Salt-Water Encroachment in the South Edisto River Estuary, South Carolina

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1586-I

Prepared in cooperation with the South Carolina State Development Board

Cummings—SALT-WATER ENCROACHMENT IN THE SOUTH EDISTO RIVER ESTUARY, SOUTH CAROLINA—Geological Survey Water-Supply Paper 1586-I

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By T. RAY CUMMINGS

HYDROLOGY OF TIDAL STREAMS

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By T. RAY CUMMINGS

ABSTRACT

Salt-water encroachment in the South Edisto River estuary in South Carolina is related to river discharge, tidal heights, and weather. Encroachment alters the chemical characteristics of water for about 25 miles inland. At a sampling station 4.5 miles southeast of Jacksonboro, S.C., salt water is detectable, but only on rare occasions. At a sampling station 7 miles southeast of Jacksonboro, however, the water has a specific conductance as great as 10,000 micromhos, and is unsuitable at times for most domestic and industrial uses.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION

This report summarizes the results of an investigation of salt-water encroachment in the South Edisto River estuary during the period January 1958 to September 1962. The principal purpose of the investigation was to determine how far salt water moves into the estuary and the chemical characteristics of water in the vicinity of the point of maximum inland movement.

COOPERATION AND COLLECTION OF BASIC DATA

The investigation was part of a cooperative program between the U.S. Geological Survey and the South Carolina State Development Board, Mr. W. W. Harper, Director. Mr. Harper was succeeded by Mr. J. D. Little, Jr. Water-quality data were collected and analyzed under the supervision of Granville A. Billingsley, District Chemist, U.S. Geological Survey, Raleigh, N.C. Discharge records were collected under the supervision of Albert E. Johnson, District Engineer, U.S. Geological Survey, Columbia, S.C. Basic data used in preparing this report have been given by Harris (1962) and in the U.S. Geological Survey's series of water-supply papers (see "References Cited," p. I 19).

CHARACTERISTICS OF ESTUARINE WATERS

Sea water varies slightly in composition from place to place over the world, but compared to the water from most rivers, it is a highly mineralized solution.[1] When sea and river water mix in an estuary, the body of salt water that results has a composition that reflects the quantity and the quality of the waters that mix and the manner in which they mix.

The movement inland of a body of salt water is called encroachment. Because salt water has a greater density than fresh water, it frequently moves inland as a density current along the bottom of a channel, while, at the same time, less dense fresh water moves seaward at the surface. At a given location in an estuary, the boundary between salt water in the bottom of the channel and overlying fresh water may be sharp and well defined, or the boundary may be absent and replaced by a gradual transition from fresh to salt water. Under other conditions, mixing of salt and fresh water may be complete, or nearly so, and the composition of the water moving inland may be homogeneous.

The manner in which sea and river water mix and the extent of salt-water encroachment depend on several factors. Among these are tides, currents, fresh-water discharge, sea level, winds, depth and configuration of an estuary, the rotation of the earth, temperature of both sea and fresh water, evaporation, and rainfall.

DESCRIPTION OF THE SOUTH EDISTO RIVER ESTUARY

LOCATION AND PHYSICAL CHARACTERISTICS

The Edisto River drains an area of about 3,000 square miles in south-central South Carolina. Drainage is generally in a southeasterly direction until the river reaches Givhans, in Dorchester County. Near Givhans the river turns south and flows about 60 miles to the Atlantic Ocean. Figure 1 is a map of the estuary.

Figure 1 shows that the Edisto River becomes the South Edisto River below the Dawho River entrance. In this report the estuary is referred to as the South Edisto River estuary, although a considerable reach of the estuarine channel is part of the Edisto River.

Near the mouth the estuary is 1½–2 miles wide, and at mean low water, it is about 35 feet deep at the deepest point. About 4 miles upstream from the mouth, the channel narrows to about a half a mile, and it is about 20 feet deep at mean low water. Twenty miles upstream

[1] Normally, sea water contains about 35,000 ppm (parts per million) of dissolved solids, the most abundant constituents being sodium and chloride. A sample of sea water collected from the Atlantic Ocean near Miami, Fla., in 1941 had the following composition, in parts per million: Calcium, 423; magnesium, 1,324; sodium, 10,970; potassium, 429; bicarbonate, 147; sulfate, 2,750; chloride, 19,770; bromide, 49; and total dissolved solids, 35,800 (Parker, Ferguson, Love, and others, 1955, p. 572).

