TECHNICAL MEMORANDUM

DRE 245

WATER BUDGET ANALYSIS
WATER CONSERVATION AREA 1

by

Steve Lin
Richard Gregg

Water Resources Division
Resource Planning Department
South Florida Water Management District

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EXECUTIVE SUMMARY

The purposes of this study were (1) to develop a methodology for computing a reliable water budget for Water Conservation Area 1 (WCA-1), and (2) to identify the parameters which significantly influence its reliability.

The U.S. Army Corps of Engineers (COE) uses three gages (1-8T, 1-7, and 1-9), to compute WCA-1 water levels for water budget computations. Water storage computations are made based on stage-storage data for each gage developed by the COE.

The principle of mass balance was used in this study. The major components considered were inflows (rainfall and pumped inflow), outflows (evapotranspiration [ET], control structure discharges, and seepage), and change in water storage. The residual term is the difference between the water budget computation based on all known or estimated components and the value computed based on actual measured conditions. ET cannot be directly measured, but can be inferred from evaporation pan data. It was computed based on the assumption that it composed all of the residual term, which was computed for each monthly time step and adjusted by appropriate evaporation pan coefficients. The residual term was used to obtain a better calibration of the ET pan coefficient. The mean and variance of total error in volume and depth of water were calculated to obtain the standard deviation for the total error (see Appendix B). This method was used for selecting the best approach for water budget computations for WCA-1. In order to improve the water budget computations for WCA-1, improvements are needed in existing data collection methods, including evaporation pan data, and updated topographic information is needed.

The results of this study can be briefly summarized as follows:

1. Using the average of three gages (1-7, 1-8C, and 1-9) for water level determinations and a variable water surface area for both rainfall and ET computations produced the best results and is recommended to be used for water budget computations. Using the average of six gages (1-7, 1-8C, 1-9, S-10 headwater, S-6 tailwater, and S-5A tailwater) produced a better comparison with the recorded means; however, the standard deviations for this scenario (a measure of variability) were much higher.

2. Computing rainfall and ET for WCA-1 using the variable area based on water stages produced the best and most consistent results.

3. The major water budget components for WCA-1 are rainfall, pumped inflow, control structure discharges, ET, and seepage. Rainfall accounts for approximately 48.6% of the inflow, with pumped inflow contributing the remaining 51.4%. The average outflow by way of control structure discharges, ET, and seepage constitute approximately 41.6%, 44.2%, and 14.2% respectively.

4. ET is one of the most important components of the water budget. Evaporation pan data from S-7 is used by the COE in their water budget analysis, and additional pan evaporation data are available from a pan at the Belle Glade Agricultural Experiment Station (BGES) and District structure S-5A. None of the available pan evaporation data, however, is totally reliable.

5. An annual pan coefficient of 0.73, based on the analyses was found to fit with the evaporation pan data from the Belle Glade Agricultural Experiment Station to compute ET values, or a coefficient of 0.87 for the S-7 evaporation pan data. These values agree fairly well with U.S. Weather Bureau study values of 0.70 - 0.75, and with the Stephens (USDA - Florida) value of 0.78 for flatwood watersheds in Florida, although the S-7 coefficient is somewhat high. A tabulation of monthly pan coefficients for the Belle Glade Agricultural

Experiment Station and S-7 is included in the main body of the text of this report.

6. The accuracy of topographic information has an important effect on the estimation of rainfall input and ET values in WCA-1, particularly under dry conditions. The contour map used by the COE and one used by the Fish and Wildlife Service were compared with radiance maps produced from enhanced LANDSAT band 7 imagery. A considerable variation exists among these maps, and an updated topographic map for WCA-1 could greatly improve the accuracy of the water budget computations.

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ACKNOWLEDGEMENTS

The authors wish to thank the many individuals within the Water Resources Division who contributed to the development of this report. These include Jorge Marban, Kent Loftin, Richard Tomasello, and Shawn Sculley for their valuable suggestions and review. In addition, the services of the Engineering Assistants in the development of the graphics in the report is greatly appreciated.

ABSTRACT

A water budget analysis is useful in gaining a better understanding of the specific hydrology of a watershed or reservoir so that better planning, management, and use of the water resources can be achieved.

Water Conservation Area 1 (WCA-1) encompasses an area of approximately 220 square miles and serves as a water storage area for urban and agricultural uses, for fresh water recharge of the surficial aquifer, and for fish and wildlife preservation. In computing a water budget for WCA-1 the principle of mass balance was applied. The major components considered were inflow (rainfall and pumped inflows), outflow (evapotranspiration, control structure releases, and seepage) and changes in water storage volumes. Different methods for the estimation of inflow and outflow were evaluated, and the sensitivity of the water budget components were analyzed. Annual and monthly pan coefficients were derived from evaporation pan data based on S-7 and the Belle Glade Agricultural Experiment Station. A best method of computing a water budget for WCA-1 is recommended.

As a result of this study, it was concluded that the WCA-1 water budget is best computed using the average of gages 1-7, 1-8C, and 1-9 for water surface elevations, the S-7 evaporation pan data and corresponding pan coefficients for the computation of ET, and a variable water surface area based on the computed average stage for both rainfall and ET determinations. The District's stage/area/storage relationships were used in this study.

INTRODUCTION

Background

The WCA-1 encompasses an area of 141,000 acres, or approximately 220 square miles, and is considered part of the Everglades ecosystem, which is a wetland area extending southward from Lake Okeechobee for about 100 miles to the tidal estuaries of Florida Bay and the Gulf of Mexico (location map, Figure 1). The WCA-1 is primarily a sawgrass prairie dotted with tree islands known as hammocks and marked by sloughs and strands of other vegetation. During periods of abundant rainfall, WCA-1 is essentially a floodplain. When rainfall is deficient, the area is often swept by sawgrass fires which may consume the peat soil.

Creation of the WCA system was authorized by a 1948 Act of Congress (House document 543, 1948). A levee system was completed around WCA-1 in 1960 (L-7, L-39, and L-40), which resulted in a borrow canal along the interior of the levees.

A water budget analysis is useful in gaining a better understanding of the specific hydrology of a watershed or reservoir so that better planning, management, and development of that basin can be achieved. The purposes of this study were: (1) to develop a methodology to compute a reliable water budget in WCA-1, and (2) to identify the parameters which significantly influence the reliability of the water budget.

System Description

Other than rainfall, ET, and seepage, inflows and outflows from WCA-1 are controlled by structures managed by the District, the COE, and by private entities (Figure 2). The water depth is generally shallow and varies throughout the year. The ground slope is from north to south, from approximate elevations of 17' NGVD to

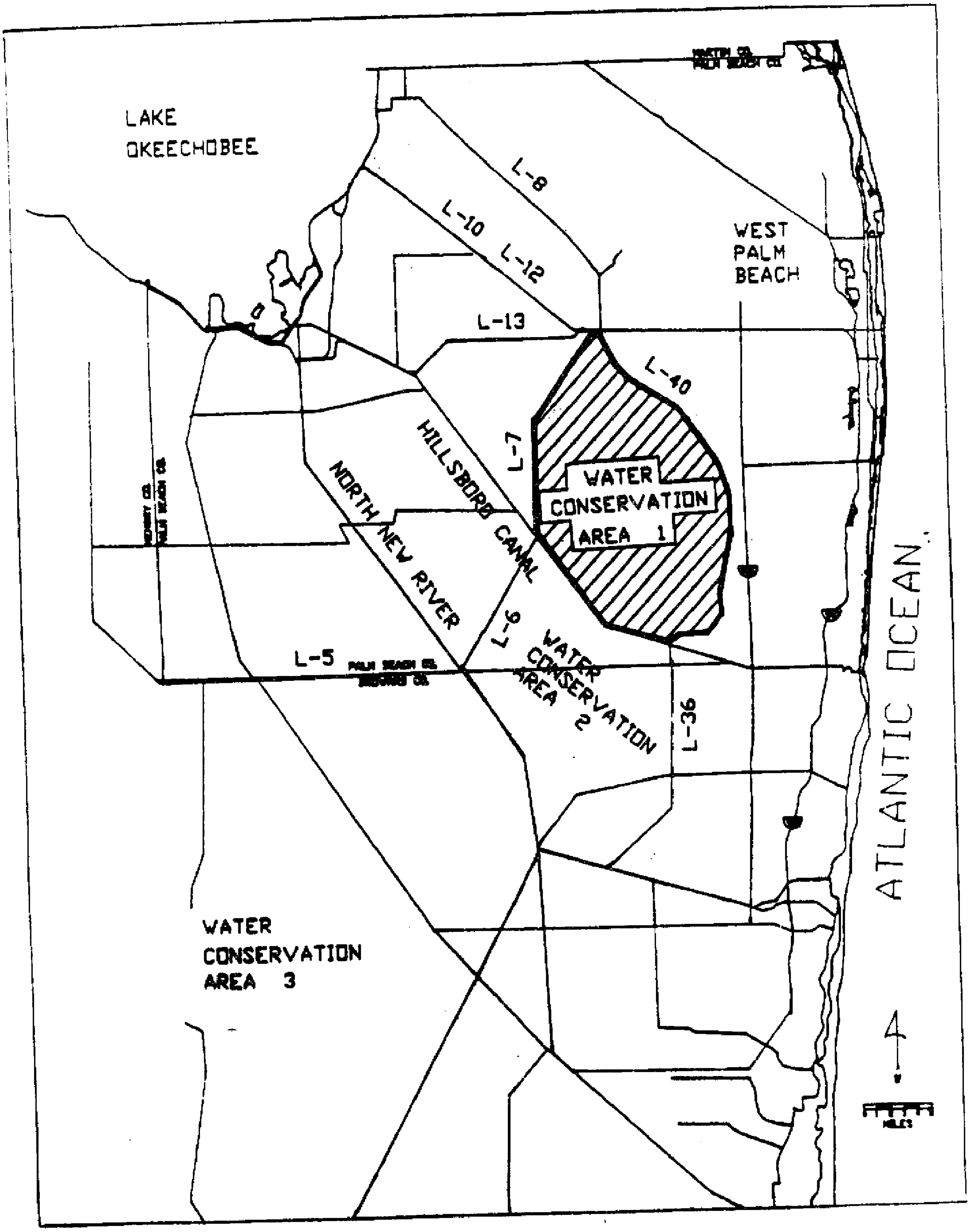


Figure 1. Location Map

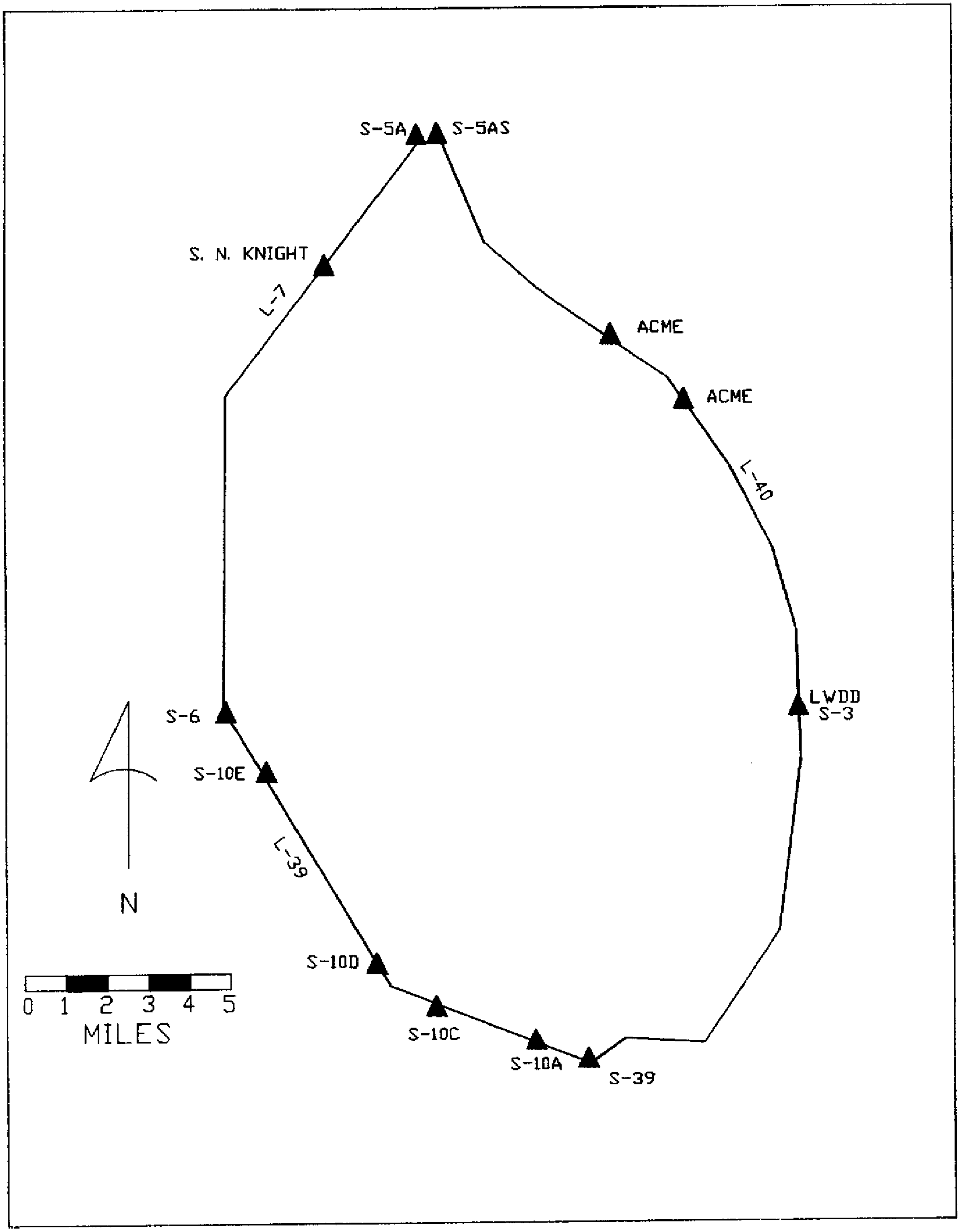


Figure 2. Structure Locations

10' NGVD. During the dry season, the northern portion is usually not inundated, and the water depth at the southern end is 4-5 feet. The interior of WCA-1 is primarily marshland, and water flow is restricted by dense vegetation. Therefore, the water levels in the interior and in the perimeter canal are often different, making the computation of a water budget complex. A description of the control structures follows:

Inflows

S-5A - This is a District and COE controlled 6-unit pumping station located at the north end of WCA-1 with a design discharge of approximately 4800 cfs. Its primary function is to provide flood protection for the L-10, L-12 and L-13 drainage basins serving the Everglades Agricultural Area (EAA). As a secondary function, it provides flood protection for the L-8 and western C-51 drainage basins. This secondary function is accomplished by the operation of auxiliary structures outside WCA-1 when water elevations are favorable.

S-6 - This is a District and COE controlled 3-unit pumping station located at the western edge of WCA-1 with a design discharge of approximately 2925 cfs. It provides flood protection for the L-6, L-15, and western Hillsboro Canal basins. If conditions require it and stages allow it, S-6 can also be used to siphon water out of WCA-1 for irrigation and/or groundwater recharge purposes.

Acme Improvement District (AID) - AID operates two pumping stations on the northeast edge of WCA-1 with a design discharge of approximately 230 cfs (north station) and 275 cfs (south station). These pumps provide flood protection for the suburban/rural area within the southern portion of AID. In addition, the southern-most pump can be used to withdraw irrigation water from WCA-1 at approximately 135 cfs.

S.N. Knight & Sons - This is an agricultural operation (sugar cane) on the northwest edge of WCA-1. In 1975 a 3-unit pumping station with a design discharge of approximately 325 cfs was installed, but was rarely used during the period of record. It is currently (1988) inoperative and is in the process of being dismantled.

Outflows

S-10 A,C,D, and E - Structures A,C, and D are gated reinforced concrete spillway structures, and E is a gated culvert structure. The design discharge of S-10 A,C, and D are 4680 cfs each, and S-10E is 438 cfs. S-10B was never constructed. Discharges are controlled by the District and the COE, and they are located along the southwestern edge of WCA-1. They are the primary sources of surface outflow. When the regulation schedules so dictate, discharges are made through them from WCA-1 to WCA-2. S-10E did not become operational until 1983 and therefore is not included in the water budget analysis for this report.

S-39 - This is a District and COE controlled reinforced concrete spillway with a control gate located at the south end of WCA-1. Its design discharge is 800 cfs. Its primary purpose is to make releases from WCA-1 for water supply purposes into the Hillsboro Canal basin. It can also be used to help maintain the WCA-1 regulation schedule if WCA-1 and WCA-2 are above regulation schedules and if downstream conditions are favorable.

S-3 - This is a Lake Worth Drainage District controlled culvert structure located on the southeastern edge of WCA-1. Water is withdrawn through the structure for irrigation and groundwater recharge purposes by the Lake Worth Drainage District by way of a pump facility upstream of the structure.

S-5A-S - This is a District controlled reinforced concrete spillway with control gates located slightly east of pump station S-5A. Its design discharge is 2000 cfs. It is primarily used to provide irrigation releases to the L-8, L-10, L-12, and C-51 basins. The primary purpose of such releases is to provide water supply to the city of West Palm Beach through L-8 and the city's M-canal. If water elevations allow, which rarely occurs, it can also be used to discharge water into WCA-1.

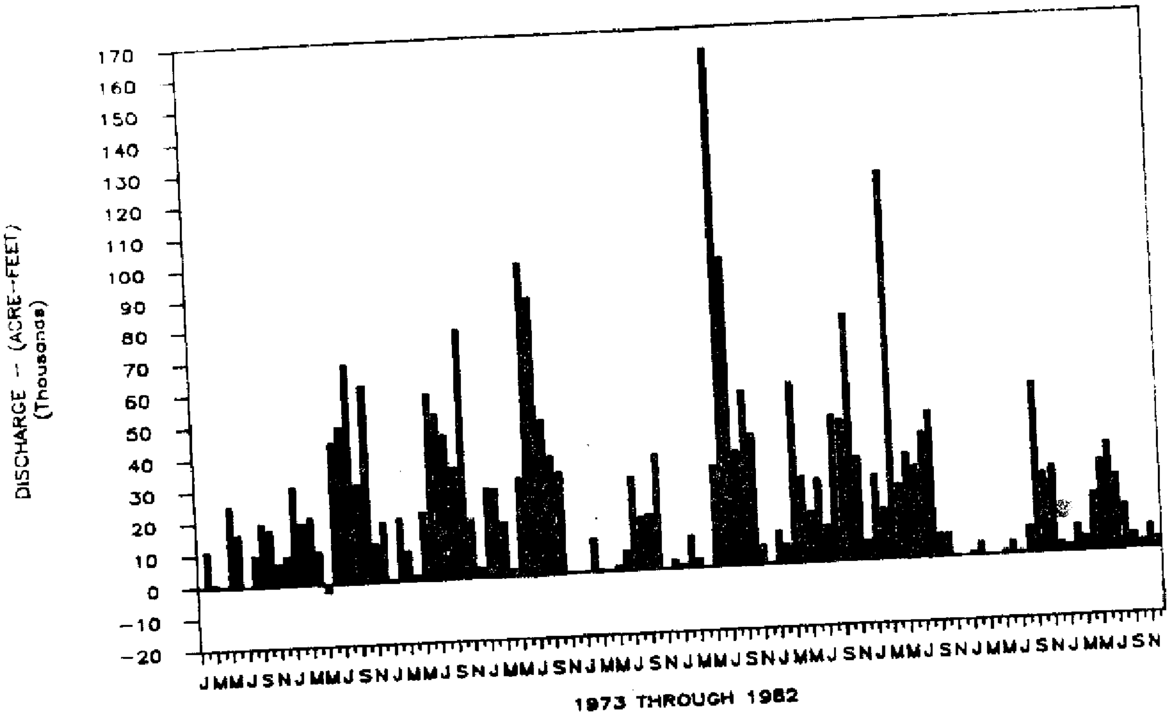
The only other outflows from WCA-1, other than ET and seepage, are the minor and intermittent ones through S-6 (siphonage) and the AID southern pump (irrigation withdrawal), as described in the Inflow section.

S-5A/S-5AS and S-6 inflows are plotted in Figures 3 and 4. Total surface water inputs and outputs are shown in Figure 5. Annual daily maximum flow data for S-5A/S-5AS, S-6, S-10, and S-39 are shown in Table 1. Minimum values for these structures are always zero or negative. Negative values indicate WCA-1 inflow through what is normally an outflow structure, or outflow through what is normally an inflow structure, by way of siphonage or structure backflow. Table 2 lists the hydraulic characteristics of the structures.

TABLE 1

ANNUAL DAILY MAXIMUM DISCHARGES (CFS)

Year	S-5A & S-5AS	S-6	S-10A, C&D	S-39
1963	3870	1720	710	235
1964	4430	2810	2760	180
1965	4400	2180	3010	225
1966	6130	2970	4878	772
1967	2460	2120	1600	270
1968	4690	2850	6000	713
1969	3790	2670	3359	723
1970	7040	2240	12149	626
1971	3150	1830	0	248
1972	3240	2134	4160	125
1973	3350	2010	4260	124
1974	2910	1930	2629	198
1975	3130	1994	2680	188
1976	3760	1910	3605	259
1977	4570	2750	7535	180
1978	3760	1890	4055	713
1979	4840	2340	3413	715
1980	4660	2390	4305	875
1981	4510	2920	3471	261
1982	4930	2706	5758	946



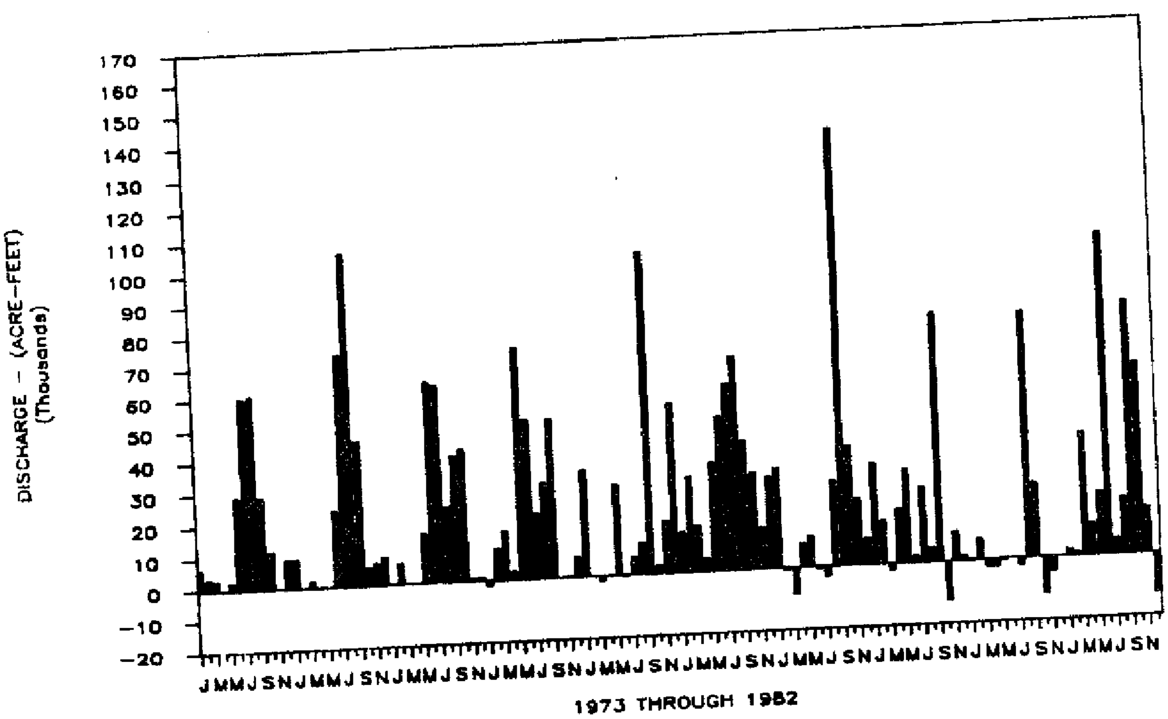
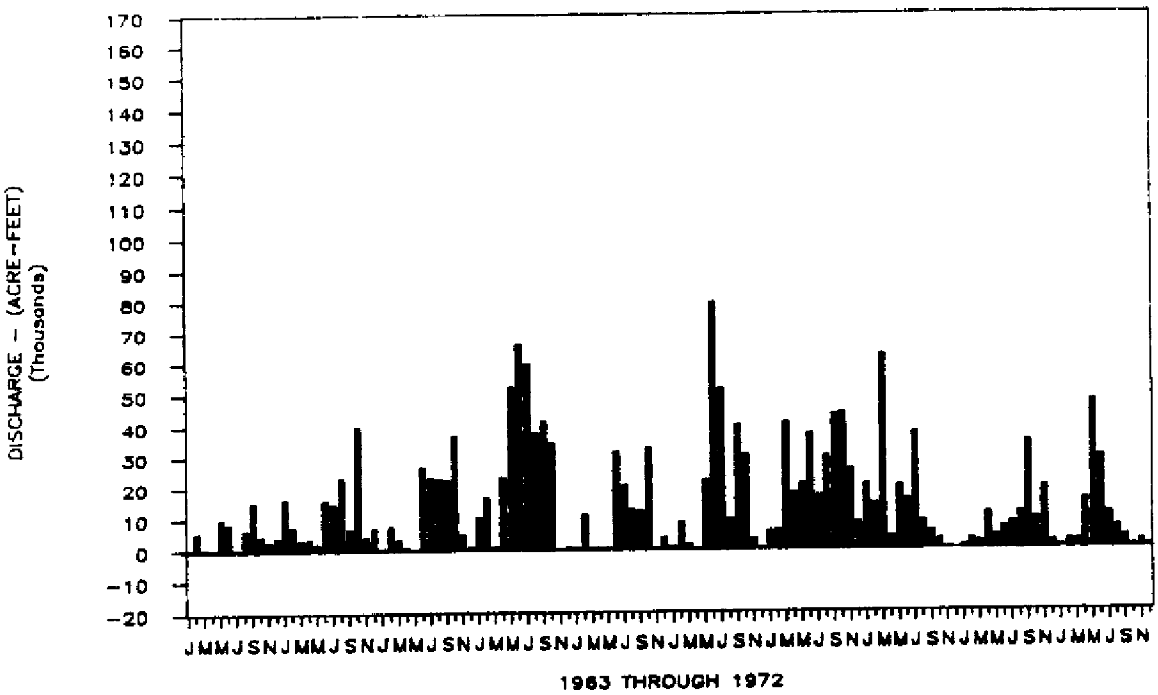


FIGURE 3 S-5A & S-5A(S) Discharge for 1963 through 1982.



