COST-EFFECTIVENESS OF THE U.S. GEOLOGICAL SURVEY STREAM-GAGING PROGRAM IN CENTRAL FLORIDA

By Robert A. Miller, Warren Anderson, and Larry D. Fayard

With a section on HISTORY OF THE STREAM-GAGING PROGRAM IN FLORIDA

by Richard C. Heath

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FACTORS FOR CONVERTING INCH-POUND TO METRIC (SI) UNITS

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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ABSTRACT

This report documents the results of a study of the cost-effectiveness of the stream-gaging program in central Florida. Data uses and funding sources were identified for the 94 continuous-record gaging stations currently being operated in central Florida with a budget of $462,000. The average standard error in estimating instantaneous discharge for the present operation is 27.8 percent.

Given a budget of $550,000 the average standard error could be reduced to 17.8 percent. However, this would require that one-third of the stations be visited at a frequency greater than monthly, with the remainder being visited less frequently. The logistics required for assigning personnel and vehicles to the field at this frequency would prohibit this approach from actually being used. By limiting the maximum number of visits to 12 per year, a budget of $550,000 would reduce the average standard error to 20.2 percent.

No stations were identified as unnecessary in the present network and no stations could be replaced by data simulation using alternative methods (flow routing or regression analysis).

In performing the analysis, it was found that one presently operating site in the Withlacoochee River basin should be replaced with dam-monitoring equipment, and that telecommunication equipment should be placed at remote sites in the Kissimmee River basin for the purpose of determining operating status of the recorder.

INTRODUCTION

The U.S. Geological Survey is the principal Federal agency collecting surface-water data in the Nation. The collection of these data is a major activity of the Water Resources Division of the Survey. The data are collected in cooperation with State and local governments and other Federal agencies. The Survey is presently (1983) operating approximately 8,000 continuous-record gaging stations throughout the Nation. Some of these records extend back to the turn of the century.

Any activity of long standing, such as the collection of surface-water data, should be reexamined at intervals, if not continuously, because of changes in objectives, technology, or external constraints. The last systematic nationwide evaluation of the streamflow information program was completed in 1970 and is documented by Benson and Carter (1973). The Survey is presently (1983) undertaking another nationwide analysis of the stream-gaging program that is planned for completion over a 5-year period with 20 percent of the program being analyzed each year. The objective of this analysis is to define and document the most cost-effective means of furnishing streamflow information.

For every continuous-record gaging station, the analysis identifies the principal uses of the data and relates these uses to funding sources. Gaged sites for which data are no longer needed are identified, as are deficient or unmet data demands. In addition, gaging stations are categorized as to whether the data are available to users in near-real-time sense, on a periodic basis, or at the end of the water year (October through September).

The second aspect of the analysis is to identify less costly alternative methods of furnishing the needed information; among these are flow-routing models and statistical methods. The stream-gaging activity no longer is considered a network of observation points, but rather an integrated information system in which data are provided both by observation and simulation.

The final part of the analysis involves the use of Kalman-filtering and mathematical-programing techniques to define strategies for operation of the necessary stations that minimize the uncertainty in the streamflow records for given operating budgets. Kalman-filtering techniques are used to compute uncertainty functions (relating the standard error of estimate of instantaneous discharge to the frequency of visits to the gaging stations) for all stations in the analysis. A steepest-descent optimization program uses these uncertainty functions, information on practical stream-gaging routes, the various costs associated with stream gaging, and the total operating budget to identify the visit frequency for each station that minimizes the overall uncertainty in the streamflow data. The stream-gaging program that results from this analysis will meet the expressed water-data needs in the most cost-effective manner.

This report is organized into five sections; the first being an introduction to the stream-gaging activities in Florida and the present program in central Florida. The middle three sections each contain discussions of an individual step of the analysis. Because of the sequential nature of the steps and the dependence of subsequent steps on the previous results, conclusions and suggestions are made at the end of each of the middle three sections. The study, including all conclusions and suggestions, is summarized in the final section.

History of the Stream-Gaging Program in Florida

The U.S. Geological Survey has made water-resources investigations in Florida since the latter part of the 19th century (Claiborne and others, 1983). These consisted of data collection at intermittent intervals at a few springs (Peale, 1886), and at river sites on the Suwannee and Withlacoochee Rivers.

The first discharge measurements were also made during the latter part of the 19th century. Silver Springs near Ocala was measured on December 20, 1898 (discharge of 828 ft^3/s); and Rainbow Springs near Dunnellon (then called Blue Springs) was measured on December 22, 1898 (discharge of 778 ft^3/s).

Gaging stations were first established in 1906 on Silver Springs near Ocala (the largest noncoastal spring in Florida), and on the Suwannee River at White Springs. The latter was the first stream-gaging station established in Florida. Only fragmentary records were collected at these stations and at other sites in the Suwannee, Withlacoochee, and Peace River basins.

During the following 20 years, until 1926, the only streamflow records collected in Florida were measurements of the Everglades canals in 1913, flow of some of the larger springs in 1913, and daily stage and discharge at the gaging station on North Prong St. Marys River (January 1921 to December 1923; published as St. Marys River at Moniac, Ga.).

The first systematic stream-gaging program was begun in 1926 when continuous-record gaging stations were established on a few streams in the northern part of Florida. The Florida district office of the Survey was officially established on August 4, 1930, and all work in this State was transferred from the Chattanooga, Tennessee, office to the Ocala, Florida, office. A few observation stations were established in the Kissimmee River basin and in the Lake Okeechobee area in 1930 and 1931.

The drought of 1939 was the principal cause for the beginning of an enlarged program by the Geological Survey in the Everglades and Lake Okeechobee area. Because of the areal interrelations of surface waters in southeastern Florida, the program necessarily covered all so-called basins of "Lake Okeechobee and the Everglades." Gaging stations were established on most of the major canals in the Everglades irrigation and drainage system by 1940. Establishment of stations on the major tributary to Lake Okeechobee (Kissimmee River with its upper chain of lakes and connecting channels that contribute to the main river), was completed for the most part in 1942, following the earlier stream gaging initiated on Fisheating Creek, Indian Prairie Canal, and other Lake Okeechobee tributaries.

Other programs developed between about 1935 and 1940, in cooperation with State and Federal agencies, to study many of the large natural streams relative to the compilation of basin runoff information and flood data. Gaging stations were established at this time on the St. Johns River, which drains about 8,800 square miles in the northeastern part of the peninsula.

In 1941, the Geological Survey began special hydraulic investigations of the more prominent springs of Florida in cooperation with the State. Presently (1983), the outflows from 27 springs are being measured.

Collection of stage records of lakes began in the mid-thirties. Stage data were obtained for about 15 lakes in 1940, 85 in 1950, and 115 in 1960. By 1970, the network included about 150 lake stations (most being an integral part of stream systems). During this period (1940-70), considerable stage data were collected on the larger streams and canals (Rabon, 1970), relative to obtaining profile information under Federal cooperation.

Only 17 stream-gaging stations were established during the World War II years, bringing the total to 114 in 1945 (Rabon, 1970).

During 1946 to about 1956, the first three-way cooperation (among county or local agency, the State, and the U.S. Geological Survey) was initiated. These programs were designed to obtain "bench-mark" data including streamflow, stage records on streams and (interconnecting) lakes, and rainfall and evaporation measurements.

In 1954, the first tidal discharge station on a major coastal river was established on the St. Johns River at Jacksonville (23 miles upstream from the mouth). Initial computations of daily discharge were in volumes of flow for each ebb and flood tide, based on tidal integrated measurements of discharge and data from three recording tide gages.

Other stream-gaging activities in the lower St. Johns River basin and its tributary, Oklawaha River, included the establishment of stations associated with the construction of the cross-Florida canal. Some of the continuing long-term sites were in operation as early as 1930 (including a few on the Withlacoochee River which would be connected by a canal with the Oklawaha River).

Upon beginning construction in 1964 of a new design of a "Cross-Florida Barge Canal," reestablishment of old stations and establishment of additional stream-gaging stations were made. These stations are presently (1983) on a continuing basis even though the canal project was halted in 1971 after more than a third of the construction was completed.

By 1956, the number of active discharge stations had increased to 169. During the next several years the Geological Survey and the State of Florida together recognized the urgent need for a more systematic program to evaluate the water resources of the State. A classification system for streamflow stations in a hydrologic network consisting of primary (long-term duration), secondary (short-term duration), and partial-record stations was therefore instituted.

The partial-record network in Florida includes, essentially, stations classified as crest stage, low flow, periodic streamflow, and lakes. After a modest beginning in 1953, the crest-stage program by 1970 included about 100 stations; most were located in northern and northwestern Florida. The low-flow program was started in the mid-1960's, and consisted of about 50 data-collection sites by 1970 (which were also located mostly in northern and northwestern areas). As a result of the State and Federal programs, the number of active continuous-record stations increased steadily to 1966 when about 300 stations were in operation (Rabon, 1970).

In 1967 a program was begun to develop a data base to extend short-term flood-peak records for small basins by use of the U.S. Geological Survey rainfall-runoff model (Dawdy and others, 1972). Long-term flood records for small basins, especially those basins of less than 10 square miles, were almost nonexistent in Florida. By 1971, 30 rainfall-runoff stations were in operation (Bridges, 1977).

The first computerized analysis of flow characteristics for Florida streams and canals was completed in 1971 (Heath and Wimberly), and included 254 stream-gaging station records through 1965. The analysis provided tables of flow duration, lowest mean discharge, and highest mean discharge for selected consecutive periods within each year. Stream-gaging records for 161 selected continuous-record stations with 7 or more years of data through 1977, were used in a low-flow frequency study (Hughes, 1981).

Flood peaks from data for 159 stream-gaging stations and 23 rainfall-runoff stations have been used in developing regional equations relating peak discharge to basin characteristics (Bridges, 1982). This study on estimating magnitude and frequency of floods on natural-flow streams in Florida supersedes previous Survey reports (Pride, 1957; Barnes and Golden, 1966).

In 1958 about 40 percent of the funds for water-resources investigations in Florida were derived from cooperating State, county, and city agencies, and about 60 percent from Federal sources. Because of the increased demand by 1970 for water information by State and other local agencies, about 80 percent came from cooperative Federal-State sources and only about 20 percent came from exclusively Federal sources (Rabon, 1970). Total funds allocated for 1970 were about four times those for 1958.

Current (1983) cooperation with the U.S. Geological Survey in Florida in water-resources investigations includes 19 State agencies (which include 3 water-management districts), 19 counties, 19 cities, and 3 Federal agencies.

Present Stream-Gaging Program in Central Florida

The Orlando subdistrict was formed about 1968 when personnel were moved from the Ocala office and combined with the already existing Orlando field office. This change was a part of the general reorganization that occurred when the three technical disciplines (surface water, ground water and quality of water) were merged to form the Florida district. The subdistrict area includes the drainage areas of four major rivers (fig. 1)--the St. Johns, the Oklawaha (tributary to the St. Johns), the Withlacoochee, and the Kissimmee. Within the subdistrict area are many small closed basins which, from a strictly technical point of view, are not a part of the drainage areas of the major rivers. The total area covered by the subdistrict is approximately 14,000 square miles.

Continuous stream-gaging activity in the Orlando subdistrict began when the Okeechobee Flood Control District installed a staff gage on the Kissimmee River at Cornwell. Readings of this gage were subsequently used to compute daily discharge of the Kissimmee River near Okeechobee beginning January 1, 1929. As of December 1930, the station at Trilby on the Withlacoochee River, four stations on the Oklawaha River, and the station on the Kissimmee River near Okeechobee constituted the continuous-record stream-gaging program within the present Orlando subdistrict boundary. Subsequent expansion of the continuous-record stream-gaging program in the Orlando subdistrict to the current 94 stations is shown in figure 2.

Today, 1983, there are within the Orlando subdistrict over 250 sites at which surface-water data are collected. They are as follows:

94 continuous-record discharge
15 low-flow discharge
38 periodic discharge (6-12 measurements/year)
16 spring discharge
20 crest stage (random discharge measurements)
87 lake stage (20 continuous-record, 67 read weekly)

In addition, ground-water sites include 67 continuous-record, 92 bimonthly, and 1,200 semiannual stations. Quality-of-water sites include 7 NASQAN sites and 26 sites sampled quarterly.

Figure 3 shows the locations of the 94 continuous-record gaging stations in the Orlando subdistrict area. Locations of other stations can be found in the annual Water-Data Report (U.S. Geological Survey, 1981).

The present (1983) budget of the Orlando subdistrict is about $2 million, with $462,000 allotted to the 94 continuous-record gaging stations and $700,000 covering the total surface-water program. About 25 people are involved in collecting, processing, and publishing surface-water data.

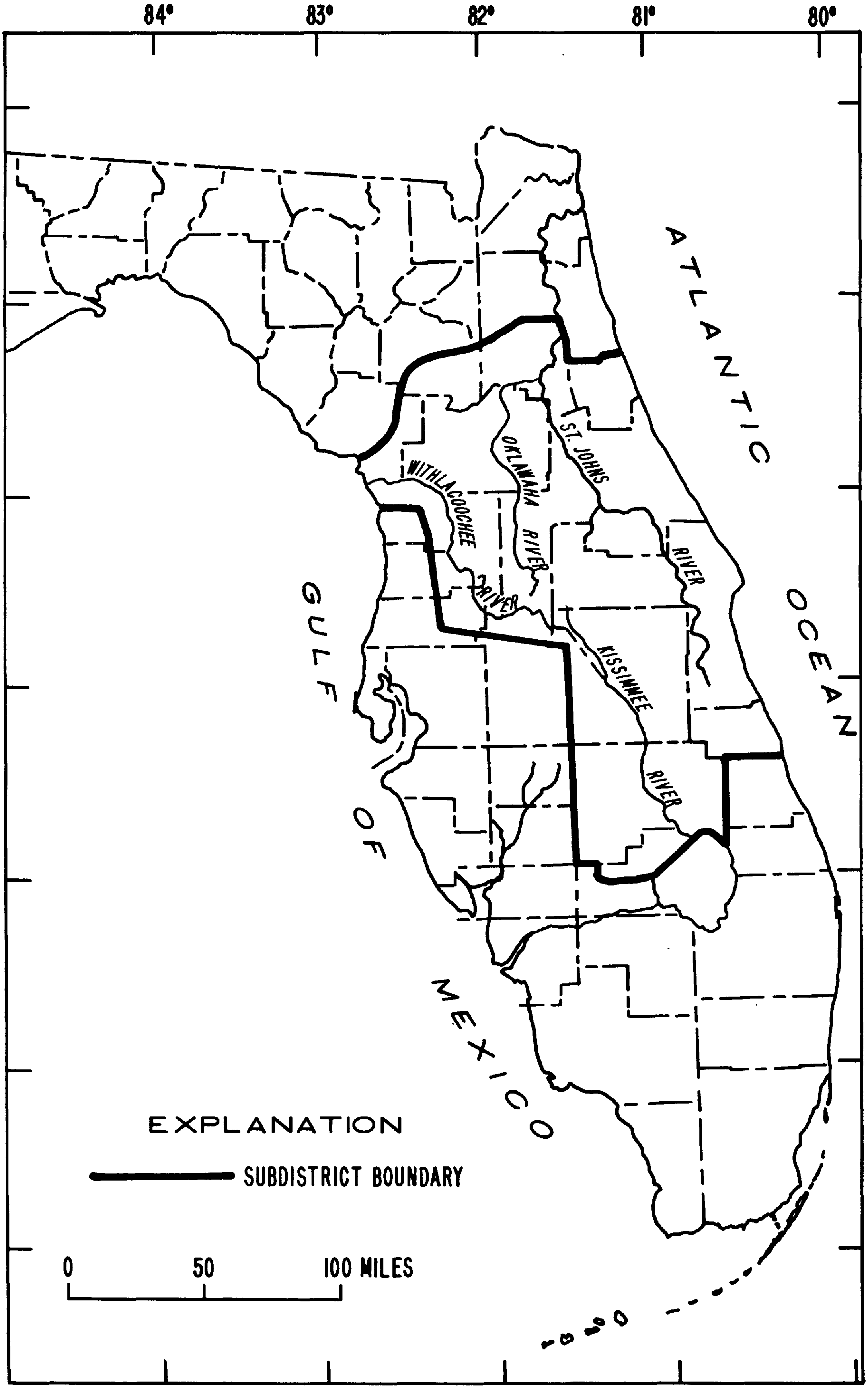

Figure 1.--Peninsular Florida with the Orlando subdistrict boundary and the major rivers of central Florida superimposed.

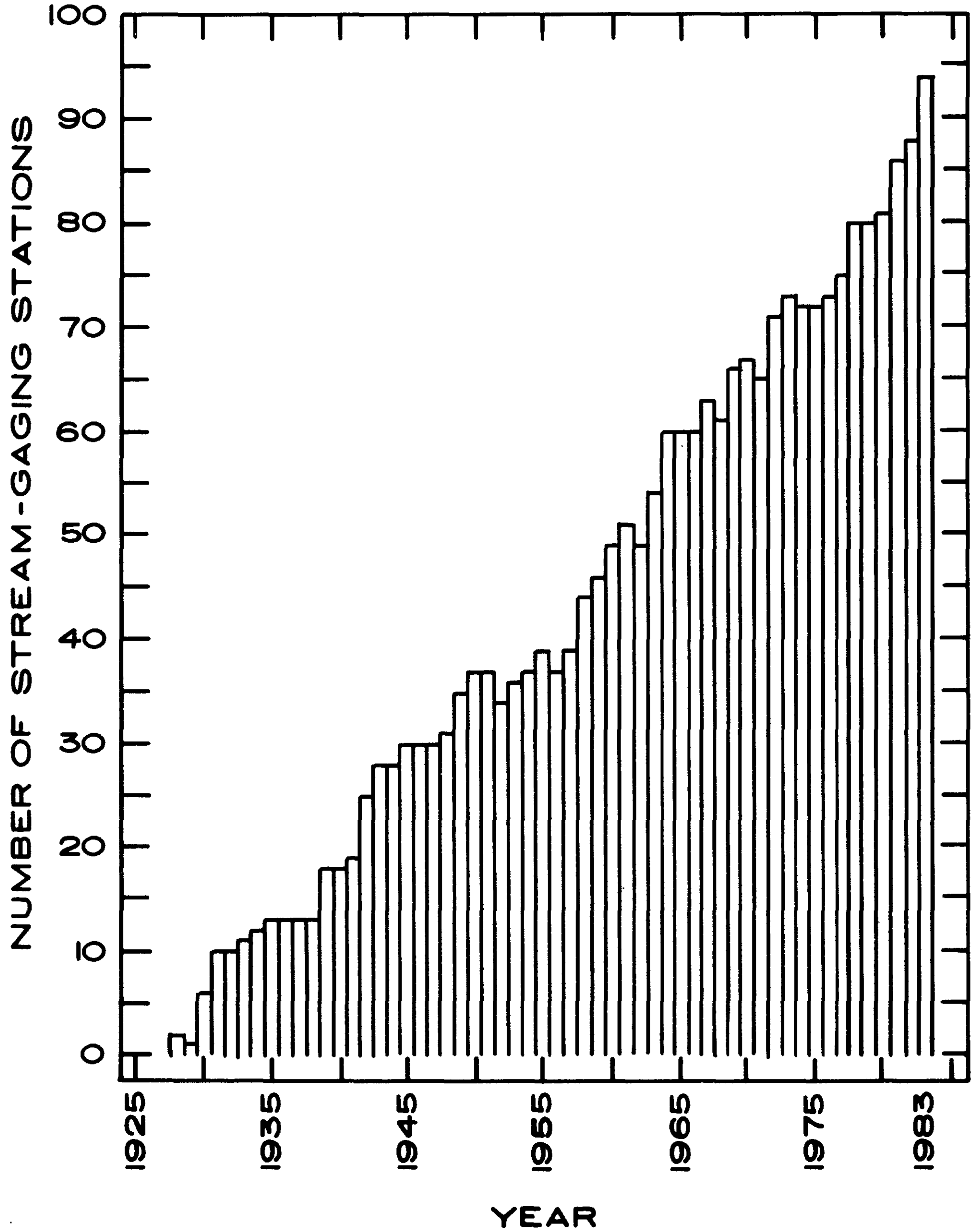

Figure 2.--Number of continuous-record gaging stations in operation within the present Orlando subdistrict boundary.

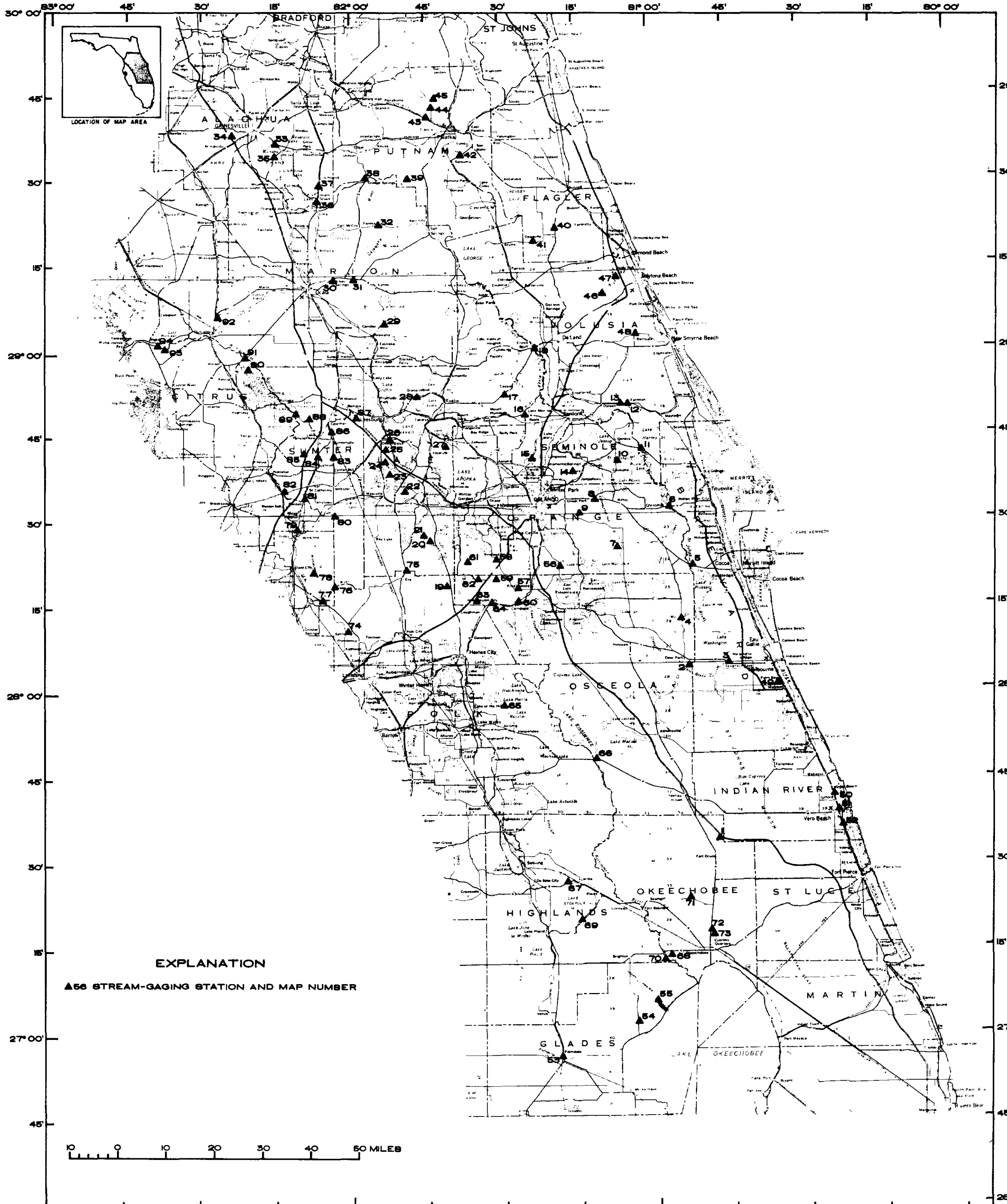

Figure 3.-- Location of stream-gaging stations in central Florida.

Selected hydrologic data, including drainage area, period of record, and mean annual flow, for the 94 stations are given in table 1. Station identification numbers used throughout this report are the last six digits of the Survey's eight-digit downstream-order station number; the first two digits of the standard station number for all stations in the Orlando subdistrict are 02, signifying the area containing coastal streams from Virginia southward and westward to Mississippi. The map reference number used in all illustrations throughout the report are shown in table 1.

