Rainfall and Freshwater Discharge in the Indian River Basin within the St. Johns River Water Management District, East-Central Florida, 1989-91

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CONVERSION FACTORS, VERTICAL DATUM, ABBREVIATIONS, AND ACRONYMS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi^2)	259	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per hour (in/h)	2.54	cubic meter per hour (m^2/h)

Equations for temperature conversion between degrees Celsius (°C) and degrees Fahrenheit (°F):

°C = 5/9 (°F - 32)

°F = (9/5 °C) + 32

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Altitude, as used in this report, refers to distance above or below sea level.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (μS/cm at 25 °C).

Additional abbreviations

hr	hour
min	minute
yr	year

Acronyms

ADDMS	Acoustic Doppler discharge measurement system
AVM	acoustic velocity meter
BRANCH	branch-network dynamic flow model
FIT	Florida Institute of Technology
NOAA	National Oceanic and Atmospheric Administration
SJRWMD	St. Johns River Water Management District
SWIM	Surface Water Improvement and Management Act
USGS	United States Geological Survey
WATSTORE	U.S. Geological Survey's National *Wa*ter Data *Sto*rage and *Re*trieval System

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ABSTRACT

The Indian River is the largest in a system of shallow, bar-built estuarine lagoons along the Atlantic coast of east-central Florida. Extensive drainage alterations within the Indian River basin have increased freshwater discharge to the river. During periods of heavy rainfall, the river receives large volumes of freshwater that decrease salinity so much that it sometimes results in fishing restrictions and loss of revenue.

Rainfall data collected during this study indicated that frequent thunderstorm activity accounted for more than 50 percent of the total annual rainfall. During the 1989-91 study period, weekly rainfall ranging from 10 to 20 inches was measured during late September through early October of each year. Daily rainfall exceeded 1 inch only 12 percent of the time, but accounted for at least 50 percent of the annual rainfall. Storms with rainfall exceeding 3 inches were 8 times more likely to occur during the wet season (June 1 through October 15) than during the dry season (October 16 through May 31).

Total freshwater discharge to the Indian River was computed by combining gaged tributary flow and ungaged basin drainage estimated from discharge-to-rainfall ratios which were extrapolated from nearby gaged basins. The discharge-to-rainfall ratio for the Indian River, based on the annual average for all basins, averaged 0.40 which also was about the ratio for the Indian River Farms and Turkey Creek tributary basins. Ratios ranged from 0.09 for the Trout Creek tributary basin to 0.78 for the Crane Creek tributary basin.

Total freshwater discharge to the Indian River was nearly twice as great during the wet season than during the dry season for the period 1989-91. Freshwater discharge averaged 881 cubic feet per second annually, ranging from 1,240 cubic feet per second during the wet season to 643 cubic feet per second during the dry season. Of the total freshwater discharge, Turkey Creek basin contributed 18.0 percent, Indian River Farms basin 16.3 percent, and South Prong Sebastian Creek basin 12.6 percent. Combined flow from the remaining basins contributed 13.5 percent. Ungaged flow contributed nearly 40 percent of the total freshwater discharge. Seasonal differences in basin discharge were greatest in the southern part of the study area.

INTRODUCTION

The Indian River is the largest in a system of shallow, bar-built estuarine lagoons along the Atlantic coast of east-central Florida (fig. 1). (Although the Indian River has many characteristics of a lagoon, it is referred to as a river in this report.) The river is connected to the Mosquito Lagoon and the Banana River in Brevard County, and is separated from the Atlantic Ocean by a narrow barrier island which is breached only at Sebastian Inlet. The northern end of the mainland basin, land west of the river, extends nearly 110 mi along the coast within the St. Johns River Water Management District (SJRWMD) from near New Smyrna Beach in southern Volusia County to the Indian River-St. Lucie County line about 5 mi south of Vero Beach (fig. 1).

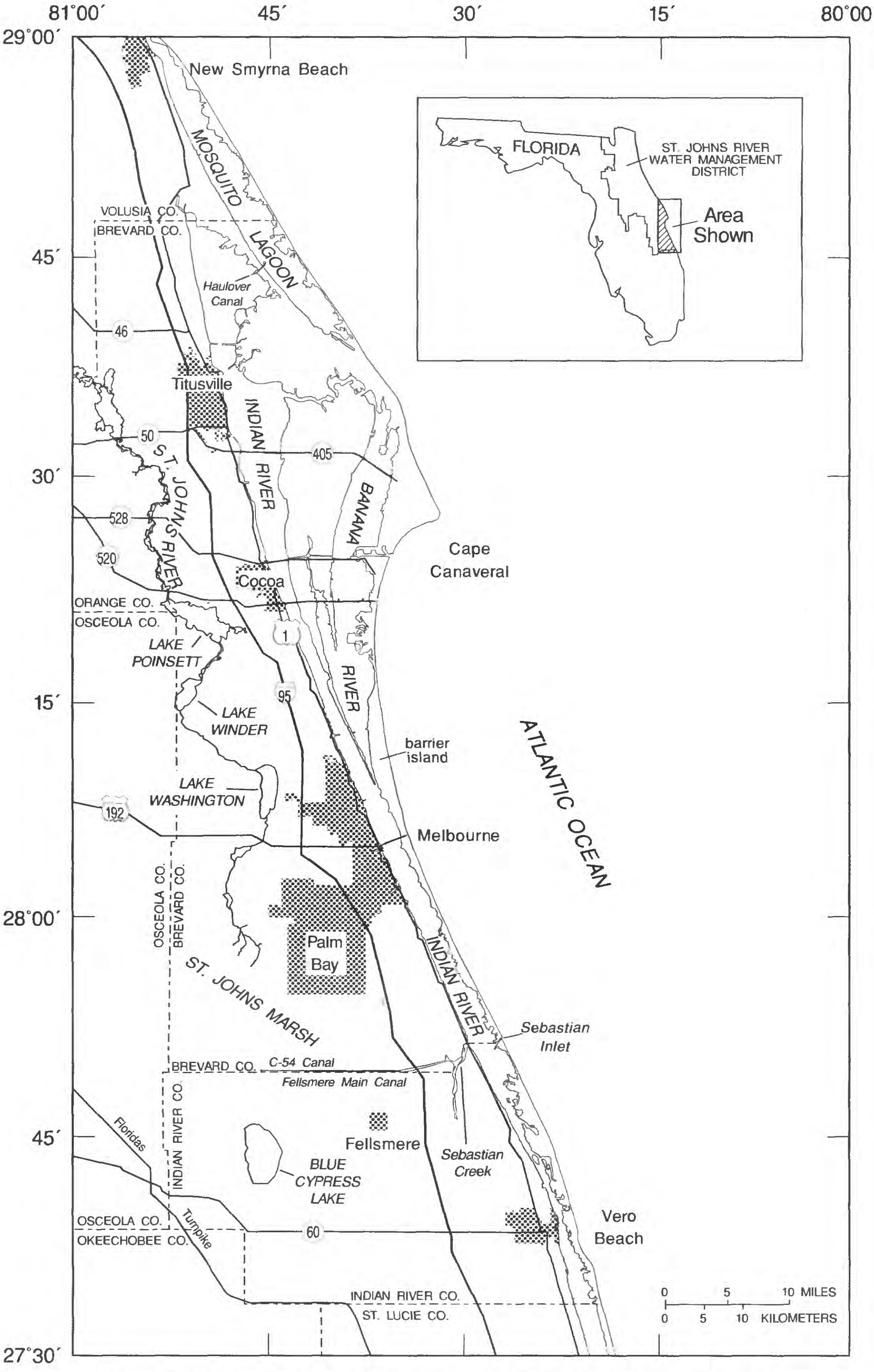

Figure 1. Location of the Indian River within the St. Johns River Water Management District.

Freshwater discharge enters the river from many tributaries and mixes with saltwater entering the river at Sebastian Inlet, creating an estuarine environment. The Indian River is a major commercial source of shellfish, providing 90 percent of the Florida harvest of clams and 15 percent of the national harvest.

Drainage modifications within the basin have increased freshwater discharge to the Indian River (Barile, 1976). Freshwater discharge consists of stormwater runoff (stormflow), tributary base flow generated by release of shallow ground water and bank storage, irrigation flow, drainage from citrus groves, and interbasin diversion through manmade canals. Extensive channelization that began in the Palm Bay area around 1922 and near Fellsmere during the 1940's has altered the natural drainage system in the mainland parts of the basin. During periods of heavy rainfall, the Indian River receives large volumes of freshwater that decrease salinity so much that it sometimes results in restrictions and loss of revenue for the commercial fishing industry (Indian River Lagoon Estuary Program, 1993). Control structures on tributaries to the river have been constructed to decrease the effects of the manmade changes upon the system; however, hydrologic data are insufficient to assess the effects of each structure and to develop appropriate management plans for the Indian River (Steward and VanArman, 1987).

The total freshwater discharge to the Indian River from controlled and uncontrolled tributaries and canals is unknown, and the hydrodynamic response to freshwater inflow and associated changes in the salinity of the Indian River are not well understood. Temporal and spatial distribution of rainfall across the basin is correlated to surface-water runoff, but is not well defined. In 1988, the U.S. Geological Survey (USGS), in cooperation with the SJRWMD, began a 4-yr study to define the magnitude of surface-water runoff discharging into the Indian River and to evaluate the effect of freshwater inflow on the river. The study included the collection of rainfall data and measurement of freshwater discharge from tributary drainage basins of the Indian River that are within the jurisdiction of the SJRWMD. The study was done as a part of the Surface Water Improvement and Management Act (SWIM), and expanded an already existing network of rainfall and streamflow gaging sites from 16 stations in 7 drainage basins to 25 stations in 12 basins.

Previous studies, primarily by the Florida Institute of Technology (FIT) using available USGS data, have concentrated on stormflow from selected areas of the basin (Barile, 1976; Luzkow, 1979; Glatzel, 1986; and Pandit and El-Khazen, 1987). Continuous streamflow records, collected since 1949, for three canals in the Vero Beach area are available (Hendricks, 1963); however, most of the historical stage and discharge records in the Indian River basin are of short duration, 1954-58. Some intermittent stage and discharge records are available for various tributaries during the early to mid-1980's (U.S. Geological Survey, 1961-91).

Purpose and Scope

This report presents data on rainfall and freshwater discharge for the northern part of the Indian River basin that lies within the SJRWMD. From these data, the total annual and seasonal freshwater discharges into the Indian River were estimated. Flow-duration curves for the largest, gaged drainage basins are presented and discussed. Results are presented from the application of a one-dimensional branch-network dynamic flow model (BRANCH) to simulate flows in one of the tidal tributaries. Also discussed in the report are how streamflow and rainfall data are used to compute discharge-to-rainfall ratios for the gaged tributary basins and how a comparable ratio can be applied to the ungaged basins to estimate discharge to the Indian River. Annual and seasonal discharge magnitudes from gaged and ungaged basins are compared. The use of acoustic meters, which became available only toward the end of this study, is discussed as a potential new method for gaging streamflow in low-velocity tidal streams within the Indian River basin. In this report, tidally affected streamflow is referred to as "tidal" and includes those tributaries where flows are affected by backwater conditions and sometimes are reversed for a day or more.

Methods

Field techniques used for installing stream-gaging stations and measuring and computing streamflow followed USGS standards that are presented by Rantz and others (1982) and Kennedy (1983). Discharge measurements were made periodically (6-10 times per year) at each stream station to develop and revise stage-discharge curves. Discharge ratings at stage-discharge gaging stations were established using USGS procedures described by Carter and Davidian (1965).

The main objective of the study was to define the freshwater flows for tributaries and canals draining into the Indian River; however, some of the tributary flows are affected by water levels in the Indian River which are influenced by tides in the Atlantic Ocean. In order to meet this objective, the total inflow to the river—including tidal and nontidal tributary flow for each of the tributaries—was analyzed.

Tidal tributary discharge was estimated using BRANCH or an index-velocity rating. The BRANCH model was used for simulating unsteady flow in only one tributary, a tidal reach of Crane Creek, where stage-discharge relations were indeterminate, but water-surface slopes were large enough to permit measurements accurate enough for slope computations. Data required for model input included cross-sectional channel geometry, water level, and discharge. Discharge measurements were made through complete tidal cycles and used for calibrating and verifying BRANCH. For flows exceeding 150 ft^3/s, discharge measurements and computed estimates generally agreed to within 5-20 percent. Flows less than 50 ft^3/s, however, were much more difficult to calibrate and had an indeterminate degree of accuracy.

The BRANCH model accounts for non-uniform velocity distributions using the momentum Boussinesq coefficient, accommodates flow-storage-conveyance separation, and can account for effects of wind shear on the water surface (Schaffranek, 1987). Wind effects on tributary discharge initially were considered in the calibration of the model. Based on a comparison of two sets of discharge estimates computed from the BRANCH model (one set accounting for the effects of wind), results indicated that tributary discharge was not sensitive to the wind velocities measured during the study. In fact, accounting for wind made model calibration more difficult. However, wind could become a significant, short-term factor in controlling discharge, especially during the passage of a hurricane or similar weather system.

An index-velocity gaging station was equipped with an electromagnetic velocity probe to measure positive or negative flow at a fixed location in the stream. Discharge measurements were correlated to point-velocity data measured by the probe to develop a set of stage-area-velocity curves. These curves were then used to compute streamflow based on velocity and stage data (Kennedy, 1984).

A modified discharge-measurement technique was developed to increase the accuracy of the measurement of tidal streamflow under stratified conditions. The measured cross section was divided into two parts: an upper freshwater layer (specific conductance of less than 25,000 $\mu S/cm$ at 25 °C) and an underlying saltwater layer. These two layers were measured separately with specific conductance measured only at the time of the discharge measurement. During the outgoing tide, the entire cross-sectional flow was positive; whereas during incoming tide, only the top (freshwater) layer continued to flow in a positive direction. Measuring stratified flows in this manner improved discharge computations, particularly during tide reversals. When cross-sectional flow was well mixed (no large salinity gradient), streamflow was measured as one layer.

Rain gages, installed and used in accordance with the instructions provided by the manufacturer, were cleaned and serviced bimonthly. A correction was applied to 5-min rainfall data to account for measurement deficits resulting from high-intensity rainfall. Missing daily rainfall record was estimated using data from nearby USGS gages, telemetered SJRWMD gages, or privately owned gages.

PHYSICAL SETTING

The Indian River is connected to the Mosquito Lagoon and the Banana River in Brevard County (fig. 1). Sebastian Inlet, 14 mi north of Vero Beach, is the only direct connection between the Indian River and the Atlantic Ocean within the study area. Haulover Canal, along the northeastern edge of the Indian River, connects the river to Mosquito Lagoon which is directly connected to the Atlantic Ocean north of New Smyrna Beach. Tidal flow in the Indian River, entering and exiting at the southern end of the study area at the Indian River-St. Lucie County line, provides a renewed source of saline water and an outlet for freshwater. There are other direct connections between the Indian River and the Atlantic Ocean outside the study area.

The Indian River surface-water drainage basin is shown in figure 2. The Atlantic Coastal Ridge and Ten Mile Ridge run north-south, roughly parallel to the Indian River, and are the natural boundary between the Indian River basin and the St. Johns River basin to the west. These ridges range in altitude from 5 to 50 ft with an average of 25 to 30 ft (Brown and others, 1962). The Atlantic Coastal Ridge runs the entire length of the study area along the mainland coast. North of Cocoa, this ridge is wide and continuous; to the south, it narrows and is discontinuous. Ten Mile Ridge joins the Atlantic Coastal Ridge from the southwest between Cocoa and Melbourne. In the southernmost part of the study area, the two ridges are nearly 7 mi apart (White, 1970).

Most of the drainage to the Indian River before land-drainage modifications was from the eastern slope of the Atlantic Coastal Ridge north of Melbourne and the "valley" between the western extension of Ten Mile Ridge and the Atlantic Coastal Ridge to the east. The natural size of tributary drainage basins progressively increases south of the point where the Atlantic Coastal Ridge and Ten Mile Ridge join. The Atlantic Coastal Ridge to the north has remained relatively undeveloped; whereas Ten Mile Ridge near Palm Bay and Fellsmere has been extensively developed and transected by canals, diverting surface water from the St. Johns River Basin eastward to the Indian River. The crest of Ten Mile Ridge decreases in altitude to the south, so the ridge is barely distinguishable in southern Indian River County. Tributary basins south of the Melbourne area are delineated by levees extending beyond Ten Mile Ridge westward into the St. Johns Marsh (fig. 2). These alterations increased the size of drainage basins in the central and southern zones.

Drainage

Much of the total tributary discharge to the Indian River in the study area is from basins in southern Brevard County along a 23-mi stretch of shoreline between Melbourne and Sebastian Inlet (fig. 2). Development of the basins draining this stretch has caused the expansion of these basins westward into the St. Johns River basin. The drainage area of the entire Indian River basin was about 796 mi^2 prior to 1912; however, by 1986 the drainage area was expanded to nearly 2,300 mi^2 by diversion of discharge from the headwaters of the St. Johns River (Glatzel, 1986; Steward and VanArman, 1987). Much of this expansion took place near the south end of the study area. Natural drainage of the St. Johns River basin (marshlands west of the Indian River) was toward the north, although some water occasionally overflowed east into the Indian River during periods of high water (Crain and others, 1975). Parts of these marshlands have been extensively channelized, so that drainage is diverted by a series of canals connected to a main

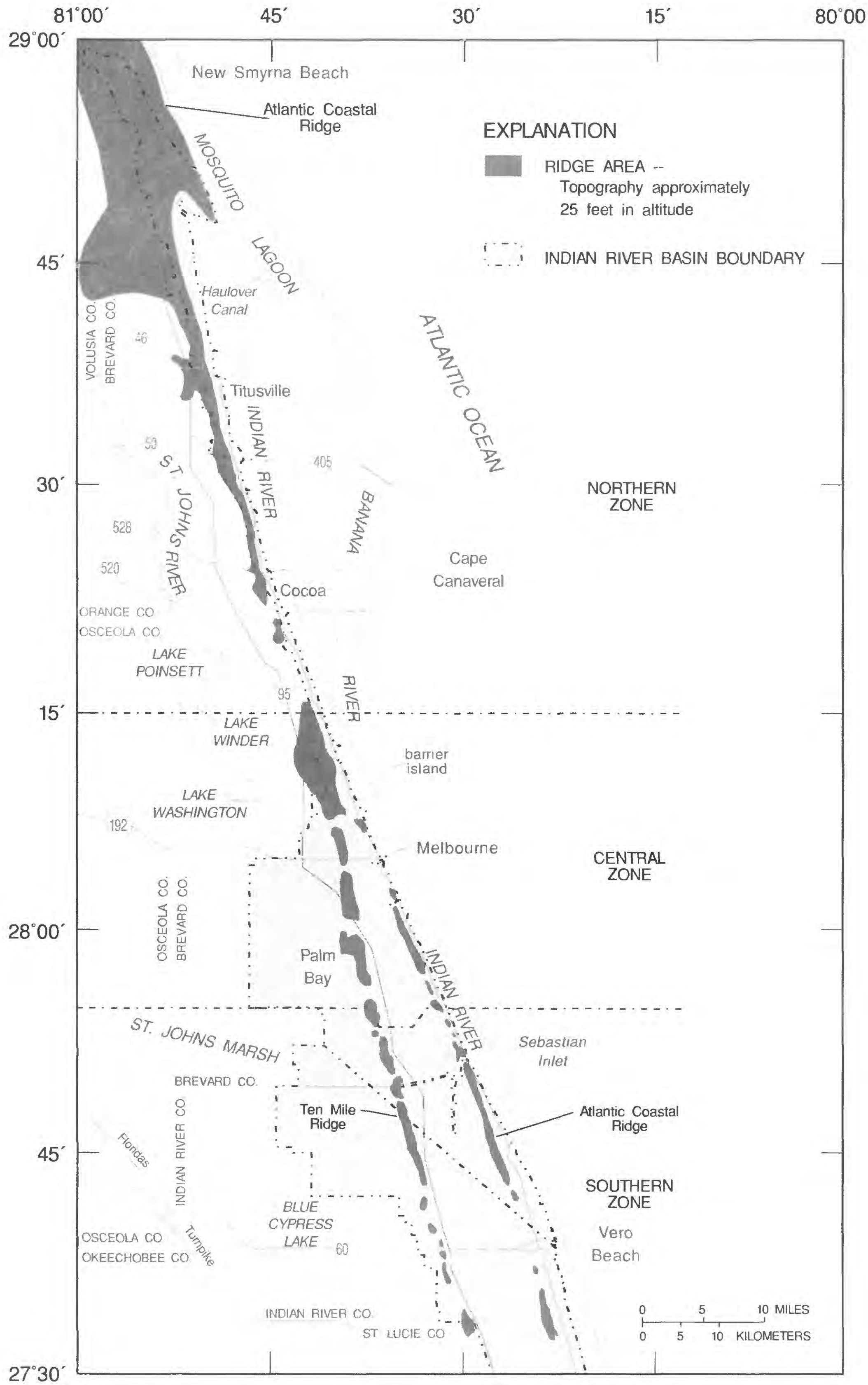

Figure 2. Landforms in the Indian River study area.

canal controlled by a structure located less than 2 mi upstream from the Indian River. These changes in land drainage and diversions of flow have increased freshwater discharge to the Indian River. In 1900, 5 percent of the total rainfall in the Palm Bay area drained into the Indian River; however, by 1974 this drainage had increased to one-third of the total rainfall in this area (Barile, 1976).

