INLAND TRAVEL OF TIDE-DRIVEN SALINE WATER IN THE ALTAMAHA AND SATILLA RIVERS, GEORGIA, AND THE ST. MARYS RIVER, GEORGIA-FLORIDA

By Myron H. Brooks and James B. McConnell

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4086

Prepared in cooperation with the

U.S. ARMY CORPS OF ENGINEERS
Savannah District

U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849

Doraville, Georgia

1983

UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information
write to:

District Chief
U.S. Geological Survey
Suite B
6481 Peachtree Industrial Blvd.
Doraville, Georgia 30360

Copies of this report can
be purchased from:

Open-File Services Section
Western Distribution Center
U.S. Geological Survey
Box 25425, Federal Center
Denver, Colorado 80225
(Telephone: (303) 234-5888)

CONTENTS

ILLUSTRATIONS

TABLES

FACTORS FOR CONVERTING INCH-POUND UNITS TO INTERNATIONAL SYSTEM OF UNITS (SI)

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
inch (in.)	25.4	millimeter (mm)
mile (mi)	1.609	kilometer (km)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
part per thousand (o/oo)	1	gram per kilogram (g/kg)
micromho per centimeter (umho/cm)	1	microsiemens (uS/cm)

NATIONAL GEODETIC VERTICAL DATUM OF 1929 (NGVD of 1929). A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

INLAND TRAVEL OF TIDE-DRIVEN SALINE WATER IN THE ALTAMAHA AND SATILLA RIVERS, GEORGIA, AND THE ST. MARYS RIVER, GEORGIA-FLORIDA

By

M. H. Brooks and J. B. McConnell

ABSTRACT

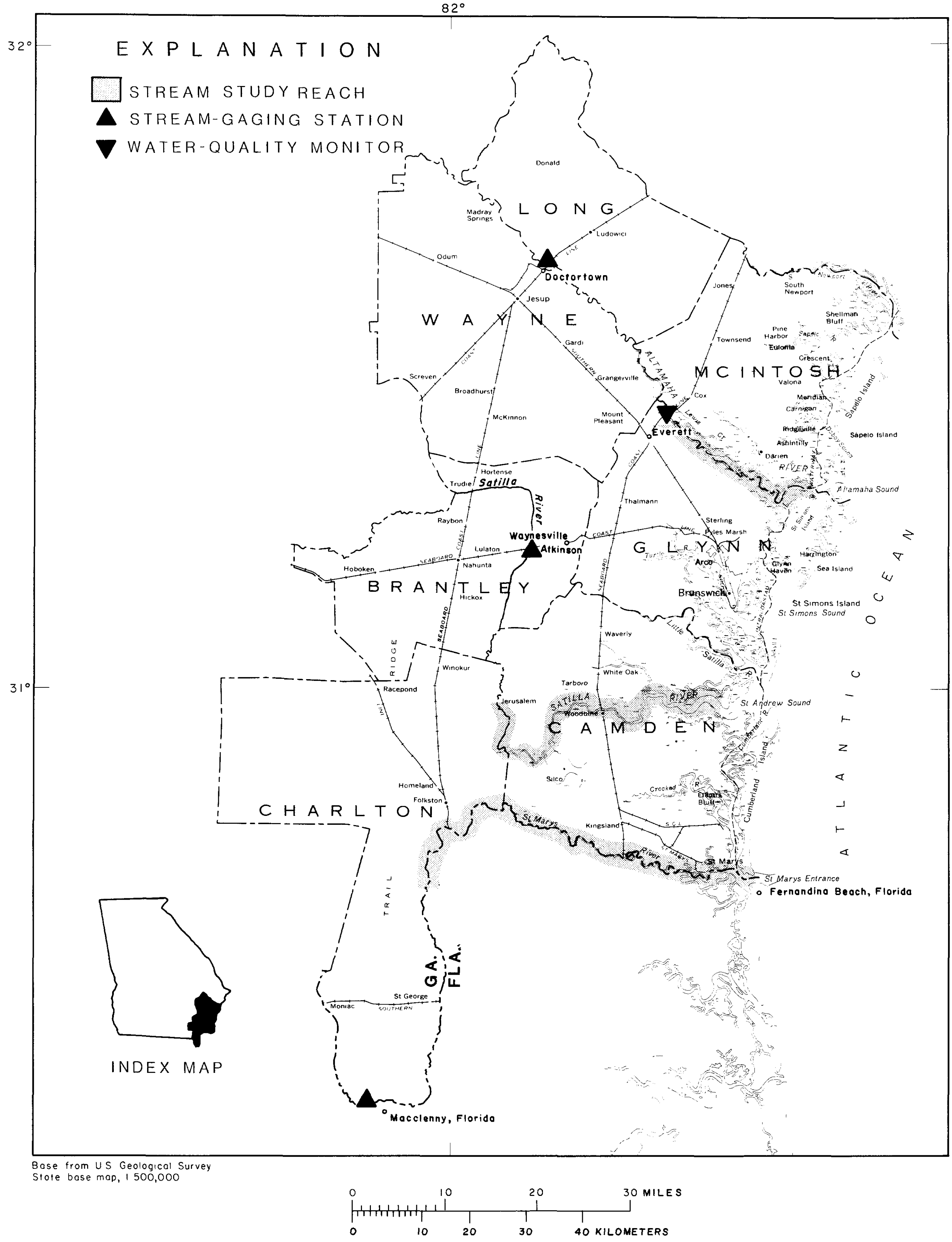
The inland travel of saline water from the ocean into the Altamaha and Satilla Rivers in Georgia, and the St. Marys River in Georgia-Florida, was investigated in November 1981. Abnormally high tides coupled with low river flows probably resulted in near maximum inland travel of saline water into these rivers. The maximum tide heights during the days of the investigations, measured by a tide-stage recorder at Fernandina Beach, Florida, were 6.3 feet (November 13) and 5.8 feet (November 14) above sea level. The maximum tide height for the 31-year period of record was 6.8 feet. Mean daily flows of the Altamaha, Satilla, and St. Marys Rivers at stream-gaging stations in the vicinity of the study reaches were 2,080, 84, and 109 cubic feet per second, respectively. Minimum flows for the period of record were 1,430, 21, and 12 cubic feet per second, respectively.

Specific conductance served as an indicator of ocean-derived saline water in the rivers and was used to determine the chlorinity gradients of the river reaches. The maximum distance saline water traveled inland during the high tides was about 24 river miles in the Altamaha River, 51.5 river miles in the Satilla River, and 40.2 river miles in the St. Marys River.

