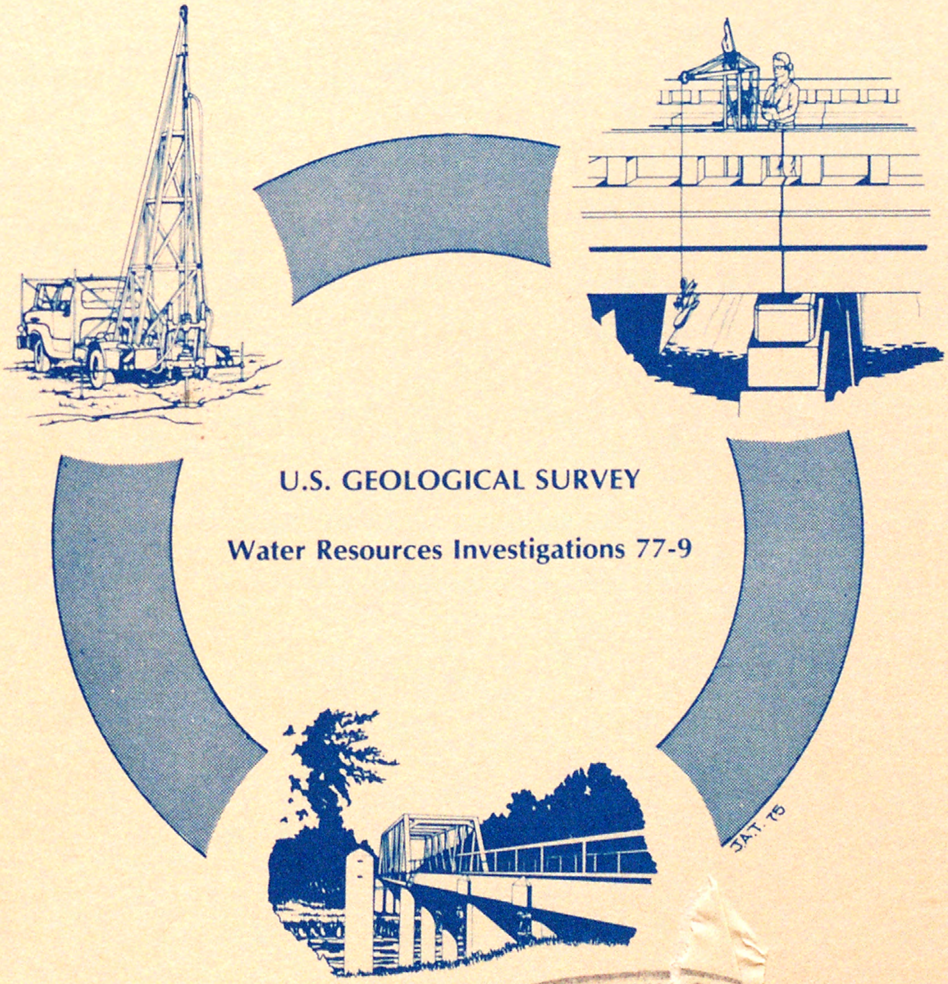
WATER RESOURCES OF OKALOOSA COUNTY AND ADJACENT AREAS, FLORIDA



U.S. GEOLOGICAL SURVEY

Water Resources Investigations 77-9

Prepared in cooperation with
OKALOOSA COUNTY,
FLORIDA

BUREAU OF GEOLOGY,
FLORIDA DEPARTMENT OF NATURAL RESOURCES

NORTHWEST FLORIDA WATER MANAGEMENT DISTRICT

and the

BUREAU OF WATER RESOURCES MANAGEMENT,
FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION

BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle WATER RESOURCES OF OKALOOSA COUNTY AND ADJACENT AREAS, FLORIDA			5. Report Date August 1977 6.
7. Author(s) Henry Trapp, Jr., C. A. Pascale, and J. B. Foster			8. Performing Organization Rept. No. USGS/WRI 77/9
9. Performing Organization Name and Address U.S. Geological Survey, Water Resources Division Suite F-240 325 John Knox Road Tallahassee, Florida 32303			10. Project/Task/Work Unit No. 11. Contract/Grant No.
12. Sponsoring Organization Name and Address U.S. Geological Survey, Water Resources Division Suite F-240 325 John Knox Road Tallahassee, Florida 32303			13. Type of Report & Period Covered Final 14.

15. Supplementary Notes Prepared in cooperation with Okaloosa County; Northwest Florida Water Management District; Bureau of Water Management, Florida Department of Environmental Regulation; Bureau of Geology, Florida Department of Natural Resources.

16. Abstracts Okaloosa County, in the northwest Florida panhandle, depends on the Floridan aquifer for water supply, although it also has abundant surface water and ground water in the surficial sand-and-gravel aquifer. Water levels have declined locally more than 90 feet (27 meters) in the upper limestone of the Floridan aquifer. This investigation was initiated to determine the extent of the decline and the potential for future water resources development. The Floridan aquifer is overlain by the Pensacola clay confining bed, and the Bucatunna Clay subdivides it into two limestone units. Water in the upper limestone is generally of good quality. The lower limestone probably contains saline water. Average daily stream discharge is about 2,500 million gallons (9.5 million cubic meters). Stream discharge does not diminish excessively during droughts, owing to high base runoff. Water levels will decline as long as pumping increases in the present areas of withdrawal. The decline could be alleviated by redistribution of pumping, artificial recharge, and the use of the sand-and-gravel aquifer or streams.

17. Key Words and Document Analysis. 17a. Descriptors

*Water supply, *Aquifers, *Flow characteristics, *Potentiometric level, *Drawdown, *Water quality, Florida, Gulf Coastal Plain, Ground water, Ground-water recharge, Hydrographs, Wells, Specific capacity, Transmissivity, Hydrogeology, Saline water intrusion, Base flow, Artificial recharge, Rainfall-runoff relations, Streamflow, Floods, Lakes, Potable water, Hardness (water), Fluoride, Chloride, Iron.

17b. Identifiers/Open-Ended Terms

Okaloosa County, Floridan aquifer, Sand-and-gravel aquifer of northwest Florida, Yellow River basin, Blackwater basin, Choctawhatchee River.

17c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
No restriction on distribution	UNCLASSIFIED	86
	20. Security Class (This Page) UNCLASSIFIED	22. Price

FORM NTIS-35 (REV. 3-72)

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USCOMM-DC 14952-P72

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AND ADJACENT AREAS,

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By Henry Trapp, Jr., C. A. Pascale, and J. B. Foster

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FLORIDA DEPARTMENT OF ENVIRONMENTAL REGULATION

August 1977

UNITED STATES DEPARTMENT OF THE INTERIOR

CECIL D. ANDRUS, Secretary

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Alkalinity.--the capacity of a solution to neutralize acid. To complete this definition, some end-point pH needs to be specified. Normally, the pH designated is a selected value between 5.1 and 4.5, or that of the methyl-orange end point, (about pH 4.0-4.6).

Anion.--a negative ion: in electrolysis, anions go toward the anode.

Aquifer.--a formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Artesian.--synonymous with confined. An artesian aquifer is confined by one or more confining beds. An artesian well is a well deriving its water from an artesian or confined aquifer. The water level in an artesian well stands above the top of the artesian aquifer it taps.

Base runoff.--sustained flow in a stream, composed largely of ground-water effluent.

Bioclastic rock.--a sedimentary rock consisting of fragmental or broken remains of organisms, such as a limestone composed of shell fragments.

Cation.--a positively charged ion: cations move toward the cathode in an electrolyzed solution.

Cone of depression.--the depression produced in the water table or other potentiometric surface by the withdrawal of water from one or more wells. If the aquifer is nearly uniform in shape or texture in the vicinity of the well, this depression has somewhat the form of an inverted cone whose apex is at the water level in the well while discharge is in progress, whose height is equal to the drawdown, and whose base is the original water table or other potentiometric surface within the area of influence.

Confining bed.--a body of relatively impermeable material adjacent to one or more aquifers.

Consumptive use.--the quantity of water discharged to the atmosphere or incorporated in the products of the process in connection with vegetative or animal growth, human use, or an industrial process.

Discharge.--outflow; can be applied to describe the flow of water from a pipe or from a drainage basin.

Direct runoff.--the runoff entering stream channels promptly after rainfall or snow melt. Superimposed on base flow, it forms the bulk of the hydrograph of a flood.

Dome.--an uplift or anticlinal-type structure, either circular or elliptical in outline, in which the rock dips gently away in all directions.

Drainage area.--that area, measured in a horizontal plane, which is enclosed by a topographic divide such that direct surface runoff from precipitation normally would drain by gravity into the drainage basin above a specified point.

Drainage basin.--a part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water.

Drainage density.--length of all channels, above those of a specified stream order, per unit of drainage area.

Drawdown (of a well from which water is being discharged).--the lowering of the water level or the equivalent reduction of pressure of the water in the well caused by withdrawal of water. The term is also applied to the lowering of water levels or pressures in other wells affected by the discharging well.

Evaporation.--the process by which water is changed from the liquid or solid state into the vapor state. In hydrology, evaporation is vaporization that takes place at a temperature below the boiling point.

Evapotranspiration.--water withdrawn from a land area by evaporation from water surfaces and moist soil and plant transpiration.

Flood-frequency curve.--a graph which shows the average interval of time within which a flood of a given magnitude will be equalled or exceeded once.

Flow-duration curve.--a cumulative frequency curve that shows the percentage of time that specified discharges are equalled or exceeded.

Foraminifera.--single-celled animals (Protozoa), generally with a test (external hard covering) composed of agglutinated particles or of secreted calcite. Some limestones are composed chiefly of the remains of foraminifera.

Head.--the height above a standard datum of the surface of a column of water (or other liquid) that can be supported by the pressure of a given point. The total head of a liquid at a given point is the sum of three components: 1) elevation head, equal to the elevation of the point above the datum, 2) pressure head, the height of a column of static water that can be supported by the static pressure at the point, 3) velocity head, which is the height to which the kinetic energy of the water is capable of lifting the water. Under usual conditions of ground-water flow, the velocity head is negligible.

Hydraulic conductivity.--a measure of the capacity of a material to transmit water. A medium has a hydraulic conductivity of unit length per unit time if it will transmit in unit time a unit volume of ground water at the prevailing viscosity through a cross section of unit area, measured at right angles to the direction of flow, under a hydraulic gradient of unit change of head through unit length of flow. It is commonly expressed in ft/d (feet per day) in current U.S. Geological Survey usage.

Hydrograph.--a graph showing stage, flow, velocity, or other property of water with respect to time.

Ion.--an electrically charged atom or group of atoms, the electrical charge of which results when a neutral atom or group of atoms loses or gains one or more electrons.

Overland flow.--the flow of rainwater or snowmelt over the land surface toward stream channels. After it enters a stream, it becomes runoff.

Percolation.--the movement, under hydrostatic pressure, of water through the interstices of a rock or soil, except the movement through large openings such as a cave.

Permeability.--a measure of the ability of a rock or soil to transmit fluid, such as water, under a hydropotential gradient. Permeability is a property of the medium alone and is independent of the nature or properties of the fluid.

Potentiometric surface.--an imaginary surface connecting points to which water would rise in tightly cased wells from a given point in an aquifer.

Recharge.--the processes by which water is absorbed and added to the zone of saturation. Recharge is also used to designate the quantity of water that is added to the zone of saturation, and also applies to the increment of water to an aquifer.

Runoff.--that part of the precipitation that appears in surface streams.

Runoff in inches.--the depth to which the drainage area would be covered if all the runoff for a given time period were uniformly distributed on it.

Specific capacity.--the specific capacity of a well is the rate of discharge of water from the well divided by the drawdown of water level within the well. It varies slowly with duration of discharge, which should be stated when known.

Stiff diagram.--a graphic plot of the principal chemical constituents of a water according to a method devised by Stiff (1951). Four parallel horizontal axes extend on each side of a zero axis, with concentrations of four cations plotted (in milliequivalents per liter) to the left of zero and four anions to the right. The resulting points are connected so as to give an irregular polygon, which may be characteristic for a particular water.

Storage coefficient.--the volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in head.

Transmissivity.--the rate at which water is transmitted through a unit width of the aquifer under a unit hydraulic gradient. It is equal to the average hydraulic conductivity of the aquifer multiplied by its thickness. In this report, transmissivity is expressed in units of ft^2/d (feet squared per day). Transmissivity was formerly called the coefficient of transmissibility, and expressed in (gal/d)/ft (gallons per day per foot). Values expressed in the old units can be converted to the new by dividing by 7.48.

Transpiration.--the quantity of water absorbed and transpired and used directly in the building of plant tissue, in a specified time. It is the process by which water vapor escapes from the living plant, principally the leaves, and enters the atmosphere. It does not include evaporation.

Water table.--an imaginary surface whose elevation coincides at every point with the position the air-water interface would assume in an uncased open hole were one placed at that point. A water table is a special case of potentiometric surface, found in an unconfined aquifer.

Water year.--in Geological Survey reports dealing with surface-water supply, is the 12-month period, October 1 through September 30. The water year is designated by the calendar year in which it ends.

Well efficiency.--the ratio of the actual specific capacity at the well design rate after 24 hours of pumping to the maximum specific capacity possible calculated from formation characteristics and well geometry and assuming a 24-hour period of continuous pumping.

WATER RESOURCES OF OKALOOSA COUNTY AND ADJACENT AREAS, FLORIDA

By

Henry Trapp, Jr., Charles A. Pascale, and James B. Foster

ABSTRACT

Okaloosa County, located in the northwest Florida panhandle, depends almost entirely on the Floridan aquifer for water supply, although it also has abundant surface water and ground water in the surficial sand-and-gravel aquifer. Water levels have declined locally more than 90 feet in the upper limestone of the Floridan aquifer. This investigation was initiated to determine the extent of the decline and the potential for future development of local water resources.

The Floridan aquifer is composed principally of carbonate rocks ranging in age from Eocene to Miocene. It is artesian, and is overlain by the Pensacola clay confining bed in most of Okaloosa County. The Bucatunna Clay member of the Byram Formation (Bucatunna clay confining bed) subdivides the Floridan into upper and lower units, which are treated as separate aquifers. Water in the upper limestone of the Floridan aquifer is of good quality in most of Okaloosa County and adjacent areas, but locally it is hard and contains chloride or fluoride in concentrations exceeding the Environmental Protection Agency's recommended limits. Data are lacking for the lower limestone, but it is believed to contain saline water throughout most of Okaloosa County.

The sand-and-gravel aquifer crops out throughout the area of investigation. It consists of very fine to coarse quartz sand with scattered pebbles and lenses of gravel and clay. Although the water in the aquifer generally contains less than 50 milligrams per liter of dissolved solids, it is acidic and hence corrosive and locally saline. Therefore it is little used. Natural discharge from the aquifer is the principal factor in the maintenance of streamflow, and may contribute significant quantities of recharge to the Floridan aquifer. The sand-and-gravel aquifer is potentially important as a future source of water for public supply and artificial recharge of the upper limestone of the Floridan aquifer.

Average annual rainfall for Okaloosa County is about 64 inches. Streams and rivers discharge daily about 2500 million gallons of water generally containing less than 20 milligrams per liter of dissolved solids into the bays and Gulf of Mexico. Stream discharge does not diminish excessively during drought, owing to a high proportion of base runoff (as much as 96 percent in the southern part of the county). Runoff in 1967, a dry year, ranged from 19 inches in the northern hill country basins to 44 inches in the coastal sandhills areas.

Water levels can be expected to decline in the upper limestone of the Floridan aquifer as long as pumping continues to increase in the present areas of major withdrawal. The decline could be alleviated by redistribution of pumping, artificial recharge, and use of the sand-and-gravel aquifer or streams as water sources.

INTRODUCTION

Location

This report describes and evaluates the water resources of a 1,425 mi^2 area in the panhandle of northwest Florida. Of this area, 1,003 mi^2 are in Okaloosa County and 422 mi^2 are in western Walton County, as shown in figure 1. The Walton County segment includes the drainage basins of Pond Creek, Shoal River, and Rocky Creek, and the coastal area extending eastward from the Okaloosa-Walton County line to the east end of Choctawhatchee Bay.

Purpose and Scope

The continued increase in the use of ground water in southern Okaloosa County for public supplies over the last 25 years has resulted in large declines in water levels in wells tapping the Floridan aquifer, at present the principal source of water supply throughout the county. The investigation to determine the extent of the declines, the potential for the continued withdrawal of water from the aquifer, and the availability of alternate water sources was made by the U.S. Geological Survey in cooperation with Okaloosa County, the Bureau of Geology, Florida Department of Natural Resources, and the Bureau of Water Resources Management, Florida Department of Environmental Regulation. Field data were collected from 1966 to 1969. This report explains why water levels have declined so drastically in some parts of the project area and provides information on the upper limestone of the Floridan aquifer, on other sources of water within the area of investigation, and on the quality of the water available from them. Alternatives for future management of the local water resource are presented.

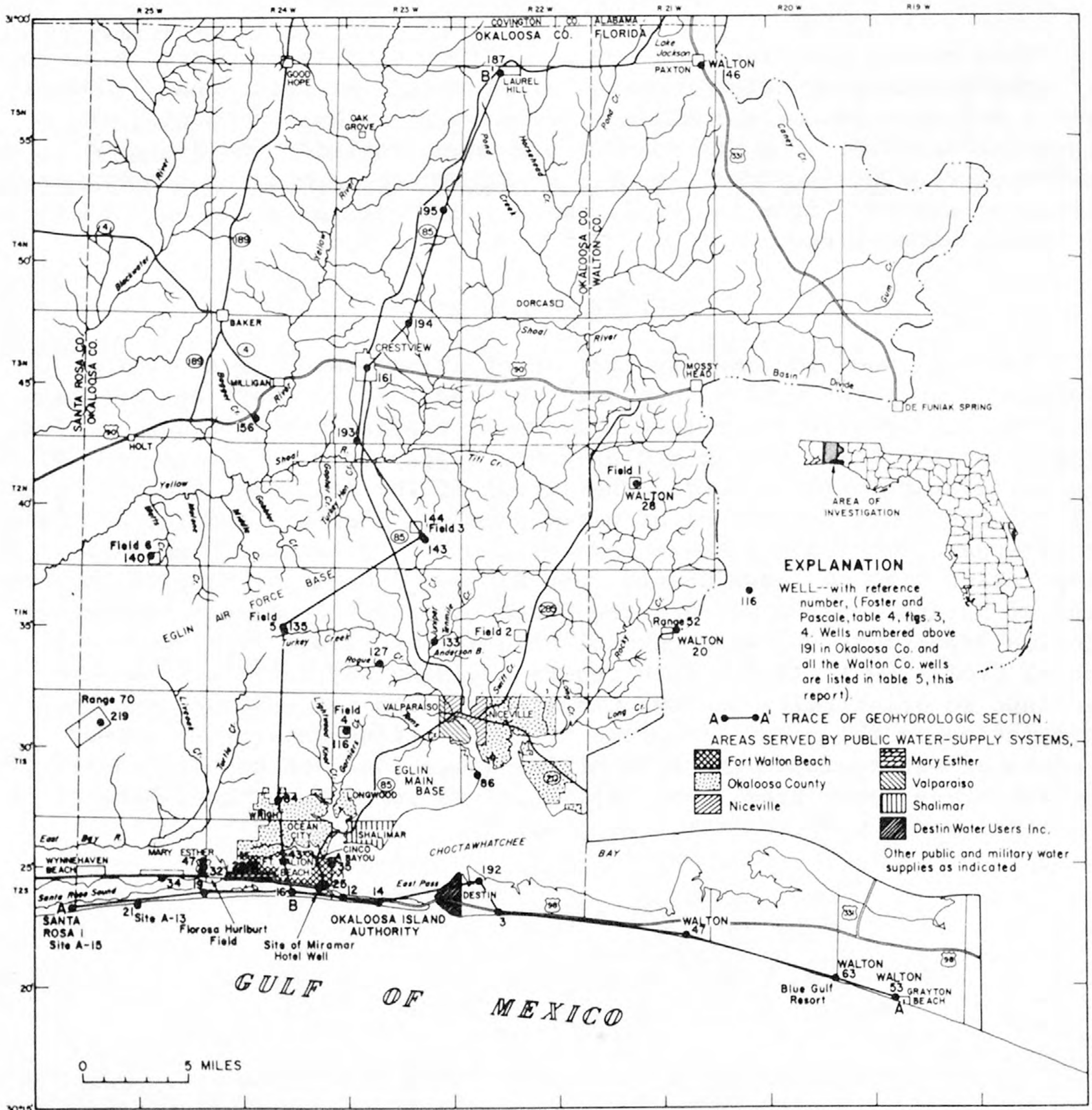

FIGURE 1.--AREA OF INVESTIGATION, GEOGRAPHIC FEATURES, AREAS SERVED BY PUBLIC WATER-SUPPLY SYSTEMS, TRACES OF GEOHYDROLOGIC SECTIONS, AND SELECTED WELLS.

Previous Investigations

Sellards and Gunter (1912, p. 105-110) describe the water resources, physiography, drainage, wells, and soils of Walton County, which originally included what is now Okaloosa County, and show some places adjacent to Choctawhatchee Bay where flowing artesian wells could have been drilled.

Matson and Sanford (1913, p. 422-426) discuss the surface features, geology, and water supply of Walton County (including the present Okaloosa County). Brief data on wells at Laurel Hill are presented in tables.

Daily discharge records have been collected at Yellow River at Milligan and at Shoal River near Crestview since 1938, Blackwater River near Baker since 1950, Shoal River near Mossy Head since 1951, and Baggett Creek near Milligan since 1964. Daily discharge records for these rivers are published by the U.S. Geological Survey in the annual series of Water-Supply Papers through 1960 and in the "Surface-Water Records of Florida, Volume 1, Streams", since 1961. Foster and Pascale (1971, p. 95) list data reports on streamflow, the quality of water, and ground-water levels.

Chemical analyses of surface water and ground water have been published in a series of Water-Supply Papers through 1964, and since 1965 in the Water Resources Data for Florida, Part 2, Water Quality Records.

Ground-water levels and artesian pressures have been measured in Okaloosa County since 1946. The measurement records have been published in the Water-Supply-Paper series of the U.S. Geological Survey.

Barraclough and Marsh (1962) describe the aquifers and quality of ground water along the gulf coast from the Choctawhatchee River to the Perdido River at the boundary between Florida and Alabama.

Acknowledgments

The authors express their appreciation to the many citizens of Okaloosa and Walton Counties who permitted the sampling of water and measuring of water levels in their wells. Special appreciation is due the Florida Department of Transportation, Okaloosa County, and Eglin Air Force Base for granting permission to drill test wells on public lands and to construct water-stage recorders on bridges within their jurisdiction.

Officials and former officials of the city of Fort Walton Beach are extended a special thanks for the many courtesies and assistance provided during the study: Winston G. Walker, City Manager; Joe Morgan, former City Engineer; E. W. Dick, former Water Superintendent; and Grady Henderson Chief Warehouseman. Thanks are due to the following members of the Civil Engineering staff at Eglin Air Force Base: W. E. Alford, Deputy Director; R. A. Hoffman, retired Chief, Engineering and Construction Division; and C. R. Smith. Well data and courtesies provided by A. G. Symons and R. H. Brown of the Layne-Central Company are gratefully acknowledged.

For use of those readers who may prefer to use metric units rather than English units, the conversion factors for the terms used in this report are listed below:

Multiply English unit	By	To obtain metric unit
inches (in)	25.4	millimeters (mm)
feet (ft)	.3048	meters (m)
miles (mi)	1.609	kilometers (km)
square feet (ft^2)	.0929	square meters (m^2)
square miles (mi^2)	2.59	square kilometers (km^2)
acres	.4047	hectares (ha)
million gallons (Mgal)	3785	cubic meters (m^3)
cubic feet (ft^3)	.0282	cubic meters (m^3)
gallons per minute (gal/min)	.06309	liters per second (L/s)
gallons per day (gal/d)	4.381×10^{-5}	liters per second (L/s)
million gallons per day (Mgal/d)	.04301	cubic meters per second (m^3/s)
cubic feet per second per square mile [$(ft^3/s)/mi^2$]	.01093	cubic meters per second per square kilometer [$(m^3/s)/km^2$]
gallons per minute per foot [(gal/min)/ft]	.207	liters per second per meter [(L/s)/m]
degrees Fahrenheit (°F)	0.556 x (°F-32)	degrees Celsius (°C)

THE HYDROLOGIC ENVIRONMENT

General Statement

The hydrologic system in the area of investigation is similar in most respects to that of other areas in northwest Florida. Rainfall is the source of the water. Some of the rain supplying the system falls within the area, and some falls outside and moves into the area in streams and underground. The surface materials are highly permeable unconsolidated sands, which provide for infiltration of much of the rainfall and subsequent storage of water. Water is lost from the area by streamflow, evaporation, transpiration, subsurface flow to the gulf and adjacent areas, and by consumptive use.

The water resources of an area depend upon the quantities and quality of water within parts of the hydrologic cycle accessible to man. When withdrawals of water plus natural discharge exceed the rate of water movement into the area, water shortages eventually will develop. The quality of the water can deteriorate through natural causes or the actions of man. Management and conservation of water resources can be accomplished only through knowledge of the quantity and quality of water available in the hydrologic system. This knowledge will enable the best prediction of where to obtain water with the least unfavorable impact on future supplies, other users, or the environment in general.

Description of Physiographic and Geologic Features

The area of investigation lies in two physiographic divisions, as described by Vernon and Puri (1964, p. 7-15): the Western Highlands of the Northern Highlands and the Coastal Lowlands. In this report, these physiographic divisions have been further subdivided to facilitate the discussion of drainage, streamflow characteristics, and potential for recharge to the underlying aquifers.

The Western Highlands are divided into the sandhills, Pond Creek-Shoal River hills, Blackwater-Yellow River hills, bay sinks, and river swamps, as shown in figure 2. The Coastal Lowlands have been divided into the flatwoods and swamps, and sand dunes, beach ridges, and wave-cut bluffs.

The sandhills constitute the areas from the coast to U.S. 90 on the north, that, except for a small area between the Shoal River and Crestview, are 50 ft or more above sea level. They are characterized by a low drainage density, resulting from a large proportion of the rainfall infiltrating into highly permeable sands, with little direct runoff. The streams that drain these hills have high base runoff and generally occupy deep, narrow ravines, which have formed by headward erosion of seeps or water-table springs. The heads of these streams are called "steepheads," owing to their steep walls and semicircular shape.

The Pond Creek-Shoal River hills lie in the northeastern part of the study area. Direct runoff is greater in these hills than in the sandhills because of a higher proportion of clay in the surficial sand, which reduces the infiltration of rainfall. Larger direct runoff has produced a higher drainage density than exists in the sandhills (fig. 2).

