SOUTH FLORIDA RESEARCH CENTER

Report T-646
An Analysis of Rainfall in Shark Slough

NATIONAL PARK SERVICE
DEPARTMENT OF THE INTERIOR

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ABSTRACT

Thiessen polygon analysis was used to estimate direct rainfall inputs into the 1000 km^2 Shark River Slough. Previous methods used to monitor precipitation in this region were reviewed. Comparisons were made between estimates based on data collected biweekly during a 22 month period (December 1977 - September 1979) among rain gauge networks containing 87, 29, 11 and 3 gauges. These results were also compared with data collected daily at three long-term NOAA stations located on the periphery of the study area. A comparison between managed surface water inflows and uncontrolled precipitation contributions to the slough during this time was also made. Data from the three long-term NOAA stations were further used to compute a reconstruction of direct rainfall inputs into the slough on a monthly and yearly basis for the period 1952 to 1979.

INTRODUCTION

Shark Slough comprises one of the largest freshwater flow sytems in south Florida. It provides critical habitat for plant and animal communities which are intricately related to, and dependent upon their water environments. The waters of Shark Slough also contribute freshwater inputs to the estuarine regions within Everglades National Park.

This report focuses on rainfall inputs into that portion of the Shark River Slough drainage basin which lies south of the Tamiami Trail, both within the confines of the park and adjacent to the park's northeast border. It is an area of approximately 1000 km^2 (245,000 acres). The two major sources of water input into the slough are direct precipitation, and surface water inflow which, since 1962, has been regulated via control structures along the northern boundary of the park. While the regulated water releases help ameliorate drought conditions and a declining water table, quantification of rainfall inputs to this region is necessary to determine the relative significance of these two water sources. Moreover, rainfall quantification is necessary for understanding and modelling the hydrologic processes of the slough, and for refining water management practices.

This report examines a 22 month period of rainfall monitoring (December 1977-September 1979) within the slough in order to: (1) quantify direct rainfall inputs, (2) compare these inputs to regulated water inputs, and (3) evaluate sources of error which might be minimized in future monitoring efforts designed to supply rainfall data for water management requirements.

Since the known climatic characteristics of an area are pertinent to the design of a rainfall monitoring network, a brief section on south Florida rainfall patterns has also been included. In addition, three long-term stations on the periphery of Shark Slough have been utilized to calculate the approximate rainfall contributions to the slough from 1950 to 1979. Determinations of rainfall input based upon these three stations also have been used to assess the accuracy of rainfall determinations acquired from the 22 months of intensive monitoring.

Rainfall Patterns in Florida

Earlier studies addressing south Florida's rainfall patterns (Woodley and Davis, 1974) have divided the climatological year into a wet season, occurring from May to October, and a dry season, occurring from November to April. During the dry season, precipitation is mainly governed by synoptic scale processes such as frontal systems. During the wet season, precipitation patterns are dominated almost entirely by convective processes (Echternacht 1975). Convective showers occur daily and their distribution is largely a function of sea breeze circulation. A third precipitation pattern is that associated with cyclonic depressions. These occur almost exclusively in the wet season, and although relatively infrequent in south Florida, they may be associated with intense rainfall of as much as 20 inches in one day.

The most obvious seasonal differences in precipitation patterns are the greater areal uniformity and reduced rainfall amounts during winter and spring, compared to summer and fall months. The spatial variability during the wet season is a function of the characteristic variability of convective rainfall. Extreme gradients of four inches in one mile and 14 inches in four miles have been observed, and the variability of rainfall within a single cumulonimbus cloud has been estimated to range from 200 to 2000 acre-feet (Woodley et al. 1974).

The average annual rainfall in south Florida ranges from 40 to 65 inches. As much as 80 percent of this rainfall occurs during the six wet-season months. The east coast, from Homestead to Pompano Beach, generally receives the greatest annual rainfall, while the Florida Keys, the areas south of Lake Okeechobee, southwest Collier County, and an area west of Fort Myers generally have the least annual rainfall (Klein et al. 1975).

South Florida's climate is classified as humid subtropical, with average daily temperatures ranging from 68° F to 82° F. Average evapotranspiration in this climate ranges from 70 percent to 95 percent of rainfall and in dry years can exceed rainfall volumes (Klein et al. 1975).

Rainfall Collection Methodology in Everglades National Park

Four data collection methods have been used by the staff of Everglades National Park to assess direct precipitation into Shark Slough. Two of these methods, involving direct measurement are: (1) daily measurement of rainfall collected in standard U.S. Weather Service eight-inch diameter, 24-inch capacity cylindrical gauges at three NOAA stations peripheral to the slough, and (2) biweekly measurement of rainfall collected in six-inch capacity wedge-gauges at 97 locations in or bordering the slough. The other two methods, utilizing remote-sensing, are: (1) radar-rainfall scanning and (2) battery-powered, tipping bucket gauges equipped to relay data via satellite.

This report relies almost exclusively upon data from the direct collection methods for quantitative rainfall assessment. Operational difficulties encountered with the remote-sensing methods, and questions concerning reliability of obtained data which arose during preliminary data analysis determined this choice. However, all methodologies are described.

Gauge and weather station locations are shown in Figure 1. The three long-term NOAA stations used were Homestead Agricultural Experiment Station, and Tamiami and Royal Palm Ranger Stations. These stations have periods of record beginning in 1910, 1943, and 1949, respectively.

The wedge-gauge network was established in Shark Slough on a temporary basis in 1977 in order to document the spatial patterns of rainfall distribution throughout Shark Slough and to assess the relative accuracy of both the three-station long-term network, and the experimental tipping bucket rainfall recording devices, in documenting precipitation inputs to the slough.

These six-inch capacity wedge gauges were monitored biweekly for 22 months from December 1977 through September 1979. Mineral oil was utilized in these gauges as an evaporation suppressant.

The experimental tipping bucket gauges were installed at 6 locations. These devices utilize two small triangular "buckets" balanced in unstable equilibrium and

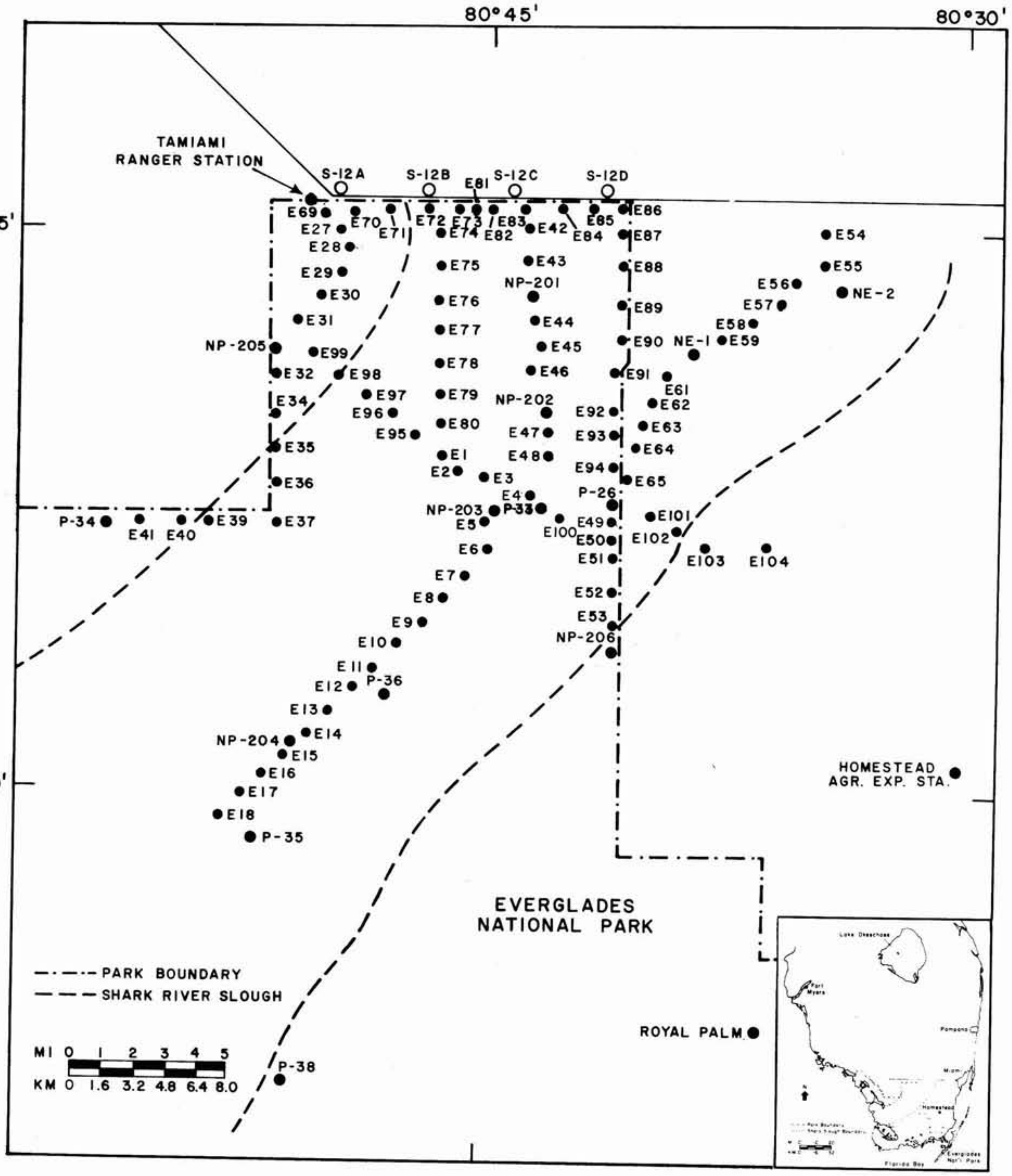


Figure 1. Location of rain gauges in Shark River Slough study area.

calibrated to tip in response to a weight equivalent to 0.01 inch (0.25 mm) of water. A conical rainfall collector funnels rainfall into each of these buckets in turn. Each time a bucket tips, it empties its contents and activates an electric switch which causes the number of tips to be summed and recorded. Data from the six tipping-buckets in the Shark Slough network was beamed via satellite to the Goddard Space Center in Maryland, then sent in coded form to the U.S. Geological Survey headquarters in Reston, Virginia where it was converted to inches of rainfall. Everglades National Park received this information summarized as daily rainfall values. Real-time data were also accessible to Everglades National Park via computer relay hookup with the USGS in Reston.

Radar rainfall-scanning was used to collect 24-hour rainfall data from July 1, 1978 to August 31, 1978 under a contract between Everglades National Park and the National Hurricane Center and Experimental Meteorological Laboratory (NHEML), a division of the National Oceanic and Atmospheric Administration (NOAA). The data-collecting was done in conjunction with cloud-seeding studies conducted by NOAA, utilizing NOAA's own radar system (WSR-57) at the University of Miami.

This technology depends upon the ability of computers to analyze radar scans of storm cells and to convert echo-intensities to rainfall depths over specified areas. The area scanned in this case was divided into grid elements 6 x 6 nautical miles in dimension, and covering the entire area of south Florida and adjacent waters. Each grid element was further subdivided into 150 squares, each of which was assigned a single rainfall depth for every thirty-minute interval. These data were supplied to Everglades National Park in the form of computer printouts of digitized data, as well as 35 mm time-lapse, black-and-white transparency films of the radar scope, and black-and-white prints of these films. These maps show location, size, and relative intensity of rainstorms.

Data from the 87-gauge extensive rainfall network were analyzed qualitatively using isohyetal mapping and quantitatively using Thiessen polygons. Both methods are commonly used to average point observations of rainfall for areal rainfall estimates (Sharon 1972, Dean et al. 1977).

In isohyetal mapping, lines of equal rainfall are drawn on the watershed area. However, because the gauges in the study area were not sufficiently distributed to define singular placement of isohyetal lines, isohyetal analysis was used only to show the geographic variability of rainfall, rather than to calculate areal rainfall.

In Thiessen polygon analysis, the perpendicular bisectors drawn between points of data collection, in conjunction with the drainage-basin boundaries, delineate polygons which are assigned weighting factors based on their percentage contribution to the basin area. Each weighting factor is multiplied by the rainfall value for the appropriate station, and the weighted rainfall totals are summed to estimate mean basin rainfall. Appendix A contains maps of the Thiessen polygon networks and subnetworks used in this report; Appendix B lists the weighting factors used for the calculation of total rainfall based on these networks. The most extensive Thiessen polygon system utilized within Shark Slough consisted of 87 wedge-gauges. Three subnetworks, consisting of 29, 11 and 3 wedge-gauges, were chosen for comparison with the 87-gauge network, which was used as the standard for judging subnetwork accuracy. Mean basin rainfall estimates based on the 87 gauge network were in turn compared with estimates based on data from the three long-term weather stations, where rainfall is monitored daily.

Biweekly rainfall values from wedge gauges which were greater than five inches, were adjusted upwards where possible to compensate for loss of rainfall capture due to splashout and overflow. Values were adjusted to equal that of the nearest tipping-bucket or long-term daily station, whenever these stations had greater rainfall values than the wedge-gauge catchment. In cases where the data from the nearest tipping-bucket was deemed unreliable, adjustments were made to the closest long-term station. Appendix C contains cumulative totals for WY 79 (exclusive of September 21-30, 1979) and for the entire period of monitoring on a station-by-station basis.

Difficulties entailed in meeting the requirements necessary for the valid application of conventional statistical techniques to rainfall network analysis have been discussed in the literature (Sharon 1972, Rodda 1970, Dunne 1978). In evaluating network adequacy, estimates calculated from the most complete network are commonly used as the "true" basin mean and the standard by which subnetwork estimates are judged. Deviations of subnetwork estimates from the standard can then be calculated and evaluated. The analysis in this report has also used the nonparametric Wilcoxan test for paired data to compare biweekly rainfall estimates from the 87-gauge network with the three long-term weather stations.

In addition to the analysis of the 91 weeks of data from January 1, 1977 to September 20, 1979, nearly thirty years of monthly data from the three long-term weather stations were analyzed to calculate rainfall inputs into that portion of the Shark Slough south of Tamiami Trail. The first year for which complete annual water year records exist for all three stations is 1952; therefore annual calculations (total rainfall, mean rainfall and standard deviations) are based on the period 1952-1979. On a monthly basis, however, records were sufficient to allow monthly calculations to incorporate data beginning as early as November 1950.

RESULTS

Intensive monitoring period: December 1, 1977 to August 20, 1979

Isohyetal analysis of cumulative 22 month rainfall, based upon the 87-gauge network, illustrated the geographic variability of rainfall in the region (Figure 2). Rainfall in the northern slough generally increased from a 70-75 inch range in the east to an 80-85 inch range in the west. Scattered pockets of rainfall ranging from 60 inches to greater than 90 inches were also apparent. Moving southward, rainfall over the slough graded in the reverse direction from a predominantly 80-85 inch range in the east to a 70-75 inch range in the west. The southern slough, with P-35 representing the southernmost data point, showed a more uniform range of 85-90 inches predominating. Thus, over the 22 month period, cumulative rainfall generally increased from 70-85 inches in the north to 85-90 inches in the south, with extremes of 60 to more than 90 inches found in small, scattered areas.