Table 1.--Selected hydrologic data for continuous-record gaging stations in central Florida, 1983

(Mean annual flow computed for five, or more, years of record)

Map No.	Station No.	Station name	Drainage area (mi²)	Period of record	Mean annual flow (ft³/s)
1	2313 42	FORT DRUM CR AT SUNSHINE ST PKWY	52.6	1969-70[1],1977-	--
2	2316 00	JANE GREEN CREEK NEAR DEER PARK	248	1953-	246
3	2320 00	ST. JOHNS RIVER NEAR MELBOURNE	968	1939-	673
4	2322 00	WOLF CREEK NEAR DEER PARK	25.7	1956-	33.3
5	2324 00	ST JOHNS RIVER NR COCOA	1331	1953-	990
6	2325 00	ST. JOHNS RIVER NEAR CHRISTMAS	1539[2]	1933-	1299
7	2330 01	ECON R AT MAGNOLIA RANCH NR BITHLO	32.9	1960,1964-67[3],1972-	16.5
8	2331 02	ECONLOCKHATCHEE R TRIB NR BITHLO	1.83	1969-80[4],1982-	--
9	2332 00	L. ECONLOCKHATCHEE RIVER NR CHULUOTA	27.1	1959-	24.0
10	2335 00	ECONLOCKHATCHEE R NR CHULUOTA	241	1935-	259
11	2340 00	ST. JOHNS RIVER ABV LAKE HARNEY	2043	1941-[5]	--
12	2341 00	DEEP CREEK NR OSTEEN	140[6]	1964-66,1981-	--
13	2341 80	DEEP CR DIVERSION NR OSTEEN	70	1935,1956,1964-66,1981-	--
14	2343 24	HOWELL CREEK NR SLAVIA	29.2	1972-79,1980-81,1981-	35.5[7]
15	2349 90	L. WEKIVA RIVER NR ALTAMONTE SPRINGS	90.7	1944,1972-79,1981-	32.3[8]
16	2350 00	WEKIVA RIVER NEAR SANFORD	189	1931-35,1935-	287
17	2352 00	BLACK WATER CREEK NEAR CASSIA	126	1962-67,1967-69,1970-80,1981-	--
18	2360 00	ST. JOHNS RIVER NEAR DE LAND	3066	1933-	3104
19	2363 50	GREEN SWAMP RUN NR EVA	43	1979-	--
20	2365 00	BIG CREEK NEAR CLERMONT	68	1958-	27.1
21	2367 00	LITTLE CREEK NR CLERMONT	14.7	1979-	--
22	2369 00	PALATLAKAHA R AT CHERRY LAKE	165	1956-57,1957-	40.4[9]
23	2370 10	PALATLAKAHA R AT M-6 NR MASCOTTE	186	1981-	--
24	2370 50	PALATLAKAHA R AT M-5 NR OKAHUMPKA	193	1981-	--
25	2372 06	PALATLAKAHA R AT M-4 NR OKAHUMPKA	208	1981-	--
26	2372 93	PALATLAKAHA R AT M-1 NR OKAHUMPKA	221	1970-76,1976-	7.82[10]
27	2377 00	APOPKA-BEAUCLAIR C NR ASTATULA	184	1942-48,1958-	80.3[11]
28	2380 00	HAINES CREEK AT LISBON	648	1942-78,1978-[12]	293[13], 251[14]
29	2385 00	OKLAWAHA RIVER AT MOSS BLUFF	879	1943,1943-55,1956-58, 1958-67,1967-	292[15]
30	2395 00	SILVER SPRINGS NEAR OCALA	Indeterminate	1932-47,1947-	807
31	2400 00	OKLAWAHA RIVER NR CONNER	1196	1930-46,1963-77,1977-	1145[16]
32	2405 00	OKLAWAHA RIVER AT EUREKA	1367	1930-34,1943-52,1981-	1401[17]
33	2409 02	PRAIRIE CREEK NEAR GAINESVILLE	114	1947-48,1956,1965-67,1978-	--
34	2409 54	HOGTOWN CREEK NEAR ARREDONDO	41.2	1971-	19.1[18]
35	2410 00	CAMPS CANAL NEAR ROCHELLE	775[19]	1948-52,1957-60,1978-	98.7[20]
36	2424 51	ORANGE LK OUTLET NR CITRA	1012	1941,1947-55,1957,1960,1982-	117[21]
37	2425 00	LOCHLOOSA SLOUGH NR LOCHLOOSA	Indeterminate	1947-55,1982-	32.6[22]
38	2430 00	ORANGE CREEK AT ORANGE SPRINGS	1119[19]	1941-42,1942-52, 1955-71,1971-75,1975-	166[23]
39	2439 60	OKLAWAHA R AT RODMAN DAM NR ORANGE SPRINGS	2747[19]	1968-	1517
40	2443 20	MIDDLE HAW CREEK NEAR KORONA	78.3	1975-	78.2

See footnotes at end of table.

Table 1.--Selected hydrologic data for continuous-record gaging stations in central Florida, 1983--Continued

Map No.	Station No.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
41	2444 20	LITTLE HAW CREEK NEAR SEVILLE	93.0	1951-	83.8[24]
42	2444 40	DUNNS CR NR SATSUMA	492	1978-	--
43	2444 73	RICE CREEK NEAR SPRINGSIDE	43.2	1973-	42.2
44	2450 50	ETONIA CREEK AT BARDIN	219	1973-	97.5
45	2451 40	SIMMS CREEK NEAR BARDIN	47.3	1973-75,1976-	45.3[25]
46	2474 80	TIGER BAY CANAL NR DAYTONA BEACH	29	1978-	--
47	2475 10	TOMOKA RIVER NEAR HOLLY HILL	76.8	1964-	55.9
48	2480 00	SPRUCE CREEK NEAR SAMSULA	33.4	1951-	31.8
49	2500 30	TURKEY CREEK AT PALM BAY	105	1981-	--
50	2525 00	NORTH CANAL NEAR VERO BEACH	Indeterminate	1950-	30.5[26]
51	2530 00	MAIN CANAL AT VERO BEACH	Indeterminate	1949-	77.0[27]
52	2535 00	SOUTH CANAL NR VERO BEACH	Indeterminate	1950-	39.1
53	2565 00	FISHEATING CREEK AT PALMDALE	311	1931-	257
54	2578 00	HARNEY POND CANAL AT S-71	Indeterminate	1962-	206
55	2592 00	INDIAN PRAIRIE CANAL AT S-72	Indeterminate	1962-	48.4
56	2629 00	BOGGY CREEK NEAR TAFT	83.6	1959-	46.2
57	2638 00	SHINGLE CR AT AIRPORT NR KISSIMMEE	89.2	1958-	64.4
58	2640 00	CYPRESS CREEK AT VINELAND	30.3	1945-	6.25
59	2641 00	BONNET CREEK NEAR VINELAND	56.1	1966-	21.3
60	2644 95	SHINGLE CREEK AT CAMPBELL	180[28]	1968-	114
61	2662 00	WHITTENHORSE CREEK NEAR VINELAND	12.4	1966-	2.59
62	2663 00	REEDY CREEK NEAR VINELAND	75	1960,1962-66,1966-	28.1
63	2664 80	DAVENPORT CREEK NEAR LOUGHMAN	23	1969-	9.08
64	2665 00	REEDY CREEK NEAR LOUGHMAN	110[28]	1939-59,1968-	69.4
65	2670 00	CATFISH CREEK NR LAKE WALES	58.9	1947-	46.9
66	2689 03	KISSIMMEE RIVER AT S-65	1607[29]	1933-	1064
67	2705 00	ARBUCKLE CREEK NEAR DESOTO CITY	379[30]	1939-	336
68	2730 00	KISSIMMEE R AT S-65E NR OKEECHOBEE	Indeterminate	1928-62,1962-64,1964-	2188[31]
69	2732 00	CANAL 41A AT S-68 NEAR LAKE PLACID	Indeterminate	1963-	271[32]
70	2733 00	CANAL 41A AT S-84, NEAR OKEECHOBEE	Indeterminate	1963-	198[33]
71	2740 00	TAYLOR CREEK NEAR BASINGER	15.7	1955-	15.1
72	2744 95	WILLIAMSON DITCH AT S-7	35.4	1964-	31.8
73	2745 00	TAYLOR CREEK AB OKEECHOBEE	98.7	1955-	--
74	3019 00	FOX BRANCH NR SOCRUM	9.5	1963-	7.67[34]
75	3108 00	WITHLACOOCHEE RIVER NEAR EVA	130	1958-	50.6[35]
76	3109 47	WITHLACOOCHEE R NR CUMPRESSCO	280	1967-	135[36]
77	3110 00	WITHLACOOCHEE-HILL OVERFLOW NR RICHLAND	Indeterminate	1930-31,1950,1958-60,1960-	20.2[37]
78	3115 00	WITHLACOOCHEE RIVER NR DADE CITY	390	1930-33,1958-62,1964-	--
79	3120 00	WITHLACOOCHEE RIVER AT TRILBY	570	1928-29,1930-	355[38]
80	3121 80	L. WITHLACOOCHEE R NR TARRYTOWN	85	1966-	38.4

See footnotes at end of table.

Table 1.--Selected hydrologic data for continuous-record gaging stations in central Florida, 1983--Continued

Map No.	Station No.	Station name	Drainage area (mi^2)	Period of record	Mean annual flow (ft^3/s)
81	3122 00	L. WITHLACOOCHEE R AT RERDELL	145	1958-	81.8
82	3125 00	WITHLACOOCHEE RIVER AT CROOM	810	1939-	460
83	3126 35	JUMPER CR CANAL NR SUMTERVILLE	28.6	1976-77,1979-	--
84	3126 40	JUMPER CR CANAL NR BUSHNELL	40	1963-	26.5
85	3126 45	JUMPER CR CANAL NR WAHOO	50.6	1979-	--
86	3126 67	SHADY BROOK NR SUMTERVILLE	8.0	1932-33,1946,1956,1961, 1965-67,1980-	--
87	3126 90	CHITTY CHATTY CREEK NR WILDWOOD	38	1959-60,1963-66,1978-	--
88	3127 00	OUTLET R AT PANACOOCHEE RETREATS	420	1962-	186
89	3127 20	WITHLACOOCHEE R AT WYSONG DAM AT CARLSON	1520	1965-	630
90	3129 75	TSALA APOPKA OUTFALL C AT S-353	Indeterminate	1968-	17.4
91	3130 00	WITHLACOOCHEE R NR HOLDER	1825	1928-29,1931-	1080[39]
92	3131 00	RAINBOW SPRINGS NEAR DUNNELLON	Indeterminate	1899,1905,1907,1917, 1929-30,1930-64,1964-	714[40]
93	3132 30	WITHLACOOCHEE R AT INGLIS D NR DUNNELLON	2020	1969-	329
94	3132 50	WITHLACOOCHEE R BYPASS CHANNEL NR INGLIS	Indeterminate	1970-	1103

[1] Discharge measurement only.
[2] Includes Tootoosahatchee Creek.
[3] One measurement each year.
[4] CSI.
[5] Gage height only, 1951-55 measurements.
[6] Includes total area drained by Deep Creek and Deep Creek Diversion Canal.
[7] Based on period 1973-79.
[8] 1973-79.
[9] 1958-81.
[10] 1971-75, 1977-81.
[11] 1959-81.
[12] Gage height only.
[13] 1943-56.
[14] 1957-78.
[15] 1944-55, 1968-81.
[16] 1931-46, 1978-81.
[17] 1931-34, 1944-52.
[18] 1972-81.
[19] Includes Paynes Prairie.
[20] 1958-60, 1979-81.
[21] 1946-55.
[22] 1947-55.
[23] 1943-52, 1956-71, 1976-81.
[24] 1952-81.
[25] 1974-75, 1977-81.
[26] 1951-81.
[27] 1950-81.
[28] Includes part of watershed in Reedy Creek Swamp.
[29] Includes areas drained by L. Weohyakapka and L. Marian.
[30] Excludes area drained by L. Weohyakapka and includes area drained by L. Sebring.
[31] 1929-62.
[32] 1964-80.
[33] 1965-80.
[34] 1965-81.
[35] 1959-81.
[36] 1968-81.
[37] 1931, 1961-81.
[38] 1931-81.
[39] 1932-81.
[40] 1966-81.

USES, FUNDING, AND AVAILABILITY OF CONTINUOUS STREAMFLOW DATA

The relevance of a gaging station is defined by the uses that are made of the data that are produced from the station. The uses of the data from each stream-gaging station in the Orlando program were identified by a survey of known data users (table 2). Also recorded as part of the survey were the source of funding and the frequency of data availability for each station. The survey documented the importance of each station and identified gaging stations that may be considered for discontinuance.

Data uses identified by the survey were categorized into nine classes, defined below. The sources of funding for each station and the frequency at which data are provided to the users were also compiled.

Data-Use Classes

The following definitions were used to categorize each known use of streamflow data for each continuous-record gaging station.

Regional Hydrology

To be useful in defining regional hydrology, the data from a gaging station must be largely unaffected by manmade storage or diversion. In this class of uses, the effects on streamflow are limited to those caused primarily by land-use and climate changes. Large amounts of manmade storage may exist in the basin providing the outflow is uncontrolled. These stations are useful in developing regionally transferable information about the relations between basin and climatic characteristics and streamflow. In the Orlando subdistrict, 81 stations are classified in the regional hydrology category.

Hydrologic Systems

Stations that can be used for accounting, that is, to define current hydrologic conditions and the sources, sinks, and fluxes of water through hydrologic systems, including regulated systems, are designated as hydrologic systems stations. They include stations used to gage diversions and return flows, and stations that are useful for defining the interaction of water systems. In the Orlando subdistrict, 86 stations are included in this category.

The bench-mark and index stations are included in the hydrologic systems category because they document current and long-term conditions of the hydrologic systems that they gage. Federal Energy Regulatory Commission (FERC) stations and international gaging stations, located on significant rivers that cross national boundaries, also are included. No stations in central Florida are found in the latter two categories.

Table 2.--Data use, source of funding, and frequency of data availability for continuous-record gaging stations in central Florida, 1983

		Data use									Source of funding				
Map No.	Station No.	Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water quality monitoring	Research	Other	Federal program	OFA program	Co-op program	Other non-federal	Frequency of data availability
1	231342	*	1										1		A
2	231600	*	1										1		A
3	232000	*	1		2			1				2			A
4	232200	*	1										1		A
5	232400	*	1					2					1		A
6	232500	*	2									2			A
7	233001	*											3		A
8	233102	*	1										1		A
9	233200	*											1		A
10	233500	*	2					1				2			A
11	234000	*						1					1		A
12	234100	*											1		A
13	234180	*											1		A
14	234324	*	1										1		A
15	234990	*	1										1		A
16	235000	*	1										1		A
17	235200	*	1										1		A
18	236000	*	2					1,4				2			A
19	236350	*	5										5		A
20	236500	*	6										6		A
21	236700	*											5		A
22	236900		6			5,6							6		A
23	237010		5			5							5		A
24	237050		5			5							5		A
25	237206		5			5							5		A

1 St. Johns River Water Management District, Greater St. Johns River Basin.
2 U.S Army Corps of Engineers, Jacksonville, Florida District, redesign of structural controls, upper St. Johns River basin.
3 City of Cocoa, Florida.
4 National Stream Quality Accounting Network.
5 Oklawaha Basin Recreation and Water Conservation and Control Authority in Lake County, Florida, water control in the Oklawaha River and chain of lakes.
6 St. Johns River Water Management District, Oklawaha River Basin Board, water control in the Oklawaha River and chain of lakes.
A Annually.

Table 2.--Data use, source of funding, and frequency of data availability for continuous-record gaging stations in central Florida, 1983--Continued

Map No.	Station No.	Data use: Regional hydrology	Data use: Hydrologic systems	Data use: Legal obligations	Data use: Planning and design	Data use: Project operation	Data use: Hydrologic forecasts	Data use: Water quality monitoring	Data use: Research	Data use: Other	Source of funding: Federal program	Source of funding: OFA program	Source of funding: Co-op program	Source of funding: Other non-federal	Frequency of data availability
26	237293		5			5							5		A
27	237700		6			6		6					6		A
28	238000		6			6							6		A
29	238500		6			6							6		A
30	239500	*				6		6					6		A
31	240000	*	2					4				2			A
32	240500	*	6										6		A
33	240902	*	6,7		7								7		A
34	240954	*	6										6		A
35	241000	*	7		7								7		A
36	242451	*	7		7								7		A
37	242500	*	7		7								7		A
38	243000	*	1										1		A
39	243960		2									2			A
40	244320	*	1										1		A
41	244420	*	1										1		A
42	244440	*	1										1		A
43	244473	*	1										1		A
44	245050	*	1										1		A
45	245140	*	1										1		A
46	247480	*	1										1		A
47	247510	*	1										1		A
48	248000	*						4					1		A
49	250030	*	1		1								1		A
50	252500	*	1		1								1		A

1 St. Johns River Water Management District, Greater St. Johns River Basin, redesign of structural controls, upper St. Johns River basin.
2 U.S. Army Corps of Engineers, Jacksonville, Florida District.
4 National Stream Quality Accounting Network.
5 Oklawaha Basin Recreation and Water Conservation and Control Authority in Lake County, Florida, water control in the Oklawaha River and chain of lakes.
6 St. Johns River Water Management District, Oklawaha River Basin Board, water control in the Oklawaha River and chain of lakes.
7 Florida State Department of Natural Resources, Division of Recreation and Parks, management of water levels in the Payne's Prarie Game Preserve.
A Annually.

Table 2.--Data use, source of funding, and frequency of data availability for continuous-record gaging stations in central Florida, 1983--Continued

Map No.	Station No.	Data use									Source of funding				Frequency of data availability
		Regional hydrology	Hydrologic systems	Legal obligations	Planning and design	Project operation	Hydrologic forecasts	Water quality monitoring	Research	Other	Federal program	OFA program	Co-op program	Other non-federal	
51	253000	*	1		1			4					1		A
52	253500	*	1		1								1		A
53	256500	*	2		2	2						2			APT
54	257800	*	8,2			8,2							8		AP
55	259200	*	8,2			8,2							8		AP
56	262900	*	8		8								8		A
57	263800	*	8		8								8		A
58	264000	*	8		8			9					8		A
59	264100	*	9		9			9					9		A
60	264495	*	8		8			8					8		A
61	266200	*	9		9			9					9		A
62	266300	*	9		9			9					9		A
63	266480	*	9		9			9					9		A
64	266500	*	9		9			9					9		A
65	267000	*	8		8								8		A
66	268903		8			8,2							8		AP
67	270500	*	8										8		A
68	273000		8			8,2		4					8		AP
69	273200		8			8,2							8		AP
70	273300		8			8,2							8		AP
71	274000	*	8			8							8		A
72	274495	*	8										8		A
73	274500	*	8			8							8		A
74	301900	*	10										10		A
75	310800	*	10					10					10		A

1 St. Johns River Water Management District, Greater St. Johns River Basin, redesign of structural controls, upper St. Johns River basin.
2 U.S. Army Corps of Engineers, Jacksonville, Florida District, redesign of structural controls, upper St. Johns River basin.
4 National Stream Quality Accounting Network.
8 South Florida Water Management District, water control in the upper Kissimmee River basin.
9 Reedy Creek Improvement District, water control in the upper Kissimmee River basin.
10 Southwest Florida Water Management, Green Swamp Basin Board.
A Annually.
P Periodically.
T Instantaneously via telemetry.

Table 2.--Data use, source of funding, and frequency of data availability for continuous-record gaging stations in central Florida, 1983--Continued

Map No.	Station No.	Data use: Regional hydrology	Data use: Hydrologic systems	Data use: Legal obligations	Data use: Planning and design	Data use: Project operation	Data use: Hydrologic forecasts	Data use: Water quality monitoring	Data use: Research	Data use: Other	Source of funding: Federal program	Source of funding: OFA program	Source of funding: Co-op program	Source of funding: Other non-federal	Frequency of data availability
76	310947	*	10										10		A
77	311000	*	10										10		A
78	311500	*	11										11		A
79	312000	*	11				12						11		AT
80	312180	*	10										10		A
81	312200	*	10										10		A
82	312500	*	11										11		A
83	312635	*	13		13								13		A
84	312640	*	13		13,11								11		A
85	312645	*	13		13								13		A
86	312667	*	13		13								13		A
87	312690	*	13		13								13		A
88	312700	*	11		13,11			13					11		A
89	312720	*	11		11								11		A
90	312975	*	11			11							11		A
91	313000	*	11,2					4				2			A
92	313100	*	11										11		A
93	313230	*	11,2			11,2		11				2			A
94	313250	*	11,2			11,2		11				2			A

2 U.S. Army Corps of Engineers, Jacksonville, Florida District, redesign of structural controls, upper St. Johns River basin.
4 National Stream Quality Accounting Network.
10 Southwest Florida Water Management, Green Swamp Basin Board.
11 Southwest Florida Water Management District, Withlacoochee River Basin Board, water control in the Withlacoochee River basin.
12 Flood Forcasting, U.S. National Weather Service.
13 Sumter County Recreation and Water Conservation and Control Authority, water control in the Withlacoochee River basin.
A Annually.
T Instantaneously via telemetry.

Legal Obligations

Some stations provide records of flows for the verification or enforcement of existing treaties, compacts, and decrees. The legal obligation category contains only those stations that the Geological Survey is required to operate to satisfy a legal responsibility. There are no stations in the central Florida program that exist to fulfill a legal responsibility of the Geological Survey.

Planning and Design

Gaging stations in this category of data use are used for the planning and design of a specific project (for example, a dam, levee, floodwall, navigation system, water-supply diversion, hydropower plant, or waste-treatment facility) or group of structures. The planning and design category is limited to those stations that were instituted for such purposes and where this purpose is still valid. Currently, 27 stations in the central Florida program are being operated for planning or design purposes.

Project Operation

Gaging stations in this category are used, on an ongoing basis, to assist water managers in making operational decisions such as reservoir releases, hydropower operations, or diversions. The project-operation use generally implies that the data are routinely available to the operators on a rapid-reporting basis. For projects on large streams, data may only be needed every few days. There are 21 stations in the central Florida program that are used in this manner.

Hydrologic Forecasts

Gaging stations in this category are regularly used to provide information for hydrologic forecasting; including flood forecasts for a specific river reach, or periodic (daily, weekly, monthly, or seasonal) flow-volume forecasts for a specific site or region. The hydrologic-forecast use generally implies that the data are routinely available to the forecasters on a rapid-reporting basis. On large streams, data may only be needed every few days. Only one station in the central Florida program is included in the hydrologic forecast category.

Water-Quality Monitoring

Gaging stations where regular water-quality or sediment-transport monitoring is being conducted and where the availability of streamflow data contributes to the utility, or is essential to the interpretation, of the water-quality or sediment data are designated as water-quality-monitoring sites. Twenty-three such stations are a part of the program. Seven are National Stream-Quality Accounting Network (NASQAN) stations, part of a countrywide network designed to assess water-quality trends of significant streams.

Research

Gaging stations in this category are operated for a particular research or water-investigations study. Typically, these are only operated for a few years. No stations in the central Florida program are used in the support of research activities.

Other

Stations in this category provide streamflow information for recreational planning, primarily for canoeists, rafters, and fishermen. No stations in central Florida are found in this category.

Sources of Funding

The two sources of funding for the Florida streamflow-data program are:

1. Other Federal Agency (OFA) program.--Funds that have been transferred to the Geological Survey by OFA's.

2. Cooperative program.--Funds that come jointly from Geological Survey cooperative-designated funding and from a non-Federal cooperating agency. Cooperating agency funds may be in the form of direct services or money.

In both categories, the identified sources of funding pertain only to the collection of streamflow data; sources of funding for other activities, particularly collection of water-quality samples that might be carried out at the site, may not necessarily be the same as those identified herein.

Twelve entities currently are contributing funds to the central Florida stream-gaging program.

Frequency of Data Availability

Frequency of data availability refers to the times at which the streamflow data may be furnished to the users. In this category, three distinct possibilities exist. Data can be furnished by direct-access telemetry equipment for immediate use, by periodic release of provisional data, or in publication format through the annual data report for Florida (U.S. Geological Survey, 1981). These three categories are designated T, P, and A, respectively, in table 2. In the current central Florida program, data for all 94 stations are made available through the annual report, data from 2 stations are available on a real-time basis, and data from 7 stations are released on a periodic, provisional basis.

Conclusions Pertaining to Data Uses

There is no known reason to eliminate any stations from further analysis because: all stations have been identified as having valid and needed uses (table 2); all stations are properly funded; and no short-term project stations exist within the stream-gaging program. Therefore, all gaging stations will be considered in the next analysis--flow routing and regression.

Based on consultation with cooperating agencies, the distribution of gaging stations shown in figure 3 is believed to be sufficient to describe hydrologic conditions in the area at this time. Several sites at Inglis Dam on the Withlacoochee River could be unified into one station through the use of new equipment and communication lines, known collectively as dam monitoring equipment. Telecommunication equipment would probably prove beneficial in the Kissimmee River basin for determining if recorders are working properly. This would prevent excessive downtime, which at present can be determined only by physically driving to the site.

ALTERNATIVE METHODS OF DEVELOPING STREAMFLOW INFORMATION

The second step of the analysis of the stream-gaging program is to investigate alternative methods of providing daily streamflow information instead of operating continuous-record gaging stations. The objective of the analysis is to identify gaging stations where alternative technology, such as flow-routing or statistical methods, will provide information about daily mean streamflow in a more cost-effective manner than operating a continuous-record gaging station. No guidelines exist concerning suitable accuracies for particular uses of the data; therefore, judgment is required in deciding whether the accuracy of the estimated daily flows is suitable for the intended purpose. The data uses at a station will influence whether a site has potential for alternative methods. For example, those stations for which flood hydrographs are required in a real-time sense, such as hydrologic forecasts and project operation, are not candidates for the alternative methods. Likewise, there might be a legal obligation to operate an actual gaging station that would preclude utilizing alternative methods. The primary candidates for alternative methods are stations that are operated upstream or downstream of other stations on the same stream. The accuracy of the estimated streamflow at these sites may be suitable because of the high redundancy of flow information between sites. Similar watersheds, located in the same physiographic and climatic area, also may have potential for alternative methods.

All stations in the central Florida stream-gaging program were categorized as to their potential utilization of alternative methods and selected methods were applied at 11 stations that best meet the criteria as candidates for simulation. The categorization of gaging stations and the application of the specific methods are described in subsequent sections of this report. This section briefly describes the two alternative methods that were used in the central Florida analysis and documents why these specific methods were chosen.

Desirable attributes of a proposed alternative method are (1) the proposed method should be computer oriented and easy to apply, (2) the proposed method should have an available interface with the Geological Survey WATSTORE Daily Values File (Hutchinson, 1975), (3) the proposed method should be technically sound and generally acceptable to the hydrologic community, and (4) the proposed method should permit easy evaluation of the accuracy of the simulated streamflow records. The above selection criteria were used to select two methods--a flow-routing model and multiple-regression analysis.

Description of Flow-Routing Model

Hydrologic flow-routing models use the law of conservation of mass and the relation between the storage in a reach and the outflow from the reach. The hydraulics of the system are not considered in hydrologic models. The method usually requires only a few parameters and treats the reach in a lumped sense without subdivision. The input is usually a discharge hydrograph at the upstream end of the reach, and the output is a discharge hydrograph at the downstream end. Several different types of hydrologic models are available, such as Muskingum, Modified Puls, Kinematic Wave, and the unit-response.

