DRE-134

DRAFT - Popalzai
Agricultural Water Use - UECPA

November 1981

INTRODUCTION

The purpose of this report is to discuss the progress on studies that are being conducted concerning agricultural water use in the Upper East Coast Planning Area (UEC) of southeastern Florida. Five hundred fifty six square miles in Martin County, 596 square miles in St. Lucie County, and 152 square miles in Okeechobee County are included in this area.

The climate is humid-subtropical with warm, wet summers and mild, dry winters. Rainfall on the area is the principal source of water for irrigated as well as non-irrigated crops. Irrigation water is drawn principally from storage in the major canal system and from groundwater. At the present time there are a few surface storage reserviors, and some use is made of free-flowing (artesian) wells when water quality in these wells is suitable.

Agricultural land use within the area includes: citrus, improved pasture, unimproved pasture, sugarcane, vegetables, ornamentals, and truck crops.

Water resources in the UEC are limited due to a lack of available water from the shallow aquifer and the expenses involved with acquiring water from deep aquifers. Most of the irrigation water comes from surface waters in SFWMD Canals 23, 24, 25 and 44. The SFWMD and the USGS therefore undertook a joint investigation to conduct actual field measurements of water use. These measures were conducted by physical monitoring of water pumpage activities in the study area.

Purpose and Scope

To collect and analyze agricultural water use data from the UEC Planning Area by the use of:

a. statistical sampling techniques,

b. direct and indirect flow measurements,

c. using vibration timers, and

d. analysis of collected data for the amount of water used for different types of irrigation systems, and the approximate water withdrawn from surface and groundwater sources.

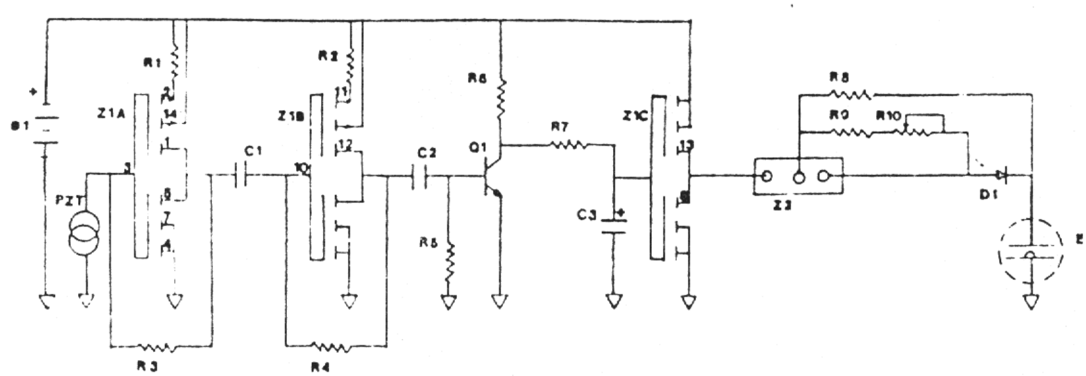
DISCUSSION

Field work for this program began on February 4, 1981. Each grower was contacted by telephone and an appointment was set up with the grower to explain the project aims and to collect data such as: their source of water; type/s of irrigation system/s used; number of acres irrigated by each system; crop type; crop yield; soil type; quantity and capacity of each pump and/or well on the property; and finally, inspection of the pump locations, determination of what type of pump was being used, and then installation of a vibration timer on each pump that would give quality data for the study.

The Vibration Timer Totalizer (VTT) is a small (1.75"x 1.75" x 1.0") self-contained device which senses vibration from whatever it is mounted ~~on~~ to, and electronically records operating time based on the assumption that vibration is present when the structure is operating and is not present when the structure is mechanically quiet.

The VTT contains its own power source, a 2.8 volt battery pack containing sufficient capacity to operate the VTT for a period of approximately three years. The recording device will record up to 1000 hours of operation and is designed to be easily removed, read and reset. The VTT mounts in a small metal bracket and is held in place with a plastic strap (commonly known as a "Tie Wrap"). The VTT bracket can be epoxied in place, with five small holes in its ~~back~~ base serving as tie-points for the epoxy. It may also be screwed in place utilizing these same holes. Additionally, the bracket may be strapped to larger, irregularly-shaped structures by using plastic banding material (similar to that used to hold boxes on pallets) through the two larger holes on the bracket base.

SCHEMATIC DIAGRAM AND PARTS LIST FOR THE VTT



USGS-VTT
JWM-00308
4/10/80

VIBRATION TIME TOTALIZER (VTT) PARTS LIST

B1	2.8 v battery	R1	680K ¼w cf
		R2	680K ¼w cf
C1	0.001 mfd	R3	18M ¼w cc
C2	0.001 mfd	R4	18M ¼w cc
C3	0.1 mfd	R5	1M ¼w cf
D1	1N457	R6	10M ¼w cf
		R7	1K ¼w cf
E1	E-Cell	R8	2.4M ¼w cf
PZT	$BaTiO_3$ crystal	R9	330K ¼w cf
Q1	2N2222A	R10	200K pot
		Z1	CD4007
		Z2	LM3342

Referring to the schematic diagram, PZT is a Ba Ti O_3 (Barium Titinate) crystal element which generates a small (30 millivolt) signal when it is mechanically flexed.

Vibration from the structure on which the VTT is mounted is transmitted to the PZT which is mounted on the printed circuit card. A small weight (lead shot) fastened onto the PZT causes it to twist and/or bend when vibration is present, thereby causing the output signal. Z1A and Z1B, two parts of the integrated circuit in VTT, are simple amplifiers which increase the voltage of the signal representing the vibration. When the voltage reaches a certain level (greater than 0.7 volts), transistor Q1 turns on and brings the voltage across C3 to zero volts. This causes Z1C's output to increase to the battery voltage (3.2 volts) supplying power to Z2.

Z2 is a constant output regulator which supplies a constant 630 nano-ampere current to E1, an electrocoulometer cell. This cell has the unique property of plating material from one electrode to the other, and the property is reversible. After use for a period of time, the E-cell is removed from the VTT and can be read by passing a reverse current of known magnitude through it. Running time of the structure being monitored can thus be determined.

CHANGING THE E-CELL

Removing and replacing the E-cell (the time recording element) is a simple procedure. The serial numbered plastic cylinder on the top of the VTT contains the E-cell and is removed by simply unscrewing the cylinder (turn in a counter-clockwise direction).

After removal of the cylinder, a replacement cylinder should be installed. It is important to replace the element, as the VTT should not be left out in the weather without an element in place. Care should be taken so as not to touch the tip of the E-cell (which is a small gold-colored dot in the center of the cylinder) as static electricity will be conducted through the cell - causing an error in recorded time.

After an element is removed, it will normally be mailed to a central location to be read, reset to zero, and then returned to the field. Currently the cells are being read by the Hydrologic Instrumentation Department of the U. S. Geological Survey office in Mississippi. The readings were compared with the pump logs that were supplied by some of the growers and the results were as close as 75%. Because of the dry season, the cells were not changed until mid-June to mid-July, 1981. It is planned that the timer memory cells will be changed on a regular monthly basis. The total water use estimation will be in the final report and we will try to estimate the amount of water used for different systems of irrigation per acre per year. This estimation will be based on our cell readings from 42 samples which cover 120,515 acres.

METHODOLOGIES

Many of the pumps in the surface water systems were two-way pumps, i.e., pumping from canals or reservoirs during the dry periods and then pumping out during the rainy periods. Because of this, it was essential that we install the timers on the most suitable pumps before the irrigation began.

The locations of all sites visited were plotted on General County Highway Maps and were verified in the office (Figure 1). A total of ~~62~~ 61 farms consisting of an area of ~~198,919~~ 197,639 acres were visited. This represents slightly over 50% of the total agricultural land in the planning area. The total agricultural land in the area is 379,399 acres (Land Resources Division, SFWMD).

Ninety-eight timers were placed on pumps for 42 of these farms, representing 120,515 acres, or almost 32% of the agricultural land in the planning area. Timers were not available for additional installations for the remaining farms. Some of the growers had complex irrigation systems that were not suitable for data collection. Some farmers were not willing to cooperate with the study.

The complete list of groves, pastures, ranches, and farms visited is included in Table 1.

Flow measurements were made on many pumps and wells by various direct and indirect monitoring techniques. Some of the different methods of direct

