1-1-1973

Effects of Hurricane Agnes on the Environment and Organisms of Chesapeake Bay: Early Findings and Recommendations

Aven M. Andersen
Chesapeake Biological Laboratory, University of Maryland

W. Jackson Davis
Virginia Institute of Marine Science

Maurice P. Lynch
Virginia Institute of Marine Science

J. R. Schubel
Chesapeake Bay Institute, Johns Hopkins University

Recommended Citation

Andersen, A. M., Davis, W. J., Lynch, M. P., & Schubel, J. R. (1973) Effects of Hurricane Agnes on the Environment and Organisms of Chesapeake Bay: Early Findings and Recommendations. Special Reports in Applied Marine Science and Ocean Engineering (SRAMSOE) No. 29. Virginia Institute of Marine Science, College of William and Mary. https://doi.org/10.21220/V5M44V

THE EFFECTS OF HURRICANE AGNES ON THE ENVIRONMENT AND ORGANISMS OF CHESAPEAKE BAY

Early Findings and Recommendations

A REPORT TO THE PHILADELPHIA DISTRICT

U.S. ARMY CORPS OF ENGINEERS

PREPARED BY THE CHESAPEAKE BAY RESEARCH COUNCIL

CHESAPEAKE BAY INSTITUTE, THE JOHNS HOPKINS UNIVERSITY
CHESAPEAKE BIOLOGICAL LABORATORY, THE UNIVERSITY OF MARYLAND
VIRGINIA INSTITUTE OF MARINE SCIENCE

January 1973

EFFECTS OF HURRICANE AGNES ON THE ENVIRONMENT AND ORGANISMS OF CHESAPEAKE BAY

Early Findings and Recommendations

A report for the U.S. Army Corps of Engineers, Philadelphia District

Contract DACW 61-73-C-9348

THE CHESAPEAKE BAY RESEARCH COUNCIL

Chesapeake Bay Institute, The Johns Hopkins University
Chesapeake Biological Laboratory, Natural Resources Institute, University of Maryland
Virginia Institute of Marine Sciences

Compiled and Edited by

Aven M. Andersen (C.B.L.), Coordinator
W. Jackson Davis (V.I.M.S.)
Maurice P. Lynch (V.I.M.S.)
J. R. Schubel (C.B.I.)

JANUARY 1973

C.B.I. Contribution Number 187
N.R.I. Contribution Number 529
V.I.M.S. Special Report in Marine Science and Ocean Engineering, Number 29

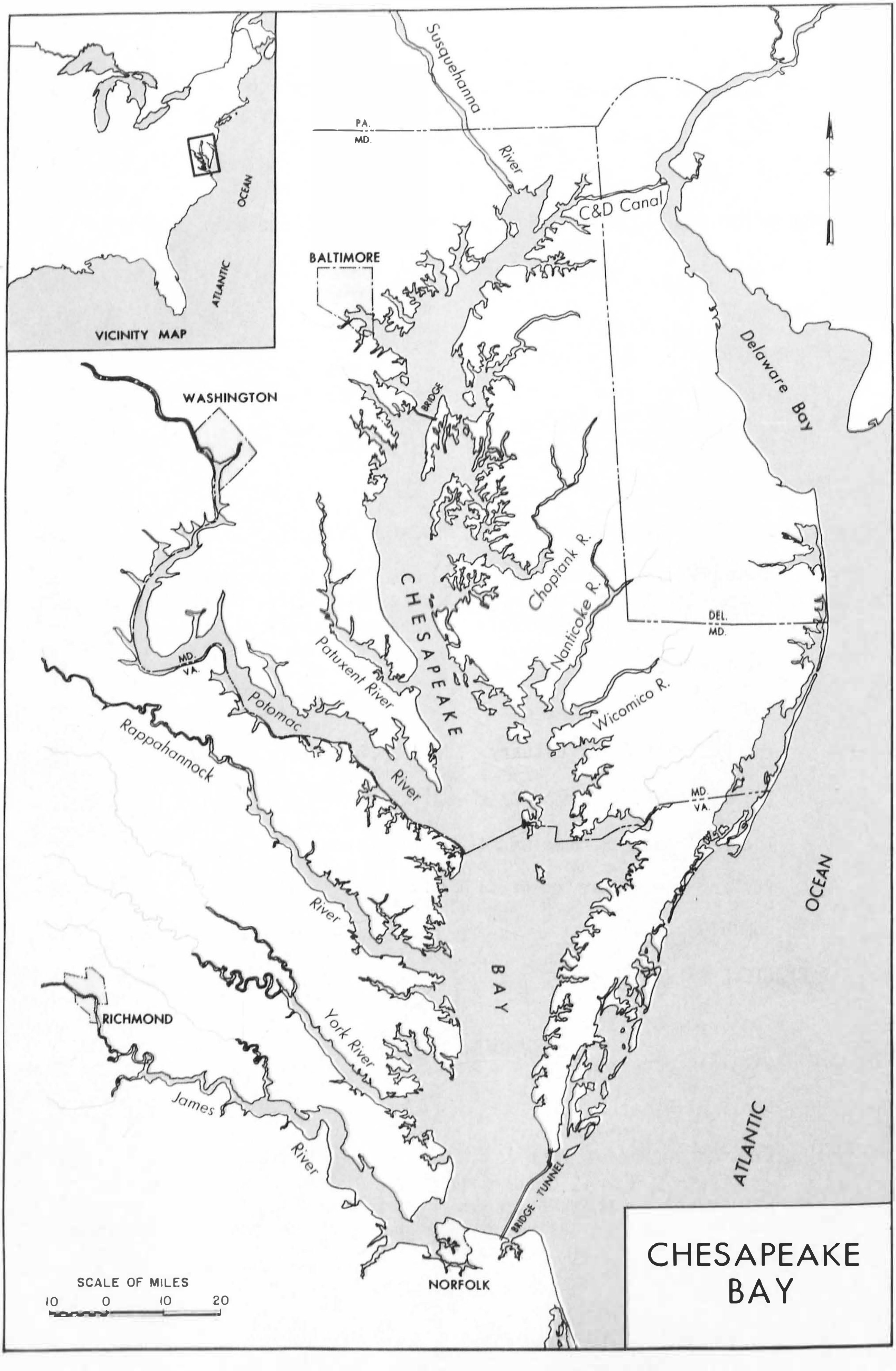

VICINITY MAP
ATLANTIC
OCEAN
Susquehanna
River
PA.
MD.
C&D Canal
BALTIMORE
WASHINGTON
BRIDGE
Delaware Bay
CHESAPEAKE
Choptank R.
Nanticoke R.
DEL.
MD.
Patuxent River
MD.
VA.
Potomac
River
Wicomico R.
Rappahannock
River
MD.
VA.
BAY
OCEAN
York River
RICHMOND
James
River
ATLANTIC
BRIDGE - TUNNEL
NORFOLK
SCALE OF MILES
10 0 10 20
CHESAPEAKE BAY

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

PREFACE

Some exceptional natural events occur without warning and some, thanks to recent scientific progress, are accurately predicted. "Agnes" of 1972 was partially forecast but developed surprising features. It was at various times a Tropical Disturbance, a Tropical Depression, a Tropical Storm, a Hurricane, and an Extratropical Storm. The massive downpour it yielded during 19-23 June, especially on 21 and 22 June, surprised and troubled most people in the Chesapeake Bay watershed where it fell.

Scientists who have observed the great estuarine system that receives the fresh water from this watershed have studied the environment and biota of the Bay with increasing competence. They have learned much about the dynamic natural patterns of salinity, temperature, sediments, nutrient chemicals, and of the even more complex patterns of response to this environmental change by large populations of animals and plants.

As the Agnes rains fell, such scientists (as well as engineers and hundreds of others concerned with the welfare of the public) became aware that a highly extraordinary event was occurring. By simple coincidence, the members of the Chesapeake Bay Research Council were together at a Chesapeake Bay Citizens' Conference in Fredericksburg, Va., where the meeting room was flooded by the heavy rains. These three scientists, directing the largest research laboratories on the Bay, almost immediately initiated surveys and special research designed to comprehend the effects of a rare and large-scale natural event and, especially, to assist in measuring and ameliorating the damages to human interests in the Bay and its tributaries. The Council, informal in structure, has served effectively in several major programs requiring coordination and complementary action.

The Virginia Institute of Marine Science mounted a wide variety of physical, chemical, and biological studies in the southern half of the Bay and on the Continental Shelf. The Chesapeake Bay Institute rescheduled boat time and expertise to observe some of the physical and chemical changes in the Bay and the sediment input from the Susquehanna River. The Chesapeake Biological Laboratory began extensive observations of effects on shellfish and other organisms in the northern half of the Bay and its tributaries. It is appropriate to note that most of these urgent projects were begun without assurance that financial support would be provided. The opportunity and emergency existed, and had to be met. Administrative and even fiscal arrangements would, hopefully, be straightened out later. The Council began to assist in effective coordination among its members and with the many other groups obtaining data, and certain specific joint plans were developed.

The Corps of Engineers also made immediate response. Aside from its truly heroic work to protect life and minimize property damage along the Susquehanna and other tributaries, it supported attention to the partially invisible but profound alterations of the nation's greatest estuary. Telephone calls by the Corps to the Council assured modest but immediate financial support for field studies of hydrographic changes and damage to the rich shellfish beds and other valuable fisheries. Additional vigorous efforts have been made by the Baltimore District, the Philadelphia District, the North Atlantic Division, and the Office of the Chief of Engineers to assure accurate assessment of damage and assist recovery in the Bay region.