Cumulative direct precipitation into Shark Slough south of Tamiami Canal during the total monitoring period (December 1, 1977 to September 20, 1979) was calculated to be 79.4 inches, based upon the biweekly data from the 87 wedge-gauge network. This estimate is 76 percent of the 103.9 inches calculated from rainfall data of the three long-term weather stations (Table 1).

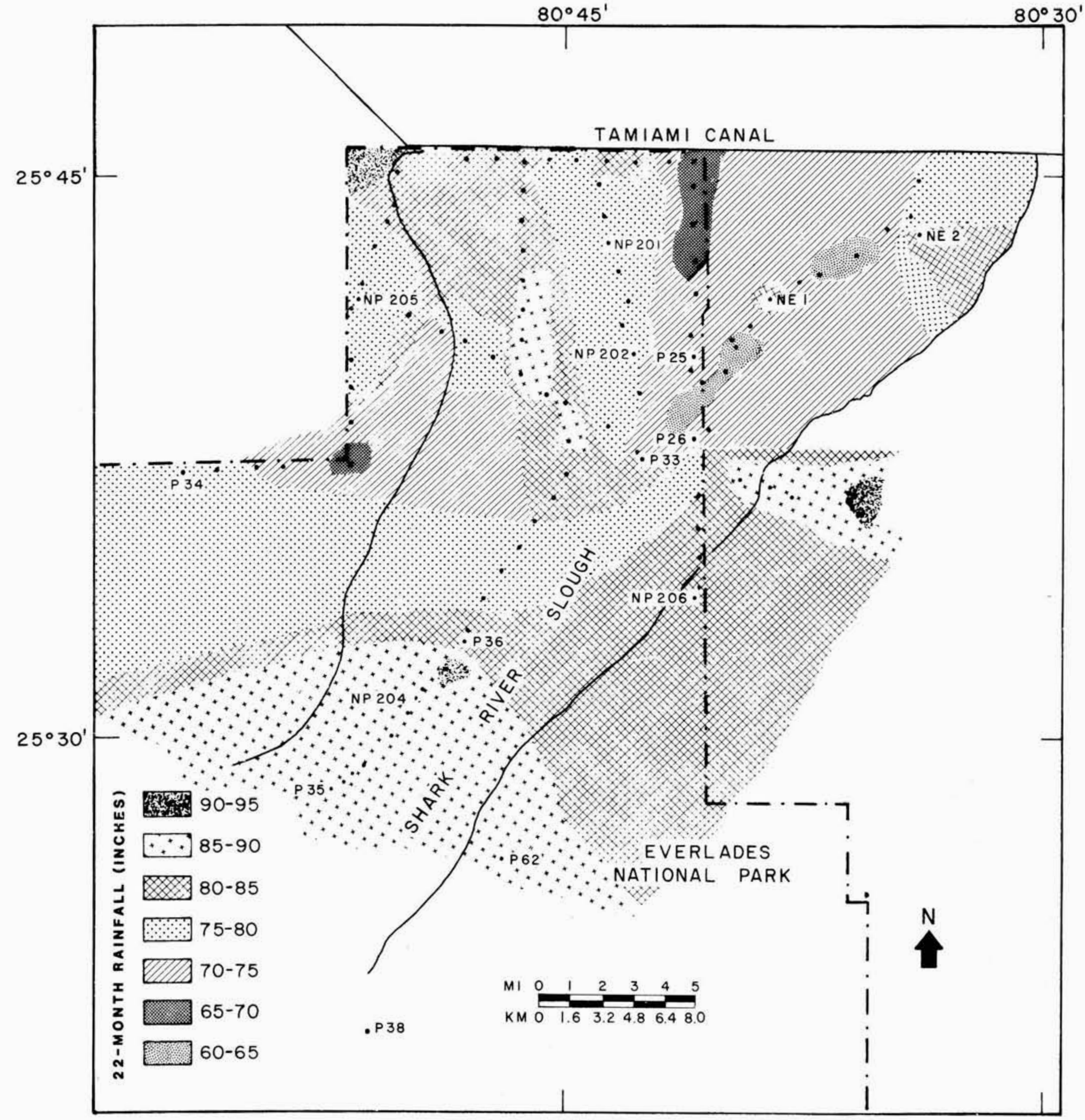


Figure 2. Isohyetal map of direct rainfall inputs into Shark Slough for cumulative rainfall: December 1, 1977 to September 20, 1979.

Table 1. Comparison of rainfall estimates based on 87-wedge gauge network vs. 3 NOAA station system.

	87-Wedge Network (inches)	3-Station Network (inches)	Deviation of 3-Station Network from 87-Gauge Network	
			Inches	%
Dec. 1 '77 to Sept 20 '79 (91 weeks)	79.43	103.90	+24.47	+24%
WY 79 exclusive of Sept. 21-Sept. 30	36.72	50.32	+13.60	+27%
*WY 79	42.05	55.65	+13.60	+24%

*A value of 5.33 inches for the period September 21-September 30, 1979 was based on the 3-station system and used for completing WY 79 totals for both networks.

For the period of WY 79, excluding September 21-30, the 87-gauge network data yielded an estimate of 36.7 inches of rainfall, 73 percent of the 3-station estimate (50.3 inches). In order to make a comparison between the two systems on a complete water year (WY) basis, rainfall inputs during September 21-30 calculated from the 3 NOAA station data were added to both estimates for the October 1, 1978 to September 20, 1979 period. The resultant WY 79 rainfall totals were therefore 42.5 inches based on the 87 gauges and 55.6 inches based on the 3 NOAA stations (Table 1). In comparing the 46 biweekly rainfall intervals from the two networks (Appendix D, Figure 3), in 35 out of the 46 intervals, the 87-wedge network provided estimates less than that of the 3 NOAA stations. The correlation coefficient for the two sets of data was calculated to be .88. In general, the greater the rainfall, the greater the discrepancy between the estimates.

Despite the differences between the estimates of the two networks, the Wilcoxan matched pairs signed ranks test showed no significant difference between the two data sets even at the 90% confidence level. (Critical values of T_s, i.e. the rank sum for n = 46, = .1, are 389 and 390; T_s for the data set was 406.)

Analysis of the subnetwork rainfall estimates relative to the complete 87-gauge network showed that both the magnitude of deviation, and the percentage deviation, increased as subnetwork size was reduced (Table 2; Figure 4). On a 51 week basis (WY 79 exclusive of September 21 to September 30, during which there was no monitoring), the 29-gauge subnetwork estimate differed by only -0.26 inches (-0.7 percent). Decreasing subnetwork size to 11 gauges increased the deviation to -1.26 inches (-3.4 percent). A reduction to 3 gauges increased the deviation to 1.65 inches (4.5 percent). For cumulative rainfall over the 22 month period, subnetwork deviations from the standard increased from -0.42 inches (-0.5 percent) with 29 gauges, to -1.65 inches (-2.1%) with 11 gauges, to a maximum deviation of 2.52 inches (3.2 percent) with 3 gauges.

There is no trend apparent by which to predict whether a given subnetwork will provide an underestimate or an overestimate relative to the standard. The relationship between reduction in network size and loss of accuracy appears to be linear for the period of WY 79; for the 22 month period totals, however, the error appears to increase at a greater rate for a reduction from 11 to 3 gauges than for a reduction from 29 to 11 gauges (Figure 5).

The significance of these deviations in terms of their volume equivalent of water input to the slough can be estimated by multiplying the deviations in feet by the total acreage of the slough basin. This acreage is taken to be 245,427 acres, the approximate maximum area of inundation during the year, as determined by Landsat photogrammetric analysis (Rose and Rosendahl, 1979). Thus, for WY 79, the 29-wedge network provides a rainfall estimate of 5318 acre-feet less than the complete network estimate. This volume difference is equivalent to only 2% of minimum scheduled S-12 annual releases. The 1.26 inch underestimate provided by the 11-wedge subnetwork represents 25,770 acre-feet less than that of the complete network, a volume equivalent to 10% of minimum scheduled S-12 annual releases. The 3-wedge subnetwork provides a 33,746 acre-feet overestimate relative to the 87-wedge network, or a volume equivalent to 13% of minimum scheduled annual S-12 releases (Table 3).

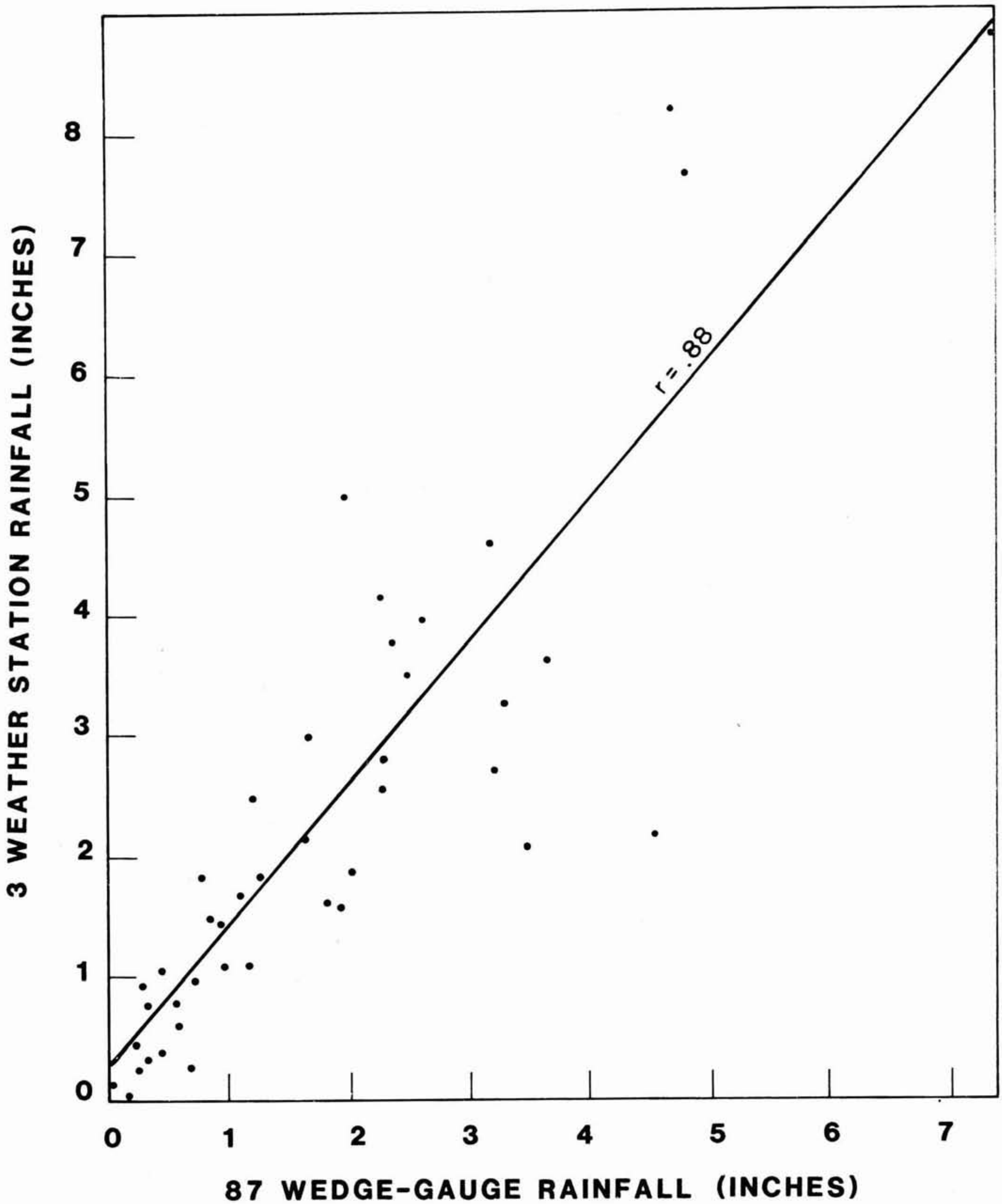


Figure 3: Correlation between biweekly rainfall totals based on three NOAA stations vs totals based on the 87 wedge gauge network.

Table 2. Comparison of rainfall estimates and percent error of subnetworks relative to standard (87-gauge network) for 22-month period and WY 79 rainfall.

	TOTALS (Rainfall in inches)				CUMULATIVE ERROR OF SUBNETWORK			PERCENT ERROR **		
Time Period	Standard	29-Gauge Sub-Network	11-Gauge Sub-Network	3-Gauge Sub-Network	29-Gauge Sub-Network	11-Gauge Sub-Network	3-Gauge Sub-Network	29-Gauge Sub-Network	11-Gauge Sub-Network	3-Gauge Sub-Network
22 months 12/01/77 to 09/20/77	79.43	79.01	77.78	81.95	-0.42	-1.65	2.52	-0.5%	-2.1%	3.2%
WY 79 Exclusive of Sept. 21-30, 1979	36.72	36.46	35.46	38.37	-0.26	-1.26	1.65	-0.7%	-3.4%	4.5%
*WY 79	42.05	41.79	40.79	43.70	-0.26	-1.26	1.65	-0.6%	-3.0%	3.9%

