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Changes in salinity structure of the James, York and Rappahannock estuaries resulting from the effects of Tropical Storm Agnes

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The Effects of Tropical Storm Agnes on the Chesapeake Bay Estuarine System

The Chesapeake Research Consortium, Inc.

THE EFFECTS OF TROPICAL STORM AGNES ON THE CHESAPEAKE BAY ESTUARINE SYSTEM

THE CHESAPEAKE RESEARCH CONSORTIUM, INC.

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Preface

During June 1972 Tropical Storm Agnes released record amounts of rainfall on the watersheds of most of the major tributaries of Chesapeake Bay. The resulting floods, categorized as a once-in-100-to-200-year occurrence, caused perturbations of the environment in Chesapeake Bay, the nation's greatest estuary.

This volume is an attempt to bring together analyses of the effects of this exceptional natural event on the hydrology, geology, water quality, and biology of Chesapeake Bay and to consider the impact of these effects on the economy of the Tidewater Region and on public health.

It is to be hoped that these analyses of the event will usefully serve government agencies and private sectors of society in their planning and evaluation of measures to cope with and ameliorate damage from estuarine flooding. It is also to be hoped that the scientific and technical sectors of society will gain a better understanding of the fundamental nature of the myriad and interrelated phenomena that is the Chesapeake Bay ecosystem. Presumably much of what was learned about Chesapeake Bay will be applicable to estuarine systems elsewhere in the world. Most of the papers comprising this volume were presented at a symposium held May 6–7, 1974, at College Park, Maryland, under the sponsorship of the Chesapeake Research Consortium,Inc., with support from the Baltimore District, U.S. Army Corps of Engineers (Contract No. DACW 31-73-C-0189). An early and necessarily incomplete assessment, *The Effects of Hurricane Agnes on the Environment and Organisms of Chesapeake Bay* was prepared by personnel from the Chesapeake Bay Institute (CBI), the Chesapeake Biological Laboratory (CBL), and the Virginia Institute of Marine Science (VIMS) for the Philadelphia District, U.S. Army Corps of Engineers. Most of the scientists who contributed to the early report conducted further analyses and wrote papers forming a part of this report on the effects of Agnes. Additional contributions have been prepared by other scientists, most notably in the fields of biological effects and economics.

The report represents an attempt to bring together all data, no matter how fragmentary, relating to the topic. The authors are to be congratulated for the generally high quality of their work. Those who might question, in parts of the purse, the fineness of the silk must keep in mind the nature of the sow's ears from which it was spun. This is not to disparage the effort, but only to recognize that the data were collected under circumstances which at best were less than ideal. When the flood waters surged into the Bay there was no time for painstaking experimental design. There were not enough instruments to take as many measurements as the investigators would have desired. There were not enough containers to obtain the needed samples or enough reagents to analyze them. There were not enough technicians and clerks to collect and tabulate the data. While the days seemed far too short to accomplish the job at hand, they undoubtedly seemed far too long to the beleaguered field parties, vessel crews, laboratory technicians, and scientists who worked double shifts regularly and around the clock on many occasions. To these dedicated men and women, whose quality of performance and perseverance under trying circumstances were outstanding, society owes an especial debt of gratitude.

It should be noted that the Chesapeake Bay Institute, the Chesapeake Biological Laboratory, and the Virginia Institute of Marine Science, the three major laboratories doing research on Chesapeake Bay, undertook extensive data-gathering programs, requiring sizable commitments of personnel and equipment, without assurance that financial support would be provided. The emergency existed, and the scientists recognized both an obligation to assist in ameliorating its destructive effects and a rare scientific opportunity to better understand the ecosystem. They proceeded to organize a coordinated program in the hope that financial arrangements could be worked out later. Fortunately, their hopes proved well founded. Financial and logistic assistance was provided by a large number of agencies

that recognized the seriousness and uniqueness of the Agnes phenomenon. A list of those who aided is appended. Their support is gratefully acknowledged.

This document consists of a series of detailed technical reports preceded by a summary. The summary emphasizes effects having social or economic impact. The authors of each of the technical reports are indicated. To these scientists, the editors extend thanks and commendations for their painstaking work.

Several members of the staff of the Baltimore District, U.S. Army Corps of Engineers, worked with the editors on this contract. We gratefully acknowledge the helpful assistance of Mr. Noel E. Beegle, Chief, Study Coordination and Evaluation Section, who served as Study Manager; Dr. James H. McKay, Chief, Technical Studies and Data Development Section; and Mr. Alfred E. Robinson, Jr., Chief of the Chesapeake Bay Study Group.

The editors are also grateful to Vickie Krahn for typing the Technical Reports and to Alice Lee Tillage and Barbara Crewe for typing the Summary.

The Summary was compiled from summaries of each section prepared by the section editors. I fear that it is too much to hope that, in my attempts to distill the voluminous, detailed, and well-prepared papers and section summaries, I have not distorted meanings, excluded useful information or overextended conclusions. For whatever shortcomings and inaccuracies that exist in the Summary, I offer my apologies.

Jackson Davis
Project Coordinator

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-- Coastal River Squadron Two, Little Creek, Virginia
-- Assault Creek Unit Two, Little Creek, Virginia
-- Explosive Ordnance Disposal Unit Two, Fort Story, Virginia
-- Naval Ordnance Laboratory, White Oak, Maryland

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-- Reserve Training Center
-- Coast Guard Station, Little Creek, Virginia
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The National Science Foundation

Food and Drug Administration

Environmental Protection Agency

U. S. Office of Emergency Preparedness

State of Maryland, Department of Natural Resources

Commonwealth of Virginia, Office of Emergency Preparedness

TABLE OF CONTENTS

C. Water Quality Effects

D. Biological Effects

THE EFFECTS OF TROPICAL STORM AGNES ON THE CHESAPEAKE BAY ESTUARINE SYSTEM

HYDROLOGICAL EFFECTS

Evon P. Ruzecki, Editor

CHANGES IN SALINITY STRUCTURE OF THE JAMES, YORK AND RAPPAHANNOCK ESTUARIES RESULTING FROM THE EFFECTS OF TROPICAL STORM AGNES[1]

Paul V. Hyer[2]
Evon P. Ruzecki[2]

ABSTRACT

The peak effect of the flood waters produced by Tropical Storm Agnes was seen on June 25 in the James, June 26 in the Rappahannock, and June 30 in the York. Recovery toward normal salinity conditions after the high runoffs proceeded discontinuously, with alternating periods of vertical stratification and destratification. During strongly stratified stages, saline water advanced upstream along the bottom. In the York and James Rivers, the most dramatic stratification occurred about July 20-25. This event resulted in bottom salinity values exceeding normal ambient values and, at the river mouths, reaching values hitherto unobserved. This event was apparently controlled by the salinity distribution in the Bay. Less pronounced stratification maxima occurred in the James about July 6 and August 18 and in the York during August. These events do not appear to be correlated with stream gauge flow records or local precipitation. These events are possible instances of overshooting of equilibrium by the intruding salt water near the bottom.