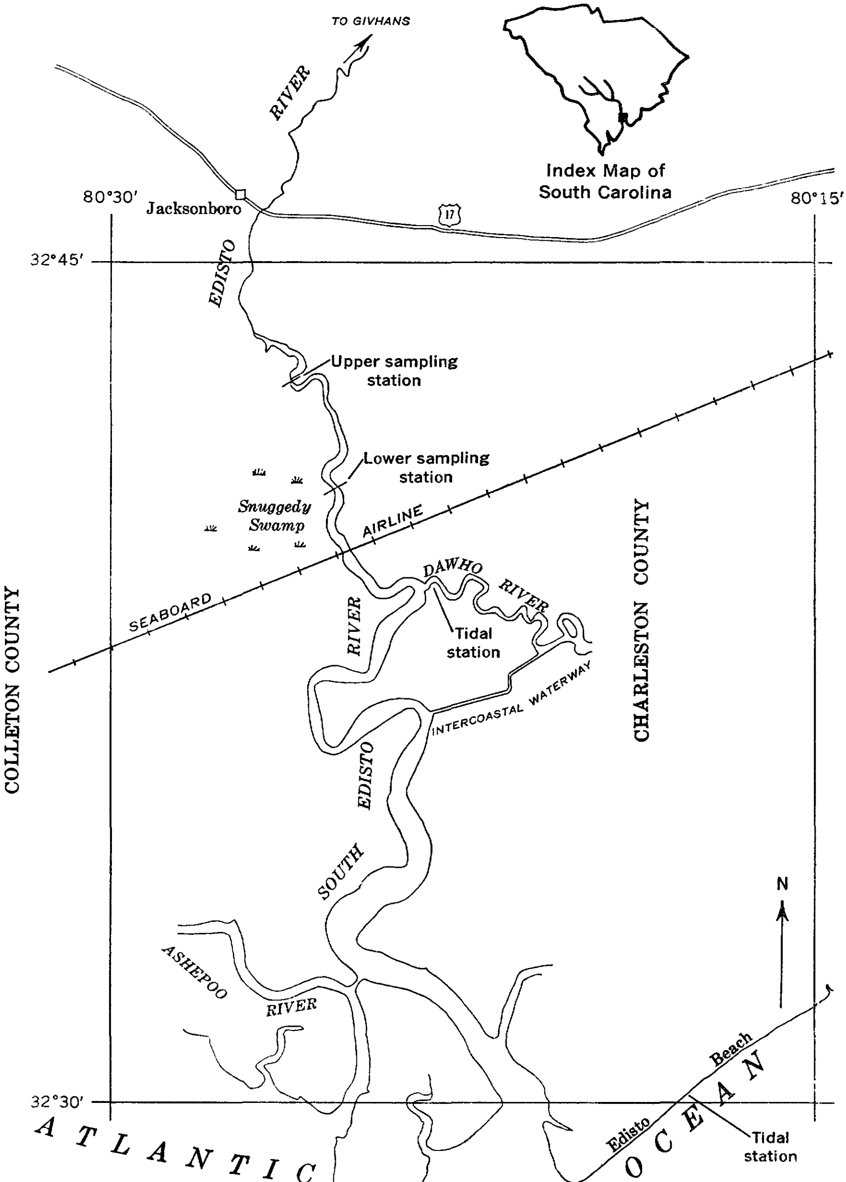

FIGURE 1.—Map of the South Edisto River estuary.

from the mouth, the channel is one- to two-tenths mile wide and about 10 feet deep at mean low water.

FRESH-WATER INFLOW

QUANTITY OF FRESH-WATER INFLOW

Fresh-water discharge to the estuary is measured at a gaging station 2.8 miles west of Givhans and about 18 miles northeast of Jacksonboro. Mean monthly discharge at the gaging station during the period 1939–65 is shown in figure 2. Discharge is normally highest in January, February, March, and April; lowest in June, July, and November. Average discharge near Givhans for the 1939–65 period was 2,652 cfs (cubic feet per second). Flow-duration curves for the period 1939–65 and the period of this investigation (1958–62) are shown in figure 3. Average discharge during the investigation was slightly higher than average discharge for the 1939–65 period.

Except during periods of heavy local runoff, there is no appreciable surface-water inflow between the gaging station and the Dawho River entrance. For this investigation, discharge is assumed to have remained constant in this reach of the river.

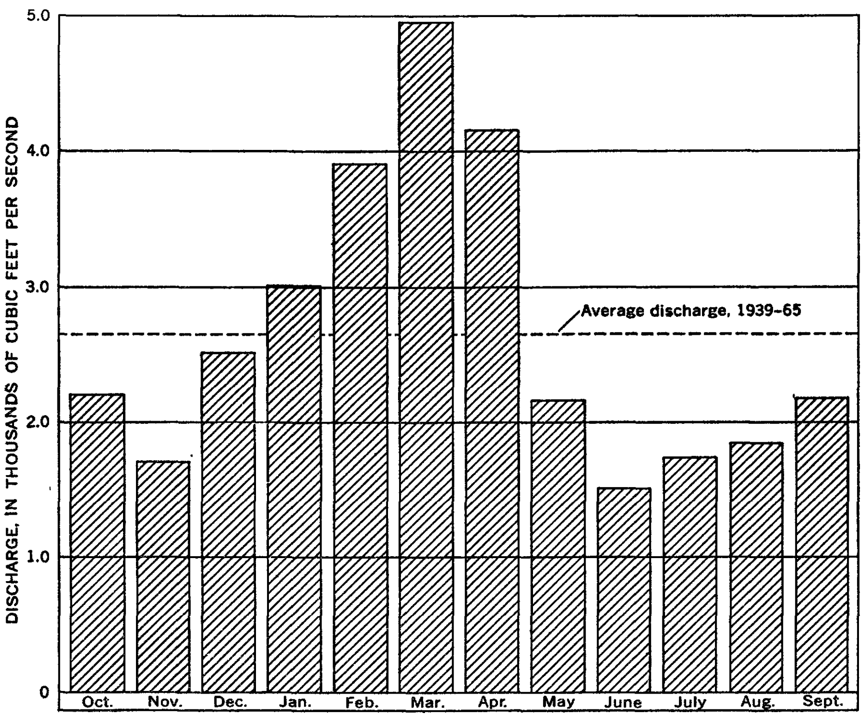

FIGURE 2.—Mean monthly discharge at Edisto River near Givhans, 1939–65.

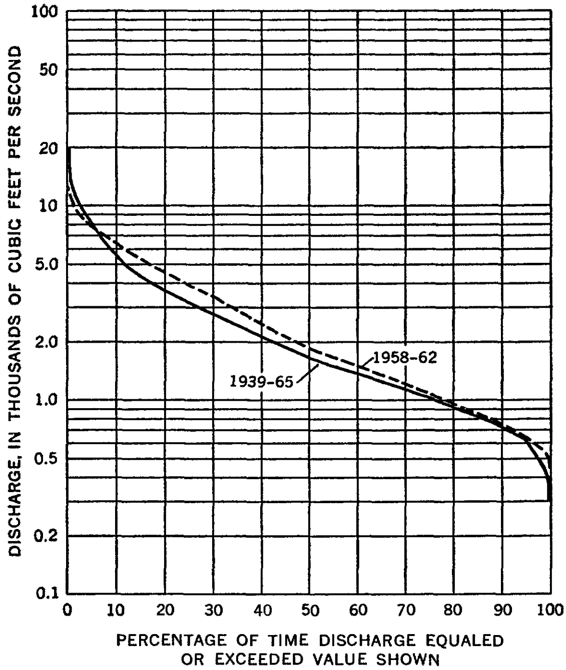

FIGURE 3.—Flow-duration curves for Edisto River near Givhans, 1939–65 and 1958–62.