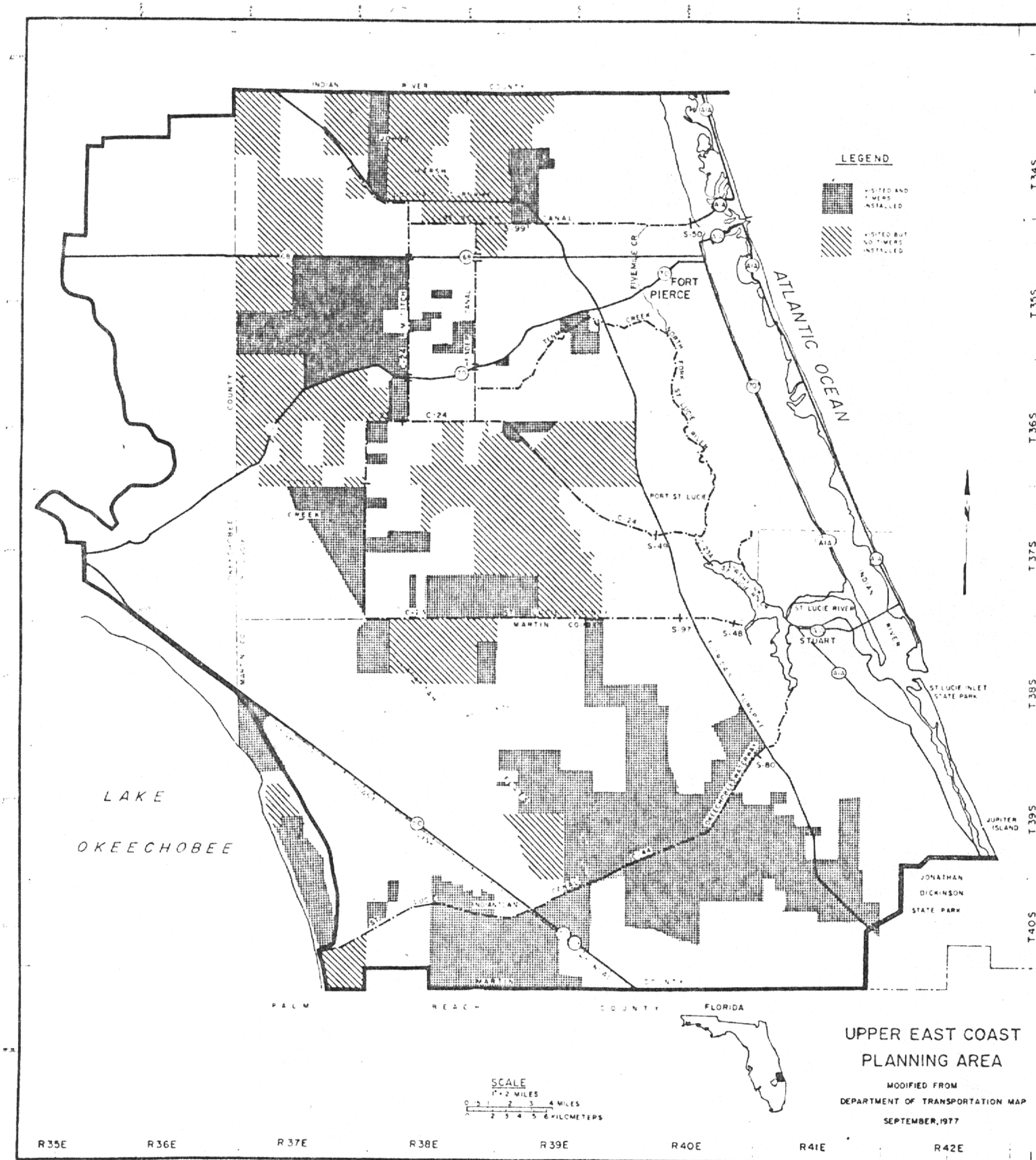


Figure 1. Locations of Sites Visited

GROVE NAME	TOTAL ACRES	NO OF WELLS	NO OF PUMPS	NO. OF TIMERS	CROP TYPE	IN STUDY	COUNTY CODE
EDSALL GROVE	640		2	2	C	Y	56
KIMO INVESTMENTS	73		1	1	C	Y	56
ADAMS PROPERTY	480		1	1	C	Y	56
ADAMS RANCH	20000	40	4	2	PC	Y	56
ALLAPATTAH WATER MANAGEMENT	1640	2	9	7	C	Y	56
ALCO GROVE	865	8		1	C	Y	56
ALCOMA ASSOCIATION	2350		5	5	C	Y	43
B-FORE GROVE (BECKER GROVES)	1280		3	1	C	Y	43
BESSEMER PROPERTIES	10280		3	3	C	Y	43
BLUE GOOSE GROWERS (ALAN WILSON)	1920		2	2	C	Y	56
BLUE GOOSE GROWERS (COLEMAN GROVE)	1155	16	13	6	C	Y	56
BOX RANCH GROVE	600		3	2	PC	Y	43
CAMAYEN CATTLE COMPANY	6500		8	2	S	Y	43
R. W. CARLTON	18000		9		PC	N	56
CAULKINS CITRUS COMPANY	3548		2	2	C	Y	43
CAULKINS INDIANTOWN GROVE	3941		2	2	C	Y	43
CAULKINS LAND DEVELOPMENT, LTD.	8124		4	4	C	Y	43
CHASTAIN RANCH	1844		1	1	P	Y	43
CLOUD GROVE (COCA-COLA)	4800		45		C	N	56
COLONIAL GROVE	360	4	4	3	C	Y	56
COW CREEK RANCH	1000	3	2		C	N	56
CULVERHOUSE CATTLE COMPANY	6700	12			P	N	56
EMERALD RANCH	5000				P	N	56
EMS RANCH (STARK)	2200	7			P	N	56
EVANS PROPERTIES, INC.	10240	13	5	3	CP	Y	56
FARSOUTH GROWERS	2500		2	2	V	Y	43
GARDINIER GROVE	1000		1	1	C	Y	43
Keep GLADES GROVE	504	2	1	1	C	Y	56
GOLDEN GROVE	420	1	1	1	C	Y	56
GRANADA RANCH	7000	27			P	N	56

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C - Citrus
P - Pasture
S - Sugar Cane
V - Vegetable

Y - Yes
N - No

Table I

GROVE NAME	TOTAL ACRES	NO OF WELLS	NO OF PUMPS	NO. OF TIMERS	CROP TYPE	IN STUDY	COUNTY CODE
HAYES GROVE	286	1	7	4	C	Y	56
P. L. HINSON	6000		2	2	P	Y	43
HOBE GROVE	5000	51	13	4	C	Y	43
HODSON GROVE (COCA-COLA)	7000		22	3	C	Y	43
JAYHAWK GROVE	1050	17			C	N	56
KAY-ONE GROVES, LTD.	1780	3	3	3	C	Y	43
KAY-TWO GROVE, LTD.	1935		6	6	C	Y	56
KAY-TWO GROVE (GREEN)	3000	8			CP	N	56
KELLY HALL GROVE	280	5		2	C	Y	56
LEO GROVES	350	1	1		C	N	56
MAYFLOWER CORPORATION	1200		5		C	N	56
MAYFLOWER GROVE-INDIANTOWN	900		1	1	C	Y	43
MEADOWBROOK DAIRY	1500		1		P	N	56
MC CARTY RANCH	2690	5			CP	N	56
MONREVE RANCH	3840		1	1	P	Y	43
OLSON GROVES, INC.	400		1		C	N	56
ORANGE CO. OF FLORIDA	3660	40	4		C	N	56
PEACOCK FRUIT & CATTLE COMPANY	17000	13	5		CP	N	56
RAINBOW GROVE, INC.	180	4			C	N	56
D.C. SCOTT RANCH	2400	5	0		P	N	56
OUT SOUTHERN FRUIT DISTRIBUTORS OUT	1280	OUT	4	OUT	C	N OUT	OUT 56
STRAZZULA BROTHERS GROVE	1594				C	N	56
SUNSWEET GROVE, INC.	640	3	2	2	C	Y	56
R. E. TEAGUE	1200		1	1	P	Y	56
R. W. TEDDER	120		1	1	C	Y	56
TEN MILE CREEK GROVE	928		1	1	C	Y	56
G. H. TUCKER	5000	1	1	1	VP	Y	43
TIEDKE GROVE (KARST GROVE SERVICES)	620		3	1	C	Y	56
TRUST J&D (CASSAN GROVE SERVICE)	160		2		C	N	56
UNITED GROVE	1100	2	4		C	N	56
XRX GROVE	192		3	2	C	Y	56
ZODIAC RANCH	640	1	1	2	C	Y	56

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C - Citrus Y - Yes
P - Pasture N - No
S - Sugar Cane
V - Vegetable

This one out

Table I (contd)

flow measurements are: flow meters, barrel test, circular orifice weir, and by the use of an orifice bucket, current meter, and a Clampitron flow meter.

For most of the flowing (artesian) wells, standard hydraulic flow calculations were applied. These hydraulic flow calculation tables and illustrations used are included ~~(Figures~~ ---------- as Tables 2, 3 and 4.

In most groves, the discharge pipes were either submerged or underground and with large diameters. In each case this prevented the use of the Clampitron system for flow measurements.

For estimating the flow from these pumps by an indirect method, calculations were determined from the pump specifications. The theory used for these calculations is as follows:

$$BHP = \frac{Q(gpm) \times H(feet)}{3960 \times Eff.}$$

where:

BHP = Brake horsepower

Q = Flow rate (GPM)

H = Total pumping head

For example, if the pump BHP is 50 and the total pumping head is 8 ft. with 75% efficiency, then

$$Q = \frac{BHP \times Eff. \times 3960}{H}$$

$$Q = \frac{50 \times 0.75 \times 3960}{8} = 18562.5 \text{ gpm}$$

indent 5

In calculating the efficiency of the pumps in the Upper East Coast Planning Area, the pumps are estimated to be 65% efficient because most of the pumps are old. The efficiency range to be expected varies with pump size, type, etc., but usually it is between 50% and 82%.