INTRODUCTION

The dissolved-salts concentration in the coastal reaches of Georgia's rivers is sufficiently low to make the water suitable for most uses. However, the water may become temporarily unsuitable for many uses when mixed with saline water that travels inland with the rising tide. Information concerning the extent of inland travel of the saline water and the degree of dilution is useful for planning and managing the water resources in the coastal reaches of these rivers.

The inland travel of saline water from the ocean into the Altamaha and Satilla Rivers in Georgia and the St. Marys River in Georgia-Florida (fig. 1) was investigated in November 1981. Strong northeasterly winds produced abnormally high spring tides along the Georgia coast during the study. The high tides, coupled with low river flows, probably resulted in near maximum inland travel of saline water into these rivers. The purpose of this study was to determine the distance the tide-driven saline water from the ocean traveled upstream and to define the specific-conductance and chlorinity gradients in the lower reaches of the Altamaha, Satilla, and St. Marys Rivers during the high spring tide and low-flow event.



Base from U.S. Geological Survey State base map, 1:500,000

Figure 1.— Location of stream-gaging stations and stream study reaches.

METHODS

Specific conductance was used as an indicator of ocean-derived saline water in the rivers. Measurements of specific conductance were used to locate the point of maximum inland penetration of saline water in the rivers and to approximate the specific-conductance and chlorinity gradients of the river reaches.

Chlorinity was determined from specific-conductance measurements by use of an empirical relation between salinity and specific conductance and between salinity and chlorinity.

The relation between salinity and specific conductance is not simple. An empirical relation from an extensive data set developed by Cox and others (1967) is:

$$S(o/oo) = -0.08966 + 28.2972R + 12.80832R^2 - 10.67869R^3 + 5.98624R^4 - 1.3231R^5, \quad (1)$$

where R is the ratio of specific conductance of the sample water to the specific conductance of seawater with both specific conductance values corrected to the same temperature.

Specific conductance is corrected to 25°C in this study. The specific conductance of 35 o/oo seawater at 25°C is 53,000 umho/cm (micromhos per centimeter). At a specific conductance ratio of unity (specific conductance of sample equals the specific conductance of 35 o/oo seawater), the salinity computed from equation 1 equals 35 o/oo.

The empirical relation between salinity and chlorinity (American Public Health Association, 1980) is:

$$S(o/oo) = 0.03 + 1.805 \times \text{chlorinity } (o/oo) \quad (2)$$

Chlorinity was calculated from specific conductance by use of the following equation which resulted from the combination of equations 1 and 2:

$$\text{Chlorinity } (o/oo) = ((-0.08966 + 28.2972R + 12.80832R^2 - 10.67869R^3 + 5.98624R^4 - 1.3231R^5) - 0.03)/1.805 \quad (3)$$

The relation defined by equation 3 is presented graphically in figure 2. The lower end of the curve (specific conductance less than 300 umho/cm) is based on measured chlorinity rather than computed chlorinity. The data points for the Altamaha, Satilla, and St. Marys Rivers, shown in figure 2, represent specific conductance and chlorinity measured on samples collected at or near the gaging stations in October 1981 at river flows similar to the flows during the study period. A discrepancy may exist between the true chlorinity and the computed chlorinity for ocean water that has been strongly diluted by river water due to a markedly different major constituent composition of the rivers compared to the major constituent concentration of the ocean water. Therefore, for this study the computed chlorinity of strongly diluted ocean water should be considered an approximation of the true chlorinity. The lower end of the curve (specific conductance less than 300 umho/cm) is judged to closely approximate the specific conductance-chlorinity relation of the three rivers at low flow.

