STATE OF FLORIDA
DEPARTMENT OF NATURAL RESOURCES
Randolph Hodges, *Executive Director*

DIVISION OF INTERIOR RESOURCES
Robert O. Vernon, *Director*

BUREAU OF GEOLOGY
Charles W. Hendry, Jr., *Chief*

Report of Investigations No. 62

WATER AVAILABLE IN CANALS AND SHALLOW SEDIMENTS IN ST. LUCIE COUNTY, FLORIDA

By

H.W. Bearden

Prepared by the
UNITED STATES GEOLOGICAL SURVEY

in cooperation with the
CENTRAL AND SOUTHERN FLORIDA
FLOOD CONTROL DISTRICT

and the

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OF
NATURAL RESOURCES

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LETTER OF TRANSMITTAL

Bureau of Geology

Tallahassee

September 5, 1972

Honorable Reubin O'D. Askew, Chairman
Department of Natural Resources
Tallahassee, Florida

Dear Governor Askew:

The Bureau of Geology is publishing as Report of Investigations No. 62, a report on the "Water Available in Canals and Shallow Sediments in St. Lucie County, Florida." This report was prepared by Mr. H. W. Bearden as a part of the cooperative program between the U. S. Geological Survey, the Central and Southern Florida Flood Control District and the Bureau of Geology.

The increased demand for water placed upon the water resources of St. Lucie County by the expanding agricultural use has brought about hydrologic changes with ensuing problems. This report documents these changes and provides data which are necessary in solving the problems.

Respectfully yours,

Charles W. Hendry, Jr., Chief
Bureau of Geology

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Tallahassee
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CONTENTS

	Page
Abstract	1
Introduction	1
Purpose and scope	2
Location and general features	2
Previous investigations	4
Acknowledgments	4
Hydrologic Setting	4
Climate	4
Topography and drainage	5
Irrigation and flood-control problems	6
Aquifers	7
Nonartesian	9
Artesian	10
Availability of water	10
Ground water	10
Storage and flow	11
Aquifer characteristics	25
Surface water	28
Canal system and storage	28
Quantitative studies	33
Canal 23	35
Canal 24	35
Canal 25	36
Quality of water	38
Pesticides	43
Summary	45
Well numbers	48
References	49

ILLUSTRATIONS

Figure		Page
1.	St. Lucie County showing the area of investigation, the drainage districts, and direction of surficial flow	3
2.	St. Lucie and Martin Counties showing existing and proposed canals of the Central and Southern Florida Flood Control District	8
3.	The location of observation wells in St. Lucie County	11
4.	Hydrographs of St. Lucie wells 41 and 42 for 1950–68	12
5.	Hydrographs of St. Lucie wells 41 and 42 and daily rainfall at Okeechobee Hurricane Gate 6 for 1966–68	14
6.	Hydrographs of St. Lucie wells 124 and 127 and daily rainfall at Okeechobee Hurricane Gate 6 for 1968	15
7.	Hydrographs of St. Lucie wells 121, 122, 123, 125, and 128 and daily rainfall at Fort Pierce for 1968	16
8.	Water-level contour map of St. Lucie County on August 17, 1967, during a time of intermediate water levels	18
9.	Water-level contour map of St. Lucie County on April 2, 1968, during a time of low water levels.	19
10.	Water-level contour map of St. Lucie County on May 2, 1968, during a time of extremely low water levels.	20
11.	Hydrograph of Canal 23 at S-97, March 1-May 31, 1968, during the dry season, and ground-water gradients adjacent to the canal at the beginning and near the end of the time of extreme low-water level in the canal	21
12.	Hydrograph of Canal 24 at S-49, March 1-May 31, 1968, during the dry season, and ground-water gradients adjacent to the canal at the beginning and near the end of the time of extreme low-water level in the canal	22
13.	Hydrograph of Canal 25 at S-99, March 1-May 31, 1968, during the dry season, and ground-water gradients adjacent to the canal at the beginning and near the end of the time of extreme low-water level in the canal	23
14.	Hydrographs of canals 23 and 24 and wells 41 and 123.	24
15.	Lithologic logs of the pumped wells (for location of wells see fig. 3) used in pumping test.	26
16.	Logarithmic graphs of type curve, nonequilibrium type curve, and plot of drawdown against time for observation well 164	27
17.	Photographs of the upstream and downstream side of control S-97 on Canal 23, October, 1968	30
18.	Hydrographs of canals 23, 24, and 25 showing periods of maximum pumping in March and April, 1968.	33
19.	The FCD Canals showing flow to the canals from ground water seepage and laterals that intersect the canal	34
20.	Graph showing ground-water gradients adjacent to Canal 25 at site 3, as water levels in the canal are recovering, after the seepage study.	38
21.	Graphs showing change in chloride content of canals 23, 24, and 25 in relation to canal water levels	40
22.	Chloride-concentration profile in Canal 23 on September 21, 1967	41
23.	St. Lucie County showing the chloride content of water and depth of shallow wells at selected sites, January and February, 1967.	42

TABLES

Table		Page
1.	Average monthly rainfall and temperature at Fort Pierce and Stuart, Fla. . .	5
2.	Results of pumping test in St. Lucie County	29
3.	Chloride content of water from selected wells during January-February and September, 1967.	44
4.	Pesticide analyses of water and sediment samples from canals at selected sites in St. Lucie County compared with canals in Broward and Dade counties (micrograms per liter—μg/1)	46

WATER AVAILABLE IN CANALS AND SHALLOW SEDIMENTS IN ST. LUCIE COUNTY, FLORIDA

By

H. W. Bearden

ABSTRACT

The development of land for agricultural use in much of St. Lucie County has decreased surface and ground water storage and greatly increased the irrigation needs. The canal network of the Central and Southern Florida Flood Control District constitutes the major supplier of irrigation water in the county. The supply is replenished by rainfall and ground-water inflow. For example, the rate of ground-water inflow to the canals ranges from 0.3 to 2.76 cubic feet per second per mile per foot of drawdown in the canal.

The shallow sediments are generally of low permeability. The coefficient of transmissivity of these materials ranges from 10,000 to 53,000 gallons per day per foot.

Because of the low permeability of the upper 20 feet of the shallow sediments and the low rates of recharge to the canal network, the development of shallow ground-water supplies will be required to meet irrigation needs during dry periods. Wells 6 inches or more in diameter developed in the zone 40 to 100 feet below land surface, would probably yield 100 to 200 gallons per minute.

The salinity of canal water increases during prolonged dry periods as the mineralized artesian water that is used for irrigation seeps into the canals.

INTRODUCTION

Between 1959 and 1965 the acreage of citrus in St. Lucie County, Florida more than doubled, and continued expansion is expected in the foreseeable future. Most of the new citrus acreages are in the central and western parts of the county. Before development, these lands normally were flooded or swampy for long periods each year. To use these lands for citrus cultivation, a system of canals had to be constructed, to protect the new citrus groves from flooding. Water-control practices were begun to regulate water levels and to provide water for irrigation. Rainfall, once stored in marsh and swamp areas, is now drained to the ocean through the canal systems. As a result of ground-water inflow to the canals, water levels have been lowered, which protects citrus feeder

roots. Draining the swampy lands has reduced the amount of water available for recharge to the aquifer. Also, the lowering of ground-water levels has resulted in a loss of aquifer storage. The irrigation of more and more land each year for citrus production continues to deplete the supply of water in the canals.

Citrus growers in St. Lucie County depend chiefly on canal water for irrigation supply, although some artesian water is used as a supplemental supply. Before large-scale citrus cultivation began, the water available from the FCD (Central and Southern Florida Flood Control District) canals was sufficient to meet the existing citrus and other agricultural needs. In recent years the amount of irrigation water available from the canals during the long dry season has proved inadequate. Also, in recent years many artesian wells that were being used for irrigation supply have been abandoned because of increased mineral content in water from them.

Yields from wells developed in the shallow aquifer in St. Lucie County generally are low in comparison with those in most of south Florida, and few wells have been developed in the aquifer other than domestic wells.

PURPOSE AND SCOPE

To plan for water requirements, the FCD, the agency with primary responsibility for flood and water control in St. Lucie County, requested that the U.S. Geological Survey investigate the availability of water in canals and in the adjacent shallow sediments for irrigation of citrus in St. Lucie County. The investigation began in July 1966.

This report portrays the availability and quality of water from canals and the adjacent shallow sediments; the configuration and fluctuations of the water table in response to seasonal rainfall and water-control measures; and the hydraulic characteristics of the aquifer at selected test sites. The report was prepared by the U.S. Geological Survey in cooperation with the FCD as a part of the southeastern water-management program. The investigation was under the general supervision of T. J. Buchanan, Chief, Miami Subdistrict, and C. S. Conover, District Chief, U.S. Geological Survey, Tallahassee, Florida.

LOCATION AND GENERAL FEATURES

St. Lucie County has an area of 450 square miles and is in the southeastern part of the Florida peninsula, as shown in figure 1. It is bordered on the east by the ocean, on the south by Martin County, on the west by Okeechobee County, and on the north by Indian River County. It

lies northeast of Lake Okeechobee. The area of investigation, indicated in figure 1, includes the major agricultural lands in the western and central parts of the county.

St. Lucie County had a population of 47,000 in 1968 (St. Lucie

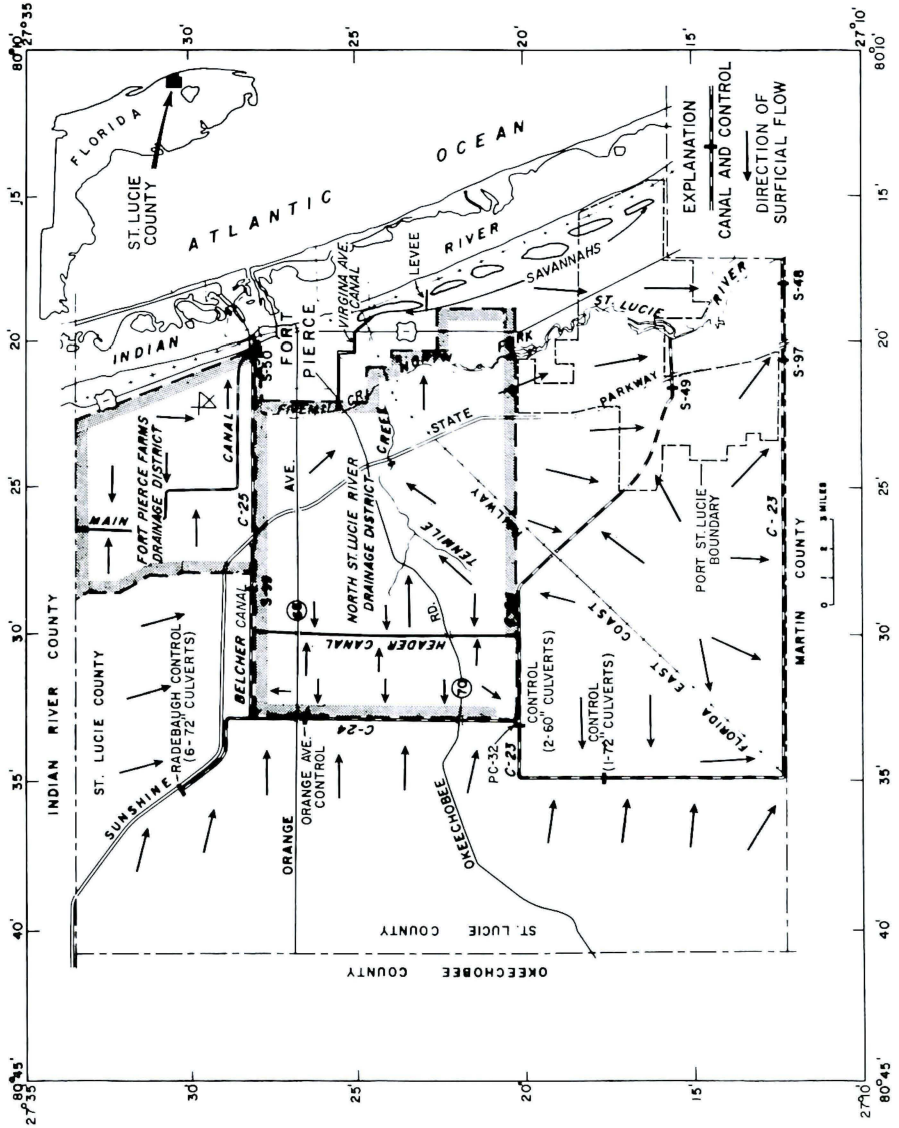


Figure 1.—St. Lucie County showing location of the area of investigation, the drainage districts, and surficial flow.

County Planning Board), concentrated mostly in Fort Pierce. The coastal area along U.S. Highway No. 1 and Indian River is a suburban area, and Port St. Lucie, 7 miles south of Fort Pierce, is becoming an important population center. The western part of the county, where most of the land has been developed for cattle ranches and citrus groves, is sparsely populated.

The economy of St. Lucie County depends mainly upon agriculture, chiefly citrus production. Before the citrus crop became dominant, cattle industry was the major contributor to the economy. Little farming is being done, other than citrus. Tourism accounts for a small part of the economy.

PREVIOUS INVESTIGATIONS

No prior detailed investigation of the water resources in St. Lucie County has been made; however, Parker and others (1955) gave general information on the geology and ground water as part of an investigation of the water resources of southeastern Florida. Long-term records of ground-water levels and water quality have been collected in two observation wells in western St. Lucie County as part of the continuing program of water-resources investigation with the FCD. Shallow core borings were made by the U.S. Army Corps of Engineers during construction of Canals 23, 24, and 25 (fig. 1).

ACKNOWLEDGMENTS

Appreciation is expressed to R. L. Taylor and R. E. Irons of the FCD for their cooperation and assistance throughout the investigation; to personnel of the Fort Pierce and North St. Lucie Drainage Districts for furnishing information concerning their operations; to Dr. David V. Calvert, Florida Indian River Field Laboratory, for information on salinity of water in canals and the effects of salinity on citrus production; and to Mr. E. E. Green, well driller, Fort Pierce, for information on wells and subsurface materials in the county. Thanks are also extended to land owners who provided information and the use of facilities during the study.

HYDROLOGIC SETTING

CLIMATE

The climate of St. Lucie County is subtropical and characterized by long, warm and humid summers and mild winters. The annual tempera-

ture in Fort Pierce averages 74°F, and the annual rainfall averages 55 inches. Table 1 shows the average monthly and annual temperature and rainfall for Fort Pierce and for Stuart, about 20 miles south of Fort Pierce in Martin County. The range in average monthly temperature

Table 1.—Average monthly rainfall and temperature at Fort Pierce and Stuart, Fla.

	Fort Pierce[1]		Stuart[2]	
Month	Temp. (°F)	Rainfall (Inches)	Temp. (°F)	Rainfall (Inches)
January	64.8	1.90	64.3	3.31
February	65.7	2.44	65.1	2.59
March	68.4	3.49	69.2	3.56
April	72.6	4.32	73.0	2.76
May	76.7	4.19	76.7	3.81
June	80.0	6.07	79.9	7.77
July	81.6	5.23	82.0	6.48
August	81.9	6.01	82.3	6.94
September	81.0	8.46	81.0	7.90
October	76.7	8.27	76.5	7.37
November	70.4	2.75	71.3	2.47
December	66.3	2.14	65.1	2.60
Annual	Ave. 73.8	Total 55.27	Average 73.8	Total 57.56

[1] U.S. Weather Bureau continuous record 1937–67
[2] U.S. Weather Bureau continuous record 1958–67

between winter and summer is only 17°F. Rainfall is unevenly distributed during the year; about 30 percent occurs during September and October and 61 percent during the June-October wet season.

TOPOGRAPHY AND DRAINAGE

Florida is within the Atlantic Coastal Plain physiographic province (Fenneman, 1938). Puri and Vernon (1964, fig. 4) included St. Lucie County in their Coastal Lowlands unit. The Coastal Lowlands unit borders the entire coast of Florida and extends over all the area south of Lake Okeechobee. Because of the low relief, little dissection by streams has taken place. The Coastal Lowlands unit has been covered by the sea; one invasion of the sea left successive shoreline terraces at 100, 70, and 42 feet above sea level, and a later invasion reached a height of 25 feet. The marine terraces corresponding to these Pleistocene shorelines are named Wicomico, Penholoway, Talbot, and Pamlico, respectively (Cooke, 1945, p. 10, 11). Another terrace at 5 feet is called the Silver Bluff Terrace because of its occurrence at Silver Bluff near Biscayne Bay in Miami (Parker and Cooke, 1944, p. 24).