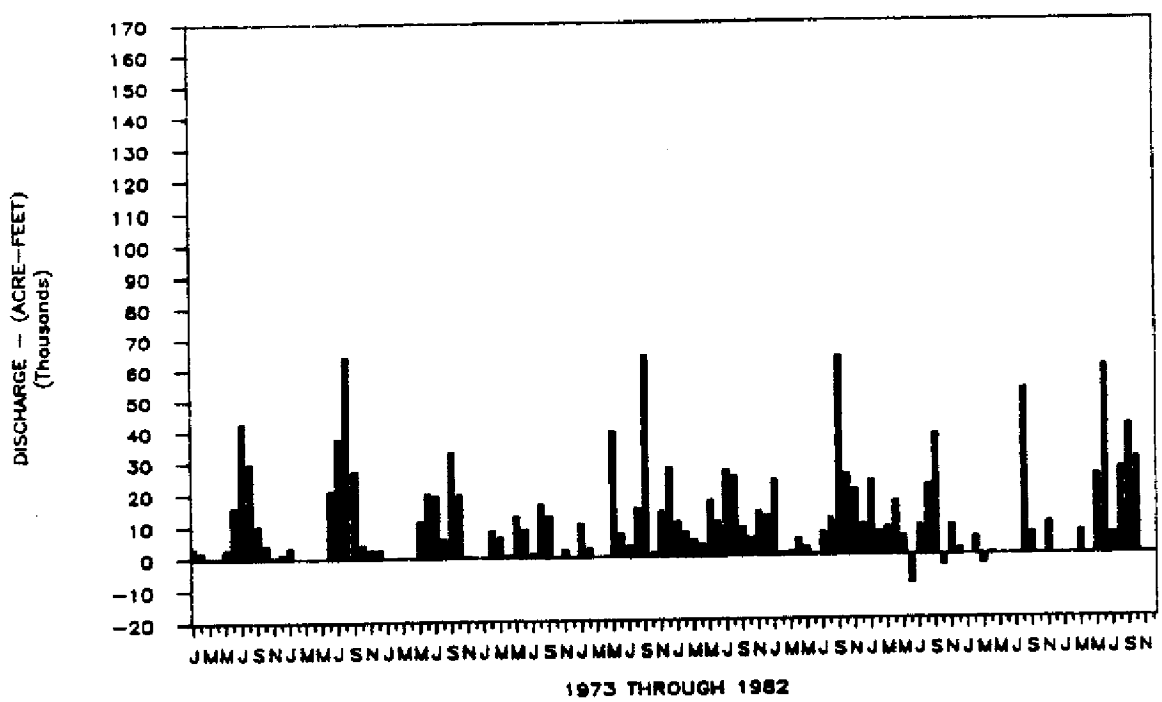
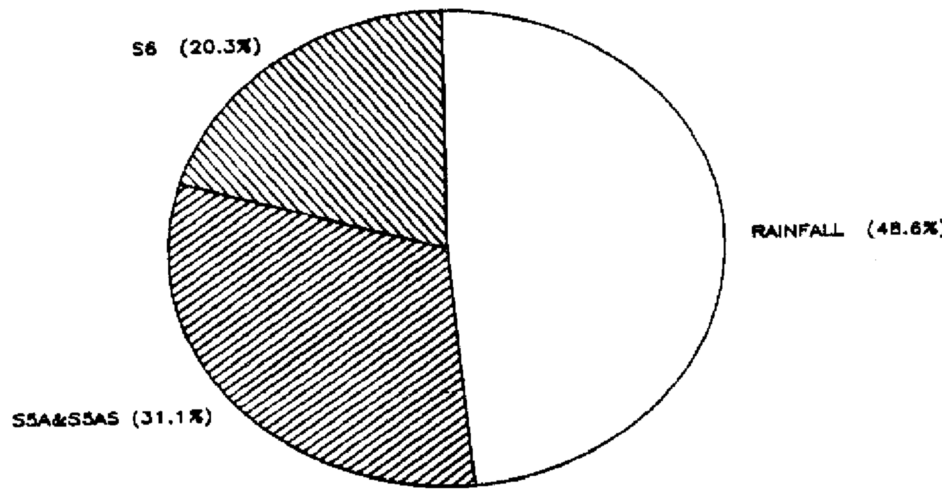


FIGURE 4 S-6 Discharges for 1963 through 1982.

INPUT



OUTPUT

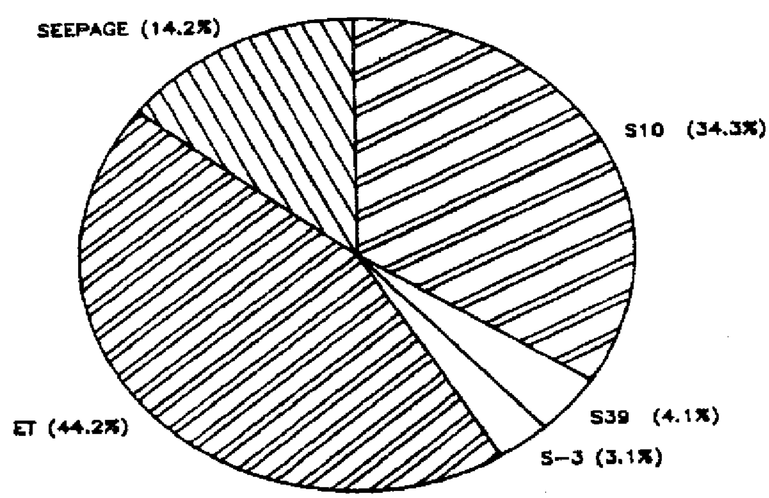


FIGURE 5 WCA-1 Surface Water Input and Output.

TABLE 2

WATER CONSERVATION AREA 1 STRUCTURES

Structure	Type	Design HW Stage (ft NGVD)	Design TW Stage (ft NGVD)	Optimum Stage (ft NGVD)	Design Discharge (CFS)
S-5A	Pump Station 6 units - 800 cfs each	13.0	24.1	HW = 10.5 (wet season) HW = 11.5 (dry season)	4800
*S-5AE	Gated Box Culvert 2 - 7 ft x 7 ft x 65 ft Reinforced Concrete Box invert elev = 1.0 ft NGVD	11.5	10.0	Not used to control stage	700
S-5AS	Gated Spillway 2 - Gates 19.3 ft high x 22.8 ft wide net crest lgth = 44.0 ft crest elev = 1.0 ft NGVD	18.0	17.9	Not used to control stage	2000
*S-5AW	Gated Box Culvert 2 - 7 ft x 7 ft x 80 ft Reinforced Concrete Box invert elev = -1.75 to .30 ft NGVD	13.0	11.5	Not used to control stage	700
S-6	Pump Station 3 units - 975 cfs each	12.5	20.8	10.0 - 12.5 in Hillsboro Canal	2925
S-10A S-10B S-10D	Gated Spillways 4 Gates each 8.0 ft high x 25.7 ft wide net crest lgth = 100 ft crest elev = 10.0 ft NGVD	17.3	16.4	Regulation Schedule in WCA1	4680 each 14000 total
S-10E	Gated Culvert 3-72 in x 40 ft CMP invert elev = 9.0 ft	17.3	16.4	Regulation Schedule in WCA1	438
S-39	Gated Spillway 1 Gate 9.2 ft high x 16.0 ft wide net crest lgth = 15.0 ft crest elev = 2.5 ft NGVD	11.0	9.0	Regulation Schedule in WCA1	800
Acme Improvement District	2 Pump Stations 230 CFS (North) 275 CFS (South)	**NA	**NA	Not used to control stage	505
S.N. Knight	1 Pump Station	**NA	**NA	Not used to control stage	325

* Auxillary structures outside WCA-1.They do not directly discharge to or from the area.
** Not Applicable.

WATER BUDGET METHODOLOGY

General Discussion

A mass-balance approach was used in this study to arrive at water budget conclusions. Basically, a mass balance analysis assumes that the change in water storage volume for the basin being considered is equal to the inflow minus the outflow. In the case of WCA-1, the inflows consist of direct precipitation and control structure inputs, and outflows consist of control structure outputs, ET, and seepage. Based on the above and on work done by Horton (1943), Harbeck (1952), and Shih (1980), the basic mass balance equation used for this study is as follows:

$$DS = P + SI - SO - ET - S \tag{1}$$

where

DS = Storage change

P = Precipitation

SI = Surface inflow

SO = Surface outflow

ET = Evapotranspiration

S = Seepage

The residual is the difference between the water budget based on all known components and the water budget computation based on actual observed conditions. This represents the volume of gain or loss contributed by ungaged sources and errors in measurement. The main source of ungaged data for WCA-1 is ET. Accordingly, the residual term was used to compute evaporation pan coefficients in this study. The actual volume was computed based on District stage-storage data, and this volume was then compared with the computed volume based on Eq. (1) for each monthly time step and an estimation of the monthly residual was obtained.

Valid topographic data is an important parameter in determining storage changes in a partially inundated area such as WCA-1. There are three sources of topographic data available for WCA-1, (1) the COE as referred to earlier (Figure 6), (2) the Fish and Wildlife Service, Department of the Interior (Figure 7), and (3) the District (Figure 8). As can be seen, there is a considerable difference between these sources in some areas. Unless noted otherwise, the topographic data used by the District is considered valid.

In this report reference is made to total area and variable area in the discussion of ET and rainfall. Total area encompasses the entire 141,000 acres of WCA-1. Variable area is based on the stage-area relationship developed by the District. In other words, as the surface water stage declines, the inundated area used for computing the ET and rainfall components of the water budget decreases.

The COE uses three gages, 1-7, 1-8T, and 1-9, along with their associated stage-storage relationships, to compute the WCA-1 water budget. In the present District study, three different gage combinations were investigated. These were (1) gage 1-8C only, (2) a three gage average using 1-8C (as opposed to 1-8T used by the COE), 1-7, and 1-9, and (3) a six gage average using 1-8C, 1-7, 1-9, S-10A headwater, S-6 tailwater, and S-5A tailwater (See Figure 9). The rationale for the six gage average was to more evenly distribute the gaging stations throughout WCA-1.While the use of the six gage average provided better results, based on mean stages and volumes, than use of the three gage average, the standard deviation (a measure of variability) was much higher. This is due to the tailwater stages at S-6 and S-5A being affected by pumping activities.

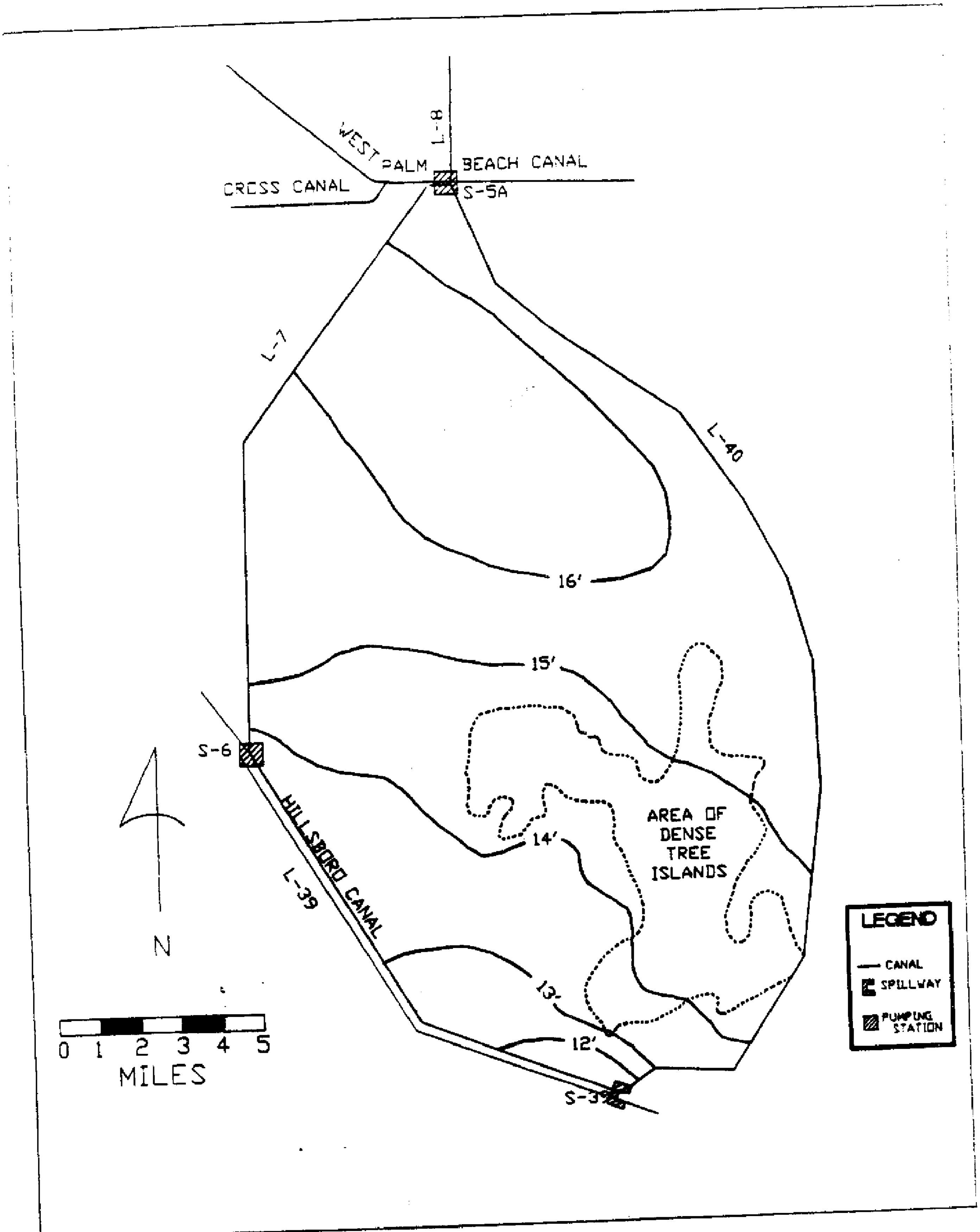


FIGURE 6. Topographic Map of WCA-1 Used by the Corps of Engineers

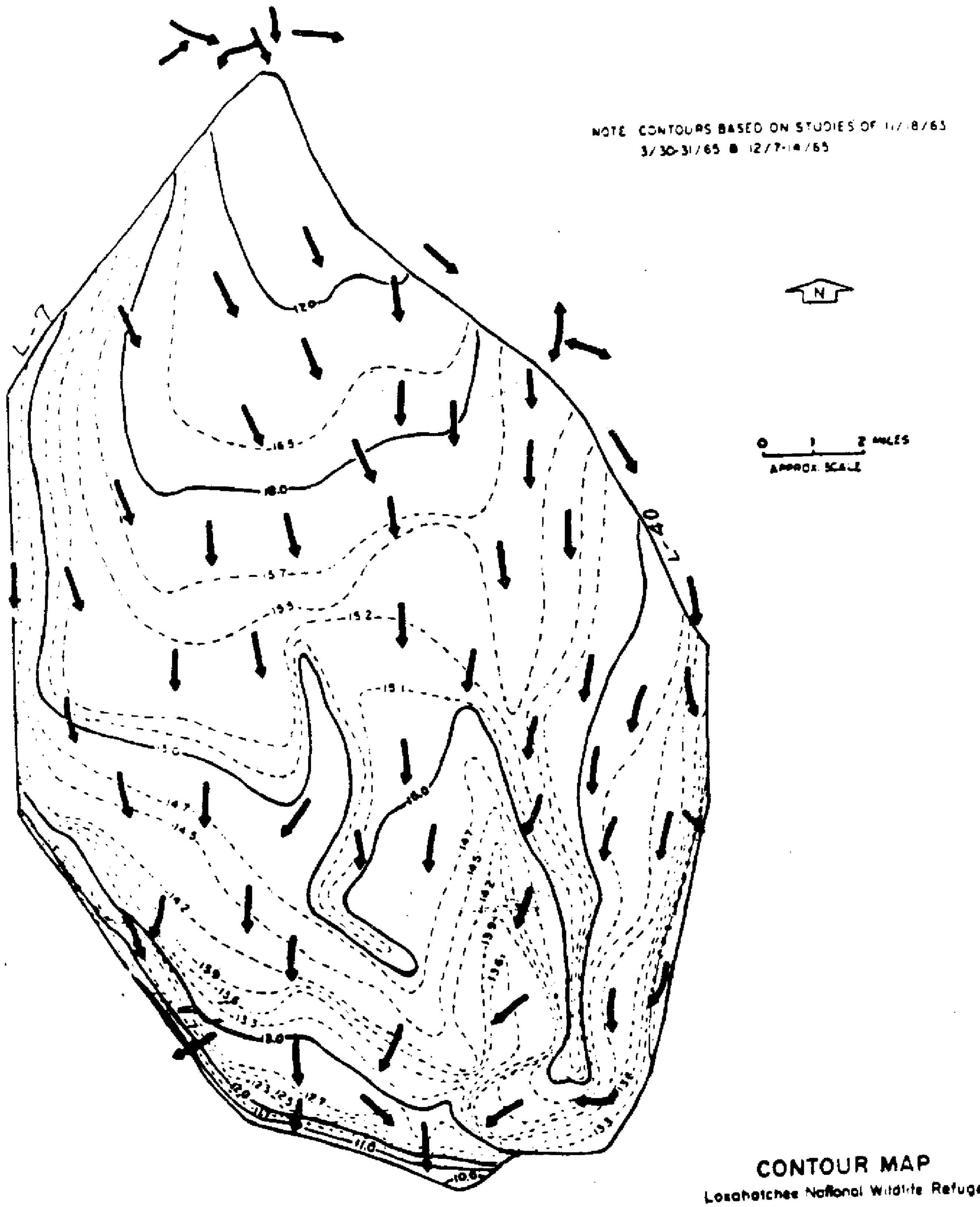


FIGURE 7. **Topographic map of WCA-1 used by the Fish and Wildlife Service, U.S. Dept. of the Interior**

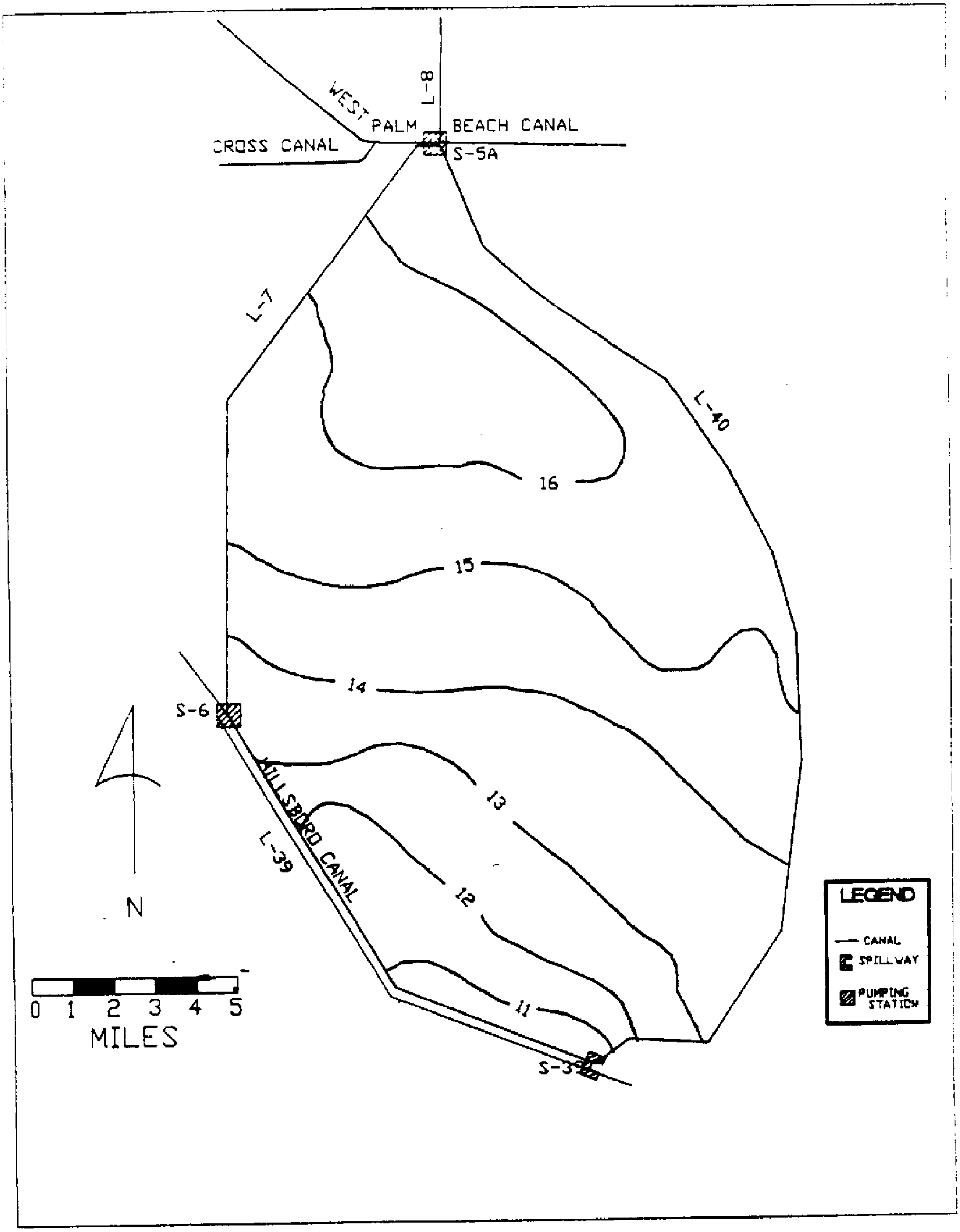


FIGURE 8. Topographic Map of WCA-1 Used by the District

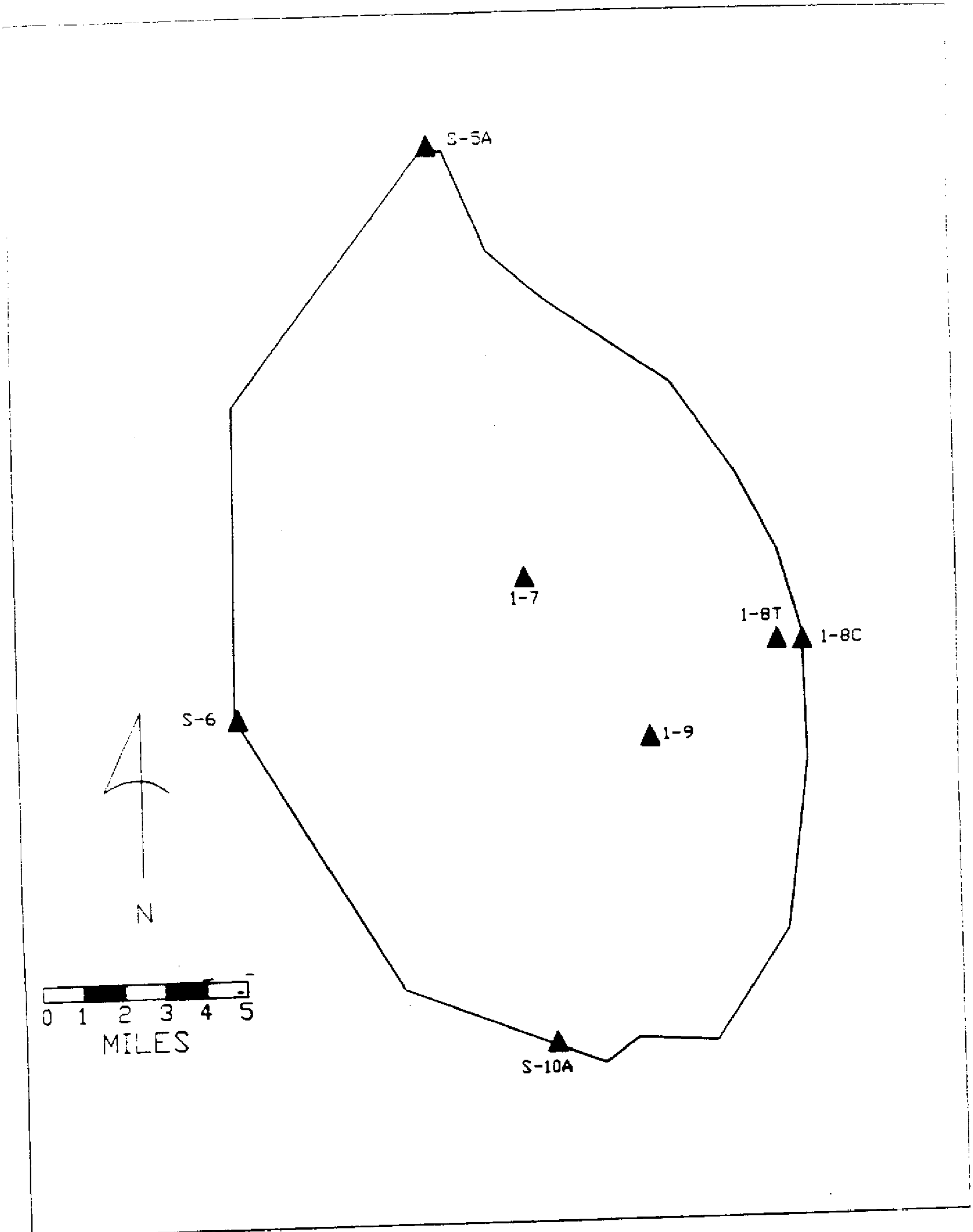


FIGURE 9. Gage Locations

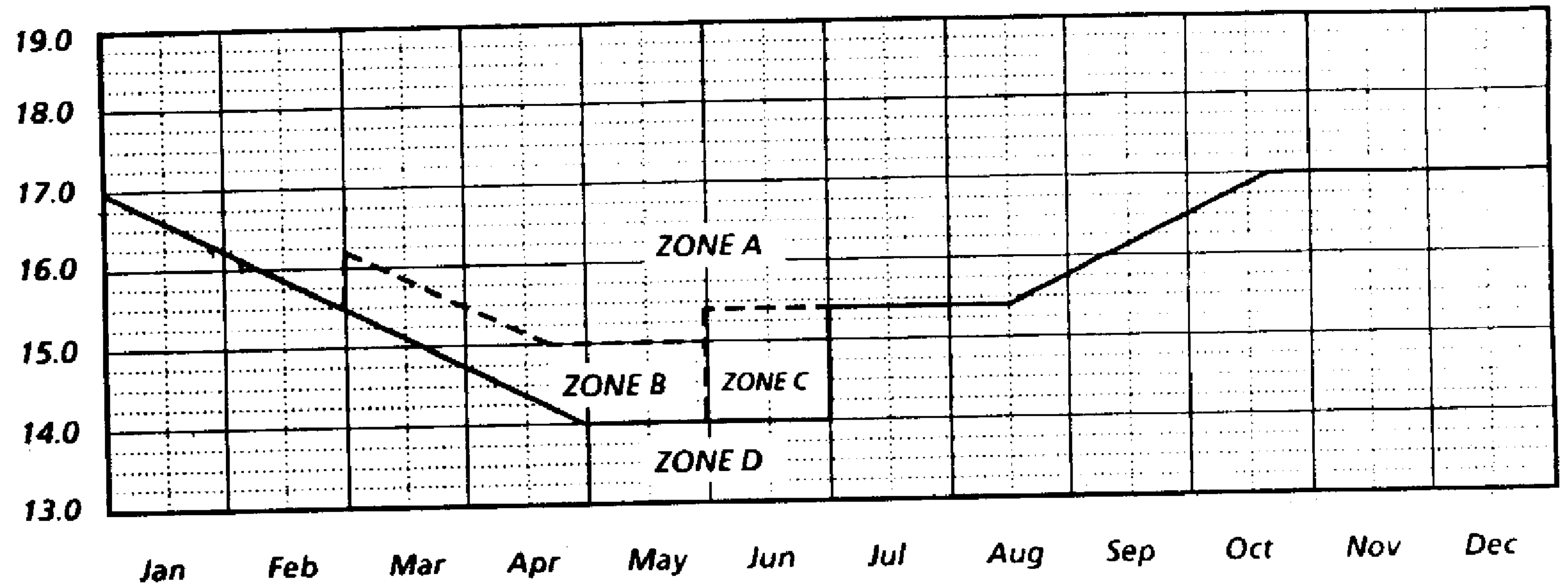
The regulation schedule for WCA-1 has been changed over the years. From 1960 until 1969, the variation was between 14 and 17 feet NGVD. From 1969 until 1975 the variation was between 15 and 17 feet NGVD. In 1975 the current regulation schedule (Figure 10) was implemented. This last revision was made to allow more flexibility and to provide benefits to plants and wildlife because it allows the water level to be lowered to 14 feet NGVD during the Spring of all but the wettest years.

Evaporation pan data is available from three sources in the vicinity of WCA-1; S-7, S-5A, and the Belle Glade Agricultural Experiment Station (BGES). This facility (BGES) is operated by the University of Florida, Institute of Food and Agricultural Services (IFAS), and has recently been renamed the Everglades Research and Educational Center. However, the BGES designation will be used in this Technnical Memorandum since that was its name during the period of record analyzed. There are, however, problems with all of the data sets. Based on the District staff's analysis, it is recommended that either the S-7 pan evaporation data be used in the water budget computations for WCA-1, along with appropriate pan coefficients, or if S-7 data is not available, the second choice should be the BGES data. See Appendix C for statistical correlations regarding the evaporation pan data.

Mass Balance Considerations

Eighteen sets of conditions were examined during this study using six scenarios consisting of different combinations of gages and pan coefficients. Three schemes for determining rainfall contributions and ET estimations were applied to each scenario for computing surface water elevations within WCA-1. The main body of this report deals only with the methodology recommended for use in computing the most reliable water budget for the area. Data on the eighteen sets of

WATER CONSERVATION AREA NO. 1 REGULATION SCHEDULE.



ZONE	RELEASES
A	Up to max. at S-10 (and S-39 when agreed).
B	Up to max. based on 30-day forecast. If stage exceeds Zone B, elev. 14.0 is foregone for year. Dashed line is schedule.
C	Stages allowed to rise in this zone if elev. 14.0 or below obtained for 30-days.
D	Water supply only.

DATES	USE GAGE	CONDITIONS
Jan 1 -Jun 30	1-8 Canal	All
Jul 1 -Dec 31	1-8 Canal	Except as noted below
	Avg. 1-7, 1-8T, 1-9	During rising stages when canal stage exceeds average.

General Notes:

1. When operating near zone limits, 30-day forecasts used to determine discharge rate.
2. No releases permitted when 1-8 canal gage reading falls below elev. 11.0 unless water is supplied from other source.
3. Indicator gages for regulation will be as follows (transition to be made when canal stage equals average stages when possible, to avoid discontinuities).

