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Robert O. Vernon, *Director*

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INTERIM REPORT ON THE WATER RESOURCES OF ESCAMBIA AND SANTA ROSA COUNTIES, FLORIDA

By
R. H. Musgrove, J. T. Barraclough, and O. T. Marsh
U. S. Geological Survey

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PREFACE

An investigation, currently in progress, deals with the water resources of Escambia and Santa Rosa counties, Florida. The mild climate and excellent water supplies are prime reasons for a trend of 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 investigation is to collect water data and combine it 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. Half of this work was financed by the Federal Government and the remainder by the State, Escambia and Santa Rosa counties, and the city of Pensacola.

This is a preliminary report that summarizes progress on the investigation up to January 1, 1960. The purpose of this report is to present detailed factual and interpretative information on the occurrence, quality, quantity, and other aspects of the area's water resources for the guidance of present and future water users. A final and more comprehensive report will be prepared after two additional years of field work.

The interim investigation was made by personnel of the Water Resources Division of the U. S. Geological Survey. Rufus H. Musgrove, hydraulic engineer, Surface Water Branch, worked part time on the project. Jack T. Barraclough, hydraulic engineer, and Owen T. Marsh, geologist, Ground Water Branch, spent full time on the investigation. The work was supervised by A. O. Patterson, district engineer, Surface Water Branch; M. I. Rorabaugh, district engineer, Ground Water Branch; and J. W. Geurin, district chemist,

Quality of Water Branch. The study was suggested by Robert O. Vernon, director, Florida Geological Survey, and the Survey has provided the State matching funds for the project.

Appreciation is expressed to the following individuals for providing information and extending courtesies which greatly facilitated the investigation:

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ABSTRACT

An investigation, currently in progress, deals with the water resources of Escambia and Santa Rosa counties, Florida. The mild climate and excellent water supplies are prime reasons for a trend of 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 investigation is to collect water data and combine it with data previously collected into an interpretative report that will be beneficial to water users.

Escambia and Santa Rosa counties, the westernmost counties in Florida, have an abundant supply of both ground and surface water of excellent quality. The streams and underground formations are major sources of supplies.

Over $7\frac{1}{2}$ bgd (billion gallons per day) of fresh water flow into the 200 square miles of estuarine bays from four major rivers. The Escambia River, the fifth largest in the State, has an average flow of over 4 bgd. Many smaller streams within the area produce large quantities of water.

The ground water occurs in two major aquifers; the sand-and-gravel aquifer and the Floridan aquifer. Almost

all the 86 million gallons of water taken from the ground each day comes from the sand-and-gravel aquifer. This aquifer extends from the water table down to various depths ranging from 350 to 1,000 feet. Water in parts of this aquifer is confined by numerous layers of clay or hardpan and is under artesian pressure. The sand-and-gravel aquifer contains a large supply of exceptionally soft and unmineralized ground water. Dissolved solids generally range from 20 to 80 ppm (parts per million).

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

An extensive clay bed — the Bucatunna clay member of the Byram formation — lies near the top of the Floridan aquifer. Water in the upper part of the Floridan aquifer above the Bucatunna clay member is fresh except in the extreme southern parts of both counties. Water in the lower part of this aquifer below the Bucatunna clay member is fresh in the northern half of both counties. In places this clay bed retards upward or downward movement of ground water and separates salt water below from fresh water above.

Recharge of the sand-and-gravel aquifer is mostly 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.

The main water problems considered thus far in this investigation are: decline of the water table and salt-water encroachment. Below-normal rainfall causes the water table to drop throughout the area. However, locally the greatest lowering of the water is caused by heavy pumping of closely spaced wells. The possibility of salt-water encroachment is especially great where pumping near salty bays and rivers lowers the water table below sea level. Evidence of upward movement of salt water has not been found. Flooding of residential areas following heavy local rains causes inconvenience where the water table intersects the ground surface or where layers of clay or hardpan permit rainwater to collect in ponds. In addition, some flooding occurs along streams after heavy rains.

The major uses of water in the area are for industrial processes, recreation, and municipal requirements. Industries use about 70 percent of the ground water withdrawn from the area, the largest single user being the St. Regis Paper Company which pumps 35 mgd (million gallons per day). The large amount of water being used by industries and municipalities, however, is only a small part of the area's usable supply.

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 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 area's water; and (2) it will provide a sound basis for planning development and use of the area's water resources.

The purpose of this report is to make available, to community and industrial planners, information collected prior to 1960 on the quantity and quality of water in the area and on certain characteristics such as fluctuations in supplies because of uneven distribution of rainfall. 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 area's water resources. 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. The wells discussed range from 30 to 1,620 feet in depth and draw water from beds of Oligocene, Miocene, Pliocene (?), and Pleistocene age. Two geologic logs are given, one of a 1,435-foot well at Cantonment and the other of a 1,101-foot well south of Pensacola.

Streamflow records have been collected on the Escambia River since 1934, on Big Coldwater River 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 an annual series of water-supply papers.

The first detailed investigation of ground water in the area was made by Jacob and Cooper (1940, U. S. Geological Survey, open-file report on the ground-water resources of the Pensacola area). 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 level 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.

In 1951, Heath and Clark 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 appears 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).

No detailed study of the geology of Escambia and Santa Rosa counties has been published. Stubbs (in Jacob and Cooper, 1940, p. 5-12) describes the upper 300 feet of the Pleistocene, Pliocene (?), and Miocene deposits in the southern half of Escambia County. Heath and Clark (1951, p. 12-15) describe the same stratigraphic interval at the western end of Fair Point Peninsula in Santa Rosa County. Cooke (1945, p. 232-233) describes a short measured section of the upper 70 feet of the Pleistocene and Pliocene (?) beds that are 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, but they differ as to the number of such terraces. 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.

Description of the Area

Escambia and Santa Rosa counties are located 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 County is the larger, but less populous, with 1,151 square miles and a 1950 population density of 23 persons per square mile. Escambia County covers 759 square miles and had a 1957 population density of 245 persons per square mile.

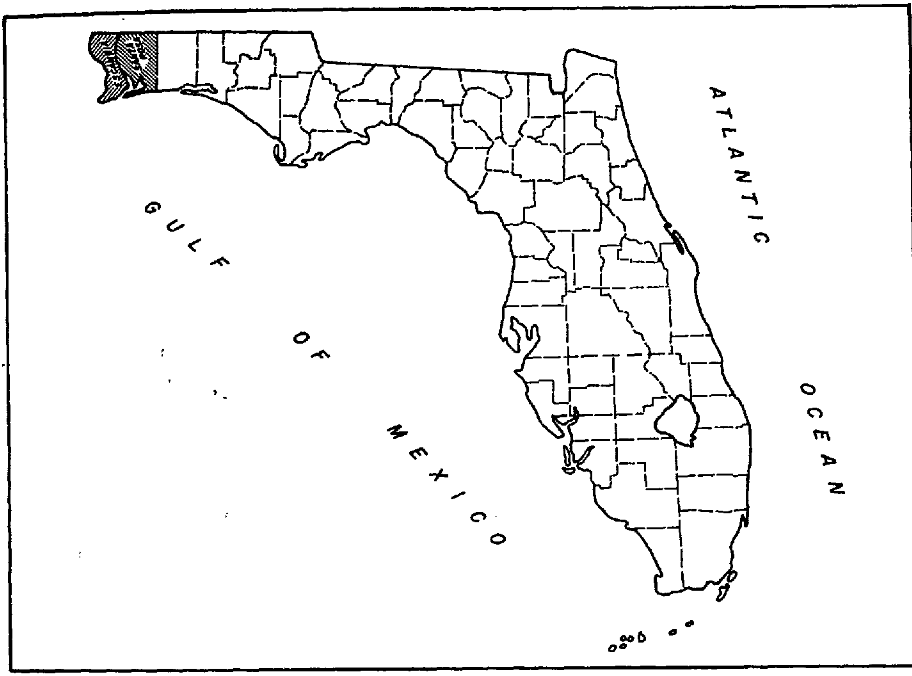

Figure 1. Location map of Escambia and Santa Rosa counties, Florida.

The two major cities in the area are Pensacola and Milton. Pensacola, located in southern Escambia County on Pensacola Bay, had a population of over 57,000 in 1957. 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 2,040 in 1950.

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 with sand dunes standing as much as 30 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 near sea level for a distance 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 elevations are 290 feet along the northern boundary of the counties.

Agricultural activities predominate in the northern half of the area. Much of the area is devoted to forest. The Blackwater River State Forest takes in the northeast quarter of 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. Fishing, shipping, military operations, and tourists also contribute to the economy of the area.

Rainfall

To evaluate the effect of rainfall on the area's water resources, a study was made of records collected by the U. S. Weather Bureau at two stations during the 33-year period, 1926-58. 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, and 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.

All points in the area receive approximately the same amount of rainfall over a long period of time. The difference between the Pensacola and Brewton averages for the 33-year period was only 0.43 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

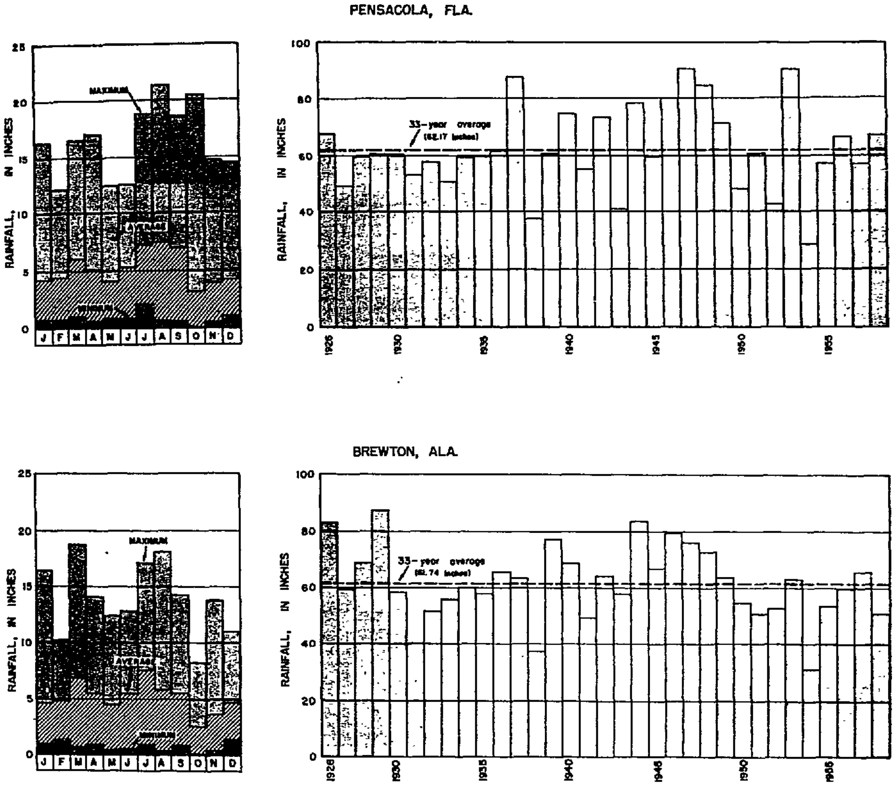

Figure 2. Bar graph of rainfall at Pensacola, Florida, and Brewton, Alabama, showing monthly averages, maximums and minimums, and yearly rainfall for the period 1926-58.

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 33 years of record at the Brewton and Pensacola stations, is 62 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.

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, rainfall of at least 4 inches each month can be expected, on the average. 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 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 area's rainfall 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. Along the coast, winter temperatures may be as much as 10° F. higher than in the northern part of the area.

GEOLOGY[1]

Introduction

General Statement

In Escambia and Santa Rosa counties, the top of the Floridan aquifer (fig. 3) lies at depths ranging from about 400 to 1,200 feet below the land surface and is virtually untapped by water wells. Above the limestones of the Floridan aquifer lies a thick sequence of sand, gravel, and clay; nearly all the wells in the area tap permeable sediments within this sequence — referred to in this report as the sand-and-gravel aquifer. In the northern half of the area, the Floridan aquifer and the sand-and-gravel aquifer are in contact with each other, but in the southern part they are separated by a thick clay unit that serves to confine the water that is present in the upper part of the Floridan aquifer. An extensive clay bed, the Bucatunna clay member of the Byram formation, underlies the upper limestone of the Floridan aquifer (fig. 3) and forms an aquiclude throughout the area (Marsh, 1961). The limestones of the Floridan aquifer rest upon relatively impermeable clay and shale.

Test Drilling

In 1959 the U.S. Geological Survey contracted to have six test wells in Escambia County and five test wells in Santa Rosa County drilled by the rotary method. There were two 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 the wells were compiled from an examination of rock

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[1]The stratigraphic nomenclature used herein is that of the Florida Geological Survey and does not necessarily conform to that of the U. S. Geological Survey.

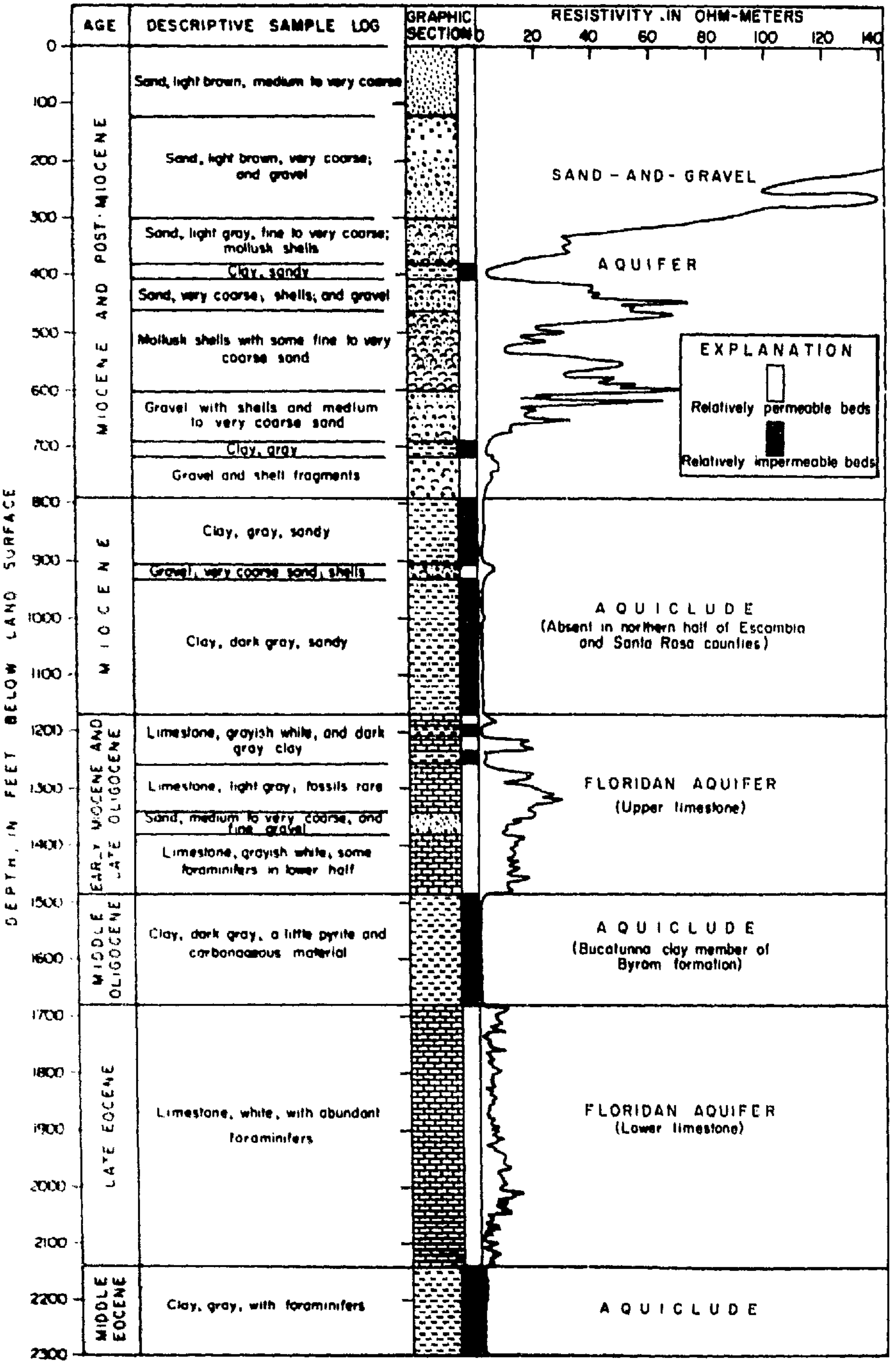

Figure 3. Geologic sequence in Escambia and Santa Rosa counties, Florida, as shown by representative log of oil test well near Pensacola.

cuttings that were collected at intervals of 5 or 10 feet. Fossils were picked from the rock cuttings and will be identified to determine the age of the sand-and-gravel aquifer. Electric logs of the two deepest wells were made to determine accurately the position of clay layers and permeable zones. Second, these test wells made it possible to install recording gages in areas where information on water levels was needed. A total footage of 2,800 feet was drilled, and the depths of the wells ranged from 60 to 750 feet.

Stratigraphy

Aquifers

Sand-and-gravel aquifer: Virtually all the wells in Escambia and Santa Rosa counties draw their water from the sand-and-gravel aquifer. This aquifer extends from the ground surface to various depths, ranging from 350 feet in the northeast corner of Santa Rosa County to 1,000 feet in the center of the area (fig. 4). In the northern half of the area the sand-and-gravel aquifer overlies a thin limestone of late Oligocene age (uppermost part of the Floridan aquifer), but in the southern half of the area the sand-and-gravel aquifer rests upon a thick clay of Miocene age.

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 5. 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 Company 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

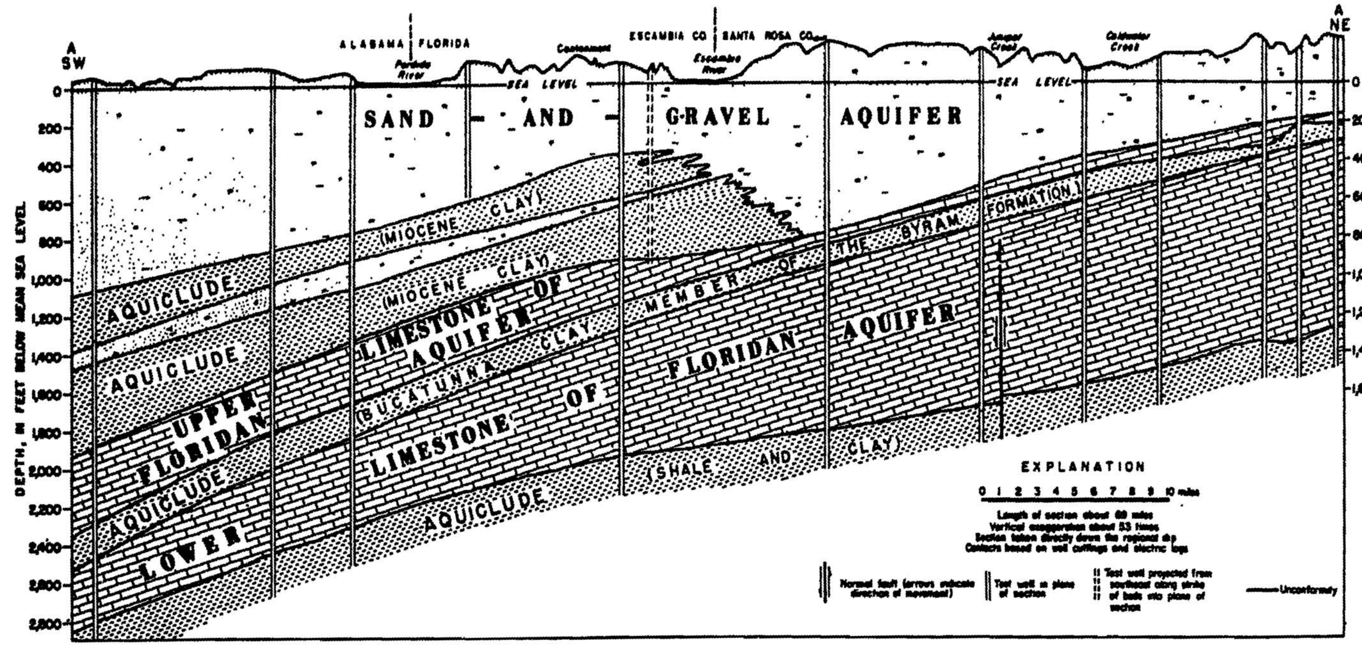

Figure 4. Geologic section across Escambia and Santa Rosa counties showing aquifers and aquicludes along section A-A' in figure 7.