INTRODUCTION

Virginia's three major estuaries emptying into the Chesapeake Bay were all affected by flood runoff from the rains of Agnes in June 1972. Instead of three special cases, however, they constitute three parts of a larger system which includes the Bay itself and all its tributaries. Fig. 1 shows the Chesapeake Bay drainage system. The stations sampled in the three major estuaries are shown. Recovery of salinity structure in each individual estuary depends therefore in part on the boundary condition at that estuary's mouth, as controlled by the Bay.

Qualitative summaries of the salinity distribution in each of the three estuaries will be presented for the major recovery period, beginning at the time of passage of Agnes and extending to about the end of August.

OBSERVATIONS

James River

Figs. 2 and 3 summarize the salinity distribution throughout the recovery period. These figures are derived from twenty-eight slack water runs performed in the two-month period following Agnes. Fig. 2 shows the recovery process at the river mouth, while Fig. 3 illustrates the recovery process by showing the progress upstream of selected isohalines. In Fig. 2 and its counterparts for the Rappahannock and York, the stage of the tide is distinguished, although

[1]Contribution No. 756, Virginia Institute of Marine Science.
[2]Virginia Institute of Marine Science, Gloucester Point, Va. 23062

there seems to be little systematic difference in the salinity structure when measured at high slack and low slack. Beginning June 24, strong stratification is evidenced by the difference in salinity between the surface and bottom, while the maximum depression of surface salinity occurred on 25 June. Bottom salinity, however, reached a minimum on June 27, a time when surface salinity had begun to recover. A period of slowly increasing salinity followed, accompanied by oscillations with a period of about four days, evident both in the salinity at the river mouth and the salinity intrusion upstream. Vertical stratification also decreased until about July 7, and, near the mouth, until July 14. However, from July 14 until July 21, there was a dramatic increase in vertical stratification at the river mouth, with a characteristic pattern of an initial decrease at the surface, followed by a considerable increase at the bottom and an increase at the surface. At the same time, salinity began to move upstream, but reached its maximum excursion several days after salinity at the river mouth reached its maximum value. This "overshoot" of equilibrium was apparently initiated by conditions in the Chesapeake Bay. Bottom salinity at the mouth of the James reached a value of 30.03 ppt on July 21, the highest value hitherto recorded for that point (Fig. 4). The station numbers shown in this figure and the other salinity contour plots represent the distance from the river mouth in nautical miles. Both this maximum value of salinity and the subsequent maximum upstream penetration of salt water were observed at low water slack. The subsequent retreat of salt water appears to be characterized by overall vertical mixing, but with a spike about two weeks after the late July event. The system finally reached a well-mixed state on August 25. Slack water data from September 1971 are included in Figs. 2 and 3 for comparison. Background data from 1973 are also included.

Rappahannock River

The freshening effect of the flood waters was evident in the Rappahannock on the first date sampled, but surface salinity at the mouth reached a minimum on June 26, accompanied by prominent vertical stratification (Figs. 5 and 6). There were thirty-three slack water runs made in the Rappahannock in the summer of 1972. By June 30, bottom salinity at the mouth had achieved a local minimum in time, but not an absolute minimum over the history of the flood. Vertical stratification was strong upstream, as evidenced by the fact that the 5 ppt isohaline met the surface. The density structure at the mouth at this time corresponded to a reverse three-layer system, with a stratified river connected to a well-mixed Bay (Fig. 7). In such a system, there is net flow inward at mid-depth and outflow at surface and bottom (Pritchard & Carpenter 1960). From the beginning of July until about July 10, salt water penetrated upstream, as a result of gravitational circulation. At the same time, however, salinity at the river mouth was decreasing due to flushing of the Bay. Bottom salinity at the river mouth reached a minimum value of 7.2 ppt. The result was a well-mixed, low-salinity, over-extended system. Salt water retreated rapidly until mid-July, with the system staying well mixed. Surface salinity at the mouth was notably constant for this period. From July 15 to July 25, an increase in bottom salinity at the river mouth set in motion an upstream transport of salt, with characteristic strong vertical stratification. The balance of July was a period of vertical mixing as can be seen by the fact that the 5 ppt isohaline became relatively steep. In early August, bottom salinity at the mouth increased rapidly, (due to recovery within the Bay) reaching a value greater than 20 ppt, while the surface salinity remained below 8 ppt (Fig. 6). The system soon reverted to a well-mixed state. However, the salt supplied by this event made possible an increase in salinity throughout the estuary.

York River

York River mouth salinity and saline intrusion history are shown in Figs. 8 and 9 respectively. A total of 38 slack water runs are summarized. Of the three major tributaries of the lower Chesapeake Bay, the York seems to have been the least affected and had the slowest response to Agnes-caused flooding. This was probably due to two main factors: the relatively small size of the York watershed and the fact that a new reservoir on the North Anna River (a secondary tributary to the York) served as a catchment basin for a good portion of the flood waters. Minimum surface salinity at the river mouth occurred on 30 June, with bottom salinity reaching a minimum two days later. Over the first ten days of July there was a trend toward recovery, albeit with fluctuations. The mouth of the York became well-mixed by 13 July. Then, as in the James, there occurred a strong perturbation originating in the bay. Bottom salinities increased dramatically, causing an increase in vertical stratification throughout the estuary. Fig. 10 shows the situation on 26 July. Bottom salinities at the mouth of the York reached the highest values hitherto observed, as was the case in the James. A period of salinity advance and a trend toward mixing but with a spike (indicating a short-period increase in salinity) occurring a week after maximum salinity was observed. The salinity advance upstream was rapid, as can be seen by the progress of the 5 ppt isohaline (Fig. 9). By August 29 the estuary was well mixed.

Another interesting feature of the York River is the high salinity lens observed on several occasions at low water slack, between Tue Marsh Light and Gloucester Point (Fig. 11). This feature probably results from upwelling of the ebbing water as it is forced out of the narrow, deep channel between Gloucester Point and Yorktown and into a reach with shallower, broader profile. A lens in the James, on the other hand, was seen on only one occasion and probably reveals transient response to Agnes flood waters.

DISCUSSION

The fluctuations observed in the salinity structure of the James, York, and Rappahannock Rivers indicate oscillatory motion and sensitivity to a time-dependent boundary condition, i.e., the salinity in the Chesapeake Bay. All three systems received an initial perturbation from the flood. The York and James received a second disturbance in the period July 20-25. The Rappahannock apparently received a second disturbance about August 7. Both disturbances occurring in the James and the late July disturbance in the York seemed to be followed by an oscillatory approach to equilibrium. Apparently the returning salt water in the lower depths gained sufficient momentum to overshoot equilibrium, so that an oscillation resulted. This behavior was not observed in the Rappahannock estuary, which is extremely long compared to the others. The initial impulse delivered to the York was apparently too gradual to cause any oscillation.