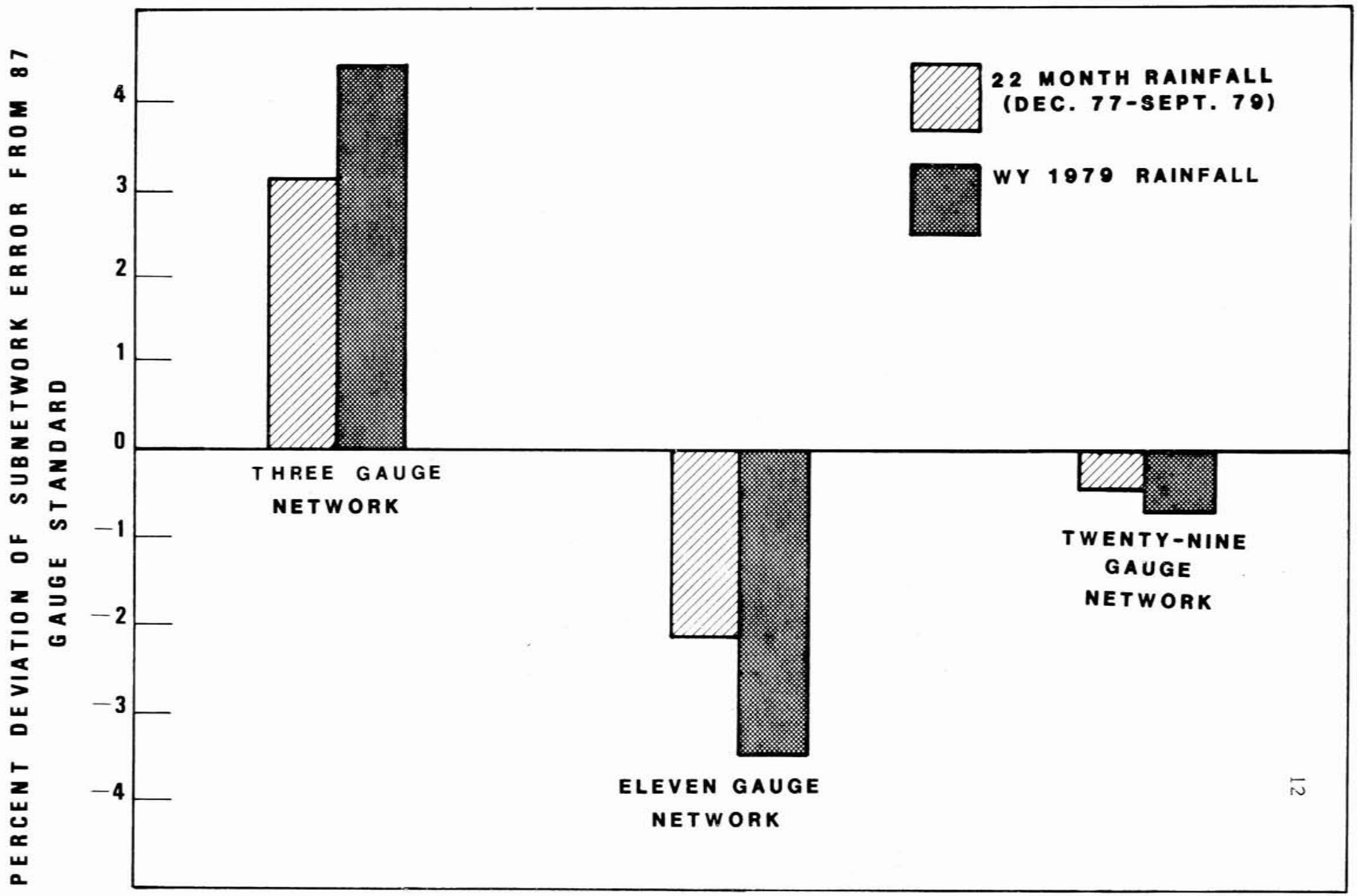
* Includes September 21-30, 1979 rainfall estimates based on Thiessen polygon analysis of rainfall at Tamiami, Royal Palm and Homestead during this period.

** Percent error is defined as follows: $\frac{(S_{87} - S_i)}{S_{87}}$ (100) where:

S_i = Subnetwork estimate

S_{87} = 87-gauge network estimate

Figure 4. Percent deviation of subnetwork estimates from 87 gauge standard for WY 79 and 22-month rainfall totals.



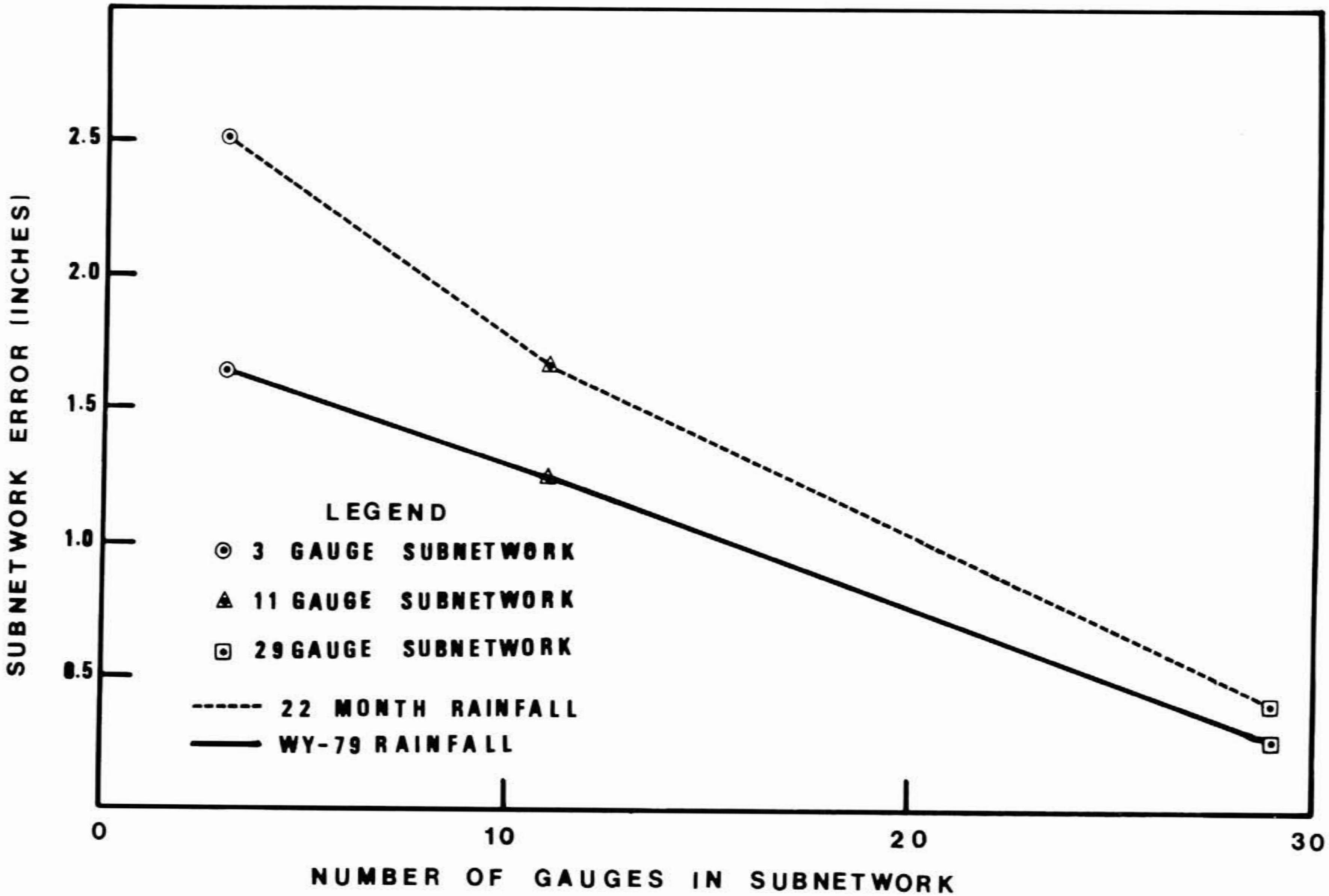


Figure 5. Subnetwork error for cumulative WY 79 and 22-month rainfall totals.

Table 3. Comparison of volume equivalents of subnetwork error for WY 79.

	Deviation	Percent of annual S-12 releases (mimimum)
29 wedge	-5,318 AF	2%
11 wedge	-25,770 AF	10%
3 wedge	+33,746 AF	13.0%

Table 4. Comparison of mean subnetwork error and standard deviations of error for the monitoring 46 intervals.

	29-Gauge	11-Gauge	3-Gauge
$\bar{x}$ error	0.08	0.14	0.29
$\bar{x}$ of $\pm$ deviations from standard	0.009	-0.04	0.05
standard deviation of error	0.15	0.26	0.45

The subnetworks were also compared to the 87-gauge standard on the basis of each collection interval (Appendix E). The mean biweekly errors of the 29, 11, and 3-gauge subnetwork rainfall estimates, relative to the 87-gauge network, were 0.08 inches, 0.14 inches, and 0.29 inches, respectively. (Error is defined as equal to the absolute value of the deviations of the subnetwork estimates from the 87-wedge network.) The standard deviations of the errors of the 29, 11 and 3-gauge subnetworks were 0.15 inches, 0.25 inches, and 0.44 inches, respectively. The mean of the $\pm$ deviations from the standard network is an order of magnitude smaller than the mean error, due to cancellation of under and overestimates. These comparisons, and the range of $\pm$ 1 standard deviation, are shown in Figure 6 and Table 4.

A trend of increasing subnetwork error with increasing mean basin rainfall is common to all networks, and becomes pronounced as rainfall exceeds four inches (Figure 7, Table 5). For example, for mean basin rainfall between three and four inches, the $\bar{x}$ error of the subnetworks ranged from .06 to .40 inches for mean basin rainfall between four and five inches, the $\bar{x}$ error of the subnetworks ranged from .49 to .72 inches. Subnetwork error for mean basin rainfall greater than 5 inches is deceptively smaller than expected, indicative of splashout and overflow errors.

Analysis of Rainfall Contributions to Shark Slough: May 1949 to September 1979

The mean annual (Water Year) rainfall, based upon data from the three station NOAA network, for the period of analysis (1952-1979) is 56.4 inches and the standard deviation is 10.1 inches. During the 27 years analyzed, annual rainfall exceeded the range of $\pm$ 2 standard deviations only once. This occurred in WY 60 when rainfall totaled 80.8 inches (24.40 inches above the mean). The year with least rainfall was WY 71, in which rainfall totaled 38.36 inches (18.04 inches below the mean). Thirteen of the 28 years showed rainfall totals above the mean, 15 had below mean totals. The annual deviations from the mean from 1952 through 1979, as well as the $\pm$ 1 and 2 standard deviation limits, are depicted in Figure 8.

It can also be seen in this figure that on a two-year basis, the three periods of least rainfall were WY's 55 and 56 which had a combined deficit of 28 inches, WY 70 and 71 which had a combined deficit of 20 inches, and WY 74 and 75 with a combined deficit of 19 inches. On a two-year basis the periods of greatest rainfall were WY 59 and 60 which had a combined surplus of 35 inches above the mean, and WY 68-69 which had a combined surplus of 34 inches above the mean. The longest interval of consecutive annual deficit occurred during the 6 years from 1970 through 1975. The longest interval of consecutive annual surplus occurred during the 4 years of 1957 through 1960.

Figure 9 shows the frequency distribution of rainfall deviation about the mean in 5 inch rainfall intervals, and the temporal distribution of wet and dry years.

Mean basin monthly rainfall based upon the three long-term stations for Shark Slough are shown in Figure 10, Table 6. On the average, June has the greatest monthly rainfall, with a mean of 9.75 inches, and December has the least rainfall ($\bar{x}$ = 1.00 inches). Rainfall during the six months of November through April averages 10.78 inches or 19 percent of annual, while rainfall during May through October averages 45.56 inches or 81 percent of annual.

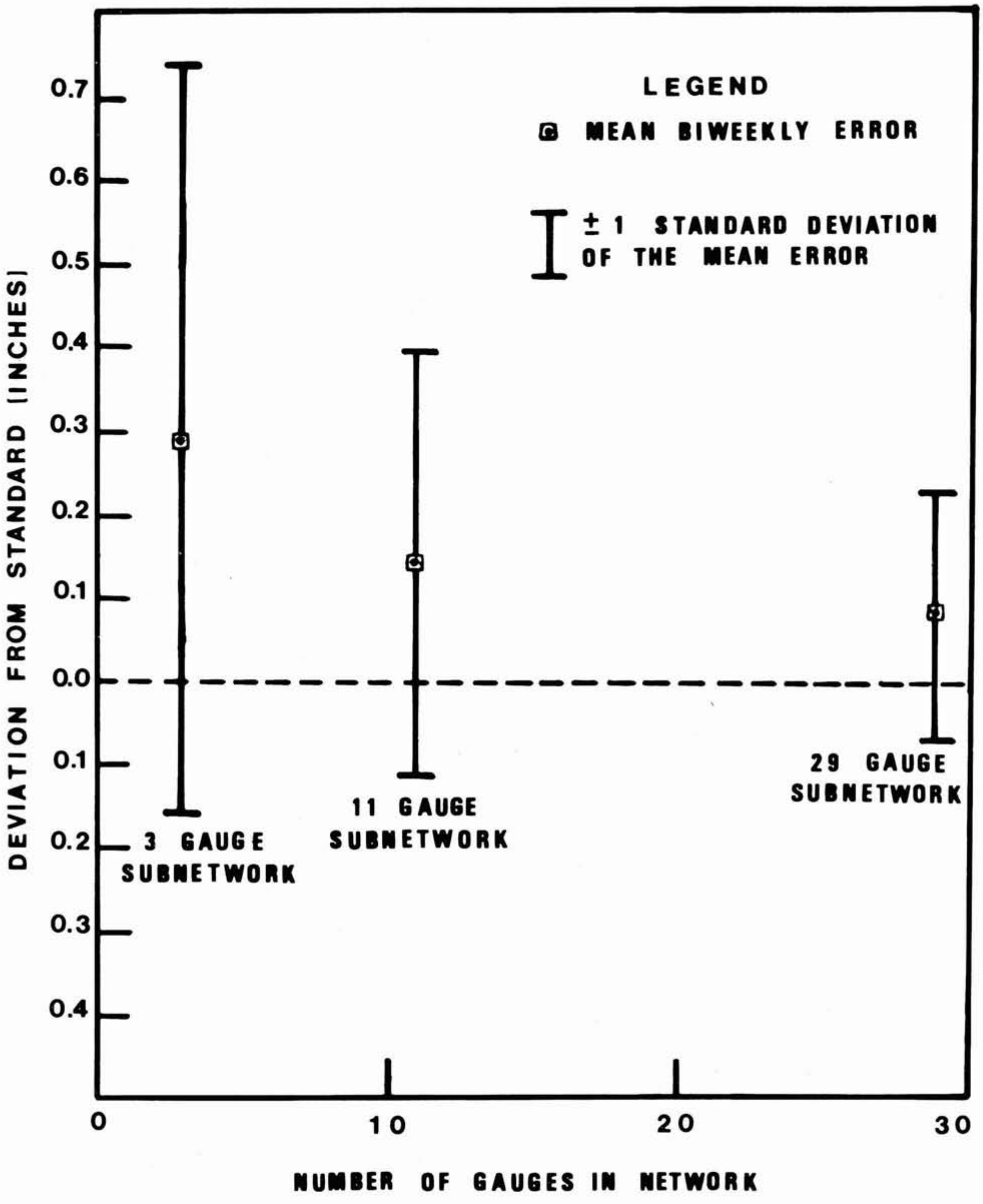


Figure 6. Comparison of mean biweekly error for the 29, 11 and 3 gauge subnetworks.

