TECHNICAL PUBLICATION SJ 83-3

A STUDY OF CROWN FLOOD IRRIGATION METHODS

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Palatka, Florida

May 1983

Project Number 2002311

GLOSSARY

1. Gross Irrigation - Total amount of water that flows onto groves from feeder canal during irrigation cycle.

2. Return Flow - Total amount of water that flows from groves into drainage canal during an irrigation cycle.

3. Total Application - Total amount of water entering into groves including rainfall during irrigation cycle (Gross Irrigation + Rainfall).

4. Net Application - Total amount of water used by groves during an irrigation cycle including rainfall (Total Application - Return Flows).

5. Effective Irrigation - Total amount of water added to groves (excluding rainfall) during an irrigation cycle (Gross Irrigation - Return Flow).

6. Net Rainfall - Portion of total rainfall that remains in soil storage and is not lost in surface runoff.

7. Evapotranspiration - The quantity of water transpired by plants during their growth, plus the amount of moisture evaporated from the surface of the soil and vegetation.

8. Consumptive Use - Amount of water theoretically needed by crop in order to have maximum production.

9. Water Use - Total amount of water used by the grove system including losses. (Gross Irrigation + Net Rainfall - Return Flow - Change in Surface and Ground Water Storage).

10. Water Use Efficiency - Ratio between consumptive use (water used by plants) and water use, expressed as a percent.

11. Effective Rainfall - Portion of total rainfall that meets the consumptive use requirements

12. Supplemental Water Requirement - Amount of water required by crops in addition to rainfall, for maximum growth. (Consumptive Use - Effective Rainfall)

13. Irrigation Requirement - Amount of irrigation water applied to meet supplemental water requirements.

14. Irrigation Efficiency - Ratio between supplemental water requirement and the irrigation requirement (Effective Irrigation), expressed as a percent.

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ABSTRACT

The Crown Flood Irrigation method is widely used by citrus growers in and around Indian River County. In this irrigation method, large amounts of water are allowed to flood irrigation furrows between the citrus beds; after the beds are saturated, excess water is drained out. Because of this large movement of water and the highly saturated soil conditions during part of the irrigation cycle, the irrigation efficiency of this method is lower than other more efficient methods. The Indian River Citrus League has expressed concern about the future of crown flood irrigation because of the Distict's consumptive use policies. This study was undertaken to document water use and efficiency of the crown flood irrigation method.

A weather station was installed in a study area within Indian River County to collect climatological data. Eight water level recorders, three observations wells, and three tensiometer sets were installed on the study grove to monitor inflows and outflows of surface water along with changes in soil moisture. Evapotranspiration was estimated using two methods: Blaney-Criddle and Christiansen. Irrigation flows were calculated based on discharge estimates through the culverts using the orifice equation. A water storage accounting procedure based on the monitoring of soil moisture content was used to confirm the discharge measurements. The water budget equation was used to determine the total water use i.e., actual water used by citrus groves including both beneficial and non-beneficial uses. Potential evapotranspiration, estimated from the Christiansen equation was used to estimate consumptive use of water for the trees. Non-beneficial uses of water include deep percolation, lateral movement of water, and excess evaporation from open water surfaces and saturated soils. Water use efficiency of the system was determined by the ratio of consumptive use to water use.

INTRODUCTION

BACKGROUND AND PURPOSE

The crown flood irrigation method is used extensively for citrus production. In general, this method requires a higher water use than more efficient methods such as drip irrigation. As a result of the high water use requirements, Indian River Citrus League expressed concern in 1979 about the impact of the St. Johns River Water Management District's (SJRWMD) proposed consumptive use rule (Chapter 40C-2 FAC) relative to the future use of the crown flood irrigation method. At that time, it was difficult to evaluate this concern because of a lack of detailed data on the operating procedures and water use requirements of crown flood irrigation. This study was initiated with the purpose of monitoring the irrigation operations of a crown flood grove over two growing seasons and documenting the actual water use.

The University of Florida Institute of Food and Agricultural Sciences (IFAS) expressed interest in a similar study. As a cooperator in this study, IFAS participated in the data collection effort. However, a separate expanded report will be published by IFAS.

DESCRIPTION OF STUDY AREA

The study area is located on Becker Road, approximately one mile south of State Route 60 and 4.5 miles west of I-95 (Figure 1) in Indian River County, Florida. The area is within the St. Johns Water Control District (SJWCD) which was formed in 1962 to manage water resources in the area. The SJWCD controls flow of water within all feeder and drainage canals and floodways within its boundary. During periods of excess rainfall (normally from June to October) water from the drainage canals is pumped into the floodway which connects to a

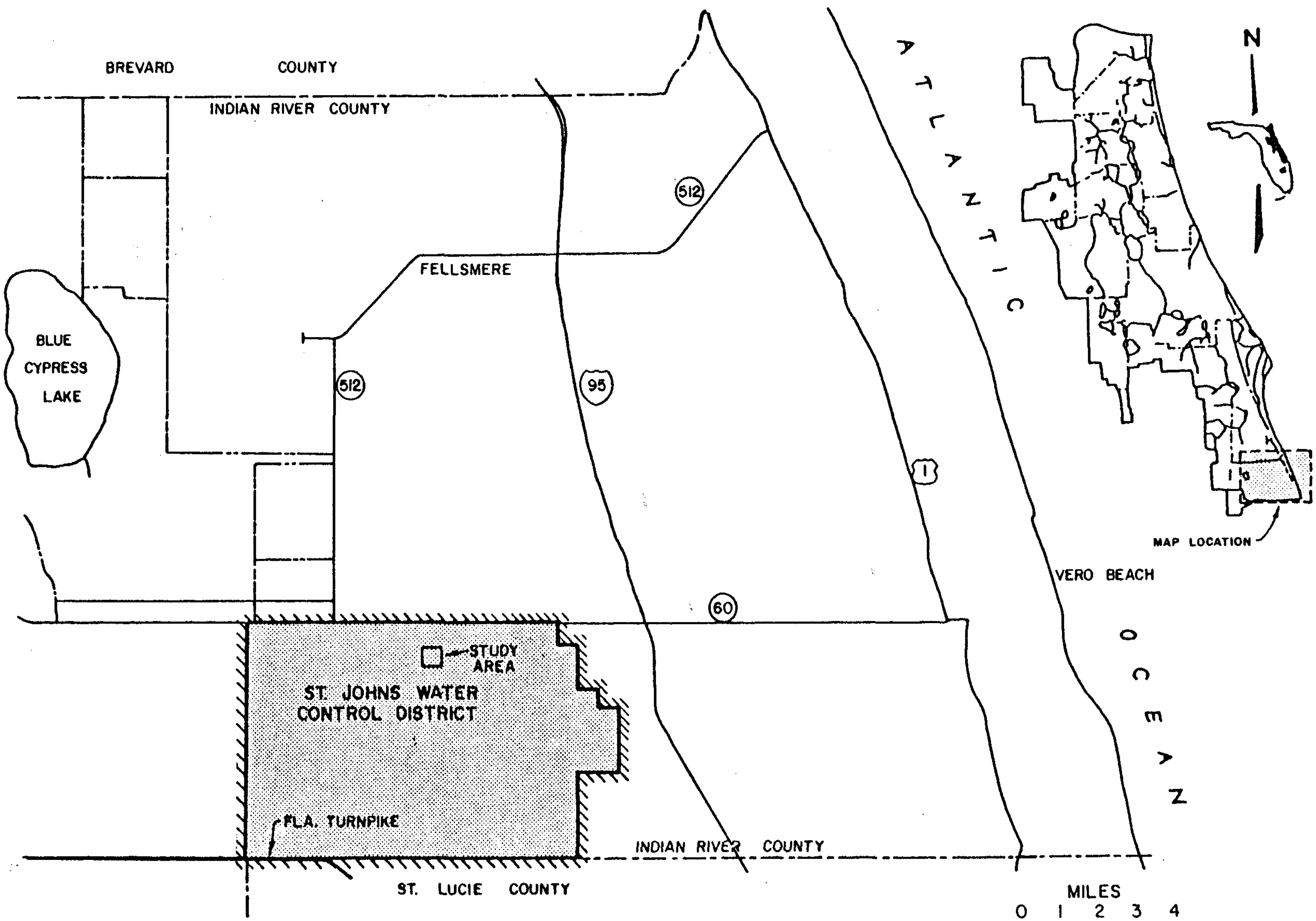


FIGURE 1. St. Johns River Water Control District Location Map.

1760-acre reservoir. Excess waters from the reservoir are released into the St. Johns River Marsh.

The SJWCD Reservoir provides the primary source of irrigation water and is supplemented with ground water when necessary. This operation is regulated by the SJWCD as shown in Figure 2. Water is released from the reservoir into the floodway and through connecting culverts into the feeder canals providing water to each individual grove. The excess water is collected in the drainage canals and then pumped by the SJWCD back into the floodway where it can be used for future irrigations.

The study area represents mature and healthy citrus groves in the region. Three individual test blocks were selected. Each test block is approximately 36.7 acres in size, bounded by roads on the east and west and by irrigation ditches on the north and south. Each tree row is about 580 feet long. The irrigation furrows are about 20 feet wide and 3.5 feet deep and beds are approximately 30 feet wide (Figure 3).

Soil at the test grove is in the Winder Fine Sand group. There are generally four soil layers in the groves. Above the original ground surface elevation of about 23.3 feet NGVD is Layer 1, a mixture of different soil types caused by the construction of the furrows (Figure 3). Underlying Layer 1, Layers 2 and 3 consist of about 0.8 feet of fine sand and 1.2 feet of clayloam, respectively. Below 21.2 feet NGVD lies a mixture of hard shell and clay (Layer 4).

DATA COLLECTION AND ANALYSIS

A weather station installed by the SJRWMD north of the entrance to the study grove (Figure 4) is equipped with the following instruments: rainguage, thermometers (air and water), evaporation pan, anemometer, pyranograph (measuring solar radiation) and sling psychrometer (measuring humidity).