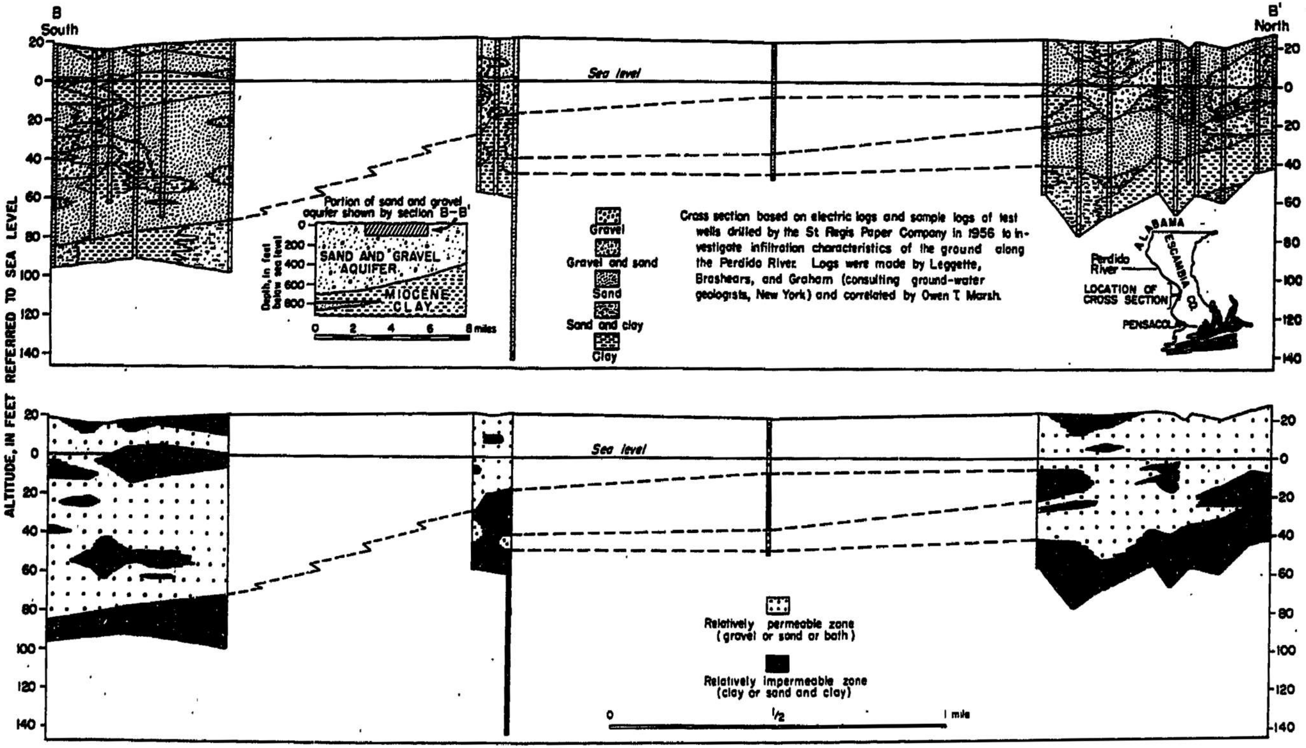

Figure 5. Geologic section showing facies changes and zones of relative permeability and impermeability in the upper part of the sand-and-gravel aquifer along the Perdido River, Escambia County, Florida.

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 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 of the sand is moderately well sorted, it 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 locally into stringers and lenses of gravel which are made up chiefly of pea-sized or slightly larger pebbles. In addition to the large lenses of clay within the aquifer, small amounts 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 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.

The sand-and-gravel aquifer has a rather high average porosity and permeability and is thus an excellent reservoir for ground water. The fact that the aquifer consists principally of relatively insoluble quartz grains 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 or hardpan overlie a saturated, permeable bed. Ground water is under nonartesian conditions where such clays and hardpan are absent. It is not uncommon for a well to tap both artesian and nonartesian water. It was not considered feasible to construct a piezometric map because of the unpredictable differences in head throughout the area. Ground water in the sand-and-gravel aquifer is derived largely 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 a thick clay bed (Bucatunna clay member of the Byram formation) near the top of the aquifer. The part that lies above this clay bed will be referred to in this report as the upper limestone and the part below the clay as the lower limestone.

The upper limestone is chiefly the Chickasawhay limestone of late Oligocene age. Within the area, this formation ranges in thickness from approximately 40 to 160 feet. Its upper surface is an erosional unconformity of low relief which dips gently toward the southwest. In the northern part of Escambia County, the Chickasawhay apparently interfingers with beds of sand and gravel. 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. A few wells in the southern part of the area obtain water from this limestone.

The upper limestone is recharged partly by downward leakage of water from the sand-and-gravel aquifer in northern Escambia and Santa Rosa counties, Florida. Additional recharge comes from rain that falls north of the area in Escambia County, Alabama, and percolates southward or southwestward through the upper limestone, which is underlain by the Bucatunna clay member of the Byram formation.

The lower limestone of the Floridan aquifer in this area consists of the Ocala group of late Eocene age. The top of the lower limestone, although an erosional unconformity, is a relatively flat surface that dips gently toward the southwest. The lower limestone rests unconformably upon shale and clay of middle Eocene age. The lower limestone ranges in thickness from about 300 feet in central Escambia County to as much as 1,200 feet in the northern part of Santa Rosa County (fig. 4). Thus, unlike most sedimentary units along the gulf coast, this limestone thins rather than thickens 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 highly porous and permeable coquina consisting of fossil fragments. This aquifer contains great 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, which constitutes most of the Floridan aquifer, is derived mainly from precipitation 15 miles or so north of the area in Escambia County, Alabama. In the northern part of Escambia and Santa Rosa counties some recharge may occur by leakage of water through the Bucatunna clay member of the Byram formation which overlies the lower limestone.

Aquicludes

Aquicludes within the sand-and-gravel aquifer: As shown by the geologic section along the Perdido River in Escambia County (fig. 5), 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 Taylor Brick Company of Molino in Escambia County mines clay from a bed that 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 commonly 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 widely used in the construction of stone walls and occasionally in the construction of 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 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 causing 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. Inconvenience 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 between the two aquifers: A thick clay unit of Miocene age (fig. 4, 6) lies between the sand-and-gravel aquifer and the Floridan aquifer in the southern part of the area. The observed thickness of this clay ranges from about 600 feet $1\frac{1}{2}$ miles southwest of Pensacola to about 240 feet 5 miles east of Milton. As shown by the structure-contour map (fig. 6), the upper surface of the clay forms a westward-trending trough which is more than 600 feet deep beneath the upper part of Perdido Bay. This results in a correspondingly greater thickness of the sand-and-gravel aquifer above the trough.

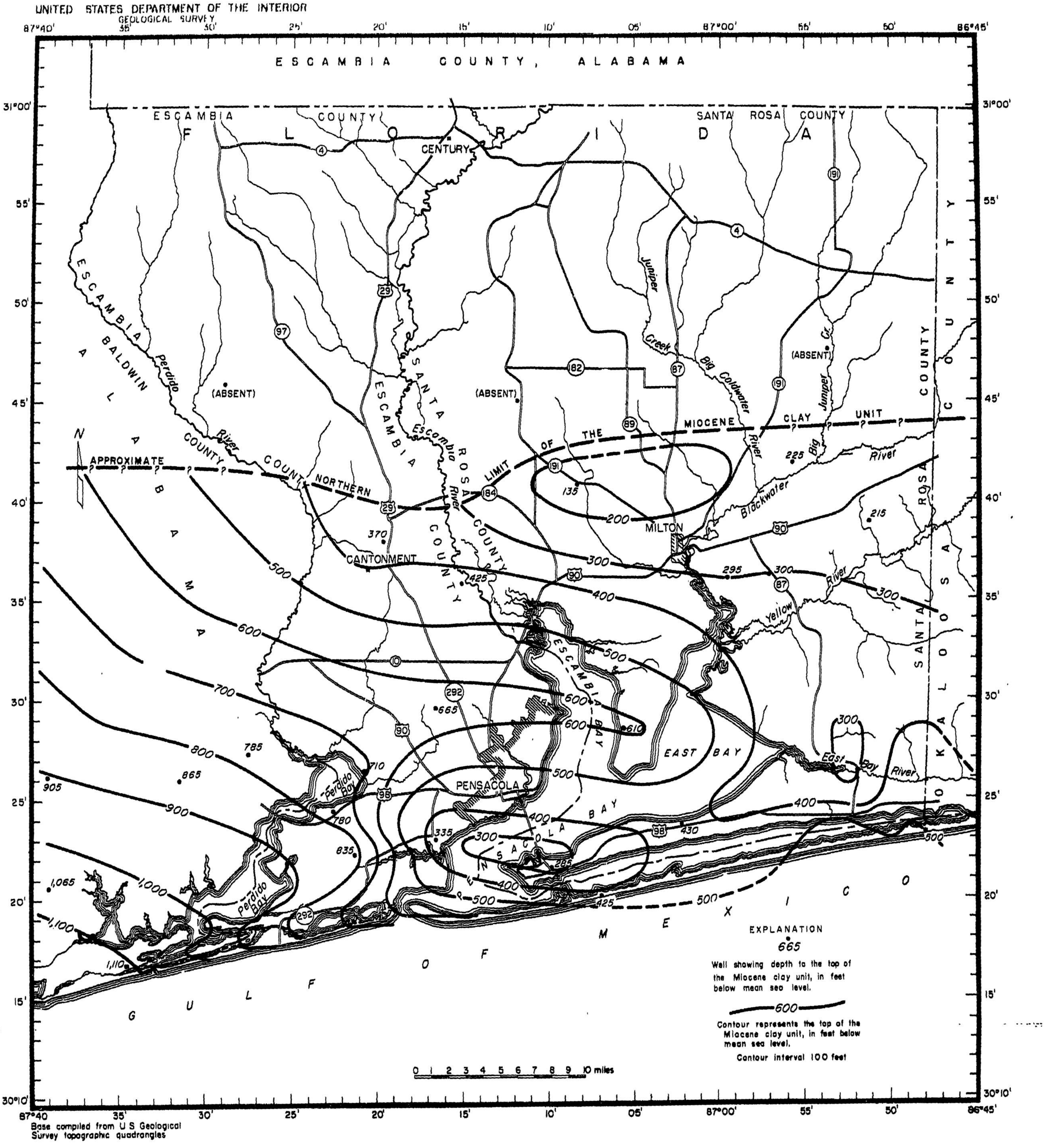

Figure 6. Map of Escambia and Santa Rosa counties showing contours on top of Miocene clay unit.

A few miles north of Cantonment, the clay interfingers with beds of sand and gravel (fig. 4). Southward from Ensley, the clay unit splits into two beds — the upper about 100 feet thick, the lower about 230 feet thick within the area — separated by as much as 140 feet of sand.

The clay that makes up this unit 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 the unit that local drillers call the "Blue Marl."

Aquicludes within the Floridan aquifer: The Bucatunna clay member of the Byram formation of middle Oligocene age (Marsh, 1961), which separates the upper and lower limestones of the Floridan aquifer, 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 unconformably 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 sandy 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 highly porous, it contains zones of dense rock which were probably caused by solution and re-precipitation of calcite. These dense layers serve to prevent or retard upward movement of water and thus may be classed as aquicludes.

The lower part 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 are discontinuous, they probably have little effect on the water in the limestone. However, they reduce the average transmissibility (see p.68) of the aquifer.

Aquiclude below the Floridan aquifer: The Floridan aquifer is underlain everywhere in the area by gray shale and clay of middle Eocene age. The top of the 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. 7). This surface strikes about N. 65° W. and dips about 30 feet per mile toward the southwest. Probably the sand-and-gravel aquifer has a gentler dip. Although the top of the Floridan aquifer has not been contoured, it is safe to assume that it also dips southwestward.

Relationship of Geology to Ground Water

Movement of Water

The direction of ground-water flow is determined primarily 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 relatively impermeable Miocene clay unit and the Bucatunna clay member, which dip gently toward the southwest, ground water in the Floridan aquifer probably is moving generally southwestward in the area. On the other hand, the dip of strata in the sand-and-gravel aquifer is so slight that ground-water flow in this aquifer is probably controlled principally by differences in head resulting from local topographic irregularities.

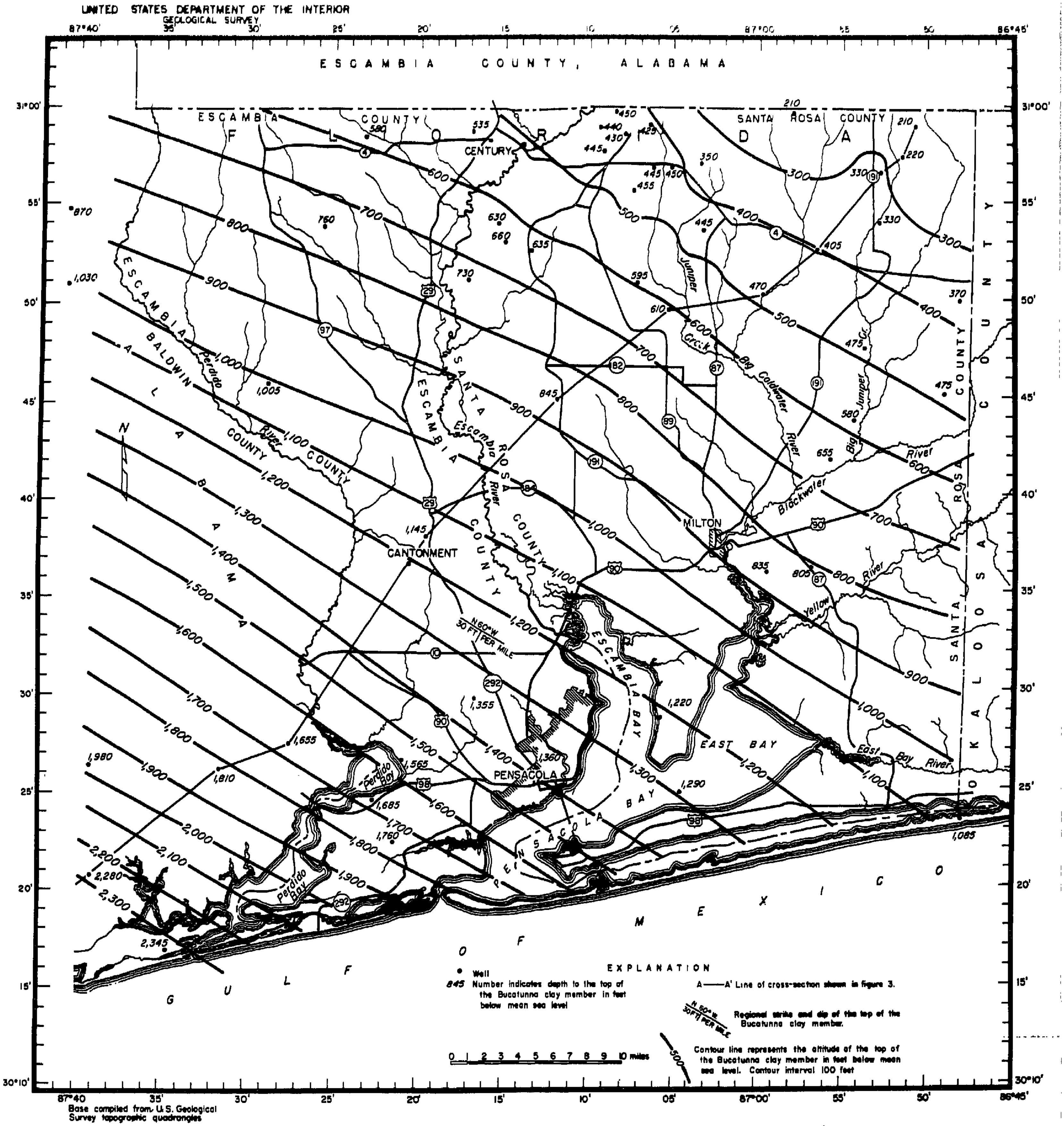

Figure 7. Map of Escambia and Santa Rosa counties showing contours on top of Bucatunna clay member of Byram formation.

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 salt water may move upward along faults in the lower part of the Floridan aquifer.

Relationship 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 large quantities of both fresh and salt water. In the northern half of the area, the uppermost few hundred feet of the limestone beneath the Bucatunna clay member (lower limestone of the Floridan aquifer) contains fresh water. At depths greater than 1,200 feet, the limestone contains salt water. In the southern part of the area, the lower limestone contains only salt 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 fresh water in the upper limestone. The water in the upper limestone becomes salty downdip, a few miles from where section A-A' (fig. 4) crosses the Perdido River. The same is true of the water in the sand-and-gravel tongue that lies within the thick Miocene clay unit (fig. 4). Although no samples of water from these salt-water zones are available for analysis, zones of fresh and salty water may be distinguished on electric logs. An analysis of more than 40 electric logs was made for this purpose in the course of the present study.

Mineralization and hardness of ground water: In addition to differences in salinity, ground water in the sand-and-gravel aquifer and the Floridan aquifer differs in amount of dissolved solids and hardness (see p. 71) because of differences in lithology of the two aquifers. As might be expected, water in the Floridan aquifer (composed mostly of limestone) is 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 sand-and-gravel aquifer, it encounters very little soluble material and consequently remains soft and virtually unmineralized. 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 is more or less mineralized because 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. Apparently the main area of subsidence did not extend far enough to the east to depress greatly the limestones of peninsular Florida.

SURFACE WATER

Escambia and Santa Rosa counties have an abundant supply of surface water. More than $7\frac{1}{2}$ bgd flow into the bays along the southern ends of the counties from the four major rivers, the Perdido, the Escambia, the Blackwater, and the Yellow. This adequate supply of surface water allows many varied activities to be carried on within the area.

