FLOW AND SALINITY IN WEST NECK CREEK, VIRGINIA, 1989-92, AND SALINITY IN NORTH LANDING RIVER, NORTH CAROLINA, 1991-92

By Jerad D. Bales and Stanley C. Skrobialowski

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 94-4067

Albemarle-Pamlico Estuarine Study Report No. 94-04

Prepared in cooperation with the

NONGAME ADVISORY BOARD, NORTH CAROLINA WILDLIFE RESOURCES COMMISSION

DIVISION OF WATER RESOURCES and

ALBEMARLE-PAMLICO ESTUARINE STUDY of the NORTH CAROLINA DEPARTMENT OF ENVIRONMENT, HEALTH, AND NATURAL RESOURCES

Raleigh, North Carolina

1994

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. GEOLOGICAL SURVEY
GORDON P. EATON, Director

For additional information write to:

District Chief
U.S. Geological Survey
3916 Sunset Ridge Road
Raleigh, North Carolina 27607

Copies of this report can be purchased from:

U.S. Geological Survey
ESIC, Open-File Reports Section
Box 25286, MS 517
Denver Federal Center
Denver, Colorado 80225

CONTENTS

ILLUSTRATIONS

Page

TABLES

FLOW AND SALINITY IN WEST NECK CREEK, VIRGINIA, 1989-92, AND SALINITY IN NORTH LANDING RIVER, NORTH CAROLINA, 1991-92

By Jerad D. Bales *and* Stanley C. Skrobialowski

ABSTRACT

Water level, flow velocity, and salinity were measured at 15-minute intervals at one site (site 1) in West Neck Creek, Virginia, during 1989-92. During the same period, water level and salinity also were measured at a second site on the creek (site 2) about 4.8 miles south of site 1. Water level in the study reach is affected by tidal fluctuations in Chesapeake Bay. The water level at site 1 ranged from -1.18 to 4.45 feet during the study period. Precipitation events and associated runoff resulted in large rises in water level at site 1, but in only small rises at site 2.

The ultrasonic velocity meter provided accurate and reliable measurements of flow velocity in West Neck Creek. The flow velocity at site 1 ranged from 0.29 feet per second to the north to 1.48 feet per second to the south. During the 308 days of record, the mean velocity was 0.15 feet per second to the south. Instantaneous flow at site 1 ranged from 50 cubic feet per second to the north to 356 cubic feet per second to the south, and daily mean flow ranged from 39 cubic feet per second to the north to 214 cubic feet per second to the south. Mean flow for the 308 days of record was 13 cubic feet per second to the south. Daily mean flow was to the south 64 percent of the time, and 80 percent of the southward flows were less than 40 cubic feet per second. The six highest observed daily mean flows at site 1 were associated with precipitation events.

Salinity at site 1 ranged from 0.1 to 24.5 parts per thousand, and the maximum salinity at site 2 was 14.5 parts per thousand. Daily mean salinity at site 1 was less than or equal to 1 part per thousand 55 percent of the time; daily mean salinity at site 2 was less than 1 part per thousand 58 percent of the time. Although the highest flows in the study reach were associated with precipitation events, the highest salinities were observed during periods of sustained north to northeasterly winds, such as those observed during late October and early November 1991. Simultaneous measurements of flow and salinity allowed the computation of northward and southward transport of salt. For the 294 days during which flow and salinity data were available, the net salt transport at site 1 was 34,510 tons to the south. Southward transport ranged from 0.3 to 4,500 tons per day, and northward transport ranged from 0.2 to 302 tons per day.

Salinity also was measured in North Landing River near the North Carolina-Virginia State line (site 3), which is south of the confluence of West Neck Creek with the river. Salinities were measured near the water surface and near the channel bottom at 15-minute intervals during 1991-92. Near-surface and near-bottom salinities seldom differed by more than 0.2 part per thousand, and salt appeared to be uniformly distributed throughout the river cross section. Little diurnal variation in salinity was observed at the site. From January through November 1991,

the daily mean salinity at site 3 was generally less than 0.8 part per thousand. From December 1991 through March 28, 1992, daily mean salinity at site 3 ranged from 0.9 to 1.3 parts per thousand, and from April through July 1992, salinity at site 3 increased from about 1.3 to about 2.5 parts per thousand. Additional study will be required to comprehensively characterize salt transport in Currituck Sound.

INTRODUCTION

West Neck Creek and its northward extension, London Bridge Creek, provide a hydraulic connection between the saline waters of Chesapeake Bay and the relatively fresh waters of North Landing River and northern Currituck Sound (figs. 1 and 2). West Neck Creek and London Bridge Creek also are known collectively as Canal Number Two (U.S. Army Corps of Engineers, 1980a).

Canal Number Two was constructed by the U.S. Soil Conservation Service to provide drainage and flood control during a time when the land that drained to the canal was used primarily for agriculture. Because of land development and alteration of runoff patterns, the U.S. Army Corps of Engineers (1980a) concluded that the canal was no longer an "adequate flood control structure." Therefore, to reduce potential flood damages, the Corps of Engineers recommended improvements to segments of the canal and construction of a 2.6-mile (mi) long bypass canal to the east of Canal Number Two. The bypass canal was completed in the late summer of 1989.

Although Canal Number Two has provided a direct connection between Chesapeake Bay and Currituck Sound for a number of years, construction of the bypass canal resulted in questions about the magnitude and direction of flow and salt transport in Canal Number Two. Of particular interest was the potential for movement of salt and urban drainage into North Landing River and Currituck Sound. However, prior to this investigation, little information on salinity in the canal and virtually no data on flows and salt loads were available.

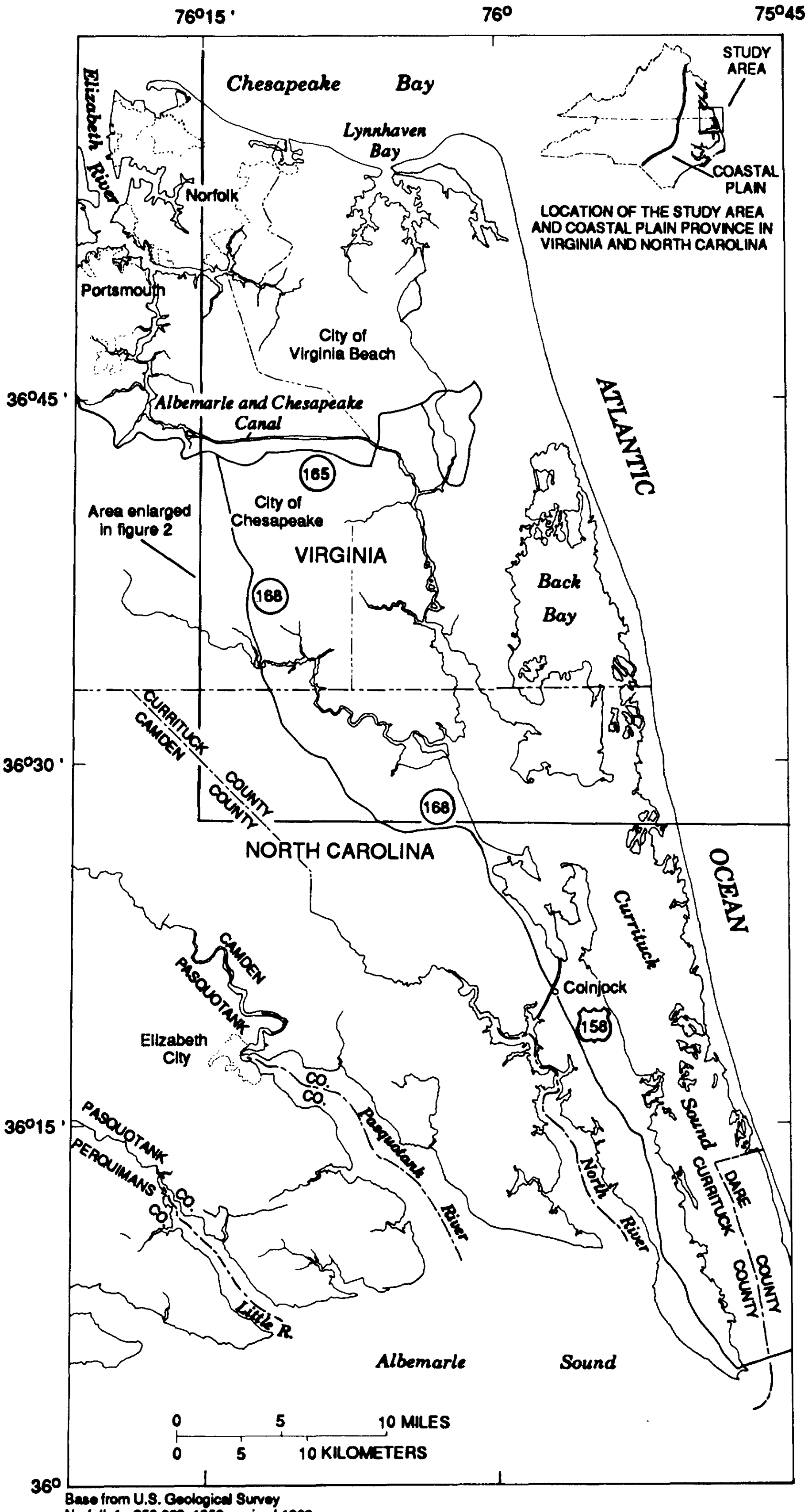
In 1989, the U.S. Geological Survey (USGS), in cooperation with the Division of Water Resources of the North Carolina Department of Environment, Health, and Natural Resources, began an investigation of the flow and salinity regime in the West Neck Creek segment of Canal Number Two, which is south of the new bypass canal. The objectives of the investigation were to (1) determine flow rates and predominant flow direction in West Neck Creek and (2) characterize the salinity regime, including salt loads, in the creek. Subsequently, in 1991 the USGS, in cooperation with the Albemarle-Pamlico Estuarine Study, began monitoring salinity in North Landing River, which is hydraulically connected to West Neck Creek, for comparison with data collected in West Neck Creek. The investigation was completed in cooperation with the Nongame Advisory Board of the North Carolina Wildlife Resources Commission and the Albemarle-Pamlico Estuarine Study.

Purpose and Scope

The purpose of this report is to describe the flow and salinity regime in a segment of West Neck Creek, Virginia, and to characterize salinity conditions at one location in North Landing River, North Carolina, in relation to observed conditions in West Neck Creek. The analysis is based on data collected at two locations in West Neck Creek during 1989-92, and at one location in North Landing River during 1991-92.

Water-level records obtained at the West Neck Creek study reach boundaries are used to characterize water-surface slope and to estimate direction of flow for the study period. Water-level records also are used with velocity data, obtained by using an ultrasonic velocity metering system, to compute flow rates at the northern end of the study reach. The observed effects of precipitation and wind on water level and flow are summarized.

Salinity data obtained from measurements at the study reach boundaries are used to characterize conditions during the study period, to evaluate the movement of salt through the study reach, and to describe the relation between salinity and flow conditions. Salt loads are computed for the northern end of the study reach for periods when salinity and flow data are available. Salinity data for North Landing River are used to characterize conditions at that site for part of the study period (1991-92) and are compared with salinity measured in West Neck Creek.



Base from U.S. Geological Survey
Norfolk 1 : 250,000, 1953, revised 1969
Eastville 1 : 250,000, 1946, revised 1969

Figure 1. Location of study area in Virginia and North Carolina.

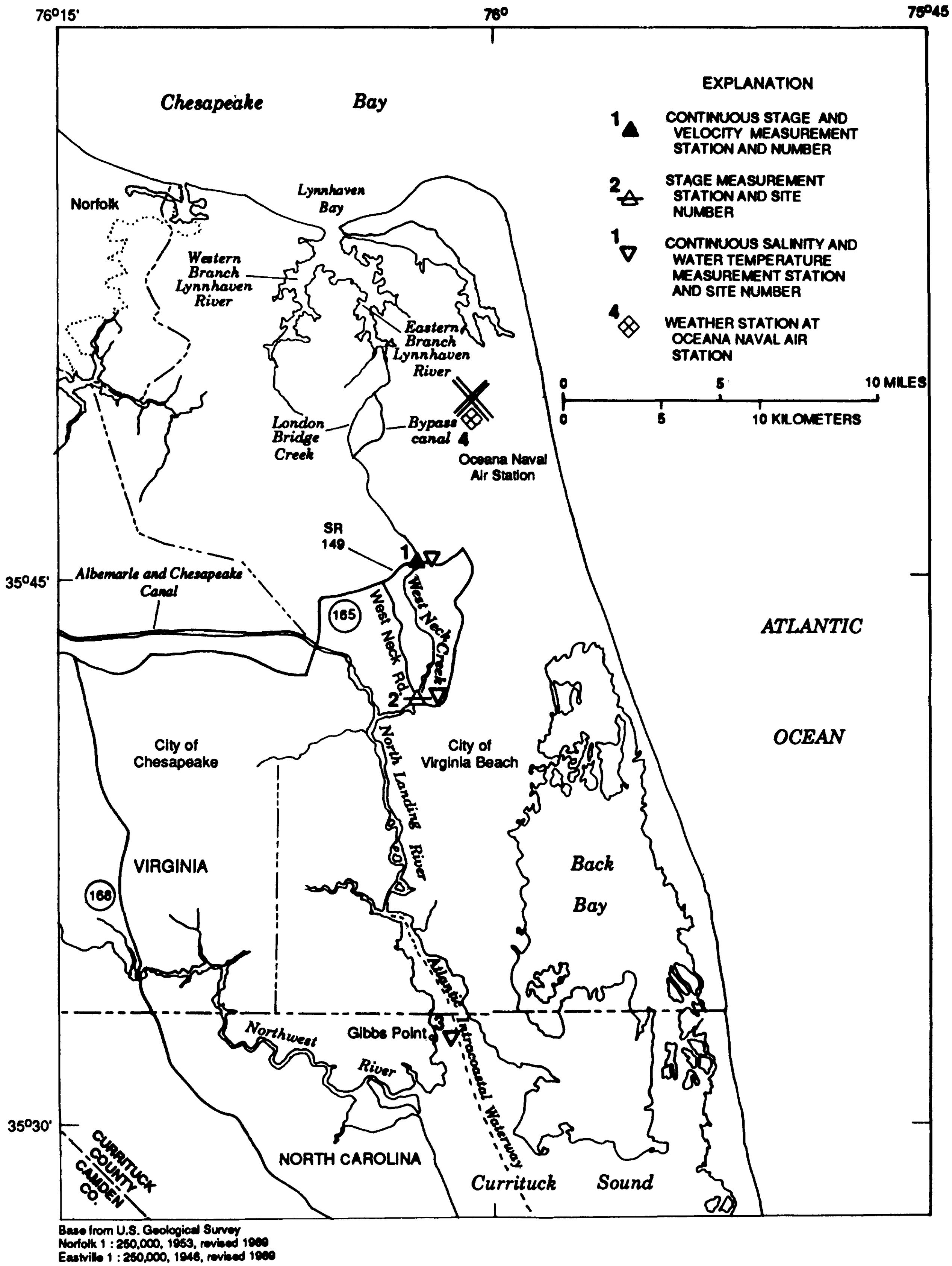


Figure 2. Data-collection sites in study area.

Stream Systems and Study Area Description

Canal Number Two is located entirely within the City of Virginia Beach, which has a population of about 400,000 and is the largest city in Virginia. The distance from the confluence of London Bridge Creek with Eastern Branch Lynnhaven River to the confluence of West Neck Creek with North Landing River is about 12 mi (fig. 2). The canal originally drained approximately 37 square miles (mi^2) (U.S. Army Corps of Engineers, 1980a), although development and associated changes in natural drainage patterns could have altered the size of the basin. The northern part of the Canal Number Two drainage area is heavily developed.

