POTENTIAL IMPACTS OF DISCHARGING TERTIARY-TREATED WASTEWATER INTO PORT ROYAL SOUND, SOUTH CAROLINA

By Gary K. Speiran and Donna L. Belval

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CONVERSION FACTORS AND ABBREVIATIONS OF UNITS

The following factors may be used to convert the inch-pound units published herein to the International System of units (SI).

Multiply inch-pound units	By	To obtain SI units
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
fathom	1.829	meter (m)
mile (mi)	1.609	kilometer (km)
nautical mile (nmi)	1.852	kilometer (km)
foot per second (ft/s)	0.3048	meter per second (m/s)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
pound, avoirdupois (lb)	453.6	gram (g)
micromhos per centimeter at 25° Celsius (umhos/cm at 25°C)	1.000	microsiemens per centimeter at 25° Celsius (uS/cm at 25°C)

Temperature in degrees Celsius (°C) can be converted to degrees Fahrenheit (°F) as follows:

$$°F = 1.8\ °C + 32$$

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ABSTRACT

An assessment of physical characteristics of Port Royal Sound was combined with the results of a dye-tracer study and with data collected from a previous environmental study to describe the impact on the water quality from discharging tertiary-treated wastewater into the sound.

Calculated velocities for the time of maximum velocity in the tidal cycle ranged from 2.32 feet per second near the bottom to 4.65 feet per second near the surface of the sound in a cross section in the vicinity of a proposed wastewater outfall. Vertical velocity distributions calculated for the time of maximum velocity were similar at all stations at which velocities were measured except the station in shallow water near the shore.

A recent bathymetric chart of the vicinity of the proposed outfall indicates that a bar extends farther along the northern shore of Hilton Head Island than indicated on earlier nautical charts of Port Royal Sound. Continued extension of this bar could alter the impact on water quality from discharge of treated wastewater into the sound. Further study may be needed to monitor changes in the bar if the outfall is located between the bar and Hilton Head Island.

Conservative calculations based on the results of the dye-tracer study indicate that the discharge of 10.9 million gallons per day of wastewater having concentrations of biochemical oxygen demand and suspended solids of 15 milligrams per liter will result in a maximum cumulative increase in concentrations of biochemical oxygen demand of less than 0.01 milligram per liter and no increase in concentrations of suspended solids at high slack tide in the part of Port Royal Sound most affected by the proposed wastewater discharge.

INTRODUCTION

Hilton Head Island is one of a series of barrier islands off the coast of South Carolina. Like many of these islands, Hilton Head has been developed into a coastal resort area. The economy of the island depends on the preservation of the ecology of the surrounding estuaries and saltwater marshes, because these areas are a major attraction and provide the habitat upon which many of the species important to recreational and commercial fishing depend.

The ecological balance of the estuaries and marshes is threatened by the disposal of wastewater as development of the island continues. To minimize the threat, the primary method of wastewater disposal on Hilton Head Island is to spray treated wastewater on land areas such as golf courses, green areas, and areas dedicated specifically to disposal of wastewater, rather than to discharge wastewater into surface waters.

As the population of Hilton Head Island increases, the amount of wastewater to be disposed of will increase. At maximum development of Hilton Head Island, 10.9 Mgal/d of wastewater will be produced in three of the six zones served by the public service districts on the island. During periods of heavy rainfall, the low land-surface altitudes, shallow water table, and low permeability of the soils on parts of the island may limit the ability of the shallow ground-water system to assimilate all of the wastewater. Only a limited volume of wastewater can be stored in the holding ponds during periods that land spraying cannot be conducted. Thus, an alternative method of wastewater disposal will be needed. The discharge of treated wastewater directly into Port Royal Sound, the estuary northeast of Hilton Head Island, is one of the alternatives.

More stringent water-quality standards are being applied by the South Carolina Department of Health and Environmental Control to wastewater sprayed on land than will be applied to wastewater discharged into Port Royal Sound. The water-quality standards for wastewater sprayed on land are a maximum concentration of 5 mg/L (milligrams per liter) for BOD (biochemical oxygen demand) and 5 mg/L for suspended solids. Standards for wastewater discharged into Port Royal Sound are a maximum concentration of 15 mg/L for BOD and 15 mg/L for suspended solids. However, the public service districts that operate the wastewater treatment plants will provide tertiary treatment of the wastewater at all times to meet the more stringent standards for wastewater sprayed on land.

Currently, wastewater receives secondary treatment before disposal by land spraying. This treatment includes the use of activated sludge processes followed by chlorination and storage in holding ponds. To meet water-quality standards for spraying on land, wastewater will also receive tertiary treatment consisting of filtration through dual media (sand and anthracite) filters for removal of suspended solids.

The objective of this report is to provide an assessment of the impact of discharging tertiary-treated wastewater into Port Royal Sound on the quality of water in the sound. This assessment is based upon an evaluation of data collected in 1983 and 1984 and the results of a previous environmental study of Port Royal Sound conducted in 1970 (South Carolina Water Resources Commission, 1972). In the environmental study the hydrology and water quality of Port Royal Sound were investigated. The environmental study included a dye-tracer waste-simulation study performed by the U.S. Geological Survey.

This study consists of two parts. First is an assessment of the physical and hydraulic characteristics of Port Royal Sound near the northern shore of Hilton Head Island. Vertical velocity distributions, mean vertical velocities, particle size distributions and concentrations of suspended sediment, particle size distributions of bottom sediment, and bathymetric characteristics of the floor of the sound in the vicinity of the proposed wastewater outfall in Port Royal Sound are evaluated. Second is an assessment of water quality and the flow regime. Current water quality is compared with the water quality during the 1970 study. A dye-tracer study was used to determine the flow patterns of the water in the sound. The potential impact on water quality of discharging tertiary-treated wastewater in the vicinity of Hilton Head Island was determined from results of these measurements.

DESCRIPTION OF THE STUDY AREA

Port Royal Sound, located northeast of Hilton Head Island (fig. 1), is one of the largest estuaries along the South Carolina coast. The sound is approximately 3 miles wide at its confluence with the Atlantic Ocean, widens to approximately 4 miles, then narrows above its confluence with the major tributaries. These tributaries are the Broad River, the Beaufort River, and the Chechessee River. The main part of the sound is called the Broad River above the confluence with the Chechessee River and extends inland approximately 24 miles. Upstream of this point, the Broad River is known as the Coosawhatchie River.

The sound is relatively deep throughout with an average depth of about 35 to 40 ft at mean low water (mean low tidal stage). The tributaries are generally 25 to 30 ft deep near their confluence at mean low water.

Like most coastal waters in the eastern United States, Port Royal Sound has semidiurnal tidal variations. These variations consist of two high and two low tidal stages per tidal day (approximately 24.8 hours). The normal tidal range is 8.1 ft in the upper estuary, and 7.0 ft at the mouth with a mean tidal range of approximately 7.5 ft (South Carolina Water Resources Commission, 1972, p. 47-72). During a new and a full moon, when the earth, moon, and sun are aligned, the gravitational pull which causes tidal variations is at its maximum. Greater tidal variations known as spring tides occur at these times in all parts of the world that have tidal fluctuations.

High tides are higher, low tides are lower, and water moves farther into the estuaries and marshes at the time of spring tides than at other times in the lunar tidal cycle. Ranges of as much as 10.3 ft in spring tides have been measured at the mouth of Port Royal Sound (South Carolina Water Resources Commission, 1972, p. 47-72).

Water velocities and direction of movement change with the tidal cycle in all water bodies that are tidally influenced. High slack tide is that period of high tidal stage when water velocities are zero. After high slack tide, water flows seaward and velocities increase to a maximum, then decrease as the time of low slack tide approaches. Low slack tide is that period of low tidal stage when water velocities again cease. After low slack tide, water moves inland, velocities increase to a maximum, then decrease as the time of high slack tide approaches. In estuaries, maximum velocities occur between the times of high and low tidal stages. However, slack tides are out of phase with high and low tidal stages (fig. 2) because of continued flow into and out of the upper part of the sound after high and low tidal stages occur. In Port Royal Sound, the times of high and low slack tide occur as much as 2 hours

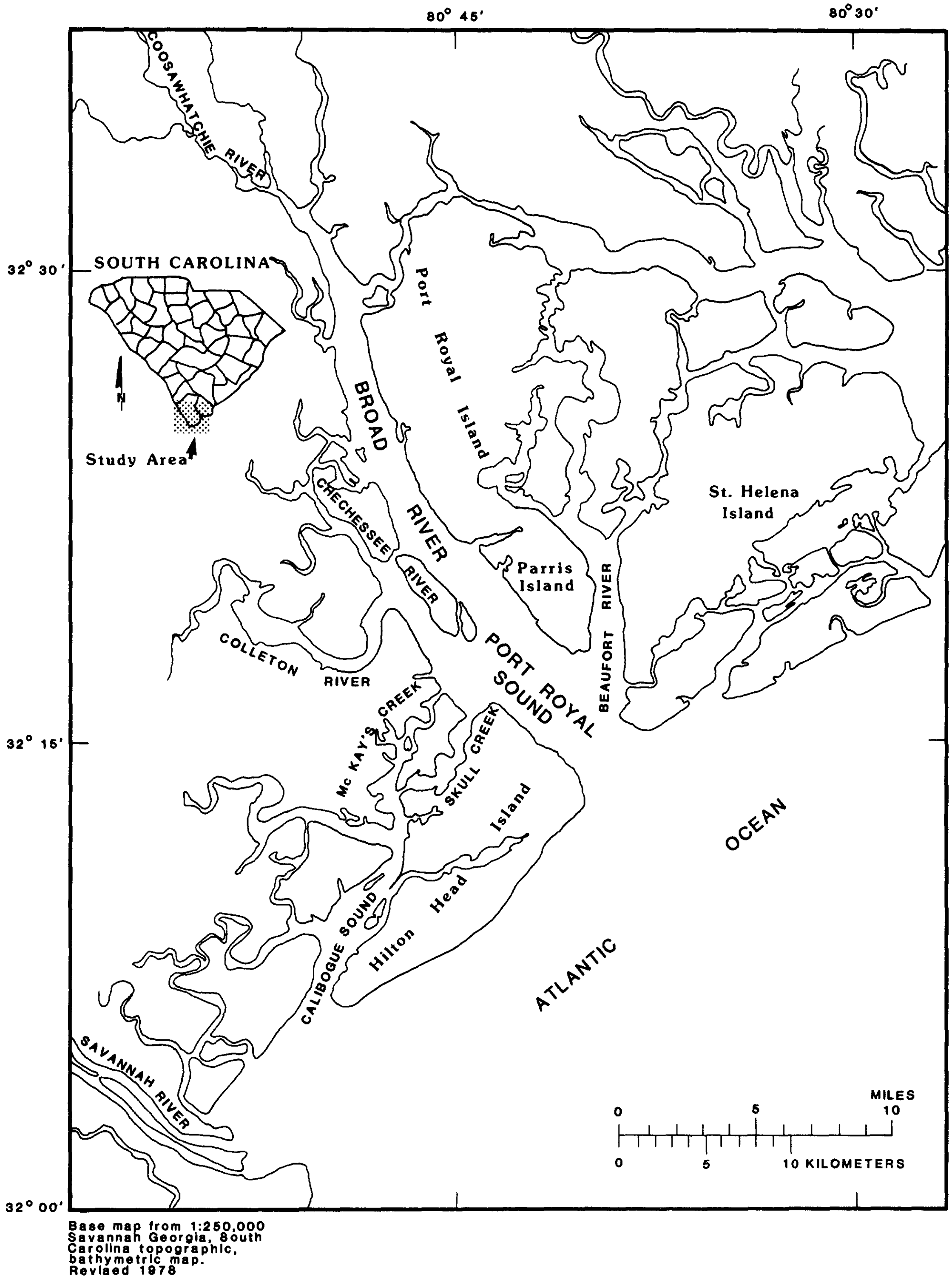

Figure 1.--Geographic and hydrologic features of the study area.