The following discussion on surface water describes briefly the scope of the data-collection program and gives interpretations of streamflow data, stream characteristics, and chemical analyses by river basins. These basins are outlined in figure 8.

The Collection of Data

The early streamflow data in Escambia and Santa Rosa counties were collected at three stations — one in each of three major river basins. The collection of data began in

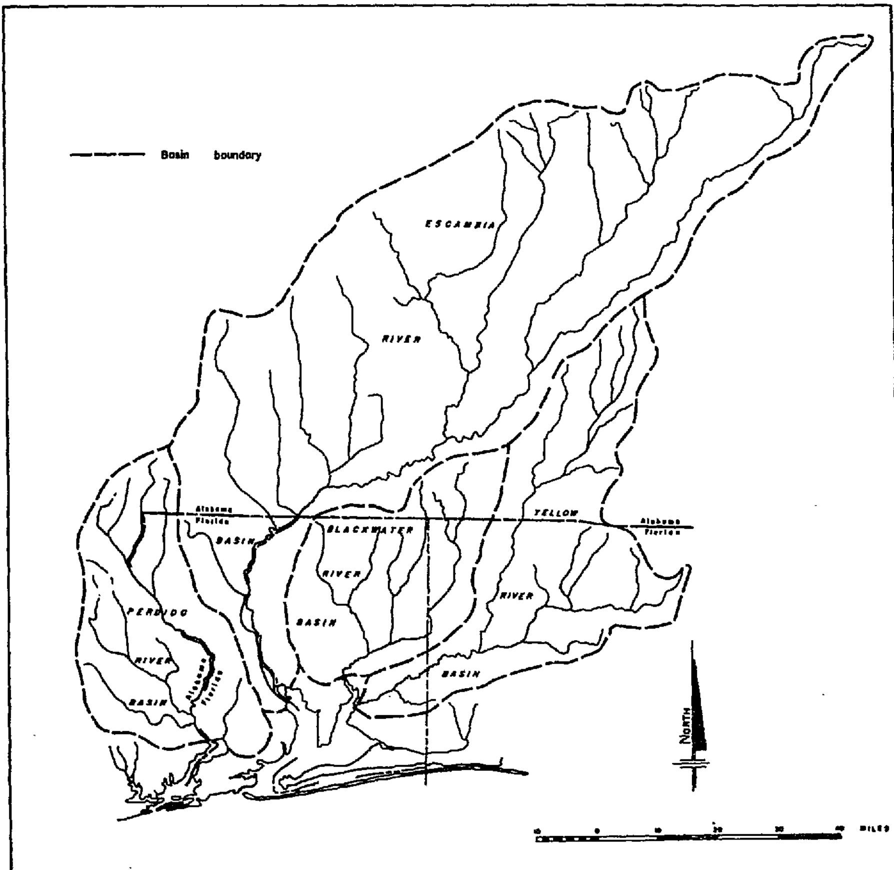

Figure 8. Basin map of the Perdido, Escambia, Blackwater, and Yellow rivers.

the Escambia River basin in 1934; in the Blackwater River basin in 1938; and in the Perdido River basin in 1941. Data at other points in these basins and also in the Yellow River basin have been collected in Alabama and Okaloosa County, Florida. To meet the demand for more information about surface water, the collection of streamflow data was started on Pine Barren Creek in the Escambia River basin in 1952, while prior to this, the collection of stage data on the lower Escambia River, in the vicinity of the Chemstrand nylon plant, was started in 1951. Chemical analyses at two stations, one on Pine Barren Creek and one on Escambia River, have been obtained on a systematic basis since 1952.

The present program of investigation was started in early 1958. This program will define the streamflow conditions in the area and determine the water supply available. Prior to the present investigation, stream gaging was limited to the larger streams. The three earliest stations gaged flow from drainage areas of 237, 394, and 3,817 square miles. Gaged flow from smaller areas helps to define the component characteristics of the larger basins and provides a basis for computing, more accurately, flow from ungaged areas. Also, as the economy of an area expands, more importance is placed on the smaller streams. For example, at Pensacola, the upper 11 square miles of the Bayou Marcus Creek basin are being developed to provide storage reservoirs that will enhance the value of the land for residential purposes. The present investigation collects data on drainage areas as small as 11.2 square miles.

Nineteen data-collection sites were established as part of the present program of investigation. Also, field reconnaissances are being made throughout the area to relate the characteristics of ungaged areas to gaged areas, to determine existing surface-water problems, and to determine future demands on surface-water supplies.

The duration of surface water records is given in figure 9, and the locations of data-collection sites are shown on the map in figure 10.

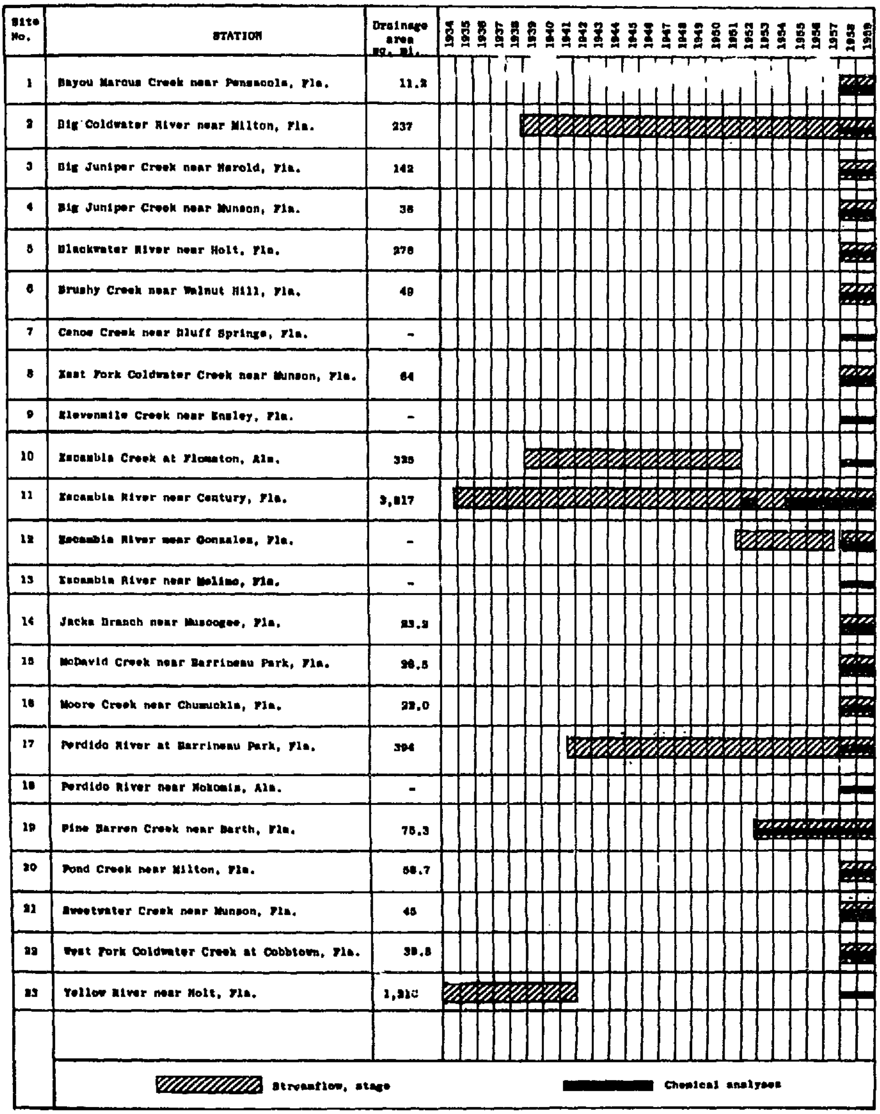

Figure 9. Bar graph showing duration and types of surface-water records in Escambia and Santa Rosa counties, Florida.

Occurrence and Quality

Surface water occurs in the area as streams, many small natural ponds, a few manmade ponds, and estuarine bays. Streams are the main source of fresh water. The area has an abundance of streams carrying great quantities of water of excellent quality. Small reservoirs created by dams are, at present, few in number. However, much of the terrain lends itself well to small reservoirs, and a larger number will probably be built as the economy of the area expands. The bays along the coast cover over 200 square miles and provide excellent facilities for boating, fishing, swimming, and shipping.

Tides from the Gulf of Mexico push salt water into the bays and into the lower reaches of the rivers. The salt-water front extends farther upstream during periods of low streamflow, and it extends even farther upstream during periods when low streamflow coincides with seasonal high tides. The chloride content and flow of Escambia River are shown on figure 11. This illustration shows that a high chloride content can be expected at the Chemstrand nylon plant, 7 miles upstream from the mouth, when the flow of Escambia River is low.

The presence of salt in the lower reaches of rivers limits the usefulness of the water for some purposes. It is also a potential source of contaminant to the adjacent supply of ground water.

The quality of the area's surface water is exceedingly good. Fresh water in the streams above tide effect is extremely low in mineral content, is soft, and has very little color. The small streams originating in the area have a maximum mineral content of about 50 ppm. The Escambia River, entering the area from Alabama, has a maximum mineral content of about 100 ppm. Minerals most prevalent in the streams are silica, calcium, sodium, iron, bicarbonate and chlorides. Except for color imparted to the water by flood runoff, the smaller streams are almost crystal clear.

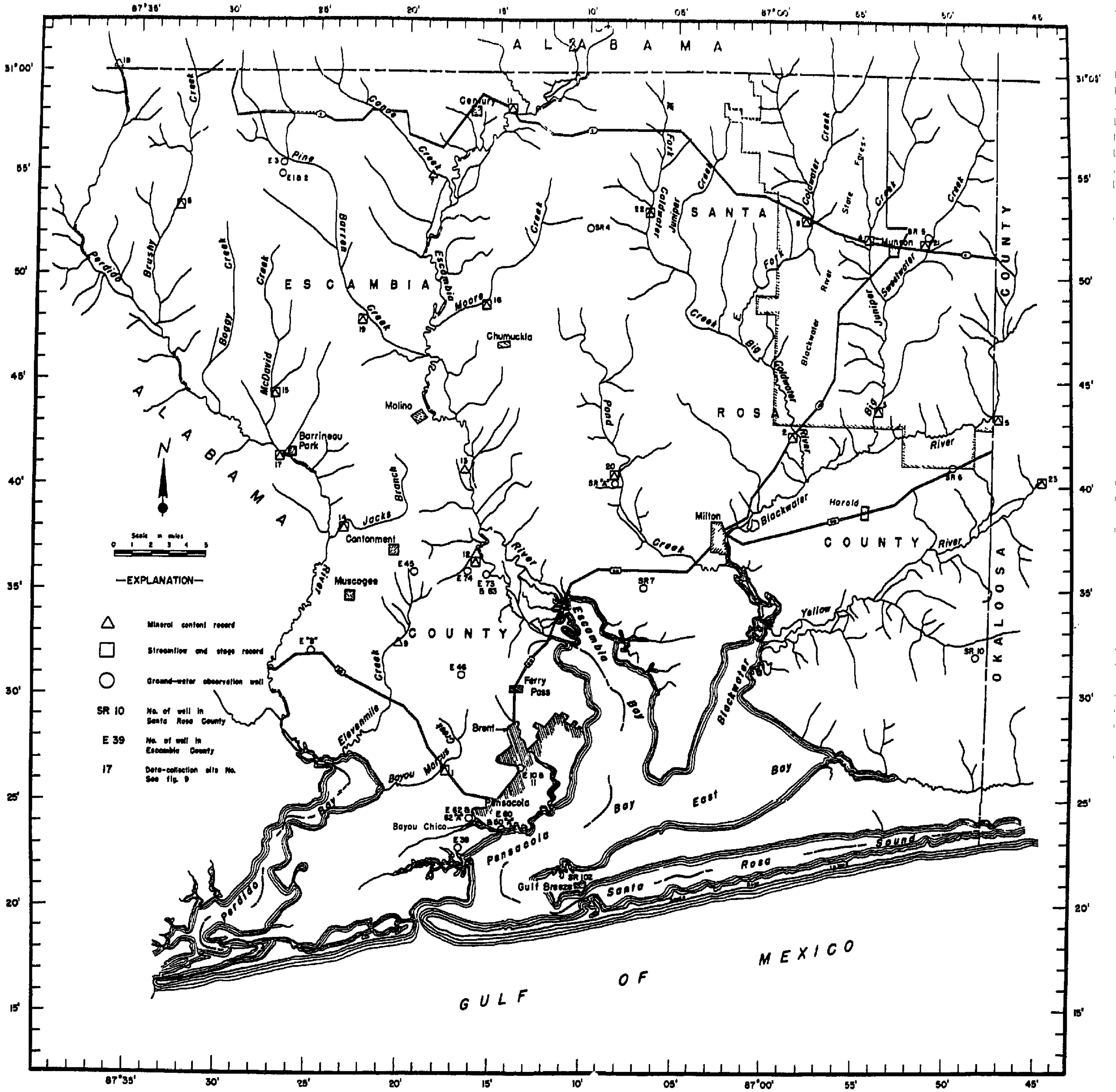

Figure 10. Map of Escambia and Santa Rosa counties, Florida, showing surface drainage and data-collection points.

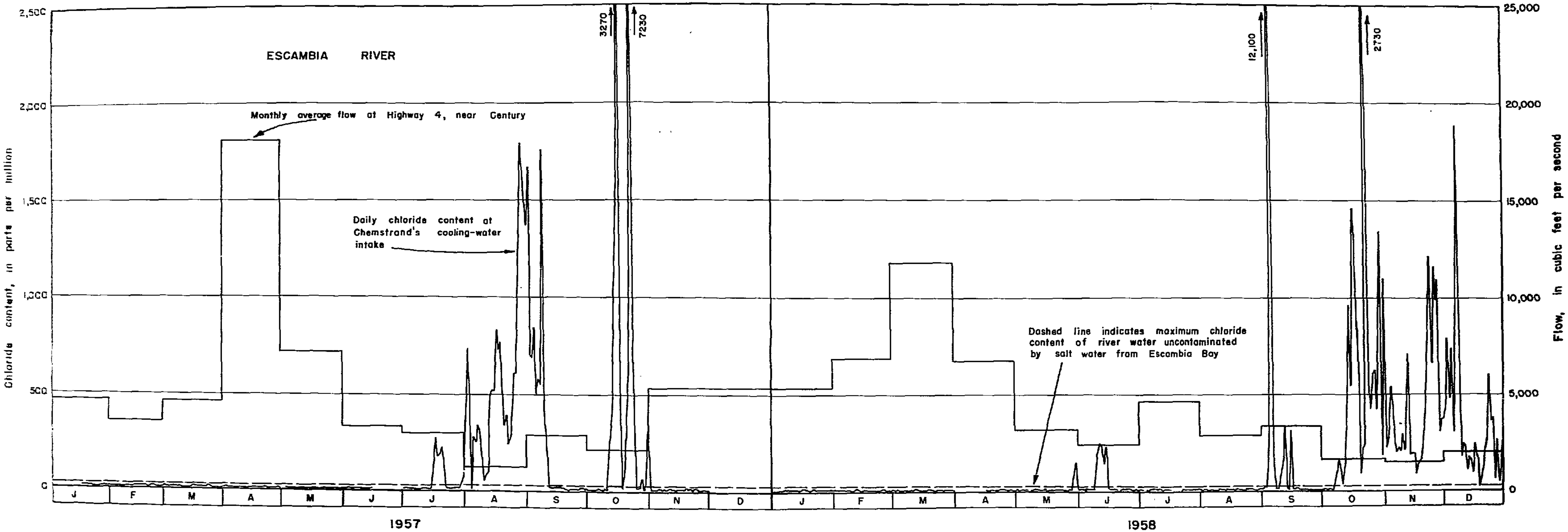

Figure 11. Chloride content of the Escambia River taken daily at Chemstrand Corporation's cooling-water intake and monthly flows of Escambia River at State Highway 4, near Century, Florida, 1957, 1958.

The ranges in mineral content for seven streams are given in table 1. The most noteworthy characteristics of the water are the low mineral content and the narrow range in concentration. The latter indicates that seasonal fluctuations are minor.

The quantity and 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 and quality of surface water within the two-county area.

Perdido River Basin

The Perdido River, the westernmost stream in Florida, forms the north-south boundary between Florida and Alabama. The part of the basin in Florida lies in a narrow band along the eastern side of the main channel. 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 Bayou Marcus Creek, which flow into Perdido Bay, are included in the discussion of the Perdido River basin.

The basin, outlined on the map in figure 8, covers 925 square miles. Of this area, 238 square miles are in Florida. Streams in the basin drain very hilly country. The hills rise 100 to 150 feet above the stream valleys. The fall of the Perdido River streambed from the northwestern corner of the State to the town of Muscogee is 150 feet, and from Muscogee to Perdido Bay the fall is 15 feet (taken from topographic maps).

Tidal fluctuations occur in the lower reach of the river. The distance upstream from the mouth to the upper limit of tide fluctuation depends on the elevation and slope of the streambed and magnitude of the river flow. Tidal effect will extend the greatest distance upstream during periods when the river flow is low and the tides are at seasonal highs. During periods of low flow, tidal effects extend upstream to

Table 1. Range in Mineral Content for Seven Streams in Escambia and Santa Rosa Counties

Stream	Number of analysis	Range in parts per million: Total dissolved solids	Silica	Calcium	Bicarbonates	Sodium	Chlorides	Iron	*Color
Big Coldwater River near Milton	13	11 - 21	2 - 11	0.6 - 2	2 - 4	1 - 2	3 - 4	0.01 - 0.4	5 - 10
Big Juniper Creek near Harold	14	13 - 24	6 - 8	.6 - 2	2 - 7	1 - 2	2 - 4	.02 - .3	4 - 25
Blackwater River near Holt	13	14 - 26	2 - 10	.8 - 1	1 - 4	1 - 2	2 - 4	.02 - .6	4 - 45
Escambia River near Century	127	47 - 101	5 - 21	1 - 17	8 - 51	1 - 10	3 - 22	.04 - .7	4 - 120
Perdido River at Barrineau Park	44	17 - 52	5 - 15	.6 - 3	1 - 13	2 - 4	3 - 5	.03 - .8	3 - 60
Pine Barren Creek near Barth	49	11 - 38	2 - 9	.4 - 2	1 - 6	.8 - 2	1 - 6	.01 - 1.2	0 - 72
Yellow River near Milligan	17	27 - 53	4 - 9	2 - 11	8 - 42	2 - 3	2 - 4	.00 - .7	5 - 60

*Expressed in platinum-cobalt scale units.

the reach of the river between the U. S. Highway 90 crossing and the town of Muscogee, 15 miles above the mouth. The salt front, however, does not extend as far upstream as the tidal effect. The upstream movement of the salt front can be retarded or stopped by low-head dams serving as salt barriers.

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 is characterized by sandbars and deep holes.

The steep hill and channel slopes cause 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 mean sea level in March 1929. This is in comparison to a usual low-water level of 28 feet above mean sea level. During the flood of April 1955, which was the highest in the 17-year period ending in 1958, the river reached a peak flow of 39,000 cubic feet per second at an elevation of 49.7 feet above sea level at the Barrineau Park gaging station.