The northern confluence of the bypass canal with London Bridge Creek is about 1.1 mi south of where London Bridge Creek flows into Eastern Branch Lynnhaven River (fig. 2). This 1.1-mi reach of London Bridge Creek is channelized to a depth of 8 feet (ft) below sea level and has a top width of about 80 ft. The bypass canal is about 2.6 mi long and has a bottom elevation of 4 ft below sea level (U.S. Army Corps of Engineers, 1980b). The bottom width of the bypass canal is about 60 ft, the top width averages 152 ft, and the banks of the canal slope at a ratio of 2 horizontal to 1 vertical. When the bypass canal was constructed, a 15-ft wide strip of marsh was planted in the intertidal zone along the side of the canal; the elevation of the marsh is at sea level.

The northern boundary of the West Neck Creek study reach (site 1) is located 3.9 mi south of the southern confluence of the bypass canal with London Bridge Creek. The distance between sites 1 and 2 (fig. 2) is about 4.8 mi, and the northern 2.6 mi of this reach are channelized. The channel is 45 ft wide at site 1 and 210 ft wide at site 2; the average water depth at both sites is about 6 ft. The confluence of West Neck Creek with North Landing River is about 1.8 mi south of site 2.

The total drainage area of North Landing River in Virginia is 116.6 mi^2, of which 4 percent is water, 35 percent is undeveloped, 44 percent is used for agriculture, and 17 percent is developed (Hampton Roads Planning District Commission, 1992). North Landing River and several of its tributaries have been designated as a State scenic river by the Virginia General Assembly. The Albemarle and Chesapeake Canal joins North Landing River 3.2 mi north of West Neck Creek. This canal, which is part of the Atlantic Intracoastal Waterway (AIWW), joins Elizabeth River about 8 mi to the west. A lock at the western end of the Albemarle and Chesapeake Canal prevents continuous inflow of high-salinity Elizabeth River water into the canal and, thus, into North Landing River.

The AIWW continues south from the Albemarle and Chesapeake Canal through North Landing River and into Currituck Sound (fig. 1). The AIWW exits Currituck Sound about 14 mi south of the North Carolina-Virginia State line through a land cut near Coinjock and joins North River. Currituck Sound, which has no direct connection with the ocean, has a surface area of 153 mi^2 (Giese and others, 1985) and is about 36 mi long from the State line to the confluence of Currituck Sound with Albemarle Sound. Saline water can enter Currituck Sound from the south only through Albemarle Sound, at the mouth of Currituck Sound, or through the North River-AIWW cut.

The study area lies in the Coastal Plain physiographic province (fig. 1). There is little topographic relief in the area; elevations range from about 0 to 30 ft (Malcolm Pirnie Engineers, Inc., 1980). The climate of the area is classified as humid-subtropical (Neilson, 1976). The mean annual precipitation is about 45 inches (in.), and precipitation is slightly higher during the summer months than during the remainder of the year. The annual average temperature is about 15 degrees Celsius (°C). Heavy rainfall and strong winds associated with tropical storms and hurricanes can occur in the summer and fall. "Northeasters," which typically occur during fall and winter months, also can generate strong winds and associated heavy precipitation and high water levels.

Previous Studies

Because of the rapid growth in Virginia Beach and surrounding areas, numerous water-quality studies have been conducted in the Lynnhaven River Basin. Few of these studies, however, have included Canal Number Two.

Neilson (1976, 1978) summarized results of water-quality studies, which included Lynnhaven River and Lynnhaven Bay, as well as eight adjacent estuaries. The studies included field surveys and water-quality modeling of point- and non-point source loads. Model results indicated that Lynnhaven Bay could experience depressed dissolved-oxygen levels under assumed future (1983 and 1995) loading scenarios. Malcolm Pirnie Engineers, Inc. (1980) conducted a subsequent investigation in the Lynnhaven Basin and focused on shoreline characteristics, bottom-sediment analysis, water-quality sampling, and water-quality modeling. One water-quality and bottom-sediment sampling station was located at the north end of Canal Number Two. The Hampton Roads Planning District Commission (HRPDC) reported on water-quality conditions in Lynnhaven River in 1982 and 1988. According to the HRPDC (1992), water-quality conditions in North Landing River and Northwest River are not well documented, but water-quality problems appear to be related to natural conditions, such as low flow velocities and high organic loadings from surrounding wetlands.

As part of the planning and design process for the construction of the bypass canal that was completed in 1989, the U.S. Army Corps of Engineers (1980a, b) reported on existing hydrologic conditions in Canal Number Two, possible alternatives to reduce flood damages along the canal, and expected future hydrologic conditions following construction of the bypass canal. Among its findings, the U.S. Army Corps of Engineers reported that (1) the estimated 100-year tidal elevation to the south of Canal Number Two was 5.0 ft; (2) the estimated 100-year tidal elevation to the north of Canal Number Two was 7.8 ft; (3) salinity in Canal Number Two ranged from 0 to 17 parts per thousand (ppt); and (4) there was no salinity stratification in the canal even during periods of extreme low flow. The Corps of Engineers also anticipated that construction of the bypass canal would lead to improved water quality in Canal Number Two because of increased flushing rates.

Overton and McAllister (1993) applied a water-quality model to Canal Number Two, the bypass canal, and North Landing River. They concluded that salt entering Canal Number Two from the north potentially could be transported southward into Currituck Sound under extreme tidal conditions that persisted for several days. Under milder conditions, simulation results indicated that salt would not be transported southward from Lynnhaven River into Currituck Sound. The model was calibrated using data collected during this study. Finally, in August 1991, the Corps of Engineers began an intensive 3-year water-quality monitoring program in Canal Number Two and the bypass canal; results from that monitoring were not available for this report (Larry Holland, U.S. Army Corps of Engineers, oral commun., 1992).

Acknowledgments

Staff from the Oceana Naval Air Station (NAS) graciously supplied meteorological data during the study. The U.S. Army Corps of Engineers, Norfolk District, provided information on the history and construction of Canal Number Two and the bypass canal. The City of Virginia Beach is gratefully acknowledged for providing right-of-way access for instrumentation installations.

DATA COLLECTION

Data were collected by the USGS at two locations in West Neck Creek and one location in North Landing River (fig. 2; table 1). West Neck Creek (sites 1 and 2) data were collected from August 1989 through March 1992 (fig. 3), and North Landing River (site 3) data were collected from January 1991 through August 1992 (fig. 3). Daily precipitation, and wind speed and direction data for August 1989 through March 1992 were obtained from the Oceana NAS weather station (site 4, fig. 2), located about 5 mi north of site 1.

Water Level

Water level was determined by using float sensors at sites 1 and 2. Data were recorded to the nearest 0.01 ft at 15-minute intervals. Gage datums were referenced to sea level by leveling to the nearest benchmark. All reported water levels are referenced to sea level.

Water Velocity and Discharge

Water velocity was measured at site 1 by using an ultrasonic velocity metering (UVM) system. UVM systems measure the velocity of flowing water by transmitting an ultrasonic pulse along an acoustic path that is at an angle of between 30 and 45 degrees diagonal to the flow. A sophisticated electronic system accurately measures the travel time of the ultrasonic pulse across the channel to determine the water velocity in the channel. Details on the theory and operation of UVM systems have been documented by Laenen (1985). Velocity measurements made with

Table 1. Description of data-collection sites in study area

[SR, State Route; na, not applicable; ---, no data available]

Site number (fig. 2)	Site name	Latitude	Longitude	Mean channel width (feet)	Mean water depth (feet)	Data-collection interval (minutes)			Salinity probe location (feet above channel bottom)
						Water level	Salinity	Velocity	
1	West Neck Creek at SR 149	36°45'16"	76°02'03"	45	6	15	30	15	3
2	West Neck Creek at West Neck Road	36°41'45"	76°02'47"	210	6	15	30	na	3
3	North Landing River at Gibbs Point	36°32'45"	76°01'51"	5,500	7	na	15	na	2 and 6
4	Oceana Naval Air Station[1]	---	---	na	na	na	na	na	na

[1]Wind speed and direction were recorded hourly at this site.

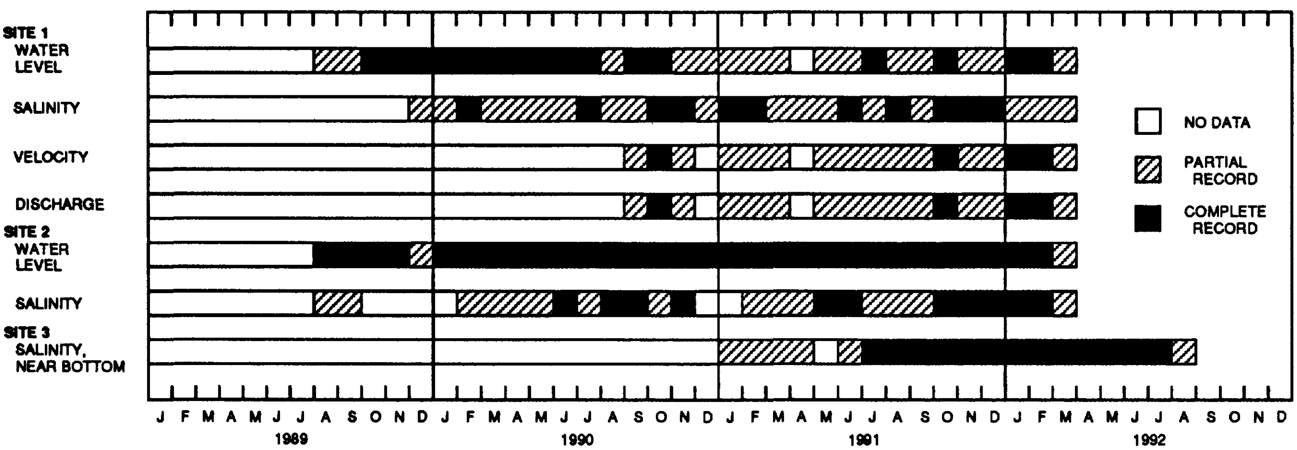


Figure 3. Summary of available data at West Neck Creek sites 1 and 2 and North Landing River site 3.

UVM systems are recognized as being reliable and accurate (International Organization for Standardization, 1985a, 1985b).

The UVM system is capable of accurately measuring low and bi-directional velocities, such as those sometimes present in West Neck Creek (Laenen and Curtis, 1989). Measurement accuracy depends on equipment limitations and the accuracy with which the acoustic path distance and angle are determined. Accuracies of measurements within 0.05 foot per second (ft/s) are typical (Laenen and Curtis, 1989).

A cross-path arrangement was used with the UVM system at site 1. Because the flow in West Neck Creek is subject to reversal, two acoustic paths at approximately right angles to each other were used to improve the accuracy of the computed flow (Laenen, 1985). Results from the two paths were averaged to give the mean velocity at 15-minute intervals. Information on signal strength also was recorded for quality-control purposes.

The velocity determined by the UVM system is a lateral average of the water velocity at the depth of the acoustic path. This velocity is commonly called the line velocity. To determine discharge, a relation between the line velocity and the cross-sectional mean velocity is required. The cross-sectional mean velocity was determined by making standard discharge measurements with a point-velocity current meter (Rantz and others, 1982), and dividing the measured flow by the measured cross-sectional area. The associated line velocity, averaged throughout the duration of the discharge measurement, also was determined.

A total of 24 discharge measurements were made at site 1 (table 2). Data from these measurements were used to develop a relation between line velocity and cross-sectionally averaged velocity (fig. 4). The relation between water level and cross-sectional area also was determined for site 1. Discharge records were then computed in the following manner: (1) the line velocity was measured by using the UVM system; (2) the cross-sectional mean velocity was determined by using the relation shown in figure 4; (3) the water level was measured; (4) the cross-sectional area was determined by using the relation between water level and cross-sectional area; and (5) the cross-sectional area was multiplied by the cross-sectional mean velocity to obtain discharge.

Salinity

Specific conductance was measured by using the USGS minimonitor (Ficken and Scott, 1989). For this application, the minimonitor included (1) a watertight can containing signal conditioners, (2) cables with waterproof connectors, (3) sensors for measuring water temperature and specific conductance, and (4) a 12-volt battery. Specific conductance was converted to salinity by using the algorithm given by Miller and others (1988).

The specific-conductance sensor is equipped with four electrodes to reduce the effects of fouling. Compensation for ambient water temperature is made by a signal conditioner so that all specific-conductance values are referenced to a temperature of 25 °C. Measurement ranges of 0 to 100, 0 to 1,000, 0 to 10,000, or 0 to 100,000 microsiemens per centimeter (µS/cm) can be selected. For a calibrated minimonitor, specific-conductance measurements are accurate to within ± 3 percent of the selected full scale in a temperature range of 0 to 40 °C. The standard range for the temperature sensor is from 0 to 50 °C, and for a calibrated system, temperature measurements are accurate to within ± 1 percent of full scale.

The minimonitor was controlled by a CR10 measurement and control module (Campbell Scientific, Inc., 1988). The CR10 is a fully programmable data logger and controller that will accept voltage inputs from multiple sensors. The CR10 was programmed to turn on the minimonitor at 15-minute intervals, allow the sensors to stabilize for 1 minute, collect data from each of the sensors, record the time, and turn off the minimonitor. An external 12-volt battery provided power to the CR10. Data were stored in an SM192 storage module with nonvolatile memory (Campbell Scientific Inc., 1987). The SM192 is equipped with an internal 3.5-volt battery to protect the memory when the module is disconnected from the external power supply.

At sites 1 and 2, the specific-conductance and water temperature sensors were located approximately 3 ft above the channel bottom. At site 3, specific conductance was measured near the channel bottom (2 ft above the bottom) and near the water surface (6 ft above the bottom). Water temperature at site 3 was measured near the water surface.

The monitors were serviced at approximately monthly intervals, at which time data were retrieved and the instrument was recalibrated if necessary. Vertical profiles of specific conductance and water temperature were measured at the time the monitors were serviced to ensure that measurements at the sensor were representative of conditions throughout the channel. Complete details on field procedures and data processing were documented by Garrett and Bales (1991).

FLOW AND SALINITY IN WEST NECK CREEK

The flow and salinity characteristics observed in the 4.8-mi study reach during 1989-92 are described in this section. The flow regime is characterized by using observed water levels at the study reach boundaries and flow measurements at site 1. Salinity characteristics at the study reach boundaries are described, and a summary of salt loads at site 1 is presented.

Table 2. Summary of discharge measurements at West Neck Creek site 1

[Positive flow is to the south. ft, foot; ft^2, square foot; ft/s, foot per second; ft^3/s, cubic foot per second; UVM, ultrasonic velocity meter]

Date	Time	Water-surface elevation (ft)	Cross-sectional area (ft^2)	Cross-sectional mean velocity (ft/s)	Discharge (ft^3/s)	Line velocity from UVM (ft/s)
09/04/91	1335	4.10	114	-0.22	-24.9	-0.22
09/04/91	1605	4.19	119	-.22	-25.9	-.26
09/05/91	1128	4.41	128	-.18	-22.9	-.17
09/05/91	1300	4.36	126	-.18	-22.8	-.18
11/06/91	1245	4.08	188	.20	37.3	.28
01/09/92	0926	4.53	191	-.19	-36.2	-.16
01/09/02	1039	4.53	188	-.18	-34.3	-.16
01/10/92	0811	4.44	160	-.17	-26.8	-.13
01/10/92	1210	4.56	185	.16	29.3	.17
01/13/92	1550	4.34	172	-.02	-4.35	-.01
01/14/92	0822	4.64	189	-.15	-28.1	-.13
01/14/92	1419	4.69	194	-.20	-39.1	-.22
01/15/92	0837	4.35	173	.07	11.4	.22
01/15/92	1248	4.00	161	[a]-.07	[a]-10.9	.05
01/23/92	0845	3.67	144	-.07	-9.65	-.06
01/23/92	1255	4.16	164	.15	25.1	.21
02/05/92	1258	3.88	155	.44	68.4	.58
02/05/92	1626	3.47	143	.17	24.4	.41
02/06/92	1303	3.41	139	.38	53.3	.51
02/06/92	1533	3.31	130	.30	38.6	.46
03/18/92	1209	3.78	155	.19	29.5	.31
03/18/92	1349	3.62	146	.02	2.38	.08
03/19/92	1209	4.04	162	.21	34.2	.31
03/19/92	1409	3.84	160	.14	21.6	.22

[a]Measurement made during flow reversal; value not used in rating.