CONCLUSIONS

The James, Rappahannock, and York estuaries were greatly disturbed first by the flood runoff from Agnes and again, over a month later, by dramatic changes of the salinity structure in Chesapeake Bay. Following these events, the James and York showed an oscillatory behavior suggesting an internal freely-oscillating seiche. Salinity conditions in the York and Rappahannock in late September were not greatly different from those a year earlier.

LITERATURE CITED

Pritchard, D. W. and J. H. Carpenter. 1960. Measurements of turbulent diffusion in estuarine and inshore waters. Bull. Int. Assoc. Sci. Hydrol. 20:37-50.

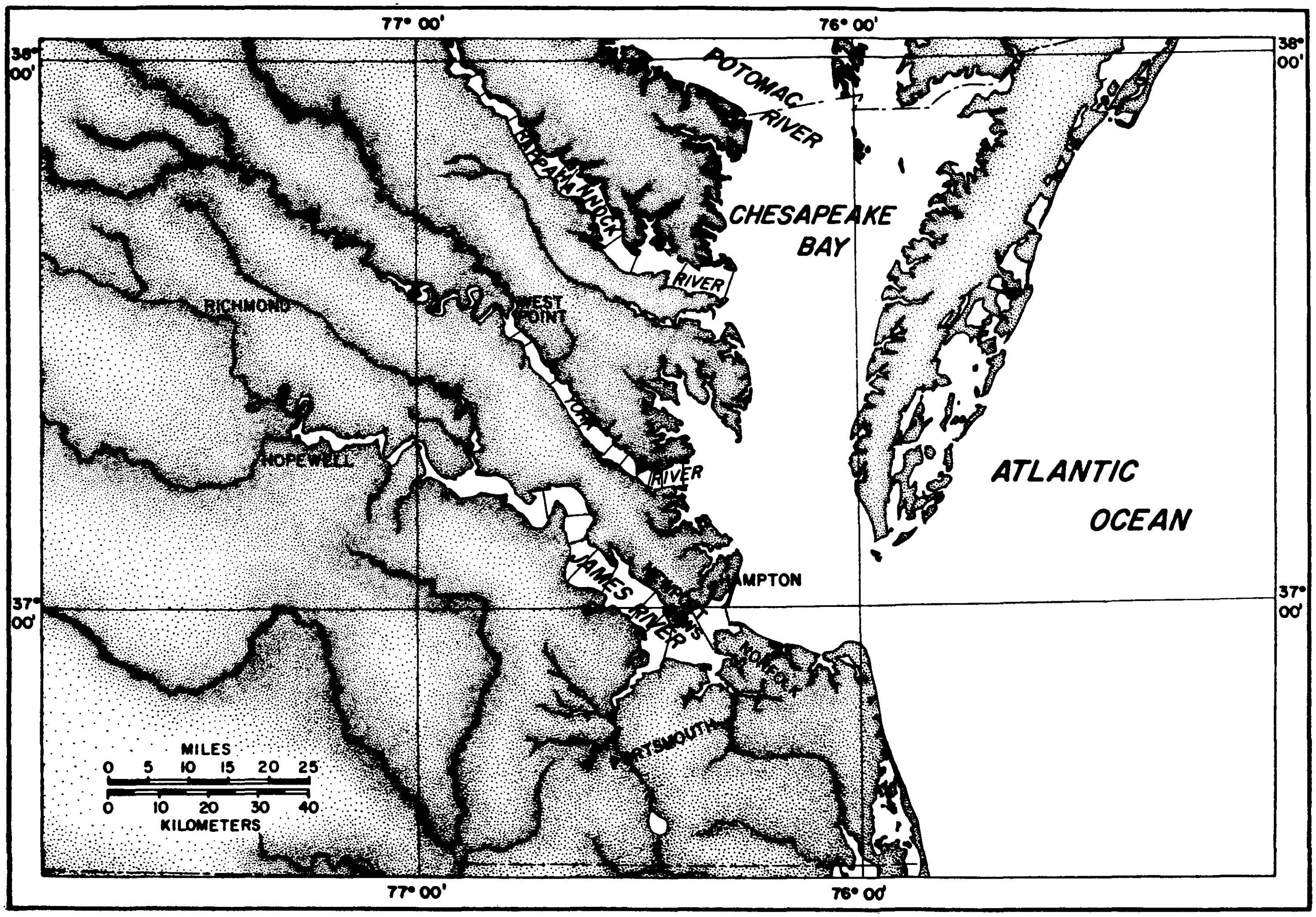

Figure 1. Post-Agnes sampling points in Virginia estuaries.