The Talbot and Pamlico Terraces cover most of St. Lucie County. The land surface is generally flat, ranging in elevation from 15 to 60 feet and averaging about 28 feet above sea level in the central and western parts of the county. Along the coast, land surface ranges in elevation from sea level to about 25 feet above. The coastal sand-hills adjacent to the Intracoastal Waterway are higher than most parts of the county and reach a maximum elevation of about 60 feet. Soils in St. Lucie County generally are sandy, with intermixed organic or fine calcareous material and are similar to most of the southern Florida soils of the Talbot and Pamlico Terraces.

Natural drainage in St. Lucie County has been altered by the construction of many canals for flood control. Surficial drainage patterns and the major canal and water-control facilities are shown in figure 1. Much of the area once known as the St. Johns River marsh in northwestern St. Lucie County has been improved for agriculture, and natural drainage outlets have been completely blocked. A part of St. Lucie County also lies within the Lake Okeechobee drainage basin, but most of the drainage changes have redirected flow eastward to the ocean rather than to Lake Okeechobee. The North St. Lucie River Drainage District and the Fort Pierce Farms Drainage District (fig. 1), in the east-central and northeastern parts of the county, control all water movement in those areas, and their drainage systems are inter-connected with the primary system of the FCD Canals 23, 24, and 25. Hundreds of secondary canals and ditches drain excess water to the primary canals, which discharge it to the ocean.

Fort Pierce and the coastal area is drained primarily by the North Fork St. Lucie River and the Tenmile and Fivemile Creeks. Fivemile Creek extends southward near the western city limits of Fort Pierce, and Tenmile Creek extends a few miles inland south of Fort Pierce.

A marshy area called the Savannahs parallels the coast a short distance inland and extends southward from Fort Pierce to the Martin County line (fig. 1). In the past, the northern sections of the Savannahs served as a reservoir that was the main source of water supply for the city of Fort Pierce. The north section of the Savannahs is approximately 2.7 miles long and has been isolated from other Savannahs to the south by a levee. Water from the Belcher Canal (C-25) can be pumped into Fivemile Creek, repumped at Okeechobee Road into Virginia Avenue Canal, and diverted to the Savannahs during droughts.

IRRIGATION AND FLOOD CONTROL PROBLEMS

Citrus acreage in St. Lucie County increased from 30,000 in 1959 to 65,000 in 1965, and an additional 20,000 acres is expected by 1974. Large marsh areas in the western section of the county have been drained

and developed. Before they were drained, rainfall was stored in them above land surface and served as potential recharge to the shallow aquifer. Rainfall now flows to the canal system and discharges to the ocean through Canals 23, 24, and 25 (fig. 1). Drainage of the marshes also caused a lowering of water levels in the shallow aquifer, thus reducing the amount of ground water in storage. The expansion in citrus acreage not only puts stronger demands on the canals for flood control during wet seasons, but also places additional demands on the canals for irrigation water during periods of extended dry weather. The canal system is replenished by rainfall runoff and by ground-water seepage.

Water for irrigation is pumped from canals or flows from wells penetrating the deep Floridan artesian aquifer. For many years, water from the Floridan aquifer has been used for citrus irrigation in much of St. Lucie County. Because water from many of the artesian wells has become saline, the water from them no longer is fit for this purpose. Continued use of poor quality artesian water for irrigation has caused the shallow aquifer to be contaminated locally and has caused an increase in the mineral content of water in the canals during prolonged dry seasons, when the use of artesian water is greatest. In extremely long drought, water from some of the smaller canals becomes too highly mineralized for irrigation use.

Agricultural agencies in St. Lucie County have proposed that additional water for irrigation be furnished by canal from Lake Okeechobee. The amount of water available for diversion from the lake for agricultural use in this area may be limited in future years because of large water requirements for the expanding urban and agricultural developments elsewhere in southeastern Florida. In 1967 the Corps of Engineers and the FCD suggested a plan for improving the use of water resources in agricultural areas of Martin and St. Lucie Counties. The plan consists of an extensive interconnected canal system for Martin County, St. Lucie County and Lake Okeechobee, as shown in figure 2. A considerable part of the rainfall in the two counties would be backpumped to Lake Okeechobee during wet seasons, and stored for use during dry seasons. Water from the Lake would be pumped to Canal 23 in St. Lucie County and distributed through Canals 24 and 25 when needed. The amount of water used during the dry season would approximately equal the amount backpumped to Lake Okeechobee during the wet season. The fate of this plan has not been decided.

AQUIFERS

Two major aquifers underlie St. Lucie County, the deep artesian Floridan aquifer, and the shallow, nonartesian, aquifer. The aquifers are separated by a thick section of poorly permeable clay and sand. The

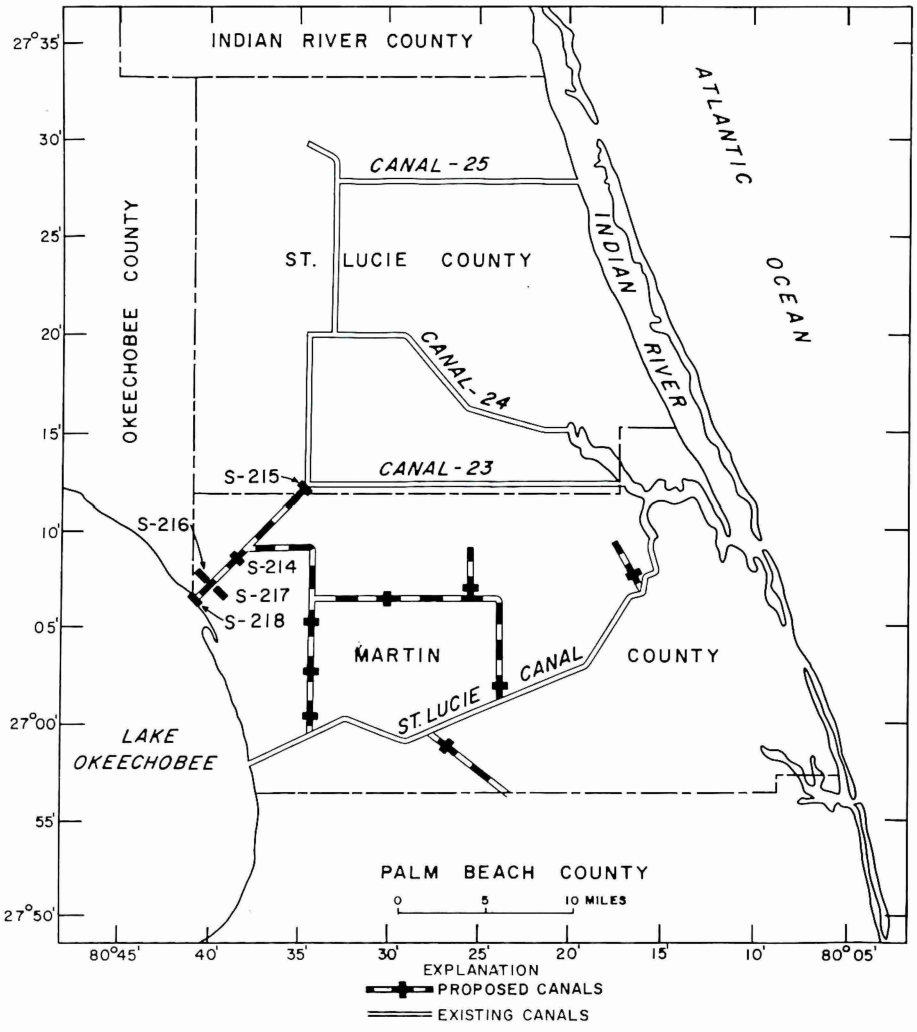


Figure 2.—St. Lucie and Martin Counties showing existing and proposed canals of the Central and Southern Florida Flood Control District.

shallow aquifer is an important source of potable water for domestic and municipal use and possibly for irrigation use. The Floridan aquifer is a source of large quantities of moderately to highly mineralized water. Where water from it is not too highly mineralized, its water is used for cattle and for irrigation of citrus.

A brief description of the geologic character of the aquifers in St. Lucie County is of interest because the occurrence, quality, and avail-

ability of ground water are directly related to the nature of the subsurface materials.

NONARTESIAN

St. Lucie County is mantled chiefly by the Pamlico Sand of Pleistocene age. The Pamlico Sand was deposited when the sea covered all the land area less than 25 feet above present sea level. The sand beds range in thickness from a few feet along the coastal ridge to less than a foot in the western part of St. Lucie County. The very fine to medium sand is generally white to light gray. The Pamlico Sand unconformably overlies the Anastasia Formation in St. Lucie County, except in the area of high elevation in western St. Lucie County, where the land was higher than the level attained by the sea during Pamlico time. The Pamlico Sand is not an important source of ground water in St. Lucie County.

The Anastasia Formation differs in composition from place to place, varying from coquina to fairly pure sand (Lichtler, 1960, p. 20–21). In St. Lucie County it consists mostly of sand, shell beds, and thin discontinuous layers of sandy limestone or sandstone. The consolidated coquina phase occurs in areas in the central part of the county. At the junction of Canals 23 and 24 coquina excavated from the bed of the canals can be seen along the canal banks. These beds lie near land surface.

The most productive parts of the shallow aquifer in St. Lucie County are in the Anastasia Formation. The more permeable materials, coarse sand and shell and consolidated sand and shell, occur at depths between 60 and 130 feet in eastern St. Lucie County and 40 and 100 feet in western St. Lucie County. These materials vary in thickness, composition, and yield, and constitute zones of moderate water supply for domestic purposes. Fine sand and some thin shell compose the upper part of the Anastasia Formation.

Few wells have been drilled in the shallow aquifer other than for domestic or municipal use because of the low yields in most areas. The city of Fort Pierce has six 10-inch water-supply wells, ranging in depth from 120 to 170 feet. The wells were designed to yield approximately 350 gpm (gallons per minute) per well, or half a million gallons per day. Most of the permeable zones are thin, and, in order to produce the required amount of water, the wells were screened in each permeable zone of the aquifer. The total footage of screens in each well ranges from 30 to 60 feet.

Most domestic wells penetrate the aquifer to a depth of about 60 feet. Open-end wells become easily plugged by sand that caves and fills the opening; therefore, wells generally are gravel packed or screened.

The most common domestic well is 2 inches in diameter and is finished with a 2-foot sand point. The average yield from this type of well is about 40 gpm.

ARTESIAN

The artesian aquifer in St. Lucie County is part of the Floridan aquifer defined by Parker (1955, p. 189), and includes "parts or all of the middle Eocene (Avon Park and Lake City Limestone), upper Eocene (Ocala Limestone), Oligocene (Suwannee Limestone), and Miocene (Tampa Limestone), and permeable parts of the Hawthorn Formation that are in hydrologic contact with the rest of the aquifer." The aquifer lies approximately 700 feet below land surface in St. Lucie County. From about 120 to 700 feet, beds of marl and clay act as confining beds to the aquifer. The depth to the bottom of the aquifer in St. Lucie County is not known because no water well has completely penetrated it.

The artesian aquifer yields water to wells by natural flow. Wells that penetrate the aquifer in St. Lucie County range in depth from 800 to 1,200 feet, and water in cased wells will rise from 35 to 50 feet above mean sea level. Hugh Welchel, the St. Lucie County agricultural agent, reports that the county has 1,150 deep artesian wells and that the average flow is 200 gpm per well.

AVAILABILITY OF WATER

GROUND WATER

The chief source of recharge to the shallow aquifer in St. Lucie County is rainfall. A large part of the rainfall evaporates, transpires, or runs off the surface, but the remainder infiltrates through the surface materials into the shallow aquifer system. The upper surface of the saturated zone of the aquifer is the water table.

The water table in St. Lucie County fluctuates seasonally, rising during rainy seasons and declining during dry periods. The gradient of the water table is generally less than that of the land surface, depending upon the thickness and permeability of the aquifers and the quantity of water moving through the aquifer. Steeper gradients are required to move a given amount of water through an aquifer of low permeability than through an aquifer of high permeability. The land and water-table gradients in St. Lucie County slope gently downward from the western border of the county to the east coast.

Ground water generally moves downgradient from the areas of recharge (high elevations) to the areas of discharge (low elevations). The

rate of movement depends upon the permeability of the materials and the hydraulic gradient.

STORAGE AND FLOW

Because virtually all water in the shallow aquifer in St. Lucie County is derived from rainfall, water levels in canals and in the shallow aquifer

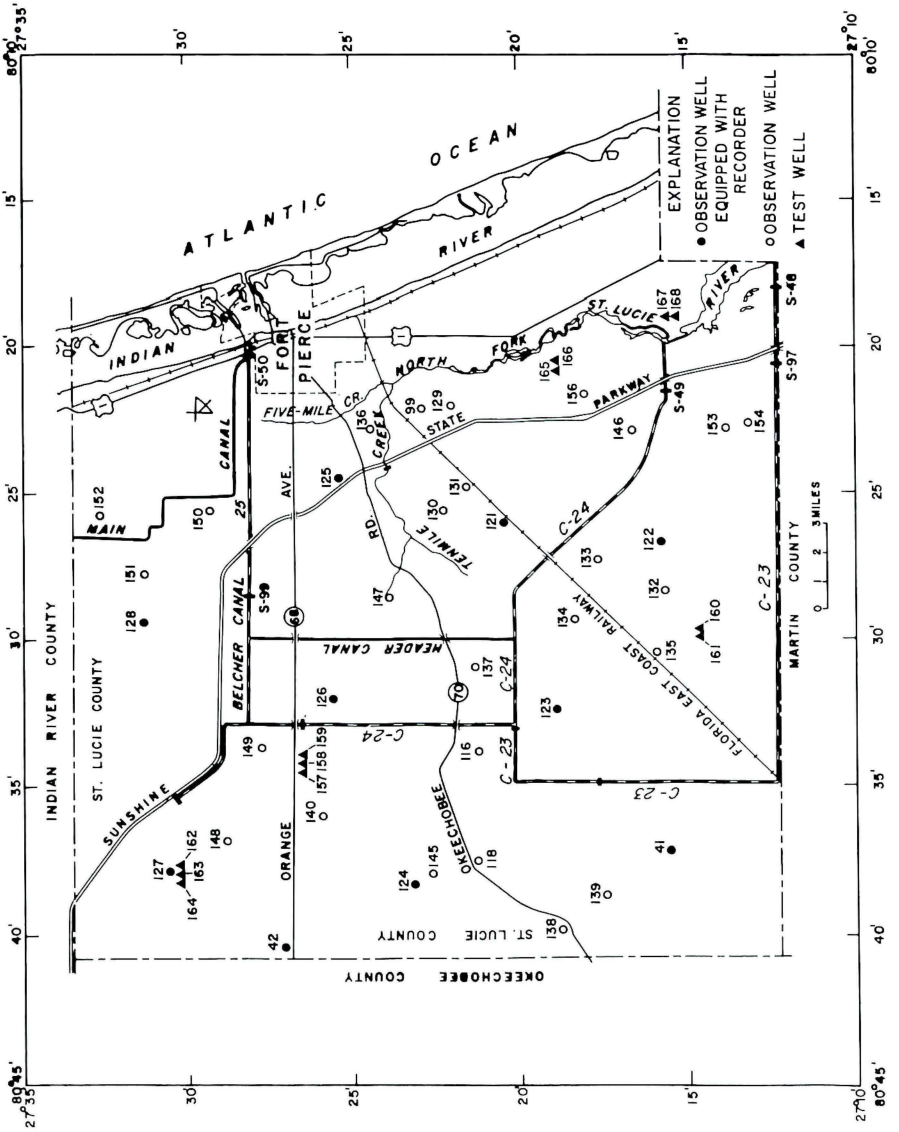


Figure 3.—The location of observation wells in St. Lucie County

are high during the rainy season and low during the dry season. Seasonal changes in aquifer storage and hydraulic gradients were determined from water-level measurements in a network of observation wells throughout the county, as shown in figure 3. All are shallow and average 14 feet in depth.

Recording water-level gages were installed on eight 4-inch shallow wells (wells 121–128) (fig. 3). On two others, well 41, near the southwest corner of the county, and well 42, at the western county boundary along Orange Avenue, recording gages have been in operation since 1950.