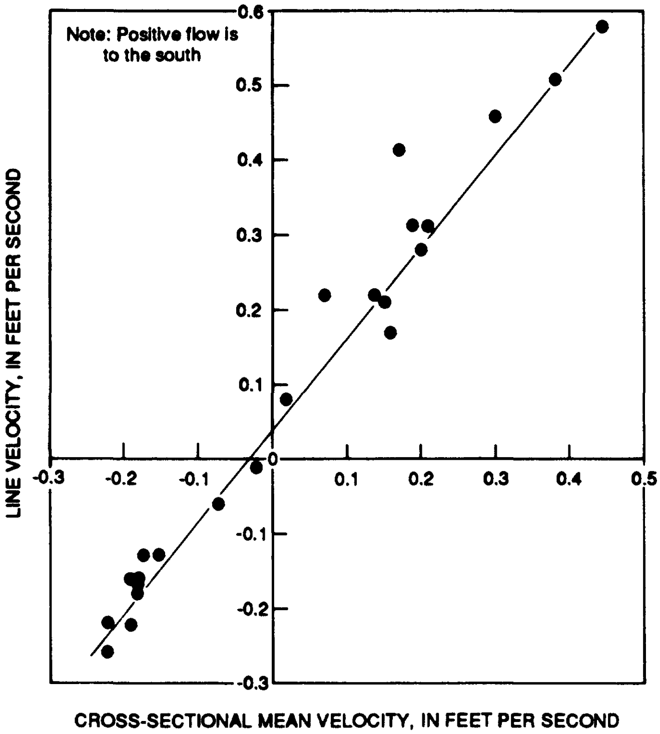


Figure 4. Relation between line velocity and cross-sectional mean velocity at West Neck Creek site 1.

Water-Level Fluctuations

Water-level fluctuations at site 1 (fig. 5) are affected by tidal fluctuations in Chesapeake Bay. As the water level at site 1 increases, the tidal fluctuations become less apparent. Water-level fluctuations at sites 1 and 2 follow the same general (low-frequency) pattern, but the semidiurnal tidal fluctuations in water level commonly seen at site 1 were generally less evident at site 2 (fig. 5), probably because of the broadening of the channel between sites 1 and 2.

Mean water level at site 1 was greater than at site 2 (table 3). Water levels were at a minimum during the winter and spring months, and maximum observed water levels generally occurred during the summer. The water level fluctuated between -1.18 and 4.45 ft, for a range of 5.63 ft, at site 1. The observed water-level range at site 2 was 4.91 ft. However, the mean daily water-level range (difference between daily maximum and daily minimum) was the same at both sites and equal to about 0.5 ft. The mean tidal range at the mouth of Lynnhaven Bay has been reported as 2.0 ft (Malcolm Pirnie Engineers, Inc., 1980).

Precipitation and associated runoff have a greater effect on water level at site 1 than at site 2. This condition is probably due to (1) the smaller channel

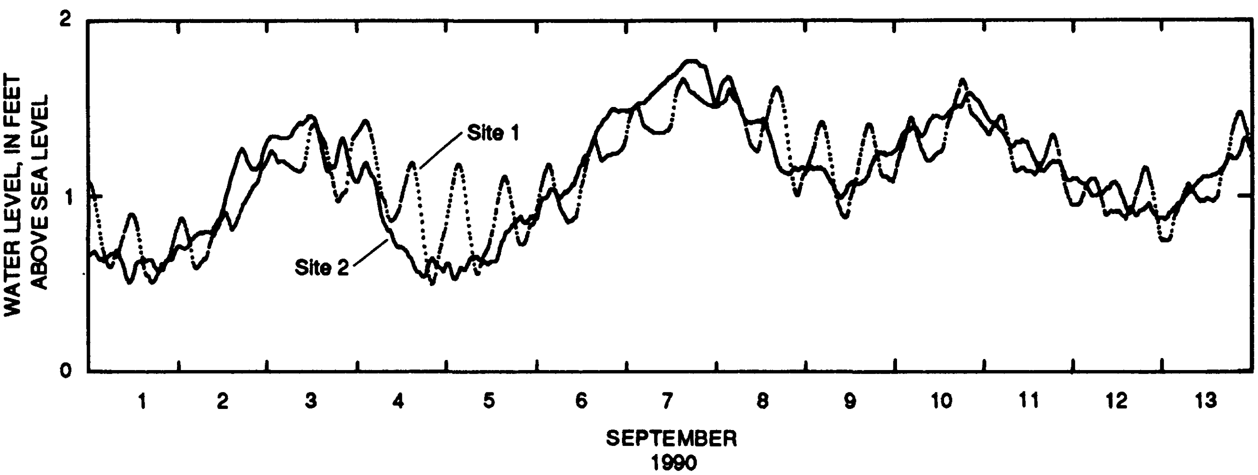


Figure 5. Water level at West Neck Creek sites 1 and 2 for September 1-13, 1990.

Table 3. Monthly water-level characteristics at West Neck Creek sites 1 and 2 based on data collected during August 1989-March 1992

[Water levels are in feet above or below sea level. na, not applicable]

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
West Neck Creek site 1													
Daily mean	1.36	1.13	0.58	0.96	0.78	0.95	0.99	1.28	1.25	1.43	1.44	1.28	1.14
Maximum observed	2.39	2.35	2.61	3.13	2.00	2.73	1.92	2.07	1.94	3.05	4.45	2.54	4.45
Minimum observed	.16	.14	-1.18	-.10	-.26	-.37	-.04	.09	.05	-.16	.43	.43	-1.18
Mean daily maximum	1.38	1.37	.88	1.24	1.05	1.21	1.22	1.55	1.50	1.68	1.68	1.54	1.34
Mean daily minimum	.89	.92	.28	.66	.47	.69	.77	1.02	1.09	1.19	1.19	1.01	.86
Mean daily range	.50	.46	.60	.57	.58	.52	.45	.53	.44	.49	.49	.53	.52
Maximum daily range	1.59	1.62	1.68	1.08	1.28	1.07	.86	1.41	1.14	1.84	2.24	1.06	2.24
Minimum daily range	.14	.14	[a]	.13	.16	.14	.24	.19	.09	.06	.13	.25	[a]
Days of record	93	60	38	73	66	77	30	31	34	65	84	54	na
West Neck Creek site 2													
Daily mean	1.13	0.98	0.36	0.80	0.59	0.85	1.02	1.28	1.28	1.39	1.39	1.21	1.00
Maximum observed	2.23	2.44	1.91	2.10	2.18	2.66	2.25	2.58	2.35	2.22	2.13	2.85	2.85
Minimum observed	-1.77	-2.06	-1.35	-.96	-1.17	-1.15	-.23	-.11	-.33	-.42	-.10	-.10	-2.06
Mean daily maximum	1.26	1.22	.67	1.07	.88	1.18	1.28	1.52	1.49	1.57	1.53	1.43	1.24
Mean daily minimum	.75	.70	.28	.54	.30	.34	.81	1.05	1.09	1.22	1.17	1.00	.77
Mean daily range	.60	.62	.55	.65	.58	.63	.48	.47	.40	.36	.35	.43	.52
Maximum daily range	1.63	1.85	1.71	1.60	1.74	1.39	1.06	1.04	1.05	.95	1.69	1.64	1.85
Minimum daily range	.13	.13	.19	.15	.10	.18	.16	.14	.12	.13	.13	.11	.10
Days of record	93	90	93	93	85	80	60	62	60	64	93	90	na

[a]Minimum range was 0.0 ft, which was due to ice in the channel.

capacity near site 1 relative to site 2 and (2) the large amounts of runoff from the developed areas north of site 1. For example, 3.57 in. of precipitation was recorded at site 4 on August 7, 1991. The water level at site 1 rose more than a foot in about 18 hours in response to the runoff, whereas the water level showed little immediate change at site 2 (fig. 6).

Instantaneous observations of water level at site 1 were compared with those made simultaneously at site 2. More than 72,000 values, representing about 760 days of record, were compared. At site 1, the water surface relative to that at site 2 was higher 44 percent of the time (fig. 7) and lower 54 percent of the time. The water levels at the two sites were simultaneously

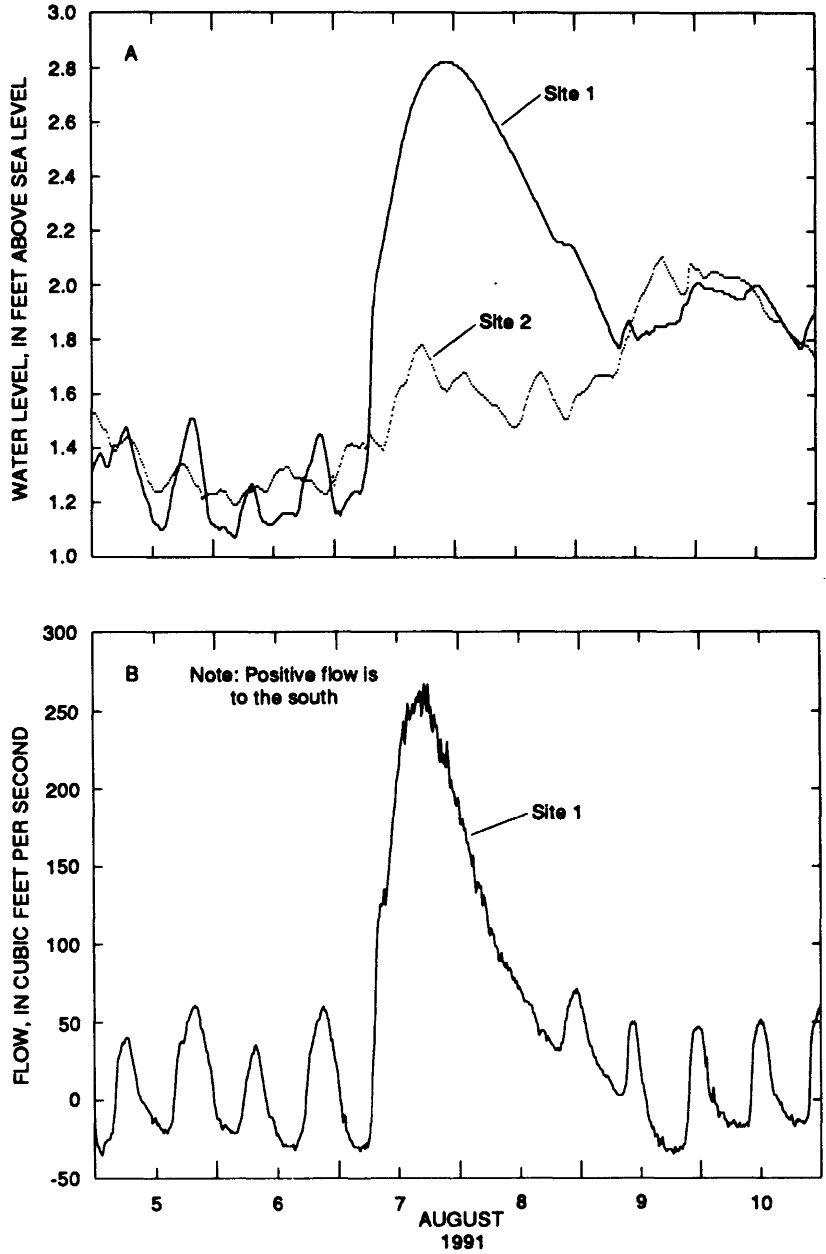


Figure 6. (A) Water level at West Neck Creek sites 1 and 2 and (B) flow at West Neck Creek site 1 for August 5-10, 1991, in response to 3.57 inches of precipitation on August 7, 1991.

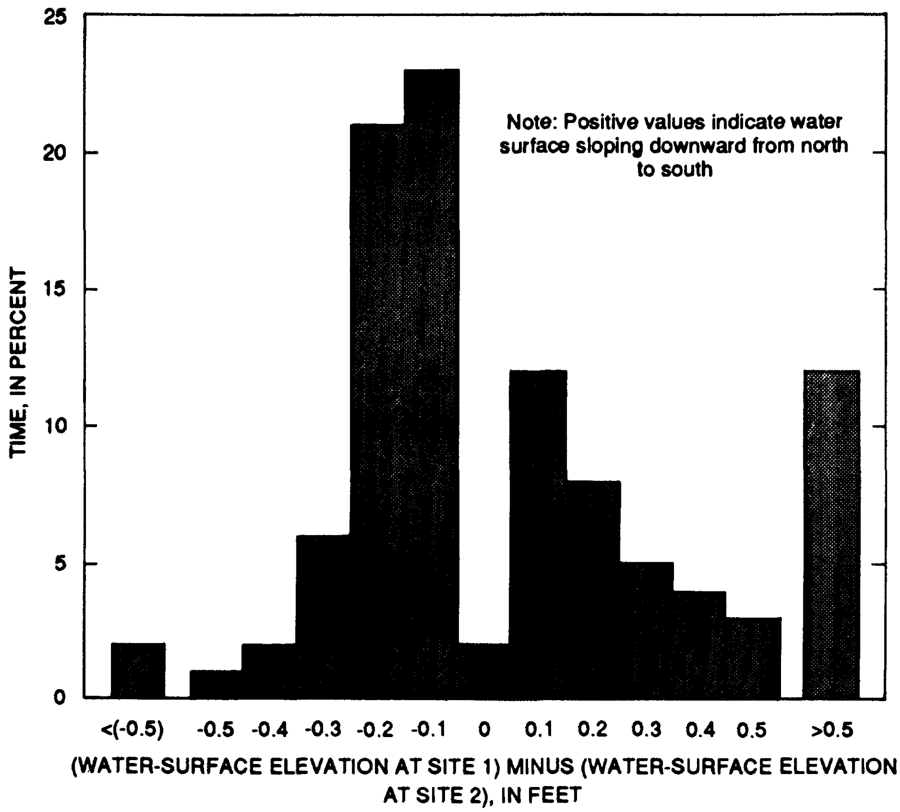


Figure 7. Frequency of occurrence of observed instantaneous water-level differences at West Neck Creek sites 1 and 2, August 1989-March 1992.

equal 2 percent of the time. Although both gage datums were referenced to sea level by leveling to the nearest benchmark, an elevation survey loop was not run between the two sites.

Flow Characteristics

For steady, homogeneous flow conditions, water moves from the region of higher water level to the region of lower water level, or the water surface slopes downward in the direction of flow. This generalization is not always true, however, for oscillating flow. Because of the inertia of the flowing water, the flow generally reverses direction sometime after the water-surface gradient reverses.