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, 1957). Regional flood frequency curves applicable to this area have been developed from this report and are presented in figure 12.

Other items to be examined in considering an area for development are data on the quantity and quality of water available. 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,

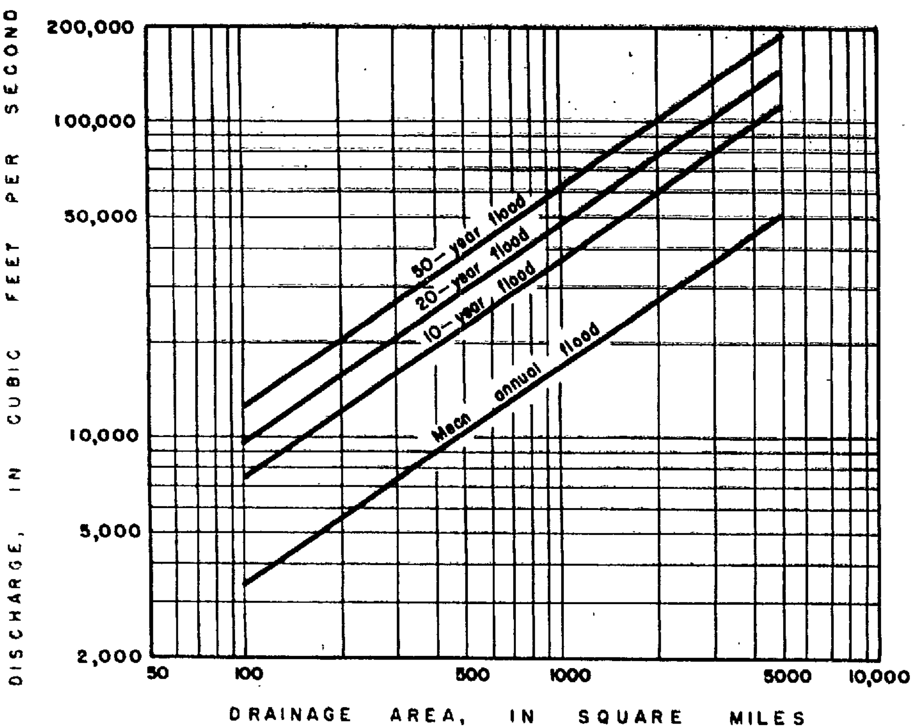

Figure 12. Regional flood frequency curves for the Perdido, Escambia, Blackwater, and Yellow River basins.

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.

Data collected at Barrineau Park (see table 1) show the river water to be of very desirable quality. The mineral content ranges from 17 to 52 ppm, with silica being the most prominent mineral, having a range from 5 to 15 ppm. The color of the water ranges from 3 to 60 units. A color of 20 units is considered the upper limit for drinking water. Results of analyses from samples collected farther upstream, near the town of Nokomis, Alabama, indicate the water there to be essentialy the same as at Barrineau Park.

The low-flow frequency curves given in figure 13 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 2.6 years, or as a 30-day average once in every 6 years.

The Perdido River basin yields copious quantities of water. The average runoff at Barrineau Park is 25.9 inches per year. That is, the average flow of 752 cfs (cubic feet per second) for 1 year would cover the drainage area of 394 square miles to a depth of 25.9 inches. This is in comparison with the State average runoff that is 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 62 inches per year; and (2) the coarse sand and gravel covering the area that release water to the streams as seepage from the water table or as artesian flow from local aquifers.

The pattern of variation of flow with respect to time is similar to the rainfall pattern. March and April are by far the months of highest runoff, and October stands out as the month of lowest runoff. The bar graph in figure 14 shows the average, maximum, and minimum monthly discharges for the Perdido River at Barrineau Park for the 18-year period 1942-59.

The flow-duration curve for Perdido River in figure 15 shows some other flow characteristics at Barrineau Park. The slope of this curve indicates the variability of flow. This stream has high flood flows, as well as relatively stable flows during medium and low-water periods. The flow of Perdido River is comparatively stable because of ground-water seepage into the stream. The period of lowest flow was caused by a prolonged period of deficient rainfall in 1954-56. The runoff at the Barrineau Park gaging station reflects the average of all contributing areas above the station.

Records of flow are being collected on four tributaries in this basin. A cursory analysis of the low-water records

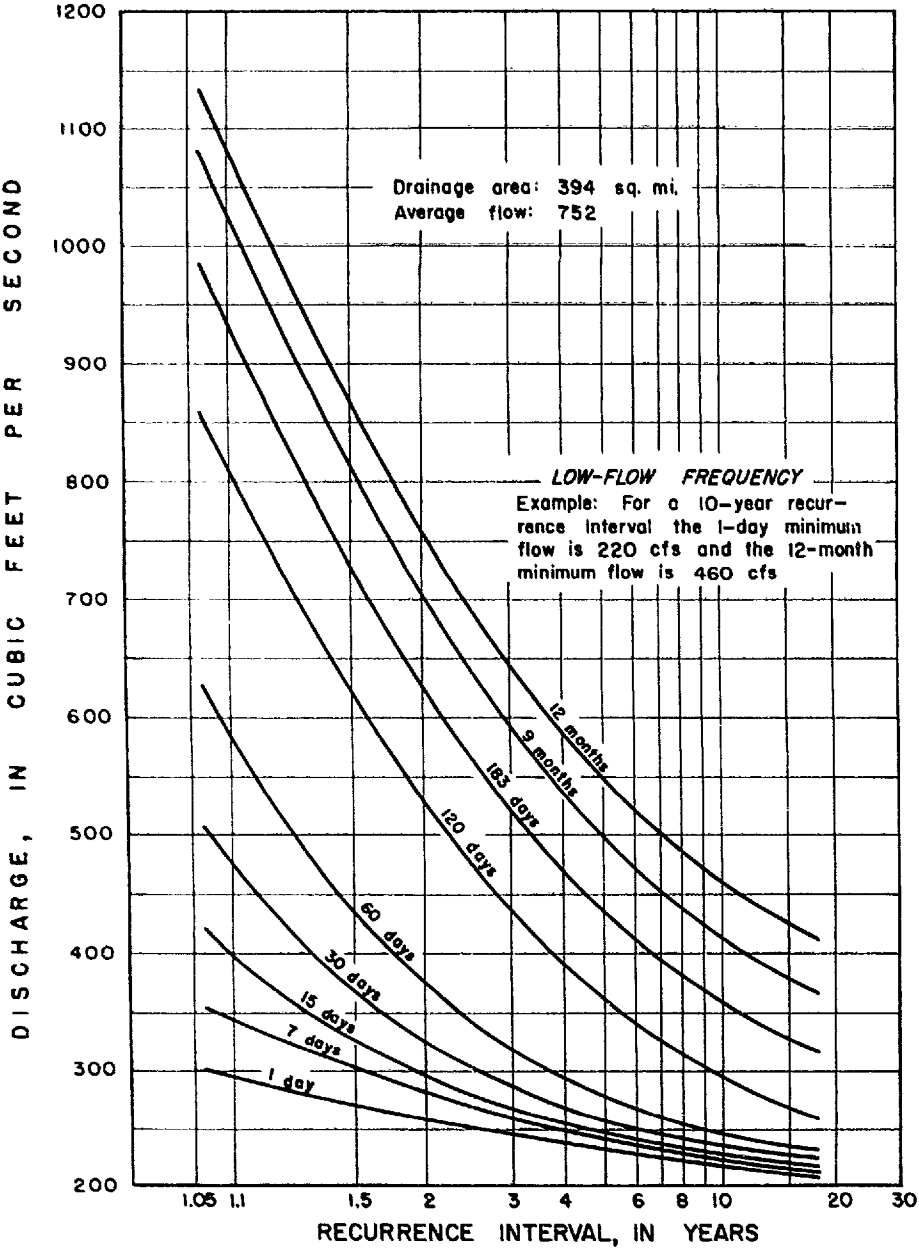

Figure 13. Low-flow frequency curves for Perdido River at Barrineau Park, Florida, 1941-58.

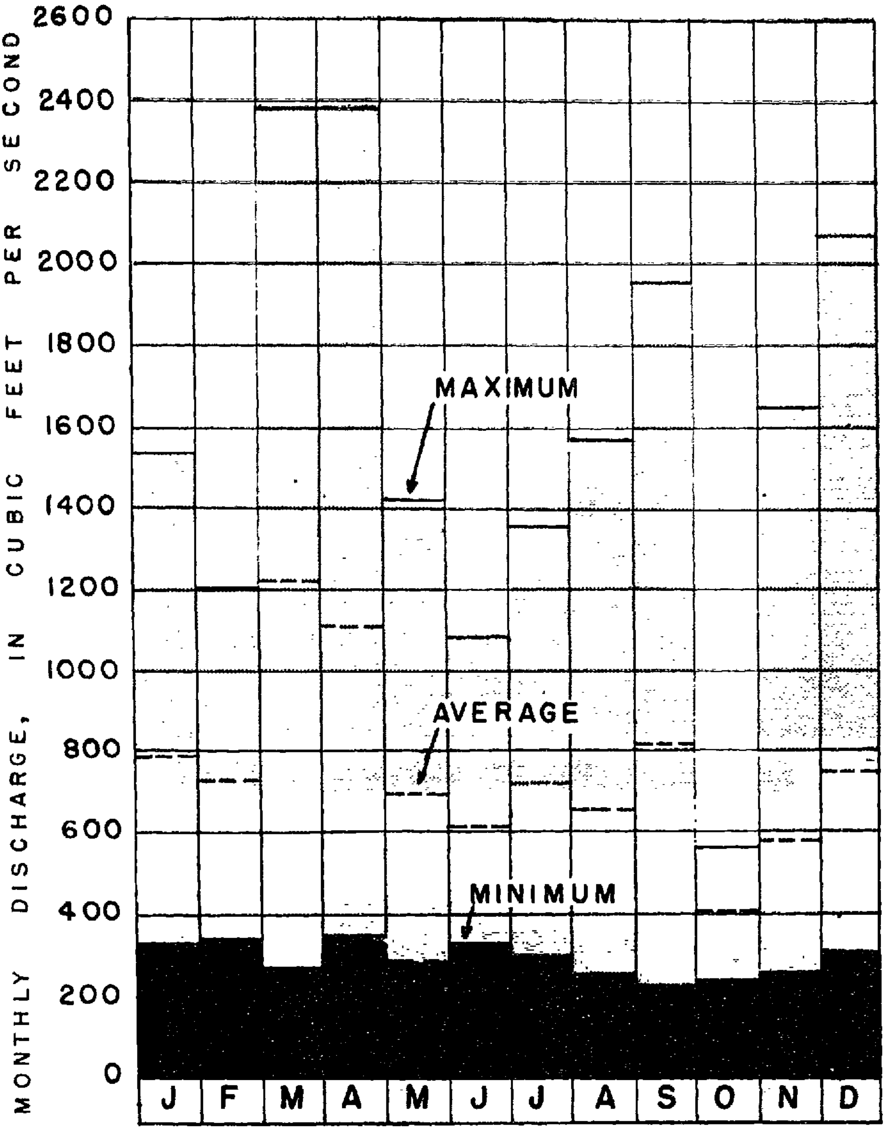

Figure 14. Bar graph of the minimum, average, and maximum monthly discharge of the Perdido River at Barrineau Park, Florida, 1942-59.

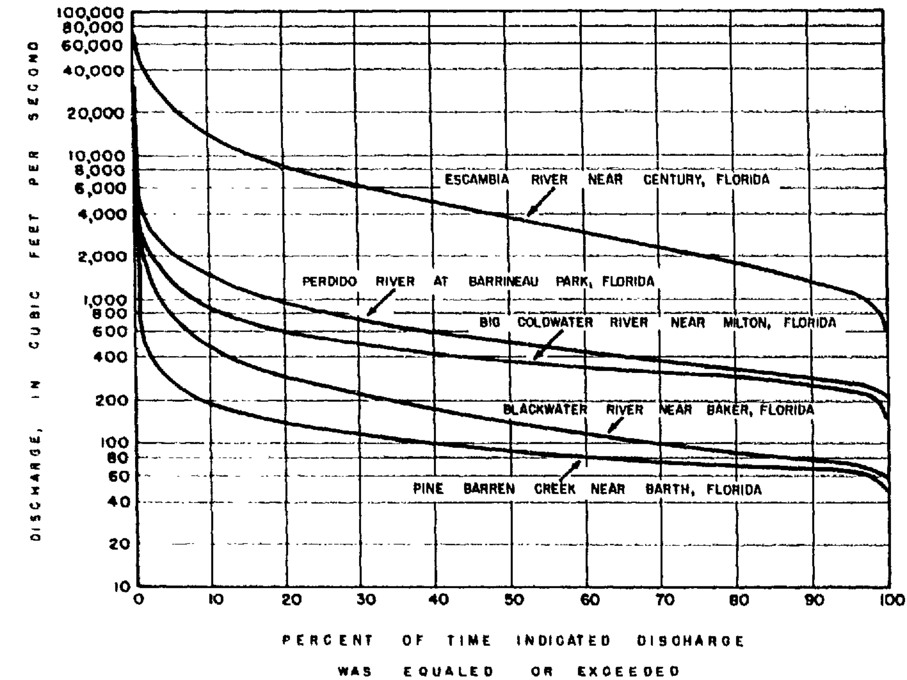

Figure 15. Flow-duration curves.

collected during the 2-year period, 1958-59, is included. The purpose of this analysis is to give an indication of the average yield from these gaged areas.

Brushy Creek drains 75 square miles — 53 square miles in the extreme northwest corner of Florida and 22 square miles in southern Alabama. The flow from this creek enters the Perdido River 13 miles above Barrineau Park. The low-water yield during the gaged period from the upper 49 square miles of this basin was at the rate of 20 inches per year (47 mgd). The low-water yield of the Perdido River at Barrineau Park during the same period was 10 inches per year from 394 square miles. Based on the ratio of the low-water yield to the average yield of the Perdido River, the average yield of Brushy Creek would be 50 inches per year. This yield ranks among the highest in the State. The water in this creek has a mineral content of about 25 ppm.

McDavid Creek joins the Perdido River a mile above Barrineau Park and has a low-water flow of about 20 cfs (13 mgd) from a drainage area of 26.5 square miles. The low-water yield of this basin is estimated to be 10 inches per year, which is equal to the low-water yield of the Perdido River above Barrineau Park. The mineral content of this water is about 20 ppm.

Jacks Branch drains 24.2 square miles north of Cantonment and has an extremely low yield compared to other streams in the area. A low flow of 4 cfs (2.6 mgd) was measured from the upper 23.2 square miles of this basin. Converted to runoff in inches, this equals 2.3 inches per year. The mineral content of Jacks Branch is about 25 ppm.

Elevenmile Creek drains into the north end of Perdido Bay and is used for industrial waste disposal. The water in this stream has a mineral content of 400 to 900 ppm and is extremely high in color.

Bayou Marcus Creek is the most downstream tributary in the Perdido River basin. It drains 25.9 square miles along the northwestern outskirts of Pensacola and empties into Perdido Bay. The lowest base flow recorded during the 2-year period, 1958-59, was 25 cfs (16 mgd). This flow is from 11.2 square miles and equals 30 inches per year, which is an extremely high base flow. The upper part of this basin above U. S. Highway 90, is being developed for storage reservoirs to enhance the value of land for residential purposes. Bayou Marcus Creek has a mineral content of about 30 ppm.

Escambia River Basin

The Escambia River is the largest source of surface water within the study area and the fifth largest in the State. The basin as outlined in figure 8 covers 4,233 square miles, of which 413 square miles are in Florida. The main channel starts near Union Springs, Alabama, as the Conecuh River and flows in a southwesterly direction to the Florida-Alabama State line near Century, Florida. Near the State line the name changes to Escambia River. The Escambia River flows in a southerly direction and empties into Escambia Bay north of Pensacola.

The Escambia River water at Century is not quite as low in mineral content, 47 to 101 ppm, as water in the nearby smaller streams. However, a mineral content of 100 ppm is not objectionable for many uses. The minerals present in the largest quantities are silica (5 to 21 ppm), bicarbonates (8 to 51 ppm), and chlorides (3 to 22 ppm). Other quality data is given in table 1.

For purposes of discussion the basin is divided into two parts, the lower and upper basins, with the divide being at Pine Barren Creek. The lower part of the river exerts a major influence on the area, not only because it serves as a source of water supply but also because of its physical size and location with respect to the fast developing industrial area at Pensacola. The upper basin has many tributaries. 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 August 24, 1954. 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.

Below Pine Barren Creek the tributaries are short and drain small areas. The ridges forming the drainage divides vary in elevation from 150 to 200 feet above sea level. The flood plain is about 15 feet above sea level near Pine Barren Creek and slopes 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. Above Pine Barren Creek the basin spreads out and larger tributaries join the main channel.

Pine Barren Creek drains an area of 98.1 square miles, most of which is in Escambia County, Florida. The creek's headwaters are near the town of Atmore, Alabama, 2 miles north of the State line. The average yield of Pine Barren Creek is 22 inches per year, about one-third of the rainfall on the basin. A very substantial base flow of 60 cfs (39.9 mgd) has been measured from an 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 reasonable to assume that the magnitude of flow at any point in the basin is proportional to the size of the area drained above that point.

The flow-duration curve for Pine Barren Creek in figure 15 shows some of the streamflow characteristics at the gaging station during the 6-year period, 1953-58.

The upper end of this curve, where it is almost vertical represents short periods of exceedingly high flows. These periods of high flow are a result of rainfall and basin physiography. As pointed out in an earlier section of this report, the area receives large amounts of rainfall. The basin has an elongated shape — about six times longer than it is wide, with steep hills and valley slopes. These factors give rise to 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 next channel, the Escambia River. The channel-bottom profile of Pine Barren Creek is given in figure 16. This channel has a 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

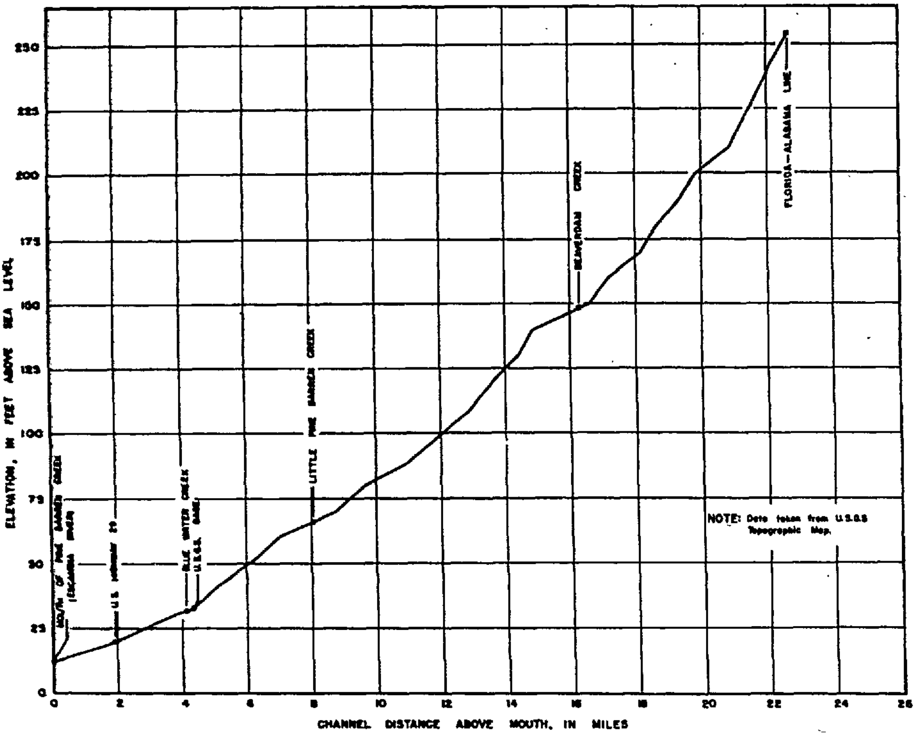

Figure 16. Channel-bottom profile of Pine Barren Creek.

daily flow for April 4, 1955, was 9,460 cfs and the peak flow on the same day was 24,800 cfs — over $2\frac{1}{2}$ times greater.