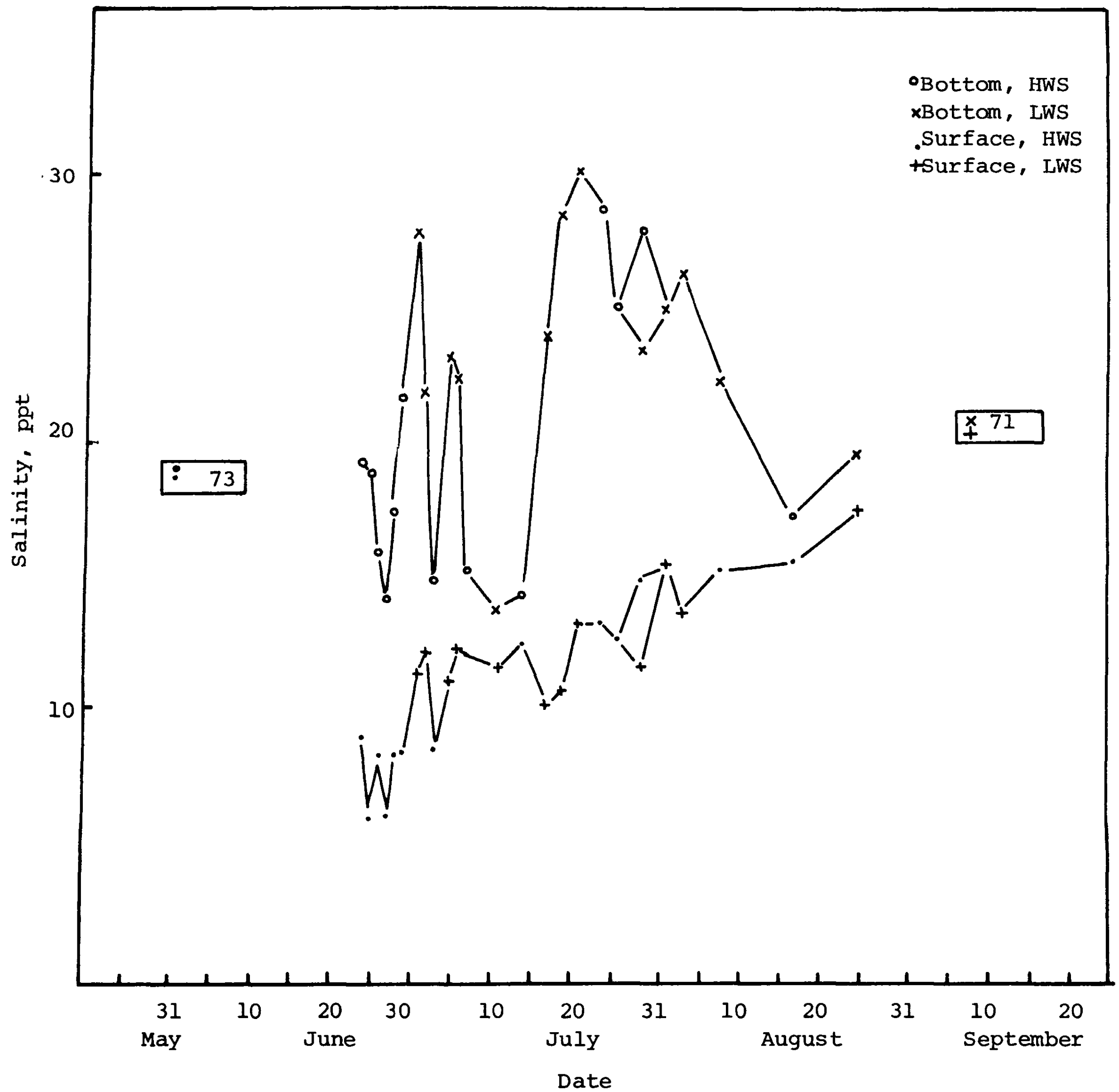

Figure 2. Surface and bottom salinity at the James River mouth as a function of time.

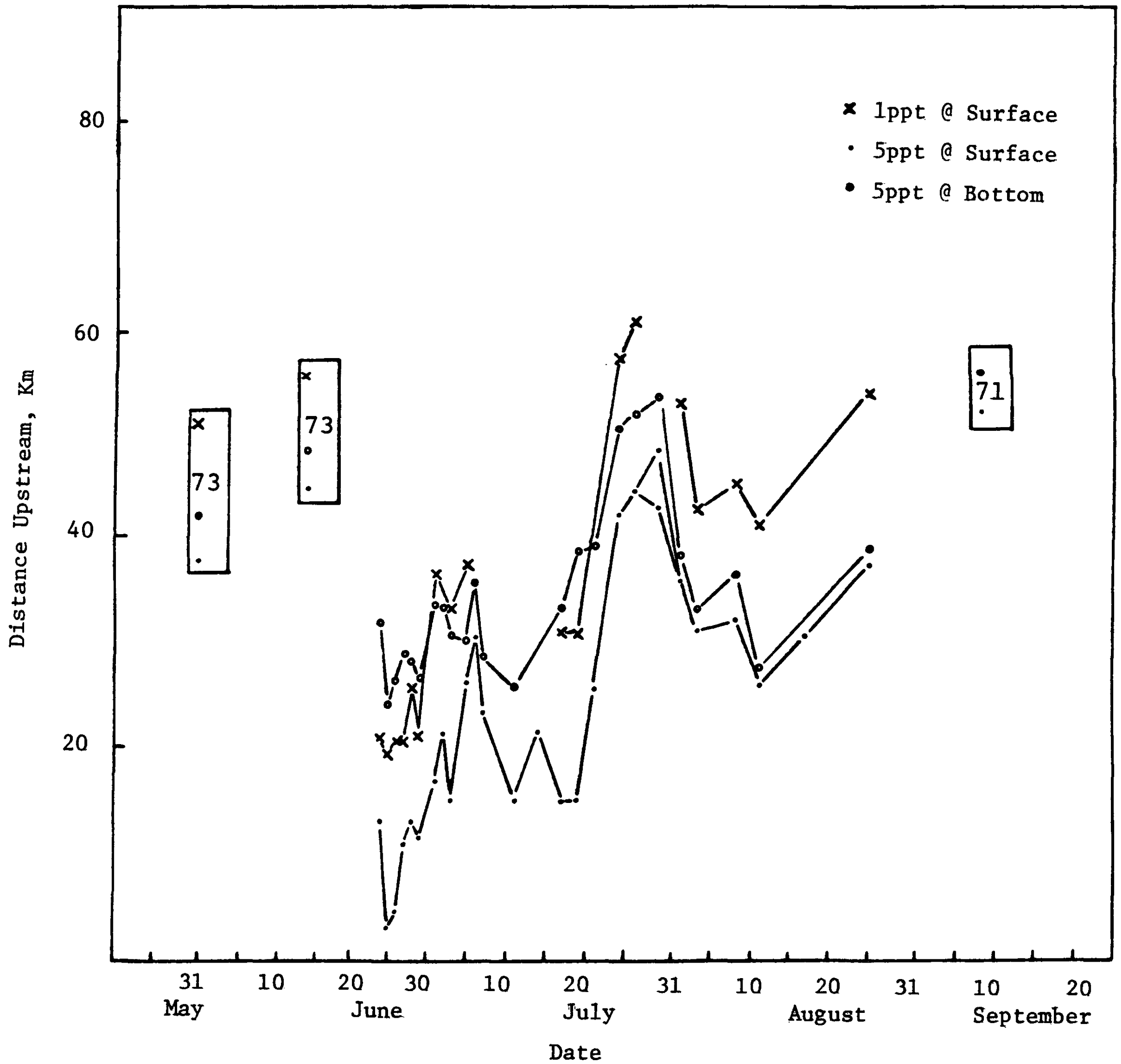

Figure 3. Saline intrusion in the James River as a function of time.