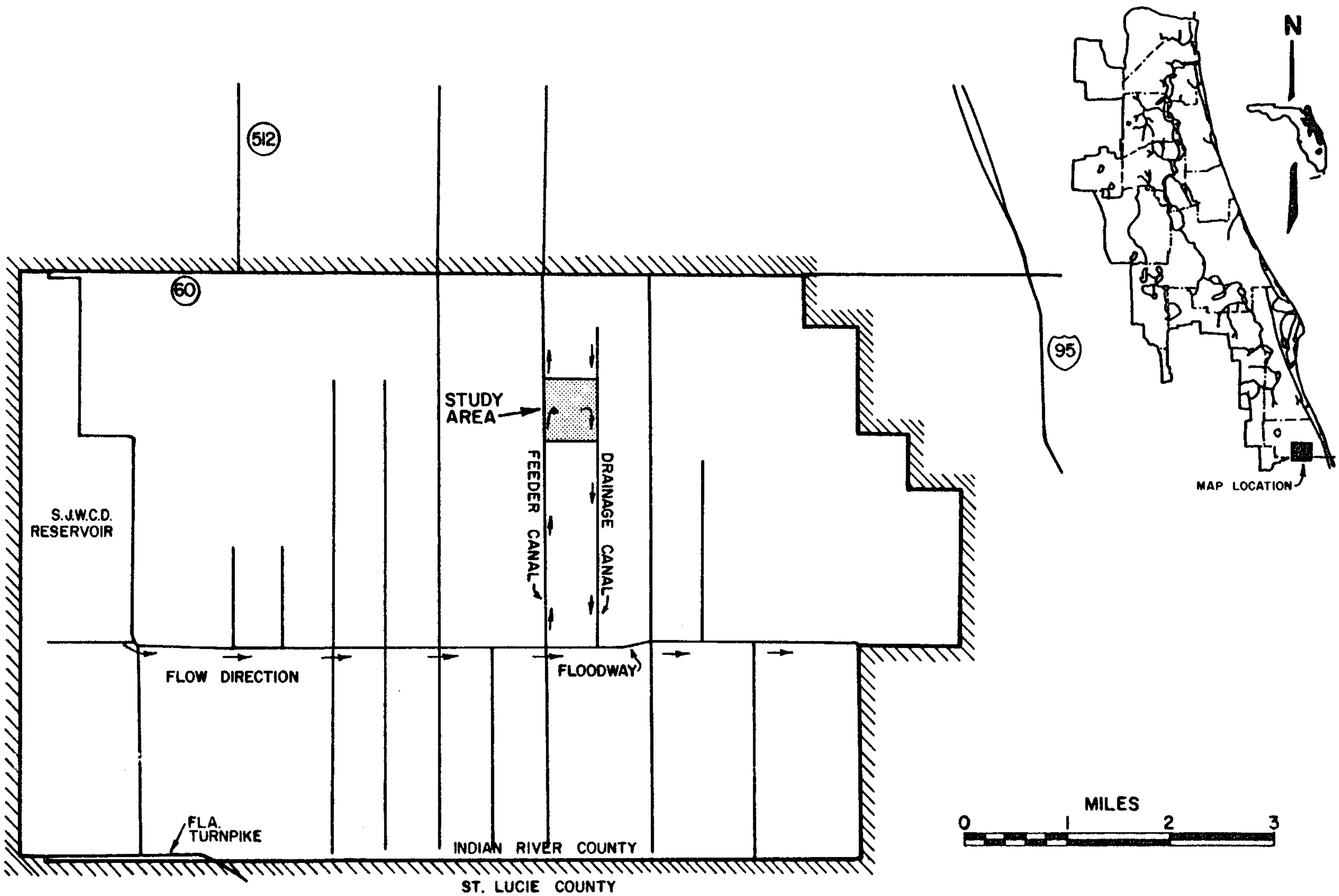
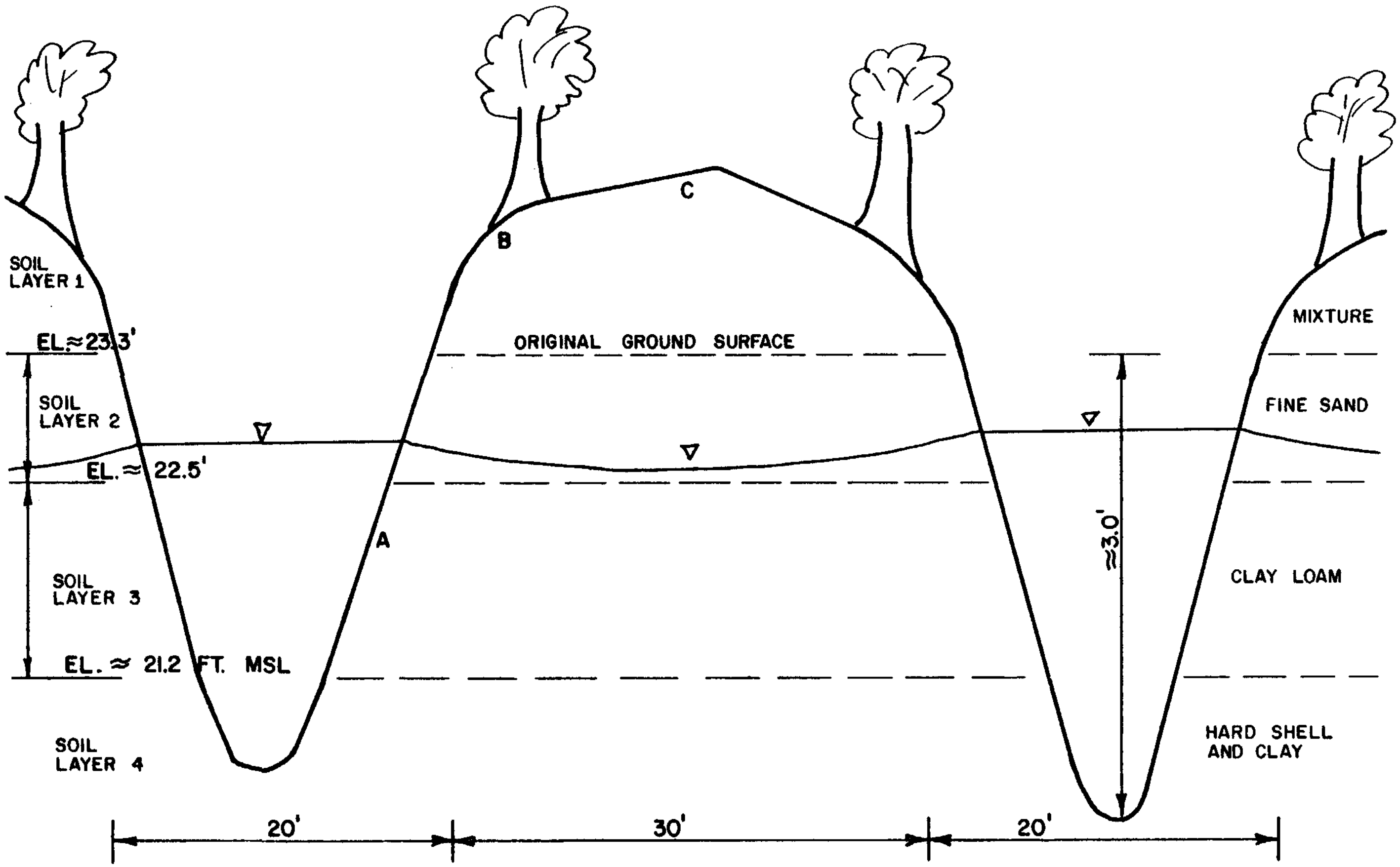


FIGURE 2. Water Circulation in St. Johns Water Control District During Typical Irrigation Cycle.



NOTE : A, B, AND C ARE OBSERVATION WELLS
AND TENSIOMETERS LOCATIONS

FIGURE 3. Typical Soil Profile at Irrigation Beds.

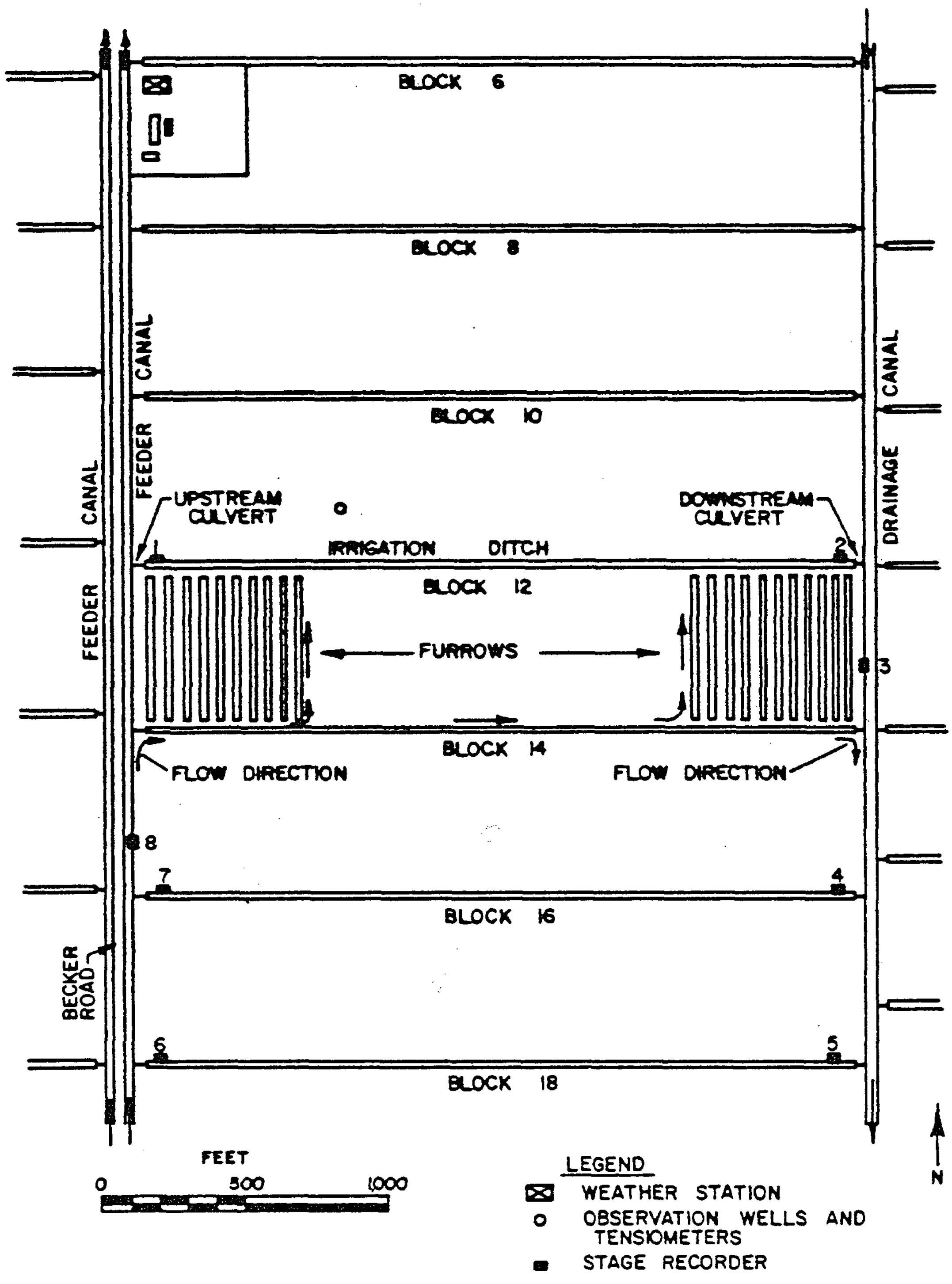


FIGURE 4. Flow of Irrigation Waters in Study Area

Data collected at this weather station was used to estimate evapotranspiration (ET) from the groves.

A system of eight stage recorders was used as shown in Figure 4 to monitor inflow and outflow of water from the groves. Discharge through the culverts was determined from stage readings using stage discharge relations developed from flow measurements.

Soil moisture in the groves was monitored by three sets of tensiometers (each set has six tensiometers). An observation well was located at each tensiometer set to record water levels. Water table elevations were measured continuously over the study period while soil moisture measurements were taken twice a week. The tensiometer sets were initially installed on December 10, 1979, with locations (A, B, and C) as shown in Figure 3. After April 6, 1981 they were moved to three different beds all located at the tree line in order to determine the variation of soil moisture over the grove. All data presented in this study was collected from Block No. 10 where tensiometers and observation wells were located (Figure 4).

From the inflows and outflows calculated for an irrigation cycle, the water use for the citrus groves was determined from the following equation:

$$\text{Water Use} = \text{Gross Irrigation} + \text{Net Rainfall} - \text{Return Flow} - \text{Change in Storage} \quad (1)$$

Water Use Efficiency was then calculated as:

$$\text{Water Use Efficiency} = \frac{\text{Consumptive Use}}{\text{Water Use}} \times 100 \quad (2)$$

where, Consumptive Use equals the amount of water necessary for normal growth of citrus trees. The difference between water use and consumptive use is the amount of water lost as a result of deep percolation, lateral seepage flow, and other evapotranspiration from the soil and the irrigation system.