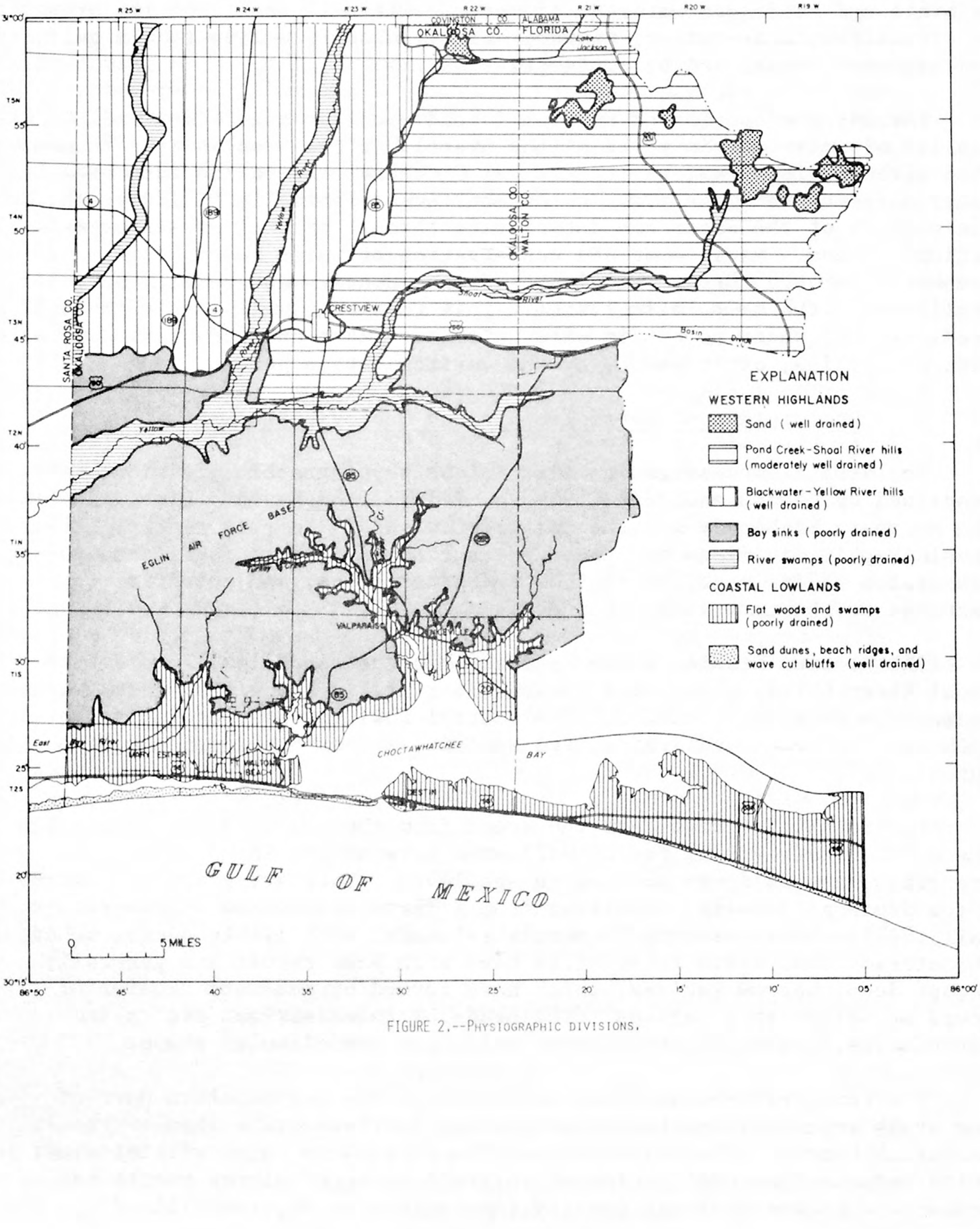

FIGURE 2.--Physiographic divisions.

The Blackwater-Yellow River hills are underlain by clayey sand, sandy clay, and clay. The direct runoff from this area is also greater than that of the sandhills and the stream pattern is more densely developed

Shallow depressions, which appear to be similar to the Carolina bays as described by Murray (1961, pp. 512-519), occur in the north and northeastern part of the Pond Creek-Shoal River hills and are here termed "bay sinks." They may have formed by collapse of surficial materials into solution cavities dissolved out of underlying limestone. The floors of these depressions have been filled with clay and sandy clay eroded from the adjacent hills. These materials of low permeability inhibit the percolation of water into the underlying limestone, so that the bays are wet except during extended drought.

River swamps in the flood plains of the Yellow, Blackwater, and Shoal Rivers and Titi Creek have been formed by the buildup of natural levees along the stream channels. Runoff from the hills adjacent to the river valleys in places is temporarily impounded by the levees; the impounded water subsequently drains slowly into the main river channels through breaks in the levees. During flood stage, water flows from the river channel into the swamps through breaks in the levees. At a very high stage, the rivers top the levees and fill the swamps.

Swamps and poorly drained flatwoods have formed on the remnants of marine terraces. In areas underlain by hardpan, which restricts the downward percolation of water into the sand-and-gravel aquifer, swamps persist except during extreme dry periods. East Bay Swamp, located in the flatwoods area just west of Fort Walton Beach, is an example of one of the larger of these.

The youngest physiographic unit is composed of sand dunes, beach ridges, and wave-cut bluffs. It is located along the gulf where it forms the barrier island (Santa Rosa Island) west of East Pass and the beach ridge along the coast east of East Pass.

The materials that underlie the land surface at shallow depth in the area of investigation vary from porous, permeable sand, to less permeable sandy clay and clayey sand. These materials form the sand-and-gravel aquifer (Musgrove, Barraclough, and Marsh, 1961, p. 11). Thicknesses of materials within the sand-and-gravel aquifer, and also of materials underlying it are shown in two geohydrologic sections, whose traces are delineated on figure 1. In general, the sand-and-gravel aquifer thickens from east to west, as shown in section A-A' (fig. 3). Its thickness ranges from about 20 to 420 ft as shown in figures 3 and 4.

The sand-and-gravel aquifer overlies relatively impermeable clay, clayey sand, and marl, which form a confining bed between the sand-and-gravel aquifer and the artesian Floridan aquifer below it. This confining bed extends throughout the area of investigation except for the

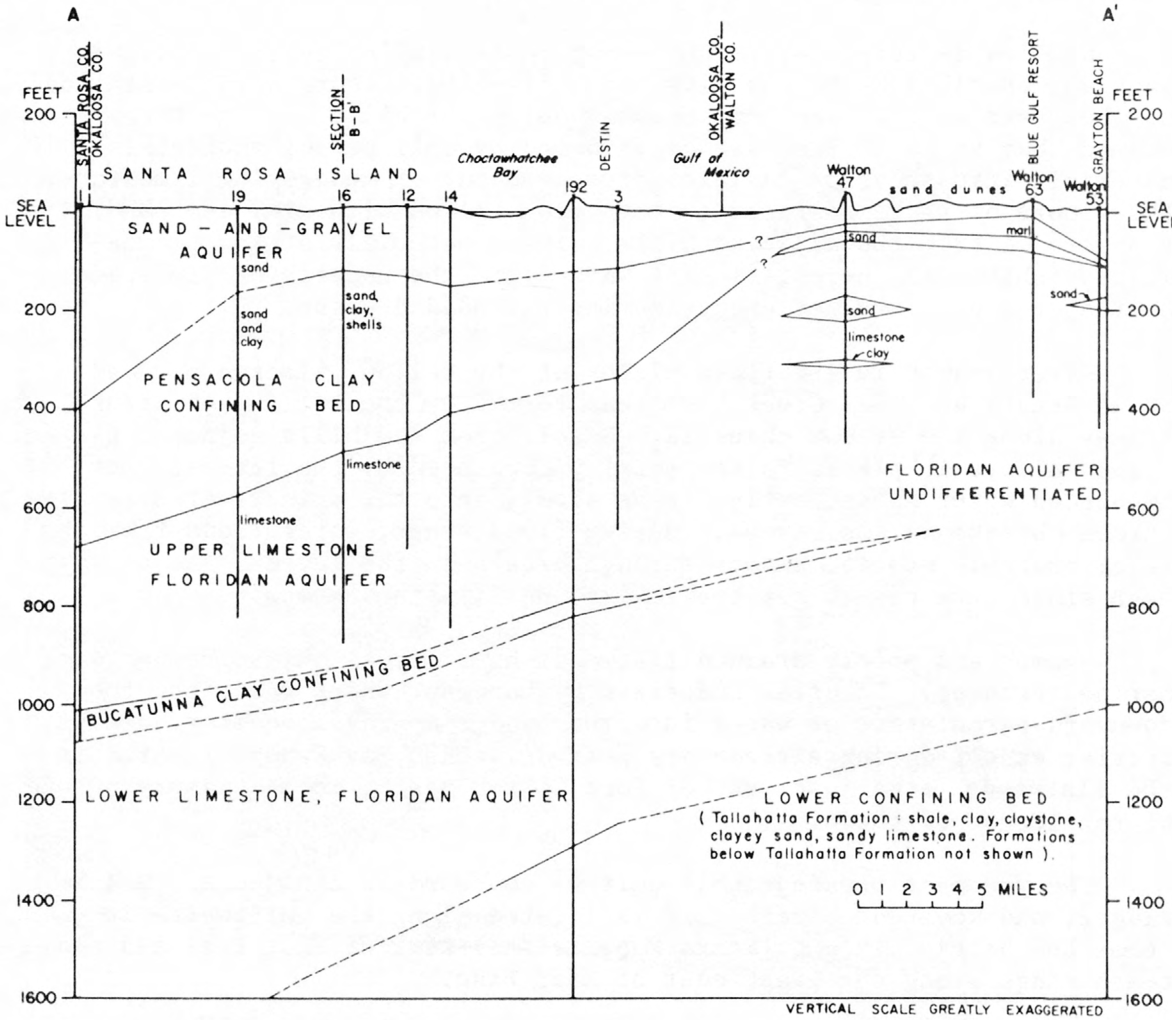

FIGURE 3.--Geohydrologic section A-A' (trace of section on fig. 1).

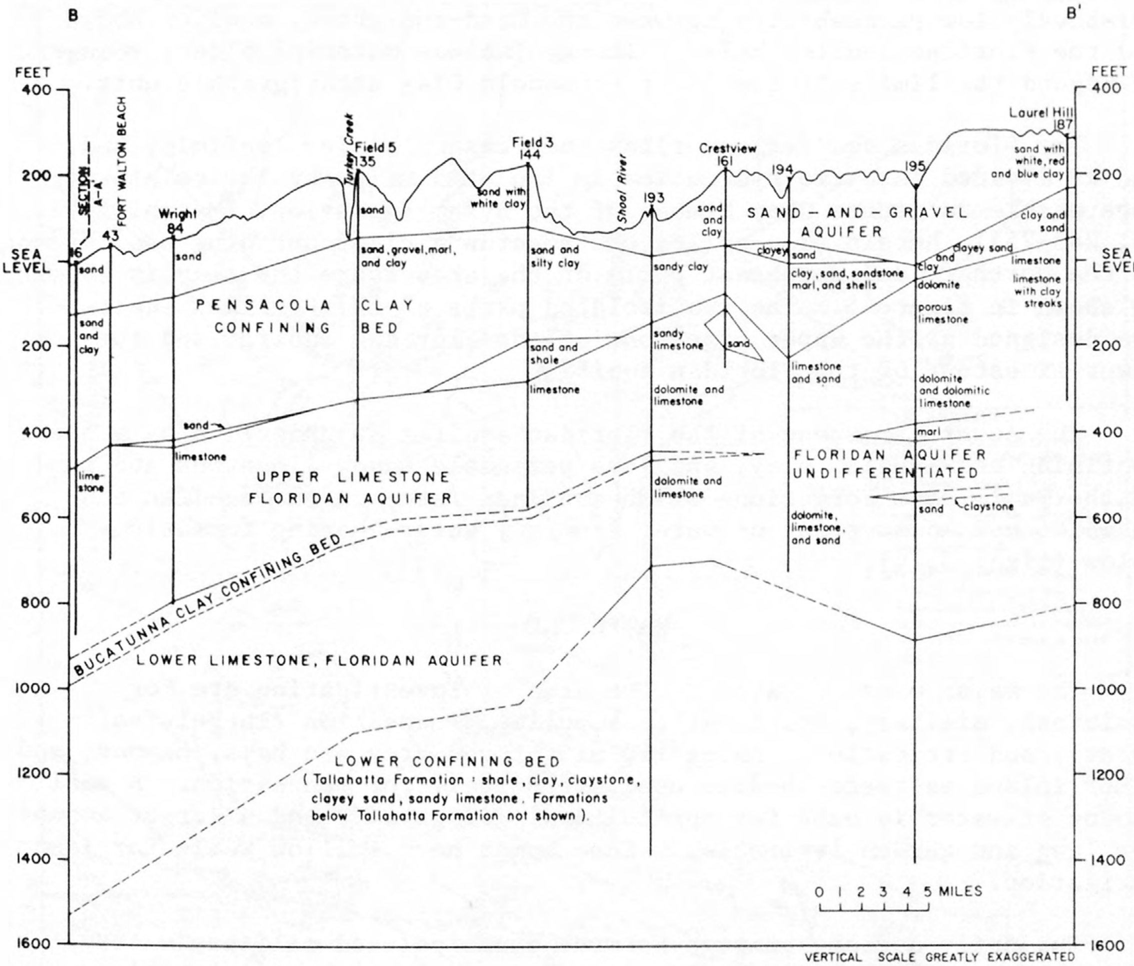

FIGURE 4.--Geohydrologic section B-B' (trace of section on fig. 1)

southeast corner. The confining bed corresponds approximately to the lower part of the Pensacola Clay of Marsh (1966, p. 54-68). However, in this report the Pensacola clay confining bed is defined as the material of relatively low permeability between the sand-and-gravel aquifer above and the Floridan aquifer below. It may include material older, younger, or beyond the limits of the lower Pensacola Clay stratigraphic unit.

The Floridan aquifer underlies the Pensacola clay confining bed, and is divided into two hydraulically isolated units by the relatively impermeable Bucatunna Clay Member of the Byram Formation, (Marsh, 1962, pp. 243-252), herein also called the Bucatunna clay confining bed, except in the northern and southeast parts of the area where the clay is absent, as shown in figure 5. The two isolated parts of the Floridan aquifer are designed as the upper limestone of the Floridan aquifer and the lower limestone of the Floridan aquifer.

The lower limestone of the Floridan aquifer is underlain by a lower confining bed--shale, clay, and less permeable sandy limestone and sand of the Tallahatta Formation--which confines water in the aquifer and inhibits upward movement of water from any water-bearing formations below (figs. 3, 4).

WATER USE

The major uses of water in the area of investigation are for municipal, military, and domestic supplies, recreation (largely salt-water), and irrigation. About 140 mi^2 of the area are bays, bayous, and other inland saltwater bodies used extensively for recreation. A small amount of water is used for agricultural irrigation, and a larger amount for lawn and garden irrigation. Some homes have shallow wells for lawn irrigation.

The daily average pumpage for the municipal and military water systems in southern Okaloosa County increased from about 1.5 Mgal in 1940 to about 11.8 Mgal in 1968. Daily pumpage varies from about 9.1 Mgal in winter when demand is low to 14.4 Mgal in midsummer when demand is high. The difference between the high and low pumpage, or 5.3 Mgal is attributed largely to lawn and garden irrigation.

History of Water-Supply Expansion

The first wells in the county supplied water to homes and small business establishments. Most of these wells were either dug or small-diameter sand-point wells, which tapped the sand-and-gravel aquifer. Flowing artesian wells were drilled later into the Floridan aquifer adjacent to the Choctawhatchee Bay and along Santa Rosa Sound.

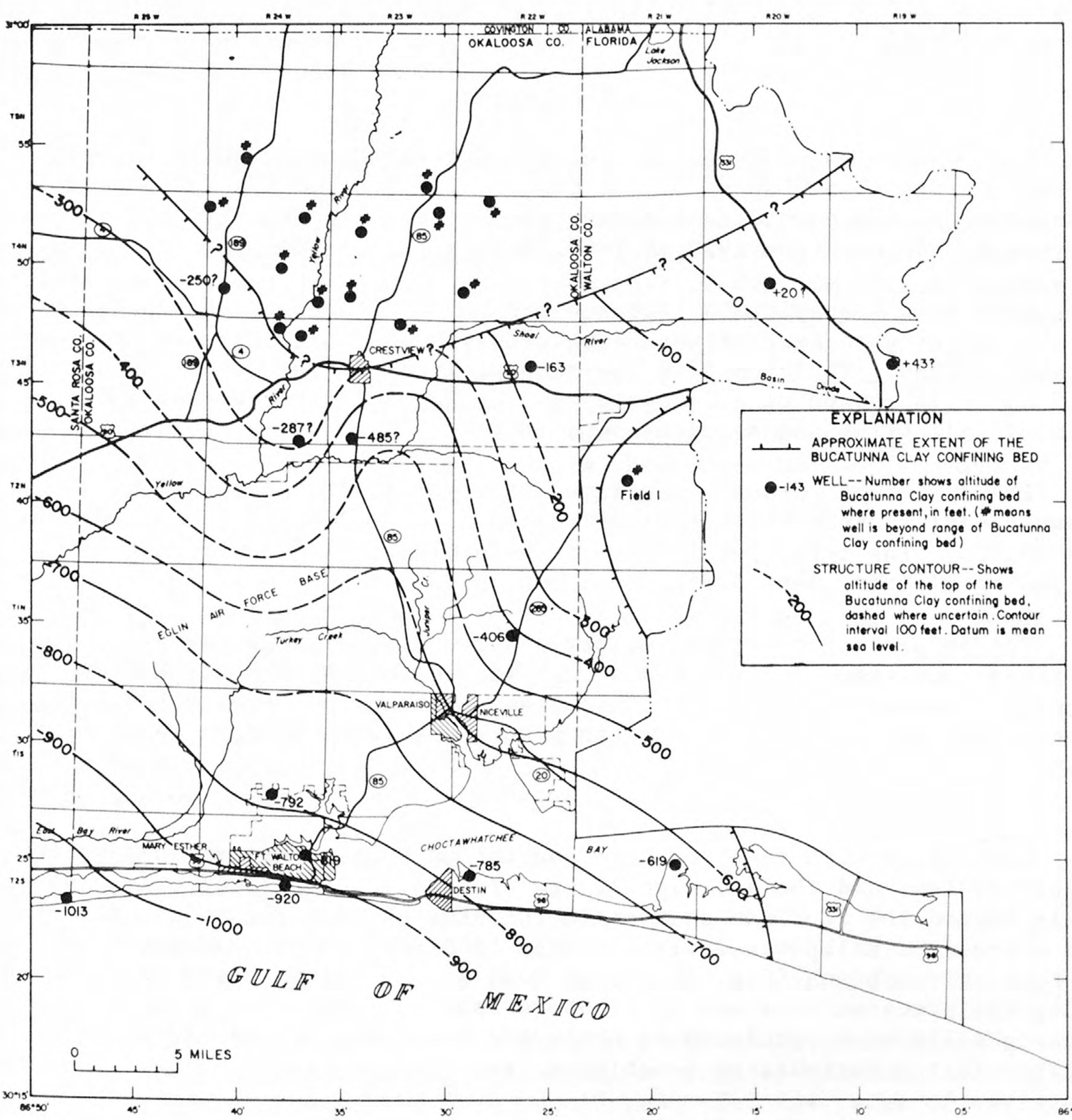

FIGURE 5.--ALTITUDE OF TOP OF BUCATUNNA CLAY CONFINING BED.

The rapid growth in population brought on by the establishment of Eglin Air Force Base during World War II created a need for more water. Cities without public-water supplies began to construct water facilities. Private water companies were organized to supply water to the urban areas near Fort Walton Beach.

Population Growth

The population of Okaloosa County increased from 9,360 in 1920 to 88,187 in 1970 (U.S. Bureau of the Census, 1970). The big increase in population in the county came during and since World War II. The largest 10-year growth was from 1950 to 1960, from 26,476 to 61,175.

Most of the population increase has been in the Fort Walton Beach area. The city of Fort Walton Beach grew from 90 people in 1940 to 19,994 in 1970. The growth in the coastal areas of the county is associated with the expansion and development of Eglin Air Force Base and its related industries and service companies.

The number of persons associated with Eglin Air Force Base has grown steadily since it was established. As of 1970, the base population was 18,325. The total population of the area associated with the base, including military dependents, is about 55,000.

The population of Walton County has grown slowly over the years. Separate population figures are not available for the part of Walton County included in the area of this investigation, but growth has evidently occurred in association with resort development along the coast.

Water Systems

Associated with the growth in population is the expansion of water-supply systems and the addition of new systems. Before 1941 only a few wells tapped the Floridan aquifer in the area of investigation. One of the older deep wells was drilled in May 1923 for the old Miramar Hotel in Fort Walton Beach (fig. 1). This well was 708 ft deep and on March 26, 1936, the artesian head was 32 ft above land surface. Ten to fifteen flowing wells were completed in the upper limestone of the Floridan aquifer in the Fort Walton Beach area from 1923 to 1940.

All the municipal and military water-supply systems in the area of investigation have been constructed since 1940. In 1942, water-supply systems were constructed at the main field of Eglin Air Force Base and at each of seven auxiliary fields. The areas served by municipal systems are shown on figure 1. All of these are in Okaloosa County. The rate of growth in municipal and military water systems is suggested by the number of wells that have been drilled for public-supply and military use since 1940: from 1940 to 1950, 20 wells were drilled; from 1951 to 1960, 15 wells; and from 1961 to 1970, 14 wells.

The per capita consumption of water based on 1970 pumpage records and population figures for the city of Ft Walton Beach averages about 140 gal/d, and ranges from about 100 gal/d in the winter to 200 gal/d in the summer. Pumpage data for Fort Walton Beach and Eglin Air Force Base are included in a report by Foster and Pascale (1971, table 6, p. 33-34).

Relationship of Quality of Water to Use

The chemical quality of water is determined by the substances it contains: dissolved and suspended minerals, dissolved and suspended organic matter, and dissolved gases. In current U.S. Geological Survey usage, these are expressed in terms of weight of solute per unit volume of solution: milligrams per liter (mg/L) and micrograms per liter (ug/L). Milligrams per liter are practically equivalent to "parts per million" (used by some laboratories and formerly used by the U.S. Geological Survey) for waters containing less than 7,000 mg/L (Hem, 1970, p. 79-81). A microgram per liter is one thousandth of a milligram per liter, or equivalent to one "part per billion."

Drinking Water Standards

The practical significance of the chemical composition of a water depends upon its intended use. The suitability of a water for public supply and domestic use can be judged by standards that have been recommended for drinking water by the Environmental Protection Agency, (1975, p. 56, 566-59, 588), and by the Florida Department of Environmental Regulation (1975, p. 92-93). Some of these standards follow, with Florida standards marked *:

*Iron should not exceed 300 ug/L.
*Sulfate should not exceed 250 mg/L.
*Chloride should not exceed 250 mg/L.
Nitrate should not exceed 10 mg/L as nitrogen (equivalent to 45 mg/L as nitrate, as used in Foster and Pascale, 1971, table 7).
Fluoride should not exceed a maximum recommended concentration that is determined by the annual average of maximum daily air temperatures in the area considered. For the range of average maximum daily air temperatures of 70.7 to 79.2°F, which would include those for Okaloosa County, the recommended maximum fluoride concentration is 1.6 mg/L.
*The color should not exceed 15 platinum-cobalt color units.

Okaloosa County and adjacent areas contain large quantities of water meeting the above standards. The principal waters within the county not meeting the standards are the obviously unpotable ones containing substantial amounts of salt (shown by high chloride concentrations). Fluoride and iron concentrations are locally excessive, and the surface waters are generally colored.

Other Factors Affecting Use

The property of hardness in water may be recognized by the increased quantity of soap required to produce lather. The use of hard water is also objectionable because it contributes to the formation of scale in boilers, water heaters, radiators, and pipes, with a resultant decrease in the rate of heat transfer and possibility of water heater or boiler failure.

Hardness is caused almost entirely by compounds of calcium and magnesium, and in tabulated data is generally expressed as "hardness as $CaCO_3$."

Carbonate hardness includes that portion of the hardness equivalent to the bicarbonate plus carbonate (or alkalinity). Noncarbonate hardness is the difference between the hardness calculated from the total amount of calcium and magnesium and the carbonate hardness. If the carbonate hardness (expressed as calcium carbonate) equals the amount of calcium and magnesium hardness (also expressed as calcium carbonate) there is no noncarbonate hardness. Noncarbonate hardness is about equal to the amount of hardness remaining after water is boiled.

No firm line of demarcation separates hard from soft water. Durfor and Becker (1964, p. 27) use the following classification:

Hardness range

Milligrams per liter of $CaCO_3$	Description
0- 60	Soft
61-120	Moderately hard
121-180	Hard
More than 180	Very hard.

According to the standard above, most of the water from the wells in the Floridan aquifer is moderately hard or hard. Surface water, or water from the sand-and-gravel aquifer is generally soft.

Hydrogen-ion concentration is expressed in terms of pH units. Hydrogen-ion concentration affects the corrosive power of water and partly determines the proper treatment that may be necessary in water-treatment plants. A pH of 7.0 at 25°C indicates that water is neutral.

Readings progressively lower than 7.0 denote increasing acid character and those progressively higher than 7.0 denote increasing alkaline character. The pH of most ground water in the United States ranges from 6.0 to 8.5, and the pH of unpolluted river water ranges generally between 6.5 and 8.5 (Hem, 1970, p. 89, 93).

Chemical analyses of ground-water samples from Okaloosa County and adjoining areas of Santa Rosa and Walton Counties collected for this investigation have been published by Foster and Pascale (1971, table 7).

WATER RESOURCES EVALUATION

Rainfall

Annual rainfall in the area of investigation averages about 64 in. The locations of rainfall data-collection sites are shown by Foster and Pascale (1971, fig. 2, p. 10). Average monthly rainfall ranges from about 3 inches in October to 8 inches in July (fig. 6). Nearly half the annual rainfall occurs between June and September as a result of thunderstorms and tropical depressions. Annual rainfall averaged 67.9, 64.9, and 63.9 in at DeFuniak Springs, Niceville, and Crestview, respectively, for the period 1939 to 1967 (fig. 6).

Rainfall varies considerably from year to year and from station to station. For example, at DeFuniak Springs annual rainfall varied from 38 inches in 1954 to 94 inches in 1947. Rainfall data collected at various locations during the investigation showed that annual rainfall was as much as 16 in less at some places than it was at DeFuniak Springs. This difference was due to isolated storms--a variation that tends to disappear in long-term records.

Streamflow

The streamflow discharged into the bays and gulf from Okaloosa County and adjacent areas in Walton and Santa Rosa Counties and Alabama on the average totals about 2,500 Mgal/d of water generally containing less than 20 mg/L of dissolved solids. This total includes runoff from both gaged and ungaged streams. Runoff from ungaged streams was estimated primarily by correlation with streams in nearby basins whose physical characteristics are similar and for which the stream discharge is known.

The runoff, in inches, for the water year 1967 is shown in figure 7 for each of the 13 drainage basins in the area. Also shown is the long-term average annual runoff for those streams gaged prior to the investigation. Runoff in 1967 ranged from 13 to 19 in for streams draining the northern basins and from 24 to 44 in for streams draining

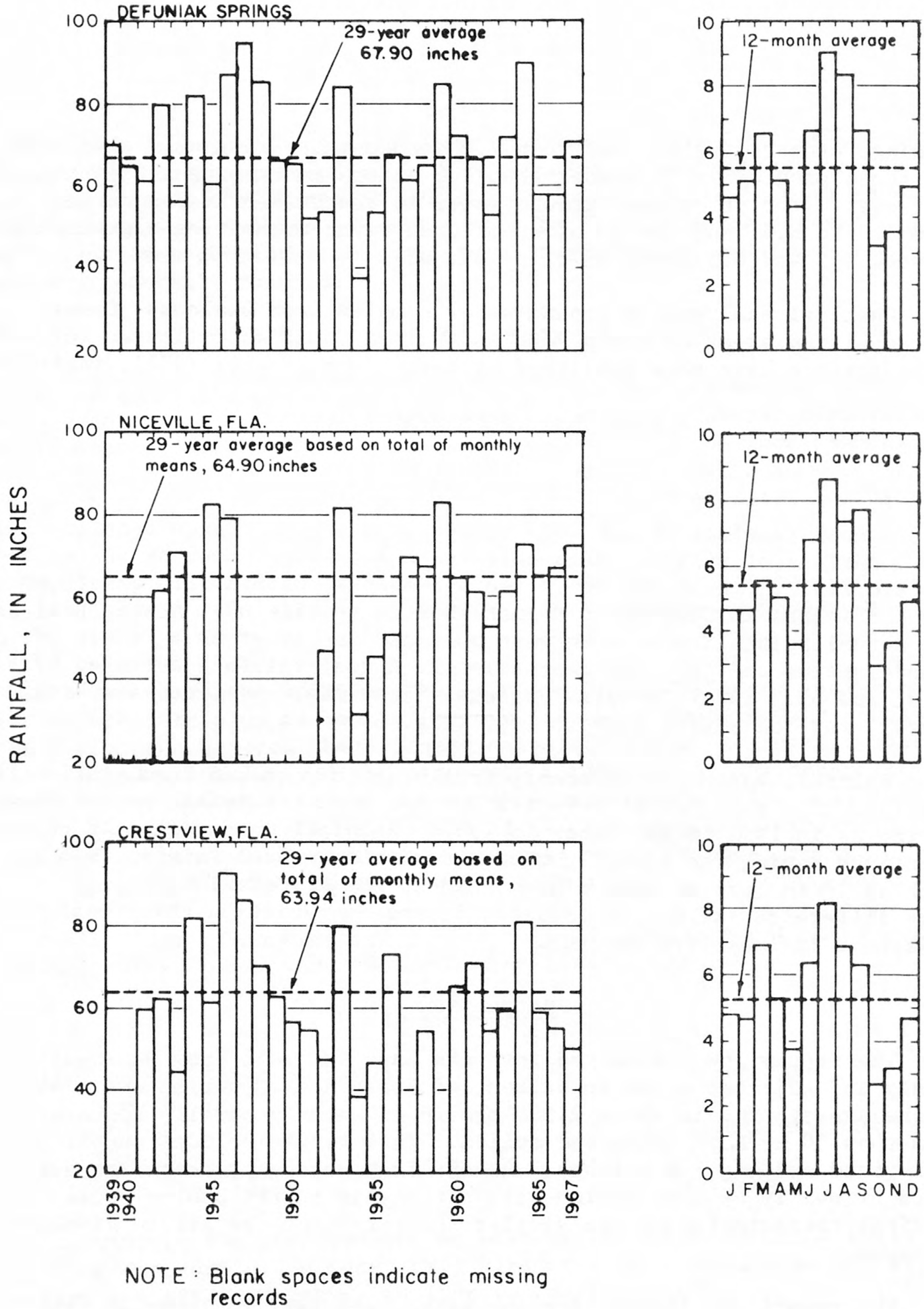

FIGURE 6.--ANNUAL AND MEAN MONTHLY RAINFALL IN OKALOOSA COUNTY AND ADJACENT AREAS.