One of the specific elements of the Corps' program is this early summary. The District Engineers of the Philadelphia District contracted with the Council, through the University of Maryland as Coordinator, to provide the best possible estimates of all known effects. We have done so, with generous and valuable assistance from a large number of private, state, and federal groups who also observed and recorded with care. These contributors are specifically identified in the Acknowledgements section of this report. We hope that they find value in this report to repay their efforts.

Many sources of support in addition to the Corps have helped to make this summary possible. The Chesapeake Bay Institute and Chesapeake Biological Laboratory are receiving partial funding from the State of Maryland and the National Science Foundation. The Virginia Institute of Marine Science has been helped by the National Oceanic and Atmospheric Agency and the Food and Drug Administration. The timely response of these agencies to this emergency is greatly appreciated.

We wish to express our commendation to Dr. Aven Andersen, CBL; Dr. Jackson Davis and Dr. Maurice Lynch, VIMS; and Dr. Jerry Schubel, CBI for completing the task of extracting a report from dozens of sources. They have effectively persuaded and coerced many associates inside and outside of the Council, and then blended the parts into an organized, responsible report. It is fair to note that much of this work was accomplished prior to the conclusion of administrative arrangements assuring financial support. These scientists, too, answered the need and arranged the details later. We appreciate their efforts and ability.

Finally, we would emphasize that this is indeed an early summary. Some studies will be continued for a year or more, and many interpretations must be deferred for various reasons. We believe that these early estimates will be verified, and we know that valuable additional comprehension of the coastal estuaries of the nation will emerge from these and other studies of Hurricane Agnes. This new knowledge will partially offset the enormous cost of the storm in property damage and human misery.

Chesapeake Bay Research Council

L. Eugene Cronin, CBL, Chairman
William J. Hargis, Jr., VIMS
Donald W. Pritchard, CBI

SUMMARY

1. Hurricane Agnes, the costliest hurricane in the nation's history, entered Chesapeake Bay on 21 June 1972, bringing record rainfalls and destructive floods to most of the Bay's drainage basins, although since the rains fell mostly to the west and north of the Bay, the rivers on the eastern shore (Delmarva Peninsula) were only moderately affected. The Susquehanna River, for example, discharged a peak flow of 1,130 cfs, the greatest instantaneous flow recorded in the 185 years that records have been kept.

2. The salinity of the Bay, already low because of an unusually wet winter and spring, was depressed to record lows by the massive input of freshwater. The 1‰ isohaline was displaced downbay to the mouth of the Little Choptank River two days after the Susquehanna crested. In the Potomac River the surface salinity remained less than 5‰ throughout July all the way to the mouth.

3. Waters in all the major estuaries responded similarly to the flood: a) estuarine waters were displaced downstream, b) compensating upstream flows of more-saline waters along the bottom produced strong vertical salinity stratifications, c) the waters mixed vertically, d) the vertical salinity gradients moderated, and e) the salinity patterns returned toward normal.

4. The estuaries on the eastern shore were only moderately flooded. They acted, therefore, as reservoirs of salt water and helped the Bay's salinity return toward normal faster than it would have if they had also been flushed out.

5. The floods dumped record amounts of sediment into Chesapeake Bay. The Susquehanna River, for example, discharged more sediment between 22

and 28 June 1972 than the total mass of sediment it had discharged during the past 10 years, and perhaps during the past 50 years. Sediment levels in the upper bay remained abnormally high until late July.

6. The important geological effect of Hurricane Agnes on the Bay was not erosion but the deposition of sediments. If the Agnes sediments remain as a distinct layer they will aid us in understanding the Bay's past and in predicting its future.

7. The Agnes floods washed tons of raw and partially treated sewage into the Bay. As a result, the levels of bacteria in Bay water rose sharply, as did the levels of nutrients.

8. The high levels of bacteria caused parts of the Bay to be closed to water-contact sports and shellfish harvesting.

9. The effect of Hurricane Agnes on heavy metals and pesticides in the Bay is unclear at this time. Many samples were collected but only a few have been analyzed. In the Rappahannock River the levels of total noncrystallinic copper were greatly elevated after Agnes; the levels of noncrystallinic zinc, however, remained normal. Agnes apparently had no effect on the levels of chlorinated hydrocarbons in the lower bay.

10. The flood waters flushed much of the plankton out of the upper bay, and from the upper parts of the estuaries of the major rivers. Although many plankton samples were collected, many remain to be analyzed and interpretation of the results is difficult because of the paucity of background data.

11. The influx of nutrients stimulated phytoplankton blooms, including "mahogany tides."

12. The low salinities brought on by Hurricane Agnes killed many of the Bay's oysters. Potomac River oysters suffered the greatest losses, with more than half of the marketable oysters dying. High mortalities also occurred to

oysters living on beds north of the Chesapeake Bay Bridge and in the upper ends of the estuaries of the major rivers. Oysters living farther down the Bay or farther down the rivers survived better. In the James River losses amounted to 5 or 10%. Losses were even less in the York River, about 2%. The economic loss to Maryland and Virginia for 1972 comes to about $12 million on an exvessel basis.

13. Oyster reproduction apparently failed in 1972. Low salinities prevented spawning, or killed the larvae, or did both. As of 1 October there had been an almost complete absence of set in Maryland or Virginia.

14. Many oyster drills, serious predators of oysters, were killed, but a predatory flatworm survived. If oyster seed were available, new areas could be put into oyster production.

15. Low salinity killed most of the Bay's adult soft-shell clams. A few adults and some seed survived, but the fishery for 1972 became a complete disaster, resulting in a loss of $4 million, exvessel price.

16. Losses of hard clams in Virginia were high, but a total economic loss has not yet been estimated.

17. Blue crabs apparently sustained little damage. Most juvenile and adult crabs avoided the unfavorable water, although a few died from low levels of dissolved oxygen, sediment, or red tide toxins. Results of early surveys indicate that crabs reproduced successfully in 1972, but a full evaluation of crab reproduction will not be ready until the spring of 1973.

18. With the exceptions of their eggs and larvae, finfish apparently suffered little damage. Most moved downbay and off the shoals. A tremendous number of eggs and larvae were swept out of the nursery grounds; their fate might never be known.

19. Most of the troublesome medusae and many of the polyps of the stinging sea nettles were destroyed by the low salinities. Some of the resistant cysts, however, survived. Although Agnes made the sea nettles disappear for 1972, they can return next year.

20. Low salinities drastically reduced or displaced a number of sponges and tunicates but caused other fouling organisms, including rope grass, sea anemones, and bryozoans, to thrive.

21. Hurricane Agnes temporarily disrupted recreational uses of Chesapeake Bay. Water-contact activities and shellfish harvesting were prohibited in parts of the Bay because of sewage pollution. Boating was seriously hindered by the floating debris. Sport fishing declined because the fish were displaced from their normal habitats.

22. Wildlife on the Bay was little affected by the storm. Some waterfowl were displaced because some shallow-water vegetation in the upper Bay was destroyed. On the other hand, some new islands formed by the flood may provide new areas for wildlife.

23. The Hurricane and floods apparently caused no damage to historical sites and artifacts on the tidewater areas of Chesapeake Bay.

RECOMMENDATIONS

Hurricane Agnes presented scientists with an unprecedented opportunity to document the effect of a catastrophic flood on the environment and organisms in a complex estuarine system. Adequate analysis of the conditions existing before, during, and after the flood would provide us with many new insights into the nature of the estuary and would aid us in predicting the effects of future events, natural or man-made and in minimizing the damage to human interests.

It is not possible to recapture all of the desirable data about the effects of the storm sequence on the Bay system, but there are several specific opportunities for enhancing the value of the considerable number of studies reported in this early summary. We recommend that the following program, as well as other pertinent special studies, be completed:

1. Complete the analysis of the samples collected during and after the storm; make the data available in a readily accessible and usable form.

2. Quantify the repopulation or reinvasion of the species that were affected by Hurricane Agnes, especially the American oyster and the soft-shell clam.

3. Conduct an excellent analysis of the hydrography of Chesapeake Bay until, at least, 1 July 1973, the anniversary of the hurricane.

4. Conduct, at least until 1 July 1973, a sufficient analysis of the changes in the sediments of Chesapeake Bay.

5. Undertake and quantitatively evaluate any remedial measures that are practical to rehabilitate the fisheries decimated by the storm, especially those in the estuary of the Potomac River.

6. Examine the long-range programs for Chesapeake Bay. Modify these programs on the basis of the new knowledge contained in this report.

For example, much of the interpretation of the effects of Agnes on the biota of the Bay has been hampered by the absence of good baseline data. Undertake the essential long-term studies to provide baseline data on the dynamics of animal populations.

Catastrophic changes are important to the environment and organisms of estuarine systems like the Chesapeake Bay and to man. Studies of the unique Agnes storm should provide many new insights and practical benefits. Continued effort and support from all levels is clearly justified.

ACKNOWLEDGMENTS

Information contained in this report comes from a number of agencies and individuals. The compilers thank them all.

Chesapeake Bay Institute

The field work conducted by the Chesapeake Bay Institute for this report was supported in part by the Oceanography Section, National Science Foundation, N.S.F. Grant GA-36091; in part by a project jointly funded by the Maryland Department of Natural Resources and the U. S. Bureau of Sport Fisheries and Wildlife with Dingell-Johnson Funds, Project F-21-2; and in part by the U.S. Army Corps of Engineers (Baltimore and Philadelphia Districts).