IRRIGATION PRACTICES

The majority of citrus groves in Indian River county use crown flood irrigation. This method is often confused with flood irrigation. In flood irrigation, the entire grove area is flooded to a depth of about 2 to 3 inches of water (Figure 5). This water is then allowed to stand in the groves and infiltrate into the soils. This method requires efficient downward percolation through soil or water will stand for too long in the root zone of the tree thus reducing productivity. In the areas where the water table is close to the surface this method of irrigation is not practical.

In crown flood irrigation, furrows are dug with the trees being planted on the beds between the furrows (Figure 6). A typical crown flood irrigation cycle can be divided into three stages; an irrigation stage, a seepage stage, and a return flow stage (Figures 6-7). During the irrigation stage, water floods the irrigation furrows and seeps into soil zone. No additional water is added to the irrigation ditch during the seepage stage; water seeps from the furrows into the beds until potentiometric levels are equalized. Finally, during the return flow stage excess water is drained from the grove. As shown in Figure 7, the surface water in the irrigation furrows is quickly removed while the excess soil water drains slowly for several days.

In this study grove, the need for irrigation is determined by the wilting point of the weeds in the irrigation furrows and also to a lesser extent by the actual citrus trees. Prior to irrigation, downstream culverts on the irrigation ditches are closed. During the irrigation stage, the upstream culverts are opened allowing water to flow from the feeder canal to the irrigation ditches. Water flows from the irrigation ditch to the individual furrows through a six inch pipe at each furrow (Figure 8). The culvert opening varies from about six