The unit-response model was selected for this analysis because it fulfills the criteria noted above. Calibration and verification of the unit-response flow-routing model is achieved using observed upstream and downstream hydrographs, and estimates of tributary inflows. Downstream hydrographs are produced by the convolution of upstream hydrographs with their appropriate unit-response functions. The convolution technique treats a stream reach as a linear one-dimensional system in which the output (downstream hydrograph) is computed by multiplying the ordinates of the upstream hydrograph by the unit-response function and lagging the results appropriately. The model has the capability of combining hydrographs, multiplying a hydrograph by a ratio, and changing the time base of a hydrograph, although in this analysis, the model is only used to route an upstream hydrograph to a downstream point. Routing can be accomplished using hourly data, but only daily data are used in this analysis. An advantage of this method is that it can be used for flows through regulated stream systems, as well as reservoirs, if the operating rules of the reservoir are known.

Two mathematical concepts can be used to produce convolution within the unit-response method: storage-continuity (Sauer, 1973) and diffusion analogy (Keefer, 1974; Keefer and McQuivey, 1974). The objective in either case is to calibrate two parameters that describe the storage-discharge relation in a given reach and the traveltime of flow passing through the reach. In the storage-continuity concept, a response function is derived by modifying a translation hydrograph technique developed by Mitchell (1962) to apply to open channels. A triangular pulse (Sauer, 1973) is routed through reservoir-type storage and then transformed by a summation curve technique to a unit response of desired duration. The two parameters that describe the routing reach are K_s, a storage coefficient which is the slope of the storage-discharge relation, and W_s, the translation hydrograph time base. These two parameters determine the shape of the resulting unit-response function.

In the diffusion analogy concept, the two parameters requiring calibration are K_o, a wave dispersion or damping coefficient, and C_o, the floodwave celerity. K_o controls the spreading of the wave (analogous to K_s in the storage-continuity method) and C_o controls the traveltime (analogous to W_s in the storage-continuity method). Two methods are available within the diffusion analogy for defining the system's response function: single response and multiple response. Selection of the appropriate response depends primarily upon the variability of wave celerity (traveltime) and dispersion (channel storage) throughout the range of discharges to be routed. Adequate routing of daily flows can usually be accomplished using a single unit-response function (linearization about a single discharge) to represent the system response. However, if the routing coefficients vary drastically with discharge, linearization about a low-range discharge results in overestimated high flows that arrive late at the downstream site; and, linearization about a high-range discharge results in low-range flows that are underestimated and arrive too soon. A single unit-response function may not provide acceptable results in such cases. Therefore, the approach of multiple linearization (Keefer and McQuivey, 1974), which uses a family of unit-response functions to represent the system response, is available. In the single linearization method, only one K_o and C_o value are used. In the multiple linearization method, C_o and K_o

are varied with discharge so that a table of wave celerity (C_0) versus discharge (Q) and a table of dispersion coefficient (K_0) versus discharge (Q) are used.

In both the storage-continuity and diffusion-analogy approaches, the two parameters are calibrated by trial and error. The analyst must decide if suitable parameter values have been derived by comparing the simulated discharge to the observed discharge.

Determination of the system's response to the input at the upstream end of the reach is not the total solution for most flow-routing problems. The convolution process makes no accounting of flow from the intervening area between the upstream and downstream locations. Such flows may be unknown but they can usually be estimated using some combination of gaged and ungaged flows. An estimating technique that proves satisfactory in many instances is the multiplication of known flows at an index gaging station by a factor, such as a drainage-area ratio.

Description of Regression Analysis

Simple- and multiple-regression techniques can also be used to estimate daily flow records. Regression equations can be computed that relate daily flows (or their logarithms) at a single station to daily flows at a combination of upstream, downstream, and (or) tributary stations. This statistical method is not limited, like the flow-routing modeling, to stations where an upstream station exists on the same stream. The explanatory variables in the regression analysis can be stations from different watersheds, or downstream and tributary watersheds. The regression method has many of the same attributes as the flow-routing method in that it is easy to apply, provides indices of accuracy, and is generally accepted as a good tool for estimation. The theory and assumptions of regression analysis are described in several textbooks such as Draper and Smith (1966) and Kleinbaum and Kupper (1978). The application of regression analysis to hydrologic problems is described and illustrated by Riggs (1973) and Thomas and Benson (1970). Only a brief description of regression analysis is provided in this report.

A linear regression model of the following form was developed for estimating daily mean discharges in central Florida:

$$y_i = B_o + \sum_{j=1}^{p} B_j x_j + e_i \quad (1)$$

where

y_i = daily mean discharge at station i (dependent variable),

x_j = daily mean discharges at nearby stations (explanatory variables),

B_o and B_j = regression constant and coefficients, and

e_i = the random error term.

The above equation is calibrated (B_o and B_j are estimated) using observed values of y_i and x_j. These observed daily mean discharges can be retrieved from the WATSTORE Daily Values File. The values of x_j may be discharges observed on the same day as discharges at station i or may be for previous or following days, depending on whether station j is upstream or downstream of station i. Once the equation is fitted and verified, future values of y_i are estimated using observed values of x_j. The regression constant and coefficients (B_o and B_j) are tested to determine if they are significantly different from zero. A given station j should only be retained in the regression equation if its regression coefficient (B_j) is significantly different from zero.

The regression equation (statistical model) should be fitted (calibrated) using data from one time period and then verified or tested on data from a different period of time to obtain a measure of the true predictive accuracy. Both the calibration and verification period should be representative of the range of flows that could occur at station i. The equation should be verified by (1) plotting the residuals e_i (difference between simulated and observed discharges) against the dependent and all explanatory variables in the equation, and (2) plotting the simulated and observed discharges versus time. These plots are used to identify if (1) the linear model is appropriate, or whether some transformation of the variables is needed, and (2) there is any bias in the equation, such as overestimating low flows.

It should be noted that the use of a regression relation to synthesize data at a discontinued gaging station entails a reduction in the variance of the streamflow record relative to that which would be computed from an actual record of streamflow at the site. This is because the variance of the original data which can not be explained by the regression equation, will not be found in the newly generated data. The reduction in variance expressed as a fraction is approximately equal to one minus the square of the correlation coefficient that results from the regression analysis.

Categorization of Gaging Stations by their Potential for Alternative Methods

An analysis of the data uses (presented in table 2) identified 35 stations at which the needed streamflow data could possibly be provided by alternative methods. Simulation of the flow at eight of these stations and of the sum of the three stations comprising the outflow from Lake Rousseau was attempted using flow-routing techniques or regression methods or both. Listed below are the stations for which simulation of the flow was attempted, with the stations used for model input indented under the station simulated.

- 232500 St. Johns River near Christmas
  - 232400 St. Johns River near Cocoa
  - 231600 Jane Green Creek near Deer Park
- 240000 Oklawaka River near Conner
  - 238500 Oklawaha River at Moss Bluff
  - 239500 Silver Springs near Ocala
  - 243000 Orange Creek at Orange Springs
- 240500 Oklawaha River at Eureka
  - 240000 Oklawaha River near Conner
  - 239500 Silver Springs near Ocala
  - 243000 Orange Creek at Orange Springs
- 243000 Orange Creek at Orange Springs
  - 242451 Orange Lake Outlet near Citra
  - 242500 Lockloosa Slough near Lochloosa
  - 245500 South Fork Black Creek near Penney Farms
- 312500 Withlacoochee River at Croom
  - 312000 Withlacoochee River at Trilby
  - 312200 Little Withlacoochee River at Rerdell
- 312645 Jumper Creek Canal near Wahoo
  - 312640 Jumper Creek Canal near Bushnell
- 312720 Withlacoochee River at Wysong Dam at Carlson
  - 312500 Withlacoochee River at Croom
  - 312640 Jumper Creek Canal near Bushnell
  - 312700 Outlet River at Panacoochee Retreats
- 313000 Withlacoochee River near Holder
  - 312700 Outlet River at Panacoochee Retreats
  - 312720 Withlacoochee River at Wysong Dam
  - 312975 Tsala Apopka Outfall Canal at S-353
  - 313100 Rainbow Springs near Dunnellon

313230 Withlacoochee River at Inglis Dam
313237 Cross Florida Barge Canal at Inglis Lock
313250 Withlacoochee River Bypass Canal near Inglis
(Sum of above 3 stations equals Lake Rousseau surface outflow)
313000 Withlacoochee River near Holder
313100 Rainbow Springs near Dunnellon

Calibration of Models

The best result obtained for calibration periods ranging from 1 to 3 years using flow-routing techniques and regression methods for each station is given in table 3.

Under the heading "Accuracy of field data and computed results" in "Water Resources Data for Florida, 1981," the following categories of accuracy and their meanings are stated. "Excellent" means that about 95 percent of the daily discharges are within 5 percent; "good" within 10 percent; "fair" within 15 percent; and "poor" greater than 15 percent. An evaluation of the modeling results can be performed by comparing the group of rows in table 3 labeled "percent of days with errors not more than" against the above standards. For each station find the row having the value of 95 percent, which is the percent of days mentioned in the standards. Move horizontally to the leftmost column to determine the percentage of error in the simulated data. For example, station 240500, when simulated using the flood-routing technique, had 95 percent of days within 15 percent error.

Table 3 indicates that simulated discharges obtained using flow-routing and regression techniques for calibration periods could not meet the criteria for "excellent" or "good" accuracy. In fact, only four of the nine stations could approximate the criterion for "fair" accuracy, $\leq$ 15 percent. All of the stations for which the best simulated discharges qualified as "fair" are stations that have very high and stable base flow and are subject to rapidly changing discharge on a relatively small percentage of days. A brief discussion of each of the four stations that approximated the "fair" accuracy rating for at least one year follows.

<u>240000 Oklawaha River near Conner, Florida</u>.--The majority of the flow at this site is gaged at Moss Bluff 13.3 miles upstream, and in Silver River, which joins the Oklawaha River 0.2 mile upstream of the station (fig. 4). Silver River conveys to the Oklawaha River the flow of Silver Springs and a small amount of surface inflow from the intervening area along Silver River. The flow at Silver Springs (239500) includes the flow from the main vent at the head of the river and the flow from numerous secondary vents between the head and the measuring section 3 miles downstream. The flow at Moss Bluff is completely regulated by a moveable gate structure, whereas the flow of Silver River is unregulated and relatively uniform, with extremes of flow differing from the mean by about 50 percent. The records for this station are rated as "good."

Table 3.--Best overall simulation of daily flows using flow-routing and regression techniques at selected gaging stations during calibration

Station No.	232500	240000	240500	240500	243000	312500	312645	312720	313000	313230 313237 313250
Technique	F	F	F	R	F	F	F	F	F	F
Total number of days	366	1096	1096	1096	366	366	366	365	365	365
Mean absolute error for total days, in percent	14.8	4.83	4.60	5.62	10.8	11.5	16.8	9.58	6.80	7.64
Number of days with negative error	147	563	484	169	240	263	166	172	146	151
Mean negative error, in percent	8.59	5.33	5.76	3.11	11.3	14.4	19.9	8.58	7.46	6.04
Number of days with positive error	219	533	612	927	126	103	200	193	219	214
Mean positive error, in percent	18.9	4.31	3.69	6.08	9.77	4.27	14.2	10.5	6.37	8.77
Total volume error, in percent	5.76	1.26	-1.75	-5.20	-4.93	-3.38	1.12	0.82	1.01	1.75
Percent of days with errors not more than										
5 percent	21	66	69	60	43	37	17	34	39	39
10 percent	39	87	90	88	66	54	43	61	80	76
15 percent	53	94	95	94	76	66	58	75	94	90
20 percent	71	98	97	97	83	78	72	88	99	94
25 percent	83	99	98	98	87	88	81	95	100	95
Percent of days with errors more than 25 percent	17	1	2	2	13	12	19	5	0	5

F - Flow-routing techniques
R - Regression methods

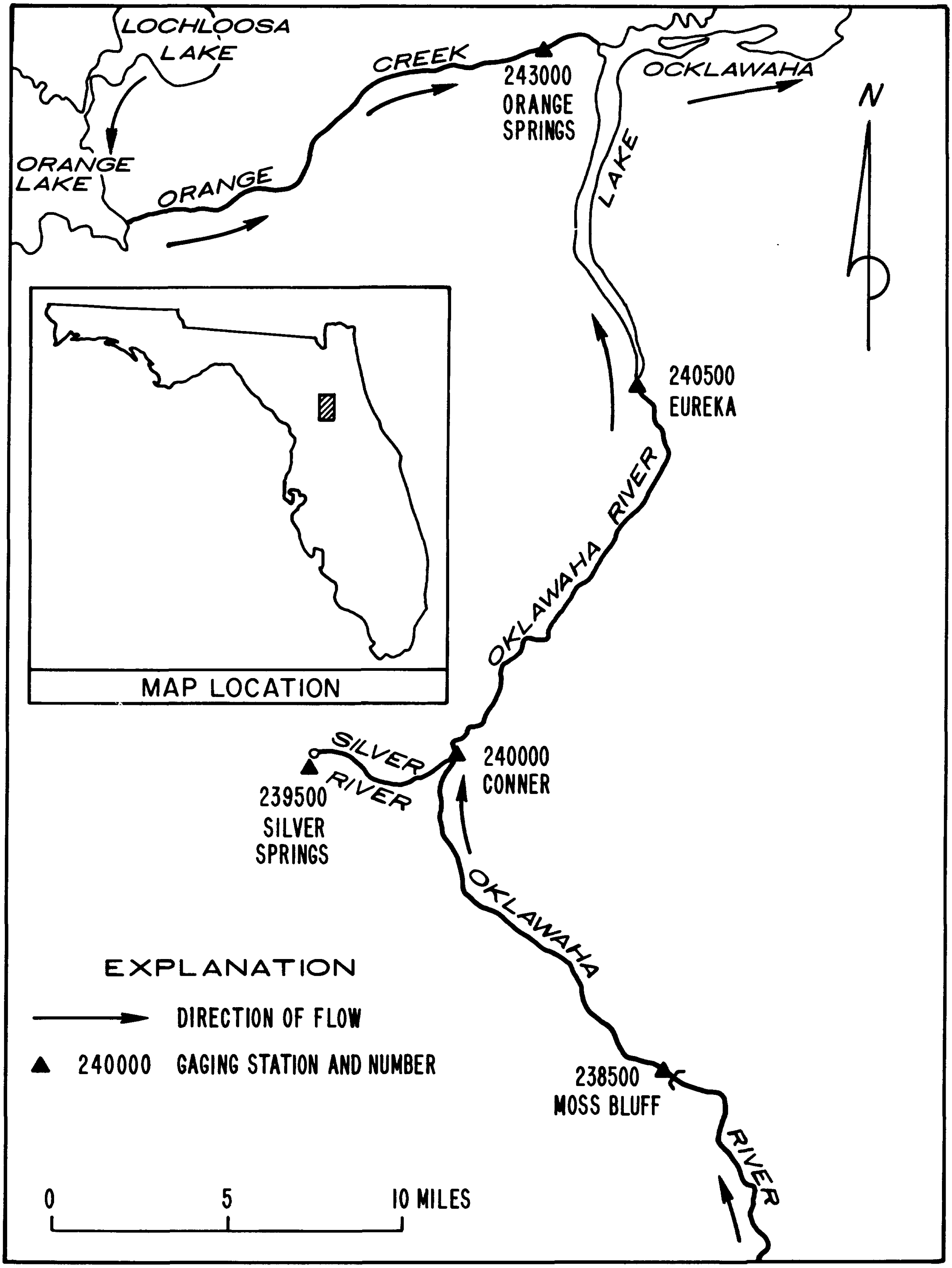

Figure 4.--The Conner and Eureka study areas.

The reach was modeled two times, first by using Moss Bluff and Silver Springs as input with intervening inflow added as a percentage of Silver Springs flow; and second by using Moss Bluff and Silver Springs as input, but intervening inflow was computed as a percentage of the flow for Orange Creek at Orange Springs. There was little difference in the results of the calibration of the two models. Therefore, both models were used for the verification process.

As shown in table 4, the daily mean simulated flows using Silver Springs for estimating intervening flow meet the criterion for "fair" records for each of the 7 years and have a single-year minimum of 91 percent at the 15-percent level. Simulated flows for water years 1978, 1979, and 1981 are shown in figures 5, 6, and 7. As can be seen in the figures, most of the errors exceeding the 10-percent "good" rating occur during periods of rapidly changing discharge. This indicates the lack of a good estimate of the ungaged inflow.

240500 Oklawaha River at Eureka, Florida.--This station is 17.9 miles downstream from the station at Conner (fig. 4). Intervening inflow is derived from swamps at elevations from 5 to 30 feet higher than the river and from the Floridan aquifer. The surface-water component of intervening inflow is much more variable than the ground-water component. Thus, the proportion of the total inflow from the two sources changes in relation to hydrologic conditions with surface water predominating during and immediately following periods of heavy rainfall, and ground water predominating during periods of sparse rainfall. The observed records for this station are rated "good."

Flow at this station was simulated by flow-routing techniques using the Conner station and Orange Springs station to estimate intervening flow, with the Conner station giving a slightly better result. The flow was also simulated using regression methods with less success than achieved by flow routing.

In the calibration process the simulated flow met the criterion for "fair" records with 95 percent of the values within 15 percent (table 4). But during verification the results for 1933, 1981, and 1982, were less than "fair." Most of the error exceeding 5 to 10 percent was concentrated on days when the discharge was changing rapidly, as can be seen in figures 8, 9, and 10. This indicates the lack of a good basis for estimating the ungaged inflow.

313000 Withlacoochee River near Holder, Florida.--This station is 17 miles downstream from the major input station at Wysong dam (fig. 11). The river overflows its banks at medium stage and spreads out over a wide wooded flood plain. When the river rises quickly, water from the river probably enters the limestone aquifer over which it flows in this reach. Thus, there may be two dispersion factors which are difficult to evaluate. The celerity of flood waves are probably highly dependent on the rate of change in stage for any given discharge. Records for this station are rated "good."

Flow at this station was simulated using flow-routing techniques for a wet period and a dry period using three stations for estimating ungaged inflow. The best result, which nearly satisfied the criterion for "fair" records, was

Table 4.--Results of application of four flow routing models that met criterion for "fair" record during calibration period

Water year or period	Total number days	Mean absolute error for total days (pct.)	Number of days with negative error	Mean negative error (pct.)	Number of days with positive error	Mean positive error (pct.)	Total volume error (pct.)	Percent of days with errors not more than indicated percent				
								5	10	15	20	25
240000 Oklawaha River near Conner, Fla. (calibration period, 10-01-43 to 09-30-46)												
Orange Creek used to estimate intervening flow												
Calibration	1096	4.83	563	5.33	533	4.31	-1.26	66	87	94	98	99
1944	366	4.30	156	6.04	210	3.00	-1.46	72	90	96	98	98
1945	365	4.76	203	5.81	162	3.46	-3.06	69	89	94	97	100
1946	365	5.44	204	4.32	161	6.86	0.31	58	83	90	98	99
1978	365	10.23	197	9.58	168	10.98	0.49	24	65	80	87	92
1979	365	6.57	58	10.75	307	5.78	0.73	43	85	94	96	98
1980	366	6.46	99	7.44	267	6.09	1.23	40	83	97	98	99
1981	365	4.50	260	5.44	105	2.18	-3.28	62	88	98	99	100
Silver Springs used to estimate intervening flow												
Calibration	1096	5.58	627	6.53	469	4.31	-3.25	52	89	96	97	99
1944	366	5.05	98	8.30	268	3.87	-0.05	56	92	96	98	98
1945	365	6.37	199	7.13	166	5.46	-3.36	48	84	94	96	98
1946	365	5.31	330	5.64	35	2.23	-5.24	51	92	98	99	100
1978	365	7.41	228	8.46	137	5.66	-3.57	40	78	91	94	96
1979	365	7.05	86	9.78	279	6.21	-0.19	40	81	93	95	97
1980	366	5.25	126	6.97	240	4.36	-0.84	56	89	97	98	99
1981	365	3.61	174	5.17	191	2.18	-1.40	78	93	98	99	100
240500 Oklawaha River at Eureka, Fla. (calibration period, 10-1-43 to 9-30-46)												
Calibration	1096	4.60	484	5.76	612	3.69	-1.75	69	90	95	97	98
1931	365	6.37	80	3.71	285	7.11	4.34	41	76	99	100	100
1932	366	4.63	74	3.23	292	4.98	3.49	54	98	100	100	100
1933	365	6.83	129	9.99	236	5.11	-5.31	48	86	90	93	96
1934	365	7.72	122	8.79	243	7.18	-0.91	30	74	95	98	98
1944	366	4.51	163	4.88	203	4.20	-0.19	70	88	95	97	99
1945	365	5.32	130	9.22	235	3.16	-3.98	68	87	93	94	96
1946	365	3.98	191	4.14	174	3.81	-0.91	70	95	98	99	100
1981	243	7.32	1	22.27	242	7.25	7.01	23	86	88	97	100
1982	365	10.91	129	12.33	236	10.13	-4.61	27	56	76	90	93

Table 4.--Results of application of four flow routing models that met criterion for "fair" record during calibration period--Continued

Water year or period	Total number days	Mean absolute error for total days (pct.)	Number of days with negative error	Mean negative error (pct.)	Number of days with positive error	Mean positive error (pct.)	Total volume error (pct.)	Percent of days with errors not more than indicated percent: 5	10	15	20	25
313000 Withlacoochee River near Holder, Fla. (calibration period 10-1-69 to 9-30-70)												
calibration (see 1970 water year)												
1966	365	10.26	340	10.26	25	3.90	-9.94	23	54	76	94	98
1967	365	9.03	261	10.75	104	4.72	-7.31	33	65	78	90	96
1968	366	15.48	118	7.32	248	19.36	6.10	25	51	63	70	74
1969	365	10.73	324	11.42	41	5.27	-9.16	16	46	80	92	99
1970	365	6.80	146	7.46	219	6.37	1.01	39	80	94	99	100
1971	365	16.77	140	8.40	225	21.98	2.49	21	46	64	77	82
1972	366	8.33	183	8.49	183	8.17	-0.84	38	63	85	94	98
1973	365	20.75	137	10.66	228	26.80	14.86	21	44	64	72	76
1974	365	12.08	47	12.47	318	12.02	8.80	17	44	71	87	93
1975	365	26.26	7	3.17	358	26.71	18.86	12	30	42	50	58
1976	366	17.35	125	11.02	241	20.62	2.45	12	28	45	68	77
1977	365	18.37	215	15.08	150	23.08	-6.12	7	26	44	61	74
1978	365	21.95	74	6.18	291	25.96	13.58	15	35	43	55	63
1979	365	9.92	130	6.72	235	11.68	4.01	33	54	72	88	98
1980	366	9.07	158	11.50	208	7.23	-3.18	35	62	83	92	97
313230, 313237, and 313250 Lake Rousseau outflow near Inglis, Fla. (calibration period 1-1-70 to 9-30-71)												
calibration	638	8.69	207	8.47	431	8.80	1.73	35	71	88	93	95
1970	273	10.10	56	15.02	217	8.83	1.72	30	64	84	92	95
1971	365	7.64	151	6.04	214	8.77	1.75	39	76	90	94	95
1972	366	11.16	81	11.82	285	10.97	3.75	26	50	77	88	94
1973	365	10.57	186	9.32	179	11.87	-2.14	40	69	80	89	94
1974	365	9.42	81	10.21	284	9.20	3.82	32	60	84	91	96
1975	365	8.13	76	5.28	289	8.88	6.09	33	67	87	95	99
1976	366	10.65	74	10.30	292	10.74	5.58	26	52	77	89	94
1977	365	8.95	120	7.58	245	9.62	4.44	30	64	84	92	97
1978	365	9.27	164	8.78	201	9.66	2.06	34	63	82	90	95
1979	365	8.82	120	8.30	245	8.33	1.45	40	71	85	90	97
1980	366	11.73	95	10.15	271	12.28	6.68	25	53	75	87	90
1981	365	10.13	92	7.69	272	10.95	6.01	24	50	77	93	98

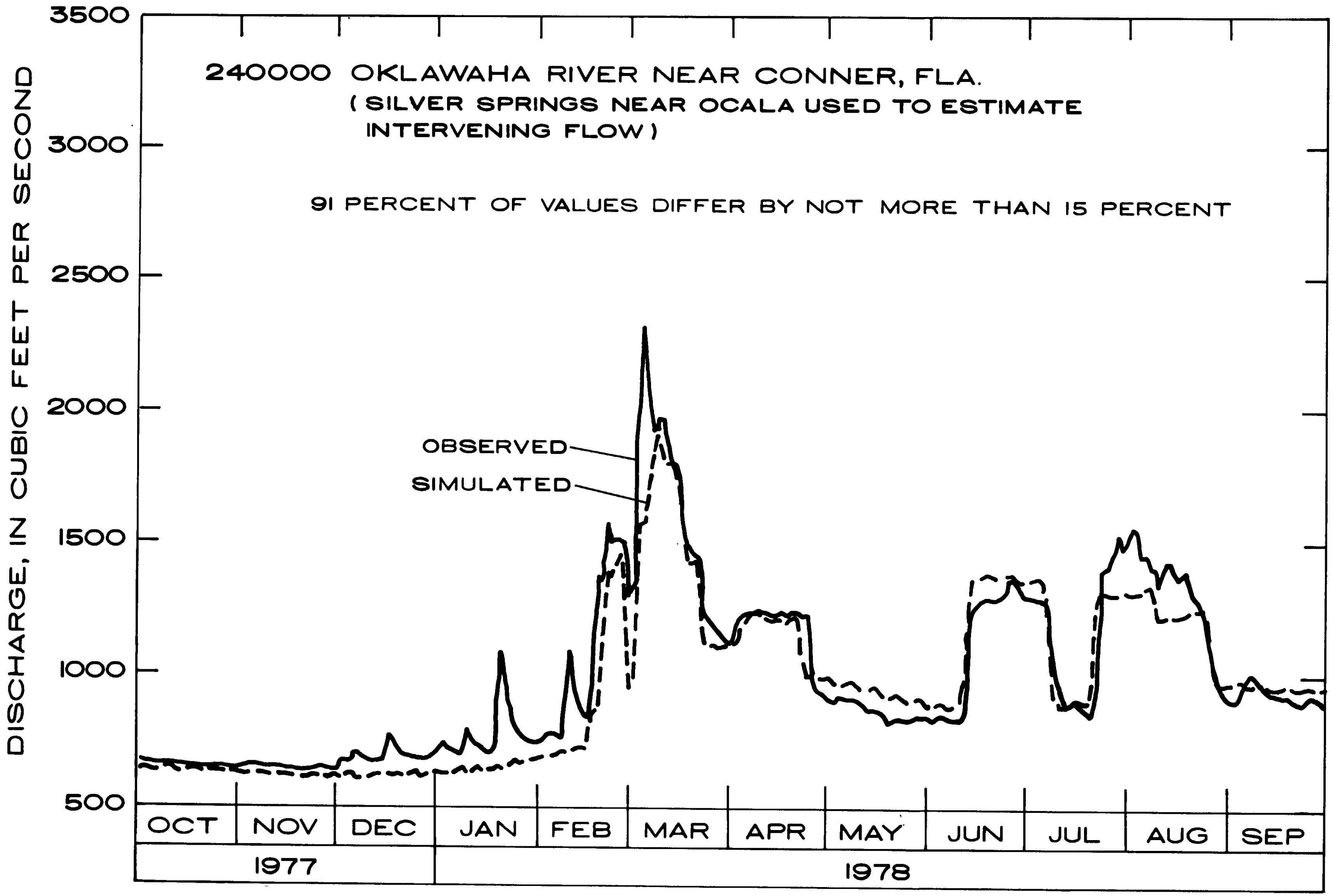

Figure 5.--Simulated and observed daily mean discharges for Oklawaha River near Conner, Florida for the 1978 water year.