The flow-duration curve for Pine Barren Creek, figure 15, shows the percent of time a specified discharge has been equalled or exceeded during a 6-year period. For example, the mean daily flows at the gaging station were greater than 62 cfs (40 mgd) for 97 percent of the time. If an industry needs a water supply of 40 mgd, a deficiency 3 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 3 percent of the time, on the other hand, could prove disastrous if it came in a continuous period of two months' duration. The data given in figure 17 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 17. 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.

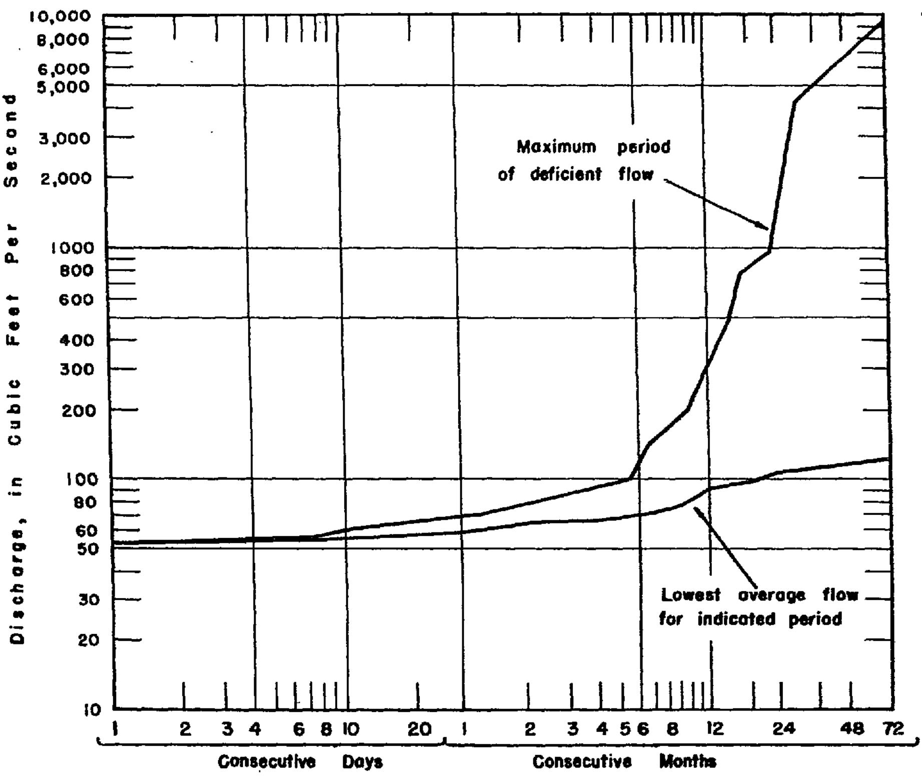

Figure 17. Discharge available without storage, Pine Barren Creek near Barth, Florida, 1952-58.

From this study it can be determined if the flow is sufficient for a particular use without storage. If storage is needed to maintain a higher flow than the stream will produce naturally, the amount of storage required can be determined from the mass-flow curve given in figure 18. The volume

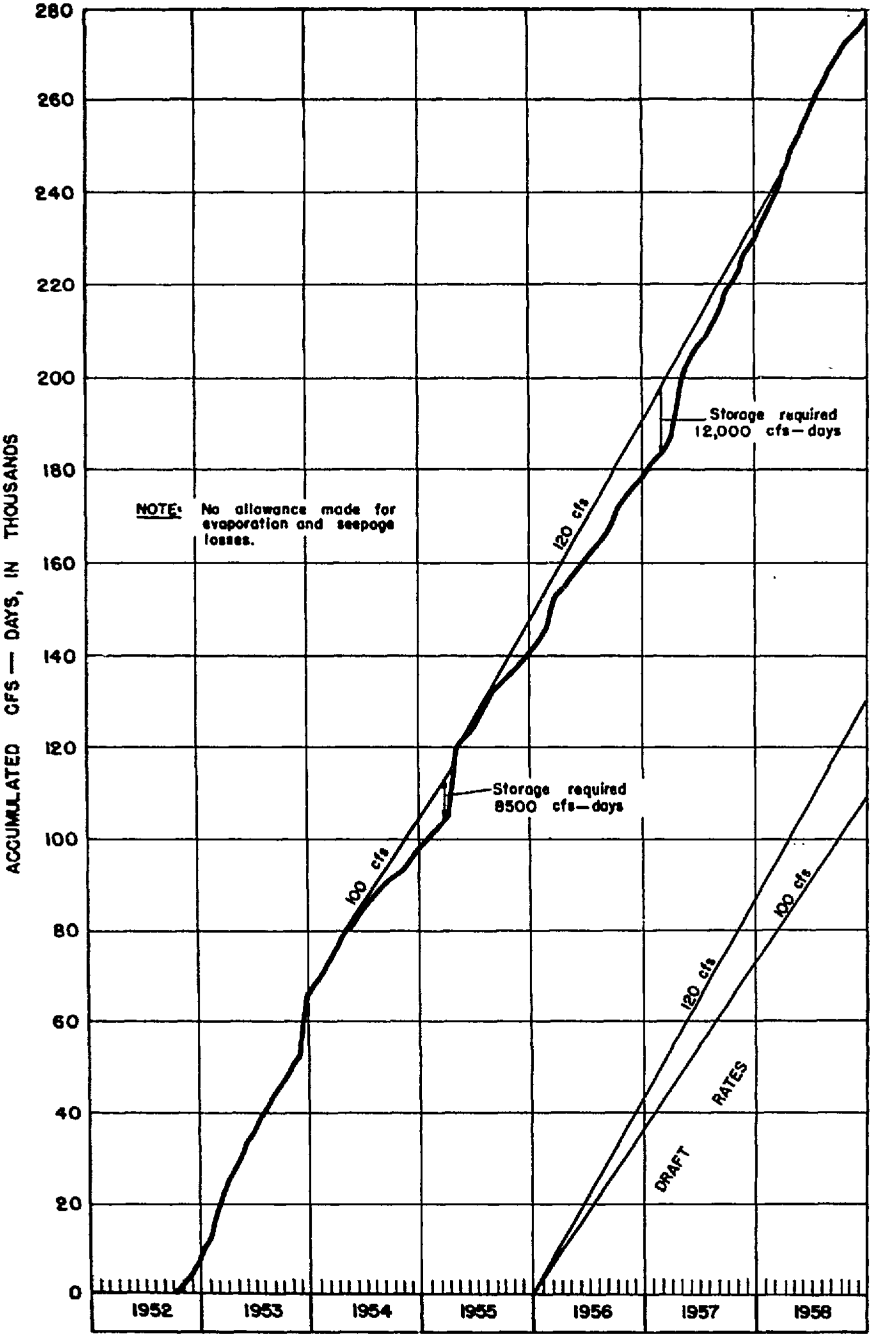

Figure 18. Mass-flow curve for Pine Barren Creek near Barth, Florida, 1952-58.

of water required in a reservoir can be determined by superimposing a line representing the flow required 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.

The Pine Barren Creek water is of excellent quality. The mineral content did not exceed 38 ppm during the period 1953-59. Silica is the predominant constituent with a maximum measured content of 9 ppm. The iron content has not exceeded 1.2 ppm. The water is almost colorless most of the time.

The Moore Creek watershed lies within Santa Rosa County. The flow from this creek enters the Escambia River just above Pine Barren Creek. Three discharge measurements indicate the yield from this basin to be approximately the same as Pine Barren Creek basin, about 22 inches per year. Pine Barren Creek was flowing at about average rate when the Moore Creek measurements were made. The average flow from the upper 22.0 square miles of the Moore Creek basin, based on these measurements, is about 35 cfs (22.6 mgd). The mineral content of the water is about 20 ppm and it has little or no color.

Canoe Creek lies mostly within Escambia County, Florida, with its headwaters 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. The water is almost crystal clear and has a mineral content of about 25 ppm.

The drainage area of the Escambia River at the Century gaging station is 3,817 square miles. The basin above the Century gaging station 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 above Century. All the large tributaries have their headwaters along the northern edge of the basin and flow south to the Conecuh River.

The seasonal distribution of flow at the Century gaging station, although from a large area located in Alabama, shows a pattern similar to that of the smaller nearby streams in Florida. The bar graph in figure 19 shows the seasonal distribution of flows at the gaging station located on State Highway 4 near Century for a 24-year period. The highest flows occur in March and April while September, October, and November flows are the lowest. The variation of flows for any month can be great. January, although not the month of highest flow, has the greatest variation of flows with the average monthly flows varying from a low of 1,900 cfs to a maximum of 31,500 cfs. The average flows for October, the month of lowest flow, have varied from 666 cfs to 6,520 cfs.

Some streamflow characteristics for the 24-year period of record at State Highway 4 are expressed by the flow-duration curve shown in figure 15. Based on the flow-duration curve, the flow has been below 1,000 cfs (646 mgd) for only 4 percent of the time. The maximum flow during the 24-year period ending in 1958 was 73,900 cfs, and the minimum flow recorded was 600 cfs (388 mgd). The computed peak discharge for the flood of March 1929, which reached an elevation of 66.1 feet above sea level and rose 4.5 feet above the floor of the bridge, was 315,000 cfs. Regional flood-frequency curves for the Escambia River basin are given in figure 12.

The average yield per unit area from the Escambia River basin appears to be evenly distributed. Based on records of the eight gaging stations that are located throughout the basin, the average yield is about 20 inches per year, ranging from a low of 18.3 inches to a high of 21.5 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 at State Highway 4 was 21.5 inches per year.

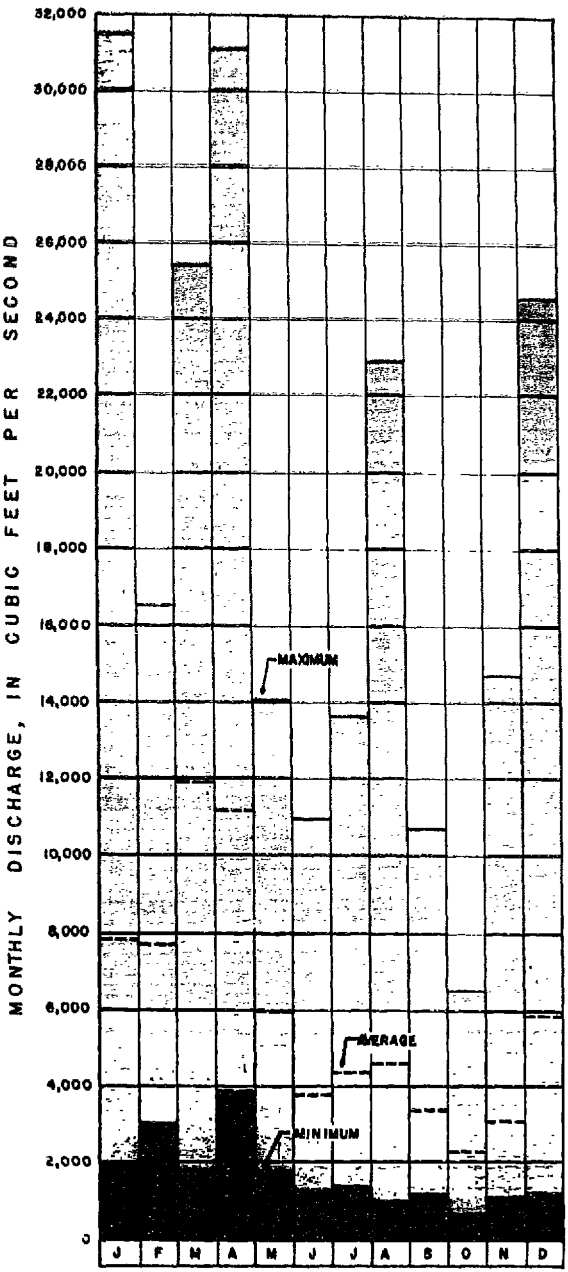

Figure 19. Bar graph of the minimum, average, and maximum monthly discharge of the Escambia River near Century, Florida, 1935-58.

Blackwater River Basin

The headwaters of Blackwater River are 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, about 3 miles west of Holt, it turns to the southwest and flows toward Milton, receiving the flow from Big Coldwater River and Big Juniper Creek on its way. 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 almost colorless and flows in clean channels of sand and gravel. The quality of the water throughout the basin is excellent, the mineral content ranging from only 11 to 26 ppm. Most of the land within the basin is covered by pine forests, but some is used for row-crop farming.

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

Pond Creek's entire drainage area of 92 square miles lies within Santa Rosa County. The creek flows in a southerly direction 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 that slope toward the main channel. 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.

There are two channels within the lower three-fourths of the Pond Creek flood plain. One of these is the natural channel which is very crooked and winding while the other is a channel dug many years ago for transporting logs. The valley slope is steep (fig. 20) with a total fall of about 200 feet from the headwaters to the mouth, a distance of 24 miles.

Pond Creek has large quantities of water that is low in mineral content. The minimum flow from the upper 58.7 square miles of drainage area during the 20 months ending September 1959 was 43 cfs (27.8 mgd). A flow of 43 cfs for a year would cover the drainage area of 58.7 square miles to a depth of 10 inches; however, the average yield of this stream is much greater — estimated to be 25 inches per year. Rainfall on the area is about 62 inches per year.

Big Coldwater River is the largest tributary feeding the Blackwater River. The total area drained by this tributary is 241 square miles, of which 230 square miles are in Santa Rosa County, Florida. All except the smallest streams in the Big Coldwater River basin have perennial flows, the magnitude of flow generally being proportional to the area

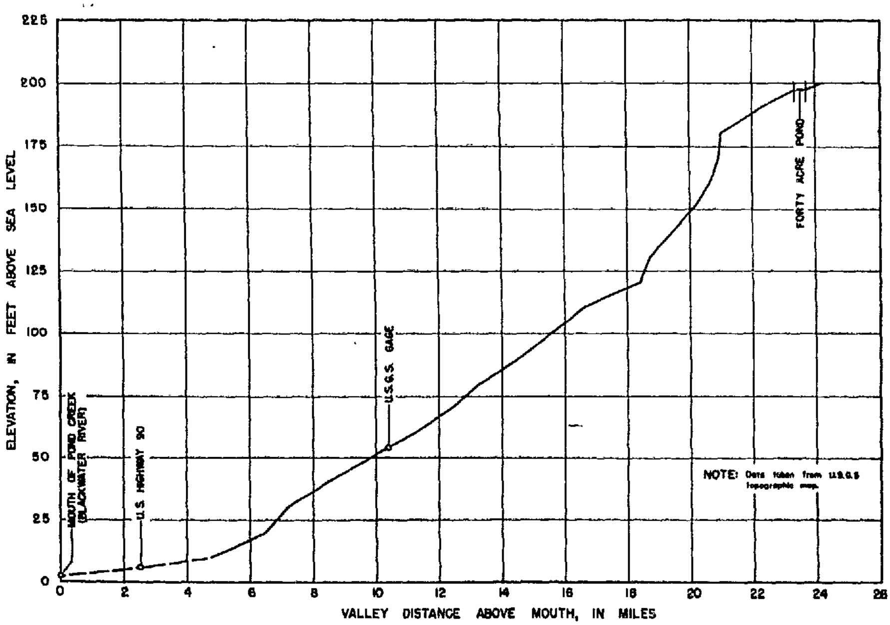

Figure 20. Channel-bottom profile of Pond Creek.

drained. The average flow, from the entire basin of 518 cfs is 2.1 cfs (1.4 mgd) per square mile of drainage area.

Streamflow records have been collected for the past 20 years on Big Coldwater River. The gaging station near Milton is located at State Highway 191 and measures flow from 237 square miles. The flow-duration curve for Big Coldwater River in figure 15 shows some streamflow characteristics at this point. Other than the peaks caused by flood waters that run off at a rapid rate, there are only minor fluctuations in flow, because a large amount of water seeping into the streambed from the ground keeps the flow fairly constant.

A useful arrangement of data is the group of low-flow frequency curves given in figure 21. They show not only what the lowest daily flow is likely to be but also how often

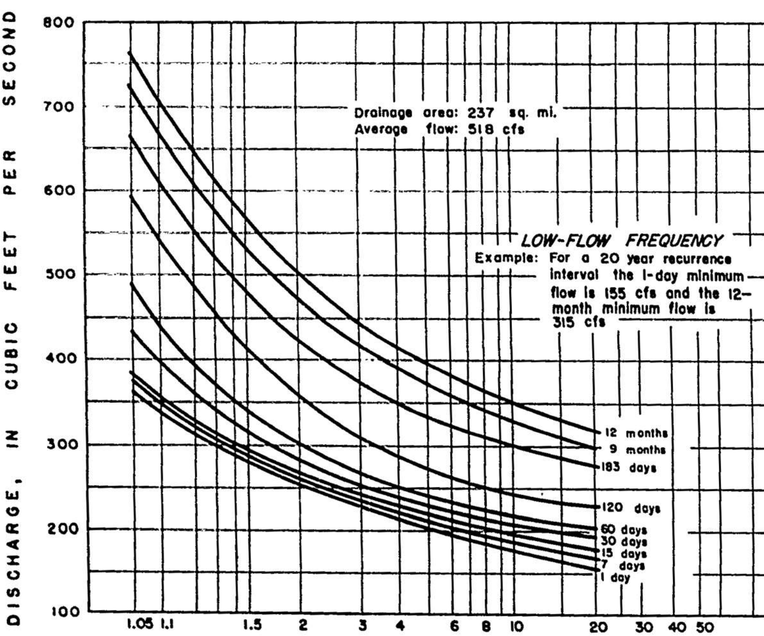

Figure 21. Low-flow frequency curves for Big Coldwater River near Milton, Florida, 1938-58.

it is likely to occur. For example, the minimum daily flow of 200 cfs (129 mgd) for Big Coldwater River on the average has a recurrence interval of about 5 years.

The seasonal distribution of runoff in Big Coldwater River basin follows very closely the pattern of rainfall. The distribution of monthly flows is given in figure 22. 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 enters Blackwater River 5 miles above Big Coldwater River, drains 146 square miles, of which 136 square miles are in Florida. The streambeds in this basin are composed of loosely packed sand and gravel, whereas the banks are steep and heavily wooded.