Climate

Because weather in the region is moderated by the Atlantic Ocean, the climate of the Indian River basin is subtropical and marked by long, warm, humid summers and mild winters with occasional freezes. Patterns of temperature and rainfall, however, vary within the region. A predominant easterly wind from the Atlantic Ocean cools coastal areas during the summer and warms them during the winter. Mean annual temperatures generally are higher in the southern and inland areas of the Indian River basin, ranging from 71.7 °F at Titusville to 73.0 °F at Fellsmere. Summer mean temperatures of 81-82 °F are nearly uniform throughout the basin; however, winter mean temperatures differ by about 4.5 °F from the north to south across the basin (Steward and VanArman, 1987). Temperature extremes within the basin can be below freezing or above 100 °F for brief periods.

During a typical year, rainfall can be characterized by two distinct seasons: a rainy season from early June to mid-October and a longer dry season from mid-October to early June. In this report, the annual wet season extends from June 1 to October 15 and the annual dry season from October 16 to May 31 of each year. The frequency of high-intensity rainstorms increases rapidly during May, peaks in July or August, and then quickly abates in October. Slow-moving or stationary frontal systems beginning in late September and early October sometimes produce heavy rainfall totaling 10 to 20 in. per week. During the winter, these fronts typically produce 1 to 2 in. of rainfall for 1 to 3 days over extensive areas. During the spring, frontal systems can produce 2 to 6 in. of rainfall. Thunderstorms in the study area occur an average of 75 days each year, accounting for more than 50 percent of the total annual precipitation (Steward and VanArman, 1987). Thunderstorms typically can produce several inches of rain in one location and little or no rain a few miles or even a few hundred feet away.

Although no hurricanes affected the area during the data-collection study period (1989-91), tropical storms generated in the Atlantic Ocean did produce substantial rainfall. Two tropical storms converged and passed near the southern part of the basin on October 9-10, 1990, producing more than 3 in. of rainfall. Hail, snow, and freezing rain account for only a very small, indeterminate amount of the total annual precipitation.

Spatial distribution of rainfall varies considerably within the Indian River basin, probably due to the configuration of Cape Canaveral and the curvature of the coastline (Steward and VanArman, 1987). Mean annual rainfall ranges from more than 56 in. near Titusville to less than 46 in. from Cape Canaveral south along the eastern edge (barrier islands) of the river basin (fig. 3). Historically, the area of greatest rainfall during the summer is near Titusville, and during the winter (December to March) is at the extreme northern and southern boundaries of the Indian River study area. In contrast, the area of least rainfall during the summer is between Palm Bay and Sebastian Inlet, but during the winter, is farther southwest near Fellsmere. During 1951-80, the maximum 24-hr rainfall ranged from 8.28 in. at Melbourne to 12.83 in. at Fellsmere (Steward and VanArman, 1987, p. 2-27). During the study, a maximum 24-hr rainfall of 8.66 in. was recorded north of the Titusville area on October 1, 1991.

Hydrographic Zones

The study area can be divided into three hydrographic zones (fig. 2): (1) The northern

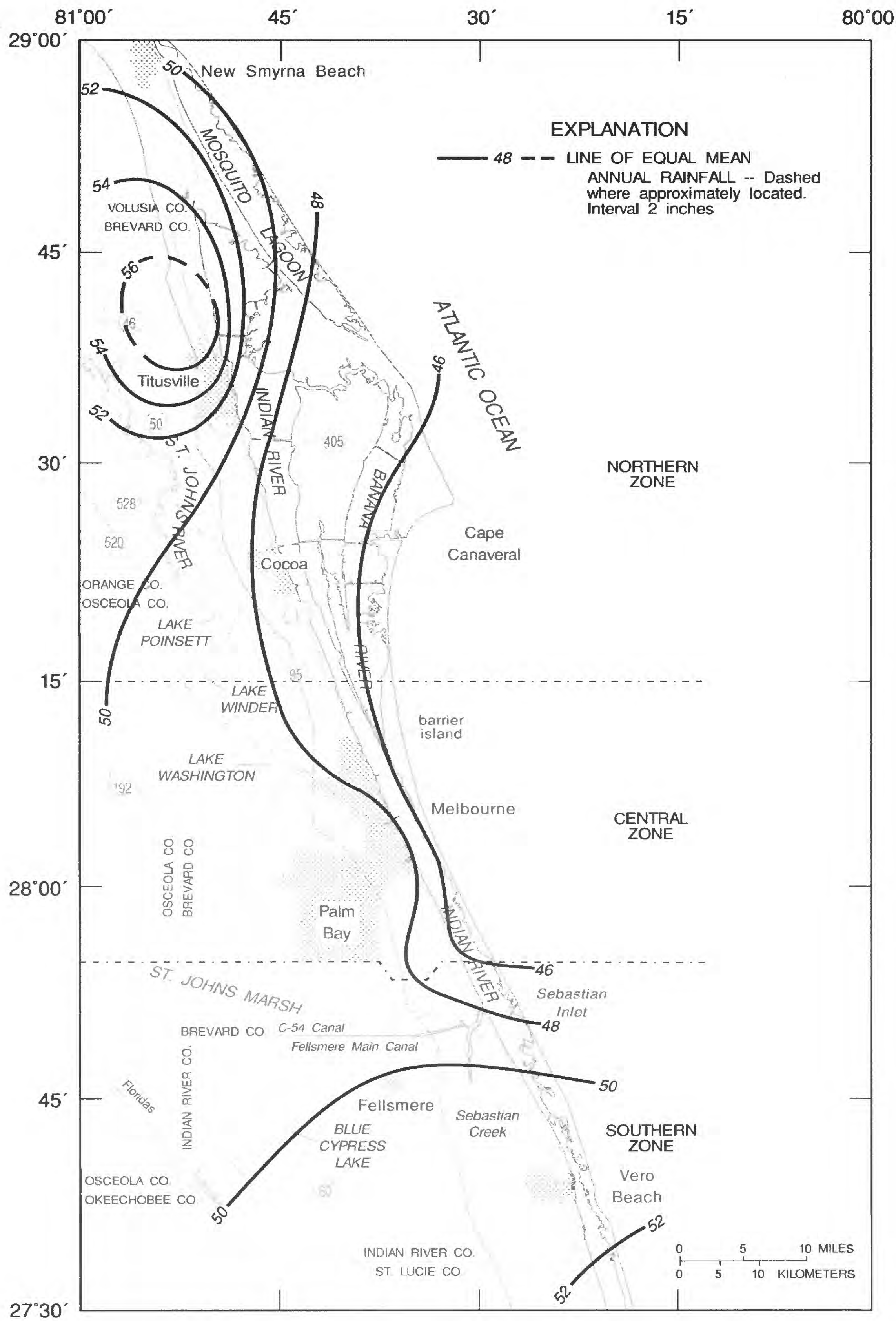

Figure 3. Mean annual rainfall in the Indian River study area, 1951-80.

zone—containing mainland basins north of the Banana-Indian River junction (lat 28°15'); (2) The central zone—containing mainland basins draining into the Indian River between the Banana-Indian River junction and about 3 mi north of Sebastian Inlet; and (3) The southern zone—containing mainland basins draining into the Indian River south of Sebastian Inlet. Division of the study area was based on location along the Indian River, aquatic habitats of the Indian River, and the potential effects of drainage from each zone on the hydrologic nature of the Indian River.

Drainage from study basins in the northern zone, which are far-removed from the remaining basins, primarily affect the estuarine environment (seagrass beds and shellfish communities) located north of Cocoa. Because of the uncertainty of the hydrodynamic nature of the Indian River in response to tidal exchanges through the inlet, basins in the southern half of the study area were divided into two zones—a central zone north of Sebastian Inlet and a southern zone south of Sebastian Inlet. This division would help identify drainage from either zone that could independently affect the local estuarine environment (fisheries and shellfish communities). Because of the size of the study area, weather systems with heavy rainfall typically affect only a part of the basin at one time. For the purpose of this report, the effects of tributary discharge resulting from localized storm events on a particular reach of the Indian River were better defined by dividing the study area into three hydrographic zones.

DATA-COLLECTION NETWORK

Twelve tributary basins were gaged in the three zones along the Indian River (fig. 4). Big Flounder Creek (14 mi north of Titusville) and Addison Creek (1 mi south of Titusville) are relatively small basins within the northern zone. Basins contained in the Melbourne-Palm Bay area of the central zone include Horse Creek, Eau Gallie River, Crane Creek, Turkey Creek, Goat Creek, Kid Creek, and Trout Creek. The remaining basins—North Prong Sebastian Creek, South Prong Sebastian Creek, and Indian River Farms—are contained in the southern zone and extend from southern Brevard County south to the Vero Beach area.

One of the largest single inflows to the Indian River within the SJRWMD is Sebastian Creek, which is the confluence of Sebastian Creek, C-54 Canal, and Fellsmere Main Canal (fig. 1). C-54 and Fellsmere Main Canals, which run parallel and very close to each other along the Brevard-Indian River County line, were not gaged by the USGS during this study. Discharge data collected by the SJRWMD were not available at the time of analyses and, therefore, are not included in this report. Occasionally, the combined discharge from these canals is estimated to be as much as 50 percent of the total inflow to the Indian River.

Boundaries of developed basins, especially in the southern part of the study area, have been substantially expanded in size. As a result, gaged drainage areas generally increase in size from north to south across the study area. The drainage-area boundary for each tributary basin west of the Indian River, was delineated based on maps by Steward and VanArman (1987), USGS topographic maps, and field reconnaissance. Some boundaries, especially those of the Goat, Kid, and Trout Creek basins, could not be verified and were estimated. Although the size of some basins varied slightly during the study, the gaged drainage-basin areas still accounted for about 57 percent of the total Indian River (mainland) basin which averaged nearly 600 mi^2. Much of the ungaged area was in the southern zone which was slightly larger than the combined ungaged areas of the northern and central zones. Gaged basins ranged in size from 0.7 mi^2 for Kid Creek to 105 mi^2 for Turkey Creek. However in 1991, the basin area for Kid Creek was estimated to have increased to approximately 1.7 mi^2.

The data-collection network, established in 12 tributary drainage basins, consists of 25 continuous-recording and partial-record gaging stations (stations recording only maximum peaks in stage). Stations are listed sequentially in table 1 beginning with the basins at the northern end of the Indian River.

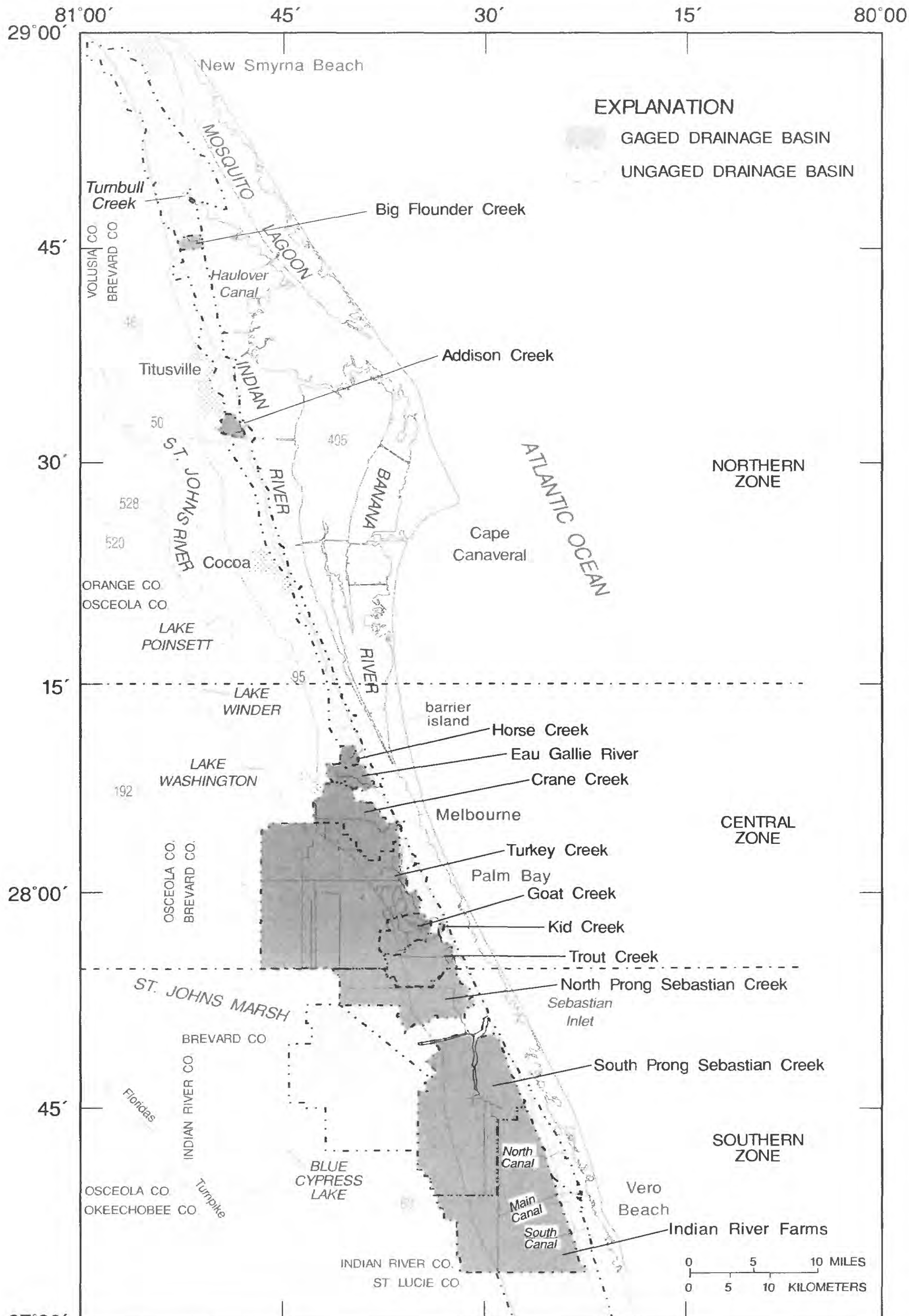

Figure 4. Location of study basins within the Indian River basin.

Table 1. Continuous- and partial-record stations of rainfall, stage, and discharge including data-recording interval, Indian River basin, Florida

[Values listed for each basin in column for gaged drainage area represent at least 90 percent of total drainage area for that basin. S.R. , State Road; R, rainfall; S, stage; Q, discharge (streamflow); P, (partial-record station) maximum stage and discharge; A, area; T, telemetered; V, velocity; Event, recording storm events only]

Station number	Station name and identification number	Latitude	Longitude	Date established	Drainage area (1991) (square miles)		Data type	Data recording interval (minutes)
					Gaged	Ungaged		
	NORTHERN ZONE				4.2	80.2		
	Big Flounder Creek basin				1.8			
1	Flounder Creek Road at Mims (284520080511601)	284520	805116	08-01-89			R	5
2	Addison Creek basin				2.4			
	S.R. 405 near Titusville (283156080484901	283156	804858	08-01-89			R	5
3	U.S. 1 near Titusville (02248510)	283220	804736	04-27-89			S,Q	5
	CENTRAL ZONE				156.6	41.0		
	Horse Creek basin				2.4			
4	Croton Road near Melbourne (280940080392001)	280940	803920	11-17-89			R	5
	(02248900)	280940	803920	04-27-89			S,Q	5
5	Parkway Drive near Melbourne (280926080385901)	280926	803859	07-20-89			P	Event
6	Eau Gallie River basin				5.7			
	Heather Glen Circle at Melbourne (02249007)	280736	803849	01-14-91			S,Q	15
7	Mosswood Drive at Melbourne (02249010)	280735	803827	01-20-87			R	60
	Crane Creek basin				18.7			
8	Babcock Street at Melbourne (02249510)	280406	803717	01-21-87			S,Q	15
9	Hickory Street at Melbourne (002249515)	280417	803648	01-23-87			P	Event
10	U.S. 1 at Melbourne (02249518)	280437	803609	02-11-87			S,A,Q	15
11	West Melbourne City Hall (280422080400501)	280422	804005	08-01-89			R,T	5
	Turkey Creek basin				105.0			
12	C-69 Canal at Eber Road at Palm Bay (280258080394301)	280258	803943	08-01-89			R,T	5
13	C-1 Canal at Red Bud Circle at Palm Bay (280047080433001)	280047	804330	08-01-89			R,T	5
14	C-10 Canal at City of Palm Bay (275956080424701)	275953	804204	08-01-89			R	5
15	Port Malabar Road at Palm Bay (02250030)	280100	803546	01-14-81			S,A,V,Q	15
	Goat Creek basin				8.1			
16	Ramblebrook Street near Valkaria (275620080361301)	275623	803613	12-12-89			R	5
17	Henderson Road at Valkaria (02250500)	275801	803357	04-26-89			S,Q,T	5
	Kid Creek basin				1.7			
18	Old Dixie Highway at Valkaria (02250600)	275735	803233	04-26-89			S,Q	5
	Trout Creek basin				15.0			
19	Summit View Golf Course at Grant (02250700)	275613	803207	04-25-89			S,Q	5
20	Grant Road at Grant (275530080324901)	275522	803250	08-01-89			R.T	5

Table 1. Continuous- and partial-record stations of rainfall, stage, and discharge including data-recording interval, Indian River basin, Florida--Continued

[Values listed for each basin in column for gaged drainage area represent at least 90 percent of total drainage area for that basin. S.R. , State Road; R, rainfall; S, stage; Q, discharge (streamflow); P, (partial-record station) maximum stage and discharge; A, area; T. telemetered; V, velocity; Event, recording storm events only]

Station number	Station name and identification number	Lati-tude	Longi-tude	Date established	Drainage area (1991) (square miles)		Data type	Data recording interval
					Gaged	Ungaged		(minutes)
	SOUTHERN ZONE				183.4	134.5		
	North Prong Sebastian Creek basin				28.5			
21	Wilden Road near Micco (02251500)	275121	803128	01-22-87			S,Q,T	15
	South Prong Sebastian Creek basin				77.8			
22	Roseland Road at Roseland (02251210)	274956	803001	02-10-87			R,T	15
	Indian River Farms basin				77.1			
23	North Canal at S.R. 605 near Vero Beach (02252500)	274132	802500	01-04-49			S,Q	15
24	Main Canal at Ogee Weir at Vero Beach (02253000)	273854	802410	01-04-49			S,Q	15
25	South Canal at U.S. 1 near Vero Beach (02253500)	273611	802324	01-04-49			S,Q	15

Stage, discharge, and climatological data collected by the USGS are stored in computerized data-base files and paper documents. Three numbering systems are used to identify stations in this report. A 15-digit number based on the latitude and longitude of the original station location is assigned to rainfall and partial-record streamflow stations. An 8-digit, "downstream order" number system is used to identify continuous-record streamflow stations. A station number also is used to reference sequentially all stations beginning at the northern end of the Indian River basin. The 15- and 8-digit number systems are used to store and retrieve data from the USGS data management system, the National Water Data Storage and Retrieval (WATSTORE) System. The station numbers are unique to this report.