Figure 10. WCA-1 Regulation Schedule

conditions considered are contained in Appendix B. A monthly time step was used in all computations in this study.

As noted previously, a mass balance approach was used in this study to arrive at water budget conclusions. The basic equation used was:

$$DS = P + SI - SO - ET - S$$

A description of the above terms follows. For the purposes of this study, all units are in acre-ft.

DS (change in storage) - This is the change in water storage in WCA-1 at the end of each time step as compared to the end of the previous time step. It may be positive or negative, and it is one of the principal parameters in a water budget analysis. When compared with the change in water storage based on actual mean stages, the difference between the two is referred to as the residual term. This residual actually represents all unaccounted inflows or outflows and errors of measurement or estimation in the terms of Equation 1.

P (precipitation) - Rainfall directly on WCA-1, using either the entire area or the variable area. For the analyses using the variable area, direct rainfall contributions were computed based only on the inundated area.

SI (surface inflows) - Measured inflows through control structures as described previously.

SO (surface outflows) - Measured outflows through control structures as described previously.

ET (evapotranspiration) - A combination of evaporation and plant transpiration. This is one of the major components of the water budget in WCA-1. It is obtained by applying an appropriate pan coefficient to evaporation pan data. It was determined by the staff that the most reliable evaporation pan data available for WCA-1 was that from either S-7 or BGES. Table 3 lists the average computed pan coefficients for these stations for the period of record. The variable area based on water stages as referred to previously was also used for some of the ET computations.

TABLE 3
MONTHLY EVAPORATION PAN COEFFICIENTS

MONTH	BGES COEFF.	S-7 COEFF
JAN	0.68	0.78
FEB	0.77	0.92
MAR	0.85	0.96
APR	0.86	0.93
MAY	0.63	0.68
JUN	0.62	0.69
JUL	0.70	0.79
AUG	0.56	1.06
SEP	0.80	1.08
OCT	0.74	0.83
NOV	0.73	0.80
DEC	0.77	0.87
ANNUAL AVERAGE	0.73	0.87

S (seepage) - Groundwater movement into and out of WCA-1. Since water levels in WCA-1 are consistently higher than surrounding levels, seepage is usually out of WCA-1. The COE estimates the seepage rate at 4 cfs per mile of levee per foot of head. The following linear equation based on water budget calculations developed by the COE for WCA-1 was used in this study to estimate the total net seepage, in cfs, from the area (Figure 11).

$$\text{Seepage} = (142.9378 * \text{Stage}) - 2076.9545 \qquad (2)$$

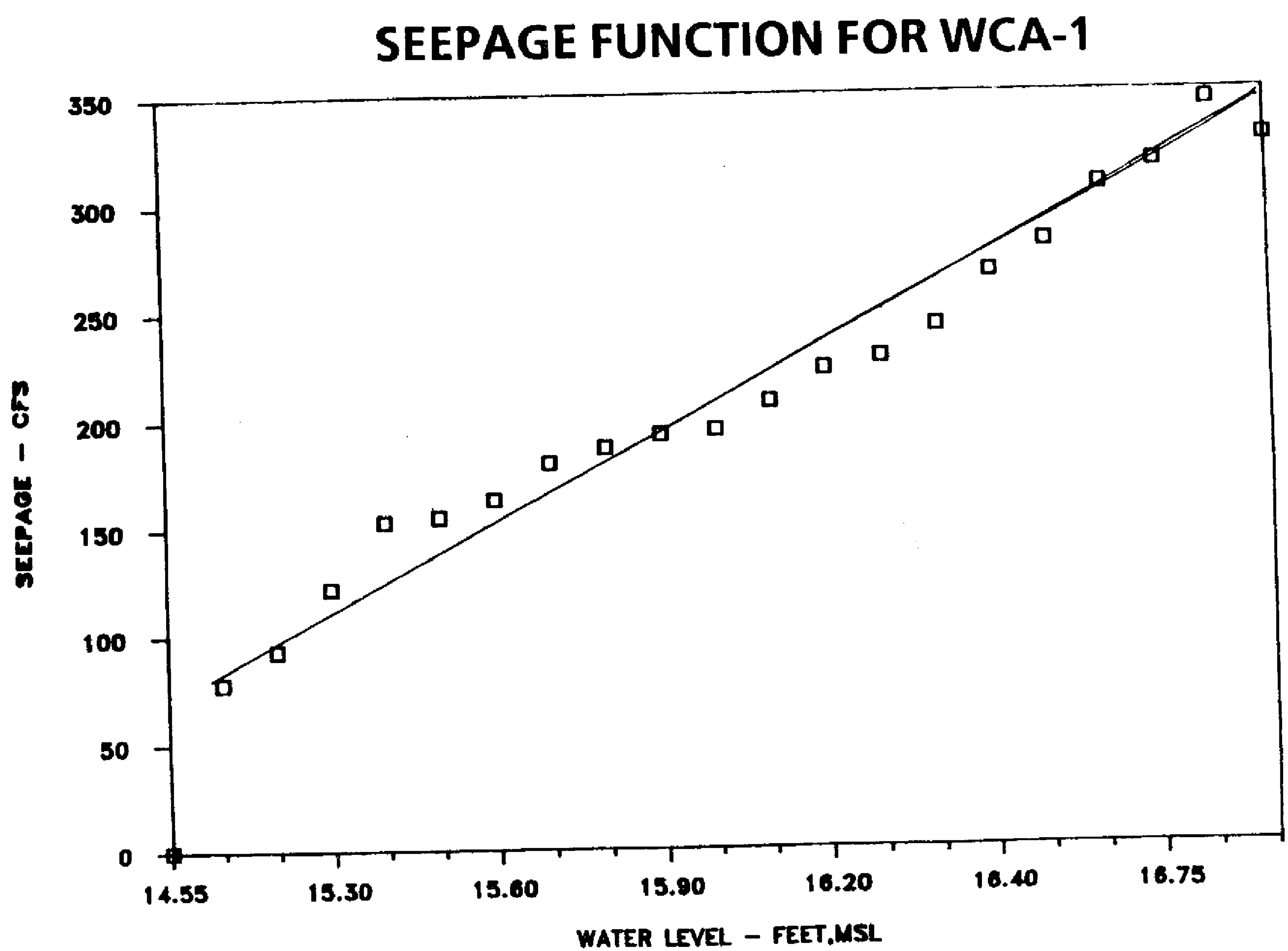


FIGURE 11. Seepage function for WCA-1 data based on the Water Budget Report of the Corps of Engineers

This equation is valid for water levels in WCA-1 between 14.7 ft and 17.5 ft NGVD. The seepage rate for stages between 14.5 ft and 14.7 ft was based on a linear interpolation between 0 and 75 cfs, and no seepage was assumed for stages below 14.5 ft due to the high ground water table east of WCA-1.

Evapotranspiration

Evapotranspiration is computed by applying an appropriate pan coefficient to a set of evaporation pan data. To compute a pan coefficient, the coefficient was initially assumed to be 1.0 and the change in storage for WCA-1 was computed using Equation (1). The actual change in storage was then computed based on measured physical data, using the three gage average (1-8C, 1-7, and 1-9) for WCA-1 stages. The difference between these two values is the residual term. The pan coefficient was then computed by dividing the residual term plus the pan evaporation by the pan evaporation, after converting all terms to the same units. This procedure was done for each monthly time step for the period of record for BGES and S-7. The procedure assumes that all of the residual term consists of ET losses, which is not precisely true. However, unless there are some substantial unknown inputs and/or outputs, which is unlikely, the computed pan coefficients should be reasonable approximations.

The S-7 evaporation pan station utilizes a float and recorder mechanism for recording data. Such set-ups have been known to produce inaccurate results. It would be advisable that a separate pan be established at this station, either manually read or read by some methodology not susceptible to the float and recorder problems. This would provide a correlation between the long term data recorded at S-7 and the actual pan evaporation.

Topography and Ponding Depth

As mentioned previously, there are three sources of topographic data for WCA-1 - the COE (1958), the District (1965), and the Fish and Wildlife Service (1963 and 1965) - and the maps do not agree in some areas. Topographic data have a significant effect on stage-storage and stage-area relationships. In order to check the accuracy of the topographic information, radiance maps of WCA-1 produced from enhanced LANDSAT band 7 imagery were obtained from the U.S. Geological Survey in Miami for February 14, March 4, and March 22, 1973. The change in water stored in WCA-1 during this period can be observed by the change in shading of the enhanced images shown in Figure 12. Darker tones correspond to lower radiance and deeper water. In addition, Figures 13 through 15 depict the water depth distribution for these same dates based on recorded water levels and the topographic information from the Fish and Wildlife Service. These maps were produced by the District's Water Resources Division in order to estimate the depth of ponding at different parts of WCA-1. WCA-1 was subdivided into 8000 points and the contour information from the Fish and Wildlife Service was digitized to generate land surface elevations for each point. The water surface elevations were primarily derived using the six gage average as described earlier in this report. However, the stage data at S-5A tailwater and S-6 tailwater are influenced by pumping activities at S-5A and S-6, so a correlation was made when there was no pumping. A water surface profile was fitted on each point to the six gages by a multivariate regression. The profile was assumed to be an elliptic parabaloid, and a regression equation was computed which described water surface elevations at each point for that day. The water depth was then obtained by subtracting the land surface elevation from the computed water surface elevation at each point. This type of information is important in evaluating the frequency of inundation provided by different water management alternatives for WCA-1.

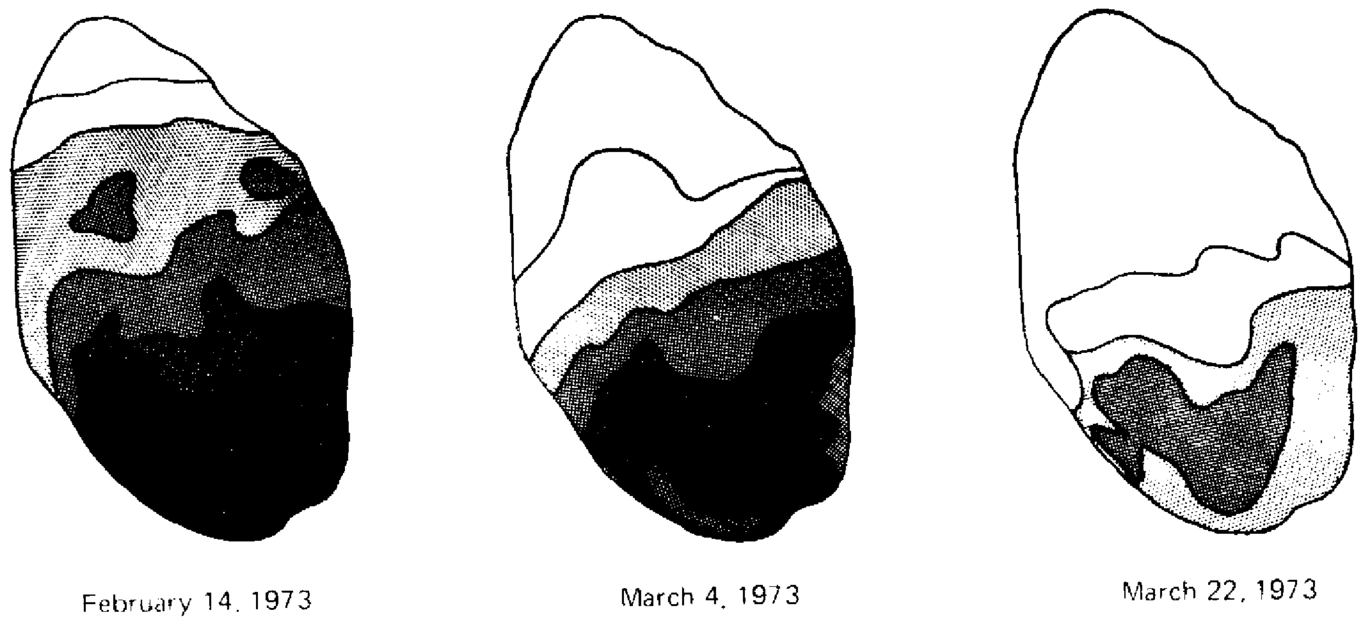


FIGURE 12. Radiance (reflectance) map of the Loxahatchee Wildlife Refuge (WCA-1) produced from enhanced LANDSAT band 7 imagery*

*Darker map tones correspond to lower radiance (reflectance) and deeper water. Black is deepest (0.6 Meter) and white is dry land.

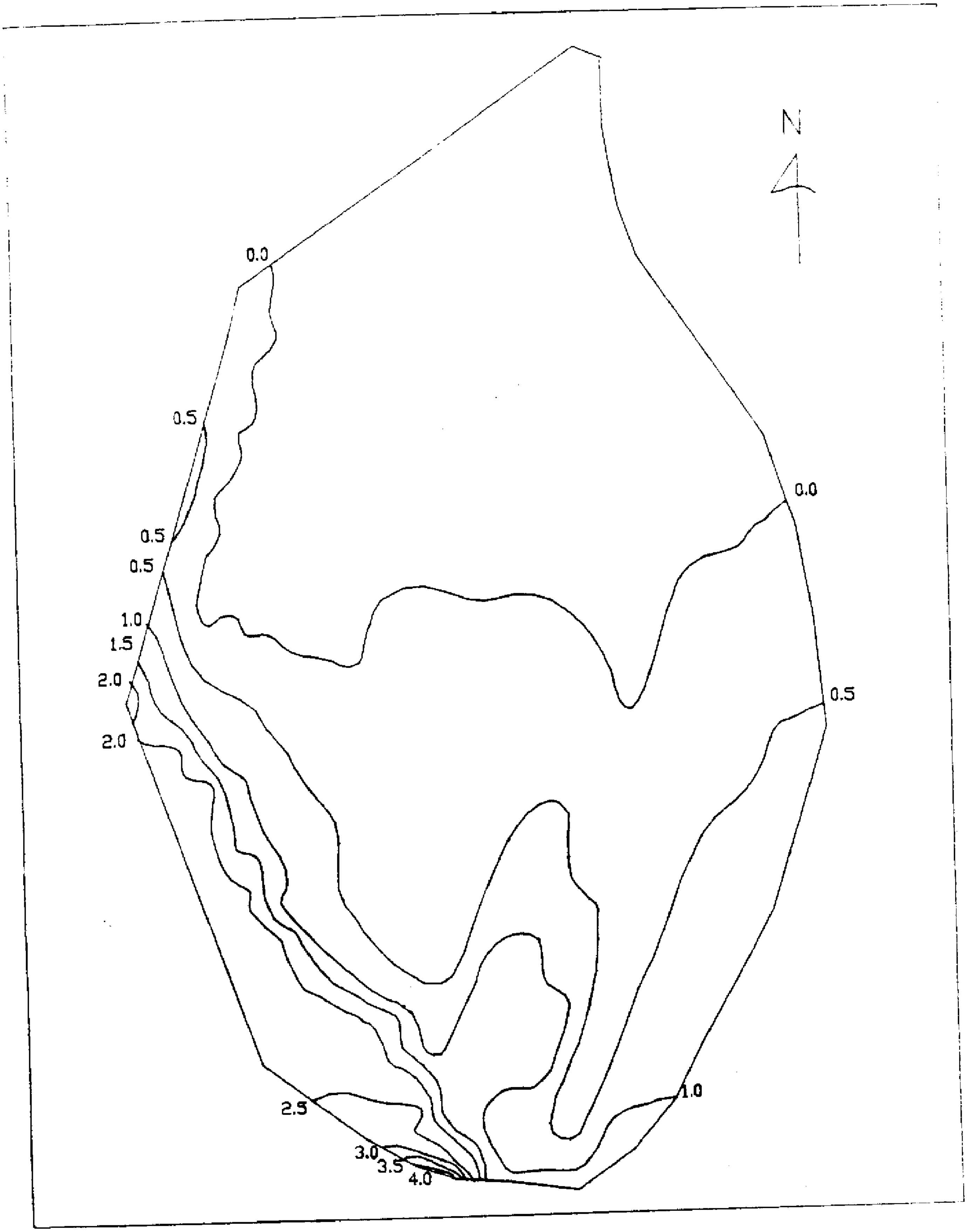


FIGURE 13. Distribution of Water Ponding Depth in WCA-1 February 14,1973.

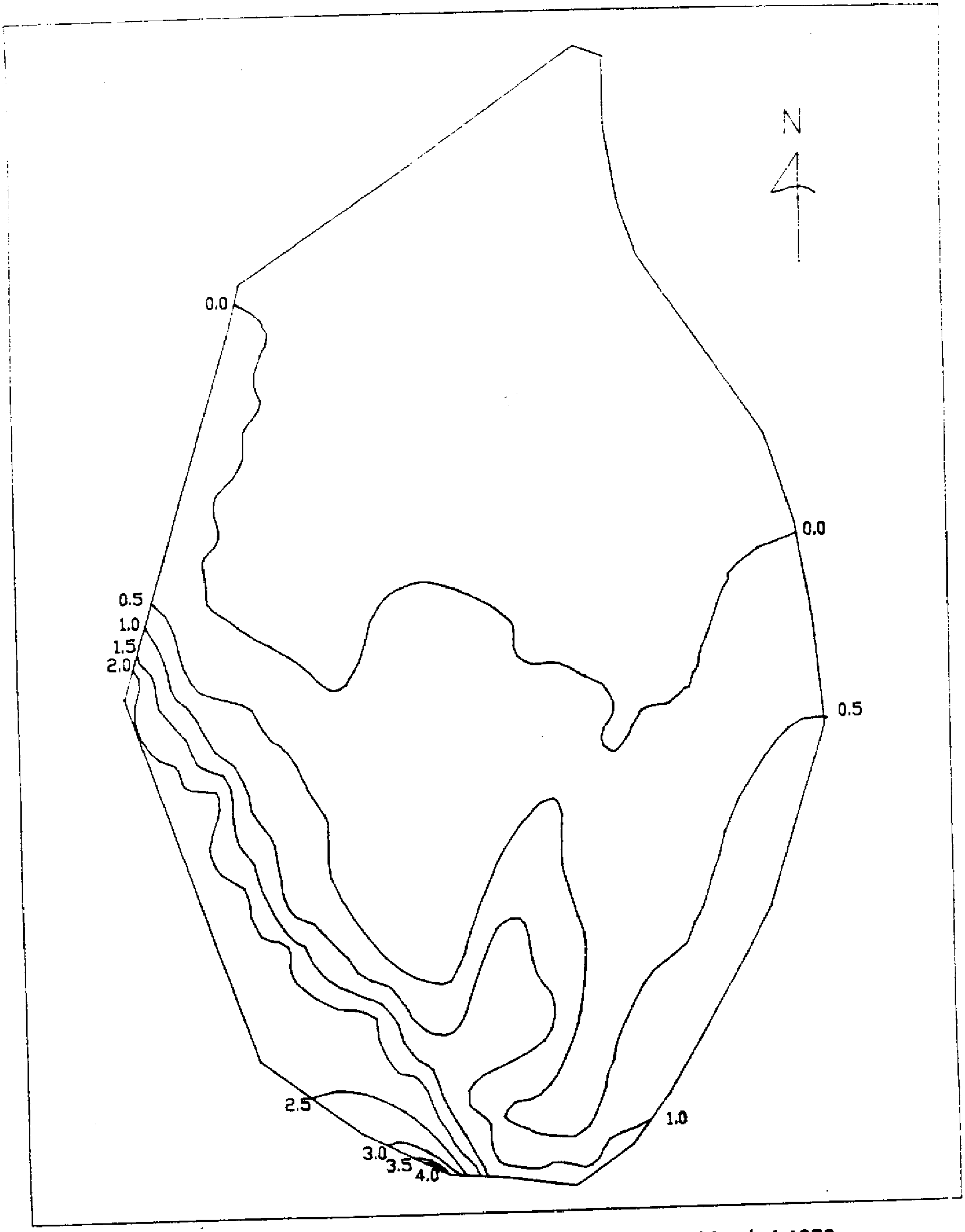


FIGURE 14. Distribution of Water Ponding Depth in WCA-1 March 4, 1973.

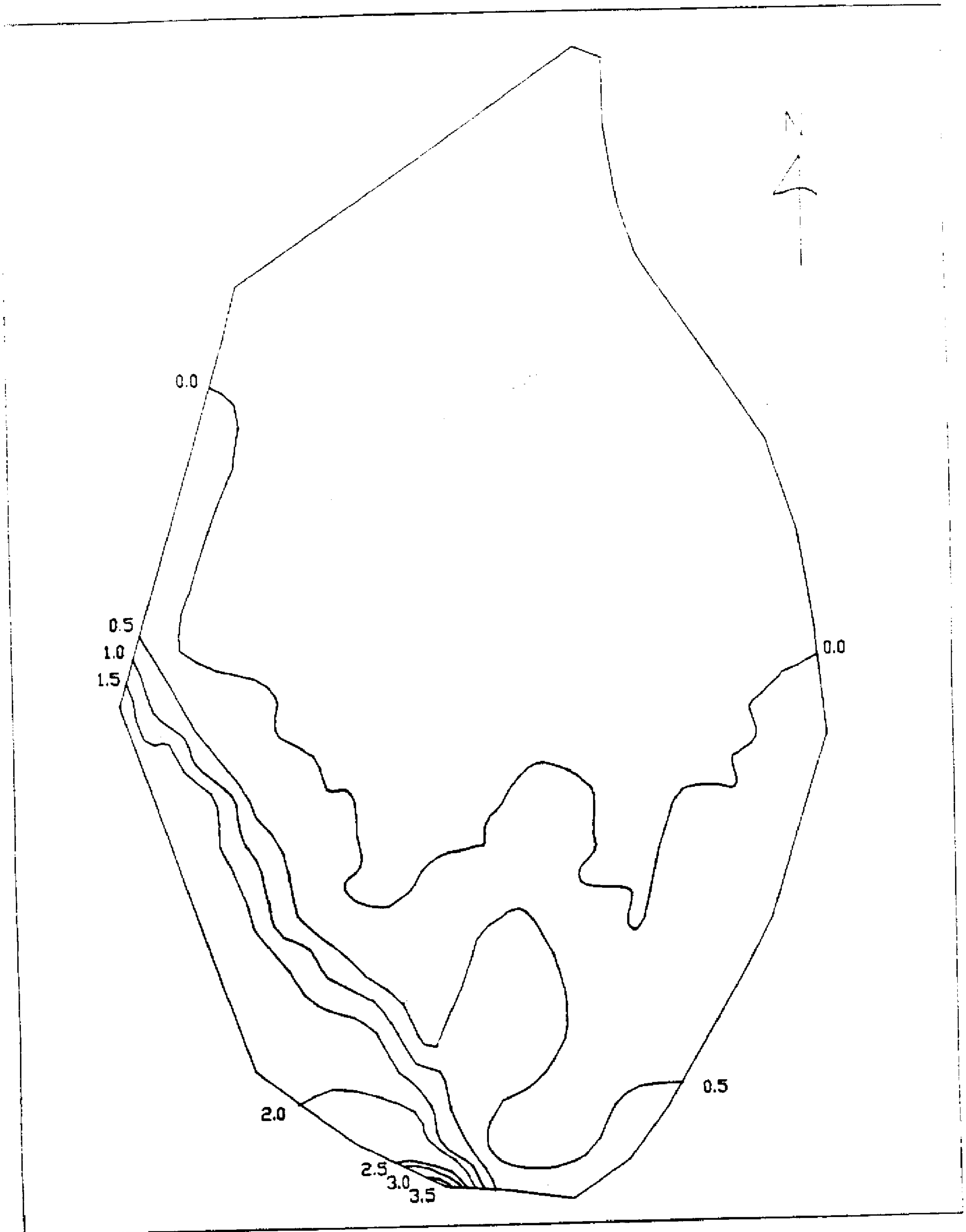


FIGURE 15. Distribution of Water Ponding Depth in WCA-1 March 22,1973.

In general, the trend of the water depth distribution agrees fairly well with the data provided by LANDSAT and the maps based on the Fish and Wildlife Service topographic data. Detailed locations of the various water depth distributions are not in agreement, however. For example, the dry areas on the Fish and Wildlife Service maps tend to cover more area than on the LANDSAT maps, and the locations of equal depth lines are not in agreement. Reliable topographic information is an important part of the water budget for WCA-1 and updated data would be useful.

Water Budget

Based on this study and on the available information, it is the District staff's opinion that the most reliable water budget for WCA-1 is obtained by using the three gage (1-8C, 1-7, and 1-9) average for stage determination, variable water surface area for both rainfall and ET computations, and S-7 evaporation pan data and pan coefficients to compute ET. The second alternative would entail the use of BGES pan evaporation data and pan coefficients (see Appendix C). Budget estimations WB1H and WB1G are based on the 3-gage average for water elevations and a variable water surface area, based on stages, for rainfall and ET computations. Budget estimation WB1H uses S-7 evaporation pan data and pan coefficients, and WB1G uses BGES data. All units are in acre-feet.

Based on the budget estimation WB1H, rainfall constitutes approximately 48.6% of the inflow to WCA-1, with surface inflows accounting for the remaining 51.4%. Surface water discharges, ET, and seepage constitute approximately 41.6%, 44.2%, and 14.2% respectively of the outflow (Table 4 and Figure 5, included previously). All values in Table 4 are in acre-feet. As can be seen, ET is the most significant outflow component. Therefore, it is important that the most reliable method available be used in computing ET rates.

TABLE 4

YEARLY WATER BUDGET COMPONENTS (AC-FT)

Year	Rainfall	Inflow	Outflow	ET	Seepage
1963	274084	178813	70315	294648	70613
1964	543765	520532	211594	416109	152444
1965	410840	495425	242846	403343	144977
1966	645050	757412	901861	406983	160084
1967	312603	253160	189307	332342	110636
1968	498259	696105	620973	419982	154341
1969	541294	660253	630009	440276	180769
1970	394506	546492	712511	438413	141970
1971	276774	245334	44100	246611	81033
1972	507663	278908	362879	496408	150256
1973	377243	332723	184700	366290	104507
1974	448961	447809	314660	464578	145713
1975	317028	369120	211626	401885	130409
1976	394684	340919	309821	489520	136944
1977	383163	474909	287313	452623	117714
1978	459920	541677	505867	430594	146245
1979	401212	466896	472020	399123	140864
1980	354966	398849	489353	444768	121864
1981	262834	200299	249069	315345	69352
1982	536771	616310	542996	479833	154572
Average	417081	441097	382723	406985	130765
Percentage	48.6	51.4	41.6	44.2	14.2

CONCLUSIONS

1. There are three sources of topographic data for WCA-1, which do not agree with each other. In addition, the most recent data is almost 25 years old. Since topographic information has a significant impact on the water budget of a partially inundated area such as this, updated topographic data for WCA-1 is needed.

2. Evapotranspiration is the most significant component of the water budget for WCA-1. Reliability in estimating evapotranspiration will increase the accuracy of water budget computations.

3. The most reliable water budget for WCA-1 is computed using:

   a. The average of three gages (1-8C, 1-7, and 1-9) for the determination of the water surface elevation within the area.

   b. Variable surface area for the determination of both rainfall and ET, based on the inundated area.

   c. Evaporation pan data and pan coefficients based on the S-7 data.

RECOMMENDATIONS

1. Updated ground contour maps of WCA-1 should be obtained.
2. Water budget computations for WCA-1 should be based on the average of gages 1-8C, 1-7, and 1-9 for water surface elevations, a variable water surface area for both rainfall and ET computations based on the inundated area, and evaporation pan data and pan coefficients based on either S-7 or Belle Glade Agricultural Experiment Station information.
3. Improvements should be made with the method of evaporation pan data used in ET computations for WCA-1.

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APPENDIX A

COMPUTER PRINTOUTS

WATER CONSERVATION AREA . (COE-ET) SCHEME 3-3 GAGES AVG.RANCOEFF.