QUALITY OF FRESH-WATER INFLOW

The chemical characteristics of fresh-water discharge to the South Edisto River estuary are summarized in table 1. Maximum and minimum values given in the table are based on 13 samples collected during the period March 1946 to January 1965. Samples were obtained over a wide range of flow conditions—from 705 to 7,690 cfs. The data in table 1 are thought, therefore, to be representative of the chemical charateristics of the water discharged to the estuary during most periods. The water is characterized by a low dissolved-solids content and low concentrations of individual dissolved substances. The water normally contains considerable organic matter, which, at times, causes the water to have a high color.

TIDAL CHARACTERISTICS

High- and low-tide predictions are published for locations along the Atlantic Coast by the U.S. Coast and Geodetic Survey. At a limited number of these locations, tides have been measured continuously over long periods of time. These tidal measuring stations are called reference stations, and daily predictions of height and time of tide

TABLE 1.—*Maximum and minimum values of dissolved substances and physical properties of water at Edisto River near Givhans, S.C., March 1946 to January 1965*

[Concentrations in parts per million, except as indicated]

	Minimum	*Maximum*
Silica (SiO_2)	0.9	7.3
Iron (Fe)	.03	.40
Calcium (Ca)	3.0	5.9
Magnesium (Mg)	.2	1.2
Sodium (Na)	[1] 2.3	4.4
Potassium (K)	.3	.9
Bicarbonate (HCO_3)	7	18
Sulfate (SO_4)	.8	4.4
Chloride (Cl)	4.0	6.0
Fluoride (F)	.0	.1
Nitrate (NO_3)	.2	1.7
Dissolved solids (residue at 180°C)	30	[2] 62
Hardness (as $CaCO_3$)	10	18
Noncarbonate hardness (as $CaCO_3$)	0	6
Specific conductance [3] (micromhos at 25°C)	33	55
pH (in pH units)	5.7	7.2
Color (in color units [4])	20	140

[1] Includes small but undetermined amount of potassium (K).
[2] Organic matter present; sum of dissolved substances 34 ppm.
[3] Specific conductance is a measure of the ability of water to conduct an electric current and is related to the dissolved-solids content of water and to the type of individual ions in solution. Most natural waters, if freed of organic matter and sediment before analysis, have a dissolved-solids content to specific conductance ratio in the range of 0.5 to 0.8.
[4] Based on platinum-cobalt scale (Hazen, 1892).

are published for each. At many other subordinate stations, tides may be predicted or determined by applying corrections to tidal predictions or measurements made at reference stations.

According to the U.S. Coast and Geodetic Survey (1966), the mean range of tide (the difference between mean high water and mean low water) at a subordinate tidal station at Edisto Beach on Edisto Island is 5.9 feet. About 20 miles upstream from the mouth, at a subordinate station at the Dawho River entrance, the mean range is 6.3 feet. About 30 miles upstream from the mouth, at a subordinate station near Jacksonboro, the mean range is 1.9 feet. The maximum upstream point at which there is a tidal effect is about 38 miles from the river mouth (Col. Robert E. Rich, Corps of Engineers, U.S. Army, Charleston, S.C., written commun., 1966).

Tides that occur in the South Edisto River estuary may be computed from tidal measurements made by the Coast and Geodetic Survey at a reference station at Fort Pulaskie, Ga. (J. M. Symons, U.S. Coast and Geodetic Survey, Rockville, Md., written commun., 1967). Fort Pulaski is about 45 miles southwest of the estuary.

The frequency of occurrence of a high tide of given height at the Dawho River entrance during this investigation is shown in figure 4. Ninety percent of the time the high tide was 5.4 feet or greater; 10 percent of the time the high tide was 7.6 feet or greater.

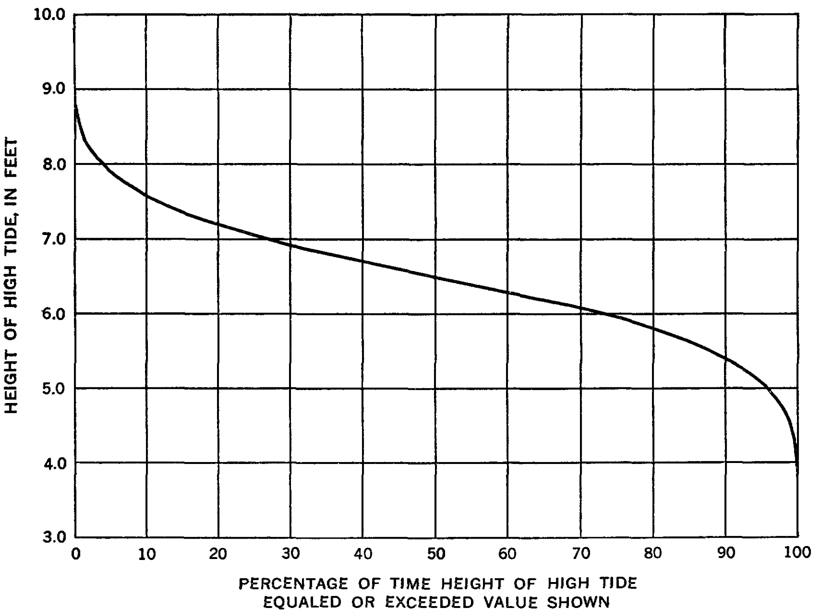

FIGURE 4.—Frequency curve for height of high tide at Dawho River entrance, January 1958 to September 1962.

