NUTRIENT AND DETRITUS TRANSPORT IN THE APALACHICOLA RIVER, FLORIDA

River Quality Assessment of the Apalachicola River Basin, Florida

United States Geological Survey Water-Supply Paper 2196–C

COVER PHOTOGRAPH:

The Landsat image on the cover shows the extent of the flood plain in the Apalachicola River Basin, Florida. The dark color of the flood plain is caused by the low reflectance from flood waters. The 200-m wide river is barely visible in the center of the 3.2 to 8.0-km-wide flood plain. The Apalachicola River flows from Lake Seminole (at the top), 171 km south, to Apalachicola Bay (near the bottom of the scene). The numerous white squares near the top of the scene are agricultural fields in Florida and Alabama. The large red area east of the river is pine forest (Apalachicola National Forest). The faint brown color on the birdsfoot delta at the river mouth is marsh. The light blue colors near the beaches at the bottom of the scene are a combination of shallow areas and areas with high suspended sediments caused by ocean currents.

The false-color composite was obtained on February 6, 1977, by a Landsat multispectral scanner and includes bands 4, 5, and 7. The scene ID is 2746-15190, and more information on this and other satellite images is available through the U.S. Geological Survey, EROS Data Center, Sioux Falls, S. Dak., 57198.

Chapter C

NUTRIENT AND DETRITUS TRANSPORT IN THE APALACHICOLA RIVER, FLORIDA

By HAROLD C. MATTRAW, JR., and JOHN F. ELDER

U.S. GEOLOGICAL SURVEY WATER-SUPPLY PAPER 2196–C

Apalachicola River Quality Assessment

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FOREWORD

The Apalachicola River Quality Assessment was designed to evaluate the numerous factors that influence the nutrient and detrital yield of the river to Apalachicola Bay. The excellent hydrologic gaging system on the Apalachicola River permitted subdivision of the flood plain into three input-output units. The systematic analysis of nutrient sources, transport, and yields in the flood plain required new study techniques and data collection methods for (1) river and wetland hydrology, (2) tree species abundance and distribution, (3) leaf-litter production and decomposition, and (4) nutrient and detritus transport. These factors are the focus of separate Water-Supply Papers in the series (number 2196) dealing with the Apalachicola River Quality Assessment. Nutrient and detritus transport and ultimate yields are discussed in this paper. Extensive information from the previous papers is cited as necessary to develop a cogent scenario for nutrient and detritus yield.

The main purpose of this characterization of nutrient and detritus sources and mechanisms is to provide a quantitative methodology for evaluating densely forested bottom-land hardwood swamps. The Apalachicola flood plain has demonstrable importance to a highly productive Apalachicola estuary. A more accurate appraisal of wetland functions is available through the quantification of the flood-plain tree-community nutrient and detritus supply to a commercially valuable mariculture. The approach used in the Apalachicola River Quality Assessment is an attempt to better understand the wetland function and to begin to quantify the roles of specific components, such as flood-plain leaf-litter fall.

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By Harold C. Mattraw, Jr., *and* John F. Elder

Abstract

The Apalachicola River in northwest Florida flows 172 kilometers southward from Jim Woodruff Dam near the Florida-Georgia border to Apalachicola Bay on the Gulf of Mexico. The basin is composed of two 3,100-square-kilometer subbasins, the Chipola and the Apalachicola. The Apalachicola subbasin includes a 454-square-kilometer bottom-land hardwood flood plain that is relatively undeveloped. The flood plain contains more than 1,500 trees per hectare that annually produce approximately 800 metric tons of litter fall per square kilometer. Spring floods of March and April 1980 carried 35,000 metric tons of particulate organic carbon derived from litter fall into Apalachicola Bay. The estuarine food web is predominantly detrital based and represents an important commercial source of oyster, shrimp, blue crab, and various species of fish.

The water budget of the Apalachicola basin is heavily dominated by streamflow. For a 1-year period in 1979-80, 28.6 cubic kilometers of water flowed past the Sumatra gage on the lower river. Eighty percent of this volume flowed into the upper river near Chattahoochee, Fla., and 11 percent was contributed by its major tributary, the Chipola River. Contributions from ground water and overland runoff were less than 10 percent.

Streamflow increases downstream were accompanied by equivalent increases in nitrogen and phosphorus transport. The nutrients were released to the river by the flood-plain vegetation, but also were subject to recycling. The increase in the amount of organic carbon transport downstream was greater than streamflow increases. The flood plain is an important source of organic carbon, especially in detrital form.

Several methods for measurement of detritus in the river and flood plain were developed and tested. The detritus data from the flood plain added semiquantitative evidence for transport of detritus from the flood plain to the river flow, probably accounting for most of the coarse particulate organic material carried by the river.

During the 1-year period of investigation, June 3, 1979, through June 2, 1980, 2.1×10^5 metric tons of organic carbon were transported from the river basin to the bay. Nitrogen and phosphorus transport during the same period amounted to 2.2×10^4 and 1.7×10^3 metric tons, respectively. On an areal basis, it was calculated that the flood plain contributed 70 grams of organic carbon per square meter per year, 0.4 gram of nitrogen per square meter per year, and 0.5 gram of phosphorus per square meter per year. The flood plain acts as a source of detrital carbon, but for the solutes, nutrient release is approximately balanced by nutrient retention.

INTRODUCTION

Purpose and Objectives of the Apalachicola River Quality Assessment

The Apalachicola River Quality Assessment was initiated in 1978 as part of a national river quality assessment program of the U.S. Geological Survey. The purpose of the Apalachicola River Quality Assessment was to evaluate the importance of the Apalachicola River and its associated flood plain in supplying nutrients and organic detritus to Apalachicola Bay (fig. 1).

The specific goals of the Apalachicola River Quality Assessment were process oriented rather than problem oriented. Its primary purpose was to investigate river-wetland relations and controlling factors that influence the yield of nutrients and detritus to the bay. Emphasis was on processes that influence nutrient and detritus flow rather than on problems involving environmental disturbance or pollution. Special attention was given to methods development because ecological studies of large river-wetland systems have been rare and few methods particularly applicable to this type of study have been described.

The subtle but profound impact of hydrologic factors on tree-community distribution and on leaf-litter production and decomposition is difficult to document, and thoroughly documented methods of study are lacking. The more direct result of seasonal flooding—the erosion of large quantities of nutrients and decaying leaf litter from the flood plain and transport into the river—is more evident. However, methods for studying transport of large organic particles in the flood plain also lack documentation. Even the present (1980) techniques used to study

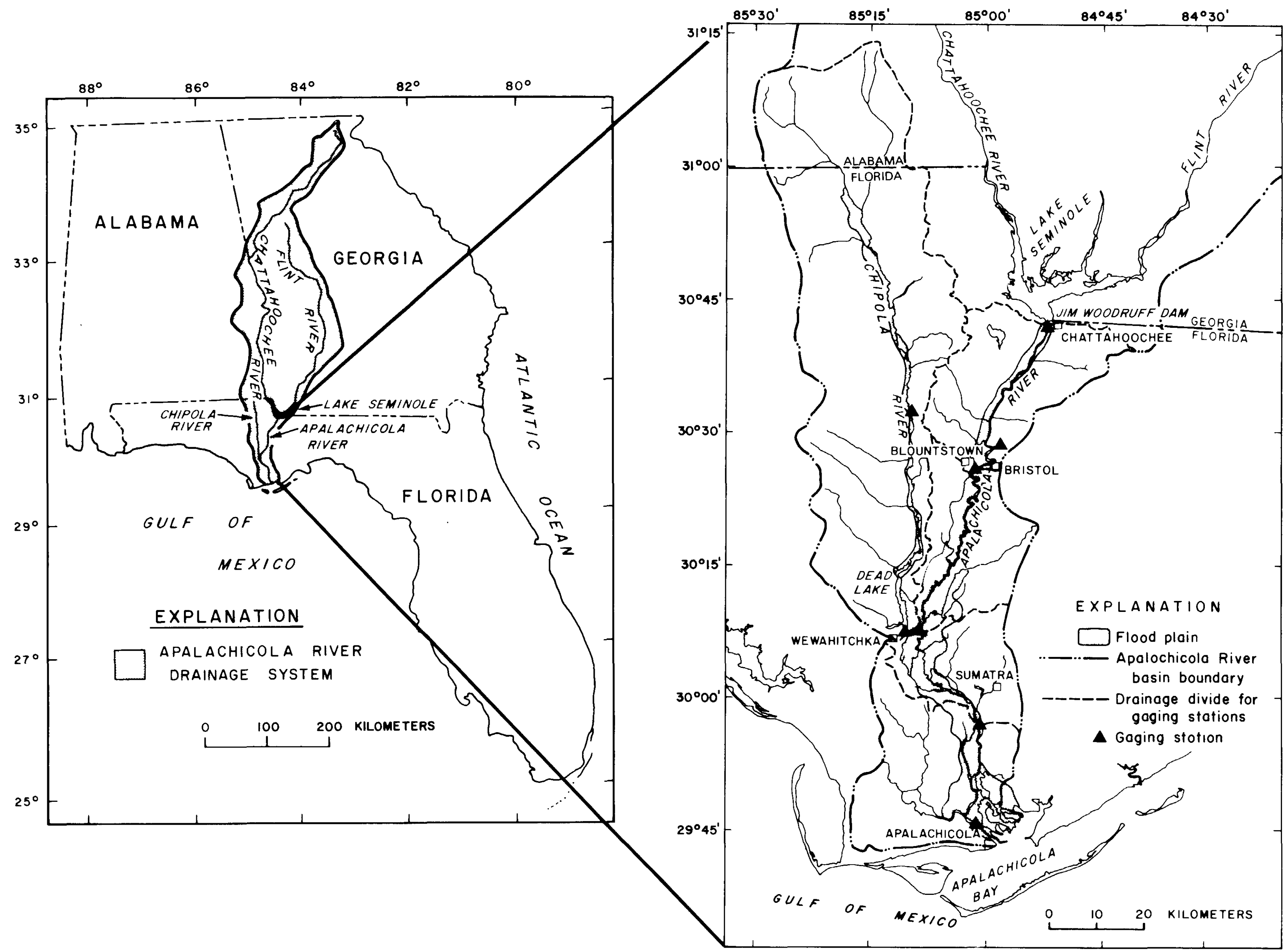

Figure 1. The drainage basins of the Apalachicola, Chattahoochee, and Flint Rivers in Alabama, Florida, and Georgia (left) and the Apalachicola and Chipola Rivers showing the flood plain and gaging station drainage divides (right).

particulate transport within the river lack standardization. To a large extent, the Apalachicola River Quality Assessment was designed to test methods with which to evaluate the influence of hydrologic factors on tree distribution, leaf-litter production, leaf-litter decomposition, and transport of nutrients and detritus. All of these methods were ultimately directed toward understanding the role of the flood plain in the nutrient and detritus yield to Apalachicola Bay.

The specific objectives of the Apalachicola River Quality Assessment were (Mattraw and Elder, 1980)

1. To determine the accumulation of trace elements and organic substances in benthic organisms and fine-grained sediments;
2. To describe how tree distribution on the flood plain is related to the pattern of flooding (duration, level, and frequency);
3. To assess the importance of leaf production and decomposition on the flood plain to detritus and nutrient yields of the basin; and
4. To identify major sources of nutrients to the river system and to quantify transport of nutrients and organic detritus in various parts of the system.

The specific purpose of this report is to address the fourth objective by presenting the results of nutrient and detritus transport determinations. The results of transport are directly dependent on an analysis of the basin water budget. The water budget and nutrient transport calculations are for the 366-day period from June 3, 1979, through June 2, 1980. The area considered is the 3,100-square-kilometer Apalachicola River basin in northwest Florida. Important aspects discussed include methods of measurement, hydrologic features that affect nutrient flow, changes in nutrient and detritus concentration over space and time, and the efficiency of flood-plain litter-fall capture by the flood waters.

Throughout this report, the term "nutrients" refers to both suspended particulate and soluble or dissolved nitrogen, phosphorus, and organic carbon. "Detritus" refers to organic particulate matter that contains leachable nutrients as well as numerous other elements associated with biological tissues. A conceptual design, methods, results, and analysis of errors are presented for the nutrient and detritus transport from the Apalachicola basin.

Setting

The Apalachicola River winds 172 km through the northwest Florida Panhandle and empties into the Gulf of Mexico (fig. 1) through Apalachicola Bay. In 1954, the Jim Woodruff Dam was constructed 1.5 km downstream from the confluence of the Chattahoochee and Flint Rivers and became the upstream limit of the Apalachicola River. The reservoir behind the dam, 15,200 ha in area, was filled by 1957. The entire Apalachicola-Chattahoochee-Flint River drainage basin is 50,800 km^2 in area, encompassing parts of Georgia, Alabama, and Florida. The part below the dam, which drains to the Apalachicola River directly, has an area of 6,200 km^2.

Jim Woodruff Dam (fig. 2) was constructed by the U.S. Army Corps of Engineers primarily to facilitate navigation on the Chattahoochee and Flint Rivers. The dam has a navigation lock 25 m wide, with about 9 m of lift from the Apalachicola River into Lake Seminole. The dam also creates storage for a hydroelectric generating plant, which supplies a part of the power needs for the city of Chattahoochee and neighboring communities.

The only major tributary of the Apalachicola River below Jim Woodruff Dam is the Chipola River. The Chipola is constrained by a low-head, interlocking, sheet-pile weir near Wewahitchka, Fla. (fig.3). The resulting pool is called Dead Lake. The drainage area of the Chipola River above Dead Lake is 3,100 km^2, exactly one-half of the drainage area of the entire Apalachicola basin. Immediately downstream from the weir, the Chipola is joined by Apalachicola River water flowing through the Chipola Cutoff distributary. These waters rejoin the main stem of the Apalachicola 21 km downstream.

A second major distributary channel of the investigated reach is located near the Sumatra gage at Brickyard Landing (fig. 4). The Brickyard Cutoff conveys water from the Apalachicola River to the Brothers River. The rating curve for the Sumatra gage is developed from measurements upstream of Brickyard Cutoff and, therefore, represents the total flow of both channels.

Twelve km south of Brickyard Cutoff, the Brothers River joins the Apalachicola. The major part of the Apalachicola River flows 10 km south, where it joins the Jackson River and flows southeast into Apalachicola Bay. The U.S. Highway 98 bridge across the bay, near the mouth of the Apalachicola River, is used by the U.S. Army Corps of Engineers as the mile 0 for navigation purposes on the river.

The flood plain of the Apalachicola River is 454 km^2 in area, expanding from a width of 1 km near Chattahoochee to 8 km near Sumatra. The composition of the Apalachicola flood-plain tree community was estimated by Leitman and others (1983). Table 1 lists the 18 most commonly observed flood-plain species, in order of abundance. The data represent tree identification from eight cruise transects across the flood plain at widely spaced locations. Leitman and others (1983) recognized 5 major forest types (table 2) and 47 tree species.

Forest-litter production in the flood plain is potentially a major source of nutrients and organic matter in the Apalachicola system. The flood plain is heavily forested with bottom-land hardwoods dominated by Ogeechee and water tupelo (*Nyssa ogeche, N. aquatica*) and baldcypress

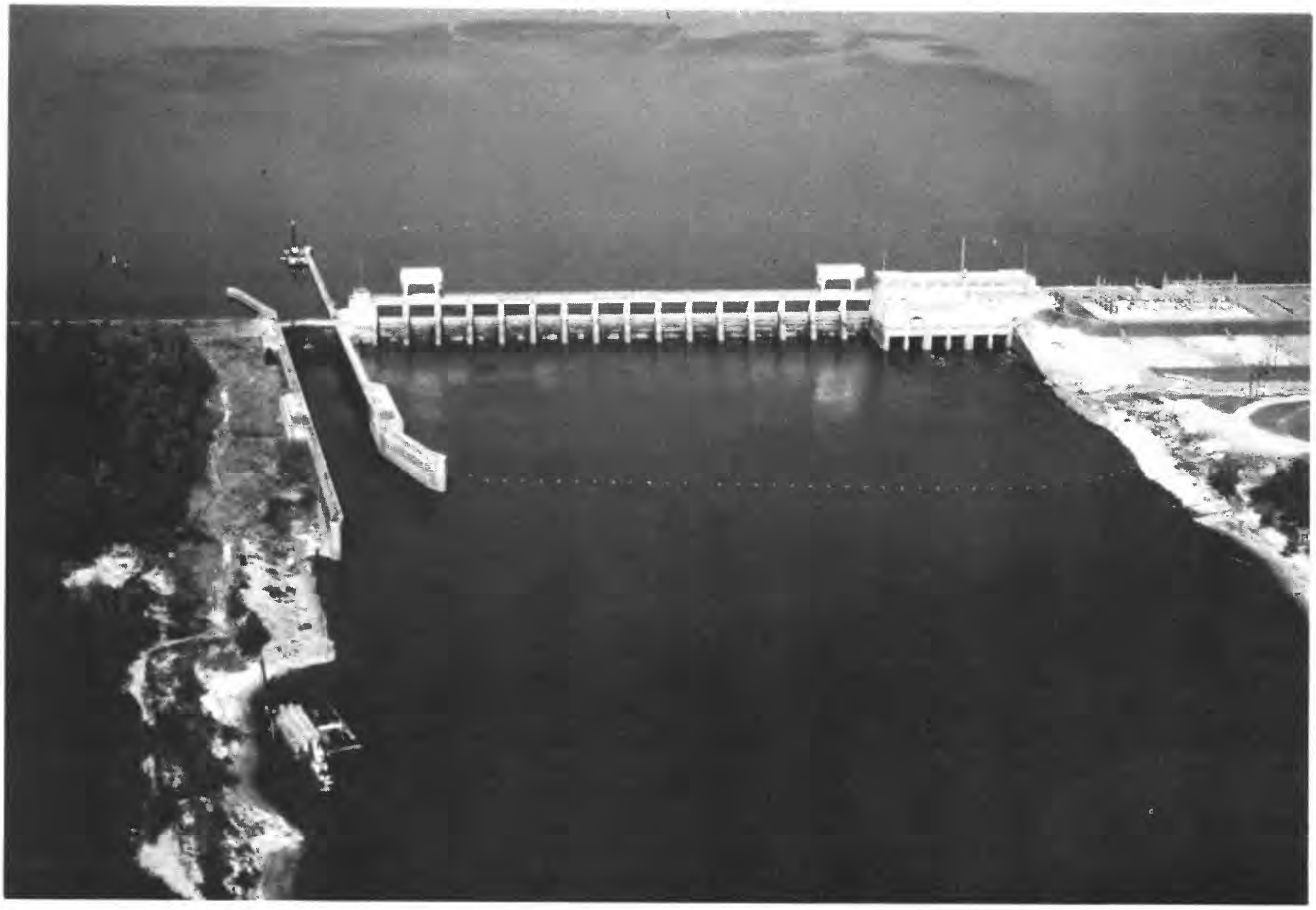

Figure 2. Jim Woodruff lock and dam (view is to the north).

(*Taxodium distichum*). Many of these species are highly sensitive to the extent and duration of flooding. The vegetation annually produces tons of leaf litter and other organic matter which must be either reincorporated into the system or transported out of it. Once litter fall reaches the flood-plain floor, annual flooding of the forest accelerates decomposition and transport of materials from the flood plain to the main-stream channels (Elder and Cairns, 1982).

Using litter-fall measurements collected at two transects between September 1979 and September 1980 and forest type composition data from the eight cruise transects, Elder and Cairns (1982) calculated a mean annual litter production of 800 g/m^2. At this rate, the trees and vines of the 454-square-kilometer flood plain produce 3.6×10^5 metric tons of litter fall annually. Much of this material decomposes and is recycled to vegetation. It is assumed that some of the soluble decomposition products leach through the soil and enter the ground-water system. Another fraction is eroded by seasonal floods and is either redeposited on the flood plain or is captured by the river and carried to Apalachicola Bay. The proportion that is transported by the seasonal flooding depends to a great extent on the magnitude and duration of the seasonal flooding. The residual nutrient content and particle size of the transported litter (detritus) are governed largely by the length of time between the litter fall and the flooding episode. The major litter-fall months in the Apalachicola flood plain are October and November (Elder and Cairns, 1982). Peak flooding is normally between January and March.

Nutrients and detritus are transported into Apalachicola Bay, which has a complex trophic structure. In an exhaustive data-gathering program, Florida State University scientists (Livingston and others, 1974) are developing a data base that demonstrates the impacts of various physical, chemical, and biological factors on the estuarine ecosystem. The role of the river in affecting the salinity structure, in supplying nutrients to phytoplankton, and in providing detritus is well documented.

The relation between the river system and the bay contributes directly to the economic welfare of Franklin County. Oysters (*Crassostrea virginica* Gmelin) depend on an adequate nutrient supply to sustain their planktonic

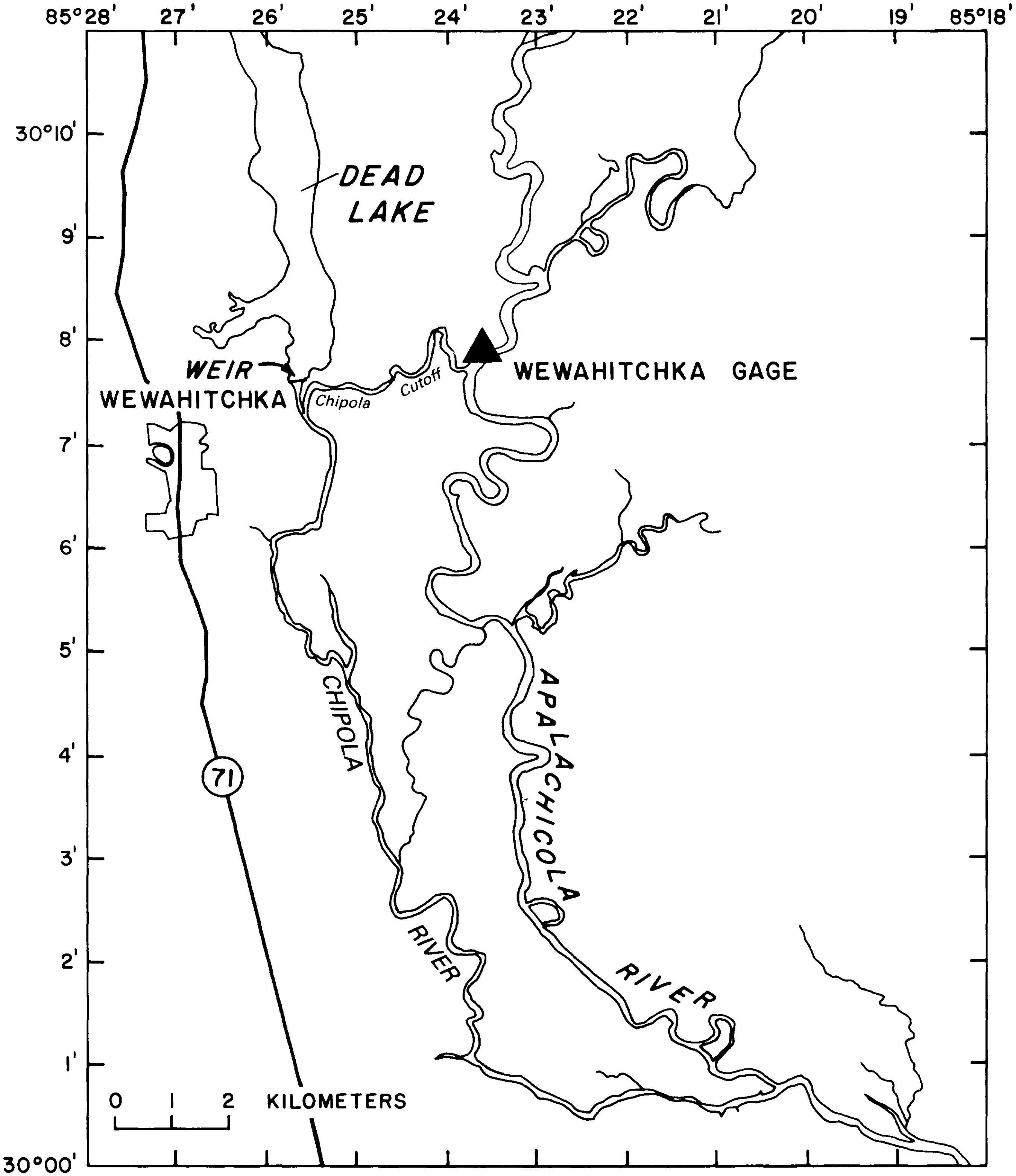

Figure 3. Dead Lake, Chipola Cutoff, and Apalachicola River near Wewahitchka, Florida.

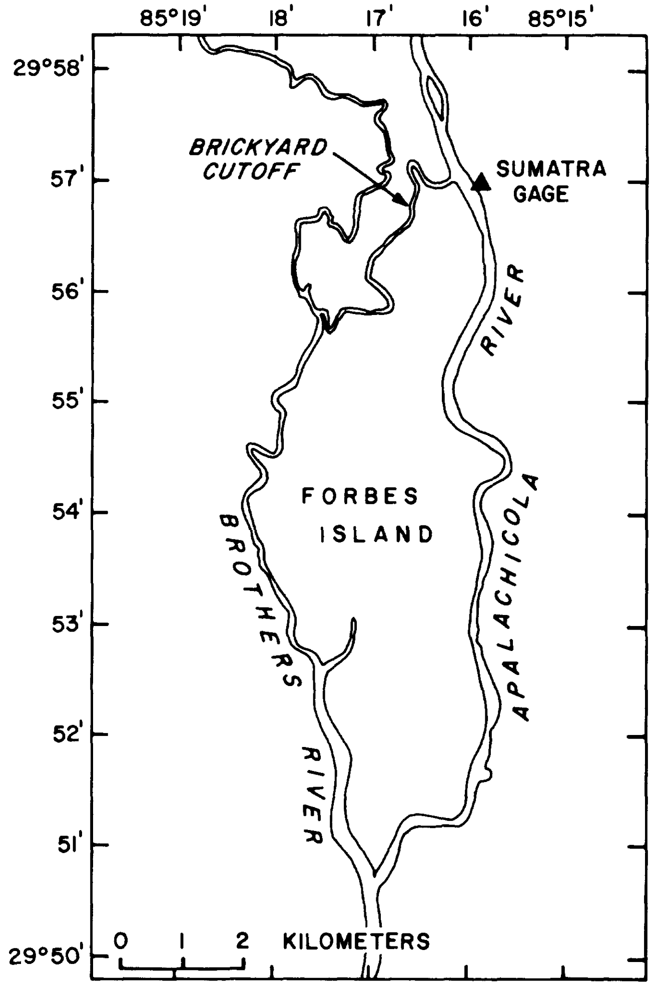

Figure 4. Apalachicola River, Brickyard Cutoff, and Brothers River near Brickyard Landing.

food supply, and the periodic pulses of freshwater discourage predation by oyster drills (*Labyrinthomysa marina*) (Menzel and others, 1966). Oyster harvesting is the major industry of the county; the second and third most economically important commercial species of marine life are shrimp (*Penaeus* sp.) and blue crab (*Callinectes sapidus*). Both the shrimp and the crab are detrivores.

Extensive otter-trawl sampling of Apalachicola Bay organisms (Livingston and others, 1976) identified the 10 dominant species of invertebrates (table 3). The most abundant, the white shrimp (*Penaeus setiferus*), uses the bay as a nursery ground and depends heavily on detritus and detritus-associated organisms. Five of the six most abundant species of invertebrates in Apalachicola Bay are benthic omnivores and depend heavily on detritus. Gravid female blue crabs from along the entire western coast of Florida migrate to the bay region to spawn (Oesterling and Evink, 1977). Juveniles apparently migrate into Apalachicola Bay. This pattern explains the abundance of juvenile blue crabs (table 3) observed by Livingston and others (1976).

Fish are also abundant in Apalachicola Bay. In general, their connection to detritus is indirect; ultimately, however, detritus is just as vital to the fish as it is to the invertebrates (Livingston and others, 1976). Decayed litter material is colonized by fungi, algae, and bacteria, which are grazed by protozoans. Isopods, amphipods, and decapods use the attached and associated organisms for food and the larger leaf and litter particles for shelter. Many fish feed on these small marine organisms. The higher trophic levels are thus dependent on an abundant nutrient and detrital supply at the base of the food web. Although the complex physical, chemical, and biological interactions of the bay estuarine system are incompletely understood, the river-derived nutrients and detritus are recognized as essential to the maintenance of the diverse ecosystem.

Table 1. Abundance of 18 tree species in the Apalachicola River flood plain

[Modified from Leitman and others, 1983]

Species	Relative basal area (in percent)
Water tupelo	29.9
Ogeechee tupelo	11.0
Baldcypress	10.6
Carolina ash	5.4
Blackgum	5.0
Sweetgum	4.8
Overcup oak	3.2
Planer-tree	2.9
Green ash	2.9
Water hickory	2.9
Sugarberry	2.8
Diamond-leaf oak	2.5
American elm	2.4
American hornbeam	2.0
Pumpkin ash[1]	1.9
Water oak	1.8
Red maple	1.5
Sweetbay	1.0

[1] Some trees identified as pumpkin ash may have been Carolina ash or green ash. Samaras (winged seeds) had dropped from the trees and seeds of all three species were mixed on the ground beneath the trees.