Stations were located within each basin based on different criteria. Stream-gaging stations were established far enough downstream in each basin to measure at least 90 percent of the total drainage for that basin, with the exception of the Eau Gallie River and North Prong Sebastian Creek basins. Stations were established downstream of control structures on discharge-regulated tributaries. Rain-gage stations generally were centrally located within each basin. Telemetry was used at seven stations for real-time data transmission to monitor localized storm events, and provided additional means by which to backup data and troubleshoot instrumentation malfunctions.

Northern Zone

Stations located in the two basins within the northern zone are shown in figure 5. Streams and ditches were not gaged in the Big Flounder Creek basin because of complex drainage patterns and stream hydraulics. Therefore, the basin was only instrumented with a rain gage at station 1. Addison Creek, south of Titusville, originally was part of the St. Johns River basin, but now is hydrologically separated from the St. Johns River (Addison Canal) by a manmade berm that prevents drainage to the creek south of State Route 405. Streamflow for the Addison Creek

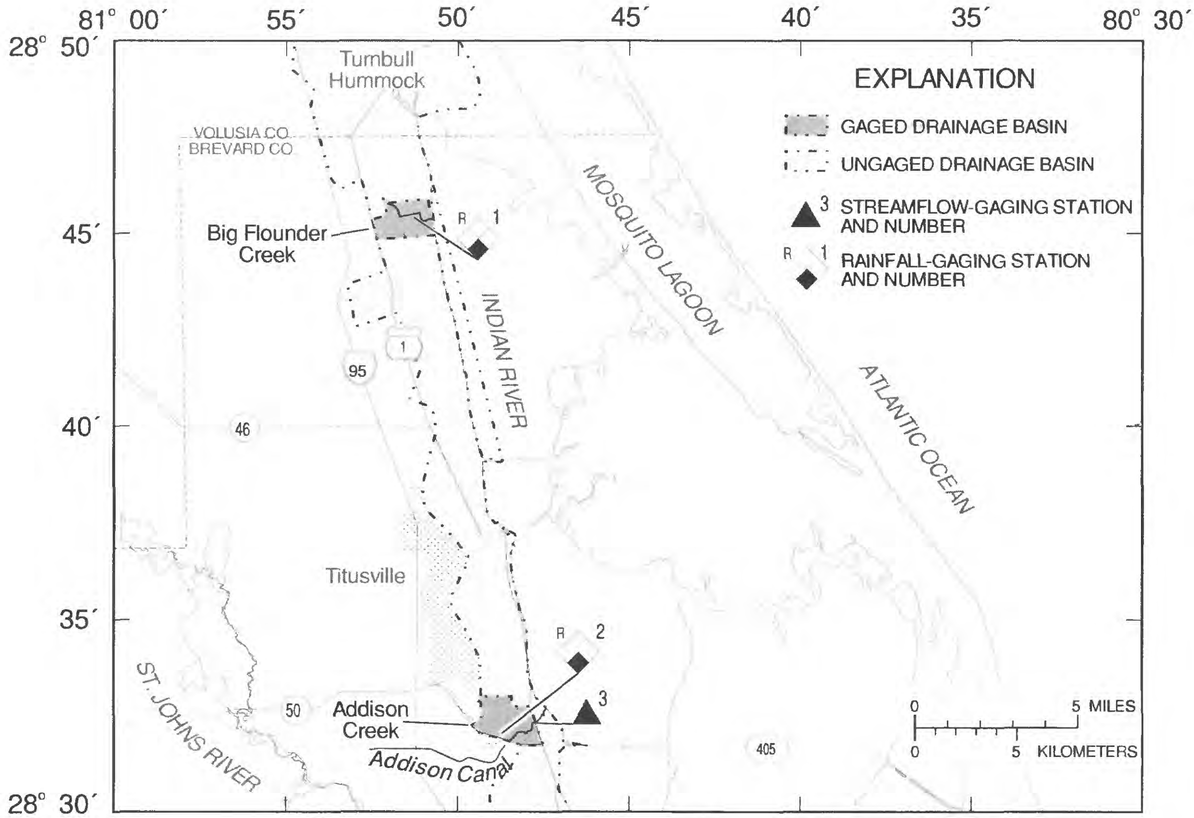

Figure 5. Gaging-station network in the northern-zone basins of the Indian River study area.

basin was gaged at U.S. Highway 1, about 1.3 mi downstream from the berm (station 3). Rainfall for the Addison Creek basin was gaged upstream from station 3, near State Route 405 (station 2).

Central Zone

The central zone of the study area contains 17 gaging stations within 7 tributary basins (fig. 6). More than one stream-gaging station was required in two of the basins because of tidal influences on large, downstream sections of the tributaries. The Crane Creek basin contains a tidal-stream gaging network (stations 8-10) that was used to quantify energy gradients (water-surface profiles) along a reach of the stream for input to the BRANCH model. Tidal movement in Crane Creek at station 10 makes simple stage-discharge gaging impractical. Additional gaging stations, including a partial-record, were used to quantify inflow entering the tidal section of Crane Creek upstream from station 10. A similar network was used to gage Eau Gallie River. However, because of the configuration and hydrodynamic character of the river (energy gradients too small to measure accurately), the network could not be used to obtain and compute

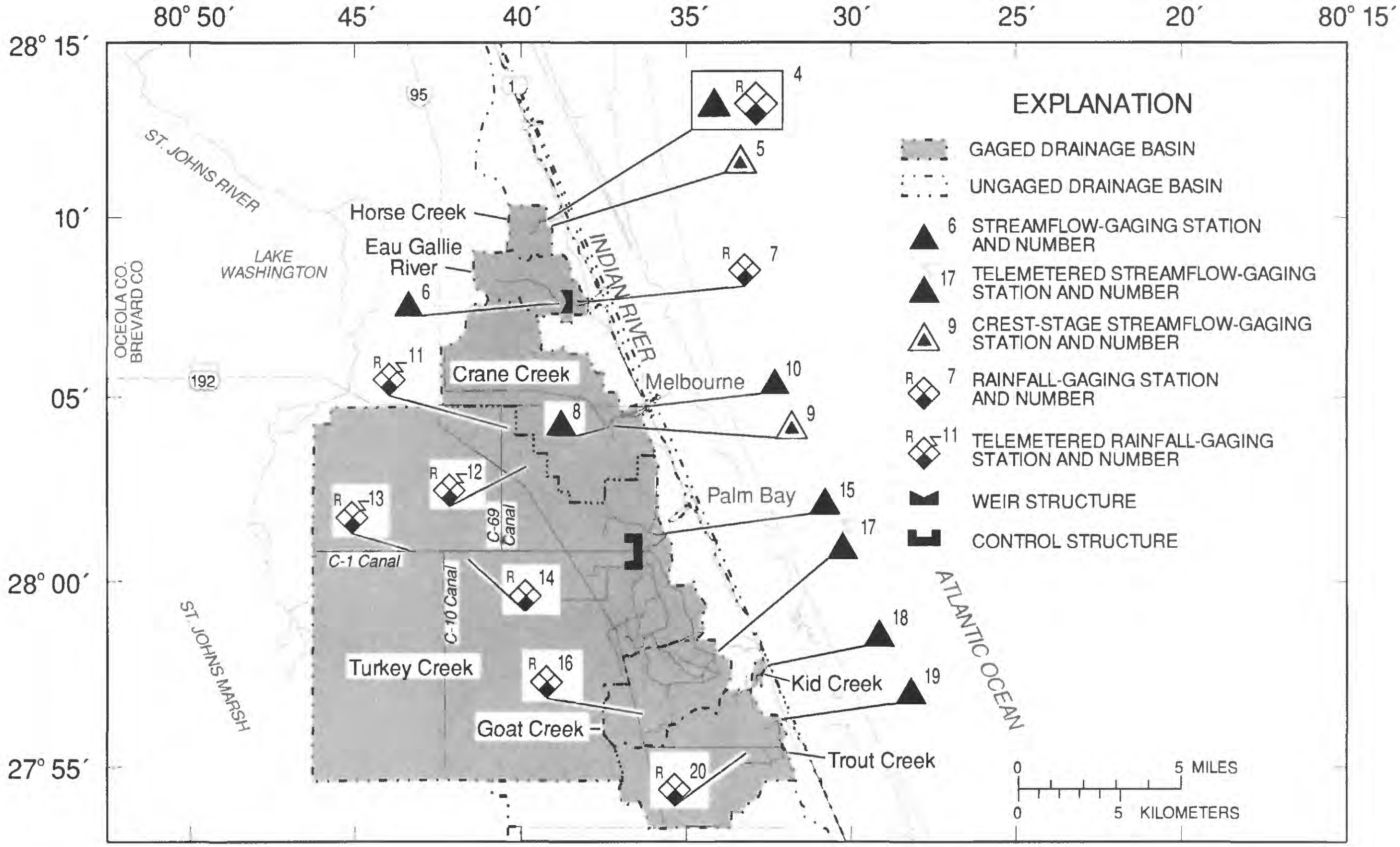

Figure 6. Gaging-station network in the central-zone basins of the Indian River study area.

accurate discharge. Therefore, a single stage-discharge station was established on a nontidal section of the Eau Gallie River upstream from a weir structure where discharge measurements were made (station 6). Also, because of tidal influences (backwater effects), an index-velocity gaging station was installed on Turkey Creek at station 15, about a mile downstream from a gated control structure.

The remaining basins were gaged with stage-discharge stations. Horse Creek was instrumented at two sites—a stage-discharge station on the main channel (station 4) and a crest-stage station measuring maximum stage on a southern tributary (station 5). Goat Creek, Kid Creek, and Trout Creek were instrumented with one station each (stations 17, 18, and 19, respectively). Rainfall was collected in all the central-zone basins, with the exception of Kid Creek. Turkey Creek was instrumented with four rainfall stations (stations 11-14) because of its large drainage area (105 mi^2). Rainfall data from station 11 also were included for Crane Creek basin even though the station was located in the extreme northern part of the Turkey Creek basin.

Southern Zone

Stations for the three basins in the southern zone of the Indian River study area are shown in figure 7. Tidal influence can affect streamflow for a considerable distance upstream from the Indian River in the North and South Prongs of Sebastian Creek. North Prong Sebastian Creek stage-discharge station 21 was located nearly 3 mi upstream from the Indian River to avoid tidal influences. As a result, a large part of the drainage basin was not measured but still included inflow from Sottile Canal. South Prong Sebastian Creek initially was gaged with a tidal-stream gaging network for input to the BRANCH model (similar to Eau Gallie River and Crane Creek) because the tributary was tidally influenced for at least 5 mi upstream from the Indian River. The hydrodynamic character of the creek, similar to Eau Gallie River, made streamflow impossible to gage accurately using this method. The complex nature of inflows to the creek made gaging farther upstream impractical. Therefore, flows from South Prong Sebastian Creek were estimated using a discharge-to-rainfall ratio estimate described later in this report.

The Indian River Farms basin includes the combined discharge of North Canal, Main Canal, and South Canal. Each of the canals was instrumented with a stage-discharge station (stations 23, 24, and 25, respectively) located downstream from a gated control structure, yet upstream from tidal effects. Discharge measurements for Main Canal were made at a weir structure.

RAINFALL

Rainfall patterns during 1990-91 varied in areal and temporal distribution within the Indian River study area. Large storms affecting the entire area were most common during September and October. Smaller storms, confined to two or three tributary basins, were most frequent during the wet season, particularly July and August, and during the dry season from late January to mid-March. Rainfall was least likely in late fall—November to December—and in early spring—March to late-May.

The magnitude, daily frequency, and intensity of rainfall generally were higher during the wet season. Rainfall during the wet season occurred almost daily, affecting at least one tributary basin. The maximum intensity of rainfall was during July and August, whereas the largest magnitude rainfall usually was in September and October. The effect of rainfall on tributary flow also was greatest in September and October when saturated-ground conditions were most likely to exist.

Areal and Temporal Distribution

Rainfall data were summarized for 1990-91 calendar years and compared by wet and dry season with mean annual rainfall (fig. 8). Mean

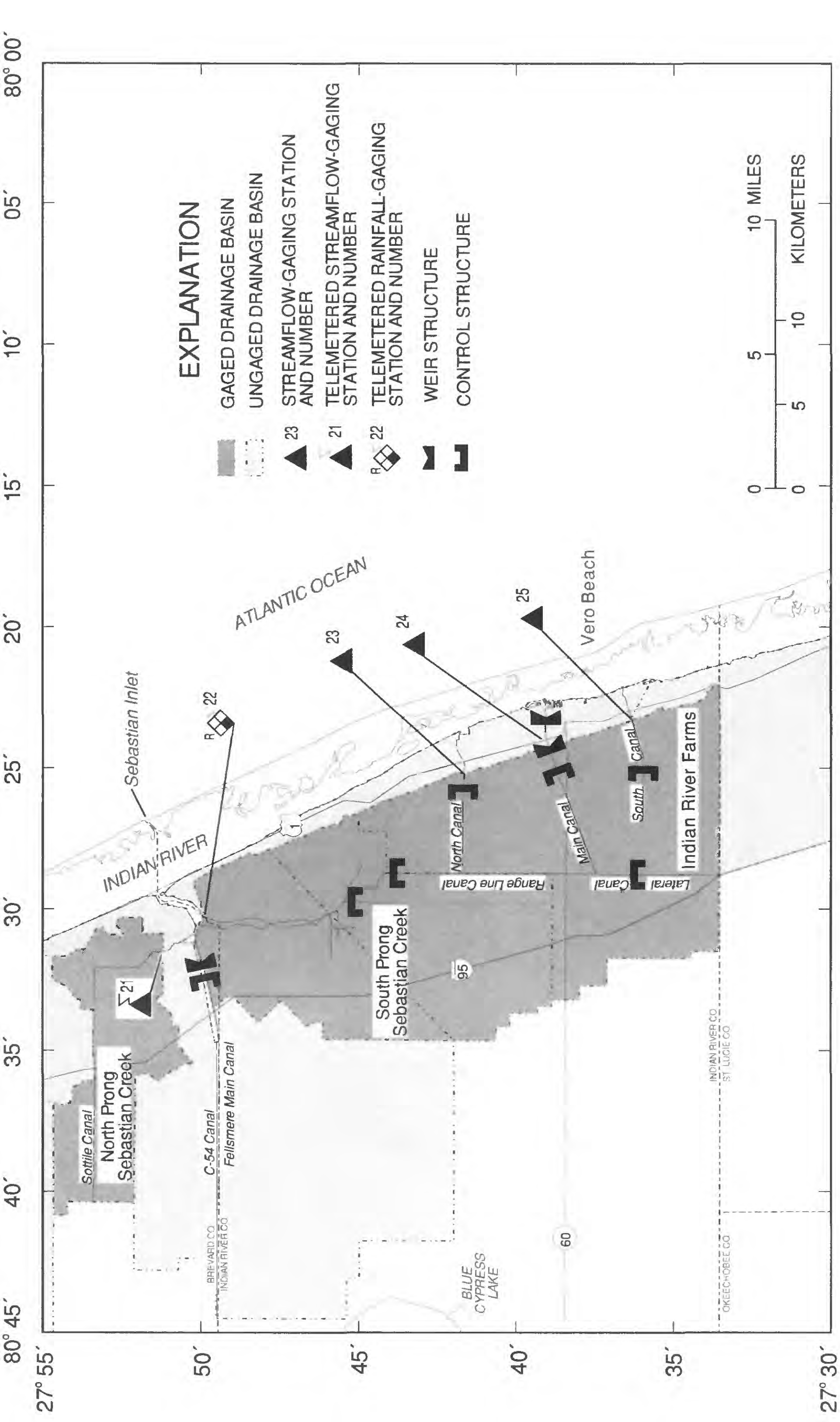

Figure 7. Gaging-station network in the southern-zone basins of the Indian River study area.

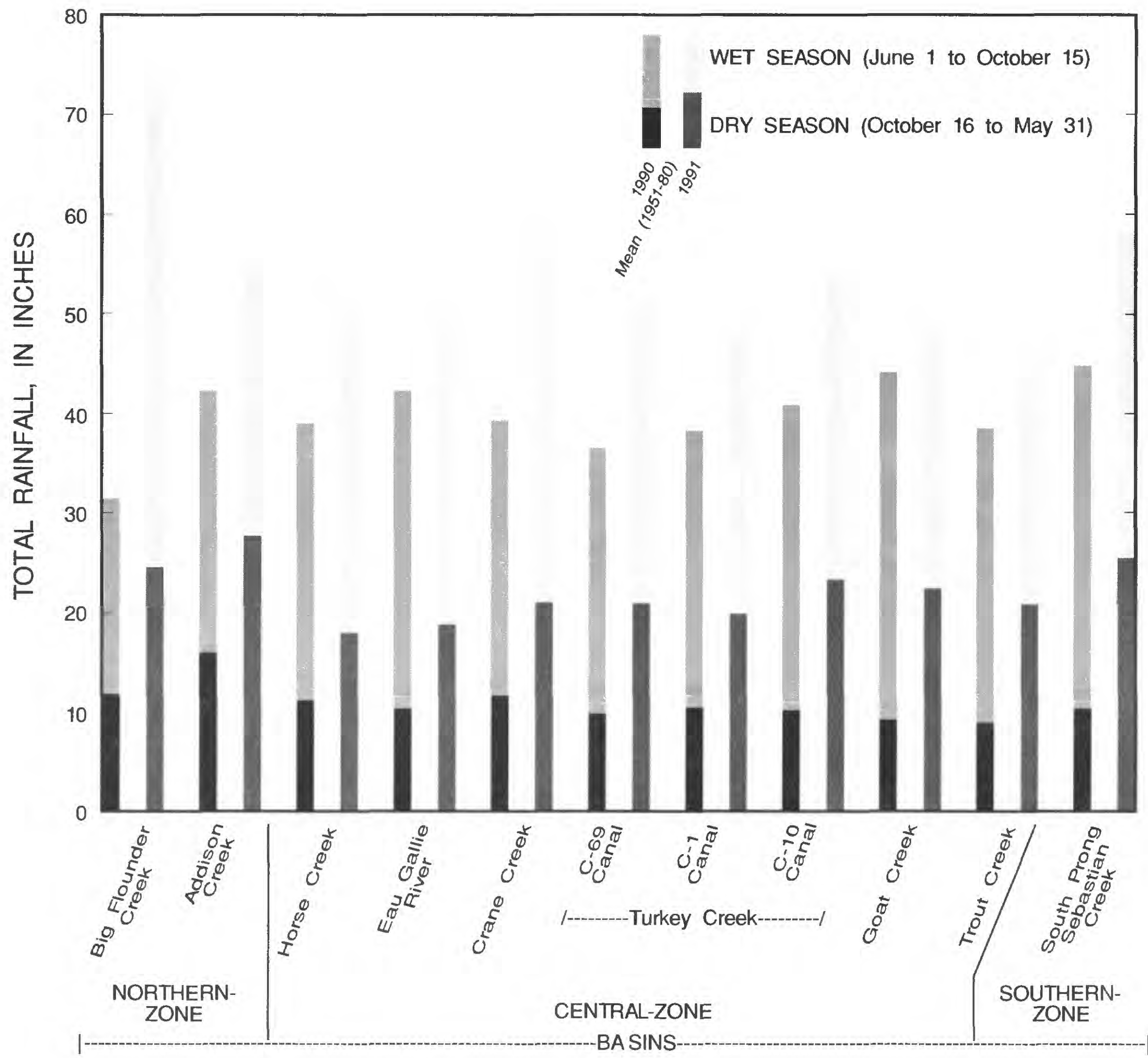

Figure 8. Distribution of seasonal (1990-91) and the 30-year mean annual rainfall for the Indian River study area.

annual rainfall, based on a 30-yr record (1951-1980) from National Oceanic and Atmospheric Administration (NOAA), ranges from 47 to 49 in. at stations in the central and southern zones and from 50 to 54 in. at stations in the northern zone (National Oceanic and Atmospheric Administration, 1982). Annual rainfall measured during the study was below the average at all stations for 1990, and above average at most stations for 1991.