METHOD OF INVESTIGATION

Based on a field reconnaissance conducted in December 1957, daily sampling stations were established in January 1958 at two locations on the Edisto River southeast of Jacksonboro. One station was located at the County Landing, 4.8 miles downstream from U.S. Highway 17 and 4.5 miles southeast of Jacksonboro. The station is referred to as the "upper" station in this report. A second station, which is referred to as the "lower" station, was located at Hill's Fishing Camp, 8.7 miles downstream from U.S. Highway 17 and 7 miles southeast of Jacksonboro. (See fig. 1).

Daily samples were collected from boat docks at each station at high tide for chemical analysis. Each sample was depth integrated. The specific conductance of the individual daily samples was measured in the laboratory. If the specific conductance of samples collected on consecutive days indicated fresh water, these samples were composited and the composites analyzed. Composite periods ranged from 2 to 31 days, depending on the length of time the water was fresh. Composite samples usually were analyzed for silica, iron, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, nitrate, dissolved solids, hardness, pH, color, and specific conductance. At times when the specific conductance of individual daily samples indicated salt water, only chloride was determined.

CHEMICAL CHARACTERISTICS OF THE WATER

Fresh-water discharge, tides, and weather exert measurable influences on the chemical characteristics of water of the South Edisto River estuary. Because these factors act simultaneously, precise correlation of the chemical characteristics of the water with any one factor is not possible. General relations can be described, however, and information provided that is important to users of the water. The following section of this report discusses the relation of specific characteristics of the water to factors that affect these characteristics.

SPECIFIC CONDUCTANCE

RELATION OF SPECIFIC CONDUCTANCE TO FRESH-WATER DISCHARGE

Figure 5 shows the variations of daily specific conductance and the variations of daily mean discharge at the lower sampling station during July and August 1958. The variations shown are typical of those that occurred during the investigation. As long as discharge was 800 cfs or greater, specific conductance did not exceed 150

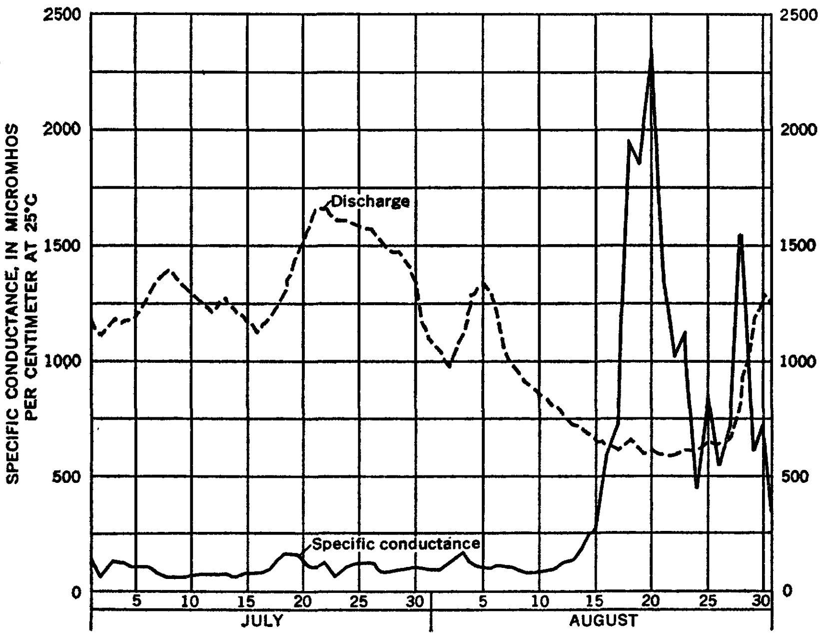

FIGURE 5.—Variations of specific conductance and discharge at high tide at Edisto River near Jacksonboro (lower station), July and August 1958.

micromhos. As discharge decreased, specific conductance increased rapidly. On August 20, when discharge was about 600 cfs, specific conductance was 2,350 micromhos. In late August, specific conductance decreased rapidly as discharge increased.

Figure 6 illustrates the relation between daily specific conductance and discharge at the lower station from January 1958 to September 1962. At average discharge (2,652 cfs), specific conductance varied from about 39 micromhos to about 250 micromhos. At a discharge of 1,000 cfs, specific conductance varied from about 45 micromhos to about 3,500 micromhos. The variation in specific conductance at a given discharge may be attributed, in part, to the movement of water in and out of the estuary through the intercoastal waterway and through the Dawho River. It is probable that this movement of water causes

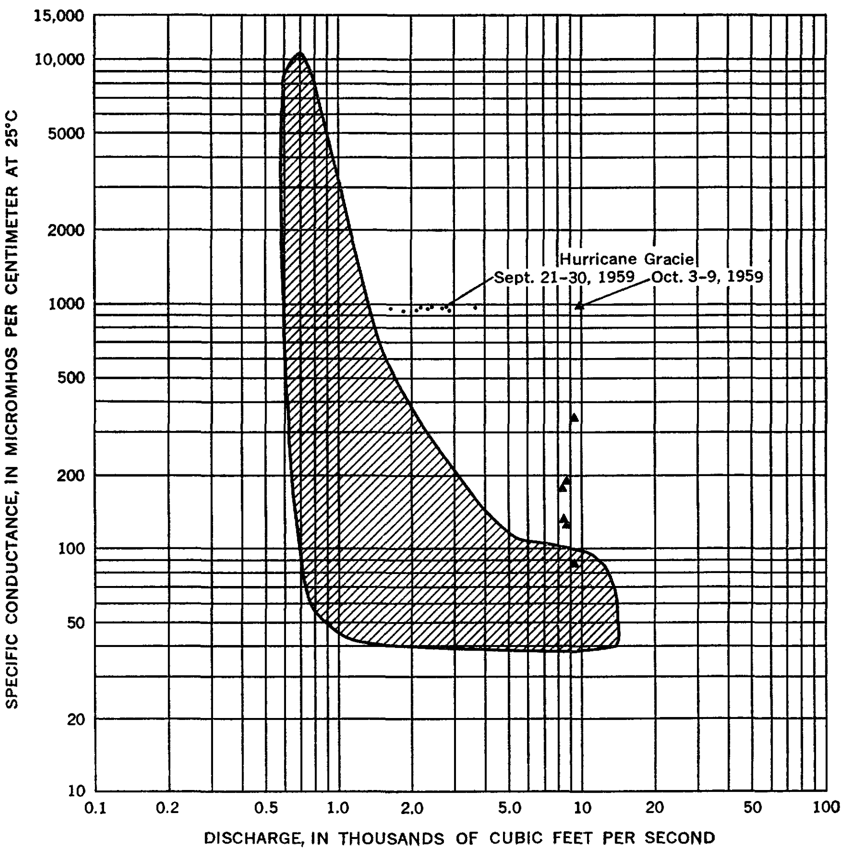

FIGURE 6.—Relation of specific conductance to discharge at high tide at Edisto River near Jacksonboro (lower station), January 1958 to September 1962. (Shaded area includes all data except those affected by Hurricane Gracie. Points represent single days.)