The line velocity measured at site 1 by using the UVM ranged from -0.29 ft/s (flow to the north) to 1.48 ft/s (flow to the south). The mean of the observed daily maximum southward velocities was 0.43 ft/s, and the mean of the observed daily maximum northward velocities was 0.12 ft/s. For the 308 days of record, the mean line velocity was 0.15 ft/s to the south.

Flow at site 1 was computed at 15-minute intervals by using the measured water-level and line-velocity data. Daily mean flow was computed from the unit values; values are presented in appendix table 1. The flow ranged from -50 cubic feet per second (ft^3/s) (to the north) to 356 ft^3/s (to the south). The daily mean flow ranged from -39 to 219 ft^3/s. The mean flow for the 308 days for which complete data were available was 13 ft^3/s to the south.

Daily mean flow was to the north 36 percent of the time (fig. 8), indicating that the net movement of water was to the north on 36 percent of the days for which complete flow data were available. Daily mean flow was to the south 64 percent of the time (fig. 8). The daily mean flow was between -40 and 60 ft^3/s 95 percent of the time, and almost half of the daily mean flows were between -10 and 20 ft^3/s. Eighty percent of the southward daily mean flows were less than 40 ft^3/s.

Flow data were sufficiently complete to warrant further evaluation for 9 months of the study period (table 4). Calculated for each of the months were the percent of the time (1) the daily mean flow was to the

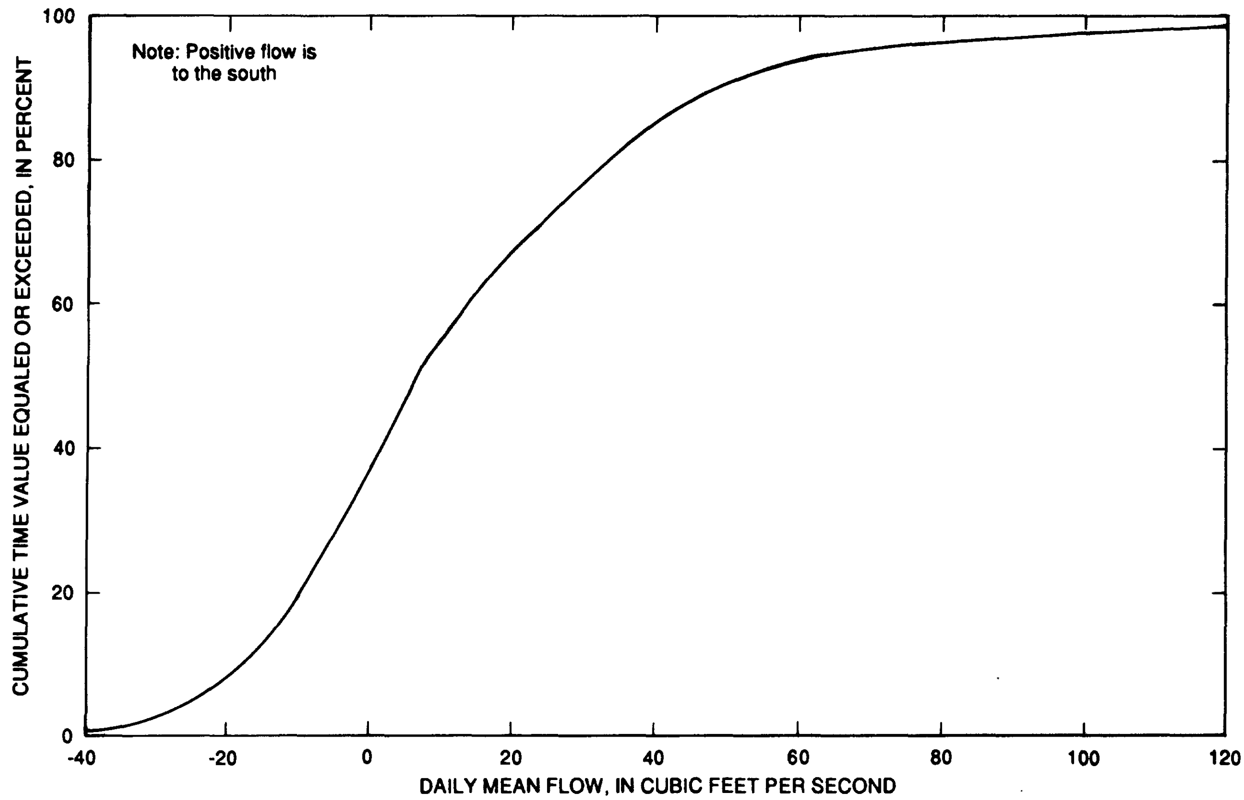


Figure 8. Cumulative frequency distribution of daily mean flow at West Neck Creek site 1, September 1990-March 1992.

south and (2) the instantaneously measured flow was to the south. In general, the instantaneous flow was southward a lower percentage of the time for a given month than was the daily mean flow. This condition further indicates that southward flow rates were greater than northward flow rates. For the 9 months (table 4), the instantaneous flow was southward 54 percent of the time, and the daily mean flow was southward 63 percent of the time.

Flow is unsteady at site 1 and has a typical semidiurnal pattern with two daily maximums and two daily minimums (fig. 6). This characteristic variation in flow can occur even when the tidal signal in the water-level record is dampened because of high water levels (for example, August 9-10, 1991; fig. 6).

Flow at site 1 is strongly affected by precipitation events. For example, the 3.57 in. of precipitation on August 7, 1991, resulted in a peak flow of 268 ft^3/s at site 1 (fig. 6). The large difference in water levels between sites 1 and 2 generated a strong, sustained flow to the south. In fact, each of the six occurrences of daily mean flow in excess of 100 ft^3/s was associated with a large precipitation event (table 5).

Wind also affects flow at site 1, but apparently not as significantly as precipitation. The highest sustained winds observed during the investigation occurred during late October and early November 1991 (fig. 9). High winds from the north and northeast resulted in a continuously southward flow from October 28 until November 2 (fig. 9). Nevertheless, flows (as well as water levels) during this extreme wind event were less than those observed during periods of high precipitation (table 5).

The daily mean flow during July 17-26, 1991, was to the north (appendix table 1). Winds during this period were generally from the south and southwest (fig. 10), resulting in a water surface that sloped fairly consistently downward from site 2 to site 1. Although the mean flow during the period was to the north, continuous northward flow occurred only during July 18-20 when wind speeds were the highest. From July 21 through July 25, the typical semidiurnal fluctuation in discharge magnitude and direction was present.

Table 4. Percentage of time daily mean flow and the instantaneous flow were to the south at West Neck Creek site 1 for selected months

Date	Daily mean flow to the south (percent of time)	Instantaneous flow to the south (percent of time)
October 1990	55	48
November 1990	44	45
March 1991	82	64
July 1991	43	40
August 1991	46	44
October 1991	87	68
January 1992	68	58
February 1992	86	76
March 1992	56	47

Table 5. Daily mean flows exceeding 100 cubic feet per second at West Neck Creek site 1, and associated precipitation

Date	Daily mean flow (cubic feet per second)	Precipitation (inches)
01-04-92	219	2.41
08-07-91	139	3.57
10-17-91	139	[a]2.43
01-05-92	124	[b]2.41
10-26-90	115	2.55
07-28-91	114	2.65

[a]Occurred on 10-16-91 and 10-17-91.
[b]Occurred on 01-04-92.

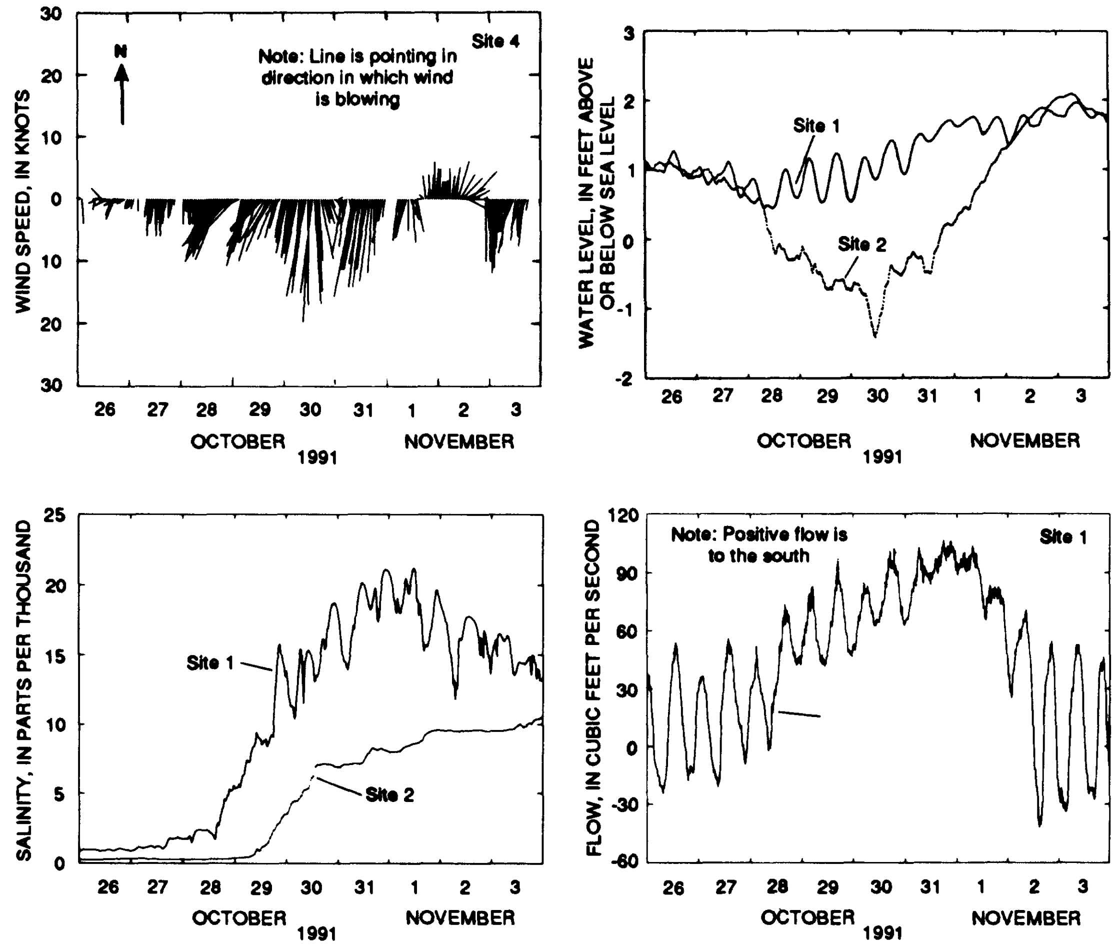


Figure 9. Wind speed and direction at Oceana Naval Air Station site 4, water level and salinity at West Neck Creek sites 1 and 2, and flow at West Neck Creek site 1 for October 26-November 3, 1991.

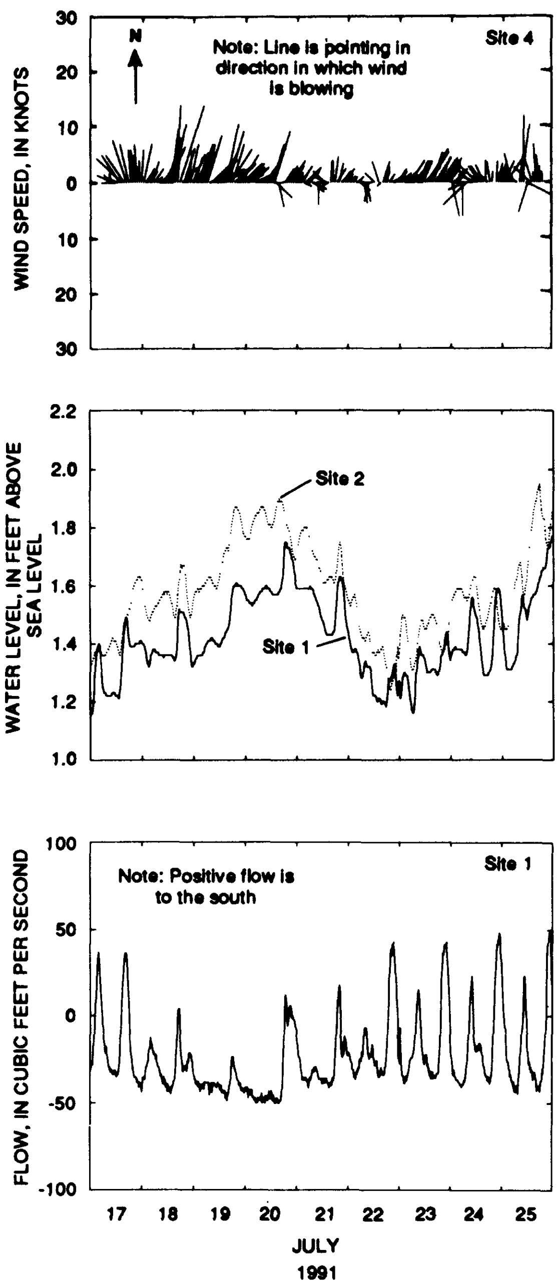


Figure 10. Wind speed and direction at Oceana Naval Air Station site 4, water level at West Neck Creek sites 1 and 2, and flow at West Neck Creek site 1 for July 17-25, 1991.

Salinity and Salt Loads

Salinity is a measure of the concentration of dissolved solids in water. Because the chemical composition of seawater is constant (Cox, 1965), the concentration and relative percentage of each of the ions constituting the dissolved solids in seawater are well known (table 6). Concentrations of the ions that compose most of the dissolved solids in seawater were determined for two samples collected at site 1. The percentages of the ions in the sample collected on November 13, 1991, were virtually the same as for seawater (table 6). The lower-salinity sample collected on January 24, 1992, had a higher percentage of bicarbonate and sulfate and lower percentage of chloride in the sample than in seawater; the percentage of sodium was lower and the percentage of calcium was higher in the sample than in seawater.

Measurements of instantaneous observations of salinity at site 1 ranged from 0.1 ppt, which occurred several times throughout the study period, to 24.5 ppt, which occurred on November 9 and 10, 1991 (figs. 11-13). Salinities greater than 5 ppt occurred at site 1 several times throughout the study period and during all seasons. The daily mean salinity at site 1 was less than or equal to 1 ppt 55 percent of the time, and less than or equal to 10 ppt 96 percent of the time (fig. 14). The daily maximum salinity was less than or equal to 1 ppt 50 percent of the time, and less than or equal to 10 ppt 94 percent of the time (fig. 14). Daily mean salinities at site 1 are presented in appendix tables 2-4.

At site 2, the minimum recorded salinity also was less than 0.1 ppt, which occurred several times throughout the study, and the maximum observed salinity was 14.5 ppt, which occurred on November 10, 1991 (figs. 11-13). The daily mean salinity at site 2 was less than or equal to 1 ppt 58 percent of the time (fig.14). The daily maximum salinity was less than or equal to 1 ppt 53 percent of the time at site 2, and was less than or equal to 10 ppt 99 percent of the time (fig. 14). Daily mean salinities at site 2 are presented in appendix tables 5-7.

Diurnal and semidiurnal fluctuations in salinity were generally small. The daily salinity range (difference between the daily maximum and daily minimum values) was less than 1 ppt 73 percent of the time at site 1, and 85 percent of the time at site 2 (fig. 15). Semidiurnal salinity fluctuations were most evident at site 1 when salinities exceeded about 5 ppt, but semidiurnal fluctuations in salinity at site 2 were rarely present (figs. 9 and 16).