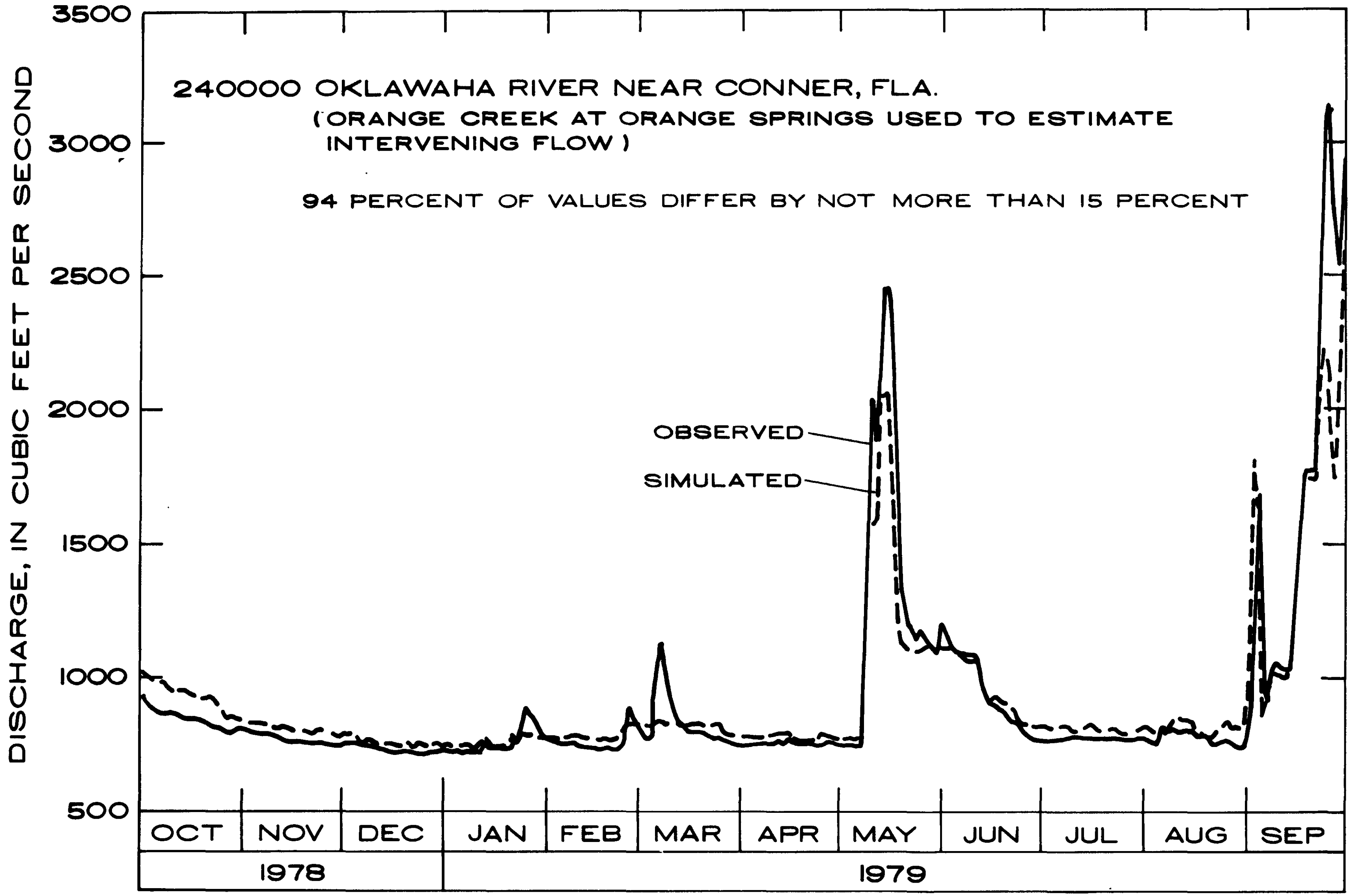

Figure 6.--Simulated and observed daily mean discharges for Oklawaha River near Conner, Florida for the 1979 water year.

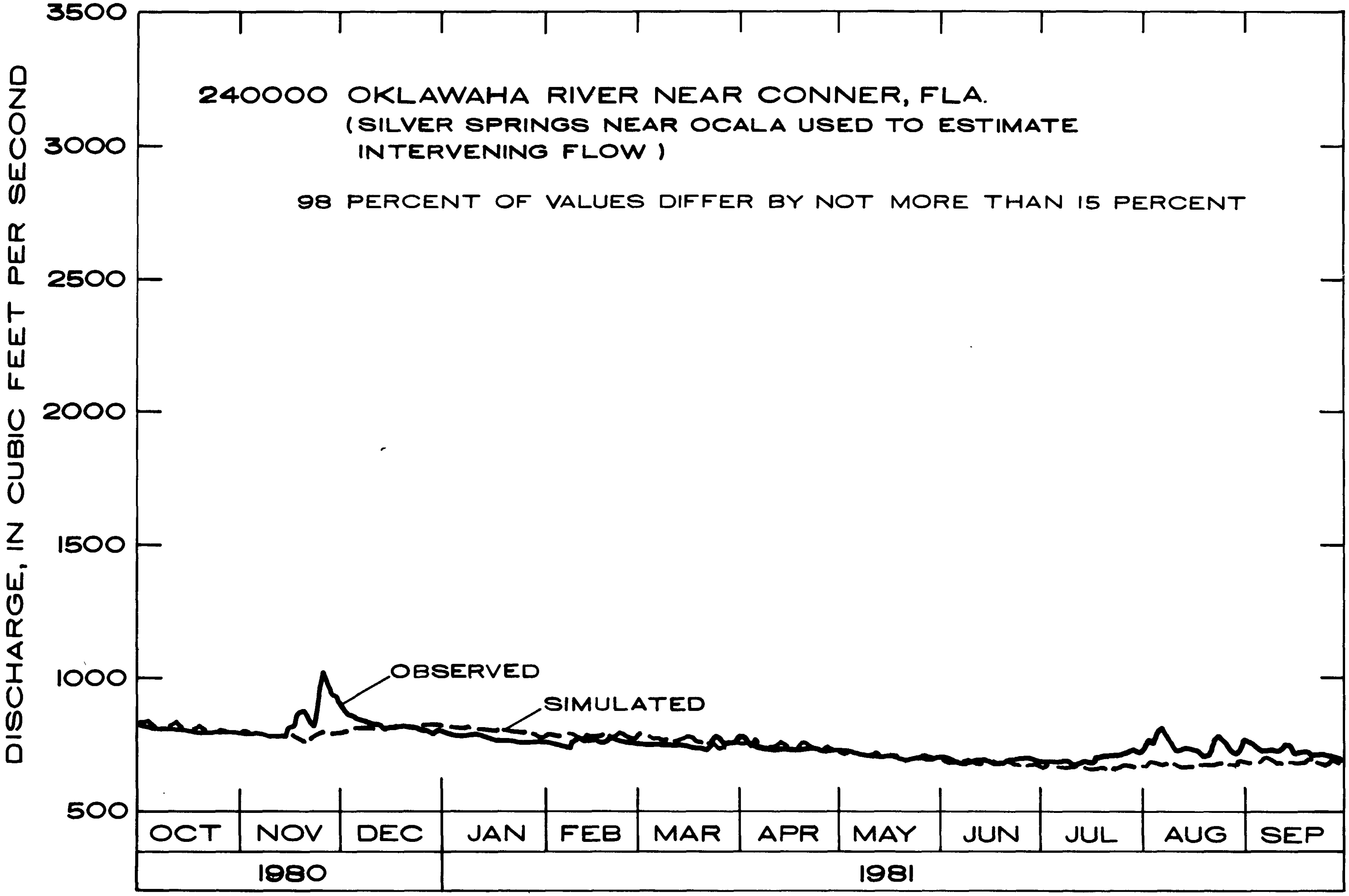

Figure 7.--Simulated and observed daily mean discharges for Oklawaha River near Conner, Florida for the 1981 water year.

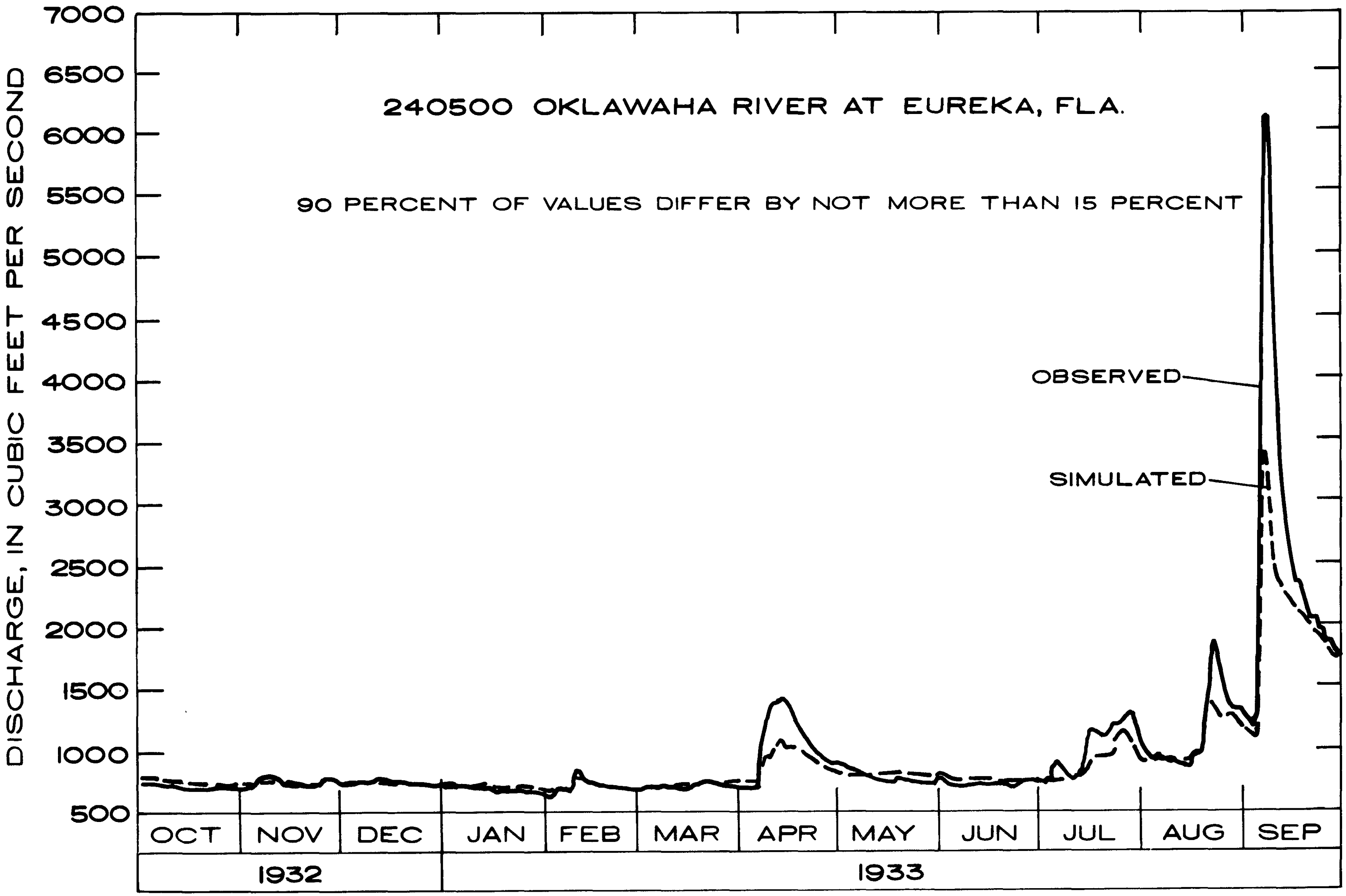

Figure 8.--Simulated and observed daily mean discharges for Oklawaha River at Eureka, Florida for the 1933 water year.

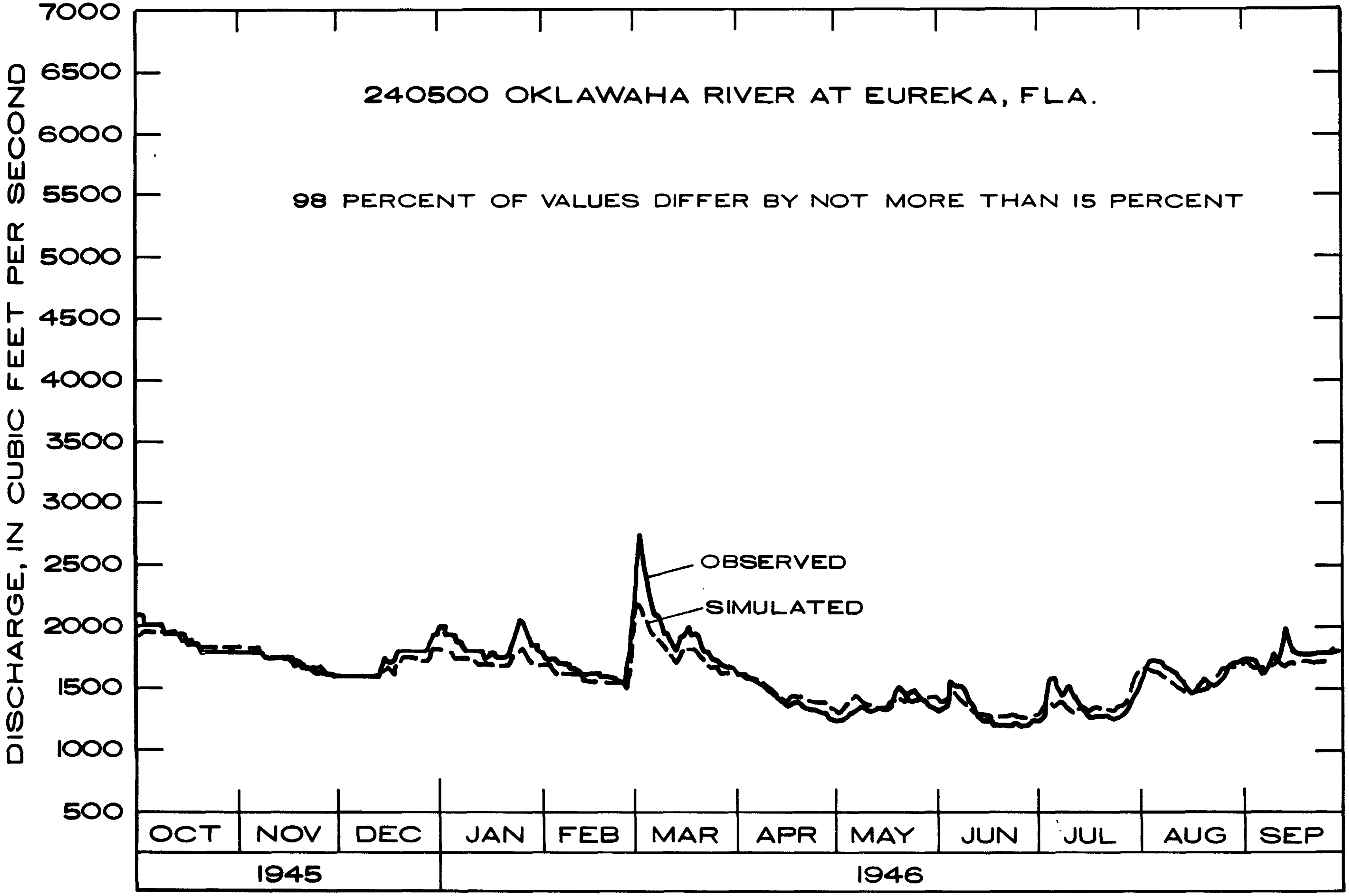

Figure 9.--Simulated and observed daily mean discharges for Oklawaha River at Eureka, Florida for the 1946 water year.

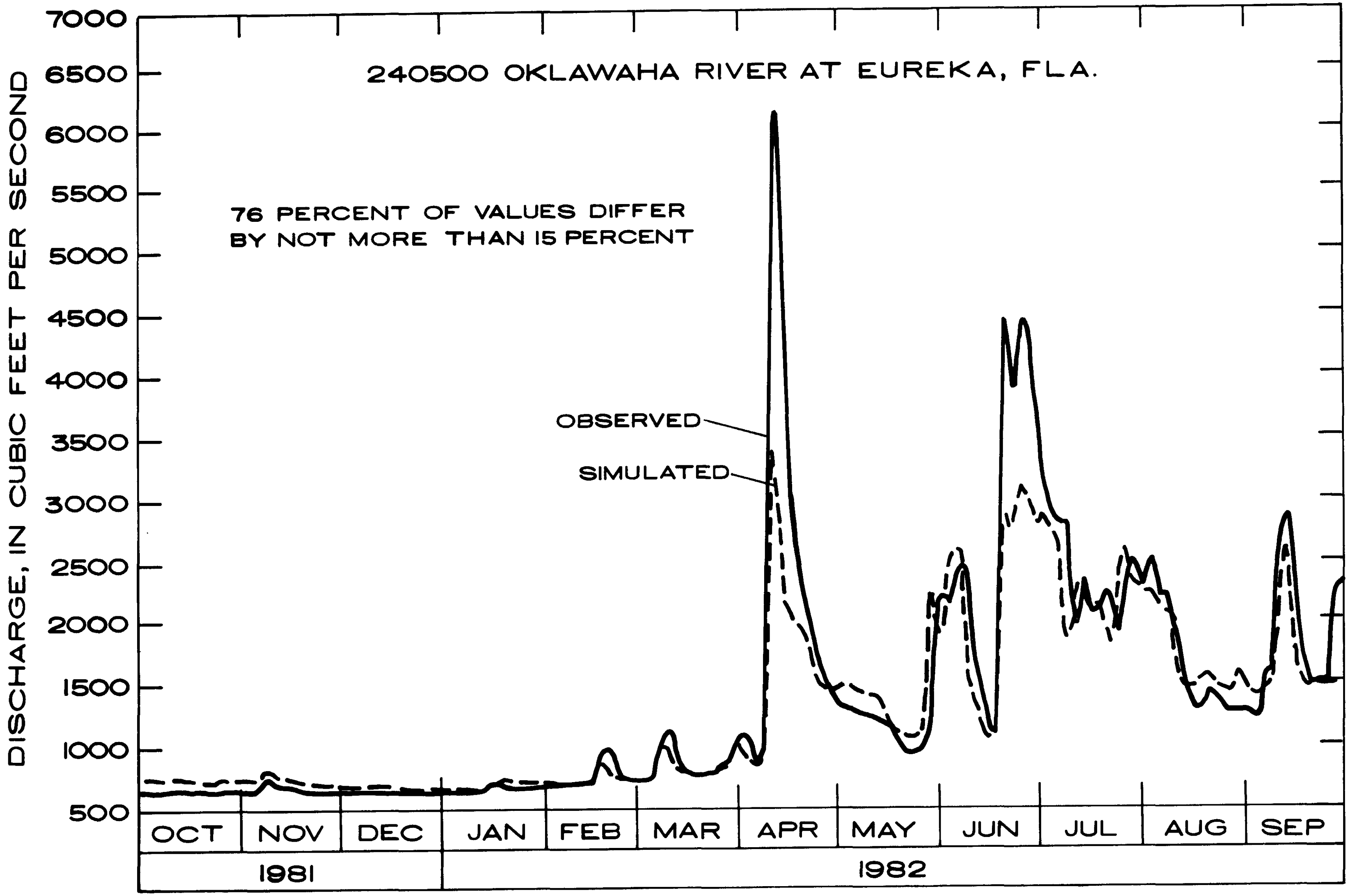

Figure 10.--Simulated and observed daily mean discharges for Oklawaha River at Eureka, Florida for the 1982 water year.

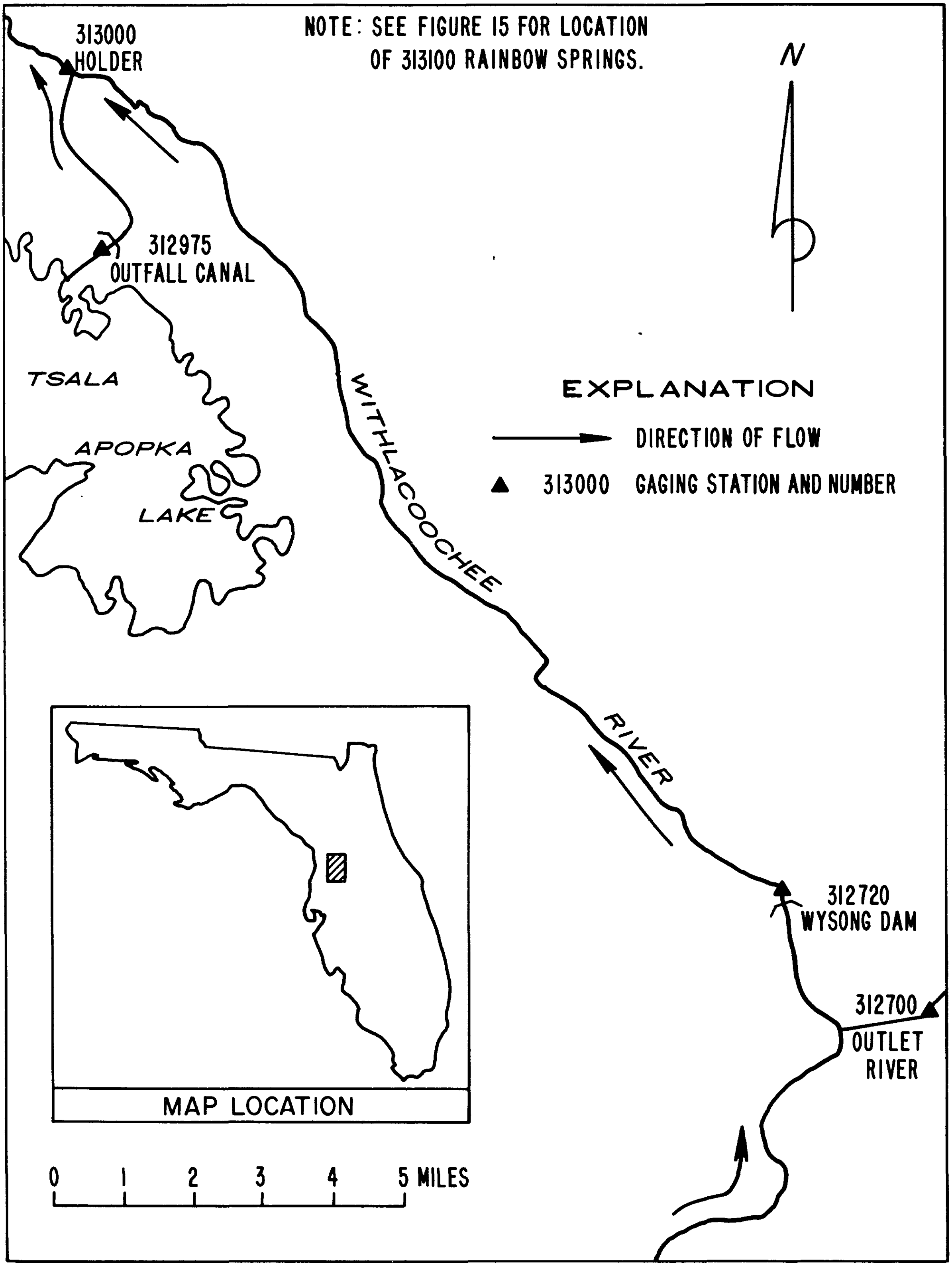

Figure 11.--The Holder study area.

achieved by using data from the Wysong station to simulate surface inflow and Rainbow Springs to simulate ground-water inflow for the wet year 1970. However, when this model was applied to the dry year, 1977, the results were extremely poor. None of the other models gave acceptable results for either wet or dry periods. Most of the larger errors occurred during periods of changing discharge (figs. 12-14).

313230, 313237, 313250 Lake Rousseau outflow.--Flow just downstream of Lake Rousseau is obtained by summing the flows for stations 313230, 313237, and 313250 (fig. 15). Records for these stations are rated "good." Most of the flow is derived from the Withlacoochee River, upstream from Holder, and from Rainbow Springs. Inflow between Holder and Inglis Dam exclusive of Rainbow Springs, probably is less than 15 percent of the outflow from Lake Rousseau. The Holder station is 27 miles upstream from Inglis Dam and 13 miles upstream from Rainbow Springs. Because of the high and fairly uniform base flow of the Withlacoochee at Dunnellon, outflow from Lake Rousseau can be simulated fairly well except during periods of rapidly changing inflow or periods when the control structures at the outflow stations are manipulated, or both (fig. 16 and 17). For the years 1970-81, 95 percent of the daily flows were commonly simulated within 25 percent error (table 4).