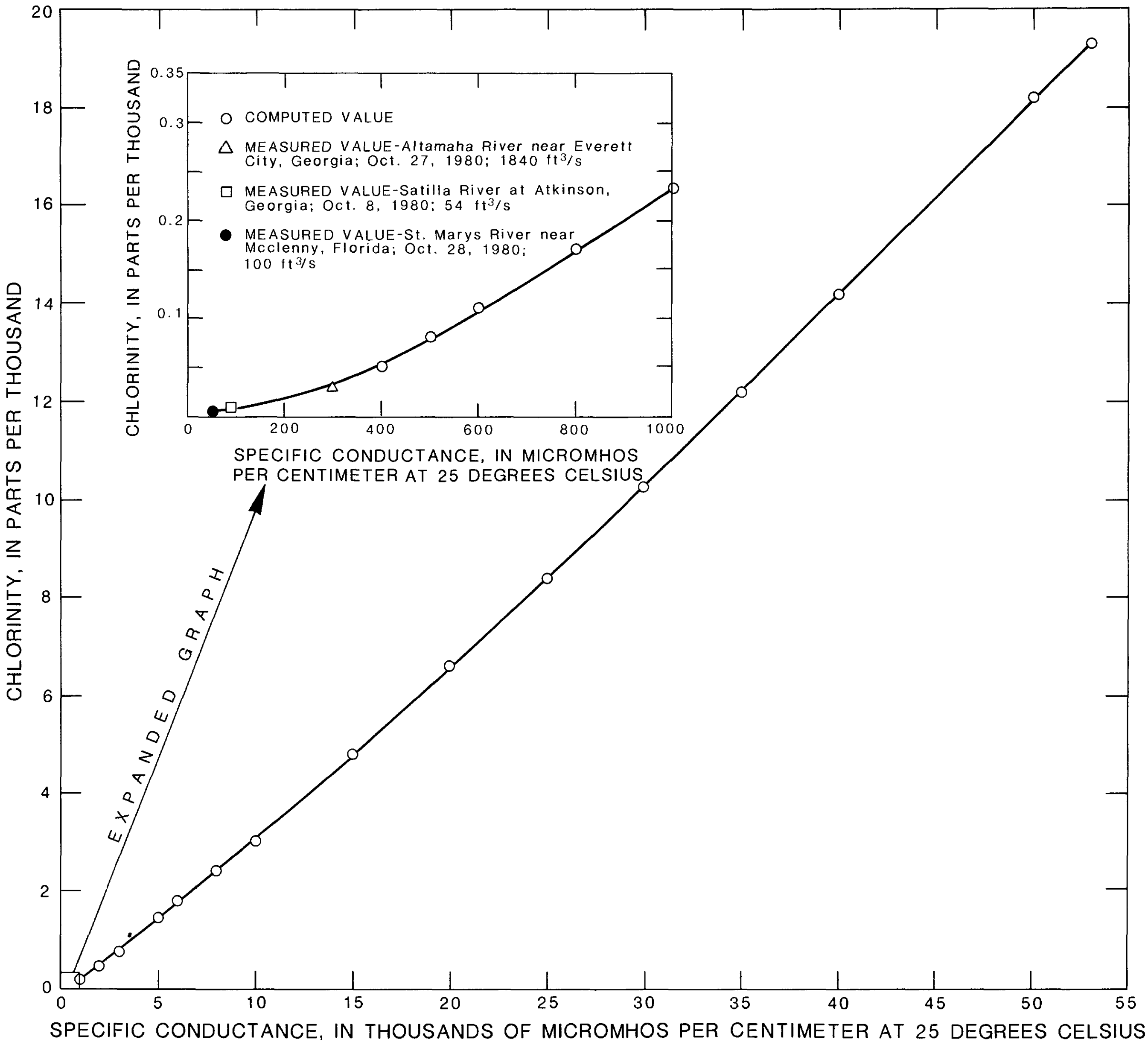


Figure 2.— Relation of specific conductance to chlorinity.

Specific conductance was measured from a boat while rapidly transversing the freshwater-saline water mixing zone of each river near the time that the saline water had traveled farthest inland on the floodtide. The maximum inland travel of the floodtide was determined by observing the increase of specific conductance at a fixed site near the upstream end of the freshwater-saline water mixing zone. A maximum specific conductance at the fixed site signaled the end of the inland travel of saline water for that floodtide. Near the time of maximum specific conductance, measurements began upstream of the saline water and continued downstream through the freshwater-saline water mixing zone to a point where the specific conductance indicated that the river had a high dissolved-salts concentration. Measurements were made near the surface and the bottom of the water column with a Yellow Springs specific-conductance meter.[1] Specific conductance for the Altamaha River also was obtained from a U.S. Geological Survey water-quality monitoring station near Everett City, Ga. In the lower reach of the St. Marys River, specific conductance was measured on samples collected near the surface, by hand from the riverbank, at high slack tide.

The times of the measurements were recorded and the locations of the measurement sites were marked on U.S. Geological Survey 7.5-minute topographic maps. Distances in RM (river miles above mouth) were obtained from the U.S. Army Corps of Engineers (1965; 1970). Where published river mileages were unavailable, the distances were determined from 7.5-minute topographic maps by use of a distance-measuring wheel. The location of the maximum inland travel of saline water was considered to be the point in the reach where specific conductance was not appreciably different from measurement sites further upstream. Specific-conductance and chlorinity profiles were constructed for the study reaches by using the maximum specific conductance measured at each site.

Maximum tide heights were obtained from a National Ocean Survey continuous tide-stage recorder located at Fernandina Beach, Fla., which was the nearest official recorder to the study area. Tide heights were expressed in feet above sea level. River flows upstream of the study reaches were determined at U.S. Geological Survey stream-gaging stations. (See fig. 1.) Flows at the upstream ends of the study reaches were determined by extrapolation downstream from the gaged sites in proportion to the increase in drainage areas. The extrapolated river flows are approximate flows, because low-flow characteristics of the reaches between the gages and the upstream ends of the study area are not known.

RESULTS

The inland travel of tide-driven saline water was measured in the Satilla River on November 13 and in the Altamaha and St. Marys Rivers on November 14. During the measurement periods, the maximum tide heights at the Fernandina Beach recorder were 6.3 ft (Nov. 13) and 5.8 ft (Nov. 14) above sea level. The maximum tide height for the period of record (1939 to 1981) was 6.8 ft above sea level on September 10, 1964 (U.S. Department of Commerce, written commun., 1982).

[1] The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Generally, river flows were low during the study period. The flow in the Altamaha River at the Doctortown gage was less than the 7-day, 10-year low flow. Flows in the Satilla River at the gage at Atkinson and in the St. Marys River at the gage near Macclenny, Fla., were about 2.4 and 6.8 times greater than the 7-day, 10-year low flow. The river-flow statistics, specific-conductance measurements, and computed salinities are presented separately for each river.