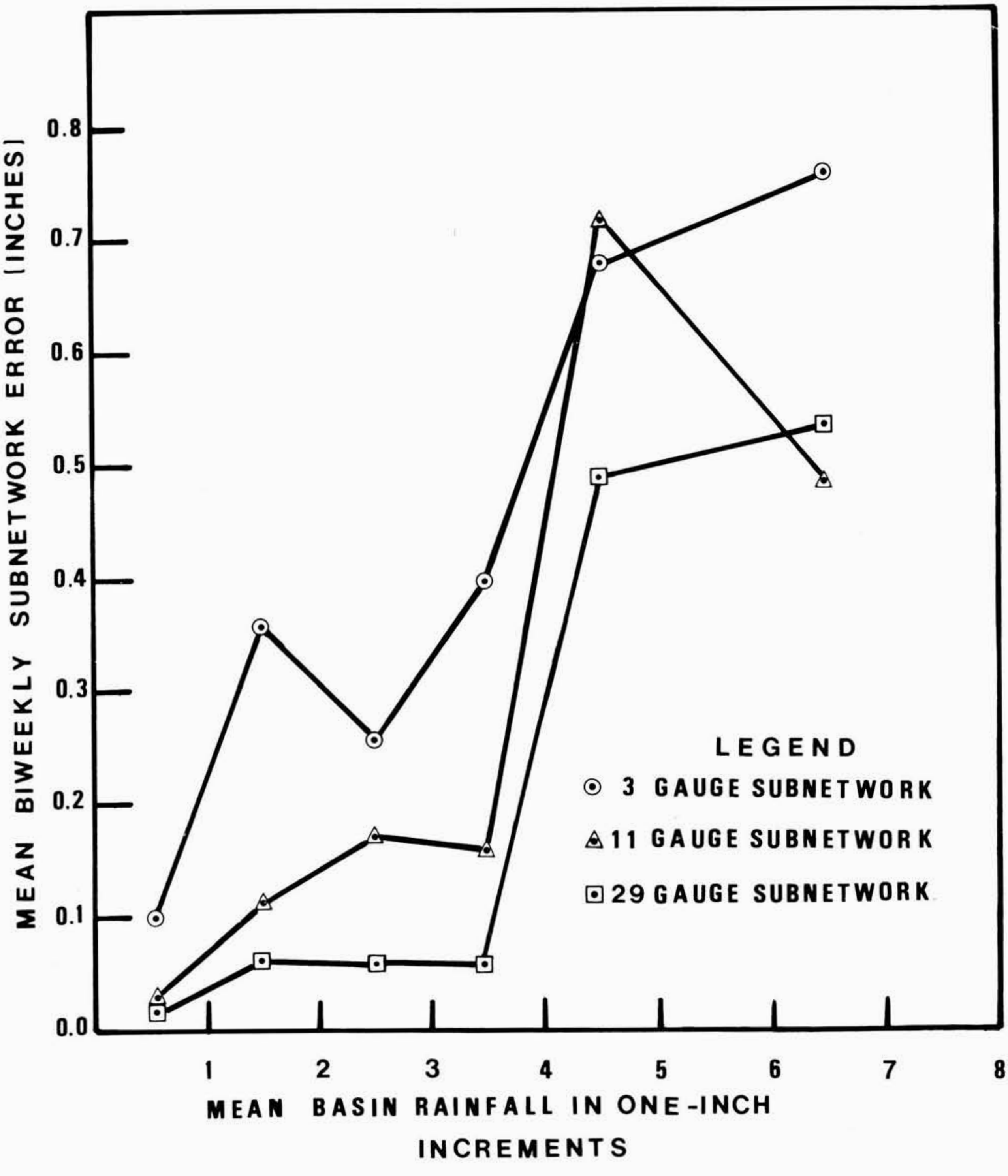


Figure 7. Trend of increasing mean error in subnetwork estimates as mean basin rainfall increases.

Table 5. Trend of increasing magnitude of subnetwork error as mean basin rainfall increases.

Mean Basin Rainfall Range	# Periods in Interval	$\bar{x}$ of Subnetwork error (inches)			Standard Deviation of Subnetwork Error (inches)		
		29 Gauge	11 Gauge	3 Gauge	29 Gauge	11 Gauge	3 Gauge
0-1	19	0.02	0.03	0.10	0.02	0.03	0.14
1-2	11	0.06	0.11	0.36	0.06	0.10	0.27
2-3	7	0.06	0.17	0.25	0.05	0.13	0.24
3-4	5	0.06	0.16	0.40	0.05	0.11	0.47
4-5	3	0.49	0.70	0.68	0.31	0.51	0.54
5	1	0.52	0.48	0.75	-	-	-

Table 6. Mean monthly rainfall into Shark Slough based on rainfall at 3 long-term NOAA stations (1949-1979)

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
$\bar{x}$	5.77	1.63	1.36	1.63	1.76	1.89	2.51	6.24	9.75	7.64	7.44	8.72
S.D.	2.73	1.25	1.00	1.39	1.03	1.64	2.11	3.70	4.31	2.59	2.11	3.09

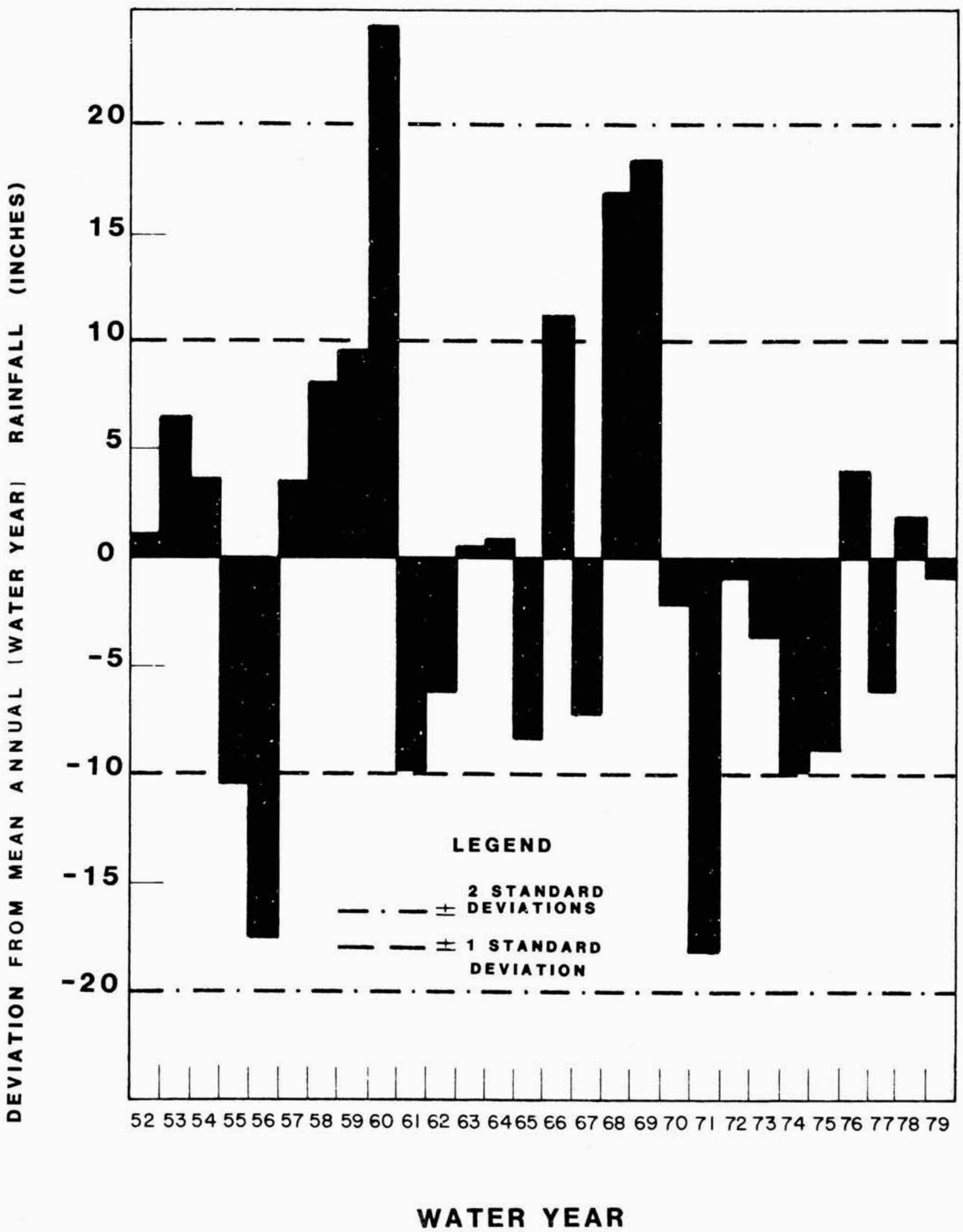
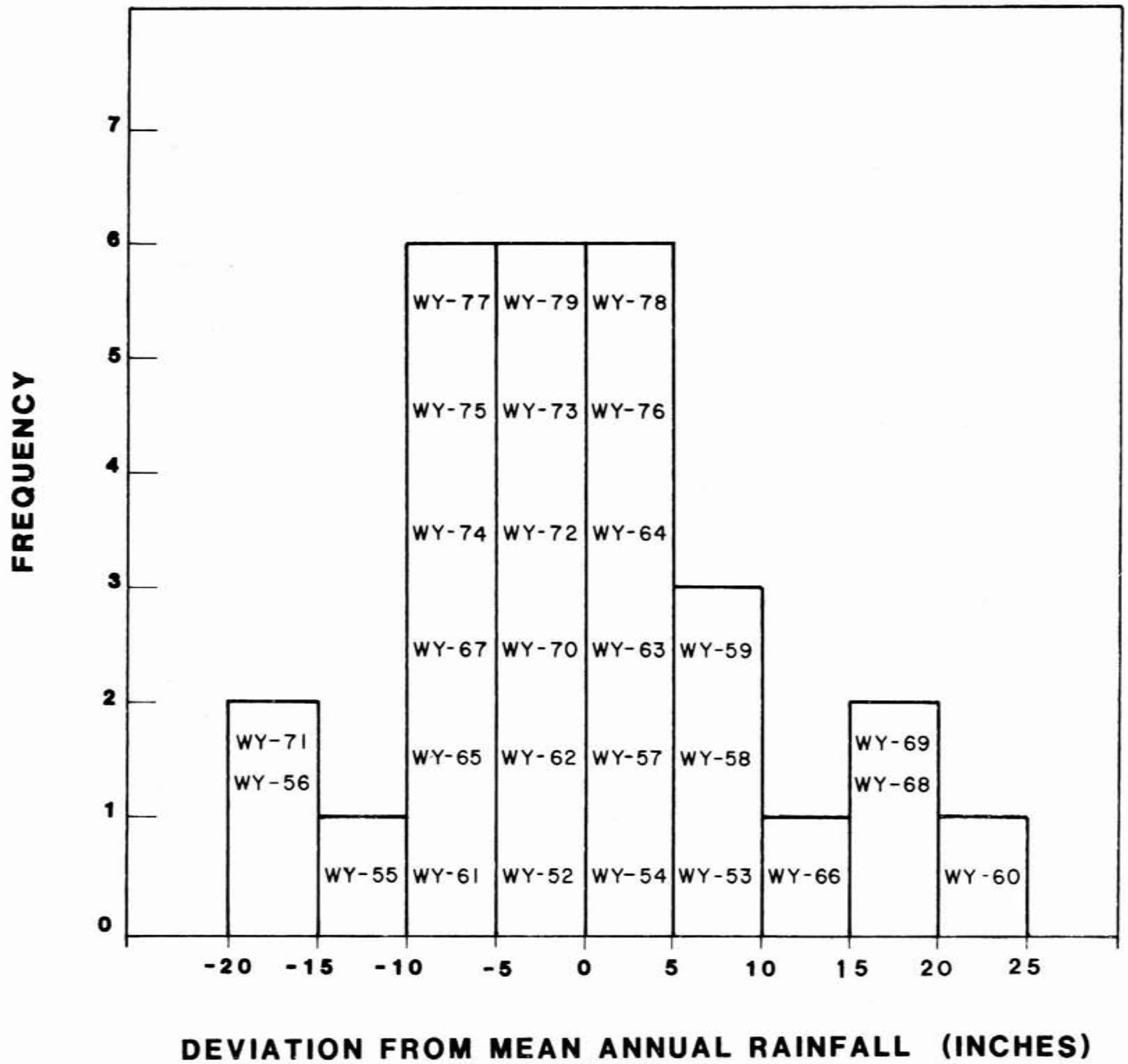
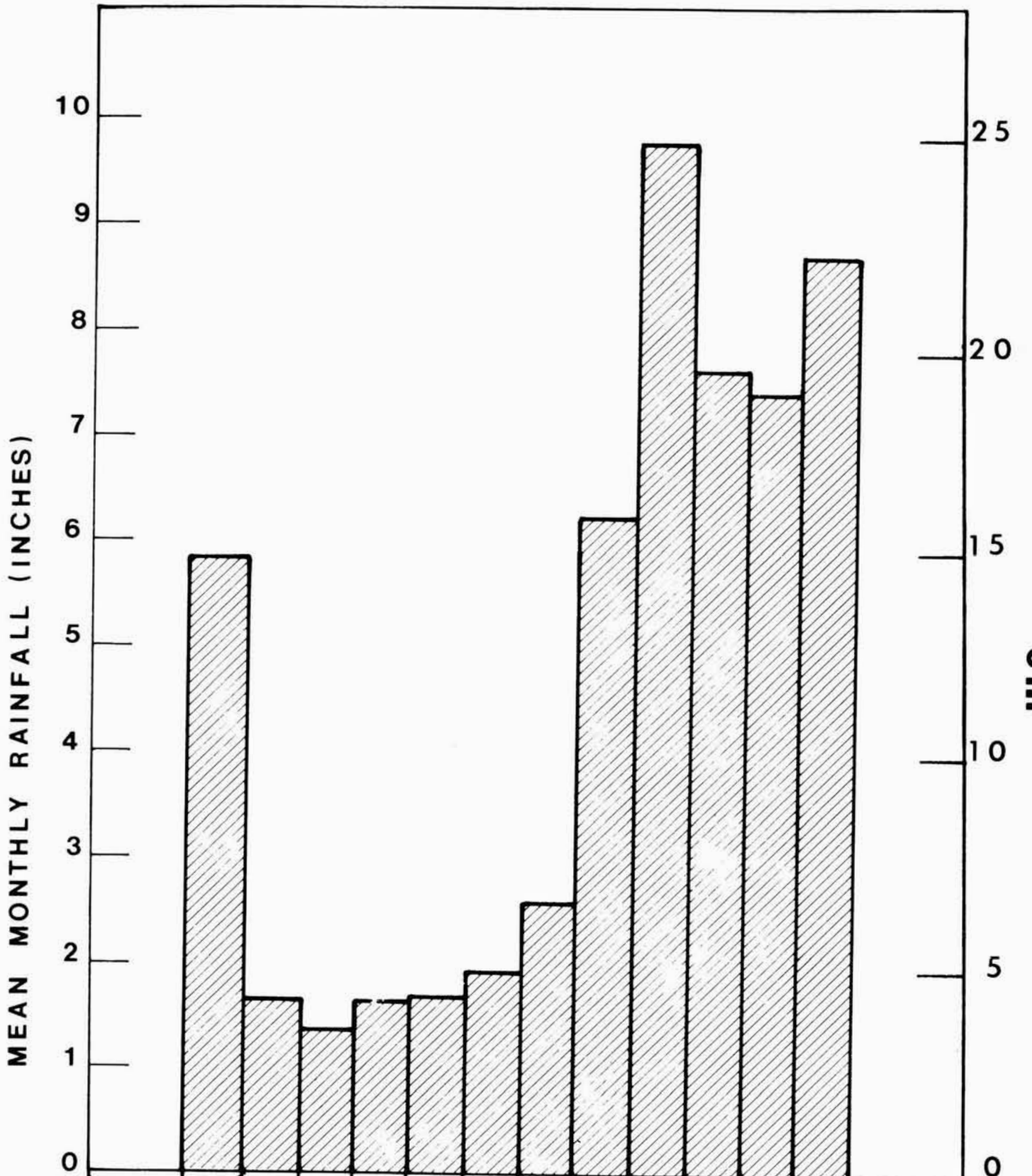


Figure 8. Deviation from mean annual (WY) rainfall into Shark Slough: 1952 to 1979.