Measured rainfall in 1990 was below the interpolated 30-yr average for the entire area, ranging from 31.43 in. at the Big Flounder Creek station to 44.80 in. at the South Prong Sebastian Creek station. Rainfall was greatest in the southern part (southern and south-central zones) of the study area. In the north, rainfall at the Big Flounder Creek station was only 63 percent of the long-term average; whereas in the south, rainfall at the Goat Creek station was 92 percent of the long-term average. Dry-season rainfall ranged from 9.00 in. at the Trout Creek station to 15.96 in. at the Addison Creek station; whereas wet-season rainfall ranged from 19.59 in. at the

Big Flounder Creek station to 34.85 in. at the Goat Creek station. Wet-season rainfall accounted for 62 percent of the annual rainfall in the northern part of the study area at the Big Flounder Creek and Addison Creek stations. The southern part of the study area had a wet season interrupted by an uncharacteristically dry September, yet accounted for nearly 80 percent of the annual rainfall at the Goat, Trout, and South Prong Sebastian Creek stations. Seasonal rainfall averages, based on a 30-yr record, were not computed for stations because daily records of rainfall within the study area were not available at the time of the analysis.

Measured rainfall in 1991 was near or above average for the entire study area. Annual rainfall ranged from 46.21 in. at the Trout Creek station (97 percent of the long-term average) to 74.30 in. at the Big Flounder Creek station (149 percent of the average and nearly 2.4 times greater than the rainfall for 1990). The Big Flounder Creek station in the north received more than 24 in. of rainfall (32 percent of the total 1991 annual rainfall) during the 15-day period, September 21-October 6, 1991. Dry-season rainfall for 1991 at most stations was nearly twice the dry-season rainfall for 1990 and ranged from 17.98 in. at the Horse Creek station to 27.71 in. at the Addison Creek station. Stations with the highest dry-season rainfall were at the northern and southern ends of the study area. Wet-season rainfall accounted for at least 50 percent of the annual rainfall at all stations and ranged from 25.32 in. at the Trout Creek station to 49.70 in. at the Big Flounder Creek station. About 30 in. of rainfall was recorded at most of the central-zone stations during the 1991 wet season.

As previously stated, the Indian River basin typically receives most of its rainfall during the wet season, June through mid-October. A cumulative-rainfall distribution (fig. 9) indicates how much

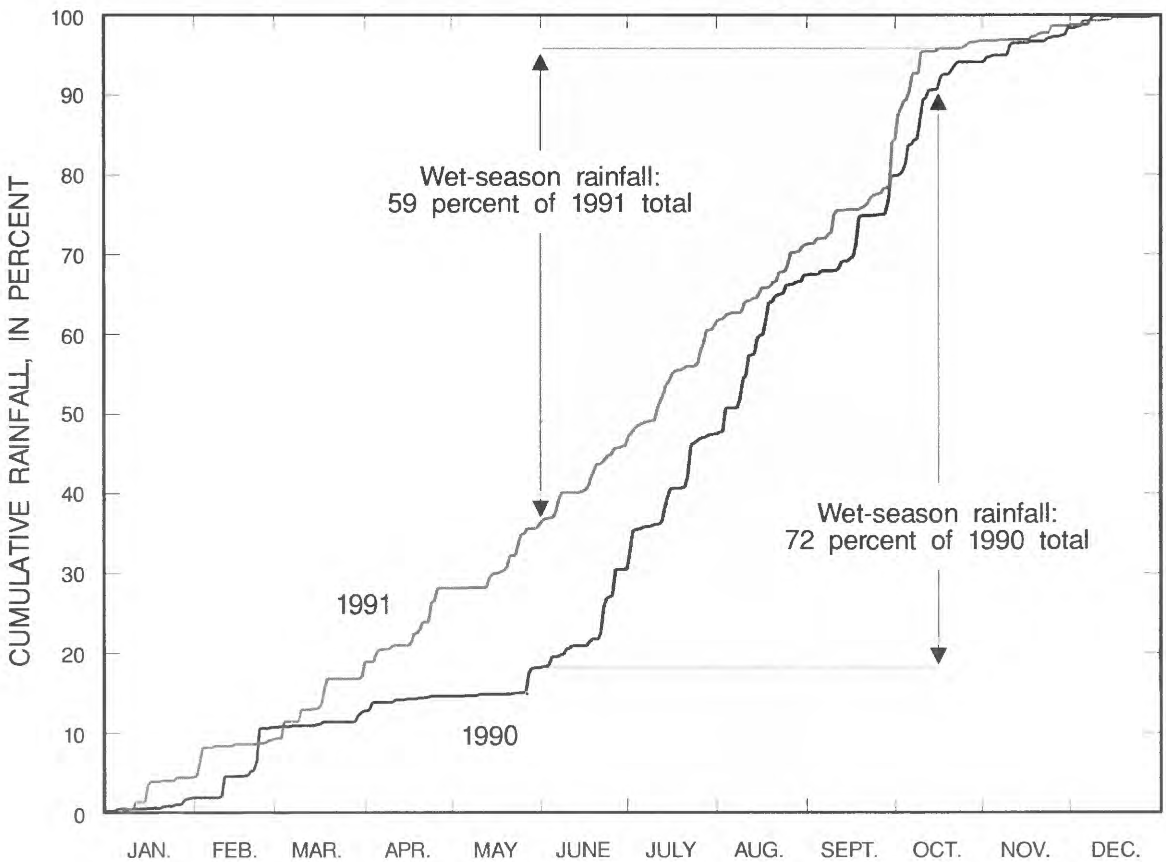

Figure 9. A combined cumulative rainfall distribution for rain-gage sites in the Indian River basin, 1990 and 1991.

rainfall is contributed during each month relative to other months. Wet-season rainfall accounted for 72 percent of the annual rainfall in 1990 and 59 percent of the annual rainfall in 1991. The combined cumulative-rainfall distribution for each year is slightly different. The cumulative-rainfall distribution for 1990 has a much steeper slope during the wet season, indicating a difference between the seasons. However, the rainfall distribution for 1991 is fairly uniform (except for a 2-week period in September and October) and indicates very little change between wet and dry seasons.

Rainfall increased at the end of May 1990 after a 3-month dry period. The largest storms were in July, August, and the first half of October. July storms affected the entire study area and accounted for 17 percent of the 1990 annual rainfall. Storms that mainly affected the southern parts of the study area accounted for nearly 20 percent of the annual rainfall in August and about 14 percent in October. A storm event on September 18, 1990, in the southern zone and southern part of the central zone, contributed to 3.4 percent of the annual rainfall.

The largest monthly rainfall for 1991 was in September and accounted for more than 13 percent of the annual rainfall. Wet-season rainfall was fairly uniform during the period; however, a 20-day period of heavy rainfall beginning in late September (primarily in the northern zone) accounted for 17.5 percent of the annual rainfall.

Frequency Analyses

Daily rainfall data were used to develop a combined rainfall-frequency curve for storms with rainfall depths of 0.01 in. or greater (fig. 10). The average (2-yr total) curve is enveloped by two curves depicting the dry- and wet-season rainfall probability. This is a set of rainfall frequency curves that shows the percent of daily rainfall equaling or exceeding an indicated depth during the period, 1990-91. Dry-season daily rainfall for days with rain (rain days) ranged from 0.01 to 3.95 in. and wet-season daily rainfall ranged from 0.01 to 8.66 in. Mean daily rainfall for rain days during the 2-yr period averaged 0.40 in.; 0.32 in. for the dry season, and 0.47 in. for the wet season. Median daily rainfall for rain days was 0.16 in. during the 2-yr period; 0.12 in. during the dry season and 0.21 in. during the wet season.

About 12 percent of storms had rainfall exceeding 1 in.; 10 percent during the dry season and 14 percent during the wet season. Storms exceeded 3 in. about 0.4 percent of the time; 0.1 percent during the dry season and 0.8 percent during the wet season, indicating that the wet season had larger storms. Therefore, storms exceeding 3 in. were 8 times more likely during the wet season than during the dry season.

Daily rainfall totals were combined to develop cumulation curves for 1990 and 1991 and show the relative contribution to annual rainfall from storms of different magnitudes (fig. 11). Both yearly curves are linear up to about 1 in. of daily rainfall, indicating that storm frequency is inversely related to storm magnitude. A curvature in the relation indicates when the magnitude increases faster than the frequency decreases. This curvature begins for both years at about 1.4 in. of rainfall. A seasonal difference in daily rainfall of less than 1.2 in. is more apparent in 1990 than in 1991. A few relatively large storms in 1990 contributed more to the rainfall during the dry season than during the wet season. The largest difference between the 1990 wet- and dry-season relations is 26.9 percent at 1.46 in.; and for 1991, 16.4 percent at 1.78 in.

Large storms can contribute a significant amount of the annual rainfall. Daily rainfall exceeded 1 in. only 12 percent of the storms (fig. 10), but accounted for about 50 percent of annual rainfall; 52 percent for 1990 and 48 percent for 1991 (fig. 11). Daily rainfall exceeding 1 in. accounted for 43 percent of the 1990 annual total during the dry season and 56 percent during the wet season. Daily rainfall exceeding 1 in. accounted for 45 percent of the 1991 annual total during the dry season and 51 percent during the wet season. For the larger storms, daily rainfall exceeded 2 in. only about 2.5 percent of the rain

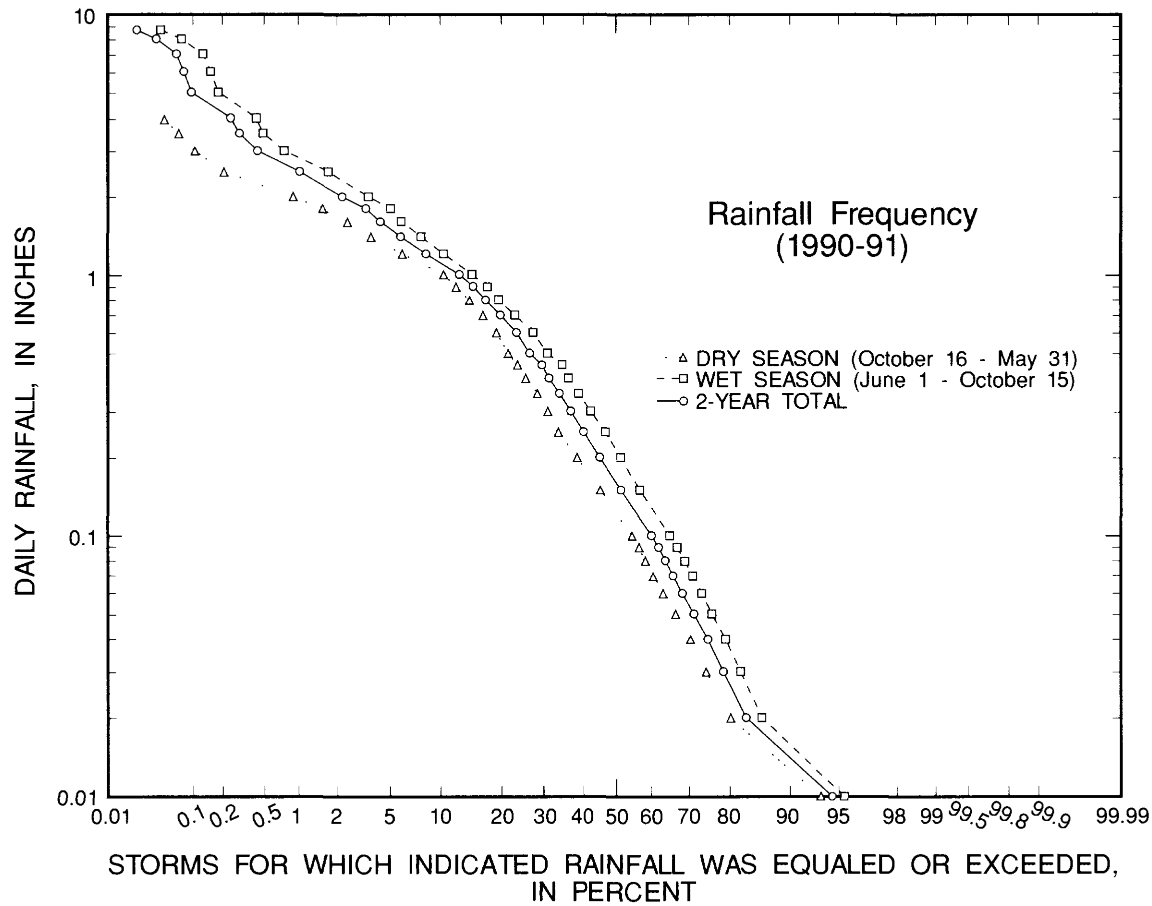

Figure 10. Frequency of daily rainfall for rain-gage sites in the Indian River basin, 1990-91.

time, but contributed to at least 15 percent of the annual rainfall (1990 and 1991); and daily rainfall exceeded 4 in. only 0.3 percent of the rain time, but contributed to about 3 percent of the annual rainfall (1990 and 1991).

Rainfall spatially varied the most during the summer when thunderstorms were more intense and localized. Rainfall intensity, following the same spatial patterns exhibited by the annual rainfall distributions, was greatest at the northern end of the study area. Maximum rainfall intensity, usually lasting 5 to 20 min, ranged from about 5.25 in/h in southern Brevard County (fig. 6, station 20) to more than 8 in/h (fig. 5, station 2) 45 mi to the north at Titusville. The remaining stations had maximum rainfall intensities of 6 to 7 in/h.

Rainfall intensities were determined from 5-min rainfall data for Addison and Goat Creek stations, located at opposite ends of the study area (fig. 12). These curves are similar in shape to the daily rainfall-frequency curve shown in figure 9 and show a distinct difference between the wet and dry seasons.

Dry-season rainfall intensity ranged from 0.12 in/h (the lowest measurable intensity is 0.01 in. per 5-min. interval) to 5.28 in/h at the Addison Creek station and to 5.64 in/h at the Goat Creek station. Wet-season rainfall intensity ranged from 0.12 to 8.28 in/h at the Addison Creek station, and to 5.88 in/h at the Goat Creek station. Rainfall intensity during the 2-yr study period averaged 0.41 in/h at the Addison Creek station and 0.38 in/h at the Goat Creek station; 0.32 in/h

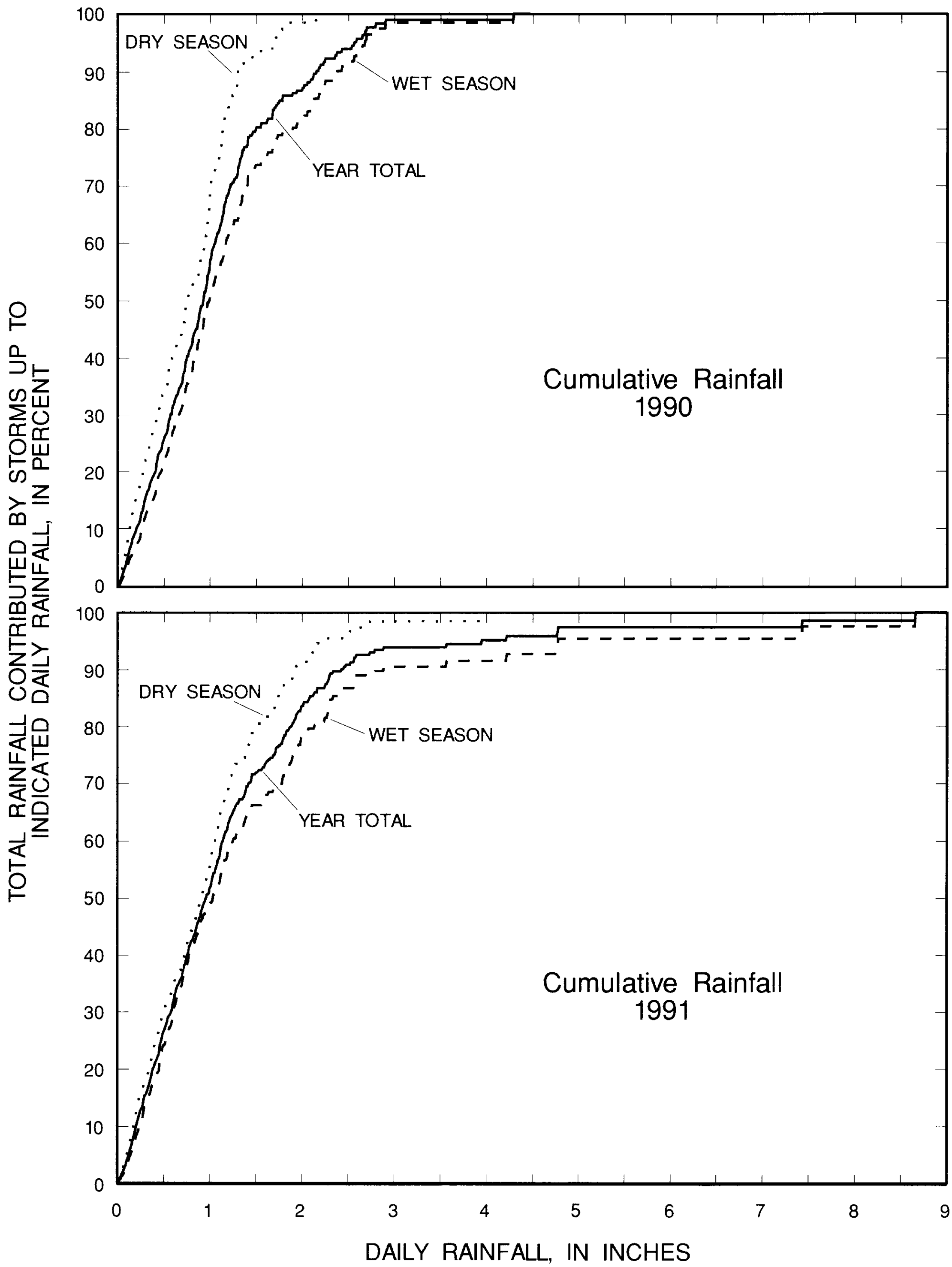

Figure 11. Cumulative depth of rainfall for rain-gage sites in the Indian River basin, 1990-91.