Table 6. Properties and relative percentages of selected constituents for seawater and for two samples collected at West Neck Creek site 1

[---, no data available; ppt, parts per thousand; mg/L as $CaCO_3$, milligrams per liter as calcium carbonate]

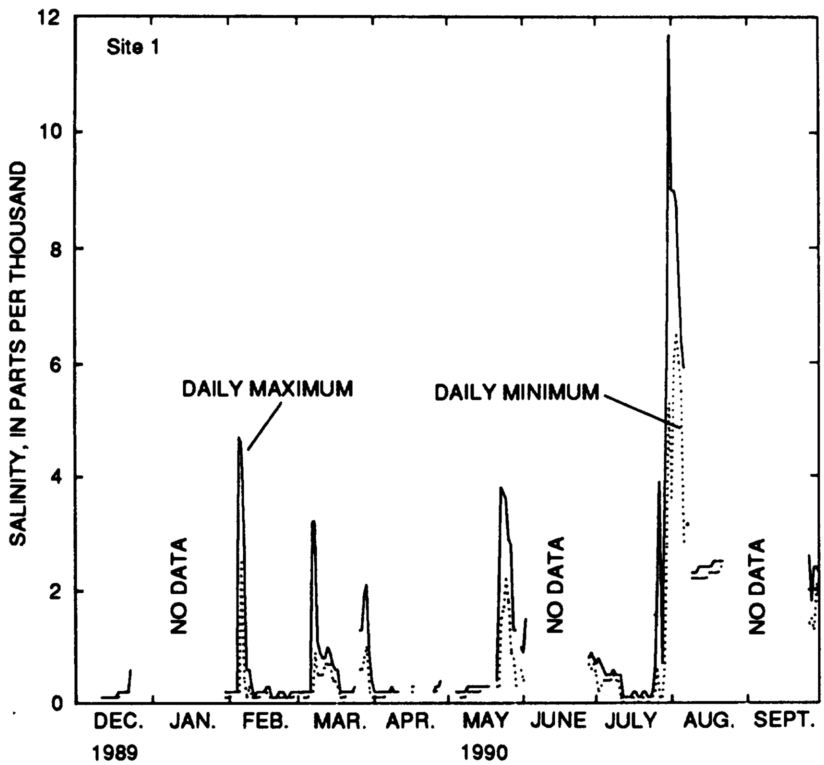
	Seawater[a]	Site 1, on 11-13-91	Site 1, on 01-24-92
Property			
pH (standard units)	---	6.6	6.6
Salinity (ppt)	34.6	9.8	.2
Hardness (mg/L as $CaCO_3$)	---	1,900	65
Constituent, in percent			
Chloride	55.0	55.4	41
Sodium	30.3	29.2	22
Sulfate	7.8	8.2	17
Magnesium	3.9	3.9	4.1
Calcium	1.2	1.6	5.6
Potassium	1.1	1.2	2.0
Bicarbonate	.4	.4	8.2
Bromide	.2	.2	0.1

[a]From Hem (1985).

Periods of high salinity typically were separated by periods in which the salinity was less than 1 ppt (appendix tables 2-7; fig. 16). In some instances, a volume of high-salinity water would move past site 1, but not reach site 2, such as occurred during November 8-10, 1990 (fig. 16). At other times, the slug of high-salinity water would be transported through the study reach (November 18-29, 1990; fig. 16). At site 2, the high salinity water arrived 30 hours after arriving at site 1 during November 18-29, 1990. The measured water velocity at site 1 ranged from 0.22 to 0.63 ft/s during November 18-19. Although the highest flows in the study reach were associated with precipitation events (table 5), the highest salinities were associated with periods of sustained north to northeasterly winds, such as the event which occurred during late October and early November 1991 (fig. 9).

Daily salt loads were computed for site 1 as the daily sum of the products of the 15-minute interval observations of salinity and flow. For the 294 days for which salinity and flow data were available for load computions at site 1, the net salt transport was 34,510 tons to the south. The mean daily transport was 117 tons to the south, and the median daily transport was 10 tons to the south. Observed daily transport to the south ranged from 0.3 ton on August 23, 1991, to 4,500 tons on October 31, 1991. Observed daily northward transport ranged from 0.2 ton on October 2, 1991, to 302 tons on November 14, 1991.

Although not apparent in the salinity data alone (fig. 16), salt moved first southward and then returned to the north during the November 18-29, 1990, event. Daily salt transport during that period ranged from 900 tons to the south on November 19 to 248 tons to the north on November 23 (fig. 17). A total of 2,580 tons of salt was transported to the south during November 18-21, but only 1,030 tons of salt, or 40 percent of the total, was returned to the north (fig. 17). This phenomenon in which more salt was transported southward than was returned to the north was repeated throughout the study period and demonstrates the necessity for measuring flow in conjunction with salinity.



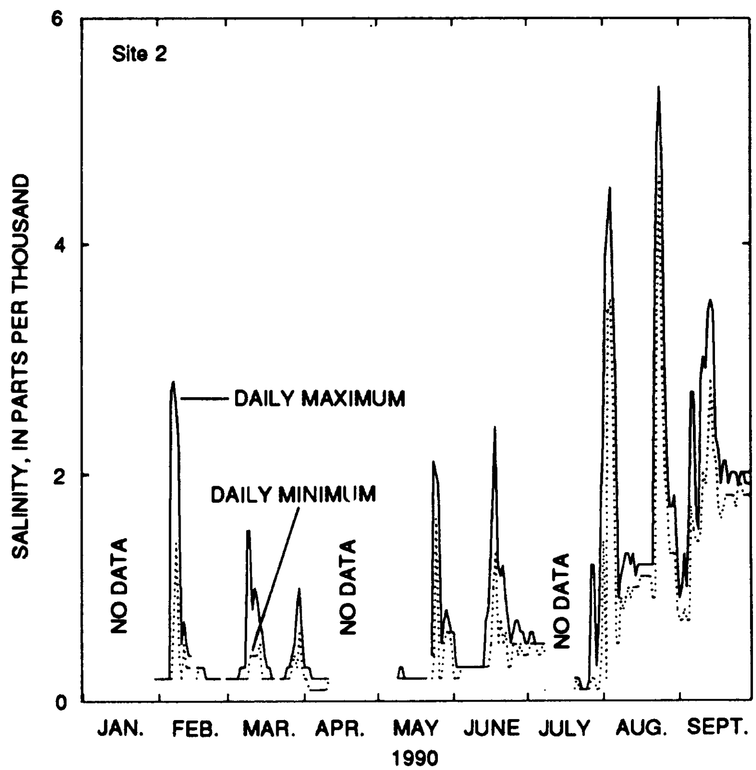


Figure 11. Daily maximum and daily minimum salinity at West Neck Creek site 1 for December 1989-September 1990 and at West Neck Creek site 2 for January-September 1990.

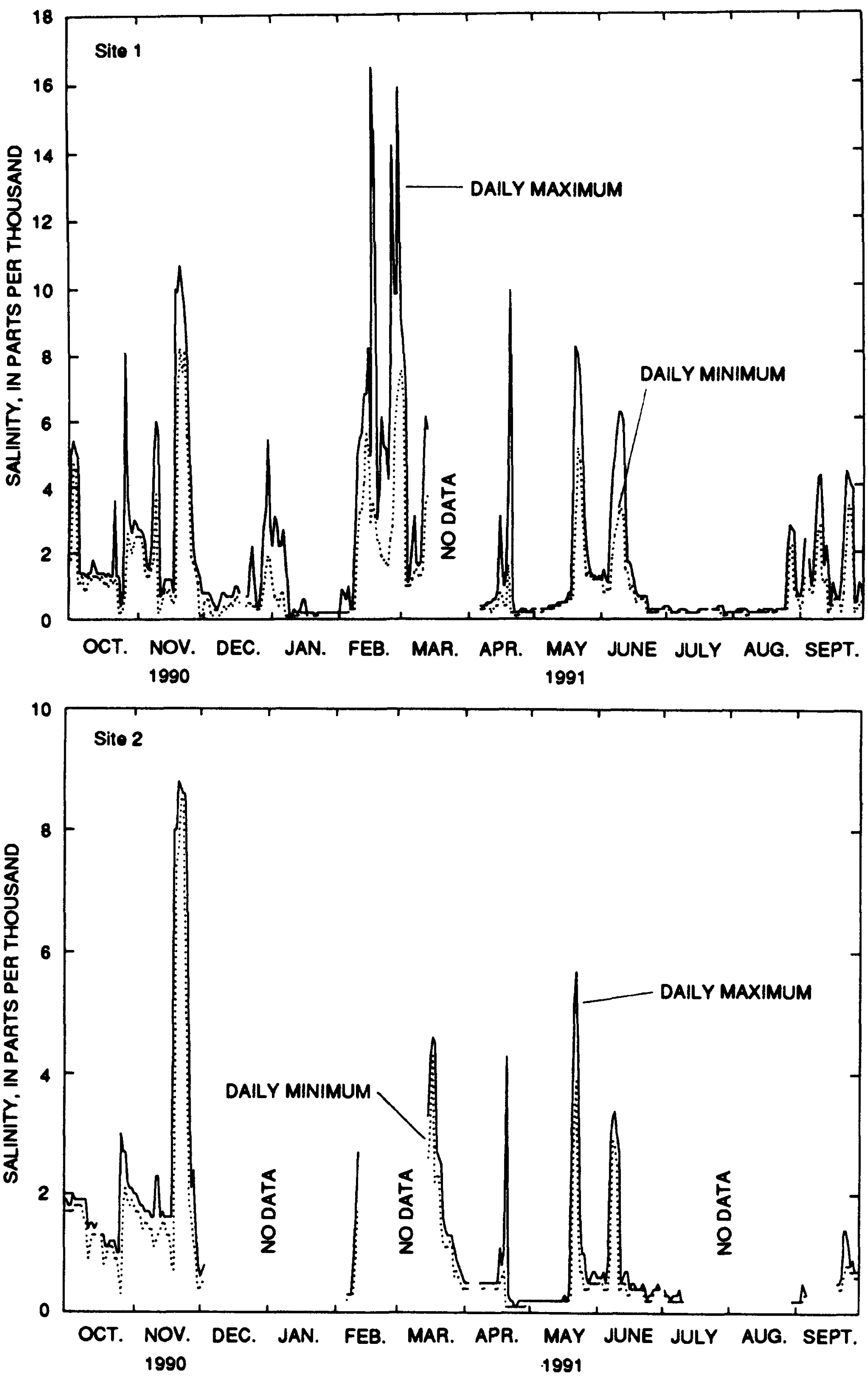


Figure 12. Daily maximum and daily minimum salinity at West Neck Creek sites 1 and 2 for October 1990-September 1991.

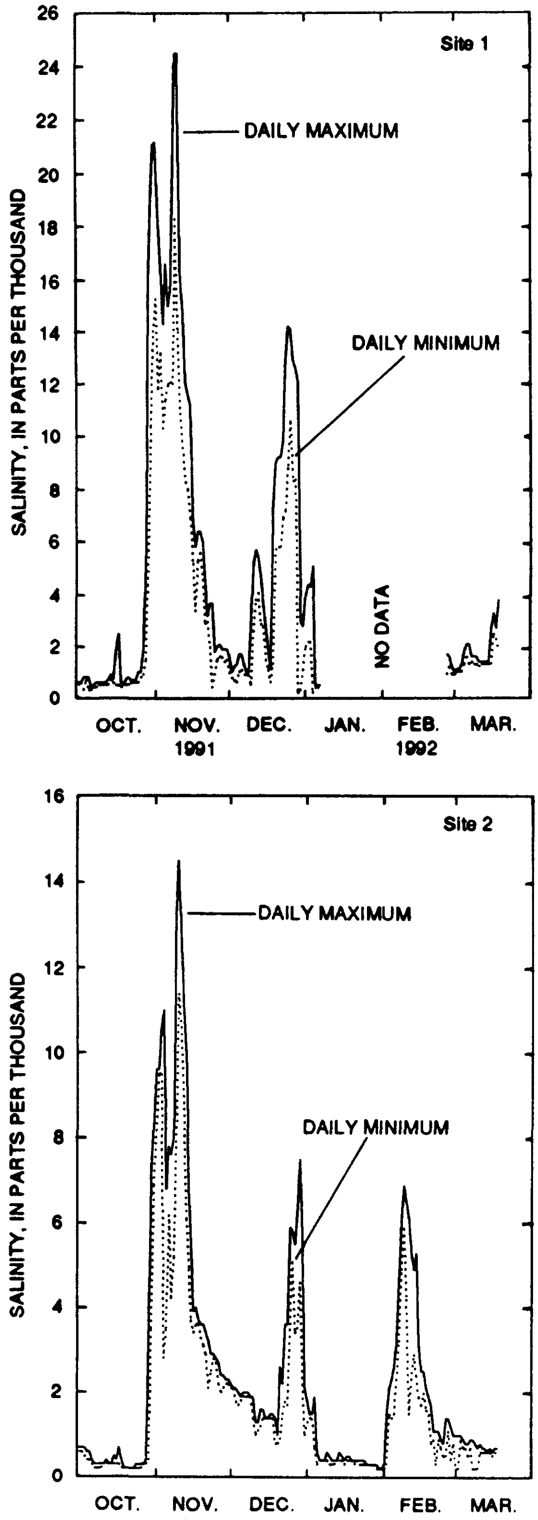


Figure 13. Daily maximum and daily minimum salinity at West Neck Creek sites 1 and 2 for October 1991-March 1992.

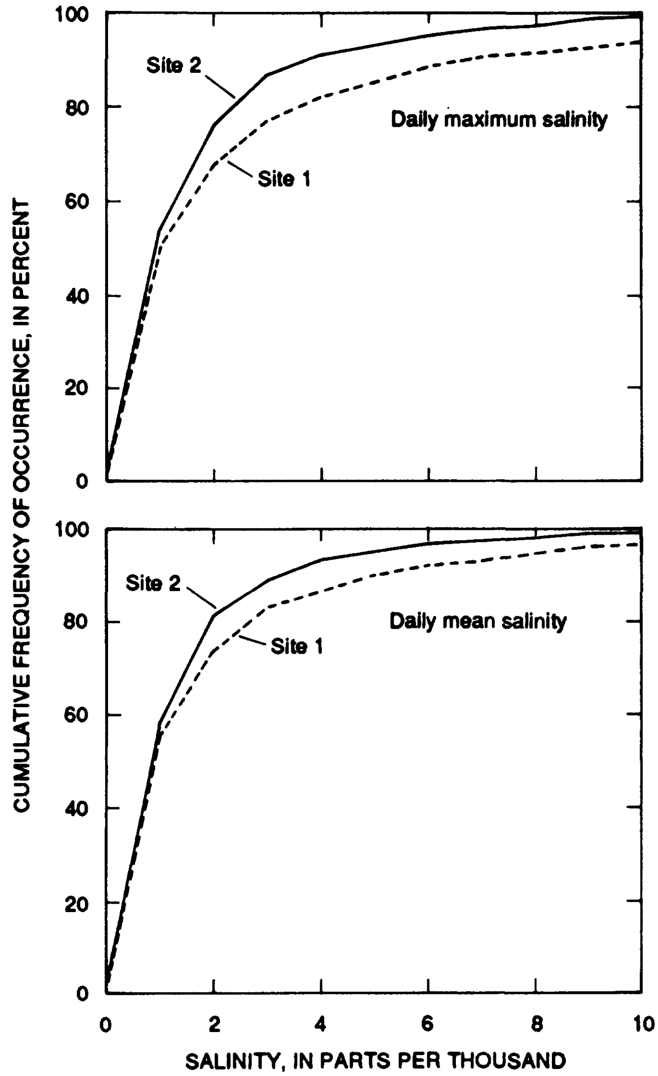


Figure 14. Cumulative frequency of occurrence of daily maximum and daily mean salinity at West Neck Creek sites 1 and 2.