Figure 9. Frequency distribution of annual (WY) rainfall deviation from the mean: WY 1952-1979.





MONTH	O	N	D	J	F	M	A	M	J	J	A	S
$\bar{X}$ (in.)	5.77	1.63	1.36	1.63	1.76	1.89	2.51	6.24	9.75	7.64	7.44	8.72
s.d.(in.)	2.73	1.25	1.00	1.39	1.03	1.64	2.11	3.70	4.31	2.59	2.11	3.09

Figure 10: Mean monthly basin rainfall for Shark Slough based on rainfall at the three long-term NOAA stations (WY 52 to WY 79).

Monthly rainfall contributions to Shark Slough during the entire period of record are shown in Figure 11 (Appendix F tabularized monthly and yearly totals). The deviations of monthly rainfall from the means are shown in Figure 12.

During the years 1968-1969, when annual rainfall far exceeded the mean, the months of May and June had exceptionally heavy rainfall. In June 1969 the rainfall total of 23.34 inches, was 13.59 inches above the mean. This exceeded the range of 3 standard deviations, an occurrence which can be expected to occur less than .26% of the time. Likewise, the rainfall total in May, 1968 of 17.70 inches (11.46 inches above $\bar{x}$) exceeded the range of + 3 standard deviations above the mean. June 1968, continued to have above-mean rainfall, with a monthly total of 16.37 inches (6.22 inches above the mean). While years of large rainfall surplus seem to be associated with one or two months of exceedingly high rainfall, drought years are primarily associated with many months of moderately low rainfall. There were no months with rainfall totals less than two standard deviations below the mean.

DISCUSSION

Estimate Accuracy

Convention dictates use of the data from the most comprehensive network as the standard against which subnetwork accuracy must be judged. Such valuations are accepted in assessing estimates of subnetworks and determining optimum gauge densities (Sharon, 1972). Although the accuracy of areal estimates can be substantiated only by use of a water balance equation and error analysis of all terms (Stohl, 1972), the difficulties of such an analysis are generally prohibitive due to insufficient information pertaining to the individual terms.

Studies concerning the problems of gauge placement and density have shown that evenly distributed, symmetrical placement considerably increases network accuracy (Kelway 1974; Tucker 1970). The 87-wedge network gauges, although placed at equal 1-mile intervals (1.16 km), were situated along existing airboat trails rather than placed in any regulary spaced grid pattern across the slough. Given equally well-placed networks, increasing the number of gauges will increase accuracy. The subnetworks in this analysis were chosen to approximate the pattern of the complete network as much as possible, and indeed showed greater accuracy with increasing gauge numbers.

Analysis of a dense network in south Florida (1 sq mi/gauge or 2.59 km^2/gauge over a 570 km^2 area) by Woodley et al. (1975), indicated that a subnetwork of 65 km^2 guage (25 mi^2/gauge) is sufficient to detect 90 percent of all showers when mean area rainfall is between 0.25 and .127 mm (.01 and .05 inches). For mean area rainfall greater than 13 mm (.51 inches), only one gauge in the 570 km^2 (220 mi^2) area was sufficient to detect virtually all rain days. The mean density of the 87 gauge network in this analysis was 4.4 mi^2/gauge. Despite the unsymmetrical distribution of gauges, resulting in a considerable range of densities from 1.0 km^2/gauge (.4 mi^2/gauge) to 69.6 km^2/gauge (26.9 mi^2/gauge) Woodley's recommended density requirements for shower detection were well met.

Rainfall catch of standard gauges is invariably less than actual rainfall reaching the ground (Sharon 1972). The primary cause of this systematic measurement error has been attributed to wind (Dreaver and Hutchinson 1974; Rodda 1970). Increasing

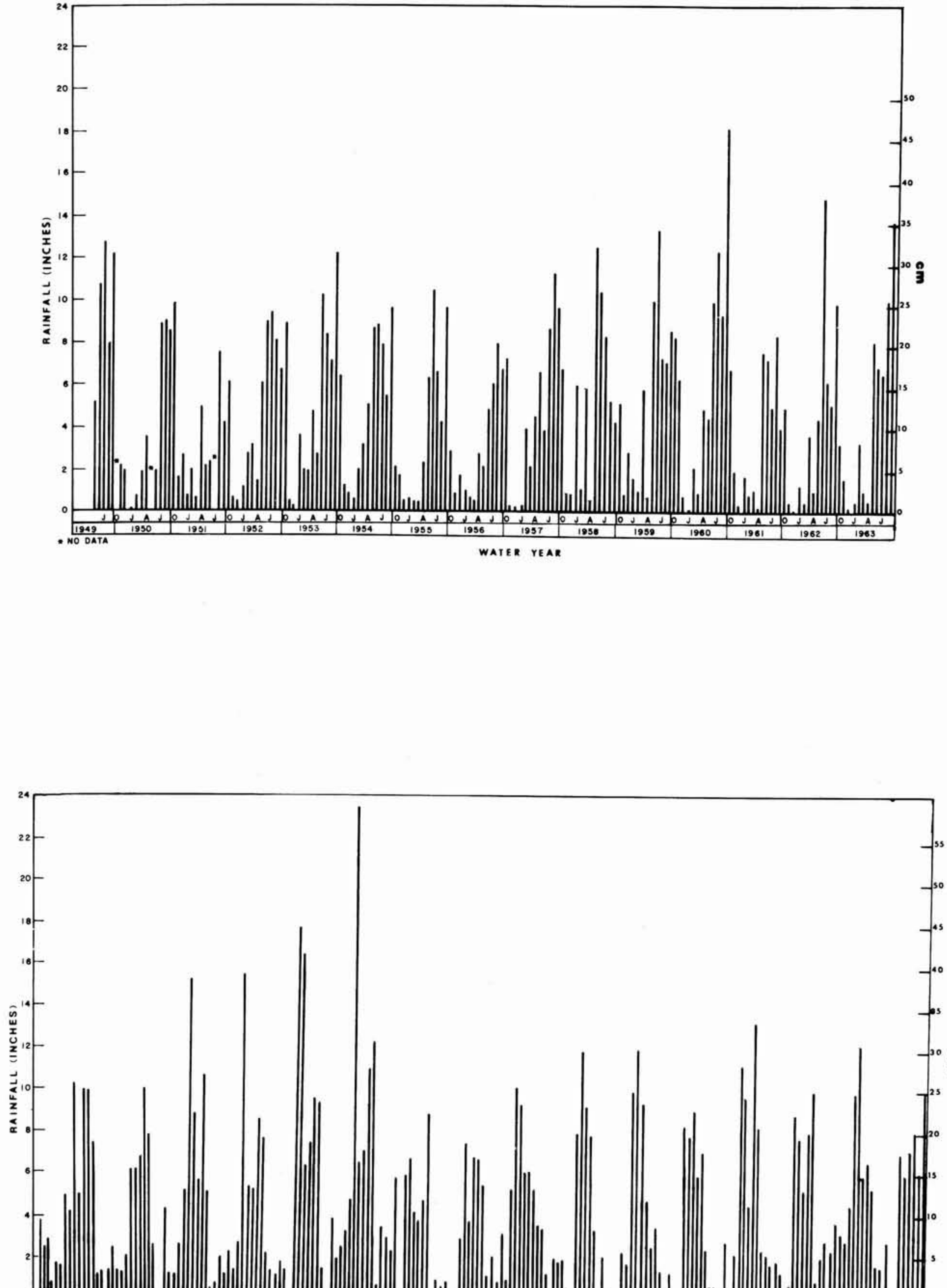


Figure 11. Monthly rainfall inputs into Shark Slough: May 1949 to September 1979.

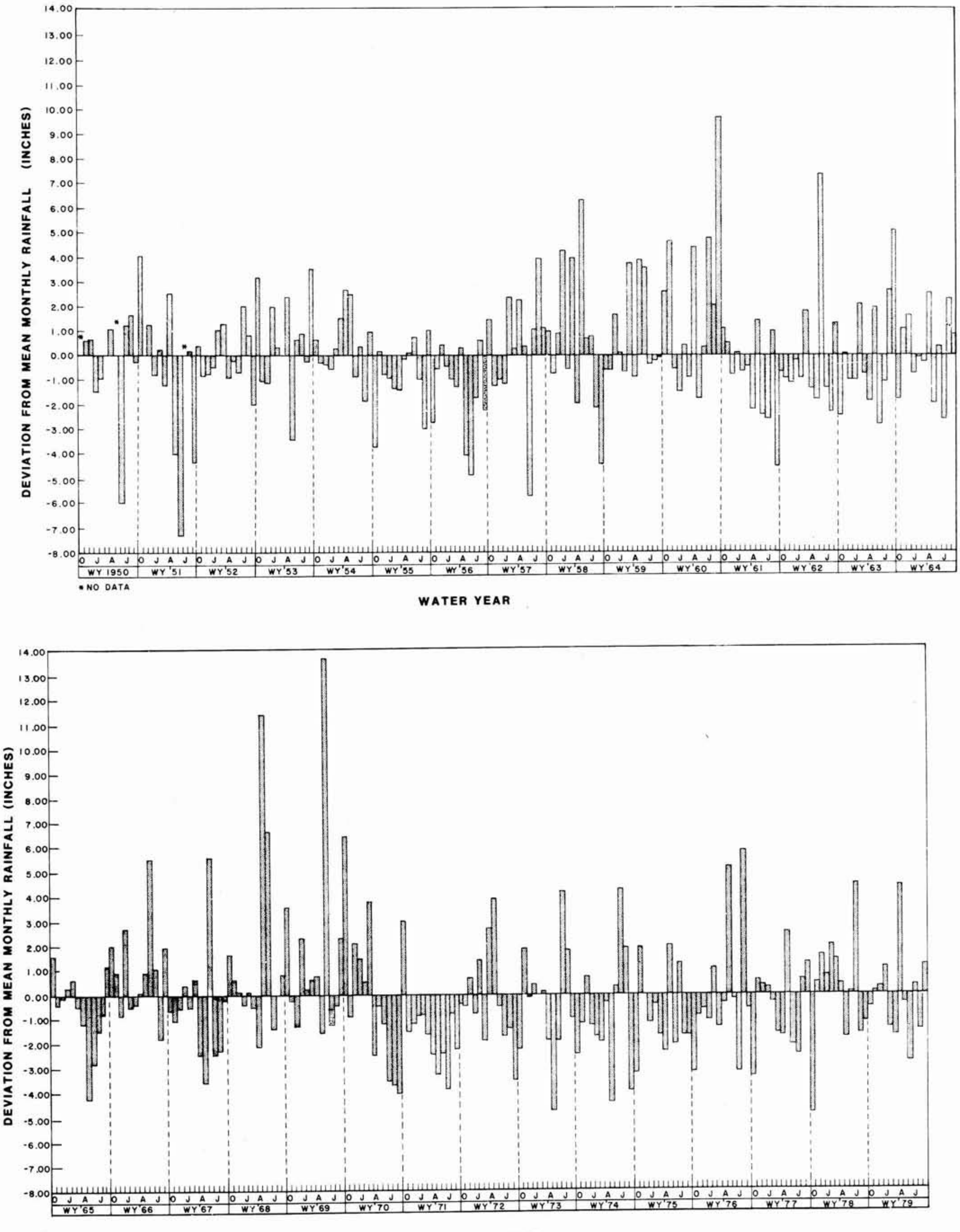


Figure 12. Deviation from mean monthly rainfall inputs into Shark Slough: WY 1950 to WY 1979.

wind velocity increases the disturbance of the horizontal air flow caused by the gauge, deflecting air away from the opening and speeding it up as it moves across. Additionally, as wind speed increases with height above ground, height of gauge rim above ground also affects rainfall catchment. The systematic errors of splashout and overflow at greater than six inches in our wedge-gauge networks clearly magnify this unavoidable underestimate.

The three long-term stations have therefore been used to provide the best available upper-limit estimate of rainfall inputs into the slough during the 22 month wedge-gauge monitoring period.

The larger volume capacity of the gauges used at these stations, as well as the daily monitoring schedule, reduces underestimates due to splashout and overflow. The location of Royal Palm and Homestead in, or near a region of particularily high summer rainfall (the Atlantic Coastal Ridge), adds a source of overestimation to rainfall estimates into the slough proper. Therefore, actual rainfall into the slough is assumed to be within the range provided by the two estimates. Rainfall during WY 79 was therefore between 42.05 and 55.65 inches. The 87-wedge network estimate was 76 percent of the 3 station estimate for both WY 79 and the 22 month monitoring period.

Reduction of the systematic measurement errors in the 87-wedge network may be accomplished by: (1) use of gauges with a larger volume capacity to reduce splashout and overflow, and (2) placement of gauges such that gauge-rim is as near ground-level as possible.

Relative Significance of Direct Rainfall Inputs vs. S-12 Releases

Based upon the 87-gauge network data, rainfall volume inputs to Shark Slough over the 22 month monitoring period totalled 1625×10^3 AF, representing 70% of the combined water contributions from direct rainfall and S-12 releases. While rainfall has been the predominant water input into the slough since the construction of man-made drainage canals, historically surface water inflow was quantitatively more important.

The volume contributions of direct rainfall and S-12 releases during this study are shown on a biweekly interval bases in Figure 13 (Appendix H). Despite the overriding importance of rainfall over the 22 month period as a whole, it can be seen that during 14 out of the 46 intervals, inputs from S-12 releases were greater than rainfall volume. Ten out of 14 of these intervals occurred within dry season months (November-April). The remaining four intervals occurred in September and October 1978. During the intervals October 6-19 and October 20 - November 2, S-12 releases contributed 66% and 81% respectively, of combined rainfall/S-12 inputs. October 1978 was an unusually dry month, during which Shark Slough received only 1 inch of rainfall (3-station estimate), which is -4.77 inches below the October period of record mean. Maximum relative contribution of S-12 releases to rainfall occurred in the interval from November 17-28, 1978, when S-12 releases accounted for 92% of the total.