changes in the chemical composition of water that moves inland. Figure 6 shows, however, that salt water is more likely to reach the lower station when the discharge of the Edisto River is low.

Storms, hurricanes, and heavy winds may alter even general relations between salt-water encroachment and fresh-water discharge. Although several storms or hurricanes occurred while this investigation was in progress, the effect of only Hurricane Gracie (September 29–30, 1959) was easily separable from other factors affecting encroachment. (See fig. 6.) As Hurricane Gracie built up and approached the South Carolina coast, high tides [2] forced water inland and held it there almost independently of river discharge. As Hurricane Gracie moved inland and tides returned to normal, heavy rains increased the flow of the river, and salt water was gradually flushed seaward.

Figure 7 illustrates the relation of daily specific conductance to discharge at the upper station during the investigation. At average discharge (2,652 cfs), specific conductance ranged from 37 to 68 micromhos. At a discharge of 1,000 cfs, specific conductance ranged from 31 to 55 micromhos. Points lying outside the shaded area in figure 7 represent single days on which the effect of salt-water encroachment

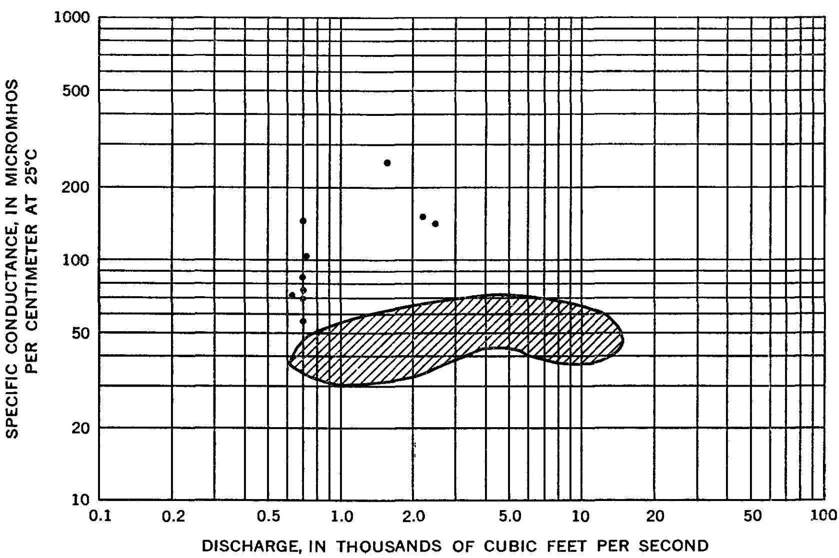

FIGURE 7.—Relation of specific conductance to discharge at high tide at Edisto River near Jacksonboro (upper station), January 1958 to September 1962. (Shaded area includes all data except those collected when salt water was detected. Points represent single days.)

[2] According to the U.S. Weather Bureau (1959), the tide at Charleston (about 30 miles northeast of the South Edisto River estuary) was 8.2 feet above normal at the time of normal low water on September 29.

was detectable. In the absence of salt-water encroachment, there is no significant relation between specific conductance and discharge. The lowest specific conductance values occur at less than average discharge, however. This is not normally expected. Heavy local rains which increase discharge may tend also to increase specific conductance by flushing more highly mineralized waters from swamp areas.

Hurricane Gracie had no measurable effect on the chemical characteristics of water at the upper station.

RELATION OF SPECIFIC CONDUCTANCE TO TIDAL HEIGHT

The tidal station at the Dawho River entrance is 3½ miles downstream from the lower sampling station. The shaded area of figure 8 illustrates the relation of daily specific conductance at the lower station to the height of high tide at the Dawho River entrance. At a high tide of 5.0 feet—a high tide equaled or exceeded 96 percent of the time (fig. 4)—the specific conductance ranged from 38 to 700 micromhos. At greater tide heights (those that occurred less frequently) the range in specific conductance was greater.

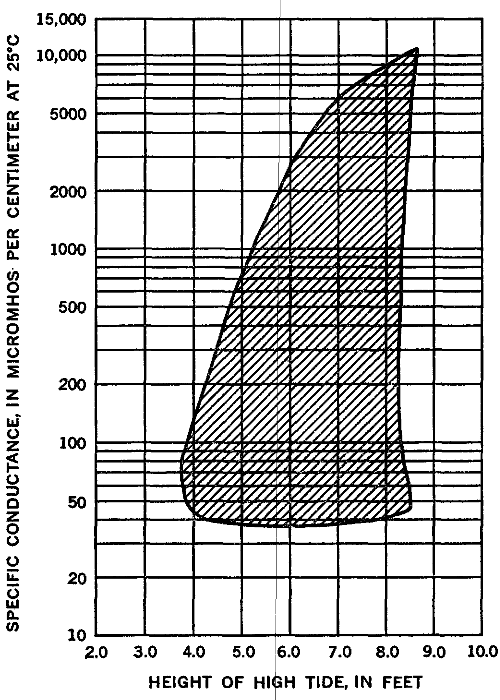

FIGURE 8.—Relation of specific conductance at high tide at Edisto River near Jacksonboro (lower station) to the height of high tide at Dawho River entrance, January 1958 to September 1962. (Shaded area includes all data obtained.)