FIGURE 7.--RUNOFF FROM DRAINAGE AREAS ABOVE 13 GAGING STATIONS IN OKALOOSA COUNTY AND ADJACENT AREAS

the southern basins. The 1967 water year was outstandingly low in rainfall, and hence also in runoff. However, the departure from normal runoff was not as great for the streams in the southern part of the area because of the ample carry-over of water in storage in the sand-and-gravel aquifer in the sand-hills area that feeds the southern streams.

The runoff for 1967 differed substantially from the long-term average. For example, the 29-year average runoff for Shoal River near Crestview was 31 in compared to 19 inches in 1967. The maximum and minimum discharge for the 29-year period are 21,700 ft^3/s and 253 ft^3/s respectively (table 1).

Base Runoff

Streamflow is the sum of direct runoff and base runoff. In areas where soil conditions prevent rapid percolation of rainfall, such as in the Pond Creek-Shoal River hills area, direct runoff is relatively large. In areas of sandy soil favoring high infiltration rates, such as in the sandhills area, direct runoff is small because most of the rainfall infiltrates into the ground and is discharged slowly as ground-water seepage or base runoff to streams.

Most streams in the area have a large base runoff, as evidenced by the low-flow discharge measurements made at more than 40 sites between 1960 and 1969 (Foster and Pascale, 1971, table 2, fig. 2). Base runoff can be estimated from stream-discharge hydrographs by separating the base runoff from that part of the storm or overland runoff that causes the sharp increase or flood peaks in stream discharge. An approximation of base runoff can be made graphically by drawing a smooth curve on the hydrograph tangent to the low points at each end of the flood peaks. Several methods of simple hydrograph separation are given by Linsley and others (1958, p. 157-161). Results of base-runoff analyses of the hydrographs of eight surface-water stations for the 1967 water year indicate that base runoff from streams in southern Okaloosa County constituted approximately 75 to 96 percent of the total flow, as shown in table 2. The high percentage of base runoff in the area is probably also related to the low total runoff experienced during 1967. Because of high base runoff, streamflow does not diminish excessively during drought, and many of the streams, therefore, could serve as reliable sources of water. However, low-flow frequency and draft-storage relations should be developed to show the dependability of streams as sources of water supply.

TABLE 1.--*Summary of streamflow data in Okaloosa County and adjacent areas.*

Gaging station (Locations shown on figure 7)	Drainage area (mi^2)	Period of record used	Average annual runoff (inches)	Average discharge			Maximum discharge (ft^3/s)	Minimum discharge (ft^3/s)
				(ft^3/s)	[(ft^3/s)/mi^2]	(Mgal/d)		
Rocky Creek near Niceville	67.0	a 1966-68	38	185	2.76	120	1,100	102
Turkey Creek near Niceville	25.0	a 1966-68	43	78.7	3.15	50.8	224	56
Juniper Creek near Niceville	29.5	a 1966-68	36	77.6	2.63	50.1	507	39
East Bay River near Wynnehaven Beach	62.0	a 1966-68	46	208	3.35	134	1,440	119
Yellow River at Milligan	624	1939-67	25	1,136	1.73	696	28,000	136
Baggett Creek near Milligan	7.8	1964-67	38	21.9	2.81	14.1	368	7.8
Shoal River near Mossy Head	123	1952-67	26	232	1.89	150	10,500	42
Pond Creek near Dorcas	94.8	b 1966-68	c 15	113	1.19	73.0	2,500	12
Titi Creek near Crestview	62.9	a 1966-68	29	134	2.13	86.6	1,450	69
Shoal River near Crestview	474	1939-67	31	1,077	2.40	734	21,700	253
Yellow River near Holt	1,210	1933-41 1966-68	d 27	d 2,400	1.98	1,550	--	--
Blackwater River near Baker	205	1951-67	20	300	1.46	194	17,200	72
Blackwater River near Holt	276	1966-68	d 19	d 380	1.38	245	--	--

a May 1966 to April 1968 (24 months)
b October 1966 to April 1968 (19 months)
c October 1966 to September 1967 (12 months)
d Estimated

TABLE 2.--*Total runoff, base runoff, and percentage of base runoff at selected gaging sites for the 1967 water year.*

Gaging station (Locations shown on figure 7)	Total runoff (inches)	Base runoff (inches)	Base runoff as percent of total runoff
Rocky Creek near Niceville	33.50	29	87
Turkey Creek near Niceville	39.37	38	96
Juniper Creek near Niceville	30.21	27	89
East Bay River near Wynnehaven Beach	44.14	33	75
Baggett Creek near Milligan	26.18	22	85
Shoal River near Mossy Head	16.14	13	81
Pond Creek near Dorcas	14.51	7	48
Titi Creek near Crestview	24.35	20	82

Flow Duration

Flow-duration curves for major streams draining the southern basins of Okaloosa County and adjacent areas are similar (fig. 8). Their relatively flat slopes, particularly at the lower end, indicate that the basins store large quantities of ground water.

The steeper slopes of the upper ends of flow-duration curves for major streams draining the northern basins (fig. 9) indicate that a much greater part of the flow is from direct runoff; the lower parts of these curves are also steeper, indicating that ground-water storage capabilities are lower than in the southern basins. Shoal River near Crestview receives considerable runoff from the sandhills area to the south where ground-water storage is substantial; hence the lower part of its flow-duration curve is flatter than those for other discharge stations in the northern basins.

Flood Frequency

Flood damage in Okaloosa County and adjacent areas has been minimal because of three factors: (1) flooding has been largely confined to the flood plains of streams; (2) industrial and residential construction has encroached only slightly on the flood plains; and (3) rapid infiltration and a large ground-water reservoir dampens the peaks and increases the length of the period of runoff.

Major floods occurred on most streams in the area in 1940 and 1953. The record flood of the Yellow River occurred in 1953, with a peak discharge at Milligan (station locations shown in fig. 7) of 28,000 ft^3/s. The peak stage was about 10 ft above bank-full stage, or 60.1 ft above sea level, and the river inundated more than a three-quarter-mile wide section of flood plain at the gage site. Fourteen days after the flood peak, the river declined to bank-full stage. In 1940, Shoal River near Crestview reached a record-peak discharge of 21,700 ft^3/s at an elevation of 61.5 ft above sea level. This peak stage was about 8 ft above bank-full stage and inundated more than a 1-mile-wide section of flood plain at the gage site. Six days after the flood peak, the river declined to bank-full stage. In 1953, Blackwater River near Baker reached a record-peak discharge of 17,200 ft^3/s at an elevation of 81.3 ft above sea level. Peak stage was about 6 ft above bank-full stage and the Blackwater River inundated more than a one-quarter-mile-wide section of flood plain at the gage site. Two days after the flood peak, the river declined to within its banks.

The probable recurrence interval was greater than 50 years for the previously described flood peak of the Yellow River and was greater than 20 years for those of the Shoal and Blackwater Rivers. Regionalized flood-frequency curves, based on the work of Barnes and Golden (1966, p.

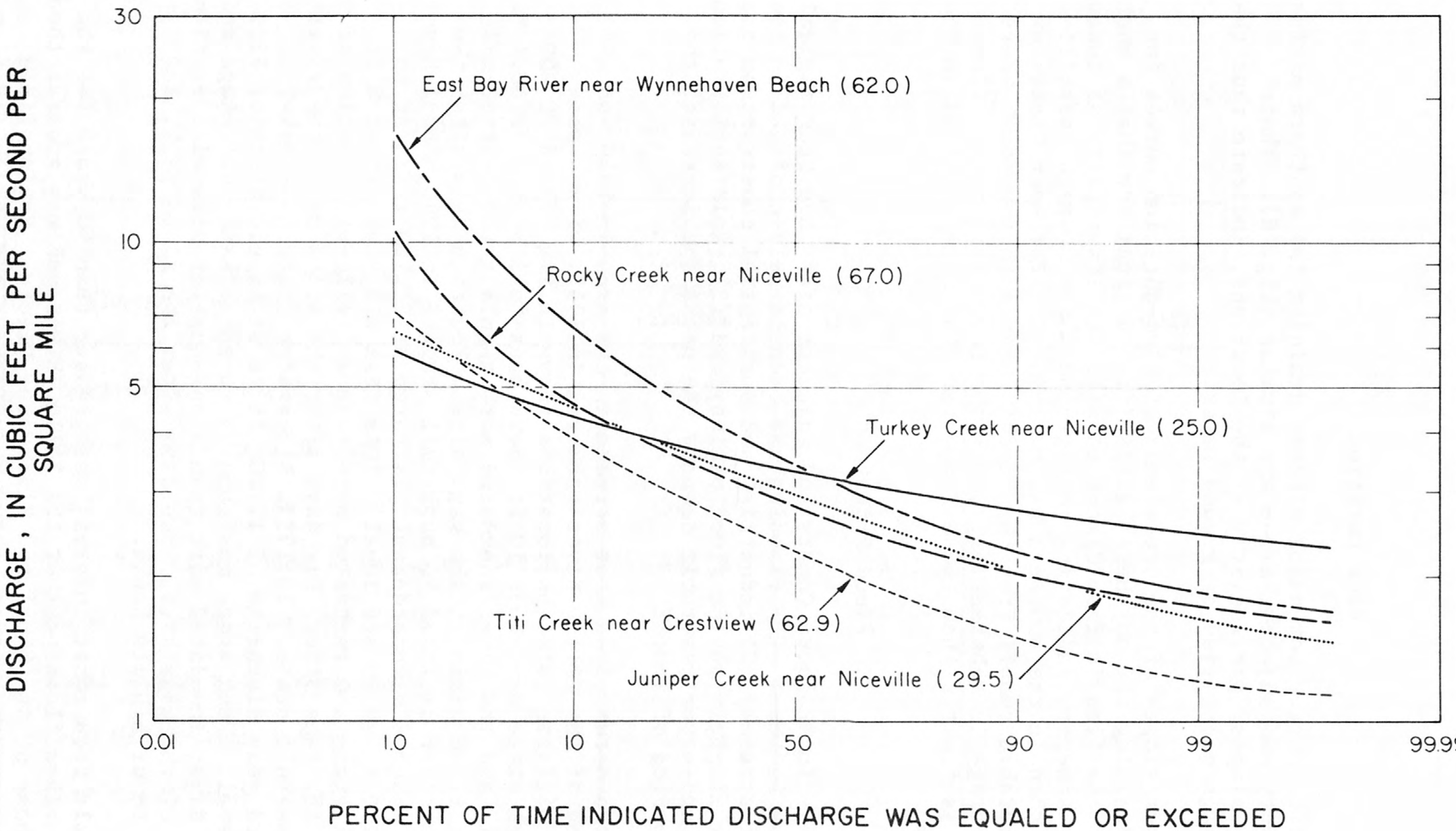

FIGURE 8.--FLOW-DURATION CURVES FOR FIVE STREAMS DRAINING THE SOUTHERN BASINS OF OKALOOSA COUNTY AND ADJACENT AREAS, 1966-68, ADJUSTED TO 1939-67. (DRAINAGE AREA IN SQUARE MILES SHOWN IN PARENTHESES.)

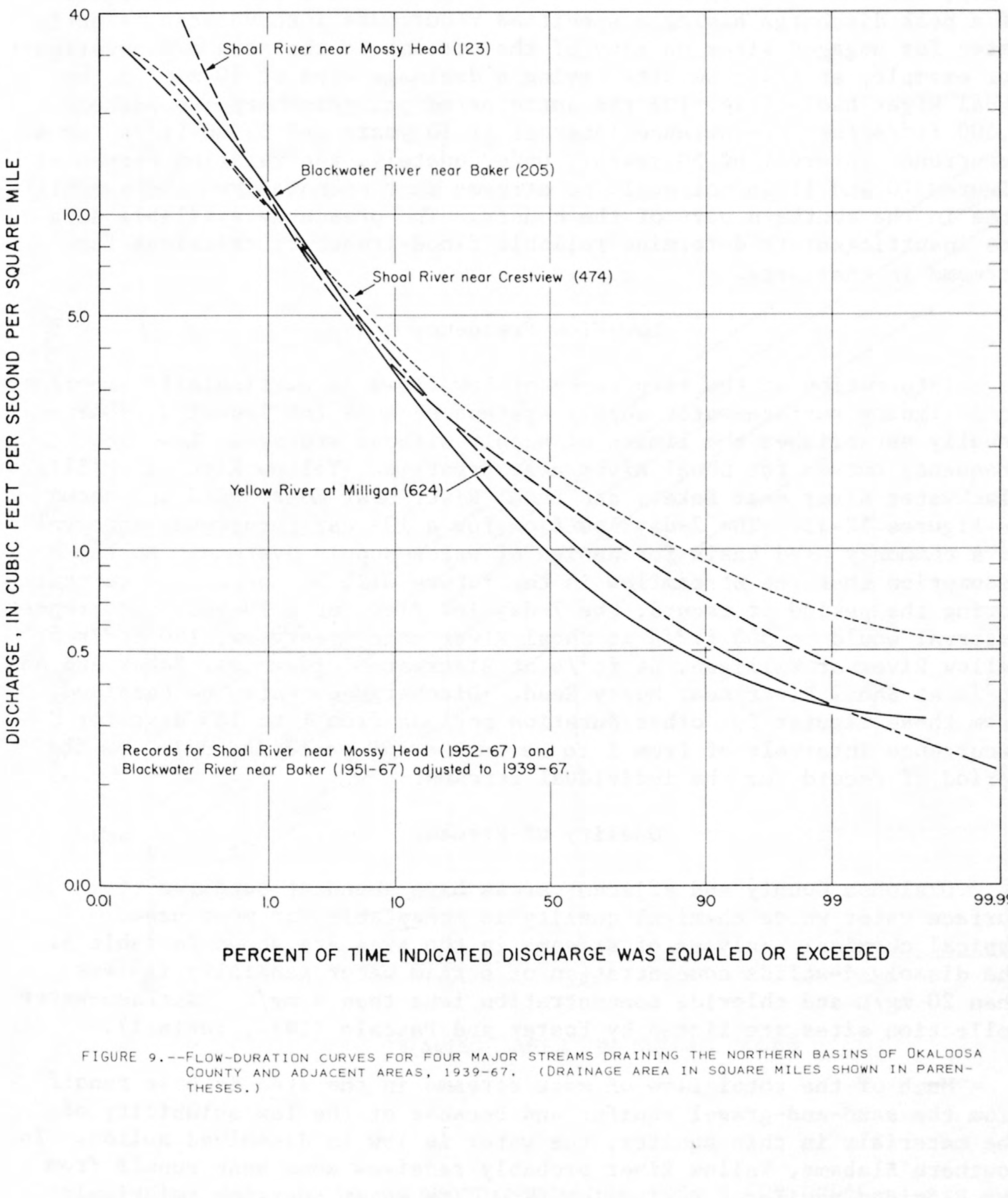

FIGURE 9.--FLOW-DURATION CURVES FOR FOUR MAJOR STREAMS DRAINING THE NORTHERN BASINS OF OKALOOSA COUNTY AND ADJACENT AREAS, 1939-67. (DRAINAGE AREA IN SQUARE MILES SHOWN IN PARENTHESES.)

7-32), are shown in figures 10 and 11. From these curves the magnitude of a peak discharge having a specified recurrence interval can be estimated for ungaged sites on many of the streams in the area of investigation. For example, at a stream site having a drainage area of 50 mi^2 in the Shoal River basin (fig. 10) the anticipated peak discharge would be 3,400 ft^3/s for a recurrence intercal of 10 years and 5,000 ft^3/s for a recurrence interval of 50 years. Unfortunately, the relation curves of figures 10 and 11 do not apply to streams that emanate from the sandhills area in the southern part of the county. The presently available data are insufficient to determine reliable flood-frequency relations for streams in that area.

Low-Flow Frequency

Information on the recurrence of low flows is particularly important in designing surface-water supply systems because the lowest discharge usually establishes the limits of supply without storage. Low-flow frequency curves for Shoal River near Crestview, Yellow River at Milligan, Blackwater River near Baker, and Shoal River near Mossy Head are shown in figures 12-15. The 7-day low flow for a 10-year recurrence interval is a commonly used basis for design of water-supply systems. On the assumption that the streamflow in the future will be comparable to that during the period of record, the 7-day low flow for a 10-year recurrence interval would be 300 ft^3/s at Shoal River near Crestview, 180 ft^3/s at Yellow River at Milligan, 64 ft^3/s at Blackwater River near Baker and 48 ft^3/s at Shoal River near Mossy Head. Discharge can also be obtained from these figures for other duration periods from 1 to 183 days for recurrence intervals of from 1 to as much as 30 years depending on the period of record for the individual streams.

Quality of Streams

Okaloosa County and adjacent areas have abundant supplies of surface water whose chemical quality is acceptable for most uses. Typical chemical analyses of streams in the area are shown in table 3. The dissolved-solids concentration of stream water generally is less than 20 mg/L and chloride concentration less than 4 mg/L. Surface-water collection sites are listed by Foster and Pascale (1971, table 1).

Much of the total flow of most streams in the area is base runoff from the sand-and-gravel aquifer and because of the low solubility of the materials in this aquifer, the water is low in dissolved solids. In southern Alabama, Yellow River probably receives some base runoff from the Floridan aquifer. During low flow, its water contains relatively high concentrations of calcium and bicarbonate ions which come from the solution of limestone in the Floridan aquifer.

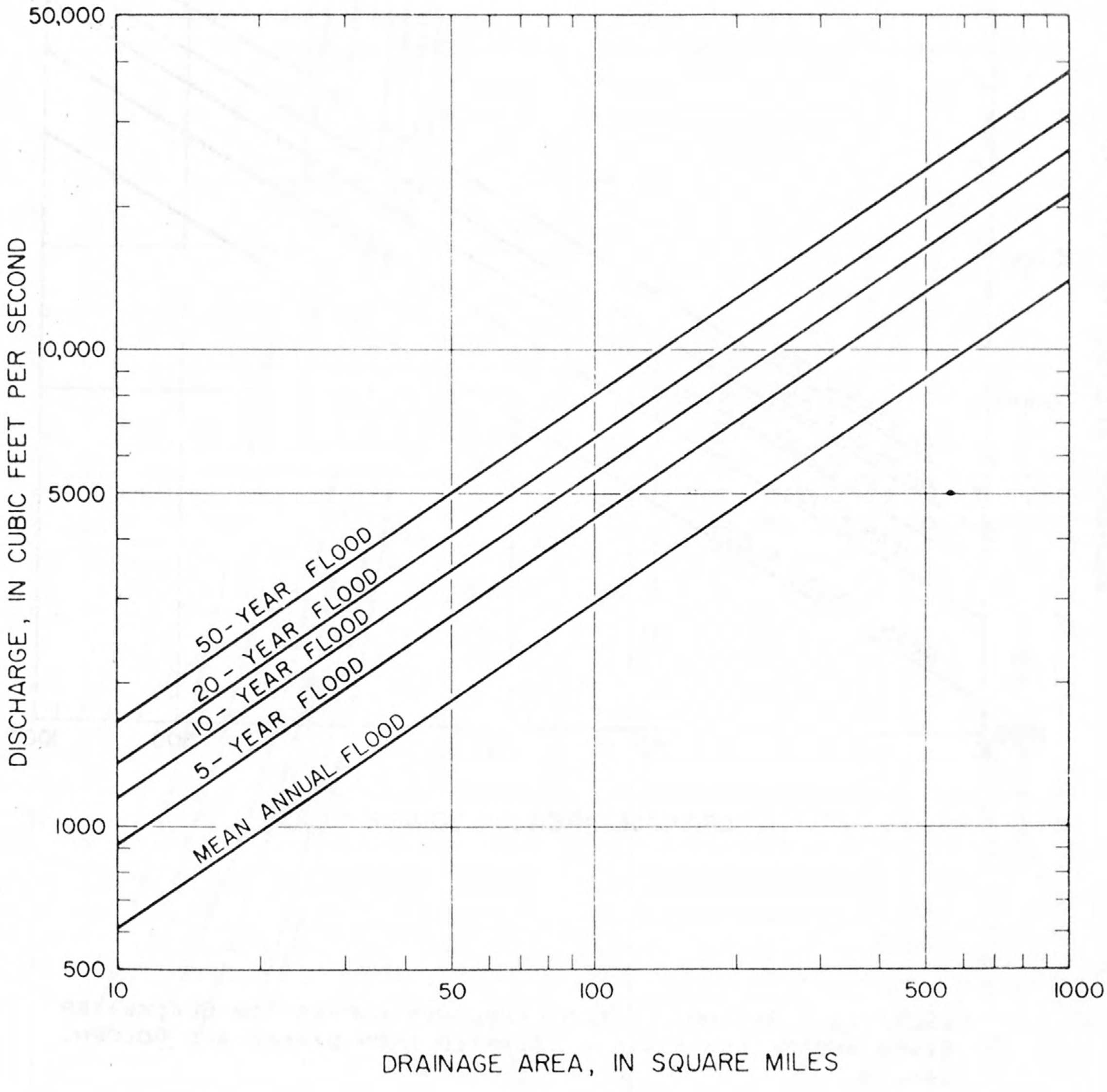

FIGURE 10.--REGIONAL FLOOD-FREQUENCY CURVES FOR SHOAL RIVER AND BASINS BETWEEN CHOCTAWHATCHEE RIVER AND LITTLE RIVER. (ADAPTED FROM BARNES AND GOLDEN, 1966.)

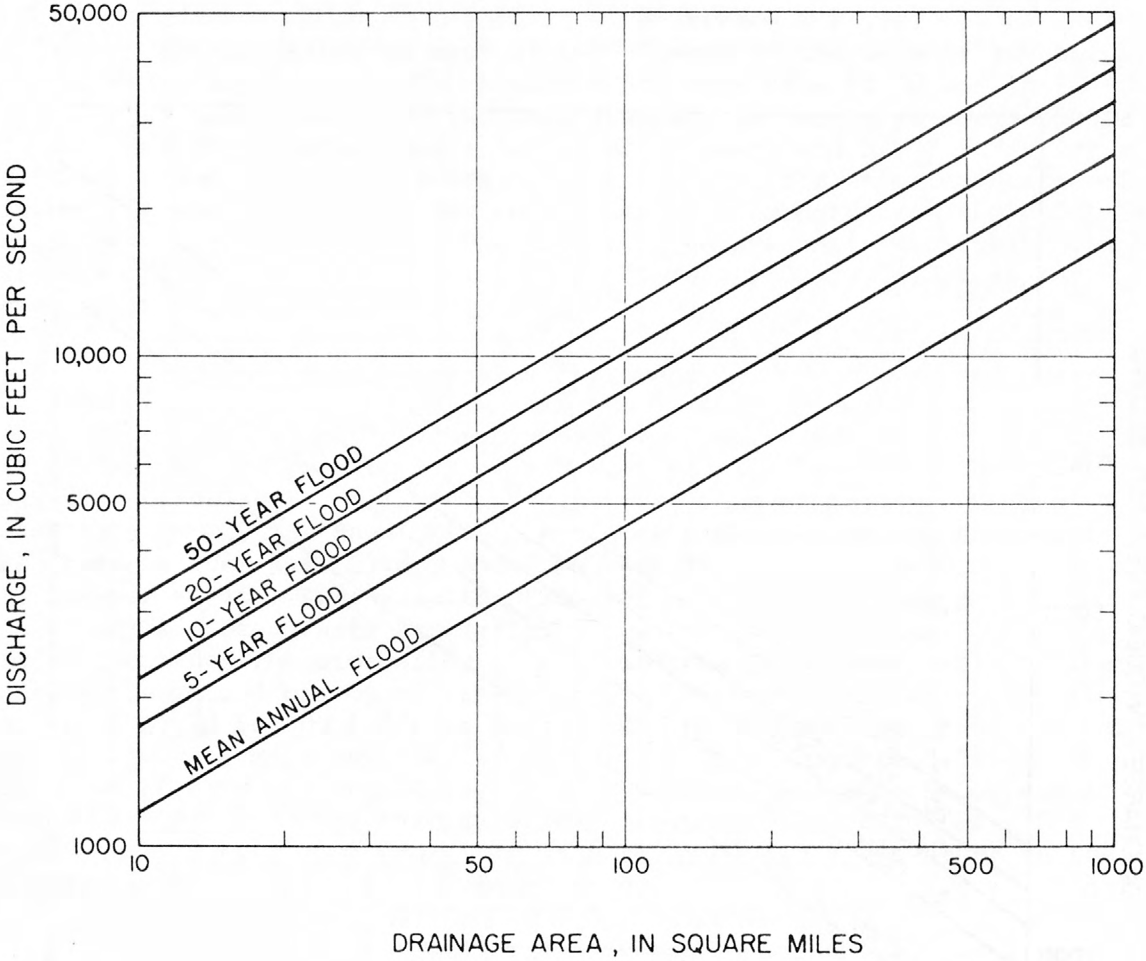

FIGURE 11.--REGIONAL FLOOD-FREQUENCY CURVES FOR BLACKWATER RIVER AND YELLOW RIVER. (ADAPTED FROM BARNES AND GOLDEN, 1966.)