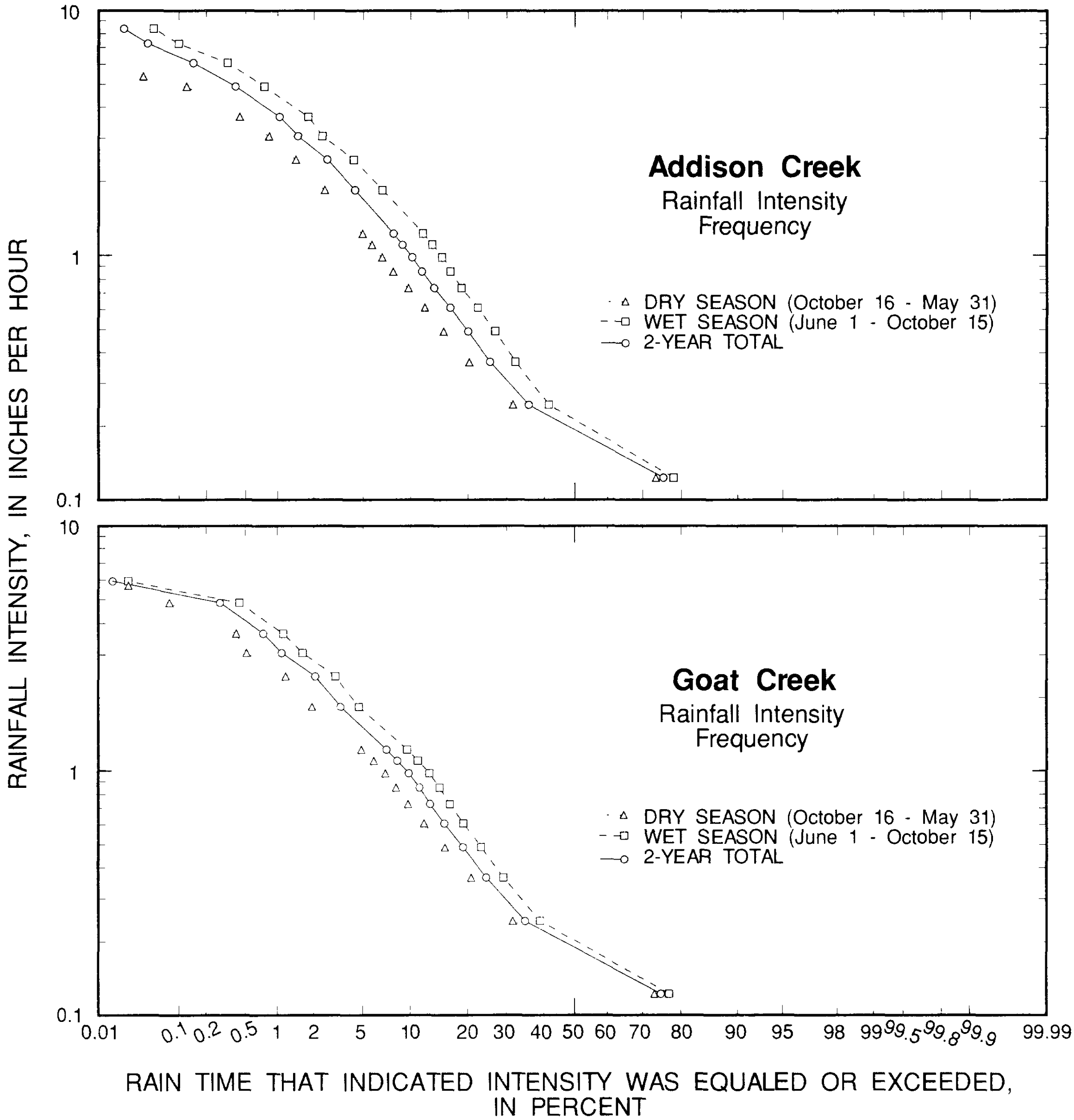

Figure 12. Frequency of rainfall intensity for selected sites in the Indian River basin, Florida, 1990-91.

at the Addison Creek and Goat Creek stations during the dry season, and 0.52 in/h at the Addison Creek station and 0.45 in/h at the Goat Creek station during the wet season. Median rainfall intensity was 0.20 in/h at both stations for the 2-yr study period; 0.19 in/h during the dry season and 0.21 in/h during the wet season.

The probability of higher rainfall intensity, particularly during the wet season, was slightly greater at the Addison Creek station. The probability of rainfall intensity exceeding 1 in/h was 10 percent on average at the Addison Creek station; 7 percent during the dry season and 15 percent during the wet season. At the Goat Creek station, the probability of exceeding 1 in/h was about 9 percent on average; 7 percent during the dry season and about 12 percent during the wet season. The probability of receiving 0.12 in/h or less rainfall was about 25 percent and varied little between seasons at both stations. Rainfall intensity exceeded 5 in/h 0.4 percent of the time at the Addison Creek station and 0.2 percent of the time at the Goat Creek station.

FRESHWATER DISCHARGE TO THE INDIAN RIVER

Freshwater-discharge rates to the Indian River are directly related to basin-drainage characteristics and seasonal rainfall conditions. Although discharge can be measured in part of the basin, the total discharge to the river cannot be directly measured. Basin-drainage characteristics and data for gaged basins can be extrapolated to ungaged parts of the study area and used to estimate total freshwater discharge to the Indian River.

The rainfall and stream-gaging network encompassed approximately 343.9 mi^2, or 57 percent, of the Indian River drainage area (600 mi^2). Stream gaging alone accounted for 261 mi^2 of the Indian River drainage area, leaving nearly 339 mi^2 of the drainage area ungaged. To estimate discharge for the ungaged area, a discharge-to-rainfall ratio was computed for each gaged basin using rainfall and streamflow data. Rainfall was estimated for drainage areas without rain gages and discharge was estimated, based on average discharge-to-rainfall ratios of the gaged basins and on measured and estimated rainfall for ungaged basins. Measured and estimated discharges for all drainage areas were combined to define the total freshwater drainage within the Indian River basin on a seasonal and an annual basis for the study period.

Gaged Streamflow

Discharge data, collected in 10 of the 12 identified tributary basins (discharge was estimated for Big Flounder and South Prong Sebastian Creeks), indicate a distinct difference in the freshwater discharge to the Indian River during the wet and dry seasons each year. Discharge data from the gaged basins were combined to produce a daily discharge hydrograph (fig. 13). Base flow, computed using a 15-day sliding minimum of low flow, is also shown in figure 13. Discharge was consistently greatest during the wet season each year. Daily base flow was greatest in September and October and least in May and June before the onset of the rainy season.

Gaged daily discharge ranged from a maximum of 4,410 ft^3/s on October 10, 1989, to a minimum of 64 ft^3/s on May 18, 1990. The maximum daily mean discharge for the dry season was 3,260 ft^3/s on February 3, 1991. During the study, the wet-season maximum daily discharge for the year coincidentally occurred on October 10 of each year, possibly indicating that an annual discharge maximum could be expected near the end of each wet season. For 1989-91, maximum daily mean discharges averaged 3,390 ft^3/s on October 10, 2,440 ft^3/s on October 11, and 1,830 ft^3/s on October 12. Daily discharge from the gaged basins of the Indian River averaged 410 ft^3/s for the 2.5-yr study period; 565 ft^3/s during the wet season and 297 ft^3/s during the dry season.

The base-flow component in figure 13 was computed using a 15-day, moving-minimum technique on the gaged daily discharges. This 15-day interval approximates the typical length of time necessary for all tributaries to return to a base-flow condition following a rainfall event. Base flow ranged from a minimum of 64 ft^3/s, the minimum daily discharge in May 1990, to 975 ft^3/s on October 7, 1991. The mean daily base flow of 223 ft^3/s indicates that slightly more than half of the discharge to the Indian River is derived from base flow, or the release of shallow ground water and bank storage.

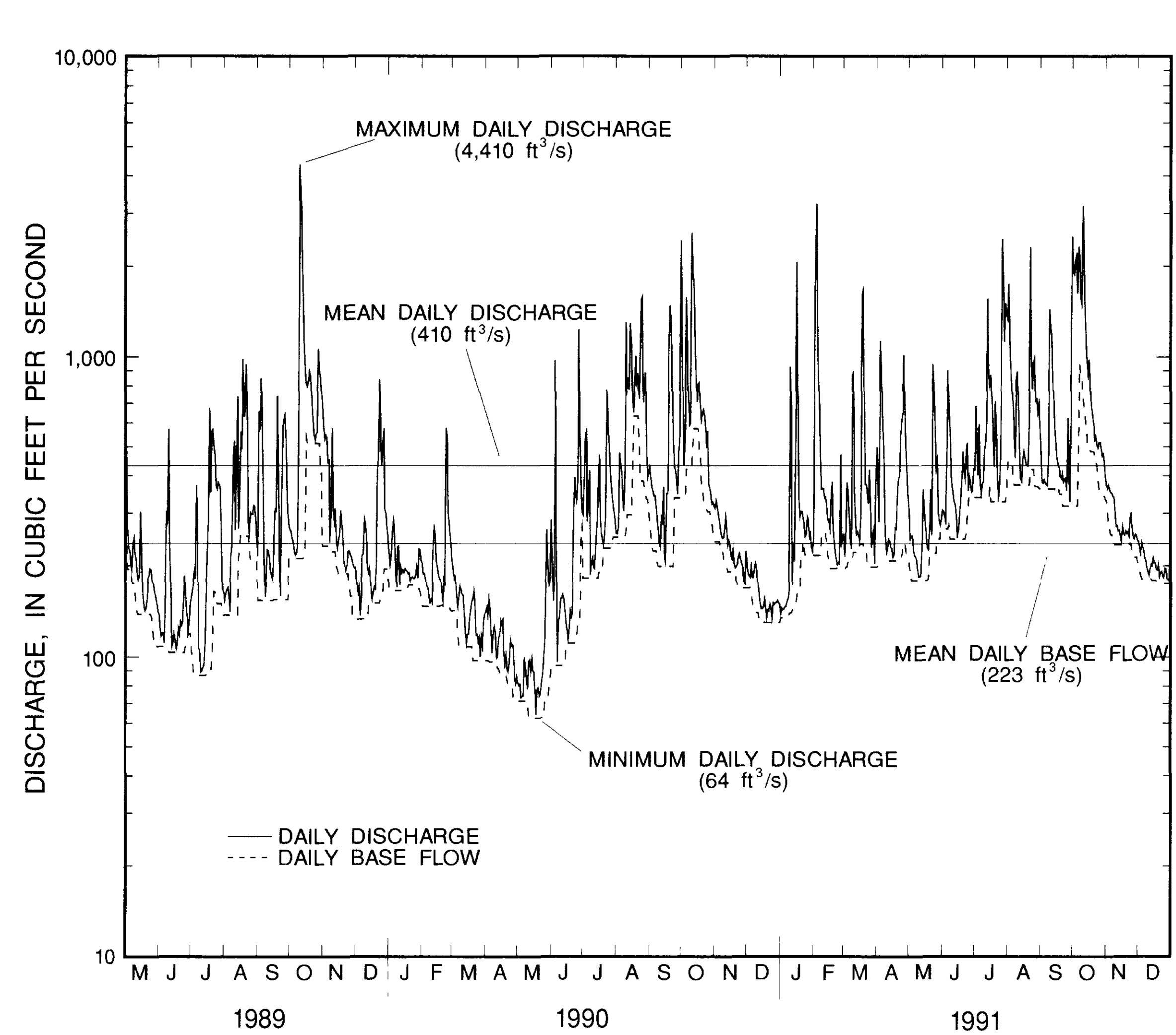

Figure 13. Gaged discharge and base flow to the Indian River, May 1, 1989, through December 31, 1991.

Base flow was subtracted from total daily discharge to compute daily and monthly cumulative stormflow distribution (fig. 14). The annual maximum stormflow averaged 2,940 ft^3/s on October 10 for the years 1989-91. The maximum daily stormflow during the wet season was 4,190 ft^3/s on October 10, 1989. The maximum daily stormflow during the dry season was 3,040 ft^3/s on February 3, 1991. Conversely, no stormflow was measured for many days during the study period. Stormflow averaged 187 ft^3/s for the period; 302 ft^3/s during the wet season and 104 ft^3/s during the dry season.

Maximum Discharge

Instantaneous discharges for most of the gaged tributary basins generally were greatest during the wet season; however, the discharge peaks in basins at the northern and southern ends of the study area were greatest during the dry

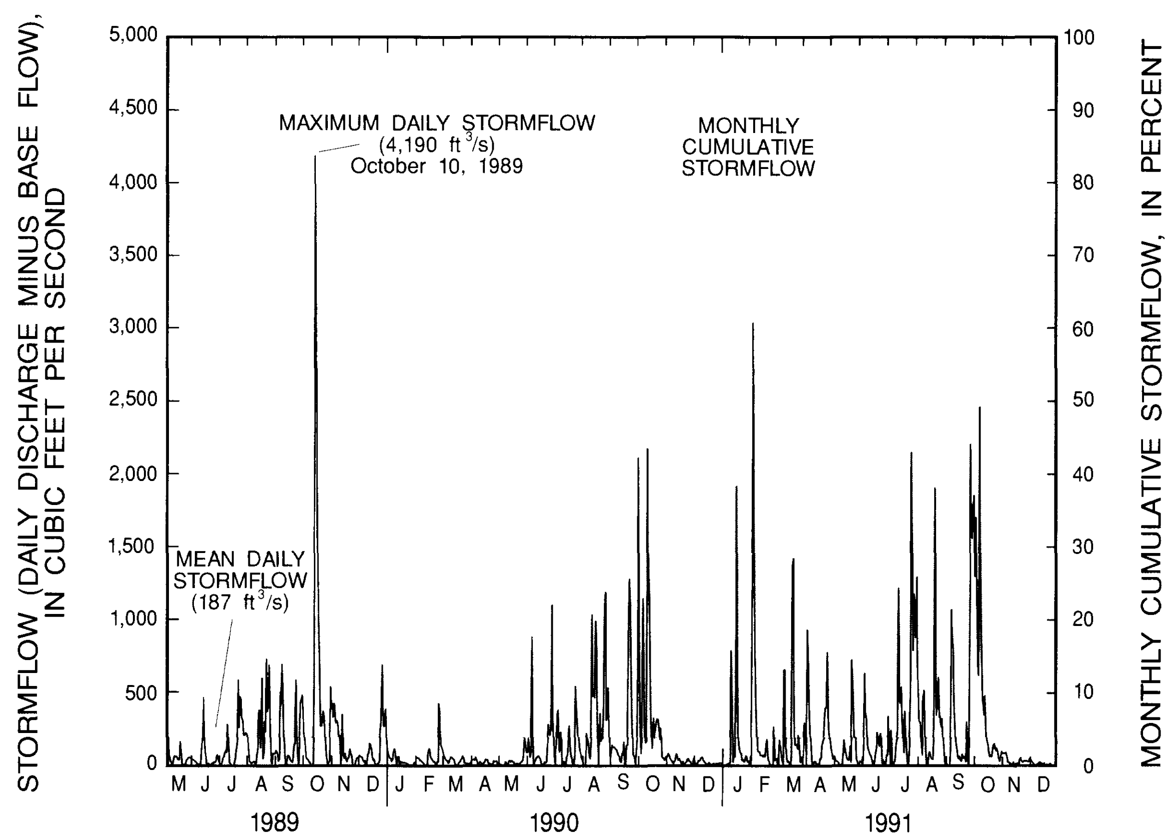

Figure 14. Gaged daily and monthly cumulative tributary stormflow to the Indian River, May 1, 1989, through December 31, 1991.

season. An annual summary of maximum discharge for the gaged tributaries is presented in table 2.

Maximum instantaneous discharges during 1989 ranged from 1.7 ft^3/s at Kid Creek to 2,640 ft^3/s at Turkey Creek, and highest daily mean discharges ranged from 0.8 ft^3/s at Kid Creek to 1,970 ft^3/s at Turkey Creek. Nearly half of the daily mean discharge maximums for 1989 occurred on October 10. The remaining peaks occurred on various days during the wet season except at Kid Creek (May 1-2), North Prong Sebastian Creek (March 4-5), and Addison Creek (December 23).

Instantaneous discharge peaks during 1990 ranged from 5.4 ft^3/s at Kid Creek to 1,200 ft^3/s at Main Canal, and daily mean discharge maximums ranged from 5.2 ft^3/s at Kid Creek to 777 ft^3/s at Main Canal. Discharge maximums were greater at stations in the south-central and southern zones in 1990 than in 1989 and, except for Addison Creek, all annual maximums were during the wet season. More than half of the maximums for 1990 were recorded during a 2-week period, September 29 to October 13, when two tropical storms affected the area. The remaining annual peaks were recorded during June and August following intense thunderstorm activity in the Indian River Farms (South Canal) and Addison Creek basins.

Table 2. Annual maximum-discharge summary for gaged tributary basins of the Indian River, May 1, 1989, through December 31, 1991

[ft^3/s, cubic feet per second; --, no data]

Tributary basin name	1989				1990				1991			
	Maximum instantaneous discharge (ft^3/s)	Date	Maximum daily mean discharge (ft^3/s)	Date	Maximum instantaneous discharge (ft^3/s)	Date	Maximum daily mean discharge (ft^3/s)	Date	Maximum instantaneous discharge (ft^3/s)	Date	Maximum daily mean discharge (ft^3/s)	Date
Northern Zone												
Addison Creek	16	July 19	15	Dec. 23	15	Feb. 23, Aug. 3	15	Feb. 24	22	Mar. 18	18	Mar. 18
Central Zone												
Horse Creek	94	Oct. 10	67	Oct. 10	85	Oct. 5	53	Oct. 10	68	Oct. 9	33	Oct. 10
Eau Gallie River	--	--	--	--	--	--	--	--	324	July 13	97	July 13
Crane Creek	1,680	Aug. 12	692	Oct. 10	710	Sept. 29	343	Oct. 10	2,020	Sept. 30	963	Sept. 30
Turkey Creek	2,640	Oct. 10	1,970	Oct. 10	975	Oct. 10	757	Oct. 11	1,780	Oct. 10	1,310	Oct. 10
Goat Creek	21	Oct. 10-11	20	Oct. 11	129	Oct. 12	111	Oct. 12	222	Oct. 6	156	Oct. 6
Kid Creek	1.7	May 1	0.8	May 2	5.4	Oct. 13	5.2	Oct. 13	16	Oct. 7	15	Oct. 7
Trout Creek	17	Oct. 28-29	9.1	Oct. 29	47	Oct. 12	43	Oct. 12	99	Oct. 6	69	Oct. 6
Southern Zone												
Sebastian Creek:												
North Prong	90	Mar. 4-5	82	Mar. 5	285	Oct. 12	263	Oct. 12	370	Oct. 6	337	Oct. 6
Indian River Farms:												
North Canal	466	Oct. 10	341	Oct. 10	778	Sept. 30	519	Sept. 30	1,120	Feb. 3	1,030	Feb. 3
Main Canal	930	Oct. 9	805	Oct. 10	1,200	Sept. 30	777	Sept. 30	1,250	Aug. 22	995	Feb. 3
South Canal	683	Oct. 10	461	Oct. 10	854	June 5	482	June 5	1,130	Mar. 18	726	Jan. 16

The maximum peak discharges at many of the basins occurred in 1991, the wettest year for much of the Indian River area since the mid-1980's. During 1991, peak instantaneous discharge ranged from 16 ft^3/s at Kid Creek to 2,020 ft^3/s at Crane Creek, and highest daily mean discharges ranged from 15 ft^3/s at Kid Creek to 1,310 ft^3/s at Turkey Creek. Again, in basins near the northern and southern ends of the study area, the maximum daily mean discharges were recorded during the dry season.

Duration Analyses

Flow-duration curves were developed for the basins contributing the greatest inflow to the Indian River drainage system—Crane Creek (fig. 15), Turkey Creek (fig. 16), and Indian River Farms basin (fig. 17). The curve for Crane Creek is based on data for a 5-yr period, 1987-91. The other two curves are based on data for a 4-yr period, 1988-91. Records prior to 1988 for Turkey Creek and Indian River Farms basins contain considerable missing data and could not be included in the flow-duration analysis. The duration curves for each basin show the percent of time daily mean discharge was equaled or exceeded during the period of record. Flow-duration analysis was done for the entire period of record and on subsets of the record representing wet- and dry-season discharges.