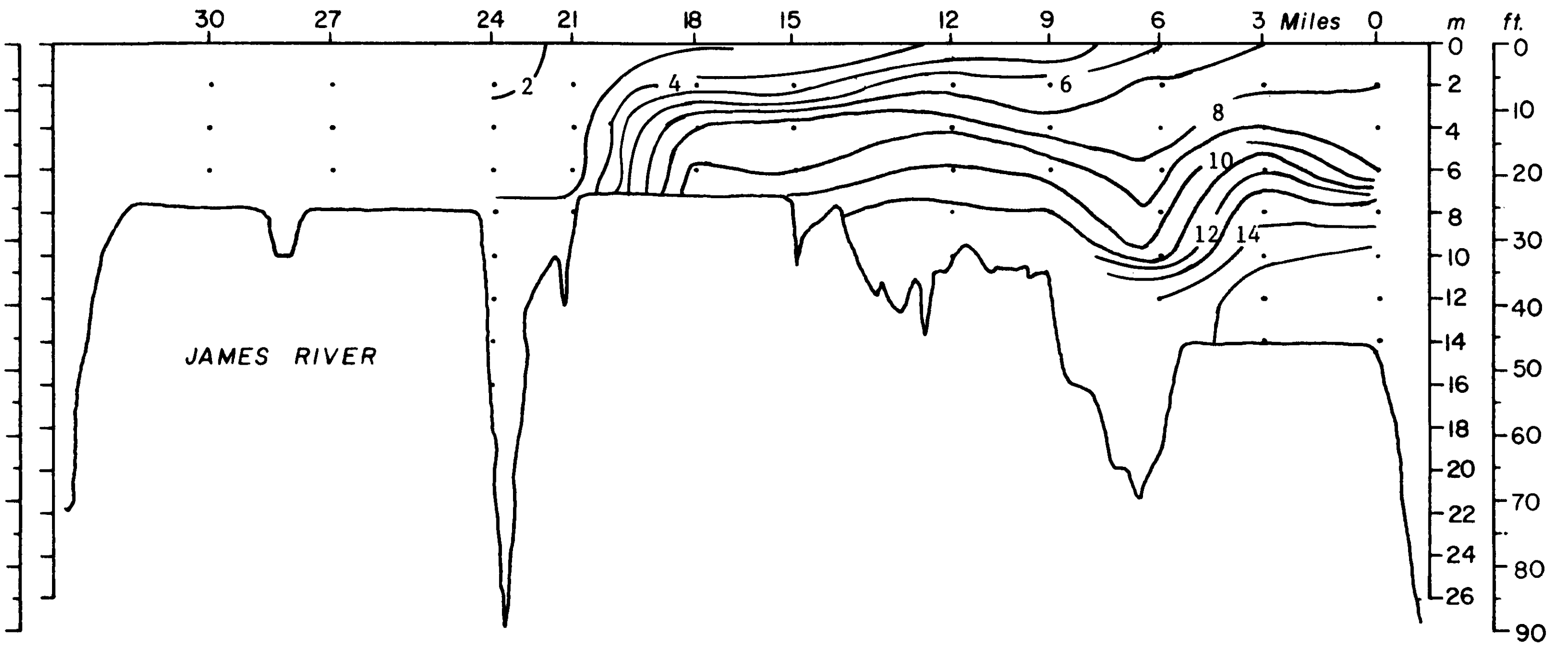

Figure 4. Salinity at low water slack, July 21, 1972.

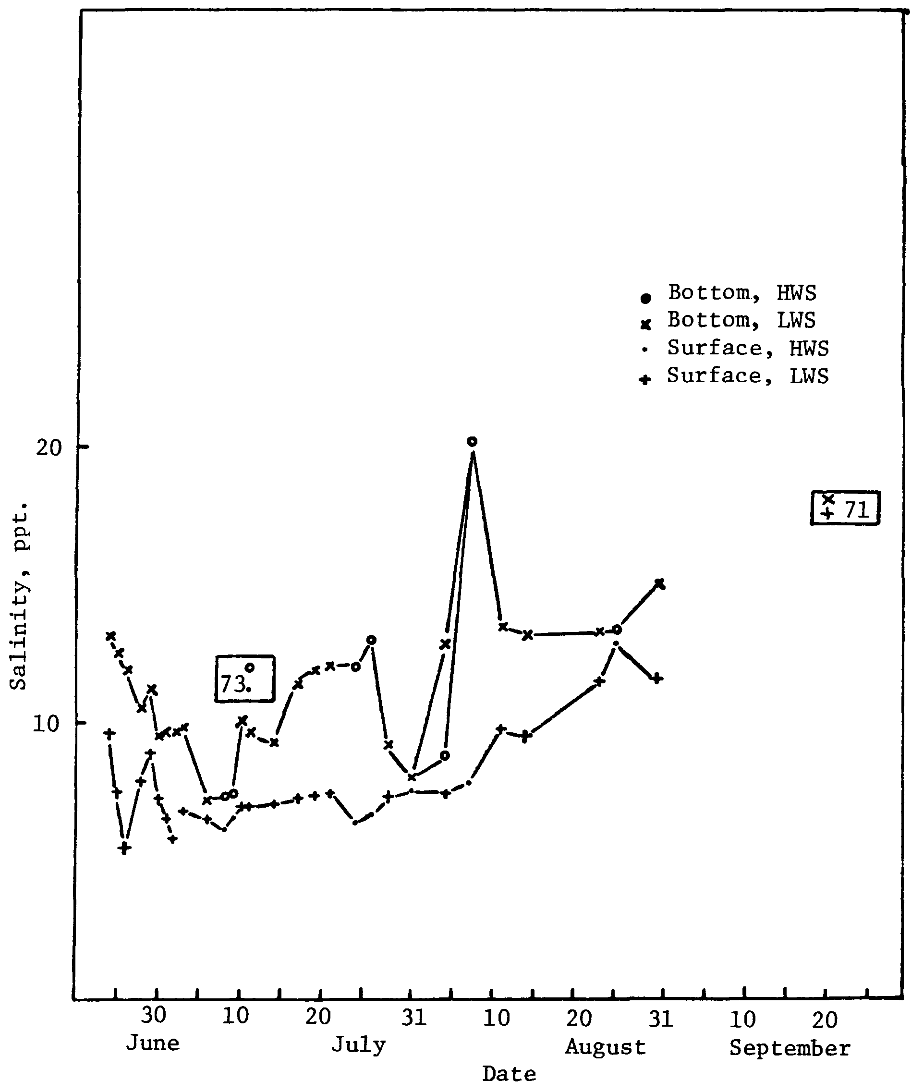

Figure 5. Surface and bottom salinity at the Rappahannock River mouth as a function of time.

