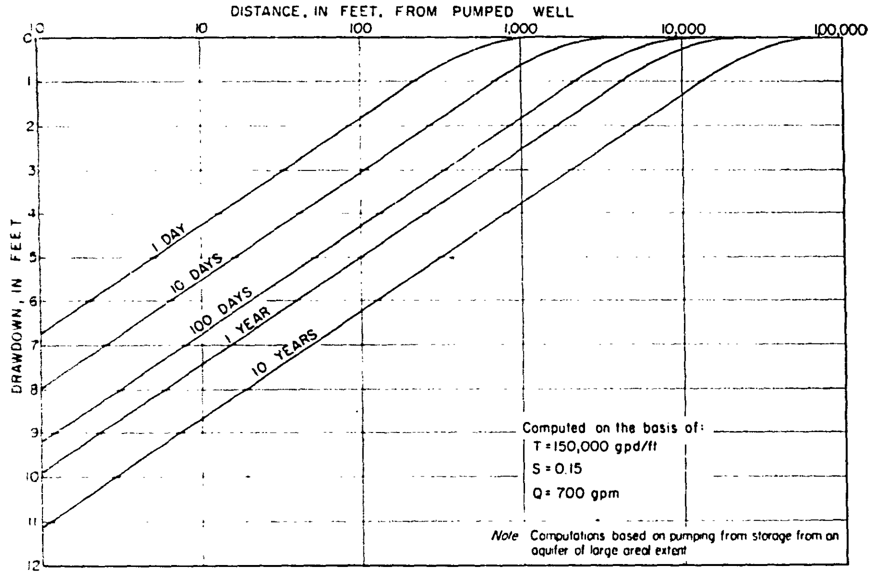

Figure 39. Graph showing theoretical drawdowns in the vicinity of a well.

lesser rates of discharge may be computed from these curves. For example, as shown in figure 39, under the assumed conditions, the drawdown 100 feet from a well discharging at 700 gpm would be 4.3 feet after 100 days of pumping. If the well had discharged 2,100 gpm for the same length of time, the drawdown at the same distance would have been three times as much, or 12.9 feet.

MINERAL CONTENT

THE SAND-AND-GRAVEL AQUIFER

The sand-and-gravel aquifer is the major source of ground water used in Escambia and Santa Rosa counties. Differences in the composition of the aquifer affect the chemical quality of the water. In some areas clay lenses likely cause ionic exchange, resulting in water of altered mineral content, and the solution of fossil shells in some formations probably contribute to the mineralization. The general area of recharge is outlined in figure 40 by the low sums of the mineral constituents in parts per million. The low mineral content in the recharge area may be due to the short time of contact between the water and the sand, gravel, and clay. As the water moves into the aquifer and down and away from the recharge area, this mineralization increases. Inset "A" in figure 40 shows

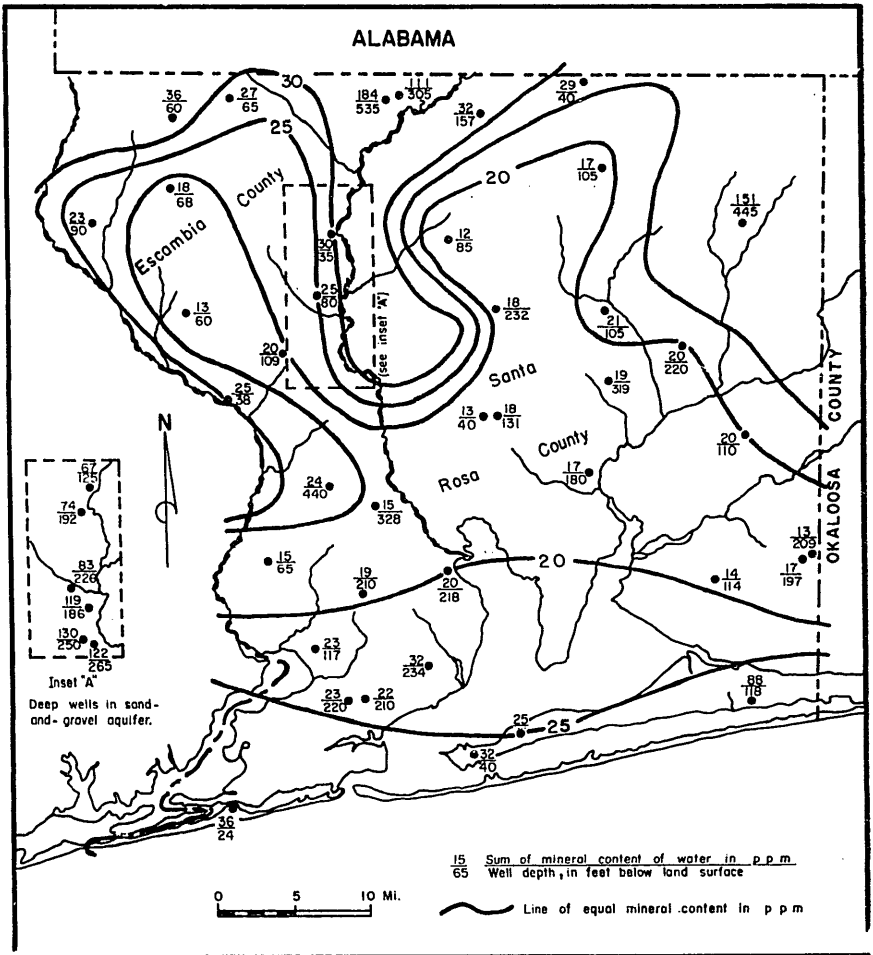

Figure 40. Map of Escambia and Santa Rosa counties showing mineral content of water from the sand-and-gravel aquifer.

mineral content of water from deep wells in the sand-and-gravel aquifer.

Except for a few areas, the sum of mineral constituents in the water of this aquifer is very low (12-36 ppm) throughout the two counties. Figure 41 shows the type of ground water based on the major constituents in solution, regardless of total concentration. All elements are divided roughly into two groups, metal and non-metals. In solution the metals calcium, magnesium, sodium, and potassium are positively charged (cations) and the non-metals carbonate, sulfate, chloride, fluo-

