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MANAGEMENT OF WATER LEVELS IN THE "FROG POND" AREA, SOUTH DADE COUNTY, FLORIDA

SOUTH FLORIDA WATER MANAGEMENT DISTRICT

Technical Publication 81-4

MANAGEMENT OF WATER LEVELS IN THE "FROG POND" AREA, SOUTH DADE COUNTY, FLORIDA

by

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Resource Planning Department
South Florida Water Management District
West Palm Beach, Florida

October, 1981

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MANAGEMENT OF WATER LEVELS IN THE "FROG POND" AREA, SOUTH DADE COUNTY, FLORIDA

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INTRODUCTION

The purpose of this report is to examine the effects of maintaining various dry season "optimal stages" in the canals in the "Frog Pond" area of southern Dade County.

Completion of the South Dade Conveyance System in the near future will provide the ability to maintain water levels in the canals adjacent to the study area higher than has previously been possible. Consequently groundwater levels will also be higher. One of the major objectives of the South Dade Conveyance System is to provide water for groundwater recharge, which would enhance groundwater availability and extend the hydroperiod of Everglades National Park and adjacent natural areas.

Optimum stages for the canal systems in the "Frog Pond" area were established during design studies conducted by the Corps of Engineers (1967). Since that time, significant changes have occurred in two areas. First, formerly unimproved land in the Frog Pond area has been brought under cultivation, and secondly, there has been a substantial increase in our understanding of the hydrogeology of the South Dade area. Both of these factors form the basis for a timely reevaluation of the optimum canal levels for the area.

The specific objectives of this report are to evaluate the impacts of various canal stages on:

-Farming in the Frog Pond area.

-Regional groundwater availability and water supplies.

-Groundwater stages and wetland hydroperiods in and adjacent to Everglades National Park.

-Operation of the South Dade Conveyance System and the Central and Southern Florida Flood Control Project of which it is a part.

LOCATION, EXTENT AND TOPOGRAPHY

The study area is located approximately 4.2 miles west of Florida City (Figure 1), and consists of about 5,000 acres. It is bordered on the east by Canal 111 (C-111) between Structures 176 and 177 (S-176 and S-177), and on the west by the L-31W borrow canal between S-174 and S-175. Both canals have similar cross sections; a bottom width of 20 feet, depth of 20 feet and a 1:1 side slope. East of, and adjacent to the L-31W borrow canal is Levee 31W (L-31W) which has a crest elevation of 5 to 6 feet (Corps of Engineers, 1967).

The topography of the study area is shown on Figure 1. Ground elevations range from less than 5.0 feet above NGVD in the southwestern part of the area, to more than 6.5 feet above NGVD at its northeastern corner. The land surface slopes gently towards the south and west.

WATER MANAGEMENT FEATURES

The Frog Pond area is included within the surface water drainage basin of C-111, which has the capacity to accept up to 530 cfs of runoff from the area. However, the secondary drainage facilities which would be needed to convey this water to the canal have not been constructed.

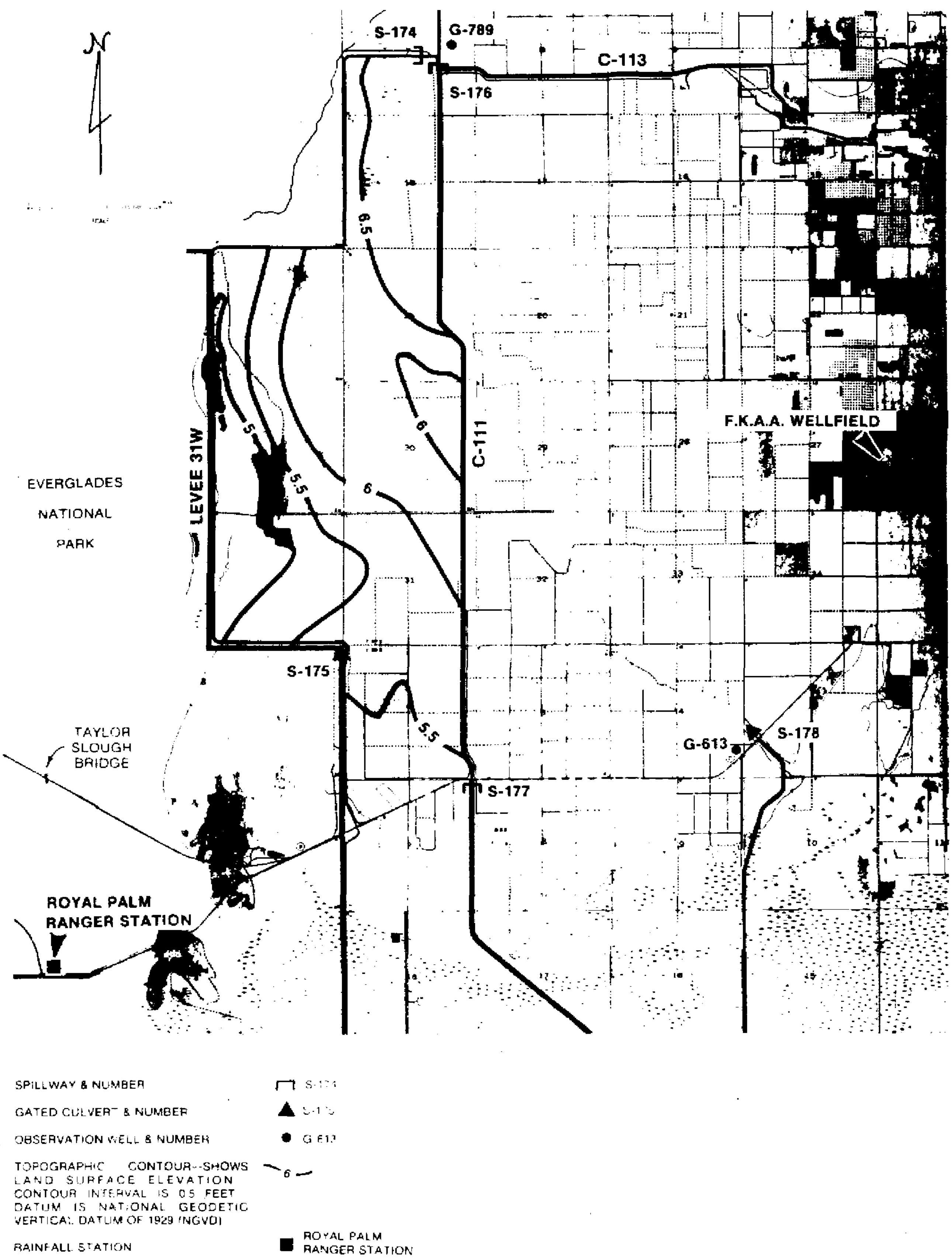

Figure 1 TOPOGRAPHIC MAP OF FROG POND AREA, SOUTH DADE COUNTY, FLORIDA

Although a portion of the Frog Pond area was originally tributary to the L-31W borrow canal, surface runoff from the area must currently drain to C-111.

The pertinent reaches of both C-111 and L-31W were designed to maitain an optimum stage of about 4.5 feet NGVD during the rainy season or whenever adequate water is available locally. During periods when local rainfall is inadequate to maintain the optimum stage, stages have historically receded on occasion, to below sea level. Pump Station 331, which is nearing completion, has been designed to maintain a water supply conveyance stage of about 3.0 feet NGVD for conditions up to a 1 in 10 year drought, given adequate storage levels in the Water Conservation Areas and Lake Okeechobee.

GEOLOGY AND HYDROGEOLOGY

The area is part of the Everglades topographic area, and is underlain by the Biscayne aquifer which consists of a series of limestones, marls, sands, and sandstones ranging in age from Miocene to Recent. The Biscayne aquifer is unconfined and highly permeable. It is recharged by direct infiltration of rainfall as well as by surface water bodies such as canals, rockpits, and surface water detention areas. Water is discharged from the aquifer to topographically low inland areas, canals, and other surface depressions, or to the ocean. Water is also lost from the aquifer by pumpage and evapotranspiration. Regional groundwater flow patterns are shown in Figures 2, 3, and 4, for average yearly lowest, average yearly, and average yearly highest groundwater conditions, respectively. These maps indicate that the Frog Pond area is on the axis of a groundwater

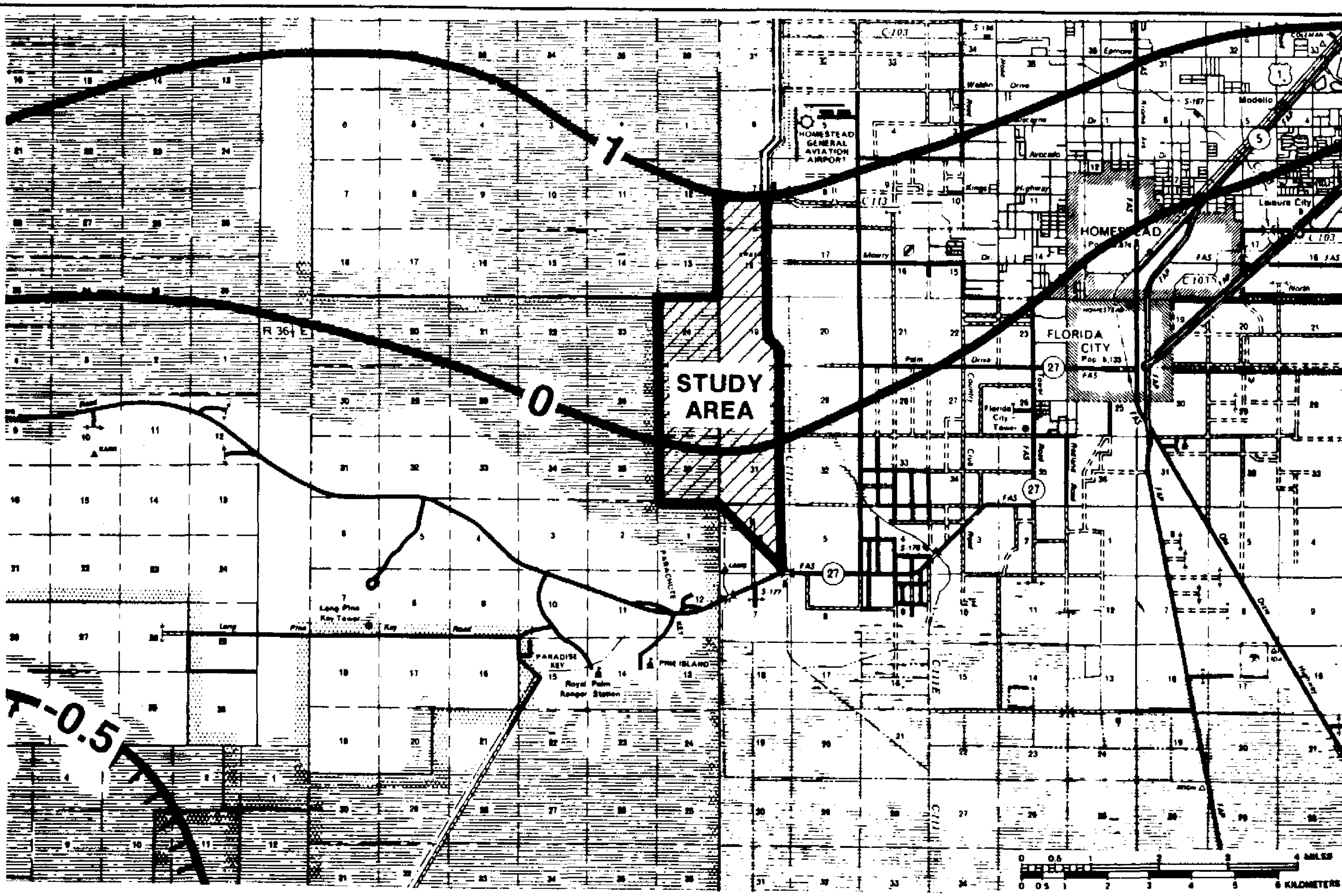

Figure 2 CONTOURS OF THE AVERAGE YEARLY LOWEST GROUNDWATER LEVEL, 1960-75 (HULL, 1978).

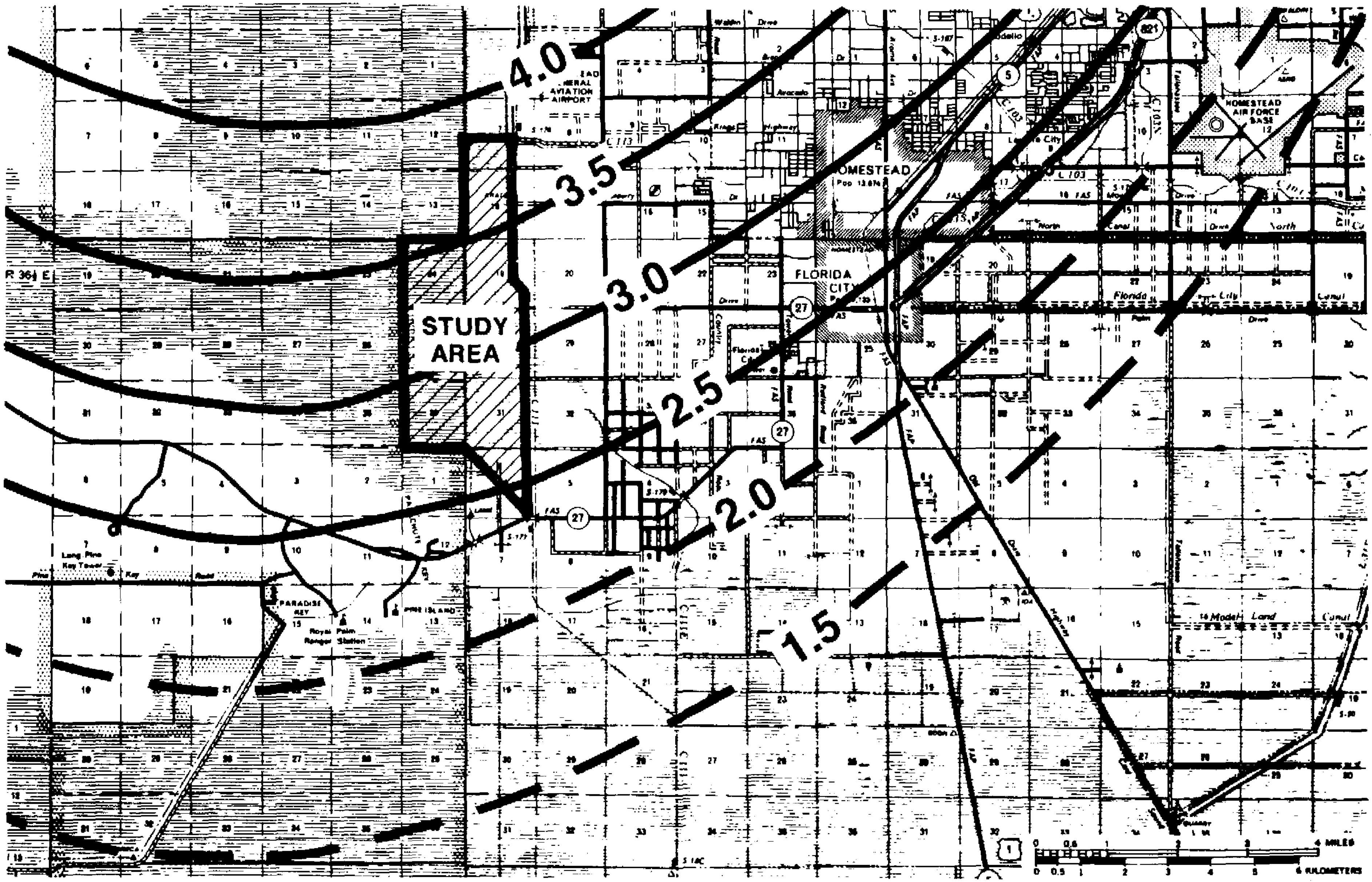

Figure 3 CONTOURS OF THE AVERAGE YEARLY GROUNDWATER LEVEL, 1960-75 (HULL, 1978).