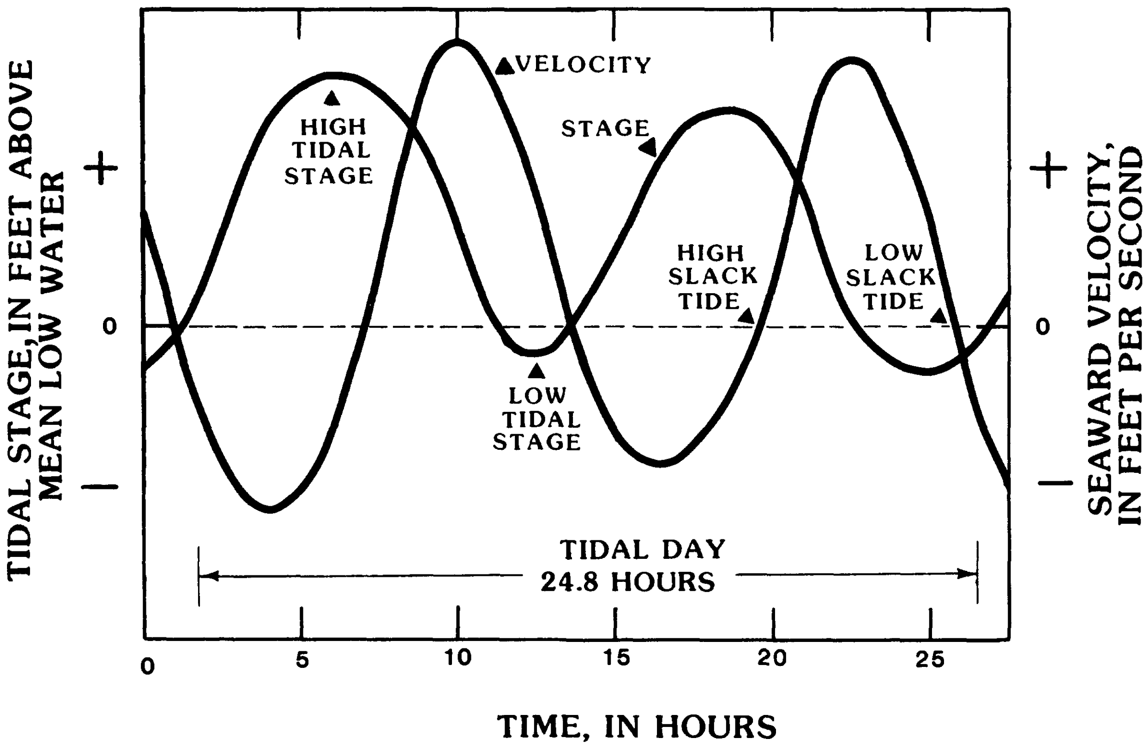

Figure 2.--Generalized stage and velocity variations in a tidal estuary.

after the times of high and low tidal stages (South Carolina Water Resources Commission, 1972, p. 47-72).

The depth, length, and width of Port Royal Sound, along with the large tidal range combine to produce maximum velocities of up to 6 ft/s and maximum instantaneous discharges in either direction of 1.5 to 2.0 million ft^3/s at the mouth of the sound (South Carolina Water Resources Commission, 1972, p. 47-72). In contrast, there is little freshwater inflow into the sound because of the small drainage area of the contributing streams. The Coosawhatchie River, which provides the greatest freshwater inflow into the sound, has a mean annual discharge over 31 years of 184 ft^3/s at the gaging station near Hampton, S.C., which gages discharge from about half of the Broad River drainage basin. This is very small relative to the bidirectional discharge of water into and out of the sound.

Port Royal Sound is an unstratified estuary because of the relatively small amount of freshwater inflow compared to the massive tidal flows. Thus, the freshwater and saltwater are thoroughly mixed vertically, and salinities decrease uniformly from the open ocean to the upper reaches of the estuary (South Carolina Water Resources Commission, 1972, p. 47-72).

METHODS

Velocity Distributions in the Vertical Section

Vertical velocity distributions are the distributions of velocity in the direction of the major flow component (usually horizontal) with depth. Velocities were measured at 5-foot intervals from near the bottom of the sound to near the water surface at five locations on April 13, 1984, to provide vertical velocity distributions in the vicinity of the proposed wastewater outfall. These velocity distributions were compared with velocities measured across the sound in 1970 to determine differences between velocities in the vicinity of the proposed outfall and those across the sound and were used to determine if results of the dye-tracer study might be significantly different at another location. The velocity measurements were made during the outgoing tide between 0830 and 1130 around the time of maximum velocity over a 10 to 15 minute period in the vertical section at each station using a Price type AA meter. Measurements were made at stations PR5W1, PR5W2, PR5W3, PR5C, and PR5E1 which are in a line approximately perpendicular to the shore of Hilton Head Island and located 200, 400, 600, 800, and 1,000 ft, respectively, from the shore (fig. 3). Measurements were not made at the same time at all stations. Instead, velocity measurements were made periodically at station PR5C before and after the measurements at the other stations.

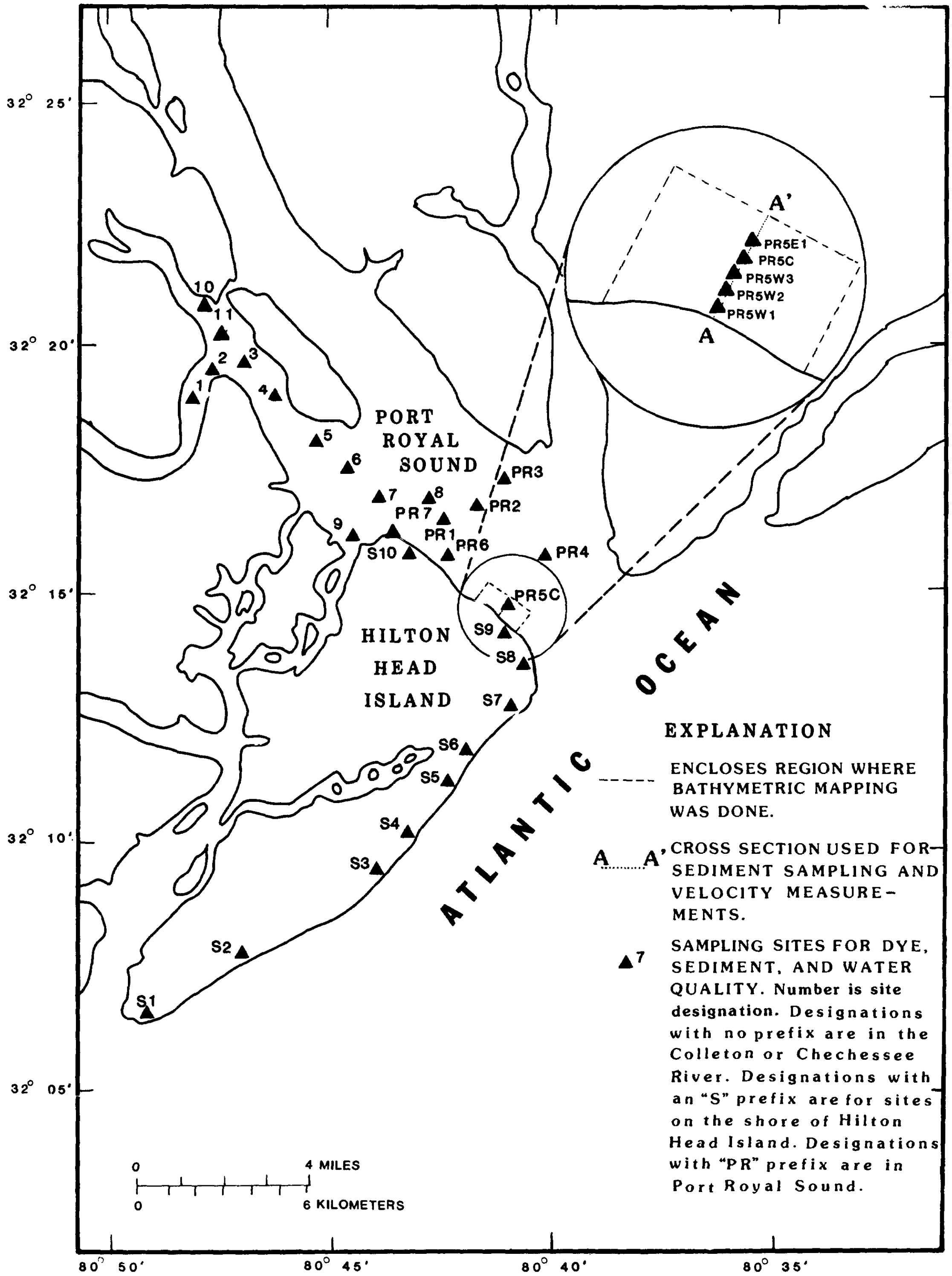

Figure 3.--Location of data-collection sites for the 1983-84 Port Royal Sound study.

Bottom and Suspended Sediment

Bottom and suspended sediment samples were collected on February 8, 1984, at the same stations where velocity was measured. Bottom sediment samples were collected with a bed material sampler suspended from a hand-held rope. Suspended sediment samples were collected with a depth integrating sampler. Bottom and suspended sediment data were used in conjunction with a comparison of bathymetric maps to aid in evaluating general sediment movement that may cause changes in the bathymetry of the sound and mixing of wastewater discharged into Port Royal Sound. Concentrations of suspended sediment in the sound also were compared with concentrations of suspended solids in the wastewater to determine the impacts of discharging wastewater on the concentrations of suspended matter in the sound.

Bathymetry

A Motorola* Mini-Ranger III Positioning System and a depth-finding system were used to collect depth information in the sound on April 11-12, 1984. These systems collected location and depth information which were recorded on paper and magnetic tape. The bathymetric map constructed from these data was compared with various maps of data collected from the 1700's through 1931 to evaluate changes in the bathymetry of Port Royal Sound and the potential effects continued changes might have on the discharge of wastewater into the sound.

Dye-Tracer Study

Dye-tracer studies are often used to simulate movement and dispersion of solutes in a body of water. This information is valuable in simulating in advance the behavior of contaminants proposed for introduction into waterways. In an estuary subject to tidal fluctuations, dilution, dispersion, and the rate of movement of the dye are significantly affected by the variable rates of tidal flow in two directions. The effects are greatest at the time of the greatest velocities which occur about midway between high and low slack tide and are least at high and low slack tide.

To determine the maximum inland movement and the peak concentrations of constituents that would result from continuously discharging tertiary-treated wastewater into Port Royal Sound, a dye-tracer study was conducted during the spring tides November 21-23, 1983. The study was conducted by injecting dye into Port Royal Sound at station PR5C in the vicinity of the proposed wastewater outfall. Approximately 665 lb of a 20 percent solution of Rhodamine WT dye were injected continuously at a rate of about 110 lb/hr (pounds per hour) on the flood tide between low slack tide at about 0215 and high slack tide at about 0830 on November 21, 1983. This high slack tide was the highest tide that occurred during the November spring tides. This means that succeeding high slack tides were lower and a net tidal flow out of the sound occurred.

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*Use of the brand name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

Initially a centrifugal pump was used for the injection. Dye was premixed with water by siphoning the dye into the intake line of the pump where it mixed with water pumped from the sound. The solution was then injected into the sound at a depth of about 20 ft. However, approximately 5 hours after the beginning of the dye injection, the centrifugal pump malfunctioned and injection was continued at a depth of 20 ft using a peristaltic pump. Because of the limited capacity of the peristaltic pump, the dye could not be diluted prior to injection.

A network of 27 sampling sites was established for monitoring concentrations of dye during the study (fig. 3). Ten sampling sites were located along the shoreline of Hilton Head Island and 17 extended from Port Royal Sound up the Chechessee River.

Water samples were analyzed for fluorescence to determine concentrations of the dye. Water samples were collected prior to injection of dye into the sound to determine background fluorescence. Background fluorescence was subtracted from all readings for samples collected during and after dye injection.

Changes in Water Quality

Water samples for water-quality analysis were collected February 8, March 26, and April 13, 1984, at station PR5C in the vicinity of the proposed outfall and station PR7 in the vicinity of station 1 of the 1970 study (South Carolina Water Resources Commission, 1972). Grab samples were collected at the surface to allow a comparison with the 1970 data because the sound is vertically mixed and this was the method of sample collection in the 1970 study.