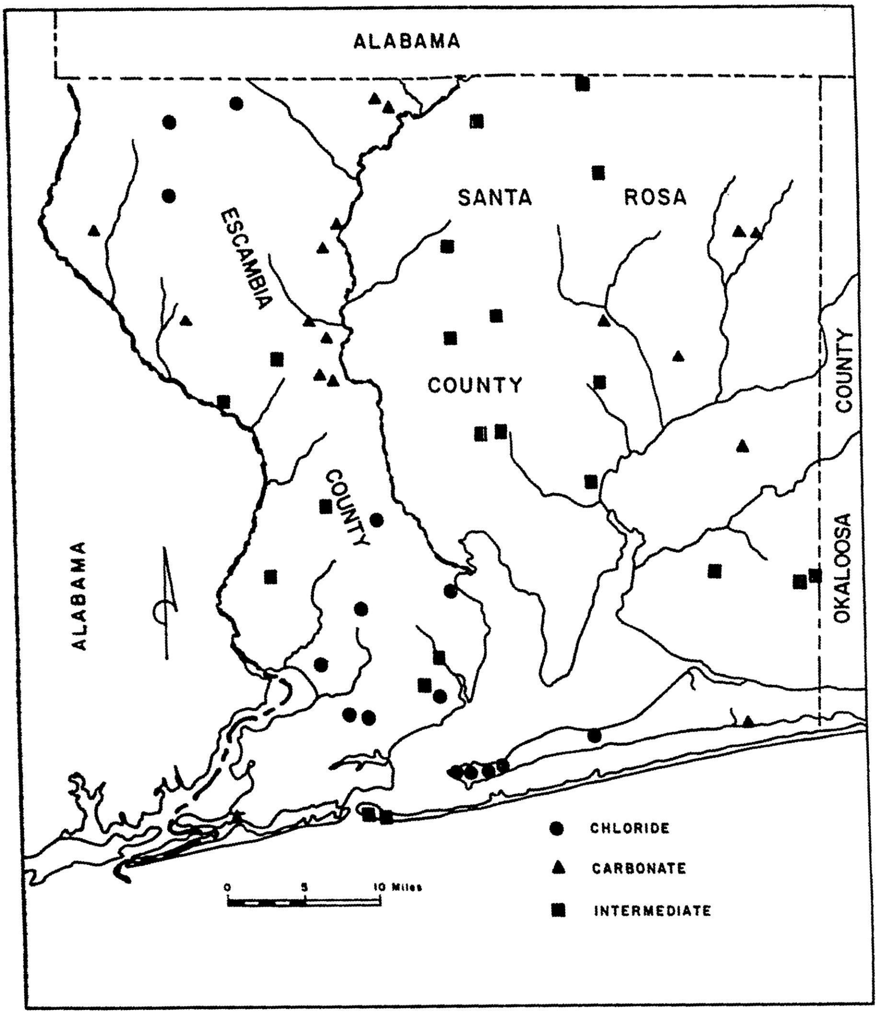

Figure 41. Map showing types of water from wells in the sand-and-gravel aquifer.

ride, and nitrate are negatively charged (anions). Chloride-type water is indicated by chloride as the major anion and is generally accompanied by a predominant sodium cation. Carbonate-type water is based on carbonate as the major anion and calcium, magnesium, and sodium, either singularly or in various combinations, being the major cations. Intermediate-type water is characterized by carbonate and chloride being almost equal and usually shows no predominance in the cations.

The chemical quality of the water from two wells located at Fort Pickens State Park on the west end of Santa Rosa Island is distinctive. They are the only two wells on Santa Rosa Island producing any quantity of fresh water from the sand-and-gravel aquifer. The analysis of the water from these two wells suggests the presence of a slight amount of sea water. Sodium and chloride are among major ions present and the magnesium exceeds the calcium, which is indicative of sea water. The water has a pH slightly above neutral and a carbonate of 95 ppm, high for this area. These two factors could be attributed to the action of the usually acid water on fossil shells. This water is thought to cross under the bay from the Pensacola area, separated from the salt water in Pensacola Bay by an impermeable clay bed. The long exposure to clay could account for the presence of high silica (20 ppm).

On Fair Point Peninsula, Heath and Clark (1951) found two aquifers in the sand-and-gravel aquifer. The upper aquifer contains the more acid water (pH 5.2 to 5.9) which has sodium and chloride for the major constituents and is low in total mineralization. Water from the lower, more fossiliferous aquifer contains carbonate as the major constituent and has a pH of 7.2. A shallow well at Gulf Beach and a deeper well at Navarre show chemical characteristics similar to the deep well at Fair Point, whereas water from a shallow well at Santa Rosa Shores resembles the water from wells in the upper aquifer at Fair Point. Water from the sand-and-gravel aquifer in the southeastern part of Santa Rosa County away from the coast has a very low mineral content and shows no predominant chemical constituents.

In the section of Pensacola bordering closely on the bays, the water from this aquifer is generally very low in mineral content but shows a predominance of sodium and chloride ions. This slight salt-water encroachment could be due to pumping in the area. Near Bayou Chico, an area of heavy pumping in close proximity to salt water, about 12 wells have been abandoned due to salt-water encroachment. This encroachment has been reduced by decreasing pumping near the salt water.

The large Chemstrand plant on the Escambia River just north of Pensacola uses both river water and ground water from the sand-and-gravel aquifer. During periods of low flow and high tides, salt water extends up the river past the plant. At these times, heavy pumping can cause salt water to enter the aquifer. This happened in Chemstrand well 035-714-4 where the chloride rose to 1,100 ppm before they abandoned the well. Due to the loss of this well, pumping was decreased in several other wells to prevent a recurrence of salt-water encroachment. The water from the other wells, even though low in mineral content, is predominant in sodium and chloride ions. In central Escambia County the water from St. Regis Paper Company wells is low in mineral content and has no predominant chemical constituent.

Water from the sand-and-gravel aquifer in central Santa Rosa County has a low mineral content and shows no predominant ions. This section appears to be the major recharge area for the county. This is indicated by both the low mineral content of the water and the favorable topography.

The water in the northwestern section of Santa Rosa County is mainly of the carbonate type. The limestone of the Floridan aquifer is closest to the surface in this area. The water in the 445-foot well (051-652-1) at the Florida State Forest Nursery near Munson shows the effect of solution of the fossil shells in the lower part of the sand-and-gravel aquifer. The water had a total hardness of 116 ppm. This type water, although considered moderately hard and undesirable for some domestic and industrial use, is excellent for agriculture.

A flowing 535-foot well (058-715-1) at Century is high in carbonate. This is probably due to contact with a limestone bed just above the aquifer. The constituents in water from this well are carbonate (89 ppm), sodium (62 ppm), and silica (12 ppm). The water contained practically no calcium, magnesium, or chloride. The presence of sodium bicarbonate is probably an example of natural softening. The water dissolves the calcium carbonate from the limestone; then by ionic exchange the calcium is replaced by sodium from clay lenses, which are numerous in the sand-and-gravel aquifer. The pH of this water is 8.4. An earlier analysis of a 305-foot well (058-715-2) in this area shows a water of a similar type.

In the area just west of and parallel to the Escambia River, from McDavid to Molino, the sand-and-gravel aquifer is apparently divided into two or more separate aquifers. Wells in the upper aquifer are nonartesian and range in depth from about 30 feet in the north to 80 feet in the south. The lower aquifer produces flowing wells which range in depth from 125 feet in the north to 282 feet in the south. These flowing wells result from the pressure of water confined beneath a continuous confining bed or possibly from numerous lenses of confining material. The flowing wells are for the most part old, and accurate drilling records and drill cuttings are not available to define definitely the geologic feature. However, the gradient defined by the well depth tends to follow southward dip of the formations. Figure 42 shows that mineralization of the

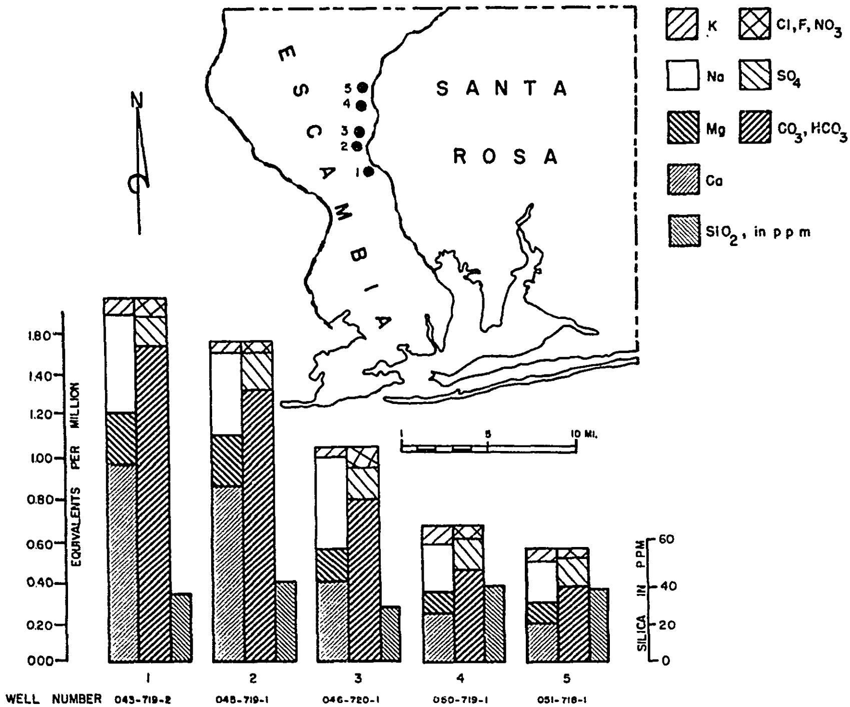

Figure 42. Graphs showing chemical composition of water from wells in the sand-and-gravel aquifer from Molino to McDavid.

water increases to the south, indicating longer contact between the water and the minerals in the ground. This limited evidence suggests the possible existence of a single confining layer extending over several miles. The increased mineralization in this area is no real problem because even the most mineralized water in the aquifer is within the limits of most municipal and industrial criteria. The only exception is that the silica content of water from all flowing wells' samples exceeds the maximum allowable limits for boiler feed water.