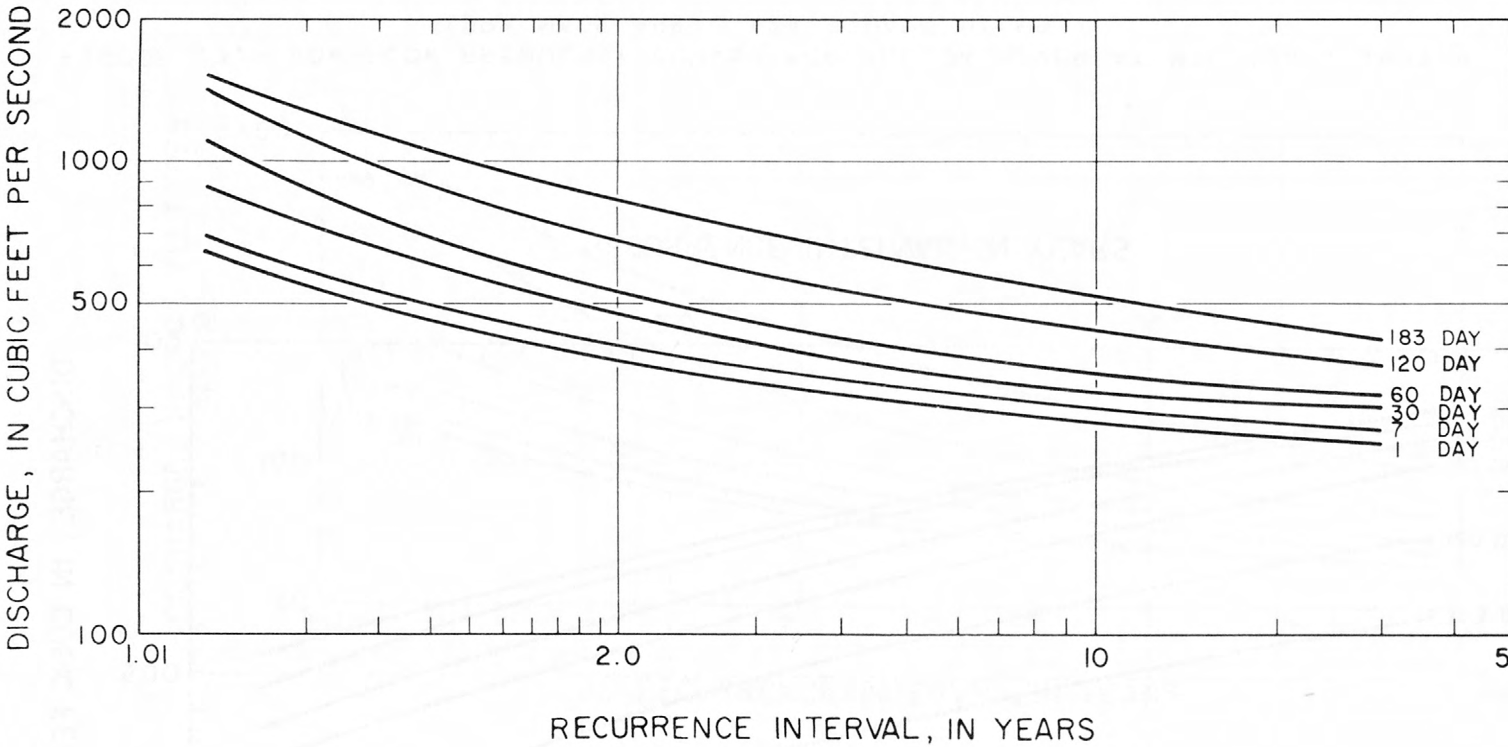

FIGURE 12.--LOW-FLOW FREQUENCY CURVES FOR SHOAL RIVER NEAR CRESTVIEW, 1939-67. (DRAINAGE AREA, 474 SQUARE MILES.)

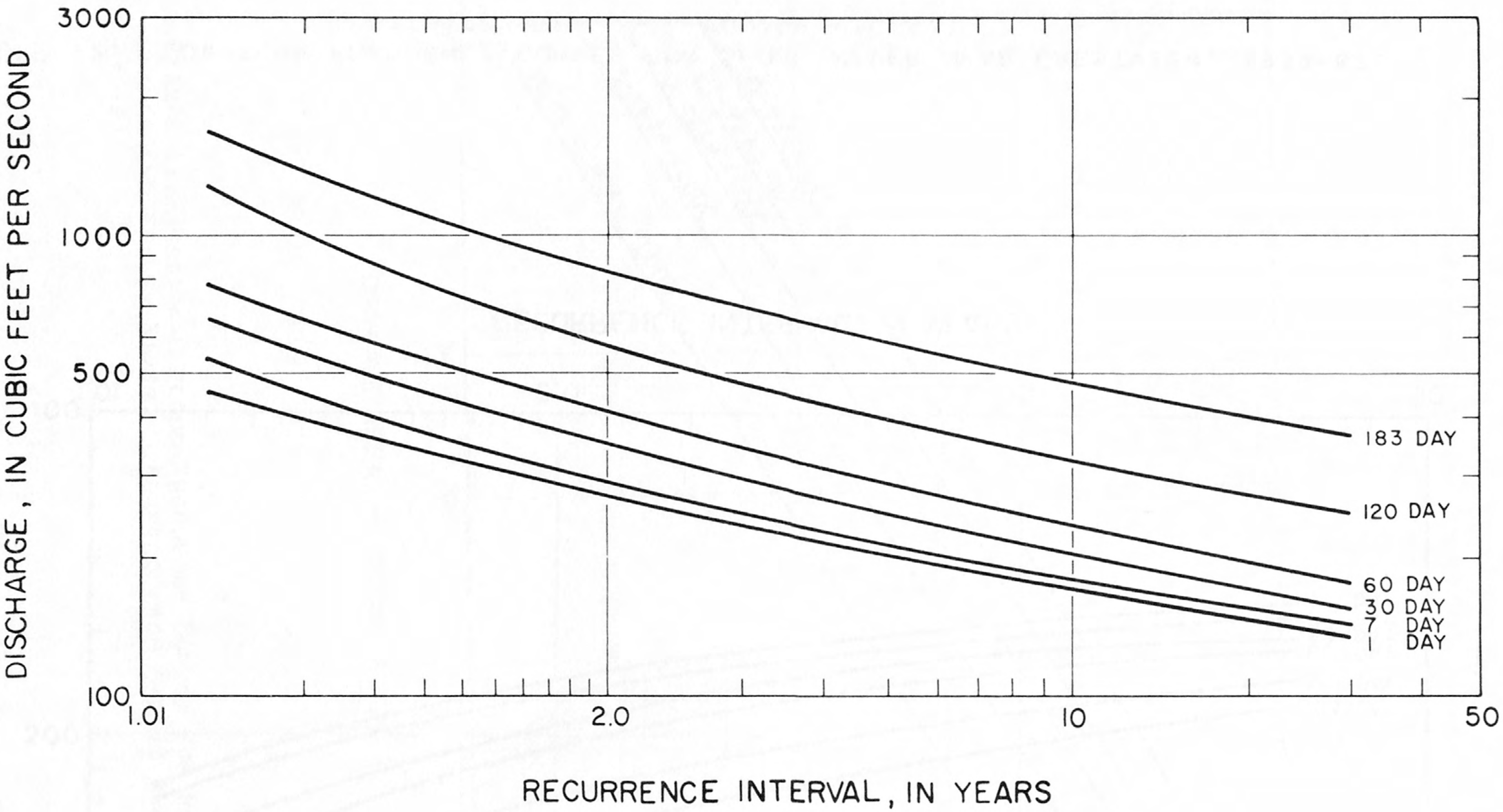

FIGURE 13.--LOW-FLOW FREQUENCY CURVES FOR YELLOW RIVER AT MILLIGAN, 1939-67
(DRAINAGE AREA, 624 SQUARE MILES.)

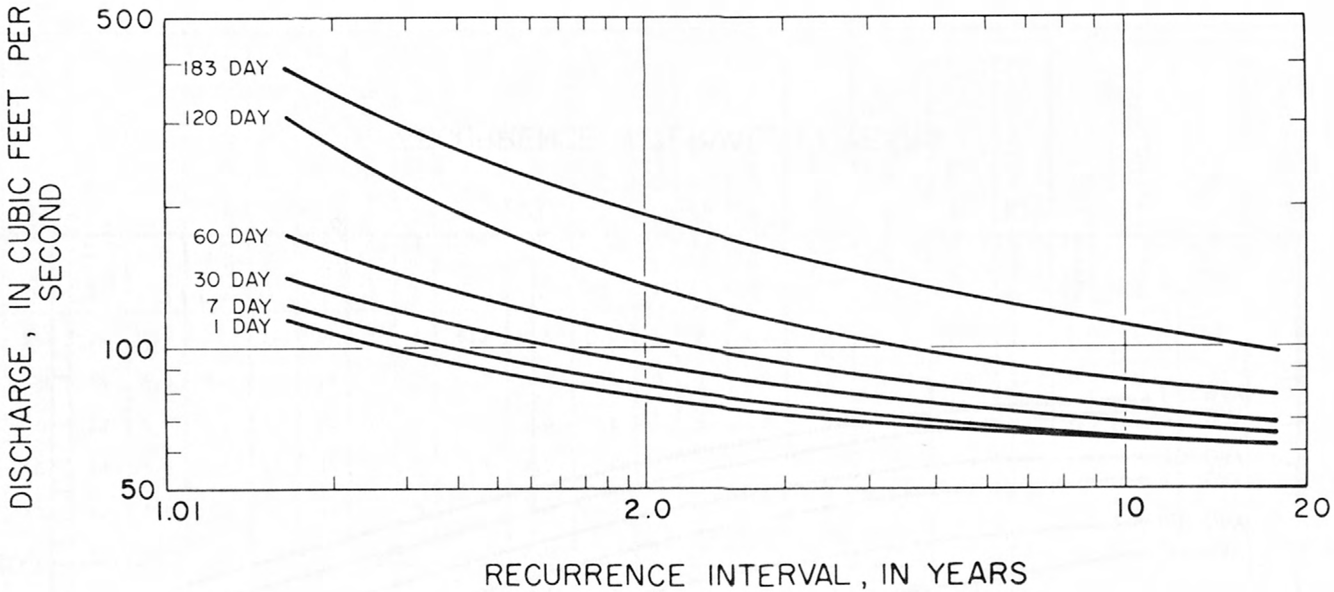

FIGURE 14.--LOW-FLOW FREQUENCY CURVES FOR BLACKWATER RIVER NEAR BAKER, 1951-67 (DRAINAGE AREA, 205 SQUARE MILES).

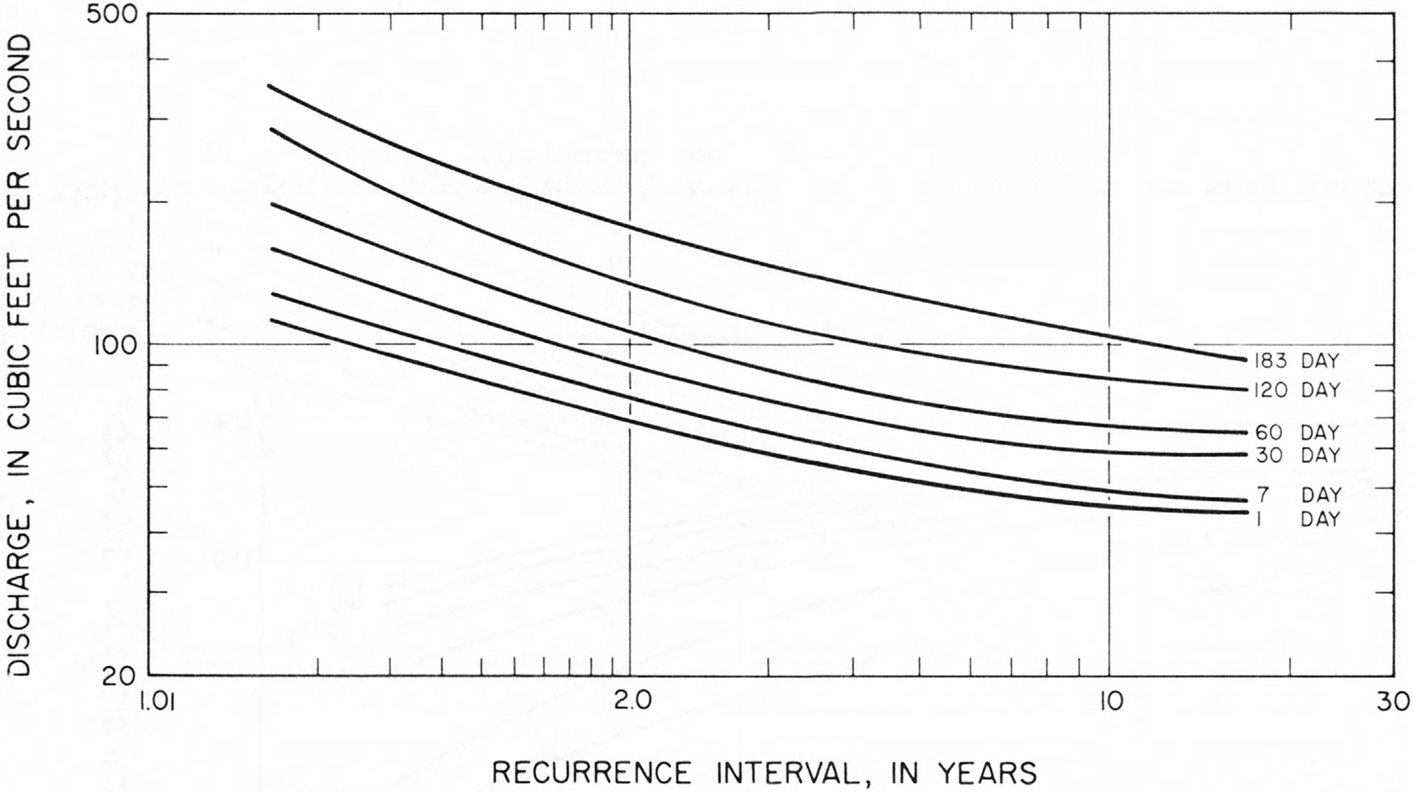

FIGURE 15.--LOW-FLOW FREQUENCY CURVES FOR SHOAL RIVER NEAR MOSSY HEAD, 1952-67 (DRAINAGE AREA, 123 SQUARE MILES).

TABLE 3.--*Chemical analyses of selected streams, May 7-9, 1968.*

Gaging station (Locations shown on fig. 7)	Discharge (ft^3/s)	Specific conductance (umho/cm^2 at 25°C)	pH (units)	Color (Platinum-Cobalt units)	Temperature (°C)	Iron (Fe) in micrograms per liter	Alkalinity as $CaCO_3$	Bicarbonate (HCO_3)	Calcium (Ca)	Chloride (Cl)	Fluoride (F)	Hardness, noncarbonate	Hardness, total (Ca, Mg)	Magnesium (Mg)	Nitrate as (NO_3)	Phosphate (PO_4)	Potassium (K)	Dissolved Solids (sum)	Silica (SiO_2)	Sodium (Na)	Sulfate (SO_4)	Dissolved Oxygen (DO)
Rocky Creek near Niceville	137	12	5.7	5	19	10	1	1	0.3	2.5	0.0	1	2	0.2	0.2	0.03	0.1	9	3.9	1.3	0.0	7.3
Swift Creek near Niceville	14	18	6.0	30	22	19	2	2	.3	3.5	.1	0	2	.2	.7	.09	.2	12	3.6	1.8	.0	7.0
Turkey Creek near Niceville	70	12	5.7	5	20	10	0	0	.1	3.0	.1	1	1	.2	.1	.05	.1	9	4.0	1.4	.0	8.3
Juniper Creek near Niceville	67	13	5.7	5	17	30	1	1	.3	3.0	.0	1	2	.2	.5	.06	.1	10	3.9	1.4	.0	8.7
East Bay River near Wynnehaven Beach	123	15	5.6	10	20	40	0	0	.2	3.5	.1	2	2	.2	.8	.04	.1	11	4.3	1.8	.2	7.3
Yellow River near Oak Grove	246	90	6.2	10	20	12	34	41	12	3.0	.1	4	38	2.0	1.1	.06	.4	52	5.7	2.5	4.8	7.0
Pond Creek near Dorcas	28	23	6.2	20	22	16	3	4	1.2	3.5	.1	2	5	.5	1.3	.07	.3	16	5.1	2.0	.0	7.2
Shoal River near Dorcas	208	25	6.4	20	23	12	6	8	1.9	3.8	.1	1	8	.8	1.2	.05	.2	18	4.3	1.5	.0	8.5
Titi Creek near Crestview	95	10	5.6	10	20	30	0	0	0.2	2.2	.1	2	2	.2	0.3	.03	.1	8	4.3	1.0	.0	6.6
Blackwater River near Baker	35	18	5.6	20	17	12	0	0	.6	3.0	.1	3	3	.4	.9	.04	.2	12	5.2	1.6	.0	8.2
Blackwater River near Holt	158	18	5.9	10	23	50	0	0	.6	3.0	.0	3	3	.4	1.0	.13	.3	15	5.5	1.8	.0	8.7

Water from streams in Okaloosa County and adjacent areas is generally colored. Most of the color comes from leaching of organic material in the soil and from the swampy areas through which these streams flow. In drinking water the color of the water--varying from 5 to 20 platinum-cobalt color units--would be objectionable but not injurious. In a given stream the color tends to increase as the discharge increases and constitutes the principal difference between the quality of water during low flow and during high flow.

Another objectionable quality of the surface water as a potential public water-supply source is its low pH. The water is acidic, and, hence, corrosive, because it contains carbonic acid, a weak acid formed by a reaction of carbon dioxide and rainwater.

Lakes

The area of investigation has about 20 named lakes; they range in size from 5 to 400 acres. Most of the lakes are near the coast and contain saline water most of the time except after periods of heavy rainfall and runoff; the others are freshwater lakes in the north part of the area. Lake Jackson (fig. 1) is the largest lake in the area, with a surface of about 400 acres.

Like most lakes and ponds in northern Walton County, Lake Jackson was formed by solution and eventual collapse of the underlying limestone to form a sink. It is a water-table lake fed by the sand-and-gravel aquifer, by rainfall, and by a small amount of surface runoff. The level of the lake rises when it rains, partly because of rainfall on the lake and partly from increased inflow from the sand-and-gravel aquifer. The level of the lake generally stands from 30 to 35 ft above the potentiometric level of the Floridan aquifer and most likely loses some water to the Floridan aquifer (Pascale, 1974, p. 47). At high stages, Lake Jackson overflows through a culvert into a tributary of Pond Creek.

Aquifers

Sand-and-Gravel Aquifer

The sand-and-gravel aquifer crops out throughout the area of investigation. It consists chiefly of very fine to very coarse quartz sand coated with white, pink, tan, reddish-brown, orange, or gray clay. Parts of the aquifer consist of 10 to 75 percent small quartz pebbles. Gravel and clay occur as isolated lenses and stringers. Limonite (iron oxide) is found in thin beds and accumulations of nodules within the aquifer at numerous locations, mostly north of U.S. Hwy. 90. Ground water in the sand-and-gravel aquifer generally is unconfined, and the configuration of the water table is related to the topography. The aquifer is recharged directly by rainfall. The saturated thickness of the aquifer ranges from 15 to 400 ft and is thickest in southwest Okaloosa County (figs. 2 and 3).

Availability of water

Large volumes of water are available from the sand-and-gravel aquifer, as evidenced by the fact that base runoff, low in dissolved solids, constitutes a large proportion of total runoff (tables 1 and 2). Intensive development of the sand-and-gravel aquifer has not taken place. For example, two wells at Range 70 (fig. 1), Eglin Air Force Base, each capable of yielding 1,000 gal/min are the only large-capacity wells that tap the aquifer in the area of investigation. The reasons that the sand-and-gravel aquifer has not been utilized more widely are: (1) the corrosiveness of the water, (2) the availability of non-corrosive water from the deeper Floridan aquifer, (3) the necessity for using well screens, (which not only add to the cost of the well but can become encrusted or corroded in time in sand-and-gravel aquifer wells), and (4) the aquifer contains saline water along the coast, where the demand for water is greatest (fig. 16).

Water-level fluctuations

Hydrographs of wells that tap the sand-and-gravel aquifer show the effects of seasonal or annual variations in rainfall (fig. 17). The period of record, (a year and a half, 1966-68), is too short to determine whether any long-term trend in water levels has resulted from man's activities.

Quality of water

The dissolved-solids concentration of water in the sand-and-gravel aquifer generally is less than 50 mg/L and hardness less than 120 mg/L. The water ranges in pH from 5.0 to 6.9.

Near the coast, water in the aquifer may contain as much as 24,000 mg/L dissolved solids. The evidence for this consists of conductivity and fluid-velocity logs and spot samples from leaking Floridan aquifer wells, including wells 37 and 39 (fig. 16, also Foster and Pascale, 1971, table 7). The origin of the highly saline water is evidently the gulf, but the process by which sea water entered the sand-and-gravel aquifer is unknown. In part at least it probably involved inundation, perhaps by extreme high tides associated with hurricanes. Representative chemical analyses of water from the sand-and-gravel aquifer are given by Foster and Pascale (1971, table 7, p. 51-53, 54-55, 57).

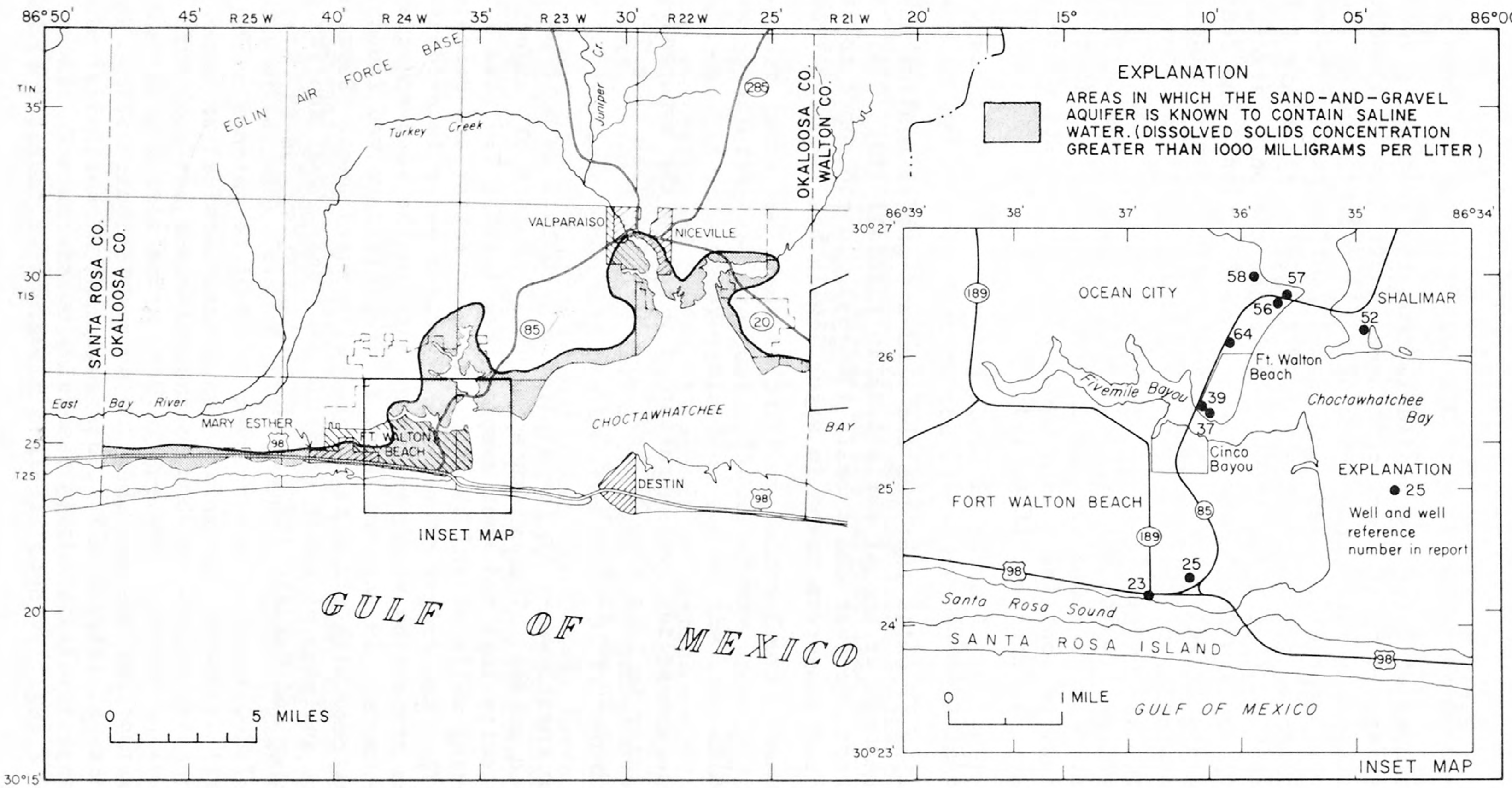

FIGURE 16.--KNOWN EXTENT OF SALINE WATER IN THE SAND-AND-GRAVEL AQUIFER, AND INSET SHOWING WELLS WHERE SALINE WATER IS KNOWN TO MOVE DOWNWARD INTO THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER THROUGH OR AROUND WELL CASINGS.

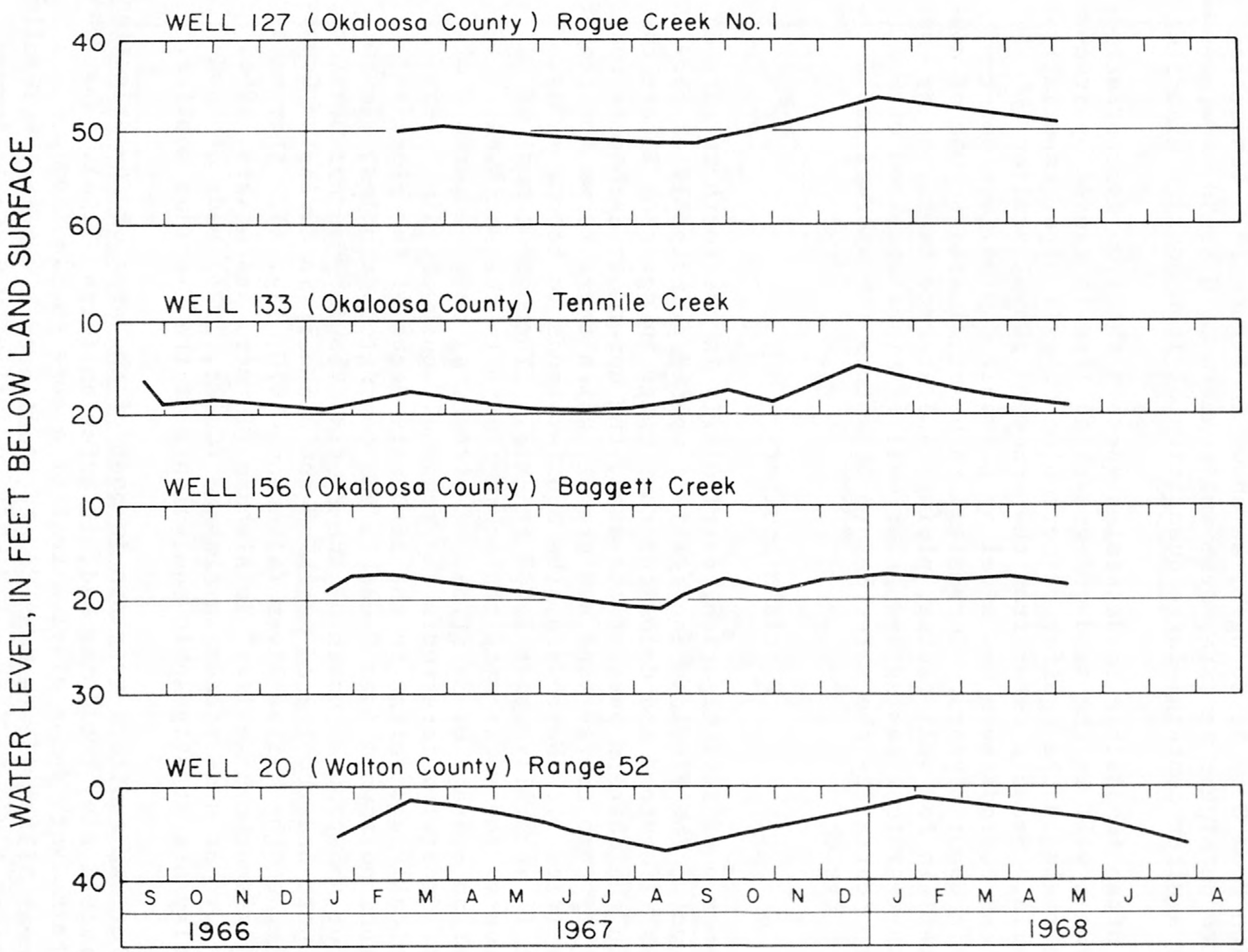

FIGURE 17.--HYDROGRAPHS OF WATER LEVELS IN FOUR WELLS TAPPING THE SAND-AND-GRAVEL AQUIFER (WELL LOCATIONS SHOWN IN FIG. 1).

The concentration of iron in the water of the sand-and-gravel aquifer varies both with depth and areally. Iron in the water ranges in concentration from 0 to 5,700 ug/L, as shown in figure 18. Concentrations tend to be higher in water from wells north of U.S. 90, where locally the aquifer contains large quantities of iron-bearing minerals.