Coordinating the C.B.I. efforts was J. R. Schubel. Other individuals who contributed assistance, information, and evaluations are:

W. B. Cronin: Temperature, salinity, and data reduction

T. W. Kana: Temperature, salinity, and suspended sediments

C. H. Morrow: Temperature, salinity, and suspended sediments

M. Glendening: Suspended sediments, nutrients, and dissolved oxygen

C. F. Zabawa: Suspended sediments, nutrients, and dissolved oxygen

L. Smith: Suspended sediments

V. Grant: Nutrients

I. Hopkins: Nutrients

Chesapeake Biological Laboratory

Contributions from the Chesapeake Biological Laboratory were supported by the Army Corps of Engineers (Baltimore and Philadelphia Districts), Columbia Liquid National Gas Corporation, Maryland Department of Natural Resources and the National Marine Fisheries Service (PL 88-309, PL 89-720). A. M. Andersen, assisted by M. D. Bilger, K-Y. Chang, J. J. Grasela, and C. D. Keefe,

coordinated the C.B.L. input. C.B.L. staff members who contributed information are:

D. G. Cargo: Seanettles

C. J. Kucera: Bacteria

E. A. Dunnington: Oysters

D. H. Hamilton: Benthos

C. E. Lewis: Hydrography

R. E. Miller: Blue crabs

H. T. Pfitzenmeyer: Soft-shell clams

D. E. Ritchie: Salinity

S. D. Sulkin: Blue crabs

Virginia Institute of Marine Sciences

The field work conducted by the Virginia Institute of Marine Sciences has been a coordinated effort involving essentially all departments and most of the professional staff at VIMS. Specific support for Agnes work was provided by the Army Corps of Engineers (Baltimore and Philadelphia Districts), Environmental Protection Agency, Food and Drug Administration, National Marine Fisheries Service (PL 88-309, PL 89-720), National Oceanic and Atmospheric Administration, and the National Science Foundation.

Coordinating the Agnes project at VIMS were W. J. Davis and M. P. Lynch. Individuals who provided evaluations of data are:

E. P. Ruzecki: Hydrographic summaries

D. Haven: Oyster damages

J. A. Loesch and D. Haven: Hard clam damages

W. A. Van Engel: Crustacean evaluation

W. Hogman: Finfish assessment

J. D. Andrews: Oyster predator and fouling organism assessments

A. Ott, J. L. Wood and M. Rhodes: Bacteriological summary

M. N. Nichols: Sedimentation summary

W. G. MacIntyre and C. L. Smith: Turbidities and nutrient flux in the southern Bay

P. L. Zubkoff and J. E. Warinner: Primary productivity and heterotrophy potentials

G. C. Grant: Zooplankton assessment

R. J. Huggett: Hazardous material assessment

R. K. Dias: Economic assessment

D. Haven and R. Morales-Alamo: Stinging nettle assessment

J. Douglas, Commissioner, Virginia Marine Resources Commission: Rehabilitation

Appendix V lists the cooperating agencies that furnished VIMS with logistic support.

Other State Agencies

Several other state agencies contributed data for this report.

The Virginia Department of Health and the Maryland Department of Health and Mental Hygiene, concerned with health aspects from pollution and possible high bacterial levels, began intensive sampling efforts, and the Maryland Department of Natural Resources increased its fishery sampling. Mr. Frank L. Hamons, Jr. (MDNR) provided much of the information on soft-shell clams. The Virginia Marine Resources Commission provided facilities and equipment.

Federal Agencies

Several federal agencies and departments, namely the National Marine Fisheries Service (Biological Laboratories in Oxford, Maryland; Sandy Hook, New Jersey; and Woods Hole, Massachusetts), NASA, the Coast Guard, and the U. S. Navy agreed to collect samples and make observations in the Bay and around the Bay mouth. Mr. David B. Townsend of the NMFS Laboratory at Oxford provided information on soft-shell clams. The Environmental Data Service, of course, provided the meteorological observations, and the Geological Survey provided the hydrological data. Facilities, including manned vessels, aircraft, and instruments, were provided by the National Oceanic and Atmospheric Administration, the Navy, the Coast Guard, the Army Transportation Corps, the Corps of Engineers, the National Aeronautics and Space Advinistration, and the U.S. Geological Survey (Division of Water Resources). NASA and the Navy agreed to provide remote sensing from high flying aircraft and satellites. The Annapolis Field Office of EPA provided summaries of data on water quality.

Other Sources

Mr. William D. Clarke of the Westinghouse Electric Corporation's Ocean Research Laboratory at Annapolis provided information on soft-shell clams.

Mr. Crosby Forrest of Poquoson, Virginia provided samples of oysters for pesticide analyses.

Mr. Peter H. Smith of the National Trust for Historical Preservation furnished information concerning damage to historical artifacts.

The Virginia Pilots' Association provided use of its pilot vessel as a sampling station.

1. INTRODUCTION

1.1 A Brief History of Hurricane Agnes[1]

Hurricane Agnes, the costliest hurricane in the nation's history, entered Chesapeake Bay on 21 June 1972; months later its effects are still evident. Agnes killed 122 Americans and destroyed an estimated $3.5 billion worth of property. Reduced to a tropical storm when it reached Chesapeake Bay, its winds did little damage (gusts reached 32 miles per hour (mph) at Richmond, Va., 49 mph at Dulles International Airport, Va., and 39 mph at Baltimore, Md.). Not so its rainfall. Flood damage is estimated at $222 million for Virginia and $110 million for Maryland and the District of Columbia. For Chesapeake Bay proper, the disastrous effects of Agnes came entirely from the flooding of the Bay with fresh water, debris, sediments, and sewage.

The massive amounts of fresh water released into the drainage basins of Chesapeake Bay caused record flood levels in most of the Bay's rivers and streams, especially the James, Rappahannock, Potomac, Patuxent, and Susquehanna Rivers. Virginia's James River crested at 36.51 feet on 23 June; a comparable level was recorded only once before--in 1771. The Susquehanna River at Conowingo, Maryland, crested at 36.83 feet on 24 June with a flow of 1,130,000 cubic feet per second--the greatest height and instantaneous flow ever recorded for the Susquehanna in the 185 years that records have been kept. Not only was the rainfall causing these conditions unusually heavy, but the heavy rains persisted for several days.

Agnes began as a depression near Cozumel off the Yucatan Coast on 15 June 1972 (Figure 1.1). By 16 June, the system intensified to a tropical storm with unusually large circulation which, by 17 June, began moving northward.

---

[1] Much of this section is based on a 1972 report by Richard M. DeAngelis and William T. Hodge for the National Oceanic and Atmospheric Administration.

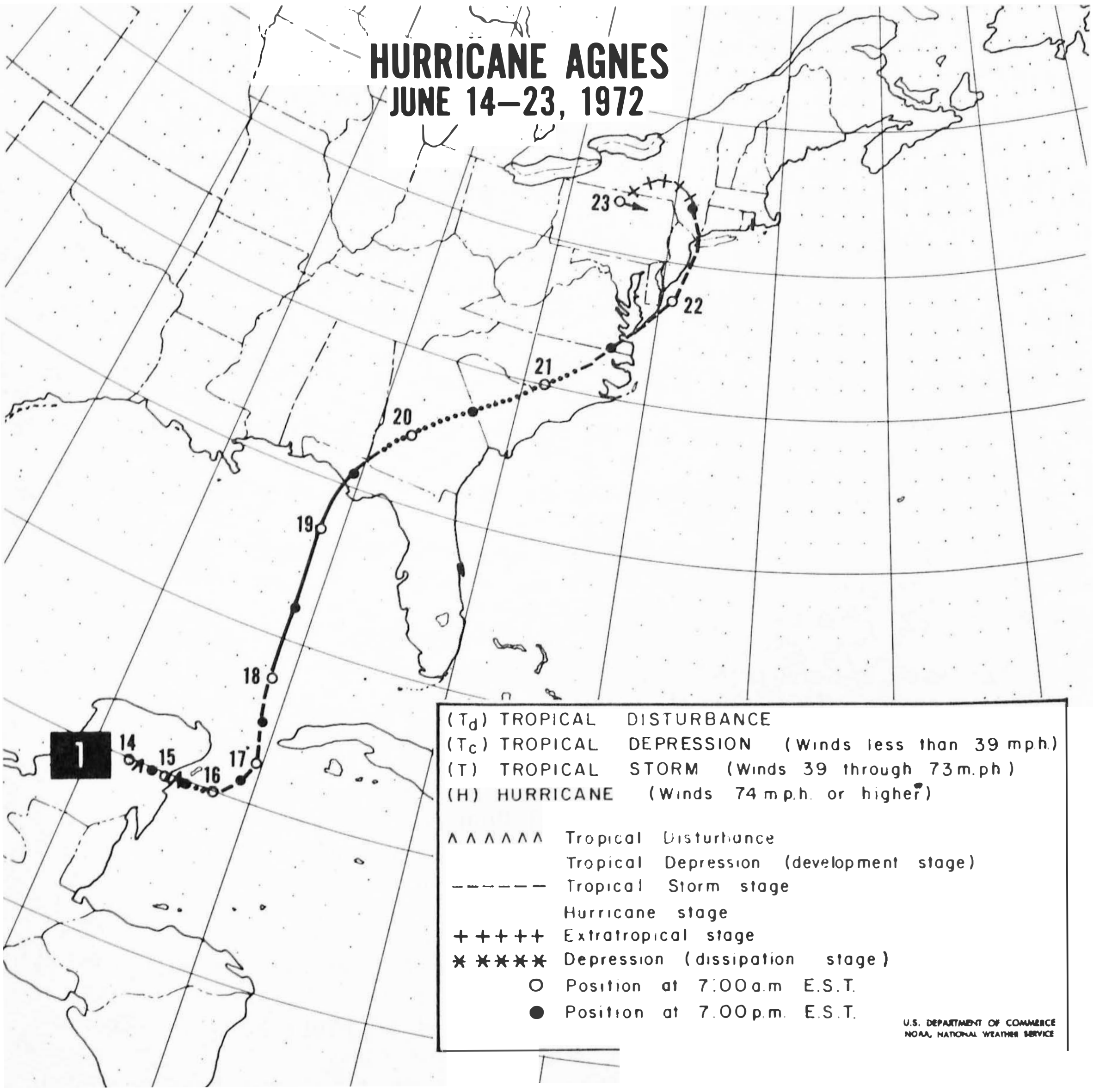


Figure 1.1. Track of the center of Hurricane Agnes. Rains and winds extended out from the storm center over long disantances. From DeAngelis and Hodge, 1972.