Hydrographs for wells 41 and 42 for 1950–68 are shown in figure 4. Effects of drainage and agricultural expansion in recent years in the areas of the wells are portrayed by changes in water level. The major citrus

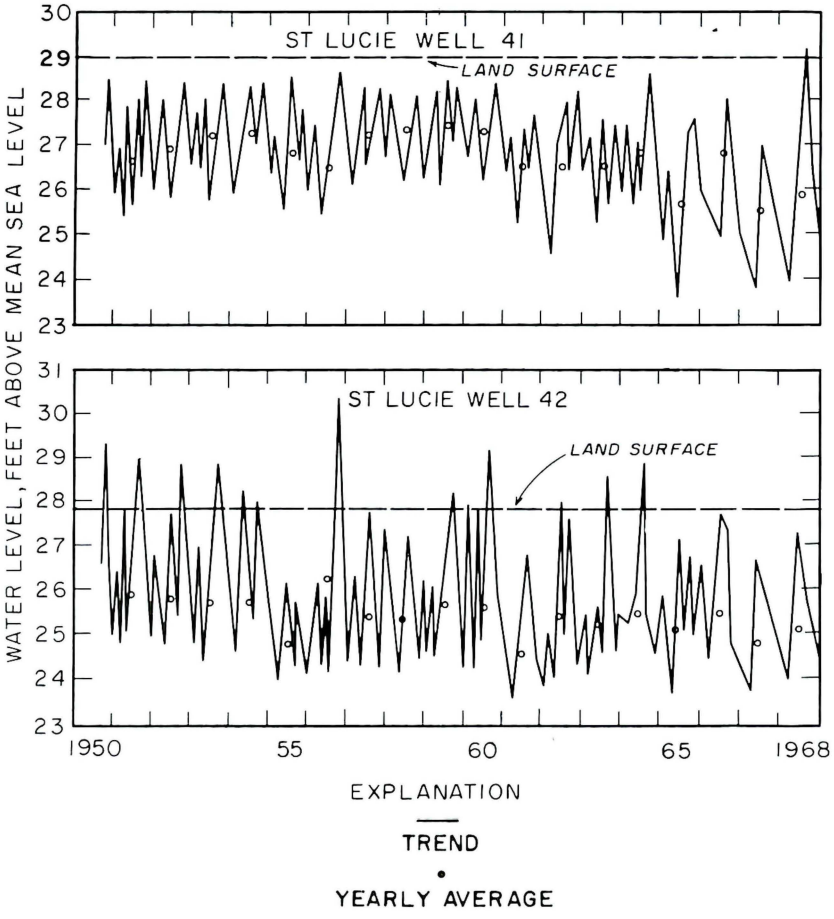


Figure 4.—Hydrographs of St. Lucie wells 41 and 42 for 1950–68.

expansion began about 1960, when canals were dug through the swampy areas to drain land for development and to protect the new plantings from flooding. Water levels in the canals were maintained low enough to protect the feeder roots of the citrus. The hydrograph of well 41 in figure 4 shows a decline in yearly average water levels, and, therefore, a reduction in the amount of ground water in storage, since 1960. Water levels during recent dry seasons were as much as 2 feet below previous low water levels. The hydrograph of well 42 in figure 4 shows little change in yearly average water levels, but the decline in peak water levels since about 1960 indicates that some drainage has occurred.

The hydrograph of well 41 in figure 4 shows a more definite pattern of declining water levels than that for well 42 because of the difference in distance from the wells to the areas of citrus development. Well 42 is near the northwestern boundary of St. Lucie County and is several miles from any large-scale citrus development.

Hydrographs showing the relation between rainfall and water levels in wells 41 and 42 from 1966 to 1968 are shown in figure 5. Hydrographs showing the relation between rainfall and water levels in wells 121–125, 127, and 128 for 1968 are shown in figures 6 and 7. The rainfall data for figures 5 and 6 were collected at Hurricane Gate 6 at Lake Okeechobee, 10 miles southwest of St. Lucie County. The rainfall data for figure 7 were collected at the weather bureau station in Fort Pierce.

The hydrographs show that the response to rainfall is generally rapid; also that the water levels are highest after periods of heavy rainfall and lowest at the end of rainless periods. Water levels in some wells respond faster than those in others, indicating that the permeability of the materials in the upper 20 feet of the shallow aquifer varies throughout the county.

Water levels in well 41 (fig. 5) for 1968 had about twice the normal range of 3 feet because of the extreme dry period and wet period during the year. Little rain fell during the first 4 months of 1968, and as a result the water levels at the end of April were near record low. However, rain for May and June approached or exceeded the record high, and by early July a near-record high water level occurred in the well.

The range in water levels in well 42 for 1968 (3.5 feet) was slightly greater than its average range of approximately 3 feet but much less than the range in well 41. For a year of average or below average rainfall, the range in fluctuation is approximately the same in both wells, about 3 feet, with the water levels at a slightly higher elevation in well 41.

The hydrographs of wells 127 (fig. 6) and 128 (fig. 7) are similar to that of well 42. Wells 127 and 128 are in the north and northwest part of St. Lucie County (fig. 3) in the area that was part of the St. Johns Marsh and in topography similar to the area of well 42.

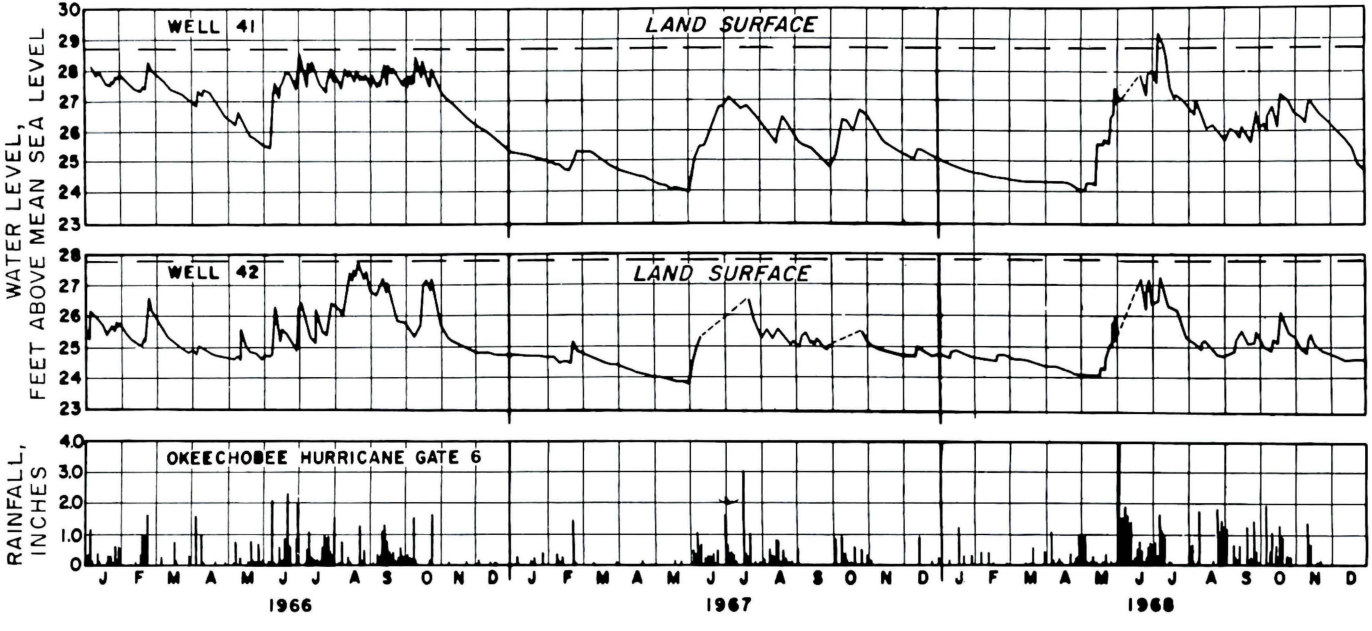


Figure 5.—Hydrographs of St. Lucie wells 41 and 42 and daily rainfall at Okeechobee Hurricane Gate 6 for 1966–68.

The hydrographs of wells 124 (fig. 6) and 122, 123 and 125 (fig. 7) are similar to that of well 41. Wells 122–125 are in the south and southwest part of St. Lucie County (fig. 3) in areas similar in topography to the area in the vicinity of well 41. However, the hydrograph of well 121 (fig. 7), in the southern part of the county, shows a much smaller range in water-level for 1968 than well 41. The wells average about 14 feet in depth and all except well 123 are developed in sandy materials that constitute most of the upper 40 to 60 feet of the shallow aquifer. These sandy, fine-grained materials are relatively low in permeability, particularly in the vicinity of well 121. The response to rainfall in well 123 is rapid because that well penetrates a very permeable coquina bed about 10 feet

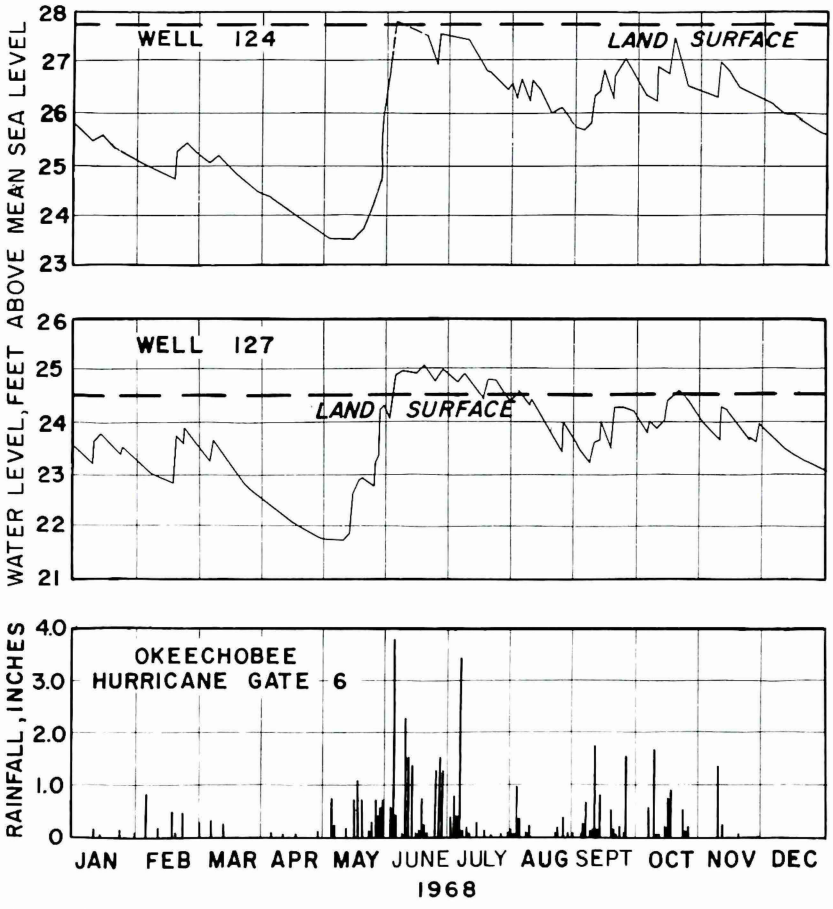


Figure 6.—Hydrographs of St. Lucie wells 124 and 127 and daily rainfall at Okeechobee Hurricane Gate 6 for 1968.

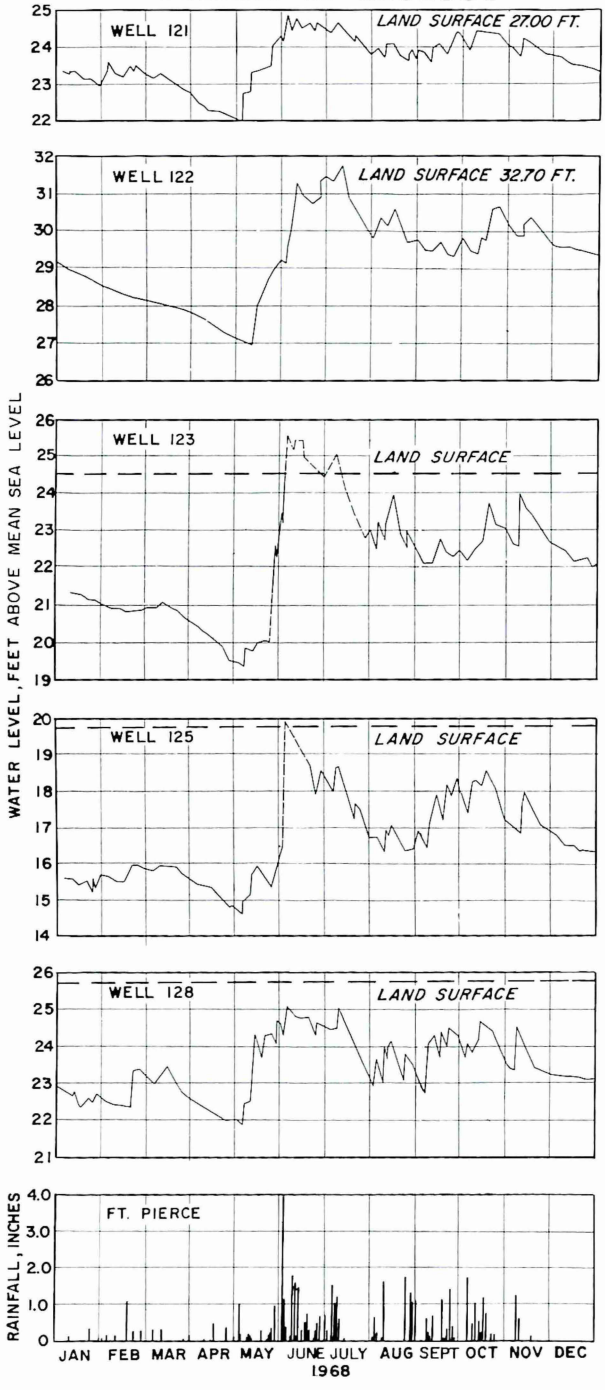


Figure 7.—Hydrographs of St. Lucie wells 121, 122, 123, 125, and 128 and daily rainfall at Fort Pierce for 1968.

below the surface. The coquina beds extend from near well 123 about 1.5 miles north to the vicinity of Canal 24.

A study of the configuration and fluctuation of the water table was made from water levels measured periodically in the observation wells that penetrate the upper part of the shallow aquifer (fig. 3). Water-levels in these wells, referred to mean sea-level datum, were used to construct water-table contour maps of the county. The shape and slope of the water table and the general direction of ground-water movement can be determined from the contours. Gross ground-water movement is downgradient, perpendicular to the contours.

The configuration and altitude of the water table during intermediate water-level conditions, August 17, 1967, is shown in figure 8. At the time of the measurements, little or no water was being pumped from the canals for irrigation. The general direction of ground-water movement, as indicated by the contours, is toward the canals and eastward toward Fivemile Creek and the St. Lucie River. In the extreme west, along Okeechobee Road, the land surface is high, and ground-water levels are correspondingly high. In the southeast, in the area encircled by Canals 23 and 24, where land surface is about 32 feet above sea level, the elevation of the ground-water mound is about 30 feet.

The steep hydraulic gradient near the coastal area is a result of steeply sloping land and the drainage effects of Tenmile Creek, Fivemile Creek, and the North Fork St. Lucie River. On Tenmile Creek a control structure just west of the Sunshine State Parkway (fig. 1) regulates water levels at a maximum elevation of 9.4 feet above mean sea level. The North Fork St. Lucie River has no control structure, allowing direct drainage to the ocean.

An extremely dry period occurred in St. Lucie County during March, April, and part of May 1968. Ground-water levels and levels in the canals began to decline about the middle of March. Because the citrus growers began pumping large amounts of water from the canals near the end of March, canal levels were lowered 3 to 6 feet in less than 2 weeks. Large amounts of water were pumped daily until the growers had filled most of their laterals and ditches. The canals were pumped to or near minimum levels allowed by the FCD (14 feet above msl), and they remained at or near that level until the rains in May.