Generally, the sand-and-gravel aquifer is a source of water of exceptionally low mineral content.

FLORIDAN AQUIFER

In Escambia and Santa Rosa counties the Floridan aquifer is not used extensively as a source of water. The sand-and-gravel aquifer is shallower and supplies sufficient water of better chemical quality.

The Floridan aquifer is used as a source of water in two locations in eastern Santa Rosa County, one location near the coast and one near the Alabama State line. The westernmost water well, No. 028-715-2, (1,561 feet deep) in the upper limestone of the Floridan aquifer was drilled north of Pensacola in 1957. This well was abandoned when the drill stem test showed a chloride content of 1,495 ppm. A 950-foot well, No. 022-652-1, drilled at Navarre Beach in 1961, produced water of good chemical quality. Eglin Air Force Base uses several Floridan aquifer wells on Santa Rosa Island and many in other parts of Okaloosa County for water supplies.

In northern Santa Rosa County the well (059-658-1) at Camp Henderson Lookout Tower in the Blackwater River State Forest produces water of good chemical quality from the lower limestone of the Floridan aquifer.

The Floridan aquifer dips to the southwest and is generally too deep for practical use. The water downdip in the aquifer tends to become high in chloride, making it unsuitable for most uses.

USE OF WATER

SURFACE WATER

Only a small part of the surface water of the area is being used. Recreation, shipping, cooling, and waste disposal are the major uses at present (1962). These uses are nonconsumptive in that no water is permanently removed from the water body. Water used for cooling is removed from a stream and returned with only a slight rise in temperature. There are no known major consumptive uses within the area, and the full potential of the surface waters is far from being realized.

Most uses of surface water are within the southern half of the area. Principal among these are recreation and shipping. The 230 square miles of bays are excellent for boating, fishing, swimming, and other recreational activities. The Intracoastal Waterway parallels the coast and allows shipping in protected waters to and from Pensacola harbor. The Chemstrand nylon plant and the Gulf Power plant use water from the lower Escambia River for cooling. During the three-year period, 1959-61, the Chemstrand nylon plant used river water for cooling at the rate of

32.4 mgd. Elevenmile Creek is used for disposal of industrial wastes. Small storage reservoirs are located on Bayou Marcus Creek to enhance the value of land.

The surface water within the northern half of the two counties is virtually unused. Several small dams on the Conecuh River in Alabama regulate slightly the flow of Escambia River. The Florida Game and Fresh Water Fish Commission operates a fish hatchery in the Blackwater River Basin near the Santa Rosa-Okaloosa County line. Some of the many small ponds in the area are used to water livestock.

GROUND WATER

Information was collected from the various users of ground water within the area in order to estimate the total amount being withdrawn. These data are essential to show areas of probable overdevelopment and areas of potential development. Information on the use of ground water can be compared with water-level graphs to estimate safe withdrawals from an area.

SAND-AND-GRAVEL AQUIFER

Almost all the ground water used in Escambia and Santa Rosa counties comes from the sand-and-gravel aquifer. The estimated daily use of ground water in both counties is about 87 million gallons—approximately 60,000 gpm. Figure 43 shows the approximate amount of ground water used daily in the two counties for industrial and public supplies. The quantities of water are represented by the height of the bars. The illustration shows that most of the water is used in southern Escambia County and southwestern Santa Rosa County.

Use by industries.—Industries use the largest amount of ground water in Escambia and Santa Rosa counties. The industries use ground water at the rate of about 50 mgd. The estimated daily pumpage by industries is as follows:

Paper and wood products	34.5 mgd
Chemical plants	13.9 mgd
Other uses (brewing, laundries, etc.)	1.6 mgd

The St. Regis Paper Company at Cantonment is the largest user of ground water in the area. The average daily pumpage is 31 mgd (not fully metered) from 25 wells. The wells were drilled in 1940, 1941, 1944, 1946, 1947, 1951, and 1957 and range in depth from 158 to 485 feet. Each well has from one to five well screens. Seven wells have been abandoned. One deep well (404 feet) was abandoned because of a high hydrogen sulfide content and six shallower wells were abandoned because of declining water levels, partially as a result of close spacing.

The Chemstrand Corporation pumped an average of 7.9 mgd (fully metered) during 1962. This figure was reduced from a high of 9.2 mgd during 1959. The plant started production in the fall of 1953. Records show an average use during the month of 3.4 in June 1954. This use increased to 9.8 mgd in March 1960. Water conservation measures such as

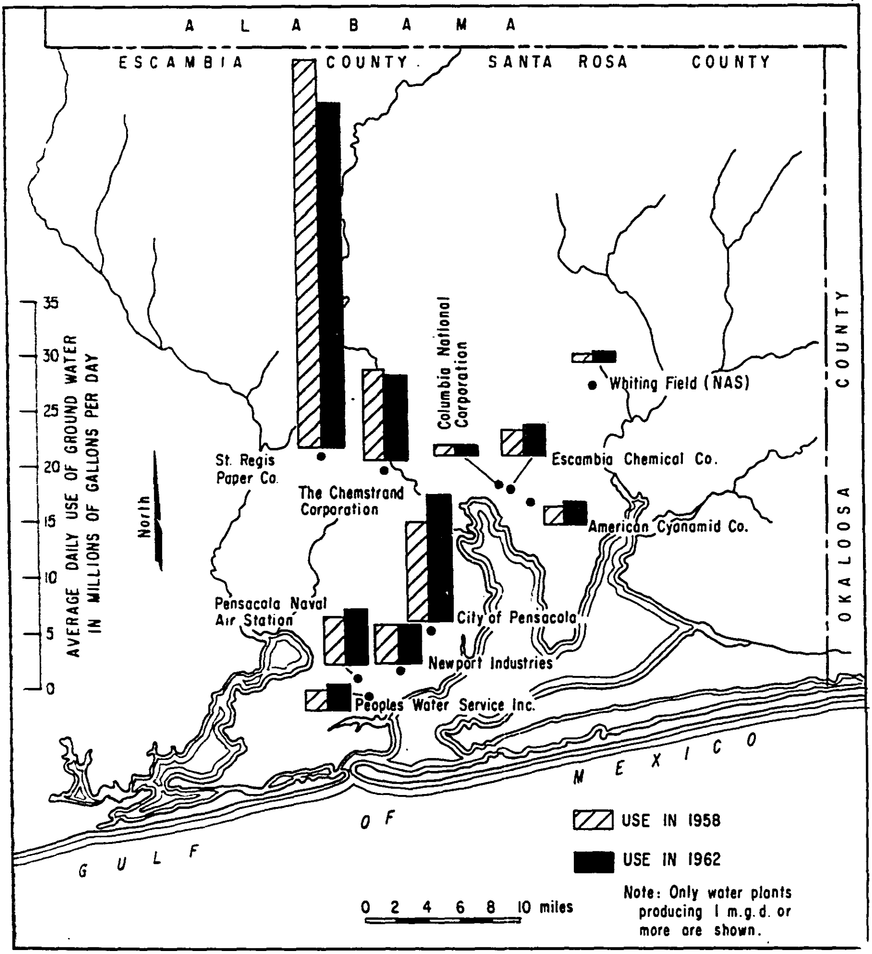

Figure 43. Map of Escambia and Santa Rosa counties showing the amount of ground water used daily for industrial and public supplies during 1958 and 1962.

the use of cooling towers, reclaiming steam condensate, and repairing leaks reduced this pumpage even though nylon production increased. The average pumpage in January 1962 was 6.3 mgd.