YEAR 1963

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	15.59	15.79	839.00	760.00	13645.15	19026.33	11272.33	142011.28	118440.00
FEB	15.71	15.65	17263.00	9780.00	26657.75	18943.29	9365.40	125787.53	132360.00
MAR	15.13	15.31	1460.00	1850.00	4394.14	36849.14	7997.60	92991.36	79140.00
APR	14.34	14.46	599.00	13470.00	1809.44	25584.71	2570.83	41713.83	37880.00
MAY	14.97	14.89	35550.00	31400.00	36565.58	20430.29	1280.82	63422.17	67440.00
JUN	15.06	15.24	24911.00	7860.00	33895.56	37296.85	4937.84	87713.90	73680.00
JUL	14.59	14.84	265.00	.00	17675.31	34844.17	3425.33	60668.09	47680.00
AUG	14.67	14.81	16601.00	1500.00	20109.15	20957.64	1557.85	59117.20	51840.00
SEP	15.39	15.55	35611.00	75.00	49275.77	17147.25	4707.51	113425.23	99420.00
OCT	15.42	15.58	22296.00	.00	29061.61	30483.10	8210.15	117266.49	101760.00
NOV	15.32	15.40	10115.00	1500.00	12775.32	18862.39	7558.45	100501.96	93960.00
DEC	15.41	15.55	13303.00	2120.00	28218.94	14223.56	7728.97	113258.47	100980.00

YEAR 1964

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	15.83	15.78	47521.00	480.00	12222.48	14076.92	9172.75	140090.73	146280.00
FEB	15.90	15.97	26711.00	460.00	26775.47	27170.68	11770.35	162539.10	154400.00
MAR	15.74	15.91	24209.00	3970.00	28161.10	37548.13	11771.89	154982.00	135840.00
APR	15.42	15.50	14017.00	21610.00	31434.10	44978.88	9279.68	108571.07	101760.00
MAY	14.96	15.08	8971.00	28118.00	23220.47	36273.79	6068.61	75098.68	66920.00
JUN	15.45	15.64	60665.00	27660.00	54751.06	33964.68	6436.56	124803.87	104100.00
JUL	15.45	15.60	63876.00	55490.00	50293.04	43652.09	8534.59	119759.30	104100.00
AUG	16.13	16.32	92144.00	18060.00	86932.11	43702.03	11484.72	207307.24	182900.00
SEP	16.29	16.22	38009.00	9766.00	43669.82	42586.20	14125.10	194694.62	203700.00
OCT	17.12	17.40	102340.00	42300.00	142125.53	34815.60	19913.11	357055.47	317800.00
NOV	17.09	17.06	16071.00	3370.00	26320.00	31490.00	21957.39	309671.61	313600.00
DEC	16.97	17.08	25998.00	310.00	17860.00	25850.00	21929.36	312729.14	296800.00

YEAR 1965

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.55	16.63	545.00	7429.00	1057.50	28787.50	19420.23	249099.02	238000.00
FEB	16.29	16.36	27198.00	35099.00	28526.56	31300.57	16500.25	213330.79	203700.00
MAR	15.43	15.51	12540.00	63175.00	9123.63	44235.79	11138.49	108583.79	102540.00
APR	14.72	14.91	2309.00	8642.00	4793.79	34266.73	4610.58	64522.15	54440.00
MAY	13.48	14.55	21509.00	12711.00	2604.27	28685.79	812.70	45523.23	17972.00
JUN	15.33	15.55	85477.00	7341.00	35388.83	19334.39	3807.18	114348.92	94740.00
JUL	15.85	15.90	75858.00	50431.00	72133.08	37070.71	9121.55	153892.66	148600.00
AUG	15.45	15.81	68630.00	48267.00	34165.57	44949.67	11151.40	144330.52	104100.00
SEP	16.12	16.05	58079.00	3622.00	57981.87	31172.07	10422.83	172450.20	181600.00
OCT	17.42	17.45	115610.00	23826.00	140706.42	37110.62	19350.45	363938.15	359800.00
NOV	16.61	16.74	23639.00	77691.00	10575.00	37012.50	21789.92	264923.08	246400.00
DEC	16.36	16.39	4031.00	5252.00	13781.61	29416.22	16851.86	216516.64	212800.00

YEAR 1966

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.60	16.58	38310.00	25383.00	46784.25	18367.15	16629.78	241555.10	245000.00
FEB	16.41	16.54	44123.00	71431.00	63097.50	28552.50	17501.26	237019.94	219300.00
MAR	15.57	15.56	18470.00	80778.00	8034.09	39008.87	12111.24	115466.33	116120.00
APR	15.15	15.26	25878.00	26425.00	16447.16	37762.08	7386.42	89515.00	80700.00
MAY	15.27	15.42	83358.00	59150.00	29425.34	37793.38	6535.78	102098.06	90060.00
JUN	16.22	16.17	165210.00	195670.00	162141.62	34750.69	9365.37	188398.27	194600.00
JUL	15.78	15.37	148001.00	239059.00	38314.35	41928.91	10713.23	98019.28	140480.00
AUG	15.85	15.78	86835.00	97471.00	69782.09	45279.17	10734.68	140895.49	148600.00
SEP	16.36	16.32	78960.00	64199.00	90916.60	30722.10	13264.21	207833.51	212800.00
OCT	17.03	17.13	66819.00	26645.00	111820.13	31651.57	19062.59	319460.75	305200.00
NOV	16.67	16.67	343.00	7469.00	5522.50	35485.00	19866.77	255341.73	254800.00
DEC	16.35	16.35	1105.00	8181.00	2763.90	25681.24	16912.60	211232.63	211500.00

YEAR 1967

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.18	16.16	932.00	6522.00	13805.83	23525.13	14756.15	186610.07	189400.00
FEB	16.11	16.20	22190.00	24068.00	42606.53	26411.70	14224.48	191605.29	180300.00
MAR	15.41	15.46	1377.00	33641.00	4255.70	38744.58	10218.87	104878.03	100980.00
APR	14.51	14.69	791.00	16055.00	.00	31335.23	3771.51	52802.73	43520.00
MAY	13.44	13.76	2370.00	14443.00	2545.57	16615.64	.00	22693.93	17516.00
JUN	15.42	14.92	38363.00	18188.00	32783.97	7628.20	374.10	64837.42	101760.00
JUL	15.28	15.34	50468.00	61241.00	43769.63	40391.44	7291.81	95555.59	90840.00
AUG	15.36	15.56	29859.00	998.00	35234.85	31009.68	7647.04	114418.54	97080.00
SEP	15.72	15.76	30362.00	584.00	51374.52	29052.05	8802.13	138054.19	133520.00
OCT	16.59	16.46	69533.00	1716.00	63664.86	30748.99	13334.89	226145.31	243600.00
NOV	16.23	16.27	440.00	7162.00	6156.75	32379.94	16221.86	200908.93	195900.00
DEC	16.06	16.10	6475.00	4689.00	16404.57	24498.93	13992.82	178783.68	173800.00

YEAR 1968

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	15.78	15.81	2274.00	7199.00	4477.64	21691.66	12000.18	144432.96	140480.00
FEB	15.78	15.81	18257.00	6632.00	24579.43	23735.10	10853.70	143994.44	140480.00
MAR	15.40	15.38	4461.00	17354.00	13299.18	34838.97	8744.75	98696.03	100200.00
APR	14.80	14.84	284.00	12957.00	4360.61	28975.11	4241.51	60699.24	58600.00
MAY	15.68	15.82	54297.00	15770.00	72688.19	27510.93	6173.04	144934.72	128880.00
JUN	16.39	16.41	243565.00	223930.00	112665.61	42363.08	12743.61	219206.48	216700.00
JUL	15.54	15.28	149906.00	282299.00	63397.03	57467.81	11199.95	91104.51	112640.00
AUG	15.86	15.64	46178.00	39385.00	58105.26	41768.42	9088.68	124175.05	149760.00
SEP	16.64	16.59	94914.00	285.00	51860.60	34823.75	14604.81	244035.14	250600.00
OCT	17.32	17.26	72109.00	658.00	70147.50	40890.00	20839.83	337419.97	345800.00
NOV	17.15	17.14	9382.00	5390.00	22442.50	34780.00	23154.41	321256.09	322000.00
DEC	16.72	16.75	478.00	9114.00	235.00	31137.50	20696.23	265813.15	261800.00

YEAR 1969

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.54	16.57	16017.00	19468.00	18565.00	22442.50	18134.28	241274.57	236600.00
FEB	16.18	16.21	11884.00	24150.00	16183.69	34291.31	15752.82	193216.86	189400.00
MAR	16.03	16.17	98289.00	96833.00	42012.16	32158.79	14099.96	187895.76	169900.00
APR	15.71	15.78	45244.00	47849.00	30356.96	48826.57	11717.99	140525.26	132360.00
MAY	15.04	14.78	36940.00	127010.00	42493.61	30381.91	6404.27	57719.65	72120.00
JUN	15.84	15.33	63397.00	61830.00	46520.57	28718.70	5512.38	94879.29	147440.00
JUL	15.95	15.83	28872.00	25920.00	45458.34	48233.69	11200.51	146545.21	160200.00
AUG	15.93	16.08	76441.00	67650.00	70026.66	47407.43	12726.87	176038.92	157880.00
SEP	16.66	16.72	87874.00	4990.00	76692.25	36659.98	15426.66	262436.80	253400.00
OCT	17.55	17.48	122318.00	30605.00	81192.50	43005.00	21911.29	368700.06	378000.00
NOV	17.40	17.48	58198.00	74909.00	62980.00	37600.00	25605.45	368583.55	357000.00
DEC	16.88	16.87	14779.00	48795.00	8812.50	30550.00	22276.17	282941.83	284200.00

YEAR 1970

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.98	17.01	47725.00	9310.00	19387.50	24322.50	20727.41	302303.54	298200.00
FEB	16.46	16.51	30511.00	73679.00	24086.06	29725.73	18947.34	232823.06	225800.00
MAR	16.80	16.40	185191.00	231027.00	92296.84	39852.83	16290.44	217711.68	273000.00
APR	15.18	15.27	27293.00	156507.00	3355.49	48738.54	11472.75	90341.91	83040.00
MAY	15.61	15.58	53497.00	12693.00	28877.68	40707.97	7361.71	117678.54	120760.00
JUN	15.74	15.59	45389.00	72480.00	67517.68	48541.57	9181.35	118511.64	135840.00
JUL	15.62	15.44	77640.00	121802.00	47703.76	33628.63	9138.56	103676.59	121920.00
AUG	15.72	15.63	55369.00	8073.00	20792.14	54128.30	9402.46	123229.68	133520.00
SEP	15.81	15.81	13078.00	4102.00	45543.36	31132.08	10590.05	143826.67	143960.00
OCT	15.97	15.89	10369.00	3906.00	43004.20	34422.65	11332.87	153523.54	162520.00
NOV	15.57	15.57	430.00	10081.00	367.09	32670.73	10478.26	116621.25	116120.00
DEC	15.21	15.19	.00	8851.00	1574.63	20541.77	7046.49	83925.80	85380.00

YEAR 1971

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	14.88	14.99	1914.00	7453.00	4593.23	14640.93	4716.63	68297.68	62760.00
FEB	14.68	14.70	7307.00	7308.00	5055.55	13153.38	2125.11	53588.33	52360.00
MAR	13.70	14.06	2450.00	11557.00	975.80	15325.82	641.17	28874.84	21720.00
APR	13.50	13.34	11350.00	11376.00	1161.70	6970.22	.00	16373.40	18200.00
MAY	14.05	13.76	5074.00	1710.00	7889.21	9899.38	.00	22721.64	28600.00
JUN	14.81	14.74	10945.00	200.00	26689.82	14578.47	568.42	55407.25	59120.00
JUL	15.10	15.14	9047.00	.00	35856.70	25332.39	3790.67	80220.45	76800.00
AUG	15.23	15.27	20406.00	.00	31221.79	30654.12	5675.63	90258.79	86940.00
SEP	16.13	16.11	88307.00	.00	42976.25	26592.09	9767.08	179736.71	182900.00
OCT	16.60	16.57	35263.00	.00	62191.12	29187.17	15603.22	240525.55	245000.00
NOV	16.84	16.86	47850.00	1990.00	31842.50	28435.00	18892.86	281061.64	278600.00
DEC	16.73	16.71	5421.00	2506.00	26320.00	31842.50	19252.33	260879.69	263200.00

YEAR 1972

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.58	16.60	2919.00	1700.00	20562.50	26907.50	18314.98	245678.67	242200.00
FEB	16.40	16.38	10971.00	2517.00	13184.78	34812.46	16676.04	215135.28	218000.00
MAR	16.08	16.20	7118.00	6230.00	40108.40	53961.99	15142.37	192050.52	176400.00
APR	16.27	16.23	33923.00	37790.00	91086.12	57130.94	13953.29	196534.05	201100.00
MAY	16.11	15.95	76342.00	143540.00	71989.14	47922.08	13552.04	159752.09	180300.00
JUN	15.91	16.05	64206.00	123570.00	94759.59	43312.63	13301.40	172508.47	155560.00
JUL	15.77	15.88	35145.00	36540.00	57063.22	59329.98	11724.83	152632.71	139320.00
AUG	15.91	15.77	21208.00	4916.00	39744.79	42709.44	10638.78	139446.00	155560.00
SEP	15.75	15.64	9244.00	577.00	22552.87	48511.69	10529.87	123857.38	137000.00
OCT	15.54	15.62	3584.00	1651.00	25032.30	38919.48	9868.42	121793.71	112640.00
NOV	15.52	15.55	10007.00	2259.00	18876.90	21257.03	8695.94	113563.34	110320.00
DEC	15.44	15.38	4241.00	1589.00	12702.47	21632.70	7857.69	98996.33	103320.00

YEAR 1973

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	15.51	15.36	10386.00	3380.00	10549.51	21099.01	7424.87	96993.41	109160.00
FEB	15.37	15.32	5886.00	2670.00	10546.82	23038.44	7510.55	94216.90	97860.00
MAR	15.11	15.03	3608.00	5400.00	9890.94	30167.38	5403.46	71594.80	77580.00
APR	14.47	14.54	101.00	7940.00	3913.72	28135.31	2485.07	45003.82	42040.00
MAY	14.01	14.32	5312.00	4600.00	9189.70	21656.86	.00	37215.04	27320.00
JUN	14.59	15.12	45469.00	.00	26331.60	26533.22	2466.08	78346.60	63280.00
JUL	15.68	15.97	103931.00	34450.00	60383.26	29307.97	7410.66	162580.30	128880.00
AUG	15.86	15.78	91622.00	105480.00	95167.60	33744.69	11032.66	163387.57	149760.00
SEP	16.47	16.16	39483.00	17500.00	74123.79	42385.70	12703.19	187387.04	227100.00
OCT	16.47	16.44	16170.00	760.00	32891.74	43003.33	16505.29	223203.68	227100.00
NOV	16.41	16.33	139.00	800.00	28650.57	37818.76	16014.04	208820.53	219300.00
DEC	16.30	16.28	10616.00	1720.00	15604.00	29398.85	15550.98	202672.02	205000.00

YEAR 1974

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.53	16.46	12822.00	350.00	49212.14	31514.04	15886.61	226216.58	235200.00
FEB	16.07	15.97	.00	15590.00	977.78	46716.07	14549.59	163059.40	175100.00
MAR	15.91	15.79	1823.00	8410.00	35777.33	52328.06	11944.09	142111.31	155560.00
APR	15.38	15.36	.00	12920.00	7772.71	48190.78	8864.75	96730.53	98640.00
MAY	15.01	15.10	.00	11260.00	20622.64	37081.71	5984.58	76802.50	69780.00
JUN	15.48	15.77	45150.00	920.00	47105.95	20537.05	7184.57	139760.82	106440.00
JUL	15.61	15.66	111775.00	117020.00	58213.36	30061.68	8889.49	126770.15	120760.00
AUG	15.84	15.86	170686.00	138050.00	51714.36	42791.81	10344.96	149406.08	147440.00
SEP	16.42	16.63	73316.00	7910.00	96121.68	41819.87	14566.30	249235.93	220600.00
OCT	16.38	16.29	10558.00	.00	31066.96	51022.37	15644.98	204231.40	215400.00
NOV	16.45	16.38	10310.00	850.00	33995.27	34907.90	15855.37	215073.59	224500.00
DEC	16.42	16.35	11369.00	1380.00	16380.55	27606.39	15998.01	210853.99	220600.00

YEAR 1975

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.10	16.09	.00	3500.00	661.60	32749.25	14701.73	177515.45	179000.00
FEB	15.79	15.78	6918.00	7310.00	3366.69	31785.50	11978.83	140753.20	141640.00
MAR	15.32	15.24	.00	10760.00	2802.80	39542.18	7840.79	87881.51	93960.00
APR	14.50	14.59	.00	15980.00	1450.04	30257.51	3385.58	47904.98	43000.00
MAY	15.06	15.06	27728.00	4940.00	22435.37	17848.38	2273.11	73813.35	73680.00
JUN	15.43	15.73	84696.00	45820.00	44031.50	20456.15	7280.75	135192.01	102540.00
JUL	15.58	15.45	82243.00	108240.00	52435.42	22122.39	7776.62	103725.12	117280.00
AUG	15.37	15.58	30021.00	12600.00	30062.71	36343.22	9002.24	117237.66	97860.00
SEP	16.40	16.40	73338.00	180.00	95053.73	34252.76	11334.51	217744.24	218000.00
OCT	16.99	16.69	62319.00	.00	46201.17	62917.17	17303.77	256995.15	299600.00
NOV	16.75	16.76	770.00	130.00	15862.50	36307.50	20068.57	266987.93	266000.00
DEC	16.43	16.40	1087.00	2166.00	2664.47	37302.65	17462.76	217669.41	221900.00

YEAR 1976

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.22	15.98	.00	19668.00	3573.41	35517.56	14237.46	163864.26	194600.00
FEB	16.21	16.25	22287.00	27459.00	59107.62	37864.10	14642.17	199058.48	193300.00
MAR	15.61	15.63	22536.00	43190.00	7971.71	48022.37	11617.31	122898.92	120760.00
APR	15.08	15.08	3427.00	13970.00	5862.25	37194.99	6291.02	75196.89	75240.00
MAY	15.82	15.65	86845.00	70270.00	65515.52	37285.83	6936.76	125039.40	145120.00
JUN	15.70	15.80	59553.00	71550.00	48060.12	40223.20	10965.07	142464.04	131200.00
JUL	15.67	15.76	22221.00	12220.00	44160.76	46159.81	10311.76	138583.75	127720.00
AUG	15.97	15.84	47524.00	28770.00	71703.96	56995.46	10507.01	147255.77	162520.00
SEP	16.44	16.42	63694.00	.00	52840.16	41097.90	14318.15	220350.27	223200.00
OCT	16.04	15.97	.00	7460.00	3987.52	52376.58	14159.75	162095.20	171200.00
NOV	15.88	15.79	5695.00	10020.00	12839.01	32097.54	11830.23	142205.75	152080.00
DEC	15.88	15.78	7137.00	5244.00	19061.46	24684.58	11128.01	140430.85	152080.00

YEAR 1977

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.18	16.13	44442.00	2410.00	28611.76	34149.52	12699.20	183387.93	189400.00
FEB	15.79	15.79	5136.00	29048.00	18389.36	32357.23	12383.40	141725.31	141640.00
MAR	15.15	15.11	.00	20883.00	774.45	39074.55	6774.32	77245.56	80700.00
APR	14.46	14.55	.00	8346.00	3903.79	29943.81	2656.60	45753.45	41720.00
MAY	15.40	15.28	76247.00	47993.00	43114.10	27786.84	2981.63	91211.42	100200.00
JUN	15.46	15.45	15017.00	16378.00	36929.78	35034.00	7664.83	103930.49	104880.00
JUL	15.23	15.20	12474.00	12441.00	15491.28	36495.22	6721.34	84851.71	86940.00
AUG	15.51	15.50	34432.00	9194.00	38468.60	33669.12	7183.64	107773.70	109160.00
SEP	16.65	16.06	167019.00	120190.00	96631.76	63495.58	10701.35	173344.18	252000.00
OCT	16.14	16.23	4025.00	8905.00	8269.03	52785.84	16255.30	195321.49	184200.00
NOV	16.20	16.33	34527.00	7825.00	41616.95	35781.77	14650.56	209242.98	192000.00
DEC	16.96	16.82	81590.00	3700.00	50962.50	32049.75	17041.33	275927.89	295400.00

YEAR 1978

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.35	16.34	24318.00	95046.00	30586.87	34266.50	18103.41	210427.60	211500.00
FEB	15.94	16.06	39406.00	57842.00	23448.50	30210.39	14337.28	174381.66	159040.00
MAR	15.52	15.15	19938.00	70670.00	14066.30	34779.31	8177.77	80808.39	110320.00
APR	15.01	14.98	8211.00	16900.00	4941.75	35718.21	5236.52	68118.29	69780.00
MAY	15.21	15.30	54245.00	24995.00	17949.50	27571.92	5458.54	92772.06	85380.00
JUN	15.65	15.71	60963.00	48924.00	65076.27	32803.91	7789.89	132070.69	125400.00
JUL	15.91	15.89	86669.00	89470.00	75297.06	43554.18	10570.90	152917.36	155560.00
AUG	15.81	15.76	93175.00	91520.00	36595.14	41563.67	11172.38	138580.27	143960.00
SEP	16.24	16.37	49572.00	240.00	77260.03	39358.89	13369.55	214674.89	197200.00
OCT	16.45	16.38	36014.00	3110.00	34208.53	40938.07	15274.51	215059.42	224500.00
NOV	16.72	16.73	27050.00	2460.00	57695.08	33168.83	17679.39	262570.63	261800.00
DEC	16.72	16.79	42116.00	4690.00	22795.00	36660.00	19075.15	271051.65	261800.00

YEAR 1979

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.35	16.17	55622.00	118130.00	28363.94	30277.38	16337.82	187701.76	211500.00
FEB	15.75	15.75	750.00	39204.00	4860.26	31085.41	12810.76	136496.92	137000.00
MAR	15.26	15.23	2635.00	21469.00	11187.21	36434.01	7789.53	86587.02	89280.00
APR	15.46	15.03	18242.00	19675.00	20051.76	34093.94	5105.10	71086.29	104880.00
MAY	15.38	15.17	12438.00	23080.00	22768.64	41108.13	6631.69	82421.43	98640.00
JUN	15.10	15.23	353.00	2689.00	22554.45	36763.07	6595.55	86896.38	76800.00
JUL	14.99	15.08	7310.00	5466.00	23236.04	27883.24	4786.60	75065.68	68480.00
AUG	15.30	15.51	39215.00	2556.00	37584.12	25365.96	6188.22	109646.98	142800.00
SEP	16.75	17.22	202307.00	78450.00	120978.00	36589.50	16868.77	331249.57	266000.00
OCT	17.02	16.89	63285.00	26380.00	35837.50	39950.00	19669.43	285914.57	303800.00
NOV	16.79	16.55	41454.00	104050.00	41360.00	30785.00	19297.45	238638.55	271600.00
DEC	16.71	16.65	23285.00	30871.00	32430.00	28787.50	18783.46	252615.42	260400.00

YEAR 1980

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	16.59	16.55	55868.00	71700.00	38775.00	34662.50	17998.97	238307.28	243600.00
FEB	15.90	15.64	22299.00	111816.00	12995.32	31531.29	13354.47	124715.06	154400.00
MAR	15.49	15.45	19316.00	38780.00	23961.81	46975.49	9540.54	104260.80	107220.00
APR	15.33	15.25	44009.00	40252.00	22373.47	41089.73	7022.18	88114.84	94740.00
MAY	15.52	15.62	36580.00	13537.00	42340.59	44527.93	8099.41	121745.19	110320.00
JUN	15.48	15.30	3674.00	15542.00	28270.11	39235.04	7484.49	92165.44	106440.00
JUL	15.66	15.60	40063.00	36760.00	51322.36	41842.43	8646.94	119362.90	126560.00
AUG	15.70	15.63	33460.00	28284.00	42851.48	39641.96	9554.26	123012.75	131200.00
SEP	16.03	15.95	117716.00	78091.00	43279.62	39943.09	11132.11	159833.98	169900.00
OCT	15.59	15.62	723.00	29908.00	25380.60	40099.46	11002.93	121810.12	118440.00
NOV	15.74	15.60	21382.00	12288.00	20273.75	23737.19	9137.10	119680.91	135840.00
DEC	15.57	15.43	3759.00	12395.00	3142.31	21499.98	8890.62	102750.70	116120.00

YEAR 1981

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	15.21	15.13	.00	16645.00	2786.20	21384.07	6747.24	78834.38	85380.00
FEB	15.42	15.19	13361.00	8461.00	16825.24	19047.44	5740.67	83840.92	101760.00
MAR	14.39	14.69	-2990.00	18256.00	4488.03	29253.30	3814.39	53104.47	39480.00
APR	13.47	13.19	1056.00	16698.00	312.47	10163.41	.00	14698.50	17858.00
MAY	14.20	13.19	.00	3231.00	4204.47	6189.18	.00	14622.82	33400.00
JUN	14.42	14.20	.00	.00	10439.87	15101.01	.00	33420.17	40440.00
JUL	14.79	14.43	.00	2552.00	16144.96	16937.35	.00	40652.45	58080.00
AUG	16.21	15.94	130767.00	74350.00	92838.10	38916.27	6656.80	159427.05	193300.00
SEP	16.22	15.83	43288.00	76633.00	58322.32	54338.84	12737.60	146853.77	194600.00
OCT	15.79	15.80	.00	16630.00	15158.96	45375.81	12555.79	142911.24	141640.00
NOV	15.87	15.83	14817.00	11113.00	36282.84	30519.16	10977.18	146234.33	150920.00
DEC	15.60	15.58	.00	4500.00	5030.91	28119.17	10122.81	116864.42	119600.00

YEAR 1982

MONTH	HIST. STAGE-FT	COMP. STAGE-FT	TOTAL INFLOW-AF	TOTAL OUTFLOW-AF	RAINFALL AF	ET AF	SEEPAGE AF	COMP. VOL-AF	HIST. VOL-AF
JAN	15.40	15.34	2927.00	4146.00	3079.80	23098.53	7911.30	95532.66	100200.00
FEB	15.39	15.29	1098.00	1513.00	22674.30	25954.24	6958.72	91622.69	99420.00
MAR	15.79	15.79	47289.00	8266.00	48999.55	37672.60	9116.46	142160.40	141640.00
APR	15.46	15.26	5833.00	26884.00	14263.26	40386.72	8116.23	89176.38	104880.00
MAY	15.88	15.85	45858.00	6455.00	48813.87	50818.72	9662.76	148877.38	152080.00
JUN	16.54	16.10	179270.00	225441.00	119567.21	49616.32	12433.35	178807.60	236600.00
JUL	16.02	16.03	43920.00	101659.00	49675.98	55429.10	14985.28	169762.71	168600.00
AUG	15.88	16.04	66992.00	49273.00	44283.97	43971.38	12864.62	171128.69	152080.00
SEP	16.85	16.99	118879.00	9194.00	93411.27	36912.52	16312.71	298998.04	280000.00
OCT	16.68	16.59	90573.00	100565.00	30667.50	46765.00	18732.96	243127.59	256200.00
NOV	16.86	16.79	13671.00	353.00	48292.50	33487.50	18941.42	272079.08	281400.00
DEC	16.41	16.53	.00	9247.00	13042.50	35720.00	18536.12	235582.98	219300.00

APPENDIX B

STATISTICAL ANALYSES

Statistical Analyses

Statistical analyses were done as part of this study using six different combinations of gages and pan coefficients (scenarios) and three methods of computing rainfall and ET additions and abstractions (schemes). A description of these scenarios and schemes follows, along with data plots for all 18 sets of conditions.

Scenarios

WB1A - The average of gages 1-8C, 1-7, and 1-9 was used to compute water elevations, and evaporation pan data from the S-7 station was used with no pan coefficient.

WB1B - Gage 1-8C was used to compute water elevations, and evaporation pan data from the S-7 station was used with no pan coefficient.

WB1C - Gages 1-8C, 1-7, 1-9, S-10A headwater, S-6 tailwater, and S-5A tailwater were used to compute water elevations, and evaporation pan data from the S-7 station was used with no pan coefficient.

WB1F - Gages 1-8C, 1-7, and 1-9 were used to compute water elevations, and evaporation pan data from the BGES station was used with no pan coefficient.

WB1G - Gages 1-8C, 17, and 1-9 were used to compute water elevations, and evaporation pan data from the BGES station, along with the computed pan coefficients, were used.

WB1H - Gages 1-8C, 1-7, and 1-9 were used to compute water elevations, and evaporation pan data from the S-7 station, along with the computed pan coefficients, were used.

Schemes

1. Rainfall computations were made based on the entire area of WCA-1, and ET computations were based on the inundated area.