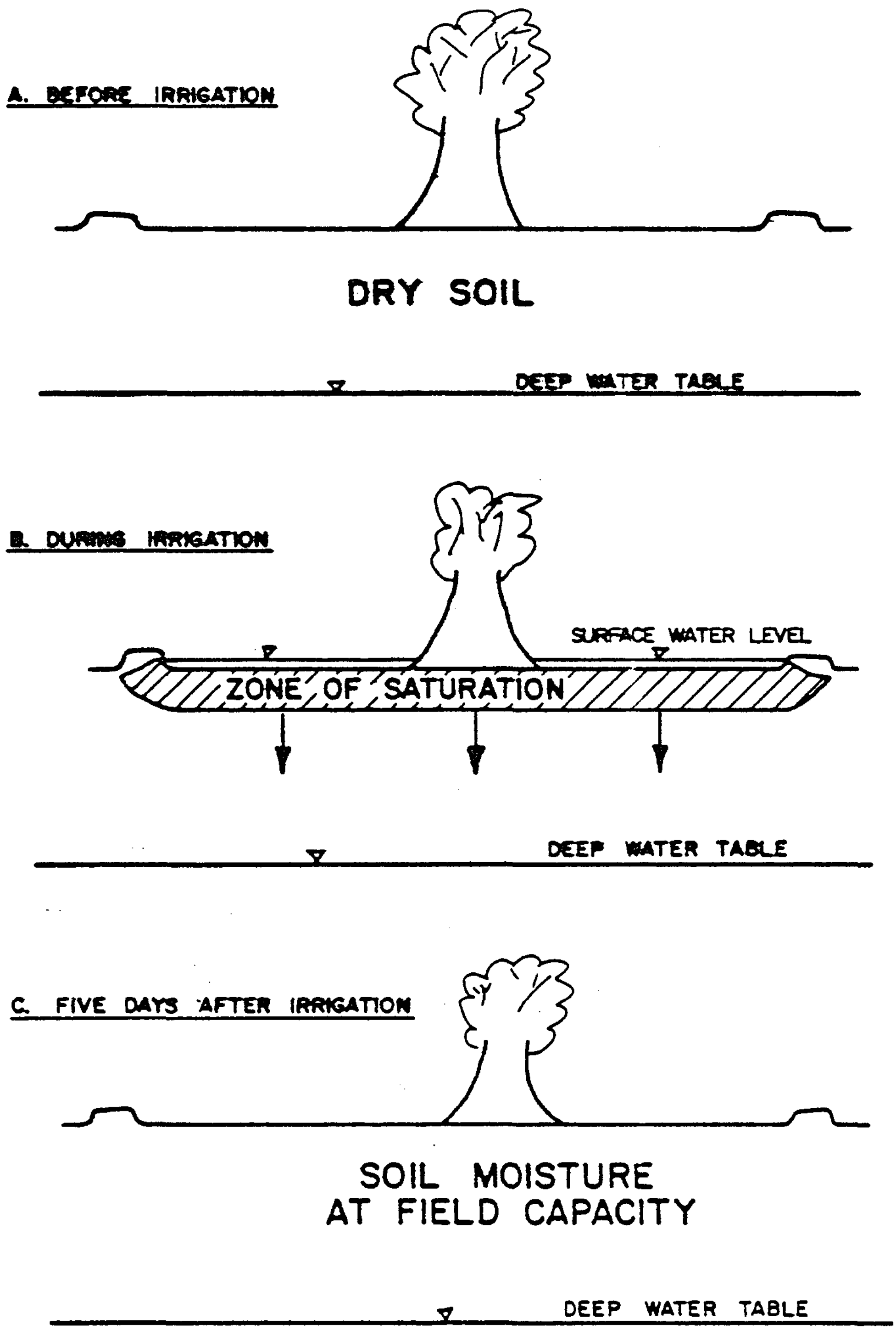


FIGURE 5. Water Movement in Flood Irrigation

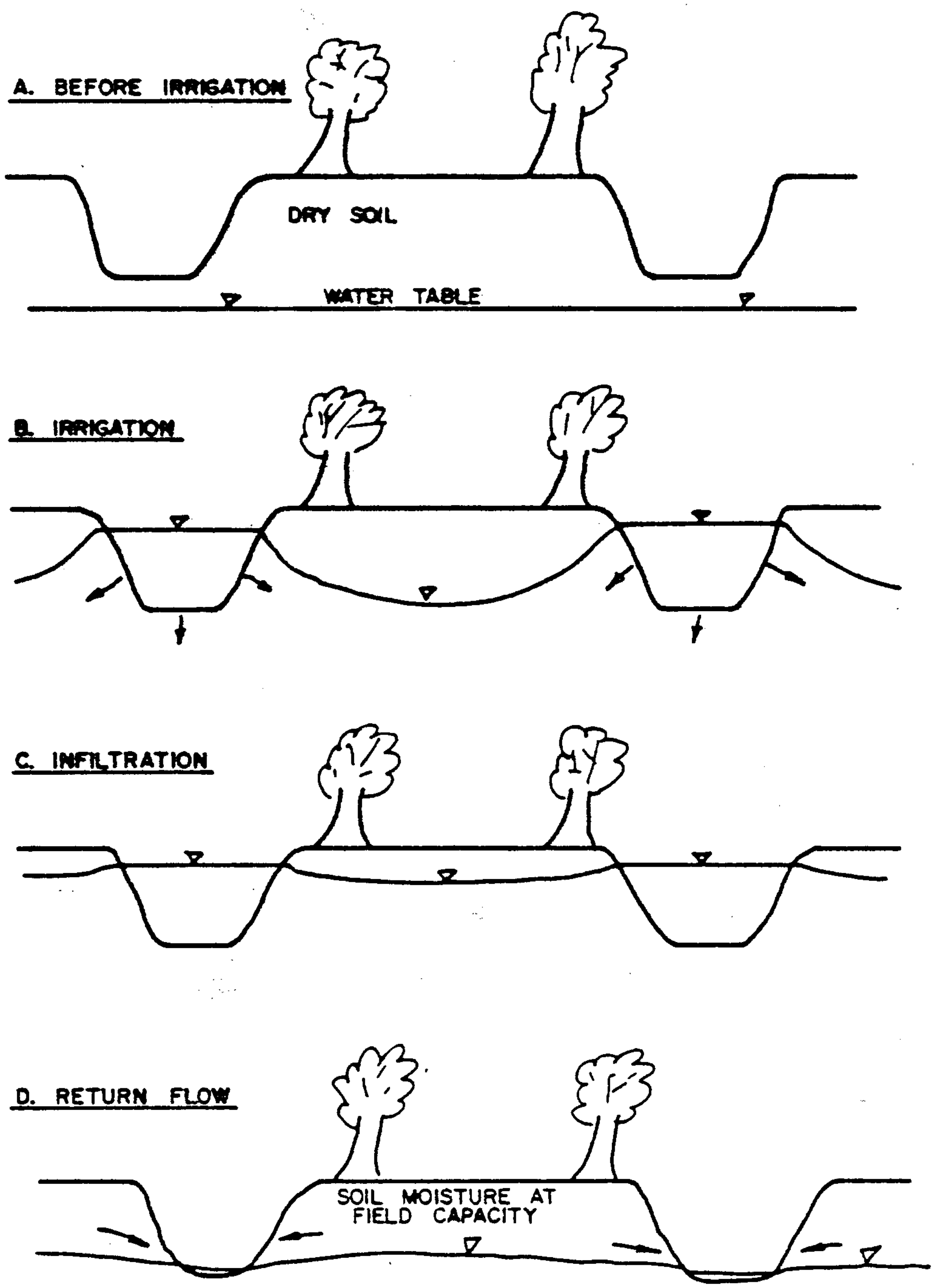


Figure 6. Water Movement in Crown Flood Irrigation

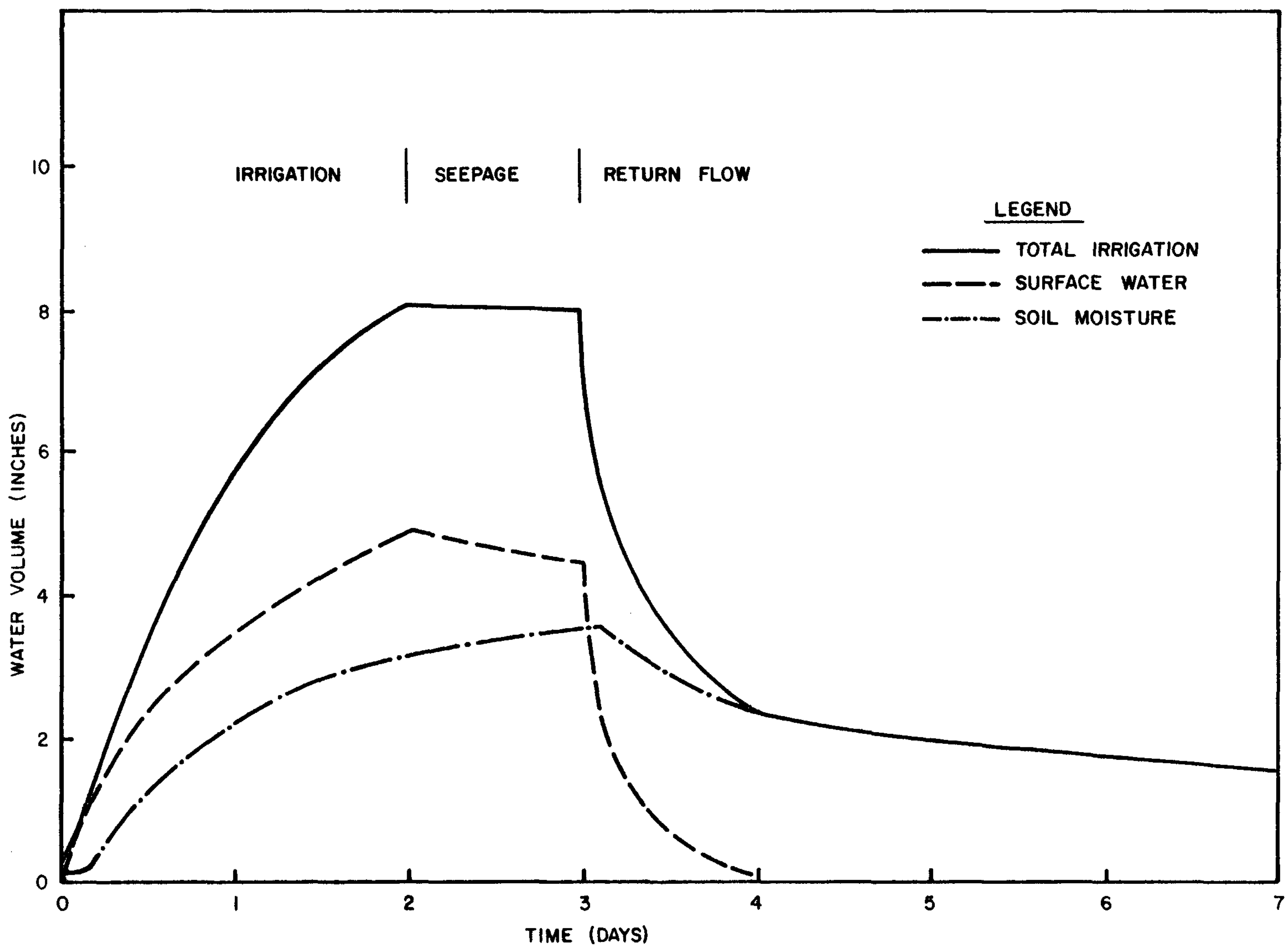


FIGURE 7. Irrigation Cycle Hydrograph.

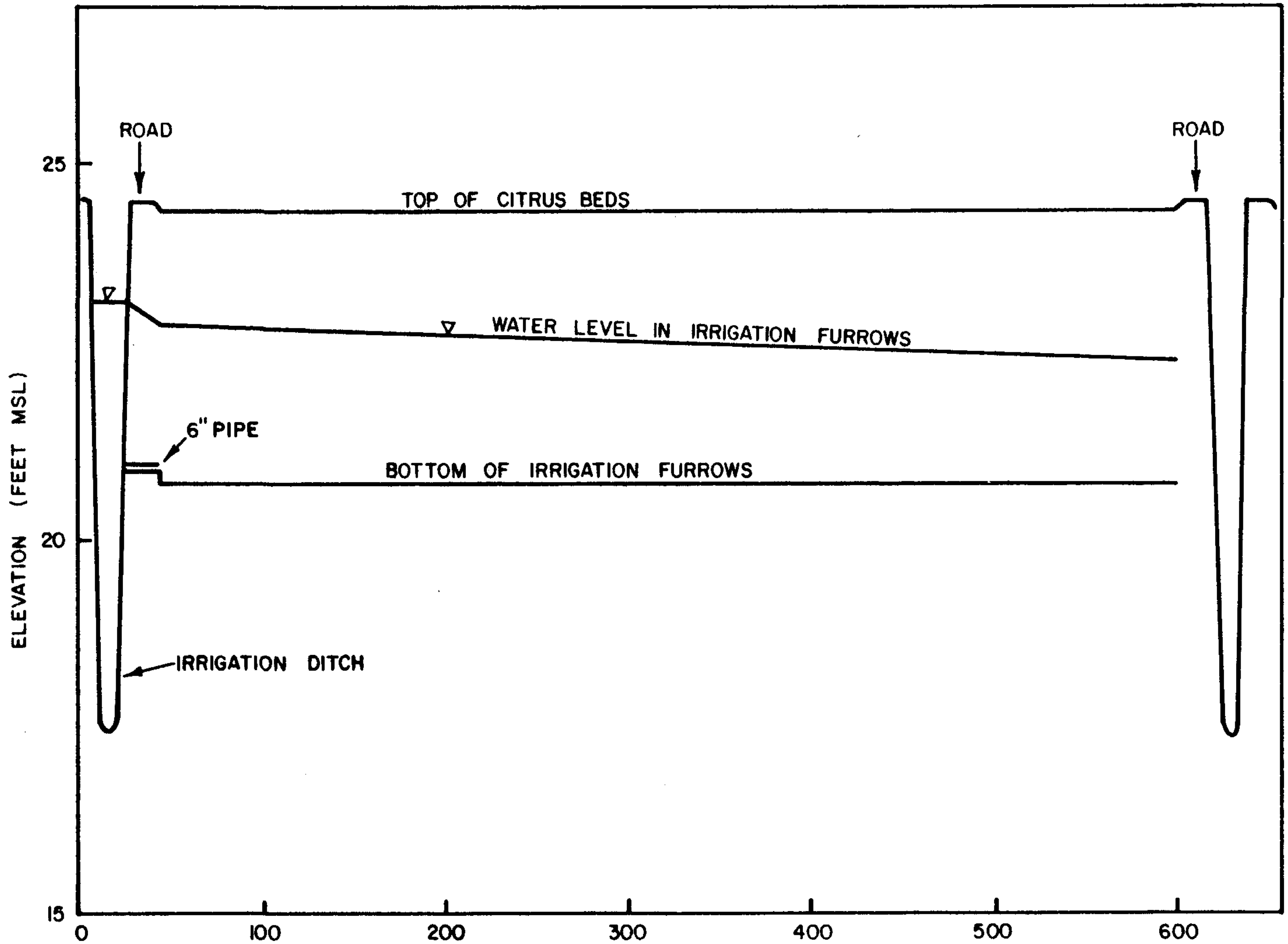


FIGURE 8. Water Levels During Irrigation.

inches when the feeder canal is at a high stage to 30 inches when the feeder canal is at a low stage. The culverts remain open until water levels in the feeder canal and irrigation ditches are equalized. After water stands in an irrigation ditch for the desirable period to allow soil near the root zone to become saturated (seepage stage; several hours to two days), the downstream culverts are partially opened allowing water to drain through the six inch pipe into the irrigation ditch then finally to drainage canal (return flow stage). The length of seepage stage depends primarily on soil moisture in the groves. Seepage stage will be longer if the soil condition is drier. The downstream culverts remain open until the next irrigation, allowing any excess water to flow from the irrigation ditch into the drainage canal during this period.

IRRIGATION WATER USE DETERMINATION

The irrigation water use was estimated using the water budget analysis given in Equation (1) and shown in Figure 9. Gross irrigation is the amount of water allowed to flow onto grove through the culvert between the feeder canal and the irrigation ditch. Return flow is water that flows from the irrigation ditch into the drainage canal immediately following an irrigation. Change in storage can be divided into two parts: changes in the ground water system and changes in the surface water system. The difference between water use and consumptive use results from water losses which include percolation, lateral seepage out of the irrigated area and evapotranspiration from soil outside the root zone and directly from irrigation system. The data necessary to carry out the water budget analysis was determined as discussed below.

RAINFALL

Average annual rainfall for the study area is 51.12 inches based on historical rainfall data at Vero Beach and Ft. Drum (Table 1). Of this rainfall, 32.63 inches occurs during the wet season (June through October); and 18.49 inches occurs during the remaining seven months. It is during the latter (dry) season that most of the irrigation is required.

Monthly rainfall measured at Becker Groves during the study period (January 1980 to August 1982) is given in Table 2. During the twelve month period from June 1980 to May 1981 the area experienced a severe drought. However, the next twelve month period from June 1981 to May 1982 the total annual rainfall was slightly above average. Therefore, data during the two year period (June 1980 to May 1982) was selected to study grove operations. The rainfall data, as segmented into dry and wet season totals, are shown in Table 2.

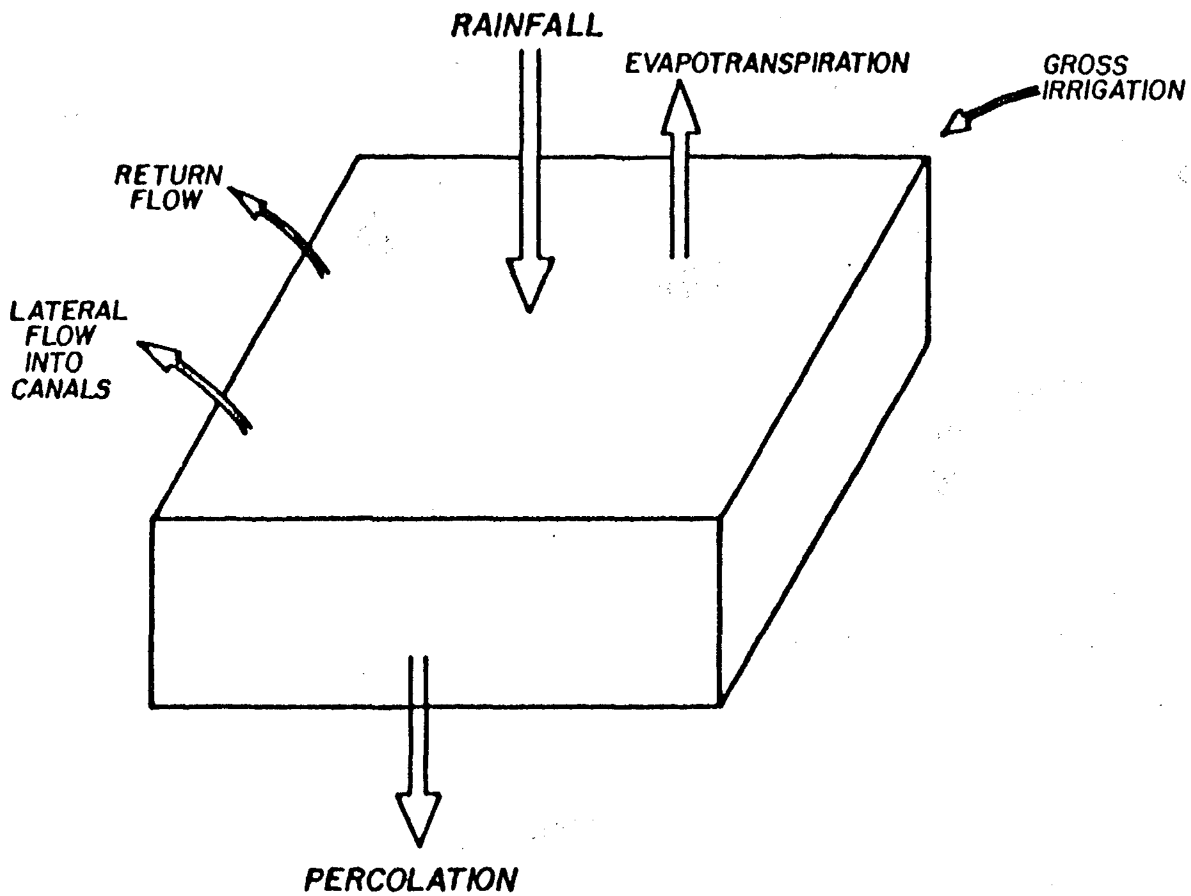


FIGURE 9. Diagram of Water Budget for Citrus Groves.