RESULTS

Velocity Distributions in the Vertical Section

Vertical velocity distributions were calculated for the time of maximum velocity for all stations in Port Royal Sound using methods in the following discussion to permit a comparison of velocity distributions and velocities at various depths at the time of maximum velocity.

Measured velocity distributions at station PR5C (fig. 4) and at stations PR5W1, PR5W2, PR5W3, PR5C (at 0830 hours) and PR5E1 (fig. 5) were plotted using dimensionless depth and velocity axes. Dimensionless depth is the ratio of the depth of each individual measurement to total depth. Dimensionless velocity is the ratio of the measured point velocity in a vertical to the mean velocity in that vertical. Dimensionless depth and velocity were used to aid in comparison of the distributions. The individual velocities in each vertical show some variation from a smooth distribution (figs. 4 and 5) which can be attributed to measurement error, short duration variabilities in velocities, or actual variations in velocities.

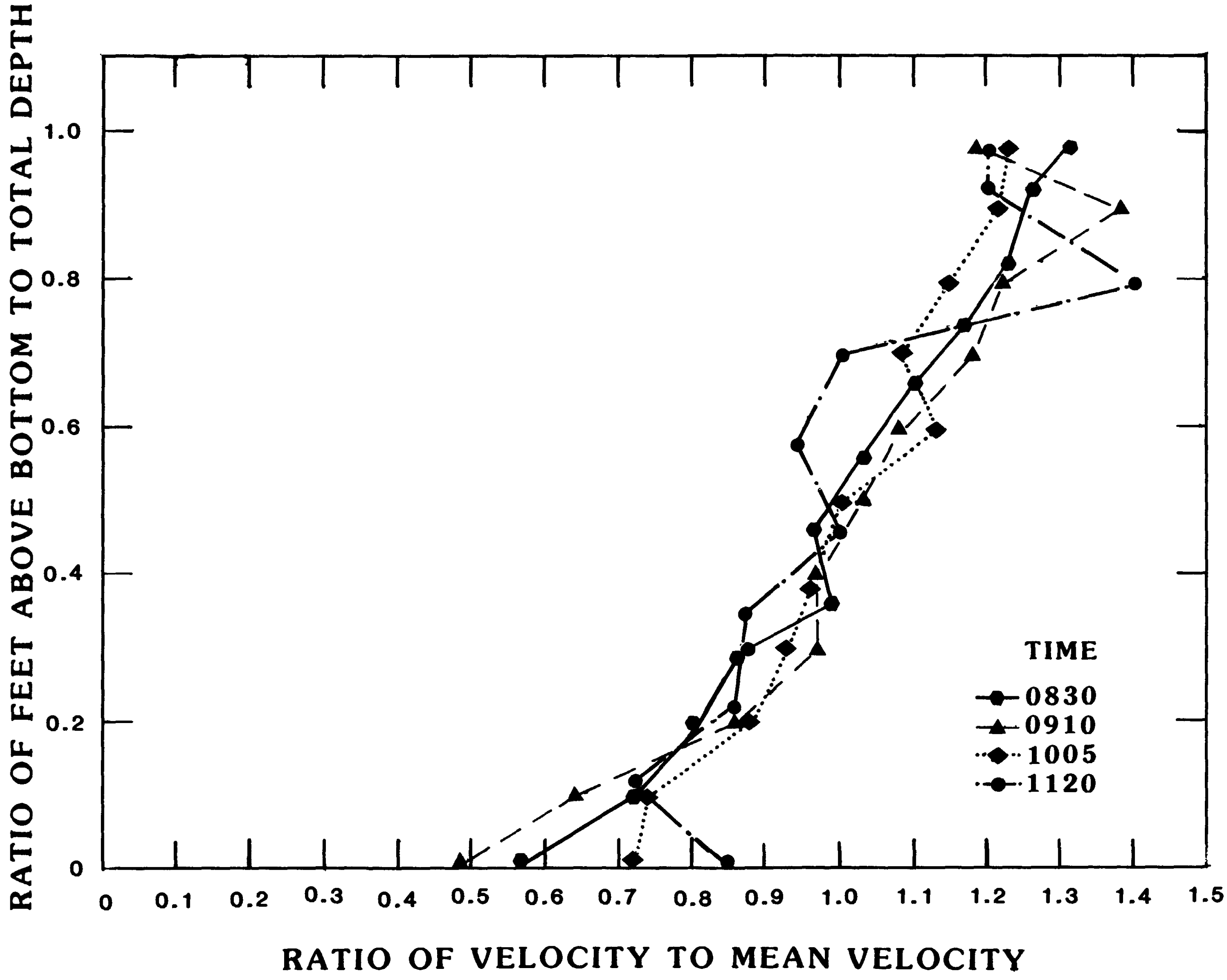

Figure 4.--Dimensionless measured vertical velocity distributions at PR5C at various times on the outgoing tide, April 13, 1984.

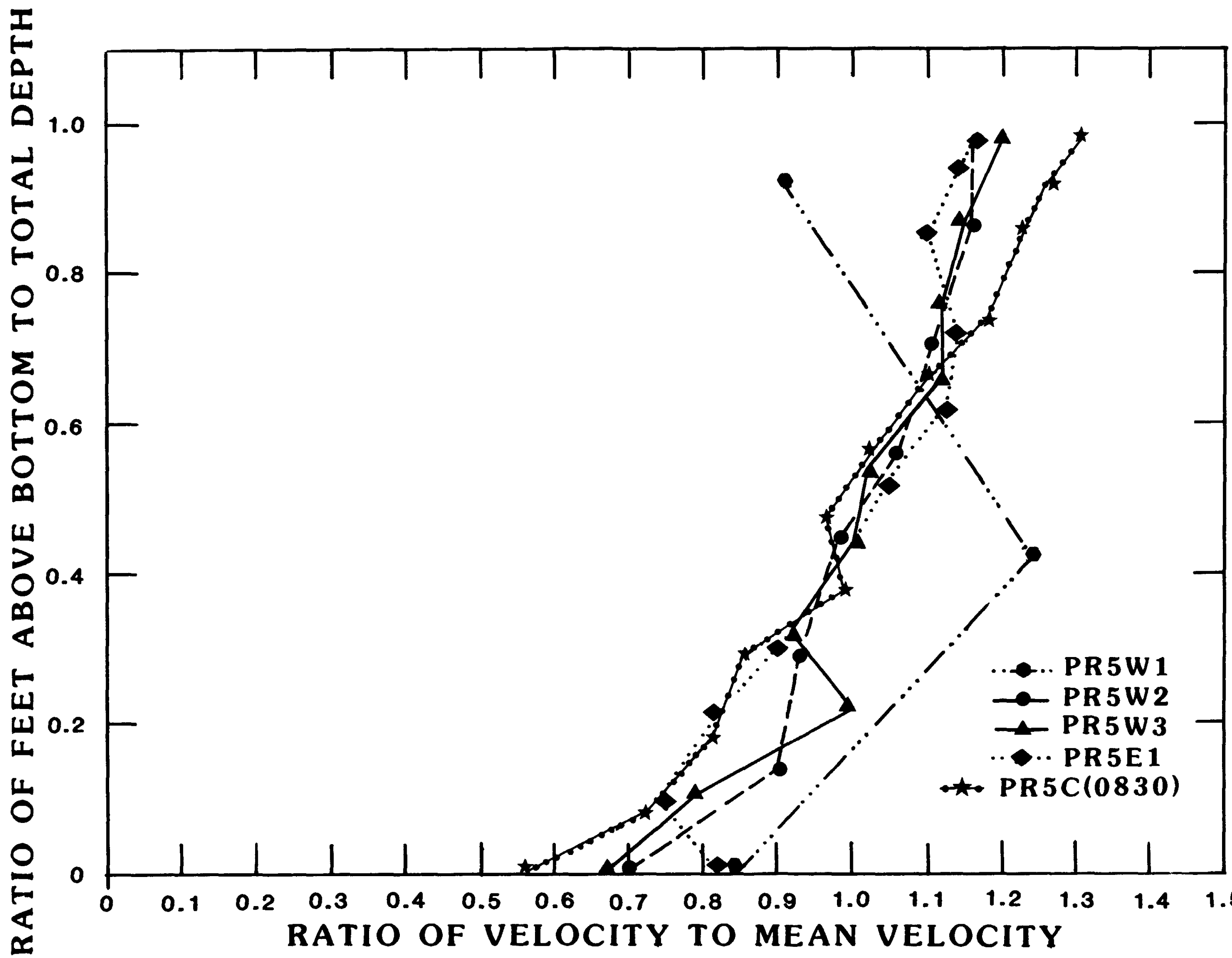

Figure 5.--Dimensionless vertical velocity distributions at all stations in the partial cross section A-A' in the vicinity of the proposed wastewater outfall on the outgoing tide in Port Royal Sound, April 13, 1984.

Vertical velocity distributions at PR5C indicate little difference in the trend of the distributions with time during the measurement period (fig. 4). Velocity distributions shown in figure 5 are similar for all stations except PR5W1 which were not used for further analysis. Thus, adjusting vertical velocity distributions at other stations through time based on the reference station, PR5C, should provide reasonable results.

The mean velocity for each of the four vertical velocity distributions at reference station PR5C was plotted against time to determine the time of maximum velocity in the tidal cycle and the maximum mean velocity at PR5C (fig. 6). The maximum mean velocity at station PR5C during the measurement period was 3.6 ft/s at about 0900 hours.

Using the curve in figure 6, measured velocities, and the time of the velocity measurement, maximum point velocity and maximum mean velocity in the tidal cycle can be calculated for selected stations other than PR5C using the following equation:

$$V_{max(x)} = V_{t(x)}\overline{V}_{max(5C)} / \overline{V}_{t(5C)}$$

where: $V_{max(x)}$ is the calculated maximum mean velocity or maximum point velocity at a selected station other than station PR5C,

$V_{t(x)}$ is the mean of the measured velocities or a measured point velocity at the selected station,

$\overline{V}_{max(5C)}$ is the maximum mean velocity at station PR5C, and

$\overline{V}_{t(5C)}$ is the mean velocity at PR5C at the time of measurement at the selected station.

The calculated vertical velocity distributions occurring at the time of maximum velocity in the tidal cycle are shown for the four stations in figure 7. The calculated maximum mean velocity at each station is the mean of the individual calculated velocities in the vertical velocity distribution for that station at the time of maximum velocity in the tidal cycle.

For station PR5C, the calculated maximum velocity was 1.73 ft/s near the bottom of the sound and was 2.29 ft/s at 5 ft from the bottom. At the other stations, the calculated maximum velocities ranged from 2.32 to 2.62 ft/s near the bottom of the sound, and from 2.38 to 3.07 ft/s 5 ft above the bottom (fig. 7). The calculated maximum velocity near the surface at PR5C was 4.95 ft/s, and the calculated maximum velocities near the surface at the other stations ranged from 3.72 to 4.60 ft/s (fig. 7).