It is often impossible to determine whether the iron concentration in water from a well in the sand-and-gravel aquifer is caused by iron-bearing materials in the aquifer or corrosion of well pipe, especially in older wells. Because water from the sand-and-gravel aquifer is acidic, it can corrode even new steel or galvanized pipe in a water system within about 2 years. Corrosion can be eliminated by use of non-ferrous materials for well casing, piping, and storage tanks, or by use of corrosion-resistant casing and other well fittings combined with treatment to neutralize the water before it enters the storage and distribution system.

Floridan Aquifer

In the area of investigation, particularly in the southern part of Okaloosa County, the Floridan aquifer is composed principally of carbonate rocks (limestone and dolomite) that range in age from Eocene to Miocene. In the eastern part of the area, the uppermost carbonate rock grades locally into coarse sand and gravel, which there forms the top of the aquifer (fig. 3). Northward, the aquifer tends to become sandy. The aquifer is generally about 1,000 ft thick. Throughout most of Okaloosa County, the surface of the aquifer dips to the southwest (fig. 19) at an average of 34 ft/mi. A structural dome centered 2 mi northwest of Crestview interrupts the regional southwest dip. Beds stratigraphically equivalent to the carbonate rocks of the Floridan aquifer extend northward into Escambia and Covington Counties, Alabama. They crop out about 20 mi north of the Florida boundary in northeastern Escambia County and about 4 mi north of the boundary in Covington County in the valley of the Yellow River (Alverson, 1970, fig. 4). They make up the "major southern aquifer" in Alabama (Turner, and others, 1968, section A'-A). At some places in Alabama (Cooke, 1926) beds of sandstone and clay are stratigraphic equivalents of the Floridan aquifer.

The Floridan aquifer, overlain in most of the area of investigation by the Pensacola clay confining bed, is artesian (figs. 3, 4). The Pensacola contains very dense clay; a test of a core sample from a test well near Milton, Santa Rosa County, indicated a vertical hydraulic conductivity of 4.9×10^{-7} ft per day (F. S. Riley, U.S. Geol. Survey written commun. 1976). Locally in the eastern part of the area, the confining bed is missing and the sand-and-gravel aquifer lies directly upon the carbonate rocks of the Floridan aquifer (fig. 19). The lower part of the sand-and-gravel aquifer is generally less permeable than the Floridan so that where the two are in direct contact the lower sand-and-gravel aquifer may act as a leaky confining bed. In general, the

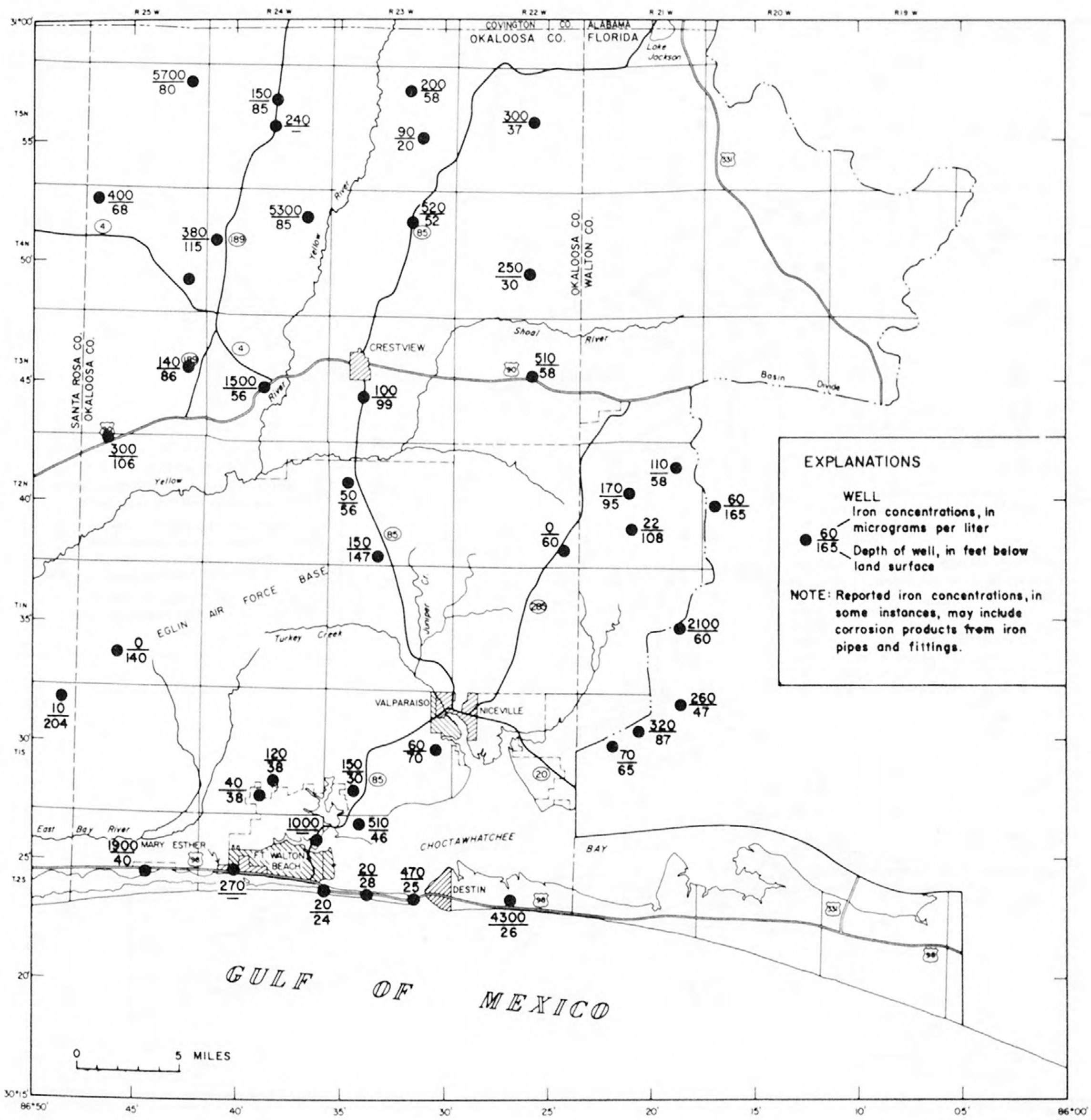

Figure 18.--Iron concentration in water from the sand-and-gravel aquifer.

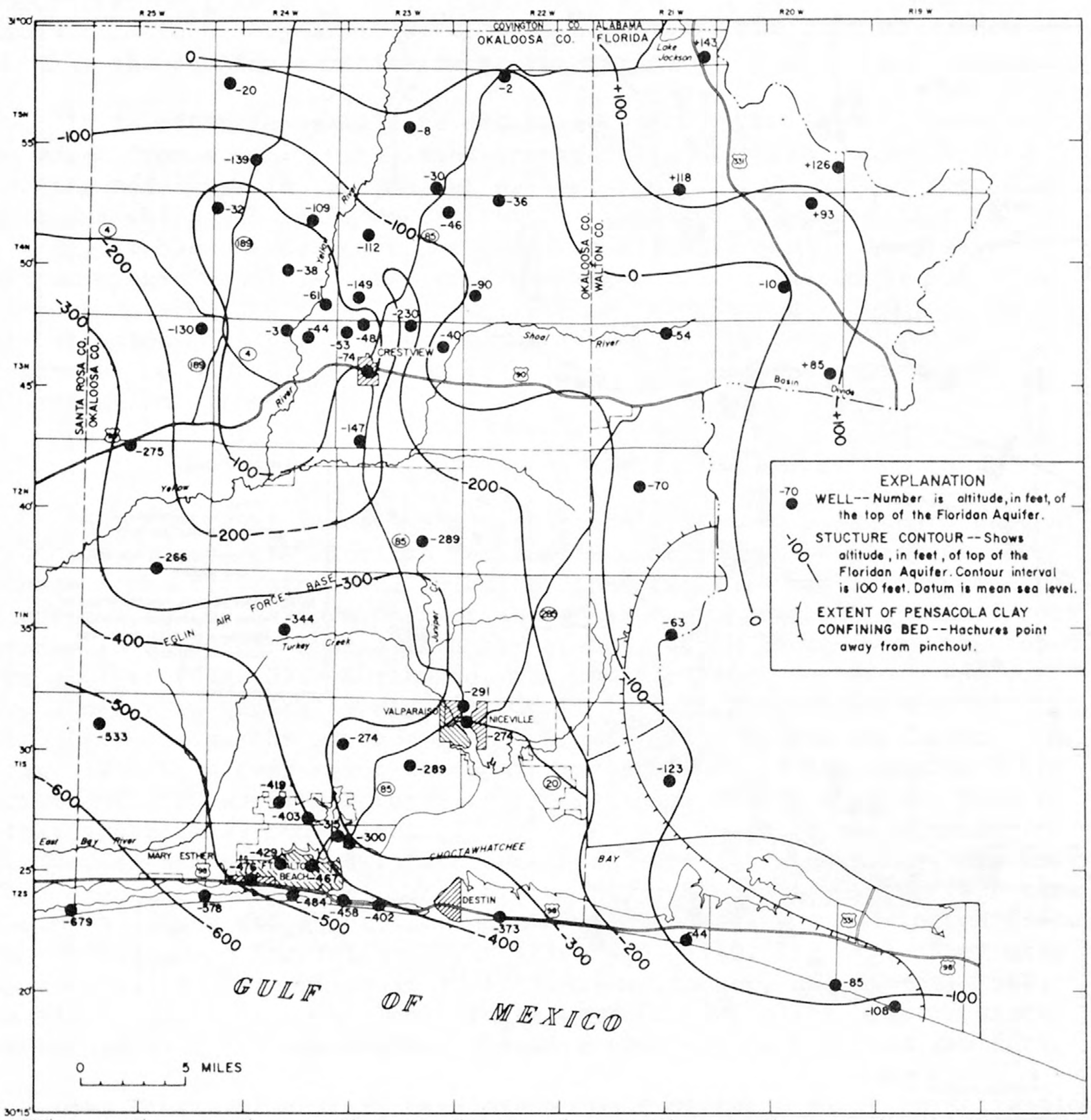

FIGURE 19.--ALTITUDE OF TOP OF FLORIDAN AQUIFER AND EXTENT OF OVERLYING PENSACOLA CLAY CONFINING BED.

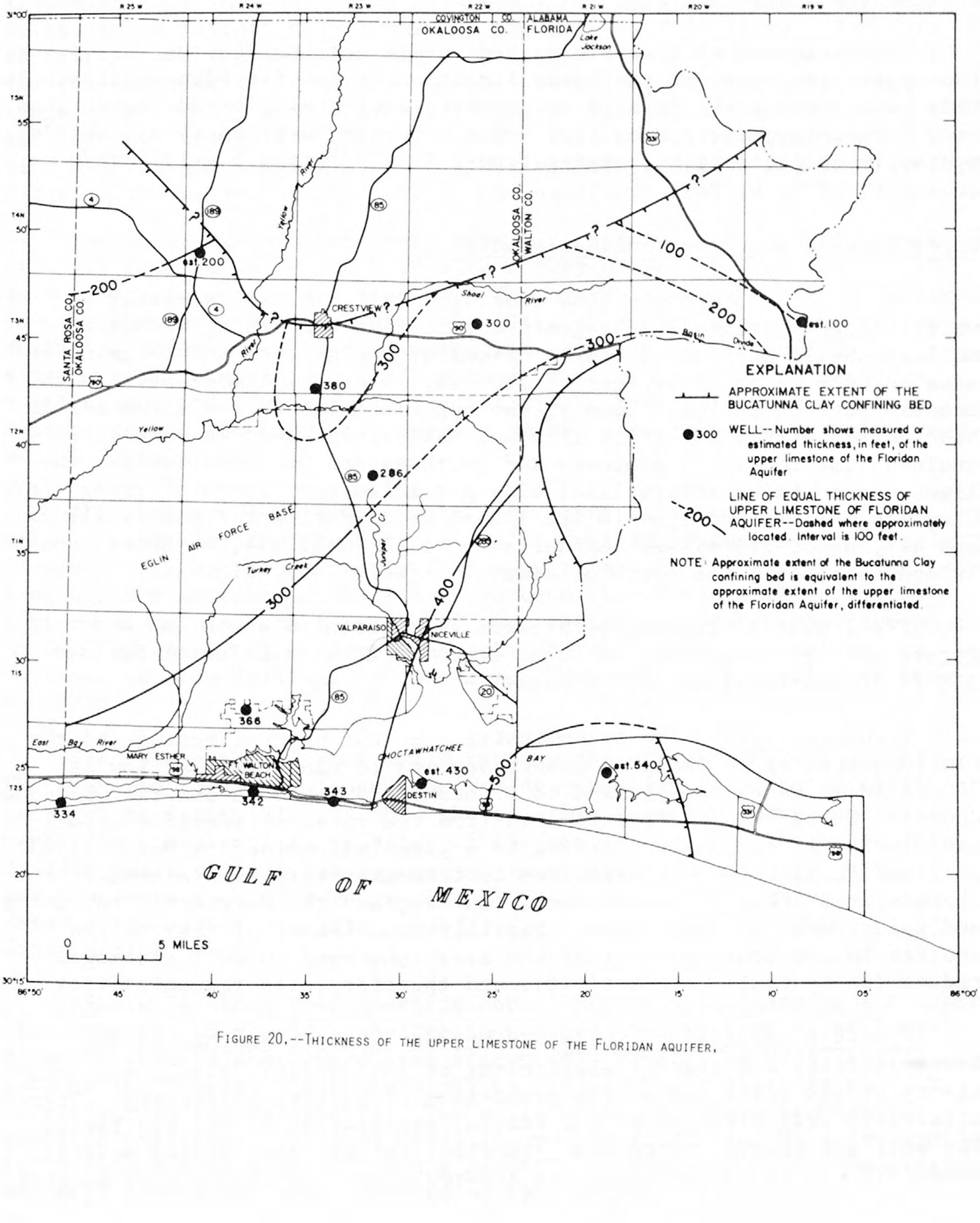

FIGURE 20.--THICKNESS OF THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER.

effectiveness of the confining bed--whether it be the lower sand-and-gravel aquifer or the Pensacola Clay--will vary in accordance with its thickness and lithology.

The Bucatunna clay confining bed subdivides the Floridan aquifer into the upper limestone and the lower limestone of the Floridan aquifer. In this report these are treated as separate aquifers. The Bucatunna is a very dense clay; cores from test wells in Santa Rosa County had vertical hydraulic conductivities ranging from 2.9×10^{-6} to 2.6×10^{-7} ft/d (Pascale, 1976, p. 28).

Upper limestone of the Floridan aquifer

The upper limestone of the Floridan aquifer consists mostly of white to cream-colored, fine-grained limestone containing abundant mollusk shells and foraminifera. Bioclastic fragments and foraminifera make up as much as 75 percent of some layers of the limestone. In the coastal part of Okaloosa County, the upper section of the limestone is bioclastic, with a lithified lime mud matrix, interbedded with fine-grained limestone. In southern and southwestern Okaloosa County, the limestone contains interstitial clay particles and layers of green clay. Clay has been encountered in the limestone at Hurlburt Field (wells 32 and 47), about 1.5 mi west of Hurlburt Field (well 34), on Santa Rosa Island (well 14), and north of Niceville (well 143), fig. 1.

The limestone generally thickens from north to south, as shown in figure 20. It ranges in thickness from 100 ft near DeFuniak Springs to 540 ft in southwestern Walton County.

Transmissivity.--The transmissivity of the upper limestone of the Floridan aquifer in Okaloosa County appears to range from as low as 300 ft^2/d on Santa Rosa Island to 27,000 ft^2/d in south-central Okaloosa County. These values are estimated from the range of specific capacities (wells 16 and 134) according to a graphical method by Meyer (1963, p. 338-340, fig. 100). Variations in transmissivity are related to changes in thickness, composition, texture, and the degree of fracturing and solution of the limestone. Particles and lenses of clay in the aquifer in the southern part of the area (observed in well cuttings) reduce its hydraulic conductivity, and therefore, its transmissivity.

Specific capacity of wells.--Specific capacity depends on the transmissivity and storage coefficient of the aquifer, radius and efficiency of the well, and on the proportion of aquifer penetrated. Transmissivity, well efficiency, and partial penetration of the aquifer by the well are generally the most important factors determining specific capacity, and if any of these are lowered, specific capacity is lowered.

The use of specific capacity data as an indication of aquifer transmissivity should proceed with caution. Specific capacities of wells can be influenced strongly by the method of drilling. The data for this study suggest that higher well efficiency (ratio of actual to theoretical specific capacity--often substantially below unity) is achieved generally with drilling the open-hole segments of wells by the air reverse-circulation rotary method. This method removes more of the fine material from wells than do other methods and thus prevents it from plugging the permeable sections of the aquifer.

The data suggest that lower specific capacities generally result from drilling wells by the hydraulic rotary method or the cable-tool method, but for different reasons. The hydraulic rotary method involves forcing mud under pressure down the drill pipe and out the bit during drilling, which tends to plug permeable sections of the aquifers. After a well is drilled by this method, the extent to which residual drilling mud and fine natural interstitial material are removed from the aquifer around the bore hole depends on the effectiveness of well treatment or development.

The cable-tool method, on the other hand, may produce efficient wells in the Floridan aquifer, but wells drilled by this method are less likely to approach full penetration than those drilled by rotary methods. Long uncased sections of hole tend to cave when being drilled by the cable-tool method, and the rate of penetration is reduced when the hole is full of water. Therefore, the driller (or the well owner) may be inclined to stop drilling as soon as an adequate water supply has been obtained.

Specific capacities of wells tapping the upper limestone of the Floridan aquifer in Okaloosa County range from 1 to 125 (gal/min)/ft as shown in figure 21. To show the possible relation between drilling method and the specific capacity of the completed well, the method of drilling each well (where known) is shown, by symbol. Although the relation is vague, it appears that within a given area of limited extent, the higher specific capabilities result from air-reverse rotary construction.

Figure 21 shows that specific capacities of wells tapping the upper limestone of the Floridan aquifer in Okaloosa County tend to be lowest on Santa Rosa Island, increasing irregularly toward the west-central part of the county. This trend may be explained, at least in part, by variations in transmissivity. Two wells exemplify the extremes of specific capacity: Okaloosa wells 16 and 134 (fig. 1). Well 16, nearly fully penetrating (fig. 3), had a specific capacity of 1 (gal/min)/ft and well 134, a specific capacity of 125 (gal/min)/ft.

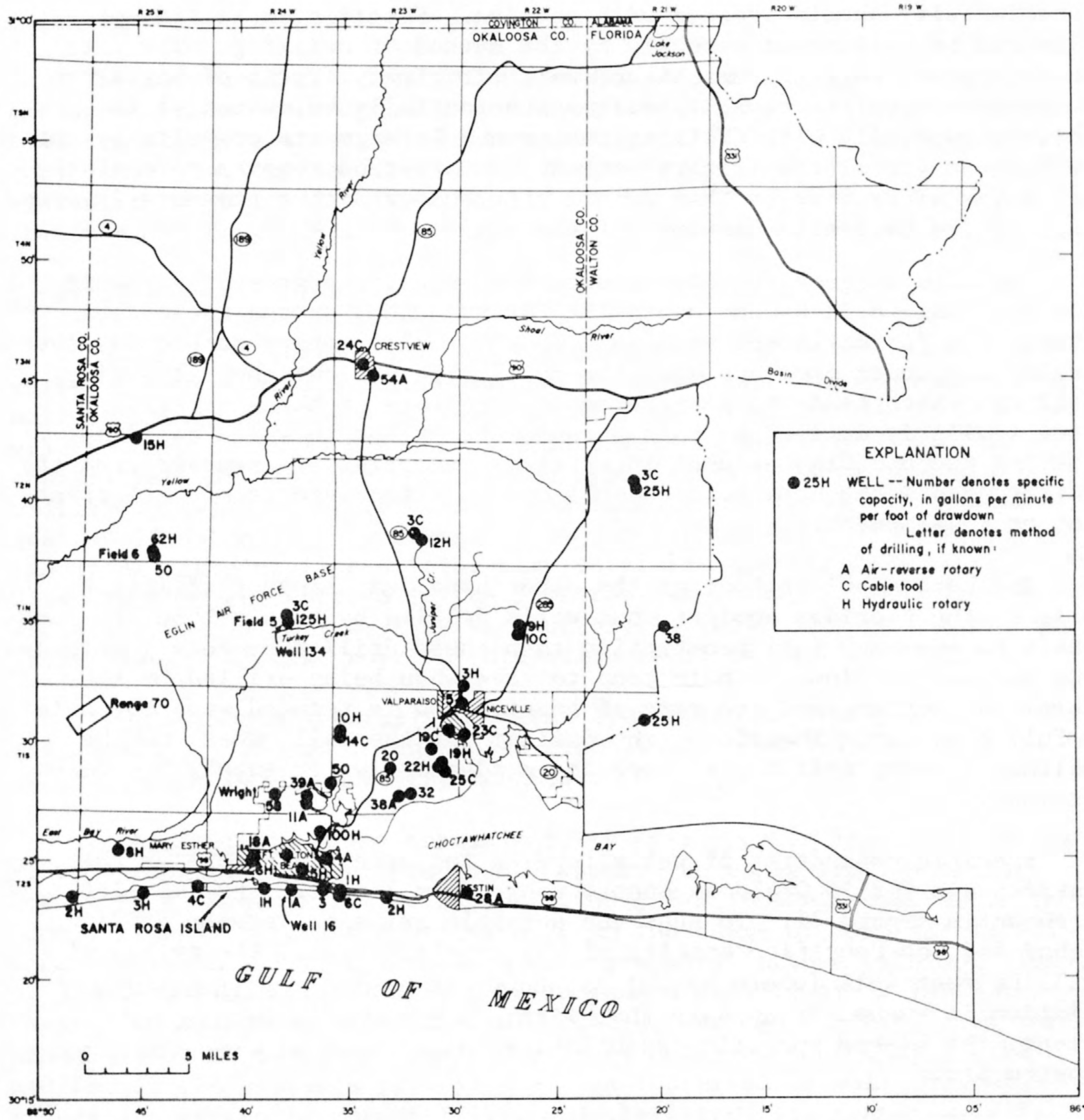

FIGURE 21.--METHOD OF DRILLING AND SPECIFIC CAPACITIES OF WELLS CONSTRUCTED IN THE UPPER PART OF THE FLORIDAN AQUIFER.

Because Okaloosa well 16, 874 ft deep, was drilled by the air reverse-circulation rotary method, and thus is assumed to have a high well efficiency, its specific capacity of 1 (gal/min)/ft--305 gal/min with a 264-ft drawdown in a 4-hour test--indicates a very low transmissivity of the aquifer at the location of that well on Santa Rosa Island.

The other extreme in specific capacity, 125 (gal/min)/ft--reported for Okaloosa well 134, located about 11 mi north of Fort Walton Beach--may be high because of an imprecise drawdown measurement or too short a pumping time, or it may be lower than the value that is potentially obtainable at the site because of incomplete penetration and possibly low well efficiency (drilled by hydraulic rotary method).

As a general rule, a relatively high specific capacity is likely to reflect high transmissivity whereas a low specific capacity may or may not reflect a low transmissivity.

Water levels.--Before wells began to discharge large quantities of water from the Floridan aquifer in southern Okaloosa and Walton Counties, the potentiometric surface of the upper limestone was substantially above land surface in much of this area. Wherever the potentiometric surface was above land surface, wells drilled into the limestone would flow. Figure 22 shows the approximate configuration of the surface as of 1942, the earliest year for which sufficient control is available for a potentiometric map, and the year that the first wells were constructed for Eglin Air Force Base. By 1968, the potentiometric surface was below sea level along the coast from Mary Esther to Destin (fig. 23). Of particular note was the development of a double cone of depression at Fort Walton Beach where the potentiometric surface had declined to 35 ft below sea level. Also, by 1968 two smaller cones of depression had formed southwest of Valparaiso on Eglin Air Force Base where the potentiometric surface had declined to 14 ft below sea level. Declines of more than 90 ft at Fort Walton Beach and of more than 60 ft southwest of Valparaiso between 1942 and 1968 are shown in figure 24.

North of U.S. 90, water-level changes in the Floridan aquifer chiefly reflect differences in rates of recharge from the sand-and-gravel aquifer which in turn is recharged directly from rainfall. The area is far from the main centers of pumping. From U.S. 90 south to the gulf, water levels are influenced by pumping, as seen in hydrographs of observation wells (figs. 25 and 26). The magnitude of annual water-level fluctuations due to pumping in this area masks the effects due to changes in rates of recharge. The large seasonal changes in pumping caused large annual fluctuations in water levels, which in well Okaloosa 25 ranged from 20 to 51 ft from 1960 to 1968, with an average of about 37 ft. Well Okaloosa 86 (fig. 25) is at the eastern edge of the well

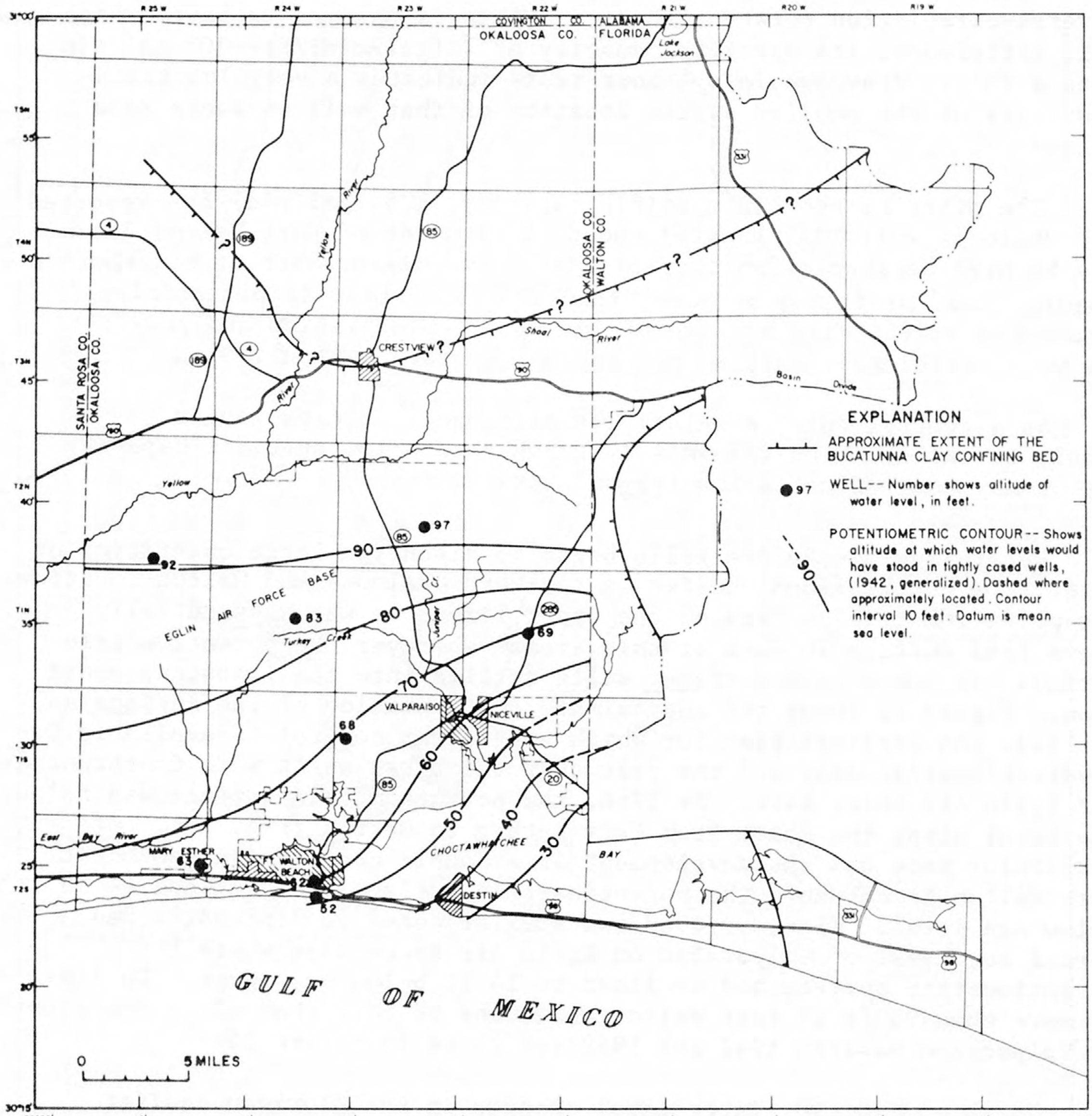

FIGURE 22.--POTENTIOMETRIC SURFACE OF THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER AS OF 1942 (GENERALIZED).