Altamaha River

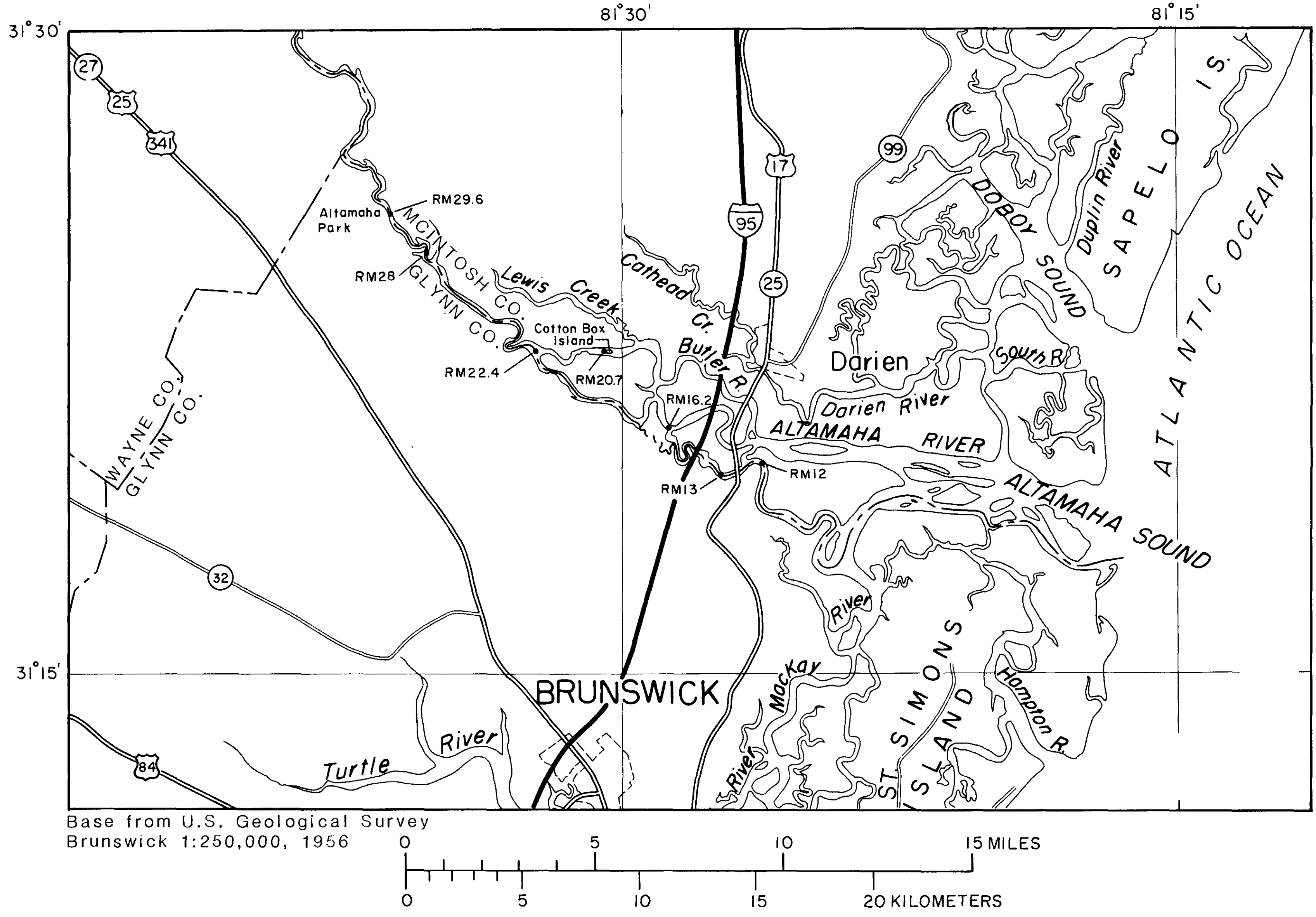
The study reach of the Altamaha River extended from RM 12 to RM 29.6 (fig. 3). A U.S. Geological Survey water-quality monitor is located at RM 29.6. The mean daily river flow at the U.S. Geological Survey stream-gaging station on the Altamaha River near Doctortown (RM 64.5) was 2,080 ft^3/s on November 14 and the estimated flow at the upstream end of the study reach (RM 29.6) was 2,100 ft^3/s. The minimum flow for the year at the gaging station was 1,790 ft^3/s on October 22. The lowest flow for the period of record at the gaging station (1931 to 1981) was 1,430 ft^3/s (Nov. 1, 1954). Frequency analysis of low flows indicates that the 7-day, 10-year low flow at the gaging station was 2,250 ft^3/s (Carter and Putnam, 1978).

Specific conductance ranged from 24,300 umho/cm at RM 12 to 250 umho/cm near RM 28. Specific conductance at the measurement sites and the corresponding chlorinities determined from figure 2 are listed in table 1. Specific conductance was reported for depths near the surface and near the bottom because the water column was not completely mixed. Specific-conductance and chlorinity gradients of the near bottom measurements for the study reach are shown in figure 4. The point of maximum inland travel of saline water was considered to be near RM 24 because the specific conductance did not decrease appreciably upstream from that point.

Satilla River

The study reach of the Satilla River extended from RM 25.7 to RM 53.5 (fig. 5). The mean daily river flow at the U.S. Geological Survey stream-gaging station on the Satilla River at Atkinson (RM 93.1) was 84 ft^3/s on November 13 and the estimated flow at the upstream end of the study reach (RM 53.5) was 92 ft^3/s. The minimum flow for the year at the gaging station was 27 ft^3/s on October 1. The lowest flow for the period of record (1930 to 1981) at the gaging station was 21 ft^3/s (Nov. 1954). Frequency analysis of low flows indicates that the 7-day, 10-year low flow at the gaging station was 38 ft^3/s (Carter and Putnam, 1978).

Specific conductance in the study reach ranged from 24,200 umho/cm at RM 25.7 to 80 umho/cm at RM 53.5. Specific conductance at the measurement sites and the corresponding chlorinities determined from figure 2 are listed in table 2. Specific conductance was reported at only one depth because the river was vertically well-mixed. Specific-conductance and chlorinity gradients for the study reach are shown in figure 6. The point of maximum inland travel of saline water was considered to be RM 51.5 because the specific conductance did not substantially decrease upstream from that point.



Base from U.S. Geological Survey
Brunswick 1:250,000, 1956

EXPLANATION

RM 13 —— MEASUREMENT SITE AND RIVER MILES UPSTREAM FROM MOUTH

Figure 3.— Location of measurement sites, Altamaha River.

Table 1.--Specific conductance and chlorinity at measurement sites, Altamaha River, November 14, 1981

Measurement site (river miles upstream from mouth)	Measurement depth (feet below water surface)	Specific conductance (micromho per centimeter at 25°C)	Chlorinity (parts per thousand)
12.0	3	22,500	7.5
	15	24,300	8.2
13.0	3	18,200	6.0
	14	18,200	6.0
16.2	3	8,600	2.6
	15	9,100	2.8
20.7	3	2,030	.5
	15	2,210	.6
22.4	3	320	.040
	15	350	.040
28.0	3	250	.025
	13	250	.025
29.6	3	250	.025
	9	250	.025