The dry period provided an opportunity to determine the relation between ground-water levels and canal levels. Measurements in all observation wells were made in April 1968, as canal levels declined, and again in May, after they had been low for a considerable length of time. Water-level gradients in the shallow aquifer adjacent to the FCD canals were determined from measurements in wells alined perpendicular to the

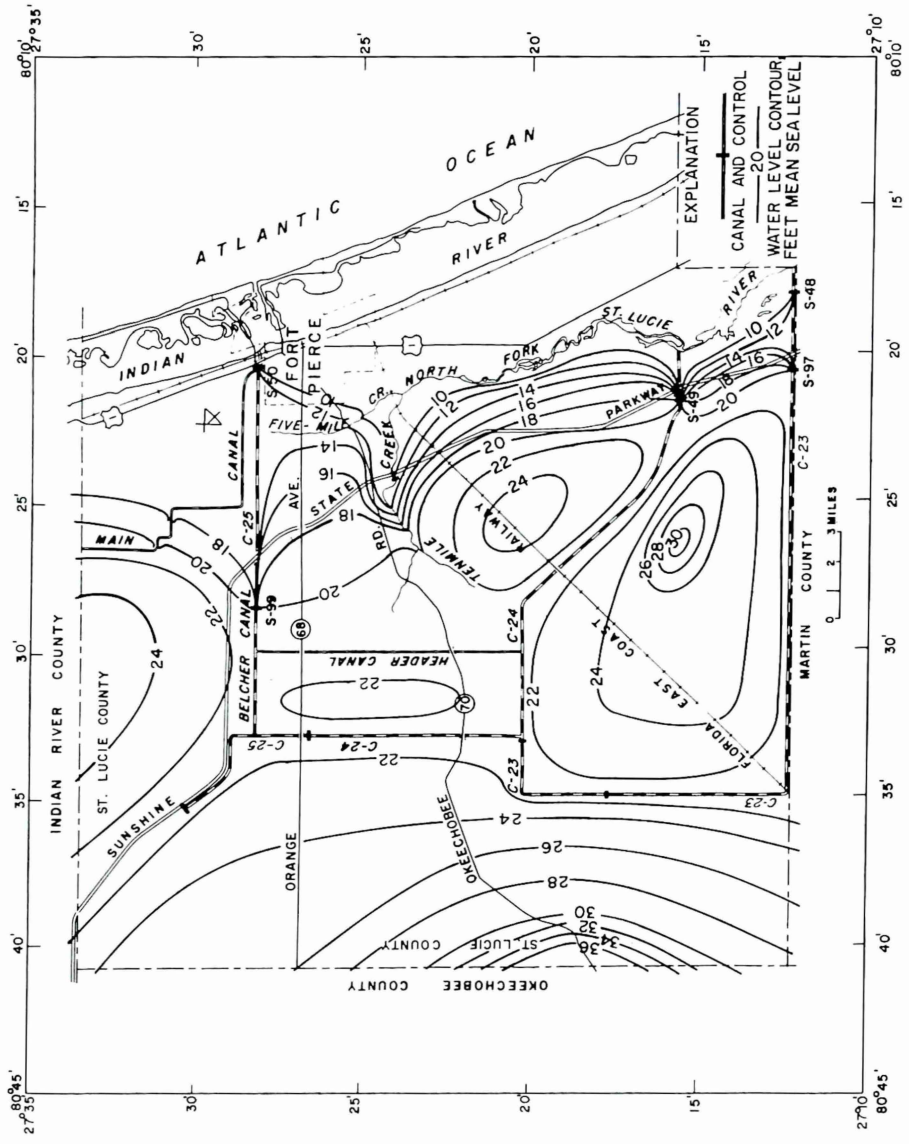


Figure 8.—Water-level contour map of St. Lucie County on August 17, 1967, during a time of intermediate water levels.

canals and spaced within 500 feet of the canals to estimate the transmissivities of the upper sediments in the vicinity of the canals.

The water-table map of figure 9 was prepared from measurements made on April 2, 1968. The configuration of the water table is similar

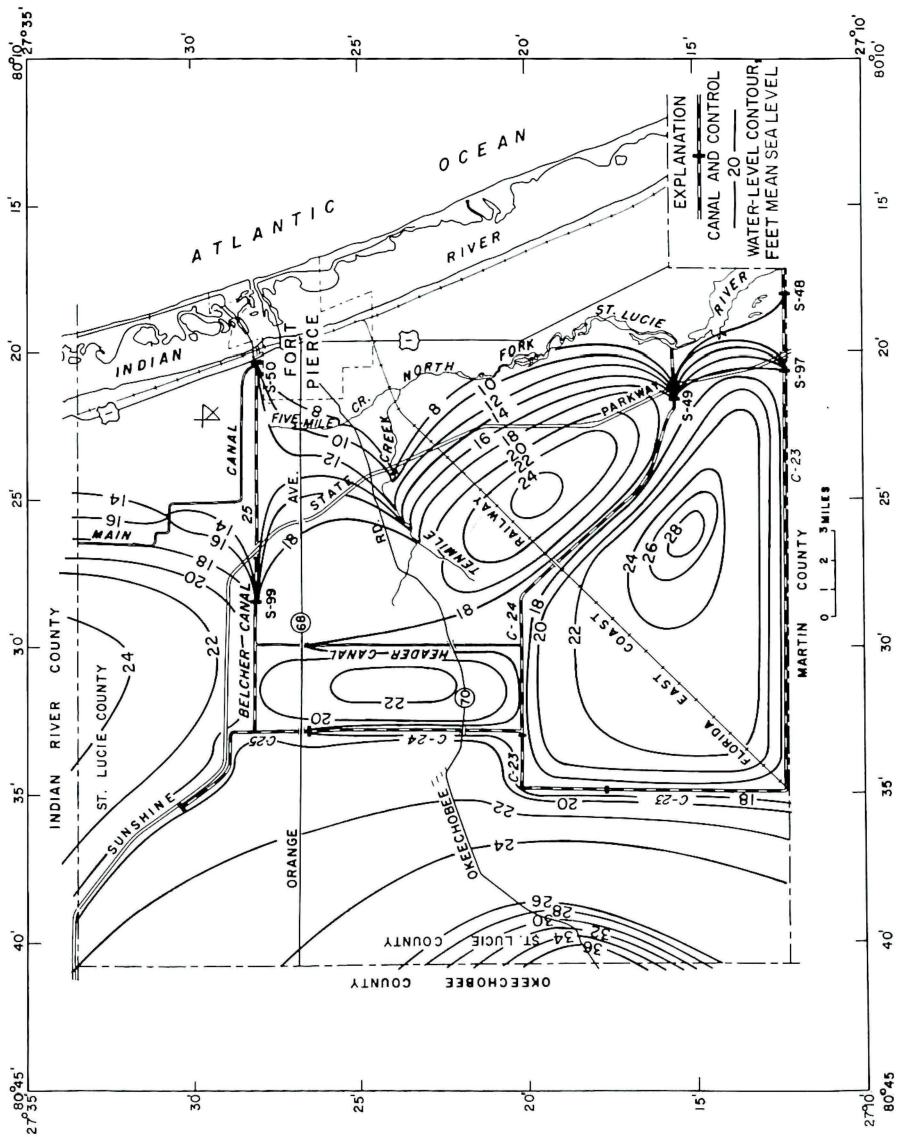


Figure 9.—Water-level contour map of St. Lucie County on April 2, 1968, during a time of low water levels.

to that in figure 8 for intermediate water-level conditions, but the main differences are the slightly lower levels in the west and the steeper hydraulic gradients adjacent to the canals.

Figure 10 shows the configuration of the water table from measure-

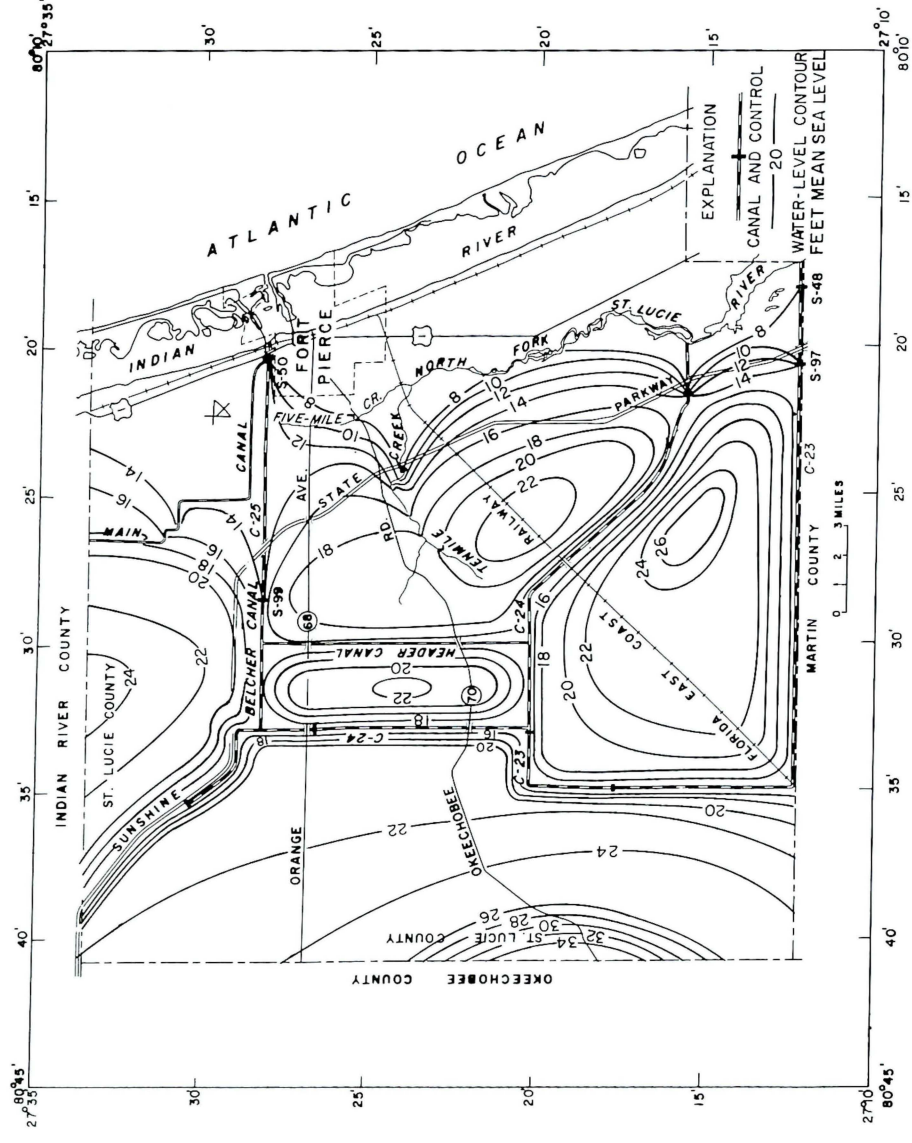


Figure 10.—Water-level contour map of St. Lucie County on May 2, 1968, during a time of extremely low water levels.

ments made on May 1, 1968. Although low canal levels had persisted since the April 2 measurements, the major changes in ground-water levels had occurred within 1 mile of the FCD canals. The configuration and elevation of the water table in areas more distant from canals showed little change from the April map. Presumably, the water table in some areas remained fairly constant, partly by maintaining high water levels in lateral canals in areas distant from the FCD canals.

The fluctuation of the water levels in canals 23, 24, and 25 for the dry

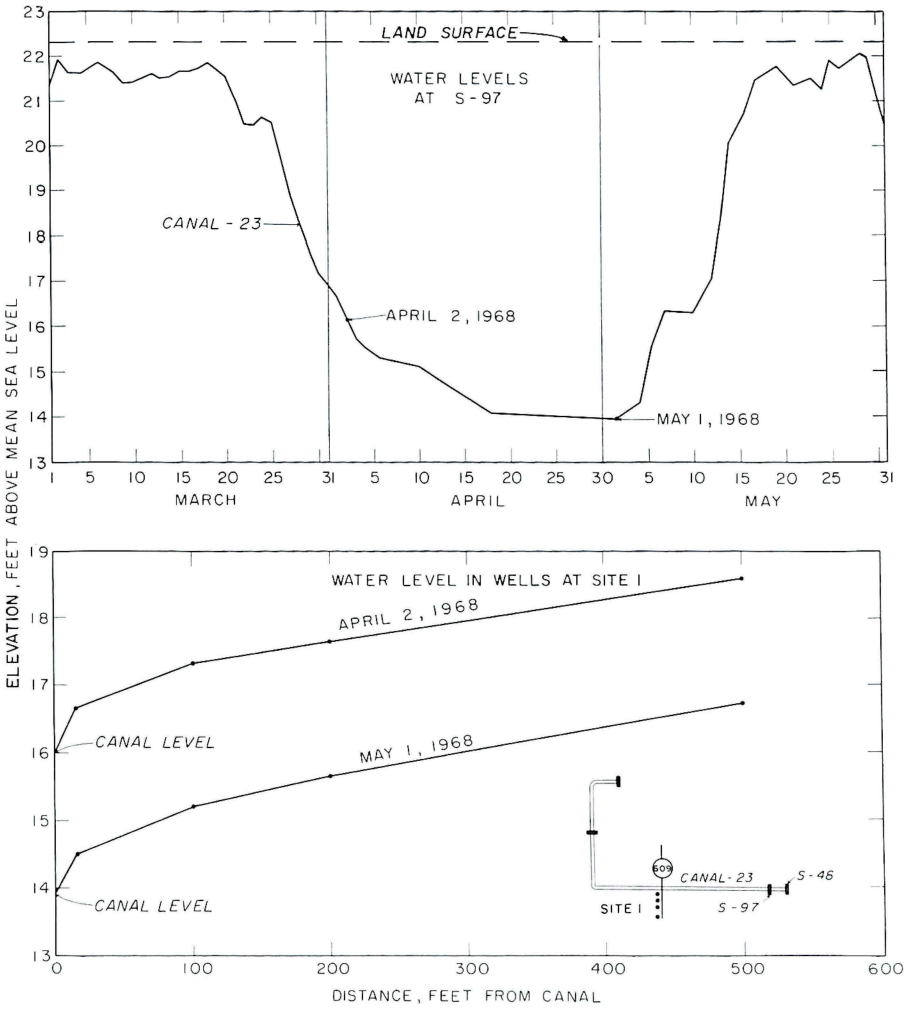


Figure 11.—Hydrograph of Canal 23 at S-97, March 1-May 31, 1968, during the dry season, and ground-water gradients adjacent to the canal at the beginning and near the end of the time of extreme low-water level in the canal.

period in March, April, and May and ground-water gradients measured April 2 and May 1–2 at selected sites adjacent to each canal are shown in figures 11, 12, and 13. The gradients generally were steep, ranging from 2.5 to 4.5 feet in 500 feet. The changes in water levels in the canals in relation to the changes in adjacent ground-water levels from April 2 to May 1 or 2 are portrayed in figures 11, 12, and 13. The changes in

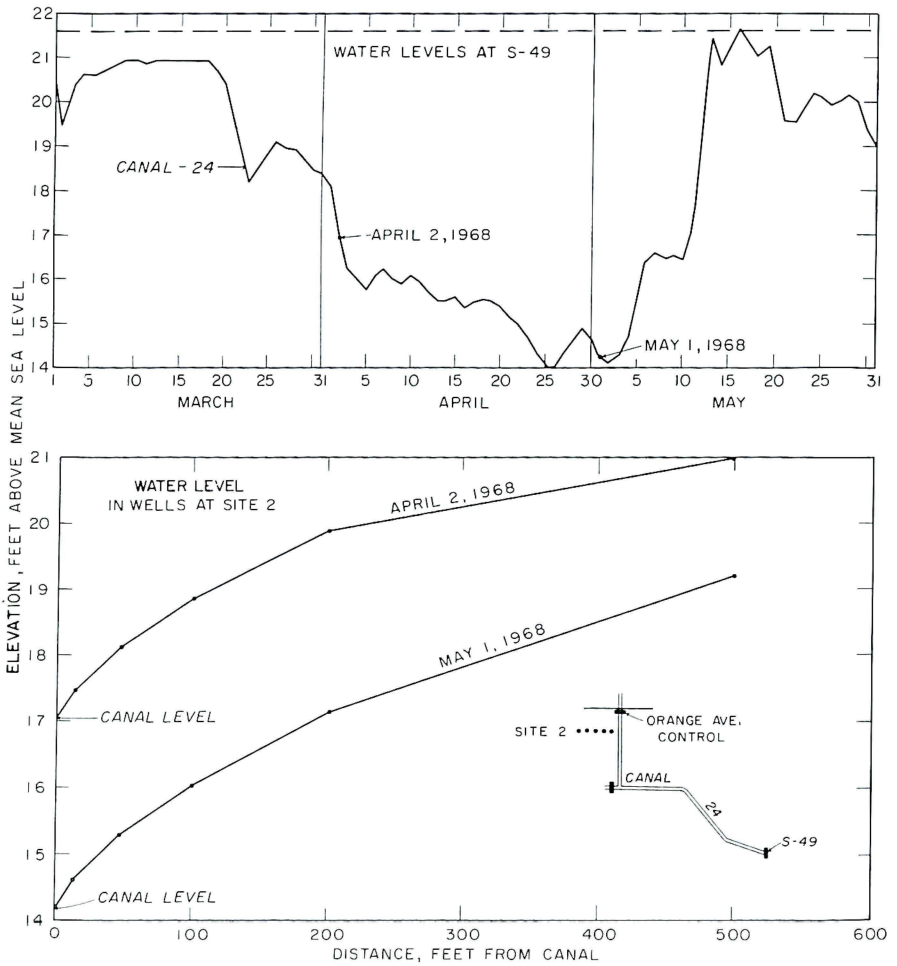


Figure 12.—Hydrograph of Canal 24 at S-49, March 1-May 31, 1968, during the dry season, and ground-water gradients adjacent to the canal at the beginning and near the end of the time of extreme low-water level in the canal.