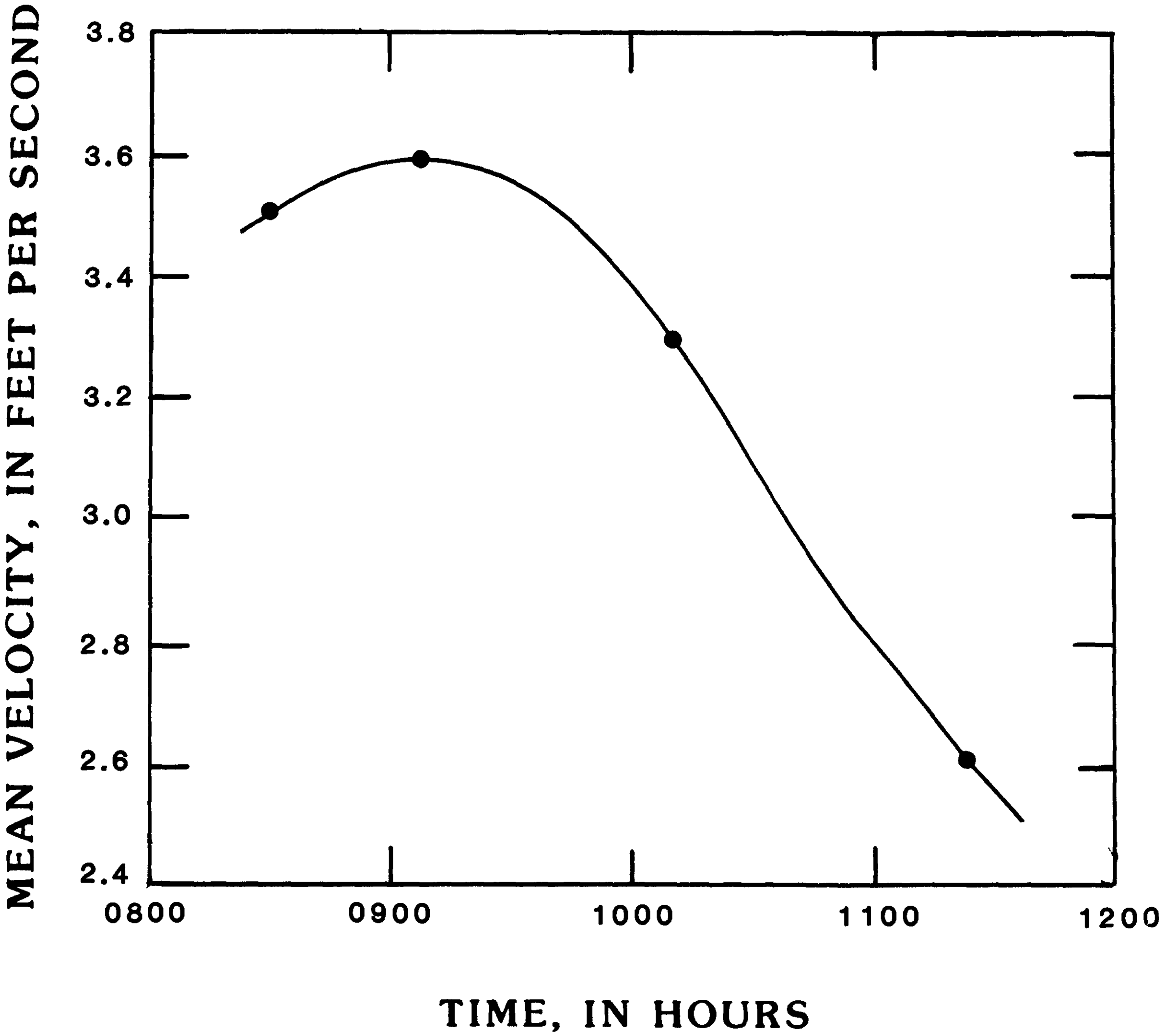

Figure 6.--Mean vertical velocities at PR5C on the outgoing tide, April 13, 1984.

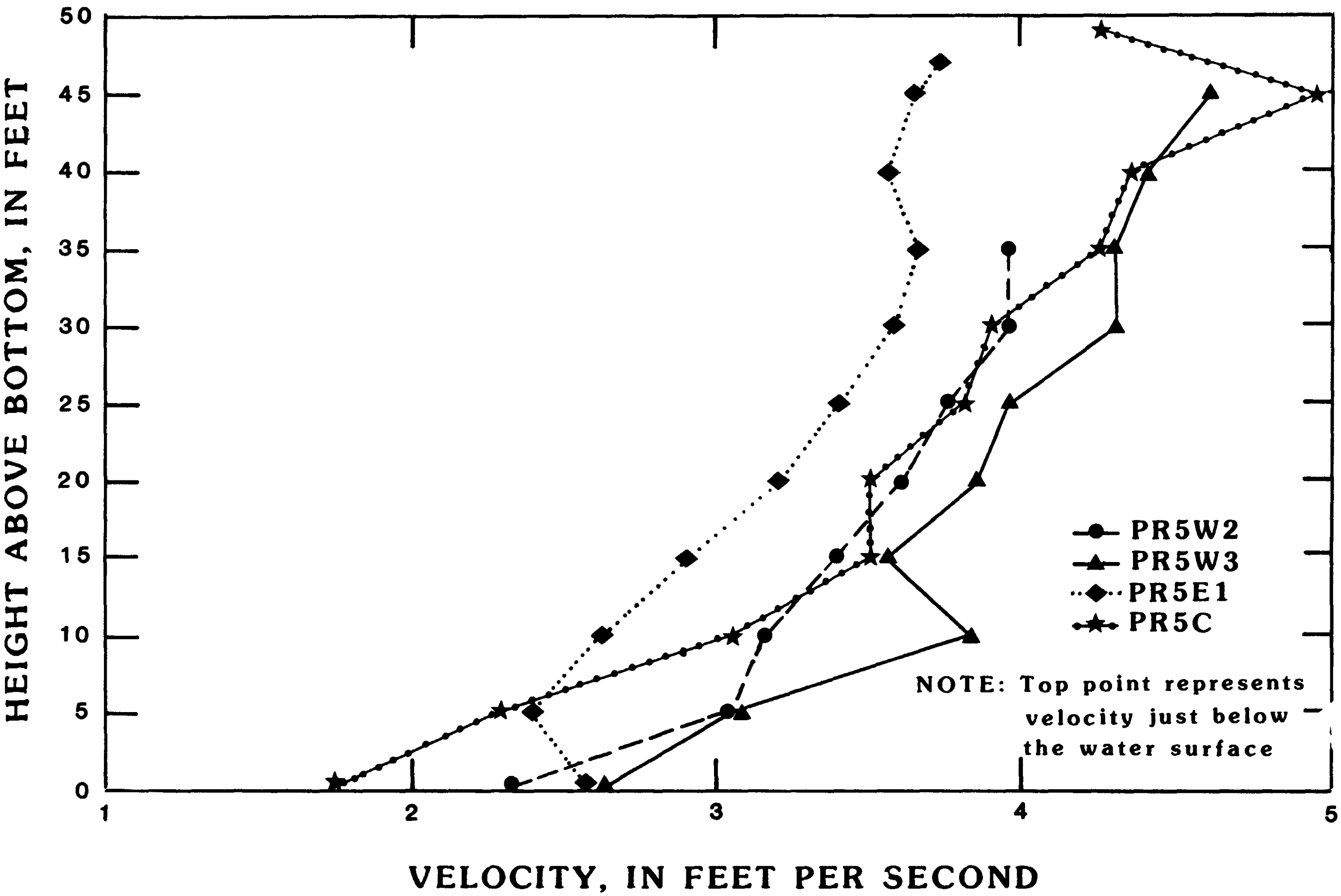

Figure 7.--Vertical velocity distributions at all stations in the partial cross section A-A' in the vicinity of the proposed wastewater outfall at the time of maximum velocity in Port Royal Sound, April 13, 1984.

The calculated maximum velocity of 4.60 ft/s is less than the maximum velocity of 6.0 ft/s observed in the previous study (South Carolina Water Resources Commission, 1972, p. 47-72). Calculated maximum mean velocities at the four stations ranged from 3.20 to 3.88 ft/s. This compares with a mean velocity across the mouth of the sound of 2.7 ft/s observed in the previous study (South Carolina Water Resources Commission, 1972, p. 47-72). Based on the similarity of the vertical velocity distributions, the results of the dye-tracer study would probably be similar for dye injected at other stations in the vicinity of the proposed wastewater outfall.

Bottom and Suspended Sediment

Particle size data show that the bottom sediment at all sites primarily consists of fine to coarse-grained sand with less than 5 percent silt and clay (fig. 8). By definition, silt and clay particles are those particles that pass through a 0.062 mm mesh sieve. A sand bar that extends from the northwestern corner of Hilton Head Island into Port Royal Sound to the vicinity of station PR5E1 was visible at low tide. The importance of this bar relative to sediment movement is discussed later in more detail.

Port Royal Sound generally has little suspended sediment. Concentrations ranged from 41 to 58 mg/L. Particle size data show that the suspended materials are generally composed of silt and clay (fig. 9). However, the percentage of sand in the suspended sediment increased from 4 percent at the station closest to the shore (PR5W1) to 35 percent at the station closest to the bar (PR5E1). This trend probably reflects the sand transported and deposited in the vicinity of the bar.

Bathymetry

The current nautical chart of Port Royal Sound (U.S. National Ocean Service, 1983) shows a bar extending about 1 mile into Port Royal Sound in an east-southeasterly direction from channel marker 3 near the northwestern corner of Hilton Head Island (fig. 10). The bar is a maximum of about 1 mile from shore. Water over the bar is as little as 2 ft deep at mean low water (fig. 10), and the bar was emergent on low tide during the dye-tracer study. The most recent depth soundings in the vicinity of the bar upon which this chart is based were made in 1931 (U.S. Coast and Geodetic Survey, 1931). The configuration of the bar indicates that the bar results from the deposition of sediment during the outgoing tide. This deposition occurs on the right side of the main flow from Skull Creek and the Chechessee River. During the outgoing tide, flow appears to be directed to the east toward the center of the sound by the northern end of Hilton Head Island. During the incoming tide, flow in the sound is probably parallel to the shore of Hilton Head Island. This may help to maintain a channel through the bar near the northwestern corner of Hilton Head Island.

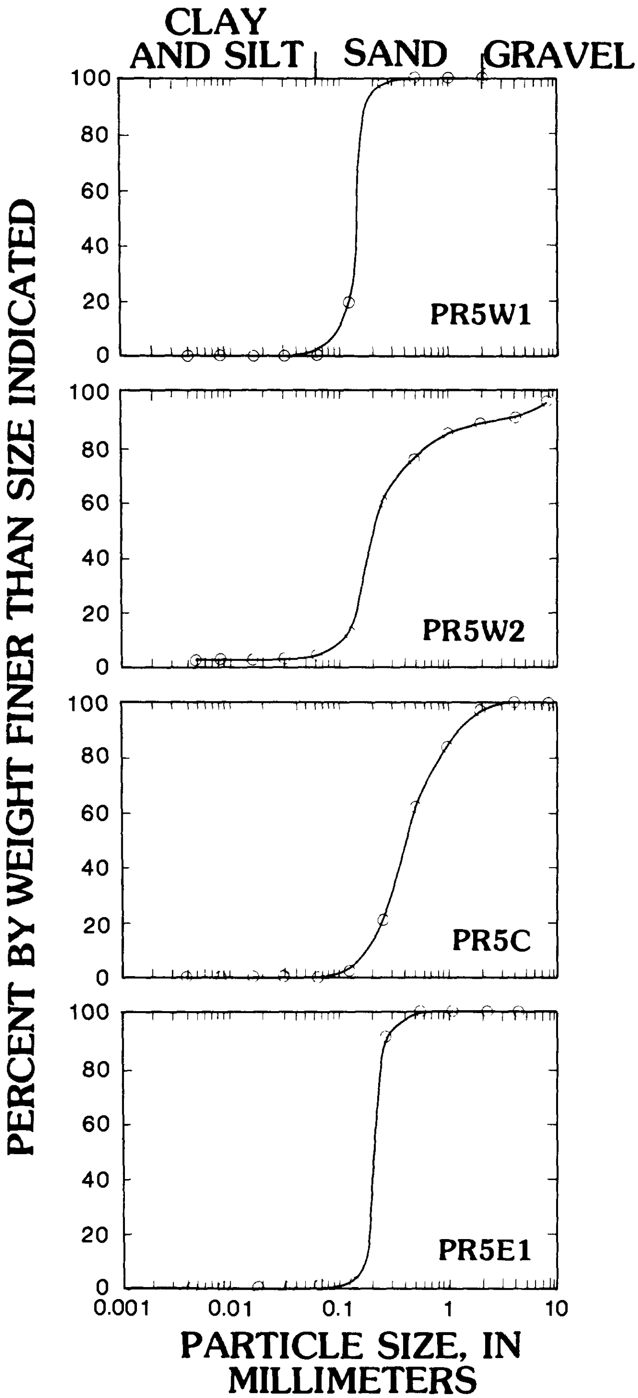

Figure 8.--Particle size distributions of bottom sediment collected February 8, 1984, at the cross section A-A' in the vicinity of the proposed wastewater outfall.