MEASURE OF FLOW FROM
HORIZONTAL AND INCLINED PIPE

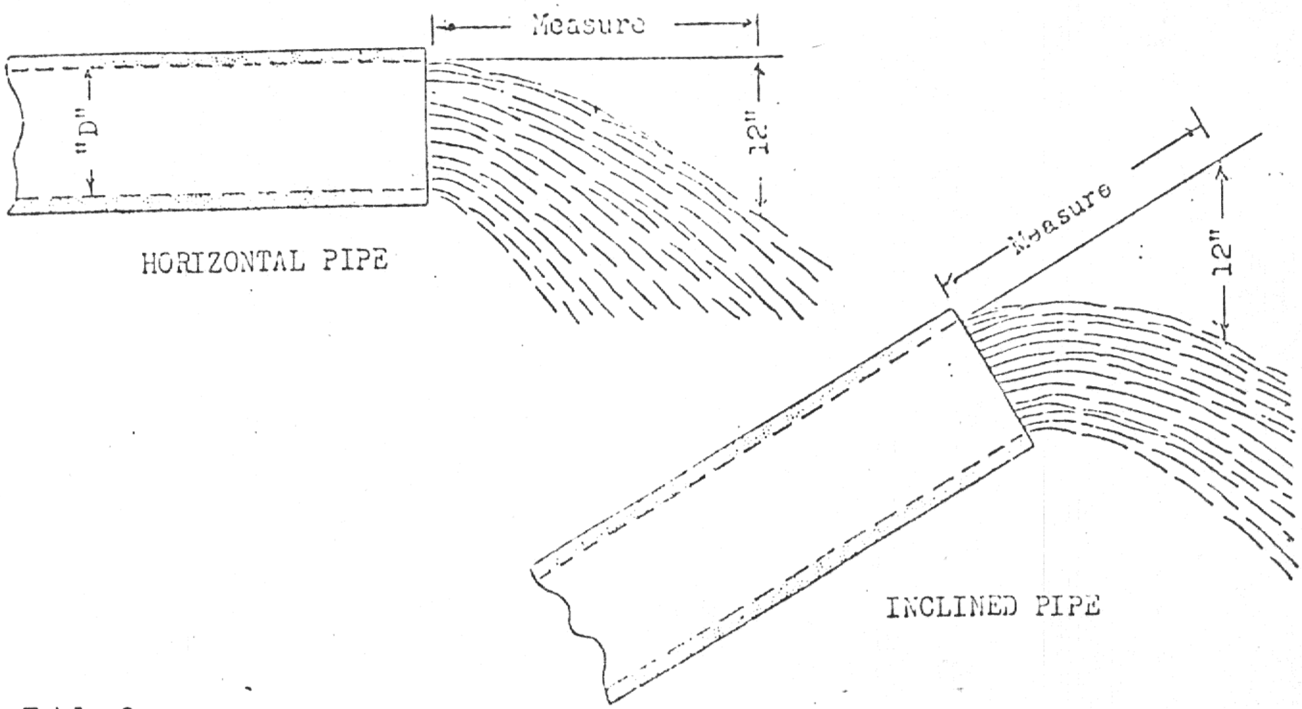


Table 2

DIAMETER OF PIPE "D"	MEASURED DISTANCE					
	12 INCHES	14 INCHES	16 INCHES	18 INCHES	20 INCHES	22 INCHES
2 INCH	41	48	55	61	68	75
3 INCH	90	105	120	135	150	165
4 INCH	150	181	207	232	258	284
6 INCH	352	410	470	528	587	645
8 INCH	610	712	813	915	1017	1119
10 INCH	960	1120	1280	1440	1600	1760
12 INCH	1378	1607	1835	2032	2286	2521

(Taken from "JOHNSON NAT'L DRILLERS JOURNAL"
Vol. 21, No. 6, Nov-Dec., 1949)

which of these credits do we use? or both?

~~AGR-SCS-Spartanburg, S.C.-July 195[illegible]~~ ~~Sheet 1 of 3~~

~~WILLIAM R. CLARKE, DISTRICT CONSERVATIONIST~~
~~U.S.D.A. SOIL CONSERVATION SERVICE~~

MEASURE OF FLOW
FROM
VERTICAL PIPE

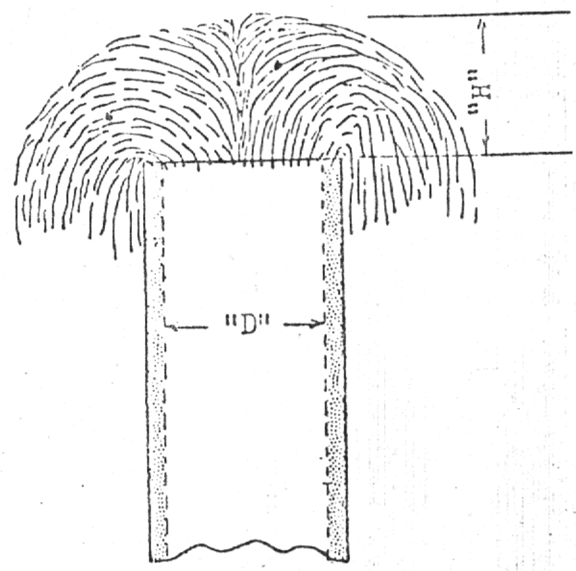
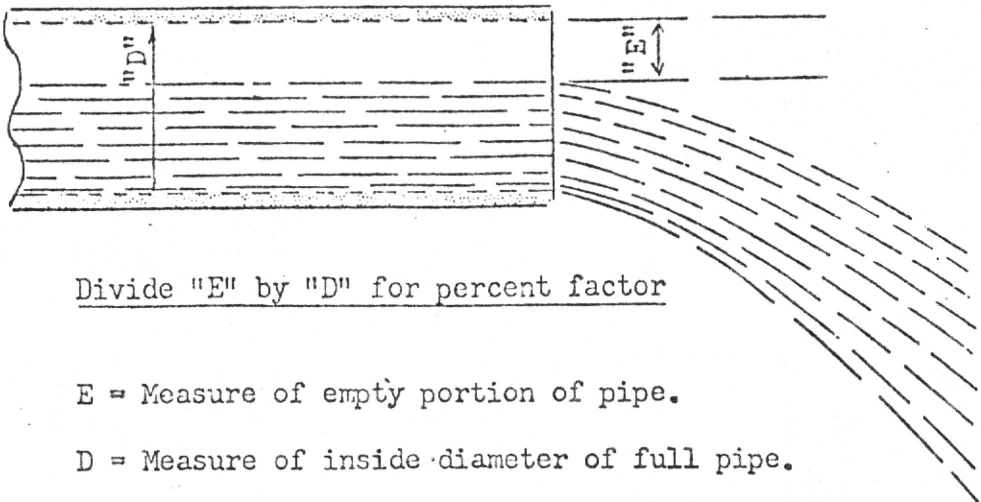


Table 3

FLOW FROM VERTICAL PIPE (USGS) - - APPROX. G.P.M.						
HEAD IN INCHES	INSIDE DIAMETER OF PIPE (IN INCHES)					
	2	3	4	6	8	10
3	35	77	135	311	569	950
3½	38	85	149	341	626	1055
4	41	92	161	369	687	1115
4½	44	98	172	396	733	1200
5	47	104	182	420	779	1280
5½	49	109	192	444	825	1350
6	52	115	202	469	872	1415
7	57	126	219	509	949	1530
8	61	135	236	548	1025	1640
10	69	153	265	621	1155	1840
12	76	169	294	685	1275	2010

(Taken from "JOHNSON NAT'L DRILLERS JOURNAL"
Vol. 21, No. 6 Nov-Dec., 1949)

MEASURE OF FLOW
FROM
PARTIALLY FILLED PIPE



Divide "E" by "D" for percent factor

E = Measure of empty portion of pipe.

D = Measure of inside diameter of full pipe.

Table 4

FACTOR	E/D	FACTOR	E/D	FACTOR	E/D
0.95	10	0.63	40	0.25	70
0.86	20	0.56	45	0.14	80
0.81	25	0.50	50	0.05	90
0.75	30	0.38	60	0.00	100
0.69	35	0.31	65		

To determine the flow of a horizontal pipe partly full, first estimate the flow if the pipe was running full, then calculate the actual flow of the partially filled pipe by using a factor based on the ratio of the full portion of the pipe to the empty portion. For instance, in an 8-inch pipe partially full, it measures 2.4 inches from the top of the pipe inside to the water surface. The ratio of diameter to depth of water is 2.4 divided by 8, or 0.30. This is 30 percent, and according to tables which have been worked out, the factor is 0.747. This is so near 75 percent that one could take 75 percent of the full pipe flow as an estimate of the actual flow. See Table I of Sheet 1 to get flow from a full pipe.

(Taken from "Johnson Nat'l Drillers Journal"
Vol. 21, No. 6, Nov.-Dec., 1944

TOPOGRAPHY AND DRAINAGE

The land surface in St. Lucie County 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 sea level. The coastal sandhills adjacent to the Intercoastal 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. Detailed soil information is shown in the Soil Surveys of Martin, St. Lucie and Okeechobee Counties.

Natural drainage in St. Lucie County has been altered by the construction of many canals for flood control. Surficial drainage patterns and the major drainage canal and water control facilities are shown in Figure 2 . Much of the area once known as the St. Johns River Marsh in northwestern St. Lucie County has been improved for agriculture, and the natural drainage outlets have been completely blocked and altered. 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 Ft. Pierce Farms Drainage District (Figure 2) 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 SFWMD Canals 23, 24, and 25. Hundreds of secondary canals and drainage ditches drain the excess water into the primary canals, which then discharge into the ocean.

Ft. Pierce and the coastal area are drained primarily by the North Fork of the St. Lucie River and Ten Mile Creek. Five Mile Creek extends ~~a few miles inland south of Ft. Pierce~~. southward near the western city limits of Ft Pierce and Ten miles creek extends a few miles inland south of Ft. Pierce