Six wells are used almost full time and three wells are on a standby basis. The three standby wells are pumped at about 500 gpm because higher rates cause an increase in the chloride content. One well has been abandoned because of salt-water encroachment. The wells at the Chemstrand plant range in depth from 312 to 384 feet and are usually equipped with two well screens.

The Escambia Chemical Corporation near Pace pumps an average of 2.9 mgd from four wells. The wells are from 260 to 300 feet deep and were drilled in 1955, 1956, and 1962. The Columbia National Corporation is also near Pace and just west of the Escambia Chemical Corporation. Columbia National has one well, 293 feet deep, which is pumped at approximately 1 mgd.

The American Cyanamid Company has two large-capacity wells, each capable of pumping more than 1,100 gpm. They also have a smaller well with a pumping rate of 150 gpm. The three wells were drilled in 1957 and are 278 to 288 feet deep. The present plant use is 1.9 mgd and the water pumped from the two large wells is metered.

The Newport Industries plant at Pensacola has been in operation since 1916. Thirteen wells have been drilled between 1915 and 1954. Seven of these wells have been abandoned due to salt-water encroachment. The chloride content of water from four of the other wells has shown a gradual increase. The increase in the salt content is very slow and the water from a well may still be used for several years after the salt content starts to increase. The chloride content of the water from two of the wells has not increased. These two wells are farther away from Pensacola Bay than the other wells.

Newport Industries is presently using five large-capacity wells which are pumped intermittently. They also use one small-capacity well. The wells range in depth from 209 to 251 feet. The current use of ground water is 3.6 mgd. Several cooling towers have reduced the ground-water pumpage.

Use by municipalities.—The second largest use of ground water in both counties is for public supply. Seventeen million gallons are used daily for this purpose. About 16 mgd is withdrawn in the greater Pensacola area.

The City of Pensacola sold ground water at an average rate of 11.4 mgd during 1962 for 75,000 people. This is about 150 gallons of water per person per day. The water is furnished from ten wells that can be pumped at 2,000 gpm each and three wells of less capacity. The wells are from 234 to 270 feet deep and are equipped with 100 feet of screen.

The City of Pensacola abandoned six wells near the water plant because of interference between the closely spaced wells and maintenance problems caused by the age of the wells. They also abandoned a well at 12th Avenue and Hayes Street due to obvious industrial waste pollution. The city wells have not experienced salt-water encroachment. Present plans call for new wells to be located about one mile apart and one mile from any surface body of salt water.

The People's Water Service in Warrington furnished 2.5 mgd from six wells in 1962. This company has not had any trouble from salt-water encroachment. One well was abandoned in 1960 due to a high iron content of the water.

The other public water supplies in the Pensacola area were estimated to pump about 2.2 mgd of ground water in 1962. Public water supplies are also located in Bagdad, Cantonment, Century, East Milton, Gulf Breeze, Jay, Milton, and Navarre Beach. The total groundwater pumpage from these supplies outside and the Pensacola area was estimated to be 1 mgd in 1962. Pensacola Beach obtains its fresh water supply through a pipe line from the City of Pensacola.

Figure 44 illustrates the increased use of ground water by the City of Pensacola. In 1933, the average yearly pumpage was 2.09 mgd; the lowest average monthly pumpage, 1.78 mgd, occurred in March and the highest average monthly pumpage, 2.42 mgd, occurred in September. In 1962, the average yearly pumpage was 11.4 mgd; the lowest average monthly pumpage, 8.25 mgd, occurred in February, and the highest average monthly pumpage, 18.6 mgd, occurred in May. The highest pumpage in one day was 22.9 mgd on May 23, 1962. Data from the graph in figure 44 indicate the increased pumping rates that will be needed in the future.

The cities of Pensacola and Gulf Breeze, and some other local suppliers benefit because of the lower mineral content of the ground water. The raw ground water requires little treatment and the water can be treated at the well site. Therefore, the wells can be drilled in the areas of need and the treated water distributed from the well sites. Many public water plants in the other areas must pump the raw water to a central point where it is treated and then distributed. Treating the water at the well sites enables the cities to use smaller diameter distribution lines. This also spaces the wells farther apart. The wider spacing is good practice because it reduces the large cone of depression caused by pumping closely spaced wells.

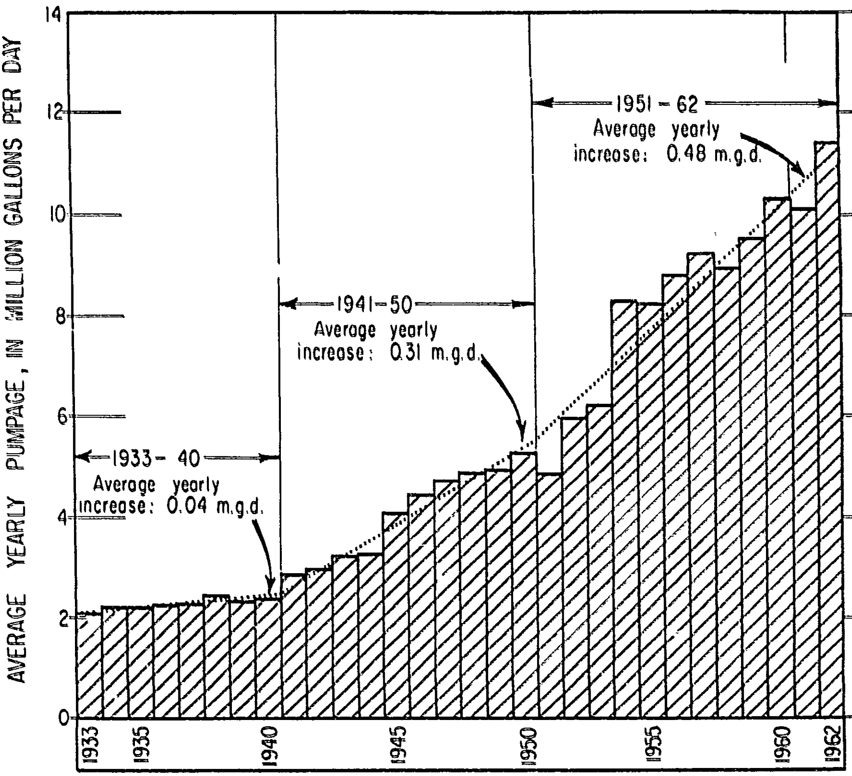

Figure 44. Graph showing pumpage from the sand-and-gravel aquifer by the City of Pensacola, 1933-62.

Use by military operations.—Military operations use about 7 million gallons of ground water per day in Escambia and Santa Rosa counties. The Naval Air Station at Pensacola uses 5 mgd from 8 wells (200 to 250 feet deep) at Corry Field. The Station has 4 other wells on a standby basis. Whiting Field uses 1 mgd from 3 wells (234 to 319 feet deep). Saufley Field, Ellyson Field, Bronson Field, and Eglin Field 7 use a total of 1 mgd.