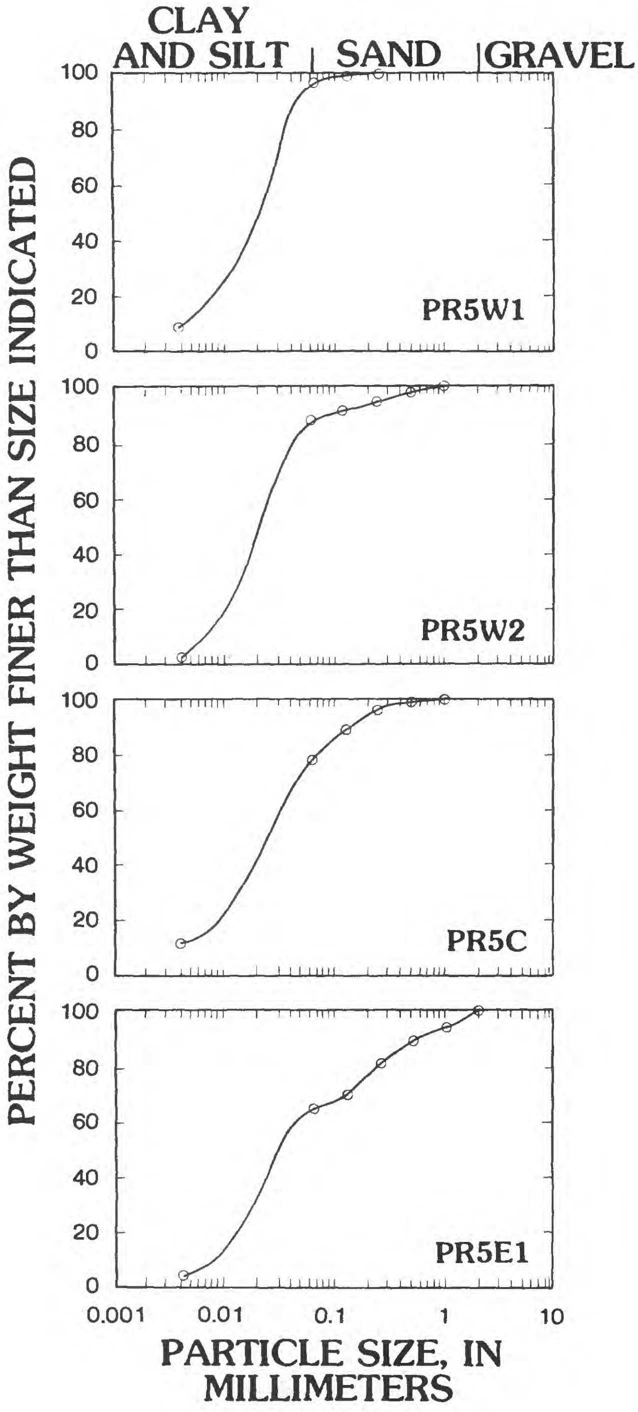

Figure 9.--Particle size distributions of suspended sediment collected February 8, 1984, at the cross section A-A' in the vicinity of the proposed wastewater outfall.

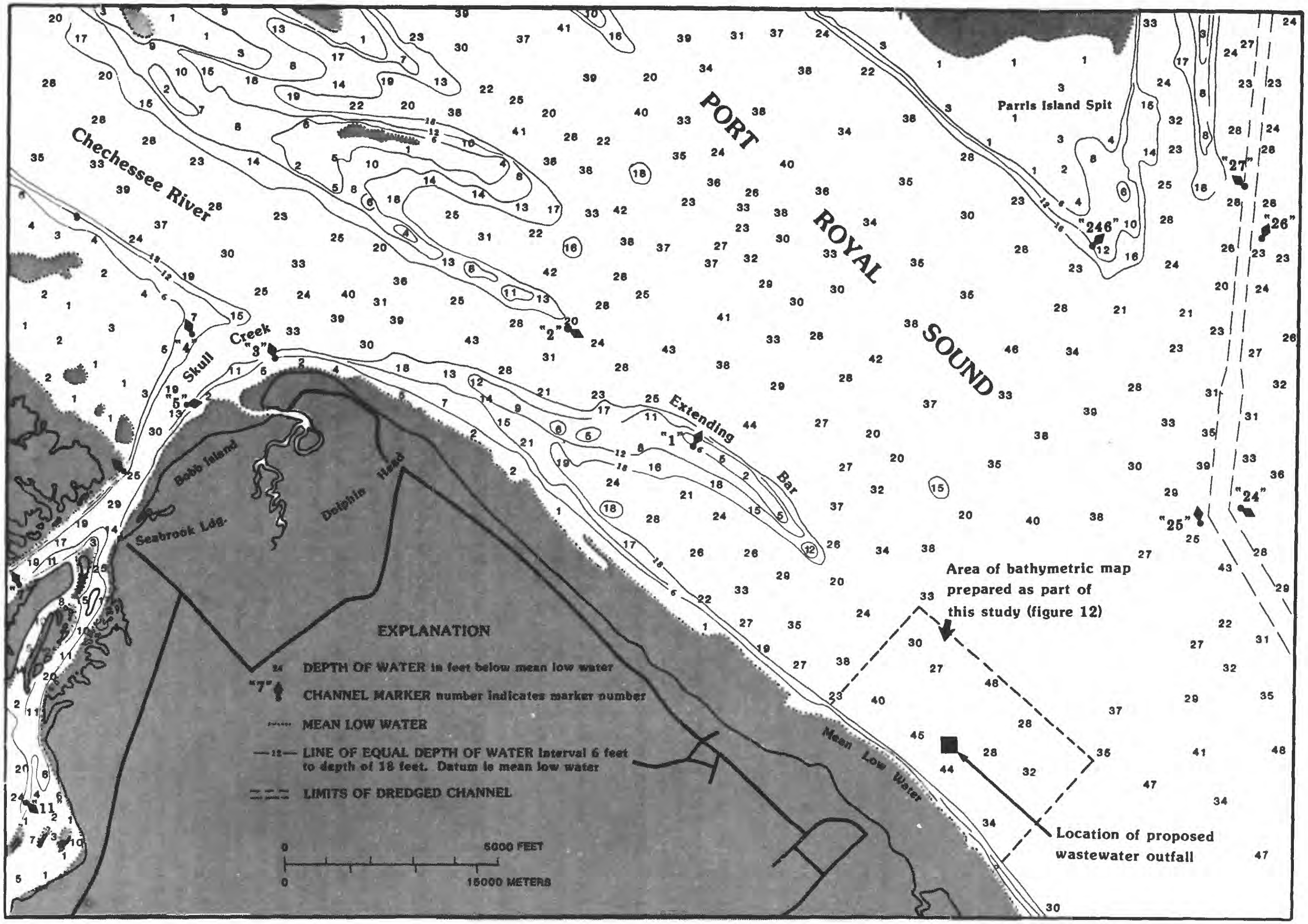

Figure 10.--Bathymetry of Port Royal Sound in the vicinity of the proposed wastewater outfall (adapted from U.S. Ocean Service, 1983).

A significant difference exists between the bathymetric charts of Port Royal Sound in the vicinity of Hilton Head Island in the 1700's (fig. 11) (South Carolina Water Resources Commission, reprint of 1778 map) and the mid 1800's (U.S. Coast and Geodetic Survey, 1862-63). The difference is less between the bathymetric charts from the mid 1800's and 1916 (U.S. Coast and Geodetic Survey, 1916). The difference is even less between the bathymetric charts from 1916 and 1931 (U.S. Coast and Geodetic Survey, 1931). Although the topography of the floor of Port Royal Sound appears to have changed between the 1700's and 1931, differences in the bathymetric mapping methods used at different times may account for some of the apparent differences in the bathymetry. However, changes in the topography also have occurred. In the descriptive report for the 1931 hydrographic study (U.S. Coast and Geodetic Survey, 1931) it was noted that the bar north of channel marker "2" (fig. 10) had receded 400 m (1310 ft) and the bar extending from Hilton Head Island had accreted 200 m (660 ft) since 1916. A comparison of the results of the 1931 hydrographic study and figure 12 indicates that the bar extending from Hilton Head Island has accreted an additional 3,500 ft between 1931 and 1984 as a result of deposition of sand and will probably continue to grow based on these changes and the greater percentage of sand in the suspended sediment at stations closer to the bar.

The depth of Port Royal Sound along a line extended into the sound from State road S-7-333 (along the cross section A-A') is shown in figure 13. Depth of the sound increases from the mean low water shoreline toward the center of the sound and then decreases in the vicinity of the bar. Exaggeration of the vertical scale makes the slope appear to be steep. However, the greatest slope is about 1 ft for every 10 ft of distance from the shore.

Growth of the bar has important implications in selecting the location of the wastewater outfall. If the outfall were located in the path of the extending bar, it may eventually be covered by as much as 35 to 40 ft of sediment. If the outfall were located beyond the bar, part of the pipe also may become covered by sediment as formation of the bar continues. However, the outfall would probably remain open to the sound.

If the wastewater outfall were located in the deep water between the bar and Hilton Head Island, dilution and dispersion of wastewater discharged into the area could be significantly altered. The bar may eventually close off the deep-water connection to the rest of the sound and reduce flow and circulation in the vicinity of the outfall.

Growth of the bar may take many years to close off or may never close off the area between the bar and Hilton Head Island. The wastewater outfall could be constructed between the bar and Hilton Head Island and growth of the bar could be monitored. If problems develop the pipe could be extended across the bar into the deeper part of the sound. A data-collection program in the area from Hilton Head Island into the sound beyond the bar could be used to monitor future changes in the bar and the impact of these changes on the discharge of wastewater.

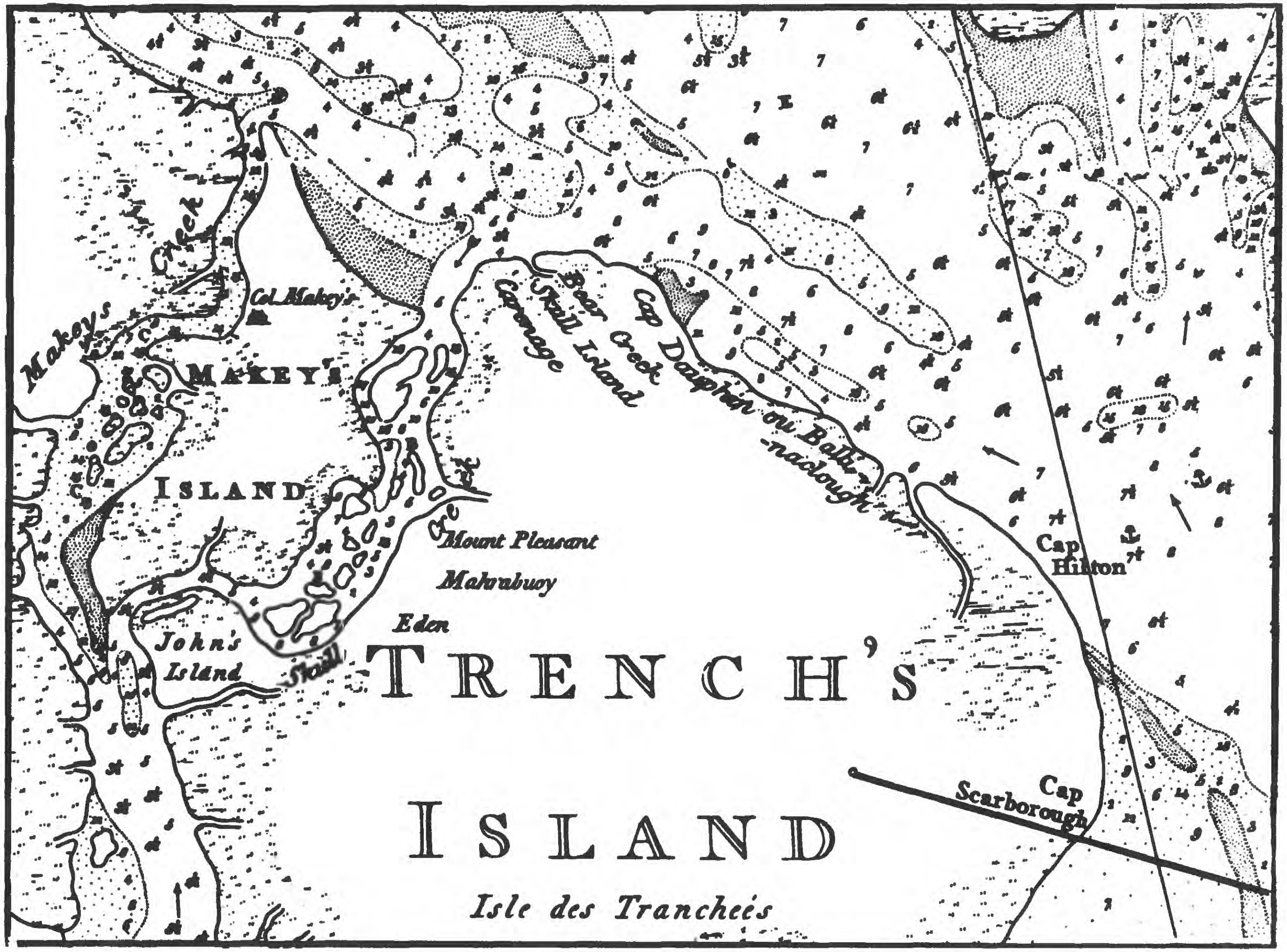

Figure 11.--Bathymetry of Port Royal Sound in the 1700's in the vicinity of the proposed outfall (adapted from South Carolina Water Resources Commission, reprint of 1778 map).