TABLE 1. LONG TERM AVERAGE RAINFALL FOR VERO BEACH AND FORT DRUM

Month	Vero Beach (1965-1980) (in)	Fort Drum (1949-1980) (in)	Average For Two Stations (in)
January	2.16	2.01	2.09
February	2.49	2.61	2.55
March	3.10	2.85	2.97
April	2.58	2.01	2.30
May	4.30	5.23	4.76
June	6.48	7.42	6.95
July	6.54	7.27	6.91
August	5.65	6.58	6.11
September	8.20	7.25	7.73
October	5.85	4.02	4.93
November	2.48	1.62	2.05
December	1.83	1.71	1.77
TOTAL	51.66	50.58	51.12

TABLE 2. MONTHLY RAINFALL AND NUMBER OF IRRIGATIONS AT BECKER GROVES FROM JANUARY 1980 TO AUGUST 1982

Month	Rainfall (in)					Number of Irrigations			
	Long Term Average	80	80-81	81-82	82	80	80-81	81-82	82
June	6.95		3.06	5.11	7.96		1	0	0
July	6.91		3.91	7.84	7.00		1	0	0
August	6.11		1.54	10.27	3.31		1	0	0
September	7.73		3.49	5.53			0	0	
October	4.93		4.34	3.00			2	1	
November	2.05		3.23	2.50			1	1	
December	1.77		2.55	0.53			0	1	
January	2.09	2.87	0.23	1.33		1	1	1	
February	2.55	1.28	3.16	2.75		0	1	0	
March	2.97	3.89	1.63	6.39		1	2	1	
April	2.30	3.36	0.26	4.49		0	1	0	
May	4.76	2.31	2.39	7.43		2	2	1	
Wet Season (June - October)	32.63		16.34	31.75			5	1	
Dry Season (Nov - May)	18.49		13.45	25.42			8	5	
TOTAL	51.12	13.71	29.79	57.17	18.27	4	13	6	0

The large variation in rainfall conditions over the two year period provided an excellent opportunity to observe the influence of rainfall amounts on the number of irrigations as shown in Table 2. During the two year study period, 19 irrigation cycles occurred. Of these 19 cycles, 13 cycles occurred during the first twelve month period when the total rainfall of 29.79 inches was far below the average 51.12 inches. During the wet season of this twelve-month period, 5 of the 13 cycles were necessary. The second twelve month period, with slightly above average rainfall, had six irrigation cycles; only one cycle occurred during the wet season with slightly below average rainfall and the remaining five occurred during the dry season even though above average rainfall occurred.

The net rainfall added to the grove storage was calculated from the measured rainfall depth and daily changes in soil moisture storage. In some cases, when rainfall occurred in large amounts or at high rates, a portion of this rainfall was lost from the grove to surface runoff. The net rainfall was estimated based on changes in measured soil moisture storage and is given in Table 3.

EVAPOTRANSPIRATION

Consumptive use represents the water requirements of the grove to maintain evapotranspiration necessary for crop growth. Evapotranspiration for the citrus groves was estimated using the information collected from the weather station by two methods: the Christiansen equation and the Blaney-Criddle equation. The Christiansen equation is:

$$ET = K\ C_{TE}\ C_W\ C_H\ C_G\ E \qquad (3)$$

where ET = evapotranspiration

K = Blaney-Criddle constant for citrus groves, 0.55

$C_{TE} = 0.476\ (T/68) - 0.146\ (T/68)^2 + 0.67$

T = air temperature (°F)

$C_W = 1.189 - 0.24\ (W/100) + 0.051 + (W/100)^2$

W = wind movement (miles/day)

TABLE 3. TOTAL, NET AND EFFECTIVE RAINFALL

Month	Total Rainfall (in)		Net Rainfall (in)		Effective Rainfall (in)	
	80-81	81-82	80-81	81-82	80-81	81-82
June	3.06	5.11	2.22	4.34	2.01	3.15
July	3.91	7.84	3.12	7.04	2.44	4.52
August	1.54	10.27	1.54	7.14	1.03	3.45
September	3.49	5.53	3.49	4.34	2.06	3.24
October	4.34	3.00	3.59	2.50	2.06	1.76
November	3.23	2.50	2.14	1.17	1.62	1.43
December	2.55	0.53	2.55	0.53	1.20	0.31
January	0.23	1.33	0.23	1.33	0.10	0.79
February	3.16	2.75	3.16	2.75	1.61	1.55
March	1.63	6.39	1.63	5.19	1.04	2.61
April	0.26	4.49	0.26	3.65	0.14	2.57
May	2.39	7.43	2.39	3.65	1.63	3.64
WET SEASON	16.34	31.75	13.96	25.36	9.60	16.12
DRY SEASON	13.45	25.42	12.36	18.27	7.34	12.90
TOTAL	29.79	57.17	26.32	43.63	16.94	29.02

$C_H = 0.499 + 0.62\ (RH/60) - 0.119\ (RH/60)^2$

RH = relative humidity

C_G = growth constant (Ref. 3)

E = pan evaporation

Due to various problems with measurement of pan evaporation during the study period, pan evaporation data could not be collected for several periods. During these periods, the pan evaporation was estimated from the other weather data using the Penman equation given below (derived from relations available in Ref. 3):

$$EP = \frac{\dfrac{D\ EL(D + 0.0105)}{0.7} - D(0.0105EA) + 0.025EA}{D + 0.025} \qquad (4)$$

where $D = 0.0328(0.0041\ TA + 0.676)^7 - 0.000019$

TA = air temperature

$$EL = \frac{\exp\ [(TA - 212)\ (0.1024 - 0.01066\ \ln\ (R))] - 0.0001 + 0.0105\ EA}{0.015 + (TA + 398.36)^{-2}\ (6.8554 \times 10^{10})\ \left\{\exp\left(\dfrac{-7428.6}{TA+398.36}\right)\right\}}$$

R = radiation in langleys

$EA = E^{0.88}\ (0.37 + 0.0041W)$

W = wind movement (miles/day)

$E = (0.0041TA + 0.676)^8 - (0.0041\ TD + 0.676)^8 - 0.000019\ (TA - TD)$

TD = dew point temperature

EP = pan evaporation

Pan evaporation calculated using Penman equation were compared to actual pan evaporation. The relationship shown in Figure 10 indicates that the Penman

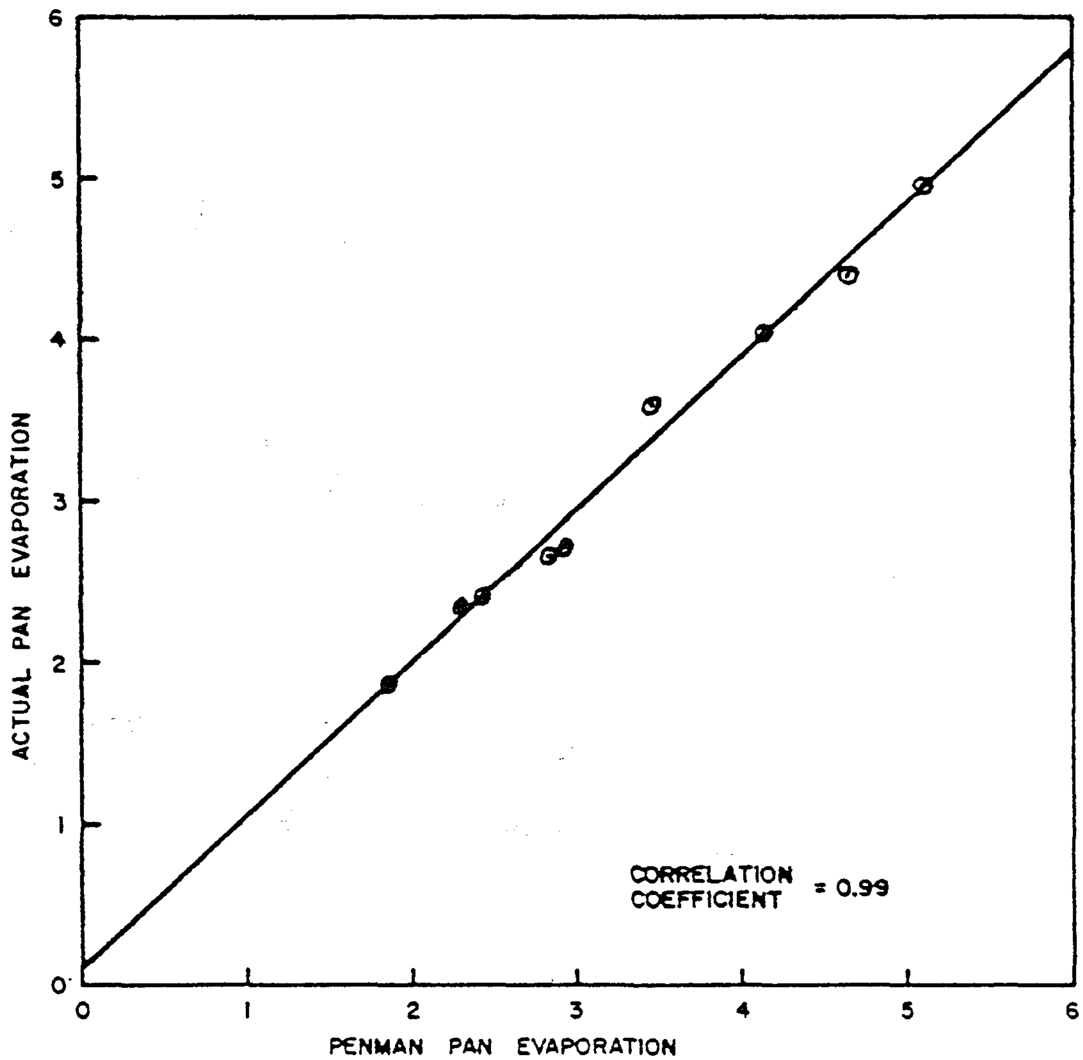


FIGURE 10. Comparison Between Actual and Estimated Pan Evaporation.

equation gives a satisfactory estimate of pan evaporation for the purpose of this study.

The Modified Blaney-Criddle equation used in this study is:

$$ET = K \frac{RSxT}{TRS} \qquad (5)$$

where ET = Evaportranspiration

T = mean monthly temperature

RS = mean monthly solar radiation

TRS = sum of mean monthly solar radiation over a year

$K = K_t \times K_c$ (6)

K_t = temperature coefficient (0.0173T - 0.314)

K_c = crop coefficient (Ref. 4)

Evapotranspiration estimates using the Christiansen and Modified Blaney Criddle equations are given in Table 4 for the two year study period from June 1980 to May 1982.