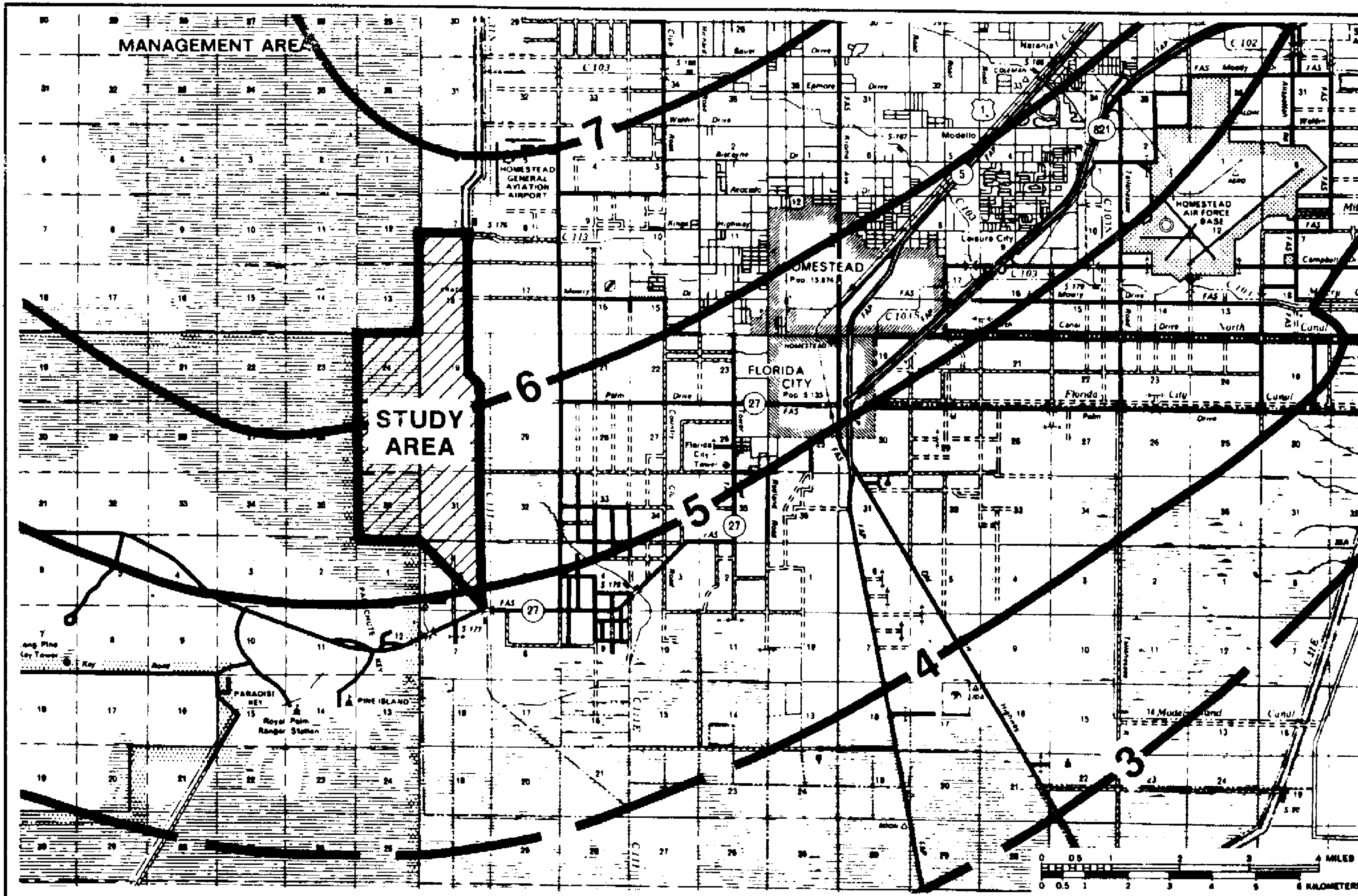

Figure 4 CONTOURS OF THE AVERAGE YEARLY HIGHEST GROUNDWATER LEVEL, 1960-75 (HULL, 1978).

"high" and therefore, under these average conditions, it is a recharge area for parts of the aquifer to the southeast, south, and southwest. However, Figure 5 shows that under extremely low groundwater conditions such as in May 1971, the area became a groundwater sink, probably due to high evapotranspiration losses in the area and low canal levels. Figure 6 shows the extent to which sea water has penetrated into the Biscayne aquifer in the vicinity of the study area.

At the study area, the rocks which make up the Biscayne aquifer are a series of oolitic limestones (the Miami Oolite), which are underlain by marls, limestones, and sandstones (Fort Thompson Formation). The aquifer thickness is estimated to be 60 to 80 feet, from a map by Klein, et al. (1975, p. 31). Both the Miami Oolite and the Fort Thompson Formation are highly permeable, with transmissivities on the order of 4 to 8 million gallons per day per foot (mgd/ft) (Appel, 1973, Figure 8). Specific yield is estimated at .20 to .25.

Geologic logs of shallow boreholes (15 to 25 feet deep) along the alignment of L-31W borrow canal, and C-111 and across the alignment of the canals in the vicinity of S-174, S-175, S-176, and S-177 show highly porous, solution-riddled, cavernous limestones at or near the surface (Corps of Engineers, 1967). The material excavated for the canal is of the same composition, and consequently excellent hydraulic communication must be assumed between the canal and the aquifer.

In the study area, groundwater recharge occurs both by direct infiltration of rainfall and by leakage from the canals when canal stages are higher than the groundwater level. Infiltration of rainfall is enhanced by rock plowing and the "ridge and furrow" method of land preparation which breaks up the surface layer and provides temporary depression

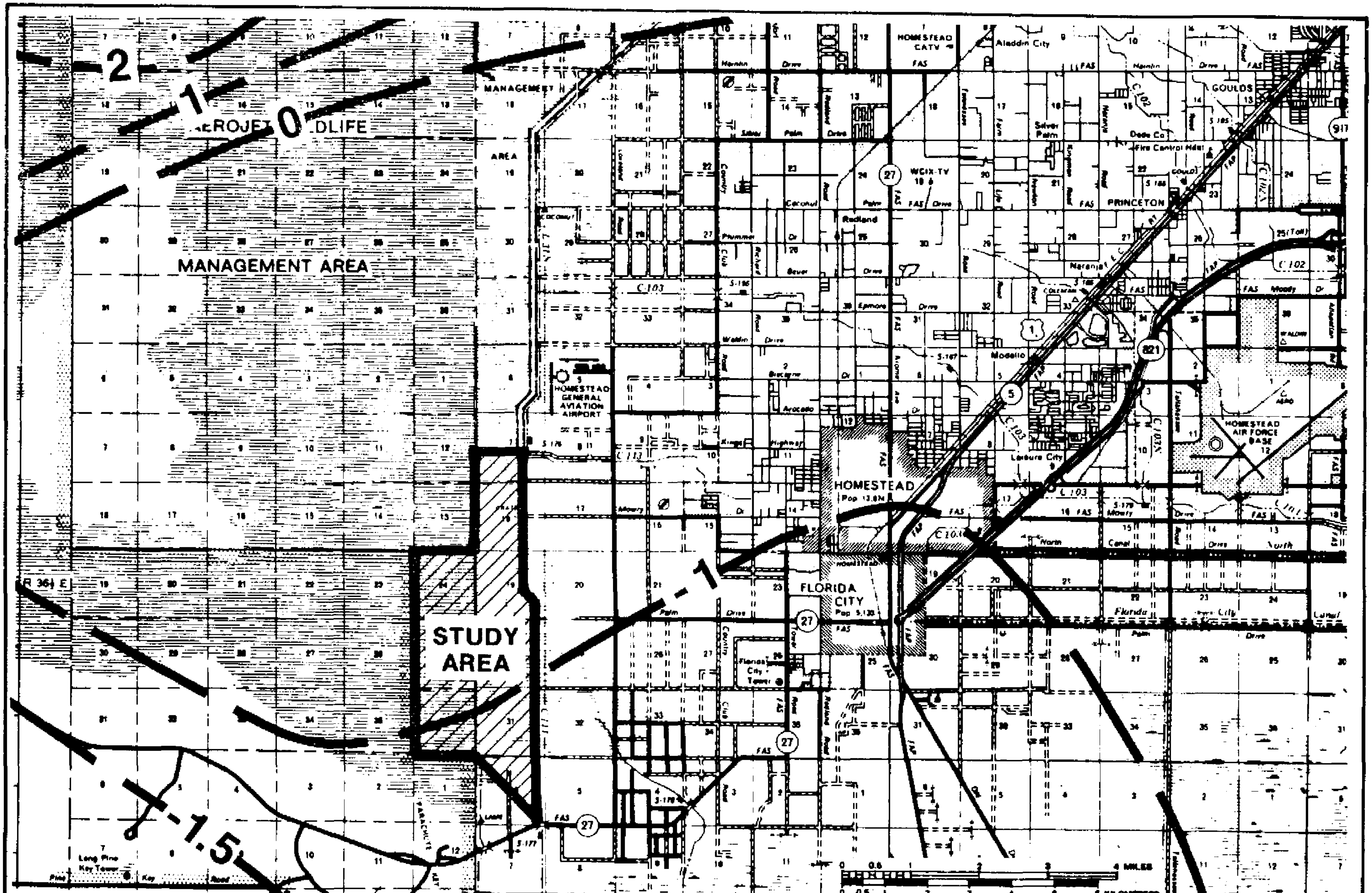

Figure 5 CONTOURS OF GROUNDWATER LEVELS DURING A DRY PERIOD, MAY 3-5, 1971 (MEYER, 1973).

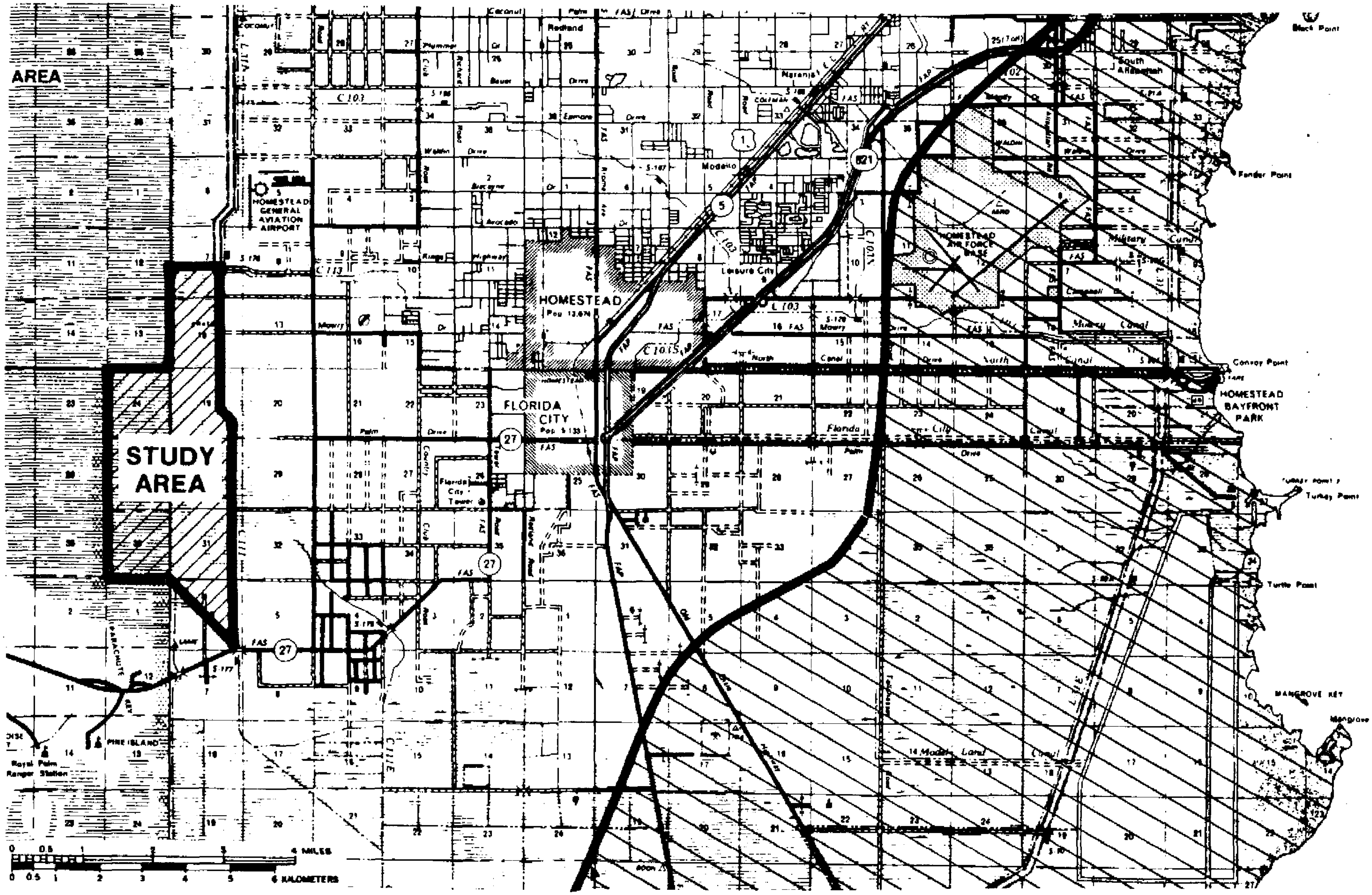

Figure 6 INLAND EXTENT OF SALTWATER INTRUSION AT BASE OF BISCAYNE AQUIFER (1,000 mg/l) 1975-76 (HULL, 1978).

storage. Groundwater discharge from the area is by leakage to the canals when canal stages are lower than groundwater levels, and by evapotranspiration. It is postulated that, in the long term, subsurface groundwater inflow to the study area equals the groundwater outflow from the area.