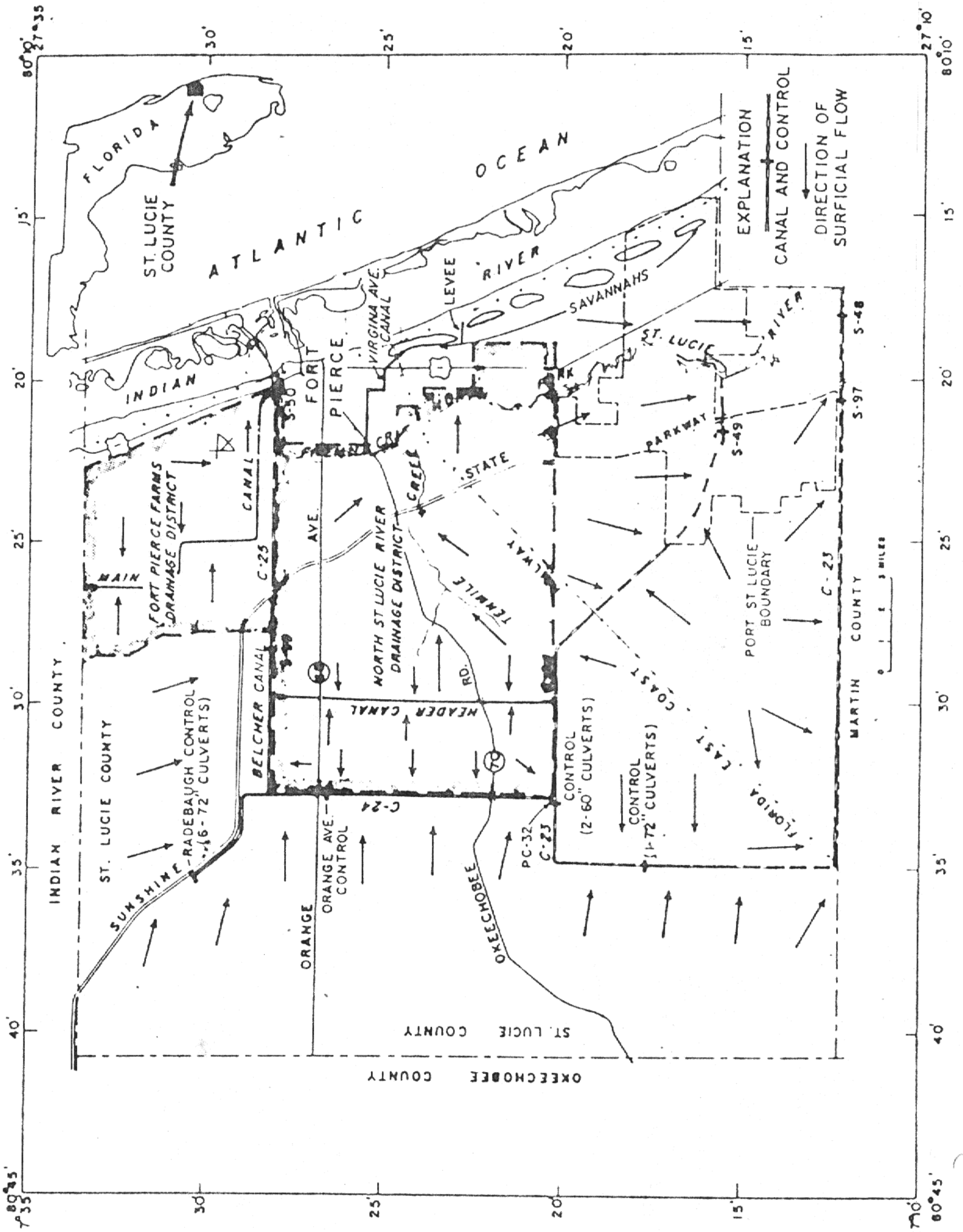


Figure 2. St. Lucie County showing locations of the area of investigation, the drainage districts, and surficial flow.*

*USGS Report of Investigations No. 62

Figure (2)

A marshy area called the "Savannahs" parallels the coast a short distance inland and extends southward from Ft. Pierce to the Martin County line (Figure 2). In the past, the northern section of the Savannahs served as a reservoir for water supply to the City of Ft. Pierce. The north section of the Savannahs is approximately 2.7 miles long and has been isolated from the other Savannahs to the south by a levee. Water from the Belcher Canal (C-25) can be pumped into Five Mile Creek, repumped at Okeechobee Road into Virginia Avenue Canal, and then be diverted to the Savannahs during drought conditions.

GROUNDWATER

Groundwater in the UEC Planning Area is used primarily for irrigation of agriculture and is obtained from either the shallow aquifer or from the deep Floridan aquifer.

SHALLOW AQUIFER

The shallow aquifer is one of the major sources of fresh water in the UEC. For determination of its potential for water supply and other uses, a cooperative program between the USGS and the SFWMD was initiated in 1976. The purpose of this study was to investigate and document the hydrologic properties of the shallow strata.

Lithology of the surficial aquifer in the UEC is primarily sand, clay, silt, shell, and limestone deposited during the Pliestocene and Pliocene Epochs.

In most of the area the aquifer is unconfined and under water table conditions. Locally, artesian conditions were noted by Parker (1955) in the vicinity of Ft. Pierce and Indiantown, where discontinuous clay lenses act as a confining unit. Impermeable and semipermeable clays and marls (calcareous clays) of the Tamiami and Hawthorn formations (Miocene) unconformably underlie the surficial aquifer from its base (Licher, 1960). Contour lines showing the altitude of the base of the aquifer indicate extensive erosion of the Miocene sediments prior to the deposition of the aquifer materials.

Lithologic logs of wells in the area show that in some locations, sediments of the Tamiami formation appear. In other locations in the UEC, lithologic logs indicate that the base of the surficial aquifer is formed by Flurial deposits containing erosional materials from both the Tamiami and Hawthorn formations.

RECHARGE

The shallow aquifer in the UECPA receives most of its recharge from rainfall in and immediately adjacent to the area.

The average rainfall is about 55 inches a year, of which 65 percent occurs from June through October. Most of the county is covered by sand that is sufficiently permeable to absorb practically all the rainfall. In general, surface water runoff is small except in the slough areas where the water table is at or above the land surface.

DISCHARGE

Groundwater is discharged into streams, springs, or lakes by direct flow into the ocean, by evapotranspiration, and by pumping from wells. Many small streams and sloughs in Martin County discharge groundwater to the Atlantic Ocean and Lake Okeechobee. In the central part of the county, where the water table is at or near the surface during most of the year, evapotranspiration is a very important means of discharge. In addition to natural means of discharge, most groundwater is carried away by canals and ditches.

DEEP AQUIFER

The Floridan aquifer system in the area consists of a number of producing zones separated by semi-permeable zones in a sequence of Oligocene and/or lower Miocene to upper and middle Eocene carbonate sediments. The Floridan aquifer, as defined by Parker on a more regional basis, includes "Parts or all of the middle 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" (Parker, 1955). The area's hydrologic geology was described in detail by Brown and Reece (1979).

Large quantities of water for irrigation are taken from the Floridan aquifer system via free-flowing wells and transported by ditches where mixing occurs with surface and shallow groundwaters of generally higher quality. In some pastures and citrus groves, flowing wells are used with no mixing.

ARTESIAN AQUIFER PROPERTIES IN MARTIN COUNTY

Wells penetrating the Floridan aquifer will flow in all parts of Martin County except at the tops of the high sandhills in the eastern part of the county where the land surface is more than 50 feet above mean sea level. The top of the Floridan aquifer in Martin County is usually between 600 and 800 feet below the land surface. The thickness of the aquifer is unknown since there is no record of a well or wells penetrating the depth of the aquifer. The deepest known wells extend from 1,300 to 1,500 feet below mean sea level.

Wells drilled into the Floridan aquifer in the area west of the fault (Figure 3) indicate an appreciable flow from about 660 to 800 feet below mean sea level. East of the fault, wells must be drilled 800 to 1,000 feet below mean sea level before they will flow.

Figure 3 is a contour map drawn on the top of the limestone of the Ocala group. West of the fault limestone usually provides the first significant flow of water, as the overlying Tampa and Suwannee beds are either very thin or are missing. East of the fault the Suwannee Limestone is relatively thick and will yield small quantities of water.