Use by agriculture.—The amount of ground water used for irrigation in both counties is small. About 0.5 mgd is used for irrigation. Lawn and garden irrigation accounts for most of the water used. Less than 10 large-capacity wells are occasionally used in this area for irrigation. Escambia County has about 300 acres under occasional irrigation. The need for irrigation water normally is not great because rainfall is fairly abundant during the growing season. However, seasonal droughts occur and a few farms have produced excellent truck crops by using ground water for sprinkler irrigation.

The amount of ground water available far exceeds the quantity needed for irrigation, especially in the northern half of the counties. In some places, part of the water used for irrigation percolates downward to recharge the sand-and-gravel aquifer near where it was pumped.

Santa Rosa and Escambia counties have about 30,000 cattle, horses, and mules. Assuming a use of 12 gallons of water per animal per day, the daily use of water would be 360,000 gpd. The swine population of both counties is about 20,000. A use of 4 gallons of water per animal per day gives 80,000 gpd. The estimated daily use of water for the 110,000 poultry flock is 15,000 gpd. The daily use of water in Escambia and Santa Rosa counties for livestock is about 0.5 mgd.

Supplies for domestic use.—A sufficient quantity of ground water for domestic use can be obtained by wells almost any place in Escambia and Santa Rosa counties. Wells in the area are usually less than 150 feet deep, and many of them are less than 100 feet deep. The wells are screened in the permeable sand or gravel. The permeable zones, in which the screens are set, are located by inspection of the drill cuttings while the well is being drilled.

The estimated number of persons using ground water from private wells for domestic purposes is 60,000 in Escambia County and 20,000 in Santa Rosa County. Assuming an average use of 150 gallons of water per person per day for domestic purposes, they would use water at a rate of 9 mgd in Escambia County and 3 mgd in Santa Rosa County. The amount used is only a small part of the total amount available. As each well withdraws only a small amount of water, and because the wells are widely spaced, the effect of this pumping on the water table is slight.

FLORIDAN AQUIFER

The quantity of water withdrawn from the Floridan aquifer by wells in Escambia and Santa Rosa counties is very small. Only about 8 wells obtain water from this aquifer in both counties. The use of water from this aquifer is small because sufficient quantities can be obtained, generally, from the overlying sand-and-gravel aquifer, because the water is usually higher in mineral content than water from the sand-and-gravel aquifer, and because deep wells are expensive.

The upper limestone of the Floridan aquifer in the southeastern corner of Santa Rosa County is important. This aquifer provides the only major source of fresh ground water at Navarre Beach on Santa Rosa Island. Well 022-652-1 was drilled in 1961 to a depth of 950 feet and had a natural flow of 110 gpm. The artesian pressure head was 51 feet above the land surface and about 56 feet above sea level. The chloride content of the water is 87 ppm and the dissolved solids is 380 ppm. Water from this well is soft as the hardness is only 16 ppm.

WATER PROBLEMS

Problems concerning water resources can be divided into those resulting from natural causes, those arising from man's use of water, and those resulting from a combination of both.

PROBLEMS FROM NATURAL CAUSES

Water problems arising from natural causes are usually associated with too little or too much rainfall, the areal geology, or by the mineral content of the water. Deficient rainfall causes the water level in wells to decline, runoff from streams to decrease, and pond levels to be lowered. Excessive rainfall may cause flooding of lands that are poorly drained and lands adjacent to streams. Problems of water development occur in areas where the geology is such that aquifers are limited. The mineral content of water may limit the usefulness of the water.

PERIODS OF LOW RAINFALL

Decline of water levels.—The relation of ground-water levels to rainfall is shown by the hydrographs of wells in this area. During periods of low rainfall, the water level declines. This may result in drying up of shallow wells and salt-water encroachment. In well 031-716-1 at Ensley, the water level dropped more than 9½ feet in 1950 and again in 1954 (fig. 34). These declines were due to a reduction in recharge brought about by below-normal rainfall.

The levels of ponds drop during low rainfall periods and some ponds go dry. Streamflow decreases during the dry periods.

Salt-water encroachment.—Low ground-water levels and below-normal streamflow, brought about by lack of rain, allow salt-water encroachment into surface and ground-water supplies. During periods of low rainfall the streamflow decreases and the salt-water front moves upstream.

Lowered ground-water levels may allow upward or lateral salt-water encroachment. Upward encroachment is possible where the lower aquifer has a higher head than that in the upper aquifer. Lateral encroachment into ground water from surface bodies of salt water is possible where ground-water has a lower level than the surface water level. The greatest danger of salt-water encroachment occurs during periods of low rainfall in areas of heavy pumping.

Lateral salt-water encroachment occurred along the north and south shoreline of Gulf Breeze peninsula in 1954. This encroachment was a result of low ground-water levels caused by the low rainfall. The salt water moved inland 30 to 40 feet from Pensacola Bay and 20 to 30 feet from Santa Rosa Sound.

PERIODS OF HIGH RAINFALL

Periods of moderately high rainfall are important because the amount of ground water in storage is increased and streamflow becomes greater. However, severe problems such as floods or ponded water may result from excessive rainfall.

Every stream in the area responds to rain falling in its basin. The height to which a stream will rise depends on the amount and distribution of rain and the physical characteristics of the river basin. The stages of some of the smaller streams in the area vary as much as 15 feet while stages of some of the larger streams vary as much as 36 feet. The magnitude and frequency of floods are important to engineers in charge of designing river appurtenances (bridges, dams) and other structures in the flood plain. Data on the magnitude and frequency of floods in the area are presented in figure 20.

Ponded water occurs in areas where the land is flat and drainage facilities are inadequate. Examples of this are found near Pensacola. Water stands in low spots for varying lengths of time after each intense rain. This ponded water leaves some areas only by evaporation and infiltration. In these areas the problem can be made worse by developments such as paved streets, houses, and lawns, that cause an increase in the rate of runoff to the ponded areas. The problem of ponded water can be solved by providing adequate drainage.

Ponded water can also occur where the water table intersects the land surface. This happened near the city of Gulf Breeze during the fall of 1959 when intense rains caused the water table to rise rapidly (fig. 38) and low lands were flooded. The figure shows the slow decline of the water table following the abrupt rises. Surface drainage, buried tile drains, or pumping are the most effective methods for removing the excess water.

MAN-MADE PROBLEMS

Water resource problems caused by man are usually associated with heavy withdrawal of ground water in an area; the pollution of ground water or surface water by industrial wastes; or structures that alter drainage, infiltration, or runoff characteristics.

LARGE DRAWDOWNS

Industries usually require a continuous supply of water. Pumping of ground water causes drawdowns of the water level in proportion to the number and spacing of wells and the rate of pumping. Such drawdowns increase the cost of pumping water, but more important, may cause the cone of depression to extend outward farther than is desirable and may cause local depletion and reduced well yield.

An example of large drawdowns can be found at Cantonment. Figure 34 shows that the water level in well 036-719-1 declined more than 42 feet from 1941 to 1956. This decline was mainly the result of heavy pumping although low rainfall was a contributing factor. During the 15-year period, the water level declined at an average rate of 2.8 feet per year. The reasons for the rise of the water level from 1957 to 1962 are covered on page 68.

SALT-WATER ENCROACHMENT

Salt-water encroachment can be a serious "side effect" when water levels near bodies of salt water are lowered. If the sediments between the salt-water body and the ground-water aquifer are relatively impermeable, the rate of salt-water encroachment is slow; if these sediments are relatively permeable, the rate of encroachment is much higher.

An example of a slow rate of encroachment is shown by industrial wells near Bayou Chico where several years of heavy pumping lowered water levels below sea level (fig. 37). As a result of this lowering, water from wells nearest the bayou slowly became salty, and it became necessary to drill replacement wells farther away from the bayou. Usually several years were required after the chloride content of the water from a well started to increase before the water became too salty for use.