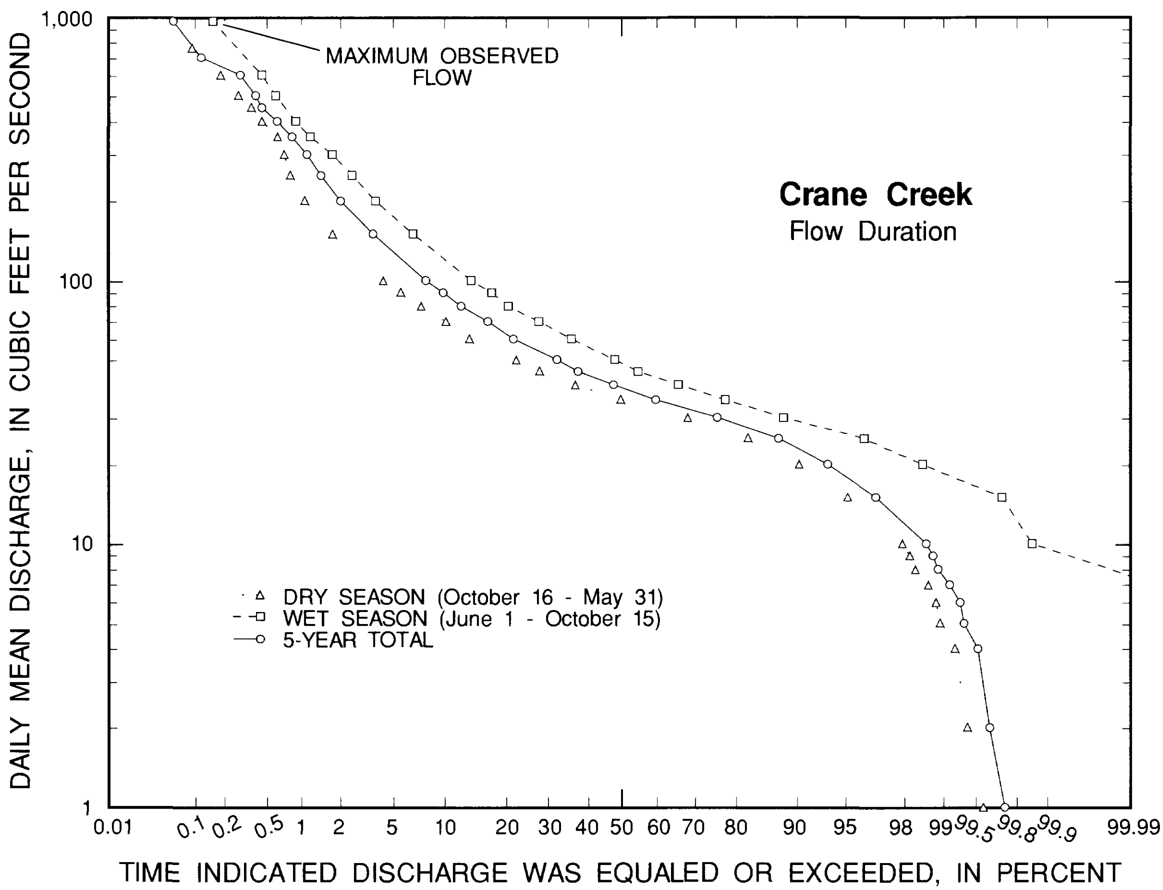

Figure 15. Flow duration for Crane Creek, 1987-91.

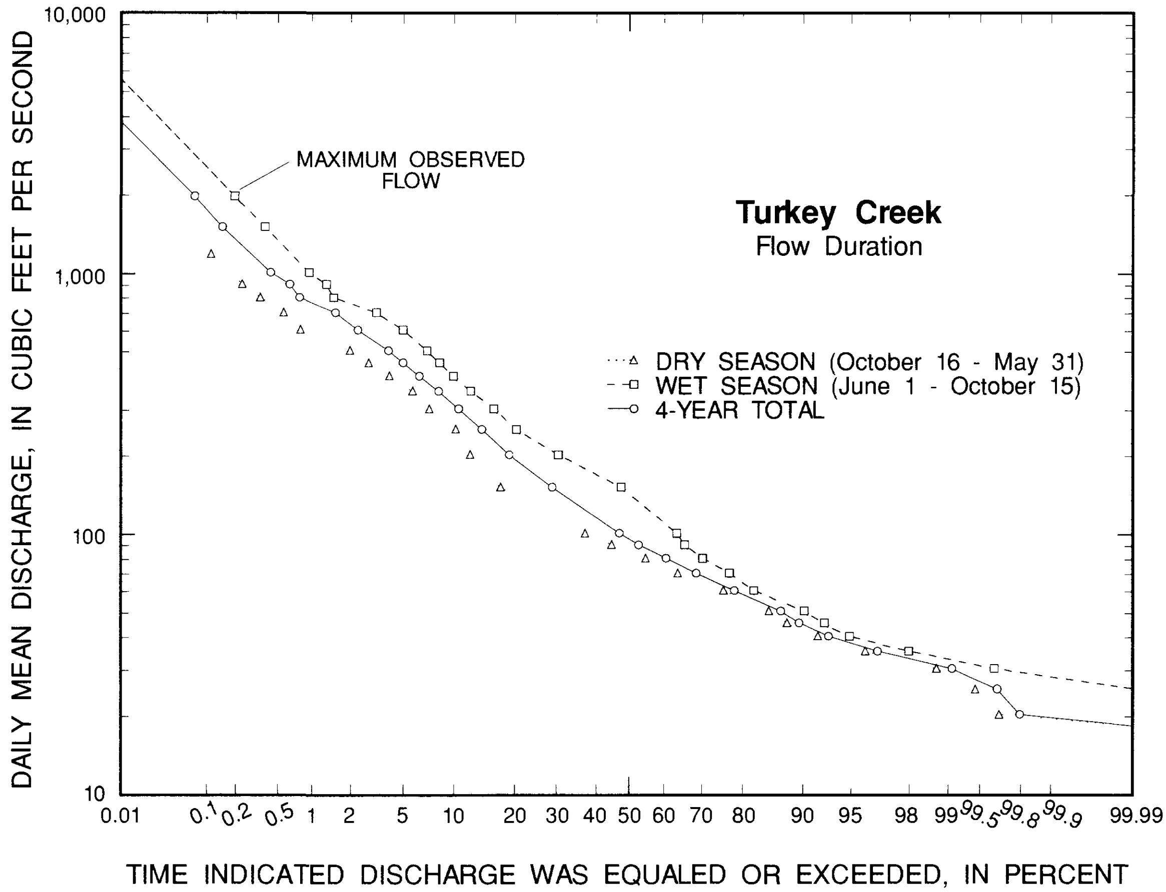

Figure 16. Flow duration for Turkey Creek, 1988-91.

Seasonal discharge trends for the Indian River Farms basin vary from those of the other two basins, principally because of climatic variation and flow regulation. Indian River County is subject to weather patterns that can affect either central or southern Florida. The rainy season for southern Florida typically begins earlier than that for central Florida and occasionally, some of this activity extends far enough north to affect the extreme southern end of the study area. Subsequently, discharge regulation of the canals in the basin has an added influence on the shape of the flow-duration curve.

Daily discharge for Crane Creek (1987-91) ranged from -17 to 761 ft^3/s during the dry season, and from 6 to 963 ft^3/s during the wet season, averaging 53 ft^3/s; 44 ft^3/s for the dry season and 68 ft^3/s for the wet season. Median daily discharge, or the discharge that is exceeded 50 percent of the time, was 39 ft^3/s; 35 ft^3/s for the dry season and 48 ft^3/s for the wet season (fig. 15). Daily discharge exceeded 10 ft^3/s 98.6 percent of the time; 97.9 percent for the dry season and greater than 99.8 percent for the wet season. Discharge exceeded 100 ft^3/s 7.7 percent

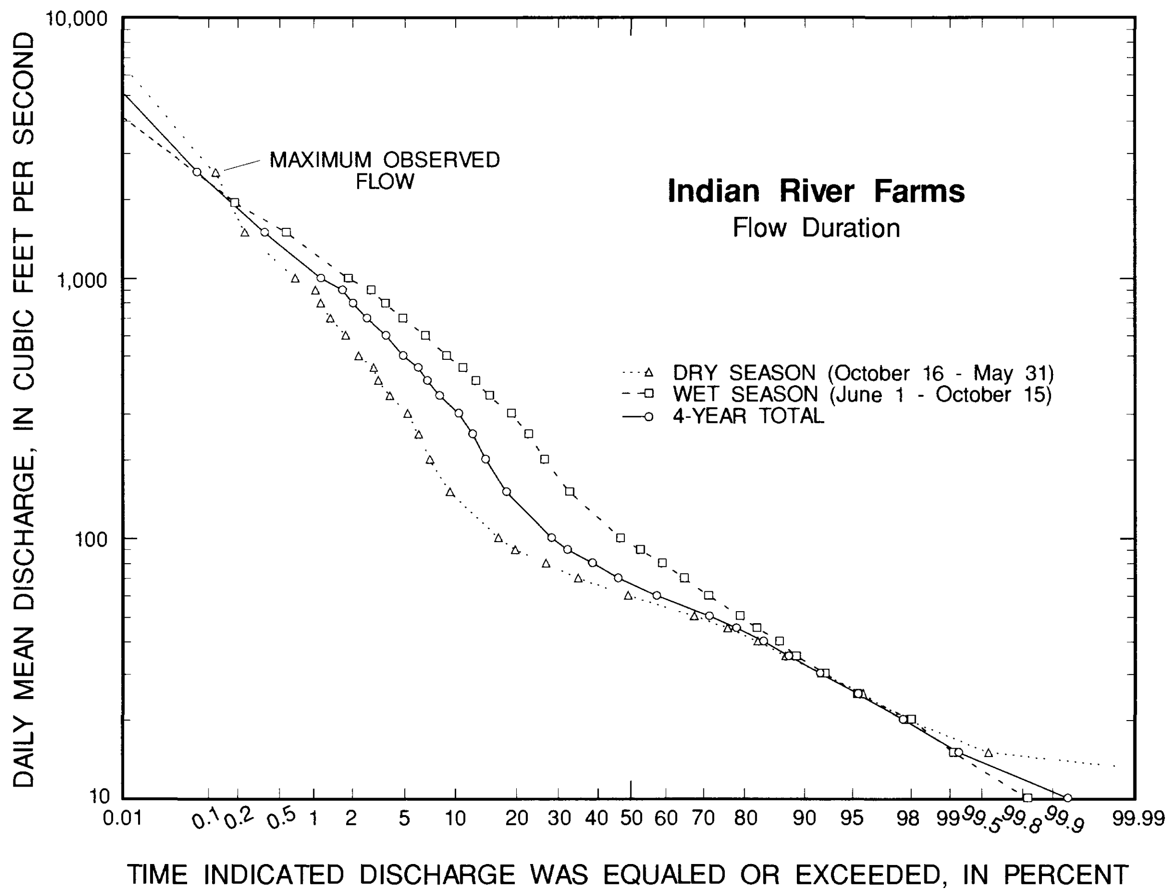

Figure 17. Flow duration for the Indian River Farms basin, 1988-91.

of the time and was at least three times more likely in the wet season than in the dry season; 13.6 and 4.1 percent, respectively. Discharge exceeded 1,000 ft^3/s about 0.06 percent of the time and also was about 3 times more likely in the wet season than in the dry season. At the low end, discharge was negative (shown as less than 1 ft^3/s) about 0.3 percent of the time; 0.4 percent during the dry season and 0.0 percent during the wet season.

Negative discharge usually can occur for short periods during the daily tide cycle, or for much longer periods when water levels in the Indian River rise high enough to reverse tributary flow. Water is temporarily held in storage areas within the tidal zone of the tributary. Negative discharges are commonly computed by the BRANCH model (with the water storage taken into account) during the incoming phase of the tidal cycle. Occasionally, a negative net-daily discharge is computed. This condition was observed in some tributaries when high discharges and heavy rainfall, measured in other tributary basins, combined with high astronomical tides causing water levels in the Indian River to rise 2 to 3 ft. The result for basins not receiving heavy rainfall was a net negative discharge for 1 to 2 days following the rainfall. Reversed flow, held in storage, caused near-flood conditions along the tributary until water levels in the river receded enough for positive tributary flow to resume.

Daily discharge for Turkey Creek (1988-91) ranged from 18 to 1,140 ft^3/s during the dry season and from 25 to 1,970 ft^3/s during the wet season, averaging 146 ft^3/s; 118 ft^3/s for the dry season and 192 ft^3/s for the wet season (fig. 16). Median discharge was 95 ft^3/s; 85 ft^3/s for the dry season and 142 ft^3/s for the wet season. Daily discharge exceeded 10 ft^3/s throughout the period of record and exceeded 100 ft^3/s 47.0 percent of the time. Discharge exceeding 100 ft^3/s were nearly twice as likely in the wet season than in the dry season; 63.5 and 37.0 percent, respectively. Discharge exceeded 1,000 ft^3/s 0.41 percent of the time; 0.17 percent for the dry season and 0.91 percent for the wet season.

Daily discharge for the Indian River Farms basin (1988-91) ranged from 13 to 2,560 ft^3/s in the dry season and from 9 to 1,920 ft^3/s during the wet season, averaging 129 ft^3/s; 95 ft^3/s for the dry season and 186 ft^3/s for the wet season (fig. 17). Median discharge was 66 ft^3/s; 59 ft^3/s for the dry season and 94 ft^3/s for the wet season. Daily discharge exceeded 10 ft^3/s greater than 99.9 percent of the time; 100 percent in the dry season and about 99.8 percent in the wet season. Discharge exceeded 100 ft^3/s 27.5 percent of the time, and was nearly three times more likely in the wet season than in the dry season; 46.4 and 16.2 percent, respectively. Discharge exceeded 1,000 ft^3/s 1.1 percent of the time; 0.66 percent in the dry season and 1.8 percent in the wet season.

The seasonal difference in flow frequency for the Indian River Farms basin is greatest between discharges of 45 and 2,000 ft^3/s, with greater flow in the wet season. However, this seasonal pattern is reversed for flow less than 20 ft^3/s and greater than 2,000 ft^3/s, when the greatest flow is more likely in the dry season. Unlike the curves for the other two basins, low flow is most frequent in the wet season. Discharge between 20 and 35 ft^3/s shows little or no seasonal trend.

Freshwater-Discharge Distribution by Drainage Basin

One of the primary purposes of this study was to determine the total freshwater discharge to the Indian River. This was performed by combining measured stream discharge from each of the gaged tributary basins and estimated discharge from the remaining ungaged basins. Annual and seasonal freshwater discharge values for the basins were compiled for comparison.

Annual Distribution

A summary of annual rainfall and discharge estimates for gaged and ungaged basins in the Indian River drainage system is shown in table 3. Rainfall and annual mean discharge for the three zones, gaged and ungaged areas, and the Indian River basin are weighted averages. Annual mean discharge is summed for each section with the discharge-to-rainfall ratios being postcomputed from these discharge sums using the weighted rainfall average. Estimated values are shown in parentheses.

Discharge-to-rainfall ratios varied from basin to basin, especially in the central zone where some basins were relatively undeveloped and others were highly urbanized. (Ratios were higher for more developed basins.) Discharge-to-rainfall ratios for individual basins changed little with a tendency to increase slightly with greater rainfall. The greatest ratios of discharge-to-rainfall were in the central zone with an annual average of 0.46. Discharge-to-rainfall ratios in the central-zone basins ranged from an average of 0.09 for Trout Creek basin to 0.78 for Crane Creek basin. (The small ratio for Trout Creek basin indicated that a large area of wetlands within the basin was very effective at retaining drainage.) Horse Creek discharge-to-rainfall ratios varied least among the gaged basins; whereas ratios for Goat, Kid, Trout,

Table 3. Annual rainfall and discharge summary for drainage basins of the Indian River

[mi², square miles; in., inches; ft³/s, cubic feet per second; Ratio = Annual mean discharge (in.)/Rainfall (in.); data in parentheses are estimated values]

Drainage basin	1989 Drainage area (mi²)	1989 Rainfall (in.)	1989 Ratio	1989 Annual mean discharge (in.)	1989 Annual mean discharge (ft³/s)	1990 Drainage area (mi²)	1990 Rainfall (in.)	1990 Ratio	1990 Annual mean discharge (in.)	1990 Annual mean discharge (ft³/s)	1991 Drainage area (mi²)	1991 Rainfall (in.)	1991 Ratio	1991 Annual mean discharge (in.)	1991 Annual mean discharge (ft³/s)
Northern Zone	84.4	35.99	0.22	8.0	73.7	84.4	35.13	0.23	8.2	50.8	84.4	64.91	0.31	20.3	126.2
Addison Creek	2.4	(36.50)	.22	8.0	2.1	2.4	42.23	.23	9.6	1.7	2.4	55.00	.31	17.0	3.0
Big Flounder Creek	1.8	(35.00)	(.30)	(10.5)	(2.1)	1.8	31.43	(.30)	(9.4)	(1.2)	1.8	74.30	(.40)	(29.7)	(3.9)
Remaining ungaged	80.2	(36.00)	(.22)	(7.9)	(69.5)	80.2	(35.00)	(.23)	(8.1)	(47.9)	80.2	(65.00)	(.31)	(20.2)	(119.3)
Central Zone	196.3	32.25	.46	14.8	317.9	197.7	39.51	.43	17.0	248.1	197.6	51.75	.48	24.6	358.1
Horse Creek	1.9	(36.00)	.65	23.5	4.9	2.4	39.02	.65	25.5	4.5	2.4	49.86	.61	30.5	5.4
Eau Gallie River	4.8	37.55	(.74)	(27.8)	(14.6)	5.7	42.22	(.73)	(31.0)	(13.0)	5.7	51.41	.69	35.5	14.9
Crane Creek	18.8	(33.25)	.82	27.4	56.5	18.8	39.31	.81	31.8	44.0	18.7	59.37	.72	43.0	59.2
Turkey Creek	105.0	(33.00)	.45	14.9	171.3	105.0	38.56	.41	15.7	121.6	105.0	51.39	.47	24.2	187.1
Goat Creek	9.1	(28.00)	.13	3.5	3.5	9.1	44.16	.25	11.2	7.5	8.1	49.33	.37	18.4	11.0
Kid Creek	0.7	(28.00)	.09	2.6	0.2	0.7	(42.00)	.14	5.8	0.3	1.7	(48.00)	.17	8.0	1.0
Trout Creek	15.0	(27.00)	.05	1.3	2.1	15.0	38.51	.09	3.6	4.0	15.0	46.21	.11	5.2	5.8
Remaining ungaged	41.0	(32.00)	(.45)	(14.4)	(64.8)	41.0	(41.00)	(.43)	(17.6)	(53.2)	41.0	(52.00)	(.47)	(24.4)	(73.7)
Southern Zone	317.9	27.57	.36	10.0	349.2	317.9	46.34	.38	17.7	413.8	317.9	64.66	.43	28.1	657.3
Sebastian Creek:															
North Prong	28.5	(26.50)	.18	4.9	15.3	28.5	(45.00)	.30	13.4	28.2	28.5	(58.00)	.33	19.4	40.7
South Prong	77.8	26.55	(.36)	(9.6)	(82.0)	77.8	44.80	(.38)	(17.0)	(97.4)	77.8	58.25	(.43)	(25.0)	(143.3)
Indian River Farms	77.1	(30.00)	.43	12.8	108.7	77.1	(49.00)	.41	20.2	114.8	77.1	(73.00)	.47	34.5	195.9
Remaining ungaged	134.5	(27.00)	(.36)	(9.7)	(143.2)	134.5	(46.00)	(.38)	(17.5)	(173.4)	134.5	(65.00)	(.43)	(28.0)	(277.4)
Total:															
Gaged	342.9	30.05	.41	12.3	[1]463.3	344.3	43.09	.40	17.3	[2]438.2	344.2	58.61	.45	26.5	[b]671.2
Ungaged	255.7	30.62	.32	9.8	[a]277.5	255.7	41.75	.35	14.6	[b]274.5	255.7	62.92	.40	25.0	[b]470.4
Indian River basin	598.6	30.29	.37	11.2	740.8	600.0	42.51	.38	16.1	712.7	599.9	60.44	.43	25.8	1,141.6

[1]Data collected May 1 through December 31, 1989.
[2]Data collected January 1 through December 31, 1990 and 1991.

and North Prong Sebastian Creeks increased about 180-285 percent during the study. Ratios for the two largest gaged basins, Indian River Farms and Turkey Creek, were about 0.40, which is the average for the Indian River basin.