Table 2. Species composition and frequency of five major tree communities in the Apalachicola River flood plain

[Modified from Leitman and others, 1983]

Forest types	Predominant species	Associated species	Percentage of 223 cruise-transect plots
A . . .	Sweetgum Sugarberry Water oak American hornbeam Possumhaw	Diamond-leaf oak Green ash American elm American sycamore Water hickory	21
B . . .	Water hickory Green ash Overcup oak Diamond-leaf oak Sweetgum American elm	Sugarberry Red maple Water oak Possumhaw American hornbeam	16
C . . .	Water tupelo Ogeechee tupelo Baldcypress Blackgum Carolina ash Planertree	Overcup oak Pumpkin ash Red maple Water hickory American elm Green ash Diamond-leaf oak Sweetbay	21
D . . .	Water tupelo Blackgum Ogeechee tupelo Baldcypress Carolina ash Pumpkin ash Planertree Sweetbay	. . . .	11
E . . .	Water tupelo Baldcypress Carolina ash Planertree	. . . .	24
U . . .	Undifferentiated	. . . .	6

Table 3. Ten dominant species of invertebrates collected by otter trawl in Apalachicola Bay

[Modified from Livingston and others, 1976]

Common name	Scientific name	Percent
White shrimp	*Penaeus setiferus*	40.1
Grass shrimp.	*Palaemonetes pugio*	20.4
Blue crab	*Callinectes sapidus*.	20.2
Pink shrimp	*Penaeus duorarum*	5.3
Brief squid	*Lolliguncula brevis*.	4.3
Brown shrimp. . . .	*Penaeus aztecus*.	2.6
Olive Nerite	*Neritina reclivata*.	1.5
Swimming crab . . .	*Portunus gibbesii*.	1.1
Grass shrimp.	*Palaemonetes vulgaris*.	0.8
Mud crab	*Rhithropanopeus harrisii*. . .	.5

Recognition of the scarcity of information that might be used to evaluate potential resource problems on the river and flood plain prompted the Florida Defenders of the Environment to sponsor a symposium on the Apalachicola Drainage System in April 1976. The proceedings were published by the Florida Department of Natural Resources, Marine Research Laboratory (Livingston and Joyce, 1977). An aspect that was emphasized by the conference speakers, but was acknowledged to be poorly defined, was the role of the seasonal flooding cycle in the transport of litter-fall debris from the flood plain to the river and, ultimately, to the bay. This aspect was selected as the focus of the Apalachicola River Quality Assessment.

The Apalachicola River Quality Assessment was designed to define the cause-and-effect relation between existing hydrologic fluctuations and the tree community that occupies the flood plain, the production and decomposition of the litter fall, and the effectiveness of litter-fall transport from the flood plain to the river and the bay. Only when these relations are defined and measured can a rational scientific evaluation of river modifications be determined.

Background

The Apalachicola River Quality Assessment is unique within the River Quality Assessment Program because it was not conceived or designed to address existing problems. The Apalachicola basin is largely undeveloped, and it provides an appropriate setting for study of natural processes that might be sensitive to future development. Many of the alternative plans of the U.S. Army Corps of Engineers (COE) to upgrade navigation have caused concern among inhabitants of the area and State regulatory agencies. There is considerable disagreement about what types of problems might arise from different management practices, as described in reports such as the draft COE Environmental Impact Statement (EIS) of the river modification effects (U.S. Army Corps of Engineers, 1976), the evaluation of management alternatives by the U.S. Fish and Wildlife Service (1979), and the Estuarine Sanctuary EIS (U.S. Department of Commerce and State of Florida, 1979). These reports differ on the types of problems that might arise.

Conceptual Design

A conceptual design of the relations among the program components was developed (Mattraw and Elder, 1980). The design called for work in three broad areas: flood-plain dynamics, nutrient and detritus sources, and nutrient yield. The data-collection procedures employed in the flood-plain dynamics components have been described by Leitman and others (1983). Three of the techniques described in that paper—those used to measure rainfall, discharge, and flood-plain velocity—are directly applicable to an evaluation of nutrient and detritus transport.

Nutrient and detritus sources include, among others, the vegetation of the flood plain. The tree species distribution (Leitman and others, 1983), or, more correctly, the forest type distribution, is an essential component in evaluating nutrient and detritus sources. The techniques used in measuring the leaf production of the five forest types have been described by Elder and Cairns (1982). Decomposition rate studies were experiments conducted at field sites under a variety of conditions representative of river and flood-plain conditions. The result of these procedures is an estimate of the annual potential supply of nutrients and detritus derived from the litter fall.

The forest-litter material that is actually transported through the flood plain and the river is measured as part of the third broad area, nutrient yield. The extent of inundation and flood-plain velocities during flooding are believed to be the major controls on the fraction of the potential nutrient and detritus supply that is transported. The data needs include systematic collection of water-quality samples, discharge, and various size fractions of particulate organic matter (detritus). Several additional components dealing with lateral inflow (streams and ground water), atmospheric input, and upstream watersheds are incorporated in the program design.

APPROACH AND METHODS

Subbasin Approach

Four main-stem stage-discharge gages provided data that could be used to calculate nutient loads to the headwaters of the Apalachicola River below Jim Woodruff Dam and to three points downstream (fig. 1). Thus it was possible to calculate water and nutrient balance for three subreaches of the river and for the system as a whole. This capability lent itself to an attempt to quantify the proportion of total loads derived from the flood plain.

Table 4 gives the location, station identification number, drainage area, organization responsible for maintenance, period of record, and average discharge for the 1979 water year for each gage on the Apalachicola River system. The calculations of nutrient yields for the Apalachicola basin were made using Chattahoochee, Blountstown, Wewahitchka, and Sumatra gage records; the yields represent their respective parts of the basin. A fifth main-stem gage, near Apalachicola, Fla. (fig. 1), is strongly affected by tides and has not been rated with sufficient precision to permit discharge computations.

Determinations of water balance and nutrient transport depend on data from discharge gaging stations that can account for flow in the main stem and in tributaries. The main-stem gages separate the basin into three subbasins, as shown in figure 5. With the addition of boundaries representing the drainage area of each main-stem river gage, areas are defined for the subbasins. The subbasins are named according to their downstream order. The upper subbasin, 963 km^2 in area, is between the gages at Chattahoochee and Blountstown. The middle subbasin, 593 km^2 in area, is between the Blountstown and Wewahitchka gages. The lower subbasin, 476 km^2 in area, is between the Wewahitchka and Sumatra gages. The Chipola River basin is actually a 3,100-square-kilometer subbasin of the Apalachicola River basin. For this report, the Chipola subbasin ends where the Chipola River joins the Chipola Cutoff. The part of the Apalachicola River basin south of the Brickyard transect was excluded because diel tidal fluctuations made discharge calculations very difficult.

Table 5 summarizes the data-collection procedures used to determine nutrient and detrius yield. Included are the frequency of collection and recent references that detail the procedure. As indicated in table 5, the techniques for measuring flood-plain detritus, suspended detritus, and bottom-load detritus are unreferenced. These procedures were devised especially for the flow conditions of the large and swift Apalachicola River and its extensive flood plain.

Intensive Data-Collection Transect Approach

Two intensive data-collection transects were established to gather detailed information on litter-fall production, leaf decomposition, and water-level fluctuation on the flood plain. The Sweetwater transect (fig. 6) runs perpendicular to the flood-plain corridor and crosses the Apalachicola River 14 km upstream of the Blountstown gage (navigation mile 87). Seven major data-gathering plots (fig. 6) were established to estimate litter fall (Elder and Cairns, 1982) for this upper river transect.

A second intensive data-collection transect representative of lower river conditions was established near Brickyard Landing (fig. 7). The Brickyard transect crosses the Apalachicola River 1 km downstream of the Sumatra gage (navigation mile 20). Clearly visible in figure 7 is the powerline right-of-way that lies parallel and 150 m north of the Brickyard transect. Nine major data-gathering

Table 4. Stage-discharge gage stations on the Apalachicola River, Florida

[Maintenance responsibility: USGS, U.S. Geological Survey; NWS, National Weather Service; COE, Corps of Engineers]

Station name and identification number	Drainage area, in square kilometers	Maintenance responsibility	Period of record	Average discharge, in cubic meters per second
Apalachicola River at Chattahoochee, C235800.	44,600	USGS	October 1928 through September 1980.	640
Little Sweetwater Creek near Bristol, 02358685.	6.35	USGS	June 1979 through September 1980.	Not determined.
Apalachicola River near Blountstown, 02358700.	45,600	NWS	January 1920 through September 1957 (stage only).	. . . .
		COE	October 1957 through September 1980.	702
Apalachicola River near Wewahitchka, 02358754.	46,100	COE	October 1955 through September 1957 (stage only).	. . . .
			October 1965 through September 1980.	728
Chipola River at Dead Lake Outlet near Wewahitchka, 02359101.	3,100	USGS	November 1979 through September 1980.	Not determined.
Apalachicola River near Sumatra, 02359170.	49,800	COE	May 1950 through September 1959; April 1965 through April 1966 (stage and miscellaneous discharge measurements).	. . . .
		USGS	September 1977 through September 1980.	833
Apalachicola River near Apalachicola, 02359230.	50,600	USGS	July 1978 through September 1980.	Not determined.

plots were established in this transect to estimate monthly litter-fall production and to measure flood-plain flow and detritus during flooding.

Data from the two intensive transects and eight cruise transects were determined to be adequate to support semiquantitative estimates of the productivity of the entire basin. The approaches, judgments, and statistical analyses of this sampling design were discussed in earlier reports (Elder and Cairns, 1982; Leitman and others, 1983).

Discharge Approach

Discharge at the main-stem gaging stations represents contributions from the entire subbasin. The reference flood elevation chosen by Leitman and others (1983) was that of a 2-year, 1-day flood. The extent of inundation by such a flood correlates closely with the distribution of bottom-land hardwood forest types. During 1980, the peak discharge at Blountstown occurred on April 2. Its discharge, 3,100 m^3/s, has a recurrence interval of approximately 4 years.

Water-Quality Sampling Approach

Sample Location and Frequency

Water-quality samples for analysis of nutrients and suspended sediments were collected at each of the major gaging stations at least monthly between February 1979 and June 1980. Samples were collected more frequently during the major flooding period in March and April 1980. Because concurrent sampling was not possible, the different sampling sites had different sample intervals. Sample collection dates for each location are listed in table 6.

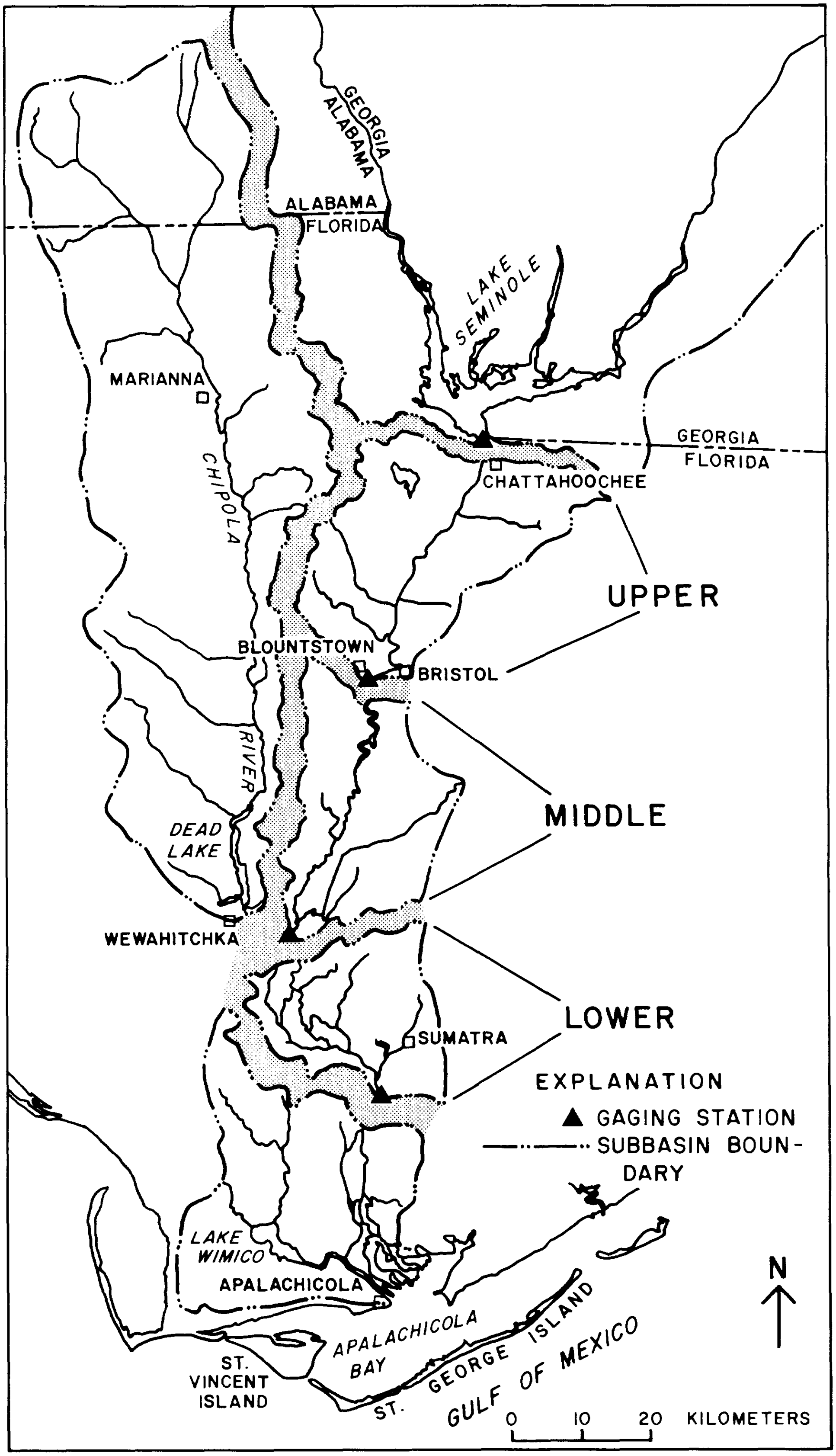

Figure 5. Apalachicola River subbasin components and gaging locations.

Table 5. Data-collection procedures used in determining nutrient and detritus transport

Procedure	Number or frequency of collection	Reference
River flow		
Stage recorder.	15 minute or hourly punched tape, graphic recorders (continuous).	Buchanan and Somers, 1968.
Tagline measurement . . .	Each total flow measurement during flood (channels in flood plain).	Buchanan and Somers, 1969.
Moving boat	Each flood flow measurement of main channel.	Smoot and Novak, 1969.
Flood-plain flow		
Price current meter	Used to measure all flow velocities except moving-boat measurements.	Buchanan and Somers, 1969.
Ground water		
Recorder	Hourly punched tape.	Buchanan and Somers, 1968.
Tape down.	Periodic.	Brakensiek and others, 1979.
Water quality		
Collection	Monthly, flood sampling.	Brown and others, 1970.
Composite	Each sample.	Guy and Norman, 1970.
Silver filter.	Each sample for suspended organic carbon.	Beetem and others, 1980.
0.45 μm filter	Each sample for dissolved constituents (solids, nutrients).	Do.
Preservation	Iced.	Do.
Shipping	Within 1 day of collection.	Do.
Laboratory analysis	Within 2 days of receipt.	Do.
Detritus		
Pumped.	Monthly.	. . . .
Bottom load.	Monthly.	. . . .
Flood-plain net	Flood sampling.	. . . .
Plastic sheets	Project period.	. . . .

Additional nutrient samples were collected at three other sites, off the main stem. One site was the Brickyard transect (fig. 7), where a composite sample was taken from Brickyard Cutoff, Brothers River, and when flooded, several points across the flood plain. To reach this area, water had to traverse a broad expanse of the flood plain and was, therefore, indicative of flood-plain outflow. Sampling on the Brickyard transect was done on the same days as at the Sumatra station (table 6).

A second off-channel site was at the mouth of the Chipola River at Dead Lake outlet (fig. 3). It was sampled on the same dates as the Wewahitchka station (table 6), except that it was not sampled during the period March 13-April 28, 1980, because Apalachicola flooding produced reverse-flow at the site. The third off-channel site was at Little Sweetwater Creek (fig. 6), a small ground-water-fed stream 10 km north of Blountstown. Its water chemistry (low pH, specific conductance, and nutrient content) was very different from that of Apalachicola River water but was similar to that of other ground-water outlets in the basin; hence, it was considered representative of ground-water input. This site was sampled on the same dates as the Blountstown station (table 6) except during the 1980 spring flood, when it was subject to backwater flood flow.

Sample Handling

A schematic diagram of the sample handling procedure is shown in figure 8. A point-integrating cable-and-reel sampler, US P-61 (Guy and Norman, 1970), was used to obtain 10 or more depth-integrated water-quality samples across the channel width or the flood plain. Each sample was emptied into a large polycarbonate mixing container (churn). When sampling was complete, the cross-sectional composite sample was mixed and total nutrient and total residue samples were drawn into 1-L polypropylene bottles. Additional samples from the churn were pumped through a 0.45-μ membrane filter by a peristaltic pump. The filtered samples were stored in 500-mL polypropylene bottles. All samples were placed in ice-filled coolers and shipped to the analytical laboratory.

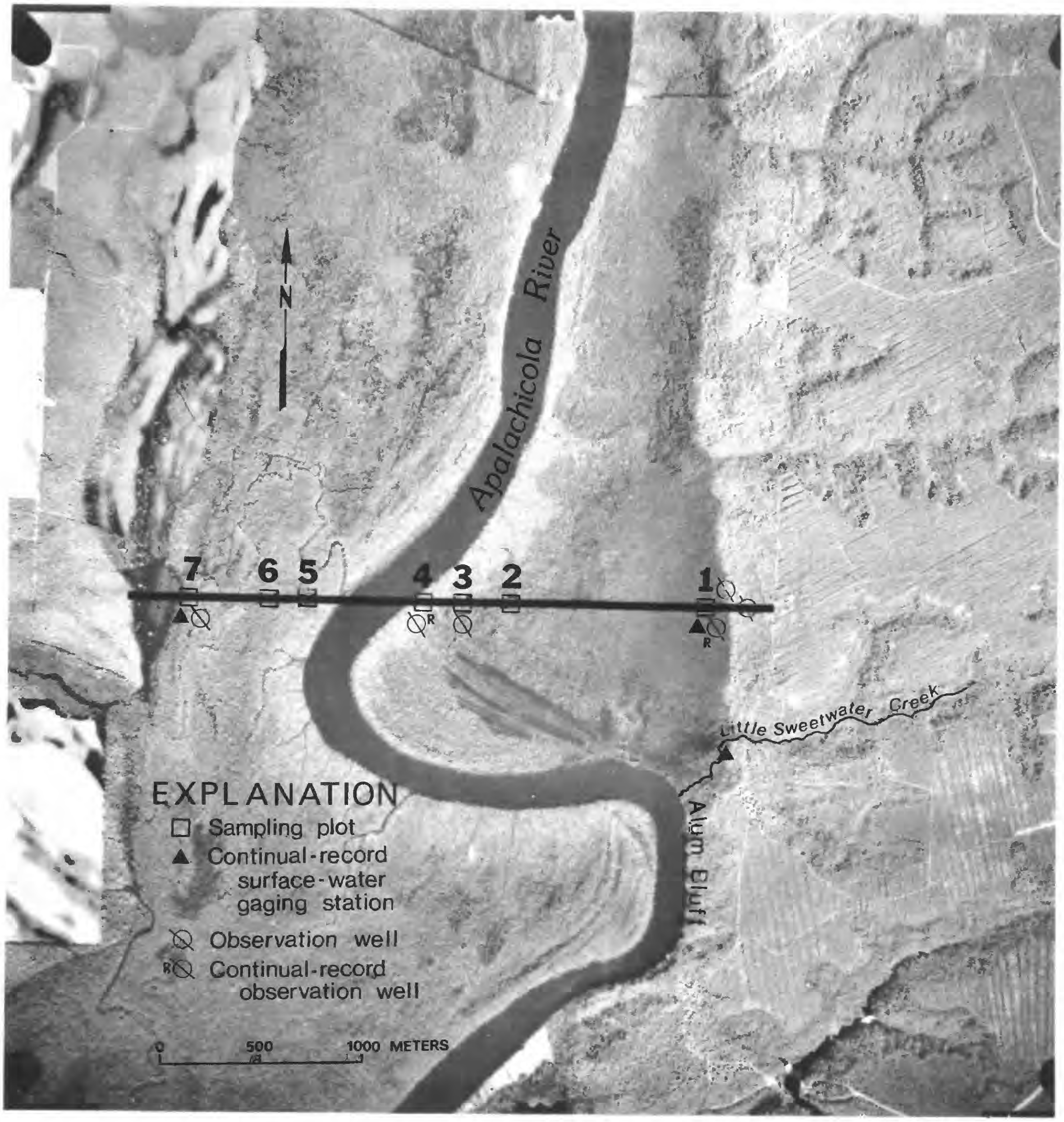

Figure 6. Locations of litter-fall sampling plots and water-level observation sites near the Sweetwater transect.

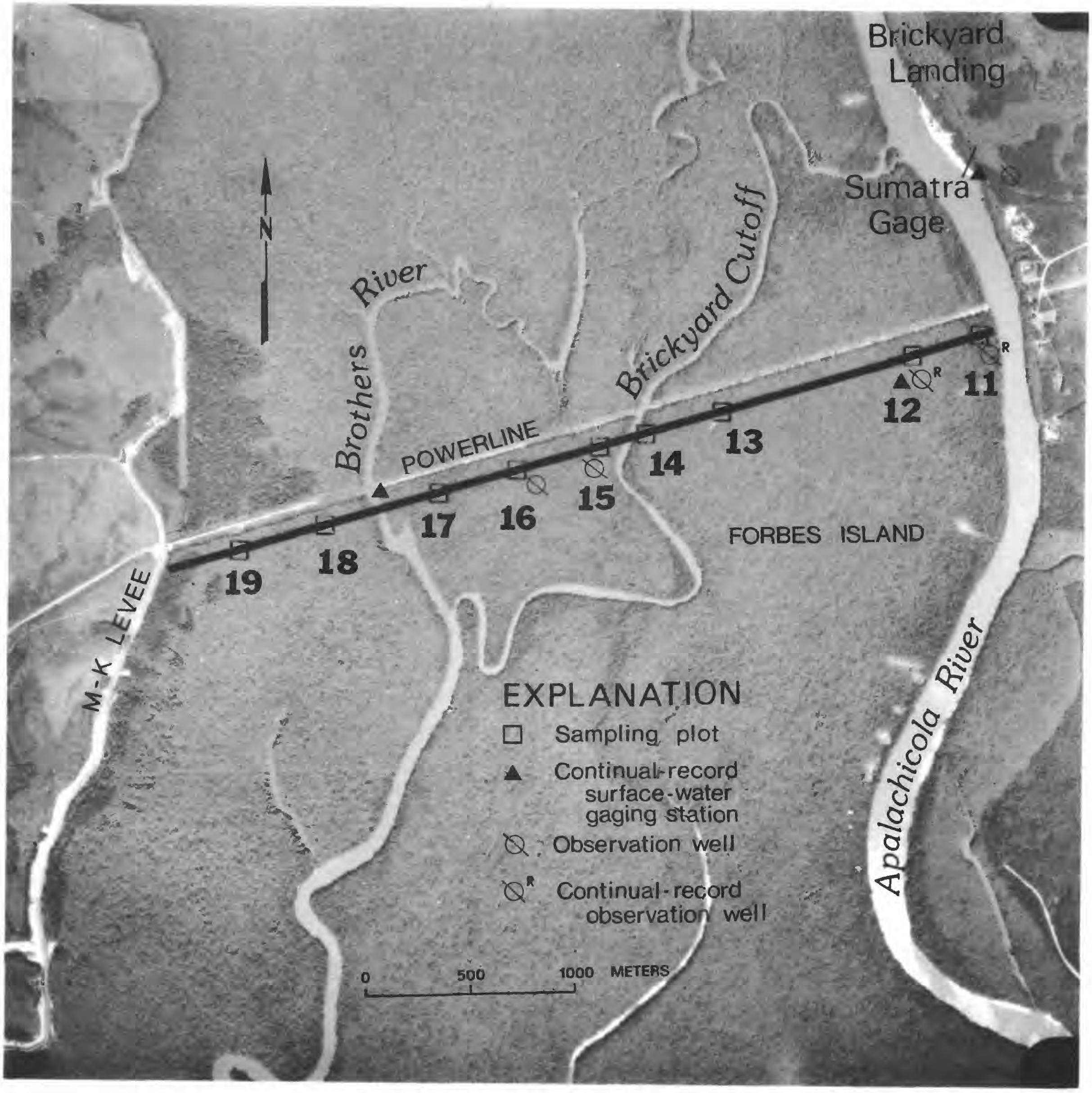

Figure 7. Locations of litter-fall sampling plots, water-level observation sites, and rainfall gage near the Brickyard transect.

Table 6. Water-quality sample collection dates at the major river-gaging stations

[Parentheses indicate dates when sampling was done for NASQAN program]

Month	Chattahoochee	Blountstown	Wewahitchka	Sumatra
1979				
February	27	28	28	....
March	(6), 14, (19)	14	15	1, 16
April	3, (10), 24	3, 24	4, 25	5, 11, 26
May	16, (21)	16	17	17
June	18	18	19	19
July	23, (31)	23	24	24
August	20, (28)	20	22	21
September	(18), 26	26	27	27
October	(25)	25	24	2, 24
November	(14), 19	19	20	20
December	18	18	17	17
1980				
January	21, (28)	22	22	23, 28
February	26	27	27	28
March	9, 10, 18, (23), 26	10 (twice), 12, 18, 26	11, 13, 19, 27	4, 11, 13, 14, 19, 27
April	2, 23	2, 23	3, 28	3, 28
May	(15), 21	20	20	19
June	(16), 25	25	24	24

Samples for carbon analysis were placed in a 100-mL stainless-steel pressure filter apparatus with a 0.45-μ silver filter. Both filtered and unfiltered samples for carbon analyses were collected in 60mL, oven-fired (500°C) glass bottles having aluminum foil cap liners. The 0.45-μ silver filter containing the suspended material was folded and placed in a petri dish for shipment.

The water-quality constituents analyzed and the general method of analysis are presented in table 7. Analytical results not presented in this report are published in "Water-Resources Data for Florida, Volume 4, Northwest Florida" (U.S. Geological Survey, 1979, 1980, 1981) and can also be accessed through WATSTORE (U.S. Geological Survey computerized water data storage and retrieval system) with the station identification numbers listed in table 4.

Bulk Precipitation Approach and Method

Bulk precipitation is the solution that results when rainfall incorporates the products of dry fallout (Whitehead and Feth, 1964). Four bulk precipitation collectors (fig. 9) were used in the Apalachicola basin near the main-river sampling sites. Samples were retrieved from the collectors monthly, coinciding with river sampling. It is recognized that the relatively simple design of the collectors did not minimize the various possible sources of error described by Galloway and Likens (1976). It was not practical for this study to collect dry and wet deposition separately or to retrieve samples at daily or weekly intervals. Some potential problems were mitigated, however, by the environmental conditions. Deposition of fine dry materials and various gases, for example, was not likely to contribute significantly to atmospheric input in this relatively humid area. Many chemical transformations that might have taken place between sample collections were of little consequence because the samples were analyzed for total organic carbon, nitrogen, and phosphorus only.

Atmospheric loading of nutrients to the subbasins for the period June 19, 1979, to June 25, 1980, was calculated using analytical data and National Weather Service rainfall records at the locations indicated in figure 10. Rainfall records for two locations were average for each subbasin to obtain a distributed rainfall depth across each subbasin. Records of rainfall near Sumatra were not available, so a recording rain gage was installed at the Brickyard transect to provide the desired rainfall coverage.

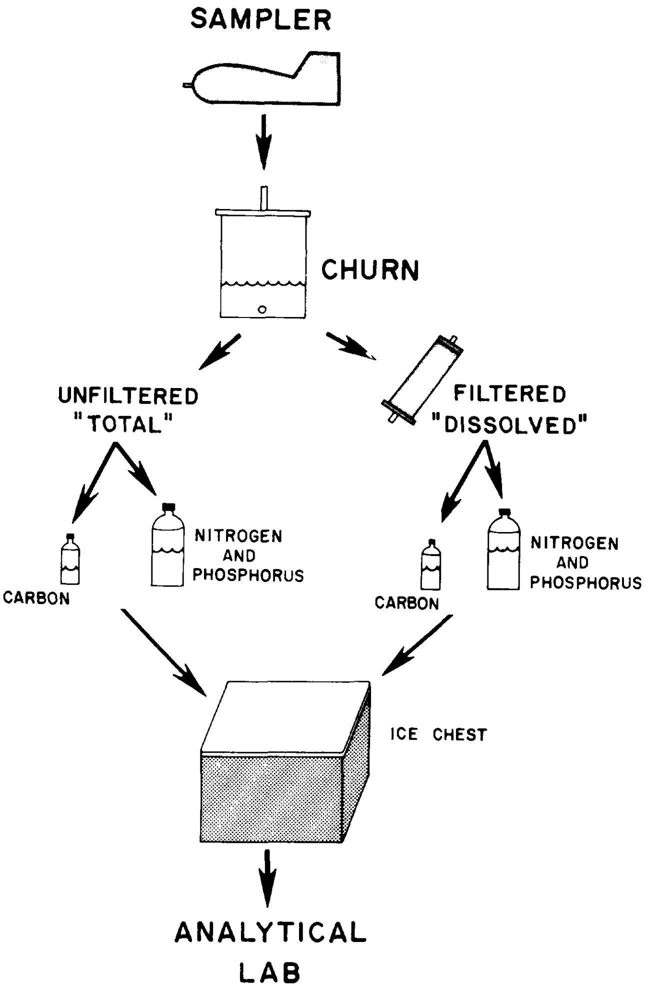

Figure 8. Water-quality sample handling procedures.