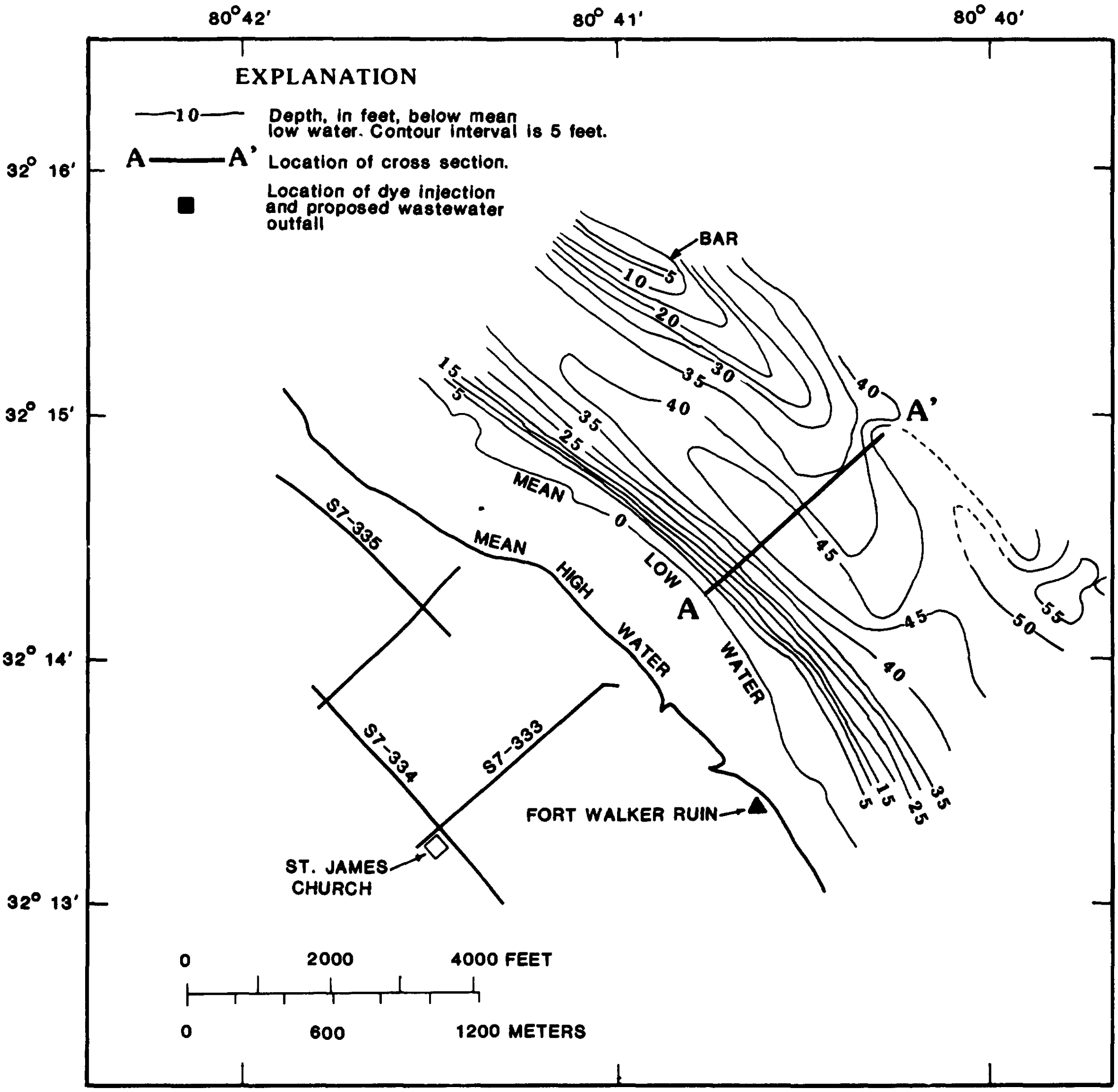

Figure 12.--The location of the dye injection, proposed outfall, and section A-A' and Bathymetry of Port Royal Sound in the vicinity of the proposed wastewater outfall, April 1984.

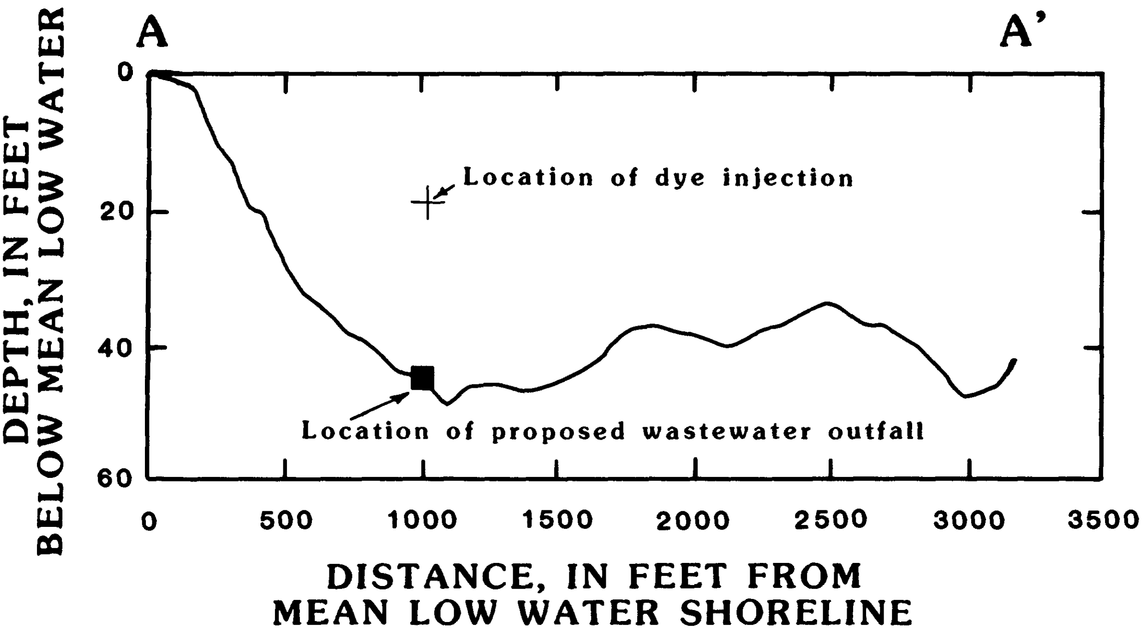

Figure 13.--Section A-A' across Port Royal Sound in line with State road S-7-333 in the vicinity of the proposed wastewater outfall, April 1984.

Dye-Tracer Study

After daylight on the morning of the dye injection, on the incoming tide dye was seen rising to the surface about 100 ft inland from the injection point although the injection was being made about 20 ft below the water surface. Upon closer investigation after the dye injection was completed, bands of dye were observed. Each band was oriented approximately perpendicular to the shoreline of Hilton Head Island and Port Royal Sound. The bands were up to about 100 ft wide, several hundred feet long, and spaced 100 to 200 ft apart. These bands extended about 1-1/2 miles inland (to the northwest), to within about 1,000 ft of station PR6. The bands may have resulted from the alternative injection method in which the dye was not diluted prior to injection. The greatest distance from the injection point at which the bands were observed is approximately the distance that dye first injected by this method could have travelled, based on the travel distance of the first peak in concentrations of dye.

Surface and depth integrated water samples were collected at the center of one band and between that band and the next band. Concentrations of dye in these samples are shown in the following table.

Concentrations of dye in the vicinity of observed bands of dye

Concentration of dye, in micrograms per liter	Surface sample	Depth integrated sample
In dye band	85	14
Between dye bands	0.00	0.10

The data indicate that the bands were discrete rather than a dispersed cloud at the surface in some areas and below the surface in other areas. Because of the lack of dispersion of the bands, data collected in the area of these bands during the first high tide after injection are not used in subsequent interpretations and presentations.

Profiles of concentrations of dye along the major axis of the dye cloud for the daytime high slack tides on November 21-23, 1983, show the effects of dispersion and the seaward movement of the dye cloud (fig. 14). The seaward movement of the dye cloud resulted from the net tidal outflow from the sound. Figure 15 shows the same effects for the daytime low slack tides on November 21-22, 1983. Peak concentrations of dye measured at high slack tide moved 3.2 miles seaward in one tidal day between November 21-22. A significant peak in the concentrations of dye was not detected within the sampling area at high slack tide on November 23.