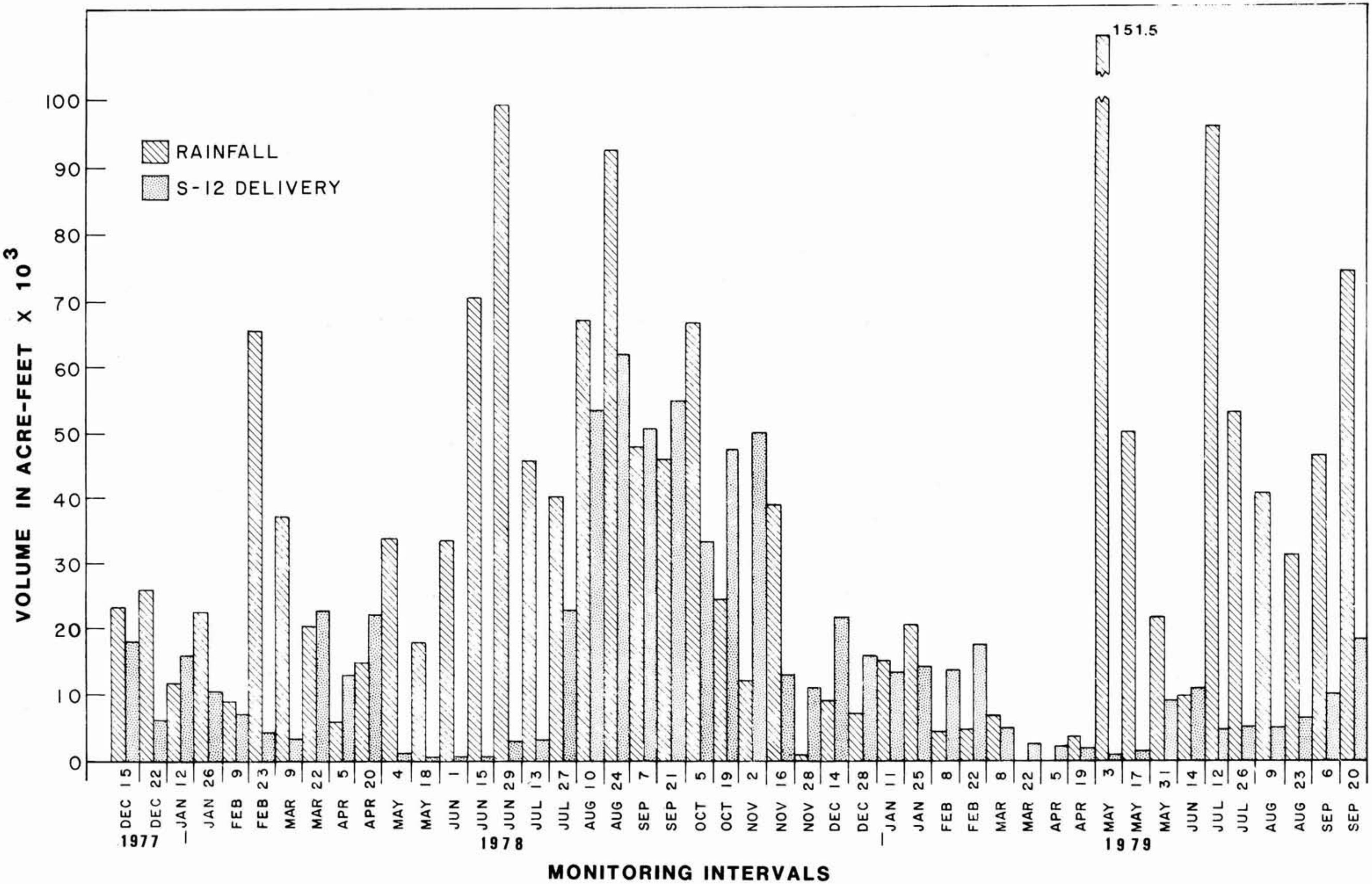


Figure 13. Volume contributions from direct rainfall (based on 87 wedge-gauge network) vs. controlled surface water releases to Shark Slough: December 1, 1977 to September 20, 1979.

This increased percent volume significance of S-12 releases during dry periods in contrast to wet periods was considered more closely by comparing (1) relative contributions of rainfall and minimum scheduled S-12 releases during an "average" wet season vs. an "average" dry season, and (2) dividing the 22 month period of monitoring into 2 wet and 2 dry periods and comparing these 4 intervals. The mean dry-season rainfall (November through April), is 10.78 inches. This represents 220.5×10^3 AF, whereas, minimum scheduled S-12 releases during the dry season total 84×10^3 AF. Average wet season rainfall from May through October is 45.56 inches, representing 931.8×10^3 AF compared with 160×10^3 AF for minimum scheduled S-12 releases. Thus, on the average, during the rainy season, direct rainfall will contribute a maximum of 85% of the combined volume from S-12 releases and rainfall inputs, while on the average during the dry season the maximum direct rainfall contribution will be 72%.

The four intervals chosen as wet and dry periods during the 22 month monitoring period and the percentage contribution of rainfall to total water volume during these intervals are shown in Table 7. Using the average of the two values (which is somewhat biased due to an extreme rain event in April, 1979), for each interval (one value based on the 3 NOAA stations, the other on the 87 gauge network), these percentages are as follows: (1) wet periods: 90% and 65%; and (2) dry periods: 77% and 43%. Therefore, percent volume contribution of S-12 releases averaged almost twice as much in the dry season as in the wet season (40% vs. 22%). This is the same ratio as was found when average wet and dry season rainfall (1952-1979) was compared to minimum scheduled S-12 releases (S-12 contribution: 28% wet season vs. 15% dry season).

Radar Rainfall Data

Radar rainfall has been used as a powerful tool in flood forecasting due to its ability to detect areal distribution, intensity and movement of rainfall cells. However, efforts by NOAA to collect radar rainfall data useful for quantifying rainfall over the period July 1-August 31, 1978, were stymied due to the technical difficulty of anomolous propagation (letter of Victor Wiggert, NOAA, to Everglades National Park). "False" radar echoes during nighttime hours were incorrectly interpreted by the digitizer as rainfall. Attempts to remedy this difficulty by use of an anomolous propagation removal device did not solve the problem. Rather, the result was that either radar echoes of rainfall of high intensity were also interpreted as AP, or not all of the AP was removed. Since rain gauge networks are not monitored on a daytime only basis, the two data bases were not comparable. Nevertheless, NOAA's radar-derived rainfall depths were compared to Everglades National Park's averaged rain gauge values (Table 8). However, the degree of discrepancy and lack of pattern was so great as to invalidate use of these data.

The radar scanning maps can be used in some cases to verify areal extent, intensities, and movement of rainfall events in the study area. In the future, radar rainfall still holds the potential for use in quantitative assessment of rainfall if

Table 7. Comparison of rainfall and S-12 releases during wet and dry season intervals in Shark Slough (December 1977-September 1979).

	WET		DRY	
	June 2, 1978- Nov. 16, 1978	Apr. 20, 1979- Sept. 20, 1979	Dec 1, 1977- June 1, 1978	Nov. 17, 1978- Apr. 19, 1979
Rainfall vol based on 87-gauge network	652×10^3 AF	580×10^3 AF	320×10^3 AF	73×10^3 AF
Rainfall vol. based on 3-stations	841×10^3 AF	781×10^3 AF	398×10^3 AF	105×10^3 AF
S-12 Releases	405×10^3 AF	79×10^3 AF	107×10^3 AF	118×10^3 AF
% Rainfall contribution based on 87-gauge network	62%	88%	75%	38%
% Rainfall contribution based on 3-station network	68%	91%	78%	47%

Table 8. Comparison of radar-rainfall derived rainfall estimates vs. rain gauge derived estimates.

Date	Block (6x6)	NOAA	Rain Gauge (average)	% Accuracy	+ or -
7/22/78-7/23/78	3	.17"	.81"	21	-
	4	.60"	.97"	62	-
	5	1.07"	.81"	132	+
	6	.95"	.47"	202	+
	11	.63"	.76"	82	-
	12	1.01"	.52"	194	+
	13	.85"	.42"	202	+
	18	.60"	.77"	80	-
	19	.47"	.64"	73	-
	20	.63"	.28"	225	+
	21	.42"	.17"	247	+
	27	.40"	.43"	93	-
7/24/78-7/26/78	3	.25"	.003"	8333	+
	4	.78"	--	--	
	5	.94"	.002"	47000	+
	6	.71"	--	--	
	11	.71"	--	--	
	12	1.06"	.001"	106000	+
	13	.95"	--	--	
	18	.74"	.013"	5692	+
	19	.71"	.007"	10142	+
	20	.90"	--	--	
	21	.67"	--	--	
	27	.77"	--	--	
7/22/78-7/23/78	Royal Palm	.22"	.83"	27	-
	Tamiami	.95"	.64"	148	
	Flamingo	.06"	.27"	22	
	Everglades City	.23"	.57"	40	
7/24/78-7/26/78	Royal Palm	.43"	.01"	4300	
	Tamiami	.71"	.12"	591	
	Flamingo	.14"	.00"	--	
	Everglades City	.37"	.63"	59	

used in conjunction with gauges for ground-truthing. The primary benefits would be that radar-rainfall information on areal distribution and intensity of rainfall allows ground network size to be decreased without decreasing estimate accuracy.

Tipping Bucket Data

A comparison of data for the tipping-bucket satellite stations and their adjacent wedge gauges was previously made for a seven month period (Table 9). Percentage accuracy (accuracy defined as conformity to the wedge gauge measurement) was found to be highly variable. Throughout the monitoring period, results were in many cases in obvious error or simply not available due to mechanical failure of the gauge or telemetry system. In addition, systematic measurement errors include: (1) overestimates during intense rainfall events due to the momentum imparted in the bucket, (2) overestimates due to the weight of debris rather than rain triggering the tipping mechanism, (3) underestimates due to lack of rainfall capture during the time the bucket assembly is in the process of tipping, (4) errors due to the circuitry or logistic problem inherent in the electronic instrumentation. Nevertheless, there were cases in evaluating the 87-wedge network in which rain gauge catchment of 5-6 inches of rainfall was clearly an underestimate, and tipping bucket data was used for upward adjustments.

SUMMARY AND CONCLUSIONS

The comparison of rainfall estimates in the Shark River Slough from a dense network of 87 rain gauges with 3 selected subnetworks showed mean biweekly error increased from .08 to .29 inches as network size decreased from 29 to 3 gauges. Error increased considerably when mean basin rainfall was greater than 4 inches. Maximum error in cumulative rainfall for WY 79 was 1.65 inches (4.5 percent) for the 3-gauge network equivalent to a volume input of 33,750 AF into the slough.

Error in cumulative WY 79 rainfall showed a linear decrease with increasing network size for the 3 selected subnetworks. However, the limited number of subnetworks analyzed was insufficient to support further generalizations or predictions regarding loss of accuracy with decreasing network size or density.

Estimates for both cumulative 22 month and WY 79 rainfall based on the dense network were 24 percent less than estimates based on the 3 weather stations, despite good correlation between the 46 interval estimates (r = .88). It was concluded that gauges used in the 87 wedge gauge network were subject to substantial loss of rainfall catch due to overflow, spashout and wind effects as a consequence of their biweekly monitoring schedule, inferior design, and small (6-inch) volume capacity inappropriate for the heavy wet season rainfall of this region. Gauges used at the weather stations minimized these losses because of their 24-inch volume capacity and superior design qualities.

Isohyetal mapping documented persistent patterns of considerable spatial variability within the slough. Extremes ranged from 60 inches to greater than 90 inches for cumulative rainfall totals at individual gauge sites for the study period

Table 9. Comparison of Rainfall Measurements from Wedge and Tipping Bucket Gauges at the Same Monitoring sites (Inches)

		15 Dec 77	22 Dec 77	12 Jan 78	26 Jan 78	9 Feb 78	23 Feb 78	5 Apr 78	18 May 78	1 Jun 78	15 Jun 78	13 Jul 78	27 Jul 78	10 Aug 78	24 Aug 78	7 Sep 78
NP-201	Tipping Bucket	1.40	0.96	0.64	2.44	0.80	3.60	0.48	1.28	1.60	2.04	1.96	5.12	-	1.40	0.84
	Wedge	0.96	1.25	0.40	1.30	0.30	2.60	0.40	1.20	2.30	1.95	2.55	4.86	-	1.55	0.80
NP-202	Tipping Bucket	1.40	1.68	0.88	3.24	0.08	1.04	0.04	1.20	1.84	5.12	1.48	2.96	-	5.96	1.52
	Wedge	1.00	1.00	0.30	1.15	0.26	3.20	0.20	1.52	2.00	4.50	1.10	1.52	-	5.20	1.80
NP205	Tipping Bucket	1.04	0.84	0.52	1.96	-	-	0.32	1.08	2.80	2.36	2.84	2.60	5.96	2.68	1.04
	Wedge	2.40	0.90	0.24	1.25	-	-	0.30	0.38	1.55	4.50	3.55	2.22	4.70	2.85	0.85

		21 Sep 78	5 Oct 78	19 Oct 78	2 Nov 78	28 Dec 78	11 Jan 79	22 Feb 79	8 Mar 79	3 May 79	17 May 79	12 Jul 79	26 Jul 79	23 Aug 79	26 Sep 79
NP-201	Tipping Bucket	1.24	2.34	1.00	0.96	0.40	1.92	0.64	2.00	-	-	-	1.40	1.64	-
	Wedge	1.70	4.98	1.10	1.01	0.48	1.12	0.17	0.38	-	-	-	2.58	2.80	-
NP-202	Tipping Bucket	2.62	2.96	0.24	0.96	-	-	-	0.50	-	2.36	-	-	-	-
	Wedge	1.85	3.65	0.72	0.24	-	-	-	0.25	-	2.85	-	-	-	-
NP-205	Tipping Bucket	3.28	3.24	0.68	0.62	-	-	0.36	0.32	3.92	-	4.28	3.56	-	4.64
	Wedge	3.10	3.60	1.40	0.60	-	-	0.28	0.03	3.60	-	4.85	1.70	-	2.55

December 1, 1977 to September 20, 1979. Mean basin rainfall for this period was determined to be 79 inches based on the 27 gauge networks and 104 inches based on the 3 weather stations.