Results of Application of the Models

The results of the calibration periods and the results of year-by-year application of the model for each of the sites discussed above are shown in table 4. The 15-percent level, which indicates the acceptability of the results as "fair," was used in evaluating the application of the models. Only in the case of Oklawaha River near Conner, when Silver Springs was used to estimate inflow, was the model successfully applied with "fair" result for the entire period of record.

Conclusions Pertaining to Alternative Methods of Data Generation

The simulated data from both the flow-routing and regression methods for all of the gaging stations tested were not sufficiently accurate to warrant their use instead of data obtained by operating continuous-record gaging stations. It is suggested that all of the stations currently in operation be continued.

The primary cause of failure of the flow-simulating techniques is lack of adequate input data for determining ungaged inflow. A study to determine the efficacy of establishing stations capable of indexing ungaged inflow accurately enough to provide acceptable simulated data may be warranted. The justification of such a step lies in the utility of having records at two or more sites for little more than the cost of one site.

In summary, no stations in the Orlando subdistrict area may be discontinued, and all of the stations will be included in the next step of this analysis.

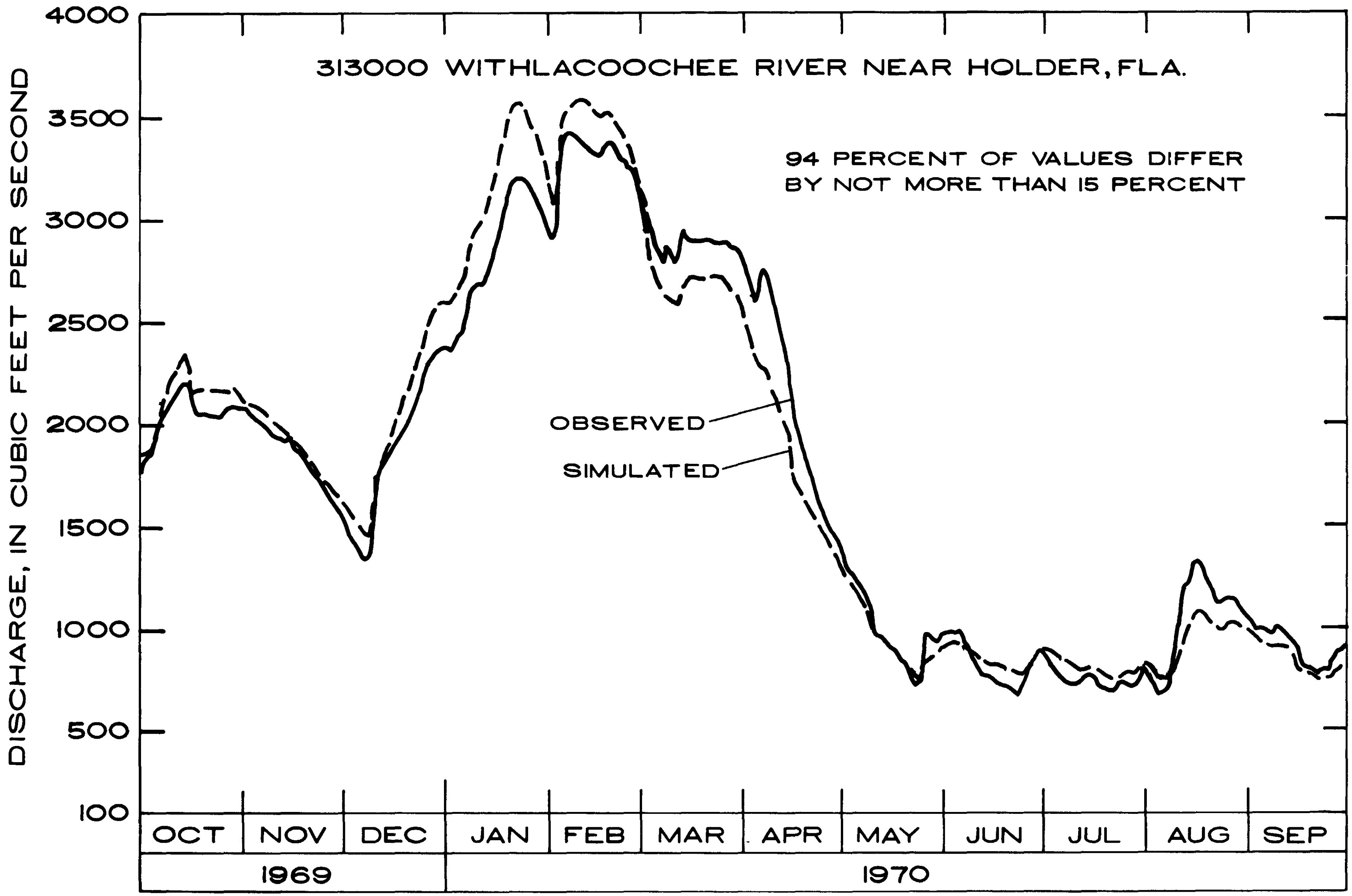

Figure 12.--Simulated and observed daily mean discharges for Withlacoochee River near Holder, Florida for the 1970 water year.

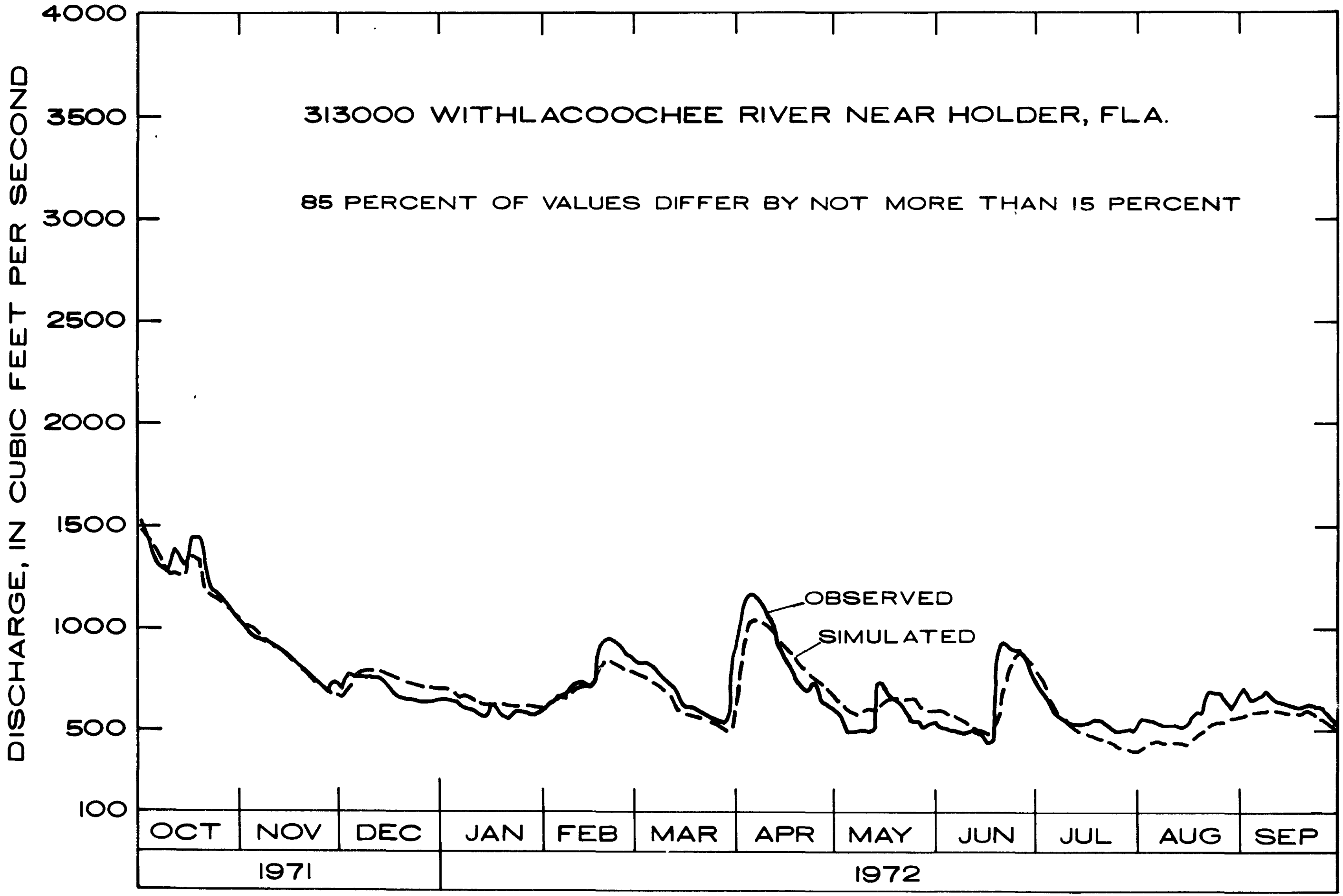

Figure 13.--Simulated and observed daily mean discharges for Withlacoochee River near Holder, Florida for the 1972 water year.

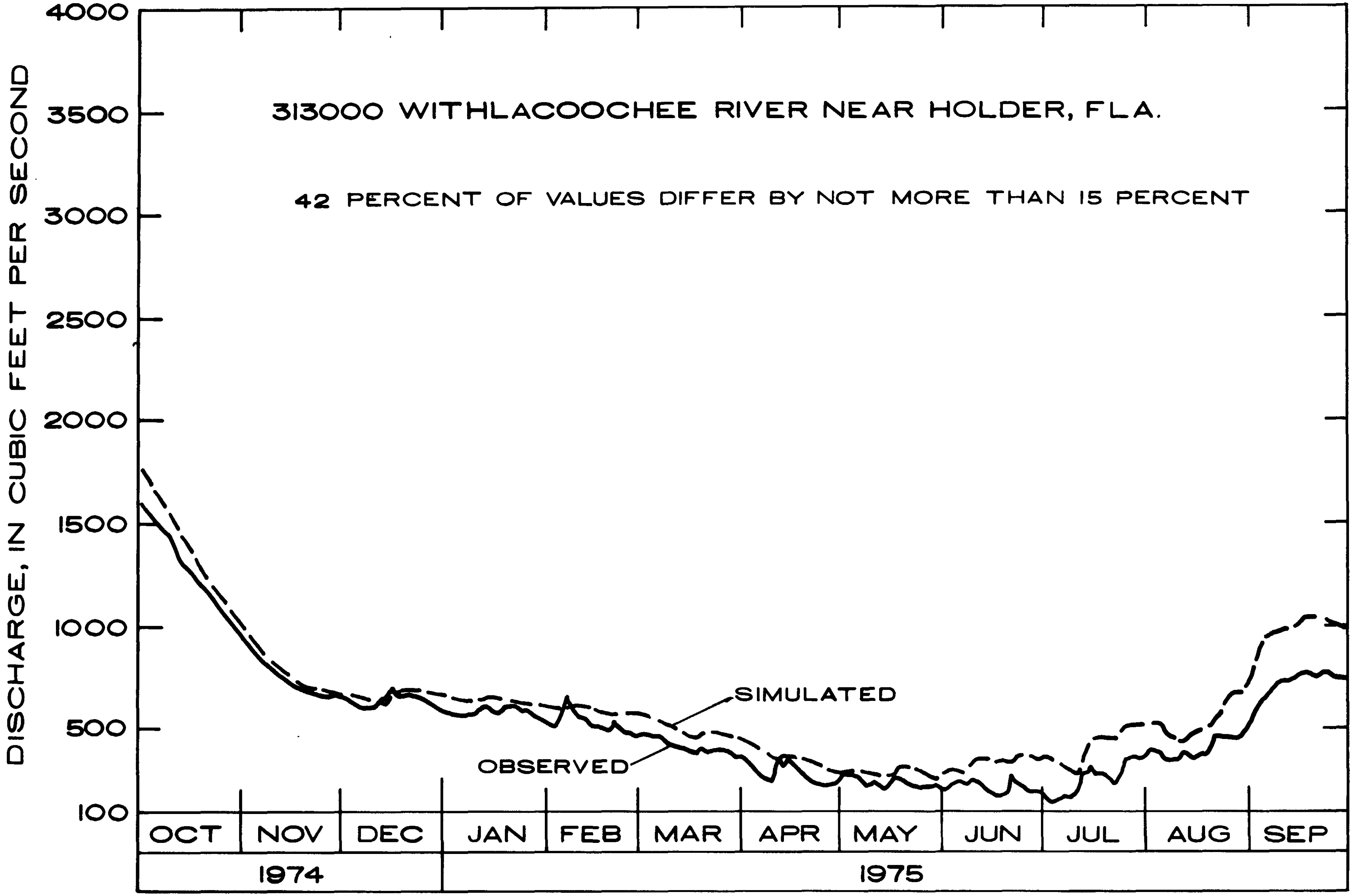

Figure 14.--Simulated and observed daily mean discharges for Withlacoochee River near Holder, Florida for the 1975 water year.

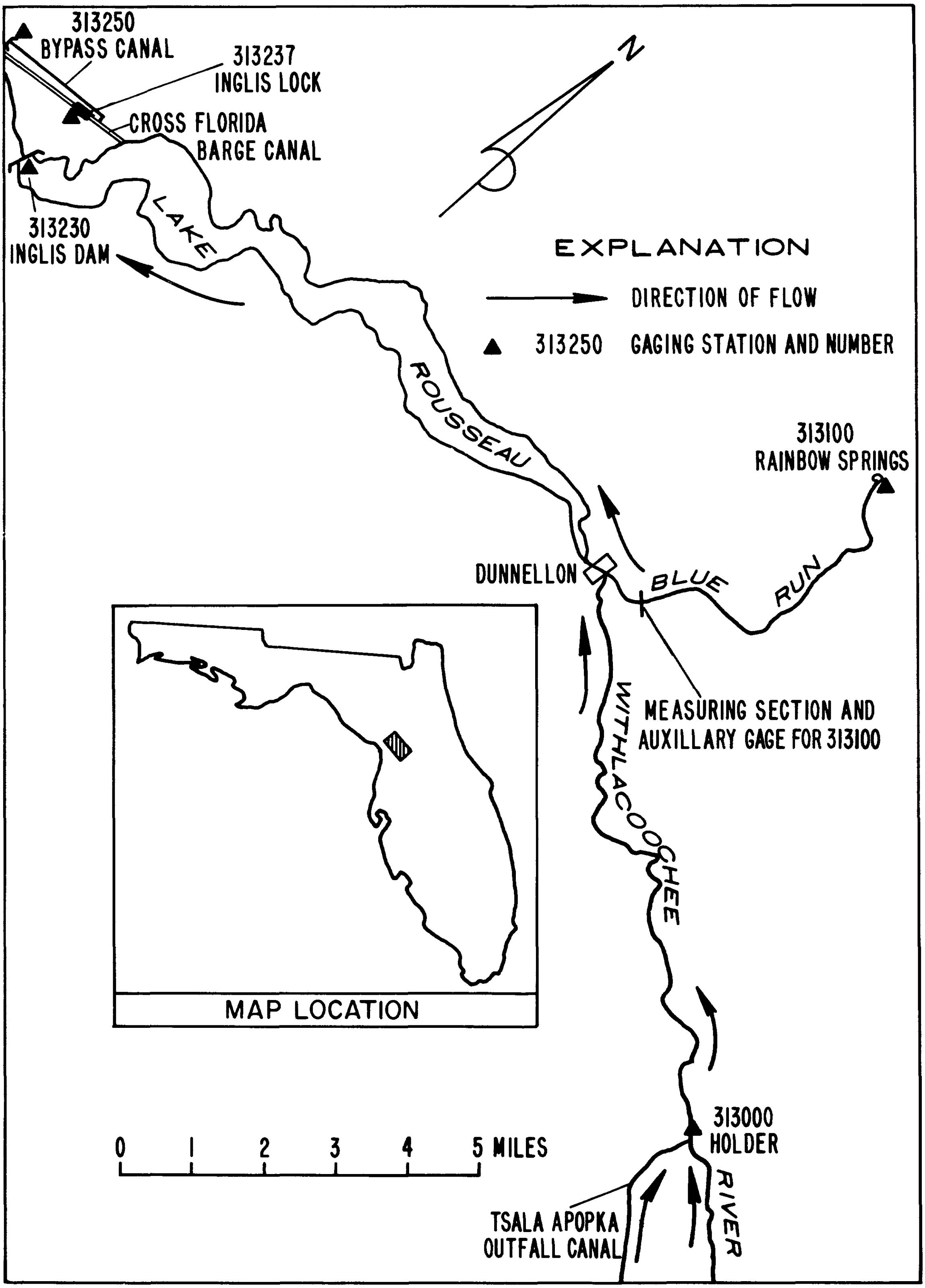

Figure 15.--The Lake Rousseau study area.

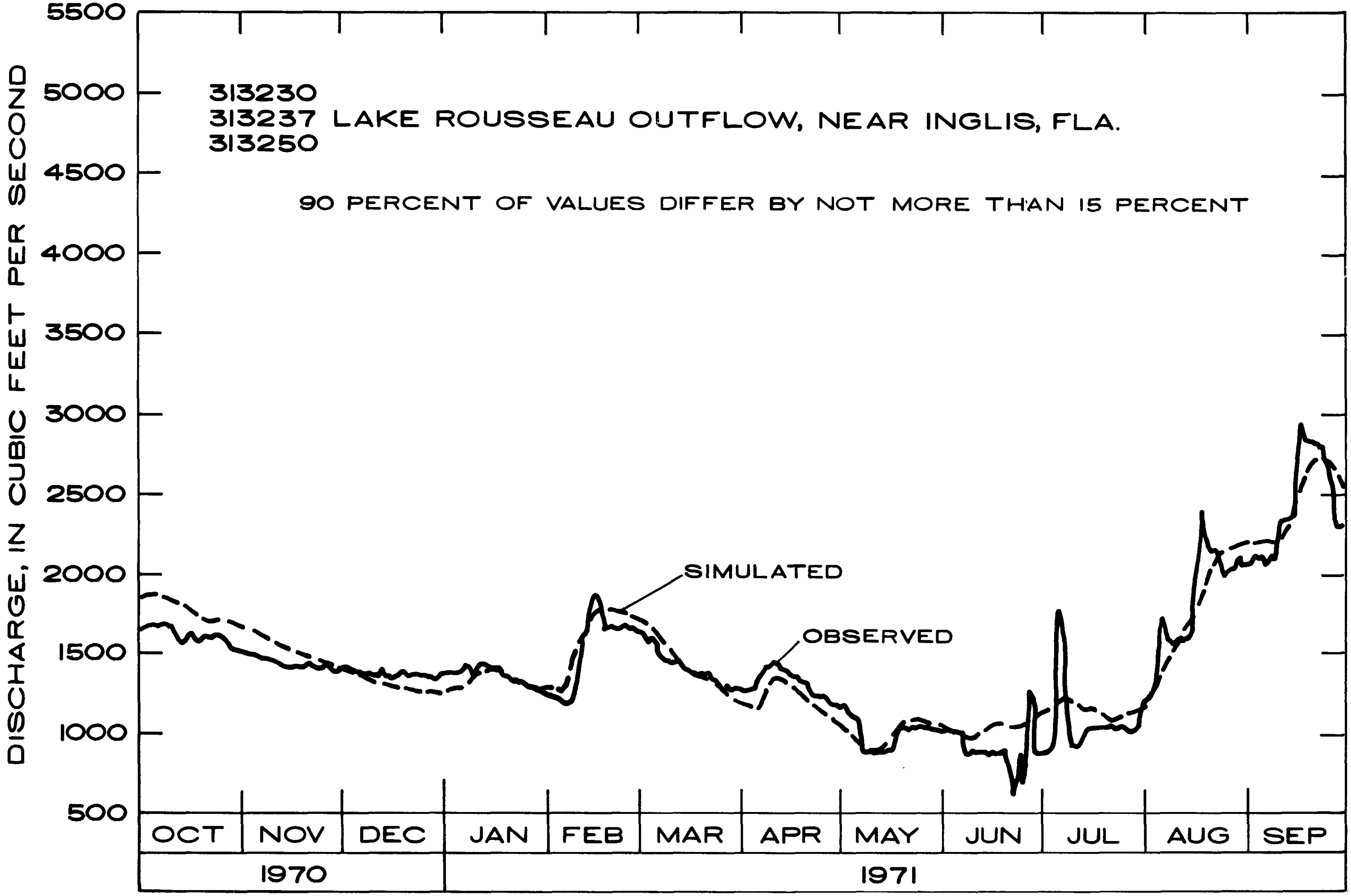

Figure 16.--Simulated and observed daily mean discharges for Lake Rousseau outflow near Inglis, Florida for the 1971 water year.

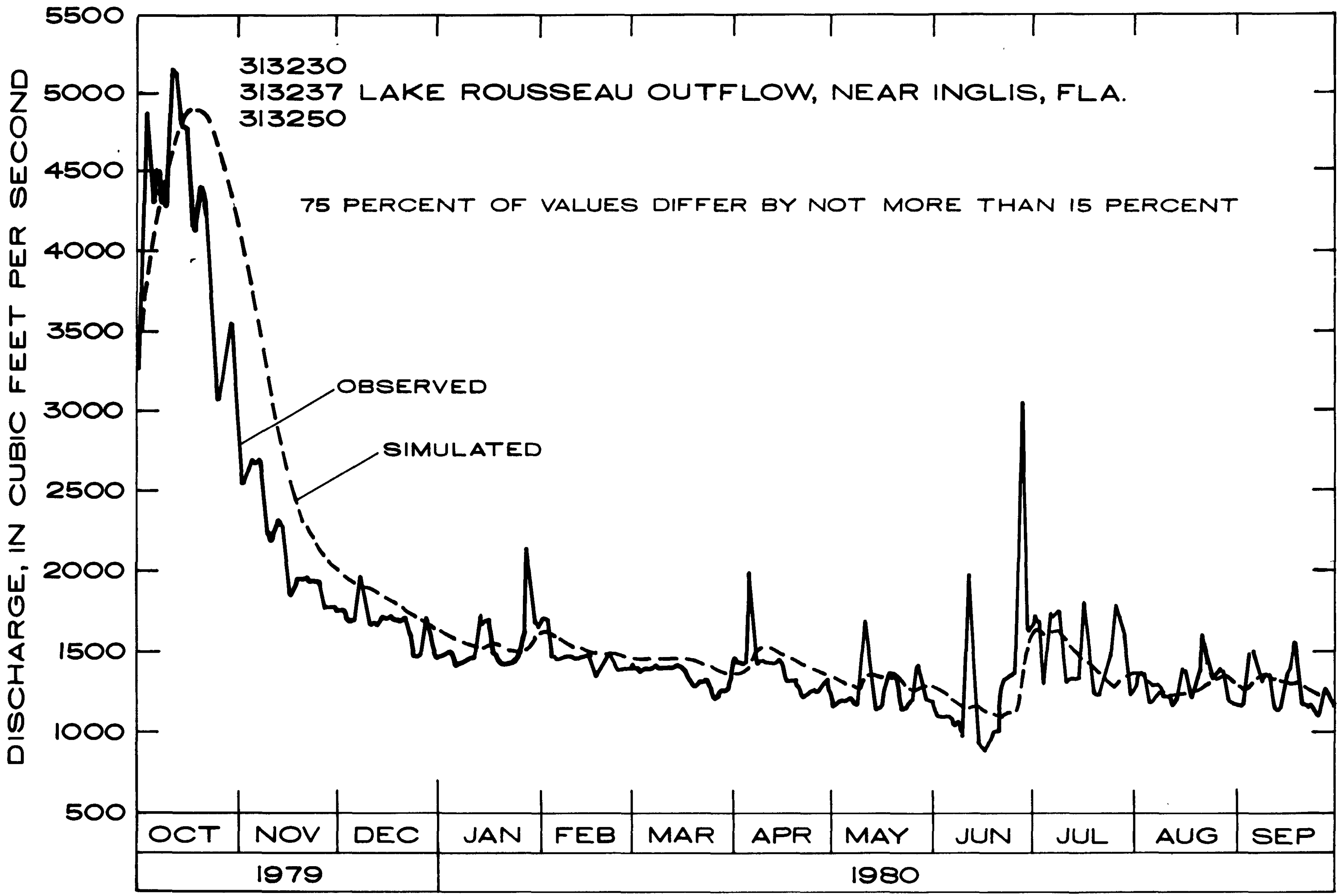

Figure 17.--Simulated and observed daily mean discharges for Lake Rousseau outflow near Inglis, Florida for the 1980 water year.

COST-EFFECTIVE RESOURCE ALLOCATION

Introduction to Kalman-Filtering for Cost-Effective Resource Allocation (K-CERA)

In a study of the cost-effectiveness of a network of gaging stations operated to determine water consumption in the lower Colorado River basin, a set of techniques called K-CERA was developed (Moss and Gilroy, 1980). Because of the water-balance nature of that study, the measure of effectiveness of the network was chosen to be the minimization of the sum of variances of errors of estimation of annual mean discharges at each site in the network. This measure of effectiveness tends to concentrate stream-gaging resources on the larger, less stable streams where potential errors are greatest. While such a tendency is appropriate for a water-balance network, it is not appropriate for most networks operated by the Geological Survey, where many uses for the streamflow data exist.

Therefore, the original version of K-CERA was extended to include as optional measures of effectiveness the sums of the variances of errors of estimation of the following streamflow variables: annual mean discharge in cubic feet per second, annual mean discharge in percentage, average instantaneous discharge in cubic feet per second, or average instantaneous discharge in percentage. The use of percentage errors does not unduly weight activities at large streams to the detriment of records on small streams. In addition, the instantaneous discharge is the basic variable from which all other streamflow data are derived. For these reasons, this study used the K-CERA techniques with the sums of the variances of the percentage errors of the instantaneous discharges at all continuous-record stream-gaging stations as the measure of the effectiveness of the data-collection activity.

The original version of K-CERA used in the lower Colorado River basin also did not account for error contributed by missing stage or other correlative data that are used to compute streamflow data. The probabilities of missing correlative data increase as the period between service visits to a gaging station increases. A procedure for dealing with the missing record has been developed and was incorporated into this study.

Brief descriptions of the mathematical program used to optimize cost-effectiveness of the data-collection activity and of the application of Kalman filtering (Gelb, 1974) to the determination of the accuracy of a stream-gaging record are presented below. For more detail on either the theory or the applications of K-CERA, see Moss and Gilroy (1980), Gilroy and Moss (1981), and Fontaine and others (1984).