The evapotranspiration estimated from the Blaney-Criddle equation was found to be greater than pan evaporation during summer months. The following correcttion factor, based on Reference 2, was applied to the Blaney-Criddle equation:

$$C = \frac{.55 \times F}{CU} \qquad (7)$$

where C = correction factor

$$CU = \sum_{i=1}^{12} ET_i$$

$$F = \sum_{i=1}^{12} \frac{RS_i \times T_i}{TRS}$$

i = Month of year

TABLE 4. COMPARISON OF EVAPOTRANSPIRATION ESTIMATES WITH PAN EVAPORATION

MONTH	PAN EVAPORATION (in.)		EVAPOTRANSPIRATION ESTIMATES					
			Blaney-Criddle (1) (in.)		Blaney-Criddle (2) Iin.)		Christiansen (in.)	
	80-81	81-82	80-81	81-82	80-81	81-82	80-81	81-82
June	6.34	6.21	6.20	6.40	5.24	5.71	4.66	4.69
July	5.74	6.16	6.02	6.62	5.10	5.56	4.30	4.65
August	4.97	4.52	5.59	5.11	4.75	4.30	3.82	3.45
September	4.06	4.22	4.79	4.63	4.07	4.06	3.05	3.29
October	3.60	3.70	3.37	3.18	2.86	2.67	2.60	2.61
November	2.36	2.71	1.94	2.19	1.63	1.84	1.62	1.78
December	1.88	2.57	1.17	1.56	0.98	1.31	1.20	1.57
January	2.41	2.51	1.02	1.54	0.85	1.29	1.44	1.54
February	2.66	2.56	2.07	2.41	1.74	2.03	1.72	1.70
March	4.40	3.88	3.13	3.39	2.63	2.85	2.96	2.61
April	5.76	4.57	5.01	4.32	4.22	3.63	4.16	3.05
May	6.46	4.99	5.92	5.10	4.95	4.29	4.78	3.64
WET SEASON	24.71	24.81	25.97	25.94	22.02	22.30	18.43	18.69
DRY SEASON	25.93	23.79	20.26	20.51	17.00	17.24	17.88	15.89
TOTAL	50.64	48.60	46.23	46.45	39.02	39.54	36.31	34.58

NOTE:
(1) Uncorrected
(2) Corrected

From Table 4 the Christiansen and the corrected Blaney-Criddle equation gave average annual ET rates of 35.44 and 39.48 inches, respectively, which shows a discrepancey of 10.2 percent. The Blaney-Criddle constant (Eq. 6) has a range of 0.45 to 0.55 for orange crop according to Ref. 4, the lower values being for humid areas. A value of 0.55, however, is commonly chosen because this equation is used to obtain an upper limit for ET. Pan coefficients were determined by a ratio between pan evaporation (supplemented by Penman equation) and the Christiansen equation or the Blaney Criddle equation. Pan coefficients using the Christiansen equation average 0.71 with a range of 0.60 to 0.78 while the Blaney-Criddle equation pan coefficients average 0.79 with a range of 0.35 to 1.00. This comparison shows that a more consistent and reasonable estimate of ET is given by the Christiansen Equation. Therefore, the Christiansen equation was used to estimate ET and thus the consumptive use of the grove. The corrected Blaney-Criddle equation can also be used to estimate the upper limit of ET in areas where meteorological data needed for the Christiansen equation are not available.

SOIL MOISTURE

Soil moisture was calculated from tensiometer data. Tensiometers read the negative soil pressure within the soil. Soil Moisture-retention data in Table 5 as determined by the IFAS, was used to convert the tensiometer readings into soil water content of the soil.

PERCOLATION

No noticeable decreases in the ground water table elevation occurred during periods without rainfall or irrigation because of the hard clay-shell mixture which underlies the groves (Fig. 3). Therefore, it was assumed in this study that percolation losses are negligible.

TABLE 5. WINDER FINE SAND - WATER CAPACITY DATA, INDIAN RIVER COUNTY

CAPILLARY POTENTIAL (mb)	WATER CONTENT, VOL.%			
	L^1	L^2	L^3	L^4
0.0	39.5	40.8	40.4	39.0
3.5	38.3	36.7	40.0	35.1
20.	31.8	24.5	36.5	32.5
30.	28.8	16.3	35.7	31.7
45.	24.6	10.0	35.0	30.7
60.	21.9	7.7	34.5	29.5
80.	19.5	7.0	34.1	38.4
100.	18.2	6.8	33.9	27.5
150.	17.3	6.1	33.4	27.1
200.	16.7	5.5	32.7	26.1
333.	15.6	5.3	32.0	25.1
1000.	12.3	5.1	31.2	24.5

Soil Layer 1 (El 23.2 ft. to 24.3 ft. NGVD, See Figure 3).

Soil Layer 2 (El 22.4 ft. to 23.2 ft. NGVD).

Soil Layer 3 (El 21.2 ft. to 22.9 ft. NGVD).

Soil Layer 4 (El 18.0 ft. to 21.2 ft. NGVD).

GROSS IRRIGATION AND RETURN FLOW

The gross irrigation and return flow during each irrigation cycle was determined by calculating the flow through the upstream and downstream culverts using the orifice equation:

$$Q = CA(2gH)^{0.5} \quad (8)$$

where: Q = discharge capacity, cfs

A = cross section area of culvert

H = head difference between upstream and downstream of culvert.

C = discharge coefficient for gate opening.

g = acceleration due to gravity (32.2 ft/sec^2)

A set of discharge coefficients was determined for a range of gate openings based on measured discharges at known head differences for each gate opening.

Using Eq. (8), the gross irrigation and return flow during irrigation cycles can be estimated based on the culvert gate opening and water stages measured upstream and downstream of each culvert by stage recorders. Several difficulties were encountered in estimating net application using this method: 1) During non-irrigation periods, the downstream culvert remains open and as a result, there is continuous exchange of flow between the irrigation ditch and drainage canal. This flow could not be measured because the head difference between the irrigation ditch and the drainage canal was smaller in magnitude than the probable error of the stage recorders. However, the net exchange over long periods was considered insignificant. 2) The distance between the stage recorders and culverts may be too great to accurately represent head differences across the culverts under some conditions when significant variation in water stage occurs over short distances (during pumping from drainage canal to floodway). 3) Most importantly, continuous records on gate openings of the culverts were not maintained. Based on discussion with the grove manager and review of limited records, it was determined that the gate openings were generally set based on the stage in the feeder canal (upstream culverts) or the irrigation ditch (downstream culverts) at the beginning of the irrigation cycle. The gate openings that were used for particular stages were estimated. Gate openings were then determined for each irrigation cycle based on stage measurements and used to calculate gross irrigation and return flow with the orifice equation.

Because of possible errors in the flow calculations, particularly due to the limited records on gate openings, gross irrigation and return flow estimates were verified with calculations based on a water storage accounting method. In this method, gross irrigation or return flow must be equal to storage changes (surface and ground water) and losses (total ET and percolation) minus rainfall occurring during the particular period of the irrigation cycle. Changes in surface water and ground water storages were calculated using data from stage recorders, observation wells, and tensiometers provided by IFAS (Table 6). Total losses from ET over irrigation and return periods could not be measured directly. The consumptive use as calculated by the Christiansen equation, was used as an estimate of total ET losses for each period. The total ET estimated over the short duration periods of gross irrigation and return flow were small in magnitude compared to the large storage changes that were measured during the same periods. As a result, any errors resulting from estimating total ET losses using the Christiansen equation over these short duration periods would be insignificant.

The gross irrigation and return flow estimated for each irrigation cycle from the water storage approach were used to verify that gross irrigation and return flow, calculated using the orifice equation were reasonable. A significant difference in the flows estimated from an irrigation cycle by the two

TABLE 6. TOTAL IRRIGATION USING WATER BUDGET EQUATION.

Irrigation Cycle	IRRIGATION PERIOD					RETURN FLOW PERIOD				
	Surface Water Storage (in.)	Soil Moisture (in.)	ET (in.)	Rainfall (in.)	Gross Irrigation (in.)	Surface Water Storage (in.)	Soil Moisture (in.)	ET (in.)	Rainfall (in.)	Return Flow (in.)
Jan 03-06,80	5.34	4.24	0.07	0.00	9.65	5.49	1.22	0.05	0.00	6.66
Mar 20-25,80	4.89	4.03	0.44	0.05	9.31	4.94	1.54	0.15	0.00	6.33
May 02-06,80	5.16	3.46	0.33	0.00	8.95	5.13	1.97	0.15	0.00	6.95
May 26-29,80	4.00	2.35	0.23	0.34	6.24	4.20	0.79	0.16	0.00	4.83
Jun 16-20,80	5.19	4.57	0.48	0.10	10.14	5.20	1.54	0.18	0.04	6.60
Jul 12-16,80	4.57	2.39	0.51	0.19	7.28	4.81	0.38	0.12	0.03	4.84
Aug 11-15,80	5.42	4.49	0.18	0.02	10.07	5.17	1.46	0.19	0.20	6.64
Oct 07-11,80	5.48	3.52	0.17	2.01	7.16	5.11	1.13	0.06	0.00	6.18
Oct 22-25,80	5.37	2.94	0.07	2.03	6.35	5.33	1.51	0.09	0.00	6.75
Nov 09-12,80	5.30	3.44	0.07	0.25	8.56	4.62	1.68	0.06	0.00	6.24
Jan 13-16,81	4.89	4.07	0.21	0.00	9.17	4.88	1.57	0.07	0.00	6.38
Feb 01-04,81	1.66	1.42	0.07	1.08	2.07	1.74	0.57	0.06	0.00	2.25
Mar 02-07,81	4.87	2.20	0.30	0.20	7.17	4.98	0.84	0.16	0.00	5.66
Mar 18-23,81	4.13	2.46	0.37	0.18	6.78	4.21	1.36	0.06	1.10	6.61
Apr 13-16,81	5.40	3.62	0.28	0.00	9.30	5.49	1.39	0.11	0.06	6.83
May 01-06,81	5.41	5.05	0.50	0.00	10.96	5.44	2.17	0.17	0.00	7.44

TABLE 6. Continued

May 27-29, 81	5.36	3.74	0.10	1.16	8.04	5.25	3.02	0.16	0.00	8.11
Oct 14-19, 81	5.37	3.41	0.27	0.09	8.96	5.43	1.62	0.17	0.00	6.88
Nov 23-25, 81	5.42	2.72	0.05	0.00	8.19	5.47	1.22	0.04	0.00	6.65
Dec 8-12, 81	5.09	3.27	0.13	0.00	8.49	5.12	1.20	0.06	0.00	6.26
Jan 8-12, 82	5.33	3.22	0.10	0.00	8.65	5.39	0.60	0.07	0.00	5.92
Mar 4-8, 82	5.22	3.09	0.05	0.76	7.60	5.25	0.74	0.07	0.95	6.87
May 13-18, 82	4.55	3.20	0.32	0.00	7.57	4.03	0.90	0.13	0.00	4.80

methods normally indicates that the actual gate opening is different from the assumed gate opening. Therefore, the gate opening was adjusted so that the two estimates were closer in agreement. Gross irrigation, return flow and net application determined by the orifice equation and adjusted with the water storage accounting method are given in Table 7 for each irrigation cycle.

TABLE 7. SUMMARY OF TOTAL IRRIGATION

Irrigation Cycle	Duration (hours)	Gross Irrigation (inches)	Duration (hours)	Return Flow (inches)	Effective Irrigation (inches)	Rainfall (inches)	Net Application (inches)
Jan 03-06, 80	48	9.16	12	6.40*	2.76	0.00	2.76
Mar 20-25, 80	84	9.41	24	6.84	2.57	0.05	2.62
May 02-06, 80	60	9.22	24	7.61	1.61	0.00	1.61
May 26-69, 80	36	6.84	12	5.81	1.03	0.34	1.37
Jun 16-20, 80	48	9.68	12	6.53*	3.15	0.14	3.29
Jul 12-16, 80	72	8.35*	24	6.45	1.90	0.34	2.24
Aug 11-15, 80	48	10.07	36	6.64*	3.43	0.22	3.65
Oct 07-11, 80	72	8.07*	24	7.38*	0.69	2.01	2.70
Oct 22-25, 80	24	6.90	24	7.65	-0.75	2.03	1.28
Nov 09-12, 80	24	8.47*	24	6.47	2.00	0.25	2.25
Jan 13-16, 81	48	7.99*	36	4.75	3.24	0.00	3.24
Feb 01-04, 81	24	2.37	24	2.66	-0.29	1.08	0.79
Mar 02-07, 81	84	5.76*	36	4.45	1.31	0.20	1.51
Mar 18-23, 81	48	5.53*	12	5.49	0.04	1.28	1.32
Apr 12-16, 81	48	9.01*	24	6.69	2.32	0.26	2.58
May 01-06, 81	60	10.76*	12	7.68*	3.08	0.00	3.08
May 27-31, 81	24	7.97*	24	7.78*	0.19	1.16	1.35
Oct 15-19, 81	72	9.10*	36	6.83	2.27	0.09	2.36
Nov 23-25, 81	24	7.12*	12	5.89	1.23	0.00	1.23
Dec 8-12, 81	48	8.25*	24	6.77	1.48	0.00	1.48
Jan 8-12, 82	48	7.20*	36	4.93	2.27	0.00	2.27
Mar 4-8, 82	24	7.50*	36	6.87*	0.73	1.71	2.44
May 13-18, 82	48	7.69	24	4.94	2.75	0.00	2.75

* Adjusted using water storage accounting method.