Ground-Water Component

The ground-water contribution to the Apalachicola River was estimated during the design phases of the Apalachicola River Quality Assessment to be less than 5 percent of the dry weather total flow (Mattraw and Elder, 1980). This estimate was based on records of discharge increases between Chattahoochee and Blountstown during low flow. Regional water-level mapping (fig. 11) of the principal artesian aquifer (Floridan aquifer) indicated that the steepest ground-water gradient toward the Apalachicola River is between these two main-stem gage locations. Low-flow discharge records and the ground-water gradient led to the establishment of several wells for observation of ground-water elevations in the Sweetwater transect (fig. 6). In addition, a surface-water gage was established on nearby Little Sweetwater Creek to observe its flow, which was principally ground-water discharge. The creek's drainage basin is 6.4 km^2. Calculations of ground-water-contributed load are based on low-flow water-quality samples from Little Sweetwater Creek that were processed like main-stem water-quality samples.

Between Chattahoochee and Blountstown, the regional pattern of ground-water contours for the Floridan aquifer (fig. 11) is north and south, parallel to the Apalachicola basin. Farther down river, the ground-water contour direction is more nearly east and west. This indicates that the ground-water contribution in the southern half of the river is much less and is more difficult to measure without an extensive system of water-table monitoring wells. Since the gain in information would have had such a small effect on the overall estimates of nutrient transport in the river system, only a few wells were installed in the lower river basin for qualitative comparisons of river levels with ground-water levels.

Detritus Methods

Suspended Detritus

Several particle-size classifications of detritus (particulate organic matter) are currently in use. The most common recognizes three major size ranges: coarse, fine, and very fine (Naiman and Sedell, 1979). Coarse particulate organic matter (CPOM) is defined as organic particles greater than 1 mm across. For this study, particles greater than 63 μ (0.063 mm) but smaller than 1 mm were classified as fine particulate organic matter (FPOM). Particles smaller than 63 μ but greater than 0.45 μ were classified as very fine particulate organic matter (VFPOM).

CPOM and FPOM were collected on 1-mm and 63-μ nested sieves attached to the side of the sampling boat. Water was pumped from depths of 0.5, 1.5, and 3.0 m for 10 minutes each as the boat slowly traversed the river cross section. The pumping rate was 10 L a minute, which produced a detritus sample representing 300 L of river water. The samples were rinsed from the sieves into labeled mason jars. The samples were shipped to the laboratory, where they were oven dried at 105°C and weighed, then ashed at 500°C and weighed again. The weight of organic matter was determined by subtracting the ash weight from the dry weight. Organic matter weights were converted to organic carbon weights by multiplying by 0.5, a conversion factor arrived at by chemical analysis of detrital material from the flood plain (Elder and Cairns, 1982).

VFPOM data were obtained from analysis of the 0.45-μ silver filter that was used to filter the dissolved organic carbon sample. The particulate matter captured on the silver filter was termed "suspended organic carbon" (SOC). This SOC sample included fine and very fine par-

Table 7. Analytical techniques used in the determination of chemical and physical characteristics of water samples

Parameter	Analytical technique[1]
Total organic carbon	Combustion, infrared absorption by carbon dioxide.
Dissolved organic carbon	Do.
Suspended organic carbon	Do.
Total inorganic carbon	Do.
Dissolved inorganic carbon	Do.
Total organic nitrogen	Colorimetric, block digester-salicylate.
Dissolved nitrate, nitrite	Colorimetric, cadmium reduction-diazotization.
Dissolved ammonia	Colorimetric, indophenol.
Dissolved organic nitrogen	Colorimetric, Kjeldahl.
Dissolved orthophosphate	Colorimetric, phosphomolybdate.
Dissolved phosphorus	Colorimetric, phosphomolybdate.
Total phosphorus	Do.
Chloride	Colorimetric, ferric thiocyanate.
Dissolved solids	Residue on ignition at 105°C.
Total solids	Do.
Temperature	Thermometer, on site.
pH	Water-quality monitor, on site.
Specific conductance	Do.
Dissolved oxygen	Do.

[1]References for organic carbon, Goerlitz and Brown, 1972; for all analyses except organic carbon, Skougstad and others, 1979.

ticles; coarse material was excluded because of the narrow opening on the sampler nozzle. Hence, the carbon concentration of VFPOM was determined by subtracting FPOM as carbon from SOC.

Bottom-Load Detritus

CPOM includes all sizes greater than 1 mm. Coarse material transported along the river bottom could not be sampled by the pump-sampling apparatus; yet, it was judged to be too important to be overlooked. Early experimentation led to a stationary net dredge (fig. 12) designed to sample coarse bottom-load particles that are transported along the bed of the river—hence the term "bottom-load" particulate organic carbon (BPOC). The stainless-steel frame of the net dredge has an 860-mm by 240-mm opening which holds a 1.5-m-long, 1-mm-mesh nylon net. Four kg of lead weight attached to the bottom edge of the frame hold the bottom leading edge flush with the river bed when the boat is anchored in place. The net is lowered to the bottom by a mounted crane and is left in place for 20 minutes. The velocity of the water entering the net is measured with an attached flow meter. The volume of water for the bottom-load sample is calculated from the cross-sectional area of the net opening, the velocity of the water, and the time the net is in place.

Several cross-sectional profiles of bottom-load organic carbon were made under different discharge conditions. In all cases, samples from the mid-20 percent of the channel accounted for close to 50 percent of the total BPOC (fig. 13). The monthly, or more frequent, bottom-load samples were all collected at midchannel, and all estimates of BPOC were based on the assumption that 50 percent of the material was outside of the sampled section. The collected organic material was hand picked from the detachable net and placed in pressure-closure plastic bags. The samples were shipped to the laboratory for oven-dry and ash weights, in the same manner as the other organic carbon size fractions.

Flood-Plain Detritus

Net collection.—The large quantity of litter fall resting on the flood-plain floor is in various stages of decomposition when seasonal flooding begins. Because only a part of the litter fall is transported, a method for estimating the fraction transported during flooding was devised. Figure 14 shows a device developed for sampling detritus moving through the flood plain. Samples were collected during flooding at numerous points in each of the two intensive transects. The device was placed well away from stream channels, but care was taken to avoid areas of dense vegetation where detritus would be trapped.

Figure 9. Bulk precipitation apparatus used for collection of total carbon, total nitrogen, and total phosphorus samples.

The flood-plain detritus net (fig. 14) has an opening 300 mm wide by 1.7 m high. The net is 2 m long and tapers to a 300-mm-diameter opening at the rear. A coarse mesh outer net is used to support an inner 1-mm-mesh collection net. The double net is closed at the trailing end with a drawstring. The side bars of the net are constructed of 10-mm threaded steel rod approximately 2 m long. The side bar rods extend about 150 mm below the bottom net support. For detritus collection, these extension rods were driven into the flood-plain floor by stepping on the bottom net support or when the water was over 1 m deep, by driving the rods from the top with a hammer. Nylon cord attached to the threaded rods above the top net support was attached to nearby trees to achieve a vertical position. The net was flushed of any debris accumulated during emplacement and the drawstring was pulled. The depth of water in the net opening, the time, and the current velocity were recorded.

The net was left in place for 2 to 24 hours, depending on accessibility and water velocity. The depth, time, and current velocity were recorded when the net was recovered. The depth and velocity used to calculate the volume of water passing through the net were the averages of the beginning and ending depths and velocities.

The entrained material was rinsed to the back of the net, the drawstring was opened, and the material was emptied into marked pressure-closure plastic bags. Like the other detritus samples, this material was shipped to the laboratory for oven-dry and ash weights.

Plastic-sheet collection.—The flood-plain detritus net was used to estimate the proportion of the litter fall that was transported under the conditions at the time the sample was collected. The suspended and bottom-load detritus data collected in the main river channel were designed to estimate the fraction that was captured by the river and ultimately was transported to Apalachicola Bay. All of these techniques were relatively short term; collections were made over periods of 20 minutes to 24 hours.

A method used to supplement short-term detritus data was a long-term collection technique intended to provide an independent measure of the amount of material in transport but remaining on the flood plain after flooding. The collection material was a 1-square-meter plastic sheet held flush to the ground with eight large nails around the perimeter. Three plastic sheets were installed at randomly selected locations in each of the 16 intensive-plot locations. The sheets were installed in early September 1979. In late December 1979, the litter fall resting on the sheets was sprayed with fluorescent orange paint. After the March-April flood had receded, 31 sheets were recovered. Seventeen sheets were not recovered because they were lost, destroyed, folded, or in some other manner invalidated.

In the laboratory, the presence or absence of fluorescent orange leaves was noted. The sample was weighed, and a subsample was separated into coarse and fine fractions with a 1-mm sieve. These fractions were dried, and their oven-dry ash weights were determined.

Data Handling

Surface-water-quality and stage-discharge records are routinely collected, prepared, and then stored in the WATSTORE computer file (Hutchinson, 1975). A generalized representation of the major steps between the collection of data and the nutrient and detritus load results presented in this report is shown in figure 15. All water-quality analyses and stage-discharge records are published annually and are also accessible through NAWDEX (Edwards, 1977).

The temporary data file labeled ARQA QW (fig. 15) represents the water-quality analytical results which

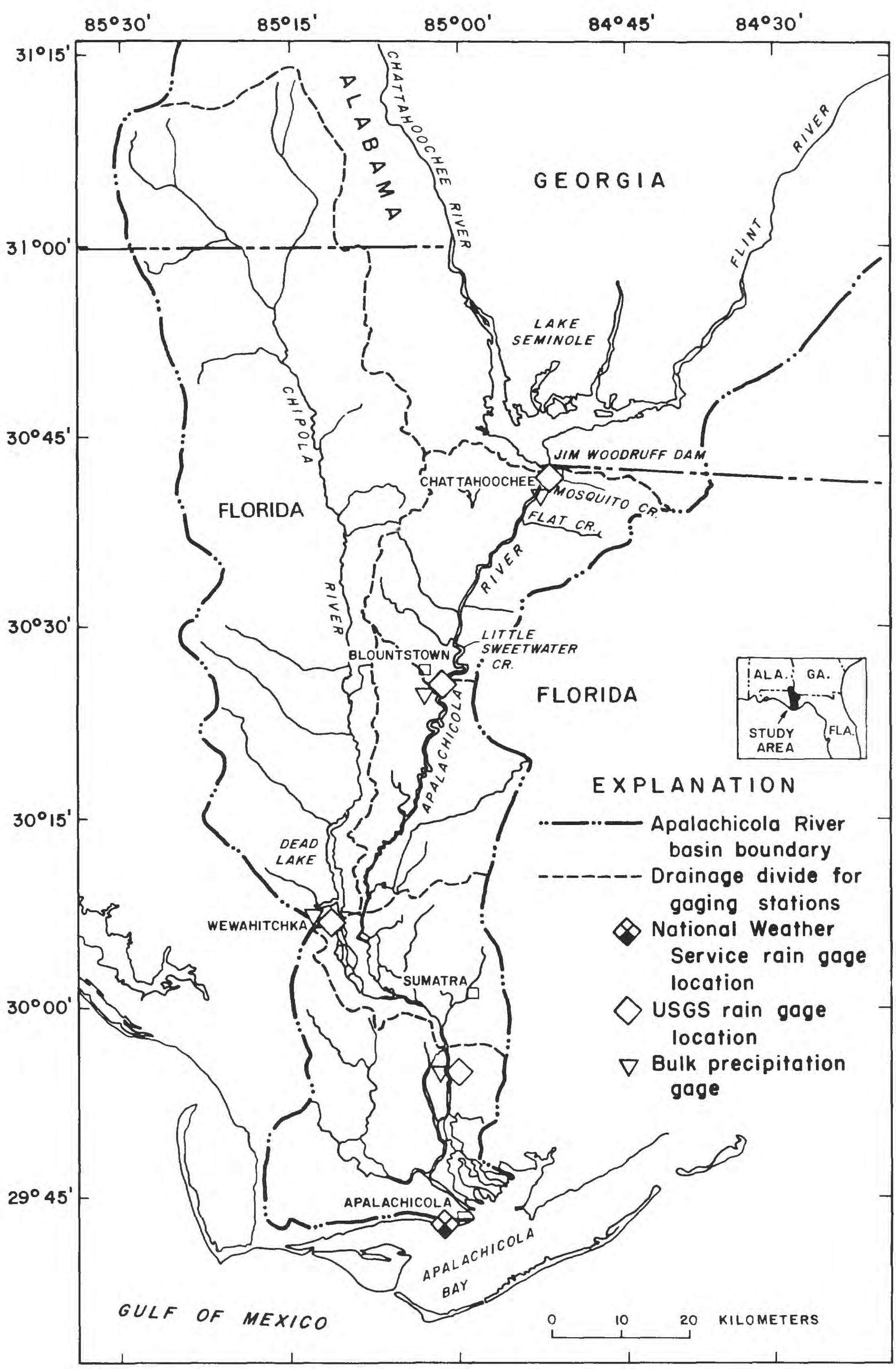

Figure 10. Locations of National Weather Service and U.S. Geological Survey rain gages and bulk precipitation sample collectors in the Apalachicola basin, Florida.

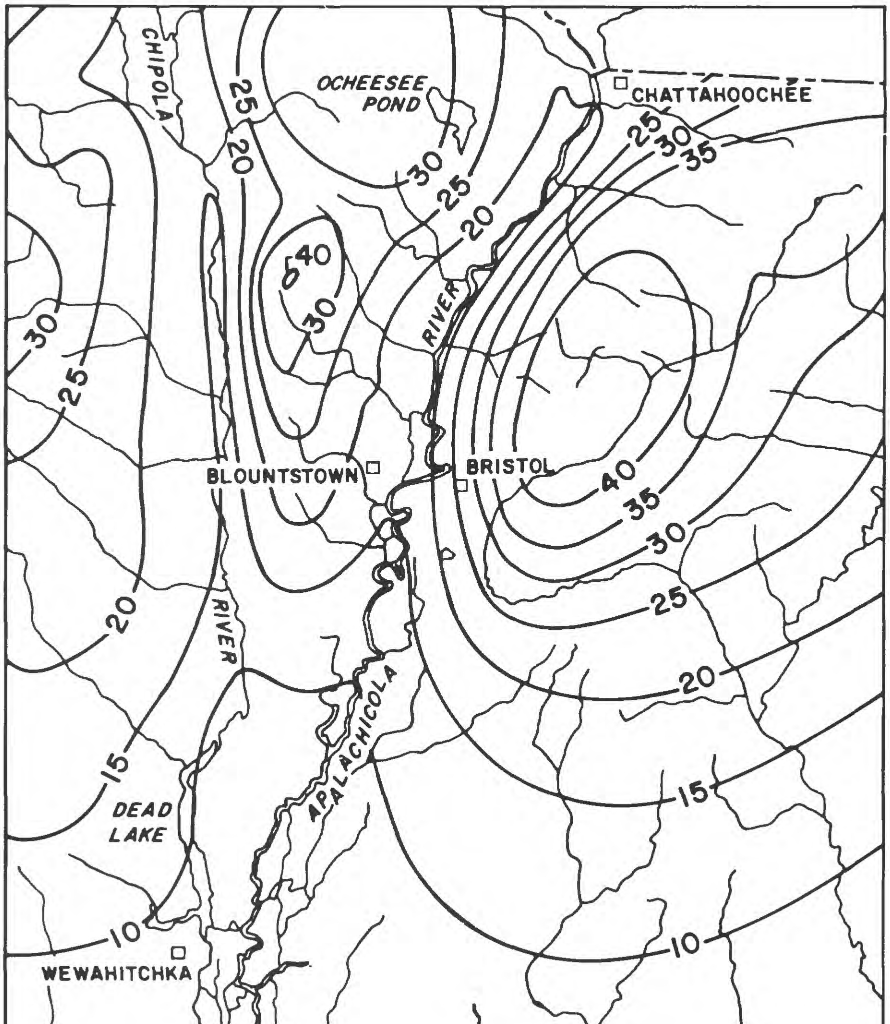

Figure 11. The potentiometric surface of the Floridan aquifer in May 1976.

Figure 12. Sampling apparatus used for collection of bottom-load particulate organic material.

were set aside primarily for computation of the water budget and transport of nutrients and detritus. The computer program to calculate transport, ARQA LOAD (fig. 15), accessed the water-quality analytical results and the average daily discharge (ARQA DV).

In an earlier study of hydraulic and nutrient budgets, Scheider and others (1978) reported on the relative accuracies of various possible methods for determining nutrient input. The best model resulted from the combination of discrete stream nutrient concentration data with continuous discharge data. Since continuous nutrient concentration data are virtually impossible to obtain, the best estimate for an interval is obtained by using the concentration at the midpoint of the interval. The product of integrated discharge from continuous records and the discrete midpoint nutrient concentration thus gives the best estimate of transport.

The ARQA LOAD program was written to calculate the midpoint date between any two sets of samples. Each water-quality data point represented the sample interval beginning at the midpoint date between the previous and current samples and ending at the midpoint date between the current and subsequent samples. The sample interval thus defined was used to calculate the mean sample interval discharge, using mean daily discharges computed from continuous streamflow record. Transport for the sample intervals is reported as metric tons of the particular constituent. The transport per day is reported only for the particular day the sample was collected and is reported as metric tons per day.

The time period chosen to represent annual transport (metric tons per year) was June 3, 1979, through June 2, 1980, a period of 366 days. This 1-year span includes a complete spring flood (March-May 1980) as well as some low flows and brief high-water peaks that characteristically occur at other times of the year. It also represents a period during which water-quality and detritus sampling was thorough. Although sampling began in February 1979, methods were in the process of refinement during the early months of the program. The period selected to represent annual transport also nearly coincides with the September 1979 to September 1980 sample collecting period for litter-fall measurements (Elder and Cairns, 1982).

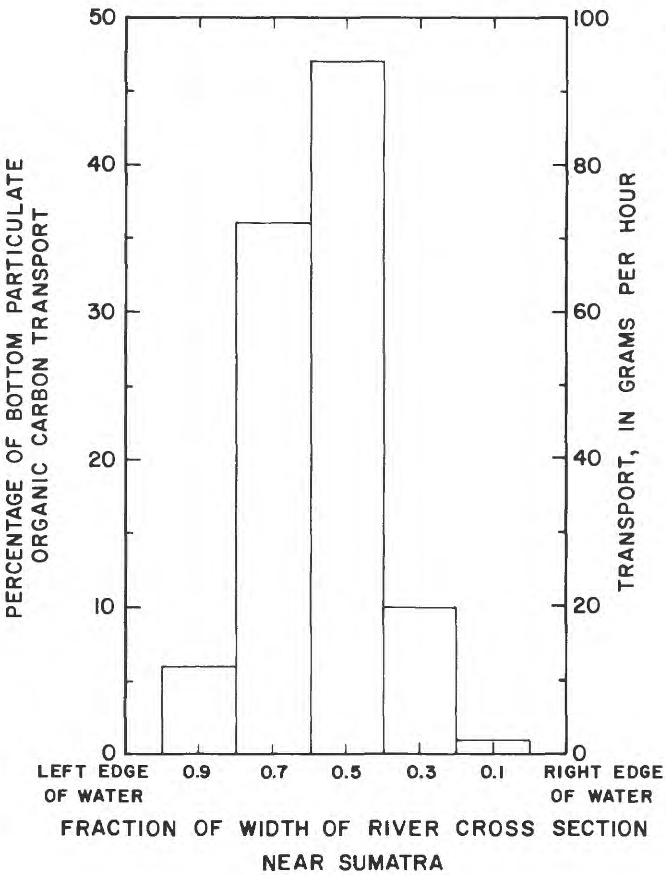

Figure 13. Results of cross-sectional sampling on July 2, 1979.

RESULTS

Because of the movement of water through the river-wetland system, physical transport of nutrients to Apalachicola Bay is possible. The computation of nutrient transport (weight) requires the collection of discharge data (volume) and concentration data (weight/volume). All data were separated by date into time periods that correspond to different hydrologic conditions during the study year. Subsequently, discharge data, combined with other water input and output information, were used to determine a water budget, and nutrient and detritus concentration data were computed on both a seasonal and an annual basis. Estimates of the magnitude and significance of error in these computations were included.

Seven Hydrologic Periods

As previously described, the annual budgets were calculated for a full year beginning June 3, 1979, and ending June 2, 1980. The year was subdivided into seven periods, according to hydrologic changes. The periods also varied a great deal in the rate of forest litter fall on the flood plain, which has important effects on nutrient and detritus transport. The seven periods may be characterized as follows:

1. *Summer* (June 3-September 8; 98 days)—Continuous low flow was interrupted only slightly by a minor peak in July; the peak was below flood stage. Litter fall was moderate. Tupelo, the most common tree in the flood plain, began to shed leaves in July.
2. *Early autumn* (September 9-October 13; 35 days)—Heavy rainstorms in the basin produced unseasonally high flows, especially in the lower river basin. After the storm, the flows rapidly decreased to a low level. Some flooding occurred in the lower flood plain. Litter fall increased substantially.
3. *Late autumn* (October 14-January 4; 83 days)—A moderate increase in flow in November-December caused some shallow flooding in the lower flood plain in December. Litter fall from most tree species was voluminous and reached maximum levels in November (Elder and Cairns, 1982).
4. *Winter* (January 5-March 8; 64 days)—Flow remained at a moderate level, producing continuous shallow flooding in the lower flood plain. Litter fall decreased considerably, but some species, particularly the oaks, planer-tree, and sweetgum, continued to shed leaves during the winter months.
5. *Spring flood rise* (March 9-March 16; 8 days)—An abrupt increase in flow produced extensive flooding over the entire length of the river basin. Discharge increased threefold in 8 days. Litter fall decreased to low levels.
6. *Spring flood peaks* (March 17-April 20; 35 days)—High flow was continuous, well above flood stage in the entire basin. Three flood peaks occurred, with maximum flow in early April of 3,850 m^3/s at Sumatra. New leaves appeared on trees and litter fall remained low.
7. *Spring flood recession* (April 21-June 2; 43 days)—The recession of the river flow was interrupted by a secondary peak of 1,900 m^3/s in late May. Litter fall increased slightly.

These periods were selected to represent different hydrologic events and were not delimited by climatic conditions, fiscal periods, or arbitrary dates. Consequently, their lengths vary considerably. Most of them are considerably longer than 1 month, minimizing errors associated with calculations over short time spans (Winter, 1981). The spring flood rise period is necessarily short to represent the rising limb of the flood. During a short period with high flows, only the discharge component of the water budget is significant. Discharge estimates based on stage-discharge relations at the continuous-recording gages are the most accurate of all water-budget components.

Figure 14. Flood-plain detritus net used to measure transported forest litter.

Therefore, an 8-day period to represent the spring flood rise is acceptable.

Water Budget

An equation that expresses the water budget of the Apalachicola River system is:

$$WO = WI + P_{ro} + P_{dp} + GW + CR - R_{et} \pm r, \qquad (1)$$

where all terms represent volumes of water and are defined as follows:

WO equals outflow at the downstream limit;
WI equals inflow at the upstream limit;
P_{ro} equals precipitation runoff;
P_{dp} equals direct precipitation in river and flood plain;
GW equals ground-water discharge;
CR equals input from mouth of Chipola River;
R_{et} equals evapotranspiration of river-derived water; and
r equals residual—the amount required to balance the equation (equivalent to an error term and not associated with any known component of the budget).

The equation may be applied to each subbasin or to the entire basin upstream of the Sumatra gage. Application of the equation is dependent on accurate estimates of budget components for each subbasin and each period. The methods and data used are described in the following sections.

The water budget described by equation 1 is depicted diagrammatically in figure 16. Numbers shown with each component are overall estimates for the 1979-80 study year; their derivations and seasonal breakdowns are detailed in subsequent tables and text. Several of the major components, shown by large circles, can be subdivided into more specific categories. Only the components or subcomponents that provide direct input to or outflow from the river-wetland system are included in equation 1.

Figure 14. Flood-plain detritus net used to measure transported forest litter—Continued.

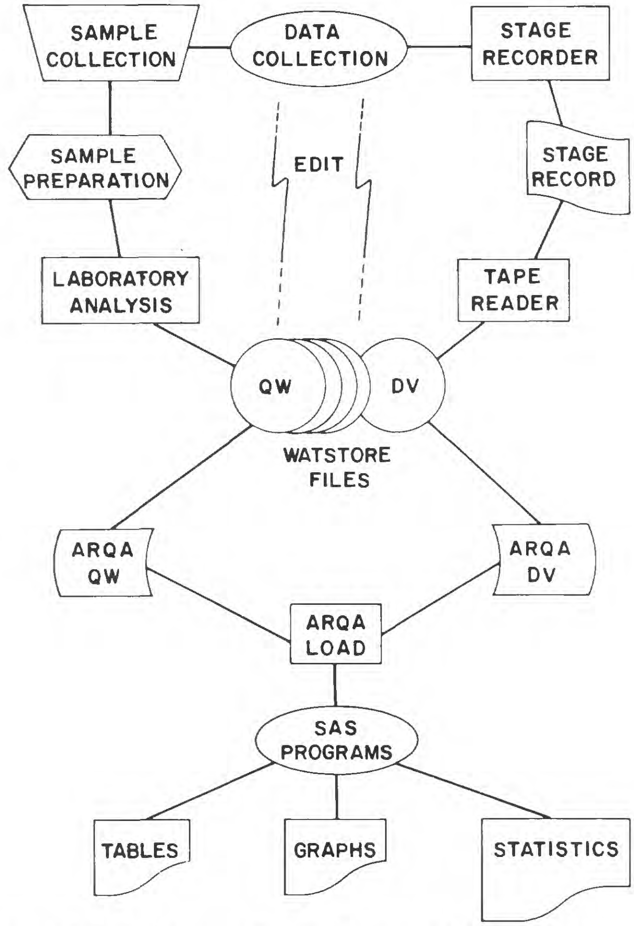

Figure 15. Major steps in data collection and handling. (See text for explanation of symbols.)

Precipitation (P) in the basin is separated into four categories:

P_{gw} equals precipitation-derived water that enters the ground-water system before it has any contact with the river or the flood plain. Percolation through the soil may alter its chemistry considerably.

P_{ro} equals precipitation that enters the river or flood plain as surface runoff. Any nutrient and detritus contribution made by the upland communities is likely to be transported by this route.

P_{dp} equals direct precipitation in the river channels and flood plain.

P_{et} equals precipitation in the uplands that re-enters the atmosphere by evapotranspiration without ever reaching the river-wetland system.

Since these are the only subdivisions of the precipitation component, it follows that:

$$P = P_{gw} + P_{ro} + P_{dp} + P_{et}. \quad (1a)$$

Similarly, evapotranspiration (ET) is composed of water from two sources: water from precipitation, just defined under the term P_{et}, and water lost to the atmosphere from the river and wetland, termed R_{et}.

$$ET = P_{et} + R_{et}. \quad (1b)$$

Ground water (GW) is also broken down into two fractions, one that comes from inside the basin, originating as precipitation (P_{gw}), and another that comes from outside the basin, (GW_o). Ground-water flow can be bidirectional; hence, both GW and GW_o can be either positive or negative.

$$GW = P_{gw} + GW_o. \quad (1c)$$

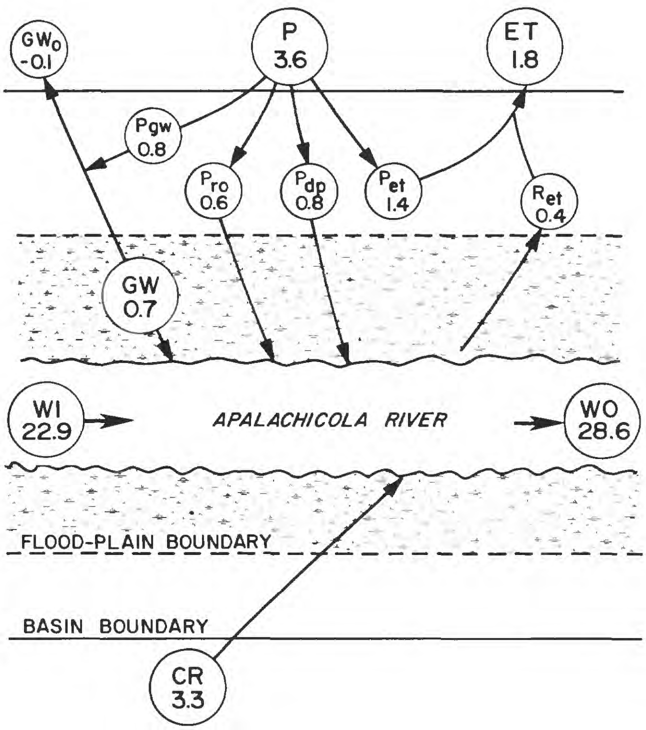

Figure 16. Representation of Apalachicola water budget. (See text for explanation of symbols; values are in cubic kilometers.)