The poor correlation of specific conductance with tidal height is due probably to the variation in the chemical composition of water below the lower station, to variations in river discharge at a given tidal height, and to the fact that samples were not always collected at exactly high tide. It is evident, however, that the lower the high tide, the less likely salt water is to reach the lower station.

RELATION OF SPECIFIC CONDUCTANCE TO FREQUENCY OF OCCURRENCE

The frequency of occurrence of a specific conductance of a given value at both the upper and lower stations is shown in figure 9. The effect of salt-water encroachment is detectable about half the time at the lower station. At the upper station, however, salt-water encroachment is rarely detectable. The specific conductance equaled or exceeded 10 percent of the time at the lower station (540 micromhos) is almost 10 times as great as the specific conductance equaled or exceeded 10 percent of the time at the upper station (57 micromhos).

Frequency curves indicate the severity and frequency of salt-water encroachment, but they do not indicate the length of time that en-

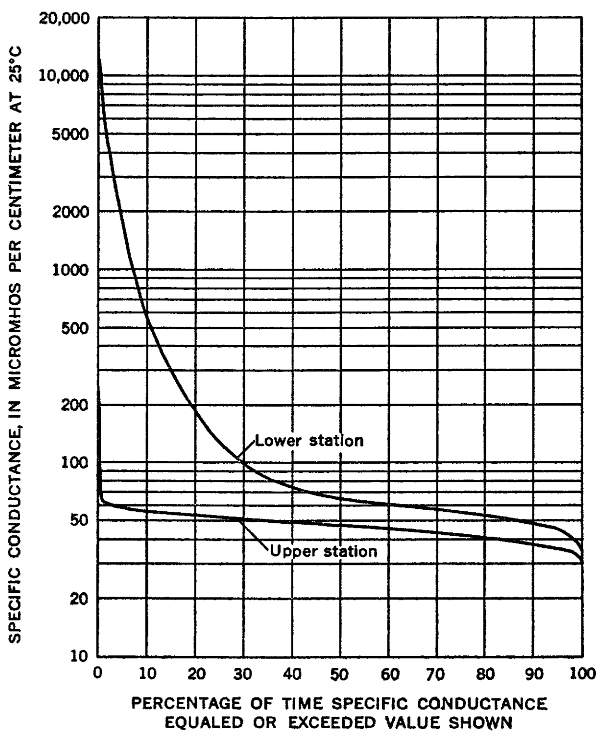

FIGURE 9.—Frequency curves for specific conductance at high tide at Edisto River near Jacksonboro, January 1958 to September 1962.

croachment of a given degree of severity occurred. The following table gives the average of the daily maximum specific conductance values for a specified period of consecutive days. For example, 7,960 micromhos was the highest such average for any 7-day period during the investigation.

Period of consecutive days	*Maximum average specific conductance (micromhos at 25° C)*	
	Lower station	*Upper station*
1	10, 700	259
7	7, 960	73
15	6, 890	63
20	6, 360	63
30	5, 460	63
60	4, 520	60
120	3, 090	53

DISSOLVED-SOLIDS CONTENT AND CHLORIDE

The dissolved-solids content of a water may be estimated from measurements of specific conductance if something is known about the chemical characteristics of the water. During this investigation, the dissolved-solids content of water usually was not determined when salt water was detected at the sampling stations. At such times only, specific conductance and chloride were determined. Fortunately, numerous studies have established the general relation between specific conductance and dissolved-solids content for waters containing principally sodium and chloride. Using data of Cox (1965) and data obtained during this investigation, the relations of specific conductance to dissolved-solids content and of specific conductance to chloride were developed. The relations are applicable to water at both the upper and lower stations. (See fig. 10.)

RELATION OF DISSOLVED-SOLIDS CONTENT AND CHLORIDE TO FREQUENCY OF OCCURRENCE

Frequency curves for dissolved-solids content and chloride have been computed for both the upper and lower stations from frequency curves of specific conductance (fig. 9) and from the relations of dissolved-solids content and chloride to specific conductance (fig. 10). Frequency curves for dissolved-solids content and chloride are shown in figure 11. Fifty percent of the time at the upper station the dissolved-solids content equaled or exceeded 30 ppm. At the lower station, dissolved- solids content equaled or exceeded 40 ppm 50 percent of the time. Five percent of the time at the upper station the dissolved-solids content equaled or exceeded 37 ppm. At the lower station, however, the dissolved-solids content equaled or exceeded 850 ppm 5 percent of the