Annual ratios for the northern zone averaged about 0.26 with much of the drainage originating from undeveloped areas. The largest discharge-to-rainfall ratios for northern-zone basins were during 1991, primarily the result of heavy rainfall (32 percent of the annual in the Big Flounder Creek basin) within a 2-week period. Basin ratios ranged from 0.22 (except for Big Flounder Creek) in 1989 to 0.40 for Big Flounder Creek in 1991.

Annual discharge-to-rainfall ratios in the southern zone averaged 0.39. The largest ratios were for the Indian River Farms basin with an annual average of 0.44. Basin ratios ranged from 0.18 for the North Prong Sebastian Creek basin in 1989 to 0.47 for the Indian River Farms basin in 1991.

Discharge-to-rainfall ratio estimates for the Big Flounder Creek and Eau Gallie River basins were computed differently than the other ratios. The estimated ratio for the Big Flounder Creek basin was increased to 0.33 from the zone average of 0.25 to account for citrus-grove drainage within the basin, a value similar to the ratio for the Indian River Farms basin which also consists mainly of citrus groves. The Eau Gallie River basin is highly developed and is similar in morphology and land use to the adjacent Horse and Crane Creek basins and, thus, the estimated ratio is an average of the two.

Freshwater discharge to the Indian River averaged 881 ft^3/s during the study, with 43.5 percent of the discharge gaged and 56.5 percent of the discharge estimated (fig. 18). (Annual discharge values are time-weighted by the number of data-collection months—8 months for 1989 and 12 months each for 1990 and 1991.) Most of the gaged discharge was from the central zone and accounted for about 25 percent of the total discharge, whereas most of the estimated discharge was from the northern and southern zones, accounting for about 35 percent and 14 percent of the total discharge, respectively. The annual distribution of freshwater discharge to the Indian River shows that the southern zone contributed 55.6 percent, the central zone contributed 34.8 percent, and the northern zone contributed 9.6 percent of the total discharge.

The southern zone contributed the greatest part of the annual discharge (489 ft^3/s) to the Indian River with the Indian River Farms basin contributing 29.4 percent of this flow. This is equivalent to the combined discharge from the North and South Prongs of Sebastian Creek. Annual discharge from Indian River Farms averaged about 144 ft^3/s during the study, which is very close to the 40-year average of 148 ft^3/s (Hendricks, 1963; U.S. Geological Survey, 1961-91). Remaining ungaged discharge contributed nearly 42 percent of the flow from the zone.

Annual discharge for the central zone was 307 ft^3/s. The Turkey Creek basin, largest in the study area, contributed the greatest annual discharge to the Indian River; nearly 52 percent of the flow in the zone. Combined discharge from the remaining gaged basins—Horse Creek, Eau Gallie River, Crane Creek, Goat Creek, Kid Creek, and Turkey Creek—contributed about 27 percent of the flow. Ungaged discharge contributed nearly 21 percent of the flow.

Annual discharge for the northern zone was 85 ft^3/s. Ungaged discharge contributed about 94 percent of the flow in the zone; whereas Addison and Big Flounder Creeks each contributed less than 3 percent of the flow. Errors in discharge for the northern zone could be proportionally greater than for the other zones because much of the discharge-to-rainfall ratio for the zone was estimated.

A sensitivity analysis was performed on the estimates of rainfall and discharge-to-rainfall ratios used to compute basin discharge. Results indicate that discharge was more sensitive to errors in ratio estimates than to errors in rainfall estimates. Annual discharge to the Indian River is within 27 percent of the computed annual

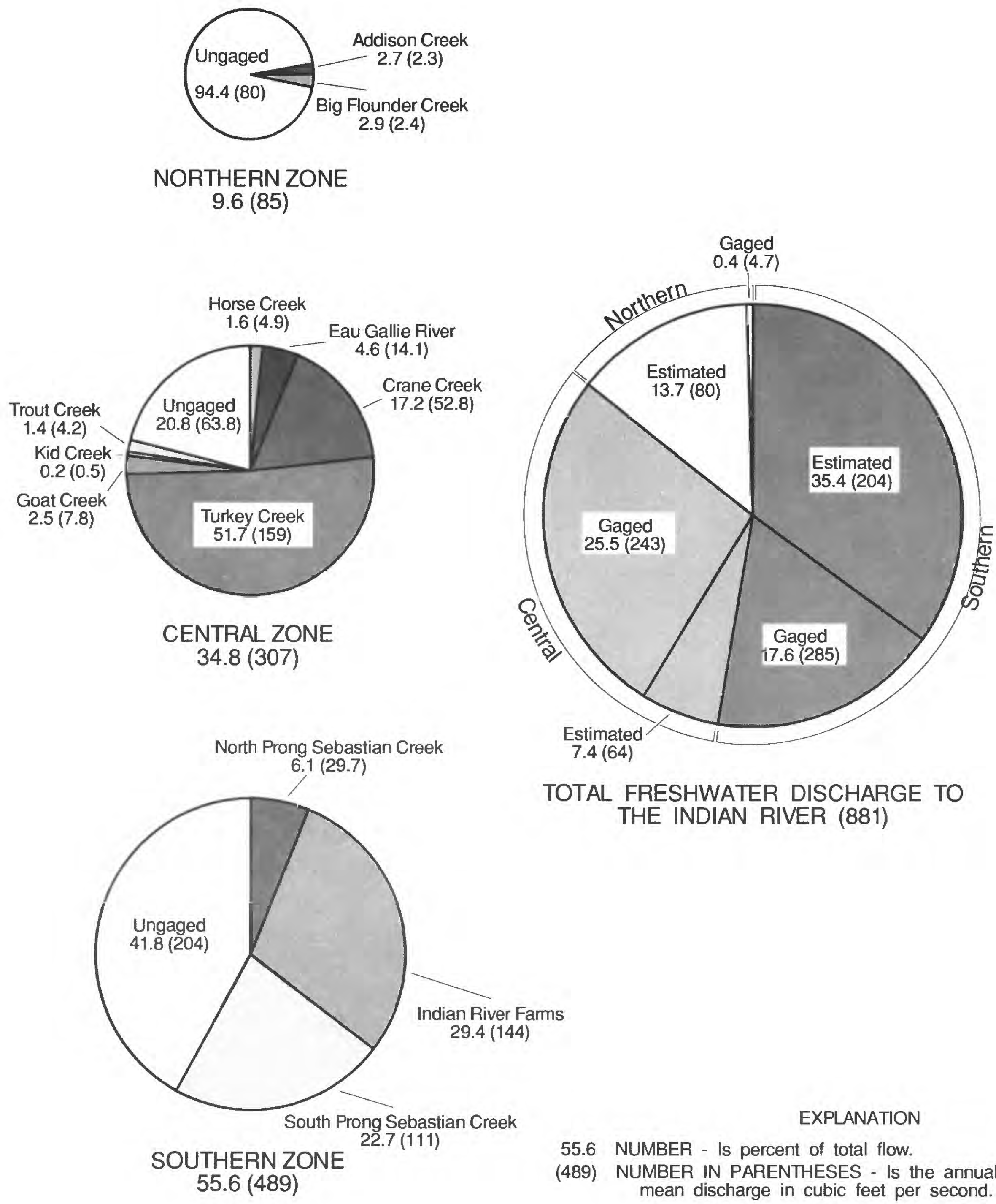

Figure 18. Annual distribution of freshwater discharge to the Indian River, 1989-91.

discharge value (table 3) when the discharge-to-rainfall ratio estimates vary by up to 50 percent. By comparison, annual discharge is within 6.5 percent of the computed value when rainfall estimates listed in table 3 are varied by up to 30 percent. Errors in annual discharge for the Indian River basin varied most in 1989 when rainfall had to be estimated for a majority of the basins. The annual discharge-to-rainfall ratios computed for the Indian River basin for 1989, 1990, and 1991 were 0.37, 0.38, and 0.43, respectively. Discharge-to-rainfall ratios for each basin were varied by up to 50 percent, resulting in annual ratios that ranged from 0.27 to 0.54. Annual discharge-to-rainfall ratios for the Indian River basin ranged from 0.29 to 0.60 while varying the rainfall estimates by up to 30 percent for each basin.

Seasonal Distribution

Freshwater discharge to the Indian River was nearly twice as great during the wet season than during the dry season, averaging 1,240 ft^3/s during the wet season and 643 ft^3/s during the dry season (fig. 19). The proportion of discharge from each zone was nearly the same for both seasons (less than 5 percent difference between seasons). The southern zone contributed most of the flow; 55.5 percent during the wet season and 59.1 percent during the dry season. The central and northern zones contributed the remaining 35.1 and 9.4 percent of the wet-season flow, respectively, and 30.9 and 10.0 percent of the dry-season flow, respectively.

The proportion of flow for each basin also varied little from season to season (within 1-3 percent of each other), although discharge for each basin during the wet season was about twice that of the dry season. Seasonal differences and seasonal rainfall variability during the study were greatest in the southern zone. The proportion of flow in the southern zone for South Prong Sebastian Creek was 23.6 percent during the wet season and 19.7 percent during the dry season, and flow in the ungaged area was 41.8 percent during the wet season and 45.1 percent during the dry season.

A summary of seasonal rainfall and discharge, similar to the annual summary (table 3), is shown in table 4. Dry and wet seasons became wetter during the study with discharge-to-rainfall ratios and discharge increasing accordingly. Wet-season rainfall and discharge were nearly twice the value as those for the dry season; however, ratios for the Indian River basin were greater during the dry season. These skewed ratios are a result of a timelag between rainfall and tributary discharge. Heavy rainfall near the end of the wet season is typical for this area. Although some of the runoff is immediately discharged to the Indian River, most of it drains slowly.

Tributary base flow, primarily streambank and subsurface storage, proceeds into the next season so that accumulated storage and end-of-the-season rainfall affects discharge and ratios in the following season. This was particularly evident during the 1990 dry season. Basins in the northern part of the central zone received about a third of the 1989 wet-season rainfall during the last week of the season. As a result, Horse Creek, Eau Gallie River, and Crane Creek each had exceptionally high discharge-to-rainfall ratios (exceeding 0.95) during the 1990 dry season. The Turkey Creek basin, however, also received a large part of its 1989 wet-season rainfall during the same week but did not have an unexpectedly large ratio for the 1990 dry season. This could indicate that the Turkey Creek basin drainage-response time is much faster, possibly because of lesser storage capacity than basins to the north. Regulation of streamflow on Turkey Creek seems not to have had any discernible effect on the seasonal ratio as compared to ratios of nearby basins.

The wet-season ratio for the Indian River basin averaged 0.35 and the dry-season ratio averaged about 0.42. The northern-zone ratio averaged 0.19 and 0.28; the central-zone ratio averaged 0.38 and 0.48; and the southern-zone ratio averaged 0.36 and 0.44, each during the wet and dry seasons, respectively. Wet-season ratios

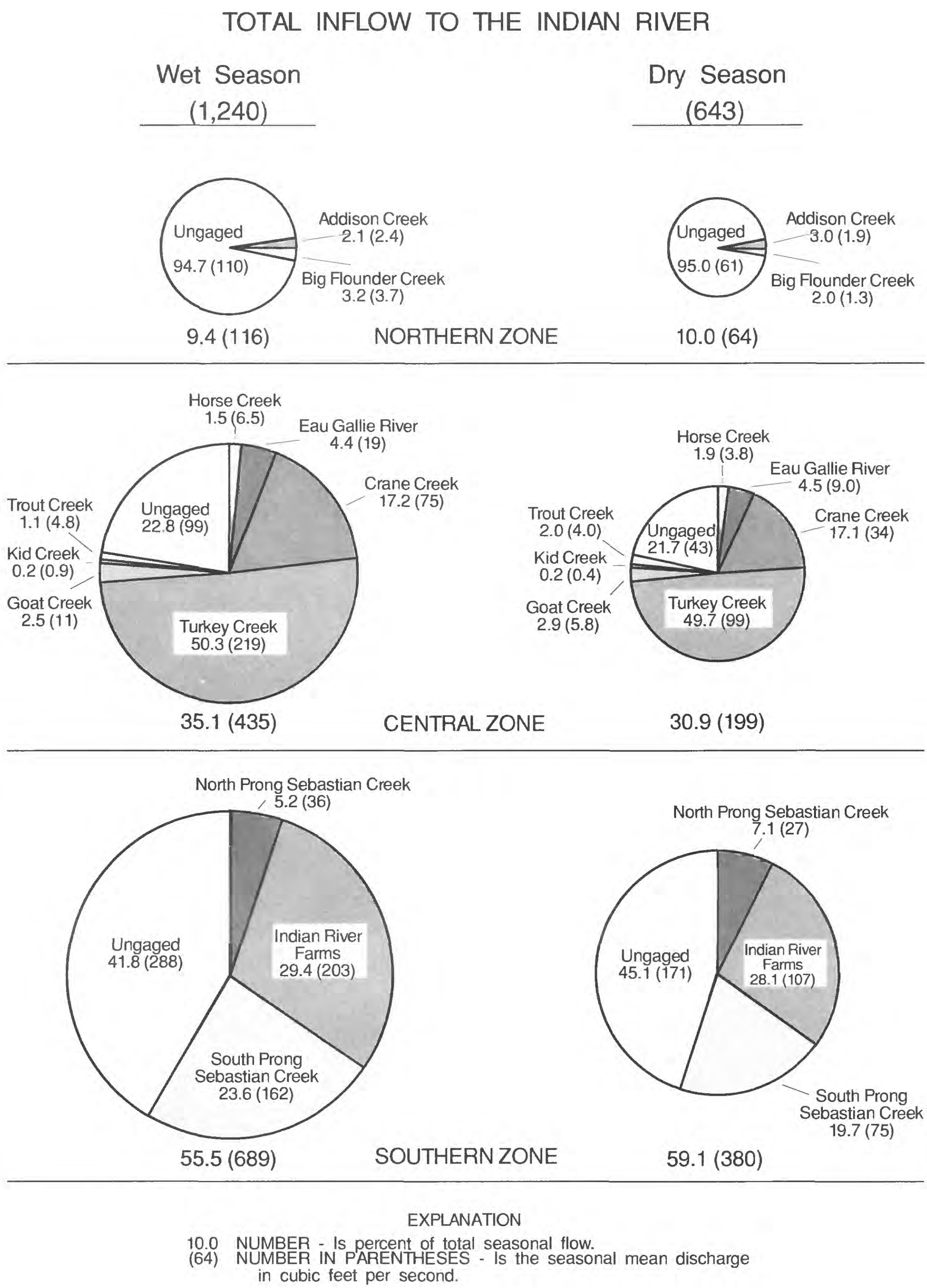

Figure 19. Seasonal distribution of freshwater discharge to the Indian River, 1989-91.

Table 4. Summary of seasonal rainfall and discharge for drainage basins of the Indian River

[mi^2, square miles; in., inches; ft^3/s, cubic feet per second; Ratio = Annual mean discharge (in.)/Rainfall (in.); data in parentheses are estimated values. Dry season, October 16 through May 31; Wet season, June 1 through October 15]

Drainage basin	Drainage area (mi^2)	Rainfall (in.)	Ratio	Annual mean discharge (in.)	Annual mean discharge (ft^3/s)	Rainfall (in.)	Ratio	Annual mean discharge (in.)	Annual mean discharge (ft^3/s)
		1989 Dry Season				1989 Wet Season			
		NO DATA FOR 1989 DRY SEASON							
Northern Zone	84.4					24.99	0.12	3.0	50.3
Addison Creek	2.4					(25.00)	.12	3.0	1.4
Big Flounder Creek	1.8					(24.50)	(.20)	(4.9)	(1.7)
Remaining ungaged	80.2					(25.00)	(.12)	(3.0)	(47.2)
Central Zone	196.3					26.50	.32	8.4	322.9
Horse Creek	1.9					(30.00)	.45	13.4	5.0
Eau Gallie River	4.8					28.71	(.57)	(16.4)	(15.5)
Crane Creek	18.8					(24.25)	.70	16.9	62.4
Turkey Creek	105.0					(28.00)	.28	7.9	162.9
Goat Creek	9.1					(18.00)	.08	1.5	2.7
Kid Creek	0.7					(17.00)	.09	1.5	0.2
Trout Creek	15.0					(16.50)	.04	0.6	1.8
Remaining ungaged	41.0					(29.00)	(.31)	(9.0)	(72.4)
Southern Zone	317.9					21.52	.31	6.7	420.5
Sebastian Creek:									
North Prong	28.5					(18.00)	.13	2.4	13.5
South Prong	77.8					20.37	(.31)	(6.3)	(96.2)
Indian River Farms	77.1					(24.00)	.37	8.8	133.9
Remaining ungaged	134.5					(21.50)	(.31)	(6.7)	(176.9)
Total:									
Gaged	342.9					23.52	.31	7.4	497.2
Ungaged	255.7					23.80	.25	5.9	296.5
Indian River basin	598.6					23.64	.29	6.8	793.7

ranged from 0.04 for Trout Creek basin to 0.70 for the Crane Creek basin, and dry-season ratios ranged from 0.13 for Trout Creek basin to 1.02 for Horse Creek basin.

Ratios for individual basins varied more during the wet season than during the dry season. Most basins had ratio extremes within 150 percent of each other. The Addison Creek wet-season ratio increased from 0.12 in 1989 to 0.32 in 1991. However, Goat Creek basin wet-season ratios increased the most, ranging from 0.08 in 1989 to 0.39 in 1991, indicating that extensive development during the study has had an effect on the rainfall-runoff characteristics of the basin. Wet-season basin ratios increased during the study, with the exception of Crane Creek. The wet-season ratio for the Crane Creek basin varied the least, ranging only from 0.62 in 1990 to 0.70 in 1989. During the dry season, Turkey Creek and North Prong Sebastian Creek basin ratios remained the same (0.44 and 0.42, respectively).

Similar to annual estimates, computed discharge is more sensitive to ratio estimates than to rainfall estimates. Seasonal discharge to the Indian River is within 27 percent of the computed

Table 4. Summary of seasonal rainfall and discharge for drainage basins of the Indian River--Continued

[mi^2, square miles; in., inches; ft^3/s, cubic feet per second; Ratio = Annual mean discharge (in.)/Rainfall (in.); data in parentheses are estimated values. Dry season, October 16 through May 31; Wet season, June 1 through October 15]

Drainage basin	Drainage area (mi^2)	Rain-fall (in.)	Ratio	Annual mean discharge (in.)	Annual mean discharge (ft^3/s)	Rain-fall (in.)	Ratio	Annual mean discharge (in.)	Annual mean discharge (ft^3/s)
		1990 Dry Season				1990 Wet Season			
Northern Zone	84.4	18.45	0.31	5.7	56.7	24.92	0.14	3.5	58.2
Addison Creek	2.4	18.61	.31	5.7	1.6	26.27	.14	3.6	1.7
Big Flounder Creek	1.8	16.18	(.35)	(5.7)	(1.2)	19.59	(.20)	(3.9)	(1.4)
Remaining ungaged	80.2	(18.50)	(.31)	(5.7)	(53.9)	(25.00)	(.14)	(3.5)	(55.1)
Central Zone	197.7	14.12	.50	7.1	164.5	29.95	.35	10.4	403.5
Horse Creek	2.4	13.79	1.02	14.1	4.0	27.82	.41	11.5	5.4
Eau Gallie River	5.7	14.23	(.98)	(13.9)	(9.3)	31.86	(.52)	(16.6)	(18.6)
Crane Creek	18.8	15.53	.95	14.8	32.8	27.62	.62	17.1	63.0
Turkey Creek	105.0	13.59	.44	6.0	74.2	28.35	.34	9.7	200.4
Goat Creek	9.1	12.57	.27	3.4	3.6	34.85	.22	7.8	14.0
Kid Creek	0.7	(12.00)	.20	2.4	0.2	(32.00)	.07	2.2	0.3
Trout Creek	15.0	11.97	.13	1.5	2.7	29.51	.07	2.0	6.0
Remaining ungaged	41.0	(16.00)	(.49)	(7.8)	(37.7)	(34.00)	(.35)	(11.9)	(95.8)
Southern Zone	317.9	14.26	.42	6.0	224.6	34.25	.35	12.0	746.6
Sebastian Creek:									
North Prong	28.5	(13.00)	.42	5.5	18.5	(34.00)	.23	7.9	44.4
South Prong	77.8	12.69	(.42)	(5.3)	(48.6)	34.41	(.35)	(12.0)	(183.2)
Indian River Farms	77.1	(15.00)	.42	6.3	57.6	(35.50)	.39	13.9	210.1
Remaining ungaged	134.5	(15.00)	(.42)	(6.3)	(99.9)	(33.50)	(.35)	(11.7)	(308.9)
Total:									
Gaged	344.3	13.72	.46	6.3	254.3	31.97	.35	11.1	748.5
Ungaged	255.7	16.26	.39	6.4	191.5	30.91	.30	9.2	459.8
Indian River basin	600.0	14.80	.43	6.3	445.8	31.52	.33	10.3	1,208.3

value (table 4) during both seasons when the discharge-to-rainfall ratio estimates vary by up to 50 percent; whereas seasonal discharge is within 5 percent of the computed discharge value during both seasons when the rainfall estimates vary by as much as 30 percent.