Streamflow

Each subbasin was delimited at its upstream and downstream ends by a continuous-recording stage recorder. Stage-discharge relations have been established for each of these sites on the basis of ratings drawn from current-meter measurements. Total period volume was calculated for each site from the daily discharge data, using the equation

$$PV = Q\, n\, K_1\, K_2, \tag{2}$$

where

PV equals period volume, or flow of water, in km^3;
Q equals mean daily discharge during the period, in ft^3/s;
n equals number of days in the period;
K_1 equals number of seconds per day (8.64×10^4); and
K_2 equals number of km^3 per ft^3 (2.83×10^{-11}).

The results of these calculations are shown in table 8. At each site, PV becomes WO for the upstream subbasin and WI for the downstream subbasin.

Precipitation

The total precipitation for each subbasin was based on National Weather Service data from nearby rain gages (fig. 10). Values of P were calculated for each subbasin, and for the entire Apalachicola basin, by the equation

$$P = \left(\frac{R_u + R_d}{2}\right) A k_3\ , \tag{3}$$

where

R_u equals rainfall at upstream site, in inches;
R_d equals rainfall at downstream site, in inches;
A equals total area of subbasin, in km^2;
k_3 equals kilometer per inch (2.54×10^{-5}).

The computations produced the precipitation estimates shown in table 9.

Once the total rainfall in the basin was known, the values of direct precipitation (P_{dp}) could be computed

Table 8. Flow volumes by gaging sites and the seven periods

[Volumes are in cubic kilometers]

Period	Dates	Gaging site			
		Chattahoochee	Blountstown	Wewahitchka	Sumatra
Summer	06/03/79–09/08/79	3.18	3.67	3.69	4.52
Early autumn	09/09/79–10/13/79	1.28	1.48	1.74	2.06
Late autumn	10/14/79–01/04/80	3.09	3.41	3.36	3.96
Winter	01/05/80–03/08/80	3.73	3.68	4.13	4.23
Spring flood rise	03/09/80–03/16/80	1.54	1.47	1.12	1.14
Spring flood peak	03/17/80–04/20/80	6.39	6.81	6.37	8.06
Spring flood recession	04/21/80–06/02/80	3.65	3.61	3.71	4.64
Total for year	06/03/79–06/02/80	22.86	24.13	24.12	28.61

Table 9. Precipitation in the seven periods and the Apalachicola basins from June 3, 1979, through June 2, 1980

[Precipitation (P) in cubic kilometers]

Period	Dates	Subbasin			
		Upper	Middle	Lower	Entire basin
Summer	06/03/79–09/08/79	0.47	0.43	0.30	1.20
Early autumn	09/09/79–10/13/79	0.29	0.29	0.23	0.81
Late autumn	10/14/79–01/04/80	0.14	0.10	0.09	0.33
Winter	01/05/80–03/08/80	0.21	0.13	0.10	0.44
Spring flood rise	03/09/80–03/16/80	0.09	0.06	0.04	0.19
Spring flood peak	03/17/80–04/20/80	0.20	0.14	0.09	0.43
Spring flood recession	04/21/80–06/02/80	0.10	0.07	0.07	0.24
Total for year	06/03/79–06/02/80	1.50	1.22	0.92	3.64

from the ratio of flood-plain area to total watershed area. Other subdivisions of precipitation were computed indirectly. Runoff (P_{ro}) was determined from historical records of measurements of small tributary streams in the basin. Both Little Sweetwater Creek near Bristol and Flat Creek near Chattahoochee (fig. 10) have been measured on several occasions during both base low-flow and higher flow conditions. Base flows in these streams are attributable to ground-water discharge; hence, the difference between mean annual flow and base flow gives an estimate of the amount contributed by runoff. This may be converted to an annual volume per unit watershed area and extrapolated to the entire basin.

The term P_{et}, or the amount of precipitation lost by way of evapotranspiration in the uplands, is computed as part of the overall evapotranspiration estimate, to be described subsequently. Once P_{et} is known, along with P_{dp} and P_{ro}, the fraction involved in ground-water recharge (P_{gw}) can be determined by difference.

Ground Water

Ground-water discharge occurs as springs in the river and along the west bank, as seeps along the steep east bank, and as streamflow in various small tributaries. Discharge seeps are quite common above Blountstown, where the limestones of the Floridan aquifer approach land surface, becoming exposed at various points in the river channel and on bluffs near the east bank. From there, the top of the aquifer dips to the south until it is about 46 m below sea level at Apalachicola (Kwader and Schmidt, 1978). The Chipola River rises on Floridan limestones near Dothan, Ala., flows through Dead Lake, and joins the Apalachicola River near Wewahitchka some 90 km south. Much of the flow of the Chipola River is derived from ground-water discharge.

Regional water-level mapping (fig. 11) of the principal artesian (Floridan) aquifer indicates the existence of steep gradients to the Apalachicola and Chipola Rivers in their upper reaches, and flat gradients normal to them in the south. This is consistent with Kwader and Schmidt's (1978) "Top of Floridan Aquifer" map and area of known ground-water discharge. Pascale and Wagner (1982), in their investigation of the water resources of the Ochlockonee River basin, explained the high and steep water levels on the east side of the Apalachicola River. They found recharge to the Floridan to be limited by overlying clay beds and by the aquifer's low permeability and transmissivity.

Estimates of ground-water discharge can be derived from various data taken from flow measurments. A series of low-flow measurements on the main channel of the Apalachicola River at Chattahoochee and Blountstown provides the most reliable data from which to estimate ground-water discharge. Between 1957 and 1980, U.S. Geological Survey personnel made 16 same-day measurements of the two sites during low-flow periods. The mean discharge increase for the 16 measurements was 20 m^3/s, or 0.6 km^3/yr. This was attributed to ground-water inflow, because there was no significant contribution from overland runoff or surface-water tributaries.

Flow measurements also were made on small streams that empty into the Apalachicola River in the upper subbasin. During dry periods, these streams are almost exclusively sustained by ground-water discharge. Total ground-water discharge of 0.4 km^3/yr was estimated by calculating mean discharge per unit watershed area on the basis of low-flow measurements (table 10) of three streams in the upper subbasin. Since this estimate does not account for seepage, spring flow, or ground-water discharge to the river during other than low-flow periods, it is assumed to be low. It is therefore quite consistent with the estimate of 0.6 km^3/yr derived from the river low-flow measurements.

Table 10. Mean discharge per unit watershed area based on low-flow measurements

[Q = low-flow discharge; A = watershed area]

Mosquito Creek, September 23, 1976

$$Q = 1.28\ m^3/s \qquad A = 223\ km^2$$

$$\frac{1.28\ m^3/s}{223\ km^2} = 0.0057\ (m^3/s)/km^2$$

Flat Creek, October 18, 1976

$$Q = 0.54\ m^3/s \qquad A = 64.5\ km^2$$

$$\frac{0.54\ m^3/s}{64.5\ km^2} = 0.0084\ (m^3/s)/km^2$$

Little Sweetwater Creek, September 16, 1980

$$Q = 0.116\ m^3/s \qquad A = 6.35\ km^2$$

$$\frac{0.116\ m^3/s}{6.35\ km^2} = 0.0183\ (m^3/s)/km^2$$

Average for three streams

$$\frac{0.0057 + 0.0084 + 0.0183}{3} = 0.0108\ (m^3/s)km^2$$

Chattahoochee to Blountstown annual ground-water discharge

$$A = 963\ km^2$$

$$0.0108\ (m^3/s)/km^2 \times \frac{1\ km^3}{10^9\ m^3} \times 3.1536 \times 10^7 \frac{s}{\text{year}} \times 963\ km^2 = 0.33\ km^3/\text{year}$$

The middle and lower subbasins presumably show much less ground-water discharge to the river because the water-level gradient shifts toward a direction nearly parallel to the river flow (fig. 11). In fact, some additional flow measurements from the lower subbasin indicate that ground-water discharge is negligible in that region. The annual water-budget estimates are therefore as follows:

Subbasin	*Annual ground-water discharge, in km³*
Upper	0.6
Middle	0.1
Lower	0

Seasonal fractions of these annual ground-water discharge volumes are determined as the amounts proportional to the time fraction involved. This assumes a constant ground-water flow rate, an assumption made because of insufficient data. A more likely relation is that ground-water discharge decreases during initial phases of a flood, then increases during the flood recession. Data are not available, however, to document such a pattern in the Apalachicola system.

Table 10 values represent estimates for the term GW in equation 1. The fraction that results from recharge within the basin (P_{gw}) was already determined from precipitation data. The remaining fraction (GW_o)—the amount of discharge to or recharge from the ground-water system ouside the basin—can be determined by difference.

Chipola River Inflow

The Chipola River is the only major tributary to the Apalachicola. Flowing south from Alabama, it forms

Dead Lake, then enters the Apalachicola near Wewahitchka. With a mean annual flow of 100 m^3/s, the Chipola River is a major surface-water input to the lower subbasin. Like some of the small streams in the upper part of the Apalachicola basin, the Chipola is spring fed at its source near Dothan, Ala.

The inflow from the Chipola River, which becomes the *CR* component in the water budget equation when applied to the lower subbasin or to the entire basin, is shown in table 11. The upper and middle subbasins obviously have no *CR* component.

Table 11. Inflow from Chipola River at Dead Lake, June 3, 1979, through June 2, 1980

Period	Number of days	Mean flow (in cubic meters per second)	Total flow (in cubic kilometers)
Summer	98	68	0.58
Early autumn	35	151	0.46
Late autumn	83	62	0.44
Winter	64	80	0.44
Spring flood rise	8	178	0.14
Spring flood peaks	35	244	0.74
Spring flood recession	43	125	0.46
Total for year	366	103	3.26

Evapotranspiration

No data from direct monitoring of evaporation or solar radiation were available. Estimates of evaporation could be made, however, on the basis of ambient temperature and estimated water-retention factors of the soil.

The method of calculation of potential evapotranspiration, as described by Thornthwaite and Mather (1957), is based on the equation

$$ET=1.6(10T/I)^a, \qquad (4)$$

where

ET equals monthly potential evapotranspiration, in mm;
T equals mean monthly temperature, in degrees Celsius;
I equals heat index $= (T/5)^{1.514}$; and
a equals exponent related to the annual heat index, I, by the expression

$$a=(6.75\times10^{-7}I^3)-(7.71\times10^{-5}I^2)+0.0179I-0.49. \qquad (5)$$

The unadjusted potential evapotranspiration rate resulting from the application of equation 4 is then corrected for month and day length. The result is the maximum potential evapotranspiration that would be expected at the given temperatures, with high soil-water retention.

In the Apalachicola basin, the wetland area may be expected to have higher *ET* rates than the uplands. This is because of the high soil moisture in large areas that remain permanently saturated or flooded. Water loss from cypress flood-plain forests has been demonstrated to be nearly equal to standard pan evaporation rates (Brown, 1981). The uplands are characterized by mostly sandy soils. Using as estimated 250-mm water-retention factor for sandy soils (Thornthwaite and Mather, 1957), the overall *ET* rate in the uplands was estimated to be 0.8 of the maximum potential *ET*. The final computation of monthly *ET* for a basin or subbasin then becomes

$$ET=(ET_{max}\times A_w)+(0.8\ ET_{max}\times A_u), \qquad (6)$$

where

ET equals water loss due to ET, in km^3;
ET_{max} equals maximum potential ET, in km^3;
A_w equals area of wetland, in km^2; and
A_u equals area of upland, in km^2.

The two terms on the right side of equation 6 represent the two previously described components of evapotranspiration (fig. 16), R_{et} and P_{et}, respectively.

Annual *ET* rates and estimates of *ET* for the three subbasins are given in table 12. The *ET* rates are somewhat higher than the annual rate of 1,016 mm (40 inches) estimated by Qureshi (1978) for the Apalachicola basin. Summer *ET* rates, however, are very similar to those determined by Brown (1981) for cypress flood-plain forests, using measurements in polyethylene chambers. Monthly *ET* varies over an order of magnitude, from 16 mm in February to more than 160 mm in July.

Table 12. Estimates of annual evapotranspiration (ET) in Apalachicola subbasins, June 3, 1979, through June 2, 1980

Subbasin	Area (km^2)		Mean annual temperature in °C	Evapotranspiration	
	Upland	Flood plain		Maximum annual rate, in millimeters	Estimated volume, in cubic kilometers
Upper	885	78	20.0	1,060	0.85
Middle	429	164	19.9	1,050	0.54
Lower	325	151	19.7	1,040	0.44

Overall Water Budget

The quantities calculated for each of the budget components and presented in tables 8, 9, 11, and 12 are combined in equation 1, to produce tables 13-16. Water inflow (*WI*) is the dominant contributor to each of the subbasins. The Chipola River adds a substantial volume of water in the lower subbasin. The ground-water contribution in the upper subbasin is significant, especially during low-flow periods (summer, late autumn, winter). Precipitation and evapotranspiration involve a sizable volume of water in the basin, but much of that is confined to the upland hydrologic cycle (fig. 16). Their roles in the river-wetland water budget, although significant, are small in comparison with streamflow.

The data show a general increase in flow from upstream to downstream sites, the increase between Chattahoochee and Sumatra being 5.75 km^3/yr, or 20 percent of the total flow at Sumatra. Exceptions occur within subbasins and within some periods. In particular, there is an apparent reversal of this trend during the spring flood rise. This may be attributed to lag time in the flood wave (2 to 3 days from Chattahoochee to Sumatra) which becomes significant in a short period when flow increases rapidly. Because of this lag, the rising limb of the flood did not actually begin at Sumatra until March 11. Thus, the spring flood rise included 2 days of relatively low flow at Sumatra.

Other cases in which the data showed a decrease in flow downstream were the winter, spring flood rise, and spring flood recession periods in the upper subbasin and the late autumn, spring flood rise, and spring flood peaks periods in the middle subbasin. Although some or all of these reversals may be real, they all may be due to error, since they are within error limits (see later error analysis). One factor that may contribute to error, particularly in the middle subbasin (table 4), is the existence of side channels in the vicinity of the Wewahitchka gage. Such channels

Table 13. Water budget in the upper subbasin (Chattahoochee-Blountstown), by periods, June 3, 1979, through June 2, 1980

[All values in cubic kilometers. See text for beginning and ending dates of periods and expalantion of abbreviations]

Period	Number of days	*WO*	=	*WI*	+	P_{ro}	+	P_{dp}	±	*GW*	−	R_{et}	±	*r*
Summer.	98	3.67	=	3.18	+	0.09	+	0.04	+	0.16	−	0.04	+	0.24
Early autumn	35	1.48	=	1.28	+	0.06	+	0.02	+	0.06	−	0.01	−	0.07
Late autumn.	83	3.41	=	3.09	+	0.03	+	0.01	+	0.14	−	0.01	+	0.15
Winter.	64	3.68	=	3.73	+	0.04	+	0.02	+	0.10	−	0.005	−	0.21
Spring flood rise	8	1.47	=	1.54	+	0.02	+	0.01	+	0.01	−	0.001	−	0.11
Spring flood peaks.	35	6.81	=	6.39	+	0.04	+	0.02	+	0.06	−	0.005	+	0.31
Spring flood recession . . .	43	3.61	=	3.65	+	0.02	+	0.01	+	0.07	−	0.01	−	0.13
Total for year.	366	24.13	=	22.86	+	0.30	+	0.13	+	0.60	+	0.08	+	0.16

Table 14. Water budget in the middle subbasin (Blountstown-Wewahitchka), by periods, June 3, 1979, through June 2, 1980

[All values in cubic kilometers. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	*WO*	=	*WI*	+	P_{ro}	+	P_{dp}	±	*GW*	−	R_{et}	±	*r*
Summer.	98	3.69	=	3.67	+	0.07	+	0.12	+	0.03	−	0.08	−	0.12
Early autumn	35	1.74	=	1.48	+	0.05	+	0.08	+	0.01	−	0.02	+	0.14
Late autumn.	83	3.36	=	3.41	+	0.02	+	0.03	+	0.02	−	0.02	−	0.10
Winter.	64	4.13	=	3.68	+	0.02	+	0.03	+	0.02	−	0.01	+	0.39
Spring flood rise	8	1.12	=	1.47	+	0.01	+	0.02	+	0.00	−	0.003	−	0.38
Spring flood peaks.	35	6.37	=	6.81	+	0.02	+	0.04	+	0.01	−	0.01	−	0.50
Spring flood recession . . .	43	3.71	=	3.61	+	0.01	+	0.02	+	0.01	−	0.03	+	0.09
Total for year.	366	24.12	=	24.13	+	0.20	+	0.34	+	0.10	−	0.17	−	0.48

Table 15. Water budget in the lower subbasin (Wewahitchka-Sumatra), by periods, June 3, 1979, through June 2, 1980

[All values in cubic kilometers. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	WO	=	WI	+	P_{ro}	+	P_{dp}	±	CR	−	R_{et}	±	r
Summer.	98	4.52	=	3.69	+	0.03	+	0.10	+	0.58	−	0.08	+	0.20
Early autumn	35	2.06	=	1.74	+	0.03	+	0.07	+	0.46	−	0.02	−	0.22
Late autumn.	83	3.96	=	3.36	+	0.01	+	0.03	+	0.44	−	0.02	+	0.14
Winter.	64	4.23	=	4.13	+	0.01	+	0.03	+	0.44	−	0.01	−	0.37
Spring flood rise	8	1.14	=	1.12	+	0.004	+	0.01	+	0.14	−	0.002	−	0.13
Spring flood peaks.	35	8.06	=	6.37	+	0.01	+	0.03	+	0.74	−	0.01	+	0.92
Spring flood recession . . .	43	4.64	=	3.71	+	0.01	+	0.02	+	0.46	−	0.02	+	0.46
Total for year.	366	28.61	=	24.12	+	0.10	+	0.29	+	3.26	−	0.16	+	1.00

Table 16. Water budget in the Apalachicola basin (Chattahoochee-Sumatra), by periods, June 3, 1979, through June 2, 1980

[All values in cubic kilometers. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	WO	=	WI	+	P_{ro}	+	P_{dp}	+	GW	±	CR	−	R_{et}	±	r
Summer.	98	4.52	=	3.18	+	0.19	+	0.26	+	0.19	+	0.58	−	0.20	+	0.32
Early autumn	35	2.06	=	1.28	+	0.14	+	0.17	+	0.07	+	0.46	−	0.05	−	0.01
Late autumn.	83	3.96	=	3.09	+	0.06	+	0.07	+	0.16	+	0.44	−	0.05	+	0.19
Winter.	64	4.23	=	3.73	+	0.07	+	0.08	+	0.12	+	0.44	−	0.02	−	0.19
Spring flood rise	8	1.14	=	1.54	+	0.03	+	0.04	+	0.01	+	0.14	−	0.01	−	0.61
Spring flood peaks.	35	8.06	=	6.39	+	0.07	+	0.09	+	0.07	+	0.74	−	0.02	+	0.72
Spring flood recession . . .	43	4.64	=	3.65	+	0.04	+	0.05	+	0.08	+	0.46	−	0.06	+	0.42
Total for year.	366	28.61	=	22.86	+	0.60	+	0.76	+	0.70	+	3.26	−	0.41	+	0.84

may divert water out of the channel for short distances, to re-enter at points downstream. These diversions may "hide" some flow from the measurement section and produce low-flow results.

Nutrient Concentrations

Nutrient Concentrations in the River

The principal elements of interest in the analysis of nutrient flow were organic carbon, inorganic and organic nitrogen, and phosphorus. Nutrients can vary as a function of time, discharge, and location. Both particulate and dissolved phases were collected routinely in riverine samples.

Figure 17 illustrates the mean concentration and standard error for total organic carbon, total nitrogen, and total phosphorus at the four main river water-quality collection stations. Variations in concentration with respect to location were small. The only statistically significant difference (analysis of variance) was in total organic carbon between Chattahoochee and Blountstown. The large increase in carbon concentrations in the upper subbasin probably resulted from high carbon production in the flood plain and high flood velocities that caused significant transport from the flood plain to the river. The relatively small temporal changes in nutrient concentrations are shown by the standard error. Temporal variations were generally random, with no clear pattern of change with season. Unlike some constituents (Daniel and others, 1979), nutrient concentrations were not closely correlated with discharge.

Bulk-Precipitation Concentrations

Bulk precipitation includes dry fallout and rainfall. Concentrations of total organic carbon, nitrogen, and

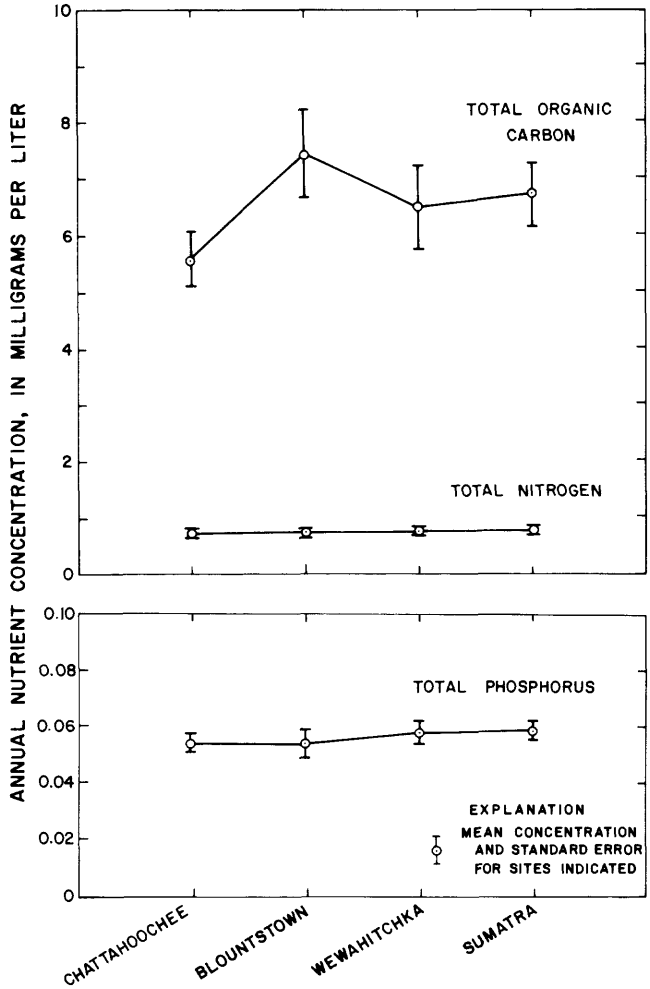

Figure 17. Mean nutrient concentrations for the period February 1979 through July 1980 at the four main river collection stations with standard error bars.

phosphorus in bulk precipitation showed variability over a considerable concentration range. The data were plotted on probability paper (fig. 18) using the method of Velz (1970, p. 522-542). Abrupt slope changes indicated that the frequency distribution of sample concentrations was skewed, probably owing to contamination of some of the samples. Calculations of loads based on means from the complete data base would result in unreliable bulk precipitation estimates. A better estimate was provided by the median value for each nutrient for all periods and subbasins. The median values are: total organic carbon, 5 mg/L; total nitrogen, 0.6 mg/L; and total phosphorus, 0.06 mg/L.

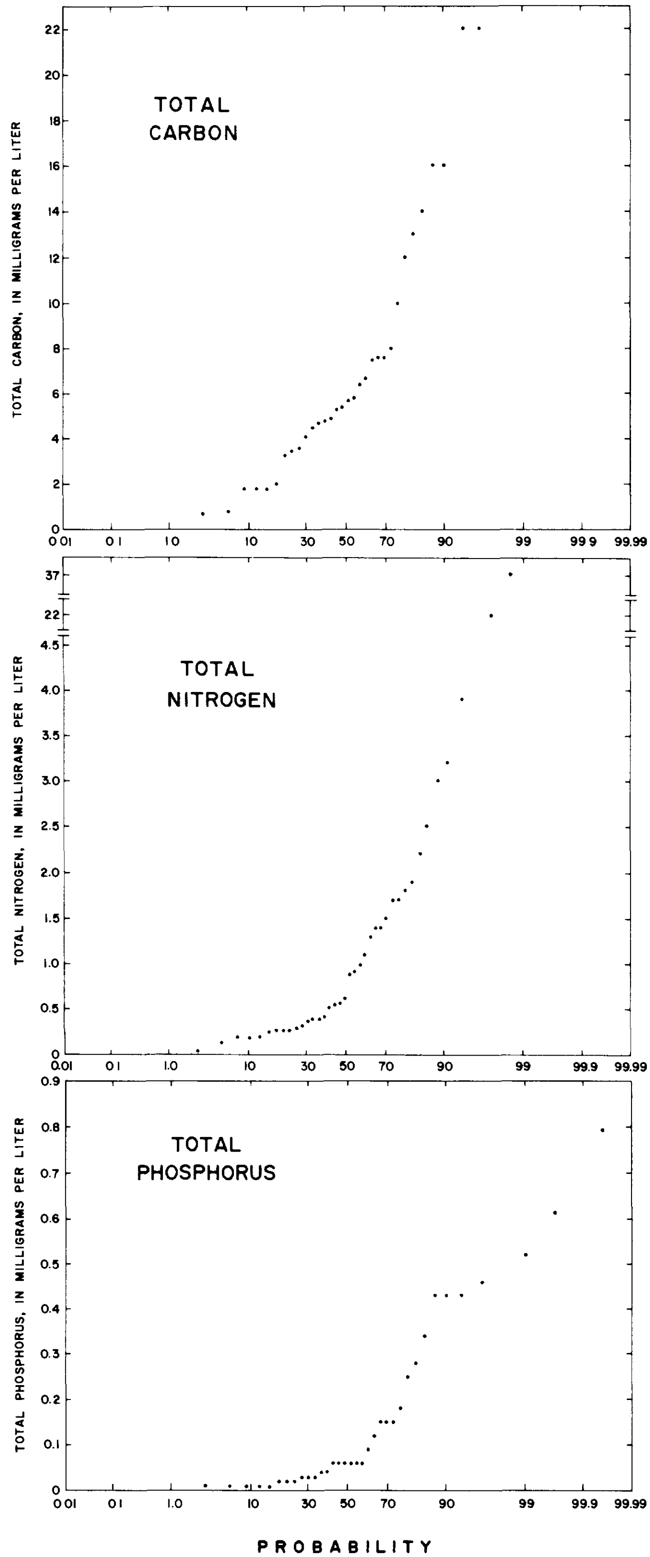

Figure 18. Total carbon, total nitrogen, and total phosphorus concentrations in bulk precipitation samples.

Ground-Water Chemistry

Ground-water inflow is a relatively minor part of total water flow in the basin (table 13-16), and its importance as a nutrient source is small. Ground water was found discharging from seeps in the upper reaches of Flat Creek and Little Sweetwater Creek (fig. 10). Water analysis (table 17) of Little Sweetwater Creek suggest that its residence time in the ground was rather short. The low levels of chloride, dissolved solids, pH, and conductance are similar to those of other seeps and springs in northern Florida (Rosenau, Faulkner, Hendry, and Hull, 1977). Water analyses of Flat Creek indicate slightly higher concentrations of dissolved solids, conductance, and phosphorus. These analyses tend to indicate water movement through the phosphate-rich limestones of the Hawthorn Formation, which crops out in this drainage basin.

Chipola River

Concentrations of most elements were nearly the same in Chipola River water (Dead Lake Outlet) as in Apalachicola River water (table 17). Total phosphorus was the exception, with 0.02 mg/L in Chipola water compared with 0.05 mg/L in Apalachicola water. The Chipola River is the only large tributary to the Apalachicola River, and, with nutrient concentrations comparable to those of the Apalachicola, its contribution to streamflow and the transport of nutrients in the Apalachicola system is appreciable.

Nutrient Transport

The two basic types of data described previously—discharge and nutrient concentration—provide the elements necessary to compute nutrient transport. The term "transport," as used here, is defined as the mass of material that moves past a given point in a given time span. Other terms, such as "flux," "load," and "flow," often are used in similar context. The term "yield" refers to total annual transport per unit area.

Total organic carbon (dissolved carbon plus suspended organic carbon) concentrations for Sumatra are shown in figure 19. Each sample concentration represents an interval of time of 1 to 34 days. The mean sample interval discharge, in cubic meters per second (m^3/s), is shown below the total organic concentration. Above the mean discharge are the seven periods used previously in the water budget summaries.