SALINITY IN NORTH LANDING RIVER

Salinity was measured in North Landing River just south of the North Carolina State line (site 3; fig. 2) from January 1991 through July 1992. For the period of record, near-surface and near-bottom salinities seldom differed by more than 0.2 ppt. Several sets of field measurements were made to ensure that salt was not bypassing the monitoring station. For all sets of measurements, the salt was uniformly distributed throughout the approximately 5,500-ft wide cross section.

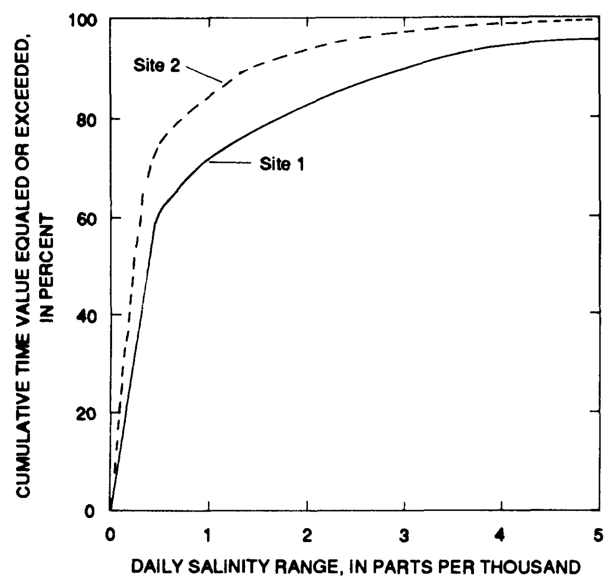


Figure 15. Cumulative frequency distribution of daily salinity range at West Neck Creek sites 1 and 2.

Little diurnal variation in salinity also was observed. The near-bottom daily salinity range (difference between the daily maximum and daily minimum values) was 0.2 ppt or less for 81 percent of the observation period. The daily range was from 0.2 to 0.5 ppt 15 percent of the time, and the maximum observed daily salinity range was 3.2 ppt. Because of the vertical and lateral uniformity of salinity and the general absence of diurnal salinity fluctuations, the daily mean salinity at the near-bottom sensor (fig. 18) provides a good representation of salinity conditions in North Landing River near the State line. Daily mean values of salinity at site 3 are presented in appendix table 8.

From January through November 1991, daily mean salinity at site 3 was relatively constant and ranged from 0.4 to 0.9 ppt (appendix table 8). Salinity was typically less than 0.8 ppt during this period. Daily mean salinity at site 3 increased in late November 1991 following the late October-early November event during which there was an extended period of high north to northeasterly winds and associated salinity increase at site 1 (fig. 9). Salinity at site 3 then remained relatively constant (between 0.9 and 1.3 ppt) until April 1992 (fig. 18; appendix table 8). Salinity

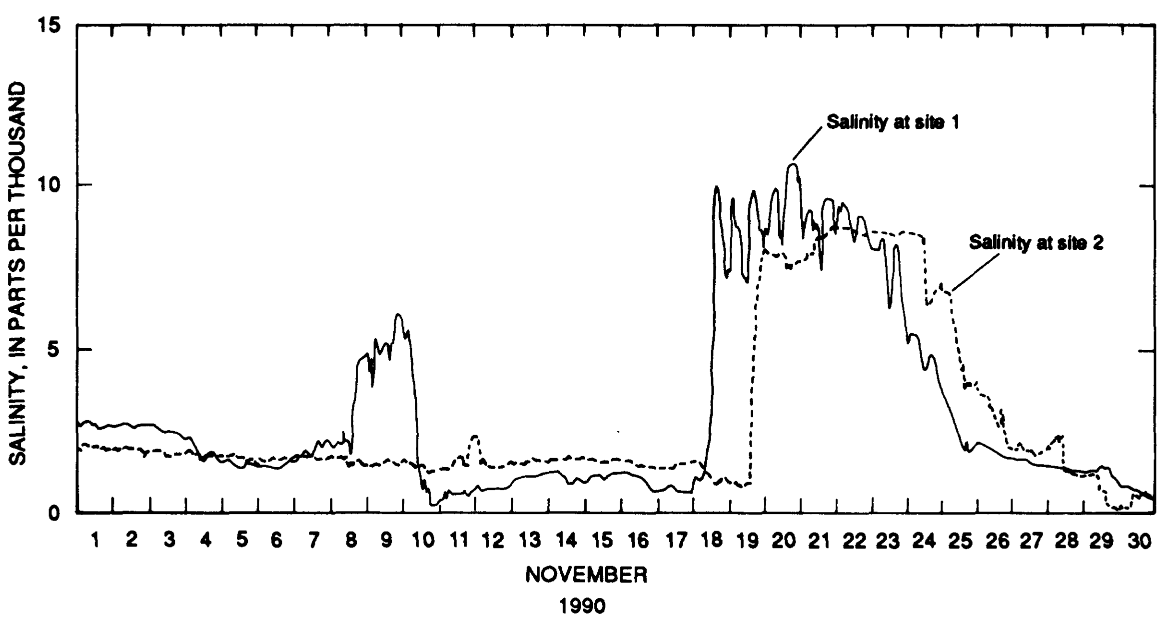


Figure 16. Salinity at West Neck Creek sites 1 and 2 for November 1990.

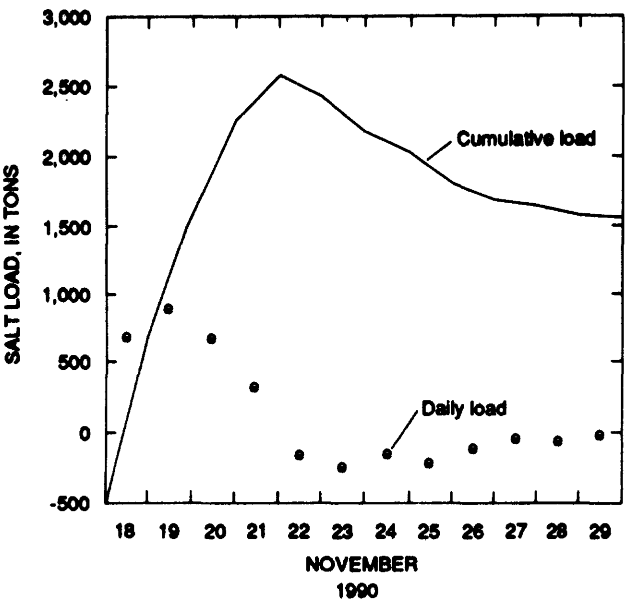


Figure 17. Daily salt load and cumulative salt load at West Neck Creek site 1 for November 18-29, 1990.

also was elevated at site 2 during the winter of 1991-92 (appendix table 7). Beginning in April 1992, daily mean salinity increased fairly steadily with time until, by the end of July 1992, daily mean salinity at site 3 was about 2.5 ppt. Salinities greater than about 3.0 ppt generally prevent successful spawning of the largemouth bass in Currituck Sound (J.W. Kornegay, North Carolina Wildlife Resources Commission, oral commun., 1993).

Salt can enter Currituck Sound by moving south from West Neck Creek through North Landing River past site 3, or by moving north from Albemarle Sound through the AIWW cut near Coinjock or through the mouth of Currituck Sound at the U.S. Highway 158 bridge (fig. 1). Salinity at the mouth of Currituck Sound reached a maximum of nearly 21 ppt during the October-November 1991 wind event (R.G. Garrett, U.S. Geological Survey, written commun., 1992). Consequently, the observed increase in salinity at site 3 that occurred between December 1991 and July 1992 cannot necessarily be ascribed to southward transport of salt through West Neck Creek and North Landing

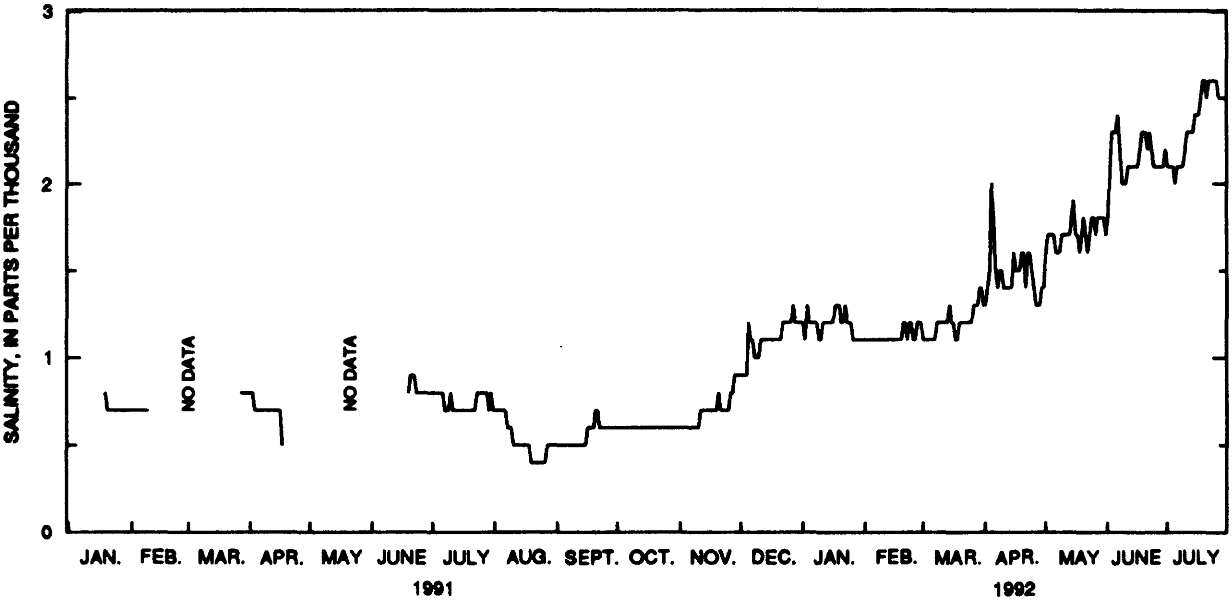


Figure 18. Daily mean salinity at North Landing River site 3 near-bottom sensor for January 1991-July 1992.

River. A comprehensive investigation in which salinity, water level, and flow are monitored in North Landing River, in the AIWW near Coinjock, and at the southern end of Currituck Sound is needed to determine the mass of salt moving into the sound and to characterize the processes affecting the salt transport.

SUMMARY

West Neck Creek and its northward extension, London Bridge Creek, provide a hydraulic connection between the saline waters of Chesapeake Bay and the relatively fresh waters of North Landing River and northern Currituck Sound. West Neck Creek and London Bridge Creek also are known collectively as Canal Number Two. To reduce potential flood damages along Canal Number Two, a 2.6-mi long bypass canal was constructed to the east of Canal Number Two in 1989. Construction of this bypass canal resulted in some concern about the effects of Canal Number Two and the new bypass canal on water quality in Currituck Sound, particularly on the potential for movement of salt and urban drainage into North Landing River and Currituck Sound. Consequently, the USGS conducted an investigation to determine flow rates and predominant flow direction in West Neck Creek, and to characterize the salinity regime in the creek and in North Landing River near the North Carolina-Virginia State line.

Data were collected at two locations in West Neck Creek from August 1989 through March 1992. At the northern site (site 1), water level, flow velocity, and salinity were measured at 15-minute intervals. Water level and salinity were measured at the southern site (site 2), which was 4.8 mi south of site 1 and 1.8 mi upstream from the confluence of West Neck Creek with North Landing River. Near-surface and near-bottom salinities were measured at 15-minute intervals in North Landing River (site 3) near the North Carolina-Virginia State line during January 1991-July 1992.

Water-level fluctuations at site 1 are affected by tidal fluctuations in Chesapeake Bay, but semidiurnal tidal fluctuations commonly seen at site 1 were generally less evident at site 2 because the channel widens between sites 1 and 2. The mean water level was greater at site 1 than at site 2. Water levels at site 1 fluctuated between -1.18 and 4.45 ft, and were generally lower during the winter months. The mean daily water-level range was 0.5 ft at sites 1 and 2. Precipitation and associated runoff have a much greater effect on water level at site 1 than at site 2.

Instantaneous observations of water level at site 1 were compared with those made simultaneously at site 2. The water surface was higher at site 1 relative to site 2 forty-four percent of the time. The instantaneous water level at site 1 exceeded that at site 2 by 0.5 ft or more 12 percent of the time, whereas the water level at site 2 exceeded that at site 1 by more than 0.5 ft only 2 percent of the time. The times when water level at site 1 exceeded that at site 2 by 0.5 ft or more generally occurred following periods of high rainfall. Although both gage datums were referenced to sea level by leveling to the nearest benchmark, an elevation survey loop was not run between the two sites.

The line velocity measured at site 1 by using the UVM ranged from -0.29 ft/s (flow to the north) to 1.48 ft/s (flow to the south). The mean of the observed daily maximum southward line velocities was 0.43 ft/s, and the mean of the observed daily maximum northward line velocities was 0.12 ft/s. For the 308 days of record, the mean line velocity was 0.15 ft/s to the south.

Flow at site 1 was computed at 15-minute intervals by using the measured water-level and line-velocity data. The maximum observed instantaneous flow to the south was 356 ft^3/s, and the maximum observed flow to the north was 50 ft^3/s. The daily mean flow ranged from -39 to 219 ft^3/s. The mean flow for the 308 days for which complete data were available was 13 ft^3/s to the south. Daily mean flow was to the north 36 percent of the time, indicating that the net movement of water was to the north on 36 percent of the days for which complete flow data were available. Sixty-four percent of the time daily mean flow was to the south. The daily mean flow was between -40 and 60 ft^3/s 95 percent of the time, and nearly half of the daily mean flows were between -10 and 20 ft^3/s. Eighty percent of the southward daily mean flows were less than 40 ft^3/s.

Flow at site 1 indicates a typical semidiurnal pattern with two daily maximums and two daily minimums. Flow at site 1 also is strongly affected by precipitation events and associated runoff. Each of the six occurrences of a daily mean flow in excess of 100 ft^3/s was associated with a large precipitation event. Wind also affects flow at site 1, but apparently not as significantly as precipitation. The highest sustained winds observed during the investigation occurred during late October and early November 1991, when high winds from the north and northeast resulted in a

continuously southward flow from October 28 through November 2. Nevertheless, flows during this extreme wind event were less than those observed during periods of high precipitation.

Instantaneous observations of salinity values at site 1 ranged from 0.1 ppt to 24.5 ppt. The daily mean salinity at site 1 was less than or equal to 1 ppt 55 percent of the time. At site 2, salinity ranged from less than 0.1 ppt to 14.5 ppt. Daily mean salinity at site 2 was less than or equal to 1 ppt 58 percent of the time. The daily salinity range was less than 1 ppt 73 percent of the time at site 1, and 85 percent of the time at site 2. Although the highest flows in the study reach were associated with precipitation events, the highest salinities occurred during periods of sustained north to northeasterly winds, such as during late October and early November 1991.

Daily salt loads were computed for site 1 as the daily sum of the products of the 15-minute interval observations of salinity and flow. For the 294 days for which salinity and flow data were available for load computations at site 1, the net salt transport was 34,510 tons to the south. The mean daily transport was 117 tons to the south, and the median daily transport was 10 tons to the south. Observed daily transport to the south ranged from 0.3 ton on August 23, 1991, to 4,500 tons on October 31, 1991. Observed daily northward transport ranged from 0.2 ton on October 2, 1991, to 302 tons on November 14, 1991.