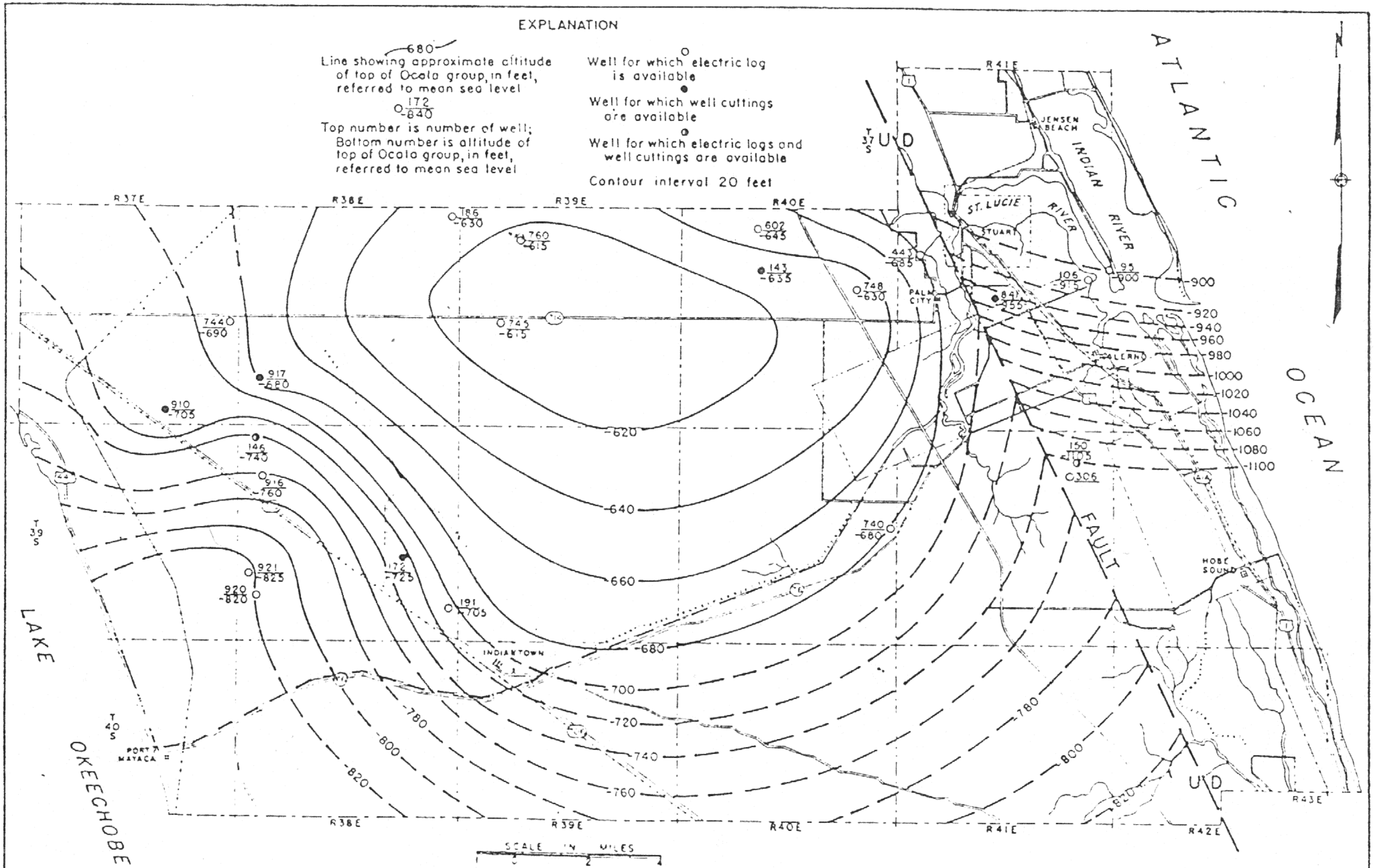


Figure 3. Approximate altitude of the top of the Ocala group in Martin County*

* USGS Report of Investigations No. 23

Most of the artesian wells in the county include limestone of the Ocala group in the producing part of the open hole, and end in the underlying Avon Park Limestone. No wells are known to penetrate the Lake City Limestone. A well north of Indiantown was reported to have been drilled to a depth of 1,800 feet and may have penetrated the Lake City Limestone. The water at that depth was reported to be too salty for irrigational use, and the well was sealed off at 1,100 feet before its initial depth could be verified. Most wells are cased only to the Hawthorn formation to a depth which the driller feels the hole will stay open. This depth differs throughout the county, ranging from 275 to 795 feet below the land surface.

ARTESIAN AQUIFER IN ST. LUCIE COUNTY

The artesian aquifer in St. Lucie County is part of the Floridan aquifer defined by Parker (1955) and "includes parts or all of the middle Eocene (Avon Park and Lake Park Limestones), 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 the 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 in 1972, reported that the county has 1,150 deep artesian wells and that the average well flow is 200 GPM.

The general direction of groundwater movement, as indicated by contours, is toward the canals and eastward toward Five Mile Creek and the St. Lucie River. In the extreme west, along Okeechobee Road, the land surface is high and groundwater levels are correspondingly high. In the southeast, in the area encircled by Canals 23 and 24, land surface is about 32 feet above sea level.

The elevation of the groundwater 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 Ten Mile Creek, Five Mile Creek, and the North Fork of the St. Lucie River. On Ten Mile Creek a control structure just west of the Sunshine State Parkway (Figure 2) regulates water levels at a maximum elevation of 9.4 feet above mean sea level. The North Fork of the St. Lucie River has no control structure - allowing drainage direct to the Atlantic Ocean.

An extremely dry period occurred in St. Lucie County during March, April, and part of May 1968. Groundwater 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 perimeter ditches. The canals were pumped to or near minimum levels allowed by the WMD (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 groundwater 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 WMD canals were determined from measurements in wells alined perpendicular to the 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 4 was prepared from measurements made on April 2, 1968. Figure 5 shows the configuration of the water table from measurements made on May 1, 1968. Although low canal levels had persisted since the April 2 measurements, the major changes in groundwater levels had occurred within 1 mile of the WMD 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 WMD canals.

The fluctuation of the water levels in Canals 23, 24, and 25 for the dry period in March, April, and May and groundwater gradients measured April 2 and May 1-2 at selected sites adjacent to each canal are shown in Figures 6, 7, and 8. 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 groundwater levels from April 2 to May 1 or 2 are portrayed in Figures 6, 7, and 8. The changes in groundwater levels 500 feet from the canals were almost proportional to canal level changes.

The water level profiles in Figures 6, 7, and 8 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.

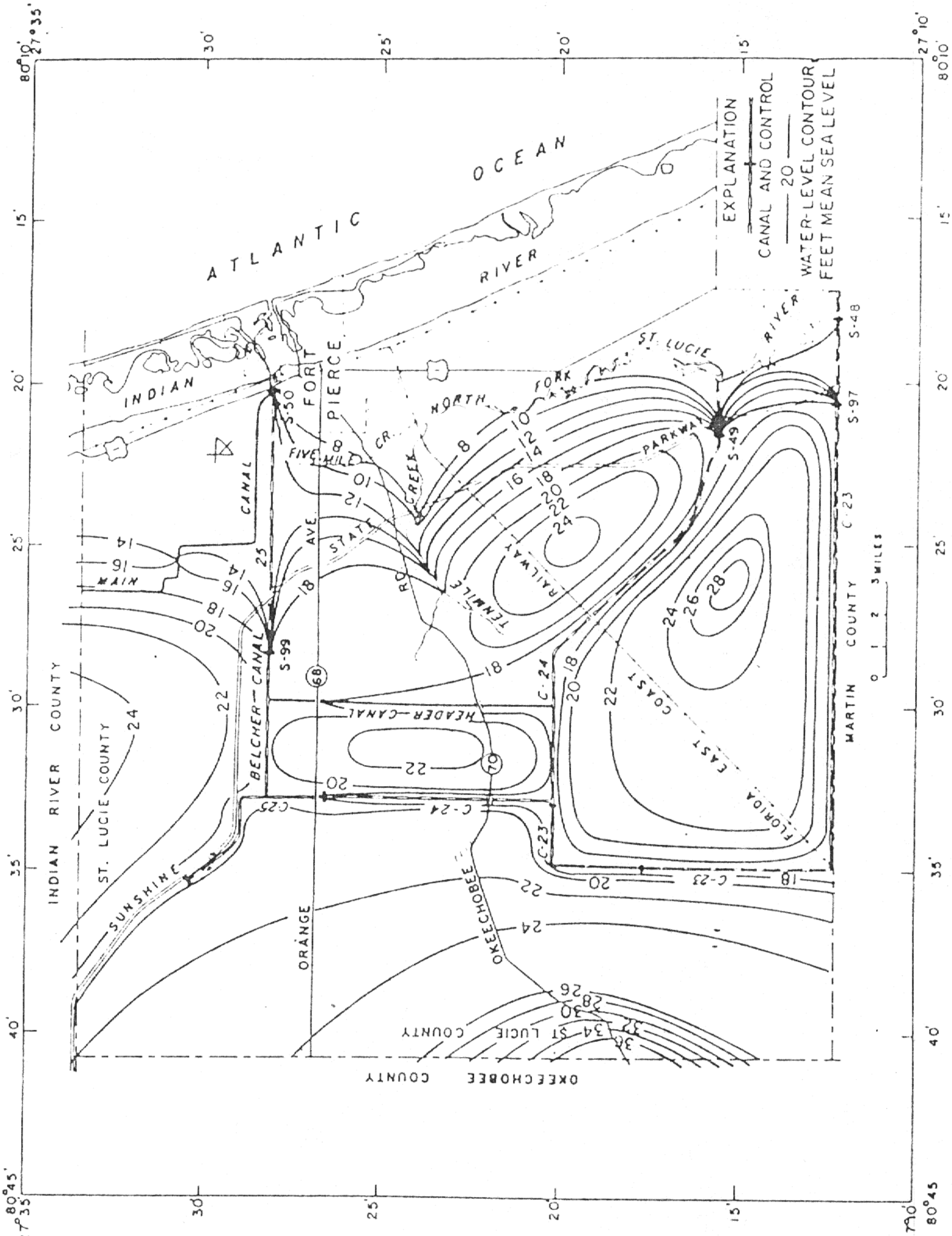


Figure 4. Water level contour map of St. Lucie County on April 2, 1968 during a time of low water levels*

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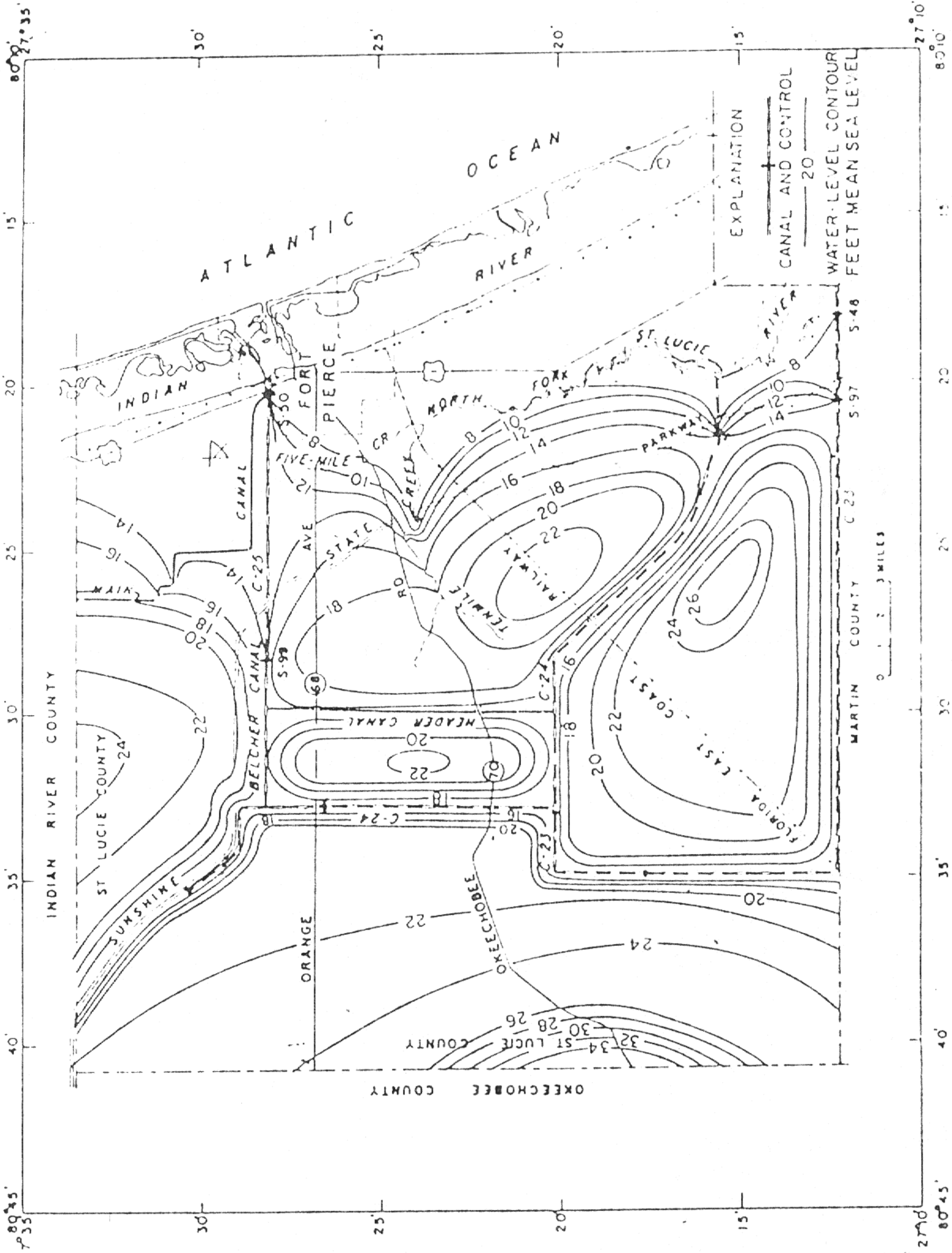