A reconstruction of monthly rainfall inputs to Shark Slough for 1952-1979 based on the 3 weather stations provided estimates for a mean annual rainfall of 56.4 inches, a standard deviation of 10 inches, and an annual (WY range from 38 to 81 inches. Water year 79 was therefore a rather average year, with a rainfall of 55.6 inches (in contrast to 42.1 inches based on the 87 gauge network estimates). During this average rainfall year, direct rainfall contributed between 70 and 75 percent of combined inputs from direct rainfall and regulated water inflows, with up to 80% of the rainfall occurring during the six month wet season. The reconstruction of rainfall inputs from 1952-1979 can be used for further evaluations of the relative significance of direct rainfall and surface water inflows for the ten years prior to the operation of the control structures compared to the 17 years since operations of these structures was begun.

LITERATURE CITED

Dean, J. D. and W. M. Snyder. 1977. Temporally and Areally Distributed Rainfall. J. Irrigation and Drainage Division, p. 221-229.

Dreaver, K. R. and P. Hutchinson. 1974. Random and Systematic Errors in Precipitation at an Exposed Site. Hydrology, Vol. 13 No. 1:54-63.

Echternacht, K. L. 1975. A Study of the Kissimmee River-Lake Okeechobee Watershed. Technical Series V. 1, No. 3. State Department of Florida Environmental Regulation.

Gibbons, S. Unpub. memo. 1978. Research findings: Comparison of radar-rainfall Derived Rainfall Estimates vs. Rain Gauge Estimates. Everglades National Park.

Kelway, P. S. 1974. A scheme of Assessing the Reliability of Interpolated Rainfall Estimates. Hydrology, Vol. 21. No. 3.

Klein, H., J. T. Armbruster, B. F. McPherson, and H. J. Freiberger. 1975. Water and the South Florida Environment. U.S. Geological Survey Water Resources Investigation. p. 24-75.

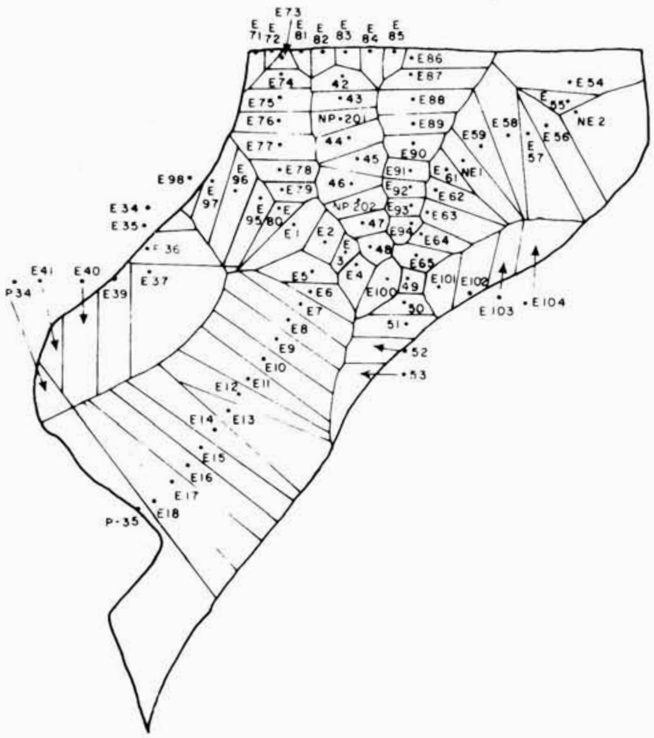
Rodda, J. 1970. On the questions of rainfall measurement and representativeness. World Water Balance: Proceedings of the Reading Symposium. Vol. 1, p. 173-185.

Rose, P. and P. C. Rosendahl. 1979. Application of Landsat Digital Data for Classification of Wetland Areas in Shark River Slough. South Florida Research Center Report T-544. National Park Service, Everglades National Park, Homestead, Florida.

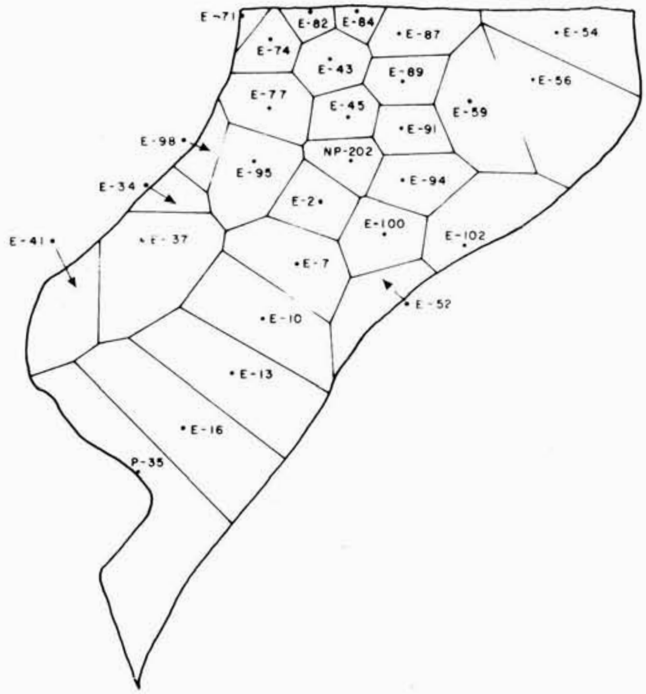
Sharon, D. 1972. Spatial analysis of rainfall data from dense networks. BIAHS. XVII:291-300.

Woodley, W. L., A. R. Olsen, A. Herndon, and V. Wiggert. 1975. Comparison of Gage and Radar methods of Convective Rain Measurement. J. App. Meteor. Vol. 14, No. 5:909-928.

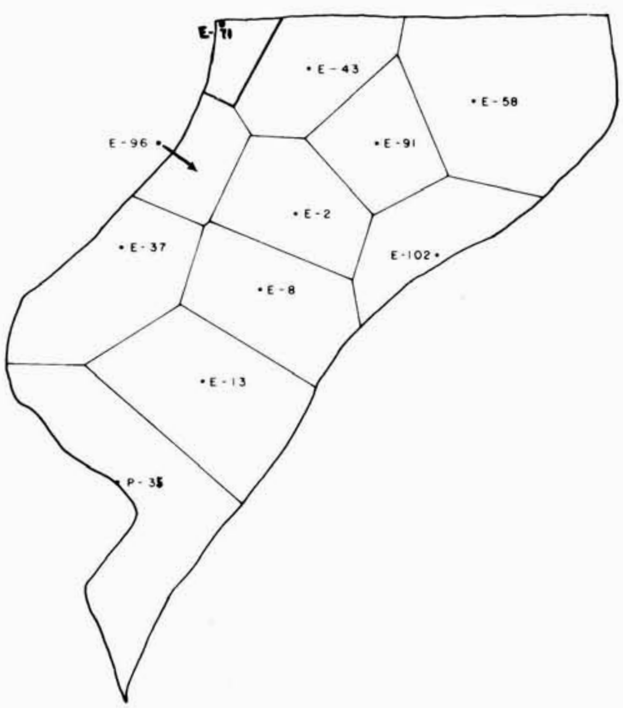
Appendix A: Thiessen polygon diagrams for the Shark Slough Rain Gauge Networks.



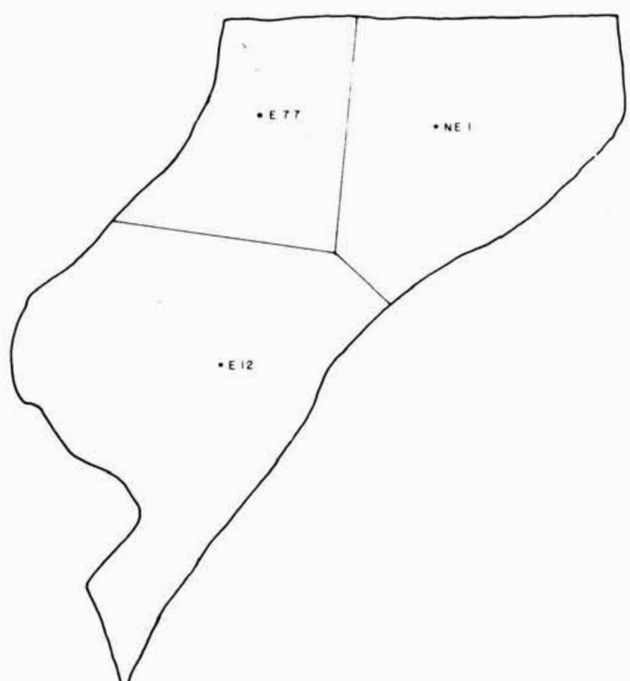
87 GAGE



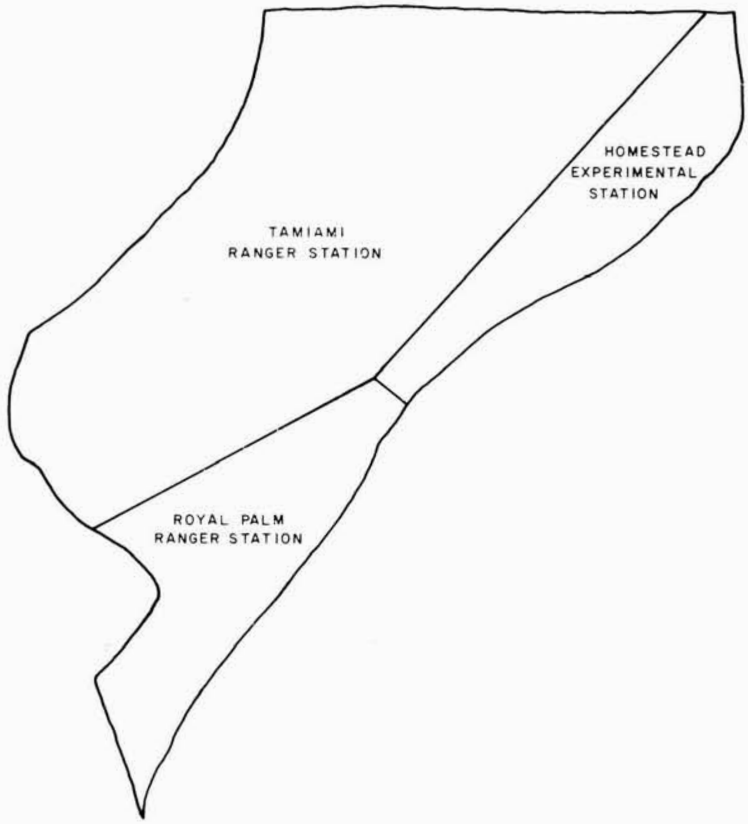
27 GAGE



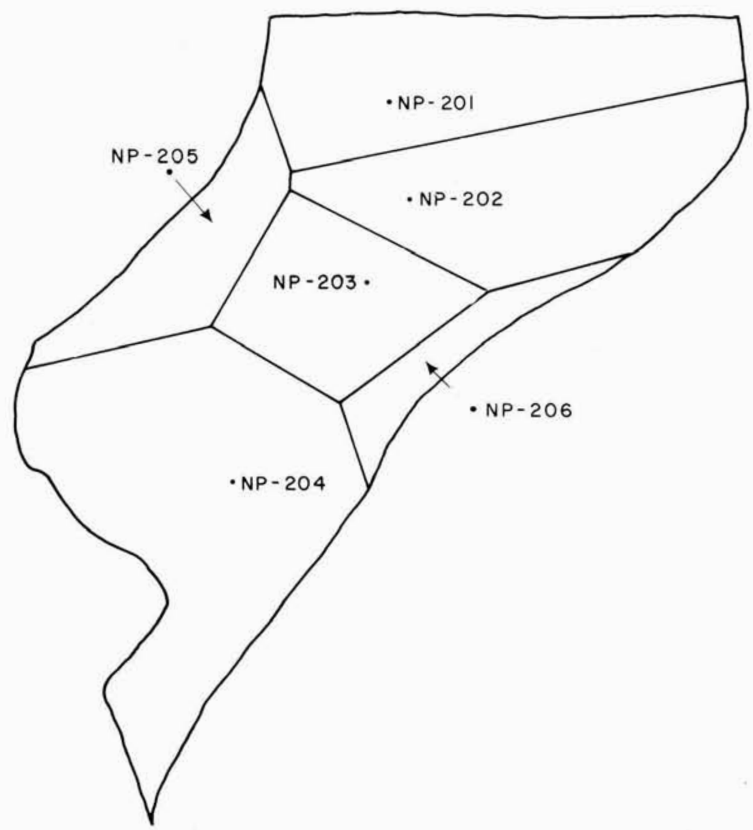
11 GAGE



3 GAGE



NOAA NETWORK



TIPPING BUCKET NETWORK

Appendix B. Thiessen Polygon Weighting Factors

1. Long-term NOAA Station Network

Stations	Weighting Factor
Tamiami	.64
Royal Palm	.18
Homestead	.18

Total 3 polygons

2. Tipping Bucket Gauge Network

Stations	Weighting Factors
NP-201	.20
NP-202	.21
NP-203	.12
NP-204	.33
NP-205	.08
NP-206	.06

Total 6 polygons

3. 87 Wedge-Gauge Network

Stations	Weighting Factor
E-1	.013
E-2	.007
E-3	.004
E-4	.007
E-5	.009
E-6	.008
E-7	.012
E-8	.016
E-9	.019
E-10	.020
E-11	.019
E-12	.020
E-13	.029
E-14	.026
E-15	.026
E-16	.028

Appendix B. Continued

Stations	Weighting Factor
E-17	.030
E-18	.028
E-34	.003
E-35	.004
E-36	.010
E-37	.042
E-39	.021
E-40	.014
E-41	.002
E-42	.008
E-43	.006
E-44	.010
E-45	.007
E-46	.008
E-47	.006
E-48	.005
E-49	.003
E-50	.006
E-51	.009
E-52	.008
E-53	.011
E-54	.028
E-55	.005
E-56	.019
E-57	.020
E-58	.016
E-59	.015
E-61	.005
E-62	.008
E-63	.010
E-64	.005
E-65	.006
E-71	.002
E-72	.001
E-73	.001
E-74	.006
E-75	.008
E-76	.010
E-77	.008
E-78	.008
E-79	.005
E-80	.006
E-81	.002
E-82	.002
E-83	.002
E-84	.003
E-85	.002
E-86	.006
E-87	.012
E-88	.012

Appendix B. continued

Stations	Weighting Factor
E-89	.008
E-90	.007
E-91	.004
E-92	.004
E-93	.004
E-94	.004
E-95	.010
E-96	.011
E-97	.011
E-98	.004
E-100	.007
E-101	.010
E-102	.011
E-103	.010
E-104	.011
NE-1	.012
NE-2	.041
P-34	.019
P-35	.070
NP-201	.008
NP-202	.007

4. 29 Wedge-Gauge Network

Stations	Weighting Factor
E-2	.021
E-7	.044
E-10	.051
E-13	.075
E-16	.088
E-34	.011
E-37	.065
E-41	.032
E-43	.020
E-45	.017
E-52	.025
E-54	.052
E-56	.067
E-59	.048
E-71	.005
E-74	.016
E-77	.028
E-82	.008
E-84	.006

Appendix B. Continued

Stations	Weighting Factor
E-87	.024
E-89	.019
E-91	.018
E-94	.026
E-95	.038
E-98	.011
E-100	.028
E-102	.040
NP-202	.018
P-35	.099

5. 11 Wedge-Gauge Network

Stations	Weighting Factor
E-2	.077
E-8	.092
E-13	.132
E-37	.107
E-43	.084
E-58	.175
E-69	.009
E-91	.069
E-96	.044
E-102	.066
P-35	.145

6. 3 Wedge-Gauge Network

Stations	Weighting Factor
E-12	.466
E-77	.197
NE-1	.337

Appendix C. Accumulated rainfall 12/1/77 to 9/20/79 for wedge gauges in Shark Slough precipitation monitoring network.