Description of Mathematical Program

The program, called "The Traveling Hydrographer," attempts to allocate among gaging stations a predefined budget for the collection of streamflow data in such a manner that the field operation is the most cost-effective possible. The measure of effectiveness is discussed above. The set of decisions available to the manager is the frequency of use (number of times per year) of each of a number of routes that may be used to service the stations and to make discharge measurements. The range of options within the program is from zero usage to daily usage for each route. A route is defined as a set of one or more stations and the least cost travel that takes the hydrographer from his base of operations to each of the stations and back to base. A route will have associated with it an average cost of travel and average cost of servicing each station visited along the way. The first step in this part of the analysis is to define the set of practical routes. This set of routes frequently will contain the path to an individual gaging station with that station as the lone stop and return to the home base so that the individual needs of a station can be considered in isolation from the other station.

Another step in this part of the analysis is the determination of any special requirements for visits to each of the stations for such things as necessary periodic maintenance, rejuvenation of recording equipment, or required periodic collection of water-quality data. Such special requirements are considered to be inviolable constraints in terms of the minimum number of visits to each station.

The final step is to use all of the above to determine the number of times, N_i, that the jth route for i = 1, 2, ..., NR, where NR is the number of practical routes, is used during a year such that (1) the budget for the network is not exceeded, (2) the minimum number of visits to each station is made, and (3) the total uncertainty in the network is minimized. Figure 18 represents this step in the form of a mathematical program. Figure 19 presents a tabular layout of the problem. Each of the NR routes is represented by a row of the table and each of the stations is represented by a column. The zero-one matrix, (w_{ij}), defines the routes in terms of the stations that comprise it. A value of one in row i and column j indicates that gaging station j will be visited on route i; a value of zero indicates that it will not. The unit travel costs, B_i, are the per-trip costs of the hydrographer's traveltime and any related per diem and operation, maintenance, and rental costs of vehicles. The sum of the products of B_i and N_i for i = 1, 2, ..., NR is the total travel cost associated with the set of decisions $\underline{N} = (N_1, N_2, \ldots, N_{NR})$.

The unit-visit cost, a_j, is comprised of the average service and maintenance costs incurred on a visit to the station plus the average cost of making a discharge measurement. The set of minimum visit constraints is denoted by the row A_j, j = 1, 2, .., MG, where MG is the number of gaging stations. The row of integers M_j, j = 1, 2, ..., MG specifies the number of visits to each station. M_j is the sum of the products of w_{ij} and N_i for all i and must equal or exceed A_j for all j if $\underline{N}$ is to be a feasible solution to the decision problem.

The total cost expended at the stations is equal to the sum of the products of a_j and M_j for all j. The cost of record computation, documentation, and publication is assumed to be influenced negligibly by the number of visits to the station and is included along with overhead in the

$$\underset{\underline{N}}{\text{Minimize}}\ V = \sum_{j=1}^{MG} \mathrm{O}_j\,(M_j)$$

$V \equiv$ total uncertainty in the network

$\underline{N} \equiv$ vector of annual number times each route was used

$MG \equiv$ number of gages in the network

$M_j \equiv$ annual number of visits to station j

$\mathrm{O}_j \equiv$ function relating number of visits to uncertainty at station j

Such that

Budget $\geq T_c \equiv$ total cost of operating the network

$$T_c = F_c + \sum_{j=1}^{MG} \mathrm{a}_j M_j + \sum_{i=1}^{NR} \mathrm{B}_i N_i$$

$F_c \equiv$ fixed cost

$\mathrm{a}_j \equiv$ unit cost of visit to station j

$NR \equiv$ number of practical routes chosen

$\mathrm{B}_i \equiv$ travel cost for route i

$N_i \equiv$ annual number times route i is used (an element of $\underline{N}$)

and such that

$$M_j \geq \mathrm{A}_j$$

$\mathrm{A}_j \equiv$ minimum number of annual visits to station j

Figure 18.--Mathematical-programing form of the optimization of the routing of hydrographers.

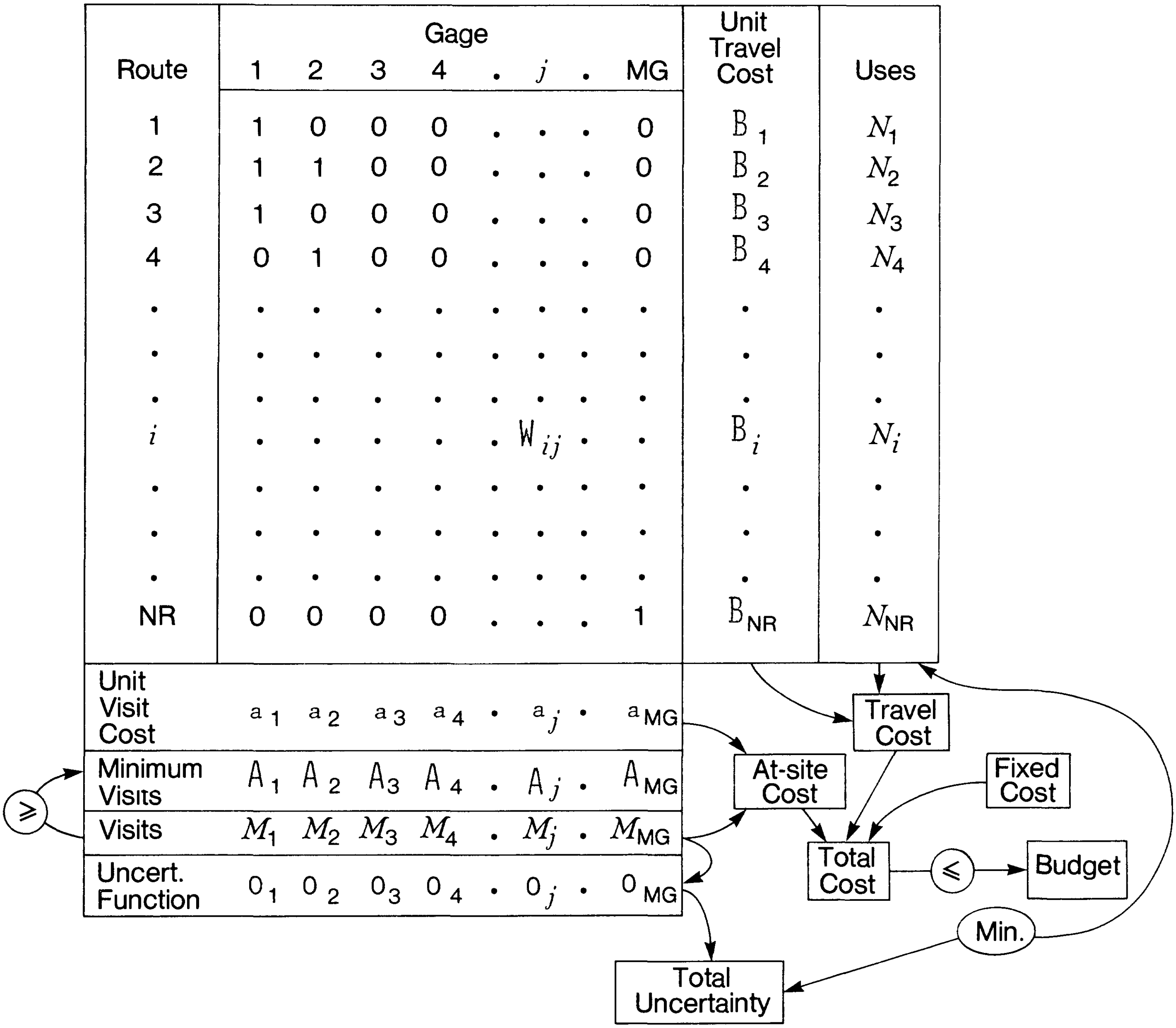

Figure 19.--Tabular form of the optimization of the routing of hydrographers.

fixed cost of operating the network. The total cost of operating the network equals the sum of the travel costs, the at-site costs, and the fixed cost, and must be less than or equal to the available budget.

The total uncertainty in the estimates of discharges at the MG stations is determined by summing the uncertainty functions, O_j, evaluated at the value of M_j from the row above it, for j = 1, 2, ..., MG.

As pointed out in Moss and Gilroy (1980), the steepest-descent search used to solve this mathematical program does not guarantee a true optimum solution. However, the locally optimum set of values for N obtained with this technique specify an efficient strategy for operating the network, which may be the true optimum strategy. The true optimum cannot be guaranteed without testing all undominated, feasible strategies.

Description of Uncertainty Functions

As noted earlier, uncertainty in streamflow records is measured in this study as the average relative variance of estimation of instantaneous discharges. The accuracy of a streamflow estimate depends on how that estimate was obtained. Three situations are considered in this study: (1) streamflow is estimated from measured discharge and correlative data using a stage-discharge relation (rating curve), (2) the streamflow record is reconstructed using secondary data at nearby stations because primary correlative data are missing, and (3) primary and secondary data are unavailable for estimating streamflow. The variances of the errors of the estimates of flow that would be employed in each situation were weighted by the fraction of time each situation is expected to occur. Thus the average relative variance would be

$$V_T = E_f V_f + E_r V_r + E_e V_e \tag{2}$$

with

$$1 = E_f + E_r + E_e \tag{3}$$

where

V_T is the average relative variance of the errors of streamflow estimates,

E_f is the fraction of time that the primary recorders are functioning,

V_f is the relative variance of the errors of flow estimates from primary recorders,

E_r is the fraction of time that secondary data are available to reconstruct streamflow records given that the primary data are missing,

V_r is the relative variance of the errors of estimation of flows reconstructed from secondary data,

E_e is the fraction of time that primary and secondary data are not available to compute streamflow records, and

V_e is the relative error variance of the third situation.

The fractions of time that each source of error is relevant are functions of the frequencies at which the recording equipment are serviced. The time, t, since the last service visit until failure of the recorder or recorders at the primary site is assumed to have a negative-exponential probability distribution truncated at the next service time; the distribution's probability function is

$$f(t) = ke^{-kt}/(1-e^{-ks}) \tag{4}$$

where

k is the failure rate in units of 1/day,

s is the interval between visits to the site in days, and

e is the base of natural logarithms.

It is assumed that, if a recorder fails, it continues to malfunction until the next service visit. Thus,

$$E_f = 1 - E[d]/s \tag{5}$$

where

d is downtime of the primary recorders,

E[.] is the expected value of the random variable contained within the the brackets.

Downtime is defined

$$d = \begin{cases} s-t & \text{if a failure occurs,} \\ 0 & \text{if no failure occurs} \end{cases} \tag{6}$$

as shown in figure 20.

The expected value of downtime is

$$E[d] = \int_0^s (s-t)\ f(t)\ dt \tag{7}$$

which when evaluated results in

$$E[d] = (ks + e^{-ks}-1)/k \tag{8}$$

t = Time to failure

s = Service interval

d = Downtime (missing stage record)

$d = s - t$

δ_n = Time of the nth visit

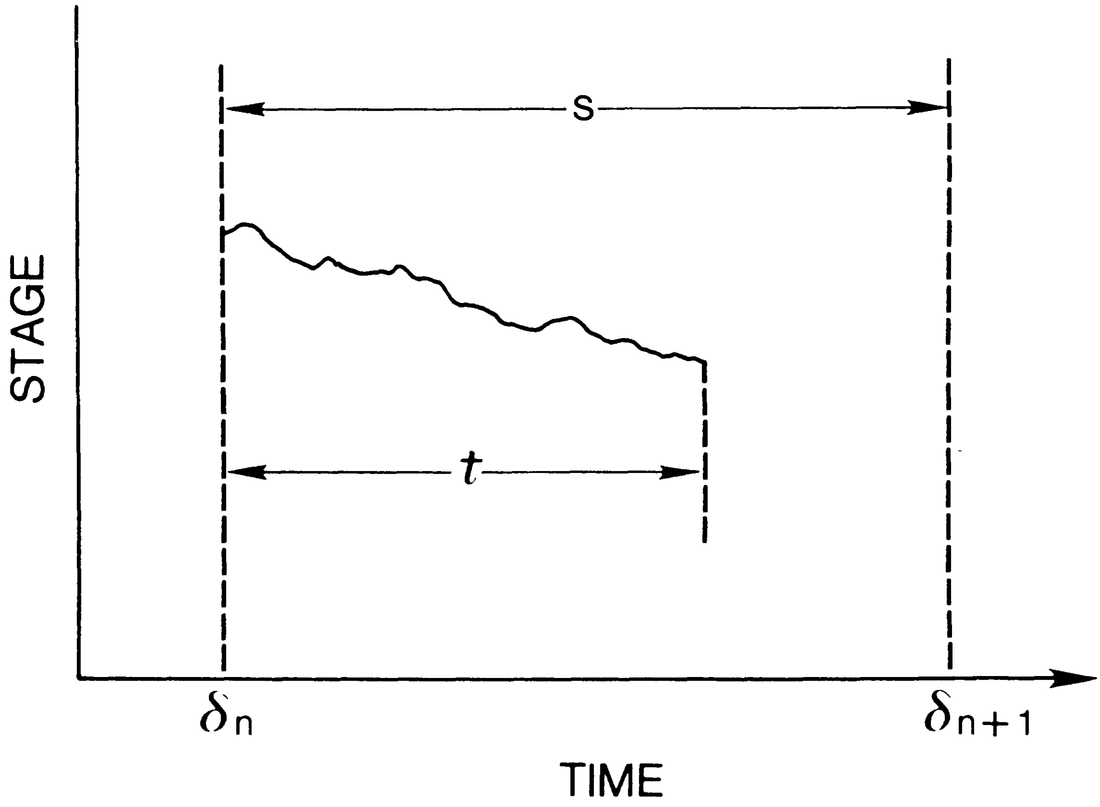

Figure 20.--Definition of downtime for a single station.

Substituting equation 8 into equation 5 and simplifying result in

$$E_f = (1-e^{-ks})/(ks) \tag{9}$$

The fraction of time, E_e, that no records exist at either the primary or secondary sites is obtainable from a bivariate application of equation 4, if it is assumed that the time between failures at both sites are independent and have negative exponential distributions with the same rate constant.

The concurrent downtime, d_2, of both stations is defined

$$d_2 = \begin{cases} \min\,(s-t_a,\ s-t) & \text{if both stations fail,} \\ 0 & \text{otherwise} \end{cases} \tag{10}$$

where t_a is the time to failure at the auxiliary site. The case in which $s-t_a$ is the minimum and equals d_2 is shown in figure 21. The value of E_e can be defined in terms of d_2 as

$$E_e = E[d_2]/s \tag{11}$$

The expected value of concurrent downtime is

$$E[d_2] = \int_0^s (s-t)\ P[t_a \leq t]\ f(t)dt + \int_0^s (s-t_a)\ P[t \leq t_a]\ f(t_a)\ dt_a \tag{12}$$

where P[.] is the probability of the event contained within the brackets occurring. Evaluation of equation 12 under the given assumptions results in

$$E[d_2] = s - \frac{2}{k}(1-e^{-ks}) - \frac{1}{2k}(1-e^{-2ks}) \tag{13}$$

which can be substituted into equation 11 to obtain E_e

$$E_e = 1 - [2(1-e^{-ks}) + 0.5(1-e^{-2ks})]/(ks) \tag{14}$$

The fraction of time, E_r, that records are reconstructed based on data from a secondary site is determined by the equation

$$E_r = 1 - E_f - E_e \tag{3}$$

$$= [(1-e^{-ks}) + 0.5\ (1-e^{-2ks})]/(ks) \tag{15}$$

The relative variance, V_f, of the error derived from primary record computation is determined by analyzing a time series of residuals that are the differences between the logarithms of measured discharge and the rating curve discharge. The rating curve discharge is determined from a relationship between discharge and some correlative data, such as water-surface elevation at

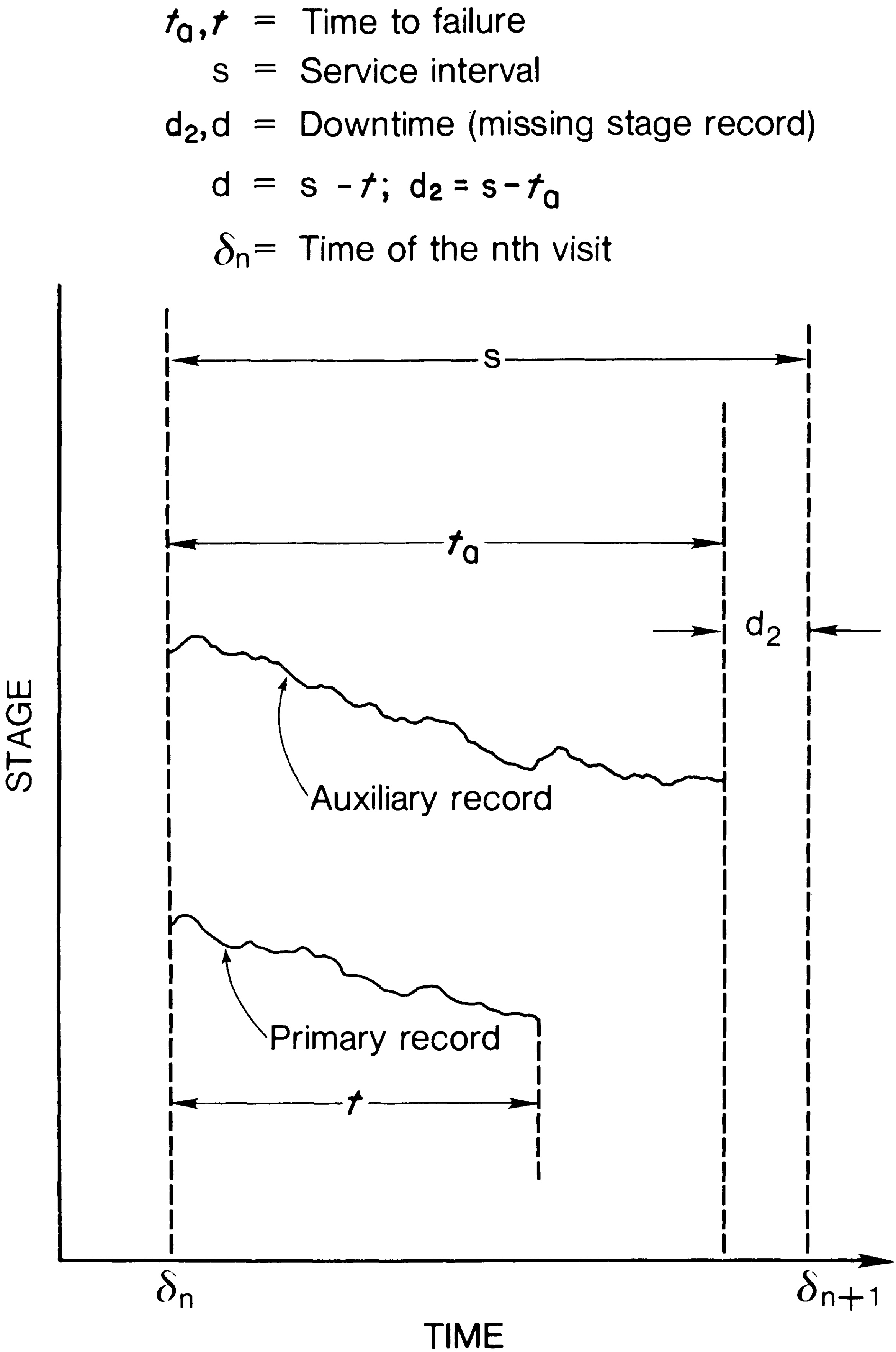

Figure 21.--Definition of joint downtime for a pair of stations.

the gaging station. The measured discharge is the discharge determined by field observations of depths, widths, and velocities. Let $q_T(t)$ be the true instantaneous discharge at time t and let $q_R(t)$ be the value that would be estimated using the rating curve. Then

$$x(t) = \ln q_T(t) - \ln q_R(t) = \ln [q_T(t)/q_R(t)] \quad (16)$$

is the instantaneous difference between the logarithms of the true discharge and the rating curve discharge.

In computing estimates of streamflow, the rating curve may be continually adjusted on the basis of periodic measurements of discharge. This adjustment process results in an estimate, $q_c(t)$, that is a better estimate of the stream's discharge at time t. The difference between the variable $\hat{x}(t)$, which is defined

$$\hat{x}(t) = \ln q_c(t) - \ln q_R(t) \quad (17)$$

and x(t) is the error in the streamflow record at time t. The variance of this difference over time is the desired estimate of V_f.

Unfortunately, the true instantaneous discharge, $q_T(t)$, cannot be determined and thus x(t) and the difference, $\hat{x}(t) - x(t)$, cannot be determined as well. However, the statistical properties of $\hat{x}(t) - x(t)$, particularly its variance, can be inferred from the available discharge measurements. Let the observed residuals of measured discharge from the rating curve be z(t) so that

$$z(t) = x(t) + v(t) = \ln q_m(t) - \ln q_R(t) \quad (18)$$

where

v(t) is the measurement error, and

$\ln q_m(t)$ is the logarithm of the measured discharge equal to $\ln q_T(t)$ plus v(t).

In the Kalman-filter analysis, the z(t) time series was analyzed to determine three site-specific parameters. The Kalman filter used in this study assumes that the time residuals, x(t), arise from a continuous first-order Markovian process that has a Gaussian (normal) probability distribution with zero mean and variance (subsequently referred to as process variance) equal to p. A second important parameter is B, the reciprocal of the correlation time of the Markovian process giving rise to x(t); the correlation between $x(t_1)$ and $x(t_2)$ is $\exp[-B|t_1-t_2|]$. Fontaine and others (1984) also define q, the constant value of the spectral density function of the white noise which drives the Gauss-Markov x-process. The parameters, p, q, and B are related by

$$Var[x(t)] = p = q/(2B) \quad (19)$$

The variance of the observed residuals z(t) is

$$Var[z(t)] = p + r \tag{20}$$

where r is the variance of the measurement error v(t). The three parameters p, B, and r, are computed by analyzing the statistical properties of the z(t) time series. These three site-specific parameters are needed to define this component of the uncertainty relationship. The Kalman filter utilizes these three parameters to determine the average relative variance of the errors of estimation of discharges as a function of the number of discharge measurements per year (Moss and Gilroy, 1980).

If the recorder at the primary site fails and there are no concurrent data at other sites that can be used to reconstruct the missing record at the primary site, there are at least two ways of estimating discharges at the primary site. A recession curve could be applied from the time of recorder stoppage until the recorder was once again functioning or the expected value of discharge for the period of missing data could be used as an estimate. The expected-value approach is used in this study to estimate V_e, the relative error variance during periods of no concurrent data at nearby stations. If the expected value is used to estimate discharge, the value that is used should be the expected value of discharge at the time of year of the missing record because of the seasonality of the streamflow processes. The variance of streamflow, which also is a seasonally varying parameter, is an estimate of the error variance that results from using the expected value as an estimate. Thus, the coefficient of variation squared, $(C_v)^2$, is an estimate of the required relative error variance V_e. Because C_v varies seasonally and the times of failures cannot be anticipated, a seasonally averaged value of C_v is used:

$$\bar{C}_v = \left[(1/365) \sum_{i=1}^{365} \left(\frac{s_i}{M_i} \right)^2 \right]^{1/2} [100] \tag{21}$$

where

s_i is the standard deviation of daily discharges for the i^{th} day of the year,

M_i is the expected value of discharge on the i^{th} day of the year, and,

$(\bar{C}_v)^2$ is used as an estimate of V_e.

The variance, V_r, of the relative error during periods of reconstructed streamflow records is estimated on the basis of correlation between records at the primary site and records from other gaged nearby sites. The correlation coefficient, p_c, between the streamflows with seasonal trends removed at the site of interest and detrended streamflows at the other sites is a measure of the goodness of their linear relationship. The fraction of the variance of streamflow at the primary site that is explained by data from the other sites is equal to p_c^2. Thus, the relative error variance of flow estimates at the primary site obtained from secondary information will be

$$V_r = (1-p_c^2)\bar{C}_v^2 \quad (22)$$

Because errors in streamflow estimates arise from three different sources with widely varying precisions, the resultant distribution of those errors may differ significantly from a normal or log-normal distribution. This lack of normality causes difficulty in interpretation of the resulting average estimation variance. When primary and secondary data are unavailable, the relative error variance V_e may be very large. This could yield correspondingly large values of V_T in equation (2) even if the probability that primary and secondary information are not available, E_e, is quite small.

A new parameter, the equivalent Gaussian spread (EGS), is introduced here to assist in interpreting the results of the analyses. If it is assumed that the various errors arising from the three situations represented in equation (2) are log-normally distributed, the value of EGS was determined by the probability statement that

$$\text{Probability } [e^{-EGS} \leq (q_c(t)/q_T(t)) \leq e^{+EGS}] = 0.683 \quad (23)$$

Thus, if the residuals $\ln q_c(t) - \ln q_T(t)$ were normally distributed, $(EGS)^2$ would be their variance. Here EGS is reported in units of percent because EGS is defined so that nearly two-thirds of the errors in instantaneous streamflow data will be within plus or minus EGS percent of the reported values.

The Application of K-CERA in Central Florida

As a result of the first two parts of this analysis, it has been suggested that 94 of the currently existing stream-gaging stations in central Florida be continued in operation. The data from these 94 stations were subjected to the K-CERA analysis with results that are described below.

Definition of Missing Record Probabilities

As was described earlier, the statistical characteristics of missing stage or other correlative data for computation of streamflow records can be defined by a single parameter, the value of k in the truncated negative exponential probability distribution of times to failure of the equipment. In the representation of f(t) as given in equation 4, the average time to failure is 1/k. The value of 1/k will vary from site to site depending upon the type of equipment at the site and upon its exposure to natural elements and vandalism. The value of 1/k can be changed by advances in the technology of data collection and recording. In this study, the fraction of lost record was calculated for each station (table 5) and combined with a bimonthly visit frequency to determine a value of 1/k that is unique to each station. Values of E_f, E_e, and E_r were then computed for each station on these individual values.