Salinity also was measured in North Landing River near the North Carolina-Virginia State line (site 3), which is south of the confluence of West Neck Creek with the river. Salinities were measured near the water surface and near the channel bottom at 15-minute intervals during January 1991-July 1992. Near-surface and near-bottom salinities seldom differed by more than 0.2 ppt, and salt appeared to be uniformly distributed throughout the river cross section. Little diurnal variation in salinity was observed at the site. From January through November 1991, the daily mean salinity at site 3 was generally less than 0.8 ppt, and from December 1991 through March 28, 1992, salinity ranged from 0.9 to 1.3 ppt. From April through July 1992, salinity at site 3 increased from about 1.3 ppt to about 2.5 ppt. A comprehensive investigation in which salinity, water level, and flow are monitored in North Landing River, in the AIWW near Coinjock, and at the southern end of Currituck Sound is needed to determine the mass of salt moving into the sound and to characterize the processes affecting the salt transport.

REFERENCES

Campbell Scientific, Inc., 1987, SM192/SM176 storage module preliminary instruction manual: Logan, Utah.

_____1988, CR10 measurement and control module operator's manual: Logan, Utah.

Cox, R.A., 1965, The physical properties of sea water, *in* Riley, J.P., and Skirrow, G., eds., Chemical oceanography: New York, Academic Press, p. 73-120.

Ficken, J.H., and Scott, C.T., 1989, Operating manual for the U.S. Geological Survey minimonitor, 1988 edition, analog-voltage model: U.S. Geological Survey Open-File Report 89-403, 92 p.

Garrett, R.G., and Bales, J.D., 1991, Water-quality data from continuously monitored sites in the Pamlico and Neuse River estuaries, North Carolina, 1989-90: U.S. Geological Survey Open-File Report 91-465, 151 p.

Giese, G.L., Wilder, H.B., and Parker, G.G., 1985, Hydrology of major estuaries and sounds of North Carolina: U.S. Geological Survey Water-Supply Paper 2221, 108 p.

Hampton Roads Planning District Commission, 1982, Hampton Roads water quality management plan: Continuing planning process - water quality studies of Lynnhaven and Northwest Rivers: Norfolk, Virginia, Hampton Roads Water Quality Authority.

_____1988, The waters of southeastern Virginia: Chesapeake, Virginia.

_____1992, Environmental management program for the southeastern Virginia portion of the Albemarle-Pamlico estuarine watershed: Raleigh, Report No. 92-543, Albemarle-Pamlico Estuarine Study, North Carolina Department of Environment, Health, and Natural Resources, 90 p.

Hem, J.D., 1985, Study and interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 263 p.

International Organization for Standardization, 1985a, Liquid measurement in open channels--measurement of discharge by the ultrasonic (acoustic) method: Switzerland, International Standard 6416, 20 p.

_____1985b, Liquid flow measurement in open channels--ultrasonic (acoustic) velocity meters: Switzerland, International Standard 6418, 13 p.

Laenen, Antonius, 1985, Acoustic velocity meter systems: Techniques of Water-Resources Investigations of the United States Geological Survey, Chapter A17, Book 3, 38 p.

Laenen, Antonius, and Curtis, R.E., Jr., 1989, Accuracy of acoustic velocity metering systems for measurement of low velocity in open channels: U.S. Geological Survey Water-Resources Investigations Report 89-4090, 15 p.

Malcolm Pirnie Engineers, Inc., 1980, Conditions in the Lynnhaven Estuarine System, Virginia Beach, Virginia: Newport News, Virginia, Study Report for Department of the Army, Norfolk District Corps of Engineers, Norfolk, Virginia.

Miller, R.L., Bradford, W.L., and Peters, N.E., 1988, Specific conductance--theoretical considerations and applications to analytical quality control: U.S. Geological Water-Supply Paper 2311, 16 p.

Neilson, B.J., 1976, Water quality in the small coastal basins: Gloucester Point, Virginia, Special Report No. 129, *in* Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science, 139 p.

_____1978, Summary of the Hampton Roads 208 water quality modelling studies: Gloucester Point, Virginia, Special Report No. 1700, *in* Applied Marine Science and Ocean Engineering, Virginia Institute of Marine Science, 31 p.

Overton, M.F., and McAllister, T.L., 1993, Flow and transport modeling of the London Bridge Creek-West Neck Creek system: Raleigh, North Carolina, Report No.93-06, Albemarle-Pamlico Estuarine Study, North Carolina Department of Environment, Health, and Natural Resources, 23 p. + appendix.

Rantz, S.E., and others, 1982, Measurement and computation of streamflow: Volume 1. Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 248 p.

U.S. Army Corps of Engineers, 1980a, Virginia Beach streams, Canal Number Two general design memorandum phase 1, Virginia Beach, Virginia: Norfolk, Norfolk District, 75 p.

_____1980b, Virginia Beach streams, Canal Number Two general design memorandum phase 1, appendices, Virginia Beach, Virginia: Norfolk, Norfolk District.

(BLANK)

APPENDIX TABLES

APPENDIX CONTENTS

Appendix table 1. Daily mean flow, in cubic feet per second, at West Neck Creek site 1 for September 1990-March 1992

[Positive flow is to the south. ---, no data available]

	1990				1991												1992		
Day	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	---	19	3.6	---	---	---	---	---	---	---	-4.8	-3.1	52	5.5	84	---	40	46	-12
2	---	6.9	-4.8	---	---	---	---	---	---	---	-2.6	-20	49	-.16	27	---	25	45	-13
3	---	1.0	---	---	27	---	27	---	---	---	40	-31	24	38	6.9	---	26	34	9.5
4	---	-24	-8.3	---	---	-13	36	---	---	---	12	-11	-11	6.4	---	---	219	27	24
5	---	-6.6	-4.4	---	---	-4.9	10	---	---	---	-1.1	10	---	48	---	---	124	39	19
6	---	-7.4	11	---	11	7.7	-20	---	---	---	2.2	3.9	---	36	---	---	57	35	6.0
7	---	-13	---	---	51	---	-25	---	---	---	-6.6	139	---	42	---	---	25	61	-15
8	---	-16	25	---	---	50	4.5	---	---	---	-12	85	---	17	---	---	-2.8	59	19
9	---	-16	17	---	---	---	13	---	---	---	3.3	8.3	---	.95	---	---	-25	37	5.6
10	---	-14	36	---	58	31	27	---	---	---	19	6.8	---	1.1	---	---	1.2	16	-11
11	---	-35	9.1	---	39	28	48	---	---	---	14	---	---	6.7	---	---	16	-3.1	-8.9
12	---	-3.5	-28	---	---	36	37	---	---	---	4.5	---	---	7.9	---	---	-10	18	-12
13	---	4.0	-9.5	---	---	---	34	---	---	---	-13	---	---	15	---	---	-18	18	-7.1
14	---	1.8	6.5	---	15	---	50	---	-5.9	---	-5.3	---	---	-.45	---	---	-21	12	3.3
15	-4.7	-10	-5.3	---	-16	---	58	---	---	---	9.6	---	---	-11	---	---	-6.2	-1.7	8.9
16	10	17	-21	---	---	---	51	---	---	---	---	---	---	31	---	---	-5.7	34	---
17	33	-7.0	7.6	---	---	---	16	---	---	---	-13	---	---	139	---	---	-20	20	-2.3
18	25	-34	51	---	---	---	26	---	---	---	-29	-16	---	43	---	---	-6.4	28	4.2
19	-7.0	-13	39	---	---	-13	40	---	---	---	-39	52	---	-2.7	---	---	14	32	22
20	-16	-.54	27	---	---	-21	14	---	---	---	-35	-4.6	---	35	--	---	5.5	21	---
21	7.1	.39	15	---	---	-8.5	-15	---	---	---	-28	-24	---	24	---	---	5.8	1.4	---
22	-14	3.8	-6.6	---	---	---	-26	---	---	---	-15	-5.7	---	11	---	---	11	-6.7	---
23	18	20	-12	---	8.7	---	.67	---	---	---	-14	.20	---	4.9	---	---	9.2	3.1	---
24	18	15	-12	---	---	---	2.5	---	---	---	-16	-2.1	---	11	---	---	25	21	---
25	-13	34	-32	---	---	---	10	---	---	---	-16	29	---	11	---	25	-7.1	37	---
26	-27	115	---	---	7.8	---	10	---	---	---	-29	41	52	8.8	---	13	8.1	67	---
27	6.6	86	-12	---	-7.5	---	-9.2	---	---	-1.3	45	5.9	28	17	---	21	7.8	25	---
28	17	39	-20	---	---	---	---	---	---	-12	114	-11	17	39	---	18	45	-13	---
29	7.7	40	---	---	---	---	---	---	---	-24	38	-16	-6.5	63	---	49	41	1.4	---
30	-4.5	23	---	---	.91	---	85	---	---	-27	32	-5.8	-4.5	75	---	35	18	---	---
31	---	3.1	---	---	8.5	---	36	---	---	---	17	-11	---	91	---	47	22	---	---

Appendix table 2. Daily mean values of salinity, in parts per thousand, at West Neck Creek site 1 for December 1989-September 1990

[---, no data available; MAX, maximum; MIN, minimum]

Day	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	---	---	0.2	0.2	0.2	---	0.6	0.6	7.0	---
2	---	---	.2	.2	.2	---	.8	.5	7.5	---
3	---	---	.2	.2	.1	---	---	.5	7.6	---
4	---	---	.2	.1	.1	0.2	---	.5	6.7	---
5	---	---	2.5	.2	.1	.2	---	.5	6.0	---
6	---	---	3.7	.2	.2	.2	---	.5	3.9	---
7	---	---	2.1	1.0	.2	.1	---	.5	---	---
8	---	---	.3	2.2	.2	.2	---	.5	---	---
9	---	---	.5	.9	.2	.2	---	.4	2.3	---
10	---	---	.1	.6	.2	.2	---	.4	2.3	---
11	0.1	---	.1	.6	.2	.2	---	.5	2.3	---
12	.1	---	.1	.8	---	.2	---	.1	2.3	---
13	.1	---	.2	.9	.2	.3	---	.1	2.3	---
14	.1	---	.2	.8	---	.3	---	.1	2.3	---
15	.1	---	.2	.6	---	.3	---	.1	2.3	---
16	.1	---	.2	.5	.3	.3	---	.2	2.3	---
17	.1	---	.2	.4	.3	.3	---	.1	2.4	---
18	.1	---	.1	.1	---	.3	---	.1	2.4	---
19	.2	---	.1	.1	---	---	---	.1	2.4	---
20	.2	---	.1	.2	---	---	---	.1	2.4	---
21	.2	---	.1	.2	---	.3	---	.1	2.5	---
22	.2	---	.2	.2	---	.7	---	.1	2.4	---
23	.4	---	.2	.2	---	2.7	---	.1	---	---
24	---	---	.1	.2	---	2.6	---	.1	---	---
25	---	---	.1	---	.2	2.9	---	.3	---	---
26	---	---	.2	.9	.3	2.4	---	1.2	---	2.0
27	---	---	.2	1.0	.3	1.9	---	1.0	---	1.7
28	---	---	.2	1.5	.3	1.1	.8	.2	---	1.7
29	---	---	---	1.6	---	.8	.7	1.7	---	2.3
30	---	0.2	---	.5	---	---	.7	4.1	---	2.2
31	---	.1	---	.2	---	.8	---	6.5	---	---
MEAN	---	---	.5	---	---	---	---	.7	---	---
MAX	---	---	3.7	---	---	---	---	6.5	---	---
MIN	---	---	.1	---	---	---	---	.1	---	---

Appendix table 3. Daily mean values of salinity, in parts per thousand, at West Neck Creek site 1 for October 1990-September 1991

[---, no data available; MAX, maximum; MIN, minimum]

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	2.6	2.6	0.7	1.6	0.2	8.2	---	0.2	1.2	0.4	0.2	0.5
2	5.1	2.6	.7	2.3	.3	7.6	---	.2	1.1	.4	.2	1.1
3	4.8	2.5	.6	2.1	.3	5.2	---	---	1.1	.2	.3	2.0
4	3.3	1.8	.5	1.6	.3	1.0	---	.3	1.0	.2	.2	---
5	1.3	1.4	.3	1.7	.3	1.1	---	.3	1.7	.2	.3	1.1
6	1.3	1.4	.4	1.7	.3	1.6	0.4	.3	3.6	.2	.3	.9
7	1.3	1.8	.3	1.1	.3	1.7	.4	.3	4.4	.2	.2	1.0
8	1.0	2.9	.3	.4	1.2	1.6	.4	.3	4.9	.3	.2	2.3
9	1.3	5.1	.5	.1	3.3	1.4	.4	.4	5.4	.3	.2	3.6
10	1.3	2.4	.6	.1	4.6	1.5	.5	.4	5.4	.3	.2	4.0
11	1.6	.5	.6	.2	4.8	2.8	.4	.4	4.5	.2	.2	2.4
12	1.4	.7	.6	.1	5.8	4.6	.5	.5	2.2	.2	.2	1.3
13	1.3	1.1	.6	.1	5.9	4.8	.6	.5	1.5	.2	.2	1.7
14	1.3	1.0	.6	.2	5.7	---	.6	.5	1.5	.2	.2	1.0
15	1.3	1.1	.8	.2	3.8	---	2.2	.5	1.4	.2	.2	.3
16	1.3	1.0	.8	.2	5.8	---	1.3	.5	1.0	.2	.2	.9
17	1.2	.7	.7	.2	4.7	---	.7	.7	.7	.3	.3	.7
18	1.2	4.6	---	.2	2.6	---	.9	.6	.7	.3	.3	.6
19	1.3	8.6	---	.2	2.6	---	3.8	3.2	.7	.3	.3	.6
20	1.2	9.7	.6	.1	2.8	---	3.6	6.3	.7	.3	.2	.7
21	1.3	9.0	.6	.1	2.2	---	.3	7.4	.7	---	.2	1.7
22	1.2	8.9	.6	.2	2.2	---	.1	6.9	.6	.3	.3	3.0
23	.9	7.5	.9	.2	2.0	---	.1	4.0	.2	.3	.3	4.0
24	.3	4.9	.6	.2	4.2	---	.1	2.5	.2	.3	.3	3.8
25	.4	2.6	.3	.2	6.1	---	.2	1.8	.3	.3	.3	3.6
26	3.9	1.9	.3	.2	7.6	---	.2	1.5	.3	.3	1.1	.3
27	3.2	1.6	.6	.2	8.2	---	.2	1.4	.3	.3	2.5	.4
28	2.5	1.3	1.5	.2	8.9	---	.2	1.3	.3	.1	2.6	.7
29	2.3	.7	2.5	.2	---	---	.2	1.2	.3	.2	1.5	.8
30	2.8	.4	2.4	.2	---	---	.3	1.2	.3	.2	.8	.6
31	2.7	---	2.3	.2	---	---	---	1.3	---	.2	.7	---
MEAN	1.9	3.1	---	.5	3.5	---	---	---	1.6	---	.5	---
MAX	5.1	9.7	---	2.3	8.9	---	---	---	5.4	---	2.6	---
MIN	.3	.4	---	.1	.2	---	---	---	.2	---	.2	---

Appendix table 4. Daily mean values of salinity, in parts per thousand, at West Neck Creek site 1 for October 1991-March 1992

[---, no data available; MAX, maximum; MIN, minimum]