Figure 5. Water level contour map of St. Lucie County on May 2, 1968 during a time of extremely low water levels*

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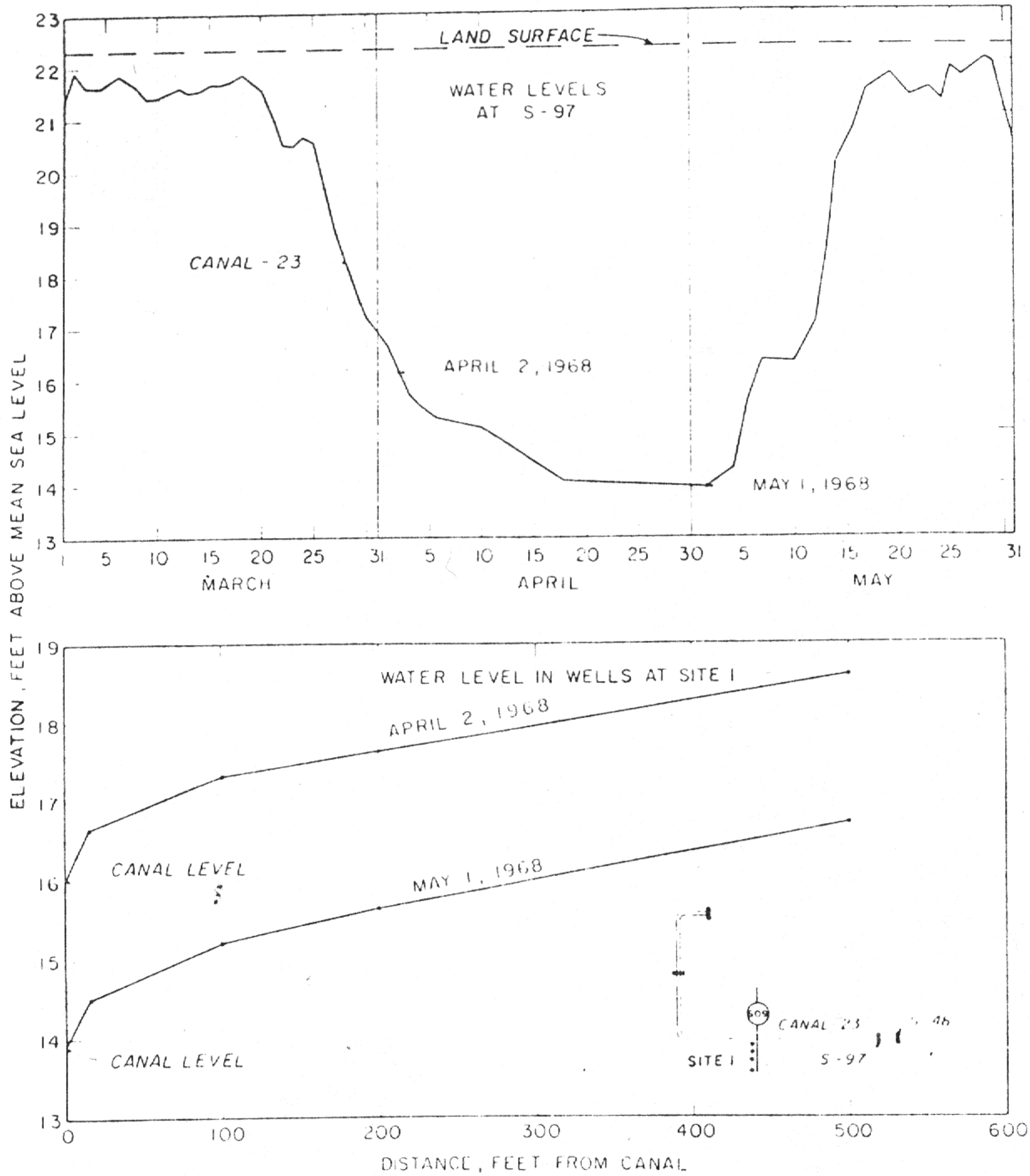

Figure 6. Hydrograph of Canal 23 at S-97, March 1 - May 3, 1968 during the dry season, and groundwater gradients adjacent to the canal at the beginning and near the end of the time of extremely low water levels in the canal.*

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Figure 6

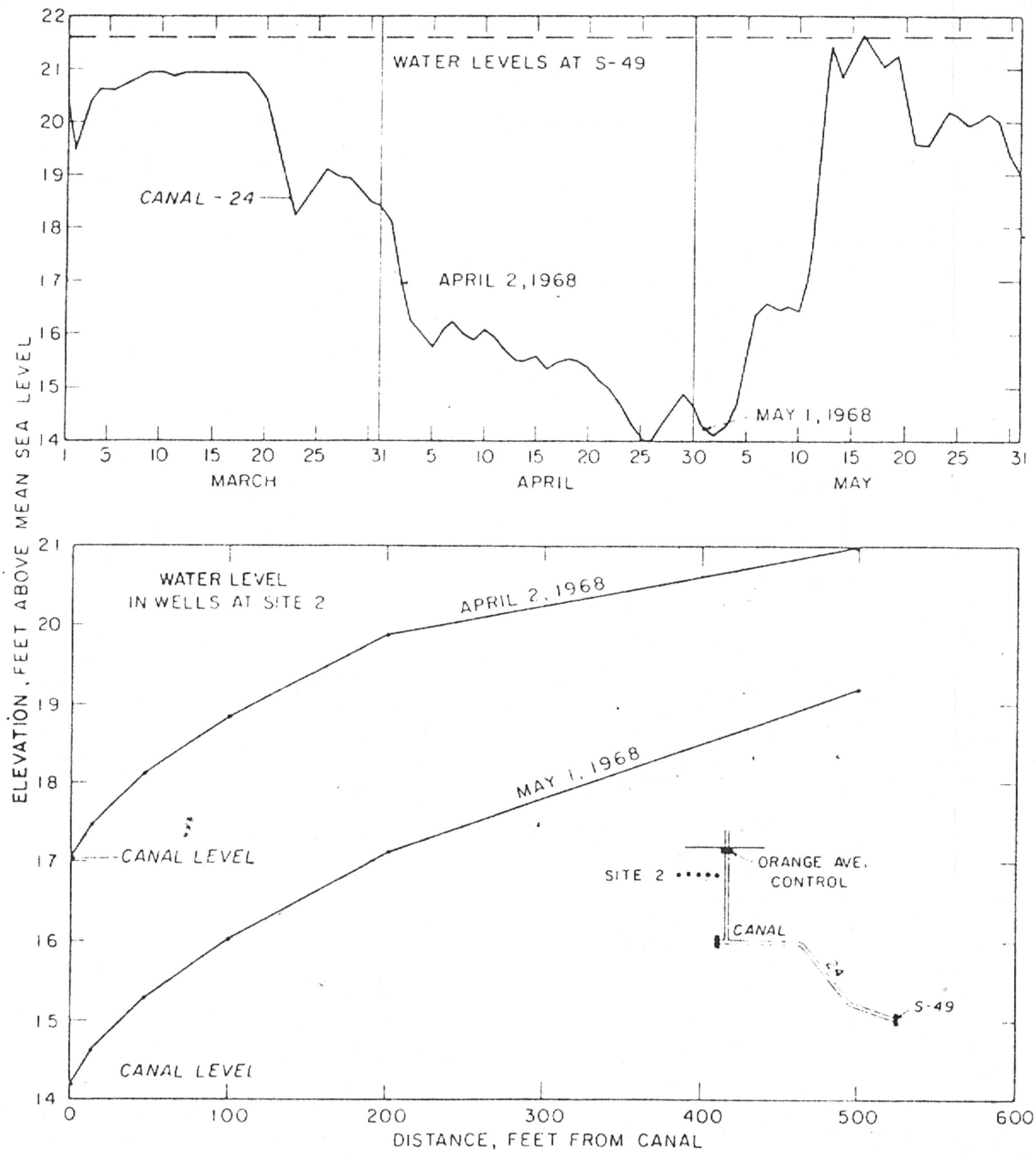

Figure 7. Hydrograph of Canal 24 at S-49, March 1 - May 31, 1968 during the dry season, and groundwater gradients to the canal at the beginning and near the end of the time of extremely low water levels in the canal*