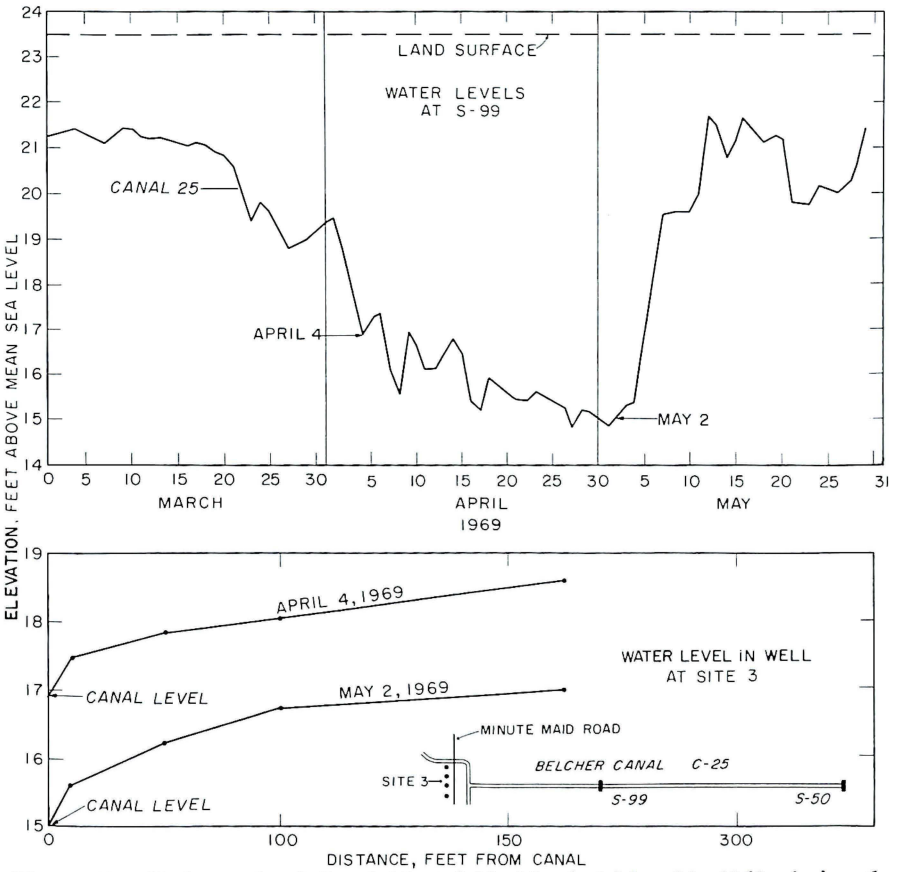


Figure 13.—Hydrograph of Canal 25 at S-99, March 1-May 31, 1968, during the dry season, and ground-water gradients adjacent to the canal at the beginning and near the end of the time of extreme low-water level in the canal.

ground-water levels 500 feet from the canals were almost proportional to canal-level changes.

The water-level profiles in figures 11, 12, and 13 can, by comparison, be used to determine which of the three sites are in areas of higher and lower permeability. Permeabilities are lowest where the water level gradient in the vicinity of the canal is steepest. Therefore, the permeability at site 2 would be less than that at site 1 or 3, and that at site 1 and 3 would be approximately equal.

There is generally good overall correlation between ground-water and surface-water fluctuation, as shown in figure 14. Levels in the aquifer and canals are low during dry periods and high during periods of excess

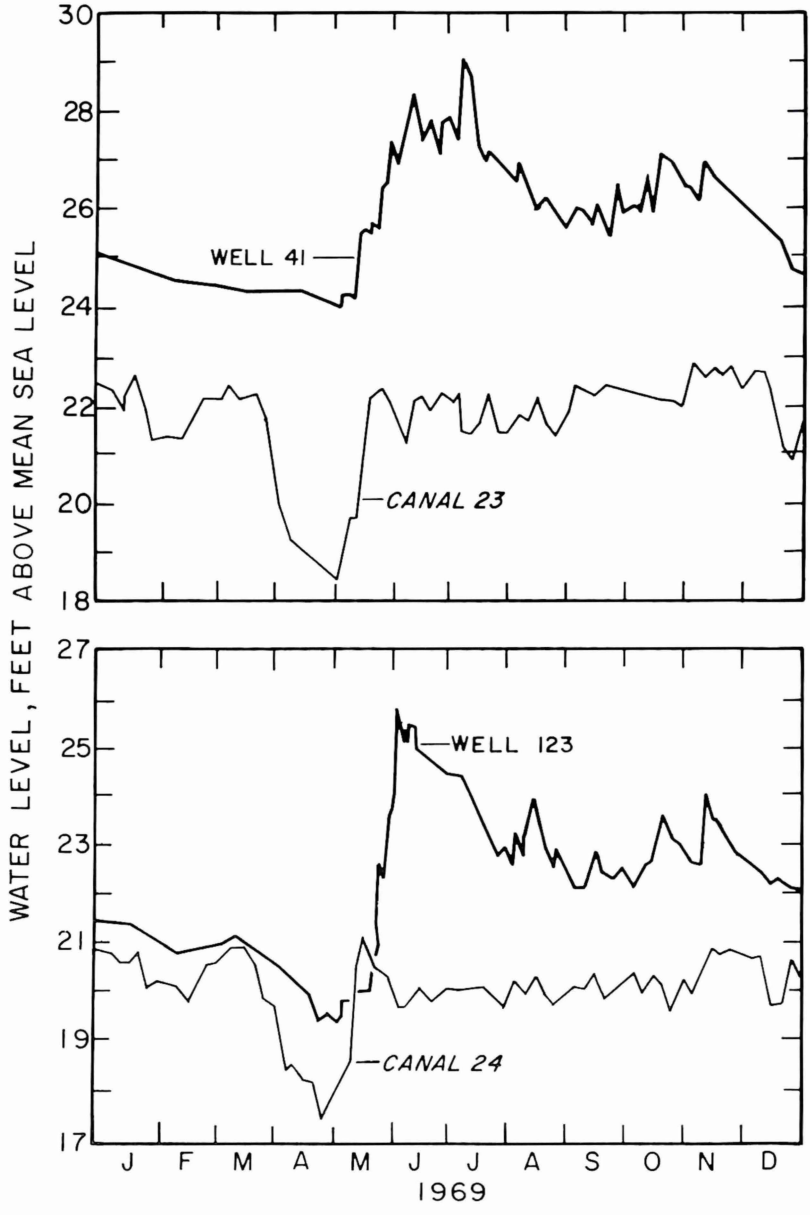


Figure 14.—Hydrographs of canals 23 and 24 and wells 41 and 123.

rainfall. However, water levels in well 41 show little direct response to changes in level in canal 23. Fluctuations of water level in well 123 correlate better with fluctuations of level in canal 24 than fluctuations of water level in well 41 with those in canal 23. The permeable beds of coquina in the area of well 123 and canal 24 account for the response to canal levels in well 123. The relation of water-level fluctuations in well 41 to water-levels fluctuations in canal 23 is typical of that of other wells with recording gages in St. Lucie County.

AQUIFER CHARACTERISTICS

The hydraulic properties of the shallow aquifer must be known in order to help evaluate the ground-water potential of an area. The principal properties of an aquifer are its capacities to transmit and store water, properties that are generally expressed as transmissivity, and the storage coefficient. Transmissivity (T) is the rate at which water of the prevailing kinematic viscosity is transmitted through a unit width of the aquifer, under a unit hydraulic gradient (Lohman and others, 1970). The storage coefficient (S) is defined as the volume of water an aquifer releases from or takes into storage per unit surface area per unit change in head. Storage coefficient (Sy) is the total volume of delayed yield from storage per unit surface area per unit change in head (commonly referred to as specific yield). The most commonly used method for determining these properties is an aquifer test, in which a well penetrating the aquifer is pumped at a known rate, and the resultant lowering of the water level in nearby nonpumped wells is observed.

Aquifer tests for this study were made at five sites in St. Lucie County. A lithologic log of each of the pumped wells except 165 is shown in figure 15. The log of well 165 was not available. The data from the aquifer tests were analyzed by the type-curve solution for water-table conditions described by Prickett (1965) for use where the effects of delayed gravity drainage are present. Under water-table conditions, water is derived from storage by gravity drainage of the interstices above the cone of depression, by compaction of the aquifer, and by expansion of the water itself as pressure is reduced. The gravity drainage of water through stratified sediments is not immediate, and the unsteady flow of water toward a well in an unconfined aquifer is characterized by slow drainage of interstices. According to Walton (1960a), three distinct segments of the time-drawdown curves may be recognized under water-table conditions; (1) the first segment may cover little more than a minute or so, (2) the second segment represents the intermediate stage in the decline of water levels when the cone of depression slows as it is replenished by gravity drainage of the sediments, and (3) the third segment represents the period during

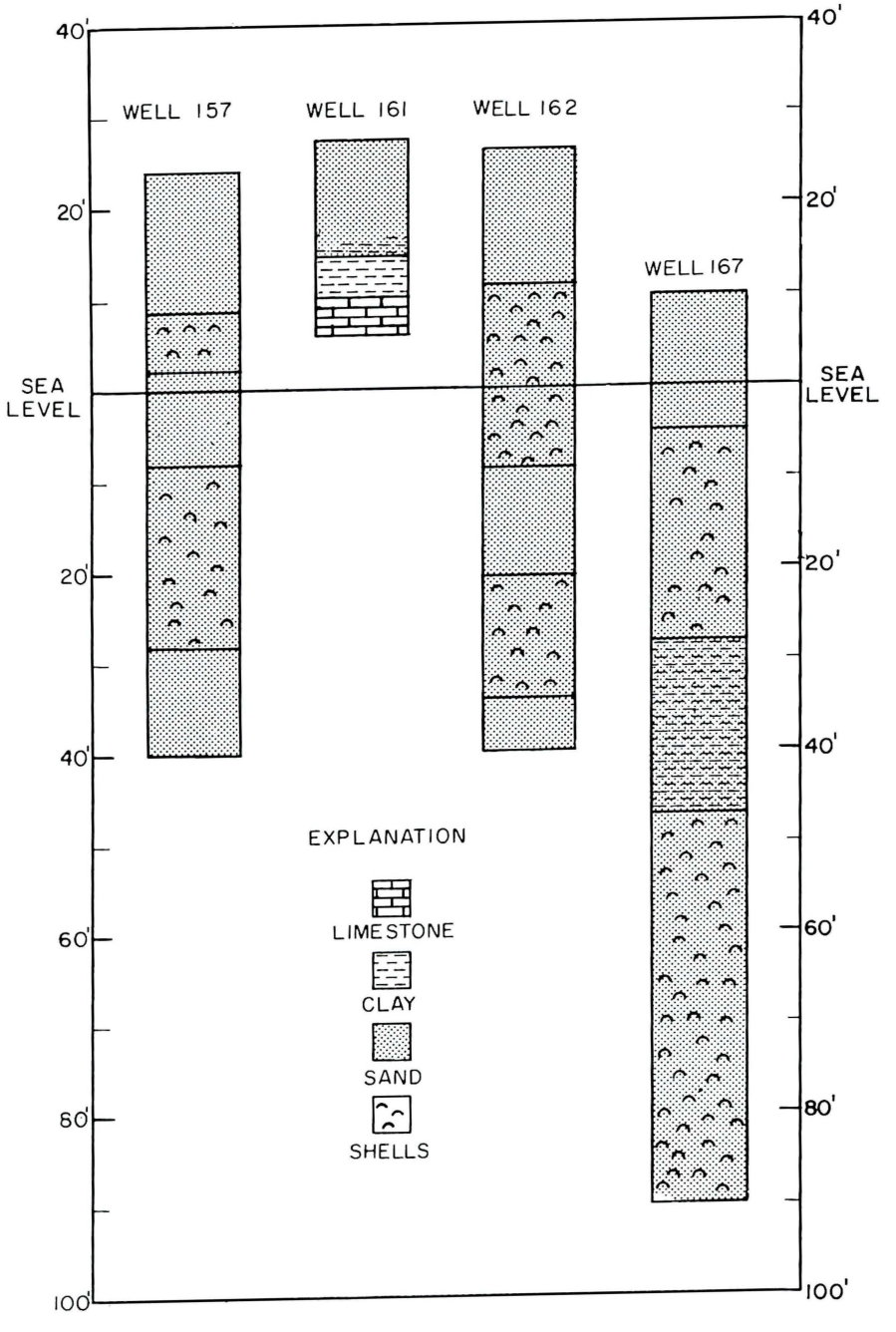


Figure 15.—Lithologic logs of the pumped wells (for location of wells see fig. 3) used in pumping test.

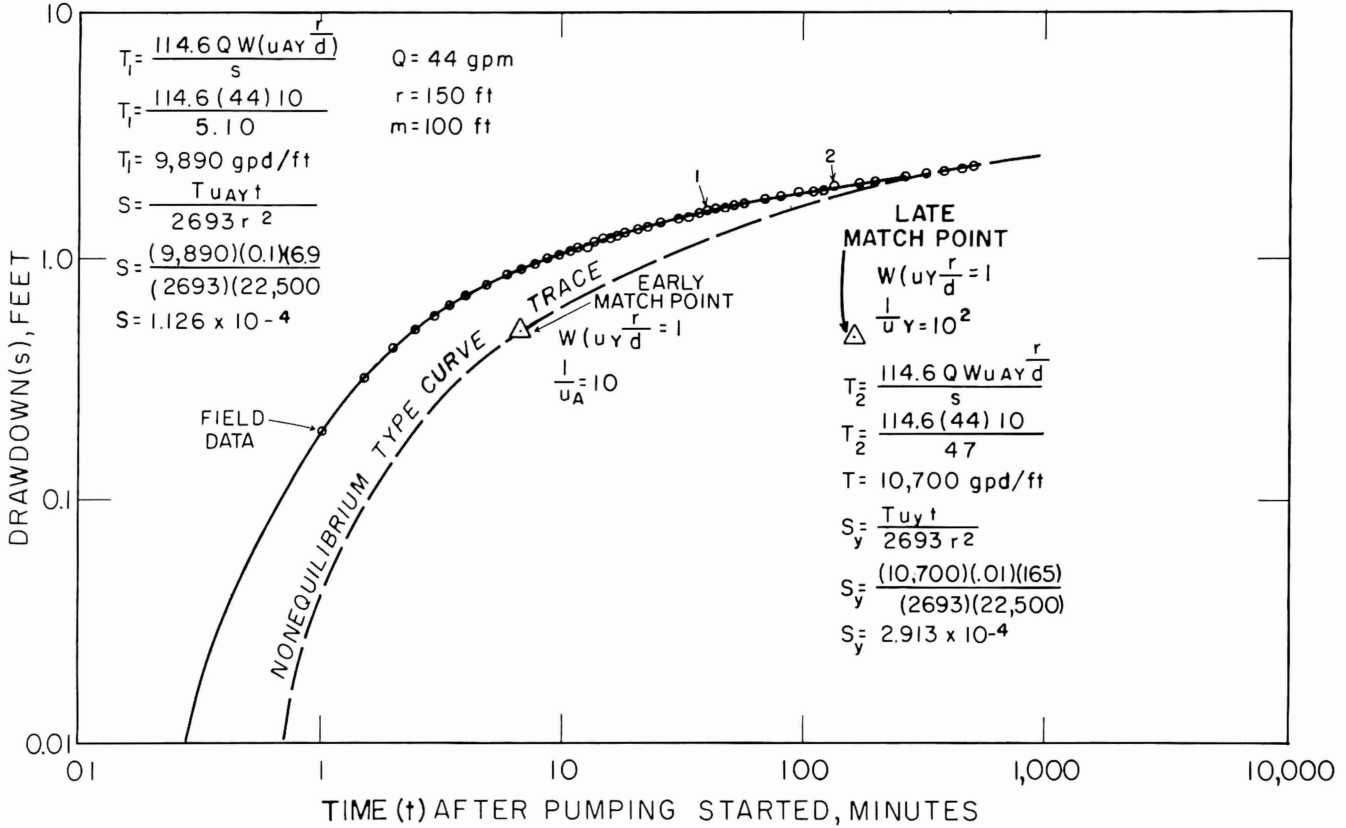


Figure 16.—Logarithmic graphs of type curve, nonequilibrium type curve, and plot of drawdown against time for observation well 164.

which the time-drawdown curves conform closely to the nonequilibrium type curve described by Theis (1935).