By 18 June, hurricane-force winds developed. Agnes moved ashore across the Florida panhandle on 19 June as a tropical storm. By 20 June, the storm had weakened to a depression and continued moving northward across Georgia into South Carolina. As the system moved northeastward across the Carolinas on the 21st and approached closer to the Atlantic Coast it intensified,and by the evening of 21 June,as it reached Virginia, it was a rejuvenated tropical storm. On 22 June, the storm moved off the Virginia Capes, up the east coast, across the western Long Island, and inland near New York City. By late evening of 22 June, the system entered its extratropical stage and on 23 June moved further inland and swung southwestward bringing more heavy rain into Pennsylvania. By 25 June, the system had looped to the east-north east and moved into Canada.

1.2 Rainfall[2]

During the week preceeding Agnes, frontal activity brought soaking rain to the region from Virginia to New England. Totals over Maryland and Eastern Virginia ranged from 0.5 to 2 inches although local amounts were reported in excess of 4 inches in Virginia and 6 inches in Maryland. Two to three inch rainfalls were common in Central Pennsylvania while through the rest of the state and over central New York, averages were near three inches. Then Agnes brought her deluge (Figure 1.2)

In Virginia, showers on the 17 and 18 June dumped up to three inches of rain over upper and central James River sub-basins. The main Agnes rainshield reached southern Virginia by 20 June. Heaviest rainfall fell on 21 and early 22 June. Rains totaled 4 to 10 inches and quickly filled small tributaries in the upper James and central Virginia counties east of the Blue Ridge Mountains. The average for the James River drainage basin was 6.12 inches from 19-23 June. The heaviest rainfall during this 4-day period averaged 8 inches on the upper Appomattox.

---

[2]Based on DeAngelis and Hodge, 1972.

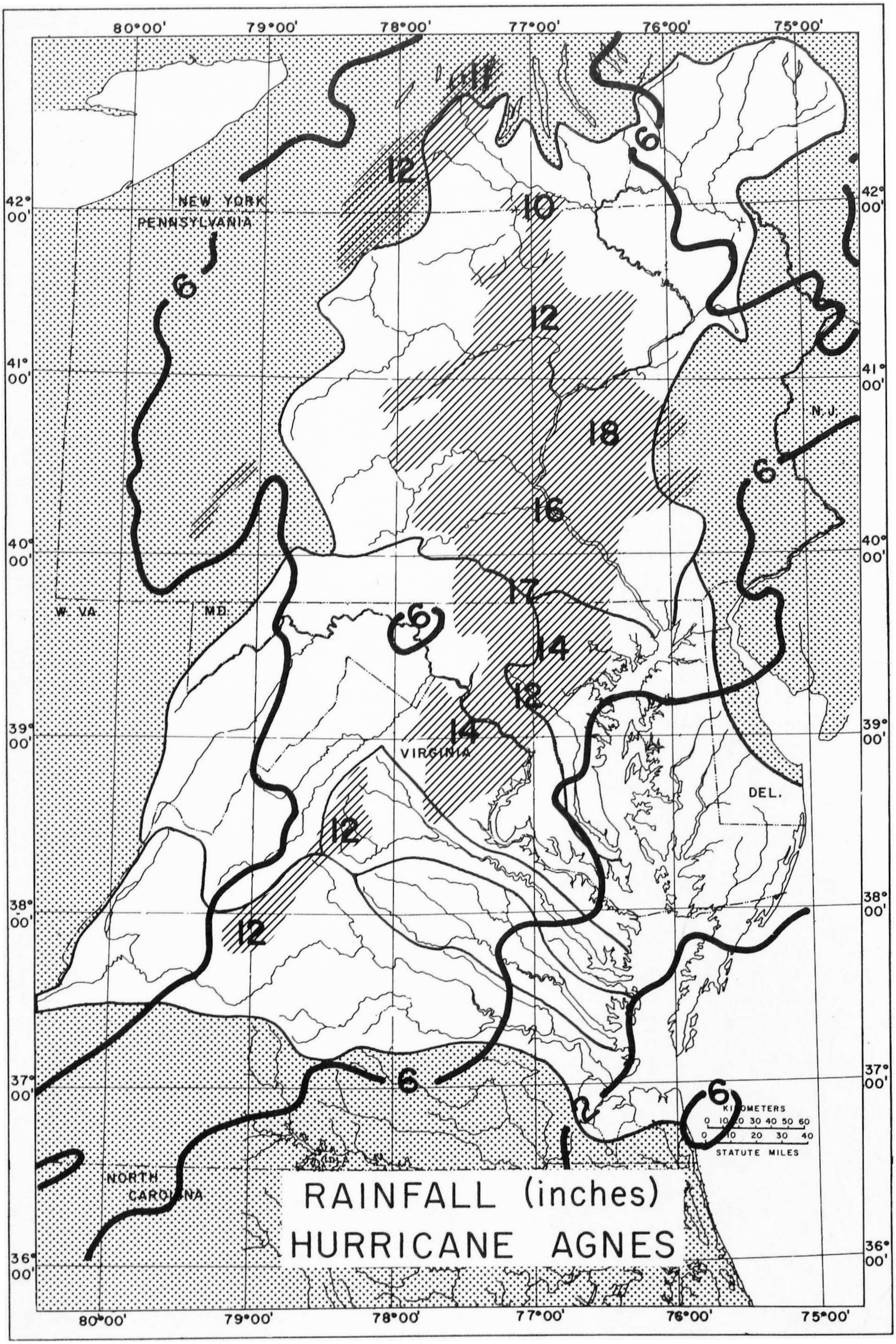


Figure 1.2. Total rainfall from Hurricane Agnes in the drainage basins of Chesapeake Bay (V.I.M.S.).

In Maryland, heavy rains in less than 24 hours, on 21 and 22 June, broke records. Maryland's heaviest rains fell in the north central part of the state where totals set all-time records. Westminster, in Carroll County, received the highest total of 14.68 inches. Woodstock, in Howard County, was second with 13.85 inches. Rainfalls of 11.55 inches at Westminster and 11.35 inches at Woodstock on 21 June are among the greatest one-day rainfalls in Maryland's history.

The District of Columbia (National Airport) reported rainfall totaling 7.19 inches for 21-22 June.

1.3 River Flows[3]

These heavy rains caused disastrous flash floodings and record or near-record discharges of the streams and rivers flowing into Chesapeake Bay. The Agnes flood-waters damaged or destroyed many stream gauging stations, therefor indirect methods and computations were employed at many stations to estimate the peak discharges that occurred. Nevertheless, it is clear that the flooding resulting from the passage of tropical storm Agnes was of record or near record proportions throughout the drainage basin of Chesapeake Bay. According to preliminary estimates by the Water Resources Division of the United States Geological Survey (U.S.G.S.) the peak discharges of many of the streams in the Chesapeake Bay drainage basin were of a magnitude that is likely to occur on the average only once in more than 100 years.

In Virginia, record flood waters reached the fall line in most of the major river basins (Table 1.1). The James crested at 36.5 feet at the Richmond City Locks on 23 June, topping the previous record high of 30.0 feet recorded in 1771. In the Appomattox, a 16-foot floodcrest at MS No. 1 bridge near the confluence with the James matched the 1940 record of 16 feet.

---

[3]Much of this section is based on a 1972 report by J.C. Kammerer, et al. for the U.S. Geological Survey.

Table 1.1. June 1972 flood peaks (in cubic feet per second) resulting from Hurricane Agnes in selected Virginia river basins.

Station	June 72[1]	June 70 mean[2]	Maximum recorded[2] (date)
<u>James River Basin</u>			
James River-Richmond	319,000	1,184	222,000 August 21, 1969[3]
Appomattox River-Matoaca	23,000	161	(no historical data)
Chickahominy River-Providence Forge	1,740	34.9	7,710 August 15, 1955
<u>York River Basin</u>			
Mattaponi River-Beulahville	17,000	125	12,300 August 23, 1969[3]
Pamunkey River-Hanover	28,000	223	40,300 August 23, 1969[3]
<u>Rappahannock River Basin</u>			
Rappahannock River-Fredericksburg	114,000	521	140,000 October 16, 1942

[1] Provided by Water Resources Division, Geological Survey, U.S. Dept. of Interior, 200 West Grace Street, Richmond, Virginia 23220

[2] From 1970 Water Resources Data for Virginia, U.S. Dept. of Interior, Geological Survey, Water Resources Division, 1971.

[3] Hurricane Camille floods.

Throughout the Virginia region, highest flows of record occurred at 40 stations and peak flows at some 25 stations have equalled or exceeded those of once in 100 year floods. In the James alone it was estimated that 134 times the normal amount of freshwater entered during the flood period.

Although the flood reached record heights in the James, its relative contribution on a percentage basis for the Chesapeake as a whole was only 13%, or 5% less than average (Figure 1.3).

The largest input from the storm, 64%, came from the Susquehanna, the river with the largest basin and the one receiving the heaviest rainfall. Many other rivers also reached record flows. Table 1.2 contains the peak recorded flows for selected rivers in Maryland and the District of Columbia, and for comparison includes the highest flows previously recorded for those rivers.