Dry-season discharge-to-rainfall ratios computed for the Indian River basin were 0.43 and 0.42, respectively, but ranged from 0.31 to 0.63 while the discharge-to-rainfall ratios were varied for basins with estimated discharge-to-rainfall ratios. Similarly, these dry-season discharge-to-rainfall ratios ranged from 0.37 to 0.59 while rainfall totals were varied for basins with estimated rainfall.

Wet-season discharge-to-rainfall ratios computed for the Indian River basin for 1989, 1990, and 1991 were 0.29, 0.33, and 0.42, respectively, but ranged from 0.21 to 0.62 while the discharge-to-rainfall ratios were varied for basins with estimated discharge-to-rainfall ratios. Varying rainfall totals for basins with estimated rainfall resulted in wet-season discharge-to-rainfall ratios for the Indian River basin ranging from 0.22 to 0.53.

Table 4. Summary of seasonal rainfall and discharge for drainage basins of the Indian River--Continued

[mi², square miles; in., inches; ft³/s, cubic feet per second; Ratio = Annual mean discharge (in.)/Rainfall (in.); data in parentheses are estimated values. Dry season, October 16 through May 31; Wet season, June 1 through October 15]

Drainage basin	Drainage area (mi²)	Rain-fall (in.)	Ratio	Annual mean discharge (in.)	Annual mean discharge (ft³/s)	Rain-fall (in.)	Ratio	Annual mean discharge (in.)	Annual mean discharge (ft³/s)
		1991 Dry Season				1991 Wet Season			
Northern Zone	84.4	30.05	0.24	7.2	71.8	44.60	0.32	14.4	238.7
Addison Creek	2.4	34.16	.24	8.1	2.3	27.29	.32	8.7	4.1
Big Flounder Creek	1.8	26.87	(.25)	(6.7)	(1.4)	49.70	(.45)	(22.4)	(7.9)
Remaining ungaged	80.2	(30.00)	(.24)	(7.2)	(68.1)	(45.00)	(.32)	(14.4)	(226.7)
Central Zone	197.6	22.44	.45	10.0	233.3	31.38	.47	14.9	578.6
Horse Creek	2.4	20.51	.60	12.4	3.5	31.88	.58	18.5	8.7
Eau Gallie River	5.7	19.85	(.64)	(12.7)	(8.5)	32.56	.64	20.8	23.3
Crane Creek	18.7	23.33	.69	16.0	35.3	38.32	.70	26.9	98.9
Turkey Creek	105.0	22.50	.44	10.0	123.6	29.96	.47	14.2	292.9
Goat Creek	8.1	22.19	.37	8.2	7.8	26.85	.39	10.4	16.5
Kid Creek	1.7	(22.00)	.16	3.5	0.7	(26.00)	.18	4.8	1.6
Trout Creek	15.0	20.88	.14	2.9	5.1	25.32	.09	2.4	7.1
Remaining ungaged	41.0	(23.00)	(.44)	(10.1)	(48.8)	(35.00)	(.46)	(16.1)	(129.6)
Southern Zone	317.9	31.61	.45	14.3	534.3	34.33	.42	14.4	899.8
Sebastian Creek:									
North Prong	28.5	(25.00)	.42	10.4	35.1	(33.00)	.27	8.9	50.0
South Prong	77.8	24.54	(.45)	(11.0)	(100.9)	32.73	(.42)	(13.7)	(209.2)
Indian River Farms	77.1	(37.00)	.46	17.1	155.6	(37.00)	.47	17.4	263.1
Remaining ungaged	134.5	(34.00)	(.45)	(15.3)	(242.7)	(34.00)	(.42)	(14.3)	(377.5)
Total:									
Gaged	344.2	26.43	.45	11.8	479.8	32.72	.45	14.6	983.3
Ungaged	255.7	30.98	.38	11.9	359.6	37.61	.39	14.6	733.8
Indian River basin	599.9	28.37	.42	11.9	839.4	34.80	.42	14.6	1,717.1

Annual and seasonal discharge and percentages of total inflow to the Indian River were computed for the drainage basins and the resulting averages are presented in table 5. Annual values are time-weighted by the number of data-collection months during the year used in the computation. For instance, the 1989 year (May 1 through December 31) has a weighted value of 8 (for 8 months) and 1990 and 1991 each have a weight of 12. The seasonal values are computed for 3 wet seasons (1989, 1990, 1991) and 2 dry seasons (1990 and 1991) during the time period June 1, 1989, through October 15, 1991. The computation of seasonal estimates did not include 3.5 months of record—May 1-31, 1989, and October 16 through December 31, 1991; these two intervals fall prior to the June 1, 1989, beginning of the first wet season of the study period and subsequent to the October 15, 1991, ending of the last wet season. This 3.5-month record, however, is included in the annual values. Note that discharge during this 3.5-month period is high enough in some of the larger basins to influence the annual value so that the annual value is outside the range of the seasonal values. For example, the annual percentage for Turkey Creek (18.0) is outside the seasonal range (15.4 to 17.7).

Table 5. Freshwater-discharge summary for drainage basins of the Indian River

[ft^3/s, cubic feet per second; < , less than. Dry season, October 16 through May 31; Wet season, June 1 through October 15]

Drainage basin	Discharge			Percent of discharge		
	Annual (ft^3/s)	Dry-season (ft^3/s)	Wet-season (ft^3/s)	Annual	Dry-season	Wet-season
Northern Zone	84.8	64.0	116.0	9.6	10.0	9.4
Addison Creek	2.3	1.9	2.4	0.2	0.3	0.2
Big Flounder Creek	2.4	1.3	3.7	.3	.2	.3
Ungaged	80.1	60.8	109.9	9.1	9.5	8.9
Central Zone	306.7	199.1	435.0	34.8	30.9	35.1
Horse Creek	4.9	3.8	6.5	.5	.6	.5
Eau Gallie River	14.1	9.0	19.1	1.6	1.4	1.5
Crane Creek	52.8	34.0	74.8	6.0	5.3	6.0
Turkey Creek	158.6	98.9	218.8	18.0	15.4	17.7
Goat Creek	7.8	5.8	10.9	.9	.9	.9
Kid Creek	0.5	0.4	0.9	.1	<.1	.1
Trout Creek	4.2	4.0	4.8	.5	.6	.4
Ungaged	63.8	43.2	99.2	7.2	6.7	8.0
Southern Zone	489.1	380.1	689.0	55.6	59.1	55.5
Sebastian Creek:						
North Prong	29.7	27.0	35.8	3.4	4.2	2.9
South Prong	110.8	74.9	162.6	12.6	11.6	13.1
Indian River Farms	143.7	106.8	202.6	16.3	16.6	16.3
Ungaged	204.9	171.4	288.0	23.3	26.7	23.2
Total:						
Gaged	531.8	367.8	742.9	60.4	57.2	59.9
Ungaged	348.8	275.4	497.1	39.6	42.8	40.1
Indian River basin	880.6	643.2	1,240.0	100.0	100.0	100.0

Three gaged basins each contribute more than 10 percent of the total freshwater discharge to the Indian River. Turkey Creek basin has the greatest annual discharge and contributes 18.0 percent of the annual discharge. Indian River Farms and South Prong Sebastian Creek basins each contribute 16.3 and 12.6 percent of the annual discharge, respectively. However, during the dry-season, Indian River Farms basin contributes most of the seasonal discharge (16.6 percent), and Turkey Creek and South Prong Sebastian Creek basins each contributes 15.4 and 11.6 percent of the seasonal discharge, respectively.

The annual and seasonal discharge contribution to the Indian River varied little among the remaining nine gaged and ungaged basins. Ungaged basins are estimated to contribute 39.6 percent of the annual discharge; 23.3 percent from the southern zone, 9.1 percent from the northern zone, and 7.2 percent from the central zone. Ungaged drainage contributed 40.1 percent of the wet-season discharge and 42.8 percent of the dry-season discharge. The combined flow from the gaged basins—Addison Creek, Big Flounder Creek, Horse Creek, Eau Gallie River, Crane Creek, Goat Creek, Kid Creek, Trout Creek, and North Prong Sebastian

Creek—contributed the remaining 13.5 percent of the annual and dry-season discharge and 12.8 percent of the wet-season discharge.

ADVANCES IN GAGING METHODS FOR LOW-VELOCITY STREAMS

Although many of the larger tributaries within the Indian River basin were gaged during this study, a large part of the Indian River basin remained ungaged because the complex hydrologic nature of the streams made gaging impractical. These streams are low-velocity systems that are difficult to measure accurately, with the possible exception of high-runoff periods. Streamflow measurement is difficult because of many factors, including astronomically induced tides in the Atlantic Ocean that influence stage in the Indian River; wind, salinity, and temperature gradients causing stratified flows; low hydraulic gradients; and the complex hydrodynamics of streamflows as they interact with other tributaries before discharging into the Indian River. Streamflow in many of the tributary basins is affected by tides reaching far enough upstream that gages must be placed in the tidal reach to measure most of the basin's drainage. Even with advanced technology, gaging these systems is costly and accuracy often is low.

Hydrodynamic characteristics within gaged tidal reaches characterized by stratified flow conditions, complex circulatory features, and extremely small head differences between gages (often less than 0.01 ft) severely limit the use of one-dimensional models as an approach to simulate flow in these areas. Unsuccessful applications of BRANCH to tidal reaches of Eau Gallie River and South Prong Sebastian Creek were due to insufficient head differences and streamflows not being homogeneous (well mixed). More accurate estimates of discharge probably could have been achieved for these tributaries if they were modeled as two- or three-dimensional systems. However, a more promising approach, which has become feasible in the last several years, is to use acoustic meters to measure streamflow in tidal and low-velocity systems (Laenen and Smith, 1983; Laenen, 1985). Acoustic devices, still being developed and tested by the USGS during the study period, were not available for use in this study. Acoustic meters are useful in measuring discharge at streamflow sites where the relation between discharge and stage varies with time because of variable backwater conditions and also where stream slopes are too flat to permit accurate measurements for slope computations (Laenen and Curtis, 1989). The decreasing cost and increasing availability of acoustic devices are making streamflow gaging more desirable in locations with complex hydrodynamics. Acoustic velocity meters (AVMs) can provide a continuous and reliable record of water velocities over a wide range of conditions.

The acoustic Doppler discharge measurement system (ADDMS), developed by the USGS, is used to make accurate, rapid discharge measurements from a moving boat which then can be compared to discharges computed from AVM-measured stream velocities (Simpson and Oltmann, 1993). Because the ADDMS requires a much shorter measurement time (2 min using the ADDMS compared with 1 hr or longer using conventional methods), it can be used for dynamic-discharge conditions. Considering the nature of the Indian River basin drainage, this technology could be applied to the tidal tributaries—Turnbull Creek, Big Flounder Creek, Eau Gallie River, and Sebastian Creek. If acoustic systems are successfully applied at these tributaries, stream-gaging coverage would be increased from 44 percent (during this study) to 73 percent of the Indian River basin within the SJRWMD. AVM stations were installed on the Eau Gallie River in 1993 and on Turnbull Creek and South Prong Sebastian Creek in 1994. Three stage-discharge stream-gaging stations were installed in each of the Big Flounder Creek and South Prong Sebastian Creek basins in 1994.

SUMMARY AND CONCLUSIONS

The Indian River is the largest in a system of shallow, bar-built estuarine lagoons in east-central Florida. Freshwater discharge enters the river and mixes with saltwater entering the river from the Atlantic Ocean, creating an estuarine environment. Drainage modifications within the basin have increased freshwater discharge to the Indian River causing the river to receive large volumes of freshwater during periods of heavy rainfall, thereby decreasing the salinity of the water so much that sometimes it results in fishing restrictions and loss of revenue. To evaluate the effect of freshwater discharge on the Indian River and to improve water management and planning, rainfall patterns and basin drainage were studied by the U.S. Geological Survey in cooperation with the St. Johns River Water Management District during the period 1989-91.

The subtropical climate of the Indian River basin is characterized by a wet (summer) season—June 1 through October 15—and a longer dry season—October 16 through May 31. Thunderstorm activity accounts for more than 50 percent of the total annual rainfall during the wet season. Rainfall and the frequency of high-intensity rainstorms were greatest during the wet season when thunderstorms were most intense and localized. During the study, weekly rainfall of 10 to 20 inches was measured during late September through early October of each year. Rainfall intensity was greatest at the northern end of the study area with a maximum 24-hour rainfall of 8.66 inches recorded north of Titusville on October 1, 1991.

Basinwide, high-magnitude rainfall events were most common during late September and early October. Localized events were most frequent during the wet season, particularly July and August. During this study, daily rainfall exceeded 1 inch only 12 percent of the time, but accounted for at least 50 percent of the annual rainfall. Storms exceeding 3 inches were 8 times more likely to occur during the wet season than during the dry season. Maximum rainfall intensity, usually lasting 5 to 20 minutes, ranged from about 5.25 inches per hour in southern Brevard County to more than 8 inches per hour at Titusville. The probability of rainfall exceeding 1 inch per hour was 9 to 10 percent on average and nearly twice as likely to occur during the wet season.

Total freshwater discharge to the Indian River was computed by combining gaged tributary flow and ungaged basin discharge. Stream-gaging accounted for 261 square miles of the study area, leaving a large part of Indian River basin drainage ungaged. To account for this ungaged drainage, discharge-to-rainfall ratios of nearby gaged basins were extrapolated to estimate discharge for ungaged areas.

Gaged-tributary discharge ranged from 64 to 4,410 cubic feet per second (ft^3/s) and generally was greatest during the wet season. The annual maximum discharge averaged 3,390 ft^3/s on October 10, 1989-91, possibly indicating that an annual maximum discharge could be expected near the end of each wet season. Gaged discharge averaged 410 ft^3/s during the study; 565 ft^3/s during the wet season and 297 ft^3/s during the dry season. Base flow averaged 223 ft^3/s, ranging from 64 ft^3/s during the dry season to 975 ft^3/s during the wet season. Gaged stormflow averaged 187 ft^3/s; 302 ft^3/s during the wet season and 104 ft^3/s during the dry season.

Flow-duration curves were developed for Crane Creek, Turkey Creek, and the Indian River Farms basins. Median daily discharge, or the discharge that is exceeded 50 percent of the time, was 39 ft^3/s for Crane Creek, 95 ft^3/s for Turkey Creek, and 66 ft^3/s for the Indian River Farms basins. Daily mean discharge exceeded 1,000 ft^3/s 0.06 percent of the time at Crane Creek, 0.41 percent at Turkey Creek, and 1.1 percent for the Indian River Farms basins, and was about three times more probable during the wet season than during the dry season.

Annual discharge-to-rainfall ratios averaged 0.26 in the northern zone, 0.46 in the central zone, and 0.39 in the southern zone. Basin discharge-to-rainfall ratios ranged from 0.09 for Trout Creek basin to 0.78 for Crane Creek basin. The largest ratios were for the highly urbanized basins in the central zone—Horse Creek, Eau Gallie River, and Crane Creek. Ratios for the two largest basins—Indian River Farms and Turkey Creek—were 0.40, about the average for the Indian River basin.

Annual freshwater discharge to the Indian River averaged 881 ft^3/s; 489 ft^3/s from the southern zone, 307 ft^3/s from the central zone, and 85 ft^3/s from the northern zone. Indian River Farms basin contributed about 29 percent of flow in the southern zone, equivalent to the combined discharge from the North and South Prongs of Sebastian Creek. Turkey Creek contributed the greatest annual discharge, or about 52 percent of flow in the central zone. The remaining basins contributed 27 percent of flow in the central zone. Gaged basins in the northern zone each contributed less than 3 percent of flow in the zone. Ungaged discharge contributed 94 percent of flow in the northern zone, 42 percent of flow in the southern zone, and 21 percent of flow in the central zone.

Freshwater discharge to the Indian River averaged 1,240 ft^3/s during the wet season and 643 ft^3/s during the dry season. The proportion of flow between seasons was less than 5 percent for each zone. The southern zone still contributed the most flow, followed by the central zone, and then the northern zone. Seasonal differences in basin discharge were greatest in the southern zone for South Prong Sebastian Creek and for the ungaged area.

Tributary base flow, primarily streambank and subsurface storage, proceeded from one season into the next, so that accumulated storage and end-of-the-season rainfall affected discharge and ratios in the following season. Wet-season rainfall and discharge were nearly twice as large as dry-season values; however, ratios generally were larger during the dry season. Discharge-to-rainfall ratios for the Indian River basin averaged 0.35 during the wet season and 0.42 during the dry season; 0.19 and 0.28, respectively, for the northern zone; 0.38 and 0.48, respectively, for the central zone; and 0.36 and 0.44, respectively, for the southern zone.

The three basins contributing to the greatest part of the total freshwater discharge to the Indian River are Turkey Creek (18.0 percent), Indian River Farms (16.3 percent), and South Prong Sebastian Creek (12.6 percent). During the dry season, Indian River Farms contributed most of the discharge (16.6 percent), with Turkey Creek and South Prong Sebastian Creek contributing 15.4 and 11.6 percent, respectively.

The annual and seasonal discharge contribution to the Indian River varied little among the remaining nine gaged and ungaged basins. Combined flow from the gaged basins contributed 13.5 percent of the annual freshwater discharge; 12.8 percent during the wet season and 13.5 percent during the dry season. Ungaged basins contributed about 40 percent of the annual freshwater discharge; 40 percent during the wet season and nearly 43 percent during the dry season.

Many of the larger tributaries of the Indian River are tidally affected, low-velocity systems that severely limit the applicability of simple flow models and make conventional stream-gaging methods impractical. Acoustic devices, still being developed and tested by the USGS during the study period, were not available for use in this study. Acoustic meters are useful in measuring discharge at streamflow stations where the relation between discharge and stage varies with time because of variable backwater conditions, and also where stream slopes are too flat to permit measurements accurate enough for slope computations. Acoustic velocity meters can provide a continuous and reliable record of water velocities, and acoustic doppler meters can be used to make accurate, rapid discharge measurements under dynamic-flow conditions. If this technology were successfully applied to the tidal tributaries—Turnbull Creek, Big Flounder Creek, Eau Gallie River, and Sebastian Creek—stream-gaging coverage would increase from 44 percent to 73 percent of the Indian River basin within the St. Johns River Water Management District.

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