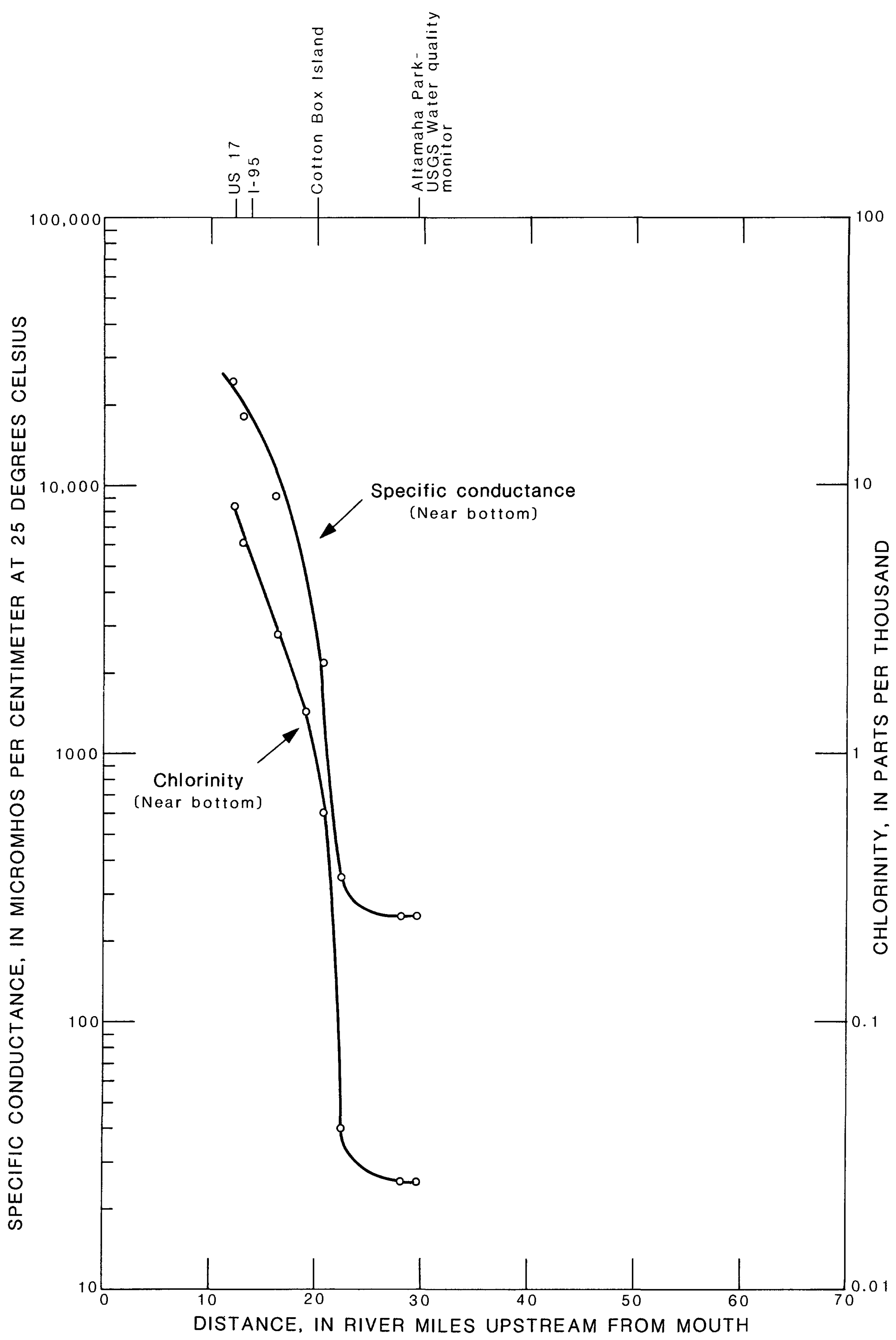
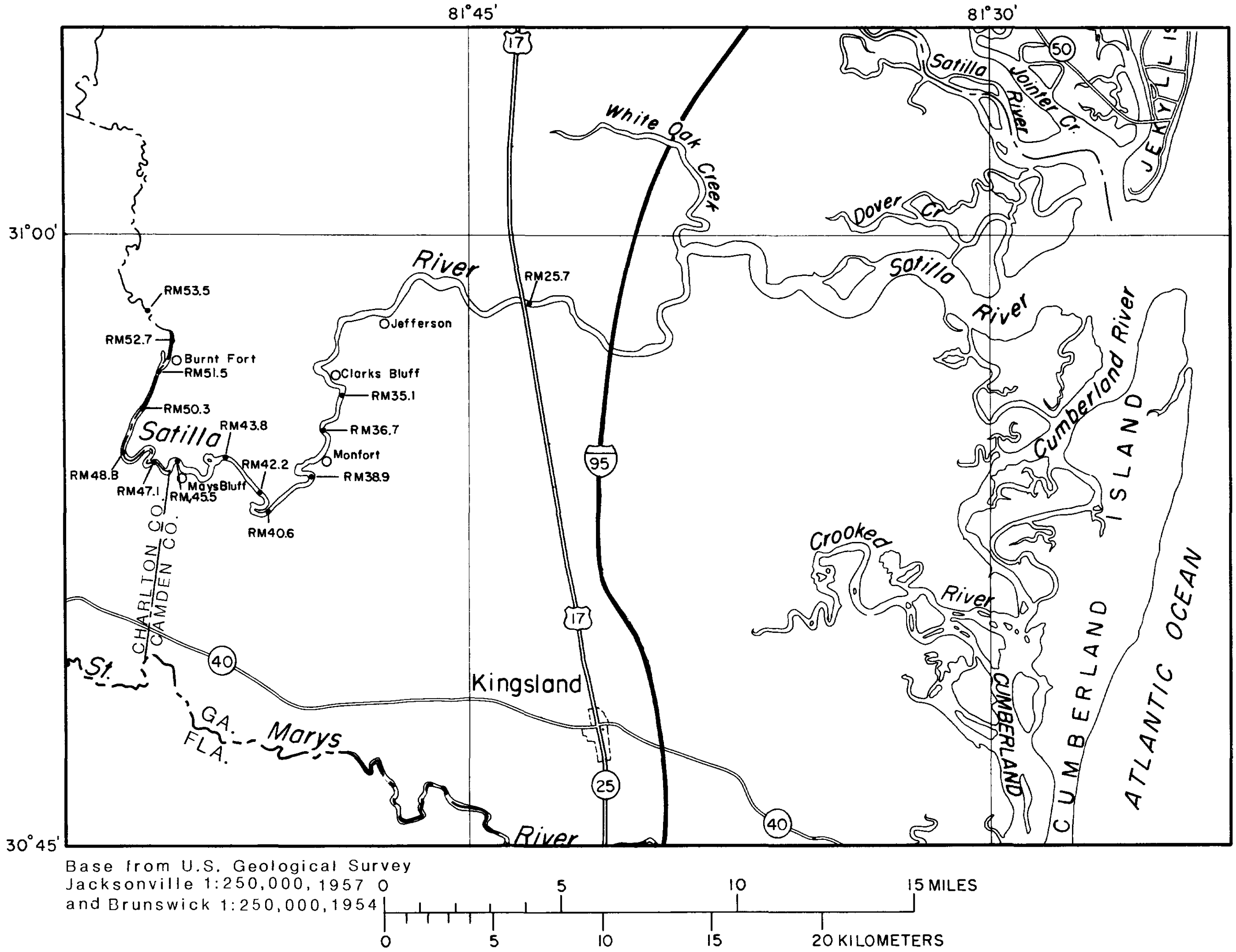


Figure 4.— Specific-conductance and chlorinity gradients, Altamaha River, November 14, 1981.