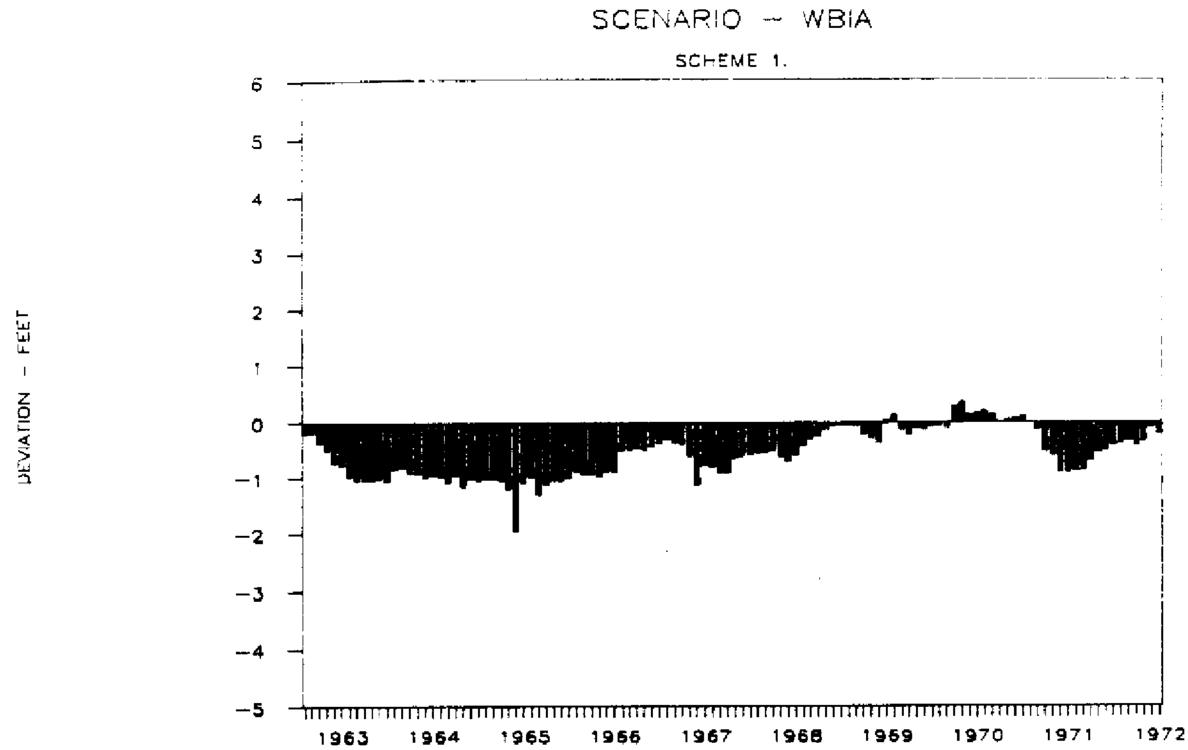
2. Both rainfall and ET computations were based on the entire WCA-1 area.

3. Rainfall and ET computations were both based only on the inundated area.

TABLE B-1

STATISTICAL SUMMARY

Scenario	Scheme	Error in Volume (AF)		Error in Stage (FT)	
		Mean	St. Dev.	Mean	St. Dev.
WB1A	1	-38363	49975	-0.3326	0.4314
	2	25848	63923	1.0329	1.8734
	3	5207	17443	-0.0519	0.1932
WB1B	1	-40834	46909	0.4857	0.6271
	2	23377	60902	0.8798	1.7092
	3	4584	24301	0.0303	0.4105
WB1C	1	-45040	48574	-0.4555	0.4945
	2	19171	63215	0.9100	1.7825
	3	4435	19183	0.0443	0.3098
WB1F	1	5720	40354	0.0795	0.5183
	2	84815	45756	2.2937	2.0384
	3	12942	17069	0.1286	0.1978
WB1G	1	-60119	49926	-0.5184	0.4107
	2	-3647	67008	0.4610	1.5469
	3	2164	16785	0.0200	0.1904
WB1H	1	-70501	59034	-0.5993	0.4748
	2	-22290	80630	0.2004	1.4199
	3	1204	16744	0.0092	0.1853



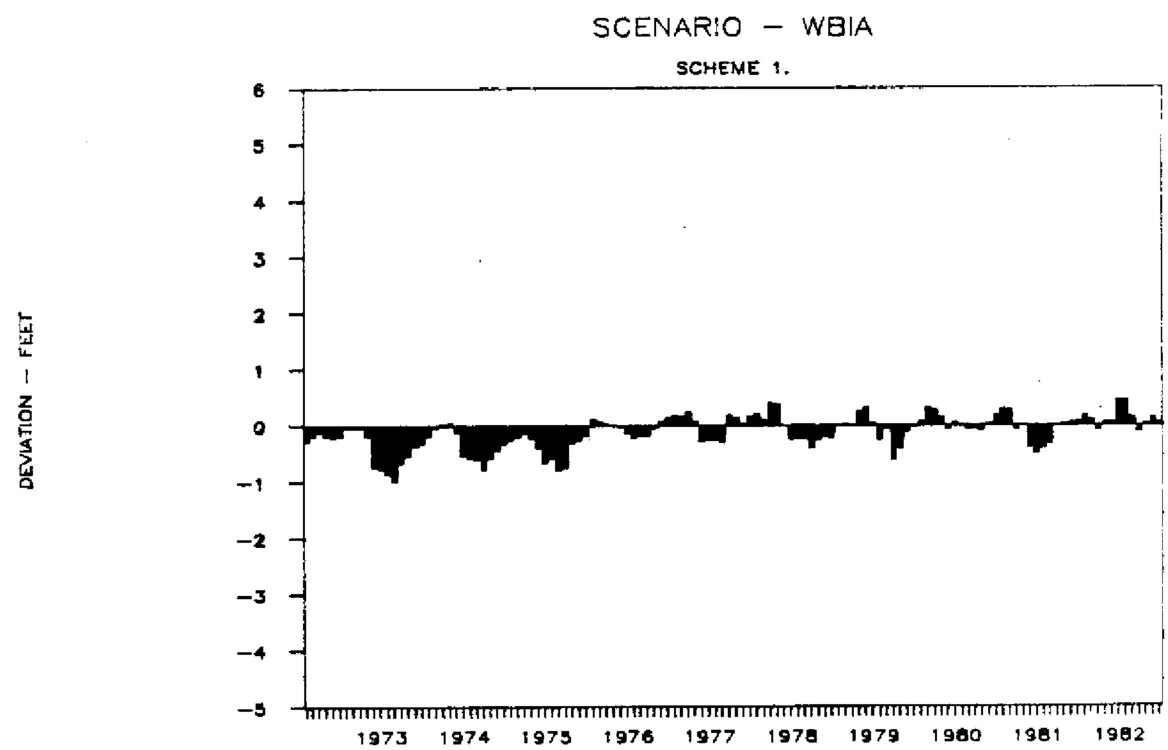
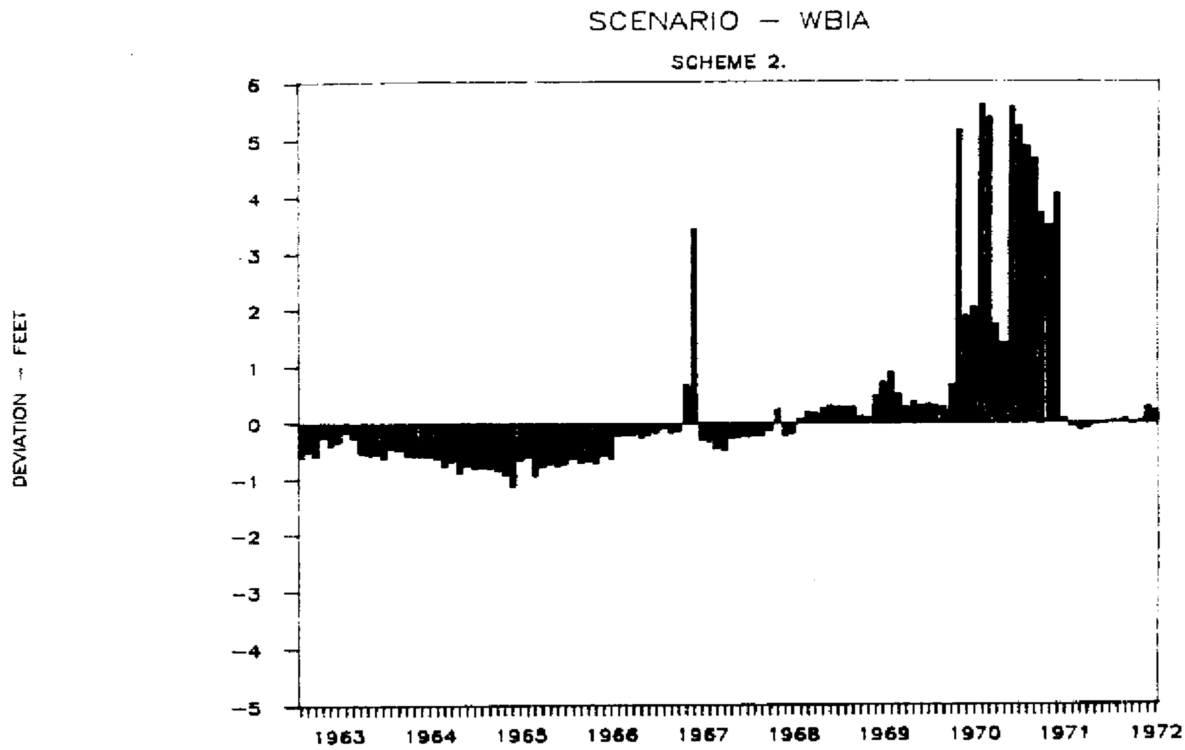


FIGURE B-1. Deviation, in feet, resulting from scenario 1, using a 3-gage average, total area for rainfall, and variable area for ET computations.



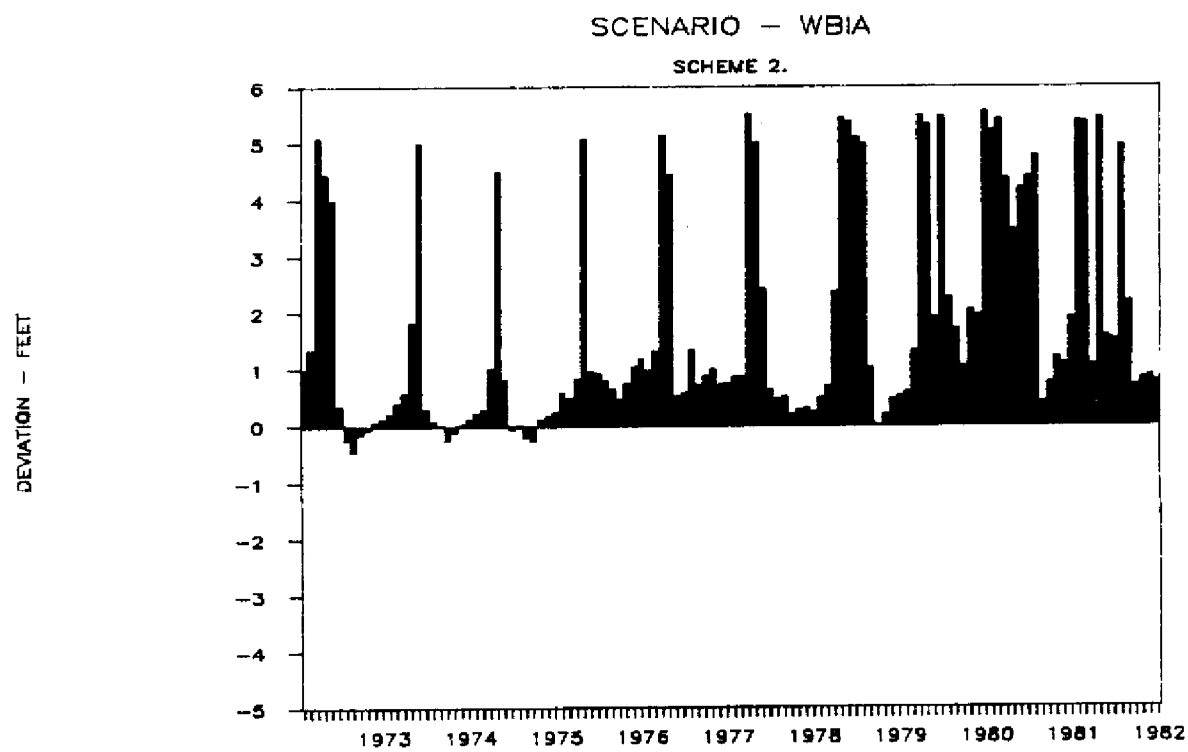
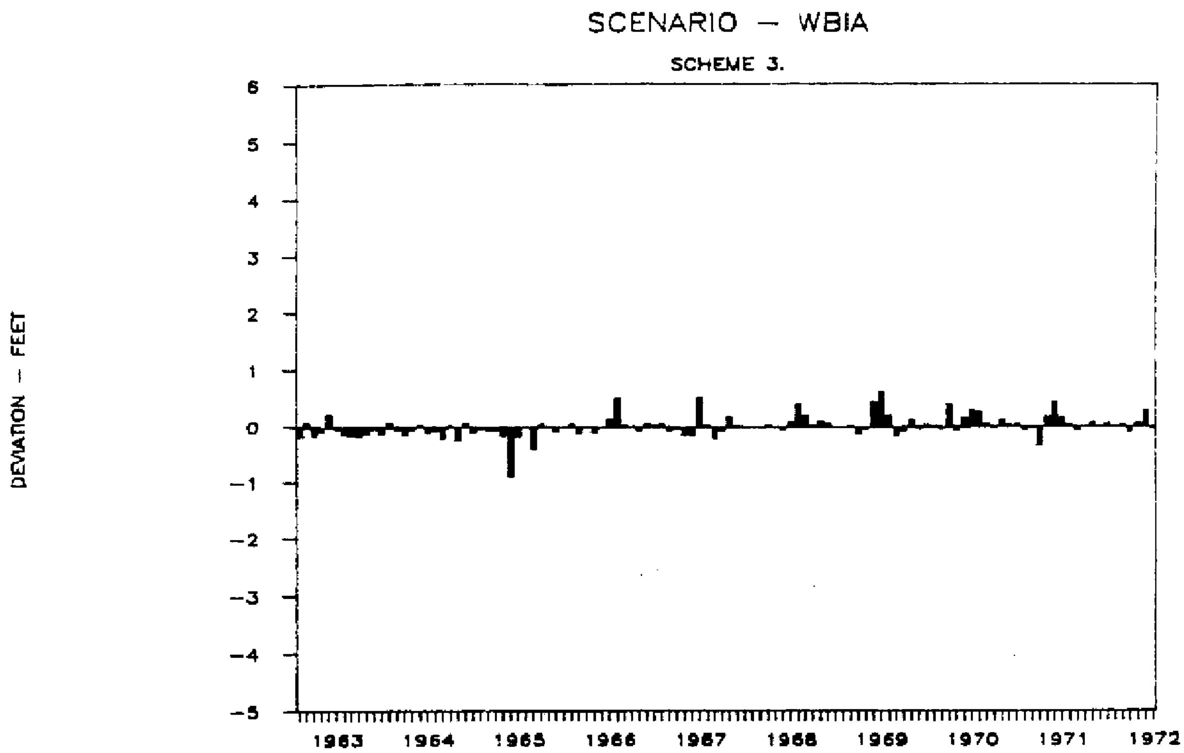


FIGURE B-2. Deviation, in feet, resulting from scenario 2, using a 3-gage average, total area for rainfall, and ET computations.



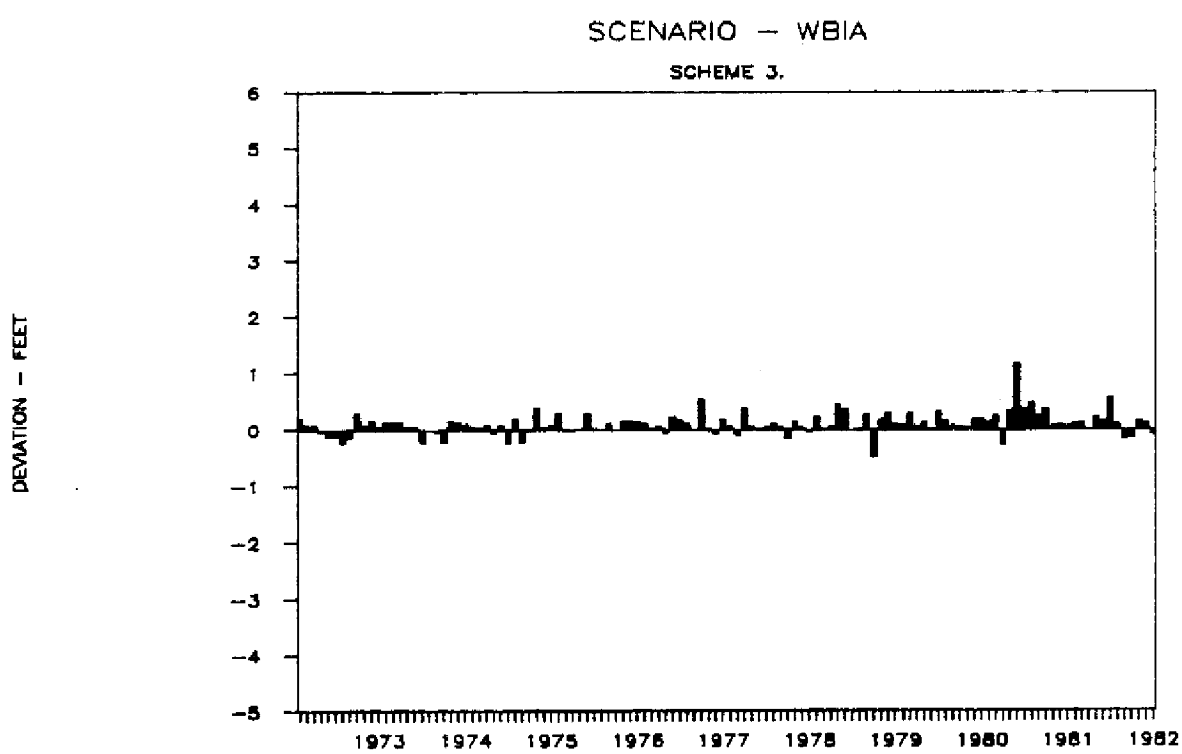
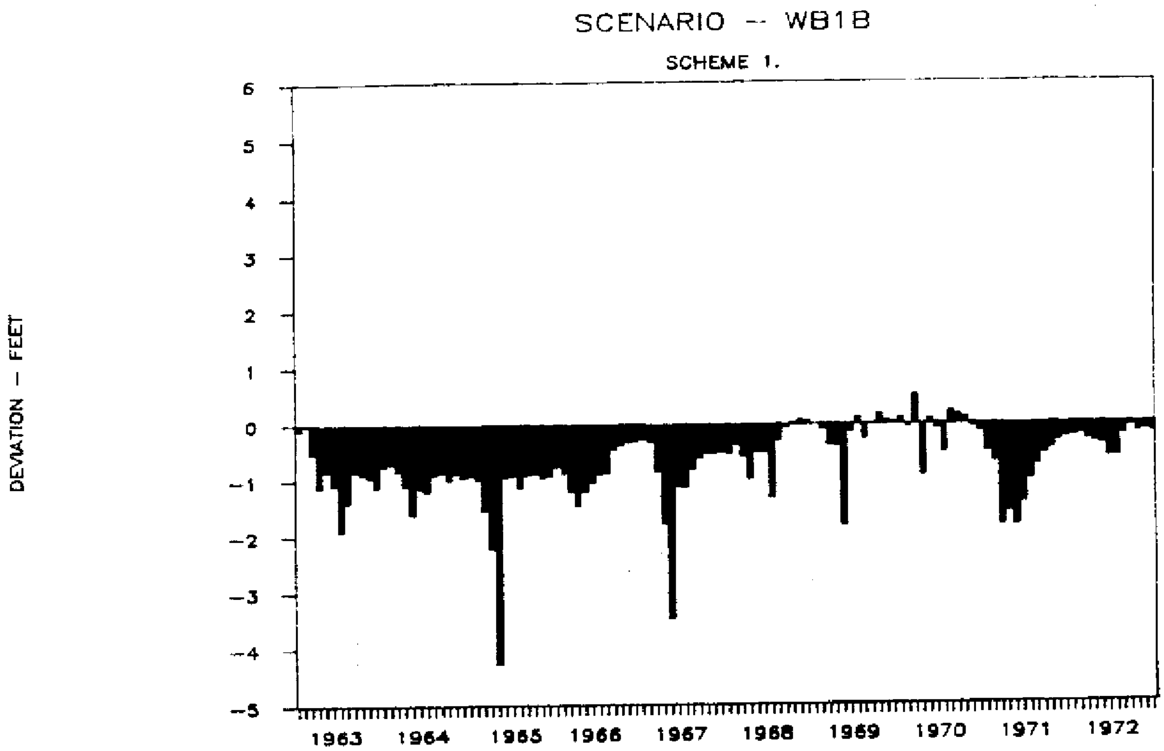


FIGURE B-3. Deviation ,in feet, resulting from scenerio 3, using a 3-gage average variable area for rainfall, and ET computations



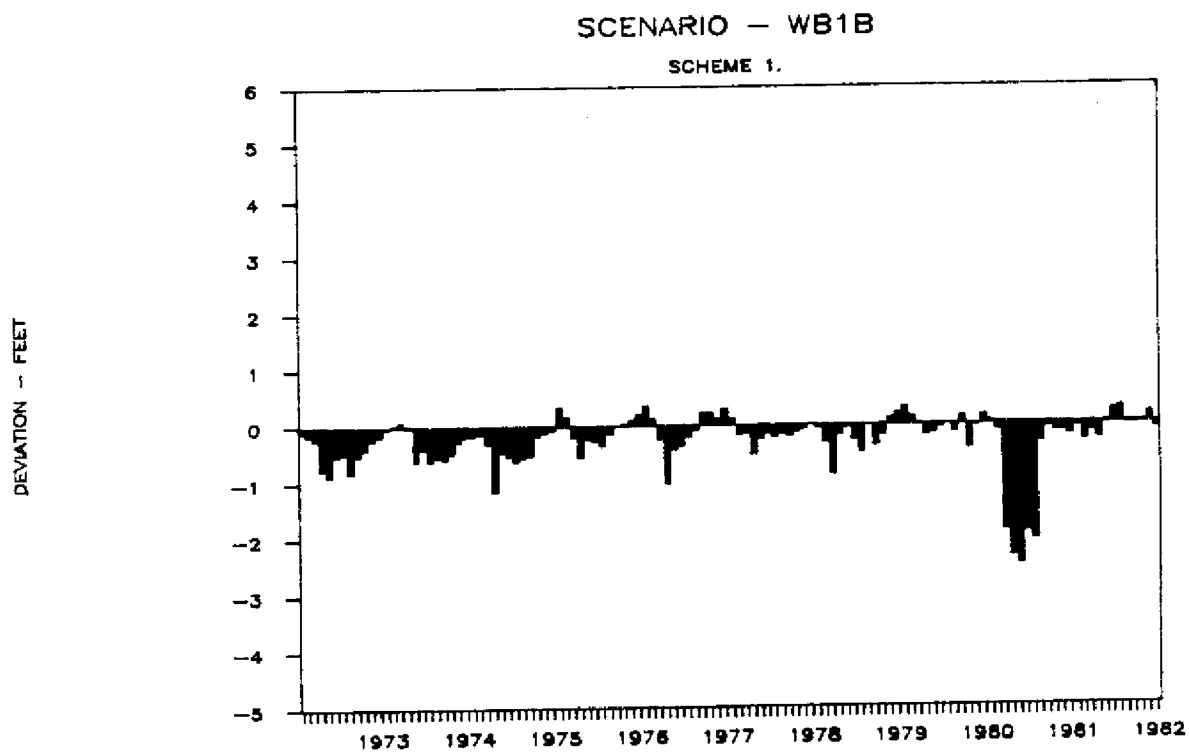
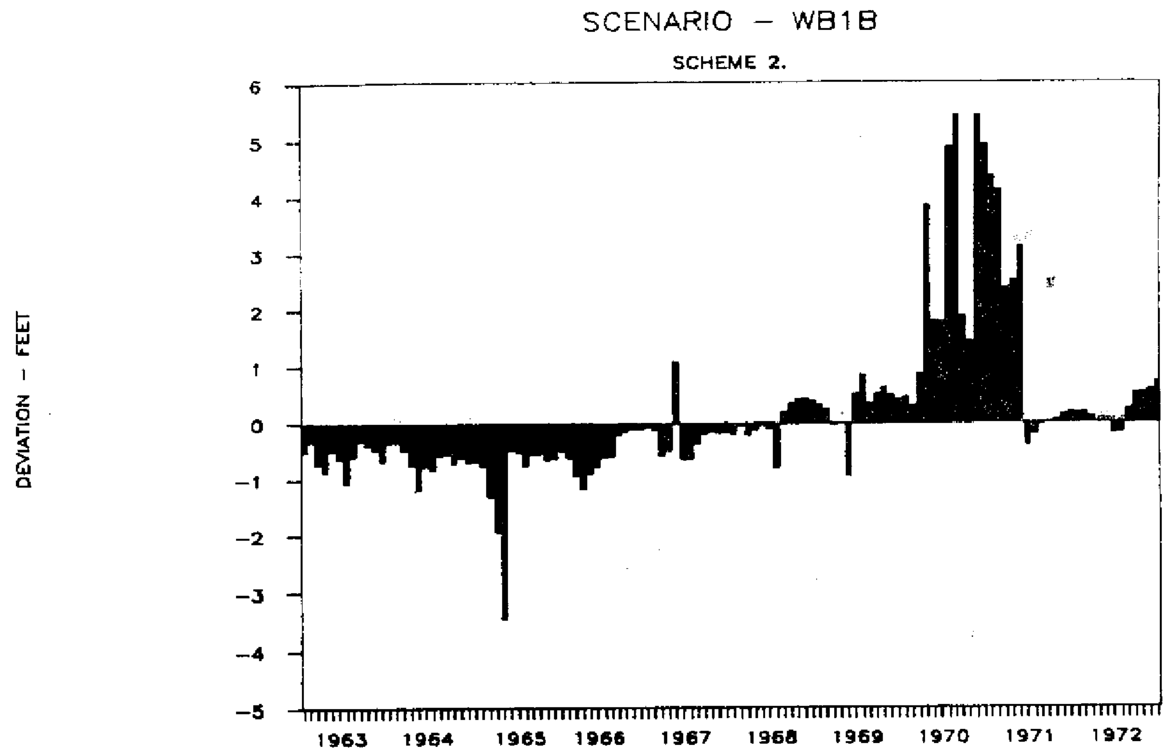


FIGURE B-4. Deviation, in feet, resulting from scenerio 4, using one gage, total area for rainfall, and variable area for ET computations