Computation of transmissivity and storage from the aquifer test data for well 164 is shown in figure 16. The method includes the use of two families of water-table type curves and two sets of match points. The early match point was obtained by matching early drawdown data to the curve for analyzing first and second segments of the time-drawdown curve. The late match point was obtained by matching late drawdown data to the curve for analyzing the third segment of time drawdown. Results of the analysis of the test data from each site is shown in Table 2.

Aquifer tests were run by Black, Crow, and Eidsness in 1962 and by Lichtler in 1957. The 1962 tests were made at three sites, two on the outskirts of Fort Pierce and one in the Fort Pierce municipal well field. The wells range in depth from 120 to 170 feet. The tests ranged in length from 8 to 36 hours. Transmissivities obtained from these tests, using the leaky-artesian method (Hantush, 1956), ranged from 22,600 to 41,800 gpd per ft (gallons per day per foot).

Lichtler used the leaky-artesian method to analyze data obtained by pumping wells in the municipal well field in Stuart, in Martin County, and wells at the Leighton farm, 10 miles west of Stuart. The wells are 75 to 125 feet deep. Transmissivity ranged from 16,000 to 80,000 gpd per ft.

Transmissivity values from aquifer tests for this report are comparable with those obtained from the foregoing tests. These low to moderate transmissivities indicate nonuniformity in the permeability of the shallow aquifer. Wells, 6-inches or larger in diameter, drilled in the zone from 40 to 100 feet below land surface in western St. Lucie County and finished with approximately 30 feet or more of screening and gravel pack, probably would yield 100 to 200 gpm. The Port St. Lucie Development has averaged 200 gpm or more from their supply wells in southeastern St. Lucie County.

SURFACE WATER

CANAL SYSTEM AND STORAGE

Canals 23, 24, and 25 of the FCD are the major components of the drainage and flow network in central and western St. Lucie County (fig. 1). The canals extend throughout the country, and all are controlled to regulate water levels and discharge. The control of flooding in the agricultural (citrus) area was the primary reason for construction of the FCD canals, but, with the increase in citrus acreage, the canals have become an important source of irrigation water. The water in the canals is derived from rainfall and ground-water seepage from the areas through which the canals flow.

Table 2.—Results of pumping tests in St. Lucie County

Date of Test	*Well No.*		*Depth (ft.)*		Distance to Observation Well (feet)	Pumping rate (gpm)	Coefficient or Transmissivity (T=gpd/ft.)		Coefficient of Storage		Maximum drawdown in Observation Well (feet)
	Pumped Well	Observation Well	Pumped Well	Observation Well			T_1	T_2	S	Sy	
12- 3-68	157	158	43	43	50	34	24,000	26,000	0.000090	0.0014	0.86
12- 3-68	157	159	43	43	150	34	57,000	49,000	0.000019	.00033	0.40
12- 4-68	162	163	58	58	50	44	7,600	8,200	.00012	.00072	3.62
12- 4-68	162	164	58	58	150	44	9,700	10,700	.00011	.00029	2.30
12- 5-68	160	161	21	21	75	35	53,000	50,000	.000078	.00019	0.63
1-20-70	167	168	105	103	585	200	4,800	12,000	.00025	.00040	4.30
3-19-70	165	166	100	100	65	400	51,000	47,000	.00083	.0092	5.70

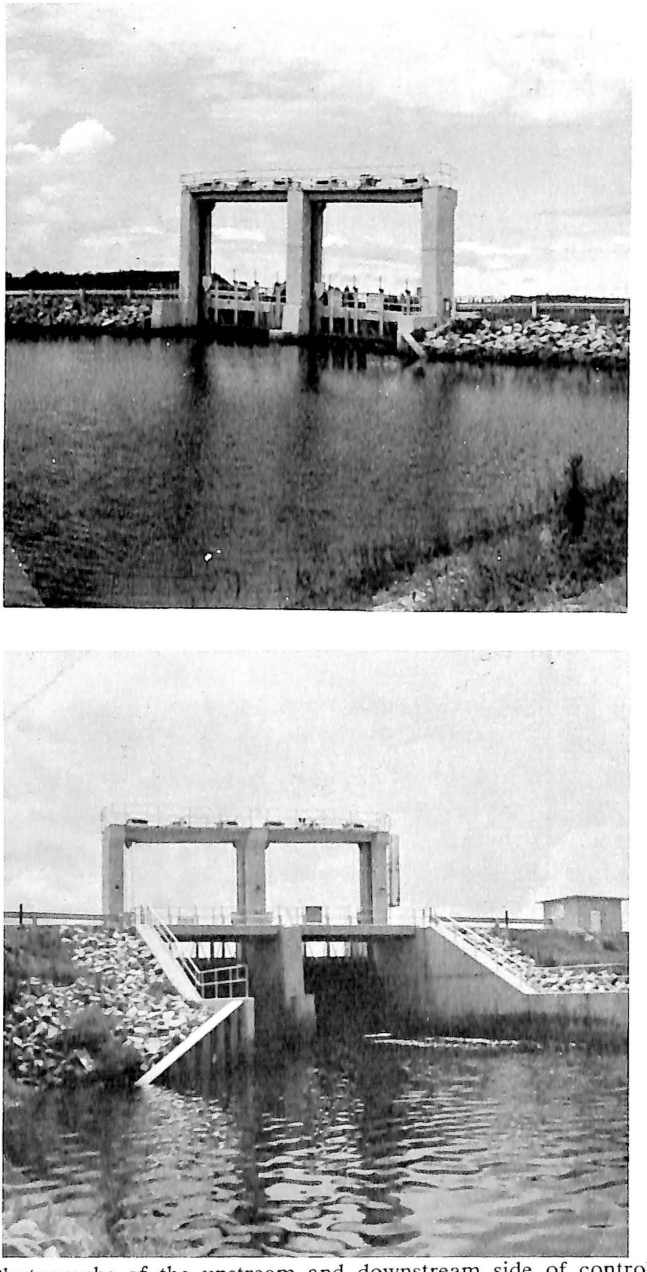


Figure 17.—Photographs of the upstream and downstream side of control S-97 on Canal 23, October, 1968.

Canal 23 has an automatic control (S-97, fig. 17) near the outlet, a 72-inch culvert control 6 miles north of the Martin County line (fig. 1), and two 60-inch culvert controls (PC-32) at the junction of Canal 23 and 24 (fig. 1). The control at S-97 is regulated to maintain water levels at about 22 feet above sea level. PC-32 is open most of the time, and the 72-inch culvert is closed most of the time. The reach of canal 23 downstream from the 72-inch culvert control is 20 miles long, and the volume of water stored in the canal above 14 feet above msl at maximum water levels is about 2,290 acre-feet. The reach of canal 23 north of the 72-inch culvert control is only 5 miles long and is shallower and narrower than the reach south of the control. The volume of water stored in it above 14 feet above msl at maximum water level is 109 acre-feet.

Canal 24 has an automatic control (S-49) that maintains the water level at about 20 feet (fig. 1). Water is diverted to Canal 24 from Canal 25 at the Orange Avenue control during periods of low water level. Canal 24 is 21 miles long, and the volume of water stored in the canal above 14 feet msl at maximum water level is about 1,710 acre-feet.

Canal 25 has an automatic control (S-99) that is adjusted to hold water levels at approximately 20 feet above msl, and a concrete dam 7 miles downstream (S-50) has a crest of 12 feet above msl (fig. 1). The control at Orange Avenue holds the water at the same level as S-99. The level east of S-99 can be held at a maximum of 12 feet; most of the time an 8 foot head exists at S-99. Canal 25 extends inland to the Radebaugh culverts (fig. 1). The Radebaugh culverts were installed with controls to maintain the water level in the canal that parallels the Sunshine State Parkway north of Canal 25. Most of the citrus-producing areas that depend on water from Canal 25 are west of S-99. The North St. Lucie River Drainage District supplies most of the water needs east of S-99. The section of Canal 25 west of S-99 is 10.4 miles long, and the volume of water stored above 14 feet above msl at maximum water level is about 647 acre-feet.

Local landowners have established two privately supported drainage districts to help control flood water and to supply irrigation water. They are the FPFDD (Ft. Pierce Farms Drainage District) in the northeastern part of the county and the NSLRDD (North St. Lucie River Drainage District) in eastern St. Lucie County (fig. 1). The NSLRDD extends from Canal 25 in the north to Canal 24 in the west and south, and joins the FPFDD in the north.

The districts have built multipurpose canals and control structures. The effectiveness of their program was increased when the districts linked their major canals to the FCD canal system. The districts regulate their controls on a day-to-day basis to maintain water levels at effective heights.

Header Canal, the major canal of the NSLRDD is 3 miles east of the north-south reach of Canal 24 and is connected to Tenmile Creek to the east and to the FCD Canals to the north and south. Most of the lateral canals in the district drain to Header Canal and Tenmile Creek. Flood waters can be pumped into Canals 24 and 25 or drained through Tenmile Creek to the North St. Lucie River.

The FPFDD is rectangular and extends 8 miles inland from the coast. The FPFDD has one major canal (Main No. 1) that crosses southward through the central part of the area and then westward about 4 miles to its confluence with Taylor Creek and Canal 25. Numerous equally spaced lateral canals intersect the main canal along its route through the district to drain flood water and to furnish irrigation water during dry periods.

The drainage network in St. Lucie County includes the FCD canals, drainage district canals, and hundreds of private drainage canals that intersect the FCD and drainage district canals. The citrus growers in the county have become dependent primarily on this network of canals to supply water for irrigation. Only a small part of the rain falling on the area can be stored. The remainder is discharged to the ocean or is lost by evaporation. Maintaining high water levels in the canals also helps maintain high ground-water levels.

Long rainless periods in St. Lucie County cause critical shortages of irrigation water. During the extreme dry period of March, April, and May 1968, for example, water was pumped to the minimum permissible pumping level of 14 feet msl in FCD Canals 23 and 24 by the middle of April and remained at these levels until the rains in May (figs. 9, 10, and 11). The rapid decline in level of the water in the canals began about March 24 during the dry period, when the grove owners began pumping at maximum capacity to meet irrigation needs. The growers pumped at maximum capacity until irrigation ditches were filled. Pumping continued at a reduced rate until the levels in the canals approached the minimum permissible pumping level and pumping was stopped completely. The rate of decline in the canal levels was almost constant for the period of maximum pumping, shown in figure 18.

Three citrus growers in the northwest part of the county have private storage reservoirs that were constructed by building levees around low marshy areas. During periods of excess rainfall, water is pumped from irrigation canals in the groves into the reservoirs. This water is used for irrigation during the dry season. Although losses from such reservoirs are usually high because of transpiration, evaporation, and seepage, one grower has been storing enough water in a 1-square-mile reservoir to irrigate several hundred acres of citrus through the regular dry season.

data included lowering levels in the canals at controls S-49, S-97, and S-99, making concurrent discharge measurements in the canals, measuring flow from all lateral canals to canals 23, 24, and 25, and measuring water levels in the wells at the sites shown in figures 9, 10, and 11 to determine gradients. The study of each canal was made independently of studies of the other canals, and at intervals of about a week. Canal levels were lowered an average of 4 feet to induce seepage into them. After the canal levels were lowered, the controls were regulated to maintain

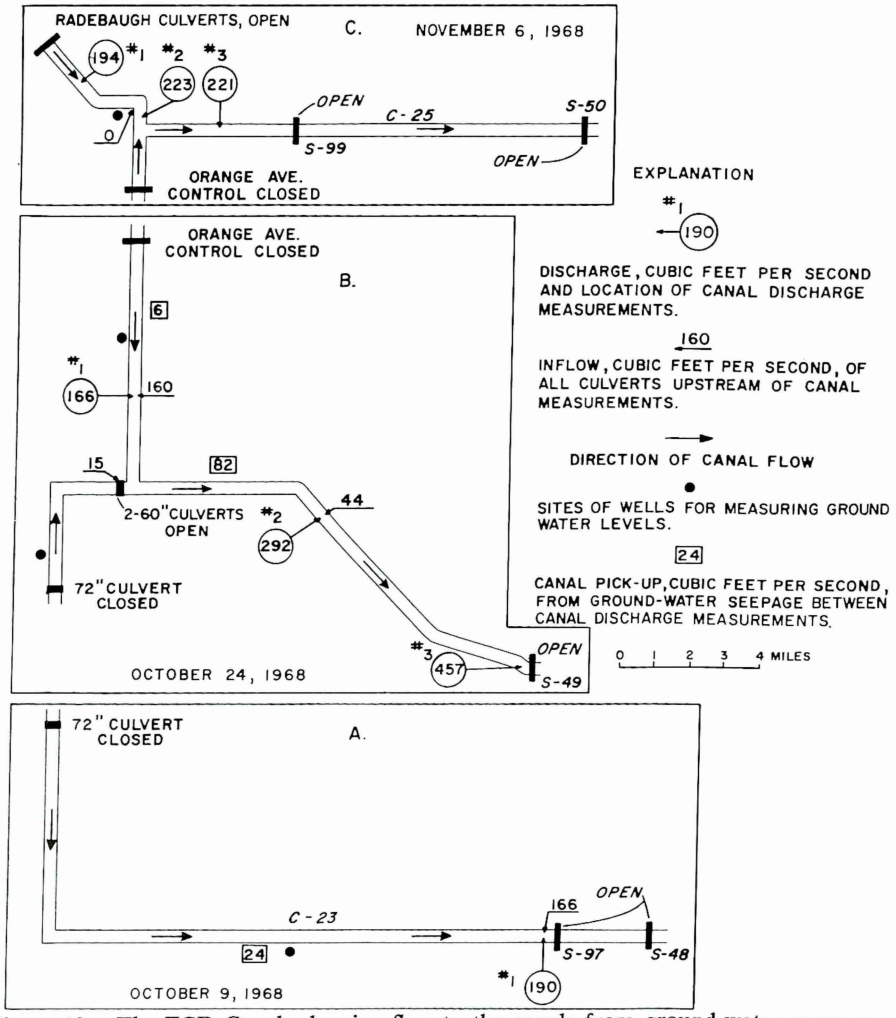


Figure 19.—The FCD Canals showing flow to the canals from ground-water seepage and laterals that intersect the canal.

a constant canal stage. Discharge measurements were made in the canals at places several miles apart, and all flow from culverts into the canals was measured. The culvert inflow was subtracted from the increase in discharge within the reach from one measuring site to another to obtain rates of ground-water seepage from canal banks for each reach of the primary canal.

After the measurements in the canals were completed, the controls were closed until the canal levels recovered to pre-test levels. The rate at which canal levels recovered was observed at recording and staff gages. The ground-water seepage rates were determined by the following volumetric formula:

$$Q = \frac{WLR - C}{T}$$

Q = seepage, in cubic feet per second
W = average width of canal, in feet
L = length of canal, in feet
R = rise in stage, in feet
T = elapsed time for rise in stage, in seconds
C = culvert inflow, in cubic feet per second

This method was used to check results obtained from the discharge measurements in the canals during the period of time when gates at S-49, S-97, and S-99 were open.

CANAL 23

The 20-mile reach of Canal 23 downstream from the 72-inch culvert (fig. 19A) was included in the study of canal 23. The 5-mile reach of Canal 23 upstream from the 72-inch culvert was included in the study of Canal 24. The water level in Canal 23 was lowered from 21.8 feet to 17.8 feet on October 7, 1968. Discharge measurements were made on October 8. A total discharge of 190 cfs (cubic feet per second) was measured in the canal a quarter of a mile above control S-97, and a total of 166 cfs was measured from all upstream lateral canals discharging through culverts into Canal 23. The total discharge from the canal minus the culvert inflow indicates a ground-water seepage rate from the canal banks of 24 cfs, or 0.3 cfs per mile of canal per foot of drawdown, for the 20-mile reach of Canal 23.

CANAL 24

All of Canal 24 plus the northern section of Canal 23, above the 72-inch culvert, was included in the Canal 24 study (fig. 19B). The water level in Canal 24 was lowered 3.7 feet, from 20.1 feet to 16.4 feet, on October 22, 1968. Discharge measurements were made October 24

along the canal at 8-mile intervals upstream from control S-49. No measurements were made on Canal 23 except at the two 60-inch culverts, where Canal 23 is interconnected to Canal 24.

The first discharge measurement in Canal 24 was made 5 miles downstream from the Orange Avenue control (fig. 19B). The discharge was 166 cfs. For that reach of canal, total culvert inflow was 160 cfs. Thus, ground-water seepage was 6 cfs, or 0.3 cfs per mile of canal per foot of drawdown. Ground-water gradients to the canal were also measured in a line of wells at a site 3 miles south of the Orange Avenue control (fig. 19B, also see fig. 12). Using the seepage pickup of 6 cfs and the gradient obtained from measurements in the line of wells as an average for the 5 mile reach of canal, a transmissivity of 11,700 gpd per ft. was obtained for the shallow materials in that area.