The preliminary reports of the Harrisburg (Pennsylvania) Office of the U.S.G.S. indicate record flooding of the Susquehanna River. This river is the long-term supplier of approximately 50% of the total fresh water input to the entire Chesapeake Bay estuarine system, and the source of more than 85% of the total fresh water input to the Bay above the mouth of the Potomac. The Susquehanna has a long-term average discharge of about 35,000 cubic feet per second (cfs) into the Chesapeake Bay. Its average annual flow pattern is typical of mid-latitude rivers--high flow in early spring produced by snow-melt and rain-fall, then tapering off during summer and early fall. The June 1972 monthly average discharge of the Susquehanna at Harrisburg of about 165,000 cfs was the highest average discharge of record for any month, and was more than 9 times the average June discharge over this same interval. The average daily discharge of the Susquehanna on 24 June 1972 of 918,000 cfs was the highest average daily flow ever recorded

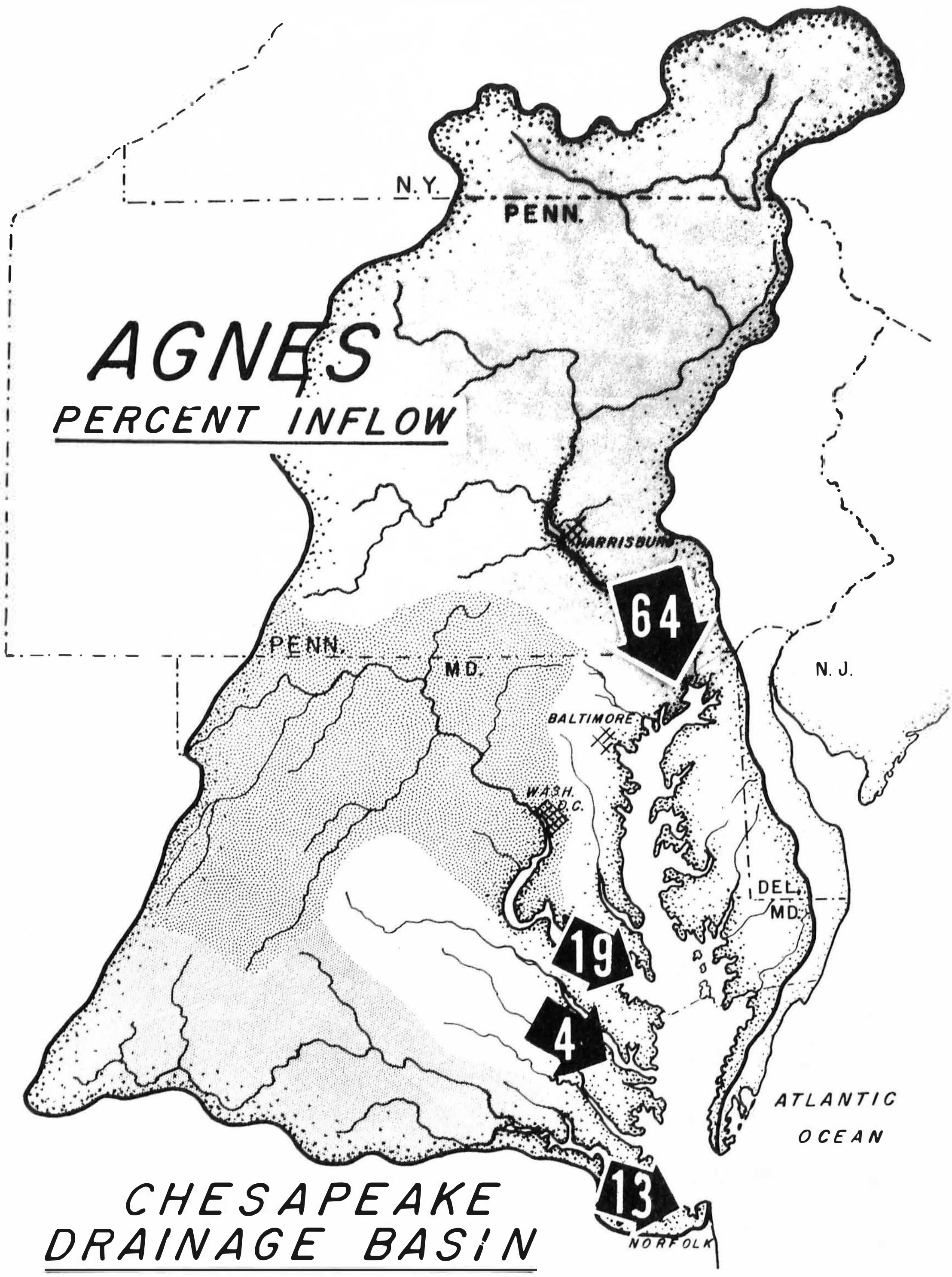


Figure 1.3. Percent of the total Agnes flood-water inflow into Chesapeake Bay for the major drainage basins (V.I.M.S.).

Table 1.2. June 1972 flood peaks (in cubic feet per second) resulting from Hurricane Agnes in selected rivers of Maryland and the District of Columbia.[a]

Station	Maximum during June 1972	Previous Maximum
Susquehanna River Basin		
Susquehann, at Conowingo, Md.	1,130,000	434,000 (1970)
Gunpowder River Basin		
Western Run, at Western Run, Md.	38,000	5,590 (1956)
Patapso River Basin		
Patapsco R., at Hollofield, Md.	80,600	19,000 (1956)
Patuxent River Basin		
Patuxent R., near Laurel, Md.	26,000	11,800 (1971)
Little Patuxent R., near Savage, Md.	35,400	6,280 (1952)
Potomac River Basin		
Monocacy R., near Frederick, Md.	82,400	56,000 (1889)
Potomac R., near Washington, D.C.	360,000	484,000 (1936)
N.W. Branch Anacostia R., near Hyattsville, Md.	16,600	7,000 (1966)

[a]From: Taylor, K.R., 1972.

at that gaging station (185 years of record) and exceeded the previous high by approximately 33 percent. The instantaneous peak flow of 1,130,000 cfs reported at 05:45 a.m. on 24 June 1972 was the highest instantaneous flow ever reported for the Susquehanna. Whereas the Susquehanna normally contributes about 50% of the total fresh water going into Chesapeake Bay, during the Agnes flood it contributed 64%, exceeding the normal input by about 14%.

Figure 1.4 shows the daily average discharge of the Susquehanna at the Conowingo Hydroelectric Plant near the mouth of the River for the period 1 January 1972 through 31 August 1972. Although Conowingo is not an official U.S.G.S. gaging station, its proximity to the head of the Chesapeake Bay and the continuity of its record even under flood conditions makes this station highly useful in any analysis of fresh water inflow to the Bay. Figure 1.5 shows the ensemble average by month of the Susquehanna River flow at Conowingo over the period 1929-1966, and the monthly average discharge for January through August of 1972. The ensemble average reveals the average seasonal flow pattern of the Susquehanna, and the comparison of the two curves clearly shows the departure of the flow during 1972 from the long-term average. Even after above-average flows during the three preceding months, the flows during June and July stand out remarkably.

The Potomac is the second largest river debouching into the Bay, normally accounting for approximately 19% of the total fresh water input. The Potomac also carried very high flows following Agnes. On the day the river crested, 24 June 1972, some lowland park and industrial areas of Washington, D.C. were flooded. The daily average discharge of the Potomac near Washington, D.C. on 24 June 1972 reached approximately 356,600 cfs--the fourth highest daily average discharge in the 83 years of record. It was exceeded only by the floods of 2 June 1889, 19 March 1936 (484,000 cfs), and