Four discharge measurements have been made on Big Juniper Creek near Harold, 3 miles upstream from the mouth. The lowest of these measurements, made August 28, 1959, was 175 cfs (113 mgd). Measurements were also made where State Highway 4 crosses Big Juniper Creek and where it crosses Sweetwater Creek. A flow of 42 cfs (27.1 mgd) was measured at the State Highway 4 crossing of Sweetwater Creek (drainage area, 45 square miles) on the same day that Big Juniper Creek at State Highway 4 (drainage area, 36 square miles) was flowing at a rate of 35 cfs (22.6 mgd). The lowest flow of Big Juniper Creek at State Highway 4 for the 20 months ending September 1959 was 25 cfs (16.2 mgd).

The Blackwater River drains 276 square miles above the Santa Rosa-Okaloosa county line and brings about 250 million gallons of water per day into Santa Rosa County. The flow-duration curve in figure 15 is based on $8\frac{1}{2}$ years of record collected at State Highway 4 in Okaloosa County. The drainage area above this point is 205 square miles. The daily flow varied during the period of record from a low of 60 cfs (39 mgd) to a high of 10,300 cfs (6,650 mgd). The average flow was 245 cfs (190 mgd). The flood of December 4, 1953, reached a crest elevation of 81.3 feet above sea level and a peak flow of 17,200 cfs.

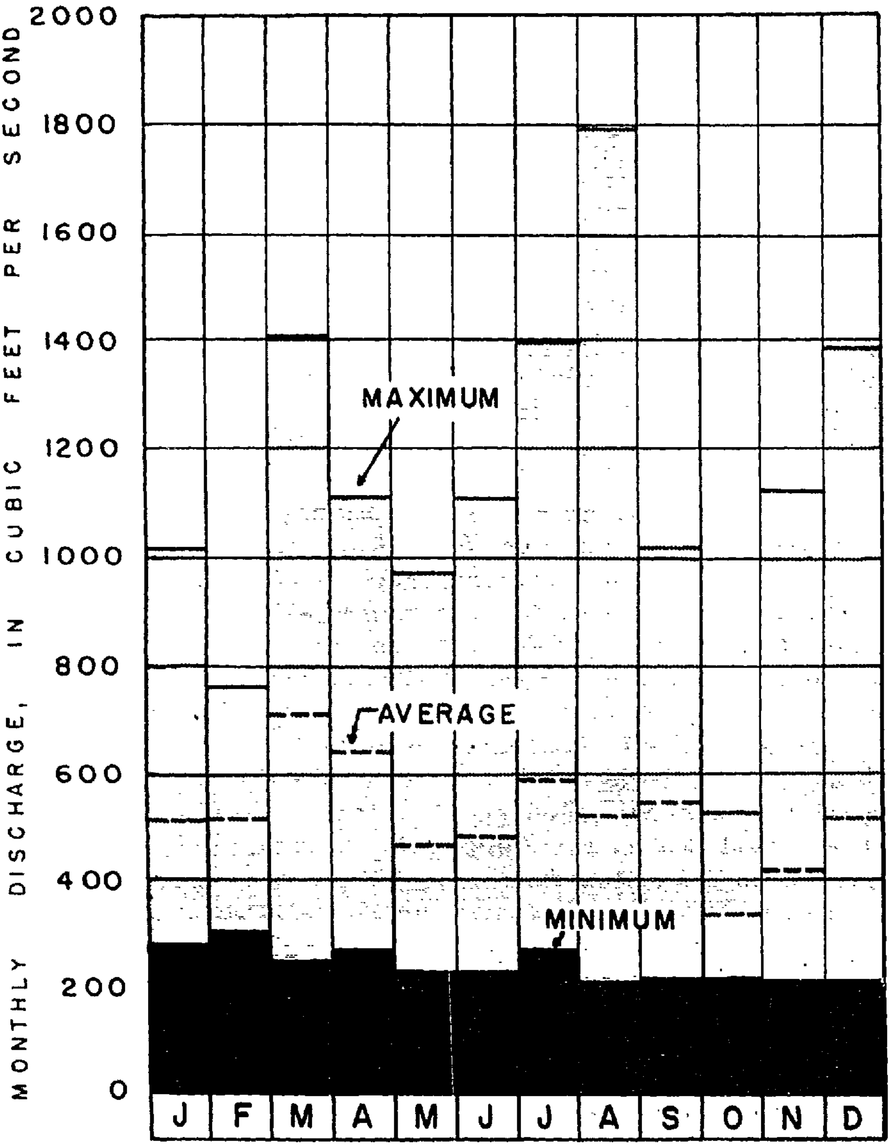

Figure 22. Bar graph of the minimum, average, and maximum monthly discharge of Big Coldwater River near Milton, Florida, 1939-58.

Yellow River Basin

The headwaters of the Yellow River are in southern Alabama, north of Andalusia and Opp. The river flows in a southerly direction, entering Okaloosa County, Florida, north of Crestview. South of Crestview, it receives the flow from Shoal River, its largest tributary, turns southwestward, and enters Santa Rosa County near Holt. From Holt it flows southwestward and into Blackwater Bay.

The Yellow River drains 1,365 square miles, of which only 115 are in Santa Rosa County. Although the percentage of the basin in Santa Rosa County is small, the river exerts a major influence on the area. 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.

The tributary streams located in Santa Rosa County are small and have exceedingly steep banks. Their channels have the appearance of gullies that were cut back into the land by water flowing in from the upper end. Some of the channels have been cut down as much as 80 feet below the adjacent land surface. Most of the flow in these streams is from springs.

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. Ground water is derived almost entirely from precipitation. Part of the precipitation returns to the atmosphere by evaporation and transpiration, part drains from the land surface into the lakes and streams, and part reaches the zone of saturation to become ground water. In addition, a small amount is suspended in the zone of aeration as capillary water. Ground water moves laterally under the influence of gravity toward places of discharge such as wells, springs, streams, lakes, or larger bodies of water.

Ground water may occur under either nonartesian or artesian conditions. Where it is not confined, its surface is free to rise and fall, and it is said to be 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 said to be 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 two major aquifers — a shallow aquifer, which is both artesian and nonartesian (the sand-and-gravel aquifer), and a deep artesian aquifer (the Floridan aquifer). In the southern half of the area, the aquifers are separated by a thick section of relatively impermeable clay; but in the northern half the aquifers are in contact with one another.

Sand-and-Gravel Aquifer

The sand-and-gravel aquifer is composed of sand but has numerous lenses and layers of clay and gravel in it. In the northeast corner of Santa Rosa County, the aquifer extends from the first saturated beds (near the 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 in 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 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.

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 1,500 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, 600 feet, near the Escambia River northeast of Cantonment (fig. 4). 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 part of the aquifer in southeastern Santa Rosa County is from 30 to 70 feet above sea level (fig. 24). At low land-surface elevations, large flows 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 Floridan aquifer in this area.

The Floridan aquifer is recharged by rain in areas of outcrop. 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 or downward leakage, and pumping.

Movement of Water

Ground water in the sand-and-gravel aquifer moves from higher toward lower elevations. Ground-water levels usually correlate with land-surface elevations. Thus, in the two counties, the general areas of ground-water recharge are indicated by 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.

Water levels in an artesian well and a nonartesian well, drilled into the sand-and-gravel aquifer, are illustrated by figure 23. The wells are at Oak Grove in northern Escambia County, and are about 6 feet apart. Relatively permeable and impermeable beds, as indicated by drill cuttings, and changes in the water levels caused by the high rainfall in 1959 are shown in figure 23.

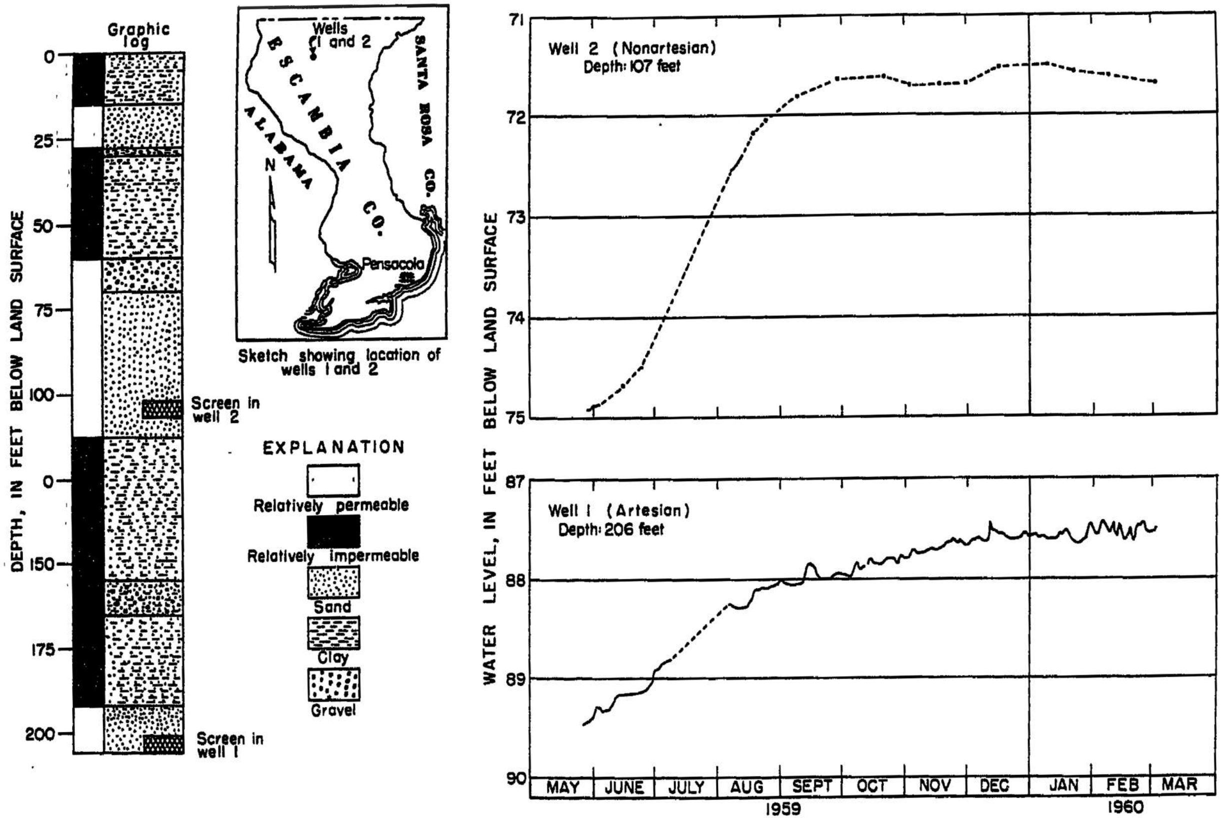

Figure 23. Water levels in an artesian well and a nonartesian well drilled into the sand-and-gravel aquifer in northern Escambia County, Florida.

Well 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 90 feet of the land surface. The artesian pressure head gradually increased about 2 feet during the period of record.

Well 2 was drilled to a depth of 107 feet and is screened from 102 to 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 about 71 to 75 feet below the land surface during the period of record. The water level had a rapid rise during June-September 1959, a slight rise from October to the end of the year, and a slow decline in the first part of 1960.

The water level in well 2 generally stands from 14 to 16 feet above the water level in well 1, and, 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.

Ground-Water Velocities

The rate of ground-water flow under natural conditions depends upon the slope of the water surface, the permeability of the aquifer, and the temperature of the water. Jacob and Cooper (1940, p. 50-51) calculated ground-water velocities in the sand-and-gravel aquifer in the Pensacola area. The average ground-water velocity between Cantonment and Warrington, 16 miles apart, was computed by Jacob and Cooper to be 0.21 foot per day, or 77 feet per year. Using the earliest water-level data available, Jacob and Cooper computed the average velocity in the sands near Pensacola Bay to be 0.37 foot per day, or 135 feet per year. The figures given represent the velocity under natural, undisturbed conditions. In the vicinity of discharging wells, the velocities would, of course, be higher.

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 in the two counties are usually relatively 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 Floridan aquifer is under sufficient artesian pressure to rise to more than 30 feet above sea level in the southeastern part of the area (fig. 24, well SR 8). Thus, the areas of flow from wells that tap the Floridan aquifer are generally at elevations less than 30 feet above sea level. Examples of areas of artesian flow of water from the Floridan aquifer are at Holley, Navarre, and Pensacola Beach.

Storage of Water

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. 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.

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 rainfall, evaporation and transpiration, natural discharge, and pumping. Long-term periodic measurements of water levels are used to determine significant changes in the water level, to correlate water levels and rainfall, and to show the influence of pumping on the water level. These 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 with rainfall. In the heavily pumped areas, water levels reflect both the influence of the pumping and rainfall.

Figure 24 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 SR 8 at Holley is 1,063 feet deep and obtains water from the upper part of the Floridan aquifer from 716 to 1,063 feet below the land surface. Well SR 10, 8 miles northeast of Holley, is 197 feet deep and obtains water from the sand-and-gravel aquifer from about 140 to 197 feet below the land surface.

The hydrograph for well SR 10 shows the water-level changes during the last 12 years in an area where there is not much withdrawal of ground water. The graph shows close correlation with rainfall and reflects a very wet period from 1944-49, a dry period from 1950-55, and a wet period from 1956-59. The effect of 90.41 inches of rainfall in 1953, the highest recorded in 80 years at Pensacola, is shown by the rise in water levels during 1953 and the first part of 1954. However, this rise in the water level was canceled

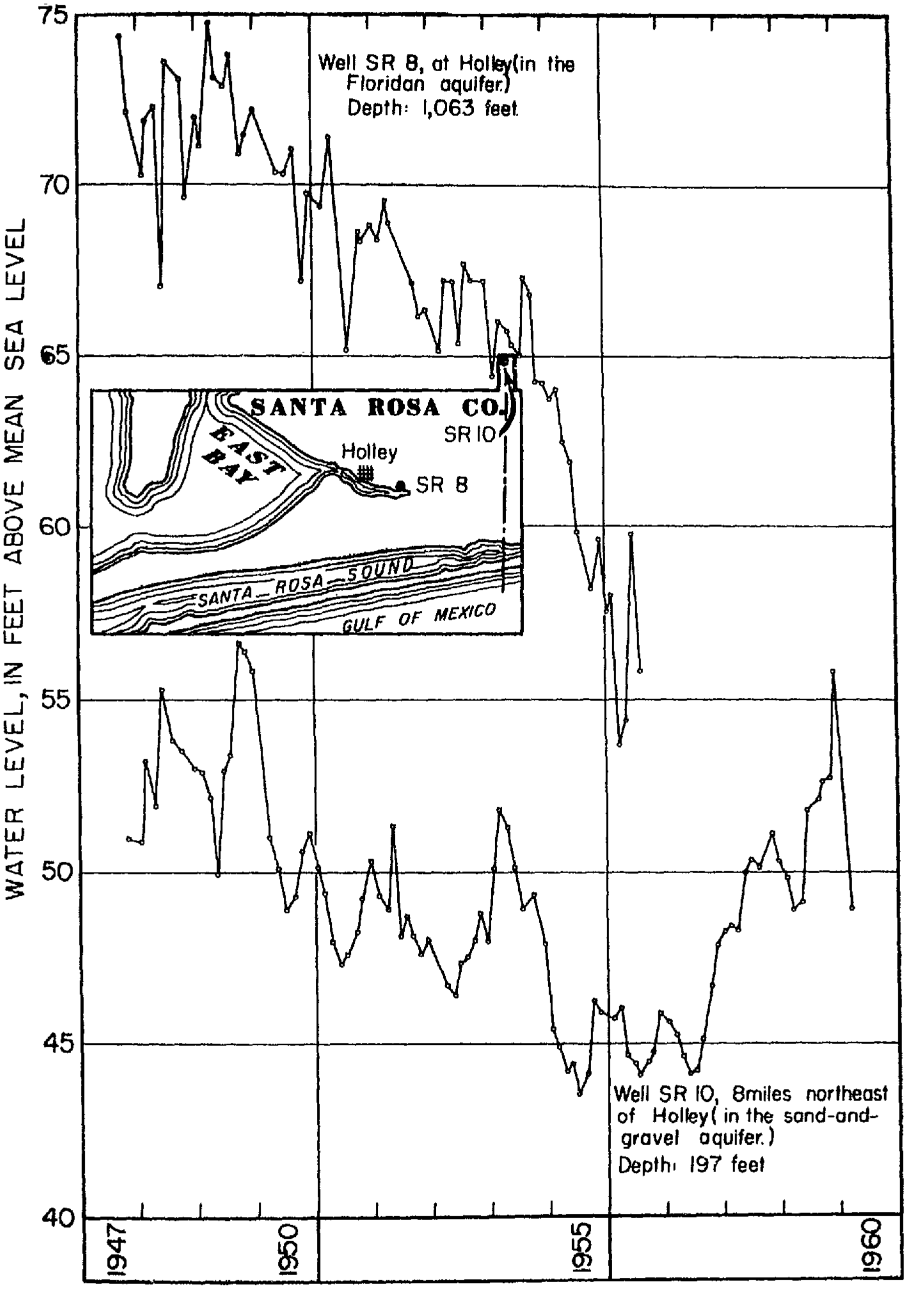

Figure 24. Hydrographs of wells SR 8 and SR 10.

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 SR 8, which penetrates the Floridan aquifer, shows similar fluctuations. The hydrograph shows the high artesian pressure head during 1947-49 and the sharp decline from 1950 through early 1956. Just after the artesian pressure started to recover, the well collapsed, and accurate measurements were no longer obtainable. The hydrograph shows a maximum fluctuation of 21 feet. Artesian pressure was highest, 75 feet above sea level, in 1949 and lowest, 54 feet above sea level, in 1956. The artesian pressure head stood above the water level in the sand-and-gravel aquifer during the entire period of record.

Well SR 8 is the only well in this area that taps the Floridan aquifer and also has a long-term record. The hydrograph is included to show the relation between artesian pressure changes and rainfall, to illustrate the fluctuations in artesian pressure in the Floridan aquifer, and to compare these fluctuations with those in the sand-and-gravel aquifer.

Figure 25 contrasts changes of the water level in an area little affected by pumping, as shown by well E 46 at Ensley, with changes of the water level in areas of heavy pumping, as shown by well E 45 at Cantonment and well E 74, 3 miles east of Cantonment. All three wells are in the sand-and-gravel aquifer. In 1948 the water table at Ensley reached its highest level during the period of record (75 feet above sea level), and in 1956 the lowest level was recorded (49 feet above sea level). From 1940 to 1959, the water level at Ensley fluctuated 26 feet. Well E 46 is 239 feet deep. The rise and fall of the water table in this area, as shown by the graph, closely parallels variations in rainfall. In general, whenever the annual rainfall was less than 60 inches, the water level declined; and whenever the annual rainfall exceeded 60 inches, the water level rose.