The nearest site to the Frog Pond area where groundwater is withdrawn by pumpage is the Florida Keys Aqueduct Authority (FKAA) wells (formerly U. S. Navy wells) at Florida City, a distance of 3.27 miles east of the eastern boundary of the study area. Current withdrawal is about 6.8 million gallons per day (mgd), and the cone of depression from each well in this wellfield is estimated to extend less than 1/4 mile from the well. According to Meyer (1973, p. 19) a groundwater level elevation of 2.5 feet at the FKAA wellfield is sufficient to prevent intrusion of sea water to the wells.

HISTORICAL RAINFALL, GROUNDWATER LEVELS, AND CANAL STAGES

In this section of the report historical rainfall and water level data will be analyzed to identify the cause, frequency of occurrence, and duration and effects of high water levels in the Frog Pond area during the agricultural growing season, November 1 to May 7.

Figure 7 shows 1-day rainfalls at Royal Palm Ranger Station for return periods between 3 and 100 years, for the dry season period, November 1 - May 7. Also shown are the upper and lower 90% confidence limits. The graph was prepared from an analysis of 31 years of data (1949-1980), using the Gumbel extremal distribution (Type 1). The location of the station with respect to the study area is shown on

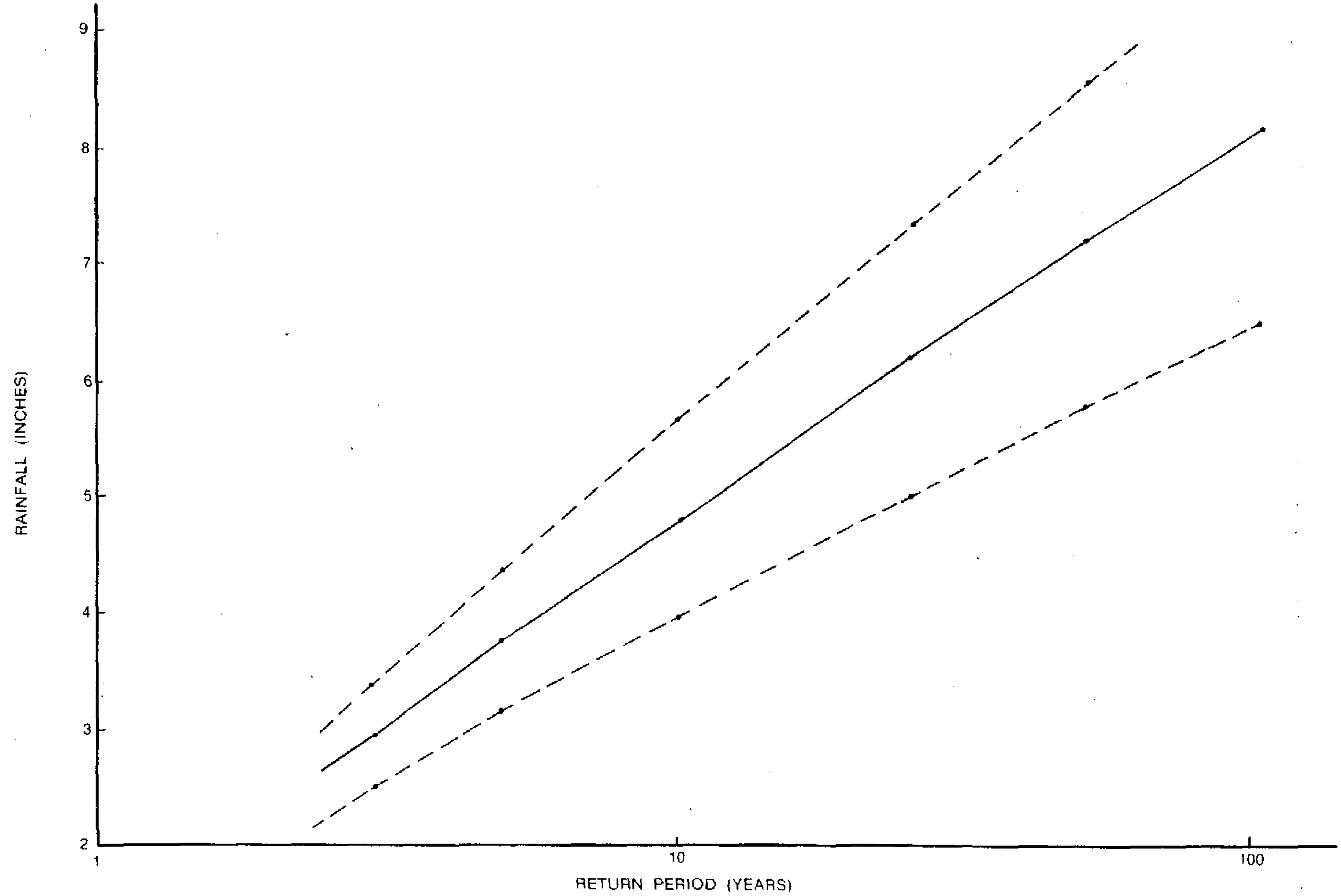

Figure 7 1 DAY RAINFALL FOR RETURN PERIODS BETWEEN 3 AND 100 YEARS; ROYAL PALM RANGER STATION, 1949-1980. (DRY SEASON, 11/1 - 5/7).

Figure 1. This graph indicates that the rainfall event with a return period of 10 years is about 5 inches per day. A 10-year return period is the usual hydrologic design frequency for South Dade County.

Examination of daily rainfall data for the Royal Palm Ranger Station, for the period 1968-1981, shows that the 10-year event has been equalled or exceeded 3 times in the past 12 years during the growing season; April 24, 1978 - 5.38 inches, April 25, 1979 - 9.14 inches, and February 19, 1981 - 5.62 inches. It should be noted that all three events occurred toward the end of the growing season.

RAINFALL AND WATER LEVELS

Rainfall may affect water levels in the Frog Pond area in two general ways: (a) through direct accretion of infiltrated rainwater; and (b) by increasing the stages in L-31W borrow canal and C-111 above groundwater levels and thus causing seepage from the canals to the aquifer.

Figures 8 and 9 show the relationship between rainfall and maximum rises in groundwater levels resulting from this rainfall in wells G-789 and G-613. Locations of wells are shown on Figure 1. Also shown on these figures is the expected relationship if all rainfall in the area contributed to groundwater storage and there was no net influent or effluent groundwater flow, for an assumed specific yield of the aquifer of 0.20. For rainfall events below about 7 inches per day (the design event for the canals), the increases in groundwater levels are less than would be predicted if all the rainfall contributed to groundwater storage and there was no net influent or effluent groundater seepage. This is explained by losses due to interception, direct runoff, evapotranspiration, and principally simultaneous seepage to the canals. For rainfall events

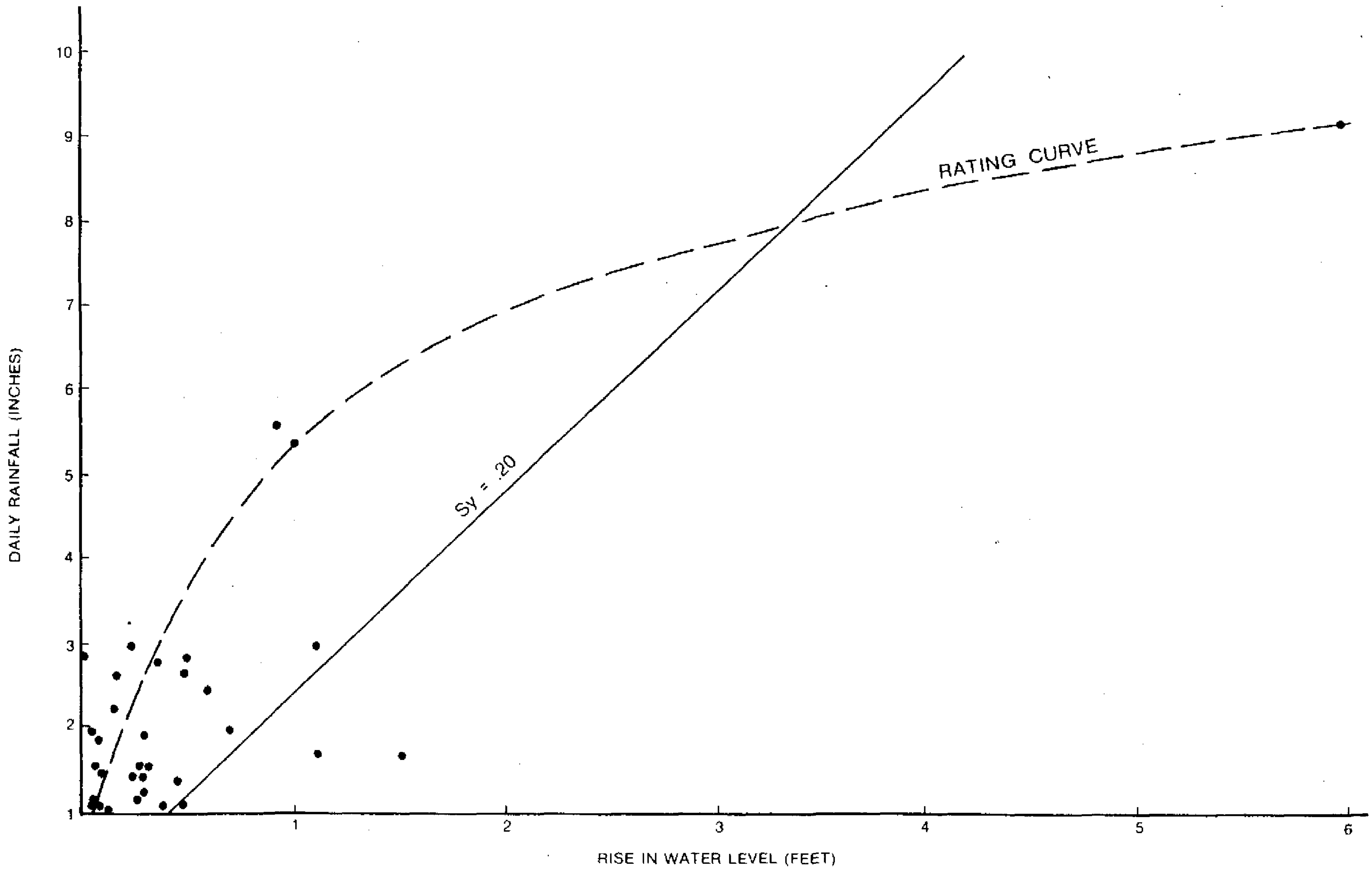

Figure 8 CORRELATION BETWEEN RAINFALL AT ROYAL PALM RANGER STATION AND RISES IN WATER LEVEL IN WELL G-789, OCTOBER 1978-MAY 1980

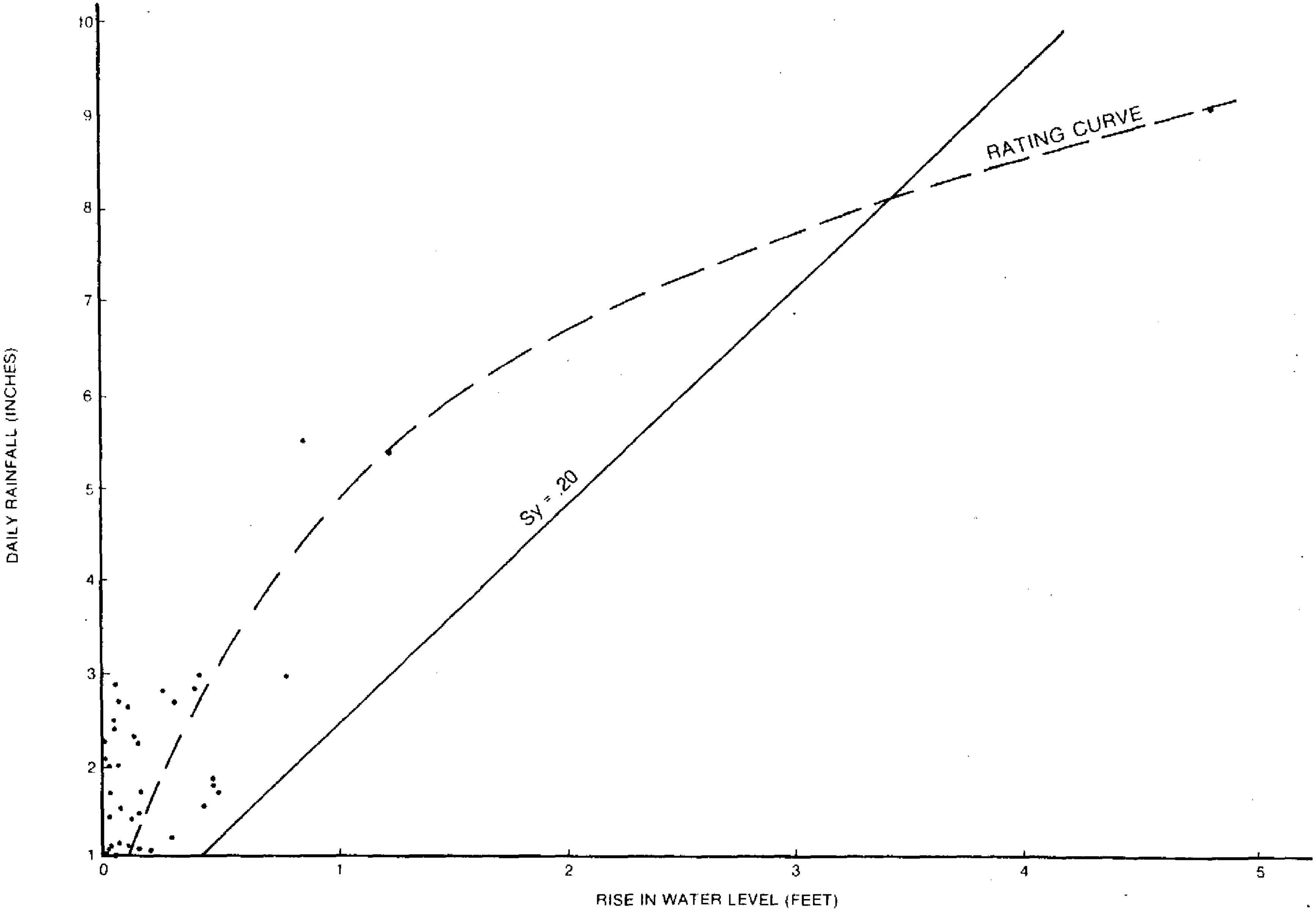

Figure 9 CORRELATION BETWEEN RAINFALL AT ROYAL PALM RANGER STATION AND RISES IN WATER LEVEL IN WELL G-613, OCTOBER 1978 - MAY 1980

greater than the design event of the canals (7 inches in one day), the increments of groundwater level rises are greater than would be expected, due to influent seepage from the canal to the groundwater. A best fit curve drawn through the plotted values can be used as a "rating curve" to predict groundwater level rises resulting from different rainfall events. Figures 10 and 11 show daily rainfall histograms at Royal Palm Ranger Station, and hydrographs for wells G-789 and G-613 for the period October 1978 to May 1979 and October 1979 to May 1980. These figures graphically illustrate the response of groundwater levels to rainfall during these periods, and show the relationships between groundwater levels at these wells and land surface elevations. Figures 12 and 13 depict the relationship between rainfall, groundwater levels and canal stage for the period October 1980 to March 1981.