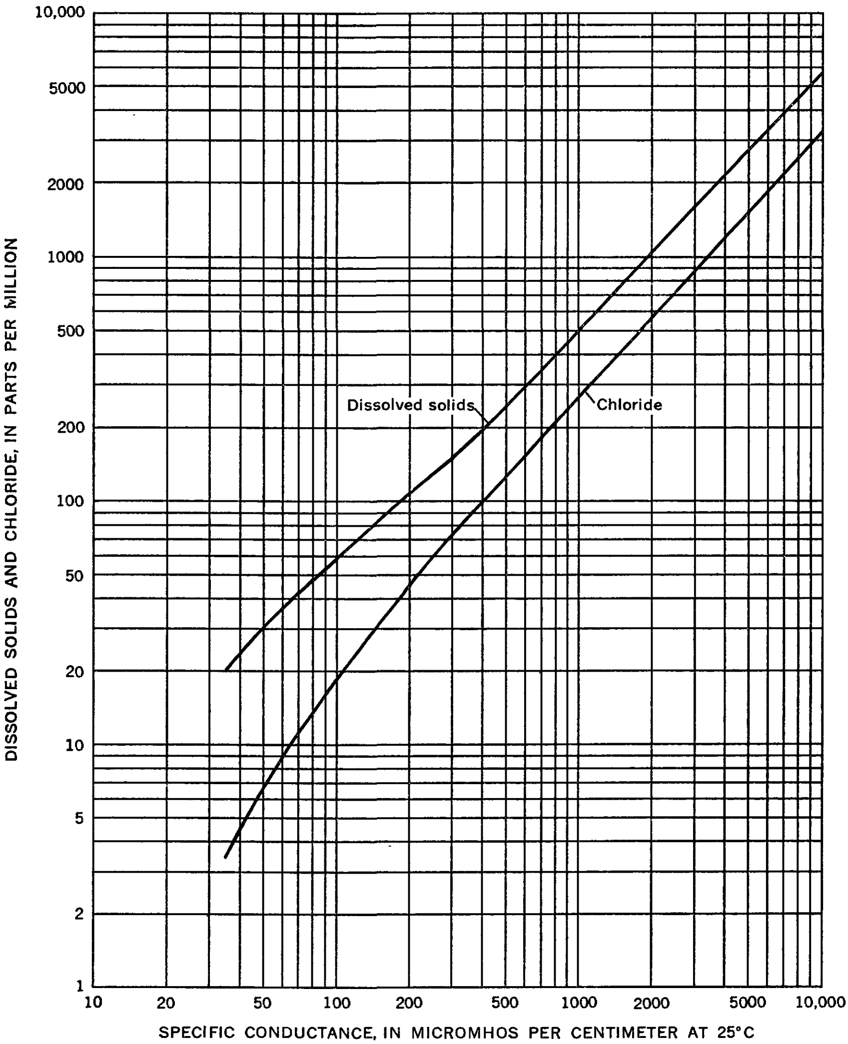

FIGURE 10.—Relation of dissolved-solids content and chloride to specific conductance at high tide at Edisto River near Jacksonboro, January 1958 to September 1962.

time. Five percent of the time chloride equaled or exceeded 8.6 ppm at the upper station, compared to 450 ppm 5 percent of the time at the lower station.

COMPOSITE SAMPLE ANALYSES

During periods when salt-water encroachment did not affect the chemical characteristics of water at the upper and lower stations, daily samples were composited, and complete chemical analyses were made

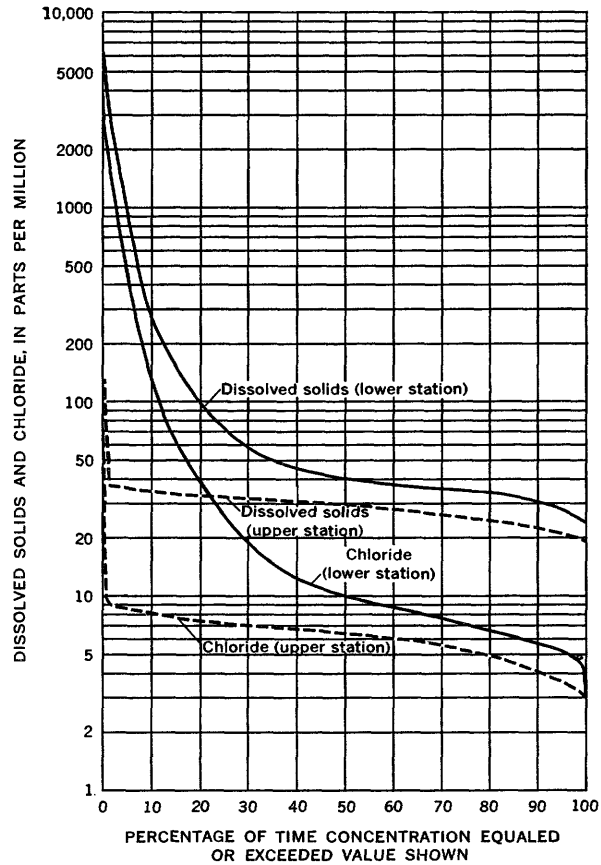

FIGURE 11.—Frequency curves for dissolved-solids content and chloride at high tide at Edisto River near Jacksonboro, January 1958 to September 1962.

on the composites (p. I 7). Table 2 gives the maximum and minimum values of dissolved substances and physical properties found when composites of the fresh water were analyzed.

In the absence of salt-water encroachment, the concentration of most substances in the water is low. Iron, color, and organic matter, however, occur in amounts greater than are common in most streams.

TEMPERATURE OF WATER

The temperature of water at both the upper and lower stations on the Edisto River was measured at the time samples were collected. At the upper station the maximum temperature recorded during the investigation was 87°F; the minimum was 32°F. At the lower station

TABLE 2.—*Maximum and minimum values of dissolved substances and physical properties of fresh water at high tide at Edisto River near Jacksonboro, S.C., January 1958 to September 1962.*

[Concentrations in parts per million, except as indicated]

	Upper Station		Lower Station	
	Minimum	*Maximum*	*Minimum*	*Maximum*
Silica (SiO_2)	1.3	9.7	1.3	9.4
Iron (Fe)	.03	.54	.02	.51
Calcium (Ca)	2.4	6.7	3.0	7.4
Magnesium (Mg)	.3	1.5	.3	2.0
Sodium (Na)	2.2	4.3	2.7	6.6
Potassium (K)	.2	1.8	.3	2.0
Bicarbonate (HCO_3)	7	20	9	20
Sulfate (SO_4)	.6	5.8	.8	7.0
Chloride (Cl)	3.0	9.0	5.0	10
Fluoride (F)	.0	.2	.0	.2
Nitrate (NO_3)	.1	1.9	.1	4.2
Dissolved solids (residue at 180°C)	28	[1] 71	32	[2] 77
Hardness (as $CaCO_3$)	9	20	12	20
Noncarbonate hardness (as $CaCO_3$)	0	9	2	11
Specific conductance (micromhos at 25°C)	35	63	43	70
pH (in pH units)	6.0	7.0	6.2	7.3
Color (in color units)	30	200	50	220

[1] Organic matter present; sum of dissolved substances 38 ppm.
[2] Organic matter present; sum of dissolved substances 45 ppm.

the maximum temperature was 89°F; the minimum was 34°F. During the fall and winter the temperature of the water increased about 2°F between the upper and lower stations. During the spring and summer the temperature increased about 4°F. The average January temperature at the upper station was 45°F; the average July temperature was 77.5°F. At the lower station the average January temperature was 46°F; the average July temperature was 83°F. Frequency curves for temperatures at both station are shown in figure 12.