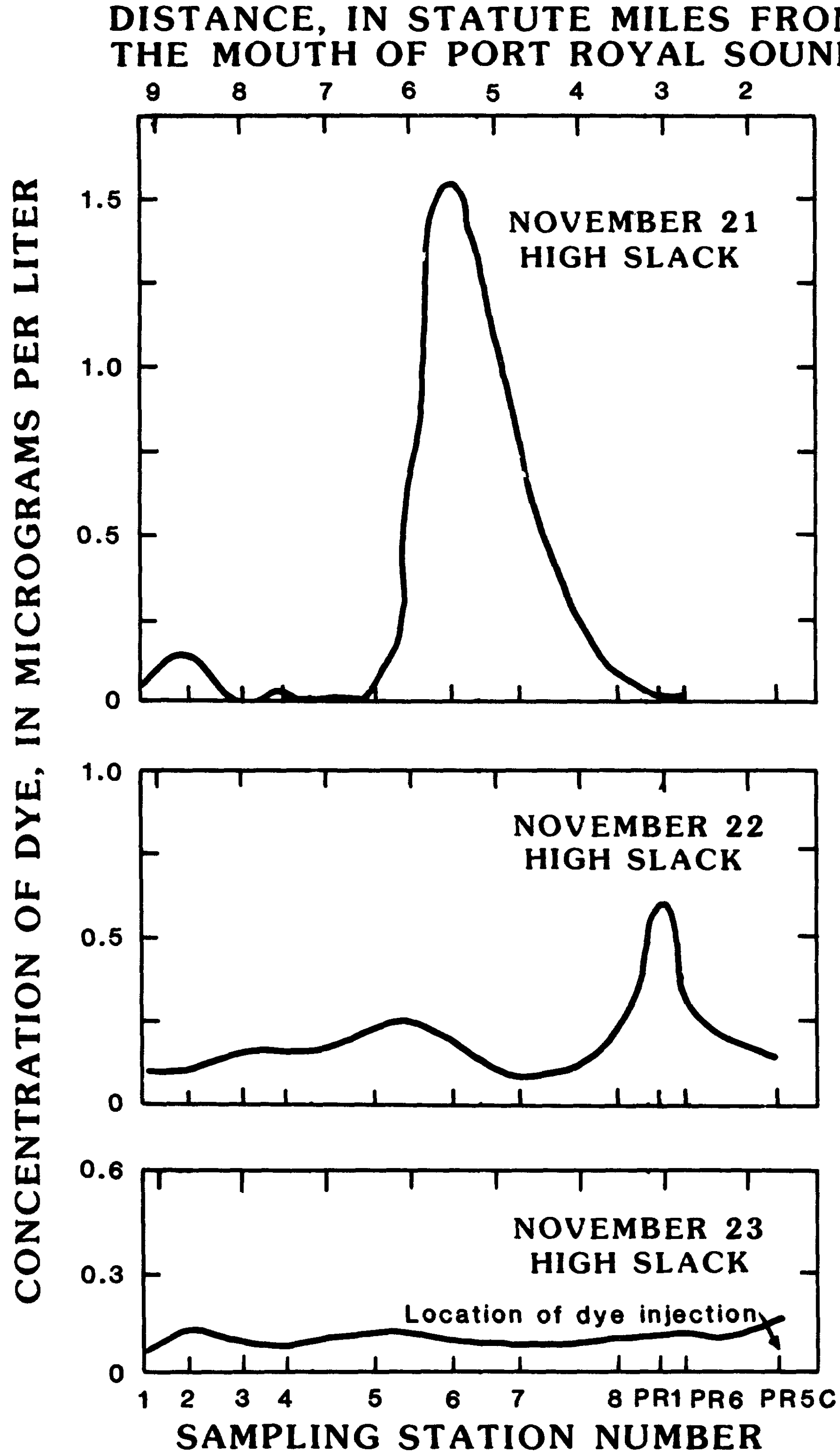

Figure 14.--Concentration of dye along the major axis of the dye cloud during high slack tide, Port Royal Sound, November 21-23, 1983.

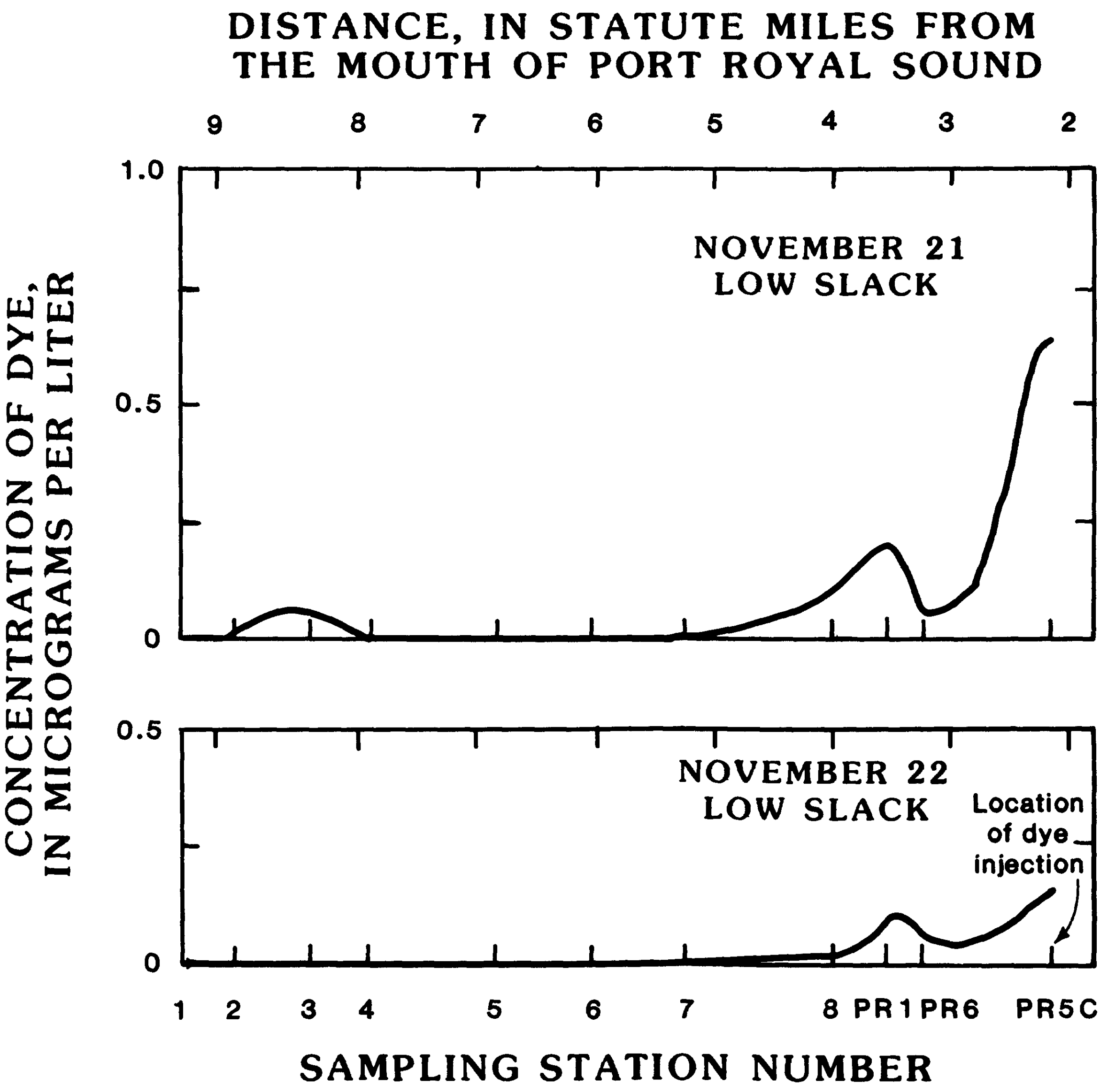

Figure 15.--Concentration of dye along the major axis of the dye cloud during low slack tide, Port Royal Sound, November 21-22, 1983.

The principle of superposition was applied to provide a conservative calculation of the cumulative concentration of dye that would occur in the center of the dye cloud at the time of high slack tide as a result of continuous dye injection during subsequent tidal cycles. Peak concentrations of dye at all high slack tides were summed to calculate the cumulative concentration of dye. For the high slack tides that concentrations of dye were not sampled, concentrations of dye were estimated by plotting peak concentrations of dye at high slack tide from figure 14 against the logarithm of time from the beginning of dye injection (fig. 16). The calculated cumulative concentrations of dye in the center of the dye cloud that would result from the continuous injection of a 20 percent solution of dye at a rate of about 110 lb/hr is shown in figure 17. The cumulative concentration of dye approaches approximately 4 μg/L. This concentration of dye in Port Royal Sound is an overestimate of the cumulative concentration of dye because it is based on the assumption of no seaward movement of the dye cloud from one tidal cycle to the next. However, the dye cloud actually moved farther seaward each tidal cycle. Thus, the peak concentration of dye injected during one slack tide in Port Royal Sound would not be added directly to the peak concentration of dye injected during the slack tide one tidal cycle earlier.

Changes in Water Quality

Water samples from station PR5C and PR7 were similar in chemical composition (table 1). Water at PR5C was slightly more saline than water at PR7 as expected of a station closer to the ocean. Water-quality data collected in 1970 at station 1 indicate that little change has occurred in the concentration of major dissolved constituents in Port Royal Sound during the past 14 years (table 1).

IMPACT OF DISCHARGING WASTEWATER ON PORT ROYAL SOUND

Changes in the quality of water in Port Royal Sound resulting from the continuous discharge of wastewater at the permitted rate and loading can be predicted using the results of the dye-tracer study and the following calculations. The loadings of constituents from the wastewater discharge into the sound are calculated from the equation:

$$L_w = C_w Q K_1$$

where: L_w = loading of a constituent in the wastewater, in milligrams per hour;

C_w = concentration of a constituent in the wastewater, in milligrams per liter;

Q = rate of wastewater discharge, in gallons per hour; and

K_1 = conversion factor of 3.875 liters per gallon.

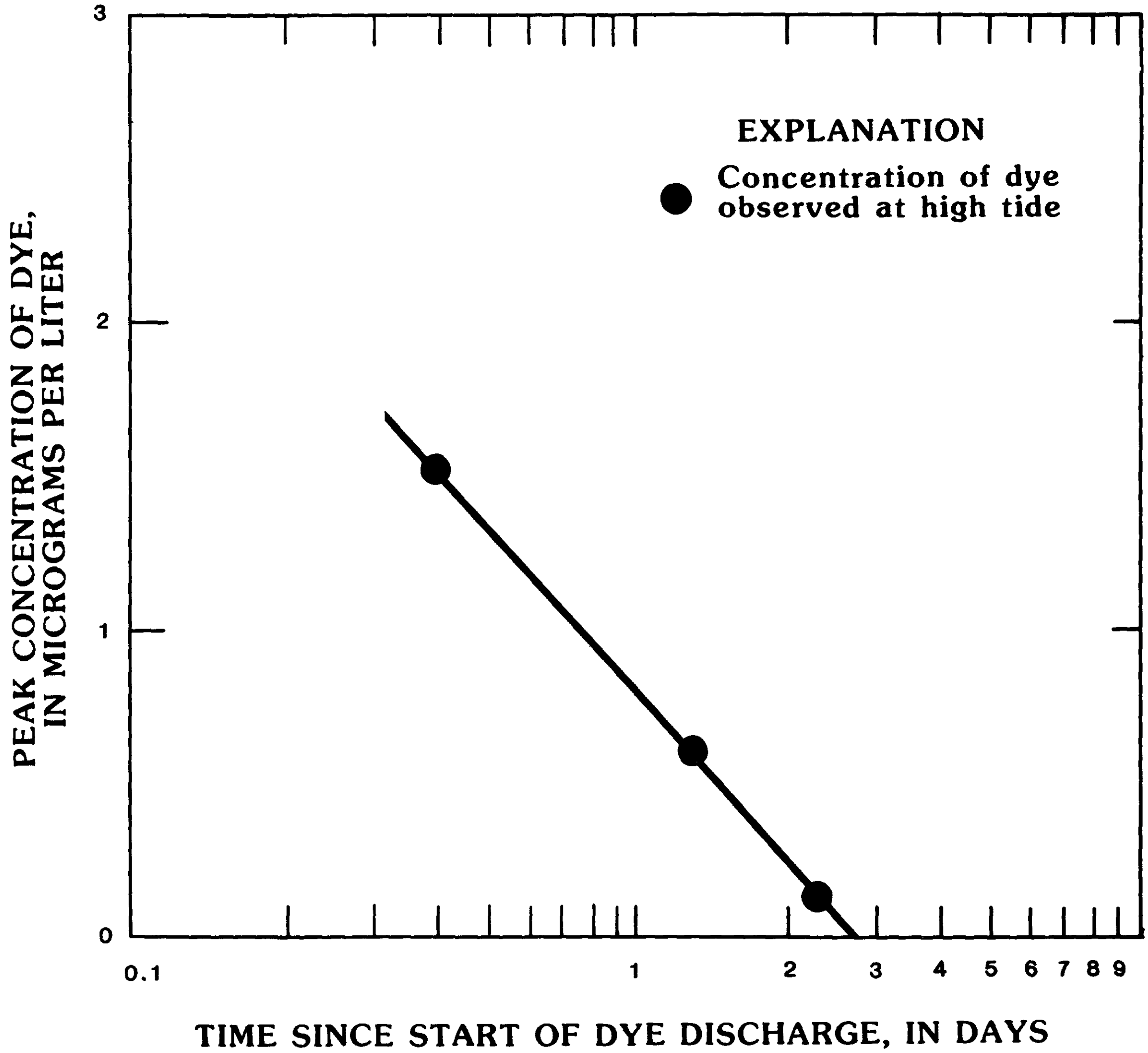

Figure 16.--Relation between peak concentration of dye at high tide and time since the beginning of the November 21, 1983, dye injection.