*USGS Report of Investigations No. 62

Figure 7

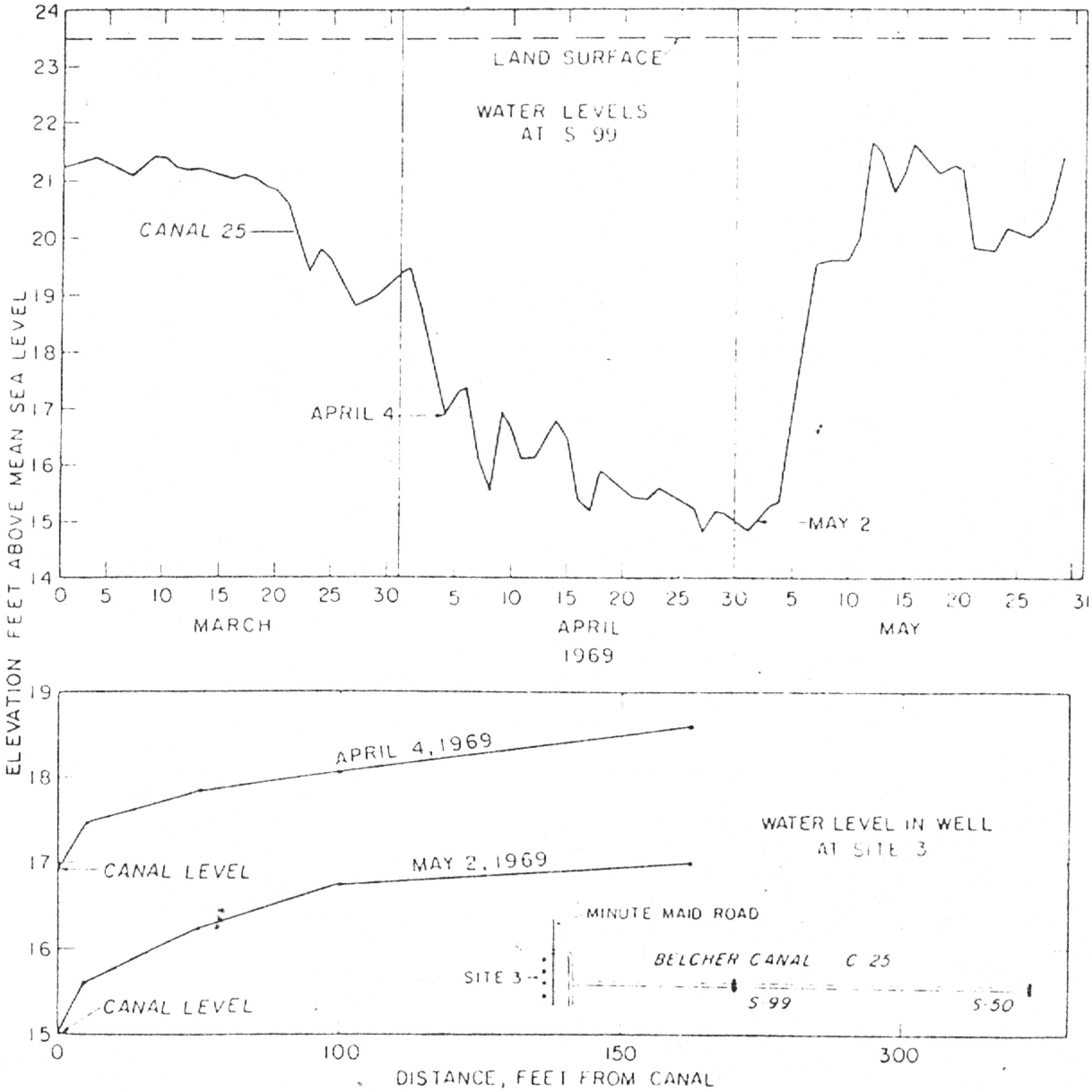

Figure 8. Hydrograph of Canal 25 at S-99, March 1 - May 31, 1968 during the dry season, and groundwater gradients adjacent to the canal at the beginning and near the end of the time of extremely low water levels in the canal*

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CANAL SYSTEM AND STORAGE

The volume of water that is potentially available for allocation for beneficial use in the St. Lucie County area consists of three components: (a) runoff generated from rainfall over the basin, (b) storage within the boundaries of the channels, and (c) groundwater seepage into the canals. The first component requires the development of catchment areas and/or surface storage for full utilization of this resource.

The second component, channel storage, is being used to the greatest extent possible at the present time as indicated by the extremely low stages reached in the canal system at frequent intervals.

The third component can be visualized as consisting of: (a) a relatively constant portion which arises from the average groundwater gradient between the canal water surface and the groundwater table a considerable distance from the channel, and (b) another portion which fluctuates much more is derived from changes in channel bank storage arising from changes in canal stage.

The majority of the present demand for allocations of surface water is satisfied by the canal storage and associated seepage components. For example, the rate of groundwater 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 (H. W. Bearden, 1972).

Canals 23, 24, and 25 of the SFWMD are the major components of the drainage and flow network in central and western St. Lucie County (Figure 2). These canals extend throughout the county, and all are controlled to regulate water levels and discharges. The control of flooding in the agricultural areas was the primary reason for construction of the SFWMD canals, but with the increase in the citrus acreage, the canals have been an important source of irrigation water.

Canal 23 has an automatic control structure (S-97) near the outlet, a 72 inch culvert control 6 miles north of the Martin County line (Figure 2), and two 60 inch culvert controls at (PC-32) the junction of Canals 23 and 24 (Figure 2). The control structure, S-97, is regulated to maintain a water level of 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 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 control culvert 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 msl at maximum water level is 109 acre feet.

Canal 24 has an automatic control structure (S-49) that maintains the water level at about 20 feet (Figure 2). Water is diverted to Canal 24 from Canal 25 at the Orange Avenue control during periods of low water levels. 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 structure (S-99) that is adjusted to hold water levels at approximately 20 feet above msl, and a concrete dam 7 miles downstream (S-50) that has a crest of 12 feet above msl (Figure 2). The control at Orange Avenue holds the water at the same level as at 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 (Figure 2). The Radebaugh culverts were installed (with controls) to maintain the water level in the canal that runs parallel to 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 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 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 Ft. Pierce Farms Drainage District(FPFDD) in the northeastern part of the county, and the North St. Lucie River Drainage District (NSLRDD) in eastern St. Lucie County (Figure 2). The NSLRDD extends from Canal 25 in the north, Canal 24 in the west and south, and joins the FPFDD in the north.

The districts have built multi-purpose canals and control structures. The effectiveness of their program was increased when these districts linked their major canals to the SFWMD canal system. The districts regulate their control 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 Ten Mile 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 Ten Mile Creek. Flood water can be pumped into Canals 24 and 25 or drained through Ten Mile Creek to the North St. Lucie River.

The drainage network in St. Lucie County includes the SFWMD canals, drainage district canals, and hundreds of private drainage canals that intersect the SFWMD and drainage district canals. The citrus growers in the county have become dependent on this network of canals as a primary source of 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 to evaporation.

Maintaining high water levels in the canals also helps to maintain high groundwater levels.

Long, dry 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 level of 14 feet msl in SFWMD Canals 23 and 24 by the middle of April and they remained at this level until the rains in May (Figures 4, 5, and 6). The rapid decline in the level of 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 9. 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 excessive 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 evaporation, transpiration, and seepage, one grower has been storing enough water in a one square mile (640 acres) reservoir to irrigate one hundred acres of citrus through the regular dry season.

QUANTITATIVE STUDIES

The system of primary canals in St. Lucie County is designed to provide drainage for the agricultural areas and to store as much water as possible. The many lateral canals convey excess rainfall directly from the swamps and farmland to the primary canals. Groundwater is contributed to the primary

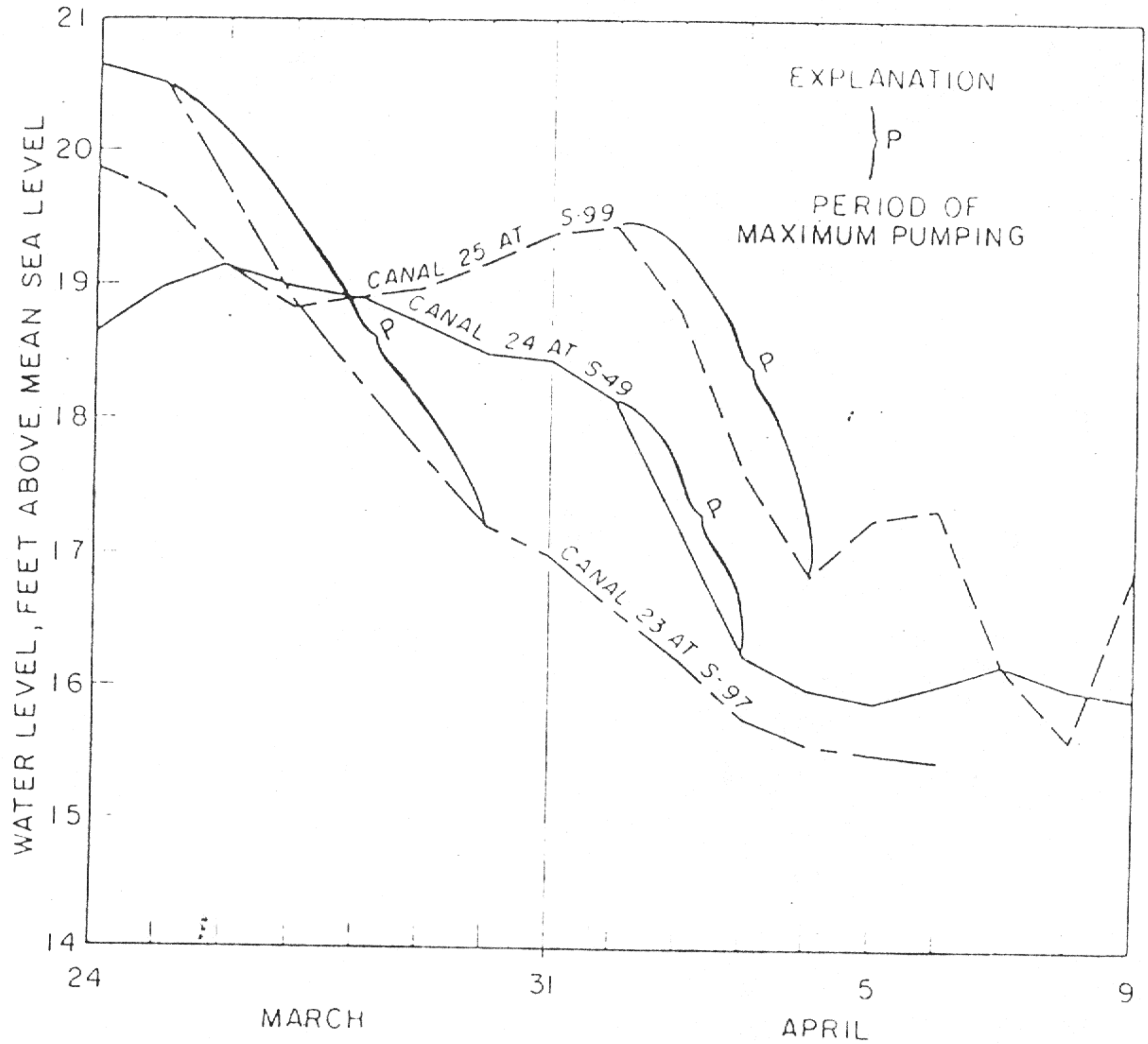

Figure 9. Hydrographs of Canals 23, 24, and 25 showing periods of maximum pumping in March and April 1968.*