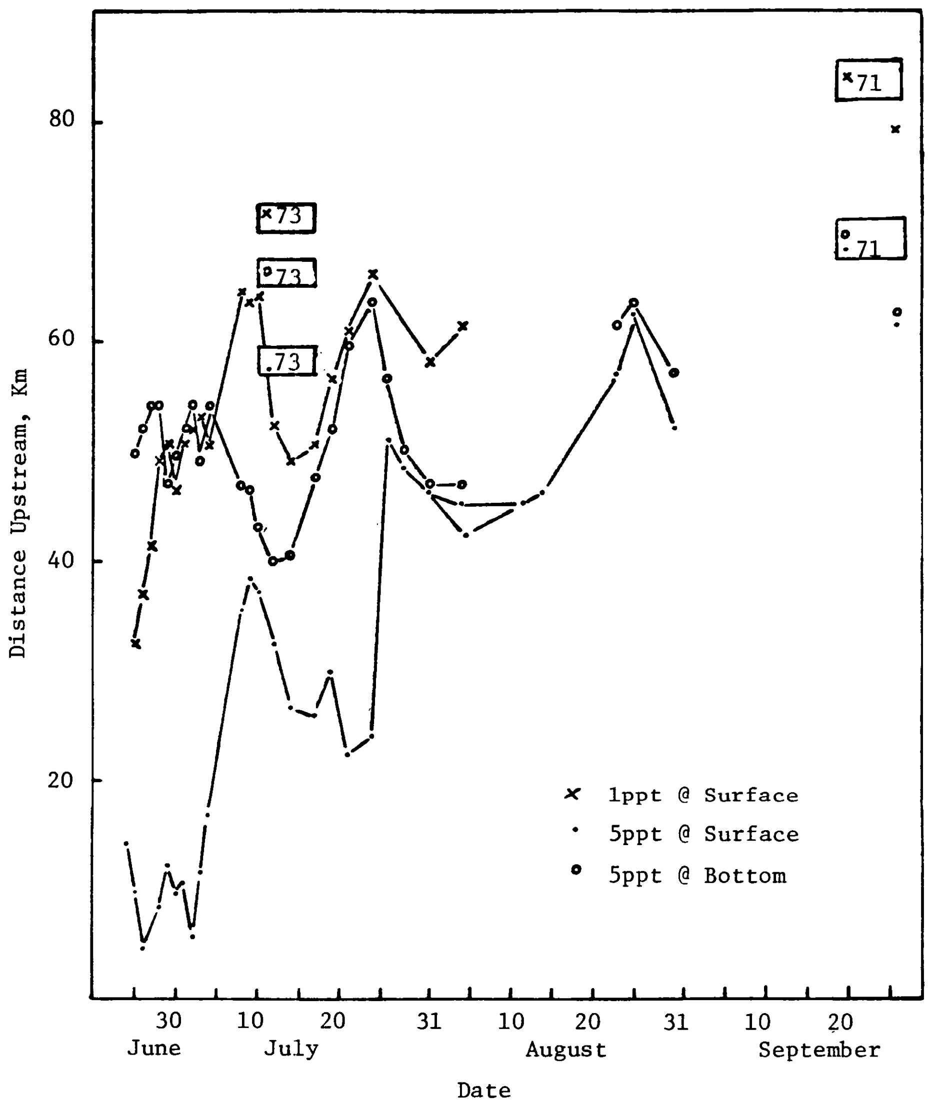

Figure 6. Saline intrusion in the Rappahannock River as a function of time.

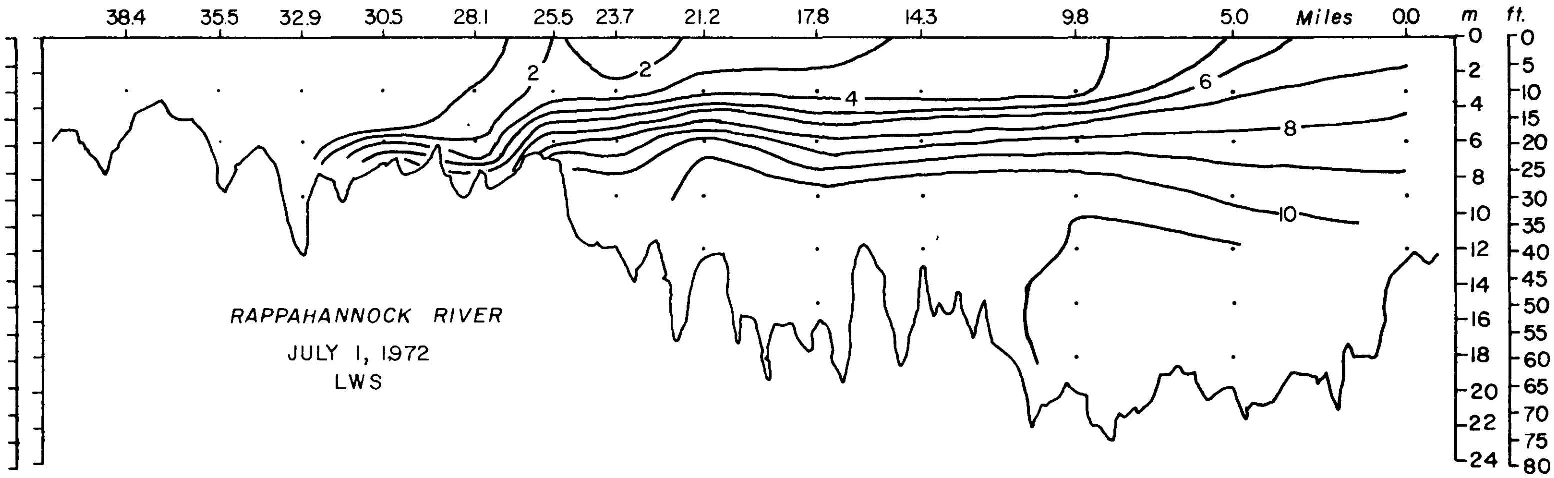

Figure 7. Salinity at low slack water, Rappahannock River, on July 1, 1972.