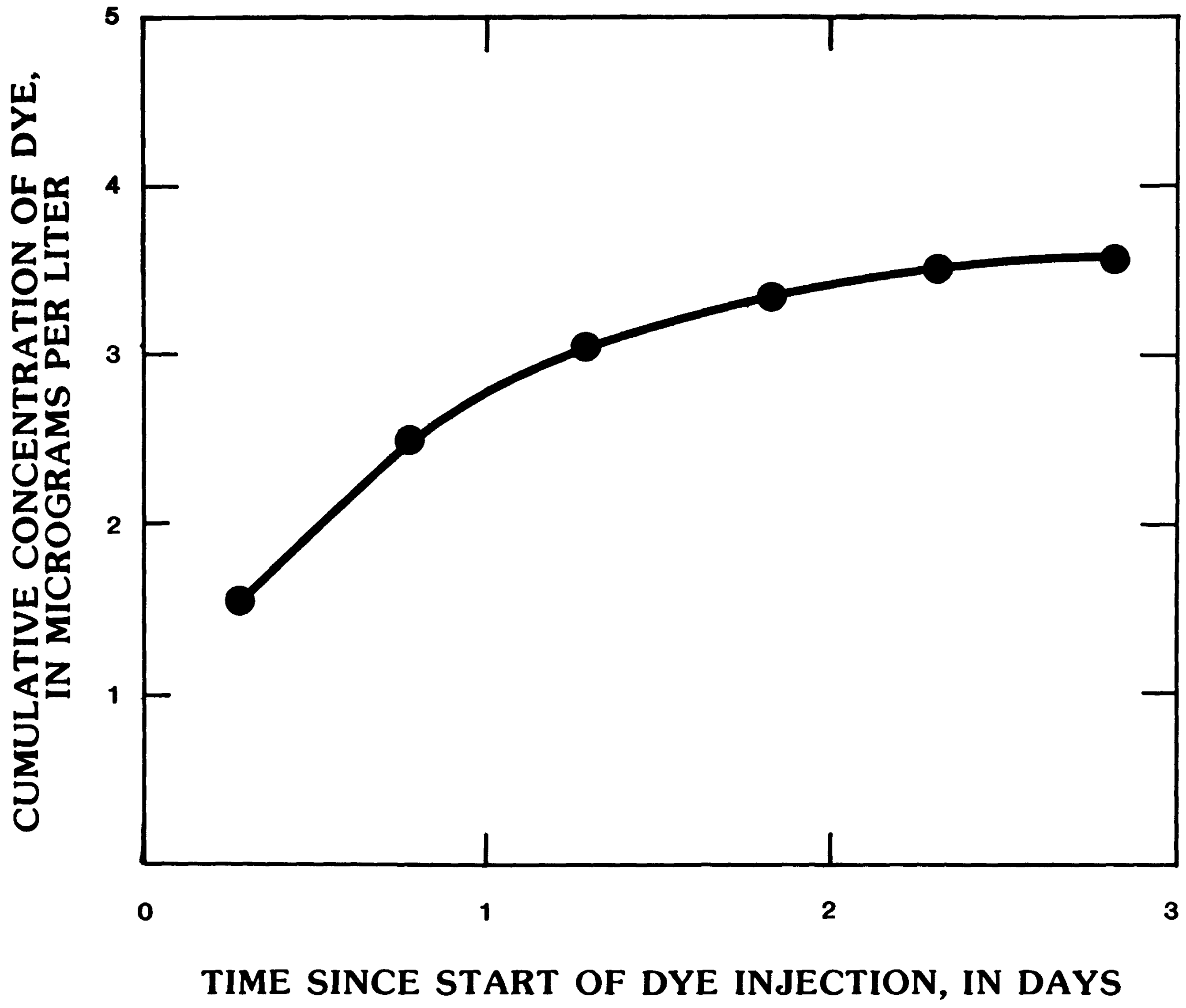

Figure 17.--Concentrations of dye resulting from the application of the principle of superposition to results of the November 1983 dye-tracer study.

Table 1.--Water quality of Port Royal Sound February, March, and April 1984 and April through October 1970

	PR5C 321445080403000			PR7 321615080430500			Station 1*		
	02/08/84	03/26/84	04/13/84	02/08/84	03/26/84	04/13/84	Maximum 04-10/70	Minimum 04-10/70	Average 04-10/70
Time	1515	1516	0800	1830	1749	1147			
Temperature (degrees C)	8.5	15.0	16.5	8.0	16.0	16.5	31.0	16.0	23.5
Oxygen, dissolved (mg/L)	11.6	--	9.5	14.2	--	9.2	9.8	5.15	6.80
ph (standard units)	7.8	8.3	7.9	7.6	7.8	8.0	9.8	5.15	--
Specific conductance, lab (µS/cm)	47,000	42,200	41,000	46,400	40,000	38,800	48,600	18,000	37,000
Calcium, dissolved (mg/L as Ca)	340	350	320	330	320	300	370	350	357
Magnesium, dissolved (mg/L as Mg)	1,100	980	170	1,100	990	170	1,050	980	1,002
Sodium, dissolved (mg/L as Na)	9,300	81,00	8,100	8,800	7,700	8,000	9,000	8,500	8,630
Potassium, dissolved (mg/L as K)	330	310	300	320	290	290	370	360	365
Chloride, dissolved (mg/L as Cl)	16,000	18,000	15,000	16,000	15,000	14,000	19,372	13,950	17,495
Sulfate, dissolved (mg/L as SO_4)	2,400	2,200	2,100	2,400	1,900	2,000	2,640	1,950	2,192
Fluoride, dissolved (mg/L as F)	0.70	0.70	0.60	0.60	0.70	0.60	--	--	--
Silica, dissolved (mg/L as SiO_2)	0.6	1.5	1.4	<0.1	2.1	1.3	--	--	--
Phosphorus, ortho, dissolved (mg/L as P)	<0.010	<0.010	0.040	<0.010	<0.010	0.010	0.15	0.01	0.04
Nitrogen, ammonia + organic, dissolved (mg/L as N)	1.1	<0.10	0.50	1.0	<0.10	0.60	--	--	--
Nitrogen, ammonia, dissolved (mg/L as N)	0.080	<0.010	0.130	0.060	<0.010	0.080	--	--	--
Nitrogen, organic, dissolved (mg/L as N)	1.0	<0.10	0.37	0.94	<0.10	0.52	1.0	0.0	0.4
Nitrogen, nitrite + nitrate, dissolved (mg/L as N)	<0.100	<0.100	<0.100	<0.100	<0.100	<0.100	--	--	--
Nitrogen, nitrite, dissolved (mg/L as N)	0.010	<0.010	<0.010	<0.010	<0.010	<0.010	--	--	--
Carbon, organic, total (mg/L as C)	2.5	2.4	2.1	1.4	3.0	1.0	--	--	--

*South Carolina Water Resources Commission, 1972.

Based on a continuous wastewater discharge of 10.9 Mgal/d and the permitted maximum concentration limits of the wastewater discharged into Port Royal Sound of 15 mg/L for a conservative constituent,

$$L_w = (15 \text{ mg/L X } 10.9 \text{ X } 10^6 \text{ gal/d X } 3.785 \text{ L/gal}) / 24 \text{ hr/d}$$

$$= 2.58 \text{ X } 10^7 \text{ mg/hr.}$$

The loading of dye to the sound is calculated from the equation

$$L_d = (W_d P K_m)/t$$

where: L_d = loading of dye, in milligrams per hour;

W_d = total weight of dye solution injected, in pound of solution;

P = fraction of dye in dye solution, in pounds of dye per pound of solution.

K_m = conversion factor of $4.54 \text{ X } 10^5$ milligrams per pound;

t = duration of dye injection, in hours.

Based on the continuous injection of 665 lbs of a 20 percent solution of dye for 6.2 hours,

$$L_d = (665 \text{ lbs sol X } 0.2 \text{ lb dye/lb sol X } 4.54 \text{ X } 10^5 \text{ mg/lb}) / 6.2 \text{ hrs}$$

$$= 9.74 \text{ X } 10^6 \text{ mg/hr.}$$

The concentration of a constituent in the sound resulting from the discharge of wastewater into the sound can be determined from the equation:

$$C_{ws} = L_w C_d / L_d$$

where: C_{ws} = concentration of a constituent in the sound, in milligrams per liter;

L_w = loading of a constituent in the wastewater, in milligrams per hour;

C_d = concentration of the dye in the sound, in milligrams per liter; and

L_d = loading of the dye, in milligrams per hour.

Using the loadings calculated above and a calculated cumulative concentration of dye of 4 μg/L at high slack tide

$$C_{ws} = (2.58 \text{ X } 10^7 \text{ mg/hr X } 0.004 \text{ mg/L}) / (9.74 \text{ X } 10^6 \text{ mg/hr}) = 0.01 \text{ mg/L.}$$

Thus, for a concentration of 15 mg/L for a conservative constituent in the wastewater effluent that is discharged into the sound, the greatest increase in the concentration of that constituent in the sound would be less than 0.01 mg/L as a result of the continuous discharge of 10.9 Mgal/d of wastewater. The small increase in concentration of a conservative constituent predicted from the results of the dye-tracer study is a result of the large volume of flow into and out of Port Royal Sound which causes significant dispersion and dilution of wastewater discharged into the sound. The 0.01 mg/L increase applies to the concentration of conservative constituents but does not consider the effects of processes such as the biochemical decay of BOD or constituents for which concentrations in the sound are greater than in the wastewater. Decay would further reduce the concentration of BOD such that the increase in concentration of BOD resulting from the continuous discharge of wastewater will be less than the conservative concentration calculated above. Constituents for which concentrations in the sound are greater than in the wastewater will not increase.

The calculated increase in the concentration of BOD of less than 0.01 mg/L is much less than the 1.4 mg/L average concentration of BOD for samples collected in the 1970 study of Port Royal Sound (South Carolina Water Resources Commission, 1972). Concentrations of suspended solids in Port Royal Sound will not increase as a result of discharging wastewater with a concentration of suspended solids of 15 mg/L because the concentration in the wastewater is less than the 41 to 58 mg/L concentrations of suspended solids in samples collected in the vicinity of PR5 on April 13, 1984. Based on this evaluation, there should be little, if any, impact on the concentrations of BOD and suspended solids in Port Royal Sound created by continuously discharging 10.9 Mgal/d of tertiary-treated wastewater having the permitted concentrations of BOD and suspended solids of 15 mg/L or the expected concentrations BOD and suspended solids of 5 mg/L.

SUMMARY AND CONCLUSIONS

Vertical velocity distributions in a cross section in the vicinity of the proposed wastewater outfall were similar at all stations except station PR5W1, the station closest to the shore. Calculated velocities for the time of maximum velocity ranged from 1.73 ft/s near the bottom to 4.95 ft/s near the surface of the sound.

Bottom sediment consisted primarily of fine to coarse grained sand with less than 5 percent silt and clay at all stations in the cross section. Concentrations of suspended sediment ranged from 41 to 58 mg/L. The suspended sediment consisted primarily of silt and clay. The percentage of sand ranged from 4 percent near the shore to 35 percent at the station closest to the sand bar located farther in the sound.

A bathymetric chart made of the vicinity of the proposed wastewater outfall indicates that a bar extends farther into Port Royal Sound than indicated on the nautical chart of Port Royal Sound. It appears that this bar consists primarily of sand and that the bar is accreting as a result of the deposition of sand in the area. Continued accretion of this bar could alter the impact on water quality from discharging of treated wastewater into the sound. Further study may be required to monitor changes in the bar if the outfall is located between the bar and Hilton Head Island.

Conservative calculations based on results of the dye-tracer study indicate that continuous discharge of 10.9 Mgal/d of wastewater having a concentration of BOD and suspended solids of 15 mg/L will result in a peak cumulative increase in the concentration of BOD of less than 0.01 mg/L and no increase in the concentration of suspended solids in Port Royal Sound. This low increase in the concentration of BOD results from the very dynamic nature of Port Royal Sound in which huge volumes of water flow alternately into and out of the sound. The resulting rapid dilution has been conservatively demonstrated by the dye-tracer study. There will be no increase in the concentration of suspended solids resulting from the discharge because the concentration of suspended solids in Port Royal Sound is greater than that of the wastewater.

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