Base from U.S. Geological Survey
Jacksonville 1:250,000, 1957
and Brunswick 1:250,000, 1954

EXPLANATION

RM 40.6 —— MEASUREMENT SITE AND RIVER MILE UPSTREAM FROM MOUTH

Figure 5.— Location of measurement sites, Satilla River.

St. Marys River

The study reach of the St. Marys River extended from RM 4.2 to RM 60.5 (fig. 7). The mean daily river flow at the U.S. Geological Survey stream-gaging station near Macclenny, Fla., (RM 100) was 109 ft^3/s on November 14, and the estimated flow at the upstream end of the study reach (RM 60.5) was 180 ft^3/s. These flows were much greater than the minimum flow for the year at the gaging station which was 30 ft^3/s on July 17 and 18. The lowest flow for the period of record (1926 to 1981) at the gaging station was 12 ft^3/s (May 22, 1932). Frequency analysis of low flows indicates that the 7-day, 10-year low flow was 16 ft^3/s (Carter and Putnam, 1978).

Specific conductance in the study reach ranged from 48,000 umho/cm at RM 4.2 to 100 umho/cm at RM 57.7. Specific conductance at the measurement sites and the corresponding chlorinities determined from figure 2 are listed in table 3. Specific conductance was reported at only one depth because the river was vertically well-mixed. Specific-conductance and chlorinity gradients are shown in figure 8. RM 40.2 was considered to be near the point of maximum inland travel of saline water because the specific conductance did not appreciably decrease upstream from that point.

DISCUSSION

The specific-conductance gradients of the rivers show the effect that abnormally high spring tides and low flows have on the inland travel of ocean-derived saline water. Saline water probably would have traveled farther inland than it did during the study period if the river flows had been near the minimum flows of record. However, the specific conductances that defined the specific-conductance gradients in the study reaches should not be exceeded for most tide and river-flow conditions. For the Altamaha and Satilla Rivers, the specific-conductance gradients for the upper halves of the study reaches were more accurately defined at the time of maximum inland travel than were the specific-conductance gradients for the lower halves of the study reaches. More accurately defined gradients occurred in the upper river reaches because measurements began in the upper reaches of these two rivers. By the time measurements were finished in the lower reaches, the tide was ebbing, which resulted in lower specific-conductance values than occurred at high slack tide. Measurements in the river reaches were made in a downstream direction even though high slack tide occurs at a sucessively later time in an upstream direction. Equipment and manpower constraints required that an effort be made first to determine the point of maximum inland penetration of saline water at high slack water and then to measure the specific-conductance gradient. For the St. Marys River, the samples collected from the riverbank in the lower reach at high slack tide accurately defined the maximum specific conductance at the measurement sites.

The specific-conductance and chlorinity gradients of the rivers (figs. 4, 6, and 8) can be used to approximate the location along the river reaches where a desired specific conductance or chlorinity will not be exceeded for most tide and river-flow conditions. For example, if a water intake needs to be located on the Altamaha River where the specific conductance will not exceed 2,000 umho/cm (approximate chlorinity of 0.5 o/oo), then the location of the intake would be in the vicinity of RM 20.5. (See fig. 4.) In selecting a desirable site, a "safety" factor should be considered to allow for:

Table 2.--Specific conductance and chlorinity at measurement sites, Satilla River, November 13, 1981

[Measurement depth about 3 feet below water surface]

Measurement site (river miles upstream from mouth)	Specific conductance (micromho per centimeter at 25°C)	Chlorinity (parts per thousand)
25.7	24,200	8.1
35.1	8,300	2.5
36.7	6,200	1.9
38.9	4,660	1.4
40.6	3,510	1.0
42.2	2,750	.8
43.8	1,810	.5
45.5	1,205	.3
47.1	840	.2
48.8	410	.055
50.3	210	.020
51.5	105	.015
52.7	92	.010
53.5	89	.010