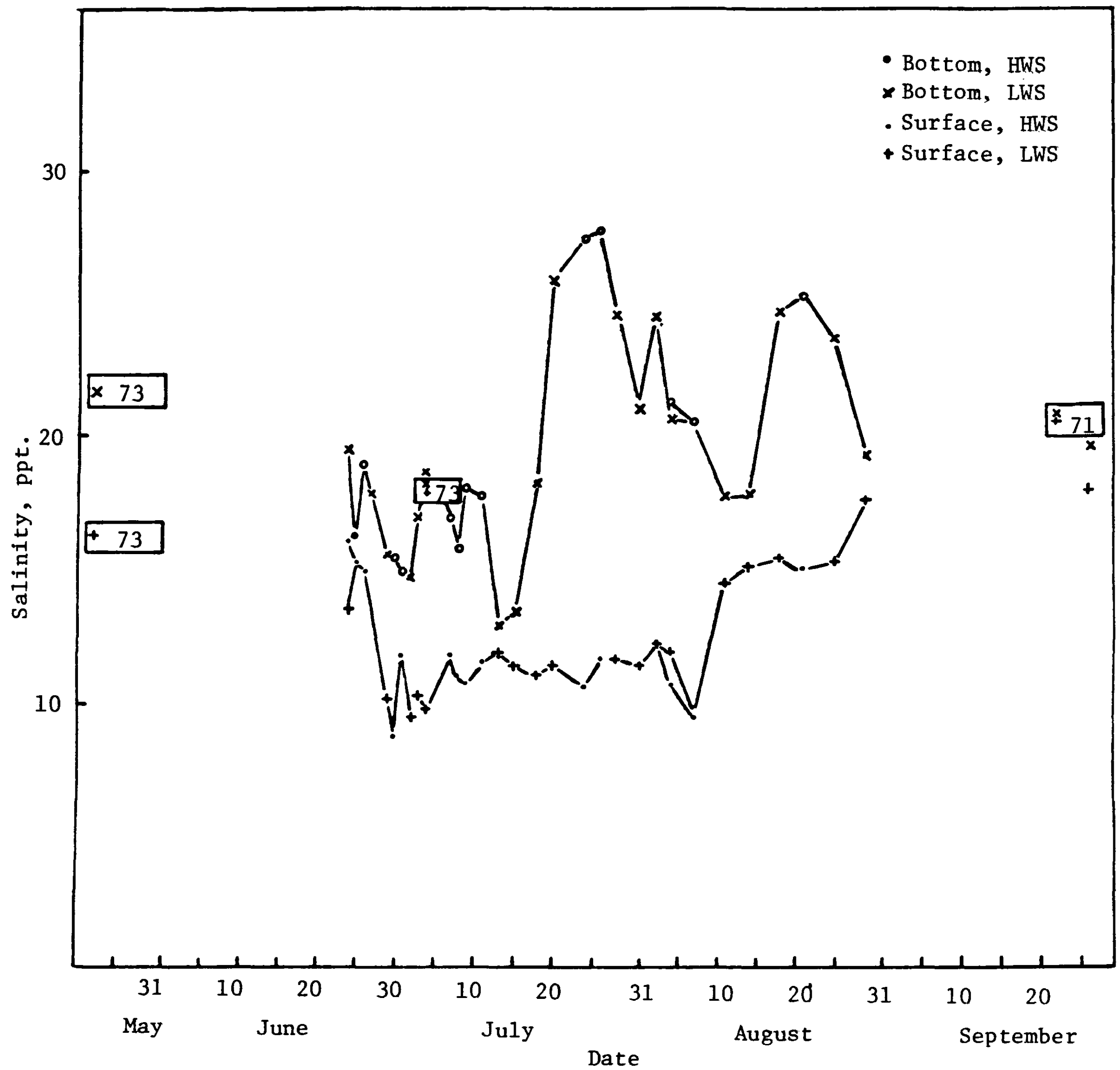

Figure 8. Surface and bottom salinity at the York River mouth as a function of time.

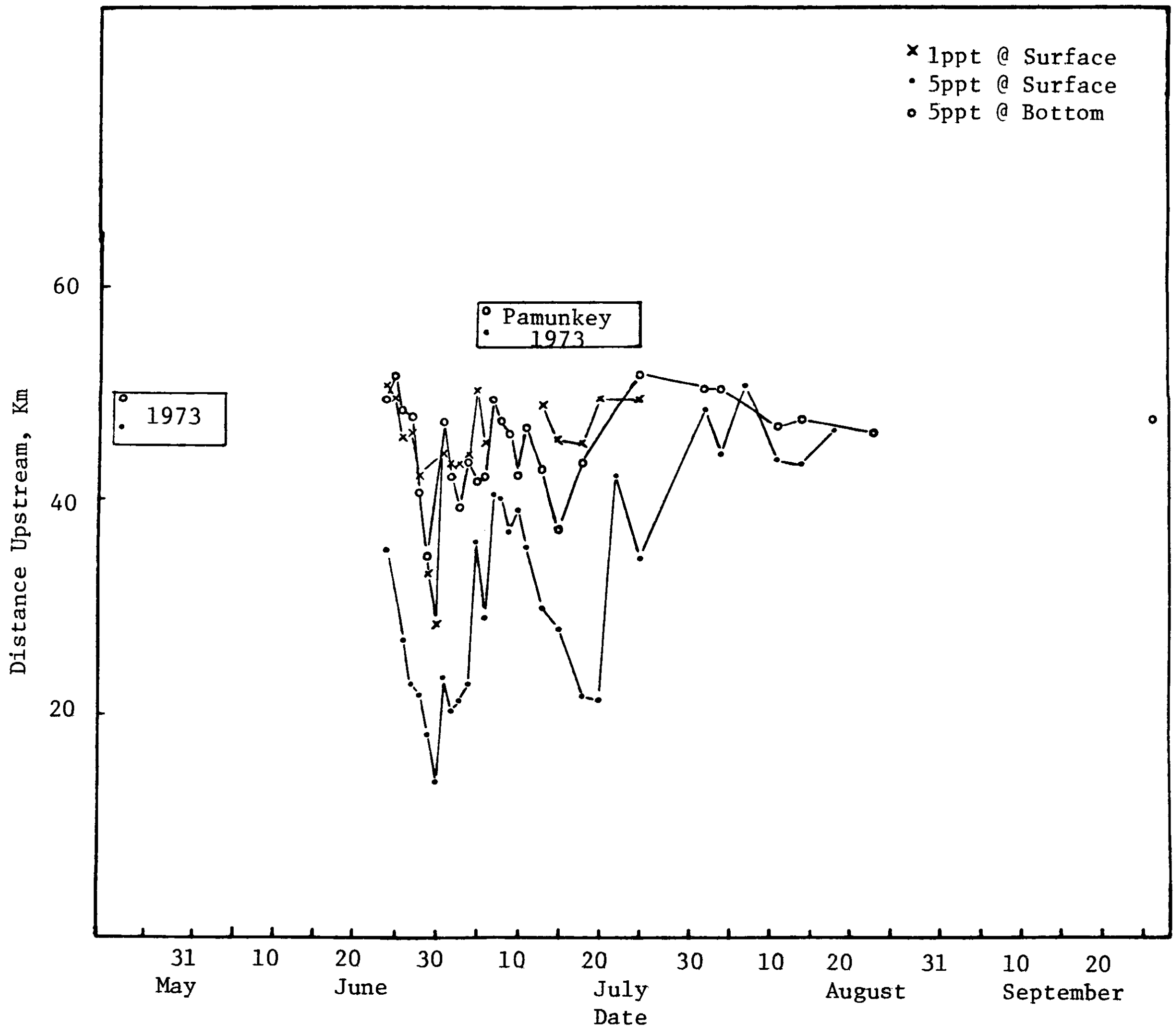

Figure 9. Saline intrusion in the York River as a function of time.