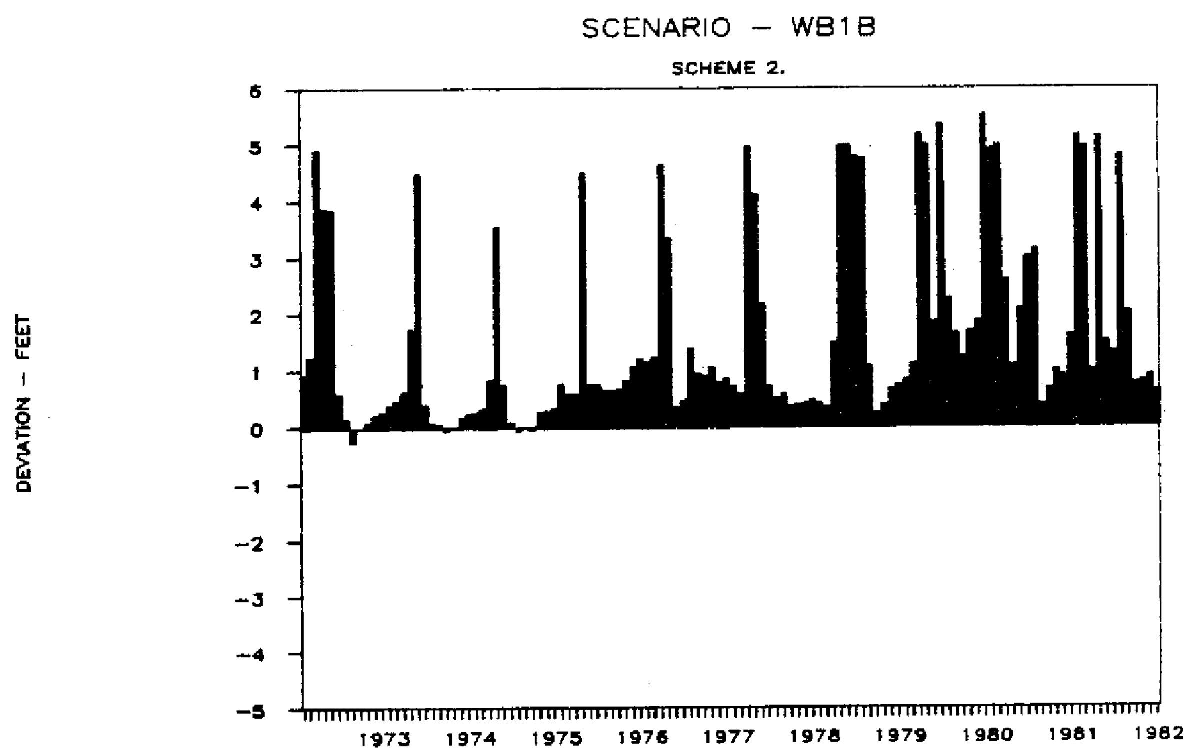
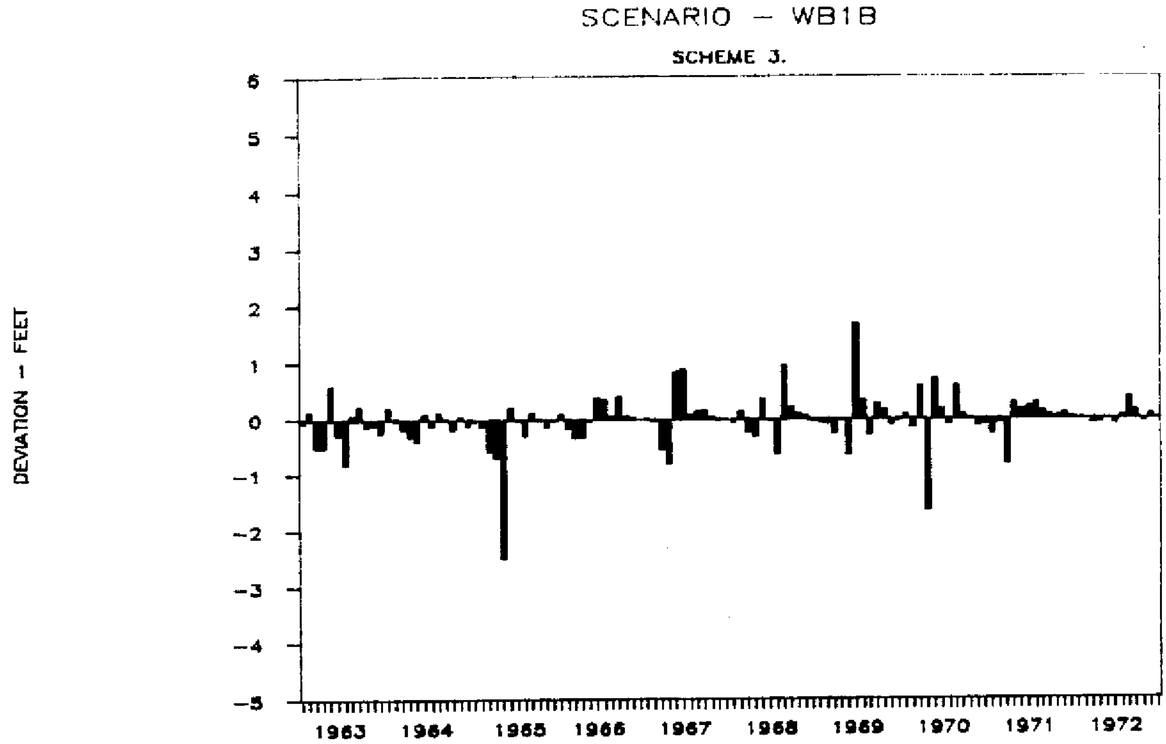


FIGURE B-5. Deviation, in feet, resulting from scenerio 5, using one gage average, total area for rainfall, and ET computations



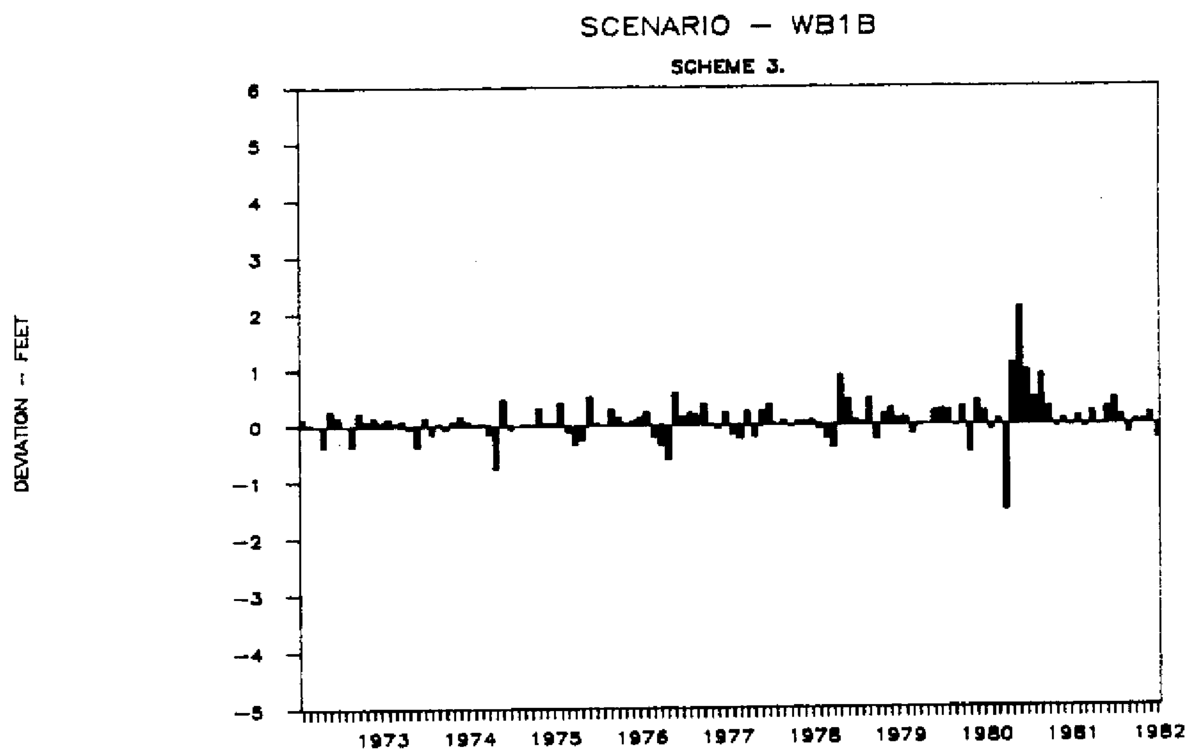
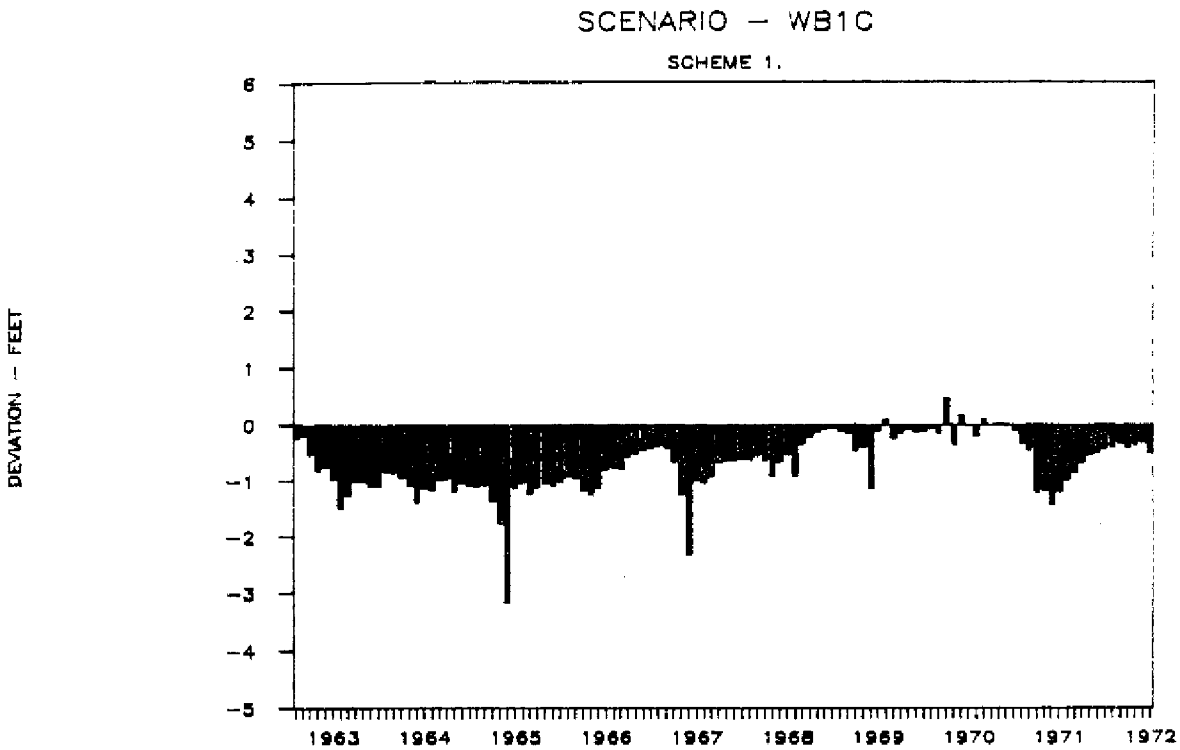


FIGURE B-6. Deviation, in feet, resulting from scenerio 6, using one gage average variable area for rainfall, and ET computations



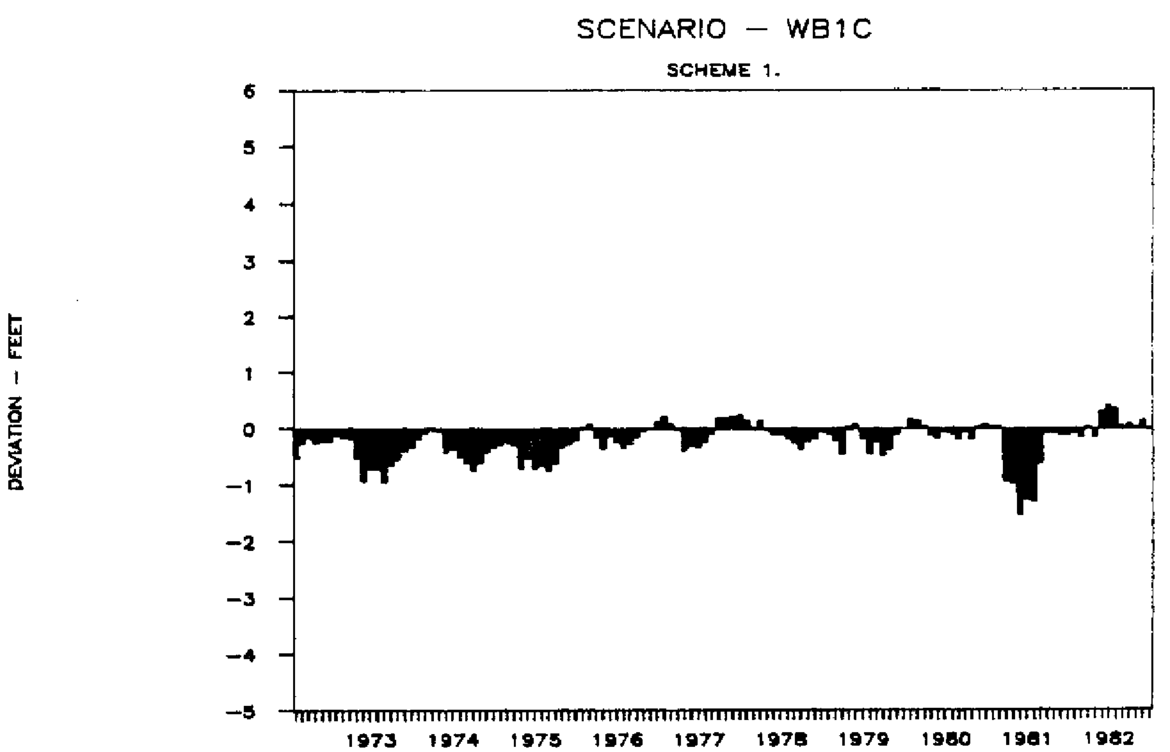
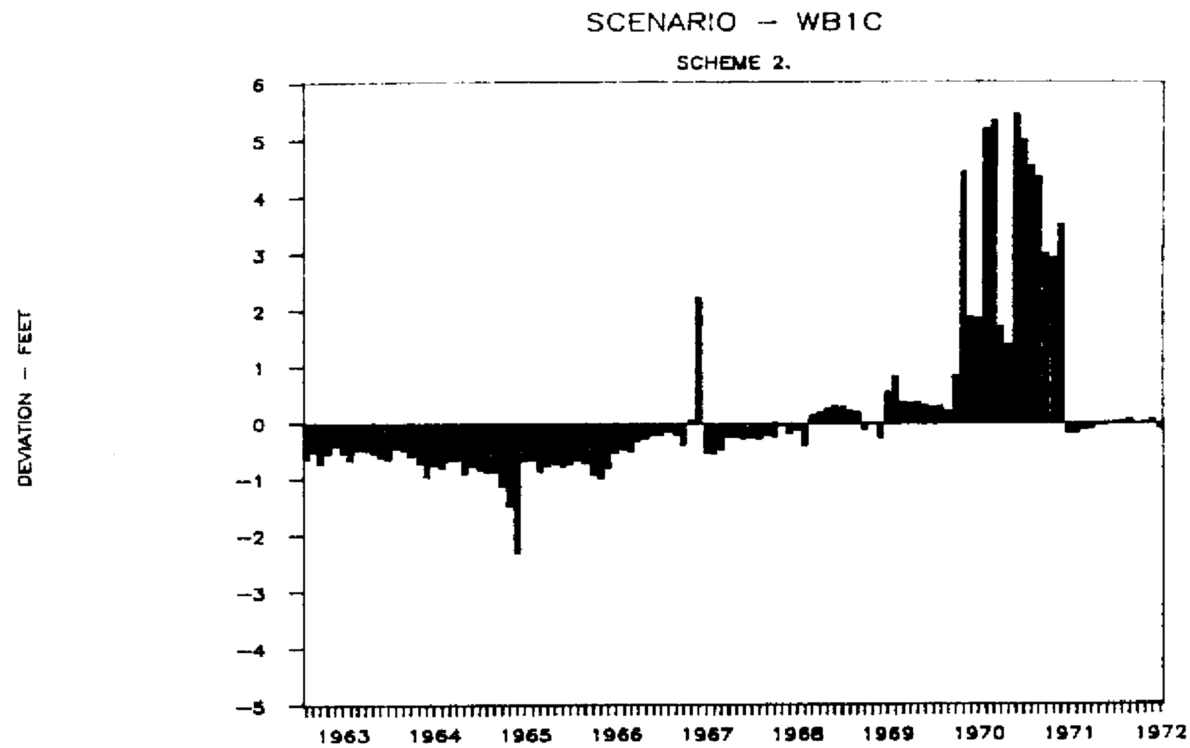


FIGURE B-7. Deviation, in feet, resulting from scenerio 7, using a 6-gage average, total area for rainfall, and variable area for ET computations



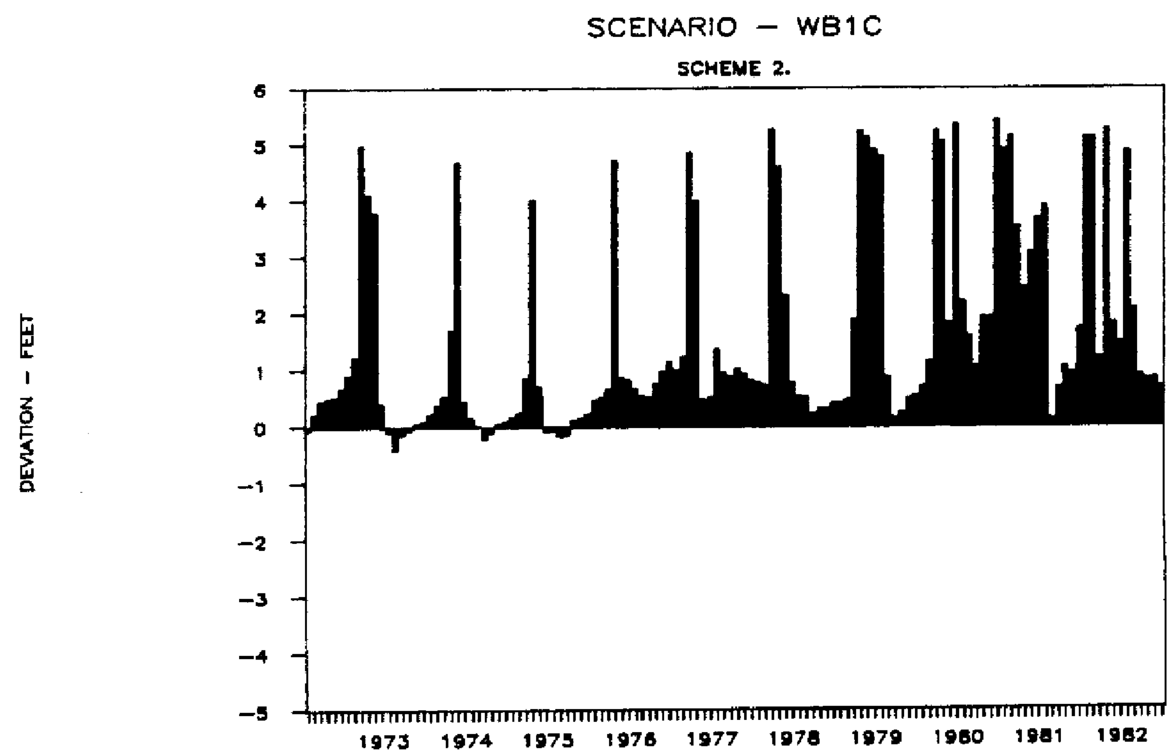
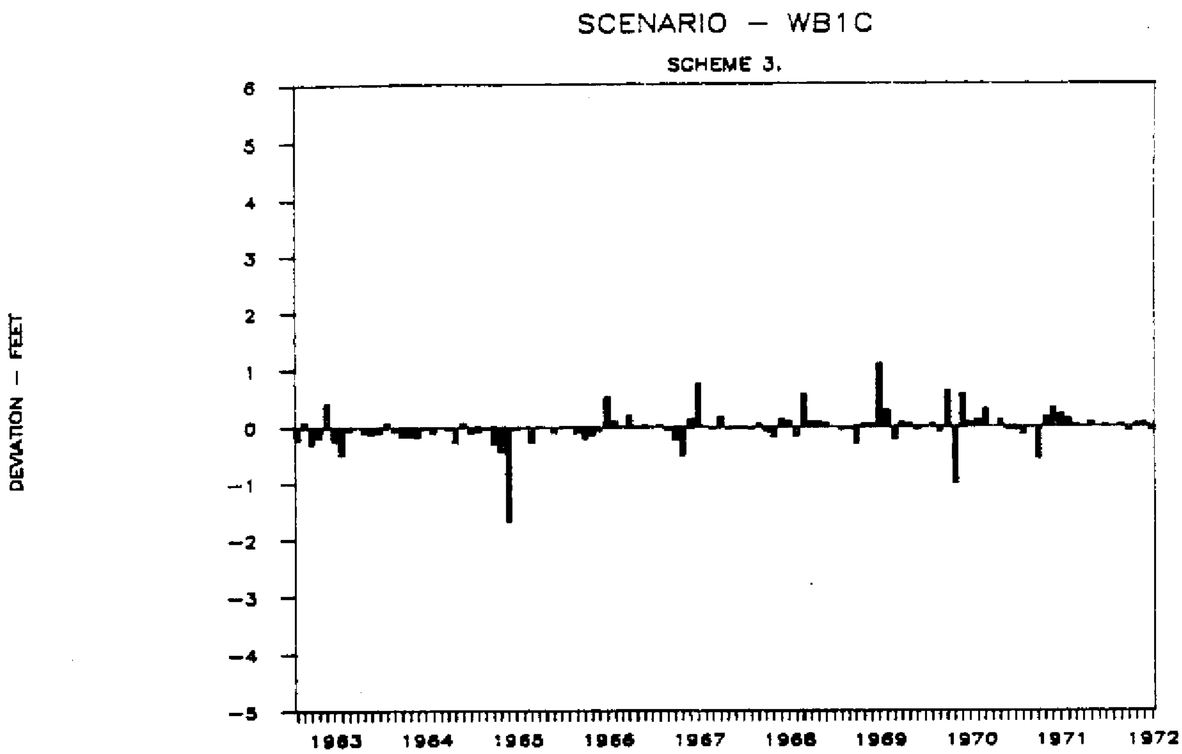


FIGURE B-8. Deviation, in feet, resulting from scenerio 8, using a 6-gage average, total area for rainfall, and ET computations



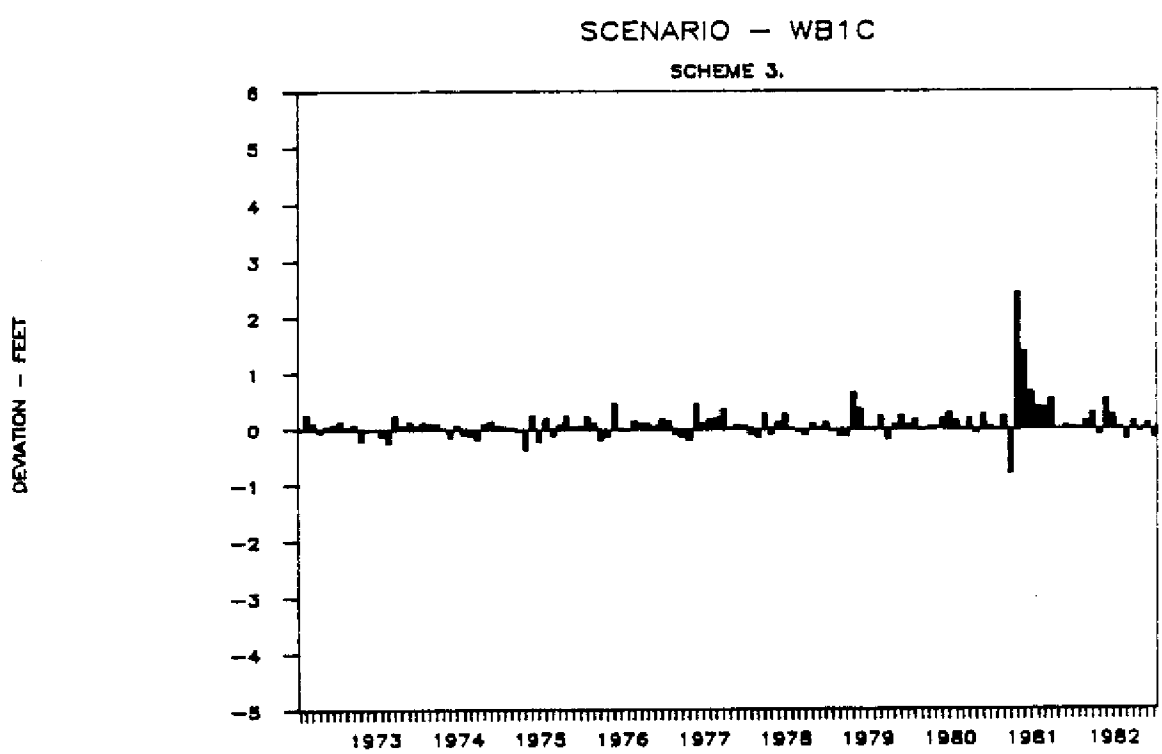
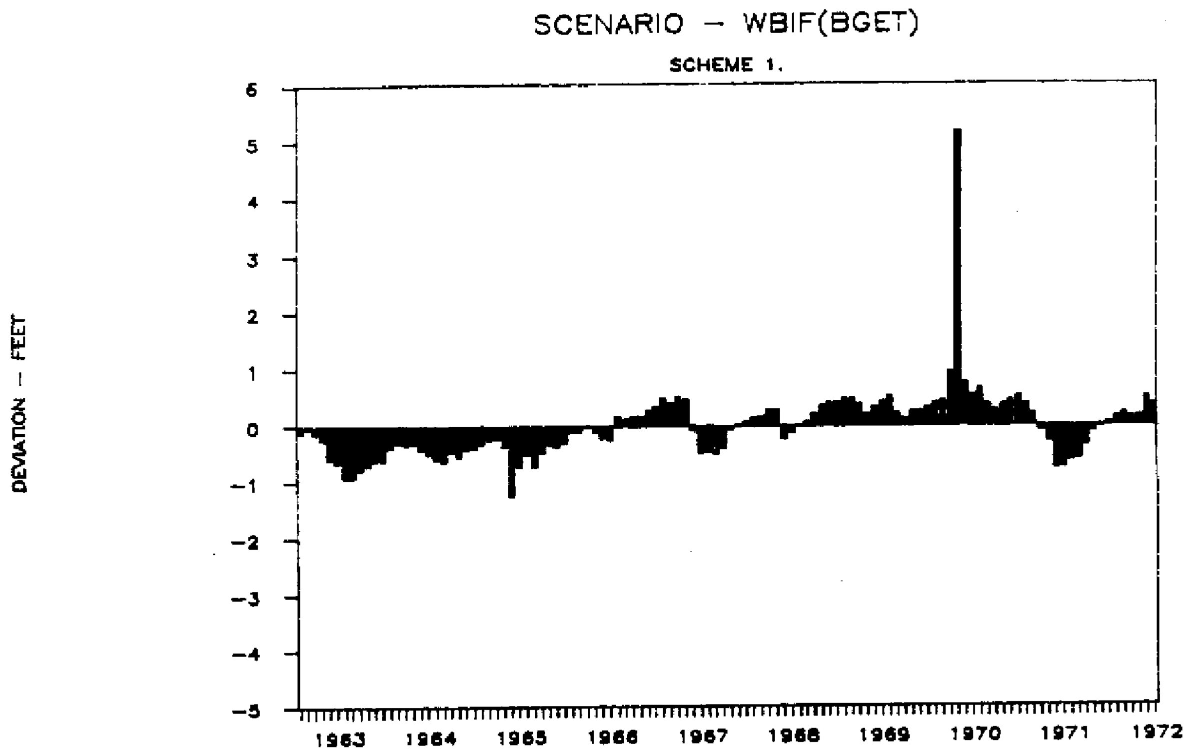


FIGURE B-9. Deviation, in feet, resulting from scenerio 9, using a 6-gage average, total area for rainfall, and ET computations