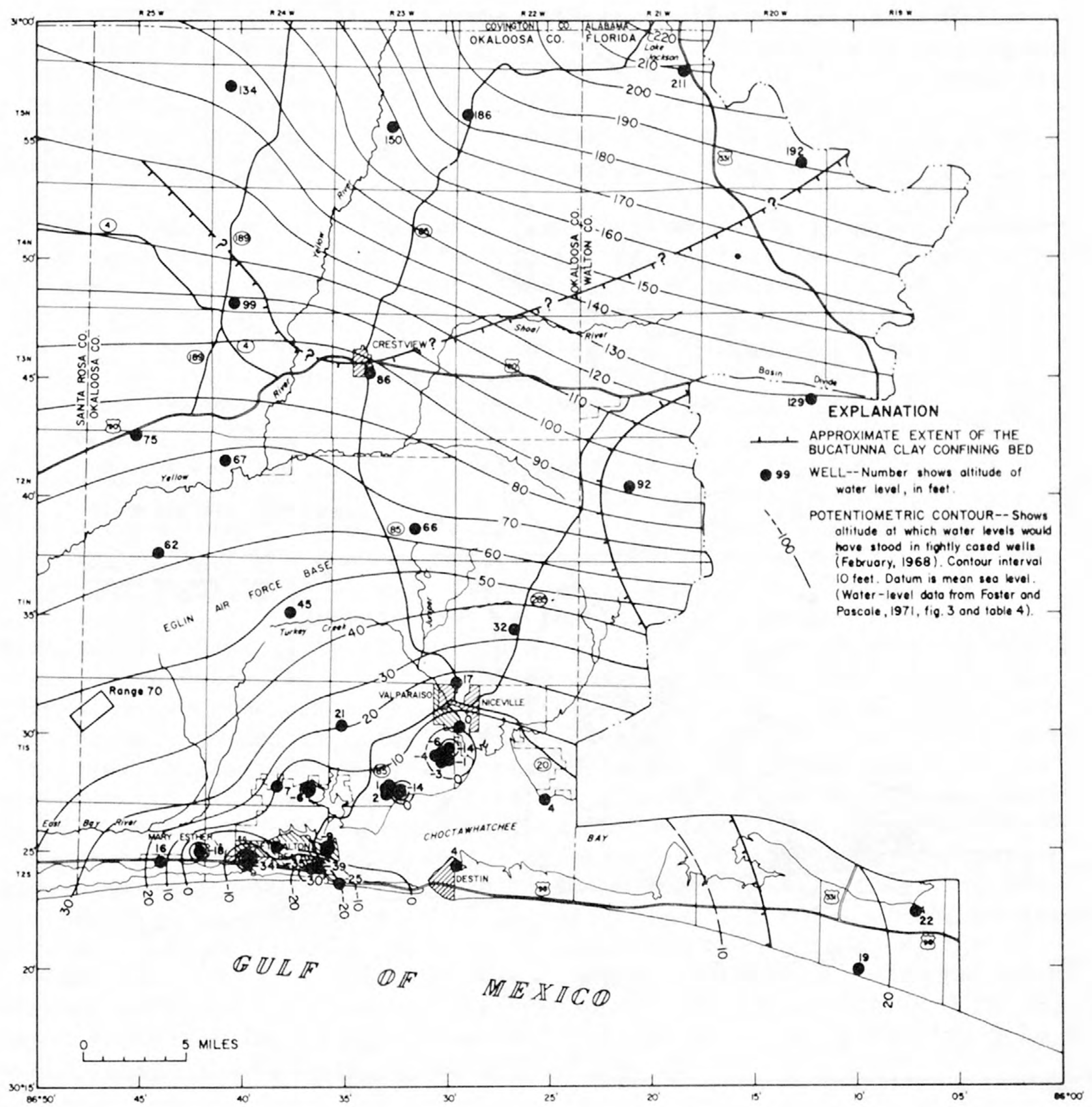

Figure 23.--Potentiometric surface of the upper limestone of the Floridan aquifer and of the upper part of the undifferentiated Floridan aquifer as of February 1968.

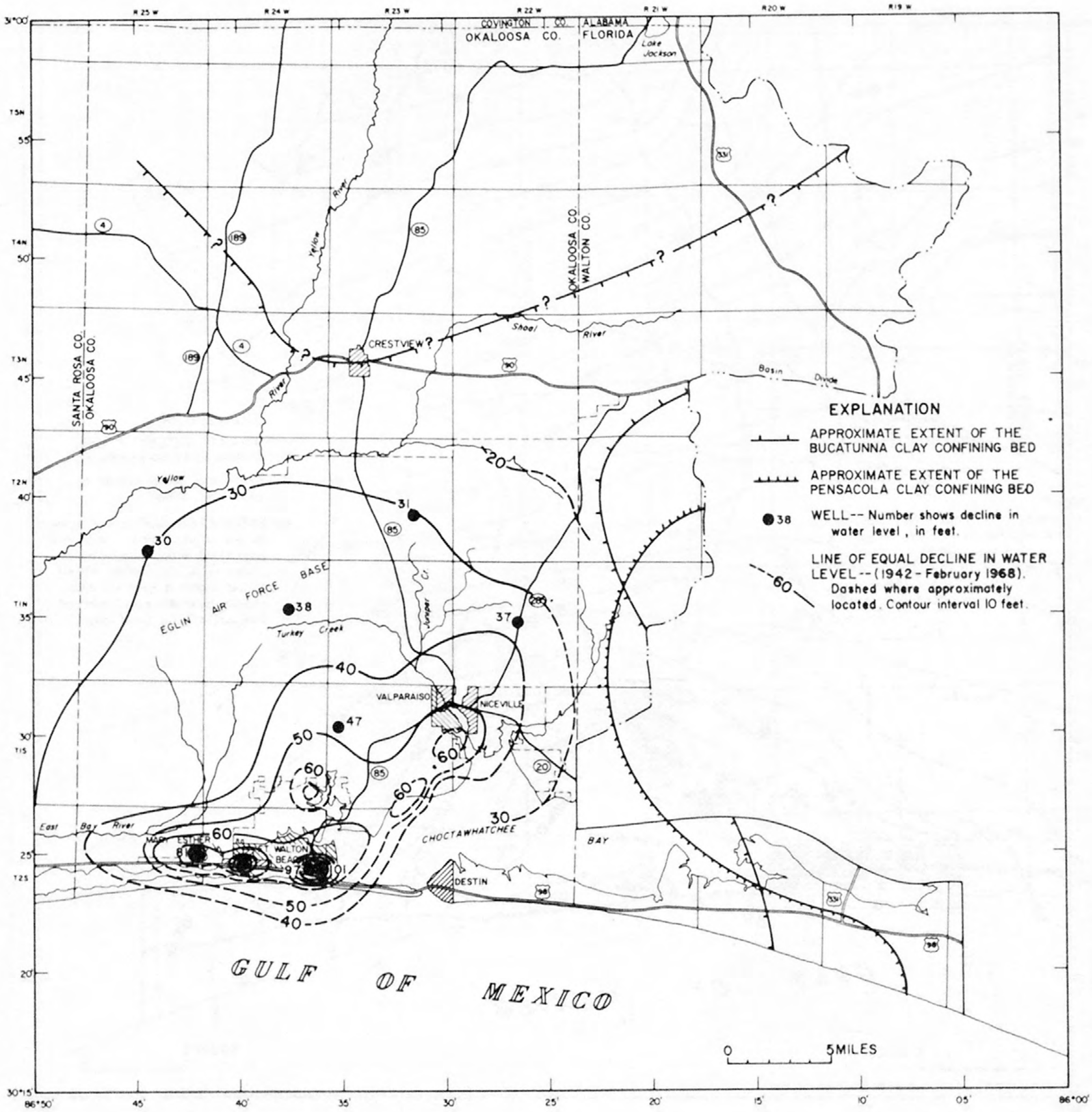

FIGURE 24.--APPROXIMATE DECLINE IN THE POTENTIOMETRIC SURFACE IN THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER, 1942-FEBRUARY 1968.

field for the main base at Eglin Air Force Base, and is farther from the center of heaviest pumping than is well Okaloosa 25 at Fort Walton Beach. In 1960-68, the annual fluctuation of water levels in well Okaloosa 86 ranged from 6 to 14 ft less than that of well Okaloosa 25. Wells 116, 134, 140, 143, (Okaloosa County) and Walton County well 28 shown on figs. 25 and 26 (well locations shown in fig. 1, locations and well data given in Foster and Pascale, 1971, fig. 3, table 4) are successively farther from the center of major pumping. The wells closest to major pumping show the greatest seasonal water-level fluctuations.

The hydrographs in figures 25 and 26 also show a long-term downward trend in water levels resulting from the annual increase in pumping. The overall decline from 1948 to 1968 basically represents the lowering of the potentiometric surface that is portrayed in fig. 24. The decline diminishes with distance from the centers of pumping. The average level in well Okaloosa 25 declined about 95 ft during the period 1948 to 1968, while the average level in well Okaloosa 140 declined 28 ft.

Quality of water.--The dissolved-solids concentration of water in the upper limestone of the Floridan aquifer increases southward, ranging from about 110 mg/l in northeastern Okaloosa County to as much as 470 mg/L in the southern and southwestern part of the county (fig. 27) not including local areas of high dissolved-solids concentration resulting from leaky wells. Corresponding to the increase in dissolved solids is a change in chemical type (Hem, 1970, p. 77, 237) from calcium-magnesium-bicarbonate water (water in which the dominant cations are calcium and magnesium, and the dominant anion is bicarbonate) to sodium-bicarbonate and, finally to sodium-chloride water. Water with low concentrations of dissolved solids (generally less than 30 mg/L) enters the aquifer from precipitation in the area of outcrop in Alabama, and from the sand-and-gravel aquifer in northern and eastern Okaloosa County. Water moving through the limestone and dolomite of the aquifer dissolves calcium, magnesium, and carbonate (changed to bicarbonate in solution). In the northeastern part of the area of investigation, the calcium concentration generally ranges from 10 to 40 mg/L, magnesium from 6 to 15 mg/L, sodium from 3 to 20 mg/L, and potassium from 1 to 5 mg/L. In the southwestern part of the area, calcium concentrations are generally 3 to 12 mg/L, magnesium 2 to 6 mg/L, sodium 80 to 200 mg/L, and potassium 5 to 8 mg/L (Foster and Pascale, 1971, table 7, p. 35-57).

The change in chemical character of the water is attributed to an ion-exchange process within the aquifer. In the southern and southwestern parts of the county, clay, in the form of particles and lenses, has been observed to be more abundant than farther north. The clay contains minerals, such as glauconite, that have a substantial ion-exchange capacity. Calcium and magnesium ions are removed from the water by the clay in exchange for sodium and potassium ions. Thus, moderately hard water is softened. Accompanying the change in chemical type is a general increase in bicarbonate from about 100 to 200 mg/L

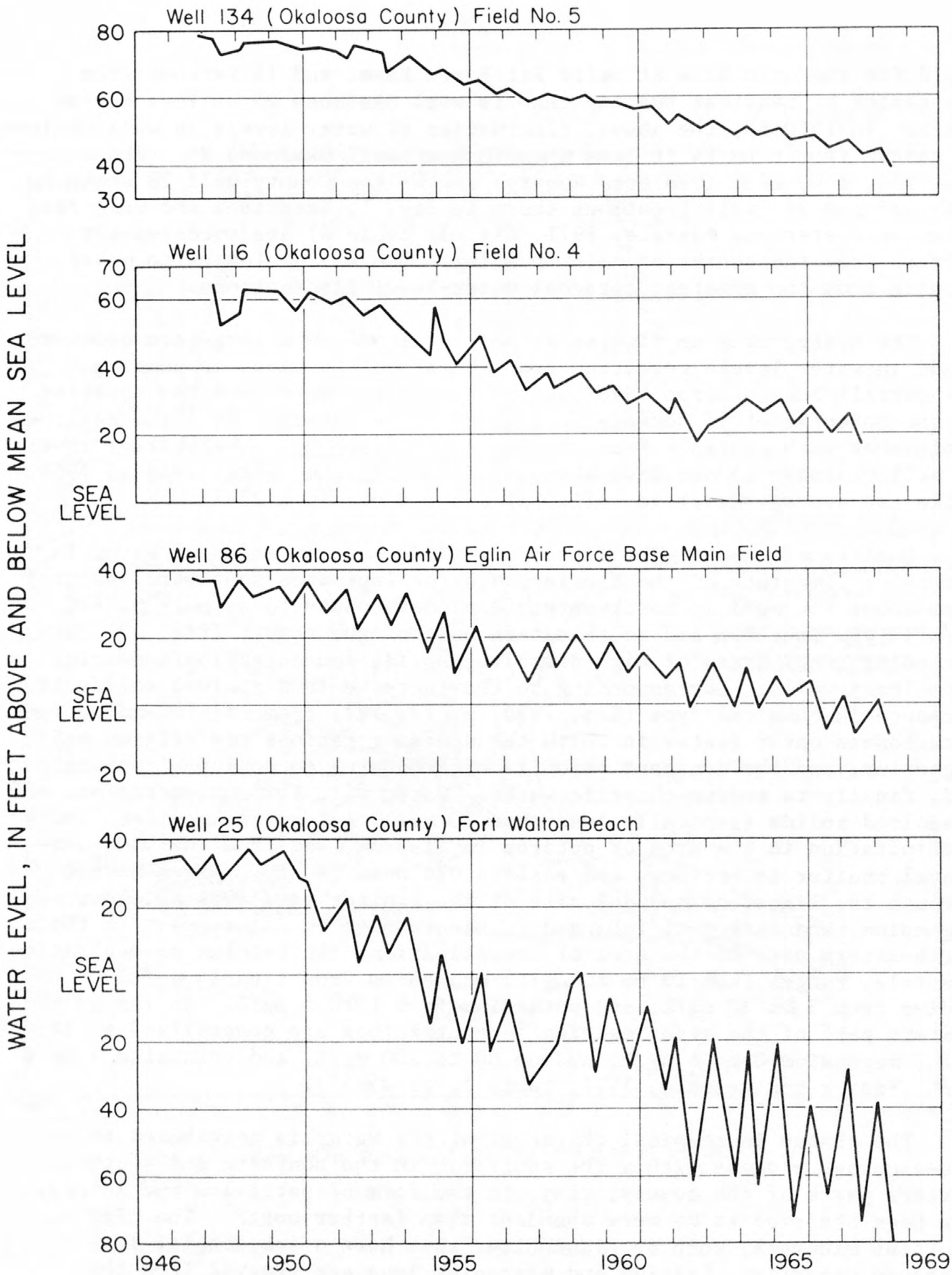

FIGURE 25.--HYDROGRAPHS OF ANNUAL HIGH- AND LOW-WATER LEVELS IN FOUR WELLS TAPPING THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER. (WELL LOCATIONS SHOWN IN FIG. 1.)

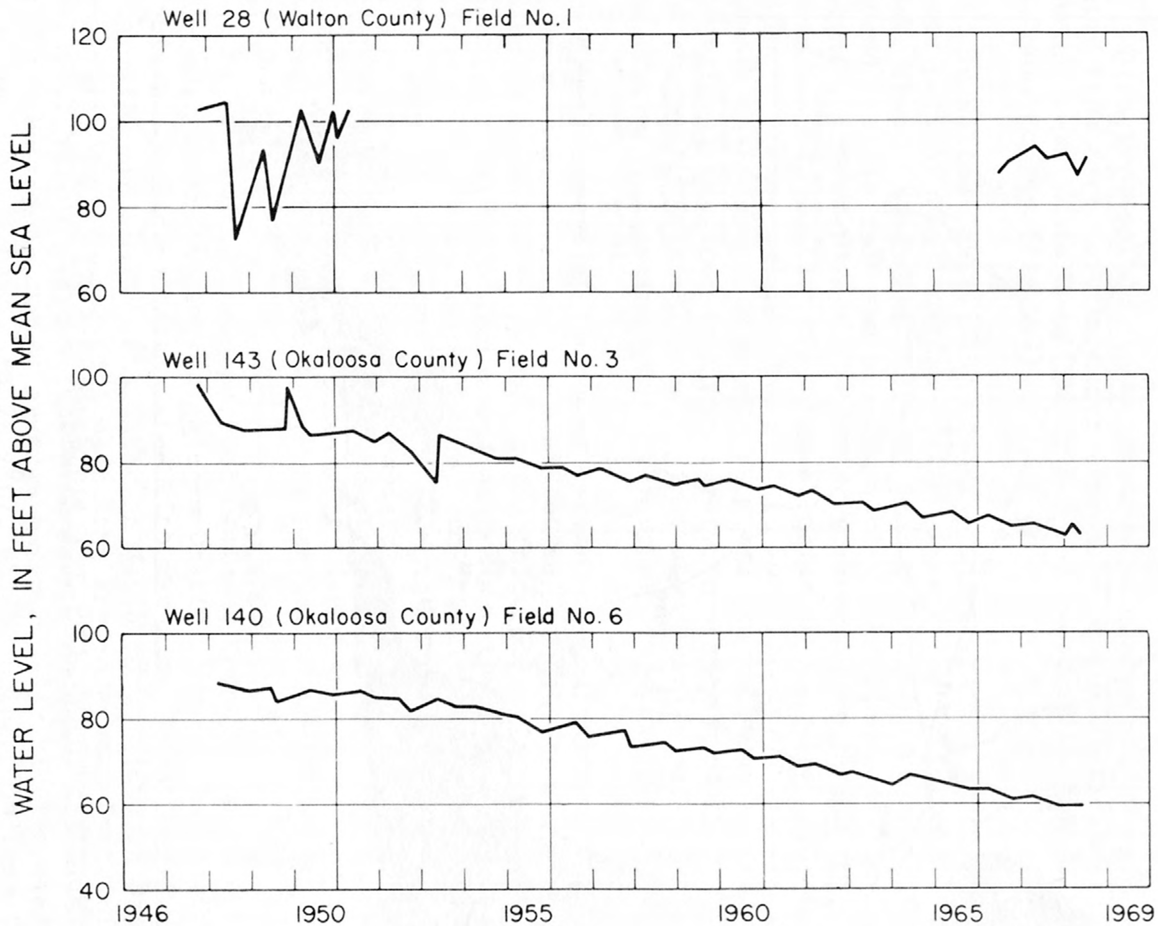

FIGURE 26.--HYDROGRAPHS OF ANNUAL HIGH- AND LOW-WATER LEVELS IN THREE WELLS TAPPING THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER. (WELL LOCATIONS SHOWN IN FIG. 1.)

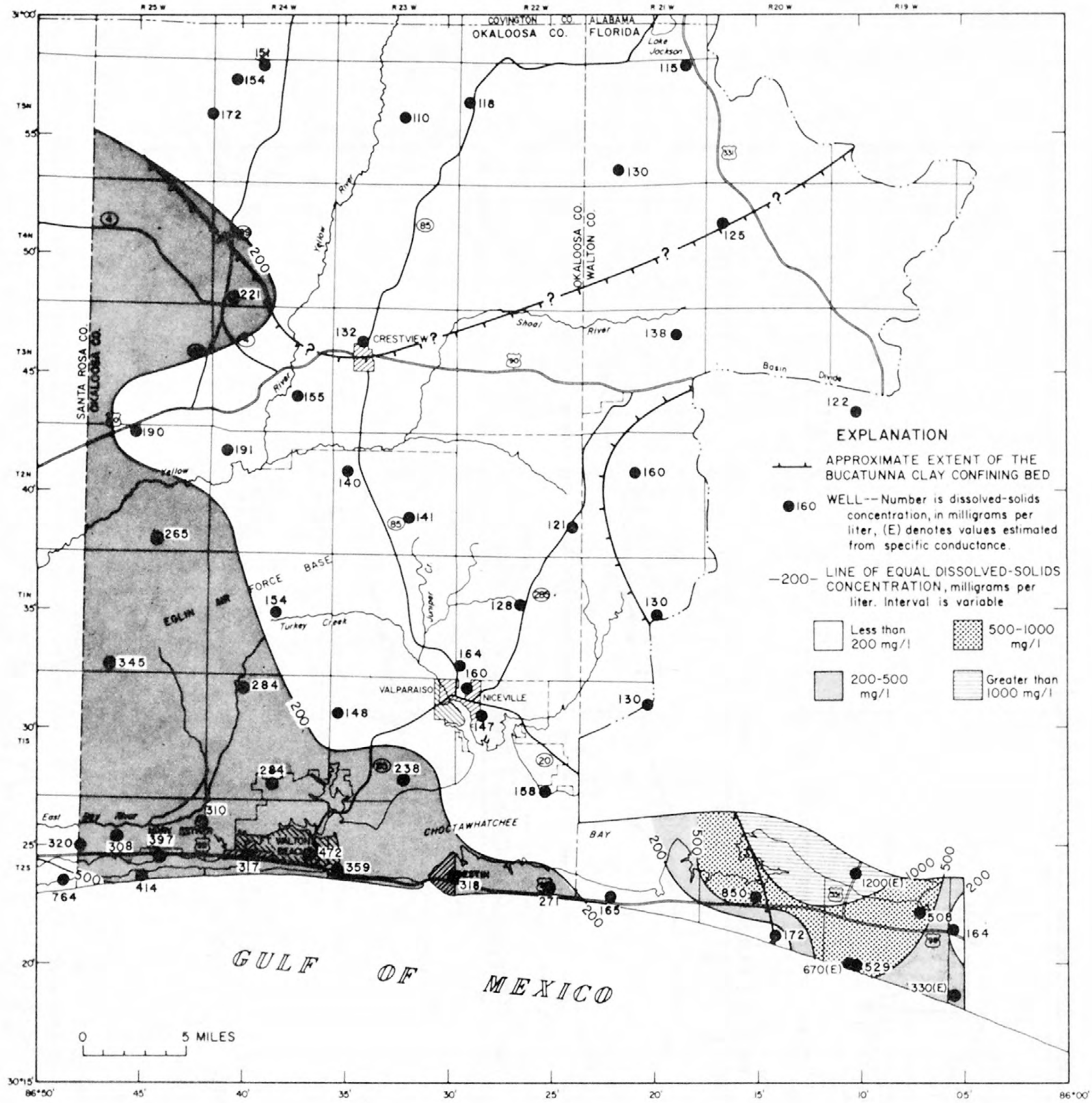

FIGURE 27.--DISSOLVED-SOLIDS CONCENTRATION IN WATER FROM THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER AND FROM THE UPPER PART OF THE UNDIFFERENTIATED FLORIDAN AQUIFER.

in the northeast to 200 to 260 mg/L in the southwest, and in chloride from a general range of 3 to 8 mg/L in the northeast to 40 to 140 mg/L in the southwest. These increases may be explained by solution of limestone and dolomite, ion exchange, and addition of sodium chloride. The changes in chemical type of water are illustrated by the Stiff diagrams (Stiff, 1951) in figure 28, which show the relative concentrations of the principal ions in the water at various locations.

Dissolved-solids concentrations in excess of 500 mg/L occur in water from parts of the upper limestone of the Floridan aquifer of southeastern Santa Rosa County and southwestern Walton County adjoining Okaloosa County (fig. 27).

In Walton County, the chloride concentration in the water from the upper part of the Floridan aquifer is substantially higher along the coast than inland (fig. 29) and from some wells exceeds 250 mg/L. Beyond the limit of the Bucatunna clay confining bed (figs. 3 and 6), salinity in water in the undifferentiated Floridan aquifer tends to increase with depth. The high chloride in the water in southwestern Okaloosa County and adjoining Santa Rosa County, where the Bucatunna clay is an effective confining bed, is probably due to incomplete flushing of residual seawater in the aquifer. Distance from the recharge area and the southwestward decrease in transmissivity are factors controlling the degree of flushing within the upper limestone of the Floridan aquifer.

The hardness of the water in the upper limestone of the Floridan aquifer is greatest in the east-central, southeastern, and northwest parts of the area of investigation (fig. 30). Inasmuch as hardness is made up chiefly of calcium and magnesium, the previously discussed variations in calcium and magnesium concentrations determine the areal variations of hardness in water from the upper limestone. In most of Okaloosa County, the water is moderately hard. In east-central and extreme northwestern Okaloosa County, it is hard. In west-central and southwestern Okaloosa County, it is soft. In west-central and southwestern Walton County, it is hard, and in part of southern Walton County it is very hard.

In the southwestern part of Okaloosa County, and in a strip along the coast extending as far east as Destin, the upper limestone of the Floridan aquifer contains water with fluoride in excess of 1.0 mg/L (fig. 31). In some of the water on Santa Rosa Island in Santa Rosa County fluoride exceeds 1.6 mg/L, the Environmental Protection Agency's (1975, p. 59570) maximum recommended concentration for drinking water in areas having an annual average maximum daily air temperature between 70.7^{o} and 79.2^{o}F (21.5^{o} to 26.2^{o}C), which include Okaloosa County.

Most of the water in the upper limestone in the area of this investigation is of good quality for drinking and public supply with respect to the constituents analyzed except in the local areas described above where concentrations of chloride and fluoride exceed recommended drinking water standards (Foster and Pascale, 1971, table 7).

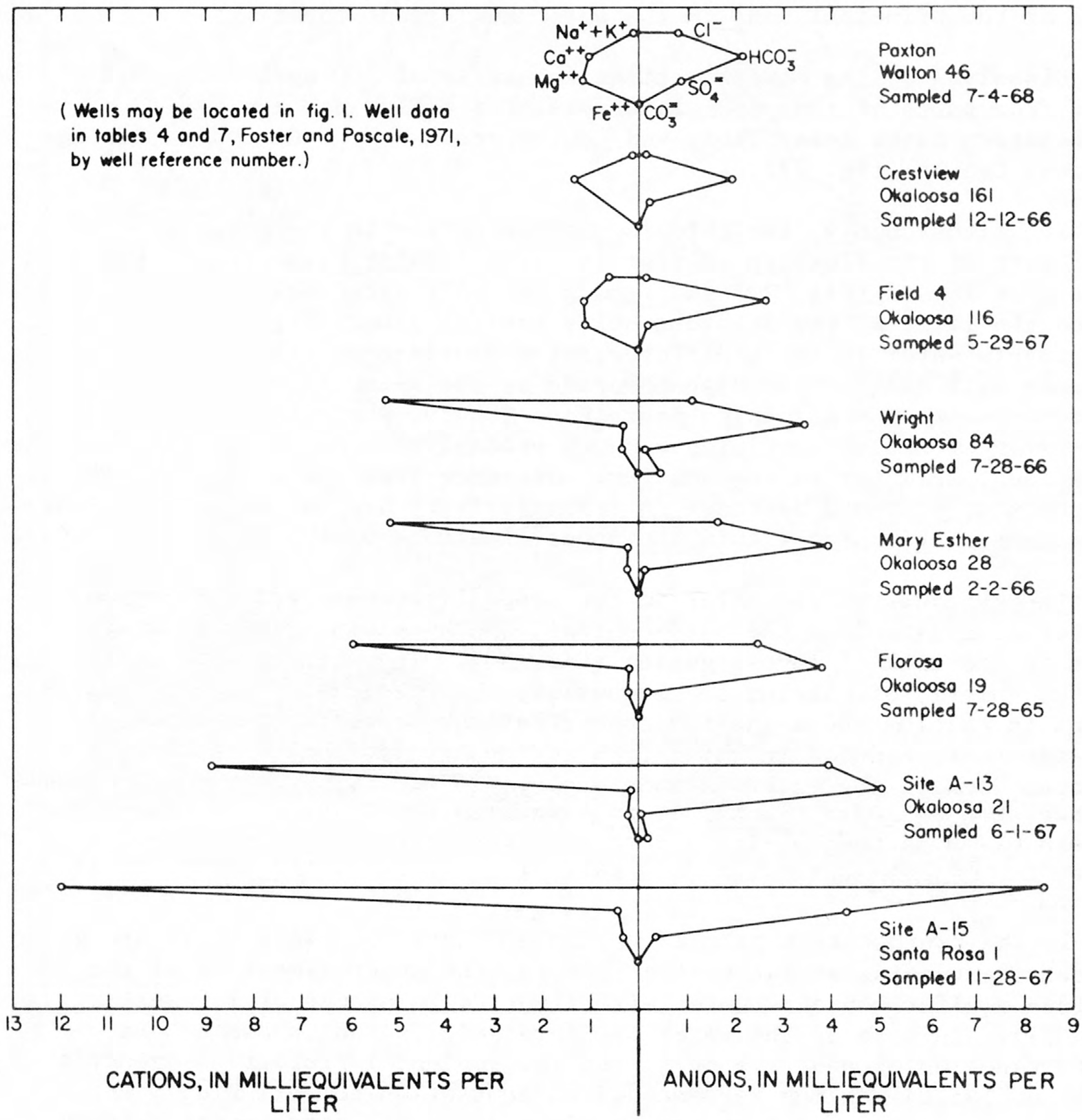

FIGURE 28.--STIFF DIAGRAMS SHOWING THE CONCENTRATIONS OF PRINCIPAL IONS IN WATER FROM WELLS IN THE UPPER PART OF THE FLORIDAN AQUIFER.