Pumping of ground water at Newport Industries averaged 2.5 mgd from 1928 to 1933. The average ground-water level at Bayou Chico prior to pumping was about 7 feet above sea level. Jacob and Cooper (1940, p. 60-64) calculated that the minimum time required for salt water from Bayou Chico to move 2,000 feet to the Newport Industries well field would be about 3.1 years, on the assumption that there was close interconnection of the aquifer and bayou and that permeability was constant. They further determined that salt-water encroachment from Bayou Chico would not begin until the ground-water level had been lowered 7 feet and that it would take a pumping rate of more than 3.4

mgd, which was reached in 1928. After 1928, the chloride content of the water pumped at Newport should have increased about 3 years later, or by 1931. The rise in salinity did not become apparent until 1937. The salt water probably took about 6 years to pass through the 20-foot thick bed of clay.

An example of rapid encroachment occurred along the Escambia River at the Chemstrand nylon plant. The salt-water encroachment into the sand-and gravel aquifer at the Chemstrand plant comes from the Escambia River by lateral movement. This conclusion was reached after considering all the known factors. Prior to pumping at the Chemstrand plant, ground water moved eastward toward the Escambia River and seeped into the river. Ground-water pumping lowered the ground-water level and eventually caused water from the Escambia River to infiltrate into the ground. The water that infiltrates is salty part of the time. The river infiltration explains why the ground-water levels at Chemstrand have generally stabilized.

The other possible source of salt-water encroachment at the Chemstrand plant is from salt water below the sand-and-gravel aquifer. A study of resistivity logs of wells indicates that the water in a thick clay section (fig. 6) below the sand-and-gravel aquifer at Chemstrand is salty. As the clay is virtually impermeable, the salt water is not believed to come from this source. This thick clay bed prevents salt water from moving up from the limestones below it. In addition, the chloride content of water from the upper limestone of the Floridan aquifer is only 400 ppm which is not salty enough to cause the high chloride content sometimes found in well 035-714-4.

The Bucatunna Clay Member is more than 200 feet thick at the Chemstrand plant. The effectiveness of this clay bed as a confining layer can be inferred by a comparison of the chloride content of water from the adjoining limestone beds. The chloride content of water from the upper limestone (above the Bucatunna) is 400 ppm and the chloride content of water from the lower limestone (below the Bucatunna) is 7,300 ppm.

Well 035-714-4 (Chemstrand Well No. 3) is the production well nearest the Escambia River. The water from this well was the first to show an increase in the chloride content. If the salt-water encroachment was from below, the center wells of a well field are usually the first ones to show an increase in the salt content of the water. In 1955, nearby pumping caused the ground-water level near the river to decline below sea level for the first time and it has remained below sea level most of the time since June 1955. In 1956, the chloride content of water from well 035-

714-4, 500 feet west of the Escambia River, increased from about 6 to more than 1,100 ppm.

During 1957 and 1958, the chloride content of the Escambia River at the Chemstrand nylon plant cooling water intake was above 25 ppm for about 25 percent of the time. Thus, the salt-water front had advanced at least 7 miles above the mouth of the river.

The flow of the Escambia River during the summer of 1955 was sufficient to keep the salt-water front downstream from the Chemstrand nylon plant. In September 1955, the flow of the Escambia River decreased and salt water probably occurred at the plant. As the ground-water level was below river level, salt-water encroachment began. The time required for the river water to move to Chemstrand well (035-714-4) 500 feet from the river was calculated. Assume an average drawdown of 20 feet (which would also be about 20 feet below sea level); an aquifer thickness, m, of 300 feet; and a porosity, p, of 30 percent. The coefficient of transmissibility, T, is 150,000 gpd per foot. The hydraulic gradient, g, would be 20 feet in 500 feet or 0.04. These values and the following calculation would give the minimum time required for river water to move to the well. No allowance is made for the time required for the water to move through the clay beds in the sand-and-gravel aquifer.

$$V = \frac{Tg}{7.48\ mp}$$

$$V = \frac{(150{,}000)(0.04)}{(7.48)(300)(0.30)} = 8.9 \text{ feet per day}$$

$$\frac{500 \text{ feet}}{8.9 \text{ feet per day}} = 56 \text{ days}$$

The time required for the salty water from the river to move to the well field would be about two months and the salt water in the well could have been expected sometime in November 1955. The salt water did not show up in the well until almost one year later. This lag can be explained by the time required for the water to pass through several thin clay beds.

Figure 45 shows the lowering of ground-water levels and their relation to the level of the Escambia River. The figure is a cross section from Cantonment eastward to the Escambia River. Early data imply that the ground-water level close to the river was 25 to 30 feet above sea level in 1940. The water table was 12 to 15 feet above sea level near the river in 1951 and about 1.5 mgd per mile was moving toward the Escambia

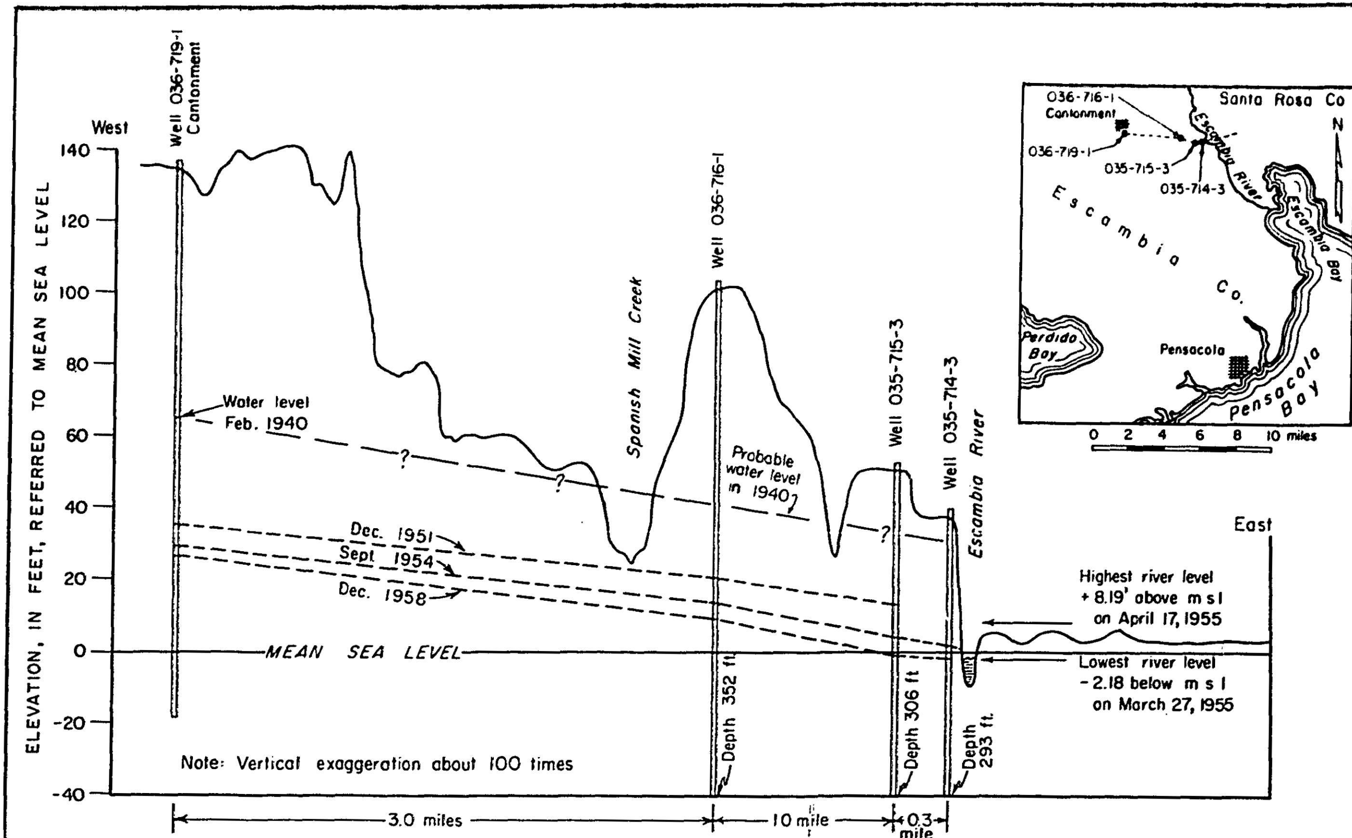

Figure 45. Cross section showing the decline of water levels in the vicinity of Cantonment.