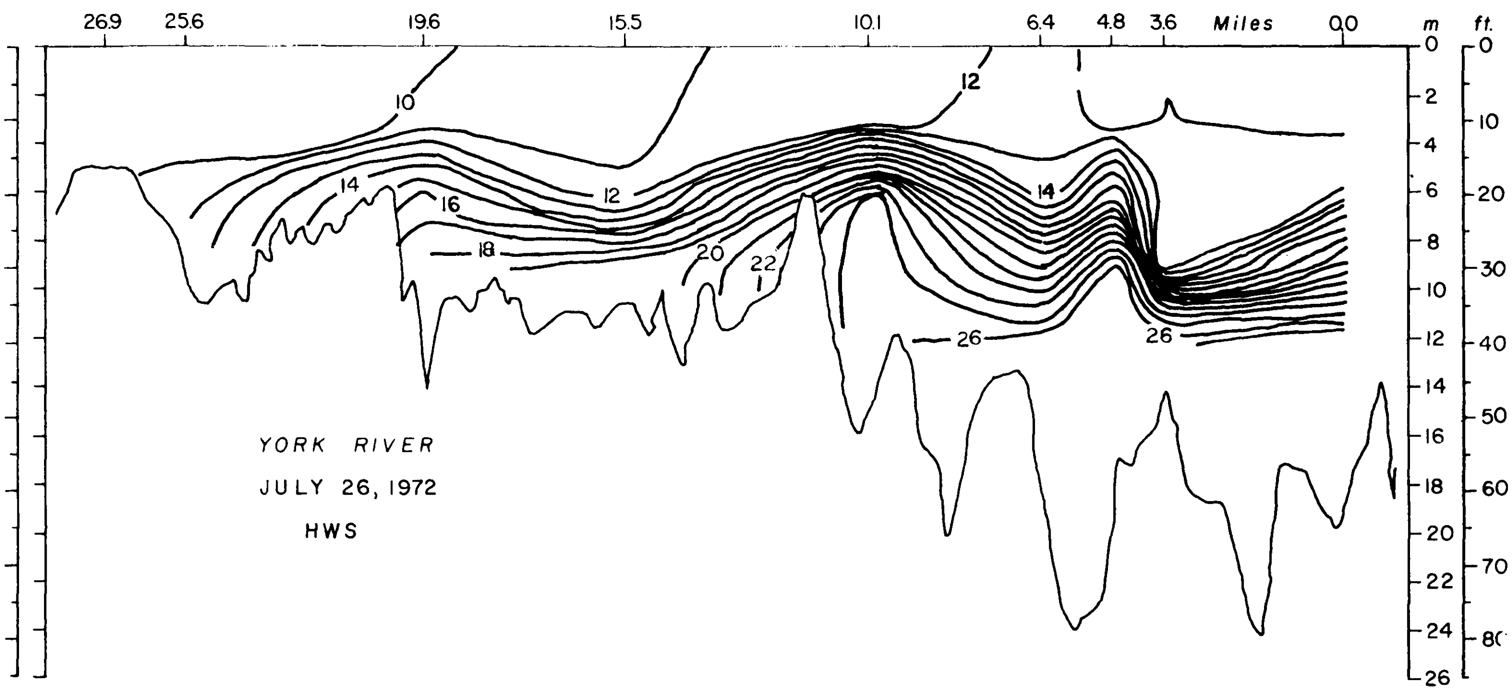

Figure 10. Salinity at high water slack, York River, July 26, 1972.

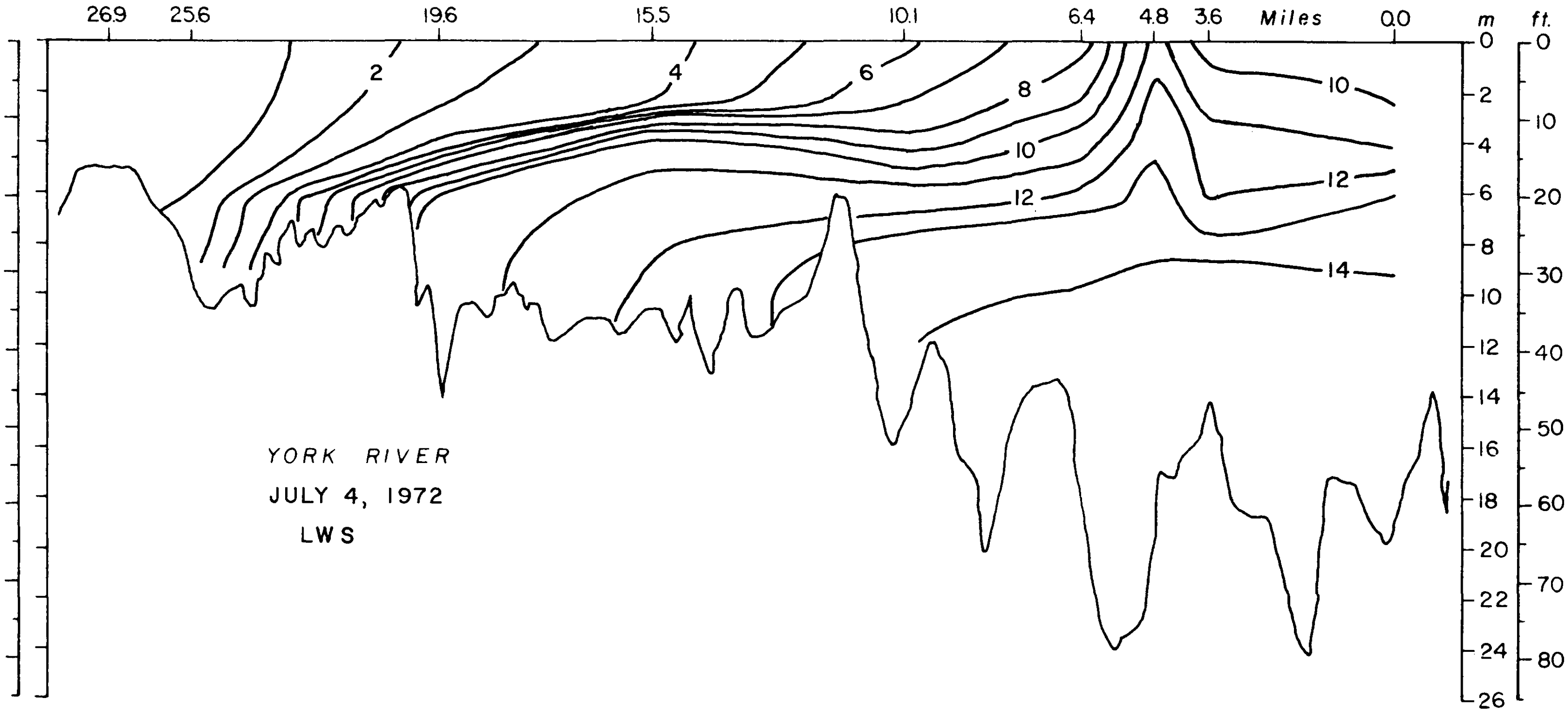

Figure 11. Salinity at low water slack, York River, July 4, 1972.