DISCUSSION OF RESULTS

GROVE OPERATIONS

The average total application and net application per cycle vary for each twelve month period (June to May) and for the wet and dry seasons within those periods as shown in Table 8. During the second twelve month period, under slighter above average rainfall, the average total application per cycle was 8.12 inches and the average net application per cycle was 2.09 inches. Average irrigation depths were greater during the first twelve month period because initial soil moisture deficits were larger due to the drought conditions. During both twelve month periods, the total application and net application per cycle were greater in the wet season than the dry season because soil deficits during the wet season are generally greater due to long periods between cycles and high consumptive use requirements.

Net application varied significantly during the study period. During the first twelve months, net application varied from 0.79 inches to 3.29 inches per cycle. A large rainfall on February 2, 1981 during an irrigation cycle caused an early termination of the irrigation cycle resulting in a low net application of 0.79 inches. Not considering this cycle, the net application varied from 1.28 inches to 3.29 inches. The net application varied from 1.23 to 2.75 inches during the second twelve months. Variation in net application can be attributed to the initial soil moisture deficit at the beginning of the cycle and the duration of the seepage stage. The soil deficit depends on the length of time since the previous irrigation cycle and the climatic conditions.

The large variation in the effective irrigation per cycle, shown in Table 7 and Table 11, is a result of rainfall that occurred during some irrigation cycles. In two cases, the return flow actually exceeded the gross irrigation resulting in an effective irrigation less than zero. During the irrigation

TABLE 8. SUMMARY OF CROWN FLOOD OPERATIONS

Data Description	June 80 - May 81			June 81 - May 82		
	Wet Season	Dry Season	Total Season	Wet Season	Dry Season	Total Season
Average Total Application Per Cycle (in.)	9.56	8.37	8.83	9.19	7.91	8.12
Total Application (in.)	47.81	58.64	106.45	9.19	39.47	48.66
Average Net Application Per Cycle (in.)	2.63	2.19	2.36	2.36	2.03	2.09
Total Net Application (in.)	13.16	15.33	28.49	2.36	10.17	12.53
Total Water Use (in.)	22.98	23.74	46.72	28.19	24.06	52.25
Water Use Efficiency (%)	80	75	78	66	66	66
Total Effective Irrigation (in.)	9.17	12.18	21.35	2.27	8.46	10.73
Irrigation Efficiency (%)	96	87	91	100	30	52

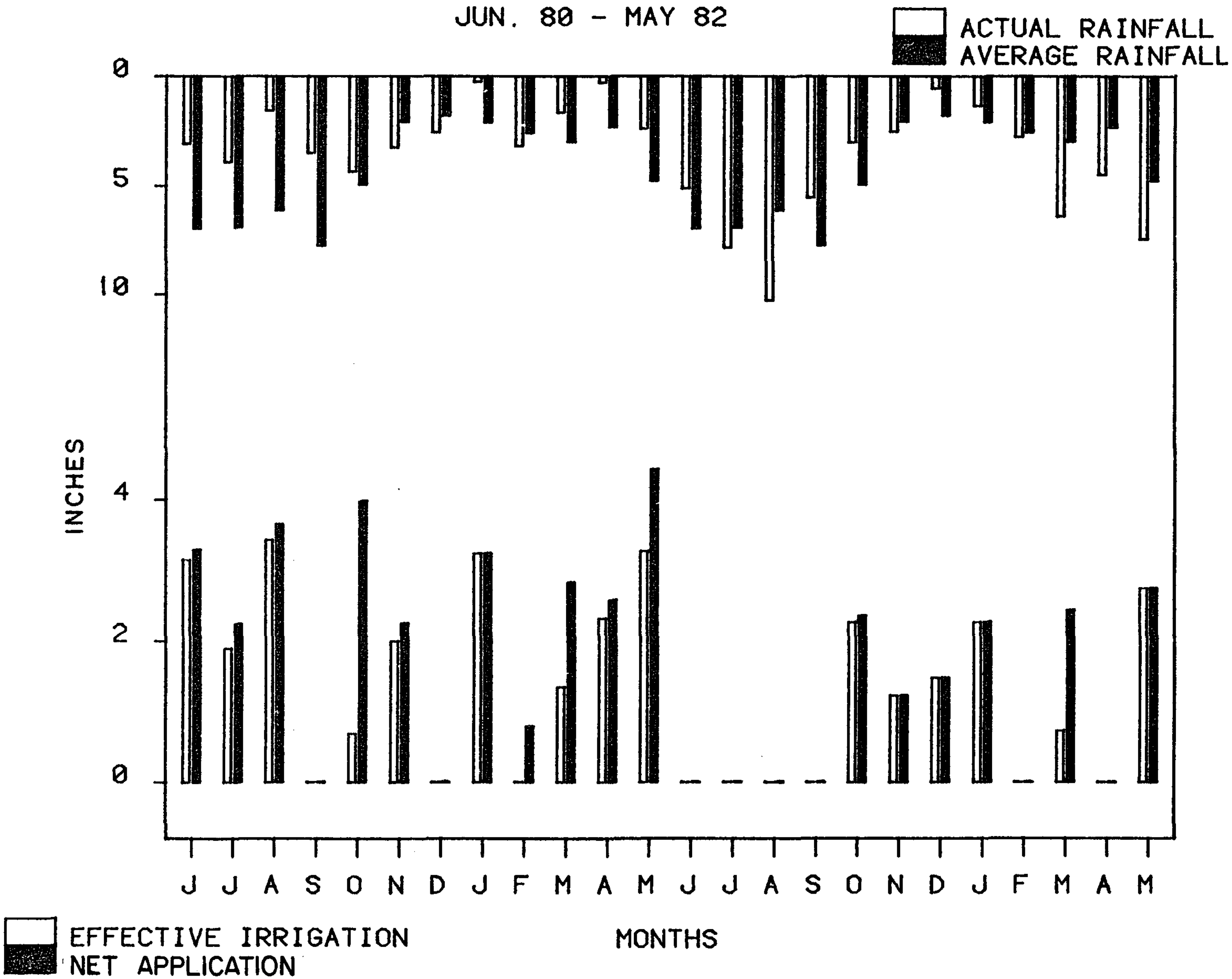


FIGURE 11. Rainfall and Irrigation Amounts During Study Period.

cycle, the net rainfall was assumed equal to the total rainfall except when this resulted in effective irrigation less than zero. In these cases, the net rainfall was reduced so that effective irrigation was zero.

On an annual basis (June to May) the total effective irrigation varied significantly as shown in Table 8. During the first twelve month period, there were 13 irrigation cycles with a total effective irrigation of 21.35 inches. This depth probably approached the maximum annual requirement for the area because the annual rainfall depth of 29.79 inches has a drought return frequency of approximately 100 years. During the second twelve month period, six irrigation cycles occurred with a total of 10.73 inches of effective irrigation. Based on the data from the second twelve month period with slightly above average rainfall, an average rainfall year would require about six irrigation cycles with an approximate effective irrigation of 12 inches.

In general, the major portion of the effective irrigation occurs in the dry season when rainfall is low and consumptive use is high. The total effective irrigation was greater in the dry season than in the wet season during both years. During the first twelve month period, the effective irrigation in the wet season nearly equaled the dry season requirement because of the extremely low rainfall. However, in the second twelve month period in which above average rainfall was experienced, only one of the six cycles occurred during the wet season. The total effective irrigation during the wet season was 2.27 inches of the total 10.73 inches of effective irrigation for the entire twelve month period. During an average rainfall year, almost all of the effective irrigation occurred during the dry season while the effective irrigation requirements in a very dry year such as the first twelve months of the study period were more evenly distributed between the two seasons.

WATER USE AND WATER USE EFFICIENCY

Water use as defined by eq. 1 is given on a monthly basis in Table 9. Monthly water use was totaled to give water use on an annual and a seasonal basis in Table 8. The total water use was 46.72 inches during the first twelve months and 52.25 inches during the second twelve months of the study. The water use efficiency represents the portion of total water added to soil storage in the groves (effective irrigation and net rainfall) that is used to meet consumptive use requirements. The remaining portion of water added to the soil is losses. This water loss may be attributed to a number of factors (Figure 8). First, water can be lost by deep percolation from the system, which although not important in this study area could be very important in other areas. Secondly, excess evaporation can occur from system due to saturation of soils during irrigation. Finally, there was unaccounted flow from the grove area into the drainage canal during several cycles. From Table 9, negative losses during some months indicates there may have actually been inflow from the drainage canals into the grove area.

The water use efficiency was determined using monthly consumptive use estimated by the Christiansen equation and measured water use. The water use efficiency as calculated by eq. 2 was 78% for the first twelve month period and 66% for the second twelve month period. The water use efficiency depends on the total water use of the grove. During periods of low water use, such as the first twelve month period, the crop uses water more efficiently. As total water use increases, the water use efficiency decreases. For this reason, there is a range of annual water use volumes which may meet the consumptive use requirements of the crop. The actual water use for a particular grove may depend on the available water resulting from climatic conditions and the specific constraints on the grove operation resulting from economic decisions to maximize production.

TABLE 9. MONTHLY WATER BUDGET

Month	Gross Irrigation (in)	Net Rainfall (in)	Return Flow (in)	Change in Ground Water Storage (in)	Change in Surface Water Storage (in)	Water Use (in)	ET (in)	Losses (in)
Jan 1980	9.16	2.87	6.40	1.29	-0.10	4.44	1.62	2.82
Feb 1980	0.00	1.28	0.00	-0.07	0.01	1.34	1.87	-0.53
Mar 1980	9.41	3.89	6.84	1.25	0.06	5.15	3.16	1.99
Apr 1980	0.00	2.61	0.00	-1.63	0.02	4.22	3.94	0.28
May 1980	16.06	2.31	13.42	1.17	0.22	3.56	4.24	-0.68
Jun 1980	9.68	2.22	6.53	-0.59	-0.21	6.17	4.66	1.51
Jul 1980	8.35	3.12	6.45	-0.05	0.06	5.01	4.30	0.71
Aug 1980	10.07	1.54	6.64	0.22	0.08	4.67	3.82	0.85
Sep 1980	0.00	3.49	0.00	-1.14	0.03	4.60	3.05	1.55
Oct 1980	14.97	3.59	15.03	1.14	-0.14	2.53	2.60	-0.07
Nov 1980	8.47	2.14	6.47	-0.70	0.02	4.82	1.62	3.20
Dec 1980	0.00	2.55	0.00	-0.06	-0.04	2.65	1.20	1.45
Jan 1981	7.99	0.23	4.75	0.86	0.11	2.50	1.44	1.06
Feb 1981	2.37	3.16	2.66	-0.28	-0.05	3.20	1.72	1.48
Mar 1981	11.29	1.63	9.94	0.22	0.06	2.70	2.96	-0.26
Apr 1981	9.01	0.26	6.69	-0.97	-0.08	3.63	4.16	-0.53

TABLE 9. CONTINUED . . . . .