The relationship between groundwater levels and canal stages immediately prior to, during, and immediately after an extreme rainfall event is further illustrated in Figures 14 and 15, for the storm of April 25, 1979 when 9.14 inches of rainfall was recorded at the Royal Palm Ranger Station. It should be noted that at well G-789, which is close to S-176 and S-174, tailwater canal levels rose rapidly and remained high for more than 54 hours. The effect of this was to keep water levels high in the aquifer adjacent to the canal. Groundwater level recession followed closely and was controlled by canal stage recession.

At well G-613 groundwater levels were lower than headwater stages at S-175 and S-177. This is probably due to the fact that this well is an appreciable distance (2-3 miles) from the structures, and is in fact closer (1/4 mile) to and probably also influenced by the stage at S-178.

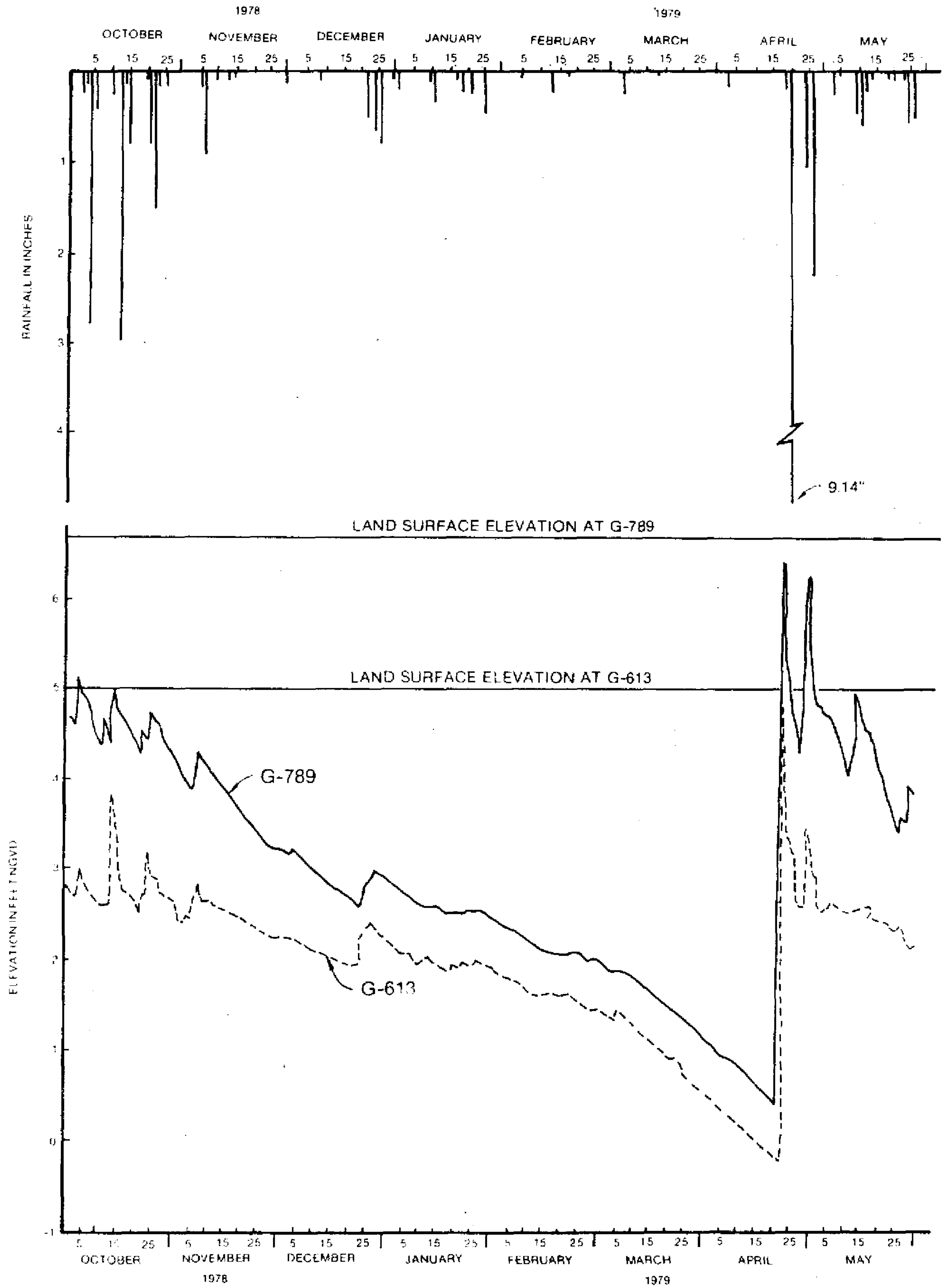

Figure 10 DAILY RAINFALL, ROYAL PALM RANGER STATION AND WATER LEVEL ELEVATIONS, WELLS G-613 AND G-789, OCTOBER 1978 - MAY 1979

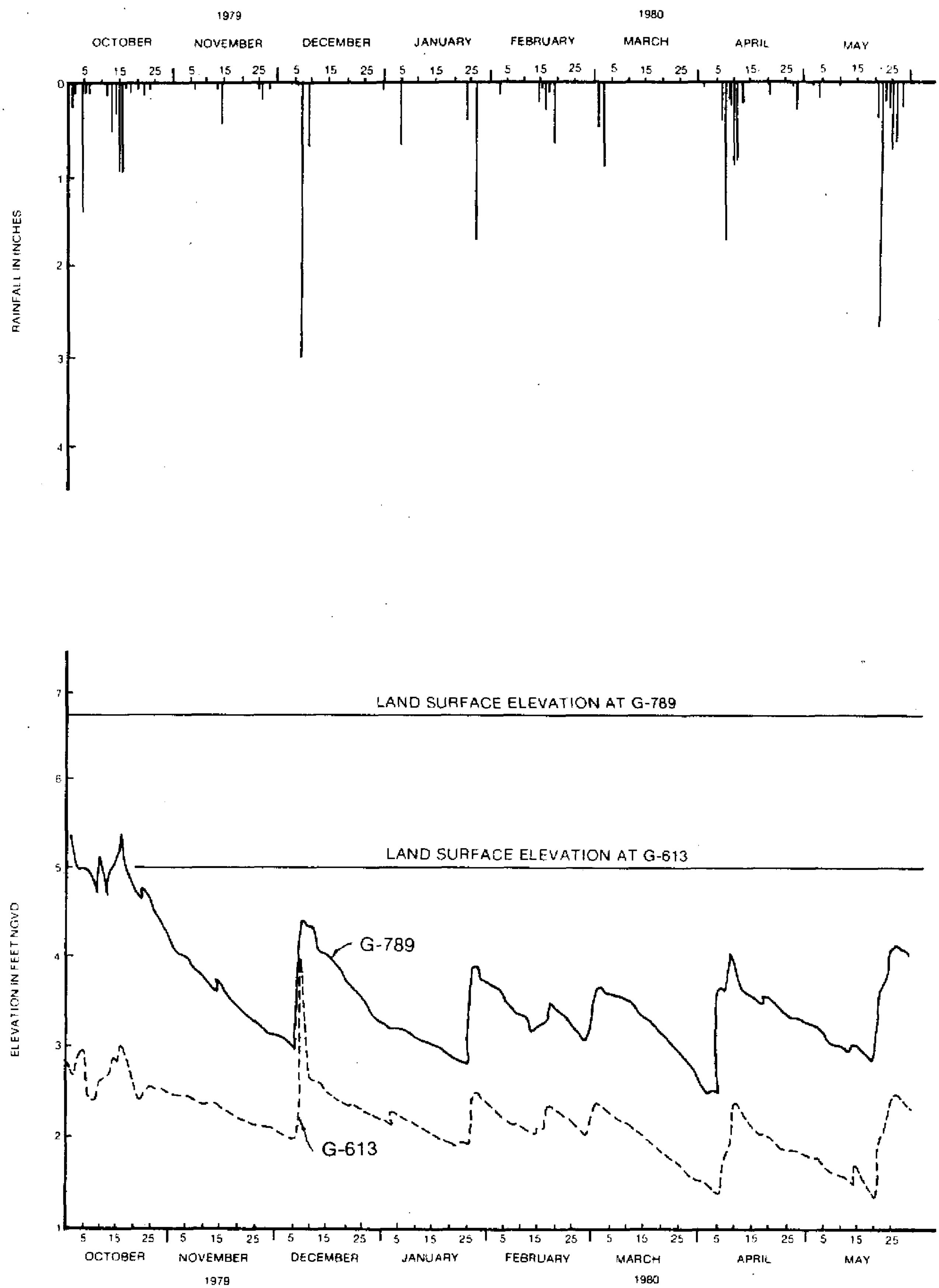

Figure 11 DAILY RAINFALL, ROYAL PALM RANGER STATION, AND WATER LEVEL ELEVATIONS, WELLS G-613 AND G-789, OCTOBER 1979 - MAY 1980

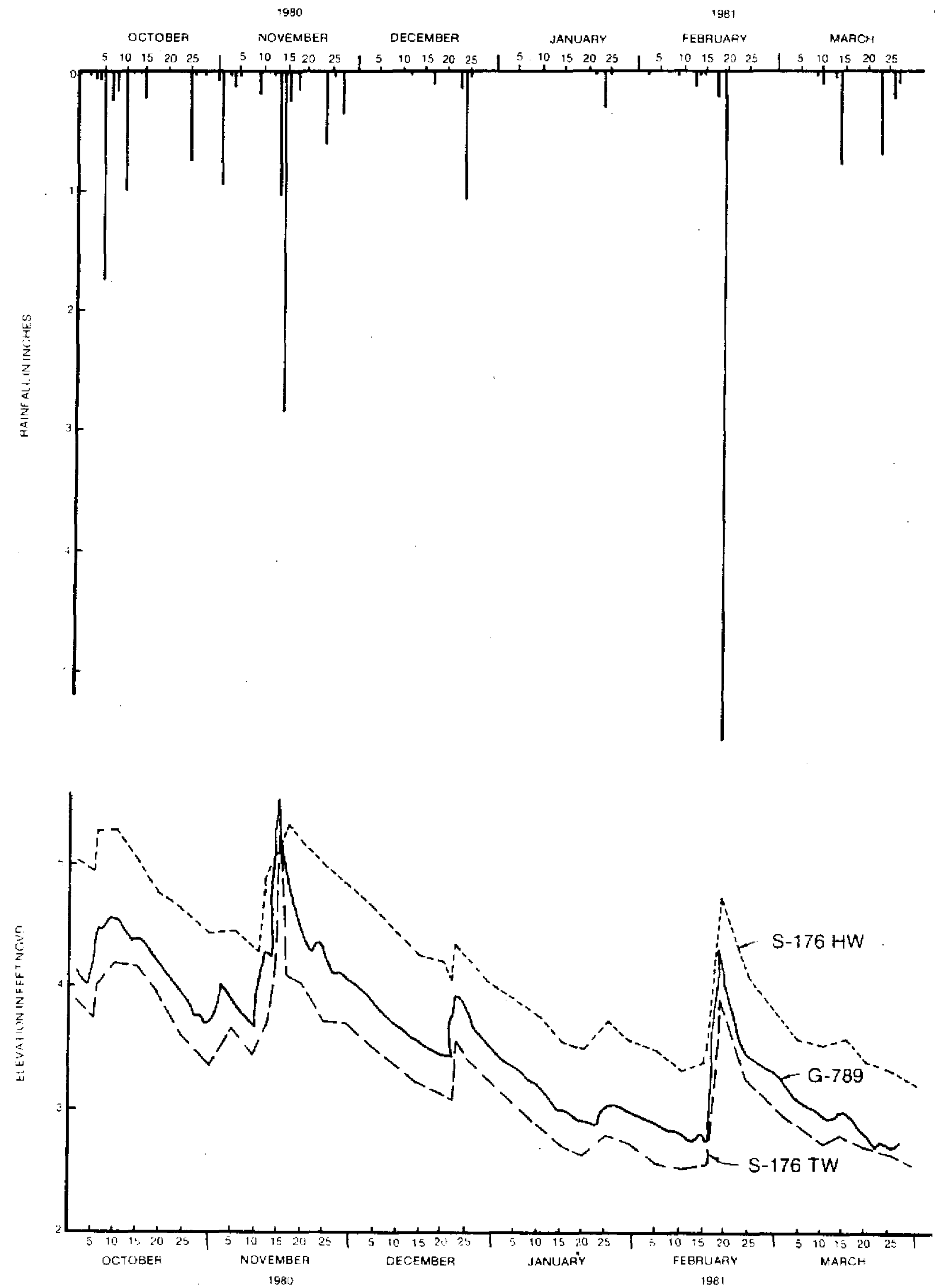

Figure 12 WATER LEVEL ELEVATIONS AT S-176 AND WELL G-789, AND DAILY RAINFALL AT ROYAL PALM RANGER STATION, OCTOBER 1980 TO MARCH 1981

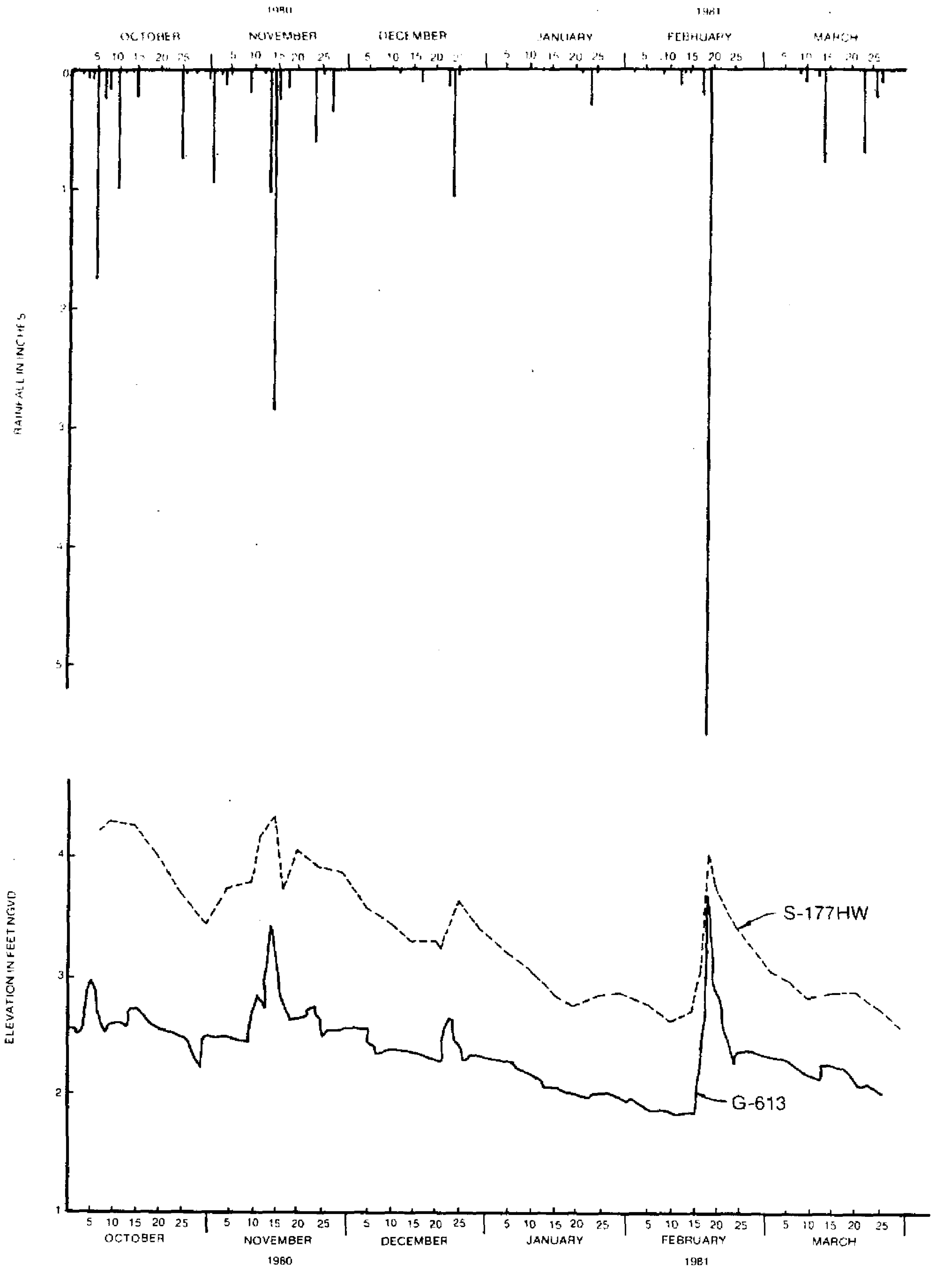

Figure 13 WATER LEVEL ELEVATIONS AT S-177 AND WELL G-613, AND DAILY RAINFALL AT ROYAL PALM RANGER STATION, OCTOBER 1980 TO MARCH 1981.