Table 5.--Statistics of record reconstruction

Station No.	Missing record (pct.)	Stations used for information transfer with (lags), in days			C_v (pct.)	p_c
231342	4.8	231600(0)	232200(0)	274000(0)	141	.693
231600	3.0	232000(0)	274000(0)		191	.720
232000	8.8	232400(-2)	232500(-3)		122	.872
232200	2.8	231342(0)	231600(0)	274000(0)	219	.712
232400	4.0	232000(2)	232500(-2)		104	.971
232500	3.6	232000(3)	232400(2)		105	.965
233001	1.6	232200(0)	233200(0)	262900(0)	163	.614
233200	6.7	262900(0)	233500(-1)		138	.809
233500	2.8	234324(0)			142	.588
234324	3.6	233200(0)	234990(0)		68.7	.758
234990	0.8	233200(0)	234324(0)		73.0	.755
235000	0.4	234324(0)	233500(0)		41.0	.736
235200	15.0	233500(0)			99.3	.479
236000	0.9	232500(0)	233500(0)	235000(0)	68.6	.877
236500	8.4	310800(0)			169	.877
236900	7.6	236500(0)	236700(0)		145	.910
238500	2.9	240000(0)			14.0	.639
239500	8.7	313100(0)			18.4	.926
240000	2.8	238500(0)			40.0	.639
240500	3.0	240000(0)			40.0	.639
240902	0.4	240954(0)			94.4	.394
240954	1.5	241000(0)			105	.386
241000	12.5	242451(0)			98.9	.998
243000	6.5	241000(0)			131	.698
243960	5.0	240000(0)			63.9	.761
244320	6.3	244420(0)			150	.770
244440		244320(0)			86.2	.397
244473	0.7	245140(0)			135	.814
245050	3.1	244473(0)			60.5	.704
245140	7.1	244473(0)			109	.814
247480	2.7	247510(0)			121	.759
247510	14.7	248000(0)			151	.755
248000	0.5	247510(0)			199	.755
252500	8.6	253500(0)			137	.726
253000	3.4	252500(0)			112	.651

Table 5.--Statistics of record reconstruction--Continued

Station No.	Missing record (pct.)	Stations used for information transfer with (lags), in days			C_v (pct.)	P_c
253500	7.6	252500(0)			150	.726
256500	1.6	296500(0)			186	.691
262900	5.5	263800(0)			147	.816
263800	6.1	264495(0)			127	.823
264000	1.2	263800(0)			214	.351
264495	7.3	263800(0)			88.9	.823
266200	4.2	266480(0)			136	.737
266300	4.9	266480(0)			109	.771
266480	6.1	236500(0)			133	.698
266500	0.9	267000(0)			119	.623
267000	11.1	266500(0)			60.8	.623
270500	16.5	256500(0)			108	.668
274495	1.8	274500(0)			181	.820
301900	7.2	310947(0)			152	.481
310800	6.7	310947(0)			186	.723
310947	11.1	310800(0)			168	.723
311000	1.8	310800(0)			155	.623
311500*	5.0	302500(0)			129	.982
312000	4.6	312500(0)			129	.982
312180	3.8	312200(0)			162	.848
312200	3.7	312180(0)			165	.848
312500	3.8	312000(0)			117	.982
312635	8.8	312640(0)			61.2	.782
312640	8.8	312645(0)			58.9	.724
312645	8.8	312640(0)			63.8	.724
312690	1.4	312700(0)			117	.487
312700	3.3	312690(0)			49.2	.487
312720	1.0	313000(0)			69.1	.914
313000	1.4	312720(0)	312975(0)		84.3	.918
313100	5.2	239500(0)			15.1	.926
313250	2.1	313000(0)			27.5	.379

*Less than three water years of data are available. Estimates of C_v and P_c are subjective.

Definition of Cross-Correlation Coefficient and Coefficient of Variation

To compute the values of V_e and V_r of the needed uncertainty functions, daily streamflow records for each of the 94 stations for the last 30 years, or the part of the last 30 years for which daily streamflow values are stored in WATSTORE (Hutchinson, 1975), were retrieved. For each of the stations that had 3 or more complete water years of data, the value of C_v was computed and various options, based on combinations of other stations were explored to determine the maximum p_c.

The results of the calculations of the coefficient of variation and the cross-correlation coefficient are shown in table 5. Shown for each station are the percentage of missing record, the station, or stations, which gave the best cross-correlation, the coefficient of variation given in percent, and the cross-correlation value. The percent of missing record varied from 0.4 for stations 235000 and 240902 to 16.5 for 270500. The coefficient of variation ranged from 14.0 percent at station 238500 to 219 percent at station 232200; the cross-correlation ranged from .351 at station 264000 to .998 at station 241000.

Kalman-Filter Definition of Variance

The determination of the variance V_f for each of the 94 gaging stations required the execution of three distinct steps: (1) long-term rating analysis and computation of residuals of measured discharges from the long-term rating, (2) time-series analysis of the residuals to determine the input parameters of the Kalman-filter streamflow records, and (3) computation of the error variance, V_f, as a function of the time-series parameters, the discharge-measurement-error variance, and the frequency of discharge measurement.

Of the 94 gaging stations in the subdistrict's program, 66 stations had sufficient and proper data available for the long-term rating analysis. The 28 stations not analyzed had either: (1) less than 15 measurements available for analysis, or (2) less than 15 measurements available after all measurements made on very short time intervals (less than 5 days), and very long time intervals (greater than 365 days) were deleted.

Of the 66 stations for which ratings were analysed, 62 stations had natural, channel control and 4 stations had structure or slope controls.

Definition of the long-term rating functions was first attempted mathematically; linear and nonlinear functions were fitted to the gage height and discharge data. This approach required many fittings per site and computer costs which were relatively high when the nonlinear functions were fitted.

Scrutiny of the data when plotted in ln (natural logarithm) space, ln of discharge against ln of stage, showed that this function was commonly a series of straight-line segments. It was then decided to fit these segments directly, interpolating the ln of discharge from the rating, and substracting it from the ln of measured discharge to determine the residual to be used in the time series of discharge residuals.

Figure 22 shows an application of the procedure for station 263800, Shingle Creek at Airport near Kissimmee. The rating curve in ln space was fitted with four distinct linear segments; the coordinates of the four segments were determined from a printer plot of the measurement data and entered into an interpolation program.

Within the program, predicted values of the ln of discharge were calculated and residuals determined. As part of the same program, the residuals were checked for the value of the mean and normality, and plotted against several variables to check for trends and runs. For the data from station 263800, the mean of the residuals was 0.022 log unit. Checking of the residual plots disclosed no trends or runs. Table 6 is an example of the residual data for station 232400, showing the measured discharge, the residual or difference of the measured and predicted discharges (ln units), and the percent error.

For the four stations having either structure or slope control, a regression equation of the following form was used:

$$\ln \text{(DISCHARGE)} = a+b*\ln \text{(GH - CONS1)} + c*\ln \text{(VAR1 - CONS2)}$$

where

ln = the natural logarithm, base e

DISCHARGE = the measured discharge

GH = the measured gage height

VAR1 = some variable, such as gate opening or water-surface slope, and

CONS1 & CONS2 = constants determined by trial and error

a, b, and c = parameters determined by regression analysis.

The largest task in fitting the equation was determining the constants CONS1 and CONS2. The values of these constants were approximately equal to the minimum value of the variable within the parentheses.

The time series of residuals is used to compute sample estimates of q and B, two of the three parameters required to compute V_f, by determining a best fit autocovariance function to the time series of residuals. Measurement variance, the third parameter, is determined from the measurement error. For the present study, the measurement error for each station was individually determined, based on the average control conditions at the station.

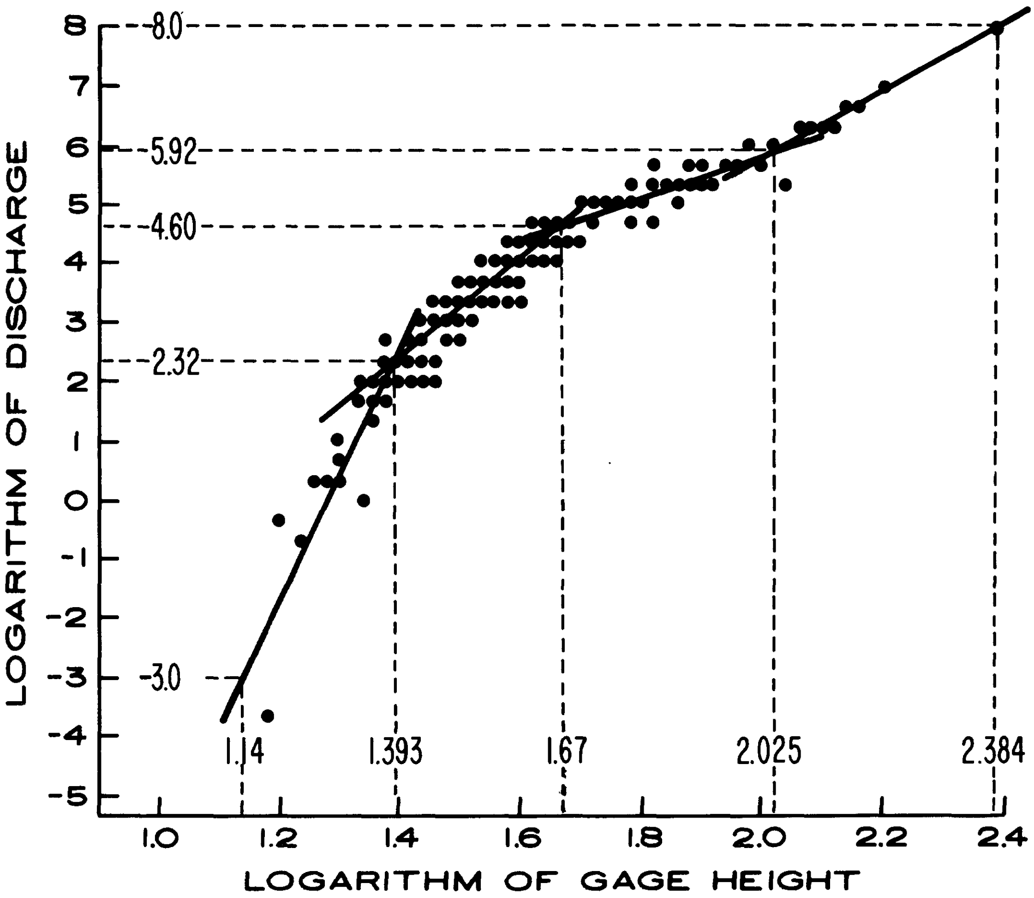

Figure 22.--Rating curve plotted in logarithmic space with superimposed straight-line segments.

Table 6.--Residual data for station 232400

Measurement No.	Date	Measured discharge (ft^3/s)	Residual (log units base e)	Percent error
182	February 13, 1980	567.00	0.38420	31.90
183	April 25, 1980	293.00	0.20551	18.58
184	July 2, 1980	152.00	0.57472	43.71
185	August 5, 1980	39.50	-.42966	-34.93
186	October 17, 1980	40.60	0.13969	13.04
187	November 19, 1980	15.00	-.71755	-51.21
188	January 13, 1981	72.30	-.01648	-1.63
189	March 11, 1981	82.90	-.35304	-29.75
190	May 6, 1981	30.80	-.66922	-48.79
191	June 5, 1981	15.20	-.99836	-63.15
192	July 1, 1981	7.34	-1.7744	-83.04
193	July 29, 1981	7.17	-1.7978	-83.43
194	September 2, 1981	27.60	-1.2019	-69.94
195	October 21, 1981	99.20	-.72687	-51.66
196	December 16, 1981	117.00	-.68099	-49.39
197	February 10, 1982	96.40	-.85887	-57.64
198	April 8, 1982	175.00	-.93877	-60.89
199	April 20, 1982	289.00	-.91329	-59.88
200	June 9, 1982	1520.00	-.49389	-38.98
201	August 5, 1982	3930.00	-.08348	-8.01
202	September 29, 1982	2860.00	0.16220	14.97
203	November 29, 1982	925.00	0.29861	25.82

As discussed earlier, q and B can be expressed as the process variance of the shifts from the rating curve and the 1-day autocorrelation coefficient of these shifts. Table 7 presents a summary of the autocovariance analysis expressed in terms of process variance and 1-day autocorrelation.

The autocovariance parameters, summarized in table 7, and data from the definition of missing record probabilities, summarized in table 5, are used jointly to define uncertainty functions for each gaging station. The uncertainty functions give the relation of total error variance to the number of visits and discharge measurements. Typical examples of uncertainty functions are given in figure 23. These functions are based on the assumption that a measurement was made during each visit to the station. For the 28 stations not having sufficient discharge measurements a zero uncertainty function was used.

Feasible routes to service the 94 stream-gaging stations were determined after consultation with personnel in the Hydrologic Data Section of the Orlando office, and after review of the uncertainty functions. In summary, 110 routes were selected to service all the gaging stations in central Florida. These routes included all possible combinations that describe the current operating practice, alternatives that were under consideration as future possibilities, routes that visited certain key individual stations, and combinations that grouped proximate stations where the levels of uncertainty indicated more frequent visits might be useful. These routes and the stations visited on each are summarized in table 8. The first 34 routes represent the current operation. Negative station numbers are used to denote all of the other hydrologic data-collection sites that are serviced on these same routes. These "dummy" station numbers may represent one or several stations that include lake-level gages, ground-water sites, crest-stage gages, low-flow partial-record stations, periodic discharge measurements, precipitation gages, and water-quality data-collection sites.

The costs associated with the practical routes were then determined. Fixed costs to operate a station typically include equipment rental, batteries, observer payments, electricity, data processing and storage, computer charges, maintenance and miscellaneous supplies, and analysis and supervisory charges. Average values were applied to each station in the program for all the above categories except analysis and supervisory costs and special equipment costs. Costs of analysis and supervision form a large percentage of the cost at each gaging station and can vary widely. These costs were determined on a station-by-station basis from past experience. Velocity-measuring equipment, such as deflection vanes and electromagnetic flow sensors, increase the costs of monitoring and analysis.

Visit costs are those associated with the time actually spent at a station. These costs vary from station to station and are a function of the difficulty and time required to service the recorder and other equipment, and to make the discharge measurement. Average visit times were calculated for each station based on an analysis of time information retrieved from discharge measurement notes. This time was then multiplied by the average salary of hydrographers in the office to determine visit costs.

Table 7.--Summary of the autocovariance analysis

Map No.	Station No.	Station name	RHO	Process variance (log base e)^2	Measurement variance (log base e)^2
1	231342	FORT DRUM CR AT SUNSHINE ST PKWY	0.974	.15570	.0049
2	231600	JANE GREEN CREEK NEAR DEER PARK	0.972	.33960	.0049
3	232000	ST. JOHNS RIVER NEAR MELBOURNE	0.940	.14110	.0143
4	232200	WOLF CREEK NEAR DEER PARK	0.986	.12280	.0025
5	232400	ST JOHNS RIVER NR COCOA	0.991	.13480	.0222
6	232500	ST. JOHNS RIVER NEAR CHRISTMAS	0.992	.11220	.0222
7	233001	ECON R AT MAG RANCH NR BITHLO	0.982	.25840	.0099
9	233200	L. ECONLOCKHATCHEE RIVER NR CHULUOTA	0.991	.05938	.0025
10	233500	ECONLOCKHATCHEE RIVER NR CHULUOTA	0.989	.12200	.0025
14	234324	HOWELL CREEK NR SLAVIA,	0.669	.00972	.0049
15	234990	L. WEKIVA RIVER NR ALTAMONTE SPGS	0.987	.27350	.0099
16	235000	WEKIVA RIVER NEAR SANFORD	0.983	.02536	.0222
17	235200	BLACK WATER CREEK NEAR CASSIA	0.985	.02719	.0099
18	236000	ST. JOHNS RIVER NEAR DE LAND	0.972	.02820	.0099
20	236500	BIG CREEK NEAR CLERMONT,	0.977	.15180	.0025
22	236900	PALATLAKAHA RIVER AT CHERRY LAKE	0.942	.07520	.0025
29	238500	OKLAWAHA RIVER AT MOSS BLUFF	0.989	.04352	.0099
30	239500	SILVER SPRINGS NEAR OCALA	0.982	.00062	.0025
31	240000	OKLAWAHA RIVER NR CONNER	0.977	.01039	.0025
32	240500	OKLAWAHA RIVER AT EUREKA,	0.994	.00842	.0025
33	240902	PRAIRIE CREEK NEAR GAINESVILLE	0.993	.03824	.0025
34	240954	HOGTOWN CREEK NEAR ARREDONDO	0.982	.00841	.0099
35	241000	CAMPS CANAL NEAR ROCHELLE	0.840	.02379	.0099
38	243000	ORANGE CREEK AT ORANGE SPRINGS	0.997	.06240	.0049
39	243960	OKLAWAHA R AT RODMAN DAM NR ORANGE SPRINGS	0.972	.01011	.0099
40	244320	MIDDLE HAW CREEK NR KORONA	0.981	.29340	.0049
41	244420	LITTLE HAW CREEK NEAR SEVILLE	0.990	.06980	.0025
43	244473	RICE CREEK NEAR SPRINGSIDE	0.978	.00599	.0025
44	245050	ETONIA CREEK AT BARDIN	0.987	.00016	.0025
45	245140	SIMMS CREEK NEAR BARDIN,	0.957	.00461	.0049
46	247480	TIGER BAY CANAL NR DAYTONA BEACH	0.987	.16220	.0099
47	247510	TOMOKA RIVER NEAR HOLLY HILL	0.987	1.107	.0099
48	248000	SPRUCE CREEK NEAR SAMSULA	0.992	.56620	.0025
50	252500	NORTH CANAL NEAR VERO BEACH	0.999	.97350	.0099
51	253000	MAIN CANAL AT VERO BEACH	0.989	.03936	.0025
52	253500	SOUTH CANAL NR VERO BEACH	0.998	1.204	.0099
53	256500	FISHEATING CREEK AT PALMDALE	0.995	.87240	.0222

Table 7.--Summary of the autocovariance analysis--Continued

Map No.	Station No.	Station name	RHO	Process variance $(\log\ base\ e)^2$	Measurement variance $(\log\ base\ e)^2$
56	262900	BOGGY CREEK NEAR TAFT	0.970	.08656	.0049
57	263800	SHINGLE CREEK AT AIRPORT	0.984	.08649	.0099
58	264000	CYPRESS CREEK AT VINELAND	0.985	.18550	.0143
60	264495	SHINGLE CREEK AT CAMPBELL	0.977	.14740	.0025
61	266200	WHITTENHORSE CREEK NEAR VINELAND	0.981	.10070	.0099
62	266300	REEDY CREEK NEAR VINELAND	0.997	.07858	.0143
63	266480	DAVENPORT CREEK NEAR LOUGHMAN	0.977	.03309	.0025
64	266500	REEDY CREEK NEAR LOUGHMAN	0.989	.06879	.0143
65	267000	CATFISH CREEK NR LAKE WALES	0.994	.04445	.0099
67	270500	ARBUCKLE CREEK NEAR DESOTO CITY	0.976	.14030	.0025
72	274495	WILLIAMSON DITCH AT S-7,	0.882	.04110	.0025
74	301900	FOX BRANCH NR SOCRUM	0.994	1.861	.0025
75	310800	WITHLACOOCHEE RIVER NEAR EVA	0.988	.14700	.0222
76	310947	WITHLACOOCHEE R NR CUMPRESSCO	0.989	.00974	.0099
77	311000	WITHLACOOCHEE-HILL OVERFLOW NR RICHLAND	0.954	.12370	.0099
78	311500	WITHLACOOCHEE RIVER NR DADE CITY	0.991	.14670	.0099
79	312000	WITHLACOOCHEE RIVER AT TRILBY	0.994	.05570	.0099
80	312180	L. WITHLACOOCHEE R NR TARRYTOWN	0.990	.27070	.0099
81	312200	L. WITHLACOOCHEE R AT RERDELL	0.973	.03847	.0099
82	312500	WITHLACOOCHEE RIVER AT CROOM	0.989	.02849	.0049
83	312635	JUMPER CR CANAL NR SUMTERVILLE	0.981	.11210	.0222
84	312640	JUMPER CR CANAL NR BUSHNELL	0.997	.09464	.0143
85	312645	JUMPER CR CANAL NR WAHOO	0.967	.00432	.0099
87	312690	CHITTY CHATTY CREEK NR WILDWOOD	0.989	.16590	.0049
88	312700	OUTLET R AT PANACOOCHEE RETREATS	0.993	.14910	.0099
89	312720	WITHLACOOCHEE R AT WYSONG DAM AT CARLSON	0.998	.30030	.0222
91	313000	WITHLACOOCHEE R NR HOLDER	0.992	.02812	.0049
92	313100	RAINBOW SPRINGS NEAR DUNNELLON	0.000	.00000	.0025
94	313250	WITHLACOOCHEE R BYPASS CHANNEL NR INGLIS	0.982	.00000	.0025

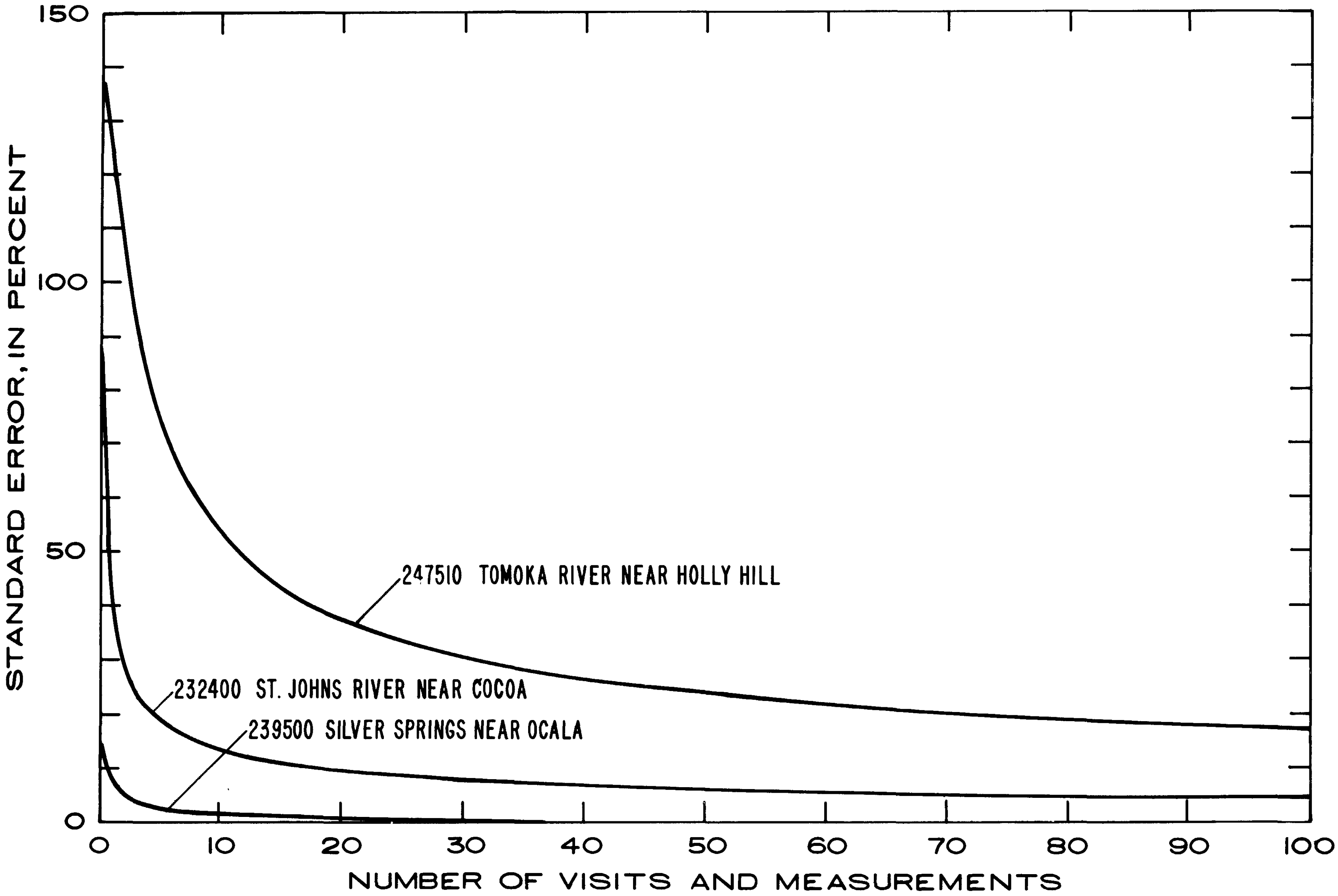

Figure 23.--Range of uncertainty functions for instantaneous discharge.