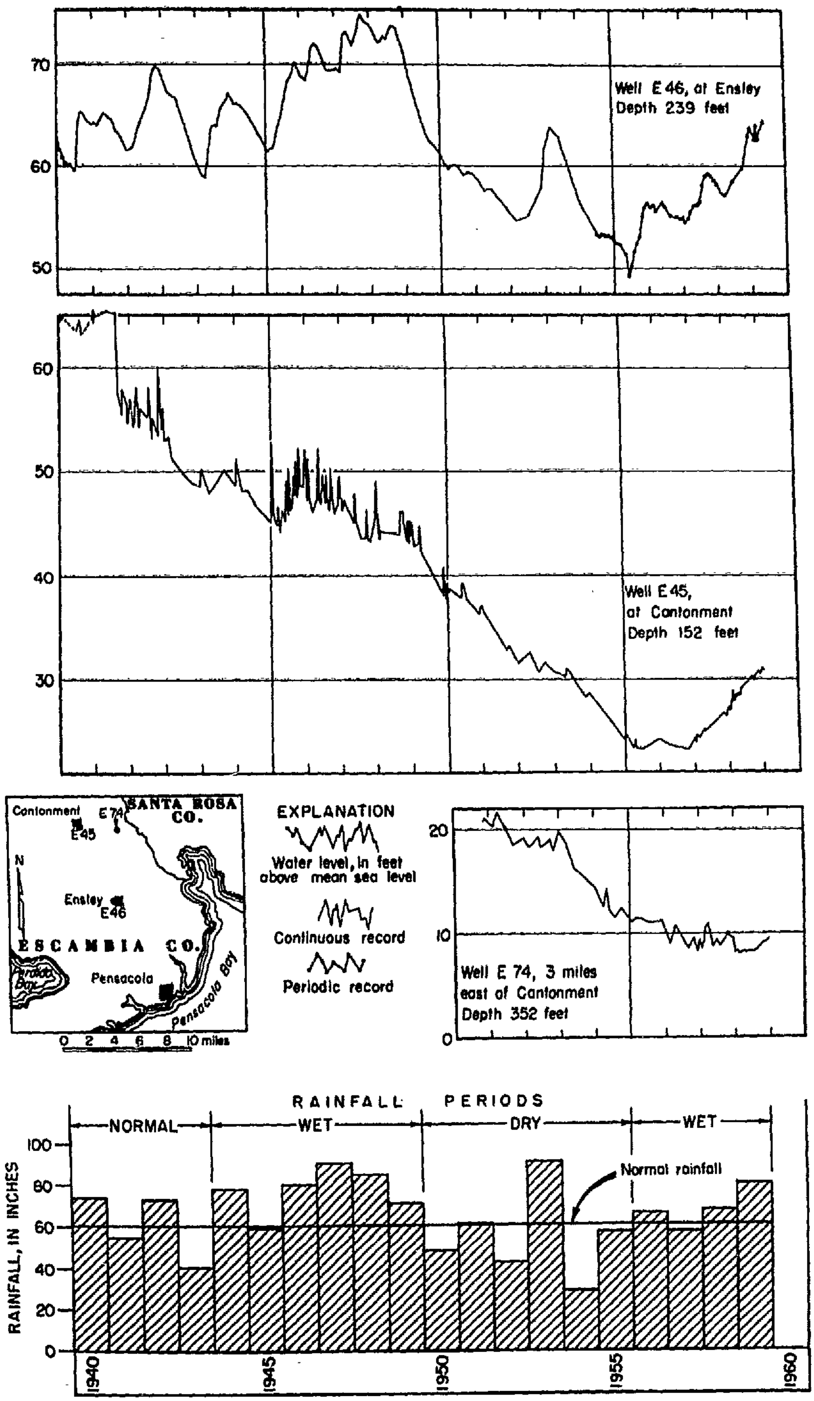

Figure 25. Hydrographs of wells E 46, E 45, and E 74 and graph of yearly rainfall at Pensacola.

Figure 25 shows changes of water level in well E 45 (152 feet deep) at Cantonment. This hydrograph shows the decline usually associated with continued, concentrated pumping in an area. During 20 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 hydrograph shows a decline in the water level of more than 42 feet from 1941-56 due to continued and increased pumping. The hydrograph shows the effect of the very high rainfall in 1946-49 as a slight rise in the water level followed by a gentle decline during the 4-year period. The sharp decline of the water level stopped in 1956, and late in 1957 the water level started to recover. The recovery is due principally to the fact that several nearby wells that were pumping water from the same zone were taken out of service and also because the rainfall has been above normal in 1956, 1958, and 1959. Some of the recovery of the water level during 1959 is due to a recharge experiment made by the St. Regis Paper Company. During this experiment 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 E 45. An inspection of the hydrograph of well E 45 and the calculated time-distance-recovery curves indicate that this amount of recharge would cause the nonpumping water level in well E 45 to rise from 1 to 2 feet.

The hydrograph for well E 74, about 3 miles east of Cantonment and about 1 mile west-northwest of the Chemstrand Corporation plant, is shown in figure 25. This well is 352 feet deep and is screened from 260-270 feet and from 340-350 feet below the land surface. The water level is probably affected by pumping at two nearby industrial plants, the St. Regis Paper Company and the Chemstrand Corporation. The graph shows a maximum change of 13 feet during the 8 years of record with the highest water level being 21 feet above sea level in 1952 and the lowest water level being 8 feet above sea level in 1959. The graph shows a rapid decline of the water level from 1954 to 1956. The decline was due to pumping and below-normal rainfall. The water level was nearly stable during 1957-59 owing to above-normal rainfall and infiltration of the Escambia River into the well field of the Chemstrand Corporation.

Figure 26 shows changes in the water level southwest of Pensacola, as recorded in three wells. Two of the wells

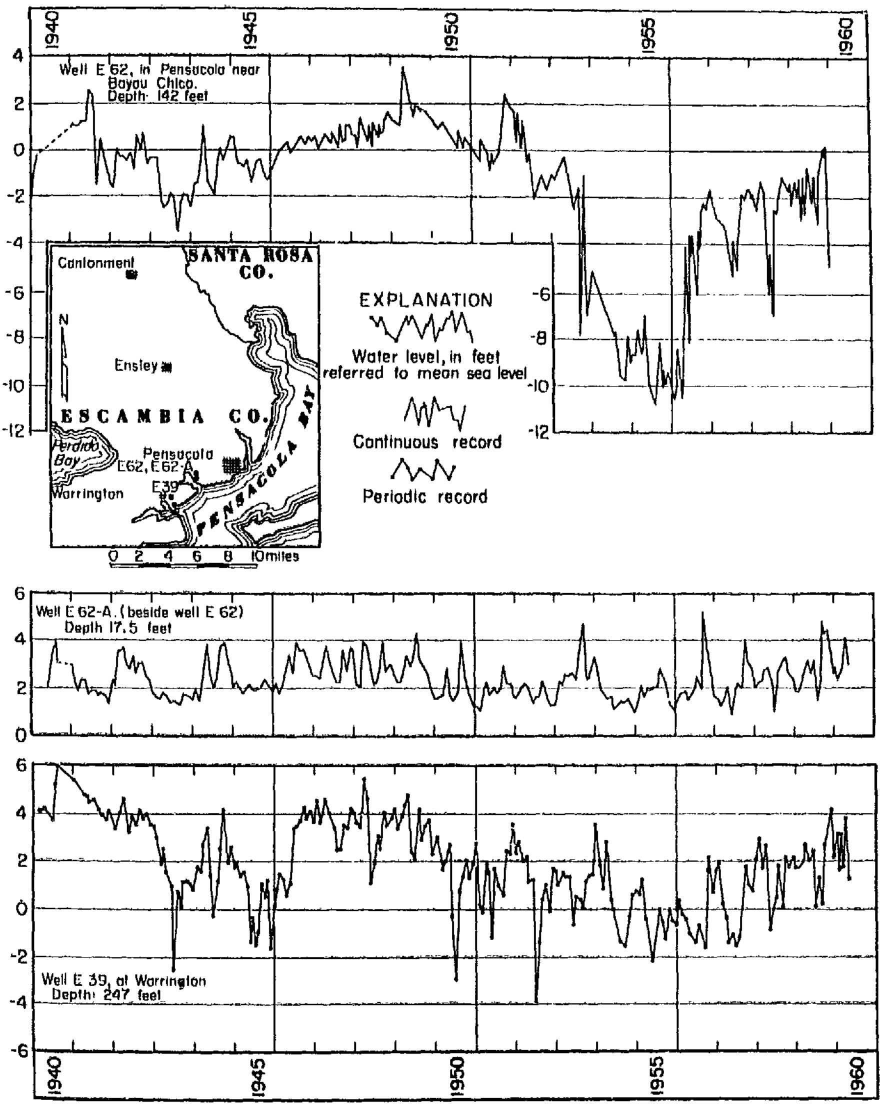

Figure 26. Hydrographs of wells E 62, E 62-A, and E 39.

(E 62 and E 62-A) are near the Newport Industries plant. Well E 39 is in Warrington, about 2 miles southwest of the plant. Well E 62 is 142 feet deep and is at Pensacola, 450 feet from Bayou Chico. The range of water-level fluctuation in well E 62 was 14 feet during the 20 years of record. The water in well E 62 was highest, 3.6 feet above sea level, in 1949 and lowest, 10.8 feet below sea level, in 1955. The water level in well E 62 is influenced by heavy pumping at Newport Industries and by changes in rainfall. The water level probably was lowered by pumping before water-level measurements were started in 1940.

The hydrograph of well E 62 shows the water level has been lowered by heavy pumping by Newport Industries. Figure 26 indicates that the water level in well E 62 has been below sea level since the summer of 1952. As salt water in Bayou Chico is only 450 feet from the well, the differences in water levels could enable salty water from the bayou to percolate into the aquifer in this area and destroy its usefulness.

Figure 26 shows the graph of the water-level changes in well E 62-A which was drilled beside well E 62. The depth of this well is 17.5 feet, and the recharge from rainfall percolates rapidly to the water table. The water level fluctuated only 4.4 feet during the 20-year period of record. The water level rose to 5.2 feet above sea level in 1956 and fell to 0.8 foot above sea level in 1951, 1955, 1957, and 1958.

The water level in well E 62-A has been above the water level in well E 62 for most of the 20 years of record. The greater head of the 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 water-level changes in well E 39 (247 feet deep) at Warrington are shown in figure 26. 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 last 20 years from 1940 to 1959, probably owing to increased use of ground water in the Warrington area. The water level declined below sea level during the summer in 12 of the 20 years of record. The years the water level dropped below sea level include 1943-45 and 1950-58. The lowering of the water level is brought about by an increase in the use of ground water during the summer.

The water level in well SR 102, half a mile east of the Gulf Breeze post office, is shown in figure 27. This well

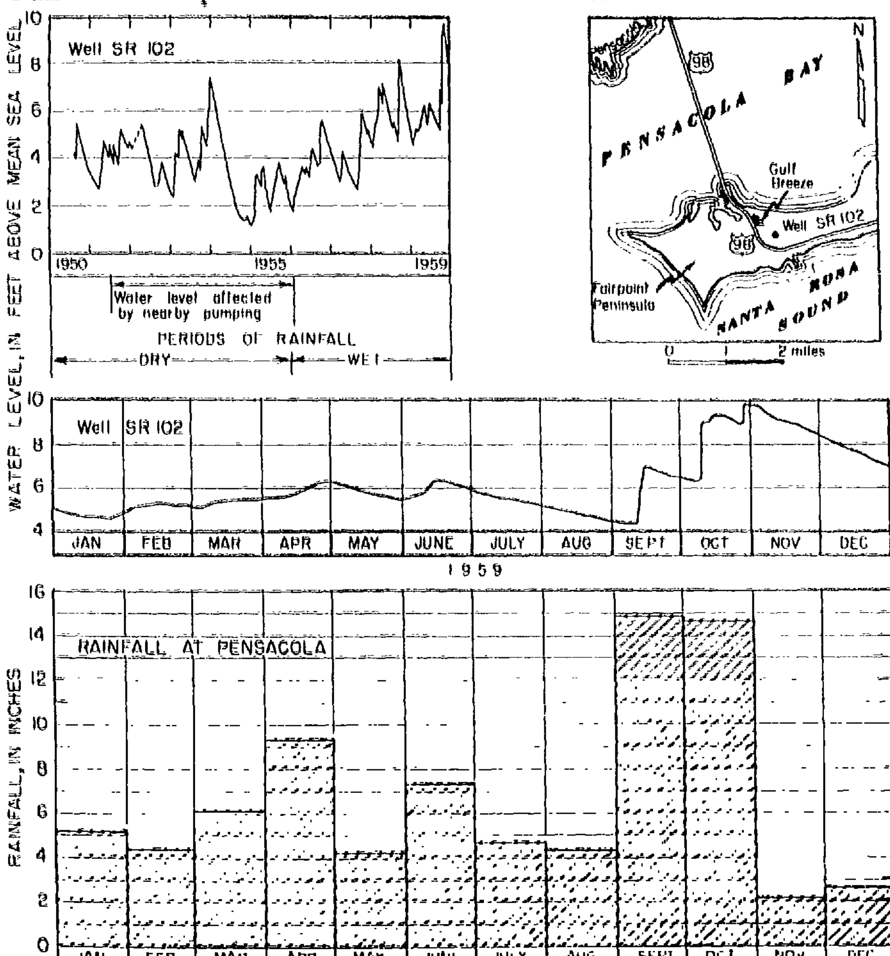

Figure 27. Hydrographs of well SR 102 and graph of rainfall at Pensacola.

was drilled to a depth of 41 feet, and the lower 10 feet of the well was equipped with a screen. During the 10-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 at Fairpoint Peninsula is derived entirely from local rainfall. Some of the rainwater percolates quickly through a 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 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 SR 102 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 pumped about 60,000 gpd during the winter and about 120,000 gpd during the summer from 1951 to 1956. After 1956, when there was no pumping and rainfall was above normal, the water level rose gradually to a record high in 1959.

The lower graph in figure 27 shows the water-level changes in well SR 102 during 1959 and the monthly rainfall at Pensacola. This hydrograph 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 on October 10 caused another rise of 2.5 feet. These rises brought the water level near or above the land surface in some areas aroung Gulf Breeze, causing some damage and considerable inconvenience.

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 aquifers 50 to 250 feet deep usually range from 66° to 73° F. This temperature range reflects the average annual air temperature, which is about 68° F. at Pensacola.

The temperature of water from aquifers in this area usually increases about 1° F. for each 52 to 85 feet of depth below 50 feet. 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.

Wells

Information has been collected on about 450 wells in this area. Of these, 253 wells are in Escambia County and 202 are in Santa Rosa County. They range in depth from about 15 feet to almost 1,400 feet, but most of them are between 30 and 300 feet deep. They range in diameter from $1\frac{1}{4}$ inches to 30 inches. Most of the domestic supply wells are $1\frac{1}{4}$ to 4 inches in diameter, and most of the industrial supply wells are 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 penetrated. 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.

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 an inverted cone 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 at that point. 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. These coefficients are generally determined by means of aquifer test on wells.

Although no 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 can 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 and the U. S. Navy (at Corry Field). These wells were drilled about 240 feet into the sand-and-gravel aquifer, and the lower half was screened. The average coefficient of transmissibility for 120 feet of aquifer, as determined by the tests, is 75,000 gpd per foot. This coefficient can 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 months 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 which would lessen the drawdown. Because of the effect of this recharge, it has been found empirically that reasonably accurate drawdowns can be predicted using a storage coefficient of 0.15 in this area. This empirical 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.

In the fall of 1950, Heath and Clark (1951, p. 31-34) made an aquifer test on the Fairpoint 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 by Heath and Clark (1951).

Several aquifer tests have been made during 1951-55 on some of the Chemstrand Corporation's wells, about 13 miles north of Pensacola. Each well is equipped with about 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 land surface. The average coefficients of transmissibility and storage determined from these tests were 150,000 gpd per foot and 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 28 illustrates how water levels are affected in the vicinity of a pumping well and may be used to predict drawdowns at various distances from the well. This figure shows theoretical drawdowns in the vicinity of a well pumping 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 lesser rates of discharge can be computed from these curves. For example, as shown in figure 28, 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.

Chemical Quality of Ground Water

Rain that falls on the earth's surface is practically free of dissolved mineral matter. However, as it travels through rocks composing the earth's crust, it gradually dissolves them. The rock minerals constitute most of the dissolved materials in ground water. Thus, the chemical character of ground water is dependent in part on the type of material through which the water flows. The quartz sand (and gravel) of the sand-and-gravel aquifer is relatively insoluble; limestone and dolomite which constitute the Floridan aquifer are among the most soluble of common rocks.

Mineralization of ground water may result from the mixing of relatively fresh water with highly mineralized sea

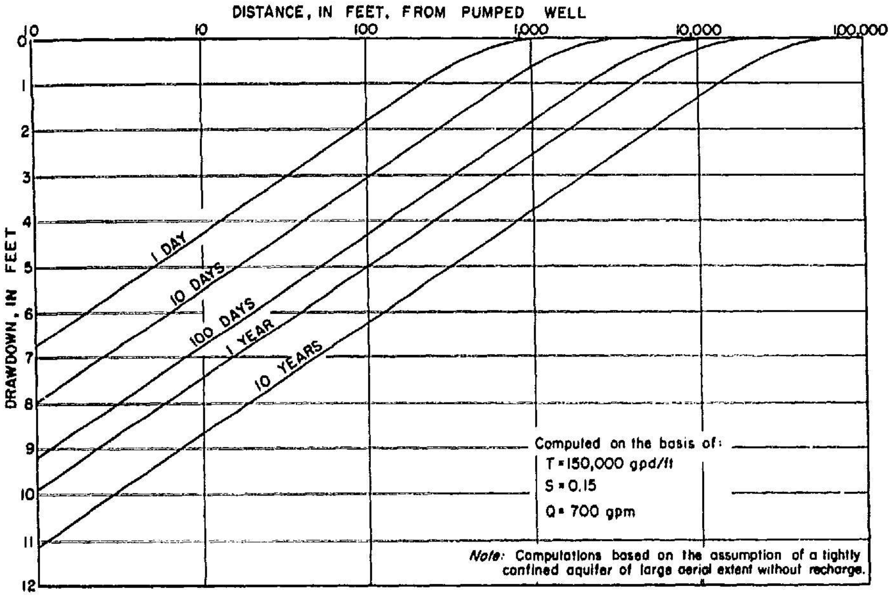

Figure 28. Graph showing theoretical drawdowns in the vicinity of a well being pumped at a rate of 700 gpm (about 1 mgd) for selected periods of time.

water that has not been completely flushed from the aquifer. Ground water also may become mineralized as a result of mixing industrial wastes with fresh water. Fresh ground water also may become mineralized in areas near salt-water bodies when the fresh-water table is lowered (usually by pumping) and the salt water moves into the aquifer.

The principal mineral constituents and physical properties of the water from wells in Escambia and Santa Rosa counties are discussed below. The concentration of mineral constituents is given in parts per million — 1 ppm is approximately equivalent to 8.34 pounds per million gallons of water.

Water containing less than 500 ppm of dissolved solids is generally considered to be of good chemical quality although, for some uses, certain constituents may be present in objectionable quantities. The concentration of dissolved solids in water from the sand-and-gravel aquifer in Escambia and Santa Rosa counties ranged from 13 to 465 ppm—generally from 20 to 80 ppm. The concentration of dissolved solids in water from the Floridan aquifer ranged from 295 to 3,960 ppm.