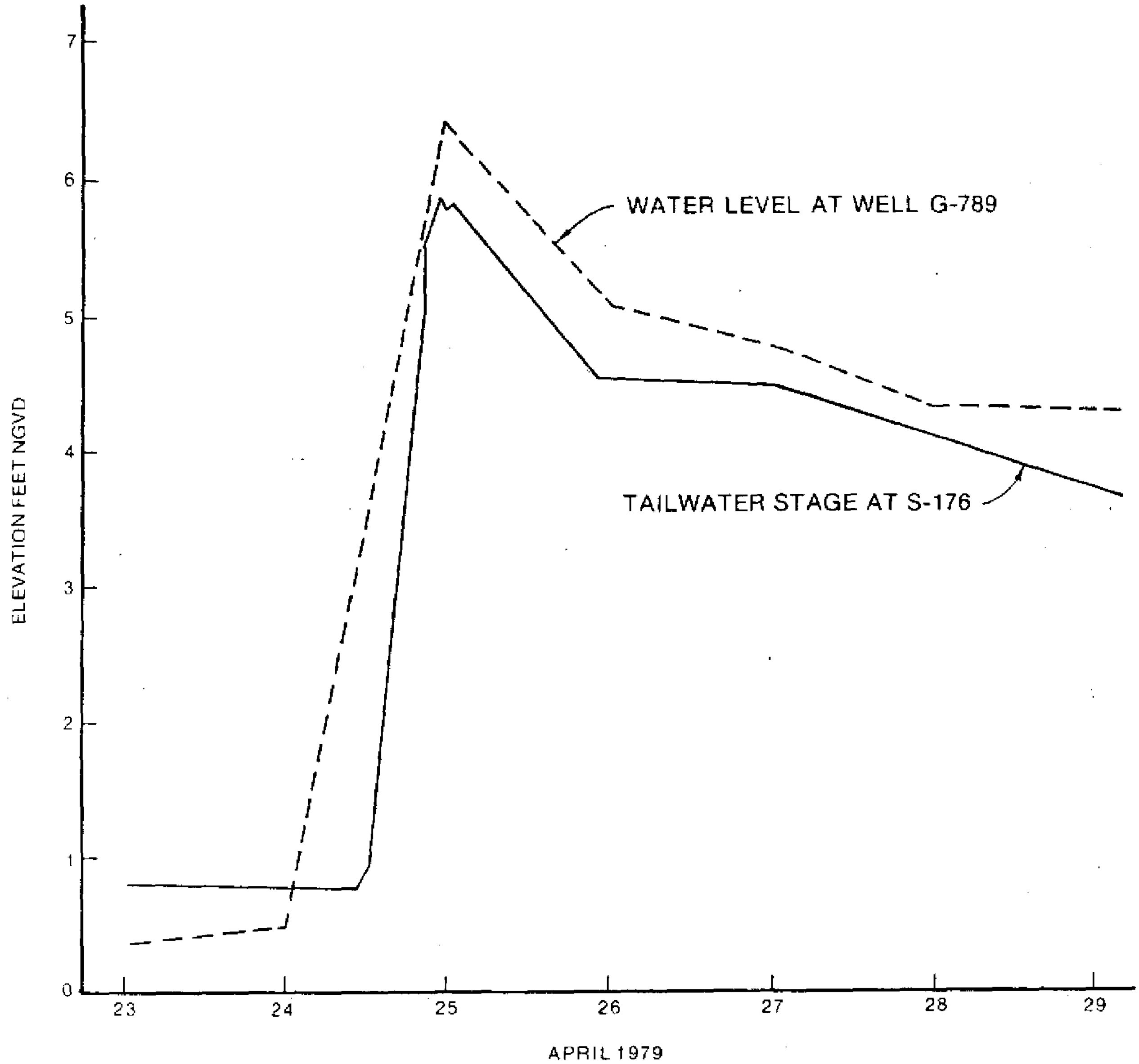

Figure 14 COMPARISON OF GROUNDWATER LEVELS AND CANAL STAGES

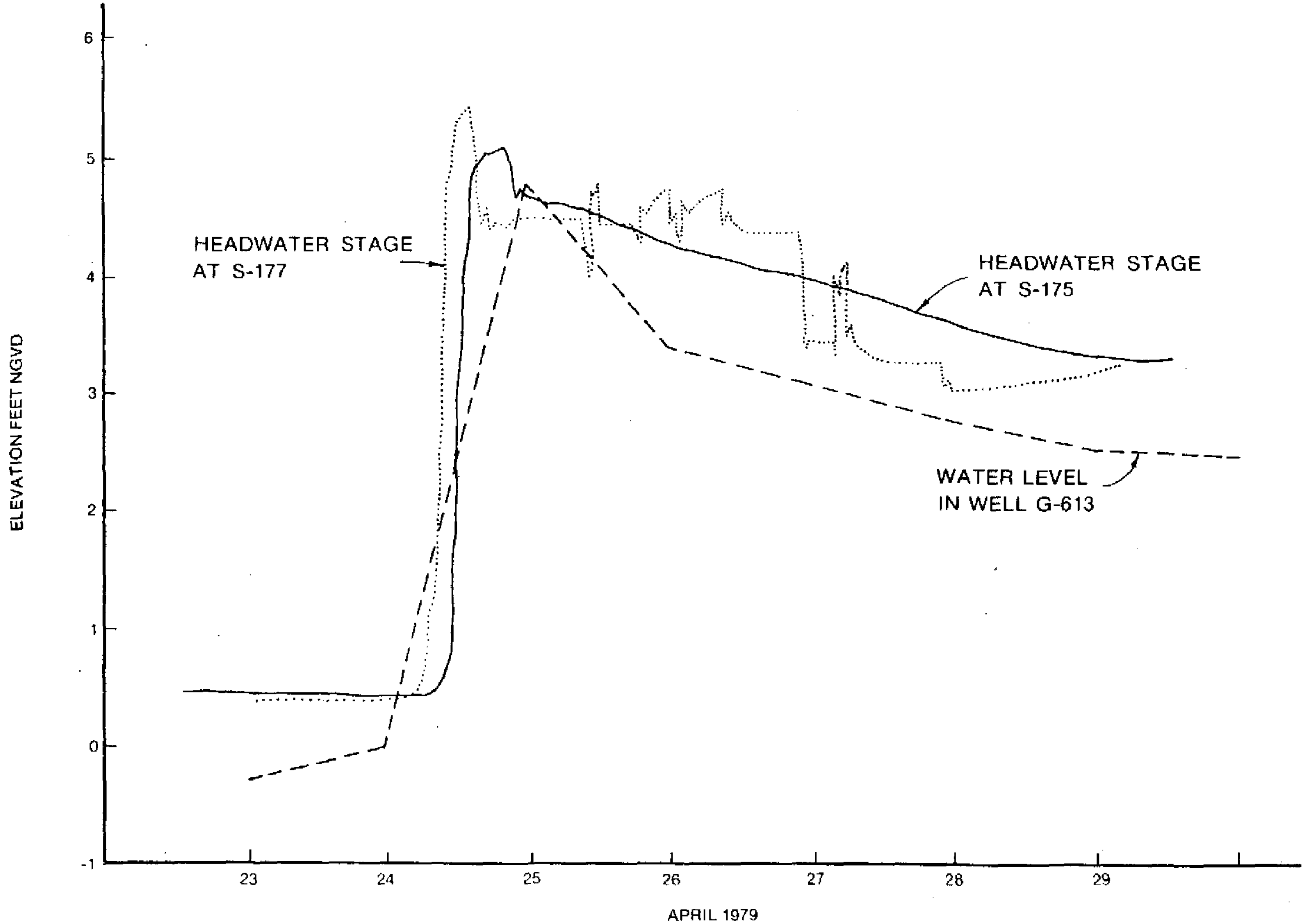

Figure 15 COMPARISON OF GROUNDWATER LEVELS AND CANAL STAGES

GROUNDWATER LEVELS

Elevations of the water table during and after a rainfall event are determined by the antecedent groundwater level and the rise in water level caused by the rain. For the study area, the rise in water level to be expected from a given storm can be predicted by referring to Figures 8 or 9.

Antecedent groundwater levels for most storms during the dry season are expected to be controlled by the levels in the canals. A straight line joining the canal levels at L-31W and C-111 perpendicular to the canal alignments would approximate the groundwater levels along this cross section of the aquifer.

Examination of stage hydrographs for these canals show that for the water years 1978 to 1979 and 1979 to 1980, canal levels have declined gradually from the end of the rainy season to the beginning of the next rainy season. As shown on Figures 14 and 15, the antecedent conditions for the April 25, 1979 storm were canal and groundwater levels close to 0 feet NGVD.

MANAGEMENT OF GROUNDWATER LEVELS FOR AGRICULTURE

This section of the report examines the possibilities for managing groundwater levels in the Frog Pond area by regulation of stages in the existing canal system. The approach taken is to define the average levels which could be maintained in the canals with a reasonable probability that unacceptably high groundwater conditions could be prevented from occurring during the agricultural growing season. In addition, the effects of higher average canal stages on agricultural practices are examined, based on stated criteria. Neither the implications of regulating canal stages on other aspects of water resources availability, nor the maximizing of benefits from the South Dade Conveyance System, will be addressed in this section. For the purpose of this report, a "reasonable probability" is defined as an event with a return period of 10 years, that is, 5 inches of rainfall in one day. "Unacceptably high groundwater conditions" are defined as a water table within 1.5 feet of the ground surface for 48 hours or more. Using these definitions, groundwater levels could be allowed to rise above the critical level as long as the levels could be brought down to acceptable limits within 48 hours.

The self-regulatory capacity of the canal/aquifer system is illustrated in Figures 16 and 17. Calculations are based on methods described by Ferris, et al. (1962) and Huisman (1970). (See Appendix for details of the method used to obtain these figures). Figure 16 shows the distribution of heads in the aquifer in the study area adjacent to the canal as a function of time and distance after the stage in the canal is lowered instantaneously by one foot. For other amounts of canal stage lowering the groundwater drawdowns at any point can be obtained by multiplying the value on the graph by the amount the canal stage is lowered. For two canal stages lowered simultaneously, the distribution of heads may be obtained by superimposing the appropriate graphs.

Figure 17 compares the drawdowns at the end of 2 days when stages in two canals, L-31W and C-111 are lowered simultaneously by 1 foot, with drawdowns when only one canal stage is lowered. The considerable improvement in drainage with lower stage regulation of the two canals is clearly indicated.