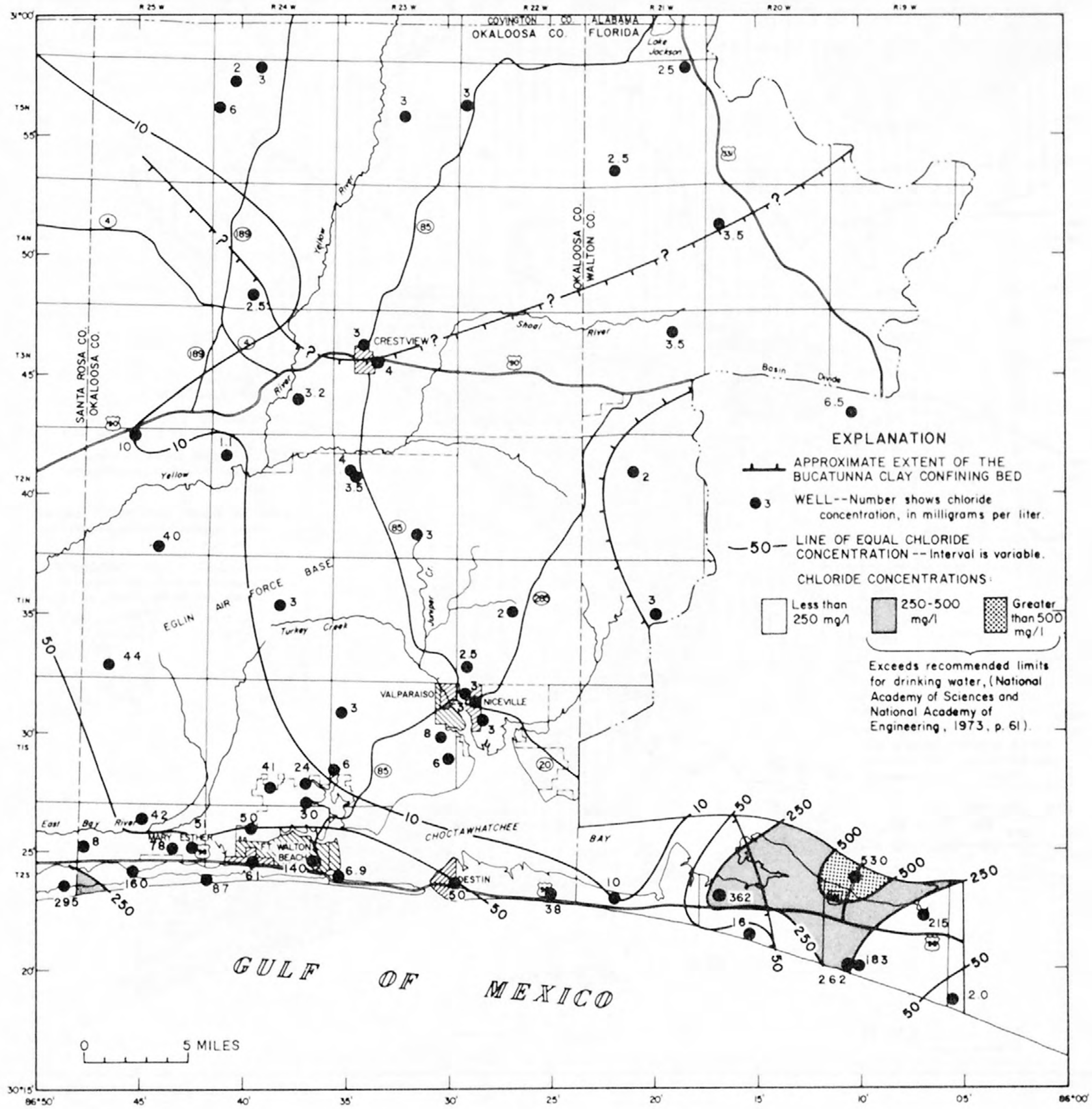

Figure 29.--Chloride concentration in water from the upper limestone of the Floridan aquifer and from the upper part of the undifferentiated Floridan aquifer.

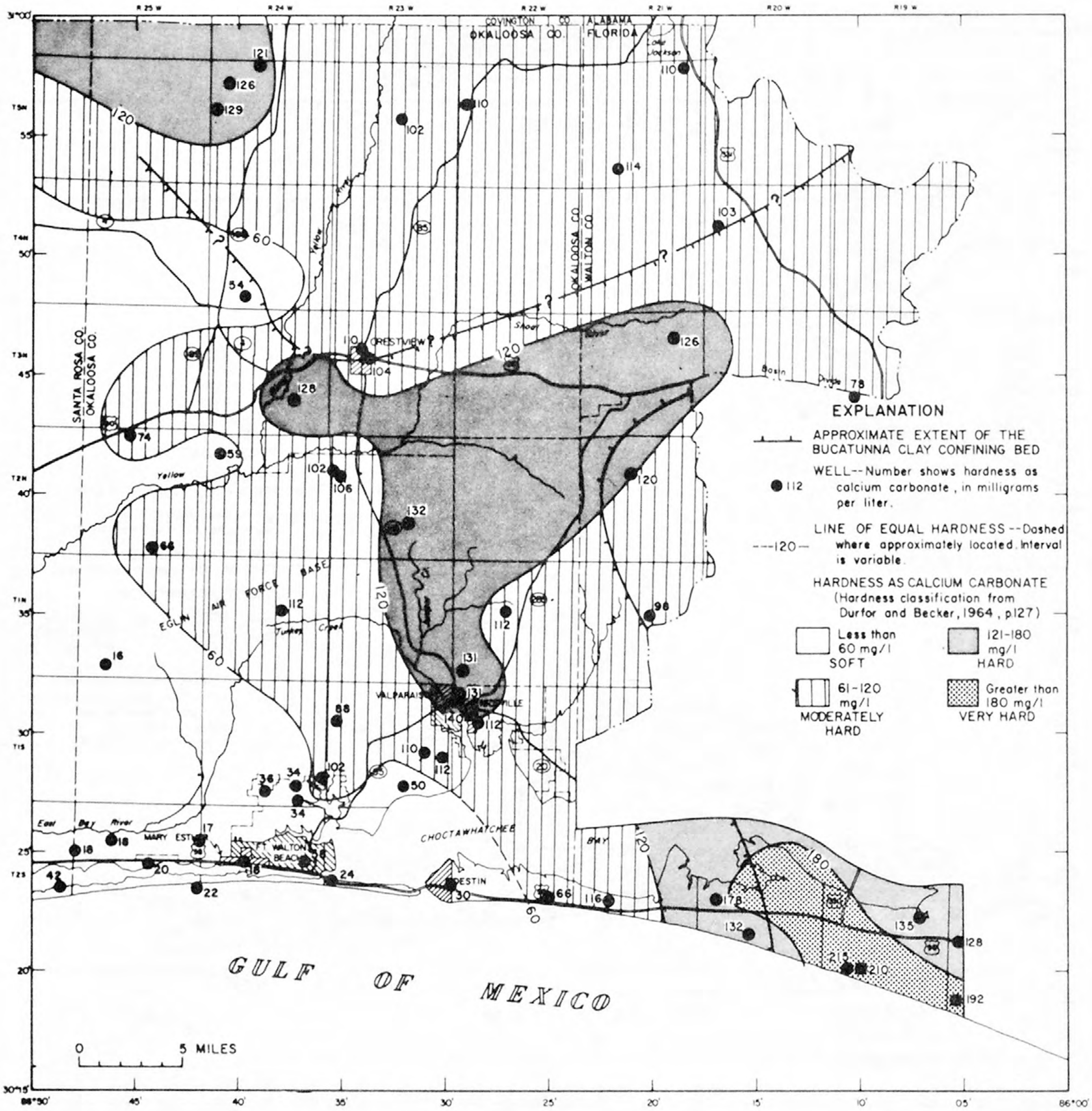

FIGURE 30.--HARDNESS IN WATER FROM THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER AND FROM THE UPPER PART OF THE UNDIFFERENTIATED FLORIDAN AQUIFER.

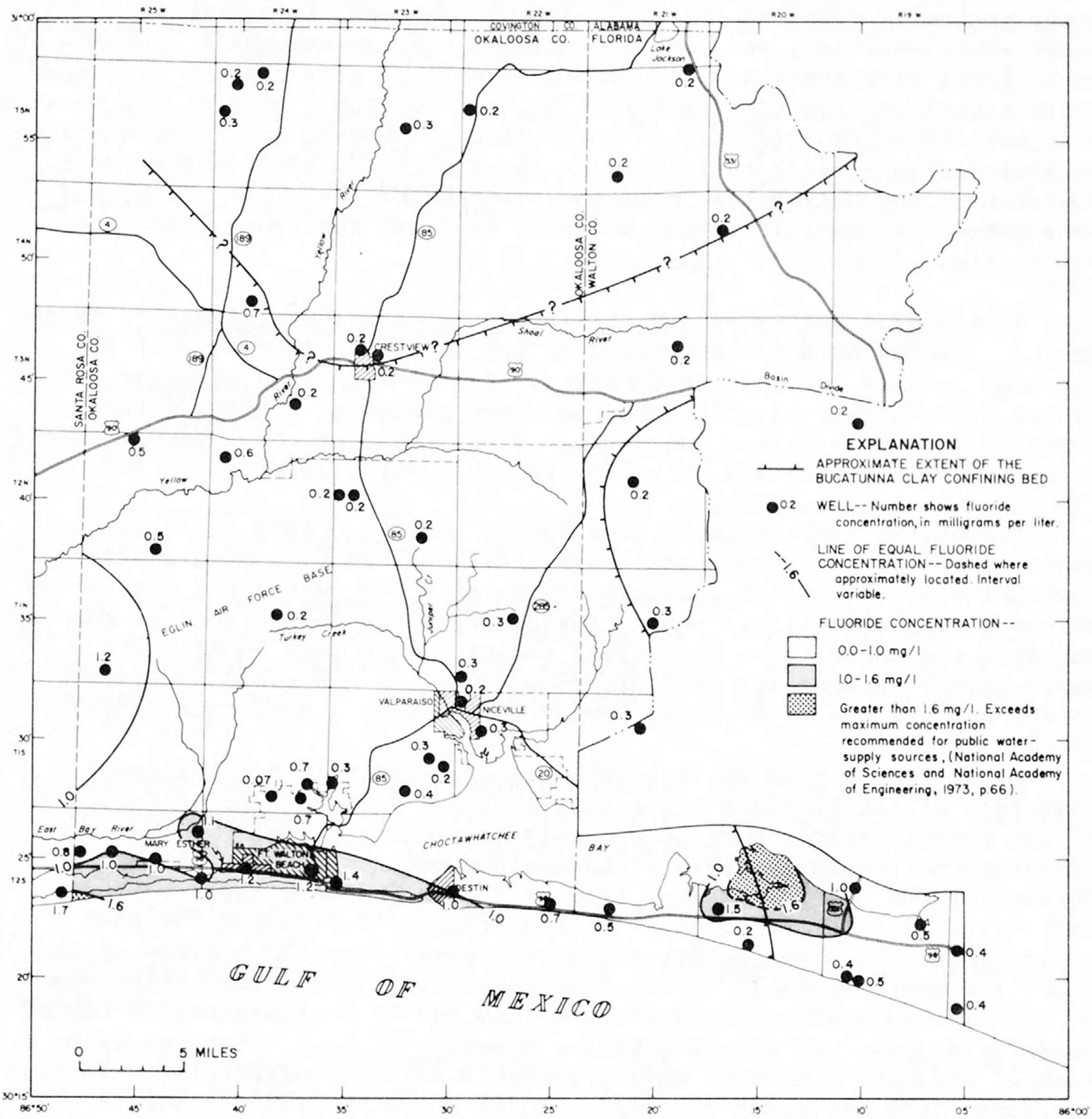

FIGURE 31.--FLUORIDE CONCENTRATION IN WATER FROM THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER AND FROM THE UPPER PART OF THE UNDIFFERENTIATED FLORIDAN AQUIFER.

Lower limestone of the Floridan aquifer

The lower limestone of the Floridan aquifer consists of white to gray, generally soft and chalky limestone composed of foraminifera, other shell material, and some crystalline calcium carbonate. Lenses of hard, light gray shale and siltstone, as well as gray clay, are irregularly distributed in its lower section. Within the limits of the Bucatunna clay confining bed (fig. 6), which confines it above, the limestone acts as an artesian aquifer that is hydraulically separated from the upper limestone. The Tallahatta Formation composed of the shale, clay, and less permeable sandy limestone and sand confines the lower limestone below (figs. 3, 4).

Availability of water and utilization of the lower limestone as an aquifer.--No water wells are known to tap the lower limestone of the Floridan aquifer in Okaloosa County as adequate supplies of water are almost everywhere available from the upper limestone. Data on the porosity, transmissivity, and storage coefficient of the lower limestone or on specific capacities of wells are, therefore, lacking.

Nearby, in western Santa Rosa County and since 1963 in Escambia County north of Pensacola, the lower limestone has been used to store chemical wastes. At the Escambia County site, the waste has not spread beyond a radius of 1.5 mi but increased pressures in the aquifer resulting from the waste injection extend radially more than 40 mi. The waste-injection facility in Santa Rosa County is described by Pascale (1975) and the one in Escambia County by Faulkner and Pascale (1975).

Water levels.--No water-level data are available for the lower limestone of the Floridan aquifer in Okaloosa County. The configuration of the potentiometric surface probably is similar to that of the upper limestone before large-scale withdrawals depressed the potentiometric surface of the upper limestone (fig. 22; also Faulkner and Pascale, 1975, fig. 3). In the vicinity of the cones of depression for the upper limestone, shown on figure 25, the potentiometric surface of the lower limestone probably is substantially higher than that of the upper. If a well were inadvertently drilled into the lower limestone in one of these areas, such as the Fort Walton Beach well field, there would be a risk of inducing a flow of water, probably saline, under relatively high pressure, into the upper limestone, which there is used for public supply.

Quality of water.--Although chemical analyses of water from the lower limestone in Okaloosa County are lacking, the interpretation of electric logs of oil test wells and data from adjoining areas suggest that the dissolved solids concentration of the water generally is in excess of 1,000 mg/L and that the water becomes even more saline to the south. Test wells that tap the lower limestone in southern Santa Rosa County yielded large quantities of saline water whose dissolved solids concentrations ranged from 5,000 to 11,200 mg/L, and a test well in central Santa Rosa County yielded a small quantity of water with a dissolved solids concentration ranging from 868 to 904 mg/L (Pascale, 1976, table 5; Pascale, 1975, table 1).

In northern Okaloosa County, where the Floridan aquifer is a hydraulic unit, wells yield potable water from beds equivalent to the lower limestone of the Floridan aquifer. In southern Walton County, water from the lower part of the Floridan aquifer is saline.

WATER RESOURCES PROBLEMS

Decline in Water Levels in Southern Okaloosa County

Declining water levels in wells constructed in the upper limestone of the Floridan aquifer in southern Okaloosa County are a matter of concern to those responsible for water supplies.

When water levels continue to decline, the question may arise: Is the aquifer being dewatered (or pumped dry)? The answer is "No."

In order for dewatering to begin, water levels would have to be drawn down below the top of the limestone. The top of the limestone around Fort Walton Beach and Eglin Air Force Base is at least 290 ft below sea level and, as of 1968, water levels were no more than 35 ft below sea level.

Another question is whether ground water is being "mined," or pumped from storage in the aquifer in southern Okaloosa County, and if so, how much of the total water pumped is being "mined?"

The answer to the first part of the question is:

1. All water discharged by wells is balanced by a loss of water somewhere.

2. This loss is always to some extent and in many cases largely from storage in the aquifer.

The answer to the second part of the question is "only a small percentage of the water pumped." This may be arrived at by considering the sources of the water pumped from wells: water pumped from an aquifer is derived from three principal sources. These are: storage, recharge, and reduction of natural discharge. Prior to development by wells, recharge and discharge were in balance in the upper limestone of the Floridan aquifer. Discharge from wells upset the balance by producing a loss from storage, shown by declining water levels, and a new state of equilibrium cannot be reached until there is no further loss from storage. This can only be accomplished by an increase in recharge, a decrease in natural discharge, or both. If there were no further increase in the rate of pumping, the cone of water-level depression would continue to expand until it induced sufficient additional recharge, or reduced natural discharge sufficiently, to equal the rate of withdrawal by wells. Under present conditions of steadily increasing withdrawals concentrated in a small area, water levels can be expected to continue to decline around the areas of pumping.

The volume of water removed from storage in an aquifer can be estimated by multiplying the volume of the cone of depression by the average value of the aquifer's storage coefficient. The storage coefficient for most confined aquifers is about 10^{-6} times the aquifer thickness in feet (Lohman, 1972, p. 8), so that using 400 ft as the average thickness of the upper limestone of the Floridan aquifer in southern Okaloosa County, the storage coefficient is about 4×10^{-4}. This value is in agreement with the range of 1.6×10^{-4} to 5.6×10^{-4} for storage coefficients determined by means of five aquifer tests of the Floridan aquifer in adjoining Walton County (Pascale, 1974, p. 56). Because of insufficient water-level data, the volume of the composite cone of depression formed in southern Okaloosa County between 1942 and 1968 (fig. 24) can be estimated only roughly. The land area of Okaloosa County within the limit of the Bucatunna clay confining bed is about 634 mi^2. From inspection of figure 24, the average drawdown over this area between 1942 and 1968 may be estimated at 35 ft. The area is then doubled to allow for those parts of the cone of depression extending under the gulf and bays, beyond the limit of the Bucatunna clay confining bed and into the adjoining counties. The volume of the cone may be estimated (by assuming it to be a cylinder whose altitude is equal to the average drawdown) at 1.2×10^{12} ft^3. Multiplying this by the storage coefficient, 4×10^{-4}, gives 480×10^6 ft^3 of water removed from storage, or 3,600 Mgal.

The volume of water removed from storage in the upper limestone of the Floridan aquifer from 1942-68, while substantial, is only about 6 percent of the total pumpage of 60,000 Mgal. Therefore, about 94 percent of the total pumpage of the water pumped from the aquifer (56,000 Mgal) is derived from increased recharge, decreased natural discharge, or a combination of the two.

The expansion of the cone of depression formed by pumping continuously from the upper limestone of the Floridan aquifer would tend to increase recharge and decrease natural discharge within the area of the cone; however, in this area the Floridan aquifer is overlain by the Pensacola clay confining bed. Changes in recharge and natural discharge probably would be small relative to total pumpage because of the low vertical hydraulic conductivity of the confining bed, at least until the cone area extended beyond its limits. The cone of depression, as indicated by the projected 20-ft line of equal decline of the potentiometric surface in figure 24, already reached the limits of the overlying Pensacola clay confining bed in southwestern Walton County by 1968; therefore recharge may have increased in this area.

Prior to extensive pumping in southern Okaloosa County, the hydraulic gradient in the upper limestone of the Floridan aquifer was toward the gulf (fig. 22), indicating that water moved toward the gulf. The static head of water in the aquifer was as much as 63 ft above sea level at the coastline. Presumably, water discharged from the limestone somewhere under the gulf. The cone of depression resulting from the heavy pumping in southern Okaloosa County has intercepted much of the water that would have discharged under the gulf under natural conditions. Therefore, much of the water pumped probably has come from reduction in natural discharge.

To the extent that the sum of the volumes of (1) water removed from artesian storage, (2) increased recharge within the land area, and (3) decreased natural discharge may be less than the volume of water pumped, the difference must be made up by freshwater moving in from the part of the aquifer underlying the gulf. This in turn would be replaced by seawater recharging the aquifer farther out. A saltwater-freshwater interface is assumed to extend roughly parallel to the coastline at an unknown distance offshore. Before pumping began, this distance was probably on the order of several miles as indicated by (1) the elevation of the potentiometric surface along the coast (fig. 22) and (2) the fact that saltwater has not yet appeared in coastal wells, although the cone of depression apparently is below sea level for some distance offshore (fig. 23).

The distance that the saltwater-freshwater interface could have advanced may be estimated as follows:

Assume that a 26-mi segment of a sharp interface has been affected by the cone of depression centered at Fort Walton Beach, that the upper limestone is 400 ft thick, and that its porosity is 13 percent. Assume also that the advance of the interface is uniform along the 26-mi segment and that a constant head is maintained at the moving interface. Then each foot of advance of the interface would displace the following volume of freshwater:

$$1 \text{ ft} \times 26 \text{ mi} \times 5{,}280 \text{ ft/mi} \times 400 \text{ ft} \times 0.13 = 7.14 \times 10^{6} \text{ ft}^{3}$$

Assume that half the 56,400 Mgal pumpage unaccounted for by removal from artesian storage, or about 3.77×10^{9} ft^{3}, was displaced by movement of the interface underlying the gulf. If this is divided by the volume of water displaced per foot advance of the interface:

$$(3.77 \times 10^{9} \text{ ft}^{3}) \div (7.14 \times 10^{6} \text{ ft}^{3}/\text{ft}) = 528 \text{ ft}$$

Therefore, if all the foregoing assumptions are correct, shoreward movement of the interface at an average rate of only 528 ft in 26 years would account for almost half the water pumped. However, pumping is not uniformly distributed along the coastline, nor are the decline contours linear in shape. For these reasons the advance of the interface would not be uniform but would be greatest opposite the centers of pumping.

The above example is presented merely to indicate the possible source of part of the water that has been pumped. In view of the likelihood that the interface is some miles offshore, 528 ft is a relatively short distance. On the other hand, the assumption that almost one-half the historical pumpage came from the part of the aquifer underlying the gulf is probably too large. Wells around Fort Walton Beach are not considered to be in immediate danger of pumping saltwater. However, continued withdrawal from the system has the potential of moving the interface landward, and accelerated withdrawal could accelerate movement of the interface.

Location of Well Fields

The concentration of pumping in the least transmissive parts of the upper limestone of the Floridan aquifer is a primary cause of large water-level declines in southern Okaloosa County. At Fort Walton Beach, estimated transmissivity is as low as 1,300 ft^2/d; but at Wright, northwest of Fort Walton Beach, estimated transmissivity is as much as 20,000 ft^2/d. The impact of transmissivity of an aquifer on drawdown in wells can be shown by the following example:

At well 35 at Fort Walton Beach (fig. 1) the estimated transmissivity is 1,500 ft^2/d based on a specific capacity of 4.4 (gal/min)/ft. Drawdown in the well is 174 ft for a pumping rate of 760 gal/min. At Wright, northwest of Fort Walton Beach, using Well 84 (fig. 1), the estimated transmissivity is 20,000 ft^2/d based on a specific capacity of 58 (gal/min)/ft. Drawdown in the well is 8 ft at a pumping rate of 466 gal/min (Foster and Pascale, 1971, table 4). At a pumping rate of 760 gal/min the estimated drawdown in Well 84 would be 13 ft. For a given volume of water withdrawn over a specific time, water-level declines in the aquifer at the two wells would be proportional to the indicated specific capacities. It, therefore, can be concluded that if the well fields supplying southern Okaloosa County had been located where the transmissivity of the aquifer is high, the local decline in water levels would have been much less for the same pumpage over the same time span.

Well Spacing

Close spacing of wells is another factor that contributes to excessive declines in water level. When the cone of depression from one pumped well intersects a second pumped well, the drawdown resulting from the second well's pumping is added to the drawdown of the first. The drawdown at a given distance from a well pumped at a given rate for a given time can be predicted by means of the Theis equation (Lohman, 1972, p. 15-19). Application of the equation is based on certain assumed conditions concerning aquifer characteristics and boundaries that are never completely met, but nonetheless, it has been applied successfully to many ground-water problems.

For example, if a well were to pump 800 gal/min for 10 years from an aquifer whose transmissivity is 1,300 ft^2/d and whose storage coefficient is 4.0×10^{-4}, the drawdown at a point 1,000 ft distant after 10 years would be 96 ft (assuming no recharge) according to the Theis equation solution. Thus, if a new well were drilled 1,000 ft from a pumping well under these conditions, its initial water level would be 96 ft lower than if it were drilled outside the influence of an existing well.

Although the Theis method may be used to predict the effect of one well's pumping upon the water level in another one nearby, the situation in southern Okaloosa County is much more complex, with many wells being pumped cyclically, interfering with each other, and the transmissivity of the aquifer apparently varying within short distances. Under these circumstances, the problem of predicting the configuration of the potentiometric surface with various distributions of pumpage would best be handled by a computer model. A computer program could also be devised for use in planning the optimum pattern of wells, and taking into account the economics of laying pipe lines as well as pumping costs. In the absence of a computer model, interference effects could be minimized by spacing wells as far apart as practicable, and by giving preference in locating new wells in areas of high transmissivity (as indicated by high specific capacities in surrounding wells, fig. 21), and avoiding areas in which large declines have occurred (fig. 24).

Artificial Recharge

Some of the abundant water in the sand-and-gravel aquifer could be used to recharge the upper limestone of the Floridan aquifer through connector wells and thereby alleviate water-level declines around the major centers of pumping. Connector wells are designed to provide hydraulic communication between two aquifers. In this case they would be wells with a screen in the sand-and-gravel aquifer, casing from the screen down to the top of the upper limestone of the Floridan aquifer, and with an open hole in the limestone. Water would flow by gravity into the well through the screen, down through the casing, and out into the deeper aquifer. Each connector could be designed so that the rate of flow into the Floridan aquifer would not be great enough to lower the water level to the extent that would permit air to come in contact with the screen, in order to minimize corrosion and encrustation. Because of acidity of the water in the sand-and-gravel aquifer, it would be desirable to use non-corrosive materials for the construction of connectors to prevent early failure of the casing and screen, or iron encrustation of the permeable zones in the Floridan aquifer. Provided that encrustation was minimized, continued recharge by acidic water from the sand-and-gravel aquifer would tend to increase the permeability of the Floridan aquifer around the recharge area by solution of the limestone. Connector wells would be effective, of course, only where the potentiometric surface in the sand-and-gravel aquifer is substantially higher than that of the upper limestone of the Floridan aquifer.

The sandhills just north of the centers of pumping appear to contain especially favorable sites for hydraulic connectors. Based on the head difference between the two aquifers and their hydraulic characteristics, it is estimated that as much as 500 gal/min or 720,000 gal/d of continuous gravity flow could move into the upper limestone of the Floridan aquifer through one connector well.