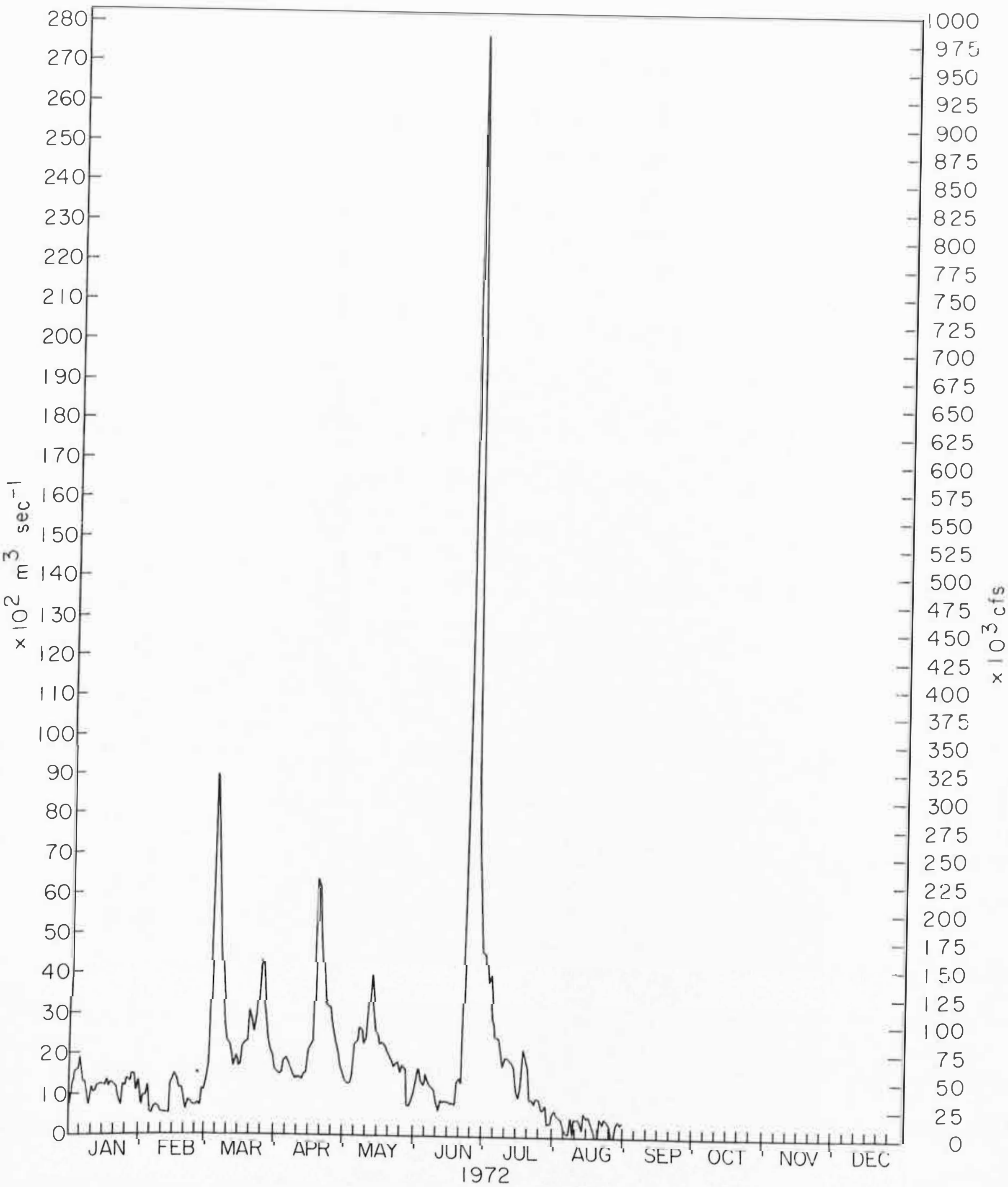


Figure 1.4. Daily average discharge of the Susquehanna River at Conowingo, Md., 1 January - 31 August 1972 (C.B.I.).

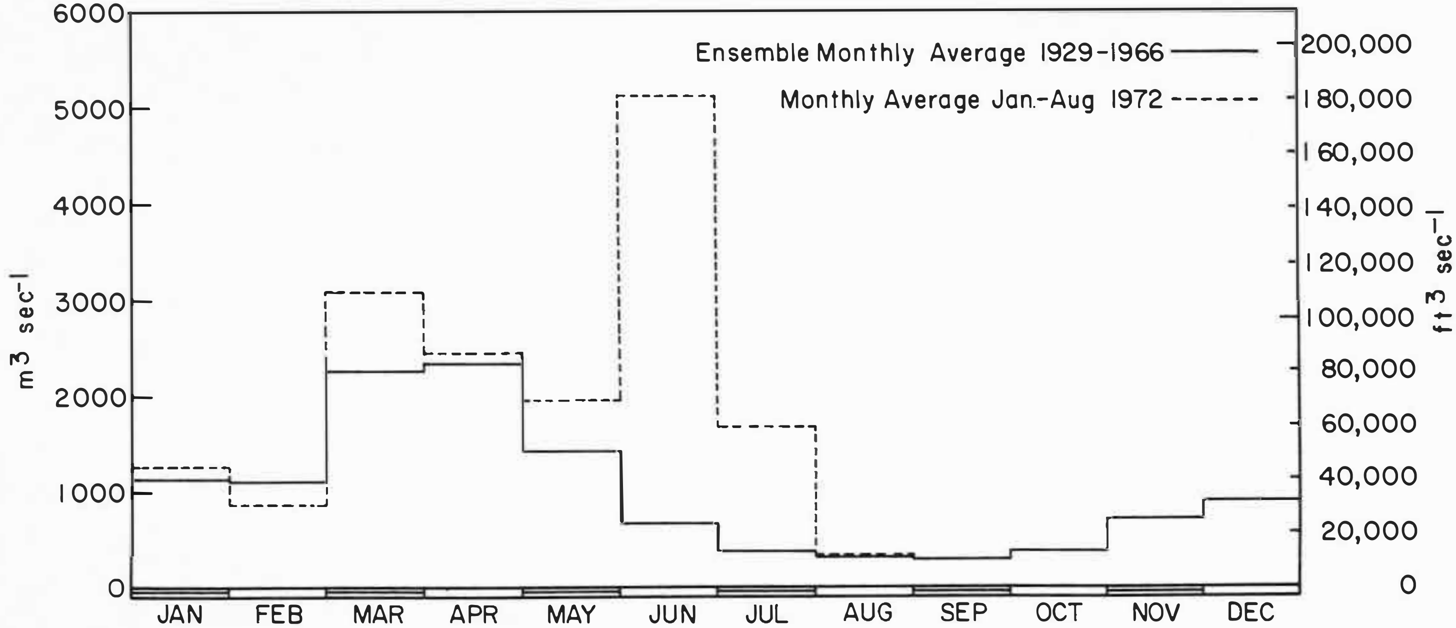


Figure 1.5. Ensemble monthly average of the Susquehanna riverflow at Conowingo, Md., over the period 1929-1966, and the monthly average discharge for January through August of 1972. (C.B.I.)

17 October 1942 (447,000 cfs). The monthly average flow of the Potomac River at Washington, D.C. for June 1972 of 47,000 cfs was more than 6 times the median flow for June during the past 30 years. Figure 1.6 is a graph of the daily average discharge of the Potomac River near Washington, D.C. for June 1972. Figure 1.7 shows the monthly discharge of the Potomac River near Washington, D.C. for January 1971 through June 1972, and the median monthly average discharge over the past 30 years.

In contrast to the rivers on the western side of the Bay, Agnes caused little severe flooding of the rivers on the Delmarva Peninsula (the Chester, Choptank, Nanticoke, Pokomoke, and Wicomico, to name the major ones). Not only are the drainage basins of these rivers small, but most of the rain fell miles to the west of them (Figure 1.2).

In summary, the U.S. Geological Survey estimated that the total combined fresh water input to the Chesapeake Bay estuarine system during June 1972 resulted in an average discharge over the month of 325,000 cfs--the highest combined monthly discharge for any month during at least the past 21 years. Of this total, the Susquehanna contributed an estimated average of approximately 186,000 cfs, or more than 57 percent of the total.

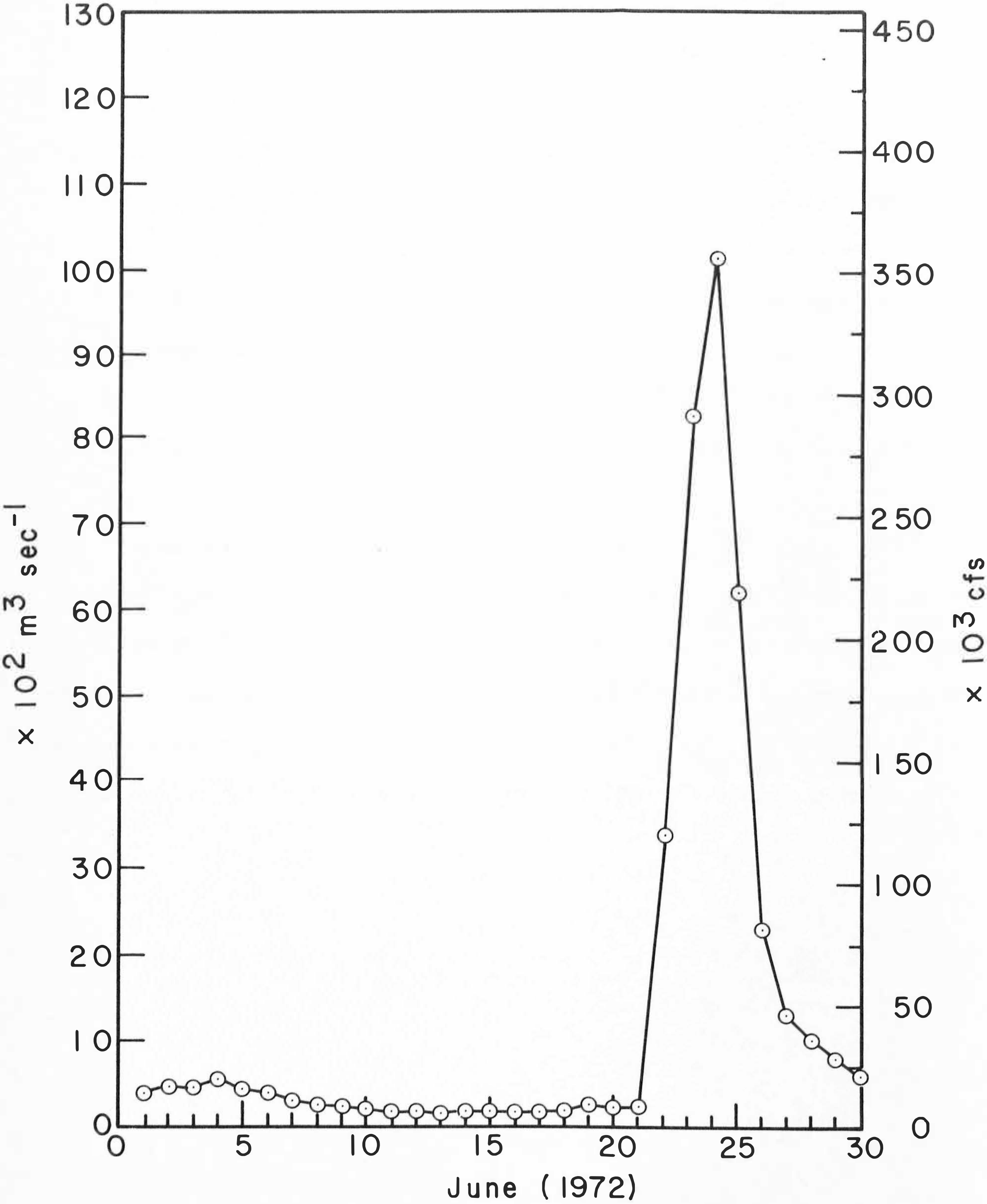


Figure 1.6. Daily average discharge of the Potomac River near Washington, D. C., for June 1972 (C.B.I.).