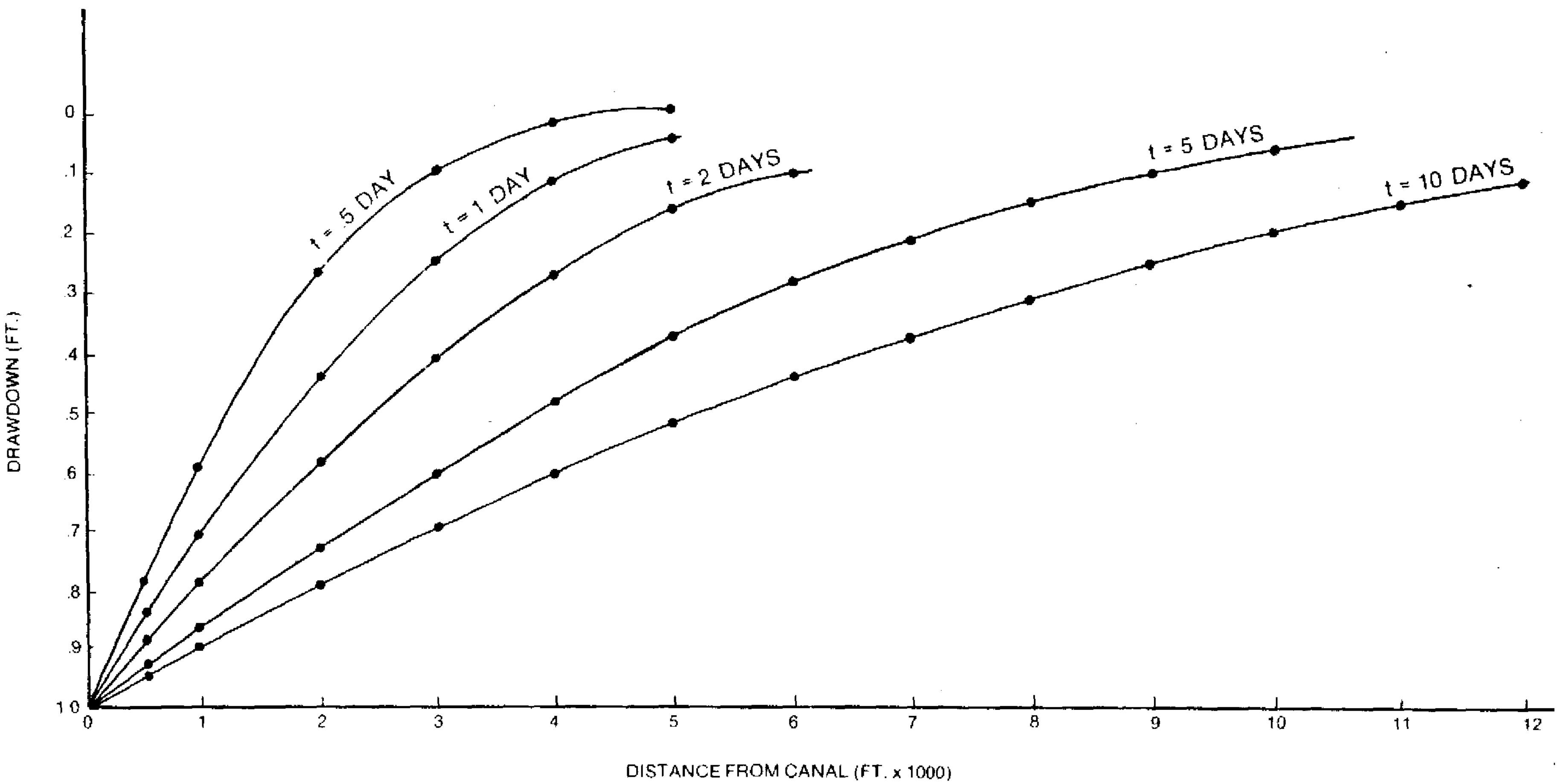

Figure 16 DRAWDOWNS RESULTING FROM A 1 FOOT LOWERING OF CANAL STAGE

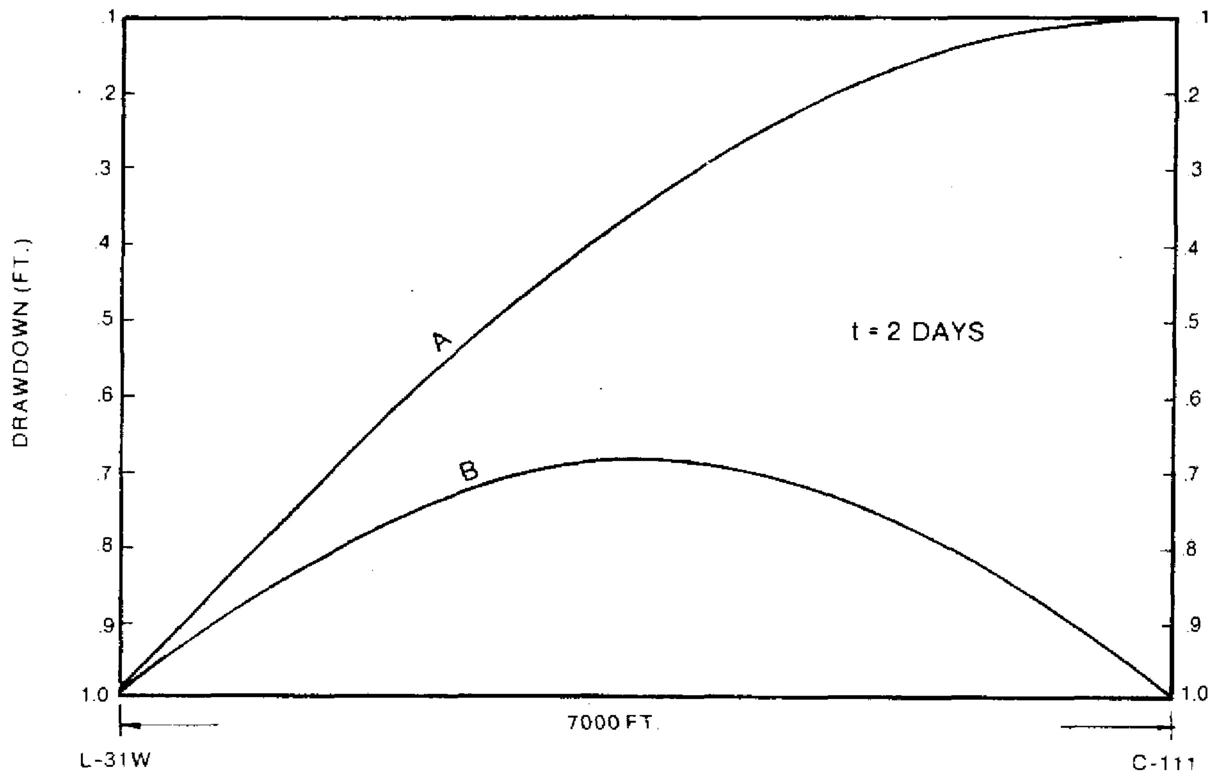

Figure 17 COMPARISON OF DRAWDOWNS RESULTING FROM 1 FOOT LOWERING OF: A—ONE CANAL STAGE B—BOTH CANAL STAGES

If both canals are at the same stage and one canal stage is lowered by 1 foot, the net additional baseflow to the canal with the lowered stage is calculated to be 132 million gallons per day.

For every 1 foot difference in stage between the two canals, 66 million gallons of water per day will be transferred from the canal with the higher stage to the canal with the lower stage (see Appendix for details of calculation).

The total quantity of water lost from the study area for each 1 foot lowering of the water table over the entire study area is calculated to be 300 million gallons. This quantity also represents the additional groundwater which would be stored in the study area for each 1 foot average increment of stage in the canals.

Table 1 shows the likely consequence of various canal stage combinations on farming in the area. To develop this table the following a priori assumptions were made:

(1) The level of protection for the farming operation will be a rainfall with a return period of 10 years, i.e. 5 inches in one day.

(2) For crop protection, the depth to water in the study area should not be less than 1.5 feet below land surface for more than 2 days.

(3) The antecedent condition for each storm will be a groundwater level controlled by the canal stage.

(4) Canal stages will be lowered immediately or soon after the rainfall. The required lowering will be discussed later.

TABLE 1. The Effects of Various Canal Stages Upon Farmable Acreage in the "Frog Pond" Area, South Dade County

CANAL STAGE (ft. NGVD) L31W	C111	MINIMUM ALLOWABLE FARMING ELEVATION (ft. NGVD)	ACREAGE AVAILABLE FOR FARMING	UNFARMABLE ACREAGE
0.0	3.0	1.5	4655	0
1.0	3.0	2.5	4655	0
2.0	3.0	3.5	4655	0
3.0	3.0	4.5	4655	0
3.5	3.0	5.00	4256	399
4.0	3.0	5.25	3778	877
4.5	3.0	5.70	2861	1794
4.5	4.5	6.0	2231	2424

*Minimum Allowable Farming Elevation obtained assuming a level of protection of a 10-year rainfall event of 5 inches. Also assuming that if the water level rises to the root zone (within 1.5 feet of land surface) the canals will be effective in reducing groundwater levels to canal stage in 48 hours.

The following additional assumptions were made based on the pervious analysis:

(1) The groundwater level increment from a 5 inch daily rainfall is 1.0 foot (see Figure 8).

(2) The groundwater levels after the rain can be reduced to their original levels in 2 days by lowering stages in both canals (see Figure 17).

From Table 1 it is seen that if stages in L-31W borrow canal and C-111 are held at 3.0 feet or less, the entire Frog Pond area should be farmable. If water levels in L-31W borrow canal are held at elevations higher than 3.0 feet while C-111 is held at 3.0 feet, some part of the study area would be unsuitable for cultivation. Estimates of the minimum elevations which could be farmed to the level of protection of a 10-year return period rainfall, as well as estimates of the unfarmable acreages are shown in this Table.

Although stages could theoretically be held at different levels in the two canals bordering the Frog Pond area, this would require continuous discharge of water brought into the area by the canal system, at either or both downstream structures (S-175 or S-177). A groundwater gradient would be established from the canal with the higher gradient to the canal with the lower gradient, thus increasing groundwater flow between the canals. To maintain the stage differentials, additional water would have to be continuously released to the reach of the canal with the higher stage, and continuously released from the canal reach with the lower stage.

The quantity of water which would be "lost" (not put to beneficial use) by holding one canal stage higher than the other cannot be easily determined, as this depends on the operation of the system. Supplemental water releases to the canal with the lower stage, which would normally be required to replenish water lost by seepage and evaporation, could possibly be reduced as this would be partially made up by seepage from the canal with the higher stage. In addition, downstream releases from the canal with the lower stage could benefit wetlands to the south.

The required lowering of canal levels is dependent on the magnitude of rainfall. Canal levels should be lowered at least 30% more than the increment of groundwater rise to assure full drainage. Stages should be reset to original levels after 48 hours to minimize groundwater loss. For example, assuming a 5 inch rain, the increment of groundwater rise would be 1 foot. If canal levels were previously held at 3.0 feet, then rose to 4 feet due to the rainfall, the levels should be lowered to at least 2.7 feet for 48 hours and then returned to 3.0 feet.

It must be emphasized that this procedure should ensure drainage of the area under the assumptions stated previously. However, if greater protection or more rapid drainage is required, additional measures could be implemented. This may include additional lowering of canal levels or the installation of secondary canals.

While it is not feasible to examine the effects of ever possible combination of canal levels and operating procedures, two additional possibilities will be mentioned as follows:

(1) A 4.5 foot NGVD level on both canals with no drawdown of either canal after a rainfall event: The initial groundwater level elevation for this condition would be 4.5 feet NGVD. With a rainfall of 5 inches, water levels would rise by 1 foot, giving a water level after the storm of 5.5 feet. Up to ground elevation 5.5 foot, water levels would be at or above

ground surface (i.e. an area of approximately 1200 acres would be flooded) and water levels would be less than 1.5 feet below the surface over the rest of the Frog Pond area. Without lowering of the canal stages, it would not be possible to remove this excess water within two days.

(2) A 4.5 foot NGVD stage in both canals with drawdown in one canal (S-177) after a rainfall event: As previously mentioned, lowering of a single canal stage will be inefficient in providing rapid drainage of the area (see Figure 17). This mode of operation is therefore not recommended.

REGIONAL GROUNDWATER IMPACTS

The South Dade Conveyance System is designed to provide groundwater recharge and consequently raise groundwater levels within the flow regime of the canals. This is expected to assist in stabilizing, or moving seaward, the saline water front shown on Figure 6, thus protecting established withdrawals and allowing for additional withdrawals.

Maximum benefits to regional groundwater availability would accrue if canal stages were held at maximum attainable levels during the dry season. For the Frog Pond area, maximum attainable levels would be determined by the quantity of water which could be delivered to, and released from, the upstream structures (S-174 and S-176). If canal levels must be lowered to protect farming in the area, the result would be a reduction in potential benefits from the system. The loss in potential benefits cannot be quantified within the scope of this report; however, the following general statements are considered to be valid:

(1) If canal stages are regulated to the maximum stage which would permit farming of all the Frog Pond area (3.0 feet in C-111 and L-31W borrow canal), there would still be a substantial benefit to groundwater storage compared to historical conditions.

(2) At present withdrawal levels, the FKAA wells at Florida City would receive adequate recharge from the canal system.

(3) Since dry season groundwater levels in the vicinity of the Frog Pond area will be held at higher levels than was historically the case, it is possible that additional groundwater outflows may improve the quality of groundwater in some areas affected by saline intrusion.

EVERGLADES NATIONAL PARK AND WETLANDS IMPACTS

Everglades National Park lies to the west of L-31W levee and canal. The levee was constructed to protect agricultural land to the east of the Park from flooding. The canal was designed to replenish the fresh water supply in the Taylor Slough area of the Park (U. S. Army Corps of Engineers, 1967). Because of the intimate connection between the hydrology of the Park and the L-31W levee/canal system, changes in regulation stages in the canal are expected to affect the hydrologic system in the Park.

A study was completed recently (Rose, Flora, and Rosendahl, 1981) to determine the effects of the L-31W system on the Everglades National Park, using Taylor Slough as the indicator for impacts on the Park. The Taylor Slough bridge (Figure 1) is approximately 1.5 miles southwest of L-31W levee and canal. Rose, Flora, and Rosendahl, 1981 (Figure 12), showed that the mean monthly stage for Taylor Slough at the bridge shows significant variations between the pre-construction period of record (1960-68) and the post-construction period of record (1969-78). Their analysis indicates that for the period November to May, mean water levels were decreased by 20, 10, 9, 11 and 9 percent during the first 5 months (November to March) and increased by 16 and 167 percent during the latter two months (April and May). Since rainfall distribution was similar during the pre- and post-construction periods, these differences were attributed to the effect of the canal/levee system. Consequently, the construction of the levee and conveyance system has had a damping effect on fluctuations of the stage at Taylor Slough. During the wet season, stages have generally been lower due to diversion of surface flow from the area (Rose, Flora and Rosendahl, 1981). During periods of very low water levels, the canal appears to have had the effect of raising average groundwater levels above pre-construction levels. This is probably due to the conveyance of water into the area via the canal which replenishes groundwater storage.

Historically, stages in L-31W canal downstream of S-174 reach a peak in October or November and begin a gradual recession to the end of the dry season in April or May. The relationship between levels in L-31W canal and stages at Taylor Slough bridge for the period November 1978 to May 1979 is shown in Figure 18. This figure indicates that there is a close correspondence between stages in L-31W canal and Taylor Slough. A 3.0 foot NGVD level in the canal correlates approximately with a level of about 2.5 feet NGVD in Taylor Slough.

Table 2 shows the water levels in Taylor Slough which could be anticipated if water levels in L-21W downstream of S-174 were held at 3.0 feet NGVD, compared with average histroic pre- and post-construction water levels (1960-1968 and 1968-1978; Rose, Flora and Rosendahl, 1981).

As shown by Table 2, the net effect of maintaining a stage of 3.0 feet NGVD in L-31W, adjacent to the Park, will be substantially higher water levels during the dry season - thus altering the cycle of high and low water levels now experienced. During the month of November, which is generally considered to be a transitional month, water levels in the Park are likely to be about 1 foot lower than the historical mean, if a stage of 30 feet were maintained.

Historic post-construction wet season (June to October) levels in the ENP have fallen below pre-construction levels during some wet months (see Table 2). Given the availability of water, it is expected that normal optimum wet season stages in C-111 and L-31W borrow canal would not change.