River from the west. Since 1955, the water table adjacent to the river has usually been below river level at the Chemstrand plant and water from the river has infiltrated into the well field. Ordinarily infiltration from the river would be a desirable feature as it would recharge the aquifer and decrease the drawdowns. However, the Escambia River is salty part of the time and infiltration introduces salt water into the sand-and-gravel aquifer adjacent to the river.

INDUSTRIAL WASTE DISPOSAL

The complex problem of disposing of industrial wastes is very important because these wastes can pollute both surface and ground-water supplies. A thorough knowledge of the geology and hydrology of an area is invaluable in planning for safe disposal of industrial waste. Some industries in this area presently discharge wastes directly into streams, bays and infiltration ponds.

Disposing of waste into surface-water bodies may cause objectionable odors, kill fish and plant life, discolor the water, and cause the accumulation of solid waste materials. A knowledge of streamflow is very helpful in determining the dilution necessary to keep the concentration of plant wastes below an objectionable level.

Discharging industrial wastes into infiltration ponds may result in pollution of the sand-and-gravel aquifer because in most cases the water level in infiltration ponds stand above the ground-water level, especially when the ground-water level is lowered by heavy pumping. Thus, the pond has the head potential to recharge the aquifer. The permeability of the coarser sediments and presence or absence of clay layers help determine how fast water from infiltration ponds will move downward and then laterally.

The disposal of industrial wastes into infiltration ponds occurs in the northern part of Pensacola. Concentrated acid wastes have been discharged into a pond for more than 70 years. This waste material has infiltrated into the ground and moved with the hydraulic gradient. A diluted form of this waste has been detected in the water from a Pensacola municipal well at 12th Avenue and Hayes Street, more than a mile from the pool. This well subsequently was abandoned. The average velocity of ground water was previously computed to be about 100 feet per year in the Pensacola area. Therefore, the acid wastes could move 6,000 feet in about 70 years (an average of about 86 feet per year).

A knowledge of the geology and hydrology in an area may prove useful to solve some problems of waste disposal. Information collected during this study enabled officials of the Chemstrand Corporation to investigate the possibility of disposing of some plant wastes underground. A thick section of limestone, the lower limestone of the Floridan aquifer, lies from 1,370 to 1,955 feet below the plant (see fig. 7). This limestone lies between two clay beds which restrict the movement of water from or into the limestone aquifer. The clay beds continue outward under the Gulf of Mexico. Water in the lower limestone moves with the hydraulic gradient to the south or south-southeast from the plant. The diluted wastes would probably be discharged into the Gulf of Mexico many miles from Pensacola and many years later.

A study of electric logs indicates all the water in the lower limestone is very salty, except possibly a small amount near the top of the aquifer. On March 20, 1963, the chloride content of the water from the lower limestone of the Floridan aquifer at the Chemstrand plant was 7,300 ppm. This salty water was coming from well 035-714-5 which was open to the aquifer at a depth of 1,390 to 1,729 feet.

Test drilling will be necessary to determine the character, the porosity and permeability of the limestone; and the artesian pressure head and salinity of the water. Monitor wells should be drilled to determine the movement of wastes and the hydraulic gradient.

This underground disposal of wastes could be used by other industries in the southern third of the area. Care must be taken to insure that fresh-water supplies above the limestone would not be contaminated by leaking or corroded well casings.

POTENTIAL WATER SUPPLIES

SURFACE WATER

Escambia and Santa Rosa counties have an abundance of fresh water —8.5 bgd flow from the area through surface streams. However, the surface-water supplies vary with respect to time and location. The fluctuation with respect to time follows the pattern of rainfall. The drainage areas and average flows of streams in Escambia and Santa Rosa counties are given in table 1. About 2.0 bgd is derived from the land area within the two counties.

The average flow from the Perdido River basin is 1.1 bgd. This flow is equivalent to 1.2 mgd per square mile over the entire basin. Not all tributary streams flow at the same rate as the average for the basin. The major tributaries of the Perdido River in Escambia County and their computed flows are: Brushy Creek, 90 mgd; McDavid Creek, 40 mgd; Jacks Branch, 16 mgd; and Bayou Marcus Creek, 60 mgd.

The Escambia River has an average flow of 4.5 bgd. Pine Barren Creek is a tributary stream in northern Escambia County and has an average flow of 134 mgd. Canoe Creek in northeast Escambia County has an estimated flow of 50 mgd, and Moore Creek in Santa Rosa County has a computed flow of 40 mgd.

Table 1. Drainage areas and average flows of streams in Escambia and Santa Rosa counties, Florida

River Basin	Drainage Area (square miles)		Average Flow (million gallons per day)	
	Total	In Escambia and Santa Rosa counties	From basin	From Escambia and Santa Rosa counties
Perdido River	925	236	*1,120	**284
Brushy Creek	75	53	90	65
McDavid Creek	34	34	40	40
Jacks Branch	24	24	16	16
Bayou Marcus Creek	26	26	*60	**60
Carpenter Creek	18	18	*20	**20
Escambia River	4,233	410	*4,540	**556
Pine Barren Creek	98	85	134	116
Moore Creek	32	32	40	40
Canoe Creek	37	24	50	30
Blackwater River	860	580	*960	**710
Pond Creek	88	88	80	80
Big Coldwater Creek	241	228	350	330
Big Juniper Creek	146	134	170	155
Yellow River	1,365	115	*1,620	**136
Coastal Drainage	300	300	*220	**220

* Total Flow into Bays................8,540
** Total Flow from Counties................1,986

The average flow from the Blackwater River basin is 960 mgd. About three-fourths, or 710 mgd, is derived from Santa Rosa County. Most of the remaining 250 mgd is from Okaloosa County, with a small amount coming from Alabama. Pond Creek has an average flow of 80 mgd. Big Coldwater Creek has the largest flow (350 mgd) of any tributary in the Blackwater River basin. Big Juniper Creek has an average flow of about 170 mgd.

An average flow of about 1,620 mgd enters Blackwater Bay from the Yellow River. Most of this flow comes from counties to the east.

GROUND WATER

SAND-AND-GRAVEL AQUIFER

Although nearly all the ground water being used in Escambia and Santa Rosa counties comes from the sand-and-gravel aquifer, the full potential of the aquifer is not utilized. Figure 5 illustrates the general area of potential development of ground-water in Escambia and Santa Rosa counties. An understanding of the limiting factors is necessary if the sand-and-gravel aquifer is to be fully utilized. The limiting factors were considered to help designate the general areas shown in figure 5.

Areas of abundant fresh ground water.—Large ground-water supplies in the sand-and-gravel aquifer can be developed in the northern half of Escambia and Santa Rosa counties. Only a minor amount of the available ground water in these areas is being used at the present time. The thickness of the sand-and-gravel deposits ranges from about 230 to almost 1,000 feet. Generally, these deposits are more than 400 feet thick. Figure 5 shows other areas where large supplies can be developed, such as northwest of Pensacola and north of Navarre. Small or domestic supplies of water can be developed most anywhere in the two counties except close to the shores of the narrow islands.