The second discharge measurement of 292 cfs was made 8 miles downstream from the first measurement (fig. 19B). For that reach of canal, culvert inflow was 44 cfs. Thus, a total of 82 cfs, or 2.76 cfs per mile of canal per foot of drawdown, was picked up from ground-water seepage. The thin but permeable beds of coquina in the area where Canal 24 turns east probably accounts for the increased ground-water contribution.

The discharge of Canal 24 above control S-49 was measured. After the measurement was made, rain increased the flow in the canal. The flow from the culverts for the 8-mile reach of canal above S-49 was not measured. The gates at S-49 were closed at the completion of measurements, and refilling of the canal began. The rate of recovery of the canal level was constant for 25 hours, as the level rose from 16.4 feet (stage at time the gate was closed) to 18.8 feet.

A discharge of 15 cfs from the 5-mile reach of Canal 23 upstream from the 72-inch culvert was measured at PC-32, where Canal 23 is interconnected to Canal 24. The flow in the canal there was composed of flow from runoff from lateral canals and ground-water seepage. No other discharge measurements were made along the section of Canal 23 included with the Canal 24 study. Water levels were measured in a line of wells at a site 1 mile north of the 72-inch culvert to determine the ground-water gradient toward the canal. A ground-water gradient of 2.5 feet in 500 feet was measured adjacent to the canal after the canal level was lowered about 4 feet.

CANAL 25

The study of Canal 25 includes only the reach of canal west of S-99 to the Radebaugh culverts (fig. 19C). This was the major area studied

because most of the citrus growers that depend on water from Canal 25 are concentrated west of S-99.

The water level in Canal 25 was lowered 3.8 feet from 20.2 feet to 16.4 feet, on November 4, 1968, because the automatic gates at S-99 failed to close properly. Discharge measurements were made on November 5 at 2-mile intervals from the Radebaugh culverts downstream to S-99 (fig. 19C). Flow through the Radebaugh culverts was 194 cfs. The two measurements, 194 cfs and 223 cfs, showed a ground-water seepage rate of 2.6 cfs per mile per foot of drawdown in the canal. No appreciable pickup could be measured in the 2-mile canal reach immediately west of S-99 and the 2-mile reach between measurements 2 and 3. There are few uncontrolled culverts interconnecting lateral canals to the canal in this area, and inflow from culverts was negligible.

Structure S-99 was closed on Nov. 6, 1968, and Canal 25 began to fill from flow at the Radebaugh culverts. Discharge was computed by the volumetric method, using water-level data from the gage at control S-99. The recovery rate in the canal decreased rapidly as the canal began to fill. Discharge calculated for each 0.5-foot rise in water level in the canal for the first 2 feet equaled 159, 103, 87, and 45 cfs, respectively.

Ground-water gradients were determined after the control was closed and the canal began to fill. The gradients in figure 20 show the relation of the water table to canal levels at different time intervals. The gradient measured 1 hour after the control was closed shows a slope of 1.04 feet in 240 feet. As the canal was refilled, the canal level rose much faster than the water table, as shown in figure 20.

A seepage study by J. I. Garcia-Bengochea of Black, Crow, and Eidsness (1960) was made in a reach of Canal 25 from S-99 to 4.5 miles west during construction of the canal. The water level in the canal was lowered from 17.0 feet to 12.0 feet, and the rate of recovery was observed at S-99. Bengochea determined that the average rate of ground-water seepage to the canal was 160 gpm per mile per foot of drawdown for that particular reach.

In view of the generally low permeability of the upper 15 to 20 feet of sediments in the aquifer, as indicated by the relatively small amount of seepage to the primary canals and the steep ground-water gradients to the canals, it is apparent that ground-water seepage to the canals is insufficient to provide the water needed for irrigation during dry periods when the area is under full citrus production. Shortages during the 1968 dry season (March-May) are also indicated in figures 9, 10, and 11 by the rapid rate of lowering of water levels in canals when a large amount of water was being withdrawn from them and the low rate of recovery of levels in the canals when withdrawal was reduced or stopped.

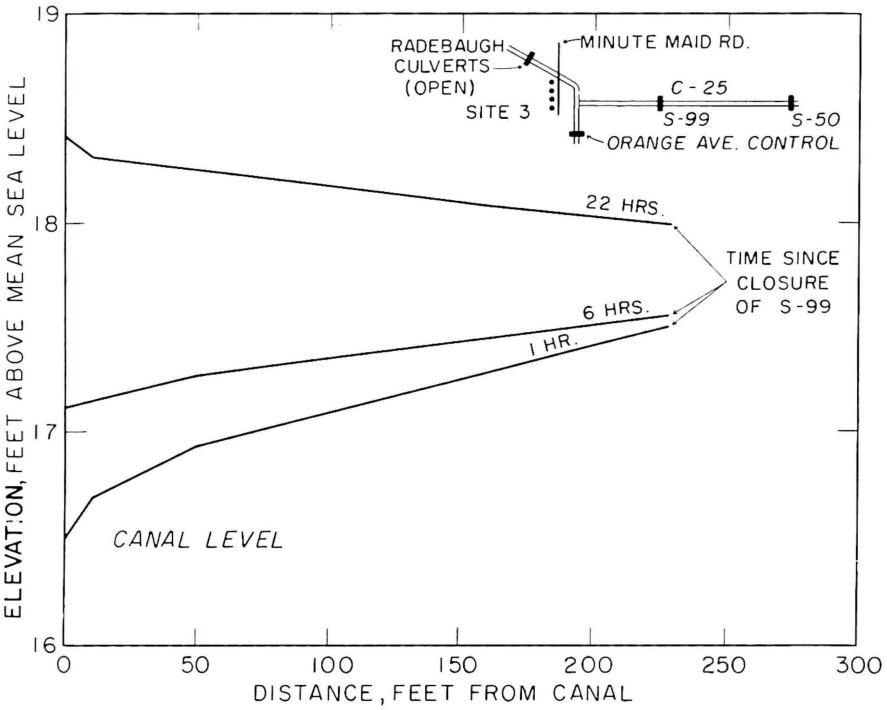


Figure 20.—Graph showing ground-water gradients adjacent to Canal 25 at site 3, as water levels in the canal are recovering, after the seepage study.

QUALITY OF WATER

Water in the shallow aquifer in St. Lucie County averages less than 100 mg/l (milligrams per liter) chloride and is generally suitable for domestic and other uses according to suggested limits of the U.S. Public Health Service (1962) for drinking water. Water from the Floridan artesian aquifer contains more than 300 mg/l chloride and is unfit for most domestic purposes and irrigation of some crops. In 1950, the average dissolved-solids content of water from 104 artesian wells sampled by the Indian River Field Laboratory was 1,703 mg/l and in 1965, 1,884 mg/l. Chloride content of water from artesian wells used for citrus irrigation usually ranges from 300 to 600 mg/l, but as much as 1,130 mg/l was detected in samples in 1969 from artesian stock wells.

Water users in the area feel the highly mineralized water of the artesian acquifer is not acceptable for citrus irrigation because of the low tolerance of citrus to salts. Tolerance limits for damage to Ruby Red

grapefruit trees were established for low-rate sprinkler systems (0.8 gpm per nozzle) by Calvert and Reitz (1965) at the following concentrations:

Damage	Dissolved-solids content, in mg/l	Approx. Sodium chloride in mg/l	Approx. chloride in mg/l
Mild	1000	500	300
Moderate	1600	1000	600
Severe	2300	1500	900

Less damage occurs at the salt concentrations shown with higher application rates. The fine mist from low-rate sprinklers evaporates rapidly, leaving a salt deposit on the leaves. If the ditch-irrigation method is used, concentrations of almost double the above can be tolerated. Tolerance limits of citrus vary with different varieties, and many of the varieties of oranges, grapefruit, and other citrus grown in St. Lucie have a higher tolerance limit than the Ruby Red grapefruit.

Water in the canal system is generally of good chemical quality but the mineral content increases during dry periods because of the continued use of mineralized artesian water, some concentration of fertilizers from the recirculation of irrigation water, and the decrease in amount of fresh water available to the canals for diluting and flushing. Artesian water is a major contributor of mineralization to the canal system.

Water from artesian wells is used in many of the citrus groves for irrigation during dry periods—in groves distant from the canals, where water is not readily available—and on ranches for watering cattle. Water from the artesian wells is discharged into a network of ditches in the citrus groves and on the cattle ranches. The ditches are connected to the owners main irrigation canals (lateral canals), which are connected to an FCD or major district canal. The artesian water is diluted with the surface water and inflowing ground water in the network of irrigation ditches and canals and eventually reaches the major canal system by seepage or free flow drainage. Many of the lateral canals are not controlled, and reflect the water levels in the major canals and regional ground-water levels.

During dry periods, when water levels in the canals are lower than normal, more artesian water is used, but the primary reason for the increase in chloride in the canal system during these periods is the lack of fresh water to flush the canals. Chloride concentration would be higher during the wet season if the canals were not flushed constantly.

Chloride content of water in Canals 23, 24, and 25 for given stages are shown in figure 21. In general, when water levels are high the

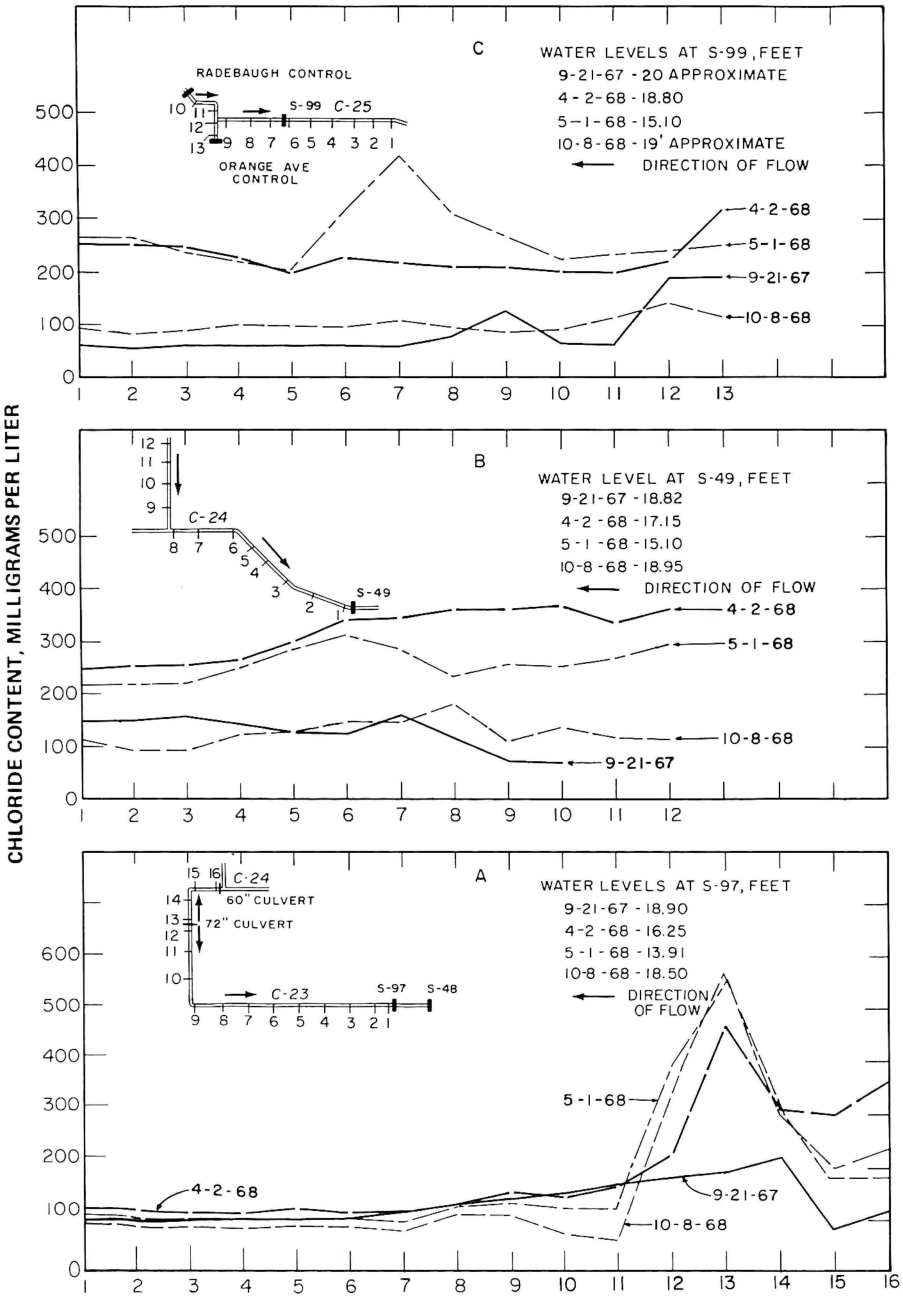


Figure 21.—Graphs showing change in chloride content of Canals 23, 24, and 25 in relation to canal water levels.

chloride content is low, and when water levels are low the chloride content is high. Little seasonal change in chloride content of the canal water took place along the east reach of Canal 23, where much of the area is still used for cattle raising. Along the west and south reaches of Canal 23, shown in figure 21A, many artesian wells are used to irrigate the large acreage of citrus in that area. The 72-inch culvert control is closed most of the time, and, if flow occurs upstream from the control, it must be diverted to the north to Canal 24. Therefore, because of the use of artesian water and insufficient flushing of the canal upstream and downstream from the control, the chloride content is highest in that part of the canal. The chloride data collected in Canal 23 on September 21, 1967 were plotted against distance west of S-97 as shown in figure 22. to better portray the increases in chloride. The chloride content began to increase rapidly at site 6 in figure 22 as the citrus area was approached, but the sharpest increase occurred at sites 11–14 in the area of the control. A grower was pumping water into Canal 23 near site 11 (fig. 22) when the sample was taken.

The chloride content of water in the shallow aquifer, as mentioned

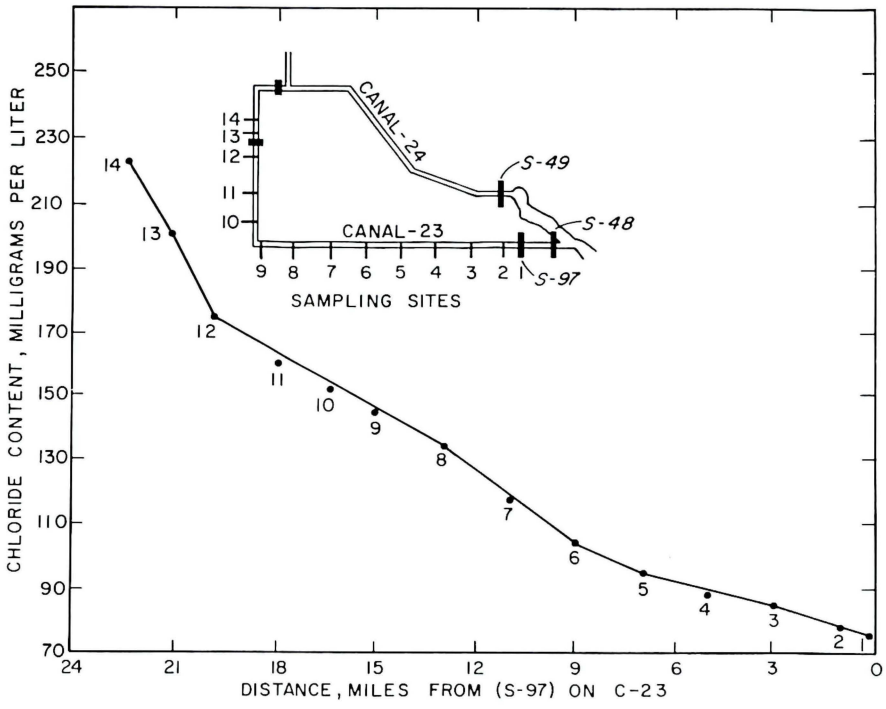


Figure 22.—Chloride concentration profile in Canal 23 on September 21, 1967.

earlier, is low in both wet and dry seasons except in citrus groves and on ranches where artesian wells are used for ditch irrigation, near the coast, and near the FCD and district drainage canals. Figure 23 shows the location and depth of private shallow wells and the chloride content