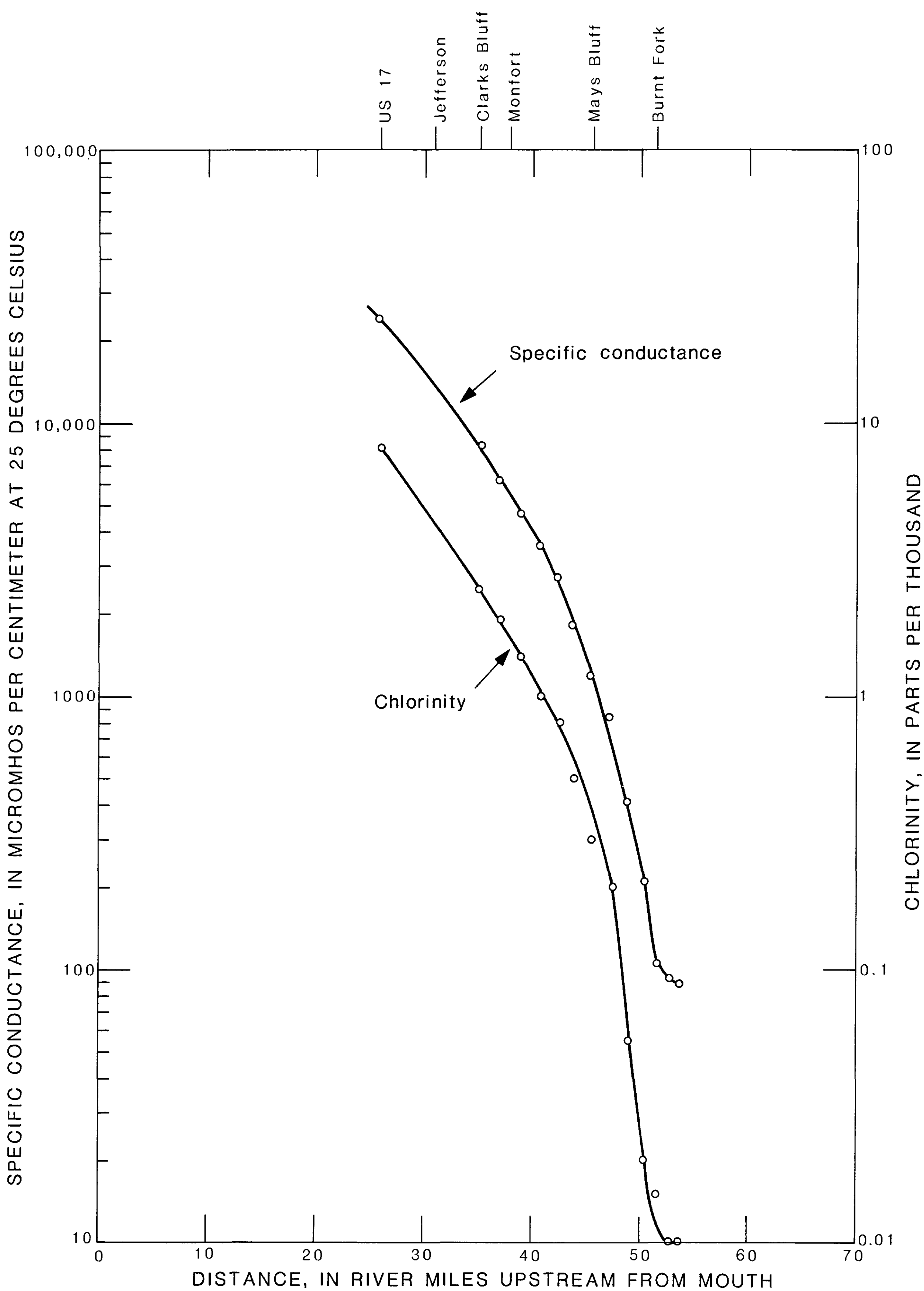
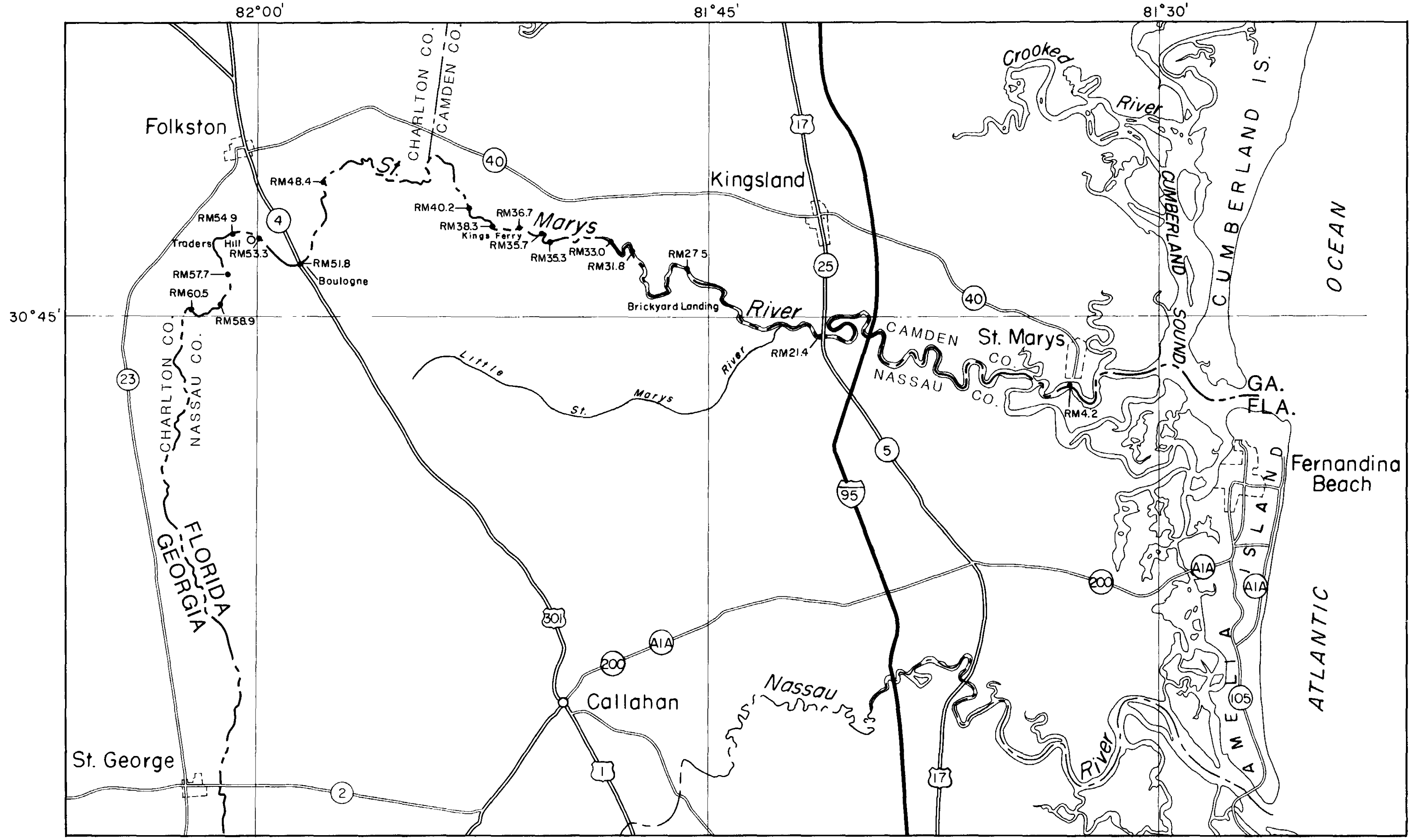


Figure 6.— Specific-conductance and chlorinity gradients, Satilla River, November 13, 1981.



Base from U.S. Geological Survey
Jacksonville 1:250,000, 1957 and
Valdosta 1:250,000, 1954

EXPLANATION

RM 21.4—MEASUREMENT SITE AND RIVER MILES UPSTREAM FROM MOUTH

Figure 7.— Location of measurement sites, St. Marys River, Georgia-Florida.