Transport was calculated for each sample interval. The sample interval volume (*IV*), computed as the mean of daily discharge during the sample interval (equation 2), was multiplied by the corresponding sample concentration (*C*) to obtain nutrient transport (*Y*) for the sample interval

$$Y=(IV)(C). \qquad (7)$$

Table 17. Mean nutrient concentrations and chemical characteristics of ground water compared with water of the Apalachicola River near Blountstown and the Chipola River near Wewahitchka

[Concentrations of first eight constituents in milligrams per liter. *N* = number of samples; std. dev. = standard deviation]

Constituent	Ground water						Surface water					
	Flat Creek near Chattahoochee			Little Sweetwater Creek			Apalachicola River near Blountstown			Chipola River near Wewahitchka		
	N	mean	std. dev.	*N*	mean	std. dev.	*N*	mean	std. dev.	*N*	mean	std. dev.
Total organic carbon	4	4.8	1.7	16	5.5	3.6	23	7.4	3.7	17	8.6	4.5
Dissolved organic carbon	...	...	...	13	4.9	3.5	19	6.7	3.7	8	7.9	4.4
Total nitrogen	8	0.82	0.18	16	0.31	0.19	23	0.77	0.26	17	0.74	0.20
Dissolved nitrogen	3	.13	.16	12	.23	.15	22	.62	.18	13	.63	.17
Total phosphorus	9	.21	.15	16	.01	.01	23	.05	.02	17	.02	.01
Dissolved phosphorus	1	.15	...	16	.01	.01	23	.02	.01	18	.01	.01
Chloride	6	3.6	1.0	11	1.9	.5	22	3.9	.5	18	4.5	.4
Total dissolved solids	6	34	7.6	15	18	6	10	60	8	12	86	7
Characteristic (range):												
pH	12	5.3–7.5		16	4.6–6.8		22	5.7–7.8		16	6.3–7.6	
Conductance (micromhos per centimeter)	12	35–46		16	10–20		23	57–127		18	80–180	

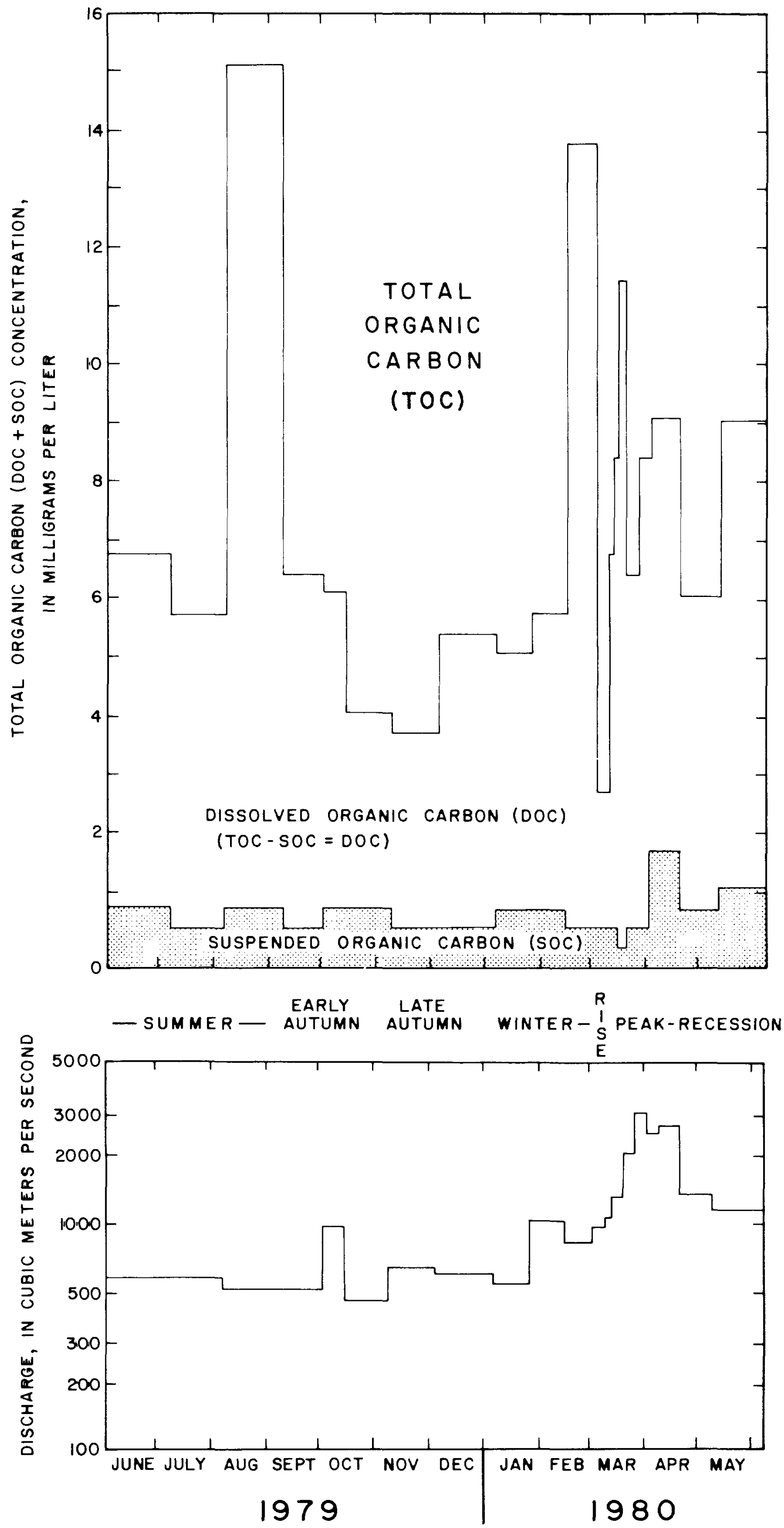

Figure 19. Total organic carbon concentrations, mean sample interval discharge, and seven hydrologic periods at Sumatra.

Transport for each of the seven periods was then calculated as the sum of the sample interval transports within the period. Annual transport was the sum of the seven transport periods. The annual transport at Sumatra was defined as the yield for the basin.

Nutrient transport in the Apalachicola River system may be expressed by an equation analogous to that used to describe the water budget:

$$Y_o = Y_i + Y_{dp} + Y_{ro} + Y_{gw} + Y_{cr} \pm Y_{fp} \pm Y_r, \qquad (8)$$

where

Y equals general symbol for transport of nutrient C, N, or P;
Y_o equals outflowing nutrient transport at downstream limit;
Y_i equals inflowing nutrient transport at upstream limit;
Y_{dp} equals nutrient input by bulk precipitation in the river and flood plain;
Y_{ro} equals nutrient runoff from upland areas;
Y_{gw} equals nutrient input by ground-water discharge;
Y_{cr} equals nutrient input by inflow of the Chipola River;
Y_{fp} equals net nutrient release or uptake by the flood-plain ecosystem; and
Y_r equals residual (includes error and other components such as atmospheric diffusion and anthropogenic sources, all judged to be of minor importance).

Nutrient Transport Residual

The Y_{fp} term may be either positive or negative, depending on whether the flood-plain ecosystem acts as a source or a sink for nutrients. This term could be subclassified according to various nutrient-consuming or nutrient-release processes, such as nitrogen and carbon fixation, denitrification, and sorption. The important quantity for the nutrient-transport calculations, however, is the overall uptake or release of the nutrient, hence the net flood-plain term, Y_{fp}.

The wetland, or flood plain, is the foremost example of a unit within which both uptake and release processes operate. Litter-fall data gathered as part of the present study (Elder and Cairns, 1982) documents the large quantity of nutritive material deposited each year on the flood-plain floor. This is a potential source of 180,000 metric tons of carbon annually. Presumably, a large fraction of this material is retained in the flood-plain soils; however, much remains to be transported to the river and eventually to the estuary. Quantification of the recycled and flood-plain-derived transported fractions was not possible by direct measurement, but transport of material in the flood plain during high-water periods was observed. Detritus movement in the flood plain was documented by use of stationary drift nets, described earlier.

Because there were no direct measurements of Y_{fp}, it must be estimated by including it as part of the Y_r term. A new term, $\pm R$, is thus created to replace the terms $\pm Y_{fp}$ and $\pm Y_r$ in equation 8. Because it includes the flood-plain term, which is potentially large, R is likely to have an absolute value considerably greater than the simple residual. The resulting equation is

$$Y_o = Y_i + Y_{dp} + Y_{ro} + Y_{gw} + Y_{cr} \pm R. \qquad (9)$$

Transport, 1979-80

The results of application of equation 9 to 1979-80 data from the three Apalachicola subbasins and the entire basin are shown in tables 18-29. In most cases, nutrient transport increased in a downstream direction; that is, Y_i tended to be smaller than Y_o, and R tended to be positive. Exceptions to this occurred quite frequently within single subbasins and periods, but as the scale is expanded either in space or time, exceptions become fewer. In certain periods and subbasins, negative R values appeared consistently for all three nutrients. Those include the winter in the upper subbasin, the late autumn in the middle subbasin, and the spring flood rise and spring flood recession in the lower subbasin. Of the 12 equations representing annual nutrient transport, only 2 had negative R values: carbon transport in the middle subbasin (table 19) and nitrogen transport in the lower subbasin (table 24).

The R term represents a major component in the overall nutrient budget because it includes the flood-plain contribution to nutrient input or uptake. Some large negative R values clearly suggest that there were periods of considerable nutrient retention in the flood plain. These periods were compensated by even greater nutrient release in other periods, however, and the annual basin budget showed positive flood-plain contributions of all three nutrients. As a fraction of the annual nonstreamflow nutrient inputs $[R/(Y_{ro} + Y_{dp} + Y_{gw} + R)]$, the residual accounts for 65 percent of the carbon, 16 percent of the nitrogen, and 78 percent of the phosphorus.

Direct precipitation in the flood plain and runoff from upland areas produced significant inputs to the river during certain periods of the year. This was particularly true during the early autumn, when there was a great deal of local rainfall. Table 21 shows that carbon input from runoff (C_{ro}) accounted for more than 60 percent of the total nonstreamflow carbon input ($C_{ro} + C_{dp} + C_{gw} + R$) in the early autumn period. Direct precipitation contributed an additional 30 percent of that amount during the same period. For the entire year, these precipitation-related inputs were of less significance for carbon and phosphorus, but still contributed over half of the nonstreamflow nitrogen input. Ground-water discharge contributed all three

Table 18. Total carbon transport in the upper subbasin, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	C_o[1]	=	C_i[2]	+	C_{dp}	+	C_{ro}	+	C_{gw}	±	R
Summer	98	51,600	=	16,000	+	200	+	1,170	+	660	+	33,570
Early autumn	35	8,200	=	5,400	+	100	+	780	+	250	+	1,670
Late autumn	83	19,200	=	12,800	+	50	+	390	+	580	+	5,380
Winter	64	15,300	=	18,300	+	100	+	520	+	410	-	4,030
Spring flood rise	8	6,900	=	3,500	+	50	+	260	+	40	+	3,050
Spring flood peaks	35	63,900	=	64,700	+	100	+	520	+	250	-	1,670
Spring flood recession	43	27,800	=	22,000	+	50	+	260	+	290	+	5,200
Total for year	366	192,900	=	142,700	+	650	+	3,900	+	2,480	+	43,170

[1] At Blountstown.
[2] At Chattahoochee.

Table 19. Total carbon transport in the middle subbasin, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	C_o[1]	=	C_i[2]	+	C_{dp}	+	C_{ro}	+	C_{gw}	±	R
Summer	98	32,200	=	51,600	+	600	+	910	+	120	-	21,030
Early autumn	35	7,200	=	8,200	+	400	+	650	+	40	-	2,090
Late autumn	83	14,300	=	19,200	+	150	+	260	+	80	-	5,390
Winter	64	18,800	=	15,300	+	150	+	260	+	80	+	3,010
Spring flood rise	8	10,000	=	6,900	+	100	+	130	+	0	+	2,870
Spring flood peaks	35	54,800	=	63,900	+	200	+	260	+	40	-	9,600
Spring flood recession	43	43,400	=	27,800	+	100	+	130	+	40	+	15,330
Total for year	366	180,700	=	192,900	+	1,700	+	2,600	+	400	-	16,900

[1] At Wewahitchka.
[2] At Blountstown.

Table 20. Total carbon transport in the lower subbasin, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	C_o[1]	=	C_i[2]	+	C_{dp}	+	C_{ro}	+	C_{cr}[3]	±	R
Summer	98	40,100	=	32,200	+	500	+	390	+	7,420	-	410
Early autumn	35	12,100	=	7,200	+	350	+	390	+	3,830	+	330
Late autumn	83	17,300	=	14,300	+	150	+	130	+	3,130	-	410
Winter	64	31,000	=	18,800	+	150	+	130	+	2,760	+	9,160
Spring flood rise	8	8,700	=	10,000	+	50	+	50	+	6,650	-	8,050
Spring flood peaks	35	73,500	=	54,800	+	150	+	130	+	5,140	+	13,280
Spring flood recession	43	31,100	=	43,400	+	100	+	130	+	640	-	13,170
Total for year	366	213,800	=	180,700	+	1,450	+	1,350	+	29,570	+	730

[1] At Sumatra.
[2] At Wewahitchka.
[3] At Dead Lake.

Table 21. Total carbon transport in the Apalachicola basin between Chattahoochee and Sumatra, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]
[All figures rounded]

Period	Number of days	C_o[1]	=	C_i[2]	+	C_{dp}	+	C_{ro}	+	C_{gw}	+	C_{cr}	±	R
Summer	98	40,100	=	16,000	+	1,300	+	2,470	+	780	+	7,420	+	12,130
Early autumn	35	12,100	=	5,400	+	850	+	1,820	+	290	+	3,830	-	90
Late autumn	83	17,300	=	12,800	+	350	+	780	+	660	+	3,130	-	420
Winter	64	31,000	=	18,300	+	400	+	910	+	490	+	2,760	+	8,140
Spring flood rise	8	8,700	=	3,500	+	200	+	440	+	40	+	6,650	-	2,130
Spring flood peaks	35	73,500	=	64,700	+	450	+	910	+	290	+	5,140	+	2,010
Spring flood recession	43	31,100	=	22,000	+	250	+	520	+	330	+	640	+	7,360
Total for year	366	213,800	=	142,700	+	3,800	+	7,850	+	2,880	+	29,570	+	27,000

[1] At Sumatra.
[2] At Chattahoochee.

Table 22. Total nitrogen transport in the upper subbasin, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	N_o[1]	=	N_i[2]	+	N_{dp}	+	N_{ro}	+	N_{gw}	±	R
Summer	98	1,750	=	2,320	+	24	+	36	+	43	–	673
Early autumn	35	1,110	=	820	+	12	+	24	+	16	+	238
Late autumn	83	2,920	=	2,030	+	6	+	12	+	38	+	834
Winter	64	2,430	=	3,580	+	12	+	16	+	27	–	1,205
Spring flood rise	8	1,200	=	830	+	6	+	8	+	3	+	353
Spring flood peaks	35	4,100	=	4,280	+	12	+	16	+	16	–	224
Spring flood recession	43	5,070	=	4,000	+	6	+	8	+	19	+	1,037
Total for year	366	18,580	=	17,860	+	78	+	120	+	162	+	360

[1] At Blountstown.
[2] At Chattahoochee.

Table 23. Total nitrogen transport in the middle subbasin, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	N_o[1]	=	N_i[2]	+	N_{dp}	+	N_{ro}	+	N_{gw}	±	R
Summer	98	2,110	=	1,750	+	72	+	28	+	8	+	252
Early autumn	35	950	=	1,110	+	48	+	20	+	3	–	231
Late autumn	83	2,750	=	2,920	+	18	+	8	+	5	–	201
Winter	64	3,110	=	2,430	+	18	+	8	+	5	+	649
Spring flood rise	8	1,340	=	1,200	+	12	+	4	+	0	+	124
Spring flood peaks	35	4,590	=	4,100	+	24	+	8	+	3	+	455
Spring flood recession	43	4,800	=	5,070	+	12	+	4	+	3	–	289
Total for year	366	19,650	=	18,580	+	204	+	80	+	27	+	759

[1] At Wewahitchka.
[2] At Blountstown.

Table 24. Total nitrogen transport in the lower subbasin, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	N_o[1]	=	N_i[2]	+	N_{dp}	+	N_{ro}	+	N_{cr}[3]	±	R
Summer	98	3,340	=	2,110	+	60	+	12	+	343	+	815
Early autumn	35	1,520	=	950	+	42	+	12	+	233	+	283
Late autumn	83	2,730	=	2,750	+	18	+	4	+	398	−	440
Winter	64	3,630	=	3,110	+	18	+	4	+	372	+	126
Spring flood rise	8	920	=	1,340	+	6	+	2	+	472	−	900
Spring flood peaks	35	5,670	=	4,590	+	18	+	4	+	527	+	531
Spring flood recession	43	3,670	=	4,800	+	12	+	4	+	215	−	1,361
Total for year	366	21,480	=	19,650	+	174	+	42	+	2,560	−	946

[1] At Sumatra.
[2] At Wewahitchka.
[3] At Dead Lake.

Table 25. Total nitrogen transport in the Apalachicola basin between Chattahoochee and Sumatra, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	N_o[1]	=	N_i[2]	+	N_{dp}	+	N_{ro}	+	N_{gw}	+	N_{cr}	±	R
Summer	98	3,340	=	2,320	+	156	+	76	+	51	+	343	+	394
Early autumn	35	1,520	=	820	+	102	+	56	+	19	+	233	+	290
Late autumn	83	2,730	=	2,030	+	42	+	24	+	43	+	398	+	193
Winter	64	3,630	=	3,580	+	48	+	28	+	32	+	372	−	430
Spring flood rise	8	920	=	830	+	24	+	14	+	3	+	472	−	423
Spring flood peaks	35	5,670	=	4,280	+	54	+	28	+	19	+	527	+	762
Spring flood recession	43	3,670	=	4,000	+	30	+	16	+	22	+	215	−	613
Total for year	366	21,480	=	17,860	+	456	+	242	+	189	+	2,560	+	173

[1] At Sumatra.
[2] At Chattahoochee.

Table 26. Total phosphorus transport in the upper subbasin, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	P_o[1]	=	P_i[2]	+	P_{dp}	+	P_{gw}	±	R
Summer	98	122	=	123	+	2.4	+	1.8	−	5.2
Early autumn	35	69	=	56	+	1.2	+	0.7	+	11.1
Late autumn	83	179	=	147	+	0.6	+	1.5	+	29.9
Winter	64	159	=	226	+	1.2	+	1.1	−	69.3
Spring flood rise	8	106	=	82	+	0.6	+	0.1	+	23.3
Spring flood peaks	35	497	=	485	+	1.2	+	0.7	+	10.1
Spring flood recession	43	247	=	221	+	0.6	+	0.8	+	24.6
Total for year	366	1,379	=	1,340	+	7.8	+	6.7	+	24.5

[1] At Blountstown.
[2] At Chattahoochee.

Table 27. Total phosphorus transport in the middle subbasin, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	P_o[1]	=	P_i[2]	+	P_{dp}	+	P_{gw}	±	R
Summer	98	165	=	122	+	7.2	+	0.3	+	35.5
Early autumn	35	98	=	69	+	4.8	+	0.1	+	24.1
Late autumn	83	164	=	179	+	1.8	+	0.2	–	17.0
Winter	64	204	=	159	+	1.8	+	0.2	+	43.0
Spring flood rise	8	101	=	106	+	1.2	+	0.0	–	6.2
Spring flood peaks	35	505	=	497	+	2.4	+	0.1	+	5.5
Spring flood recession	43	300	=	247	+	1.2	+	0.1	+	51.7
Total for year	366	1,537	=	1,379	+	20.4	+	1.0	+	136.6

[1] At Wewahitchka.
[2] At Blountstown.

Table 28. Total phosphorus transport in the lower subbasin, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	P_o[1]	=	P_i[2]	+	P_{dp}	+	P_{cr}[3]	±	R
Summer	98	164	=	165	+	6.0	+	10	–	17.0
Early autumn	35	89	=	98	+	4.2	+	13	–	26.2
Late autumn	83	189	=	164	+	1.8	+	11	+	12.2
Winter	64	284	=	204	+	1.8	+	8	+	70.2
Spring flood rise	8	76	=	101	+	0.6	+	11	–	36.6
Spring flood peaks	35	604	=	505	+	1.8	+	18	+	79.2
Spring flood recession	43	246	=	300	+	1.2	+	4	–	59.2
Total for year	366	1,652	=	1,537	+	17.4	+	75	+	22.6

[1] At Sumatra.
[2] At Wewahitchka.
[3] At Dead Lake.

Table 29. Total phosphorus transport in the Apalachicola basin between Chattahoochee and Sumatra, by periods, June 3, 1979, through June 2, 1980

[All equation values in metric tons. See text for beginning and ending dates of periods and explanation of abbreviations]

Period	Number of days	P_o[1]	=	P_i[2]	+	P_{dp}	+	P_{gw}	+	P_{cr}	±	R
Summer	98	164	=	123	+	15.6	+	2.1	+	10	+	13.3
Early autumn	35	89	=	56	+	10.2	+	0.8	+	13	+	9.0
Late autumn	83	189	=	147	+	4.2	+	1.8	+	11	+	25.0
Winter	64	284	=	226	+	4.8	+	1.3	+	8	+	43.9
Spring flood rise	8	76	=	82	+	2.4	+	0.1	+	11	–	19.5
Spring flood peaks	35	604	=	485	+	5.4	+	0.8	+	18	+	94.8
Spring flood recession	43	246	=	221	+	3.0	+	0.9	+	4	+	17.1
Total for year	366	1,652	=	1,340	+	45.6	+	7.8	+	75	+	183.6

[1] At Sumatra.
[2] At Chattahoochee.

nutrients in amounts somewhat less than the amounts originating from direct precipitation.

Detritus

Concentrations

Mean concentrations of coarse (>1 mm), fine (0.063-1 mm), and very fine (<0.063 mm) particulate organic carbon are shown in figure 20. Data from the four major gaging sites and six hydrologic periods are included (early and late autumn data were combined because relatively few measurements were obtained during these two periods).

Concentrations of coarse particulate organic carbon (CPOC) ranged from none detectable at Chattahoochee to 0.07 mg/L during the three spring flood periods at Sumatra. CPOC samples obtained at Chattahoochee were consistently less than 0.01 mg/L. A general trend of downstream increase in CPOC mean concentration was observed throughout all periods. The mean concentrations at Blountstown, Wewahitchka, and Sumatra were at least 50 percent higher during the three spring flood periods than during the other periods.

Fine particulate organic carbon (FPOC) concentrations generally increased from Chattahoochee to Wewahitchka and decreased slightly from Wewahitchka to Sumatra. Averaged over the full year, FPOC concentrations were approximately 12 times greater than CPOC concentrations.

Concentrations of very fine particulate organic carbon (VFPOC) increased slightly from Chattahoochee down river, with little change from Blountstown to Sumatra. Averaged over the full year, VFPOC concentrations were approximately 3.4 times greater than FPOC. Concentrations during the three spring flood periods averaged 1.0 mg/L, while the mean concentration during the other periods was approximately 0.7 mg/L.

A fourth detritus fraction measured with a stationary, 1-mm net dredge was bottom particulate organic carbon (BPOC). Figure 21 shows the period concentrations for the four main river sampling locations. The capture of BPOC below Jim Woodruff Dam near Chattahoochee was less than 0.01 mg/L, except during the spring flood rise. Detectable, but relatively low, concentrations were measured downstream at Blountstown. During most of the year, BPOC concentrations near Wewahitchka were intermediate to those at Blountstown and Sumatra. BPOC mean concentrations were consistently highest for all periods at Sumatra; concentrations in summer were low (0.1 mg/L) and increased twelvefold during the autumn. Concentrations increased even more during the winter and spring flood rise at Sumatra, but decreased during the flood peaks. With the return of flood waters from the flood plain to the main channel during the spring flood recession, BPOC concentrations at Wewahitchka and Sumatra reached their highest levels of the year. High BPOC concentrations during the flood rise may have been due to initial removal of material deposited on or near the river bank, whereas the high concentrations during the recession were more likely the result of rapid drainage from the interior of the flood-plain forest.

Transport

The particulate organic carbon fraction, known as detritus, is a relatively small part of the total organic carbon transport shown in tables 18-21. The transport of detrital materials may be further examined by particle-size categories. Detritus transport measurements (fig. 22) showed that there were substantial gains of large-particle detritus (CPOC and BPOC, both having particle sizes greater than 1 mm) from Chattahoochee to Sumatra. The coarse fractions made up only a small part of total carbon but showed more than sixtyfold gains from Chattahoochee to Sumatra. The fine particulate fraction (0.063-1.0 mm) also increased, showing a threefold to fourfold gain from Chattahoochee to Wewahitchka and Sumatra. Consistent increase with downstream distance was not exhibited by the very fine particulate fraction. Since VFPOC was the dominant carbon fraction, its downstream changes were closely reflected by the total suspended carbon, and only a slight increase was observed at Sumatra.

The relation between detritus transport and time is shown in table 30. The suspended fraction transport rates were generally higher during the three spring flood periods than during earlier, drier periods. Bottom-load POC transport rates increased from summer to winter, then showed only a slight increase during the spring flood rise and recession periods.

Flood-Plain Transport

The transport of detritus in the flood plain during flooding was verified by trapping transported material in stationary nets, as described previously. Between March 11 and April 28, 1980, 21 flood-plain detritus collections were made in nets randomly located near the intensive plots. All nets collected measurable amounts of detritus, generally about two-thirds organic. The amounts varied greatly, from 0.001 to 0.5 g of material per cubic meter of water. The mean of the 21 samples was 0.05 g/m^3, with a standard deviation of 0.10 g/m^3. Data for the individual collections are given in "Supplementary Data I."

Deposition on Flood-Plain Floor

Estimates of the amount of material deposited in the flood plain were obtained from thirty-one 1-square-meter

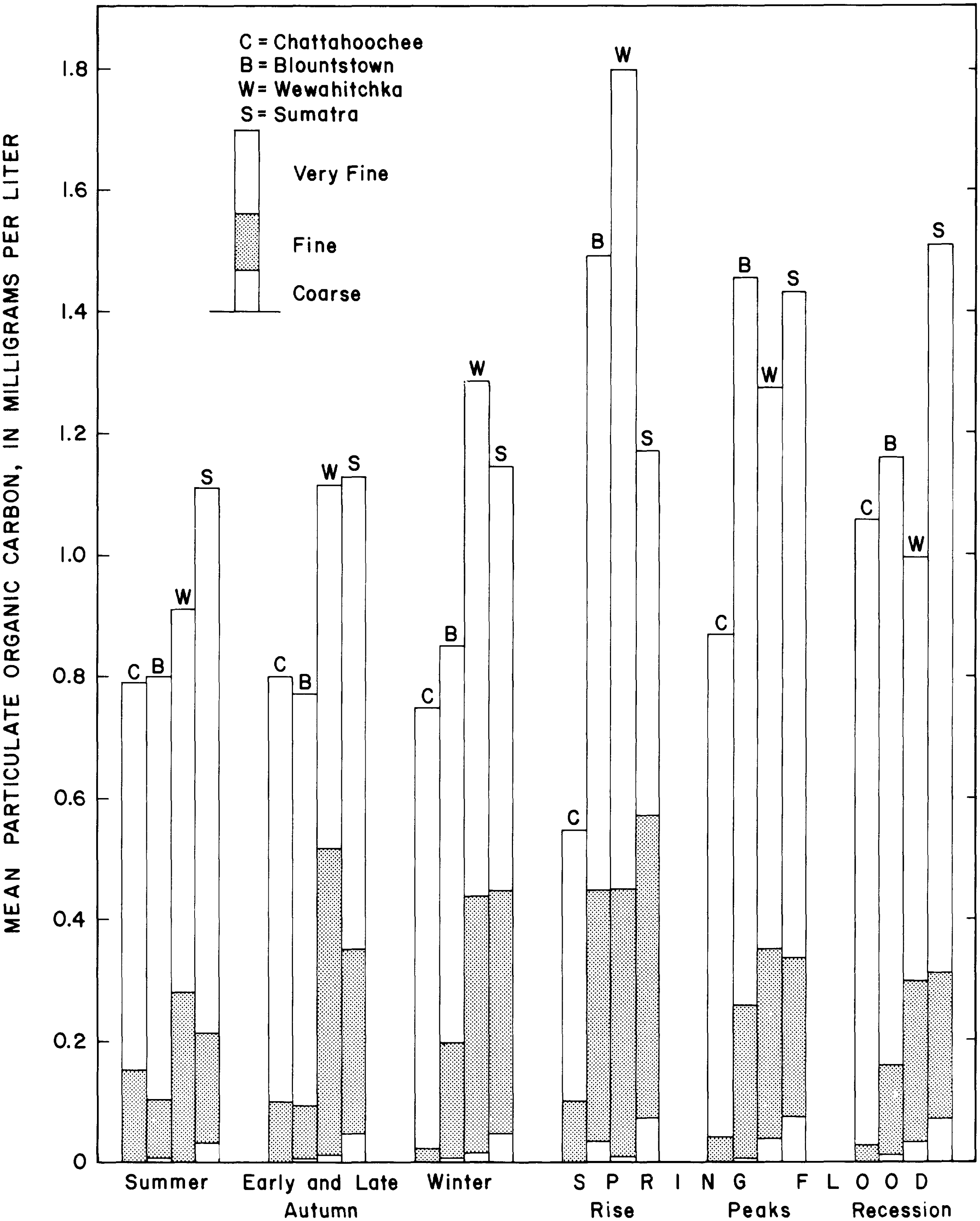

Figure 20. Particulate organic carbon concentrations.