Factors which limit the amount of fresh ground water.—

1. Concentrated pumpage: Heavy, continued pumping can cause a cone of depression to extend a considerable distance outward from a well field, perhaps far enough to overlap a cone created by another well field. Both well fields then, in effect, compete for the water and the resultant drawdown of the water level is correspondingly greater. The areas where large supplies have been developed are shown in figure 5. Additional development in these areas should be carefully planned.

2. Proximity to salt water: The Gulf of Mexico, Santa Rosa Sound, and all the bays contain salty water. In addition, wedges of salt water extend for varying distances up the streams that empty into the bays. Where the water table has been depressed by pumping, salt water from these sources may invade fresh-water supplies. Figure 5 shows the areas of potential danger from salt-water encroachment.

3. Presence of clay lenses: The sand-and-gravel aquifer contains lenses of clay and sandy clay which decrease the permeability of the aquifer. The total amount of clay is highly variable. As these clay lenses are relatively impermeable they limit the quantity of water that can be withdrawn from the aquifer at any given place.

However, in certain areas these clay beds retard the encroachment of salt water. For example, the clay bed 60 to 80 feet below the surface in the vicinity of Gulf Breeze retards the vertical movement of the underlying water when heavy pumping lowers water levels in the overlying sands. The water just below the clay bed is salty near the shorelines of the Gulf Breeze Peninsula.

Another example of clay beds that prevent salt-water encroachment is at Fort Pickens on the western tip of Santa Rosa Island. Here, the clay and sandy clay beds are almost 300 feet thick. Below the clay beds is a sand aquifer where fresh water for the Fort is obtained. The clay keeps the salt water out even though the water level in this sand has been below sea level since at least 1913. The chloride content of the water from the wells at Fort Pickens is about 80 ppm and has not increased appreciably since 1940. The fresh water in the sand is believed to come from the mainland southwest of Pensacola and to move southward under Pensacola Bay.

4. Industrial wastes: Wastes from industrial plants can contaminate ground-water supplies when the wastes are discharged into ponds or on the ground. Wastes discharged into streams or rivers also can contaminate ground-water supplies where pumping lowers the ground-water level below stream or river level.

5. Residual salt water: Salt water that is not completely flushed from the sand-and-gravel aquifer is another limiting factor. This salt water probably entered the aquifer in the past when sea level stood higher than at present. Such salt water was found at a depth of 75 feet at Fair Point on Gulf Breeze Peninsula.

FLORIDAN AQUIFER

The Floridan aquifer is almost untapped by water wells in Escambia and Santa Rosa counties. A detailed appraisal of the possibility of developing large supplies of potable water from this aquifer was not possible in 1962. Studies of well cuttings and electric logs from oil-test holes and deep water wells have established the location and thickness of the aquifer. Little is known of the ability of the upper limestone of the Floridan aquifer to transmit water except in the southern part of Santa Rosa County. The water transmitting and water storing properties need to be determined by test drilling and aquifer tests. The chemical quality of the water needs to be determined from water samples collected during the test drilling.

Wells drilled into the upper limestone of the Floridan aquifer in southern Santa Rosa County have large yields. The water is under artesian pressure and wells 5 to 6 inches in diameter drilled at lower elevations yield from 50 to several hundred gallons per minute by natural flow.

A study of electric logs indicates that the water in the upper limestone of the Floridan aquifer is fresh except in the southwestern part of Santa Rosa County and the southern half of Escambia County. The logs also indicate that the water in the lower limestone of the Floridan aquifer is fresh in the northern part of both counties and salty in the southern part.

Any proposed user of water from the upper limestone of the Floridan aquifer in southeastern Santa Rosa County might expect a gradual decline of the artesian pressure head. The decline of the artesian pressure head is presently centered around Fort Walton Beach. At Holley and Navarre, the artesian pressure head declined about 20 feet from 1942 to 1961. The same rate of decline of about one foot per year is expected to continue in the Holley-Navarre area. This decline means that in the future some wells will stop flowing and the yield by natural flow from other wells will decrease somewhat.

REFERENCES

Barraclough, J. T.
1962 (and Marsh, O. T.) Aquifers and quality of ground water along the Gulf Coast of Western Florida: Florida Geol. Survey Rept. Inv. 29.

Black, A. P.
1951 (and Brown, Eugene) Chemical character of Florida's waters—1951: Florida State Board Cons., Div. Water Survey and Research Paper 6.
1953 (and Brown, E., and Pearce, J. M.) Salt water intrusion in Florida: Florida State Board Cons., Div. Water Survey and Research Paper 9.

Brown, Eugene (see Black, A. P., 1951, 1953).

Calver, J. L.
1949 Florida kaolins and clays: Florida Geol. Surv. Inf. Circ. 2.

Carlston, Charles W.
1950 Pleistocene history of coastal Alabama: Geol. Soc. America Bull., v. 61, no. 10, p. 1119-1130.

Clark, W. E. (see Heath, R. C.)

Collins, W. D.
1923 The industrial utility of public water supplies in the United States: U.S. Geol. Survey Water-Supply Paper 496.
1928 (and Howard, C. S.) Chemical character of waters of Florida: U.S. Geol. Survey Water-Supply Paper 596-G.

Cooke, C. Wythe
1945 Geology of Florida: Florida Geol. Survey Bull. 29.

Cooper, H. H., Jr., (see Jacob, C. E.)

Ferguson, G. E.
1947 (and Lingham, C. W.; Love, S. K.; and Vernon, R. O.) Springs of Florida: Florida Geol. Survey Bull. 31.

Gunter, Herman (see Sellards, S.)

Heath, R. C.
1951 (and Clark, W. E.) Potential yield of ground water on the Fair Point Peninsula, Santa Rosa County, Florida: Florida Geol. Survey Rept. Inv. 7.

Howard, C. S. (see Collins, W. D.)

Howe, Henry V.
1936 Stratigraphic evidence of Gulf Coast geosyncline: Proceedings of the Geol. Soc. of America for 1935, p. 82 (abstract).

Jacob, C. E.
1940 (and Cooper, H. H., Jr., and Stubbs, S. A.) Report on the ground-water resources of the Pensacola area in Escambia County, Florida: U.S. Geol. Survey open-file report.

Lingham, C. W. (see Ferguson, G. E.)

Lohr, E. W.
1954 (and Love, S. K.) The industrial utility of public water supplies in the United States, 1952; Pt. 1—States east of the Mississippi River: U.S. Geol. Survey Water Supply Paper 1299.

Love, S. K. (see Ferguson, G. E.; Lohr, E. W.)

MacNeil, F. S.
1949 Pleistocene shore lines in Florida and Georgia: U.S. Geol. Survey Prof. Paper 221-F.

Marsh, O. T.
1962 Relation of the Bucatunna Clay Member (Byram Formation Oligocene) to geology and ground water of westernmost Florida: Geol. Soc. of America Bull. v. 73, p. 243-252.

Matson, G. C.
1913 (and Sanford, S.) Geology and ground water of Florida: U. S. Geol. Survey Water-Supply Paper 319.

Musgrove, R. H.
1961 (and Barraclough, J. T.; Marsh, O. T.) Interim Report on the Water Resources of Escambia and Santa Rosa counties, Florida: Florida Geol. Survey Inf. Circ. 30.

Patterson, A. O.
1955 Surface water in Florida: Florida Engineering and Industrial Experiment Station Bull. 72, p. 32-34.

Pearce, J. M. (see Black, A. P.)

Pride, R. W.
1958 Floods in Florida, magnitude and frequency: U.S. Geol. Survey open-file report.

Sanford, S. (see Matson, G. C.)

Sellards, E. H.
1912 (and Gunter, Herman) The water supply of west-central and west Florida: Florida Geol. Survey 4th Ann. Rept.

Stubbs, S. A. (see Jacob, C. E.)

Vernon, R. O. (see Ferguson, G. E.)