May 1981	18.73	2.39	15.46	1.06	0.36	4.24	4.78	-0.54
Jun 1981	0.00	4.34	0.00	-1.52	-0.08	5.94	4.69	1.25
Jul 1981	0.00	7.04	0.00	2.34	-0.11	4.81	4.65	0.16
Aug 1981	0.00	7.14	0.00	0.73	0.16	6.25	3.45	2.80
Sep 1981	0.00	4.34	0.00	-1.86	-0.19	6.39	3.29	3.10
Oct 1981	9.10	2.50	6.83	0.03	-0.06	4.80	2.61	2.19
Nov 1981	7.12	1.17	5.89	0.62	0.13	1.65	1.78	-0.13
Dec 1981	8.25	0.53	6.77	-0.66	0.28	2.39	1.57	0.82
Jan 1982	7.20	1.33	4.93	-0.28	-0.16	4.04	1.54	2.50
Feb 1982	0.00	2.75	0.00	-0.14	-0.19	3.08	1.70	1.38
Mar 1982	7.60	5.19	6.87	2.05	0.02	3.85	2.61	1.24
Apr 1982	0.00	3.65	0.00	-0.63	-0.08	4.36	3.05	1.31
May 1982	7.69	3.65	4.94	1.56	0.15	4.69	3.64	1.05
Jun 1982	0.00	5.86	0.00	-0.62	-0.09	6.57	3.45	3.12
Jul 1982	0.00	5.63	0.00	-1.80	-0.05	7.48	3.73	3.75
Aug 1982	0.00	3.31	0.00	0.15	0.12	3.04	3.56	-0.52

The water use during the first twelve month period was primarily restricted by availability because of the drought conditions. During the second twelve month period, the water use was primarily a result of the grove operations designed to optimize production. The water use efficiency of 66% during this period is representative of a grove efficiency to be expected during average rainfall years.

IRRIGATION REQUIREMENT AND IRRIGATION EFFICIENCY.

The primary objective of this study was to determine water use and water use efficiency. However, in the consumptive use permitting process, the irrigation requirement and irrigation efficiency rather than the water use, is of primary interest. The irrigation requirement is commonly defined as:

$$IR = (ET - ER)/IE \qquad (9)$$

where:

IR = irrigation requirement

ET = potential crop ET (consumptive use)

ER = effective rainfall

IE = irrigation efficiency

Typically, the irrigation requirement of a grove is estimated using eq. 9 with ET calculated using Blaney-Criddle, ER determined using the procedures given in SCS TR 21 and IE based on the particular method of irrigation. SCS estimates for low volumes, sprinkler, and crown flood are 0.9, 0.7 and 0.5, respectively.

To calculate irrigation efficiency in this study, ET is estimated using the Christiansen equation as discussed earlier, IR is assumed to be equal to the effective irrigation applied, and ER is estimated indirectly using the procedure given in SCS TR-21 (Table 3). The irrigation efficiency can therefore be determined by rearranging eq. 9 as follows:

$$IE = (ET - ER)/IR \qquad (10)$$

The ET, ER and IR are given in Table 10 for each month of the study. In addition the supplemental water requirement (ET - ER), is given in Table 10.

Irrigation efficiencies using eq. 10 are given in Table 8 for the two twelve month periods. The irrigation efficiency was 91% during the first twelve month period and 52% during the second twelve month period. The irrigation efficiency, like the water use efficiency, is higher during periods of low water use when the crops use applied irrigation water more efficiently. The irrigation efficiency of 52% determined for the second twelve month period is a reasonable estimate for the grove under average rainfall conditions. However, there is some uncertainty in this estimate because of the approximations necessary to determine the effective rainfall. There is greater confidence in the water use efficiency of 66% because it is calculated directly from collected data and does not require estimation of effective rainfall. The irrigation efficiency of 52% appears reasonable in comparison to the water use efficiency of 66%. The data indicates that, in general, rainfall was used more efficiently for crop growth than applied irrigation water.

The wet season and dry season irrigation efficiencies shown in Table 8 are very uncertain and do not appear to be reasonable. Uncertainty results because the SCS method given in TR-21 for determining effective rainfall, while reliable on an annual basis, is much less reliable in determining effective rainfall on a monthly basis.

TABLE 10. MONTHLY VALUES FOR DETERMINATION OF IRRIGATION EFFICIENCY

Month	Consumptive Use (in)		Effective Rainfall (in.)		Supplemental Water Requirement (in)		Effective Irrigation (in)	
	80-81	81-82	80-81	81-82	80-81	81-82	80-81	81-82
June	4.66	4.69	2.01	3.15	2.65	1.54	3.15	0.00
July	4.30	4.65	2.44	4.52	1.86	0.13	1.90	0.00
August	3.82	3.45	1.03	3.45	2.79	0.00	3.43	0.00
September	3.05	3.29	2.06	3.24	0.99	0.05	0.00	0.00
October	2.60	2.61	2.06	1.76	0.54	0.85	0.69	2.27
November	1.62	1.78	1.62	1.43	0.00	0.35	2.00	1.23
December	1.20	1.51	1.20	0.31	0.00	1.20	0.00	1.48
January	1.44	1.54	0.10	0.79	1.34	0.75	3.24	2.27
February	1.72	1.70	1.61	1.55	0.11	0.15	0.00	0.00
March	2.96	2.67	1.04	2.61	1.92	0.06	1.35	0.73
April	4.16	3.05	0.14	2.57	4.02	0.48	2.32	0.00
May	4.78	3.64	1.63	3.64	3.15	0.00	3.27	2.75
WET SEASON	18.43	18.69	9.60	16.12	8.83	2.99	9.17	2.27
DRY SEASON	17.88	15.89	7.34	12.90	10.54	2.57	12.18	8.46
TOTAL	36.31	34.58	16.94	29.02	19.37	5.56	21.35	10.73

CONCLUSIONS

Crown flood irrigation operations have been monitored over a two year period. As a result of the data collection and analysis, the total water use and water use efficiency of the grove were determined. The results are summarized as follows:

1) During one twelve month period with slightly greater than average rainfall (June 1981 to May 1982), the total water use was 52.25 inches, the water use efficiency was 66% and the total effective irrigation was 10.73 inches during six irrigation cycles. Based on this data, an average rainfall year would require about six irrigation cycles with a total effective irrigation of twelve inches. This information can be used to compare the requirements of crown flood to other irrigation methods under average rainfall conditions.

2) During the twelve month period (June 1980 to May 1981) when a drought of approximately 100-year frequency occurred, and total water use was 46.72 inches, the water use efficiency was 78% and the total effective irrigation was 21.35 inches. This data indicated that the water use efficiency is higher during periods when water use is severely restricted.

3) The average net application per cycle was 2.32 inches which is 26% of the average total application of 8.47 inches applied per cycle during the two year study period.

4) The grove irrigation efficiency was estimated as 52% for the twelve month period experiencing slightly above average rainfall (June 1981 to May 1982). This compares well with earlier estimates made by SCS for crown flood irrigation. Due to drought conditions during the first twelve month period, the irrigation efficiency was substantially higher.

5) The results of this study can be applied to areas with hydrogeologic conditions similar to the study area. This area was determined for Indian River County based on information given in Reference 5. Figure 12 shows an area where

shallow aquifer well yields are poor (less than 100 gal/ min) indicating low permeability of soils. Soil profiles given also show this area to have a clay layer under the soil surface similar to that of the study area. Thus, the area shown in Figure 12 indicates the portion of Indian River County in which the results of this study are applicable.

6) The results of this study may be refined and expanded with additional data collection on crown flood groves with different hydrogeologic conditions, irrigation systems and operation procedures.

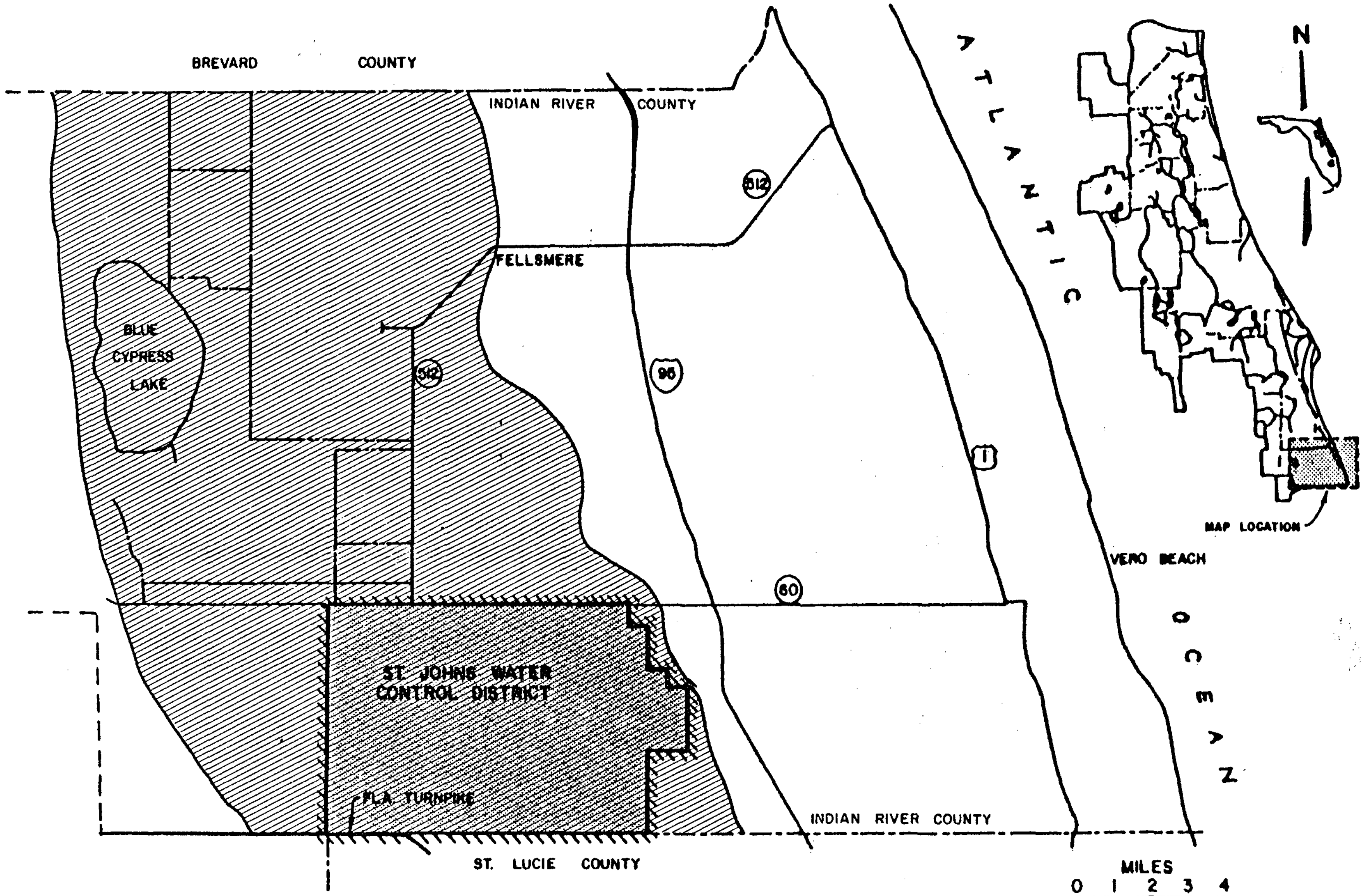


FIGURE 12. Location of Low Permeable Soils within Indian River County.

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