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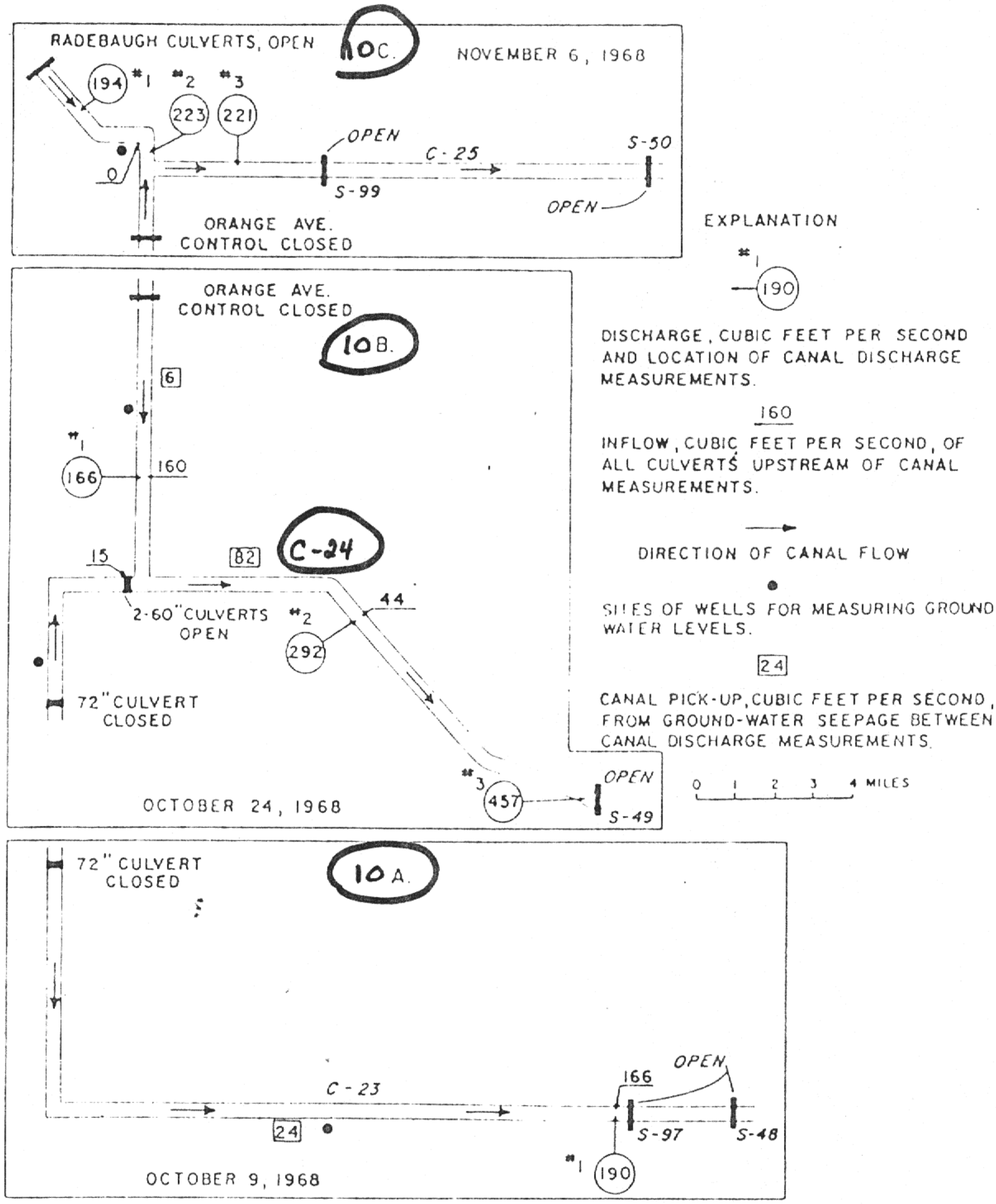
system by seepage. Groundwater becomes important to local water users during long dry periods when water levels in the canals drop as a result of irrigation use and evapotranspiration. During the dry periods, when the water table declines, many of the shallow lateral canals become dry and many of the deeper lateral canals are controlled - preventing any flow to primary canals.

Figure 10 shows that, near the end of the 1968 wet season (October - November), quantitative studies of Canals 23, 24, and 25 were made to determine canal bank seepage rates and the relation of groundwater gradients to canal levels. The quantitative collection of field data to determine gradients included lowering levels in the canals at control structures S-49, S-97, and S-99; making concurrent discharge measurements in the canals; measuring flow of all lateral canals to Canals 23, 24, and 25; and measuring water levels in the wells at the sites shown in Figures 4, 5, and 6. The study of each canal was made independently of other canals, and at intervals of about one a week. Canal levels were lowered an average of 4 feet to induce seepage into them. After the canal levels were lowered, the control were regulated to maintain a constant canal stage. Discharge measurements were made several miles apart in the canals, and all culvert flow into the canals was measured. The rates of groundwater seepage from canal banks for each reach of the primary canal was obtained by the culvert inflow subtracted from the increase in discharge within the reach from one measuring site to another.

After the measurements in the canals were completed, the control structures were closed until the canal levels recovered to pre-test levels. The rate of canal level recovery was measured by recording and staff gages. The groundwater seepage rates were determined by the following volumetric formula:

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

0 changes



Figures 10A, 10B, and 10C. The SFWMD Canals showing flow to the canals from groundwater seepage and laterals which intersect the canals.*

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where Q = seepage, in cubic ft. 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 flow 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 the 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 (Figure 10A) was included in the study of Canal 23. The five 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 in October 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 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 groundwater 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 (Figure 10B). The water level in Canal 24 was lowered 3.7 feet - from 20.1 feet to 16.4 feet - on October 23, 1968. Discharge measurements were made October 24 along the canal at eight 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 with Canal 24.

The first discharge measurement in Canal 24 was made 5 miles downstream from the Orange Avenue control (Figure 10B). The discharge was 166 cfs. For the reach of the canal, total culvert inflow was 160 cfs. Thus, the groundwater seepage was 6 cfs, or 0.3 cfs per mile of canal per foot of drawdown. Groundwater gradients to the canal were also measured in a line of wells at a site three miles south of the Orange Avenue control (Figures 7 and 10B). Using the seepage pickup of 6 cfs and the gradient obtained from the measurements in the line of wells as an average for the five mile reach of the canal, a transmissivity of 11,700 gpd per foot was obtained for the shallow materials in that area.

The second discharge measurement of 292 cfs was made eight miles downstream from the first measurement (Figure 10B). 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 groundwater seepage. The thin but permeable beds of coquina in the area where Canal 24 turns east probably accounts for the increased groundwater contribution.

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

A discharge of 15 cfs from the five 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 at this point was composed of runoff flow from lateral canals and groundwater seepage. No other discharge measurements were made along the section of Canal 23 included in the Canal 24 study. ~~The~~

~~determ~~ ~~water~~ ~~culvert~~ ~~to the~~

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 the canal west of S-99 to the Radebaugh culverts (Figure 10C). This was the major area studied because of the concentration of citrus growers west of S-99 who depend on water from Canal 25.

Because the automatic gates at S-99 failed to close properly, the water level in Canal 25 was lowered 3.8 feet from 20.2 feet to 16.4 feet on November 4, 1968. Discharge measurements were made on November 5 at two mile intervals from the Radebaugh culverts downstream to S-99 (Figure 10C). Flow through the Radebaugh culverts was 196 cfs. The two measurements, 194 cfs and 223 cfs, showed a groundwater seepage rate of 2.6 cfs per mile per foot of drawdown in the canal. No appreciable pickup could be measured in the two mile canal reach immediately west of S-99 and the two mile reach between measurements 2 and 3. There are few uncontrolled interconnecting lateral canals to the primary canal in this area, therefore, inflow from the culverts was negligible.

Structure 99 was closed on November 6, 1968, and Canal 25 began to fill from the flow through the Radebaugh culverts. Discharge was computed from the water level data of the gage at S-99 by the volumetric method. 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.

The groundwater gradients were determined after the control was closed and the canal began to fill. The gradients in Figure 11 show the relation of the water table to canal levels at different time intervals. The gradient which was measured one 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 11.

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 was lowered from 17.0 to 12.0 feet, and the rate of recovery was observed at S-99. Bengochea determined that the average rate of groundwater 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 and the relatively small amount of seepage to the primary canals and the steep gradients to the canals, it is apparent that the groundwater 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 4, 5, and 6 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.