Table 8.--Summary of the routes that may be used to visit stations in central Florida

Route No.	Stations serviced on the route							
1	301900	310947	311000	311500	312000	312180	312200	312500
	-32	-33	-34	-35	-36			
2	310800	-37						
3	312667	312690	-21					
4	312700	312720	-22					
5	312635	312640	312645	312975	313000	313100	313230	313237
	313250	-23	-24	-25	-26			
6	236900	-41						
7	237010	237050	237206	-42				
8	237293	-43						
9	237700	238000	-44					
10	238500	239500	240000	-45	-46			
11	240902	240954	241000	242451	242500	243000	243960	244032
	244440	244473	245050	245140	-11	-12	-13	-14
	-15							
12	240500	-16						
13	235000	235200	-51					
14	236000	-52						
15	244320	244420	247480	247510	-53	-54	-55	
16	248000	-56						
17	236500	236700	-91					
18	234990	-92						
19	233102	234324	-93					
20	234100	234180	-94					
21	233200	-95						
22	264000	264100	-81					
23	236350	266200	266300	266480	-82			
24	262900	263800	-83					
25	264495	266500	-84					
26	267000	-85						
27	233500	234000	-61					
28	232500	233001	-62					
29	232200	232400	-63					
30	231600	-64						
31	232000	250030	-65					
32	231342	256500	257800	259200	268903	270500	273000	273200
	273300	274000	274495	274500	-71	-72	-73	-74
	-75							
33	252500	253000	253500	-76	-77	-78		
34	257800	259200	268903	273000	273200	273300		
35	310800							
36	301900	310947	311000	311500	312000	312180	312200	312500
37	312635	312640	312645					

Table 8.--Summary of the routes that may be used to visit stations in central Florida--Continued

Route No.	Stations serviced on the route						
38	312667	312700	312720					
39	312690	312975	313000	313100	313230	313237	313250	
40	236900	237010	237050					
41	237206	237293	237700					
42	238000	238500						
43	239500	240000						
44	240500	240902	240954	241000	242451	242500	243000	243960
	244032	244440	244473	245050	245140			
45	235000	235200	236000					
46	244320	244420	247480	247510	248000			
47	236350	236500	236700					
48	233102	233200	234324					
49	234100	234180	234990					
50	264000	264100	266200	266300				
51	266480	266500	263800					
52	262900	264495						
53	267000							
54	233500	234000						
55	232500	233001						
56	231600	232200	232400					
57	232000	250030						
58	231342	252500	253000	253500	256500	257800	259200	268903
	270500	273000	273200	273300	274000	274495	274500	
59	262900	233001	233102					
60	233200	232500						
61	232400							
62	233500	234000						
63	234100	234180	234324					
64	267000	268903	231342	253500	253000	252500	250030	232000
65	231600	232200						
66	270500	273200	256500	257800	259200	273000	273300	274000
	274495	274500						
67	234990	235000	235200					
68	236000							
69	248000	244320	244420					
70	247480	247510						
71	240954	240902	241000	242451	242500	243000	243960	244032
	244440	244473	245050	245140	240500			
72	236900	237010	237050					
73	237206	237293						
74	237700	238000	238500	239500	240000			
75	312635	312640						
76	312645	312667	312690					

Table 8.--Summary of the routes that may be used to visit stations in central Florida--Continued

Route No.	Stations serviced on the route					
77	312700	312720				
78	312975	313000	313100	313230	313237	313250
79	236500	236700				
80	310800					
81	301900	310947	311000			
82	311500	312000	312180			
83	312200	312500				
84	231342					
85	231600					
86	232200					
87	233001					
88	235200					
89	236500					
90	244320					
91	247510					
92	248000					
93	252500					
94	253500					
95	256500					
96	264000					
97	270500					
98	301900					
99	310947					
100	231342	231600				
101	232200	233001				
102	235200	244320				
103	247510	248000				
104	252500	253500				
105	264000	270500				
106	301900	310947				
107	266200	236350	266480			
108	264000	264100	266300			
109	264495	263800				
110	266500	267000				

Route costs include the vehicle cost associated with driving the number of miles it takes to cover the route, the cost of the hydrographer's time while in transit, and any per diem associated with the time it takes to complete the trip.

K-CERA Results

The "Traveling Hydrographer Program" utilizes the uncertainty functions along with the appropriate cost data and route definitions to compute the most cost-effective way of operating the stream-gaging program. In this application, the first step was to simulate the current practice and determine the total uncertainty associated with it. To accomplish this, the number of visits being made to each gaging station and the specific routes that are being used to make these visits were fixed. Current practice indicates that discharge measurements are made each time that a station is visited on a bimonthly trip. The resulting average error of estimation for the current practice in central Florida is plotted as a point in figure 24 and is 27.8 percent.

The solid line in figure 24 represents the minimum level of average uncertainty that can be obtained for a given budget with the existing instrumentation and technology. The line was defined by several runs of the "Traveling Hydrographer Program" with different budgets. Constraints on the operations other than budget were defined as described below.

To determine the minimum number of times each station must be visited, consideration was given only to the physical limitations of the method used to record data. The effect of visitation frequency on the accuracy of the data and amount of lost record is taken into account in the uncertainty analysis. A minimum requirement of six visits per year, equally spaced in time, is required to insure equipment operation. Some stations are visited monthly to provide streamflow data at a more frequent interval.

Minimum visit requirements should also reflect the need to visit stations for special reasons such as water-quality sampling. In central Florida all water-quality work is being done on integrated trips with the surface-water fieldwork and, therefore, did influence minimum visit requirements. Most of the previously mentioned nonstreamflow sites (dummy sites) require six visits per year and impose this constraint on any streamflow site on the same route.

The results in figure 24 and table 9 summarize the K-CERA analysis and are predicated on a discharge measurement being made each time that a station is visited. Ideally, the ratio of measurements to visits would be optimized for each site individually. It should be emphasized that these data are based on various assumptions (stated previously) concerning both the time series of shifts to the stage-discharge relation and the methods of record reconstruction. Where a choice of assumptions was available, the assumption that would not underestimate the magnitude of the error variances was chosen.

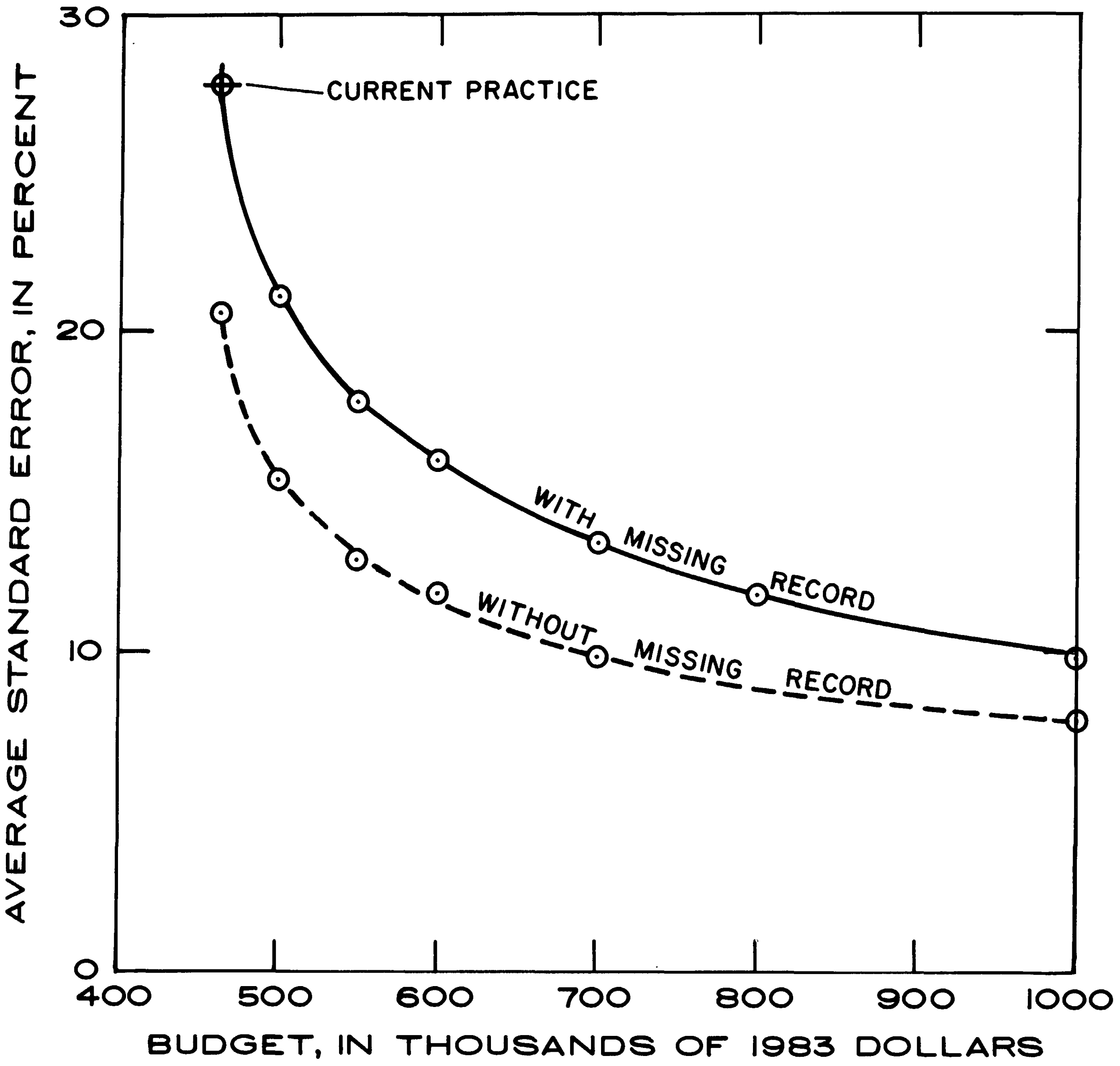

Figure 24.--Average standard error per gaging station as a function of budget.

Table 9.--Selected results of K-CERA analysis

Identification map No.	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)				
	Budget, in thousands of 1983 dollars				
	Current operation 462	500	550	550[1/]	1000
Average per station[2/]	27.8	21.1	17.8	20.2	9.8
231342 1	36.1 [29.5] (6)	29.0 [23.8] (10)	24.8 [20.3] (14)	26.7 [21.8] (12)	12.4 [10.0] (58)
231600 2	48.9 [44.8] (6)	29.3 [26.6] (19)	24.2 [21.9] (28)	36.6 [33.4] (12)	14.0 [12.5] (84)
232000 3	37.9 [35.1] (6)	36.4 [34.0] (7)	29.3 [27.7] (14)	30.9 [29.1] (12)	15.4 [14.4] (62)
232200 4	32.4 [19.9] (6)	21.4 [13.1] (14)	17.9 [10.9] (20)	23.1 [14.1] (12)	10.0 [6.1] (65)
232400 5	17.9 [17.2] (6)	17.9 [17.2] (6)	15.6 [15.1] (8)	12.9 [12.5] (12)	8.8 [8.5] (27)
232500 6	16.4 [15.6] (6)	15.3 [14.5] (7)	12.9 [12.3] (10)	11.9 [11.3] (12)	7.8 [7.4] (29)
233001 7	35.3 [32.0] (6)	25.7 [23.3] (12)	21.6 [19.5] (17)	25.7 [23.5] (13)	12.2 [11.0] (55)
233200 9	25.1 [12.3] (6)	23.2 [11.3] (7)	18.3 [8.9] (11)	17.5 [9.6] (13)	9.0 [4.4] (45)

See footnotes at end of table.

Table 9.--Selected results of K-CERA analysis--Continued

Identification map No.	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)				
	Budget, in thousands of 1983 dollars				
	Current operation 462	500	550	550[1/]	1000
233500 10	25.9 [18.0] (6)	25.9 [18.0] (6)	22.5 [15.6] (8)	18.5 [12.7] (12)	11.4 [7.7] (32)
234324 14	12.9 [10.1] (6)	12.9 [10.1] (6)	12.5 [10.0] (7)	11.6 [9.8] (10)	10.0 [9.1] (24)
234990 15	28.2 [28.1] (6)	23.3 [23.1] (9)	19.5 [19.4] (13)	20.3 [20.1] (12)	11.4 [11.3] (39)
235000 16	10.1 [9.9] (6)	8.6 [8.5] (9)	7.3 [7.3] (13)	7.6 [7.5] (13)	4.3 [4.2] (43)
235200 17	35.8 [11.9] (6)	24.0 [7.4] (14)	20.2 [6.1] (20)	25.8 [11.1] (13)	10.8 [3.3] (71)
236000 18	12.5 [12.6] (6)	12.5 [12.3] (6)	12.5 [12.3] (6)	9.8 [9.6] (12)	8.2 [8.1] (18)
236500 20	37.3 [28.6] (6)	25.5 [19.8] (13)	21.7 [15.6] (18)	26.6 [20.6] (12)	11.8 [9.0] (60)
236900 22	31.1 [26.2] (6)	29.7 [25.4] (7)	24.3 [21.7] (13)	24.9 [22.2] (12)	12.9 [11.7] (57)

See footnotes at end of table.

Table 9.--Selected results of K-CERA analysis--Continued

Identification map No.	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site) — Budget, in thousands of 1983 dollars: Current operation 462	500	550	550[1]	1000
238500	21.7	21.7	18.9	15.5	10.1
29	[11.1]	[11.1]	[9.7]	[8.0]	[5.3]
	(6)	(6)	(8)	(12)	(29)
239500	3.1	3.1	3.1	2.3	1.5
30	[1.7]	[1.7]	[1.7]	[1.4]	[1.0]
	(6)	(6)	(6)	(10)	(21)
240000	8.6	8.6	8.6	6.9	5.0
31	[7.1]	[7.1]	[7.1]	[5.8]	[4.2]
	(6)	(6)	(6)	(10)	(21)
240500	6.5	6.5	6.0	4.6	2.9
32	[3.7]	[3.7]	[3.5]	[2.7]	[1.7]
	(6)	(6)	(7)	(12)	(31)
240902	9.6	9.6	8.9	6.9	4.4
33	[8.0]	[8.0]	[7.4]	[5.7]	[3.7]
	(6)	(6)	(7)	(12)	(31)
240954	22.4	22.4	20.8	16.0	10.1
34	[6.2]	[6.2]	[5.9]	[4.6]	[3.0]
	(6)	(6)	(7)	(12)	(31)
241000	19.9	19.9	18.6	15.5	12.0
35	[14.1]	[14.1]	[14.0]	[13.6]	[11.6]
	(6)	(6)	(7)	(12)	(31)
243000	25.7	25.7	23.7	18.1	11.3
38	[6.9]	[6.9]	[6.4]	[4.8]	[3.1]
	(6)	(6)	(7)	(12)	(31)

See footnotes at end of table.

Table 9.--Selected results of K-CERA analysis--Continued

Identification map No.	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)				
	Budget, in thousands of 1983 dollars				
	Current operation 462	500	550	550[1/]	1000
243960 39	12.0 [7.7] (6)	12.0 [7.7] (6)	11.2 [7.3] (7)	8.8 [5.9] (12)	5.7 [3.9] (31)
234320 40	42.3 [36.9] (6)	25.1 [21.3] (18)	20.9 [17.6] (26)	30.8 [26.4] (12)	11.8 [9.8] (83)
244420 41	20.2 [12.9] (6)	13.8 [8.7] (13)	11.4 [7.2] (19)	14.3 [9.1] (12)	6.6 [4.3] (59)
244473 43	8.4 [5.2] (6)	8.4 [5.2] (6)	7.8 [4.9] (7)	6.1 [4.0] (12)	3.9 [2.6] (31)
245050 44	7.8 [0.7] (6)	7.8 [0.7] (6)	7.2 [0.7] (7)	5.5 [0.5] (12)	3.4 [0.4] (31)
245140 45	19.2 [6.1] (6)	19.2 [6.1] (6)	17.7 [5.8] (7)	13.5 [4.8] (12)	8.4 [3.2] (31)
247480 46	25.4 [22.5] (6)	17.6 [15.5] (13)	14.7 [12.9] (19)	18.4 [16.2] (12)	8.6 [7.6] (59)
247510 47	68.9 [65.4] (6)	35.1 [31.1] (23)	28.4 [24.8] (35)	48.9 [44.7] (12)	16.8 [14.4] (103)

See footnotes at end of table.

Table 9.--Selected results of K-CERA analysis--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)				
	Budget, in thousands of 1983 dollars				
Identification map No.	Current operation 462	500	550	550[1/]	1000
248000 48	33.0 [31.9] (6)	22.1 [21.3] (13)	18.2 [17.5] (19)	23.1 [22.3] (13)	9.9 [9.5] (66)
252500 50	32.8 [17.0] (6)	23.2 [11.8] (12)	19.1 [9.8] (18)	23.2 [11.8] (12)	10.8 [6.2] (62)
253000 51	19.9 [10.2] (6)	19.9 [10.2] (6)	19.9 [10.2] (6)	15.5 [7.9] (10)	10.3 [5.2] (23)
253500 52	37.6 [25.6] (6)	26.7 [17.7] (12)	21.9 [14.4] (18)	26.7 [17.7] (12)	12.3 [8.3] (62)
256500 53	37.7 [34.4] (6)	29.1 [26.3] (10)	24.8 [22.3] (14)	26.7 [24.1] (12)	14.6 [13.2] (42)
262900 56	30.1 [23.1] (6)	23.2 [18.2] (11)	18.9 [14.8] (17)	22.4 [17.4] (12)	9.8 [7.7] (66)
263800 57	25.7 [18.7] (6)	22.4 [16.3] (8)	18.4 [13.4] (12)	18.4 [13.4] (12)	9.8 [7.1] (44)
264000 58	33.1 [25.2] (6)	23.0 [17.6] (13)	18.2 [14.0] (21)	23.9 [19.3] (14)	10.6 [8.2] (64)

See footnotes at end of table.

Table 9.--Selected results of K-CERA analysis--Continued

	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)				
	Budget, in thousands of 1983 dollars				
Identification map No.	Current operation 462	500	550	550[1/]	1000
264495 60	29.2 [27.3] (6)	23.5 [21.8] (10)	20.1 [18.5] (14)	21.6 [20.0] (12)	10.2 [9.2] (55)
266200 61	27.6 [20.9] (6)	22.9 [17.4] (9)	19.3 [14.7] (13)	20.0 [15.2] (12)	10.4 [7.9] (47)
266300 62	17.6 [7.8] (6)	16.3 [7.2] (7)	13.0 [5.7] (11)	12.4 [5.5] (12)	7.2 [3.3] (36)
266480 63	27.2 [13.2] (6)	21.3 [10.5] (10)	16.9 [8.4] (16)	19.5 [11.8] (14)	8.8 [4.4] (60)
266500 64	16.1 [13.6] (6)	15.0 [12.7] (7)	12.2 [10.3] (11)	11.6 [9.9] (12)	6.6 [5.6] (40)
267000 65	18.3 [9.4] (6)	18.3 [9.4] (6)	15.9 [8.0] (8)	13.0 [6.4] (12)	8.2 [4.0] (31)
270500 67	42.5 [30.6] (6)	29.8 [20.5] (13)	23.6 [15.8] (21)	31.0 [21.4] (12)	12.6 [8.0] (75)
274495 72	23.7 [19.5] (6)	23.7 [19.5] (6)	23.7 [19.5] (6)	23.7 [19.5] (6)	18.2 [16.4] (18)

See footnotes at end of table.

Table 9.--Selected results of K-CERA analysis--Continued

Identification map No.	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)				
	Budget, in thousands of 1983 dollars				
	Current operation 462	500	550	550[1/]	1000
301900 74	62.2 [55.6] (6)	32.7 [27.1] (21)	27.3 [22.4] (30)	43.5 [37.0] (12)	14.4 [11.7] (110)
310800 75	40.0 [22.1] (6)	34.7 [19.1] (8)	27.3 [14.9] (13)	28.4 [15.6] (12)	14.7 [8.0] (46)
310947 76	42.0 [6.0] (6)	22.0 [3.1] (21)	18.4 [2.5] (30)	29.4 [4.1] (12)	9.6 [1.4] (109)
311000 77	33.6 [30.1] (6)	23.2 [21.3] (17)	19.6 [18.0] (25)	26.7 [24.4] (12)	11.5 [10.6] (78)
311500 78	19.7 [18.3] (6)	16.0 [15.1] (9)	12.8 [12.2] (14)	13.8 [13.1] (12)	7.8 [7.5] (39)
312000 79	12.3 [9.5] (6)	9.7 [7.8] (9)	7.6 [6.3] (14)	8.3 [6.8] (1)	4.5 [3.9] (39)
312180 80	30.3 [26.0] (6)	24.8 [21.1] (9)	19.9 [16.8] (14)	21.5 [18.2] (12)	12.1 [10.2] (39)
312200 81	22.6 [14.7] (6)	21.1 [13.9] (7)	17.9 [12.1] (10)	16.5 [16.3] (12)	9.4 [6.6] (39)

See footnotes at end of table.

Table 9.--Selected results of K-CERA analysis--Continued

Identification map No.	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)				
	Budget, in thousands of 1983 dollars				
	Current operation 462	500	550	550[1/]	1000
312500 82	10.6 [8.7] (6)	9.8 [8.1] (7)	8.1 [6.9] (10)	7.3 [6.3] (12)	4.1 [3.6] (39)
312635 83	24.0 [22.7] (6)	21.4 [20.1] (8)	18.0 [16.8] (12)	18.0 [16.8] (12)	10.6 [9.7] (38)
312640 84	14.9 [8.9] (6)	12.9 [7.6] (8)	10.6 [6.2] (12)	10.6 [6.2] (12)	6.1 [3.7] (38)
312645 85	14.7 [5.6] (6)	12.8 [5.1] (8)	10.5 [4.3] (12)	10.5 [4.3] (12)	5.9 [2.6] (39)
262690 87	23.6 [20.7] (6)	23.6 [20.7] (6)	18.5 [16.1] (10)	16.9 [14.7] (12)	11.0 [9.5] (29)
312700 88	17.9 [16.1] (6)	17.9 [16.1] (6)	17.9 [16.1] (6)	12.9 [11.3] (12)	9.5 [8.3] (23)
312720 89	12.7 [12.5] (6)	12.7 [12.5] (6)	12.7 [12.5] (6)	9.3 [9.2] (12)	6.9 [6.8] (23)
313000 91	8.3 [7.4] (6)	8.3 [7.4] (6)	8.3 [7.4] (6)	7.3 [6.5] (8)	6.5 [5.8] (10)

See footnotes at end of table.

Table 9.--Selected results of K-CERA analysis--Continued

Identification map No.	Standard error of instantaneous discharge, in percent [Equivalent Gaussian spread] (Number of visits per year to site)				
	Budget, in thousands of 1983 dollars				
	Current operation 462	500	550	550[1]	1000
313100 92	1.5 [0.0] (6)	1.5 [0.0] (6)	1.5 [0.0] (6)	1.3 [0.0] (8)	1.1 [0.0] (10)
313250 94	3.7 [0.1] (6)	3.7 [0.1] (6)	3.7 [0.1] (6)	3.2 [0.0] (8)	2.9 [0.0] (10)

1/ Site visits per trip limited to a maximum of 12.
2/ Square root of (total variance/number of stations).

It can be seen that the current policy results in an average standard error of estimate of instantaneous streamflow of 27.8 percent. This policy requires a budget of $462,000 to operate the 94-station stream-gaging program. The range in standard errors is from a low of 1.5 percent for station 313100 (Rainbow Springs near Dunnellon) to a high of 68.9 percent at station 247510 (Tomoka River near Holly Hill).

The travel program was run with the current budget and minimum visit constraints and allowed to optimize the total variance. Not enough funds were available after the routes requirements were satisified to permit any more routes to be run. This first run had a requirement that the current routes be used before optimization. A second run was made with the same budget and minimum visit constraints, but the travel program was allowed to choose the routes. The program could not improve upon the total variance resulting from the currently used routes.

With a budget of $550,000, the travel program optimization resulted in an average standard error of 17.8 percent. However, this solution requires that 31 of the 94 stations be visited at a frequency greater than 12 times per year. One station (247510) would require 35 visits per year. This solution is not realistic. Therefore, the travel program was rerun with the same budget but with a maximum of 12 site visits per year imposed. This resulted in an average standard error of 20.2 percent.

The maximum budget analyzed was $1 million which resulted in an average standard error of estimate of 9.8 percent. Thus, doubling the budget in conjunction with policy change would more than halve the average standard error that would result from the current policy and current budget. For this budget, extremes of standard error are 1.1 percent for station 313100, and 18.2 percent at station 274495. Thus, it is apparent that significant improvements in accuracy of streamflow records can be obtained if larger budgets become available.

The analysis was also performed under the assumption that "no correlative data at a gaging station was lost," to estimate the uncertainty that was added to the stream-gaging records because of less than perfect instrumentation. The curve, labeled "Without missing record" in figure 24, shows the average standard errors of estimation of streamflow that could be obtained if perfectly reliable systems were available to measure and record the correlative data. For the minimal operational budget of $462,000, the impacts of less than perfect equipment are greatest; average standard errors increase from 20.6 to 27.8 percent. At the other budgetary extreme of $1 million under which stations are visited more frequently and the reliability of equipment should be less sensitive, average standard errors increased from 7.8 percent for ideal equipment to 9.8 percent for the current systems of sensing and recording of hydrologic data. Thus, improved equipment can have a very positive impact on streamflow uncertainties throughout the range of operational budgets that possibly could be anticipated for the stream-gaging program in central Florida.

Conclusions from the K-CERA Analysis

As a result of the K-CERA analysis, the following comments and suggestions are offered:

1. The present funding for the stream-gaging program is appropriate. This analysis has identified stations that require more frequent measurements, and some that need less frequent measurements. The workload can be shifted to provide necessary measurement frequency within the present budget for most stations.

2. Two stations require more time and manpower to provide needed measurement frequency to reduce the standard error. The funding for these sites will be renegotiated with the respective cooperators.

3. Plans are being considered to hire local residents as observers for stations that have high percentage of lost record due to equipment failure or vandalism. These increased costs will be renegotiated with the respective cooperators.

SUMMARY

Currently (1983), there are 94 continuously-recording gaging stations being operated in central Florida at a cost of $462,000 per year. Twelve separate sources contribute funding to this program.

The current policy for operation of the 94-station program has an average standard error of estimate for instantaneous discharge of 27.8 percent. It was shown that the overall level of accuracy of the records at these 94 sites could be improved with a $550,000 budget and a 12-visit maximum constraint to an average error of 17.8 percent, if the allocation of gaging resources among gaging stations was altered. However, this increase in funds is not feasible with the present funds available in the cooperative program. Selected stations having large average errors will be referred to cooperators for increased funding to improve the standard error.

A major component of the error in streamflow records is caused by loss of primary record (stage or other correlative data) at the gaging stations because of malfunctions of sensing and recording equipment. Operating under the present budget and practices, the average standard error could be reduced to 20.6 percent if no records were lost. Upgrading of equipment and development of strategies to minimize lost record appear to be key actions required to improve the reliability and accuracy of the streamflow data generated.

Studies of the cost-effectiveness of the stream-gaging program should be continued and should include investigation of the optimum ratio of discharge measurements to total site visits for each station, as well as investigation of cost-effective ways of reducing the probabilities of lost correlative data. Future studies also will be required because of changes in demands for streamflow information with subsequent addition and deletion of gaging stations. Such changes will impact the operation of other stations in the program both because of the dependence between stations of the information that is generated (data redundancy) and because of the dependence of the costs of collecting the data from which the information is derived.

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