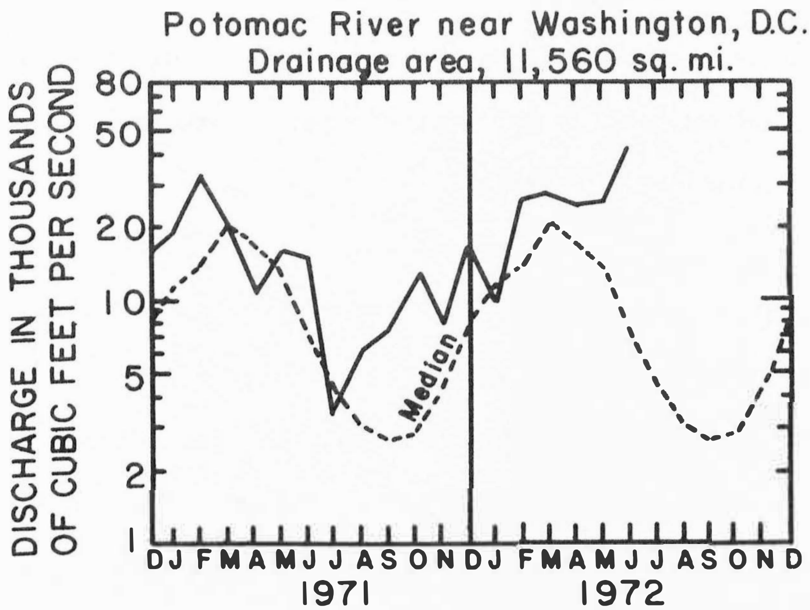


Figure 1.7. Monthly average discharge of the Potomac River near Washington, D. C., for January 1971 through June 1972 (———), and the median monthly average discharge over the past 30 years (-----). (C.B.I.)

SECTION 2. SALINITY PATTERNS

2.1 General

The late winter of 1971 and the early spring of 1972 was an unusually "wet" period with river inflow to the Bay well above average. In fact, the discharge of fresh water from the two major rivers, the Susquehanna and Potomac, for the 10-month period August 1971 through May 1972 had exceeded the long-term mean flow for that same 10-month period by over 50%. Consequently, the salinities in the Chesapeake Bay and in its tributaries were already well below the normal values for early summer before tropical storm Agnes passed across the watershed of the Bay.

2.2 The Upper Bay

With the flooding from Agnes, salinities in the upper Chesapeake Bay fell sharply, such that at any given position the salinity reached values less than any previously recorded for that position. The lag between the time of maximum fresh water discharge and the time of minimum salinity varied with position and depth. The fact that the fresh water discharges from all five of the major rivers and from many of the minor streams were long-term record highs resulted in minimum salinities being reached almost everywhere in the surface layers of the upper Chesapeake Bay (defined for purposes of this report as the portion of the Bay above the mouth of the Potomac River) within the period 26 to 29 June. In some reaches of the upper Bay minimum salinities in the near bottom waters were not attained, however, until about 15 July.

Figures 2.1 and 2.2 show the variation in salinity along the axis of the Chesapeake Bay from the head of the Bay at Havre de Grace to the mouth of the Potomac River, on specific dates after Agnes. Figure 2.1 gives curves for the longitudinal salinity variation of the surface and bottom waters as observed on four surveys: three weeks before the storm (6-7 June), just after the inflow of fresh water into the Bay crested (26-29 June), early July (6-7 July), and ~~the middle of July (14 15 July).~~

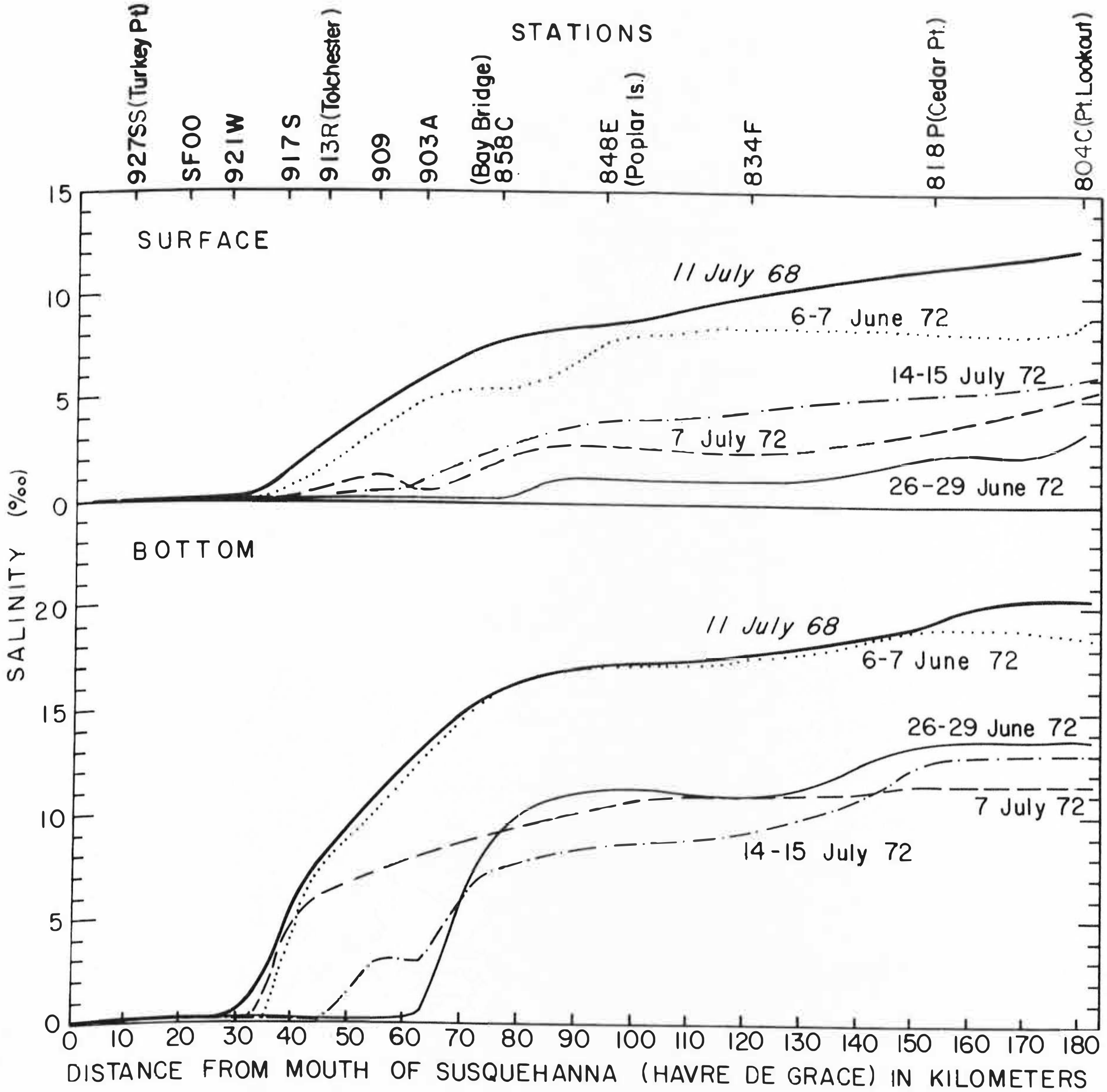


Figure 2.1. Variations in the surface and bottom salinities along the axis of the Bay from its head at Havre de Grace to the mouth of the Potomac River estuary on specific dates before, during, and after Agnes. The variations observed at about this time during a more normal year, 1968, are also shown for comparison. (C.B.I.)