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	0.6	18.7	1.3	2.8	---	1.0
2	.6	16.1	1.0	3.7	---	1.1
3	.6	14.9	1.0	3.4	---	1.1
4	.8	12.8	1.2	1.4	---	1.2
5	.5	14.6	1.4	.4	---	1.6
6	.3	13.3	1.3	.4	---	2.0
7	.4	14.1	1.1	.4	---	1.6
8	.5	15.9	.9	---	---	1.5
9	.5	21.3	.9	---	---	1.5
10	.6	20.5	1.6	---	---	1.5
11	.5	13.9	4.0	---	---	1.3
12	.5	12.8	5.0	---	---	1.4
13	.6	10.7	4.8	---	---	1.4
14	.8	11.0	4.0	---	---	1.4
15	.6	8.7	3.3	---	---	1.4
16	.7	5.8	2.1	---	---	1.8
17	1.0	4.9	1.6	---	---	2.9
18	.5	5.9	.9	---	---	2.5
19	.5	6.0	4.1	---	---	2.4
20	.5	5.4	7.8	---	---	---
21	.6	3.5	7.6	---	---	---
22	.6	3.1	7.8	---	---	---
23	.7	3.5	8.3	---	---	---
24	.6	1.7	10.2	---	---	---
25	.8	1.4	12.8	---	---	---
26	.9	1.8	12.5	---	---	---
27	1.3	2.0	11.9	---	1.4	---
28	2.9	1.8	11.4	---	1.4	---
29	9.3	1.8	4.0	---	1.0	---
30	14.7	1.7	1.3	---	---	---
31	18.2	---	1.8	---	---	---
MEAN	2.0	9.0	4.5	---	---	---
MAX	18.2	21.3	12.8	---	---	---
MIN	.3	1.4	.9	---	---	---

Appendix table 5. Daily mean values of salinity, in parts per thousand, at West Neck Creek site 2 for January-September 1990

[---, no data available; MAX, maximum; MIN, minimum]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	---	0.2	0.2	0.3	---	0.4	0.5	1.7	0.8
2	---	.2	.2	.3	---	.3	.5	3.2	.8
3	---	.2	.2	.2	---	.2	.5	3.9	1.0
4	---	.2	.2	.1	---	.3	.5	4.1	.8
5	---	.2	.2	.1	---	.3	.4	3.3	.9
6	---	1.0	.2	.2	---	.3	.5	1.4	2.3
7	---	2.1	.2	.2	---	.3	.5	.8	2.2
8	---	2.2	.3	.2	---	.3	.5	1.0	1.5
9	---	1.5	.5	.2	0.2	.3	---	1.0	1.4
10	---	.3	.8	.2	.2	.3	---	1.1	2.3
11	---	.6	.6	.2	.2	.3	---	1.2	2.5
12	---	.4	.7	---	.2	.3	---	1.1	2.4
13	---	.4	.7	---	.2	.3	---	1.2	3.0
14	---	.4	.6	---	.2	.4	---	1.0	3.3
15	---	---	.4	---	.2	.5	---	1.1	2.9
16	---	.3	.3	---	.2	.8	---	1.1	2.2
17	---	.3	.2	---	.2	1.4	---	1.2	1.9
18	---	.3	.2	---	.2	2.1	---	1.2	1.8
19	---	.3	.2	---	.2	.8	---	1.2	1.8
20	---	.2	.2	---	.2	.9	.1	1.2	2.0
21	---	.2	---	---	.2	.8	.2	1.0	1.9
22	---	.2	.2	---	---	.8	.2	1.4	1.9
23	---	.2	.2	---	.3	.5	.1	4.4	1.9
24	---	.2	.2	---	1.5	.4	.1	5.2	1.9
25	---	.2	.2	---	1.8	.5	.1	3.9	1.9
26	---	.2	.3	---	1.0	.6	.1	2.4	1.9
27	---	---	.3	---	.3	.6	.7	1.9	1.9
28	---	.2	.5	---	.6	.5	.7	1.5	1.9
29	---	---	.5	---	.7	.5	.2	1.5	1.8
30	0.2	---	.8	---	.6	.4	.2	1.5	1.9
31	.2	---	.4	---	.6	---	1.3	1.1	---
MEAN	---	---	---	---	---	.5	---	1.9	1.9
MAX	---	---	---	---	---	2.1	---	5.2	3.3
MIN	---	---	---	---	---	.2	---	.8	.8

Appendix table 6. Daily mean values of salinity, in parts per thousand, at West Neck Creek site 2 for October 1990-September 1991

[---, no data available; MAX, maximum; MIN, minimum]

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.
1	1.8	2.0	0.6	---	---	---	0.5	0.2	0.5	---	---	0.2
2	1.7	1.9	.6	---	---	---	.5	.2	.6	0.4	---	.2
3	1.7	1.8	.6	---	---	---	.5	.2	.6	.3	---	.2
4	1.8	1.7	---	---	---	---	---	.2	.6	.2	---	.4
5	1.9	1.6	---	---	---	---	---	.2	.4	.2	---	.3
6	1.9	1.6	---	---	0.3	---	---	.2	.4	.2	---	.3
7	1.9	1.7	---	---	.3	---	---	.2	1.8	.2	---	---
8	1.9	1.5	---	---	.3	---	.5	.2	3.1	.3	---	---
9	1.8	1.4	---	---	.4	---	.4	.2	3.2	.3	---	---
10	1.7	1.4	---	---	1.4	---	.4	.2	2.8	.2	---	---
11	1.1	1.5	---	---	2.2	---	.5	.2	1.8	.2	---	---
12	1.3	1.5	---	---	---	---	.5	.2	.4	---	---	---
13	1.4	1.5	---	---	---	---	.5	.2	.5	---	---	---
14	1.4	1.6	---	---	---	---	.5	.2	.6	---	---	---
15	1.4	1.6	---	---	---	2.9	.5	.2	.5	---	---	---
16	---	1.4	---	---	---	3.7	.5	.2	.4	---	---	---
17	1.3	1.4	---	---	---	4.4	.8	.2	.4	---	---	---
18	1.1	1.2	---	---	---	3.9	.7	.2	.4	---	---	---
19	1.0	3.2	---	---	---	2.6	.8	.3	.4	---	---	---
20	1.1	7.8	---	---	---	2.5	1.6	1.0	.4	---	---	.5
21	1.1	8.3	---	---	---	2.2	.2	4.4	.4	---	---	.4
22	1.1	8.6	---	---	---	1.3	.2	5.3	.4	---	---	.5
23	1.1	8.6	---	---	---	1.4	.1	3.3	.4	---	---	1.0
24	1.0	7.6	---	---	---	1.3	.1	1.2	.2	---	---	1.1
25	.8	5.2	---	---	---	1.3	.1	.8	.2	---	---	1.1
26	1.5	3.0	---	---	---	1.2	.1	.7	.3	---	---	.7
27	2.3	1.9	---	---	---	.7	.1	.5	.3	---	---	.8
28	2.4	1.7	---	---	---	.8	.2	.5	.4	---	---	.7
29	2.1	1.3	---	---	---	.7	.2	.5	.4	---	---	.6
30	2.0	.7	---	---	---	.6	.2	.6	.4	---	0.2	.7
31	2.0	---	---	---	---	.5	---	.6	---	---	.2	---
MEAN	---	2.9	---	---	---	---	---	.8	.8	---	---	---
MAX	---	8.6	---	---	---	---	---	5.3	3.2	---	---	---
MIN	---	.7	---	---	---	---	---	.2	.2	---	---	---

Appendix table 7. Daily mean values of salinity, in parts per thousand, at West Neck Creek site 2 for October 1991-March 1992

[---, no data available; MAX, maximum; MIN, minimum]

Day	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
1	0.6	8.7	2.2	1.5	0.3	0.9
2	.6	9.6	2.1	1.4	.8	.9
3	.6	9.9	2.0	1.4	1.7	1.0
4	.5	8.4	1.9	1.4	2.0	.9
5	.5	4.7	1.9	.3	2.0	.7
6	.3	7.1	1.9	.4	2.7	.6
7	.3	6.2	1.9	.4	3.9	.8
8	.2	6.6	1.9	.4	5.6	.8
9	.3	10.8	1.9	.5	6.2	.7
10	.3	13.0	1.6	.4	5.4	.6
11	.3	11.8	1.2	.3	5.5	.7
12	.3	9.6	1.1	.4	3.4	.7
13	.3	8.1	1.4	.4	3.5	.6
14	.3	5.8	1.5	.5	3.5	.6
15	.3	4.5	1.4	.4	2.6	.6
16	.3	3.5	1.4	.4	2.2	.6
17	.4	3.7	1.4	.4	2.2	.6
18	.2	3.7	1.5	.4	1.8	.6
19	.2	3.6	1.1	.4	1.7	---
20	.2	3.3	.9	.4	1.2	---
21	.2	3.1	1.5	.4	1.0	---
22	.2	2.7	1.8	.4	1.0	---
23	.2	2.7	2.4	.4	1.0	---
24	.2	2.8	2.2	.3	.8	---
25	.3	2.8	4.8	.3	.6	---
26	.3	2.5	5.5	.3	.7	---
27	.3	2.3	4.6	.3	1.3	---
28	.3	2.2	4.4	.3	1.0	---
29	1.4	2.3	6.7	.2	.9	---
30	5.9	2.2	3.4	.2	---	---
31	7.6	---	1.4	.2	---	---
MEAN	.8	5.6	2.3	.5	2.3	---
MAX	7.6	13.0	6.7	1.5	6.2	---
MIN	.2	2.2	.9	.2	.3	---

Appendix table 8. Daily mean values of salinity, in parts per thousand, at the North Landing River site 3 near-bottom sensor for January 1991-July 1992

[---, no data available; MAX, maximum; MIN, minimum]

Day	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
1	---	0.7	---	0.8	---	---	0.8	0.7	0.5	0.6	0.6	0.9	1.2	1.1	1.1	1.3	1.6	1.8	2.1
2	---	.7	---	.8	---	---	.8	.7	.5	.6	.6	.9	1.1	1.1	1.1	1.4	1.7	2.1	2.1
3	---	.7	---	.7	---	---	.8	.7	.5	.6	.6	.9	1.3	1.1	1.1	1.5	1.7	2.3	2.1
4	---	.7	---	.7	---	---	.8	.7	.5	.6	.6	.9	1.2	1.1	1.1	2.0	1.7	2.3	2.1
5	---	.7	---	.7	---	---	.8	.7	.5	.6	.6	1.2	1.2	1.1	1.1	1.8	1.7	2.3	2.0
6	---	.7	---	.7	---	---	.8	.7	.5	.6	.6	1.1	1.2	1.1	1.1	1.5	1.6	2.4	2.1
7	---	.7	---	.7	---	---	.7	.6	.5	.6	.6	1.1	1.2	1.1	1.1	1.4	1.6	2.2	2.1
8	---	.7	---	.7	---	---	.7	.6	.5	.6	.6	1.0	1.2	1.1	1.2	1.5	1.6	2.0	2.1
9	---	.7	---	.7	---	---	.7	.6	.5	.6	.6	1.0	1.1	1.1	1.2	1.5	1.7	2.0	2.1
10	---	---	---	.7	---	---	.8	.5	.5	.6	.6	1.0	1.1	1.1	1.2	1.4	1.7	2.0	2.2
11	---	---	---	.7	---	---	.7	.5	.5	.6	.7	1.1	1.2	1.1	1.2	1.4	1.7	2.1	2.3
12	---	---	---	.7	---	---	.7	.5	.5	.6	.7	1.1	1.2	1.1	1.2	1.4	1.7	2.1	2.3
13	---	---	---	.7	---	---	.7	.5	.5	.6	.7	1.1	1.2	1.1	1.2	1.4	1.7	2.1	2.3
14	---	---	---	.7	---	---	.7	.5	.5	.6	.7	1.1	1.2	1.1	1.3	1.4	1.8	2.1	2.3
15	---	---	---	.7	---	---	.7	.5	.5	.6	.7	1.1	1.2	1.1	1.2	1.6	1.9	2.1	2.4
16	---	---	---	.7	---	---	.7	.5	.6	.6	.7	1.1	1.2	1.1	1.2	1.5	1.7	2.1	2.4
17	---	---	---	.5	---	---	.7	.5	.6	.6	.7	1.1	1.3	1.1	1.1	1.5	1.7	2.2	2.4
18	---	---	---	---	---	---	.7	.5	.6	.6	.7	1.1	1.3	1.1	1.1	1.5	1.6	2.3	2.5
19	0.8	---	---	---	---	0.8	.7	.4	.6	.6	.7	1.1	1.3	1.1	1.2	1.6	1.7	2.3	2.6
20	.7	---	---	---	---	.9	.7	.4	.7	.6	.8	1.1	1.2	1.2	1.2	1.6	1.8	2.3	2.6
21	.7	---	---	---	---	.9	.7	.4	.7	.6	.7	1.1	1.2	1.2	1.2	1.4	1.7	2.2	2.5
22	.7	---	---	---	---	.9	.7	.4	.6	.6	.7	1.2	1.3	1.1	1.2	1.6	1.6	2.3	2.6
23	.7	---	---	---	---	.8	.8	.4	.6	.6	.7	1.2	1.2	1.2	1.2	1.6	1.7	2.2	2.6
24	.7	---	---	---	---	.8	.8	.4	.6	.6	.7	1.2	1.2	1.2	1.2	1.5	1.8	2.1	2.6
25	.7	---	---	---	---	.8	.8	.4	.6	.6	.7	1.2	1.2	1.1	1.2	1.4	1.8	2.1	2.6
26	.7	---	---	---	---	.8	.8	.4	.6	.6	.8	1.2	1.1	1.1	1.3	1.3	1.7	2.1	2.6
27	.7	---	0.8	---	---	.8	.8	.5	.6	.6	.8	1.3	1.1	1.2	1.3	1.3	1.8	2.1	2.5
28	.7	---	.8	---	---	.8	.8	.5	.6	.6	.9	1.2	1.1	1.2	1.3	1.3	1.8	2.1	2.5
29	.7	---	.8	---	---	.8	.7	.5	.6	.6	.9	1.2	1.1	1.2	1.4	1.4	1.8	2.1	2.5
30	.7	---	.8	---	---	.8	.8	.5	.6	.6	.9	1.2	1.1	---	1.4	1.4	1.8	2.2	2.5
31	.7	---	.8	---	---	---	.7	.5	---	.6	---	1.2	1.1	---	1.3	---	1.7	---	2.5
MEAN	---	---	---	---	---	---	.7	.5	.6	.6	.7	1.1	1.2	1.1	1.2	1.5	1.7	2.2	2.4
MAX	---	---	---	---	---	---	.8	.7	.7	.6	.9	1.3	1.3	1.2	1.4	2.0	1.9	2.4	2.6
MIN	---	---	---	---	---	---	.7	.4	.5	.6	.6	.9	1.1	1.1	1.1	1.3	1.6	1.8	2.0

☆ U.S. GOVERNMENT PRINTING OFFICE: 1994-552-941/00902

CONVERSION FACTORS, VERTICAL DATUM, TEMPERATURE, SALINITY, AND ABBREVIATIONS

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
acre	4,047	square meter
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Mass	
ounce, avoirdupois (oz)	28.35	gram
ton, short (2,000 lb)	907.2	kilogram
	Specific Conductance	
micromho per centimeter at 25 degrees Celsius (µmho/cm at 25 °C)	1.000	microsiemen per centimeter at 25 degrees Celsius

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

Temperature: In this report, temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$°F = 1.8\,(°C) + 32$$

Salinity: In this report, salinity is reported in parts of salt per thousand parts of water, or parts per thousand (ppt). One ppt is equivalent to 0.18 ton of salt per acre-foot of water.

In this report, use of the hyphen (-) in dates means "through" the time period indicated.

Abbreviations of units used in this report in addition to those in conversion table:

ft/s	foot per second
µS/cm	microsiemen per centimeter at 25 degrees Celsius
mg/L	milligram per liter