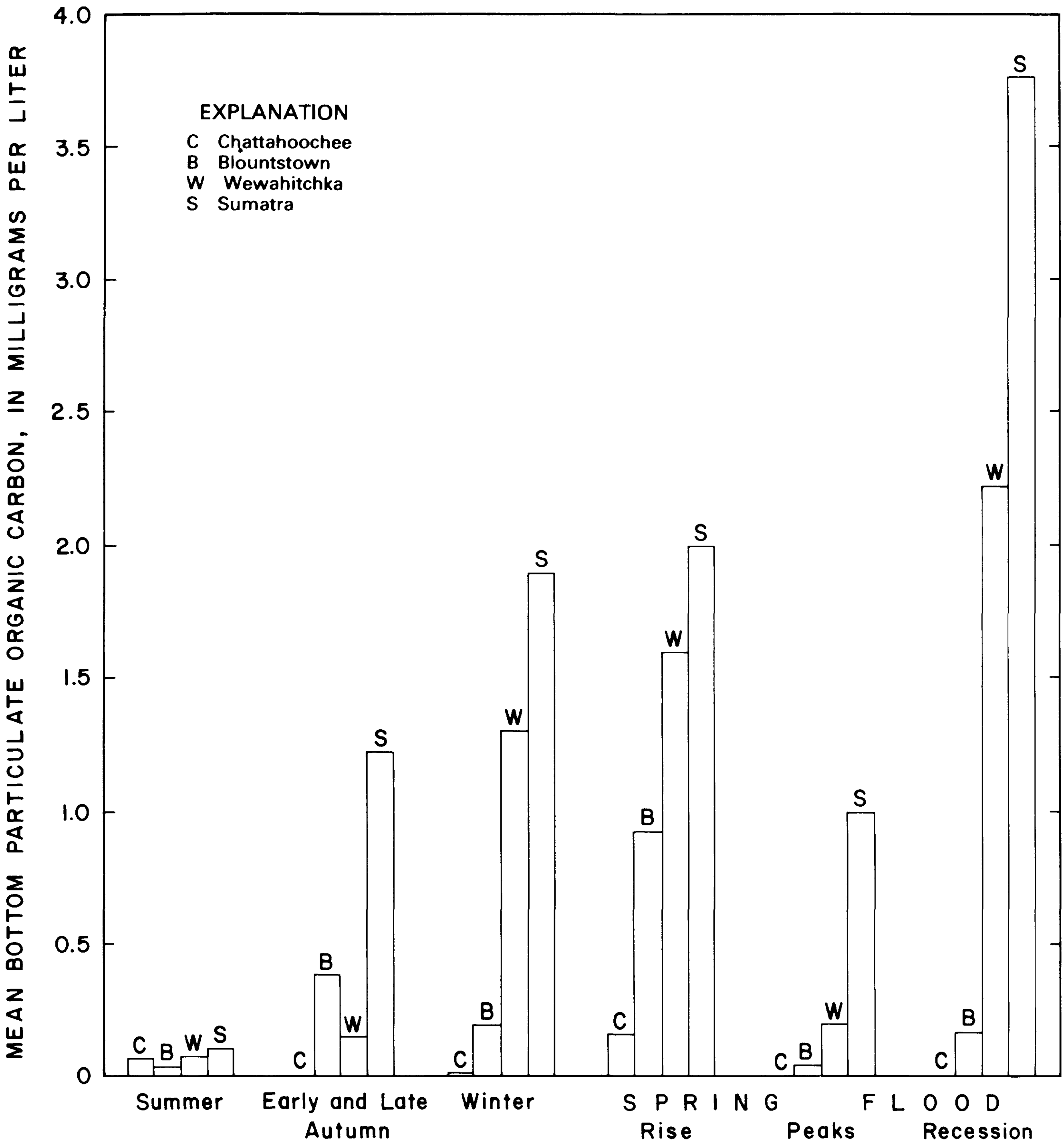

Figure 21. Bottom particulate organic carbon concentrations.

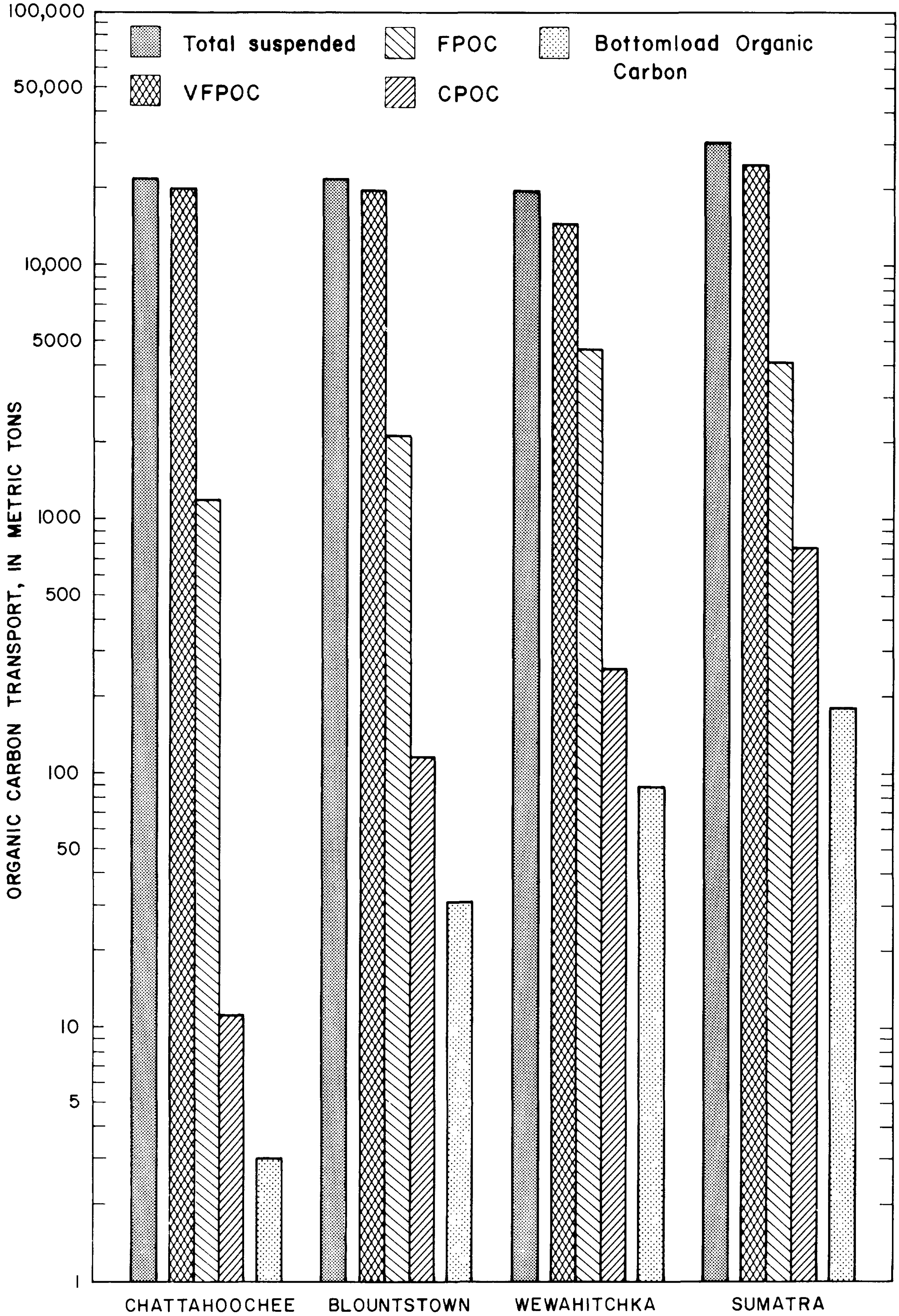

Figure 22. Annual particulate organic carbon transport.

Table 30. Daily detritus fraction transport at Sumatra, by periods, June 3, 1979, through June 2, 1980

[VFPOC, very fine particulate carbon; FPOC, fine particulate organic carbon; CPOC, coarse particulate organic carbon; BPOC, bottom load particulate organic carbon. Total suspended organic carbon = VFPOC + FPOC + CPOC; slight discrepancies due to rounding. All data shown in metric tons per day]

Period	Total suspended organic carbon	VFPOC	FPOC	CPOC	BPOC
Summer	42	37	4	0.9	0.1
Autumn (early and late)	38	29	8	1.1	0.31
Winter	52	37	14	1.2	0.90
Spring flood rise	66	22	39	4.6	1.00
Spring flood peaks	335	294	32	8.8	0.51
Spring flood recession	130	114	13	3.5	1.05

plastic sheets distributed randomly at 14 plots in the Sweetwater and Brickyard transects (figs. 6 and 7). Summarized results for both inorganic and organic deposition are shown in table 31. Data for the individual collections are given in "Supplementary Data II."

The weight of material deposited on the plastic sheets varied widely because the sheets were located in extremely different environments where depth of flooding, velocity of flow, and litter fall differed. Plot 4 was the only sheet location not flooded during the investigation, so it served as a control area.

In the flood plain as a whole, most of the material deposited was inorganic. By contrast, the organic fraction was predominant at plot 4. The amount of organic material at plot 4 was higher than the amount at most other plots, especially those in swampy areas. Levee plots were subject to a great deal more deposition, both organic and inorganic, than swamp plots.

Error Analysis

Water Budget

Systematic or additive error is error that accumulates in the same direction during each consecutive step. Compensating error occurs when measurement error is both plus and minus, so that the sum of a series of operations may have an absolute error smaller than many of the individual parts. The residuals shown in table 16 are primarily due to independent, nonadditive measurement and estimation errors. The total flow past the Sumatra gage during the various periods included residuals ranging from −54 percent to +9 percent. With the exception of the spring flood rise period, all errors were less than 10 percent. The large negative residual for the spring flood rise period was the result of the 3-day discharge lag and flood-plain storage. The largest positive residual occurred during the spring flood recession, when much of the "lost water" was recovered at Sumatra. For the three spring flood periods, the total residual (+0.53 km^3) was 3.8 percent of the total flow past the Sumatra gage during those periods. The residual, or unexplained, discharge for the year was 0.84 km^3, or 2.9 percent. Although each component of the water budget is associated with an error estimated to be 5 percent or greater, the annual residual is smaller than 5 percent. Error compensation over the long term contributed to the decrease in the annual residual percentage relative to that of any single period. Similar long-term error compensation is suggested by the residuals of the separate subbasins (tables 14-16).

Winter (1981) reported probable error levels for different water balance components and various methods of measurement or calculation. His work dealt with lakes, but many of the conclusions apply to any aquatic system. Among the annual water balance error sources, streamflow (determined by a stage-discharge relation using a recording stage gage) was one of the most accurate at 5 percent per year. Precipitation (determined by areal averaging of National Weather Service rainfall data) is subject to 10 percent error in 1 year. Evaporation errors range from 10 to 15 percent per year. These may be reasonable estimates of the errors associated with the Apalachicola water-budget terms *WO* or *WI*, *P*, and *ET*, respectively. Evapotranspiration was not determined by the methods discussed by Winter, but data from other studies (Qureshi, 1978; Brown, 1981) indicated that *ET* rates in Florida flood-plain environments are quite consistent for any given month. The *ET* term is thus judged accurate to at least 25 percent.

Ground-water estimates are probably the most uncertain of any of the Apalachicola water-budget terms; however, the amount of water involved is only 0.7 km^3, or 2.4 percent of the 28.61 km^3 measured discharge for the entire basin. In the upper subbasin, there are enough data to make ground-water estimates fair to good; a 30 percent error per year is presumed adequate. In the middle and lower subbasins, the ground-water component is near

Table 31. Deposition of material during 9 to 11 months[1] on plastic sheets randomly located at intensive plots

[Plot 4 was never flooded]

Plots	Number of sheets	Deposition, in grams per square meter					
		Organic			Inorganic		
		Mean	Standard deviation	Range	Mean	Standard deviation	Range
All	31	150	180	1.5–851	2,200	5,100	15–20,570
4	4	180	50	137 –232	110	30	80– 152
All except 4	27	140	190	1.5–851	2,500	5,400	15–20,570
Swamp[2]	14	60	60	1.5–175	520	540	15– 1,856
Levee[3]	17	220	210	18 –851	3,500	6,700	80–20,570

[1] All sheets were in place during the heavy litter-fall period and the spring flood. Dates of removal of the sheets varied (see "Supplementary Data II").

[2] Plots 1, 7, 12, 13, 15, 16, 17, and 18 (see fig. 6 and 7).

[3] Plots 3, 4, 5, 6, 11, and 14 (see fig. 6 and 7).

zero, and percentage errors become meaningless. An error of ± 0.3 km^3 per year is estimated in these reaches. Combining the three subbasins, the error, if additive, could be 100 percent.

All stream discharge terms (*WO*, *WI*, and *CR*) are likely to be accurate, in part because they are based on frequent measurements. Stage readings recorded hourly are translated to daily discharge means, which are averaged over longer time periods. With such frequent measurements, independent, nonadditive measurement errors become negligible over the long term. Systematic errors in discharge estimates are possible. An inaccurate discharge measurement, for example, might displace the stage-discharge rating curve, affecting most or all daily means with errors of the same sign. All Apalachicola main channel sites have been frequently measured at various stages, however, giving strong documentation of the ratings.

Nutrient and Detritus Concentrations

As one means of evaluating the accuracy of water-quality data, a set of samples from two Apalachicola sites, Chattahoochee and Sumatra, were used for a standard-addition recovery test. Water samples were injected with measured volumes of standards from the EPA Environmental Monitoring Laboratory. Separate tests were conducted for nitrate, ammonia, and organic nitrogen, dissolved and total phosphorus, and total organic carbon. Each injected sample was accompanied by a natural sample (not injected), and both were handled and analyzed in the usual fashion. Reliability of the data was judged by how closely the results for injected samples reflected the sum of the natural concentration plus the known standard additions.

All standard-addition recoveries of nitrogen, carbon, and total phosphorus were within 11 percent of actual concentrations. The recovery efficiency for dissolved orthophosphate was lower, primarily because the concentrations were near the analytical detection limits and the precision of the analyses was ± 0.01 mg/L. The absolute discrepancies were the same magnitude for dissolved and total phosphorus, but when converted to percentage recoveries, they are much better for total *P*.

Precision for some of the nutrient analyses was given by the U.S. Geological Survey Water Quality Laboratory's Services Catalog (Beetem and others, 1980). At the levels found in Apalachicola water, precision values for analyses of dissolved nitrogen fractions and dissolved orthophosphates ranged between 14 and 20 percent. No precision estimates were given for total carbon analyses.

An additional source of data used to evaluate the accuracy of phosphorus data came from having parallel analyses of reactive phosphate performed by a separate laboratory. Results from the Department of Oceanography laboratory at Florida State University were provided by P. N. Froelich (written commun., 1981) for samples collected in March and June 1980. Twelve values were available for comparison with results on duplicate samples from the U.S. Geological Survey National Water Quality Laboratory, Atlanta, Ga. After rounding all values to the nearest 0.01 mg/L, 8 of the 12 samples produced the same results from both laboratories: two were different by 0.01 mg/L and two, by 0.02 mg/L.

The probable maximum errors for the nutrient-concentration data were estimated on the basis of control data from standard-addition tests and from the laboratories of USGS and Florida State University. Carbon and nitrogen data are estimated to be subject to 15 percent error, and phosphorus data, to a 25 percent error. Assuming these are random errors, as samples are pooled, the expected relative error becomes smaller. Hence, concentration data collected the same way and averaged over several months or a full year are subject to smaller errors.

Detritus measurements are subject to considerable sampling error because of the probability of nonuniform distribution of the material in the natural environment. Analytical methods to determine dry and ash weight of suspended material, however, are simple and nearly free of interference.

Detritus sampling methods were original for this investigation; thus there is no documentation as to their accuracy. Discrepancies between replicate detritus samples could be the result of either natural variability or inconsistencies in sampling procedures. Field tests of various detritus sampling techniques obtained results such as those illustrated in figure 13, suggesting that these methods were adequate for characterizing the detritus transport process. It is assumed that a 15 percent error may be associated with particulate carbon transport. Even if substantially different, this error will have little effect on the overall carbon budget since most carbon transport is in soluble form.

Transport

By using the nutrient transport model derived from continuous streamflow records and discrete nutrient concentration measurements at interval midpoints, transport calculation errors were minimized (Scheider and others, 1978). Errors associated with measurement of discharge and the precision of chemical analyses, however, are carried over into the calculation of transport. Using percentage error estimates for discharge and nutrient concentrations, transport errors are computed for each sample interval (the length of time represented by one water chemistry sample). The total transport error for a particular sample interval (combining discharge and concentration errors), or over a hydrologic period (combining errors for included sample intervals), are computed by the equation

$$E = \sqrt{\sum_{i=1}^{n} e_i^2}, \qquad (10)$$

where

E equals total error;
e_i equals error for ith component or sample interval; and
n equals number of component or sample intervals.

This formula was suggested by Winter (1981) as a good estimator for combining errors from various components. It can also be used to combine interval errors to determine long-term error, provided that the component errors (e_i) are independent and not additive. This requirement is met by these data since both discharge and concentration data depended on measurements that were totally independent and were equally likely to be erroneous in either a high or a low direction. The results of calculation or errors using equation 10 with regard to annual nutrient transport are illustrated in figure 23. The error bars about each annual transport for the four main-stem river gage locations and the Chipola River below Dead Lake Outlet provide a means by which to judge differences among transport rates at different locations. A general downstream increase in nutrient transport is apparent, particularly for carbon. The actual increase between any two adjacent sites should not be overemphasized because of the overlapping error bars computed with equation 10.

DISCUSSION

Flood-Plain Role in Nutrient Transport

A central purpose of this investigation is the assessment of the role of the flood plain in nutrient transport in the Apalachicola River. Direct measurements of this role were not possible, but the various kinds of data that were gathered provided pieces of information that could be considered together to arrive at clues pertaining to wetland functions.

An enormous nutrient source is present in the Apalachicola flood plain. The dense bottom-land hardwood forest contains more than 1,500 trees per hectare (Leitman and others, 1983). This vegetation produces some 800 g/m^2 of litter fall annually, which places it among the most productive of forests in warm temperate regions (Elder and Cairns, 1982). Much of the litter material is subject to rapid decomposition to both soluble and small-detrital nutrient residues.

The hydrology of the Apalachicola system, coupled with its high productivity, is critical to the potential nutrient flow from the flood plain. Leitman and others (1983) found that 57 percent of 223 sample points in the flood plain were in environments that are generally saturated or flooded during the dry season (autumn) and that all but 3 of the 223 points were below the 2-year, 1-day high flood stage for the period 1958-80. During inundation, velocities in the flood plain range from 0 to 0.3 m/s, with most points subject to velocities of at least 0.1 m/s (Leitman and others, 1983). In channelized areas in the flood plain, velocities almost as high as the river flow may be observed during high flood stages.

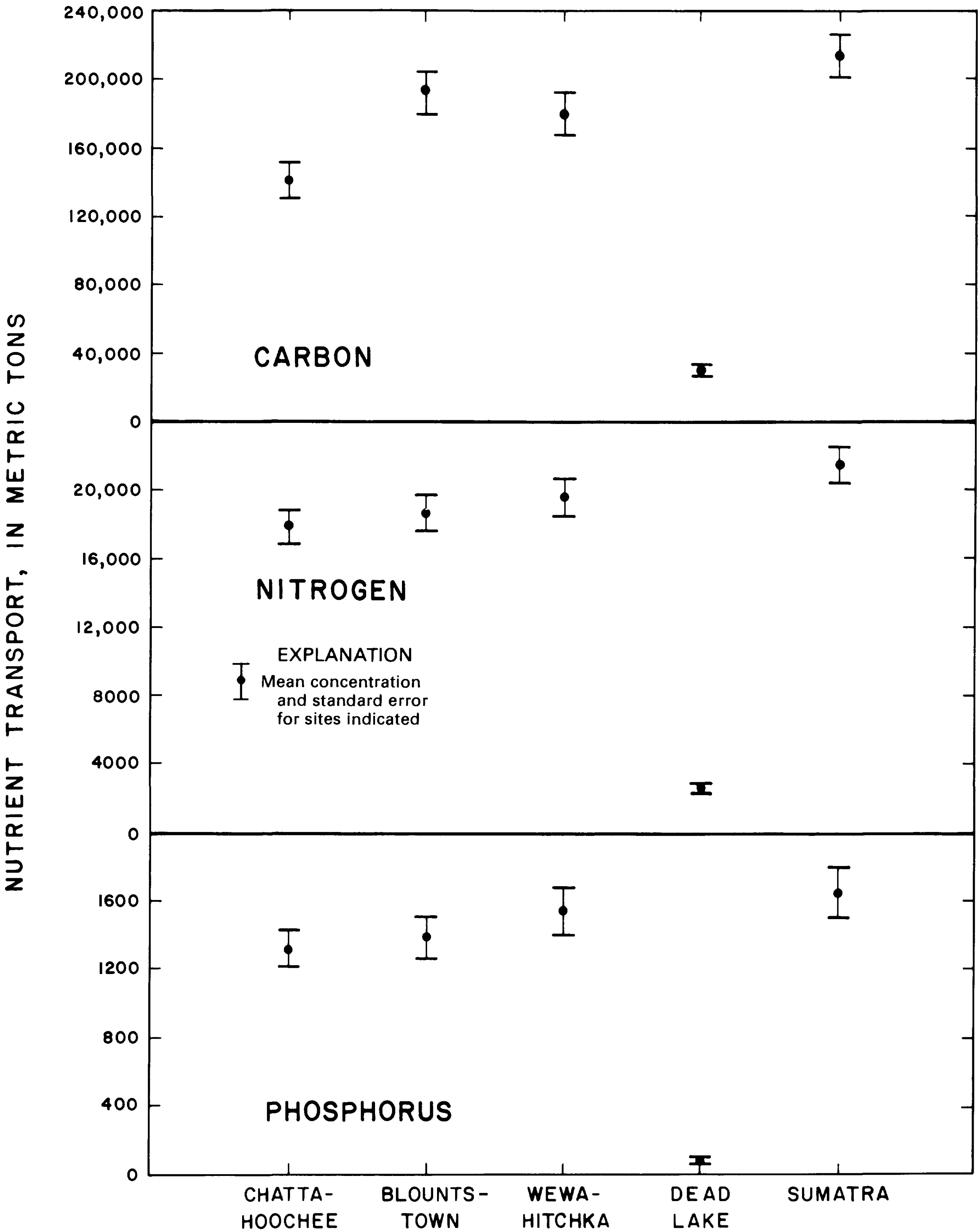

Figure 23. Annual nutrient transport at four Apalachicola River sites and the Chipola River Outlet at Dead Lake, showing error ranges.

These hydrologic characteristics of the flood plain are important not only for transport of nutrients and detritus, but also, over the long term, for the very existence of the vegetation that produces that detritus. Leitman and others (1983) found high statistical correlations between forest type distribution and nine different water parameters, such as flood depths, velocity, and duration of flooding. Hence, hydrologic characteristics influence the type of detritus produced as well as the quantity transported.

High productivity of dense vegetation in the flood-plain forest implies active uptake of nutrients, tending to counterbalance nutrient and detritus release. Nutrient uptake is likely to diminish concentrations of dissolved nutrients more than particulates (Stanley and Hobbie, 1981). The trends shown in figures 21-23 indicate that concentrations of detritus increase in a downstream direction much more than do concentrations of dissolved or total organic carbon. This means that the solute:particulate ratio, although large throughout the river, decreases appreciably in a downstream direction. The flood plain is the primary producer and consumer of carbon in the basin and must have a great deal to do with the change in solute:particulate ratio. One of the net effects of the flood plain is conversion of some organic carbon from dissolved to particulate species due to vegetative assimilation of dissolved carbon and subsequent release of organic material through litter deposition.

The annual residuals shown in tables 21, 25, and 29 are all positive, indicating that nutrient input to the river cannot be totally balanced by the sum of precipitation, ground-water, and surface-water inflow. The residual values incorporate the combined errors of all components, but in the cases of carbon and phosphorus, such errors would not likely be additive such that we would observe the high positive R values shown on the tables. Flood-plain-derived nutrients probably make up the difference. This seems an especially plausible explanation since the highest relative R value is for carbon, which is less likely to be retained by the wetland than is nitrogen or phosphorus (Peverly, 1982). Export of the three elements has also been documented in studies by Day and others (1977) of a swamp system in Louisiana very similar to the Apalachicola flood plain.

The nitrogen budget (table 25) shows a nearly precise balance between nitrogen import and export in the wetland. The annual nitrogen residual, although positive, was less than 1 percent of the total outflow at Sumatra and may be attributed to error. Wetlands do have the capacity, under certain circumstances, to retain nitrogen from through-flowing waters (Brinson, 1977; Sloey and others, 1978). As an essential plant nutrient, nitrogen is likely to be retained in the forest ecosystem, at least during the growing season (Vitousek and Reiners, 1975). The waters of the Apalachicola system are nitrogen rich; however, with a nitrogen:phosphorus ratio in excess of 10, the system is probably not nitrogen-limited. Nitrogen fixation and denitrification within the flood-plain forest could provide most of the internal nitrogen needs. Excess nitrogen input might flow through the system quite readily under such conditions.

Variable values such as those for Blountstown may mean the values were correct or were artifacts caused by sampling or analytical error. It is assumed that all data are correct unless there is evidence of error, such as a sampling inconsistency. Data also may be rejected if they are so inconsistent with other data that they are judged unrealistic. In the case of the Blountstown carbon data, however, there was no justification for rejecting the data. The results serve to illustrate the value in considering increased time and area; as the perspective is changed from one period and subbasin to the full year and the entire basin, the fluctuations are more likely to balance each other and more realistic estimates may be derived.

A notable case in which a high negative R value was caused by abnormally low concentration is shown in table 24. In May 1980, the total nitrogen concentration was 0.68 mg/L at Sumatra, somewhat less than its usual range of 0.75-1.00 mg/L. A low nitrogen outflow estimate for the lower subbasin produced a high negative R value for the spring flood recession and for the entire year's budget for that subbasin.

Large negative residuals occurred in the spring flood rise period for all three nutrients in the lower subbasin (tables 20, 24, and 28). This was a reflection of the flood wave lag that produced a similar negative residual in the water budget for that period (table 16). The lag effect disappeared when data from all periods were combined into an annual value.

The phosphorus export:import ratio in the Apalachicola system (table 29) is comparable to that of carbon. The annual residual is positive and is an appreciable fraction (11 percent) of total transport at Sumatra, suggesting an overall export from the flood plain. This result is in contrast with some other studies (Brinson, 1977; Mitsch and others, 1979; Peverly, 1982) which show either net retention of phosphorus or a fluctuation between import and export. The large amount of detritus output from the Apalachicola flood plain may be a factor contributing to phosphorus export by providing a surface for sorption of the element.

In examining the entire set of data in tables 18-29, the reader should keep in mind that the main purpose of these data is to arrive at some realistic estimates for annual riverine yield. The purpose is not to highlight changes over short lengths of time or small geographic areas. Focusing on the narrow perspective reveals considerable variability in water flow and nutrient concentration. For example, table 19 shows that in the summer period, carbon inflow (C_i) at Blountstown was 60 percent higher than carbon outflow at Wewahitchka. This produced a large negative R value for that period and, eventually, for the entire year. The high C_i at Blountstown in the summer period resulted from three extraordinarily high total organic carbon (TOC) concentrations in the samples collected at Blountstown in June, July, and August—all of them greater than 12 mg/L. These high concentrations were not matched at other sites. A similar high TOC concentration at Blountstown occurred in November 1979, producing the high C_i in the late autumn season and subsequent high negative R value (table 19).

River Basin Nutrient Yield

Figures 24, 25, and 26 illustrate cumulative nutrient transport and changes with season, over the full year from June 3, 1979, through June 2, 1980. The scope is the entire basin. Y_o represents outflow at Sumatra, and Y_i represents inflow at Chattahoochee. It is evident that nutrient inflow was the largest single contributor to nutrient yield in the basin. The percentage of Y_o contributed by Y_i ranged from 40 percent (carbon in early September and nitrogen in late August) to more than 100 percent (phosphorus in early July). The sum of the remaining components, which were estimated from field data, is represented on the graphs (figs. 24-26) by the separation between the two lowermost curves. Nearly all of this quantity in each case is attributable to surface-water inflow from the Chipola River, embodied in the Y_{cr} term.

Seasonal effects on nutrient transport were minor except during the spring flood periods. Rapid increases in cumulative transport occurred during the early stages of the spring flood, in March and April. Although carbon and phosphorus transport increased rapidly in the early flood stages, the inputs diminished considerably in the latter stages (late April and May), leaving a difference between input and outflow. This gap is the residual, shown by the shaded part in the illustrations. This residual amounts to 13 percent of the total annual carbon transport and 11 percent of the annual phosphorus transport; it is presumed to come principally from the flood plain. Flood-induced carbon export from the flood plain appears to have occurred primarily during the latter peaks and recession of the spring flood. The nitrogen residual was 1 percent of the annual transport, reflecting an approximate balance between export and import.

Transport of particulate organic matter is especially prone to sharp surges due to flooding. To illustrate this, figure 27 compares cumulative transport of all fractions of carbon at Sumatra with the transport curves that would be observed if the rates were constant throughout the year (using January 4, 1980, as the date for determining constant rate). Observed data in the spring months of 1980 were offset considerably from the constant rate curves. On close inspection, the most critical "flushing periods" for the different fractions appear to be quite distinguishable. For example, the principal CPOC surge occurred in April, while the FPOC was released somewhat earlier and began to slow down in April. Bottom-load material (BPOC) showed one of its greatest surges in November, coinciding with the period of heaviest litter fall, then increased again in the winter and spring periods as greater areas became inundated.