SUITABILITY OF WATER FOR USE

The suitability of a water for use depends largely on the chemical characteristics and physical properties of the water. Water suitable for one use may not be suitable for another, and thus water must be judged by criteria appropriate to the intended use. The degree to which a water fails to meet appropriate criteria usually determines the treatment required. If extensive treatment is necessary, use of a water supply may not be economically feasible.

DOMESTIC USE

Chemical-quality standards for water used for drinking and culinary purposes on interstate-commerce carriers have been established

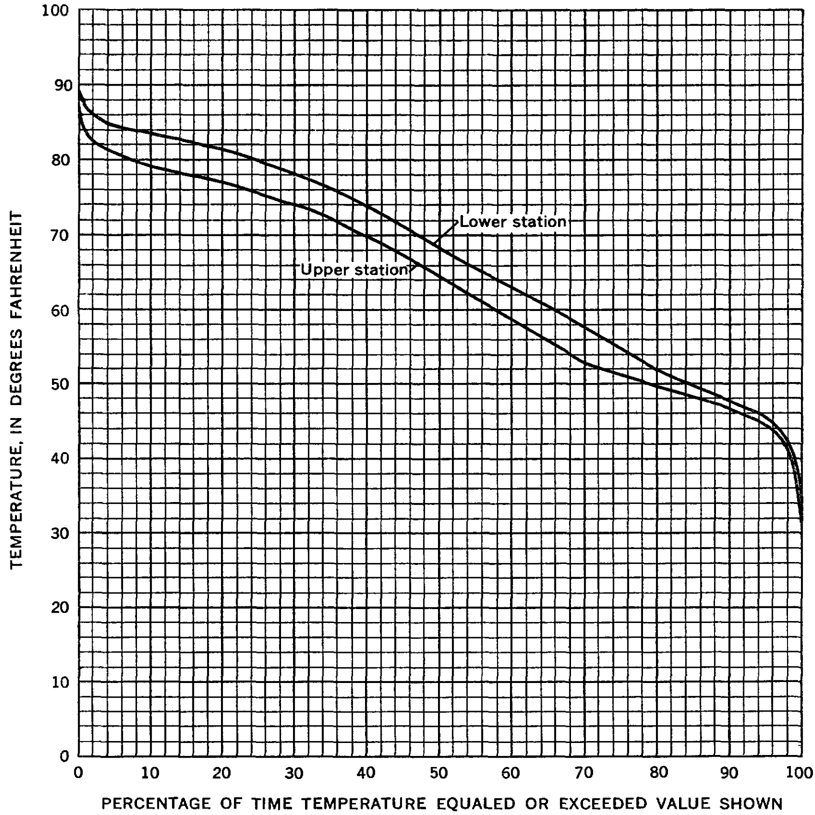

FIGURE 12.—Frequency curves for temperature of water at high tide at Edisto River near Jacksonboro, January 1958 to September 1962.

by the U.S. Public Health Service (1962). These standards have been endorsed by the American Water Works Association, and are commonly used to evaluate water intended for human consumption. Some of the maximum concentration limits of significance to the evaluation of water in the report area are, in parts per million: iron, 0.3; chloride, 250; and dissolved-solids content, 500. A maximum color of 15 units also has been recommended. Although specific limits have not been set for organic matter, even small amounts are unacceptable to most consumers.

Hardness, a measure of the ability of water to consume soap, has been arbitrarily classified in parts per million, as follows: 60 or less, soft; 61–120, moderately hard; 121–180, hard; and 181 or more, very hard.

Using these criteria, water at the upper station is suitable for domestic use at all times, providing the water is treated when necessary to remove iron, color, and organic matter. At the lower station, the dissolved-solids content of the water equals or exceeds the recommended maximum limit (500 ppm) 7 percent of the time. (See fig. 11.) The recommended maximum limit for chloride (250 ppm) is also equaled or exceeded about 7 percent of the time. The water is usually soft, except when salt water is detectable. Treatment to remove iron, color, and organic matter also will be necessary at the lower station.

INDUSTRIAL USE

The water-quality requirements of industry depend largely upon the specific use to be made of water. Reports by Moore (1940) and the California State Water Quality Control Board (1963) contain information on industrial water-quality standards and may be consulted for criteria applicable to a specific use. Generally, water that has a low dissolved-solids content and a low hardness, and does not vary greatly in quality or temperature, meets the requirements of many industries. Water at the upper station meets these general criteria at all times. At the lower station, water will be unsuitable for most industrial users on occasion, but the frequency can be determined only if the intended use is known. The iron, color, and organic matter characteristics of water at both stations are objectionable to many industries, particularly those that use water in a process. Treatment to remove these characteristics usually will be required.

CONCLUSIONS

Salt-water encroachment alters the chemical characteristics of water of the Edisto River about 25 miles upstream from the mouth. The distance that salt water moves inland depends on the discharge of the river, tidal heights, and weather. Precise correlations of these factors with specific chemical characteristics are not possible in the report area because water that moves inland varies in chemical composition from time to time.

The effect of salt-water encroachment is detectable on rare occasions 4.5 miles southeast of Jacksonboro (the upper station). Only minor changes in the characteristics of the water occur at this point, however. At a point 7 miles southeast of Jacksonboro (the lower station), the effect of encroachment is detectable about half the time. Less frequently, the water is highly mineralized. Water is suitable for most uses at the upper station at all times, providing it is treated to remove iron, color, and organic material. If water at the lower station is similarly treated, it is suitable for domestic use about 93 percent of the time. The water will be unsuitable for most industrial uses at the lower station on occasion, but the intended use must be known to determine how frequently the water is unsuitable.

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