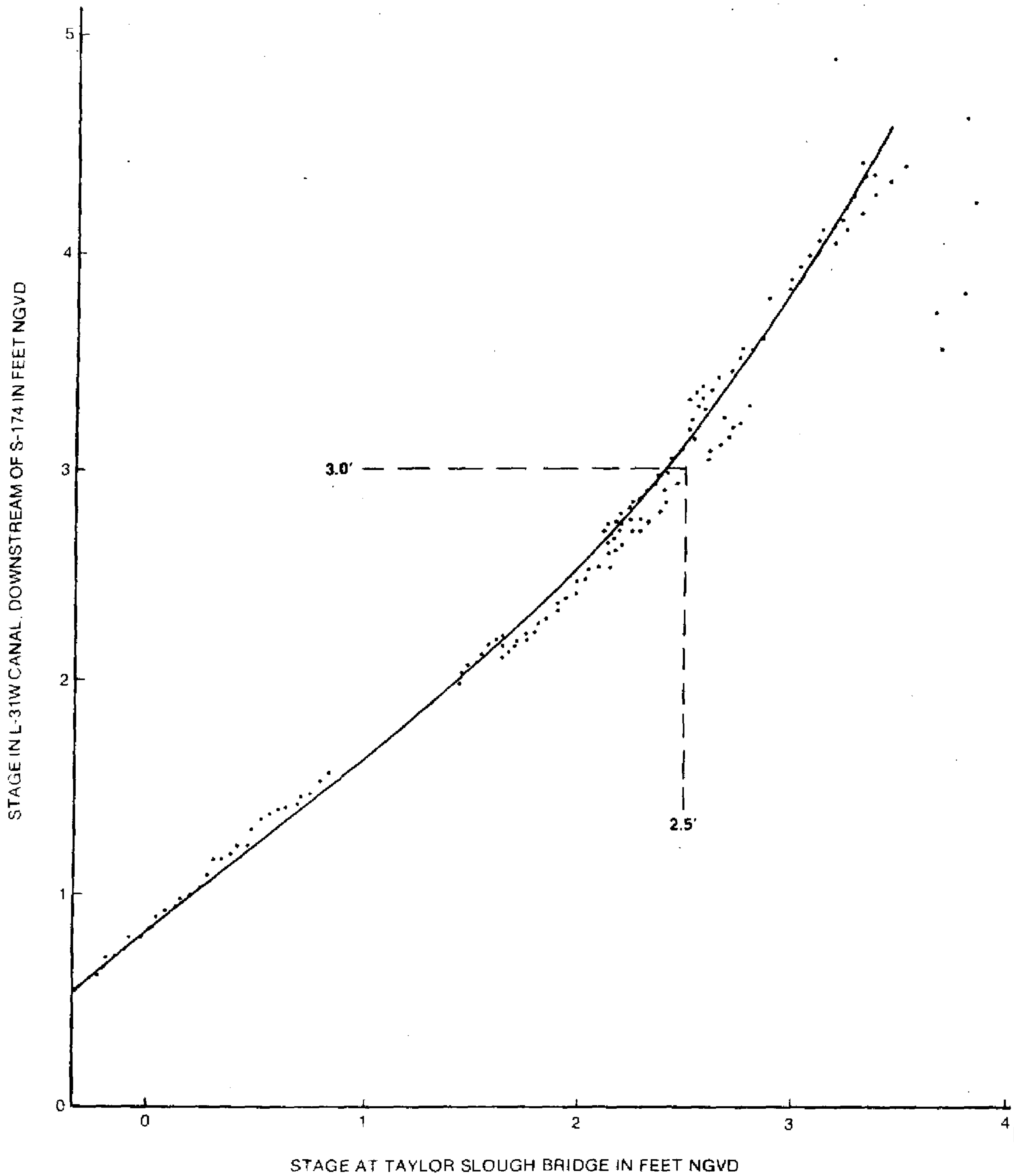

Figure 18 COMPARISON OF STAGE IN L-31W CANAL, DOWNSTREAM OF S-174 WITH STAGE AT TAYLOR SLOUGH BRIDGE, NOV. 1978 TO APRIL 1979.

Pumping Station 332 located at the intersection of L-31W and Taylor Slough has been designed to augment flow in the Slough especially during the wet season, and consequently raise water levels in the ENP. Pumping Station 332 is expected to be operational in 1981 or 1982 (Rose, Flora and Rosendahl, 1981).

TABLE 2. HISTORIC PRE-AND POST-CONSTRUCTION AND EXPECTED STAGES IN TAYLOR SLOUGH IN FT. NGVD

MONTH	HISTORIC MEAN (1) 1960-1968	HISTORIC MEAN (2) 1968-1978	EXPECTED LEVELS WITH 3.0 FT.CANAL STAGE, NOVEMBER-MAY	DIFFER-ENCE (3)	DIFFER-ENCE (4)
Jan.	2.06	1.87	2.50	+0.44	+0.63
Feb.	1.85	1.65	2.50	+0.65	+0.85
March	1.32	1.20	2.50	+1.18	+1.30
April	0.55	0.64	2.50	+1.95	+1.86
May	0.33	0.88	2.50	+2.17	+1.62
June	3.60	2.57			
July	3.69	3.25			
Aug.	3.12	3.17			
Sept.	3.65	3.67			
Oct.	3.91	3.33			
Nov.	3.46	2.77	2.50	-0.96	-0.27
Dec.	2.48	2.22	2.50	+0.02	+0.28

(1) Pre-Construction

(2) Post-Construction

(3) Difference between expected levels and pre-construction historic means

(4) Difference between expected levels and post-construction historic means

SOUTH DADE CONVEYANCE SYSTEM

Purpose for Existing

The primary reason for the construction of the South Dade Conveyance System is that it was mandated by an act of Congress, to be used to supply the remaining 55,000 acre-feet per year of the Everglades National Park's allotment of 315,000 acre-feet per year. This act guaranteed the Everglades National Park (ENP) a minimum at 315,000 acre-feet per year except under District-wide drought conditions when the park would receive 16 percent of the surface water supplied from the system.

A secondary reason is to maintain groundwater stages in south Dade for salinity control when water is available in the Water Conservation Areas and/or Lake Okeechobee. As an example:

> October 1974 to May 1975 was drier than October 1970 to May 1971 and the demands were much greater than the 1971 demands. However, October 1974 Lake Okeechobee stage was 15.24 feet NGVD with a May 1975 stage of 12.04 feet NGVD while the October 1970 stage was 14.13 feet NGVD with the lake dropping to a low of approximately 10.3 feet NGVD in May of 1971.
>
> Very low groundwater stages existed in south Dade for both dry seasons. However, if the South Dade Conveyance System had existed in 1974 it could have maintained groundwater stages in south Dade, and supplied the ENP with their full allotment from Lake Okeechobee.

Mode of Operation

The system is designed to supply, when available either in the Water Conservation Areas or Lake Okeechobee, 1955 cubic feet per second from Water Conservation Area 3A (CA-3A) with a stage of 7.5 feet NGVD at S-333 and S-151 (see Table 3 and Figure 19).

Of this amount, 1350 cfs is to be discharged at S-333 and 605 cfs at S-151. The water discharged at S-333 is conveyed by an enlarged L-29 borrow to S-334 at L-30. Design Water Surface (DWS) at S-333 is 7.0 feet NGVD and the DWS upstream of S-334 is 5.0 feet NGVD. The projected loss of water between S-333 and S-334 is 120 cfs by flow to the south through culverts under U.S. Highway 41.

The 1230 cfs from S-334 will be added to the 500 cfs remaining from the 605 cfs discharged at S-151 to make a projected total of 1730 cfs at a DWS of 4.7 feet NGVD. Towards the east, the Alexander Orr Wellfield is supplied with 145 cfs from the 1730 cfs; 1585 cfs goes south to supply the Taylor Slough and Panhandle portions of the ENP (a minimum of 55,000 acre-feet per year) and for water supply and salinity control in South Dade.

At the junction of L-31N and C-1 the flow equals approximately 1490 cfs (95 cfs loss due to seepage); 305 cfs is supplied to C-1 and 1185 cfs sent south: 1160 cfs at a stage of 3.0 feet NGVD arrives at Pump Station S-331. This is pumped up to a stage of 6.0 feet NGVD; 260 cfs is supplied to C-102 at a stage of 5.4 feet NGVD, 210 cfs is supplied to C-103 at a stage of 4.7 feet NGVD, and approximately 205 cfs is lost due to seepage. Four hundred and eighty five (485) cfs are supposed to arrive at the junction of L-31N and L-31W at S-174 and S-176 at a stage of 4.6 feet NGVD. Two hundred and seventy five (275) cfs is supplied to C-111 at S-176 at a

TABLE 3. Water Supply

	STAGE FEET NGVD	Q cfs
L-29 @ S-333	7.0	1350
L-20 @ S-334	5.0	1230
L-30 @ S-337	5.2	605
L-30 @ S-335 upstream	5.0	525
downstream	4.8	525
L-30 @ L-29 or L-31N	4.7	500
L-31N @ US 41	4.7	1585
L-31N @ C-1 upstream	3.5	1490
downstream	3.5	1185
L-31N @ S-331 upstream	3.0	1160
downstream	6.0	1160
L-31N @ C-102 upstream	5.4	1115
downstream	5.4	855
L-31N @ C-103 upstream	4.7	740
downstream	4.7	530
L-31N @ S-174 upstream	4.6	485
downstream	3.1	210
L-31N @ S-176 upstream	4.6	275
C-111 @ S-176 downstream	3.0	275
C-111 @ C-113 upstream	3.0	275
downstream	3.0	135
C-111 @ S-177 upstream	3.0	135
dwonstream	2.0	135
C-111 @ C-111E upstream	2.0	97
downstream	2.0	97
C-111 @ C-18C upstream	2.0	75
downstream	1.4	75

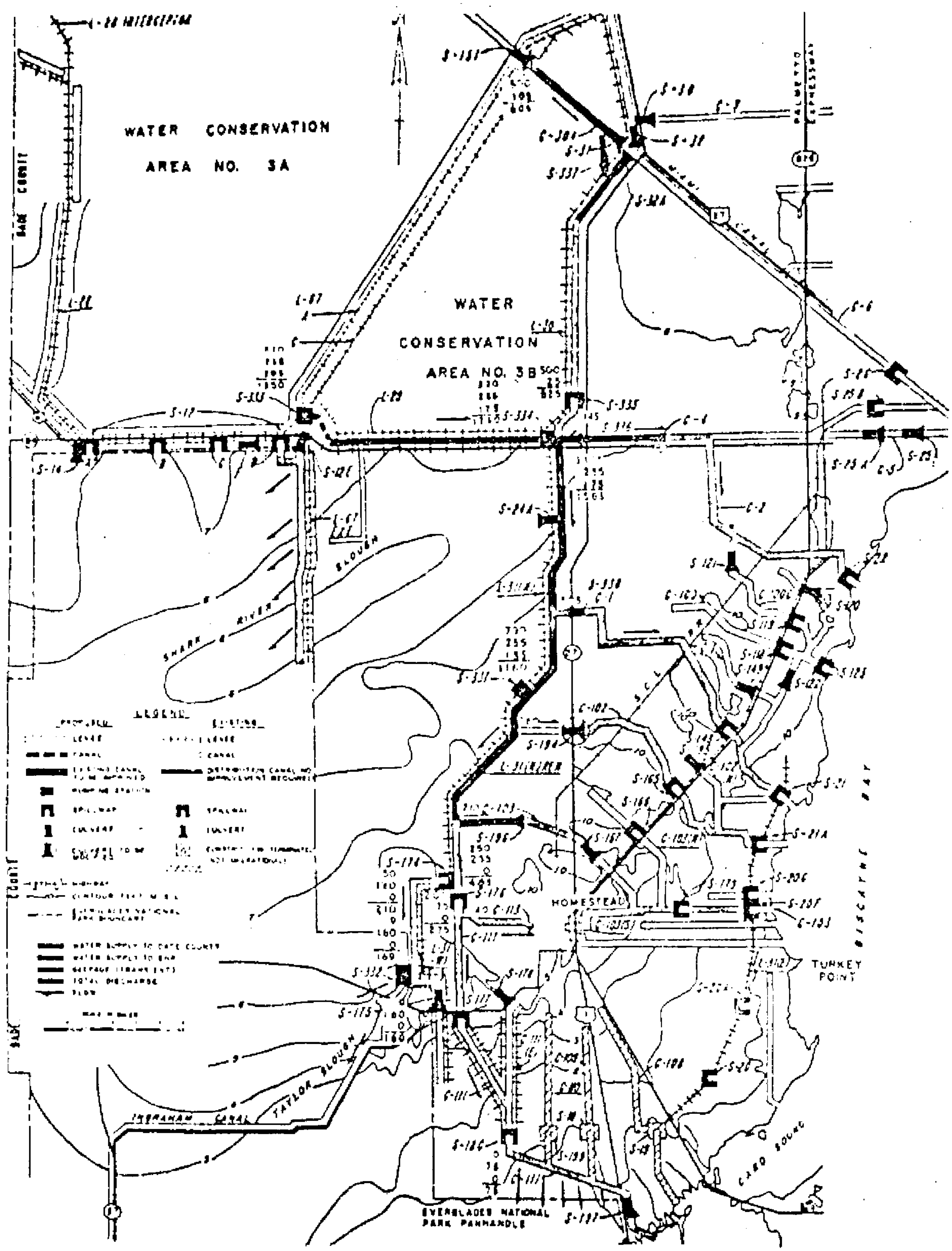

Figure 19 CONVEYANCE CANALS TO EVERGLADES NATIONAL PARK AND SOUTH DADE COUNTY

tailwater stage of 3.0 feet NGVD; 140 cfs is supplied to C-113, 60 cfs is lost due to seepage and 75 cfs is available for discharge at S-18C at stage of 2.0 feet NGVD to help supply the required minimum of about 18,000 acre-feet a year to the Panhandle area of the ENP. Two hundred and ten (210) cfs is available for discharge through S-174 to supply approximately 160 cfs to the Taylor Slough area of ENP via Pump Station S-332. The minimum allotment equals approximately 37,000 acre-feet a year. The intake stage at S-332 is about 3.0 feet NGVD. The system is designed to maintain an approximate stage of 2.0 feet NGVD at the coastal structures when water is available.

When the Water Conservation Area 3A (CA-3A) is above regulation and regulatory discharges are required, the system is capable of making much larger discharges. The discharges will be limited by the maximum stage that the Indian Village on the north berm of L-29 can stand and the design capacity of S-331 pump in the L-31N borrow of approximately 1160 cfs. If the stage in the L-29 borrow can be raised to slightly above 8 feet NGVD, approximately 450 cfs will flow south through the culverts under U.S. Highway 41 to the N.E. Shark River Slough. By making regulatory discharges down through South Dade it might be possible to bring the headwater stages at S-148, S-165, and S-167 up to their optimum of about 5.5 feet NGVD occasionally.

GRAVITY DRAINAGE SYSTEM FOR DRAINING AREA BETWEEN C-111 AND BORROW L-31W

The area of concern consists of approximately 4970 acres of land varying in elevation between 4.5 and about 7.0 feet NGVD. Rain storms of 5 to 7 inches have created temporary flooding problems on portions of the area with resulting loss of crops. Investigation indicates that present surface drainage consists of minor ditching with 4 - 36 inch cmp culverts draining into C-111. This gives less than 0.5 inches of runoff protection. The inflow curves for C-111 allow an inflow of 530 cfs for the above acreage. This gives 2½ inches of runoff protection. A possible drainage system to give this protection consists of the following elements (see Figure 20 and Table 4):

Culverts: 5 - 84 inch CMP X 50 feet
1 - 72 inch CMP X 50 feet

Proposed Drainage - Three Separate Systems:

A - 9,300 feet with 32,000 cubic yards excavation
B - 29,800 feet with 150,000 cubic yards excavation
C - 32,000 feet with 137,000 cubic yards excavation
319,000 cubic yards excavation total.

Canals range in size from 12 feet bottom width at -4 feet NGVD to 5 feet bottom width (BW) at 0.0 feet NGVD with side slopes of 1 horizontally and vertically.