The operation of connector wells by gravity would depend upon the maintenance of sufficient difference in head between the aquifers. This difference will decrease as the source aquifer is drawn down around the well and as a mound builds up on the potentiometric surface of the recipient aquifer. Whether these effects are sufficient to cut the flow below the hypothetical yield of 500 gal/min can be tested by the following estimates and calculations:

At Range 70 on Eglin Air Force Base in southwestern Okaloosa County, well 219 (fig. 1) has a specific capacity of 125 (gal/min)/ft after 9 hours pumping (C. R. Smith, Civil Engineering Division, Eglin Air Force Base, written commun. 1976). Extrapolating from a method by Theis (1963, p. 332-336), and assuming water-table conditions and a storage coefficient of 0.3, the transmissivity may be estimated at 24,000 ft^2/d.

Using $\underline{T}$ = transmissivity as estimated above, rounded to 20,000 ft^2/d

$\underline{S}$ = storage coefficient, estimated at 0.3

$\underline{r}$ = radius, 0.5 ft

$\underline{Q}$ = discharge, assumed to be 500 gal/min or 95,000 ft^3/d

a method by Jacob and Lohman (Lohman, 1972, p. 23-24) was adapted to solve for discharge per unit constant drawdown ($\underline{Q}/\underline{s_w}$) for time ($\underline{t}$) in days by the equations:

$Q/s_w = T\ 2\pi G(\alpha)$, where $\underline{G}$ is a function of α (Lohman, 1972, table 7, p. 24, and $\alpha = Tt/Sr^2$.

The following results were obtained:

Time (t)	Qs_w	
Days:	$(ft^3/d)/ft$	(gal/min)ft
1	18,800	97.0
10	16,400	83.4
100	14,000	72.7
1,000	12,400	64.4
10,000	11,200	58.0

This shows that, using the above assumptions, if a 10-ft difference in head between the two aquifers could be maintained and no dewatering of the upper aquifer occurred, a 12-inch connector well theoretically could deliver 580 gal/min after 10,000 days of continuous operation.

At well 219, the altitude of the water level was about 85 ft in 1966. The altitude of the potentiometric surface in the upper limestone of the Floridan aquifer at Range 70 was about 48 ft in 1968 (fig. 23). Thus, the difference in head at Range 70 would have been about 37 ft before the installation of a hypothetical connector well. Although, from the preceding discussion, this difference would appear to be ample for a flow of 500 gal/min, the reduction in head difference caused by mounding in the Floridan aquifer must also be considered. This can be predicted by use of the Theis equations adapted from Lohman (1972, p. 15-16) in the form:

$s = QW(u)/4\pi T$, and

$u = r^2S/4\ Tt$,

where $\underline{s}$ = the mounding, in feet,

T = transmissivity, estimated at 20,000 ft^2/d, from the average of specific capacities 62 (gal/min)/ft at Field 6, 125 (gal/min)/ft at Field 5, and 58 (gal/min)/ft at Wright (fig. 21) by a method by Meyer (1963, p. 338-341, fig. 100),

$\underline{W(u)}$ = well function of $\underline{u}$ (Lohman, 1972, table 5, p. 16),

$\underline{r}$ = well radius in feet, assumed to be 0.5 feet,

$\underline{S}$ = storage coefficient, estimated at 4×10^{-4}, and

$\underline{t}$ = time in days.

The following results were obtained:

Time (t) (Days):	s (Feet):
1	8
10	9
100	10
1,000	11
10,000	12

These show that after 10,000 days of operation, the head difference between the aquifers would not be reduced by more than 12 ft by mounding in the upper limestone of the Floridan aquifer.

The above analysis assumes no dewatering (reduction in transmissivity) in the upper aquifer. Since the upper aquifer has water-table conditions, dewatering would occur. The effect would be to reduce Q more quickly than has been shown, which would then tend to reduce the mounding effect in the Floridan. When all effects are considered, it is reasonable to expect that connector wells could deliver about 500 gal/min to the upper limestone of the Floridan aquifer for a significantly long period of time in this area.

Alternative Sources of Water

The decline in water levels in the upper limestone of the Floridan aquifer in southern Okaloosa County could be alleviated by use of alternative sources of water. These include the sand-and-gravel aquifer and various streams. Water from the sand-and-gravel aquifer would require adjustment of the pH to avoid corrosion if used unmixed, but treatment could be minimized if it were blended with Floridan aquifer water. The resulting blend would be softer and lower in dissolved solids than the presently used unmixed Floridan aquifer water.

The streams of Okaloosa County are at present virtually untapped as sources of water. The flow of the larger streams persists through drought (figs. 8-9, 12-15) so that they could serve as reliable water sources without extensive storage reservoirs. Except for its objectionable color, surface water is similar in quality to the water in the sand-and-gravel aquifer, and the results of blending surface water with Floridan aquifer water would be similar to blending water from the two aquifers. The potential for contamination of such a surface supply would have to be recognized. Placing surface-water intakes out of reach of tidal saltwater, either by locating them upstream from tidal incursions or behind artificial barriers, would be necessary.

Saltwater Contamination in the Upper Limestone of the Floridan Aquifer

Three potential processes by which saline water could encroach into the upper limestone of the Floridan aquifer in southern Okaloosa County are: 1) inland movement of saline water from the parts of the aquifer underlying the Gulf of Mexico or saltwater bays, 2) upward movement of saline water from the lower limestone of the Floridan aquifer through or around the Bucatunna clay confining bed, and 3) in coastal areas the downward movement of saline water from the sand-and-gravel aquifer through the Pensacola clay confining bed.

Although the slope of the potentiometric surface of the upper limestone of the Floridan aquifer favors movement of saline water inland from the gulf to wells near the coast, saline water has not yet appeared in the wells tapping the upper limestone, except for contamination through leaky wells. Years of pumping at Fort Walton Beach and Eglin Air Force Base have resulted in the formation of cones of depression along the gulf and Choctawhatchee Bay in which the potentiometric surface is below sea level (fig. 23). Water moves from high to low points on the potentiometric surface within an aquifer, so that it moves toward the centers of the cones from underneath the bays and the gulf as well as from inland. Under these conditions, the eventual appearance of saline water in the centers of the cones of depression is to be expected. However, a 19-year record of chloride analyses of water from two wells on Santa Rosa Island offshore from the Fort Walton Beach area does not show a significant increase in chloride (fig. 32). The probable reasons that saline water originating from the gulf has not appeared in the wells are the evidently effective seal provided by the overlying Pensacola clay confining bed, and the slow rate of advance of the saltwater-freshwater interface, perhaps a few hundred feet in 26 years. These factors do not preclude the eventual encroachment of saline water; the probability of encroachment increases with the growth of the cone of depression.

The low concentration of chloride in water from wells tapping the upper limestone in the Fort Walton Beach area also indicates that movement of water from the lower limestone to the upper limestone in this area has been negligible up to 1968, assuming that water in the lower limestone is saline, as it is in adjoining southern Santa Rosa County. The potentiometric surfaces of water in the two limestones probably were similar before pumping began. The lowering of the potentiometric surface in the upper limestone as the result of pumping has created an upward gradient, tending to cause movement of water upward from the lower limestone through the Bucatunna clay confining bed into the upper lime-

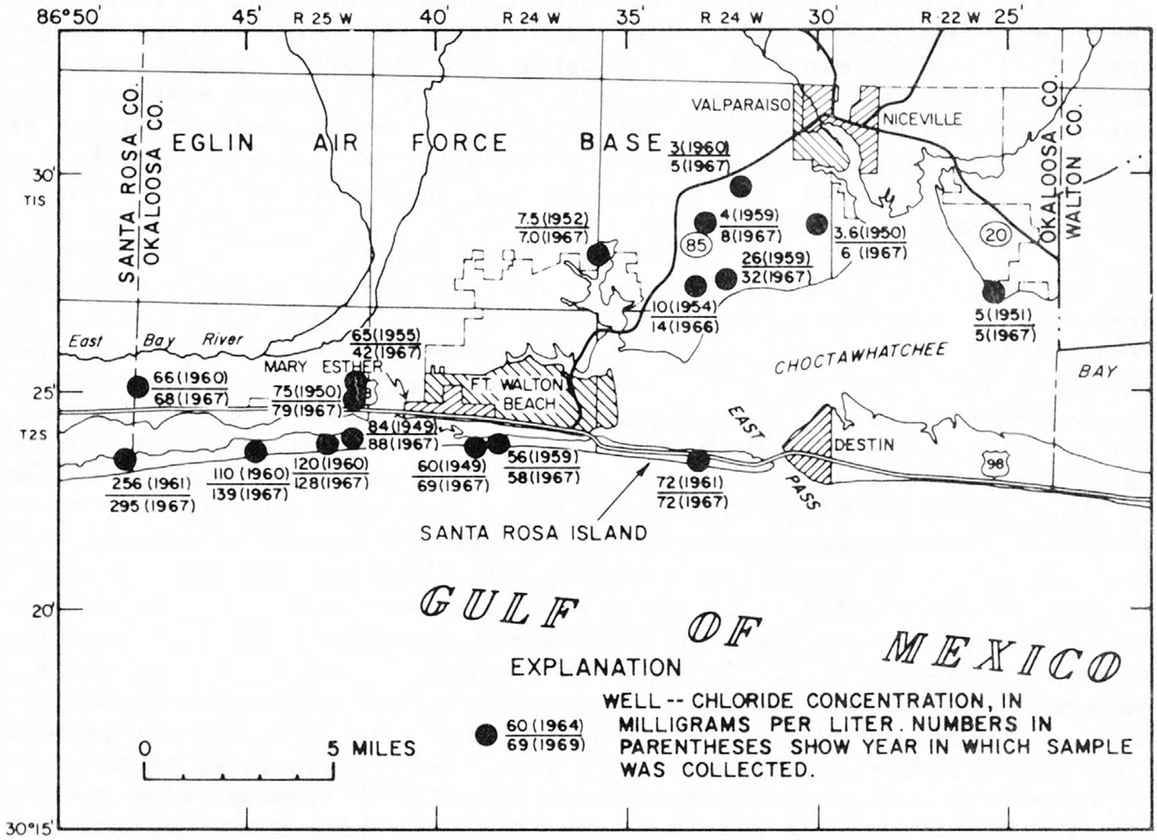

FIGURE 32.--CHLORIDE CONCENTRATIONS IN EARLY AND RECENT SAMPLES OF WATER FROM WELLS TAPPING THE UPPER LIMESTONE OF THE FLORIDAN AQUIFER IN THE COASTAL AREA OF OKALOOSA COUNTY.

stone. The low vertical permeability of the clay presumably has prevented the upward flow of water from the lower limestone in quantities large enough to affect appreciably the quality of water pumped from wells. The Bucatunna clay confining bed thins eastward along the coast, however, pinching out in southwestern Walton County about 8 mi east of the Okaloosa-Walton County line (figs. 3 and 6). If the potentiometric surface in the upper limestone were further depressed near the pinchout of the confining bed, whether by local pumping or by expansion of the large composite cone of depression centered at Fort Walton Beach, an upward movement of saline water could be induced.

Saline water is found in part of the sand-and-gravel aquifer along the gulf and bays (fig. 16). Although the Pensacola clay confining bed appears to be intact in these areas, saline water can leak into the upper limestone from above through wells whose casing have become corroded or that have leaky couplings or casing seats. By means of conductivity logging, nine wells in the Fort Walton Beach area were found to be defective, permitting saline water to leak into the upper limestone of the Floridan aquifer (fig. 16). Inasmuch as the leaky wells are in the area of lowered head in the upper limestone of the Floridan aquifer (fig. 23), the saline water, once inside a well, will tend to recharge the upper limestone.

Movement of saline water through wells is best avoided by making them leak-proof. Pressure cement grouting of well casings along their full lengths during construction would accomplish this purpose. Plugging of unused and leaky wells would prevent further movement of saline water into the aquifer.

SUMMARY AND CONCLUSIONS

Ample supplies of water of good quality are available in Okaloosa County and adjacent areas. The artesian Floridan aquifer, specifically its upper limestone, is the chief source of water. The surficial sand-and-gravel aquifer, although capable of yielding large quantities of water, is little used. The streams have favorable flow characteristics for potential water sources but are virtually unused.

The greatest concentration of population in the area of investigation--and consequently the greatest water demand--is in the southern part of Okaloosa County along the gulf and associated bays. There the principal centers include Fort Walton Beach, Niceville, Valparaiso, Mary Esther, Shalimar, Destin, and Eglin Air Force Base. As the population grew in the southern part of the county, largely as a result of the establishment and growth of the air force base, the daily average pumpage increased from about 1.5 Mgal in 1940 to about 11.8 Mgal in 1968.

Continually increasing pumpage of ground water, concentrated largely at Fort Walton Beach and Eglin Air Force Base, has resulted in an expanding composite cone of depression in the potentiometric surface of the upper limestone of the Floridan aquifer along the coast. From 1940 to 1968, water levels in wells have declined more than 90 ft at Fort Walton Beach and locally to as much as 35 ft below sea level. The volume of water removed from storage in this period, about 3,600 Mgal on the basis of the net decline in water levels, is only about 6 percent of the total pumpage, which is estimated at 60,000 Mgal. The remaining 94 percent of the water pumped, 56,400 Mgal is believed to come from reduced discharge from the Floridan aquifer, from an increase in recharge to the aquifer within the land area of the cone of depression, and, to some extent from that part of the aquifer underlying the gulf.

Removal of freshwater from storage in that part of the aquifer underlying the Gulf of Mexico must have caused a landward advance of the saltwater-freshwater interface, probably on the order of several hundred feet in 26 years.

The cone of depression in the potentiometric surface of the upper limestone of the Floridan aquifer will continue to grow as long as pumping continues to increase in the present areas of major ground-water withdrawal. If pumping were held to a constant rate, the cone would continue to grow until sufficient additional natural discharge is intercepted or additional recharge is induced to equal the rate of discharge by wells. Continued growth of the cone of depression is undesirable because of: 1) increased pumping costs resulting from increased lifts; 2) the danger of eventual saline-water encroachment from the part of the aquifer underlying the gulf and other saltwater bodies; and 3) the danger of saline water moving up from the lower limestone of the Floridan aquifer.

The rate of local decline in water levels could be alleviated by the following procedures:

(1) redistribution of pumping. Much of the pumping is concentrated in parts of the aquifer having low transmissivity, resulting in severe local declines. Also, well interference occurs because of close spacing. To the extent practicable, new large-capacity wells could be placed in areas where the aquifer has high transmissivity, and spaced far enough apart to minimize well interference.

(2) Artificial recharge of the upper limestone of the Floridan aquifer. Connector wells could be constructed so as to allow water to flow from the sand-and-gravel aquifer into the upper limestone.

(3) Reduction of the rate of pumping from the upper limestone by using the sand-and-gravel aquifer or streams as sources of water.

In Okaloosa County and adjacent areas, surface water is abundant. The water generally contains less than 20 mg/L of dissolved solids but is colored and moderately acidic. Water from the sand-and-gravel aquifer is free of color and otherwise similar in quality to surface water, but locally contains excessive iron. In the coastal areas, the lower part of the sand-and-gravel aquifer contains saline water. The dissolved solids concentration in water from the upper limestone of the Floridan aquifer ranges from 100 to 400 mg/L in Okaloosa County, generally increasing to the southwest. A change in chemical type from calcium magnesium bicarbonate to sodium bicarbonate water from northeast to southwest is attributed to the ion exchange action of clay minerals, which are more abundant in the upper limestone of the Floridan aquifer in the southwest part of the county than elsewhere. In the adjoining coastal portions of Santa Rosa and Walton Counties, the upper limestone of the Floridan aquifer contains sodium chloride type water with more than 500 mg/L dissolved solids. The water in the lower limestone of the Floridan aquifer is believed to be saline in Okaloosa County, but chemical analyses are lacking.

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Year	WSP	Year	WSP	Year	WSP
1946,	1072	1949,	1157	1952,	1222
1947,	1097	1950,	1166	1953,	1266
1948,	1127	1951,	1192	1954,	1322
				1955,	1405

Ground water levels in the Unites States: Water-Supply Papers as follows:

Year	WSP	Year	WSP	Year	WSP
1956-58,	1538	1959-63,	1803	1964-68,	1978

Quality of surface waters of the United States: Annual Water-Supply Papers as follows:

Year	WSP	Year	WSP	Year	WSP
1958,	1571	1960,	1741	1962,	1941
1959,	1641	1961,	1881	1963,	1947
				1964,	1954

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1961, 1962, 1963, and 1964 Surface water records of Florida, Vol. 1, Streams: Water Resources Div.

1965, 1966, and 1968 Water resources data for Florida, pt. 1, Surface water records, Vol. 1, Streams: Water Resources Div.

TABLE 4.--*Wells used as control in this report in addition to those listed by Foster and Pascale (1971, table 4).*

Well number	Owner or name	Florida Bureau of Geology number	Location			
			Section		Township	Range
		OKALOOSA COUNTY				
192	H. L. Hawkins, Kelly No. 1	W-3225	NW¼SE¼	29	2 S.	23 W.
193	Texas Co., Carver No. 1	W-1336	SW¼NW¼	32	3 N.	23 W.
194	City of Crestview	W-3550	NW¼NW¼	3	3 N.	23 W.
195	Texas Co., B. H. Hart No. 1	W-1350	SE¼SE¼	1	4 N.	23 W.
196	Opportunities No. 1	W-1330	NE¼SW¼SW¼	15	5 N.	23 W.
197	Opportunities No. 2	W-1331	NE¼SW¼	35	5 N.	23 W.
198	California Co., Blackman Unit No. 1	W-2961	NW¼NW¼	28	5 N.	24 W.
199	Texas Co., W. E. Duggan No. 1	W-1349	SW¼SW¼SE¼	8	4 N.	23 W.
200	R. T. Adams, B. H. Hart No. 1	W-1530	NE¼NE¼	5	4 N.	22 W.
201	Sun Oil Co., Harbison-Wright No. 1	W-3300	SW¼SE¼	13	4 N.	22 W.
202	Brady Belcher No. 2	W-3186	SE¼NW¼	28	4 N.	22 W.
203	Texas Co., Opportunities No. 5	W-1334	SW¼NE¼	30	4 N.	22 W.
204	W. F. Burke No. 1	W-1343	SE¼SE¼	30	4 N.	23 W.
205	Savage Turpentine No. 2	W-1337	NW¼NE¼	36	4 N.	24 W.
206	W. L. Rice 1B	W-1341	SW¼NE¼	11	4 N.	24 W.
207	R. C. Cobb No. 1	W-1342	NE¼NW¼SE¼	22	4 N.	24 W.
208	Geo. Robertson No. 1	W-1340	NW¼SW¼	6	4 N.	24 W.
209	Cecil Haden, McCart No. 1	W-2754	NE¼SE¼	30	4 N.	24 W.
210	Texas Co., W. E. Moore No. 1	W-1345	SW¼NE¼	1	3 N.	25 W.
211	J. G. Moore No. 1	W-1346	NE¼	3	3 N.	24 W.
212	Savage Turpentine No. 3	W-1338	NW¼	2	3 N.	24 W.
213	A. R. Temple, Duggan Lumber No. 1	W-3506	SE¼SW¼	35	3 N.	24 W.
214	Texas Co., Opportunities No. 6	W-1335	in center	6	3 N.	23 W.
215	L. C. Powell No. 1	W-1339	NE¼NW¼NW¼	5	3 N.	23 W.
216	Opportunities No. 4	W-1333	NE¼	11	3 N.	23 W.
217	Sun Oil Co., Brady Belcher No. 1	W-2935	NW¼NW¼	18	3 N.	22 W.
218	Sealy, Brady Belcher-Britton Est. No. 1.	W-4576	SW¼SE¼SW¼	10	3 N.	22 W.
219	U.S. Air Force, Range 70, No. 1	--	SW¼NW¼SW¼	8	1 S.	25 W.
		SANTA ROSA COUNTY				
1	U.S. Air Force, Site A-15, Bldg. 12512	--	SE¼NE¼NE¼	25	2 S.	26 W.
2	Site A-15, Bldg. 12516	WGI-1246	SW¼NW¼NE¼	25	2 S.	26 W.
3	Site A-17A, Bldg. 12596	--	SE¼NW¼SE¼	27	2 S.	26 W.
4	Site A-18, Bldg. 12605	--	SE¼NW¼SW¼	27	2 S.	26 W.
5	Site A-18, Bldg. 12604	--	SE¼NW¼SW¼	27	2 S.	26 W.

TABLE 4.--*Wells used as control in this report in addition to those listed by Foster and Pascale (1971, table 4).* --Continued

Well number	Owner or name	Florida Bureau of Geology number	Location			
				Section	Township	Range
	SANTA ROSA COUNTY--Continued					
6	U.S. Air Force, Eglin AFB, Bldg. 1492	--	SW¼SW¼NW¼	6	2 S.	26 W.
7	Bldg. 1492	--	SW¼SW¼NW¼	6	2 S.	26 W.
8	Bldg. 1462	--	SW¼SE¼NE¼	12	1 S.	27 W.
9	Bldg. 1462	--	SW¼SE¼NE¼	12	1 S.	27 W.
10	U.S. Air Force, Field 7, No. 2, Bldg. 7204	--	NE¼SW¼NW¼	1	1 S.	26 W.
11	Bldg. 7102	W- 262	SW¼NE¼NW¼	1	1 S.	26 W.
12	Eglin AFB, Bldg. 8979	--	SE¼SE¼SE¼	17	1 N.	26 W.
	WALTON COUNTY					
1	A. Goldwaithe	--	SE¼SW¼NW¼	19	3 S.	18 W.
2	do.	--	SE¼SW¼NW¼	19	3 S.	18 W.
3	Grayton Beach State Park	--	NW¼NE¼NW¼	16	3 S.	19 W.
4	Van R. Butler	--	NW¼NE¼NE¼	17	3 S.	19 W.
5	Eric Allen	--	SW¼NE¼SW¼	3	3 S.	20 W.
6	Destin Fire Tower	--	SE¼NW¼NW¼	6	3 S.	18 W.
7	A. L. Gorby	--	NE¼NE¼SW¼	3	3 S.	20 W.
8	Eric Allen	--	SE¼SW¼NW¼	3	3 S.	20 W.
9	Walton 13	--	NW¼NE¼NE¼	35	2 S.	19 W.
10	Donald C. Bishop	--	SW¼SW¼SW¼	28	2 S.	20 W.
11	M. T. Fontarn	--	NE¼NW¼NW¼	33	2 S.	21 W.
12	State of Florida	--	SW¼NW¼NE¼	20	2 S.	19 W.
13	U.S. Air Force, Eglin AFB, Bldg. 1412	--	NE¼SE¼NE¼	9	1 S.	21 W.
14	Bldg. 1412	--	NE¼SE¼NE¼	9	1 S.	21 W.
15	Bldg. 8861	--	NW¼SE¼SE¼	8	1 S.	21 W.
16	Bldg. 8722	--	SE¼NW¼NW¼	2	1 S.	21 W.
17	Bldg. 8776	--	NE¼NE¼NW¼	10	1 S.	21 W.
18	Bldg. 8776	--	NE¼NE¼NW¼	10	1 S.	21 W.
19	Bldg. 8720	--	NW¼SE¼SE¼	15	1 N.	21 W.
20	Bldg. 8738	--	NW¼NE¼SW¼	14	1 N.	21 W.
21	Bldg. 1402	--	NE¼NE¼NW¼	19	2 N.	20 W.
22	Bldg. 1402	--	NE¼NE¼NW¼	19	2 N.	20 W.
23	Bldg. 9500	--	NW¼NW¼NE¼	21	2 N.	21 W.
24	Bldg. 9513	--	SE¼SE¼SE¼	16	2 N.	21 W.
25	Bldg. 9531	--	SW¼NW¼SW¼	15	2 N.	21 W.
26	Bldg. 9516	--	SE¼NE¼SE¼	16	2 N.	21 W.
27	Bldg. 9522	--	NE¼SE¼NE¼	16	2 N.	21 W.

TABLE 4.--*Wells used as control in this report in addition to those listed by Foster and Pascale (1971, table 4).*
--Continued

Well number	Owner or name	Florida Bureau of Geology number	Location			
				Section	Township	Range
	WALTON COUNTY--Continued					
28	U.S. Air Force, Field 1, No. 2, Bldg. 1204	--	SE¼SW¼SW¼	9	2 N.	21 W.
29	No. 1, Bldg. 1102	W- 249	NW¼SE¼SW¼	9	2 N.	21 W.
30	U.S. Air Force, Eglin AFB, Bldg. 9373	--	NE¼NE¼SW¼	11	2 N.	21 W.
31	Bldg. 9352	--	SE¼NW¼NE¼	10	2 N.	21 W.
32	Boy Scouts of America	W-5520	SW¼NE¼NW¼	25	3 N.	26 W.
33	P. A. Simmons	--	SW¼SW¼NE¼	23	3 N.	21 W.
34	Mossy Head Fire Tower	--	SE¼SW¼NE¼	23	3 N.	21 W.
35	D. M. Sweeney	--	NW¼NE¼SW¼	23	3 N.	21 W.
36	R. F. Warren	--	NW¼NW¼NW¼	28	3 N.	21 W.
37	Mello Raposo	--	NE¼NE¼NE¼	11	3 N.	21 W.
38	J. E. Cartwright	--	NW¼NW¼NW¼	6	3 N.	19 W.
39	First American Farms	--	NW¼SW¼NE¼	21	4 N.	21 W.
40	H. B. Coffey	--	NE¼NW¼NE¼	16	4 N.	20 W.
41	Cecil Geoghagen	--	NE¼NW¼NE¼	18	4 N.	20 W.
42	James Davis	--	NE¼NE¼NW¼	32	5 N.	21 W.
43	D. C. Carnley	--	SE¼SE¼NE¼	29	5 N.	21 W.
44	Y. E. Folsom	--	SE¼SE¼NE¼	9	5 N.	20 W.
45	Joe Tucker	--	NE¼NE¼SE¼	5	5 N.	21 W.
46	Florida Welcome Station	--	NE¼NW¼NW¼	1	5 N.	21 W.
47	Florida Bureau of Geology	W-8865	NE¼NE¼	35	2 S.	21 W.
48	Lalonde No. 1[1]	W-8877	SE¼	22	1 S.	21 W.
49	Eglin No. 3[1]	W-8353	NE¼SE¼SE¼	15	1 N.	21 W.
50	Eglin No. 1[1]	W-8351	SW¼	9	2 N.	21 W.
51	Shoal River No. 1[1]	W-8354	SW¼SW¼NE¼	3	3 N.	21 W.
52	Otis Mathis No. 1[1]	W-8102	NE¼SW¼	36	6 N.	21 W.
53	Price No. 1[1]	W-8591	SW¼SW¼SW¼	9	3 S.	19 W.
54	Florida Bureau of Geology[1]	W-8103	SW¼SW¼	35	5 N.	21 W.
55	do.	W-8019	SE¼NW¼	2	4 N.	20 W.
56	do.	W-8356	SE¼SE¼	25	5 N.	20 W.
57	Thompson Exploration, Yawkey No. 2	W-3580	NW¼NE¼	6	4 N.	18 W.
58	Sun Oil Co., Brady Belcher No. 4	W-3672	NW¼NW¼	25	4 N.	21 W.
59	A. R. Temple, Harbison Lumber No. 1	W-4945	SW¼NW¼	27	4 N.	20 W.
60	Sun Oil Co., Brady Belcher No. 3	W-3409	SW¼NW¼	33	4 N.	21 W.

Footnotes are at end of table.

TABLE 4.--*Wells used as control in this report in addition to those listed by Foster and Pascale (1971, table 4).* --Continued

Well number	Owner or name	Florida Bureau of Geology number	Location			
				Section	Township	Range
	WALTON COUNTY--Continued					
61	Florida Bureau of Geology[1]	W-7972	SE¼NW¼	13	3 N.	20 W.
62	A. R. Temple, Harbison-Lumber No. 2	W-2962	NW¼NW¼	15	3 N.	19 W.
63	Blue Gulf Resort[1]	--	NW¼NE¼NW¼	12	3 S.	20 W.
64	H. L. Hawkins, Coffeen No. 1	W-3365	NE¼NE¼	14	2 S.	21 W.
65	D. E. L. Byers, E. Edward No. 1	W-1591	SW¼SW¼	28	5 N.	21 W.

[1] Sample log by Florida Bureau of Geology given in: Pascale, C. A., Essig, C. F., Jr., and Herring, R. R., 1972, table 9.

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