The characteristics of the water budget are such that the flood-plain role in nutrient transport is critical. The Apalachicola River water budget is heavily dominated by streamflow; all inputs and losses within the basin are small relative to the flow in the main channels. In the absence of major pollution sources, nutrient inputs associated with precipitation, ground water, and overland runoff are unlikely to appreciably augment the huge nutrient pool in the river water. The flood plain, with its substantial nutrient production and its direct, prolonged interaction with the flowing river water, is therefore the only factor in the basin that is likely to have considerable influence on the nutrient and detritus yield of the river.

It is not accurate to infer from this analysis that precipitation, ground-water flow, evapotranspiration, and other means of water and nutrient exchange in the Apalachicola basin are unimportant. They are minor only when compared with the total pool associated with streamflow. Rainfall and evapotranspiration rates in this warm temperate zone are higher than in most areas of the country (Qureshi, 1978), but they nevertheless have relatively little effect on overall streamflow (table 16).

Tables 21, 25, and 29 show that annual transport of carbon, nitrogen, and phosphorus was substantially greater at Sumatra than at Chattahoochee. Streamflow at Sumatra was also greater than at Chattahoochee (table 16). If the Sumatra outflow:Chattahoochee inflow ratios are derived from the annual basin-wide budgets of tables 16, 21, 25, and 29, and figure 22, the results are as follows:

Constituent	*Outflow:inflow ratio*
Water	1.25
Carbon	1.50
Nitrogen	1.20
Phosphorus	1.23
Total detritus	1.41
VFPOC	1.25
FPOC	3.50
CPOC	70

Increased water flow without simultaneous nutrient inputs would simply result in lower nutrient concentrations and no change in nutrient transport. The outflow:inflow ratios show that this did not happen. Instead, there was a nutrient input that matched flow increase in the cases of nitrogen and phosphorus and exceeded flow increase in the case of carbon.

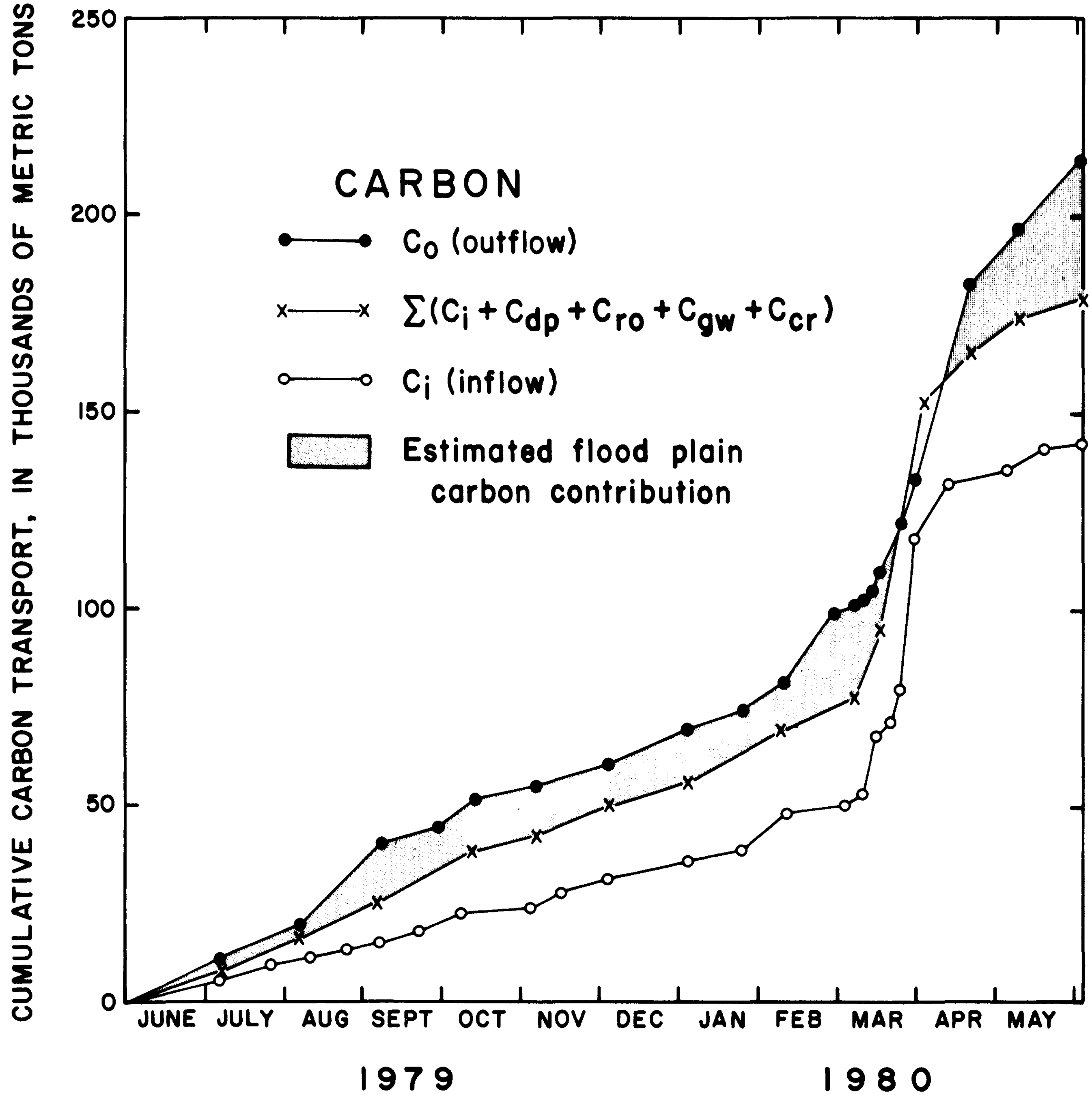

Figure 24. Cumulative carbon transport in the Apalachicola River basin from June 3, 1979, through June 2, 1980.

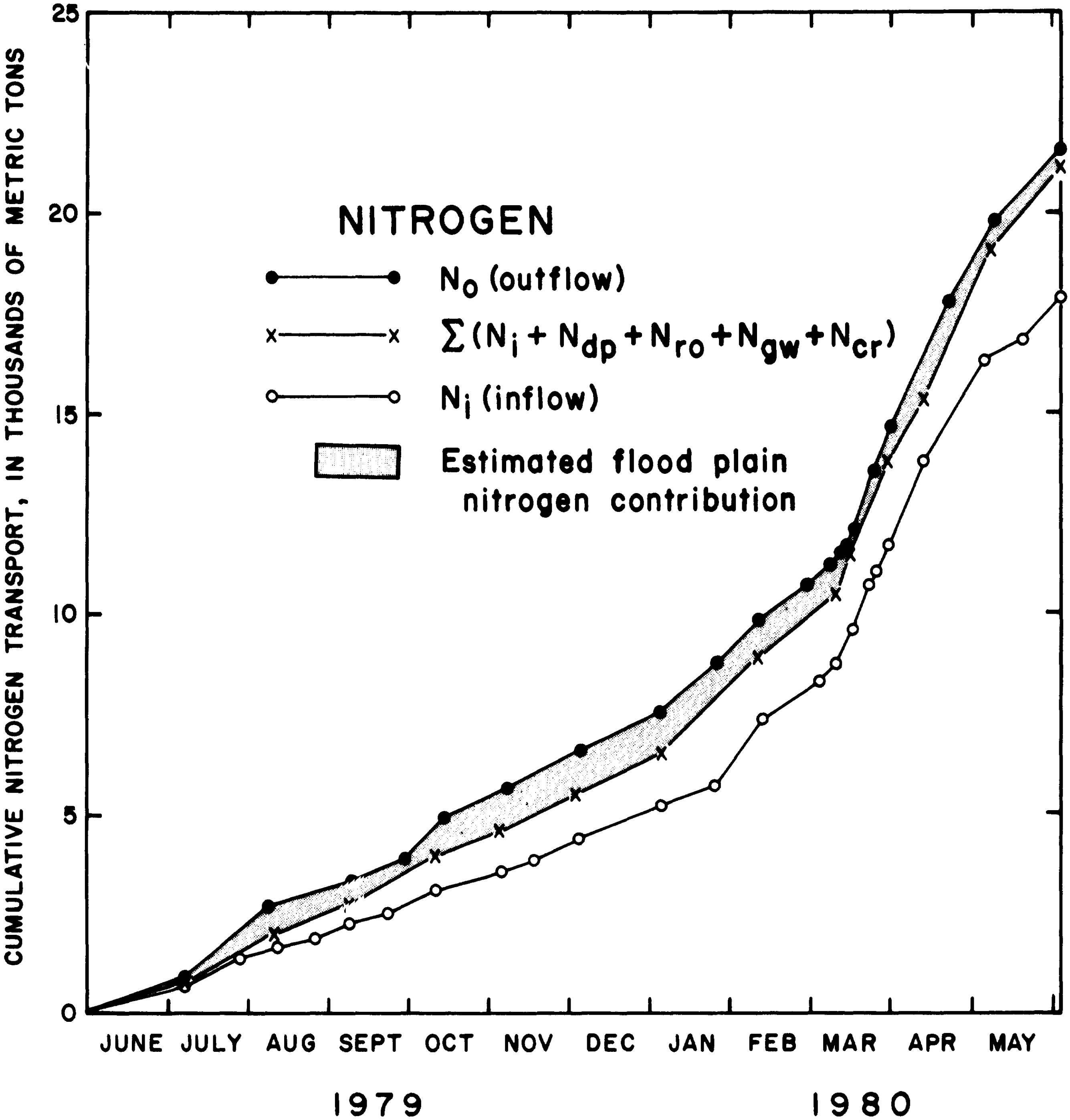

Figure 25. Cumulative nitrogen transport in the Apalachicola River basin from June 3, 1979, through June 2, 1980.

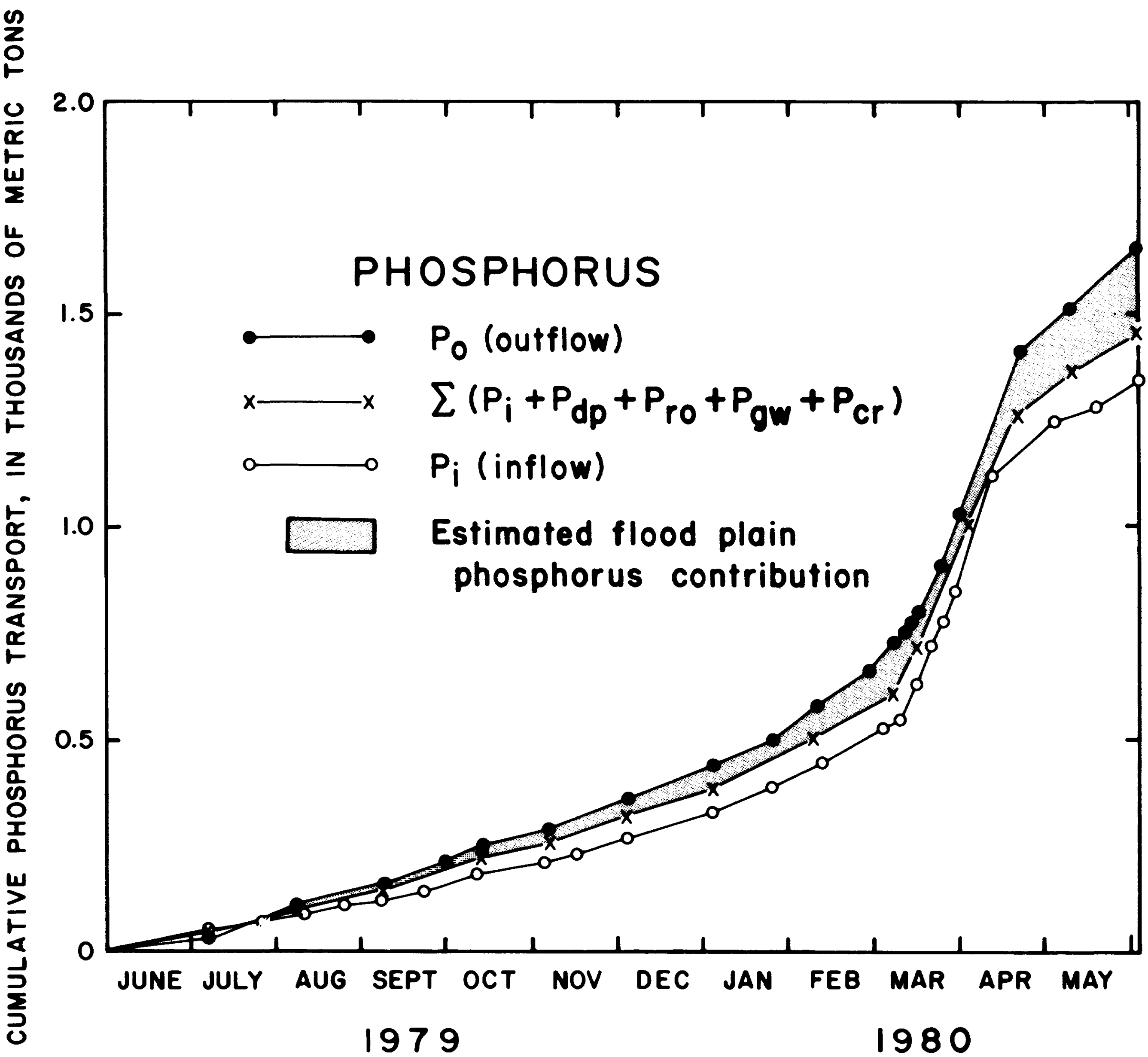

Figure 26. Cumulative phosphorus transport in the Apalachicola River basin from June 3, 1979, through June 2, 1980.

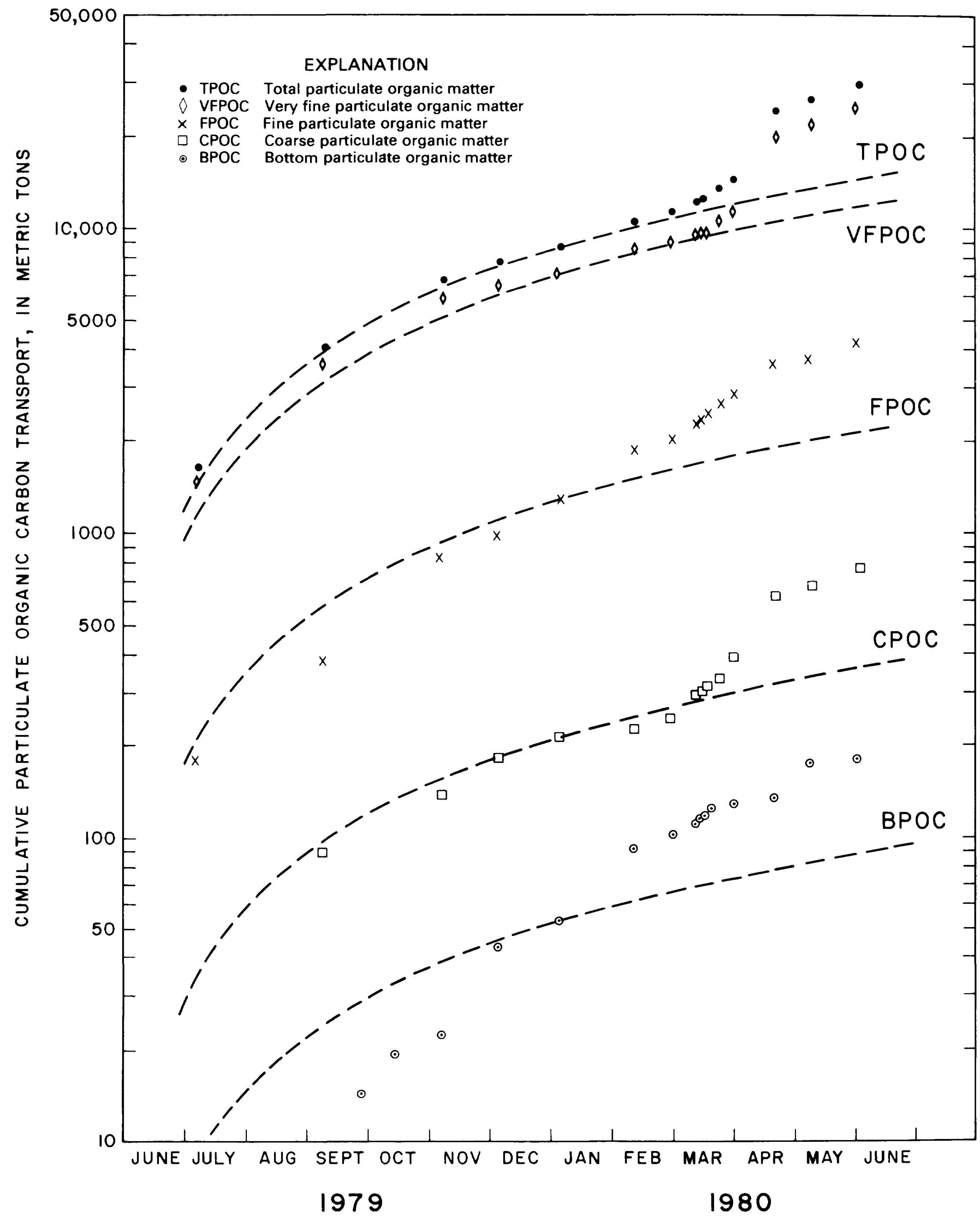

Figure 27. Observed versus constant rate (dashed line) transport of five particulate organic carbon fractions in the Apalachicola River basin from June 3, 1979, through June 2, 1980.

The overall conclusion from this analysis is that the Apalachicola wetland functions as a natural transformer-filtration system for waters passing through the basin. Exchanges result in some net increase in organic carbon and phosphorus transport, much of it in the form of particulate matter (detritus), but no net increase or decrease in nitrogen transport.

The implied effects of such a wetland role on estuarine ecology are that it favors secondary productivity and a detrital-based food web. Primary productivity is usually limited by phosphorus in estuarine systems, particularly during spring runoff (Taft and Taylor, 1976). This is especially likely in the Apalachicola system, with its high nitrogen:phosphorus ratio which is not appreciably altered by interaction with the flood plain. With the limitation on primary production, heterotrophic activity assumes relatively greater importance in the estuarine food web. The heterotrophs depend on a plentiful source of organic material. Detrital loads in the river water discharging to the bay provide an excellent substrate for bacterial growth (Fenchel, 1970) and a base for support of a thriving population of detrital feeders (Darnell, 1961), including many economically valuable shellfish species.

An alternative view might be suggested by the total organic carbon data. If the dissolved fraction is the main energy source for the estuary, the flood-plain role would appear much less significant. As shown by the outflow:inflow ratio and the data in figure 22, the total organic transport at Sumatra is not greatly different from that at Chattahoochee. If the flood plain were not there, the riverine yield of total organic carbon might not be greatly reduced. This interpretation requires several assumptions: (1) dissolved organics are not converted to particulates in the river channel by such processes as precipitation, adsorption, and bioassimilation; (2) dissolved organics are not changed in the river channel to forms that are less bioavailable; and (3) dissolved rather than particulate organics are most important in sustaining the estuarine productivity. Further research would be needed to determine the validity of these assumptions.

Sources of Nutrients

Considerable attention has been given thus far to nutrient inflow from the flood plain to the river. It is important that other sources be examined also to approach a full understanding of the interaction of various components.

Currently (1981), nearly all nutrients entering the Apalachicola streamflow by intrabasin pathways, such as ground water and surface runoff, are natural in origin. Anthropogenic sources are minor owing to the relatively undisturbed character of the basin. Wastewater effluents consist primarily of a few treatment plants serving small municipalities.

Industry and agriculture are more prevalent in the basins of the two headwater rivers, the Chattahoochee and the Flint. Effects of agriculture in southwest Georgia were studied recently by Radtke and others (1980). They found that agriculture did not produce high concentrations of chemical constituents in stream water, even during periods of storm runoff. They attributed this to the permeability of the soil, which permits extensive percolation and adsorption of materials from the water deposited on agricultural lands. A recent investigation of the upper Chattahoochee River basin (Stamer and others, 1978) found that nonpoint sources of nutrient loads contributed more nutrients to streamflow than point sources.

Atmospheric deposition, as precipitation and dry fallout, contributes significant amounts of nitrogen and phosphorus to the Apalachicola-Chipola basin. As shown in tables 18-29, however, these inputs are quite small relative to total nutrient loads in the river. Atmospheric inputs often constitute a major chemical influence on any lakes in the area that do not undergo a large water exchange. Such impacts of atmospheric deposition have been observed elsewhere (Elder and Horne, 1978; Dethier, 1979). The Apalachicola River system, however, is continually replenished by the Chattahoochee and Flint Rivers, and atmospheric sources of nutrients are not significant.

Recent studies of precipitation chemistry in Florida have shown that nitrogen and phosphorus concentrations elsewhere in the state are generally somewhat higher than concentrations in the precipitation of the Apalachicola basin, while organic carbon concentrations are highly variable. Hendry and Brezonik (1980) found mean concentrations of organic carbon, nitrogen, and phosphorus at Gainesville, Fla., to be 9.5, 0.82, and 0.085 mg/L, respectively, all somewhat higher than the median concentrations found in this study at the Apalachicola sites (fig. 18). Irwin and Kirkland (1980) monitored 24 bulk precipitation sites in Florida; a Tallahassee site had nitrogen and phosphorus concentrations comparable to those of the Apalachicola basin, but organic carbon concentration was considerably lower. Central and southern Florida nutrient concentrations were generally higher than Tallahassee concentrations. In general, the analytical results of Apalachicola bulk precipitation samples were consistent with what might be expected for a relatively undisturbed, densely forested area.

Flood-Plain Detritus Contributions

Some approximation of detritus transport can be drawn from detritus nets and plastic sheets used in the flood plain. Although these approaches give only rough estimates, they serve as a test of the determinations of flood-plain contributions to detritus and total detritus transport in the system. It is emphasized that the values derived are for the sole purpose of testing earlier calculations; they are not quantitative and should not be treated as such.

Flood-Plain-Net Estimate of Detritus

The data from the nets used to collect detritus in the flood plain ("Supplementary Data I") can be used to estimate the amount of coarse particulate carbon transported from the flood plain. The data show considerable variability, as would be expected because of the differences in the sites where the detritus was collected; however, overall mean weights provide information that serves as a comparison with carbon transport measured in the river.

The amount of flood-plain water flow during the 1980 flood rise and peak can be estimated from flow distribution data given by Leitman and others (1983, figs. 25 and 26). The flood-plain part of the discharge at the Sweetwater transect was 27 percent at high stage (Q=2,490 m^3/s on March 18) and 10 percent at medium stage (Q=1,640 m^3/s on March 11). At the Brickyard transect, the corresponding values were 44 percent (Q=2,920 m^3/s on March 19) and 35 percent (Q=1,980 m^3/s on March 14). These percentages may be used to estimate actual flow in the flood plain during the 1980 flood, assuming that the maximum percentage applies to the flood peaks period and the mid-stage percentage applies to the flood rise and recession periods. Flow percentages multiplied by total discharge values at Blountstown and Sumatra (*WO* in tables 13 and 15) give the following estimates for flood-plain flow:

Period	Flood-plain flow, in km^3 — Sweetwater	Brickyard
Rise	0.15	0.40
Peaks	1.84	3.55
Recession	.36	1.62
Total 1980 flood	2.35	5.57

The mean concentration of coarse particulate organic material captured in the flood-plain nets was 0.09 g/m^3 at Sweetwater and 0.02 g/m^3 at Brickyard ("Supplementary Data I"). Multiplying these values by the flood-plain flow just calculated and by the factor 0.5 to account for the concentration of carbon in organic matter, one arrives at the estimates of 100 metric tons CPOC transport at Sweetwater and 60 metric tons CPOC transport at Brickyard. Actual transport determinations from the CPOC and BPOC samples collected in the river during the entire flood period were 160 metric tons at Blountstown (slightly downstream of Sweetwater) and 1,000 metric tons at Sumatra. Coarse particulate carbon flow from the flood plain as estimated by the net collectors was, therefore, nearly equal to measured transport near the Sweetwater transect but more than an order of magnitude smaller than measured transport near the Brickyard transect.

Plastic-Sheet Estimate of Detritus

The organic deposition on plastic sheets (table 31) was considerably less than the 800 $(g/m^2)/yr$ litter-fall rate found by Elder and Cairns (1982). Presumably, the differences are due to losses from the sheets resulting from decomposition and flood scouring and, perhaps, to some other factors such as removal by animals or wind. It should be noted that the plastic sheets were in place for somewhat less than a full year (9 to 11 months); hence, the litter fall on them would be slightly less than the annual rate.

The organic deposition on the sheets at plot 4 was somewhat higher than the mean deposition at all other plots (table 31), suggesting that the lack of flooding at plot 4 resulted in less removal of litter fall. Under this assumption, the removal caused by flooding can be estimated by comparing plot 4 data with data from all other plots, after first correcting for such effects as collection time and forest-cover type.

The collection time effect, caused by the sheets being in place for less than 1 year, was corrected by subtracting from annual litter-fall amounts (Elder and Cairns, 1982) the amounts for the months that were not sampled by the sheets. For example, the sheets at plot 4 were removed in early June 1980, after being in place for 9 months, so the amount of litter-fall during June, July, and August was subtracted from the annual total to estimate actual litter fall on the sheets.

The plot locations do not correspond proportionally to the different forest-cover types in the intensive transects (Leitman and others, 1983). At the Brickyard transect, for example, two of the nine plots are on levees, yet only 5 percent of the transect is composed of levee forest-cover types. The litter-fall data, as well as the plastic-sheet data, must be weighted according to the transect distance represented by each plot to more accurately characterize the entire transect. When this is done, the mean plastic-sheet sample weight (organic material only) for plots other than plot 4 is 89 g/m^2.

The results of these calculations are as follows:

	Litter fall (grams per square meter)	Plastic sheet sample (grams per square meter)	Loss (grams per square meter)	Percentage loss
Plot 4	733	182	551	75
All other plots	831	89	742	89

A greater removal of organic material, amounting to 14 percent of the total, is calculated for the flooded sites. Assuming that this difference is due to flood scouring, the annual carbon loss from the entire flood plain can be calculated. The organic material is considered to be 50 percent carbon.

$$(0.14) \times [800(g/m^2)/yr] \times (0.5) = 56g\ C/m^2/yr = 56\ \text{metric tons}\ C/km^2/yr$$

The area of the flood plain above Sumatra is 393 km^2; hence:

$$56\ \text{metric tons}\ C/km^2/yr \times 393\ km^2 = 22{,}000\ \text{metric tons}\ C/yr$$

This compares closely with the estimate of 27,000 metric tons C/yr (table 21) previously determined as the flood plain yield plus residual *R*.

Significance of Flood-Plain-Net and Plastic-Sheet Estimates

The flood-plain nets and plastic sheets provide two sources of data from within the flood plain which supplement the particulate carbon transport measurements in the river. Both approaches depend on random samples taken at locations that differ widely in environmental conditions. The data are thus subject to considerable variability and should be treated as qualitative supporting evidence that substantial amounts of the riverine detritus originate in the flood plain.

The flow of coarse detritus in the flood plain, as determined by the net sampling, could account for nearly all CPOC and BPOC transport measured in the river. At the Sweetwater transect, the estimated detrital flow of 100 metric tons in the flood plain was quite close to the total riverine transport of 160 metric tons measured at Blountstown. Presumably, the amount found at Blountstown had been transported into the river from the flood plain upstream. Some of the detritus sampled at the Sweetwater transect may have entered the river above Blountstown, and some may have entered below. Farther downstream, as the detrital load increases in the river owing to inputs along the way, the flood-plain detrital flow would be expected to become a continually smaller fraction of riverine detrital flow. The estimates from the Brickyard transect confirm this expectation.

The plastic-sheet approach to estimating flood-plain carbon flow further corroborates the findings of the other approaches. The fact that the final estimate of 22,000 metric tons of particulate organic carbon transport/year is quite close to the river sample amount of 27,000 metric tons/year is an indication that the method does provide realistic estimates.

Neither the stationary nets nor the plastic sheets provide data that show how far the organic particles move. The fact that they do move, however, suggests that some must move from the flood plain to the stream channels. The general flow downstream and toward the channels should prevent complete recycling of the materials within the flood-plain ecosystem.

Nutrient Yields for the Apalachicola-Chattahoochee-Flint River System

Annual nutrient yield converted to an areal basis ($g/m^2/yr$, equivalent to metric $tons/km^2/yr$) reveals sharp differences among various basins and the flood plain (table 32). Compared with the entire Apalachicola-Chattahoochee-Flint basin, the Apalachicola flood plain is extremely high in carbon and phosphorus yield per unit area. Carbon and phosphorus areal yields from the flood plain are more than 15 times greater than from the basin as a whole. The Apalachicola and Chipola basins exhibit more areal nutrient yield than the Chattahoochee-Flint basin. The nutrient yields of the Chattahoochee-Flint watersheds are apparently affected by nutrient retention in the 16 reservoirs in the system.