The system is designed to operate to control flooding for a 1 in 10 year storm of approximately 7 inches rainfall. With a stage of 3.5 feet NGVD in C-111, the stage at the upper end of system "B" will be about 4.7 feet NGVD. Natural ground levels equal approximately 5.25 feet NGVD. The stage at the upper end of system "C" will be about 4.6 feet

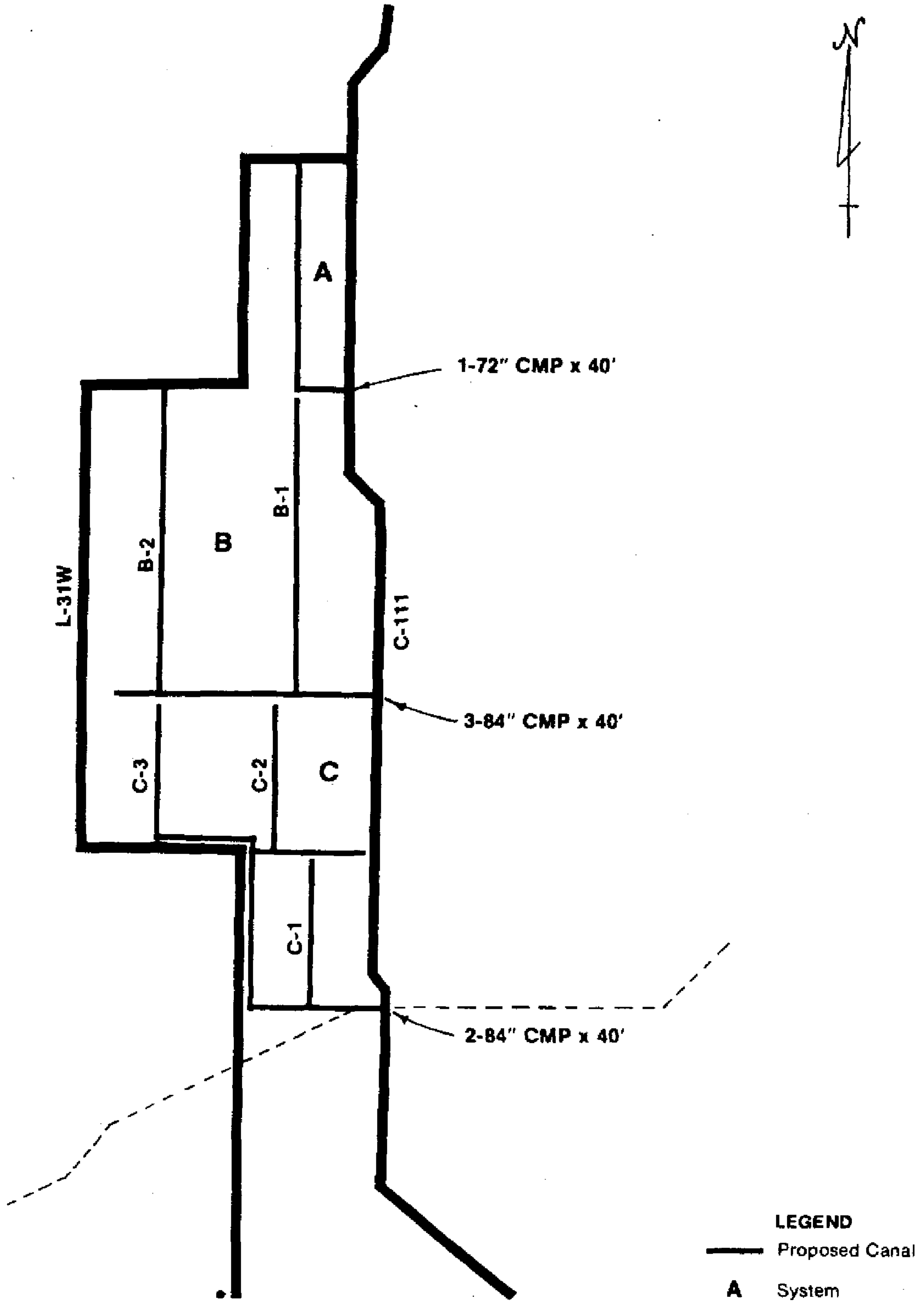

Figure 20 GRAVITY DRAINAGE SYSTEM FOR DRAINAGE AREA BETWEEN CANAL C-111 AND BORROW L-31W.

TABLE 4. Details of Gravity Drainage System for Draining Between C-111 and Borrow L-31W

	SYSTEM A	
0 + 00 to 20 + 00	6' BW @ -1' msl	1 on 1 side slopes
20 + 00 to 46 + 00	5' BW @ -1' msl	
46 + 00 to 72 + 00	5' BW @ -1' msl	
	SYSTEM B	
0 + 00 to 28 + 00	12' BW @ -4' msl	1 on 1 side slopes
28 + 00 to 73 + 00	12' BW @ -3' msl	
	Lat B-1	
0 + 00 to 28 + 00	8' BW @ -3' msl	
30 + 00 to 60 + 00	6' BW @ -2.5 msl	
60 + 00 to 104 + 00	5' BW @ -1' msl	
	Lat B-2	
0 + 00 to 26 + 00	10' BW @ -3' msl	
26 + 00 to 66 + 00	6' BW @ -3' msl	
66 + 00 to 106 + 00	5' BW @ -1' msl	
	SYSTEM "C"	
0 + 00 to 50 + 00	12' BW @ -4' msl	1 on 1 side slopes
50 + 00 to 104 + 00	12' BW @ -3' msl	
104 + 00 to 132 + 00	10' BW @ -2' msl	
	Lat C-3	
0 + 00 to 20 + 00	6' BW @ -2' msl	
20 + 00 to 45 + 00	5' BW @ -1' msl	
	Lat C-2	
0 + 00 to 13 + 00	5' BW @ -2' msl	
8600'	5' BW @ 0.0' msl	
	Lat C-1	
0 + 00 to 52 + 00	5' BW @ 0.0' msl	

NGVD. The natural ground elevation equals approximately 5.5 feet NGVD. This will give protection for the land above 5 feet NGVD against the 1 in 10 year storm.

The approximate cost of this sytem is $230,000 to $250,000.

SUMMARY AND CONCLUSIONS

The following summarizes the major conclusions reached as a result of this study:

(1) The daily rainfall event for the dry season, with a return period of 10 years is 5 inches. Five inches of rainfall can be expected to cause groundwater levels to rise by about 1 foot in the Frog Pond area.

(2) There is good hydraulic connection between the aquifer and the canal. A 1 foot difference in canal levels will cause a net transfer of 66 million gallons per day between the canals. For each average 1 foot lowering or raising of the two canal stages, 300 million gallons will be lost from, or contributed to, groundwater storage in the Frog Pond area. For a daily rainfall event of 5 inches or less, the rise in groundwater levels could be dissipated within 48 hours by lowering canal levels. Following the rainfall event, the canal would have to be lowered by the amount of the incremental rise plus an additional 30 percent of the incremental rise in groundwater levels to accomplish this.

(3) If both canal levels are held at 3.0 feet it would be possible to farm the maximum acreage in the area; the level of protection being a 5 inch rainfall. For extreme rainfall events, probably above 7 inches per day, rapid lowering of canal levels may not be possible.

(4) If both canals are held at 4.5 feet and canal levels are not lowered to dissipate the rise in groundwater levels from a

heavy rain event, little if any land within the Frog Pond would be protected from a 5" storm. Were the canals lowered after storms at these stages, about one-half of the Frog Pond acreage would have 1 in 10 year protection.

(5) A secondary gravity drainage system could be constructed at a cost of $230,000 to $250,000 to control flooding for a 1 in 10 year storm of about 7 inches of rainfall, given control stages of 3.5 feet. This would give protection for the land above 5 feet mean sea level.

(6) Regulating canal levels to protect farming in the Frog Pond area may result in a reduction of the potential benefits to regional groundwater availability and increase the amount of water required to operate the South Dade Conveyance System.

(7) With respect to Everglades National Park and adjacent wetlands, the effect of maintaining a 3.0 foot or 4.5 foot stage in L31-W borrow canal will be a general increase in water levels compared to both pre and post construction levels. Water levels in the Park may show an overall decline in November, at the 3.0 foot canal stage. The recent cycle of high and low water levels in the Park would, therefore, be significantly altered.

GENERAL COMMENTS

The analyses in this report may require modification, based on future experience with operation of the system. The calculations should not be blindly extrapolated to other canal systems. The relationship between rainfall and rises in groundwater levels is approximate. The scatter in data points shown on Figures 8 and 9, especially for rainfall events below 3 inches, may be explained by differences in rainfall at the Frog Pond site as compared to the Royal Palm Ranger Station due to localized rainfall, differences in rainfall intensity, or lack of synchronization between rainfall measurements and groundwater level measurements. For rainfall below 3 inches it is the authors' judgement that the canal system should be able to discharge the consequent base flow without adverse effects on agriculture. Rainfall extending over more than one day has not been explicitly considered in this report. If the rainfall intensity is moderate, i.e. about 3 inches or less per day, it is believed that the longer period of time allowed for the canals to drain the aquifer will offset the higher total rainfall volume and will moderate rises in groundwater levels.

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APPENDIX

CALCULATION OF CANAL/AQUIFER RELATIONSHIP

The time-variant effect of changes in canal stage on groundwater levels in an aquifer adjacent to the canal can be determined analytically, using a formula developed by Ferris et al., (1962):

$$s = s_c \left(1 - \frac{2}{\sqrt{\pi}} \int_0^{x/2\sqrt{Tt/Sy}} e^{-u^2}\, du\right) \qquad (1)$$

Where,

- s = change in groundwater level at point x distant from the canal at time t.
- s_c = instantaneous change in canal level
- T = transmissivity of aquifer
- t = time after instantaneous change in canal level
- x = distance from canal
- Sy = specific yield of the aquifer
- u = $x\sqrt{Sy/4Tt}$

Equation (1) may be rewritten:

$$s = s_c\, W(u_h) \qquad (2)$$

Where,

$$W(u_h) = 1 - \frac{2}{\sqrt{\pi}} \int_0^{x/2\sqrt{Tt/Sy}} e^{-u^2}\, du$$

$W(u_h)$ may be approximated by (Huisman, 1970):

$$W(u_h) = 1 - \sqrt{\pi}\, u$$

for $u \leq 0{\cdot}10$.

Values of $W(u_h)$ for various values of u are given by Huisman (1970, pp. 240-241) where the notation F_1 is used for $W(u_h)$.

The assumptions made in developing this equation are (Ferris, 1962):

(a) The aquifer is artesian.

(b) The canal fully penetrates the aquifer.

(c) The canal occurs along an infinite straight line.

(d) The aquifer is semi-infinite in extent.

(e) The head in the canal is abruptly changed at time t=o.

(f) The direction of groundwater flow is perpendicular to the direction of the canal.

(g) The change in the rate of discharge from the aquifer is derived from changes in storage by drainage after t=o.

For a water table aquifer, it is generally felt that assumptions "a" and "g" are approximately satisfied if changes in head in the aquifer are small compared to the thickness of the aquifer. Assumption "b" is approximately satisfied if the canal penetrates an appreciable thickness of the aquifer. The effect of partial penetration can be determined from the equation (Huisman, 1970):

$$\Delta s_c = \frac{Qo}{\pi kL} \left(\frac{\pi b}{yH} + \ln \frac{4H}{\pi b}\right) \qquad (3)$$

Where,

Δs_c = additional instantaneous change in canal

Q_o = flow to canal

k = permeability = T/H

L = length of canal

b = width of canal bottom

y = depth of penetration of canal

H = saturated thickness of the aquifer

For the canal/aquifer conditions in the Frog Pond area, Δs was calculated to be .0008 foot.

To satisfy assumption "c" the actual canal alignments are approximated by two straight canals, the distance between them being taken as the average distance. Since the canals extend outside the area of study the effects of finite length are considered negligible.

Assumption "d" is satisfied up to and until the cone caused by the canal level changes intercepts a boundary. If the extent of this cone is defined as a water level change of not more than 0.05 feet, this occurs after 2 days in the study area.

With respect to assumption "e", it is felt that canal structures are capable of effecting rapid canal level changes, under conditions which are less than the design event of 7 inches of rainfall per day. In any case, if the time t is measured from the time that the desired level in the canal is attained, the analyses undertaken for this project can be considered to be conservative.

Calculations in this report are based on a transmissivity (T) value of 5,000,000 gallons per day per foot, and a specific yield of 0.20. The following table gives the calculated drawdown values for a 1 foot lowering of one canal, which are plotted as Figure 16 in the text.

CALCULATION OF BASE FLOW TO CANAL

Base flow to a canal is defined as the increment of flow in the canal derived from groundwater storage in a given area. The base flow contributed to both sides of a canal per unit length of canal as a result of instantaneous lowering of the canal stage at time t after the stage is lowered, is given by the equation (Ferris, et al., 1962):

TABLE: Drawdowns in the aquifer adjacent to the canal, for a one foot lowering of canal stage

Time After Lowering of Canal Stage (in days)	Distance from Canal (in feet X 1000)																
	.1	.2	.3	.4	.5	1	2	3	4	5	6	7	8	9	10	11	12
0.5	.9571	.9133	.8700	.8320	.7882	.5863	.2720	.1009	.0294	.0066							
1.0	.9684	.9391	.9077	.8875	.8480	.7026	.4400	.2462	.1232	.0544							
2.0	.9774	.9571	.9346	.9122	.8920	.7882	.5863	.4121	.2762	.1725	.1009						
5.0	.9865	.9729	.9594	.9459	.9312	.8652	.7287	.6058	.4883	.3883	.3000	.2265	.1658	.1198	.0820		
10.0	.9910	.9808	.9707	.9616	.9515	.9020	.8100	.7131	.6256	.5400	.4621	.3920	.3292	.2700	.2210	.1791	.1430

$$Q_b = \frac{2s_c}{\sqrt{\pi t}} \sqrt{SyT} \qquad (4)$$

Where,

Q_b = base flow contributed to both sides of the canal

s_c = instantaneous change in canal level

t = time after instantaneous change in canal level

Sy = specific yield of aquifer

T = transmissivity of aquifer

The total base flow for a given reach of canal is obtained by multiplying Q_b by the length of the canal reach. The amount contributed from one side of the canal is obtained by dividing Q_b by 2.

CALCULATION OF VOLUME OF WATER LOST FROM OR CONTRIBUTED TO STORAGE IN THE AQUIFER AS A RESULT OF CHANGES IN WATER LEVEL IN THE AQUIFER

The volume of water lost from, or contributed to storage in the aquifer as a result of changes in water level in the aquifer may be calculated as follows:

$$V = A \times \Delta h \times Sy \qquad (5)$$

Where,

V = volume of water lost from, or contributed to the aquifer

Δh = net average change in water level over the area

A = area covered by aquifer

Sy = specific yield of aquifer

Calculations in the text are based on a specific yield of 0.20 and an area of 5000 acres.