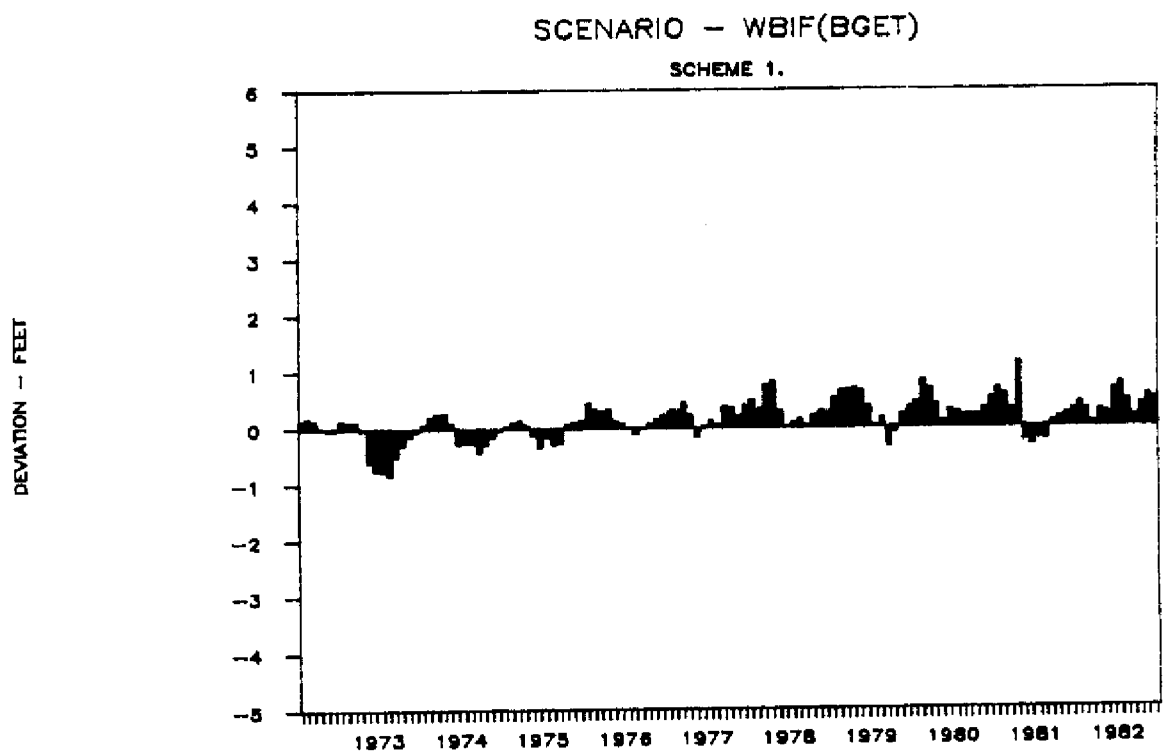
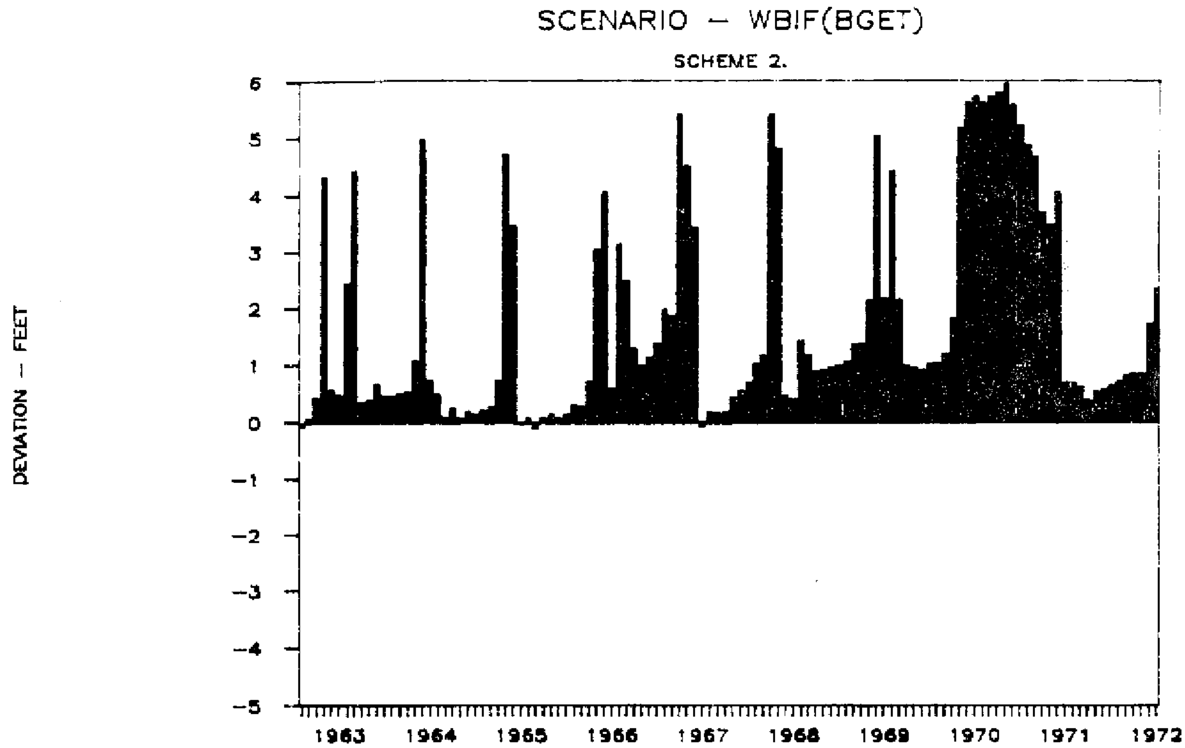


FIGURE B-10. Deviation, in feet, resulting from scenerio 10, using a 3-gage average, total area for rainfall, variable area with Belle Glade pan data for ET computations



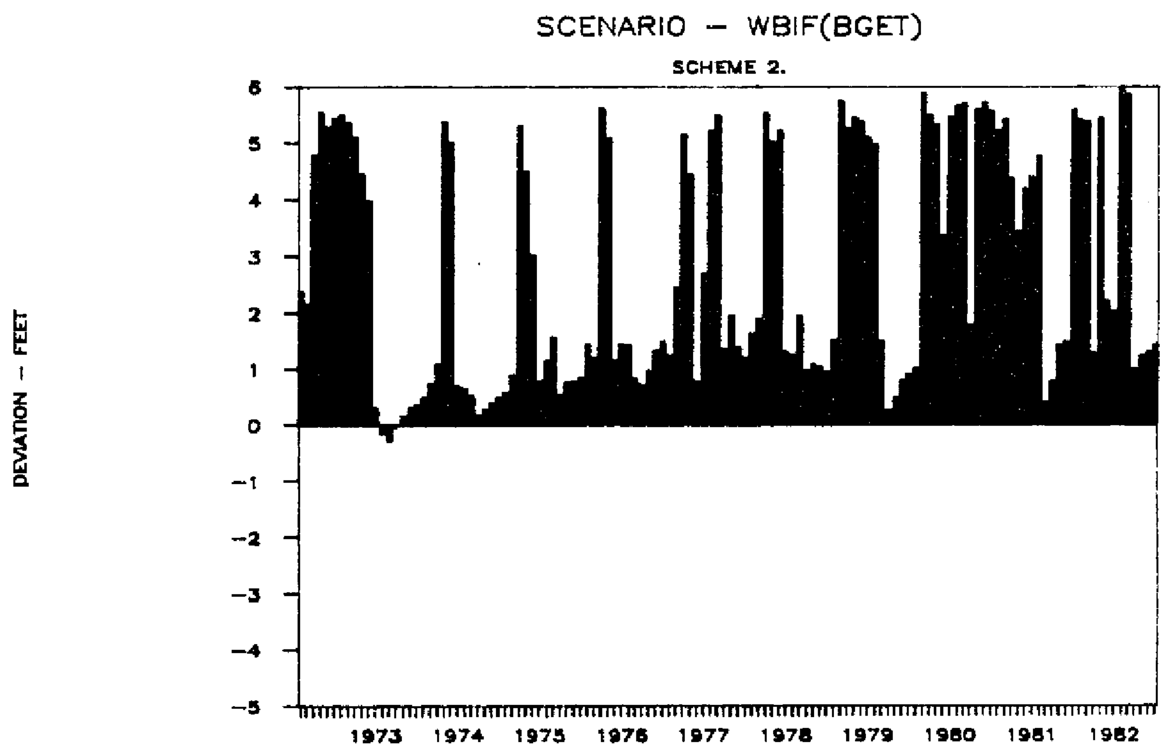
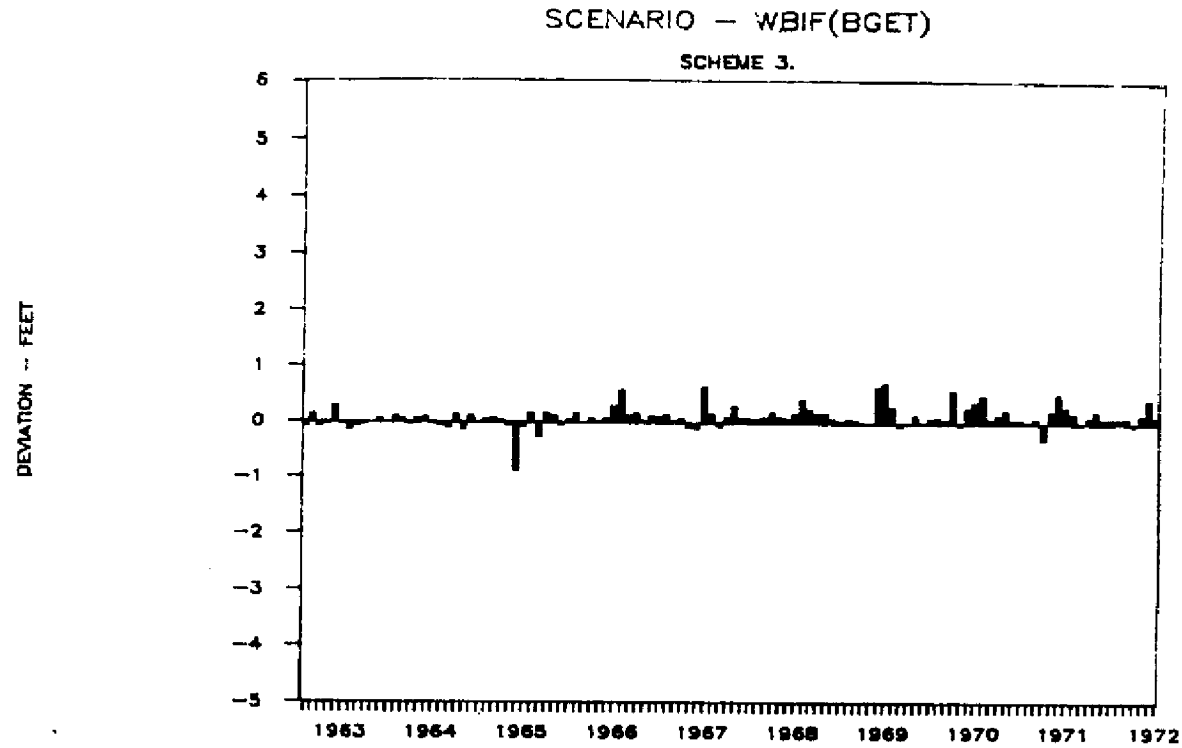


FIGURE B-11 Deviation, in feet, resulting from scenerio 11, using a 3-gage average, total area for rainfall, and ET computations. Belle Glade pan data was used in ET computations



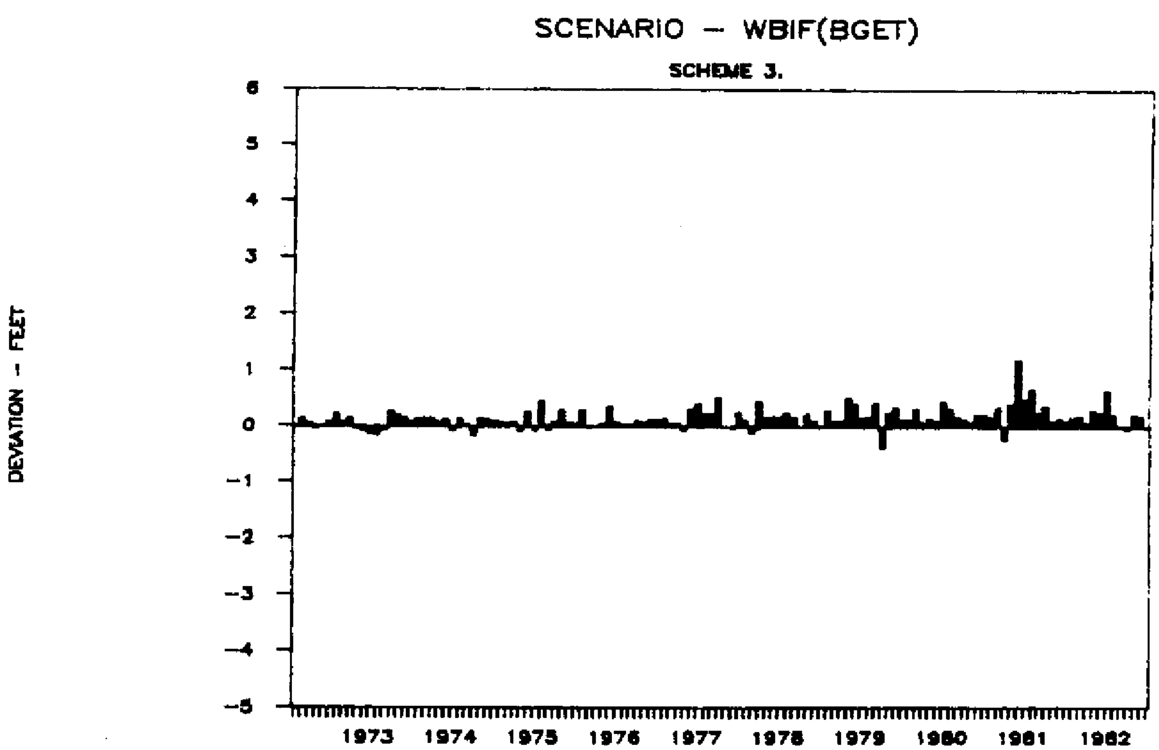
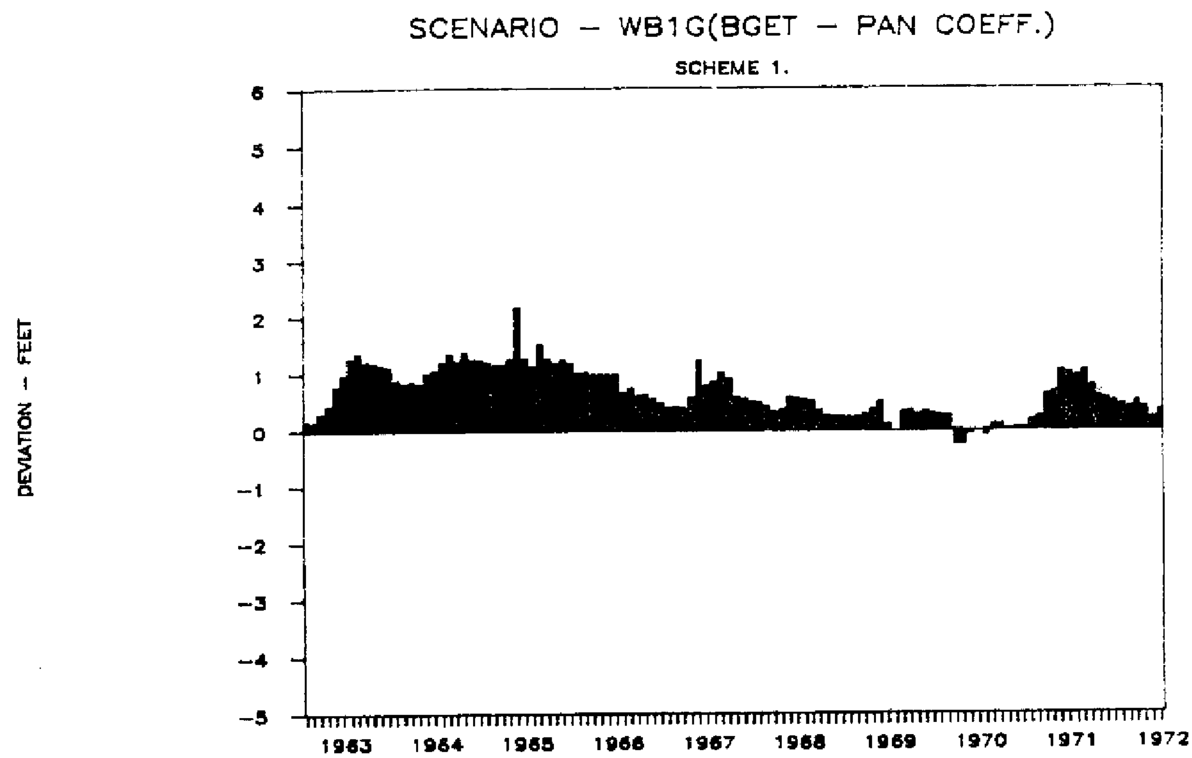


FIGURE B-12. Deviation, in feet, based on scenerio 12 using a 3-gage average as indicator gage, variable surface area for both rainfall and ET computations. ET data was based on Belle Glade pan data.



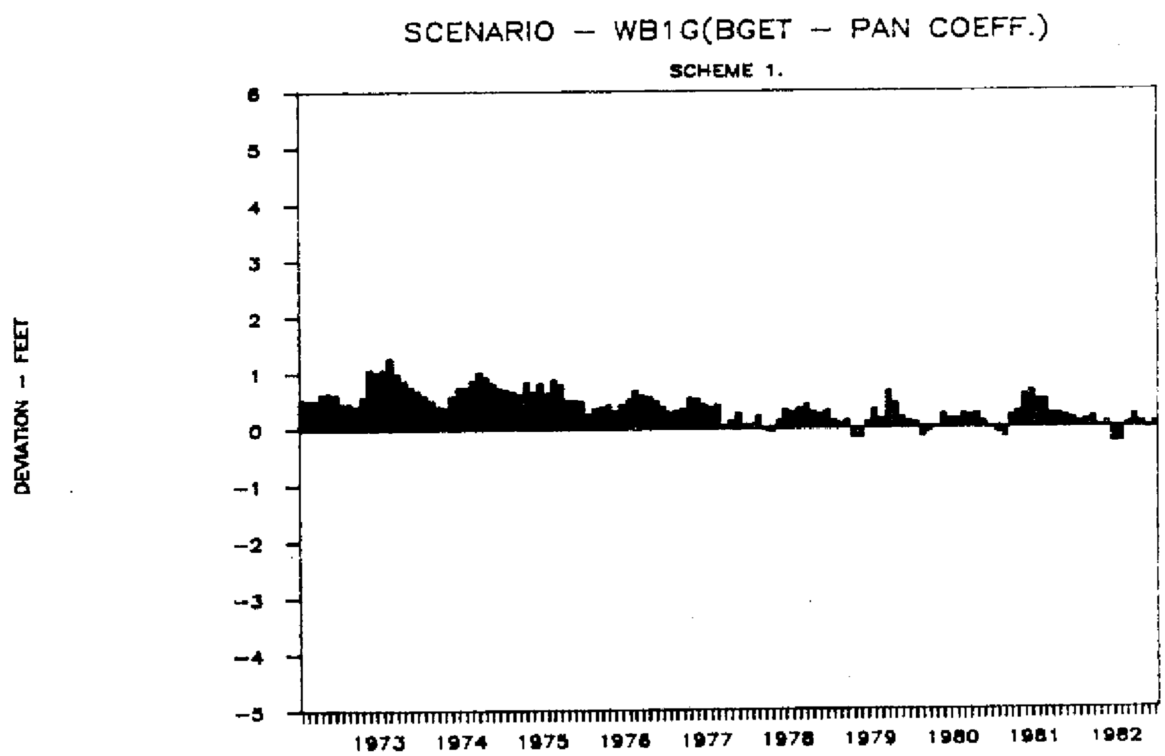
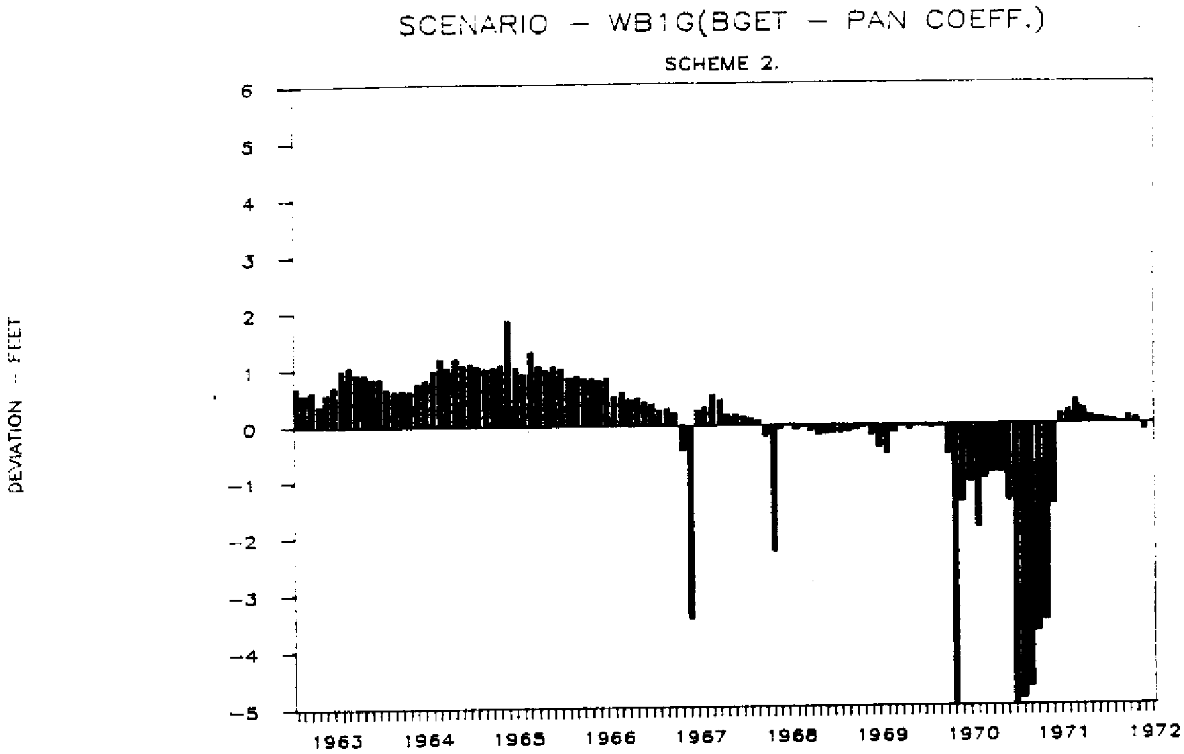


FIGURE B-13.Deviation, in feet, resulting from scenerio 13, using a 3-gage average total area for rainfall, variable area with Belle Glade pan data and pan coefficient for ET computations



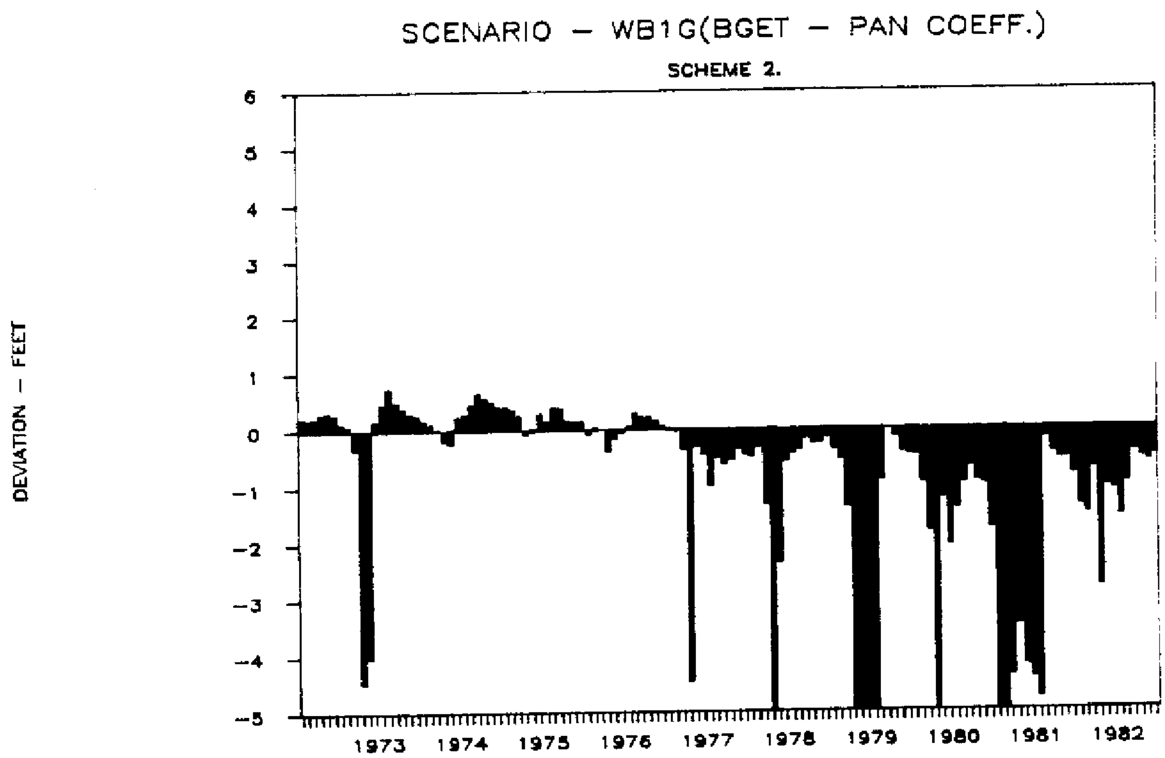
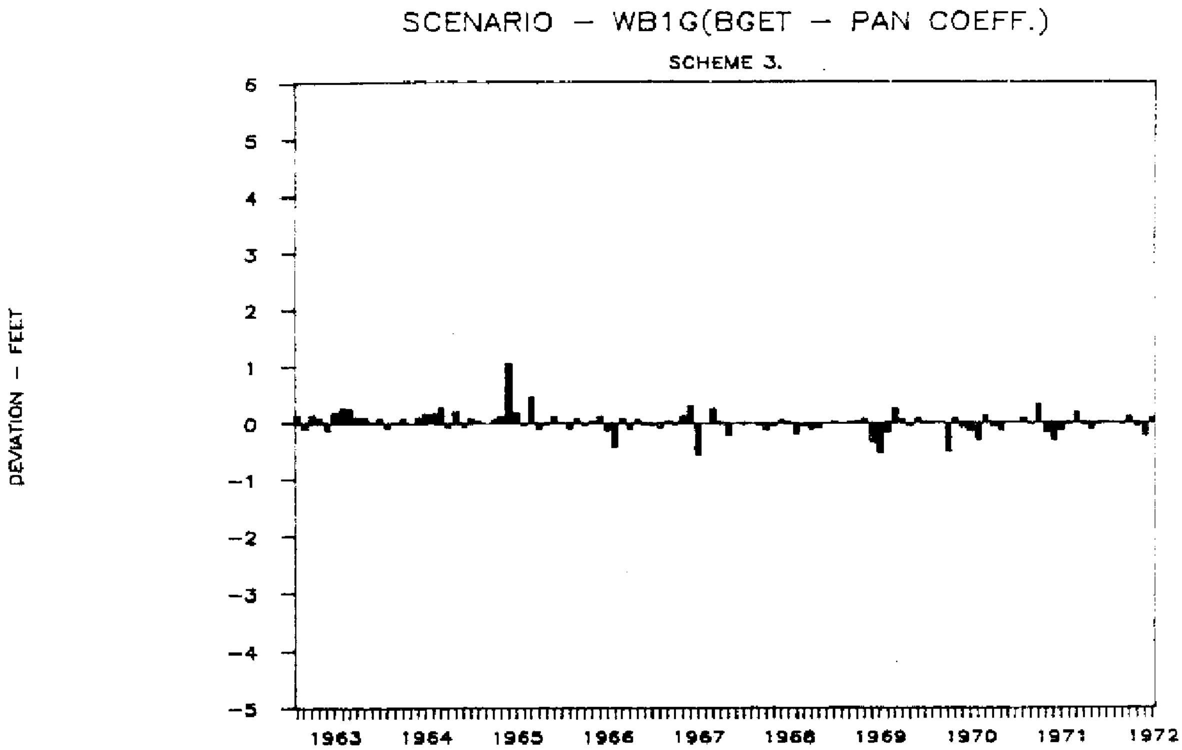


FIGURE B-14.Deviation, in feet,resulting from scenerio 14,using a 3-gage average, total area for rainfall, and ET computations. Belle Glade pan data and Pan coefficient was used in ET computations