Gauge	Rainfall (inches)	Gauge	Rainfall (inches)	Gauge	Rainfall (inches)
E-1	80.68	E-47	75.44	E-83	80.97
E-2	78.21	E-48	73.29	E-84	80.74
E-3	81.12	E-49	80.47	E-85	71.32
E-4	82.20	E-50	84.55	E-86	66.77
E-5	86.48	E-51	81.14	E-87	74.70
E-6	82.93	E-52	84.36	E-88	65.88
E-7	82.06	E-53	85.07	E-89	67.07
E-8	79.62	E-54	78.42	E-90	72.24
E-9	76.52	E-55	78.80	E-91	70.48
E-10	80.04	E-56	70.67	E-92	72.97
E-11	76.61	E-57	63.54	E-93	64.91
E-12	79.55	E-58	63.69	E-94	65.51
E-13	91.38	E-59	70.61	E-96	75.98
E-14	89.79	E-61	72.59	E-97	73.29
E-15	84.95	E-62	65.35	E-98	84.29
E-16	84.54	E-63	66.05	E-99	76.55
E-17	88.9	E-64	71.83	E-100	74.04
E-18	88.09	E-65	70.54	E-101	88.11
E-34	76.94	E-71	84.90	E-102	85.80
E-35	77.85	E-72	79.76	E-103	89.41
E-36	74.03	E-73	82.28	E-104	91.05
E-37	67.83	E-74	79.22	NE-1	82.02
E-39	73.81	E-75	83.22	NE-2	84.20
E-40	73.57	E-76	81.99	NP-201	78.18
E-41	74.65	E-77	88.96	NP-202	76.04
E-42	75.75	E-78	86.57	P-34	77.76
E-43	77.49	E-79	86.40	P-35	90.20
E-44	79.85	E-80	86.33		
E-45	79.20	E-81	78.82		
E-46	74.84	E-82	70.11		

Appendix D. Comparison of mean basin biweekly rainfall totals for Shark Slough based on 87 wedge gauge network monitored biweekly vs. 3 long-term NOAA stations (at Tamiami, Royal Palm and Homestead) monitored daily.

Monitoring Interval	Rainfall based on 87 wedge gauge network	Rainfall based on 3 weather stations
Dec 1 - Dec 15, 1977	1.15	1.07
Dec 16 - Dec 22	1.27	1.80
Dec 23 - Jan 12, 1977-78	0.56	0.77
Jan 13 - Jan 26	1.09	1.67
Jan 27 - Feb 09	0.43	1.04
Feb 10 - Feb 23	3.22	2.73
Feb 24 - Mar 9	1.81	1.61
Mar 10 - Mar 22	0.98	1.02
Mar 23 - April 05	0.30	0.91
Apr 06 - Apr 20	0.71	.27
Apr 21 - May 04	1.64	2.16
May 05 - May 18	0.88	1.40
May 19 - June 01	1.64	2.99
June 02 - June 15	3.45	2.09
June 16 - June 29	4.83	7.66
June 30 - July 13	2.26	4.15
July 14 - July 27	1.96	5.00
July 28 - Aug 10	3.30	4.60
Aug 11 - Aug 24	4.53	2.19
Aug 25 - Sep 07	2.34	3.77
Sep 08 - Sep 21	2.25	2.58
Sep 22 - Oct 05	3.29	3.26
Oct 06 - Oct 19	1.20	2.47
Oct 20 - Nov 02	0.58	1.78
Nov 03 - Nov 16	1.89	1.59
Nov 17 - Nov 28	0.06	0.11

Appendix E. Comparison of mean basin biweekly rainfall totals (inches) for Shark Slough based on 87 wedge network vs. subnetworks of 29, 11, and 3 wedge gauges.

Endpoint of Intervals	87 Wedge	29 Wedge	11 Wedge	3 Wedge
Dec 15, 77	1.15	1.14	1.14	1.04
Dec 22, 77	1.27	1.34	1.31	1.31
Jan 12, 78	0.56	0.56	0.52	0.70
Jan 26, 78	1.09	1.14	1.07	1.12
Feb 09, 78	0.43	0.44	0.44	0.50
Mar 09, 78	1.81	1.60	1.56	1.35
Mar 22, 78	0.98	0.99	.98	0.95
Apr 05, 78	0.30	0.26	0.29	0.49
Apr 20, 78	0.71	0.70	0.60	1.36
May 04, 78	1.64	1.61	1.58	1.32
May 18, 78	0.88	0.80	0.86	1.04
Jun 01, 78	1.64	1.52	1.47	2.08
Jun 15, 78	3.45	3.51	3.21	3.23
Jun 29, 78	4.83	5.32	5.69	6.13
July 13, 78	2.26	2.32	2.18	1.14
July 27, 78	1.96	1.98	2.29	2.46
Aug 10, 78	3.30	3.16	3.12	2.08
Aug 24, 78	4.53	4.34	4.66	5.14
Sep 07, 78	2.34	2.37	2.08	2.45
Sep 21, 78	2.25	2.15	1.87	2.23
Oct 05, 78	3.29	3.24	3.35	3.69
Oct 19, 78	1.20	1.19	1.14	1.02
Nov 02, 78	0.58	0.60	0.65	0.64
Nov 16, 78	1.89	1.92	2.05	2.53
Nov 28, 78	0.06	0.07	0.08	0.00
Dec 14, 78	0.44	0.45	0.51	0.44
Dec 28, 78	0.34	0.34	0.35	0.37
Jan 11, 79	0.75	0.79	0.70	0.85
Jan 25, 79	0.97	0.94	0.89	1.07
Feb 08, 79	0.22	0.23	0.22	0.26
Feb 22, 79	0.23	0.20	0.19	0.13
Mar 08, 79	0.32	0.33	0.38	0.41
Mar 22, 79	0.00	0.00	0.00	0.02
Apr 05, 79	0.00	0.00	0.00	0.00
Apr 19, 79	0.17	0.18	0.17	0.02
May 03, 79	7.40	7.92	6.91	8.15
May 17, 79	2.46	2.32	2.59	2.22
May 31, 79	1.05	1.10	0.98	0.77
Jun 14, 79	0.71	0.73	0.72	0.62
Jul 12, 79	4.70	3.90	3.58	4.58
Jul 26, 79	2.59	2.56	2.85	2.02
Aug 09, 79	2.02	2.08	2.05	2.11
Aug 23, 79	1.52	1.57	1.56	2.45
Sep 06, 79	2.29	2.28	2.33	2.88
Sep 20, 79	3.63	3.61	3.36	3.49

Appendix F. Monthly and Annual (Water Year) Mean basin rainfall inputs (inches) to Shark Sough based on data from 3 NOAA stations at Tamiami, Royal Palm and Homestead (1949-1979).

*Water Year (WY)	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	WY Total
49								5.52	10.69	12.86	8.05	12.32	—
50		2.24	1.99	0.11	0.75	1.90	3.59		3.75	8.90	9.08	8.48	—
51	9.79	1.63	2.65	0.82	1.99	0.66	5.03	2.18	2.39		7.55	4.25	—
52	6.12	0.70	0.47	1.18	2.82	3.17	1.52	5.99	9.01	9.41	8.19	6.72	55.30
53	8.93	0.50	0.22	3.65	2.05	1.88	4.81	2.74	10.35	8.40	7.19	12.24	62.96
54	6.37	1.32	1.00	0.58	1.99	2.93	5.11	8.70	8.83	7.99	5.50	9.68	60.00
55	2.03	1.74	0.65	.068	0.49	0.51	2.38	6.29	10.51	6.60	4.40	9.72	46.00
56	3.05	1.05	1.82	1.17	0.75	0.56	2.82	2.15	4.89	5.96	8.03	6.58	38.84
57	7.20	0.38	0.35	0.45	4.11	2.14	4.82	6.60	4.02	8.72	11.35	9.85	59.99
58	6.83	0.88	2.27	5.94	1.22	5.83	0.56	12.55	10.43	8.39	5.31	4.38	64.59
59	5.13	0.99	3.07	1.70	1.11	5.75	1.65	10.16	13.36	7.35	7.24	8.67	66.18
60	8.35	6.30	0.88	0.11	2.13	0.97	6.96	4.57	10.11	12.51	9.56	18.38	80.83
61	6.84	2.12	0.53	1.69	1.04	1.43	0.34	7.70	7.34	5.11	8.44	4.20	46.78
62	5.00	0.61	0.10	1.42	0.56	3.63	1.10	4.45	17.11	6.26	5.17	10.01	55.42
63	3.35	1.71	0.32	0.60	3.48	1.08	0.61	8.20	6.90	6.56	10.11	13.84	
64	3.93	2.64	2.97	0.78	1.72	1.64	4.98	4.24	10.15	5.01	9.67	9.55	57.28
65	7.42	1.24	1.27	1.36	2.37	1.389	1.32	2.09	6.99	6.12	6.62	9.95	48.32
66	7.78	2.55	0.45	4.37	1.31	1.20	2.58	7.25	15.24	8.76	5.61	10.56	67.66
67	5.13	0.53	0.74	2.06	1.20	2.48	0.15	2.68	15.37	5.31	5.17	8.49	49.31
68	7.53	2.19	1.44	1.23	1.85	1.38	0.43	17.70	16.37	6.28	7.46	9.53	73.39
69	9.34	1.47	0.06	3.87	1.96	2.50	3.26	4.67	23.34	6.35	7.02	11.07	74.91
70	12.23	0.72	3.48	3.07	2.29	5.67	0.03	5.78	8.62	4.15	3.80	4.70	54.54
71	8.82	0.11	0.19	0.71	0.86	0.35	0.05	2.92	7.38	3.77	6.67	6.53	38.36
72	5.42	1.25	2.09	0.88	3.323	0.98	5.24	10.11	9.27	5.94	6.02	5.22	55.65
73	3.56	3.50	1.27	2.02	1.77	1.97	0.64	1.51	7.89	11.79	9.20	7.75	52.87
74	3.37	0.43	2.07	0.34	0.07	0.04	2.25	1.81	10.03	11.96	9.39	4.85	46.61
75	2.59	3.54	1.37	0.49	1.39	0.21	0.21	8.25	7.71	8.95	5.77	7.06	47.54
76	2.61	0.69	0.72	0.54	2.81	0.50	2.16	11.41	9.54	4.50	13.23	8.16	56.87

*Water Year (WY)	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	WY Total
77	2.37	2.19	1.71	1.89	1.45	0.31	0.78	8.73	7.70	5.19	8.00	10.10	50.33
78	1.01	2.11	2.91	2.39	3.77	3.32	2.90	4.44	9.88	12.13	5.88	7.52	58.25
79	5.26	1.71	1.65	2.74	0.40	0.21	6,89	5.91	6.98	7.99	5.95	9.90	55.59
Mean	5.77	1.63	1.36	1.63		1.89	2.51	6.24	9.75	7.64	7.44	8.72	56.34
Stand. Deviation	2.73	1.25	1.00	1.39		1.64	2.11	3.70	4.31	2.59	2.11	3.09	10.13

*Water years begins October 1 and ends September 30

Appendix G. Comparison of volume equivalents of direct rainfall estimates based on 87 wedge-gauge network vs. controlled surface water inflows via S-12 structures for 46 monitoring intervals: December 1, 1977-September 20, 1979

Endpoint of Interval	Rainfall Volume to Nearest 500 Acre-Feet	S-12 Release Volumes to Nearest 500 Acre Feet	Combined Rainfall + S-12 Release Volumes to Nearest 500 Acre Feet
15 Dec 77	23,500	18,000	41,500
22 Dec 77	26,000	6,000	32,000
12 Jan 78	11,500	16,000	27,500
26 Jan 78	22,000	10,500	32,500
09 Feb 78	8,000	7,000	15,000
23 Feb 78	66,000	4,500	70,500
09 Mar 78	66,000	3,500	40,500
22 Mar 78	20,000	22,500	42,500
5 Apr 78	6,000	13,000	19,000
20 Apr 78	14,500	2,251	17,000
04 May 78	33,500	1,500	35,000
18 May 78	18,000	1,000	19,000
01 Jun 78	33,500	1,000	34,500
15 Jun 78	70,500	1,000	71,500
29 Jun 78	99,000	3,000	102,000
13 Jul 78	46,000	3,000	49,000
27 Jul 78	40,000	22,500	62,500
10 Aug 78	67,500	53,500	121,000
24 Aug 78	92,500	62,000	154,500
07 Sep 78	48,000	51,000	99,000
21 Sep 78	46,000	55,000	101,000
05 Oct 78	67,000	33,000	100,000
19 Oct 78	24,500	47,500	72,000
02 Nov 78	12,000	50,000	62,000
16 Nov 78	38,500	12,500	51,000
28 Nov 78	1,000	11,000	21,000
14 Dec 78	9,000	21,500	30,500
28 Dec 78	7,000	20,500	27,500
11 Jan 79	15,500	13,000	28,500
25 Jan 79	20,000	14,000	34,000
08 Feb 79	5,500	14,000	19,500
22 Feb 79	4,500	12,500	17,000
08 Mar 79	6,500	5,000	11,500
22 Mar 79	0	2,500	2,500
05 Apr 79	0	2,000	2,000
19 Apr 79	3,500	2,000	5,500
03 May 79	151,500	2,000	153,500
17 May 79	50,500	3,000	52,500
31 May 79	21,500	14,000	35,500

Endpoint of Interval	Rainfall Volume to Nearest 500 Acre-Feet	S-12 Release Volumes to Nearest 500 Acre Feet	Combined Rainfall + S-12 Release Volumes to Nearest 500 Acre Feet
14 Jun 79	14,500	11,500	20,000
12 Jul 79	96,000	5,000	101,000
26 Jul 79	53,000	4,500	57,500
09 Aug 79	41,500	4,000	45,500
23 Aug 79	31,000	6,000	37,000
06 Sep 79	47,000	11,500	58,500
20 Sep 79	74,000	18,000	92,000
Total	1,624,500	698,000	2,322,632

*S-12 release values from March 23, 1979 - September 20, 1979 are based upon revisions dated 12/4/79.