The nitrogen budget of the Apalachicola-Chattahoochee-Flint system is clearly distinct from the carbon and phosphorus budgets, as shown by the data in table 32. Nitrogen yield from the Apalachicola flood plain is the same as the yield from the basin as a whole. Another distinction is seen in the comparisons of the Apalachicola and Chipola drainage areas. The Apalachicola yields more carbon and phosphorus, but less nitrogen, than the Chipola. It should be stressed that these yields apply to net yield rather than gross yield, since they are based on output minus input. Hence, the data do not indicate whether actual nitrogen yield from the flood plain was low or nitrogen retention was high.

Carbon transport rates on an areal basis have been reported for a number of other systems and provide an interesting comparison with those shown in table 32. Schlesinger and Melack (1981) compiled the results of numerous studies from various ecosystem types and found that, with few exceptions, the carbon output from river watersheds ranges from 1 to 10 g/m^2 annually. Factors that seemed to favor high yield included steep topographic relief, high runoff, high primary productivity, and production of detritus as litter fall rather than below ground productivity in root systems (as in grasslands). Wetland watersheds were shown to be among the most productive. A regression of total organic carbon transport versus watershed size indicated that the mean annual world carbon export rate from watersheds should be 7.2 g/m^2. Most measured amounts are found to be lower than this, however, with the exception of wetland areas.

Table 32. Nutrient yields, on an areal basis, for various drainage areas of the Apalachicola-Chattahoochee-Flint River system

Drainage basin	Area (km^2)	Annual output minus input (tons)			Areal yield ($g/m^2/yr$)		
		Carbon	Nitrogen	Phosphorus	Carbon	Nitrogen	Phosphorus
Apalachicola-Chattahoochee-Flint . . .	50,800	213,800	21,480	1,652	4	0.4	0.03
Chattahoochee-Flint	44,600	142,700	17,860	1,340	3	.4	.03
Apalachicola-Chipola	6,200	71,100	3,620	312	12	.6	.05
Apalachicola.	3,100	41,500	1,060	237	13	.3	.08
Chipola	3,100	29,600	2,560	75	10	.8	.02
Apalachicola flood plain	393	27,000	170	180	69	.4	.46

Further evidence of the high nutrient yield of wetlands was provided by Mulholland and Kuenzler (1979). Compiling data from various wetland and upland watersheds, they found a close linear relation between annual runoff and carbon transport. The relation was quite different for the two watershed types, however, with the resulting conclusion that, given equal runoff, wetland watersheds would be expected to yield five times more carbon per unit area than upland watersheds. A large number of other studies, including those of Odum and de la Cruz (1967), Heald (1971), and Day and others (1977), have demonstrated high rates of carbon export from wetland systems. By contrast, Woodwell and others (1977) reported net carbon *import* in a Long Island salt marsh, an inconsistency that adds credence to the argument that wetlands can act as both sinks and sources of organic material (de la Cruz, 1979).

The carbon export from the Chattahoochee-Flint basin, limited as it is by the dams on the rivers, is less than the 7.2 $g/m^2/yr$ postulated by Schlesinger and Melack (1981) as a world average. The output from the Apalachicola part of the system is 13 $g/m^2/yr$, well above average. The 69 $g/m^2/yr$ yield from the flood plain gives strong evidence that the wetland yield accounts for the high overall yield of the whole Apalachicola basin.

Areal yield of phosphorus in the Apalachicola basin is higher than in most other systems. Mitsch and others (1979) reported a phosphorus output of 0.34 $g/m^2/yr$ from an Illinois cypress swamp, which is 0.18 $g/m^2/yr$ lower than the Apalachicola flood-plain output. Other studies (Richardson and others, 1978; Whittaker and others, 1979) have shown phosphorus export rates considerably lower (less than 0.02 $g/m^2/yr$) for other, more dissimilar systems. Most reported nitrogen export rates from the same systems are also lower than that of the Apalachicola, although there is considerable variability. Such variability may be partially attributed to nitrogen assimilation rates, which can have enormous seasonal variability (Stanley and Hobbie, 1981).

It is commonly believed that wetland environments generally function as sinks for nitrogen and phosphorus (Brinson, 1977; Simpson and others, 1978). This has been documented (Sloey and others, 1978) where wetlands may be utilized for sewage treatment or other nutrient assimilation roles. The Apalachicola system shows an overall annual export of phosphorus and nearly a balance between import and export of nitrogen. In view of the seasonal variability seen for the various hydrologic periods and the changing output/input ratios described in the nutrient-transport section, it seems likely that the system does act as a nutrient sink for certain periods during each annual cycle.

Long-Term Factors Influencing Nutrient Transport

There is evidence that the nutrient and detritus transport measured in the 1979-80 study year may be considered a good indicator of what may be expected in other years. A great deal of historical stage and discharge record was examined by Leitman and others (1983). They found that during the entire period of record (1929 to 1980), the seasonal distribution of flow shows a strong tendency for flows greater than 1,000 m^3/s to occur in the spring months each year. The completion of the Jim Woodruff Dam in 1957 did not appreciably alter this pattern. Regulation by dams, however, did have some effect in diminishing the extremes, as shown by slightly flatter flow-duration curves since 1957. The 1980 mean discharge was slightly higher than the average for 1958-80, and the 1980 spring flood had a 1-day peak of 4-year recurrence interval (0.25 probability).

The 1979-80 nutrient data, in the context of the historical hydrologic record, suggest a long-range pattern of nutrient transport that is stimulated annually by spring floods. The annual flooding and the extensive natural bottom-land hardwood forest are the critical elements for continual high productivity and mobilization of nutrients in the system. The dams on the Chattahoochee and Flint Rivers and the Jim Woodruff Dam at the headwaters of the Apalachicola apparently have had little effect on the nutrient flow pattern, but any new dam or other construction in the Apalachicola basin that alters the integrity of the flood plain is likely to disrupt nutrient flow considerably.

There were no hurricanes or extremely severe rainstorms in the Apalachicola basin during 1979-80; hence, the effects of major storms could not be quantified. Hurricanes have struck the northwest Florida coast in the vicinity of the city of Apalachicola approximately 25 times during the past century. Such storms would presumably produce extremely high rainfall and, in some cases, extreme winds which would dramatically alter the normal water and nutrient flow through the Apalachicola system. An example of the effects of a severe rainstorm in 1969 in the adjacent Ochlockonee River basin was described by Bridges and Davis (1972). The amount of rainfall in that storm exceeded the 1 in 100-year probability, and Ochlockonee River floods substantially exceeded 50-year flood levels. Significant amounts of the discharge flowed through the flood plain during the storm. It should be noted that the hurricane season is between June and November. These storms, therefore, would have the effect of adding an additional flood in a normal low-flow period, rather than compounding the usual spring flood.

SUMMARY

The Apalachicola River in northwest Florida is formed by the confluence of the Chattahoochee and Flint Rivers and has a 50,800-square-kilometer drainage system encompassing parts of three states. With an average discharge of 640 m^3/s at Chattahoochee, Fla., the Apalachicola is the largest river in Florida and ranks 21st in magnitude of discharge in the conterminous United States. The river falls 12 m in its 172-km course from Lake Seminole, at the Florida-Georgia state line, to Apalachicola Bay in the Gulf of Mexico. Each winter and spring, its rising waters flood the adjacent wetlands for 3 to 5 months. The flood plain, which broadens downstream from 1 km wide just below Lake Seminole to more than 8 km wide near the mouth, is thickly forested with cypress, tupelo, and mixed hardwood trees, which thrive on the periodic inundation. At the end of its course, the river empties into the Apalachicola Bay, which is one of the most productive shellfish regions in the United States.

The bottom-land hardwood forest, which occupies the 454 square mile Apalachicola River flood plain, has experienced several generations of cutting but retains the same variety and general distribution of tree species that existed prior to timber harvest. The production, decomposition, and transport of leaf litter byproducts in the Apalachicola basin are considered representative of undisturbed bottom-land hardwood ecosystems. The description of the flood-plain contribution to the overall transport of nutrients and detritus to Apalachicola Bay includes the following specific findings:

1. The water budget of the Apalachicola basin is heavily streamflow-dominated; water volumes involved in precipitation, ground-water flow, surface-water runoff, and evapotranspiration are relatively minor compared with main-stem flow.
2. Small errors of rating curves at the four main-stem gaging stations accounted for most of the possible water-budget error. Total annual errors appeared very small because flow errors were largely compensating rather than additive. Water-budget calculations for seven time periods between June 3, 1979, and June 2, 1980, for three subbasins showed that the most satisfactory balances were obtained when longer periods and all three subbasins of the river/flood plain were combined.
3. Annual flooding, which usually occurs on the Apalachicola in late winter or early spring, causes appreciable surges in nutrient transport, especially in particulate organic form. During the 86-day flood event in 1980, approximately half of the annual outflow of organic carbon, nitrogen, and phosphorus and 60 percent of the detritus were transported past Sumatra, the final main-stem gaging station.
4. Total annual organic carbon outflow at Sumatra in 1979-80 was 50 percent higher than inflow at Chattahoochee. This increase was greater than the 25 percent increase in streamflow. Nitrogen and phosphorus increases, on the other hand, were similar to the discharge increase, indicating that the basin input of these elements to the river just matched the river's gain in water volume.
5. Flood-plain detritus nets used to estimate flood-period transport of coarse particulate organic carbon measured substantial flood-plain transport at the Sweetwater and Brickyard transects. Bottom load and suspended detritus transport in the main-stem river channel increased downstream.
6. Plastic sheets were used in combination with litter-fall estimates to make a passive net estimate of detritus transport. The amount of annual organic carbon removal calculated from these data was close to the amount determined by actual measurements.
7. On an areal basis, the Apalachicola basin exports greater quantities of carbon (13 $g/m^2/yr$) and phosphorus (0.08 $g/m^2/yr$) than most watersheds. Some nutrient ex-

port can be attributed to flood-plain contributuions, although the flood plain also acts as a nutrient sink during certain periods of the year.

8. Over the long term, the system is dependent on annual spring floods and a healthy, productive, bottom-land hardwood forest in the flood plain to maintain nutrient and detritus flow to the bay. In the absence of major alterations to the system, the floods and the flood-plain forest will continue to be present each year and the annual nutrient-flow pattern should continue.

SELECTED REFERENCES

Avery, T. E., 1967, Forest measurements: New York, McGraw-Hill, 290 p.

Beetem, W. A., Friedman, L. C., Perryman, G. R., and Watterson, C. A., eds., 1980, 1981 Water Quality Laboratory services catalog: U.S. Geological Survey Open-File Report 80-1279, 251 p.

Brakensiek, D. L., Osborn, H. B., and Rawls, W. J., coordinators, 1979, Field manual for research in agricultural hydrology: U.S. Department of Agriculture, Agriculture Handbook 224, 547 p.

Bridges, W. C., and Davis, D. R., 1972, Flood of September 20-23, 1969, in the Gadsden County area, Florida: Florida Bureau of Geology Information Circular 79, 37 p.

Brinson, M. M., 1977, Decomposition and nutrient exchange of litter in an alluvial swamp forest: Ecology, v. 58, no. 3, p. 601-609.

Brown, Eugene, Skougstad, M. W., and Fishman, M. J., 1970, Methods for collection and analysis of water samples for dissolved minerals and gases: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chap. A1, 160 p.

Brown, Sandra, 1981, A comparison of the structure, primary productivity, and transpiration of cypress ecosystems in Florida: Ecological Monographs, v. 51, no. 4, 403-427.

Buchanan, T. J., and Somers, W. P., 1968, Stage measurement at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chap. A7, 28 p.

———1969, Discharge measurements at gaging stations: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chap. A8, 65 p.

Daniel C. C., III, Wilder, H. B., and Weiner, M. S., 1979, Water quality of the French Broad River, North Carolina; An analysis of data collected at Marshall, 1958-77: U.S. Geological Survey Water-Resources Investigations 79-87, 53 p.

Darnell, R. M., 1961, Trophic spectrum of an estuarine community based on studies of Lake Pontchartrain, Louisiana: Ecology, v. 43, no. 3, p. 553-568.

Day, J. W., Butler, T. J., and Conner, W. H., 1977, Productivity and nutrient export studies in a cypress swamp and lake system in Louisiana, *in* Wiley, M. L., ed., Estuarine processes, v. 2: New York, Academic Press, p. 255-269.

de la Cruz, A. A., 1979, Production and transport of detritus in wetlands, *in* Wetland functions and values—The state of our understanding: National Symposium on Wetlands, Lake Buena Vista, Florida, 1978, Proceedings, p. 162-174.

Dethier, D. P., 1979, Atmospheric contributions to stream water chemistry in the North Cascade Range, Washington: Water Resources Research, v. 15, no. 4, p. 787-794.

Edwards, M. D., 1977, The National Water Data Exchange (NAWDEX): U.S. Geological Survey Open-File Report 77-259, 9 p.

Elder, J. F., and Cairns, D. J., 1982, Production and decomposition of forest litter fall on the Apalachicola River flood plain, Florida: U.S. Geological Survey Water-Supply Paper 2196, Chap. B, 42 p.

Elder, J. F., and Horne, A. J., 1978, Ephemeral cyanophycean blooms and their relationships to micronutrient chemistry in a southern California reservior: University of California, Sanitary Engineering Research Laboratory Report 78-1, 182 p.

Fenchel, Tom, 1970, Studies on the decomposition of organic detritus derived from the turtle grass *Thallassia testudinum*: Limnology and Oceanography, v. 15, no. 1, p. 14-20.

Galloway, J. N., and Likens, G. E., 1976, Calibration of collection procedures for the determination of precipitation chemistry: Water, Air, and Soil Pollution, v. 6, p. 241-258.

Goerlitz, D. F., and Brown, Eugene, 1972, Methods for analysis of organic substances in water: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chap. A3, 40 p.

Greeson, P. E., ed., 1978, River-quality assessments: American Water Resources Association symposium, Tucson, 1977, Proceedings, 191 p.

Guy, H. P., and Norman, V. W., 1970, Field methods for measurement of fluvial sediment: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chap. C2, 59 p.

Heald, E. J., 1971, The production of organic detritus in a south Florida estuary: University of Miami Sea Grant Program, Technical Bulletin 6, 110 p.

Hendry, C. D., and Brezonik, P. L., 1980, Chemistry of precipitation at Gainesville, Florida: Environmental Science and Technology, v. 14, p. 843-849.

Hutchison, N. E., compiler, 1975, WATSTORE user's guide: U.S. Geological Survey Open-File Report 75-426, v. 1, 300 p.

Irwin, G. A., and Kirkland, R. T., 1980, Chemical and physical characteristics of precipitation at selected sites in Florida: U.S. Geological Survey Water-Resources Investigations 80-81, 70 p.

Kilkus, S. P., LaPerriere, J. D., and Bachman, R. W., 1975, Nutrients and algae in some central Iowa streams: Journal of Water Pollution Control Federation, v. 47, no.7, p. 1870-1879.

Kwader, Thomas, and Schmidt, Walter, 1978, Top of the Floridan aquifer of northwest Florida: Florida Bureau of Geology Map Series 86.

Leitman, H. M., Sohm, J. E., and Franklin, M. A., 1983, Wetland hydrology and tree distribution of the Apalachicola River flood plain, Florida: U.S. Geological Survey Water-Supply Paper 2196, Chap. A, 52 p.

Livingston, R. J., Iverson, R. L., Estabrook, R. H., Keys, V. E., and Taylor, John, Jr., 1974, Major features of the

Apalachicola Bay system—physiography, biota, and resource management: Florida Scientist, v. 37, no. 4, p. 245-271.

Livingston, R. J., and Joyce, E. A., Jr., eds., 1977, Proceedings of the conference on the Apalachicola drainage system; Florida Department of Natural Resources: Marine Research Laboratory, Research Publication 26, 177 p.

Livingston, R. J., Kobylinski, G. J., Lewis, F. G., III, and Sheridan, P. F., 1976, Long-term fluctuations of epibenthic fish and invertebrate populations in Apalachicola Bay, Florida: Fishery Bulletin, v. 74, no. 2, p. 311-321.

Mattraw, H. C., Jr., and Elder, J. F., 1980, Nutrient yield of the Apalachicola River flood plain, Florida—River-quality assessment plan: U.S. Geological Survey Water-Resources Investigations 80-51, 21 p.

Menzel, D. W., Hulings, N. C., and Hathaway, R. R., 1966, Oyster abundance in Apalachicola Bay, Florida, in relation to biotic associations influenced by salinity and other factors: Gulf Research Reports, v. 2, no. 2, p. 73-96.

Mitsch, W. J., Dorge, C. L., and Wiemhoff, J. R., 1979, Ecosystem dynamics and a phosphorus budget of an alluvial cypress swamp in southern Illinois: Ecology, v. 60, no. 6, p. 1116-1124.

Mulholland, P. J., and Kuenzler, E. J., 1979, Organic carbon export from upland and forested wetland watersheds: Limnology and Oceanography, v. 24, no. 5, p. 960-966.

Naiman, R. J., and Sedell, J. R., 1979, Characterization of particulate organic matter transported by some Cascade Mountain streams: Journal of the Fisheries Research Board of Canada, v. 36, no. 1, p. 17-31.

Odum, E. P., and de la Cruz, A. A., 1967, Particulate organic detritus in a Georgia salt marsh—Estuarine ecosystem, *in* Lauff, G. H., ed., Estuaries: Washington, D.C., American Association for the Advancement of Science Pub. 83, p. 383-388.

Oesterling, M. L., and Evink, G. L., 1977, Relationship between Florida's blue crab population and Apalachicola Bay, *in* Livingston, R. J., and Joyce, E. A., Jr., eds., Proceedings of the conference on the Apalachicola drainage system; Florida Department of Natural Resources: Marine Research Laboratory, Research Pub. 26, p. 101-121.

Pascale, C. A., and Wagner, J. R., 1982, Water resources of the Ochlockonee River area, northwest Florida: U.S. Geological Survey Water-Resources Investigations Open-File Report 81-1121, 114 p.

Peverly, J. H., 1982, Stream transport of nutrients through a wetland: Journal of Environmental Quality, v. 11, no. 1, p. 38-41.

Qureshi, Zia, 1978, Surface water resources of northwest Florida: Water Resources Bulletin, v. 14, no. 3, p. 710-718.

Radtke, D. B., McConnell, J. B., and Carey, W. P., 1980, A preliminary appraisal of the effects of agriculture on stream quality in southwest Georgia: U.S. Geological Survey Water-Resources Investigations Open-File Report 80-771, 40 p.

Richardson, C. J., Tilton, D. L., Kadlec, J. A., Chamie, J. P. M., and Wentz, W. A., 1978, Nutrient dynamics of northern wetland ecosystems, *in* Good, R. E., and others, eds., Freshwater wetlands, ecological processes and management potential: New York, Academic Press, p. 217-241.

Rosenau, J. C., Faulkner, G. L., Hendry, C. W., Jr., and Hull, R. W., 1977, Springs of Florida: Florida Bureau of Geology Bulletin 31 (revised), 461 p.

Rosenau, J. C., and Meadows, P. E., 1977, Potentiometric surface of the Floridan aquifer in the Northwest Florida Water Management District, May 1976: U.S. Geological Survey Water-Resources Investigations Open-File Report 77-2, map.

Scheider, W. A., Moss, J. J., and Dillan, P. J., 1978, Measurement and uses of hydraulic and nutrient budget, *in* Lake restoration, proceedings of the national conference, August 22-24, 1978, Minneapolis, US EPA 440/5-79-001, p. 77-83.

Schlesinger, W. H., and Melack, J. M., 1981, Transport of organic carbon in the world's rivers: Tellus, v. 33, no. 2, p. 172-187.

Simpson, R. L., Whigham, D. F., and Walker, Raymond, 1978, Seasonal patterns of nutrient movement in a freshwater tidal marsh, *in* Good, R. E., and others, eds., Freshwater wetlands, ecological processes and management potential: New York, Academic Press, p. 243-257.

Skougstad, M. W., Fishman, M. J., Friedman, L. C., Erdmann, D. E., and Duncan, S. S., eds., 1979, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 5, Chap. A1, 626 p.

Sloey, W. E., Spangler, F. L., and Fetter, C. W., Jr., 1978, Management of freshwater wetlands for nutrient assimilation, *in* Good, R. E., and others, eds., Freshwater wetlands, ecological processes and management potential: New York, Academic Press, p. 321-340.

Smoot, G. F., and Novak, C. E., 1969, Measurement of discharge by the moving-boat method: U.S. Geological Survey Techniques of Water-Resources Investigations, Book 3, Chap. A11, 22 p.

Stamer, J. K., Cherry, R. N., Faye, R. E., and Kleckner, R. L., 1978, Magnitudes, nature, and effects of point and nonpoint discharges in the Chattahoochee River basin, Atlanta to West Point Dam, Georgia: U.S. Geological Survey Open-File Report 78-577, 74 p.

Stanley, D. W., and Hobbie, J. E., 1981, Nitrogen recycling in a North Carolina coastal river: Limnology and Oceanography, v. 26, no. 1, p. 30-42.

Taft, J. L., and Taylor, W. R., 1976, Phosphorus dynamics in some coastal plain estuaries, *in* Wiley, M. L., ed., Estuarine processes, v. 1: New York, Academic Press, p. 79-89.

Thornthwaite, C. W., and Mather, J. R., 1957, Instructions and tables for computing potential evapotranspiration and the water balance: Drexel Institute in Technology Laboratory of Climatology, Publications in Climatology, v. 10, no. 3, p. 185-306.

U.S. Army Corps of Engineers, Mobile District, 1976, Apalachicola, Chattahoochee, and Flint Rivers, Alabama, Florida, and Georgia, Final impact statement operation and maintenance: Mobile, Ala. 179 p.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Office of Coastal Zone Management, and State of Florida, Department of Environmental Regulation, Bureau of Coastal Zone Managment, 1979, Final environmental impact statement, Apalachicola River and bay estuarine sanctuary: Washington, U.S. Government Printing Office, 48 p. 13 app.

U.S. Fish and Wildlife Service, 1979, Evaluation of alternatives report for Corps of Engineers study of navigational improve-

ments of the Apalachicola River below Jim Woodruff Dam, Florida: Unpublished report on file in Panama City, Fl., office of U.S. Fish and Wildlife Service, 82 p.
U.S. Geological Survey, 1980-82, Water resources data for Florida—Northwest Florida: Annual reports as follows: 1980, Water-Data Report FL79-4; 1981, Water-Data Report FL80-4; 1982, Water-Data Report FL81-4.
Velz, C. J., 1970, Applied stream sanitation: New York, Wiley Interscience, John Wiley & Sons, 619 p.
———1978, River-quality assessment—A rational scientific basis for pollution control and water-quality management, *in* Greeson, P. E., ed., River-quality assessments, Tucson, Ariz., 1977, Proceedings: Minneapolis, Minn., American Water Resources Association, p. 3-10.
Vitousek, P. M., and Reiners, W. A., 1975, Ecosystem succession and nutrient retention—A hypothesis: Bioscience, v. 25, no. 6, p. 376-381.
Whitehead, H. C., and Feth, J. H., 1964, Chemical composition of rain, dry fallout, and bulk precipitation an Menlo Park, California, 1957-59: Journal of Geophysical Research, v. 69, p. 3319-3333.
Whittaker, R. H., Likens, G. E., Bormann, F. H., Eaton, J. S., and Siccama, T. G., 1979, The Hubbard Brook ecosystem study—Forest nutrient cycling and element behavior: Ecology, v. 60, No. 1, p. 203-220.
Winter, T. C., 1981, Uncertainties in estimating the water balance of lakes: Water Resources Bulletin, v. 17, no. 1, p. 82-115.
Woodwell, G. M., Whitney, D. E., Hall, C. A. S., and Houghton, R. A., 1977, The Flax Pond ecosystem study—Exchanges of carbon in water between a salt marsh and Long Island Sound: Limnology and Oceanography, v. 22, no. 5, p. 833-838.

SUPPLEMENTARY DATA I

Flood-plain detritus data from stationary nets located randomly on the flood plain during the spring flood, 1980. All locations were on or near the Sweetwater and Brickyard transects.

Date collected (1980)	Duration of sampling (hrs:min)	Flow-through volume (m^3)	Detritus concentration, in mg/m^3	
			Inorganic	Organic
		Sweetwater transect		
3/11	1:00	537	160	260
3/12	5:10	119	110	390
3/12	21:00	2,068	0.3	0.6
3/18	1:30	393	16	22
3/18	21:00	378	18	20
3/26	4:00	1,116	2	3
3/26	3:10	734	9	14
4/02	4:30	2,254	4	6
4/02	6:30	725	30	49
4/23	2:40	1,290	4	8
		Brickyard transect		
3/14	23:05	4,741	34	54
3/14	24:00	1,399	1	2
3/17	7:30	1,321	62	108
3/17	4:35	1,194	3	6
3/19	4:10	1,511	0.6	1.4
3/19	5:10	861	6	9
3/27	5:30	1,170	2	6
3/27	4:05	1,300	2	4
4/03	3:30	308	12	26
4/28	4:15	667	3	5
4/28	5:50	242	10	20

SUPPLEMENTARY DATA II

Deposition on plastic sheets randomly placed in Sweetwater and Brickyard plots on or about September 1, 1979, and collected on the date indicated. Coarse (>1 mm) and fine (<1 mm) fractions are given for most samples; for others, only total samples were analyzed. The area of all sheets was 1 m^2, except 4D, which was 4 m^2.

Plot	Sheet	Collection date (1980)	Inorganic deposition, in grams per square meter			Organic deposition, in grams per square meter		
			Coarse	Fine	Total	Coarse	Fine	Total
1	A	8/4	31	320	351	58	94	152
3	A	6/3	.....	.....	1,075	.....	.....	284
	B	6/3	.....	.....	1,787	.....	.....	851
	C	6/3	4	223	227	2	16	18
4	A	6/3	143	9	152	230	2	232
	B	6/3	101	6	107	208	4	212
	C	6/3	86	3	89	145	2	147
	D	6/3	.....	.....	80	.....	.....	137
5	A	6/3	91	122	213	24	6	30
	B	6/3	.....	.....	828	.....	.....	130
	C	6/3	70	230	300	24	8	32
6	A	6/3	45	823	868	14	68	82
	B	6/3	112	1,378	1,490	95	135	230
	C	6/3	169	287	456	68	24	92
7	A	6/3	0.3	424	424	0.2	2.4	2.7
	B	6/3	1.1	122	123	0.8	0.7	1.5
	C	6/3	3	1,853	1,856	2	11	13
11	A	7/9	379	205	584	81	22	103
12	B	8/5	22	419	441	23	36	59
	C	8/5	53	509	562	60	44	104
13	A	8/5	11	195	206	15	17	32
	C	8/5	36	769	805	47	81	128
14	A	5/6	38	18,699	18,737	25	319	345
	B	6/6	255	11,643	11,898	179	369	548
	C	5/6	12	20,559	20,571	14	179	193
15	A	8/5	1	106	107	1	9	10
	B	8/5	53	38	91	21	3	24
16	C	8/5	73	1,403	1,476	49	126	175
17	A	8/5	75	58	133	38	5	43
	B	8/5	45	581	626	17	58	75
18	A	8/5	10	5	15	6	1	7

Metric Conversion Factors

For readers who prefer to use inch-pound units rather than metric units, the conversion factors for the terms used in this report are listed below:

Multiply metric unit	By	To obtain inch-pound unit
	Length	
μm (micrometer)	0.00003937	in. (inch)
mm (millimeter)	.03937	in. (inch)
m (meter)	3.281	ft (foot)
	1.094	yd (yard)
km (kilometer)	.6214	mi (mile)
m/s (meter per second)	3.281	ft/s (Foot per second)
	Area	
m^2 (square meter)	10.76	ft^2 square foot
	1.196	yd^2 (square yard)
	0.0002471	acre
ha (hectare)	2.471	acre
km^2 (square kilometer)	0.3861	mi^2 (square mile)
	Volume	
m^3 (cubic meter)	35.31	ft^3(cubic foot)
	1.308	yd^3 (cubic yard)
	0.0008107	acre-ft (acre-foot)
	264.2	gal (gallon)
L (liter)	1.0567	qt (quart)
m^3/s (cubic meter per second)	35.3145	ft^3/s (cubic foot per second)
km^3 (cubic kilometer)	0.2399	mi^3 (cubic mile)
	810,700	acre-ft (acre-foot)
	264,200	Mgal (million gallons)
mL (milliliter)	0.0338	oz (fluid ounce)
	Mass	
mg (milligram)	0.0000353	oz (ounce)
g (gram)	0.0353	oz (ounce)
	0.0022	lb (pound)
kg (kilogram)	2.2046	lb (pound)
t (metric ton)	2,204.6	lb (pound)
	1.1023	short (ton)
t/ha (metric ton per hectare)	892.18	lb/acre (pound per acre)
	0.4461	ton per acre
t/km^2 (metric ton per square kilometer)	8.9218	lb/acre (pounds per acre)
	0.004461	tons per acre
g/m^2 (gram per square meter)	8.9218	lb/acre (pound per acre)
	Temperature	
°C (degree Celsius)	1.8 (+32°)	°F (degree Fahrenheit)
	Concentration	
mg/L (milligrams per liter)	1.0	ppm (parts per million)
μg/L (micrograms per liter)	1.0	ppb (parts per billion)

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