Table 3.--Specific conductance and chlorinity at measurement sites, St. Marys River, November 14, 1981

[Measurement site about 3 feet below water surface; *, specific conductance measured from samples collected from the riverbank at high slack tide]

Measurement site (river miles upstream from mouth)	Specific conductance (micromho per centimeter at 25°C)	Chlorinity (parts per thousand)
4.2	48,000*	17.3
21.4	25,200*	8.5
27.5	14,250*	4.6
31.8	5,250*	1.6
33.0	3,100*	.9
35.3	1,300	.3
35.7	850	.2
36.7	505	.1
38.3	230	.020
40.2	145	.010
48.4	125	.010
51.8	115	.010
53.3	115	.010
54.9	110	.010
57.7	100	.010
58.9	100	.010
60.5	100	.010

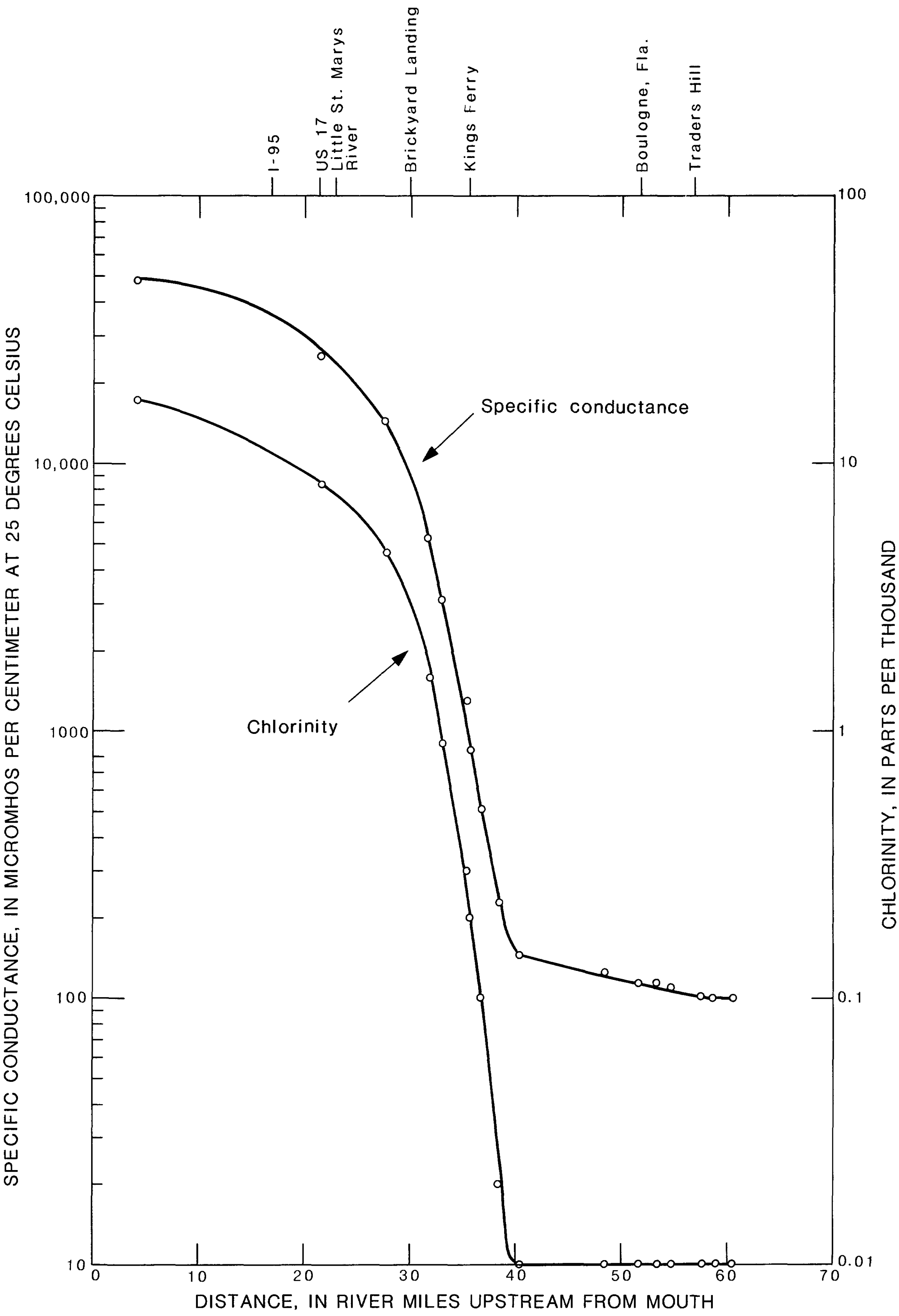


Figure 8.— Specific-conductance and chlorinity gradients, St. Marys River, Georgia-Florida, November 14 ,1981.

(1) the uncertainty of the specific-conductance gradients in the lower reaches of the Altamaha and Satilla Rivers, (2) the uncertainty in the specific conductance-salinity relation for strongly diluted seawater, and (3) the possibility that a combination of extreme hydrologic events could cause higher salinities farther inland than occurred during this study period.

The findings presented in this report could be verified and improved by the collection of data during low flow, high spring tide events that occur in the future. Data would be collected to accurately locate the points of maximum inland travel of saline water and to accurately define the specific-conductance and chlorinity gradients in the lower reaches of the rivers investigated. The relation between specific conductance and chlorinity for each river would be determined experimentally by analyzing river-water samples for chlorinity.

REFERENCES CITED

American Public Health Association, 1980, Standard methods for the examination of water and wastewater (15th ed.): Washington, D.C., 1134 p.

Carter, R. F., and Putnam, S. A., 1978, Low-flow frequency of Georgia streams: U.S. Geological Survey Water-Resources Investigations 77-127, 104 p.

Cox, R. A., Culkin, F., and Riley, J. P., 1967, The electrical conductivity/chlorinity relationship in natural seawater: Deep Sea Research, v. 14, p. 203-220.

U.S. Army Corps of Engineers, 1965, Satilla River, Georgia, St. Marys and Suwannee Rivers, Georgia and Florida: Review Report, U.S. Engineer District, Savannah, Georgia, 272 p.

_____ 1970, Altamaha River survey: U.S. Army Engineer District, Savannah, Georgia, sheets 3-30.

DEFINITION OF TERMS

Chlorinity.--The weight of chloride, bromide, and iodide, reported as chloride, dissolved in one kilogram of water. Chlorinity is commonly reported as grams per kilogram or parts per thousand (o/oo).

Salinity.--The total solids in water after all carbonates have been converted to oxides, all bromide and iodide have been replaced by chloride, and all organic matter has been oxidized. Salinity is usually reported as grams per kilogram or parts per thousand (o/oo).

Seven-day, 10-year low flow.--The average low flow for 7 consecutive days with a 10-year recurrence interval.

Specific conductance.--Electrical conductance, or conductivity, is the ability of a substance to conduct an electrical current. By definition, specific conductance is the reciprocal of the resistance measured between two platinum electrodes separated by 10 mm and having a cross section of 10 mm^2. Specific conductance is usually expressed as micromhos (reciprocal megaohms) per centimeter at 25 degrees Celsius.

*U.S. GOVERNMENT PRINTING OFFICE: 1984-748-369/5069 Region 4.