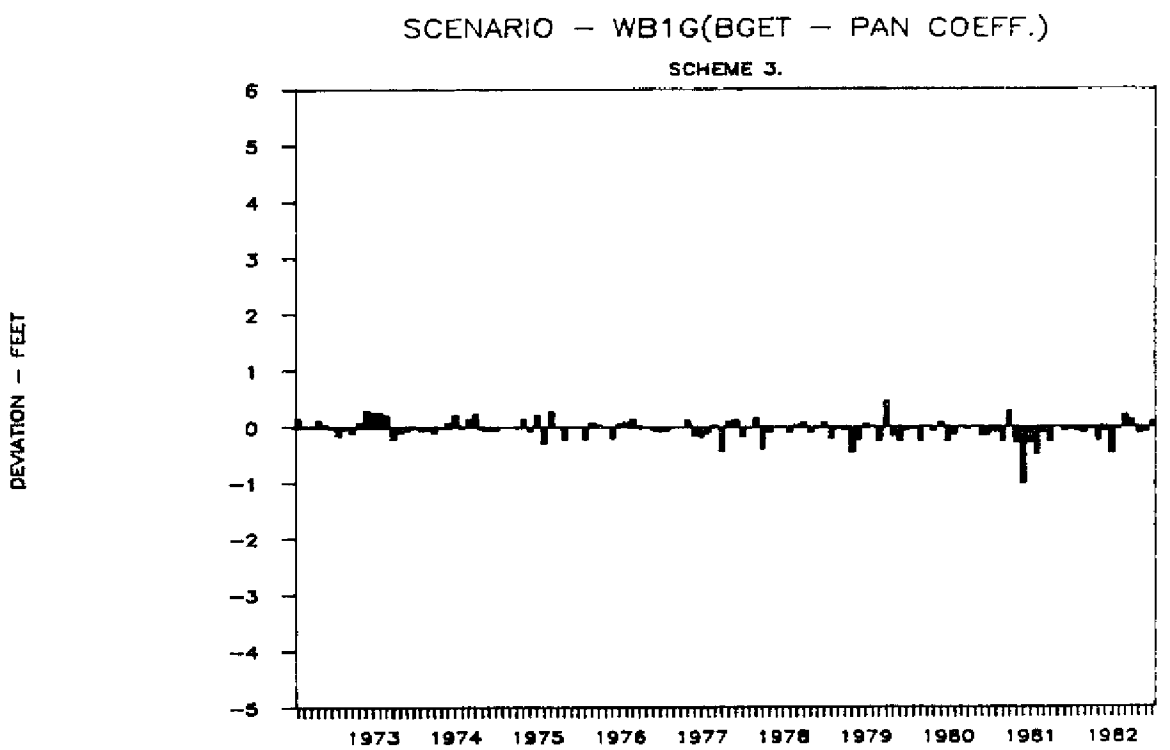
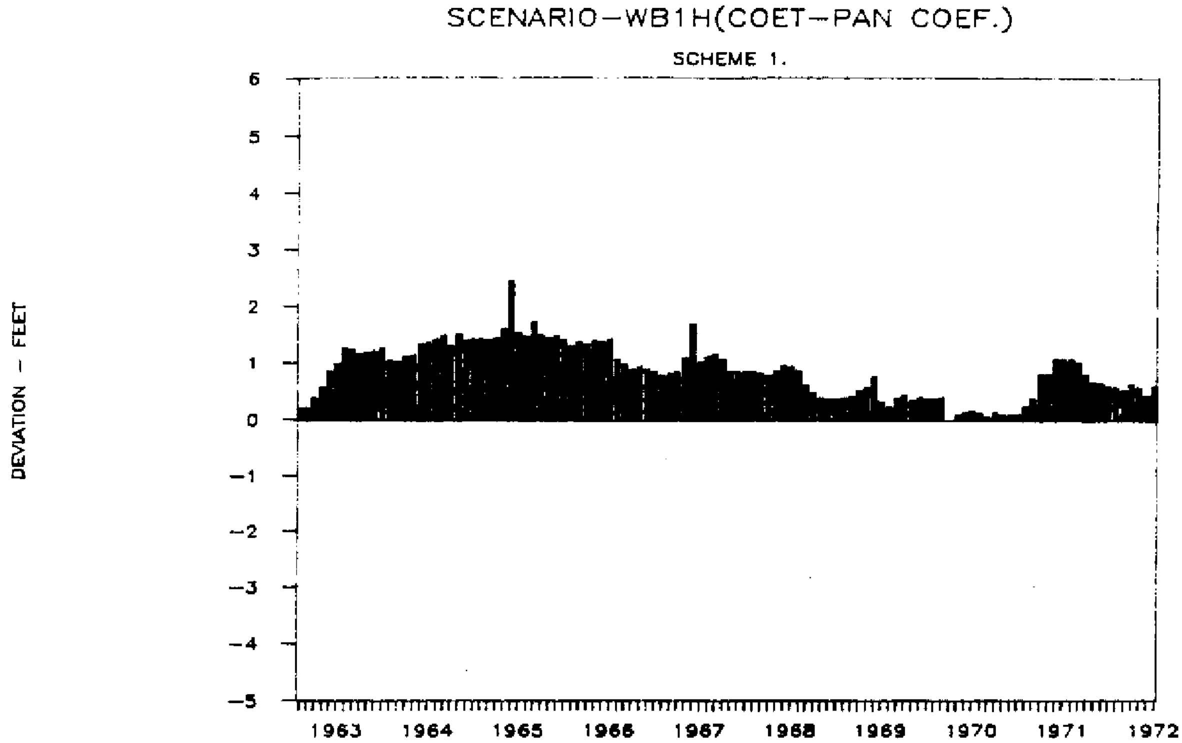


FIGURE B-15. Deviation, in feet, based on scenerio 15, using a 3-gage average as indicator gage and variable surface area for both rainfall and ET computations. Monthly pan coefficient based on Belle Glade pan data was used



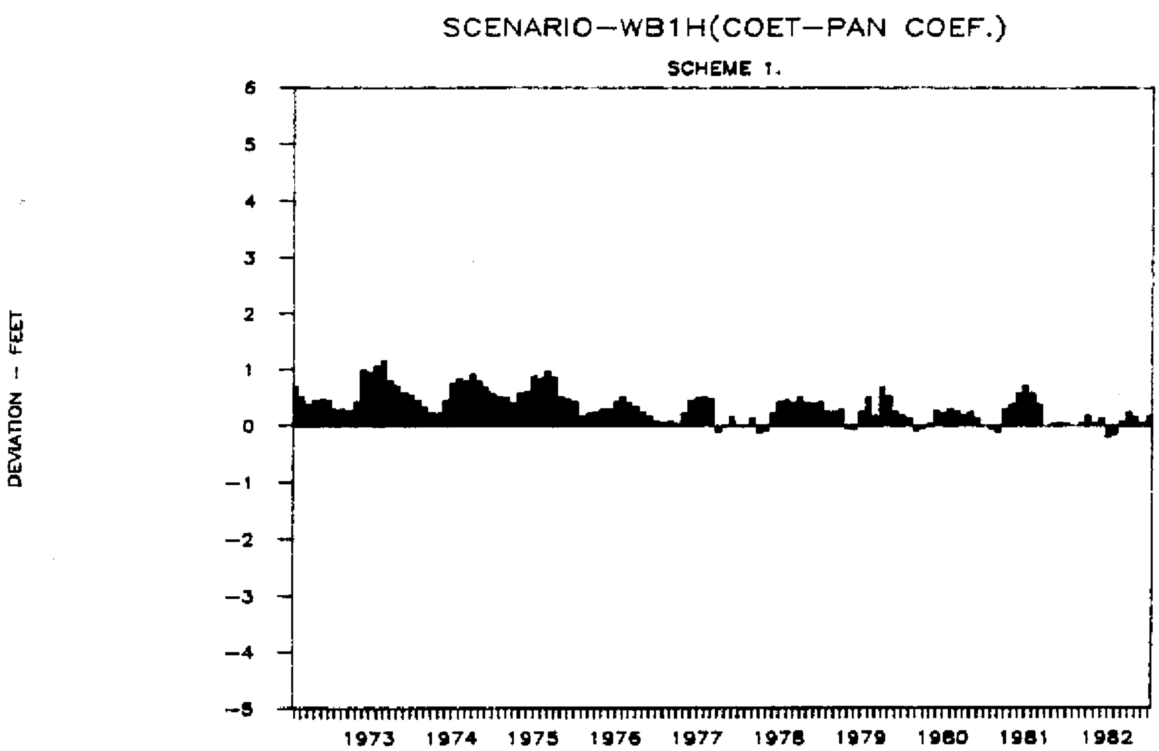
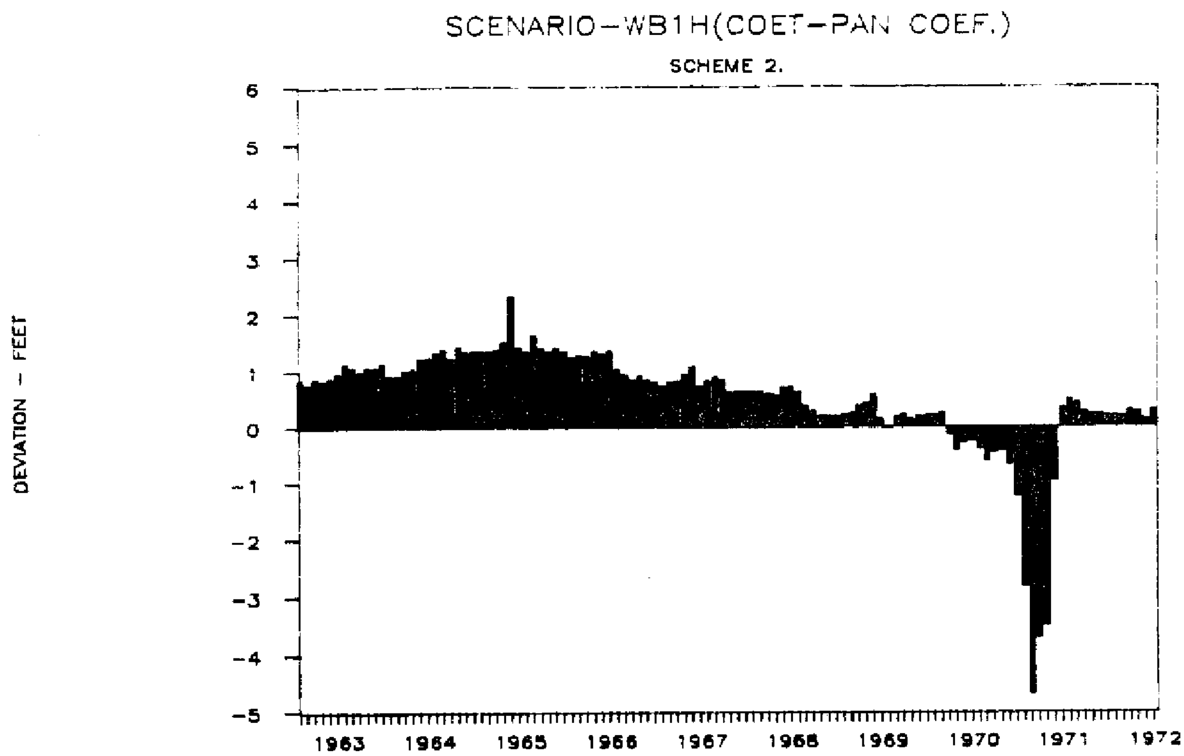


FIGURE B-16. Deviation, in feet, resulting from scenerio 16, using 3-gage average, total area for rainfall, variable area with pan coefficient based on COE pan data for ET computation.



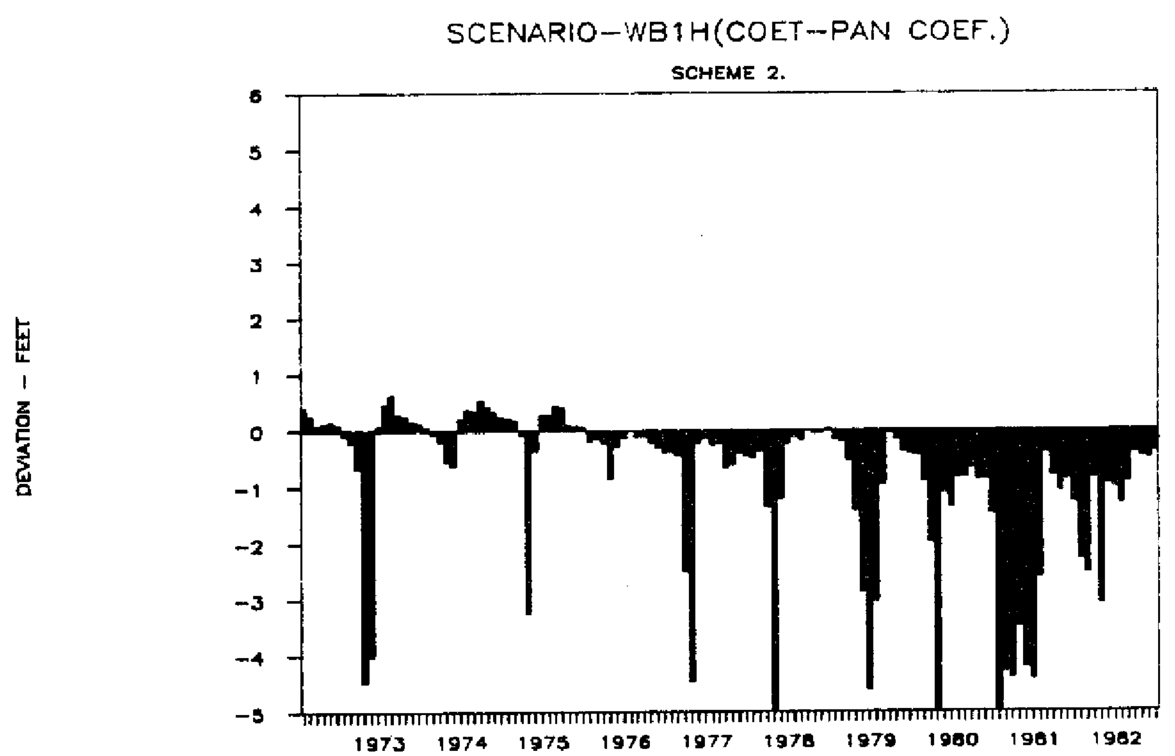
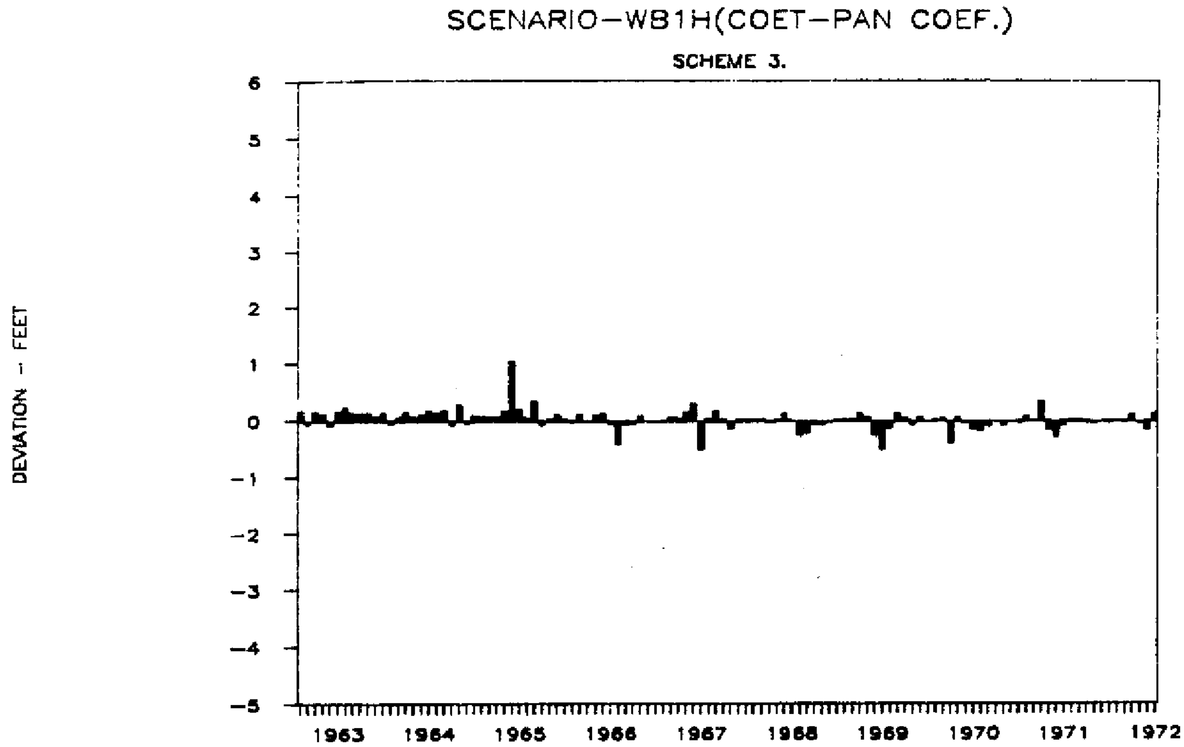


FIGURE B17. Deviation, in feet, resulting from scenerio 17, using a 3-gage average, total area for rainfall, and ET computations. Pan coefficient based on COE pan data was used in ET computations.



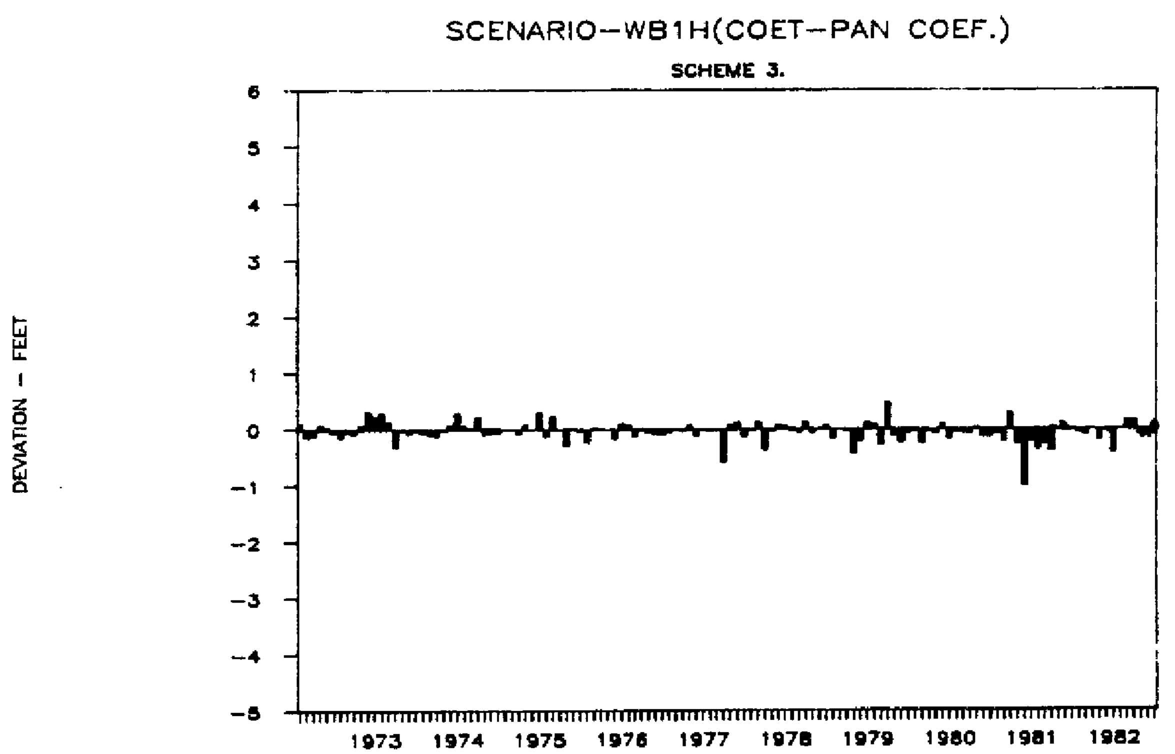


FIGURE B-18.Deviation,in feet,based on scenerio 18, using a 3-gage average as indicator gage and variable surface area for both rainfall and ET computations. Monthly pan coefficient determined from pan data used by the Corps of Engineers in WCA-1

APPENDIX C

EVAPORATION PAN STATISTICAL DATA

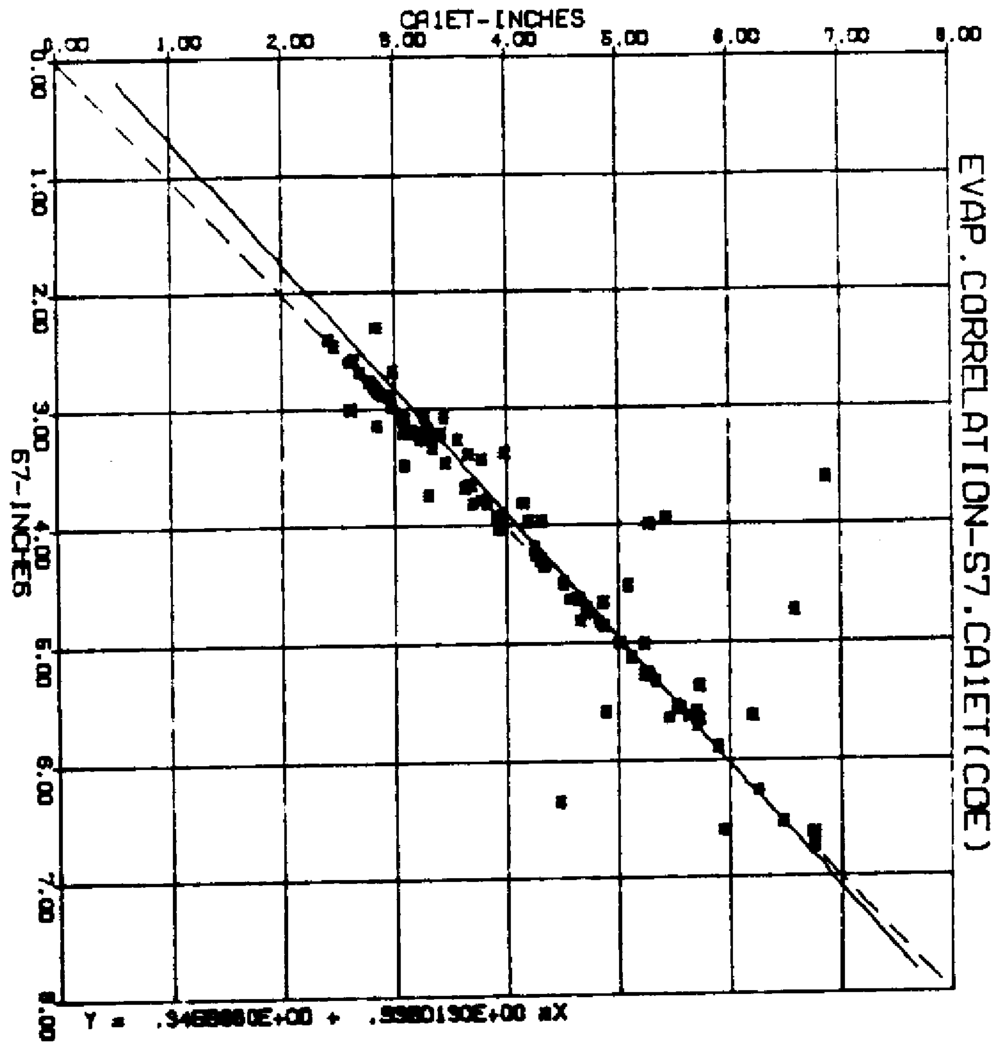


Figure 19. **Correlation of evaporation data used by the Corps of Engineers in WCA-1 and data recorded at S-7**

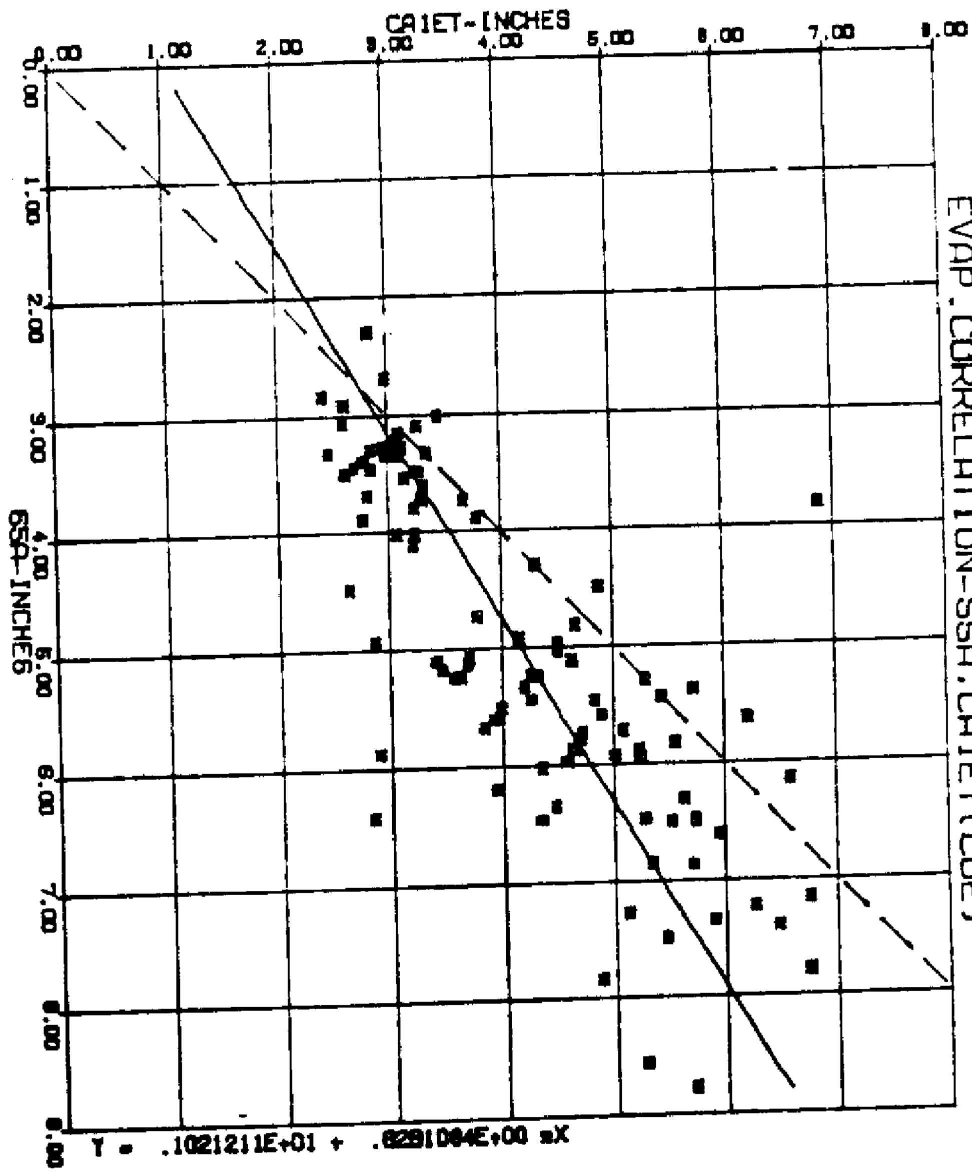


Figure 20. Correlation of evaporation data used by the Corps of Engineers in WCA-1 and data recorded at S-5A

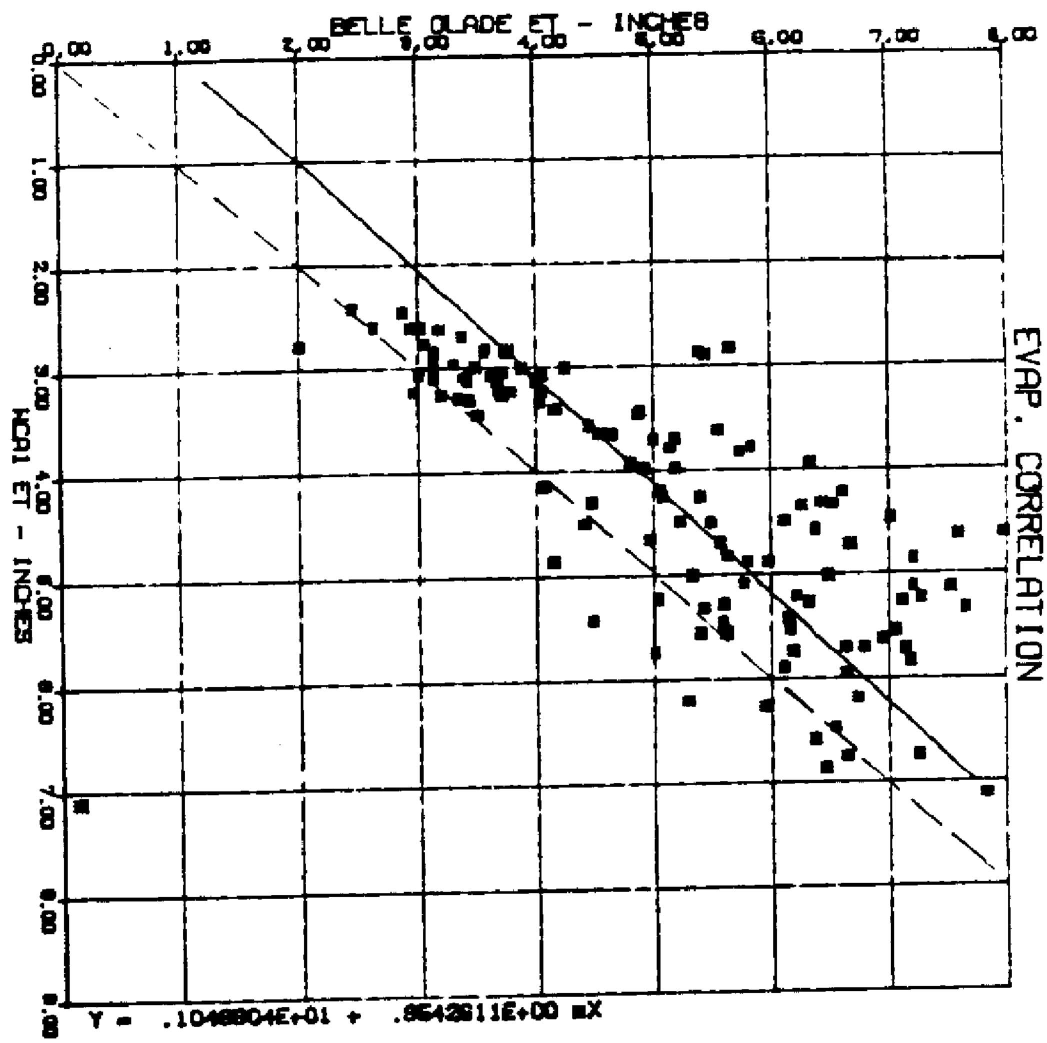


Figure 21. Correlation of evaporation data used by the Corps of Engineers in WCA-1 with pan data recorded at Belle Glade Experimental Station