Hardness of water is generally recognized because it increases the consumption of soap and causes the formation of scale in steam boilers or other vessels in which the water is heated. Water having a hardness of less than 60 ppm is considered soft; 60 to 120 ppm, moderately hard; 121 to 200 ppm, hard; and more than 200 ppm, very hard. The hardness of water is caused chiefly by calcium and magnesium. Ground water from the sand-and-gravel aquifer ranged in hardness from 3 to 379 ppm but was generally less than 25 ppm. Ground water from the Floridan aquifer ranged in hardness from 24 to 87 ppm.

As the chloride salts constitute about 90 percent of the dissolved solids in sea water, the chloride content of coastal ground water is generally a reliable index of the amount of contamination from the sea. Water having a chloride content of not more than 250 ppm is acceptable for a public supply, and water having a chloride content of less than 500 ppm does not taste objectionably salty to most people. The chloride content of water from the sand-and-gravel aquifer ranged from 1.0 to 16,100 ppm, but most of the samples contained from 3 to 15 ppm. The chloride content of water from the Floridan aquifer ranged from 19 to 2,050 ppm.

The high chloride concentrations in ground water in Escambia and Santa Rosa counties are from three sources. The first source is salt water that entered the formation during higher stands of the sea and has not been completely flushed from the aquifer. Examples of this are found in the lower part of the Floridan aquifer in the southern half of both counties, in the upper part of the Floridan aquifer in the southernmost part of both counties, and in the sand-and-gravel aquifer at depths below 150 feet near Gulf Breeze. The second source of high-chloride content in ground water is from lateral encroachment from salt-water bodies. This encroachment occurs where pumping has lowered the water table below sea level, as near Bayou Chico. The third source comes from industrial wastes that have a high chloride content, as in northern Pensacola.

Fluoride is present in minor amounts in most ground water. Water containing more than 1.5 ppm of fluoride may cause mottling of children's teeth. In concentrations of about 1 ppm, fluoride is beneficial to dental health by reducing tooth decay and is added to some public supplies for this reason. The fluoride content of water from the sand-and-gravel aquifer ranged from 0.0 to 8.5 ppm, but the water usually contained less than 0.1 ppm. The fluoride content of water from the Floridan aquifer ranged from 0.8 to 6.5 ppm.

Iron occurs in almost all rocks, but the quantity of iron dissolved by ground water is small in comparison with the quantity of more soluble minerals. Water containing more than 0.3 ppm of iron causes stains on fixtures, utensils, and clothing; and water containing 0.5 to 1.0 ppm or more has objectionable taste. Iron as bicarbonate may be removed by aeration and filtration. The iron content of water from the sand-and-gravel aquifer ranged from 0.0 to 3.1 ppm. However, the iron content of water from this aquifer is usually less than 0.1 ppm. The iron content of water from the Floridan aquifer ranged from 0.03 to 5.0 ppm.

The pH indicates the degree of acidity or alkalinity of a water and is an important indication of its corrosive tendencies. A pH below 7.0 indicates acidity, and a pH above 7.0 indicates alkalinity. The corrosiveness of water usually increases as the pH decreases and is also dependent on such factors as dissolved carbon dioxide, dissolved oxygen, degree of salinity, and temperature. The pH of the water samples from the sand-and-gravel aquifer ranged from 4.1 to 7.3, generally from 5.0 to 6.3, which indicates the water is acid and corrosive. The pH of the water samples from the Floridan aquifer ranged from 8.0 to 8.4, which indicates the water is moderately alkaline and not corrosive.

Most industries and public systems treat the ground water to reduce its corrosiveness. Treatment includes the addition of lime, soda ash, or some form of phosphate. This treatment stops most of the corrosion of water pipes, water heaters, and metals that the water contacts. Most of the "yellow water" associated with untreated well water is a result of the corrosion of the water upon metals.

Hydrogen sulfide is dissolved in some waters from the sand-and-gravel aquifer and most waters from the Floridan aquifer. This gas gives the water a distinctive taste and odor. Waters containing it are usually called "sulfur water."

USE OF WATER

Surface Water

Only a small part of the area's surface waters are being used. Recreation, shipping, cooling, and waste disposal are the major uses of today (1960). 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 200 square miles of bays are excellent for boating, fishing, swimming, and other recreational activities. The Intercoastal 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 purposes. Elevenmile Creek is used for disposal of industrial wastes. Small storage reservoirs are located on Bayou Marcus to enhance the value of land.

The surface waters within the northern half of the two counties are 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 on the various uses 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 daily consumption of ground water in both counties is estimated to be about 86 million gallons — approximately 60,000 gpm. Figure 29 shows the approximate amount of ground water used daily in the two counties. The quantities of water are represented by the size of the circles. 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 61 mgd. The daily pumpage by industries is estimated as follows:

Paper and wood products................45 mgd
Chemical plants..........................15 mgd
Other uses (brewing, laundries, etc.) .... 1 mgd

Use by municipalities: The second largest use of ground water in both counties is for public supply. Twelve million gallons are used daily for this purpose. The city of Pensacola used an average of 10 mgd during 1959. Other public water supplies are located at Milton, Jay, Century, Warrington, Gulf Breeze, and Ferry Pass.

The city of Pensacola and other local suppliers make a practical use of the low mineral content of the ground water. Because the raw ground water requires little treatment, 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 must pump the raw water to a central point where it is treated and then distributed. Pensacola's method enables the city to use smaller diameter distribution lines and to space the wells farther apart. This wider spacing is good practice because it eliminates the large cone of depression caused by pumping closely spaced wells.

Use by agriculture: The amount of ground water used for irrigation in both counties is small. Lawn and garden irrigation accounts for most of the water used for irrigation. Probably not more than 10 large-capacity wells have been drilled in this area for irrigation. The need for irrigation water is not great because rainfall is fairly abundant during the growing season.

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

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 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.

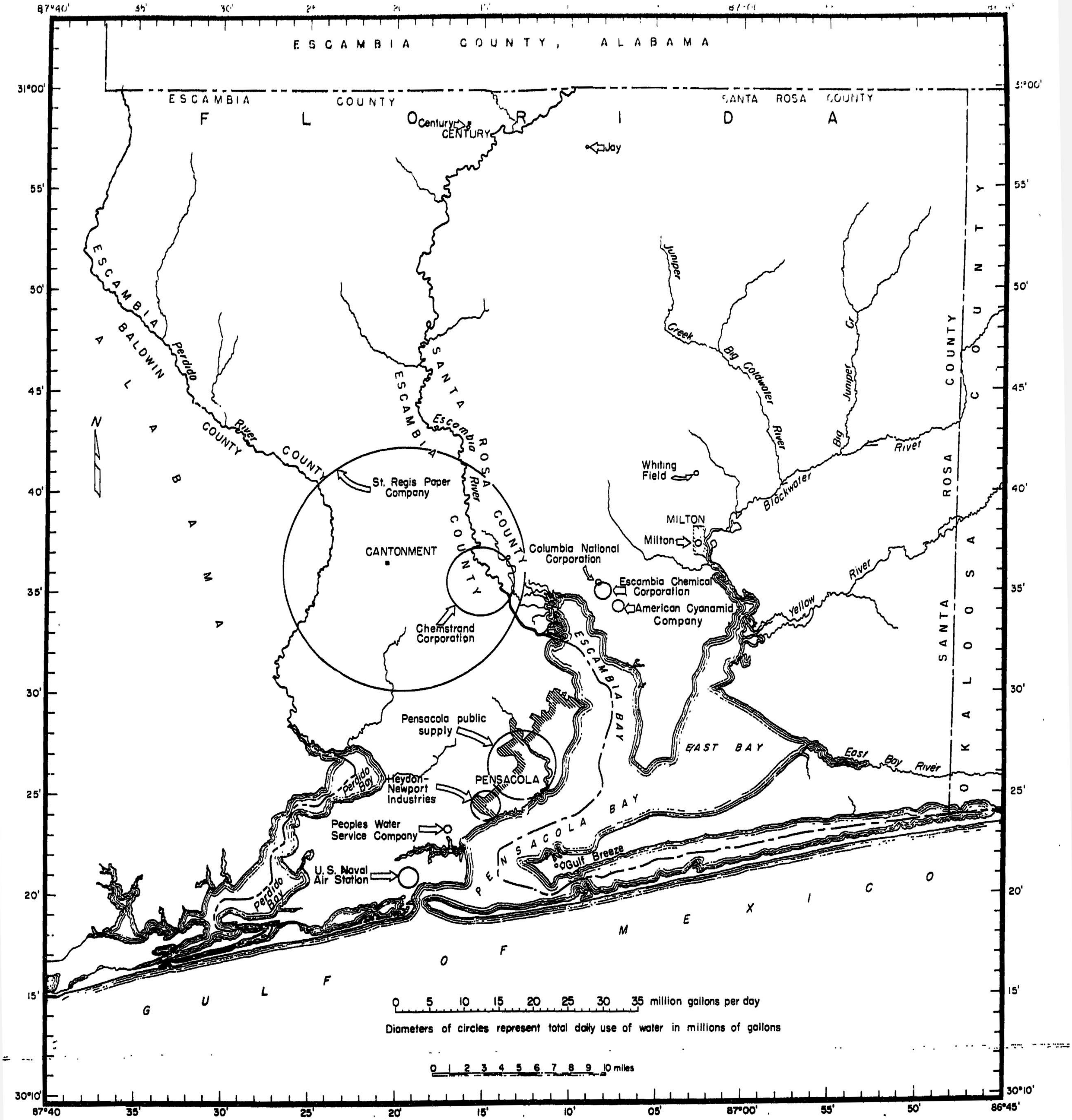

Figure 29. Map of Escambia and Santa Rosa counties showing the daily consumptive use of ground water by industries and municipalities during 1958.

The number of persons using ground water from private wells for domestic purposes is estimated to be 60,000 in Escambia County and 20,000 in Santa Rosa County. The water used by these people, estimated to be 9 mgd in Escambia County and 3 mgd in Santa Rosa County, 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 small. Probably not more than five wells obtain water from this aquifer. 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 high in mineral content, and because deep wells are expensive.

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. Deficient rainfall causes the water level in wells to decline, runoff from streams to decrease, and pond levels to be lowered. Excess rainfall may cause flooding of lands that are poorly drained and lands adjacent to streams.

Periods of Low Rainfall

Decline of water levels: The relationship of the change in 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 results in additional pumping costs, drying up of shallow wells, and salt-water encroachment. In well E 46 at Ensley, the water level dropped more than $9\frac{1}{2}$ feet in 1950 and again in 1954 (fig. 25). These declines were due to a reduction in recharge brought about by below-normal rainfall.

The level of ponds drops during low rainfall periods and some ponds dry up entirely. 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. The streamflow decreases during periods of low rainfall and the salt-water front moves upstream during this period. Studies are necessary to determine salinity values and the range of movement of the salt-water front.

Lowered ground-water levels may allow upward salt-water encroachment or lateral encroachment. Upward encroachment is possible where the upper aquifer contains fresh water and the lower aquifer contains salt water and the head in the lower aquifer is higher than the head in the upper aquifer. Lateral encroachment into ground water from surface bodies of salt water is possible where the ground-water level does not have sufficient head. The danger of salt-water encroachment occurs during periods of low rainfall in areas of heavy pumping.

Periods of High Rainfall

Periods of moderately high rainfall are desirable 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. It is important for local residents having property that is subjected to flooding to know the level to which a river will rise. 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 12.

Another problem associated with intense rainfalls is ponded water. Ponded water occurs in areas where the land is flat and drainage facilities are inadequate. Examples of this can be 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 community of Gulf Breeze during the fall of 1959 when heavy rains caused the water table to rise rapidly (fig. 27) and low lands were flooded. The figure shows the slow decline of the water table following abrupt rises. Surface drainage or pumping are the most effective methods for removing the excess water.

Manmade Problems

Water resources 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

Large industries usually require a continuous supply of water. Prolonged pumping of ground water causes drawdowns of the water level in proportion to the number of wells, rate of pumping, and spacing of wells. Such drawdowns increase the cost of pumping water and cause the cone of depression to extend farther outward than is desirable.

An example of large drawdowns can be found at Cantonment. Figure 25 shows that the water level in well E 45 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.

Salt-Water Encroachment

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

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. 26). 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 increasing before the water became too salty for use.

An example of a rapid encroachment occurred along the Escambia River at the Chemstrand nylon plant. Nearby pumping caused the ground-water level to fall below sea level for the first time in 1955, and it has remained below sea level most of the time since 1955. In 1956, there was an increase from 10 ppm to more than 1,100 ppm in the chloride content of water from a well about 500 feet west of the Escambia River.

Figure 11 shows the chloride content of the Escambia River at the Chemstrand nylon plant cooling water intake. During 1957 and 1958, the chloride content of the Escambia River was above 25 ppm for about 25 percent of the time. Thus, the salt-water front can advance at least 7 miles above the mouth of the river.

Figure 30 shows the lowering of ground-water levels and their relation to the level of the Escambia River. The

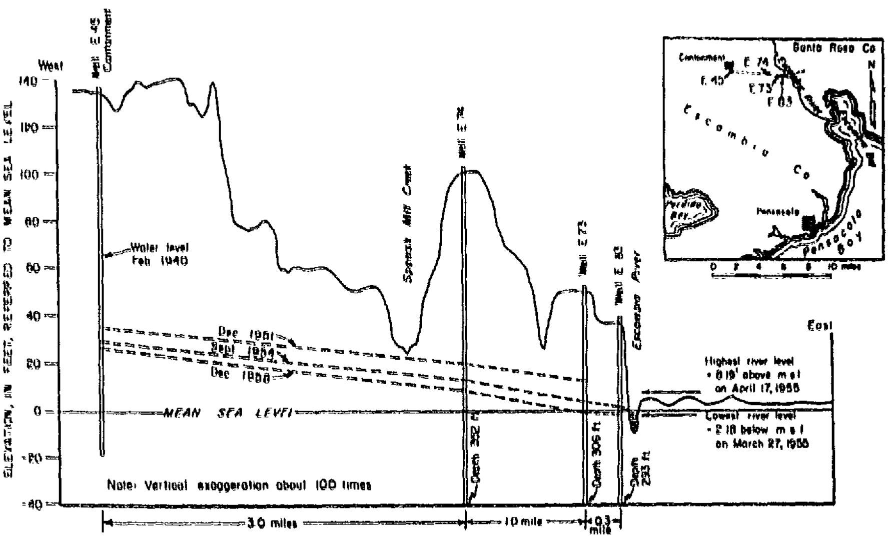

Figure 30. Cross section showing the decline of water levels in the vicinity of Cantonment, Florida.

figure is a cross section from Cantonment eastward to the Escambia River. The water table was above the river level in 1951 and doubtless was contributing water to the Escambia River. Since 1955 the water table, adjacent to the river, has usually been below river level and water from the river has infiltrated into the well field. Ordinarily this infiltration from the river would be a desirable feature because it would recharge the aquifer and decrease the drawdowns. However, because the Escambia River is salty part of the time (fig. 11), the infiltration introduces salt water into the sand-and-gravel aquifer adjacent to the river.

A study of electric-log resistivities indicates that the water in a thick clay section (fig. 4) below the sand-and-gravel aquifer at Chemstrand is salty. As this clay is virtually impermeable, the salt-water encroachment is not believed to come from this source. Also, the well nearest the Escambia River was the first to show an increase in the chloride content of the water. In addition, infiltration of water from the river into the aquifer could explain the fact that the ground-water level has generally stabilized. These conditions indicate strongly that the salt water in some wells at the Chemstrand nylon plant is coming from the Escambia River by lateral encroachment.

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 valuable 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. The effect of introducing wastes into a stream can be observed at Elevenmile Creek in southern Escambia County.

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

An example of disposing of industrial wastes into an infiltration pond can be found 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 down the hydraulic gradient. A diluted form of this waste has been detected more than a mile from the pool in a municipal supply well which was subsequently abandoned. The problem of ground-water pollution in this area is being investigated currently.

POTENTIAL WATER SUPPLIES

Surface Water

Escambia and Santa Rosa counties have an abundance of fresh water — over 7.5 bgd flow from the area through surface streams. However, the surface-water supplies vary with respect to time and location. The fluctuations with respect to time follow the pattern of rainfall. The supply at any point is related to the size of the area drained. The average flow is computed for each major river in the area and is given below.

The average flow from the Perdido River basin is 1 bgd. This flow is equivalent to 1.1 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, 130 mgd; McDavid Creek, 40 mgd; Jacks Branch, 30 mgd; and Bayou Marcus Creek, 70 mgd. The Styx River enters the Perdido River from Alabama about 1 mile south of U. S. Highway 90 and has a computed flow of 220 mgd.

The Escambia River has an average flow of over 4 bgd. Pine Barren Creek is a tributary stream in northern Escambia County and has an average flow of 100 mgd. Canoe Creek in northeast Escambia County and Moore Creek in Santa Rosa County each have a computed flow of 30 mgd.

The average flow from the Blackwater River basin is 1 bgd. About three-fourths, or 750 mgd, is derived from Santa Rosa County. Most of the remaining 250 mgd is from Okaloosa County, with a small amount coming from Alabama to the north. Pond Creek has an average flow of 110 mgd. Big Coldwater River has the largest flow (340 mgd) of any tributary in the Blackwater River basin. Big Juniper Creek has an average flow of about 210 mgd.

An average flow of about 1,600 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. An understanding of the factors that might be detrimental to this supply is necessary if it is to be fully utilized.

Areas of abundant fresh ground water: Ground-water supplies in the sand-and-gravel aquifer can be developed in areas of northern Escambia and Santa Rosa counties. Only a small amount of the available ground water in these areas is being used in 1960. The sand-and-gravel deposits range in thickness from about 230 to almost 1,000 feet. Generally, these deposits are more than 400 feet thick.

Small supplies of water also can be developed in other parts of the counties. However, in these areas some of the factors listed below may limit the amount of water that could be withdrawn.

Factors limiting availability of fresh ground water: The factors that might limit the availability of fresh ground water in this area are as follows:

1. Concentrated pumping: 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 a different well field. Both well fields then, in effect, compete for the water, and the resultant drawdown of water level is correspondingly greater.

2. Proximity of 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.

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 lenses 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 water. This clay bed retards encroachment of salt water from below the bed when heavy pumping has drawn down water levels in the overlying sands.

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 water from this aquifer is not possible in 1960. 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 aquifer's ability to transmit water except in the southeastern part of Santa Rosa County. The water transmitting and water storing properties would have to be determined by test drilling and pumping tests. The chemical quality of the water would need to be determined from water samples collected during the test drilling.

Wells at lower elevations drilled into the upper part of the Floridan aquifer in southeastern Santa Rosa County have large yields. The water is under artesian pressure, and wells 5 to 6 inches in diameter can yield from 250 to almost 1,000 gpm by natural flow.

A study of electric logs indicates that the water in the upper part of the Floridan aquifer (above the Bucatunna clay member) is fresh except in the extreme southern parts of both counties. The logs also indicate that the water in the lower part of the Floridan aquifer (below the Bucatunna clay member) is fresh in the northern half of both counties and salty in the southern half.

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