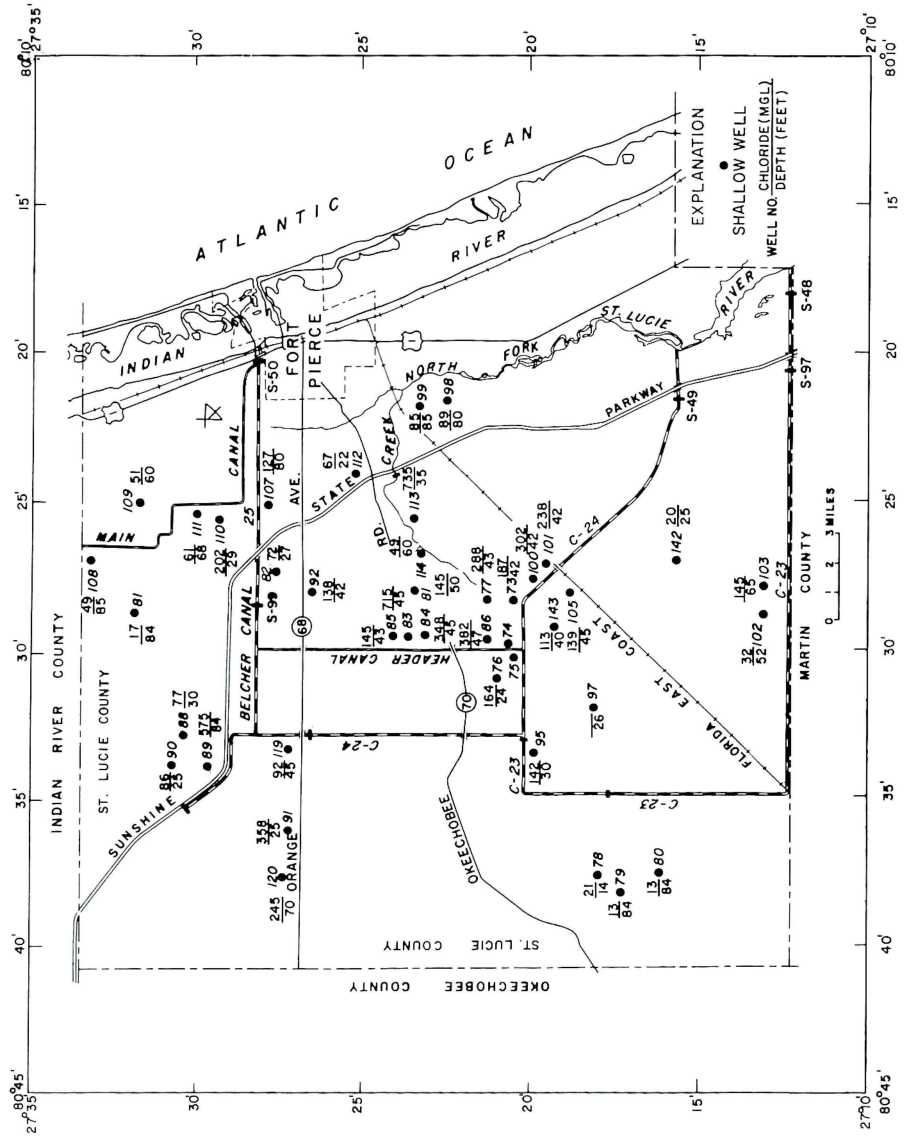


Figure 23.—St. Lucie County showing the chloride content of water and depth of shallow wells at selected sites, January and February, 1967.

of the water sampled during January-February and September of 1967. The water of higher chloride concentration is from wells in or near some known agricultural development, primarily citrus, where artesian wells are used or near the canals where contaminated water from the canals is used to irrigate the groves. The citrus groves, especially the new ones, have been located as near as possible to the FCD canals.

A closer comparison of shallow wells affected by irrigation water is shown in Table 3. The wells whose water is extremely low in chloride, such as wells 78–81 and 142, are somewhat remote from any canals or citrus development. Some of the wells sampled in January and February were sampled again in September during the rainy season. A comparison of the analyses of wells sampled during the two periods (Table 3) shows little change in the chloride content.

The salinity data suggest that the higher salt concentration in the aquifer near the canals is the result of canal-water seepage to the aquifer. However water levels in the aquifer are nearly everywhere higher than the canal levels throughout the year and especially so during the dry period, and, therefore, ground water moves to the canals. As mentioned earlier, the canal water increases in chloride content when artesian water that is being used for irrigation or watering cattle drains into the canal system. Water in the aquifer also has increased in chloride content in many areas when artesian water has been applied to the land and infiltrates to the water table. In areas where artesian water is not used, water in the aquifer increases in chloride content when the mineralized canal water is applied to the land.

The high chloride content of water is beginning to pose problems. Chloride in water in the FCD canals in certain areas has reached levels (fig. 21) that could cause slight damage to citrus. During the drought in 1967, growers were forced to discontinue use of the water in the Header Canal because of damage to trees.

PESTICIDES

The quantity of pesticides used each year in St. Lucie County is becoming an important factor in future water quality. As mentioned earlier, the acreage of citrus in St. Lucie County has more than doubled since the late 1950's; the use of pesticides has probably increased in the same proportion. Three main sprayings per year are recommended by the Advisory Committee of the Florida Citrus Commission, the post bloom (spring), the summer, and the fall sprayings. In 1967, 45 percent of all pesticides used in Florida were used on citrus and 39 percent on vegetables. (Higher and Kolipinski, 1970).

Table 3.—Chloride content of water from selected wells during January-February and September, 1967.

Wells influenced by irrigation water from FCD canals, secondary canals, and areas of agricultural development			Wells not influenced by irrigation water from FCD canals, secondary canals, and areas of agricultural development		
	Chloride (mg/l)			Chloride (mg/l)	
Well No.	January-February	September	Well No.	January-February	September
73	187	198	78	21	
74	422		79	13	15
75	322	515	80	13	15
76	162		81	17	19
77	288		90	86	
82	72	72	94	51	
83	715		98	89	
84	348		99	85	
85	145		108	49	
86	382	352	109	51	43
87	145		112	67	
88	77	77	142	20	
89	575	565			
91	358	355			
92	138	141			
95	142	139			
97	332				
100	302				
101	238				
102	32				
103	145	147			
105	139				
107	127	127			
110	202				
111	61	62			
113	735				
114	49	49			
119	92	67			
120	245	252			
143	113				

Most of the pesticides used on vegetables and citrus are toxic to human beings and animals. The two major classes of pesticides are organophosphates and chlorinated hydrocarbons. The organophosphates are more toxic than chlorinated hycarbons, but they do not persist and they become ineffective after 1–2 weeks. Some of the common and very toxic organophosphates (usually containing sulfur) are malathion, parathion, guthion

dimethoate, and ethion. The chlorinated hydrocarbons are applied mainly to farm crops such as vegetables. The most common of the chlorinated hydrocarbons are DDT, dieldrin, lindane, endrin, and heptachlor. They do not have the initial effectiveness of the organophosphates, but they last for several weeks on plants and for several years in the water and soil.

Water and sediment samples for pesticide analyses were taken in Canal 24 at the Okeechobee Road bridge and Header Canal at the State Road 68 bridge. Water samples were taken 2 feet below the water surface, and sediment samples were taken near the deep part of the channel. The water and sediment samples were analyzed by the U.S. Geological Survey Water Quality Laboratory in Washington, D.C., for the chlorinated hydrocarbons only, except for water samples taken on November 1, 1967, which were analyzed for two of the organophosphates, malathion, and parathion, as shown in table 4. DDT was the only pesticide found except for small traces of Lindane and Dieldrin in the water sample taken from Header Canal on October 7, 1968. Almost all the pesticides in the canals were concentrated in the sediments (Table 4). The concentration in the sediments was higher on the average during October and November, probably as a result of sprayings of summer crops (vegetables). The concentration of pesticides in the water changed little, as the canals had been flushed by summer rains before the sampling in October.

Pesticide content of water and sediment in canals in St. Lucie County in 1967–68 was low in comparison with that in canals sampled along the lower southeast coast of Florida. Two of the canals of highest pesticidal content are shown in Table 4.

SUMMARY

The development of land for citrus has brought hydrologic changes and problems concerning water requirements for the St. Lucie County area. In past years native pasture and swamp land acted as detention reservoirs for irrigation water for the earlier developed land. However, with the expansion of the citrus industry, those lands were drained and developed, and water that was stored in these areas during wet seasons is now discharged to the ocean. Areas devoted to citrus increased from 30,000 acres in 1959 to 65,000 acres in 1965. As a result of groundwater inflow to the canals, water levels have been lowered, which protects citrus feeder roots. Draining the swampy lands has reduced the amount of water available for natural recharge. Also, the lowering of groundwater levels has resulted in a loss of aquifer storage. The irrigation

Table 4.—Pesticide analyses of water and sediment samples from canals at selected sites in St. Lucie County compared with canals in Broward and Dade Counties (micrograms per liter—μg/l).

Sampling Site	Date	Lindane	Aldrin	Heptachlor	Heptachlor Epoxide	Dieldrin	Endrin	DDD	DDE	DDT	O,P'DDT	P,P'DDT	Malathion	Parathion
Water Samples														
Header Canal at State Road	11-01-67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
68—St. Lucie Co.	2-28-68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01				
	10-07-68	0.01	0.00	0.00		0.01	0.00	0.00	0.00	0.01				
Canal 24 at State Rd. 70	11-01-67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00
St. Lucie Co.	02-28-68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01				
	10-07-68	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.01				
Plantation Canal	10-17-67	0.10	0.00	0.00	0.00	0.00	0.00	0.01	0.01		0.00	0.02	0.40	0.00
nr. Ft. Lauderdale-Broward Co.	02-27-68	0.00	0.00	0.00	0.00	0.07	0.00	0.05	0.00	0.09				
	10-04-68	0.01	0.00		0.00	0.02	0.00	0.01	0.00	0.02				
Snake Creek Canal nr. Miami	10-17-67	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00		0.00	0.20	0.00
Dade Co.	02-27-68	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.01				
	10-24-68	0.00	0.00	0.00		0.01	0.00	0.01	0.00	0.01				
Sediment Samples														
Header Canal at State Road	11-01-67	0.00	0.00	0.00	0.00	0.00	0.00	2.0	1.0		0.00	2.0		
68—St. Lucie Co.	04-04-68	0.00	0.00	0.00	0.00	0.00	0.00	1.7	0.5	2.0				
	10-07-68	0.00	0.00	0.00		0.6	0.00	3.5	2.0	2.5				
Canal 24 at State Rd. 70	11-01-67	0.00	0.00	0.00	0.00	0.00	0.00	10.0	2.0		0.00	5.0		
St. Lucie Co.	04-04-68	0.00	0.00	0.00	0.00	0.00	0.00	1.9	0.5	1.0				
	10-07-68	0.00	0.00	0.00		0.00	0.00	1.5	0.0	0.0				
Plantation Canal nr. Ft.	10-17-67	0.00	0.00	0.00	0.00	0.00	0.00	20.0	10.0		0.00	10.0		
Lauderdale—Broward Co.	05-02-68	0.00	0.00	0.00	0.00	0.00	0.00	760.0	195.0	217.0				
	10-04-68	0.00	0.00	0.00		2.6	0.00	25.0	8.9	4.0				
Snake Creek Canal nr. Miami	10-17-67	0.00	0.00	0.00	0.00	0.00	0.00	30.0	3.0		0.00	20.0		
Dade Co.	05-02-68	0.00	0.00	0.00	0.00	0.00	0.00	20.0	12.0					

of more and more land each year for citrus production continues to deplete the supply of water available in the canals.

The FCD canal network is the major source of irrigation water in St. Lucie County. This drainage system is insufficient to supply irrigation water through extended dry periods, and shortages occur even in the normal dry season. The system is recharged by rainfall on canal areas and ground-water inflow from the area through which the canals flow. Some artesian water of poor quality is added to the system.

Seepage studies were made in October-November 1968 to determine hydraulic connection between the uppermost 20 feet of the shallow aquifer and canals 23, 24, and 25. Discharge measurements indicated seepage rates of 0.3 to 2.76 cfs per mile per foot of drawdown in the canals during this period of high ground-water levels. Gradients determined from water-level measurements in lines of wells adjacent to the canals were almost as steep as the gradients measured in the extreme dry period of March-May 1968, when ground-water levels were abnormally low. Water-level contour maps prepared from measurements during the extreme dry period of March-May 1968 show that major water level changes occur only within a mile of the FCD canals. The maps indicate that the potential of the uppermost 20 feet of the shallow aquifer to recharge the FCD canals during periods of insufficient rainfall is inadequate to meet future irrigation needs.

Pumping-test data indicate that relatively small to moderate amounts of fresh water are available from wells ranging in depth from 40–100 feet. The coefficient of transmissivity of the shallow aquifer ranges from 10,000 gpd per foot to 57,000 gpd per foot. Results of aquifer tests in the city of Fort Pierce by Black, Crow, and Eidsness (1962) and in Martin County by Lichtler (1957) are similar to those of tests for this report in western St. Lucie. The thicknesses and depth below land surface of coarse sand and shell zones are inconsistent in the area, and as a result, ground water yields from wells vary. Wells 6 inches or larger in diameter, with approximately 30 feet or more of screening and gravelpack in the zone 40 to 100 feet below land surface, will probably yield 100 to 200 gpm.

The salinity of the water in canals in St. Lucie County increases during prolonged dry periods, as mineralized artesian water becomes mixed with the canal water and the supply of fresh water becomes insufficient to flush the canals. The citrus growers and other agriculturalists in the county depend on the water in the canal network for irrigation, especially during dry periods. The increase in salinity of canal water during these critical periods has resulted in leaf burn to some citrus groves and discontinued use of water for irrigation from some of the major drainage

district canals. During extreme dry periods the chloride content increased as much as 300 mg/l at some sites in the major canals. Some dissolved minerals from fertilizers also tend to concentrate in the water as the water is reused.

The canals in St. Lucie County are nearly free of pesticides. DDT and its decomposition products occurred in small quantities in the sediment.

WELL NUMBERS

In order to coordinate data from wells on a nationwide basis, the U.S. Geological Survey has adopted a well-location system that locates the well by a 16-digit number based on latitude and longitude. The consecutive county well numbers used in this report are referred to the nationwide system, as follows:

County No.	Latitude-Longitude No.	County No.	Latitude-Longitude No.
41	271538N0803706.1	122	271551N0802651.1
42	272654N0804016.1	123	271853N0803237.1
73	272021N0802833.1	124	272314N0803813.1
74	272019N0802950.1	125	272524N0802428.1
75	272020N0802956.1	126	272541N0803148.1
76	272042N0803049.1	127	273034N0803743.1
77	272109N0802819.1	128	273117N0802917.1
78	271820N0803837.1	129	272207N0802146.1
79	271726N0803816.1	130	272225N0802523.1
80	271617N0803735.1	131	272136N0802429.1
81	273148N0802834.1	132	271547N0802813.1
82	272722N0802707.1	133	271742N0802708.1
83	272340N0802938.1	134	271826N0802951.1
84	272339N0802947.1	135	271610N0803022.1
85	272054N0802950.1	136	272425N0802233.1
86	272110N0802947.1	137	272122N0803042.1
87	272257N0802823.1	138	271837N0803942.1
88	273014N0803252.1	139	271731N0803842.1
89	272924N0803351.1	140	272602N0803558.1
90	273228N0803349.1	142	271551N0802651.2
91	272707N0803607.1	143	271928N0802905.1
92	272634N0802754.1	144	271359N0803303.1
94	272600N0803038.1	146	271649N0802241.1
95	272014N0803349.1	147	272355N0802824.1
97	271807N0803153.1	148	272844N0803636.1

County No.	Latitude-Longitude No.	County No.	Latitude-Longitude No.
98	272227N0802122.1	149	272742N0803333.1
99	272257N0802148.1	150	272911N0802513.1
100	271949N0802748.1	151	273116N0802743.1
101	271946N0802633.1	152	273234N0802553.1
102	271307N0802851.1	153	271346N0802237.1
103	271306N0802754.1	154	271318N0802228.1
105	271962N0802729.1	156	271808N0802126.1
107	272804N0802442.1	157	271448N0802955.1
108	273330N0802649.1	158	272641N0803404.2
109	273117N0802609.1	159	272641N0803403.1
110	272906N0802525.1	160	271448N0802955.2
111	272940N0802513.1	161	271448N0802955.1
112	272514N0802424.1	162	273028N0803727.1
113	272320N0802527.1	163	273028N0803727.2
114	272308N0802627.1	164	273028N0803728.1
116	272122N0803342.1	165	271858N0802042.1
118	272134N0803731.1	166	271858N0802043.1
119	272653N0803313.1	167	271547N0801902.1
120	272656N0803734.1	168	271542N0801902.1
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