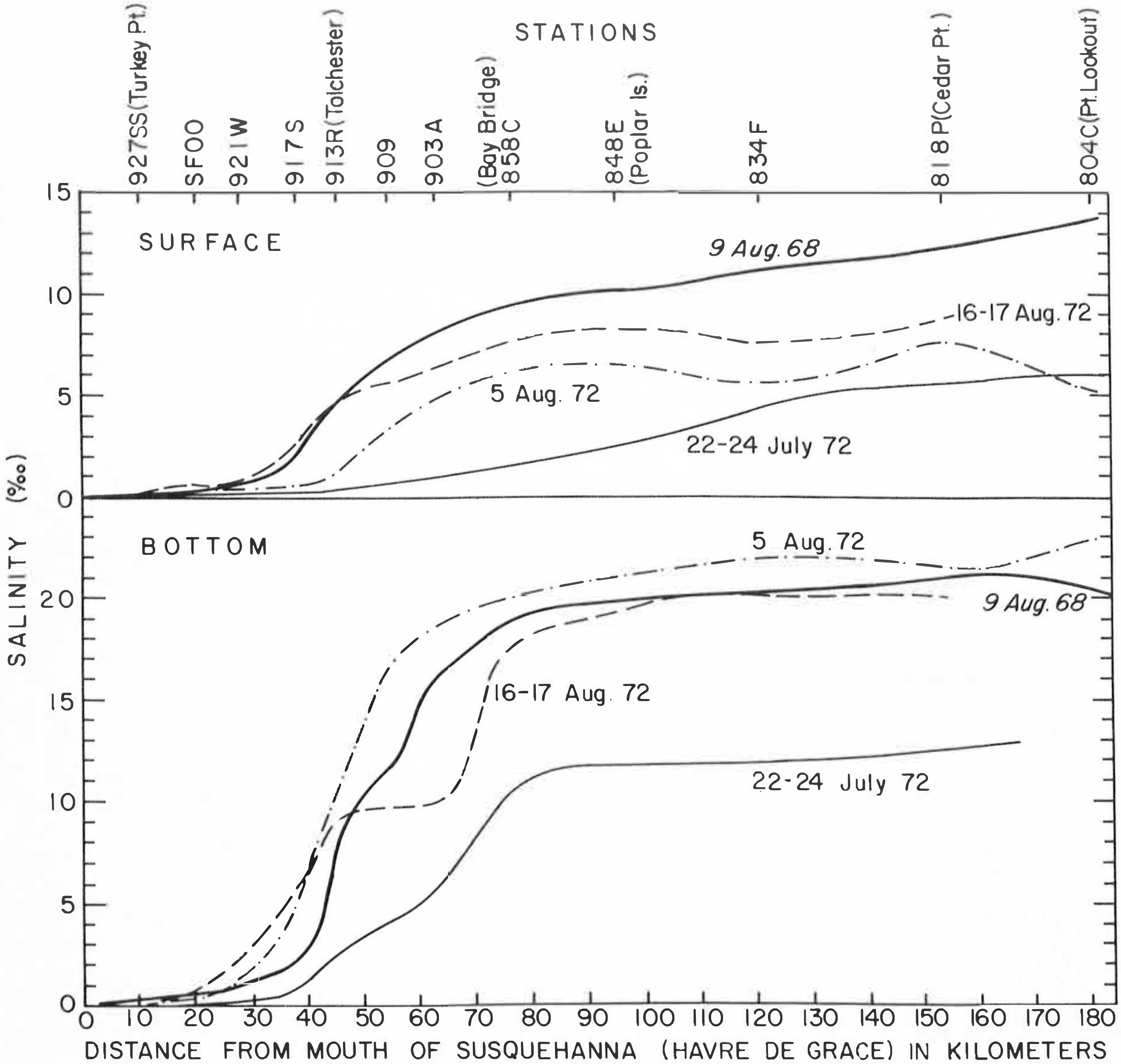


Figure 2.2. Variations in the surface and bottom salinities along the axis of the Bay from its head at Havre de Grace to the mouth of the Potomac River estuary on specific dates during late July and August following Agnes. Data from a more typical year are also shown for comparison. (C.B.I.)

the middle of July (14-15 July), for the surface and the bottom. Also shown on this figure is the longitudinal salinity variation during a more normal year, as depicted by the curve marked 11 July 1968. Figure 2.2 covers the period 22 July through 17 August 1972. For comparison with these curves the data for 9 August 1968 are also given.

Note that by the 26 June 1972, two days after the Susquehanna crested, the Bay was fresh (less than 0.5‰) from top to bottom all the way south to Love Point at the northern end of Kent Island. The salinities of the surface waters of the Bay were 1‰ or less from the head of the Bay to the mouth of the Little Choptank. About 3 weeks earlier, on 6-7 June 1972, the zone with surface salinities less than 1‰ extended only to Tolchester, and the surface salinity at the mouth of the Little Choptank was about 8.5‰.

Longitudinal-vertical sections of the salinity distribution along the axis of the Bay constructed from data collected on a series of surveys made from three weeks prior to Agnes to about 10 weeks after Agnes are included in Appendix I.

2.3 The Potomac River Estuary

As was the case for the Susquehanna, fresh water flow in the Potomac had been well above the normal seasonal flow regime for some 10 months prior to Agnes. Thus the sharp decline in salinities resulting from the flooding of the Potomac following Agnes were from a base line already depressed below normal salinity values.

Figures2.3 and 2.4 give the variations in salinity along the axis of the Potomac for the specified dates following the passage of Agnes, for the surface and bottom waters. The Potomac normally has salinities suitable for oyster production in the lower 40 miles of the estuary. On the 28th of June, just 4 days after the inflow of fresh water crested at Little Falls above Washington, D. C., salinities everywhere in the estuary above a depth of about 16 feet were less than 5‰. At the mouth of the estuary the salinity of the upper 15 feet was between 3‰ and 4‰. Surface water with salinities less than 1‰ extended downstream to within 11 nautical miles of the mouth of the estuary.

This condition of having salinities less than 5‰ throughout the upper 10 to 15 feet of the estuary all the way to the mouth extended through most of the month of July. On the 1st of August 1972 the salinities in the surface layers at the mouth of the estuary were between 5‰ and 6‰, and surface waters having salinities of less than 5‰ extended to within 4 miles of the mouth of the river.

By the 29th of August intrusion of more saline water along the bottom and subsequent vertical mixing had increased surface salinities such that water having salinities greater than 5‰ were found in the lower 27 miles of the estuary at the surface, and in the lower 42 miles at the bottom. Though by this date the surface salinities no longer have values lying outside the expected range when considering the whole year, they are lower than is usually found in late August—early September. Furthermore, the large vertical variation in salinity is more typical of late spring than of early fall.

It is of interest to note the mechanism of recovery of the Bay involves up-estuary flow of more saline water in the deeper layers of the Bay, and thence into tributaries such as the Potomac, with subsequent slow vertical mixing of the salt into the low salinity surface waters. As a result the vertical gradients in salinity (i.e., the differences between the more saline deeper waters and the surface waters) were larger than any previously recorded throughout much of the Chesapeake Bay and the Potomac

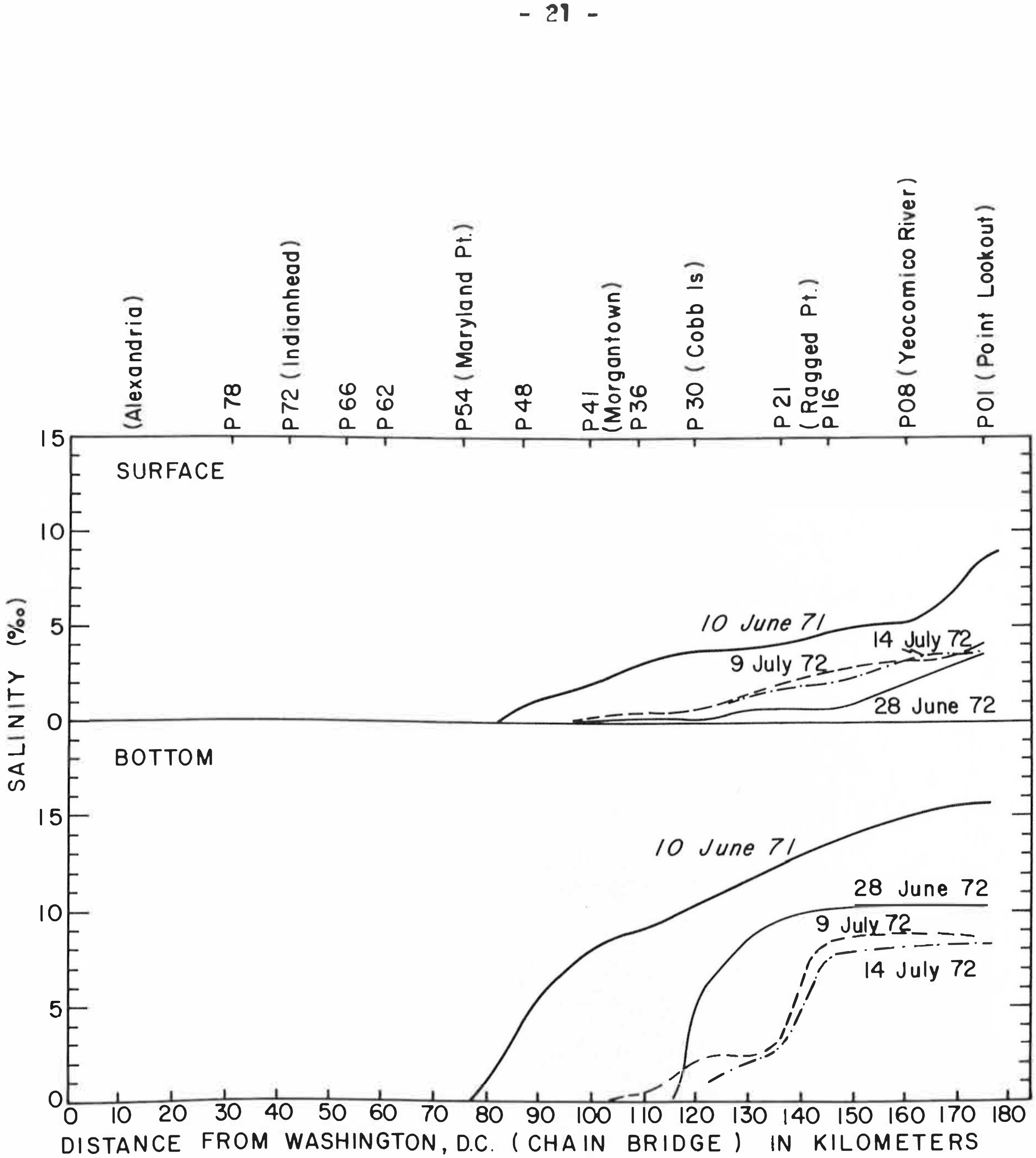


Figure 2.3. Variations in the surface and bottom salinities along the axis of the Potomac River estuary on specific dates following Agnes. Data from a more typical year are also shown for comparison. (C.B.I.)

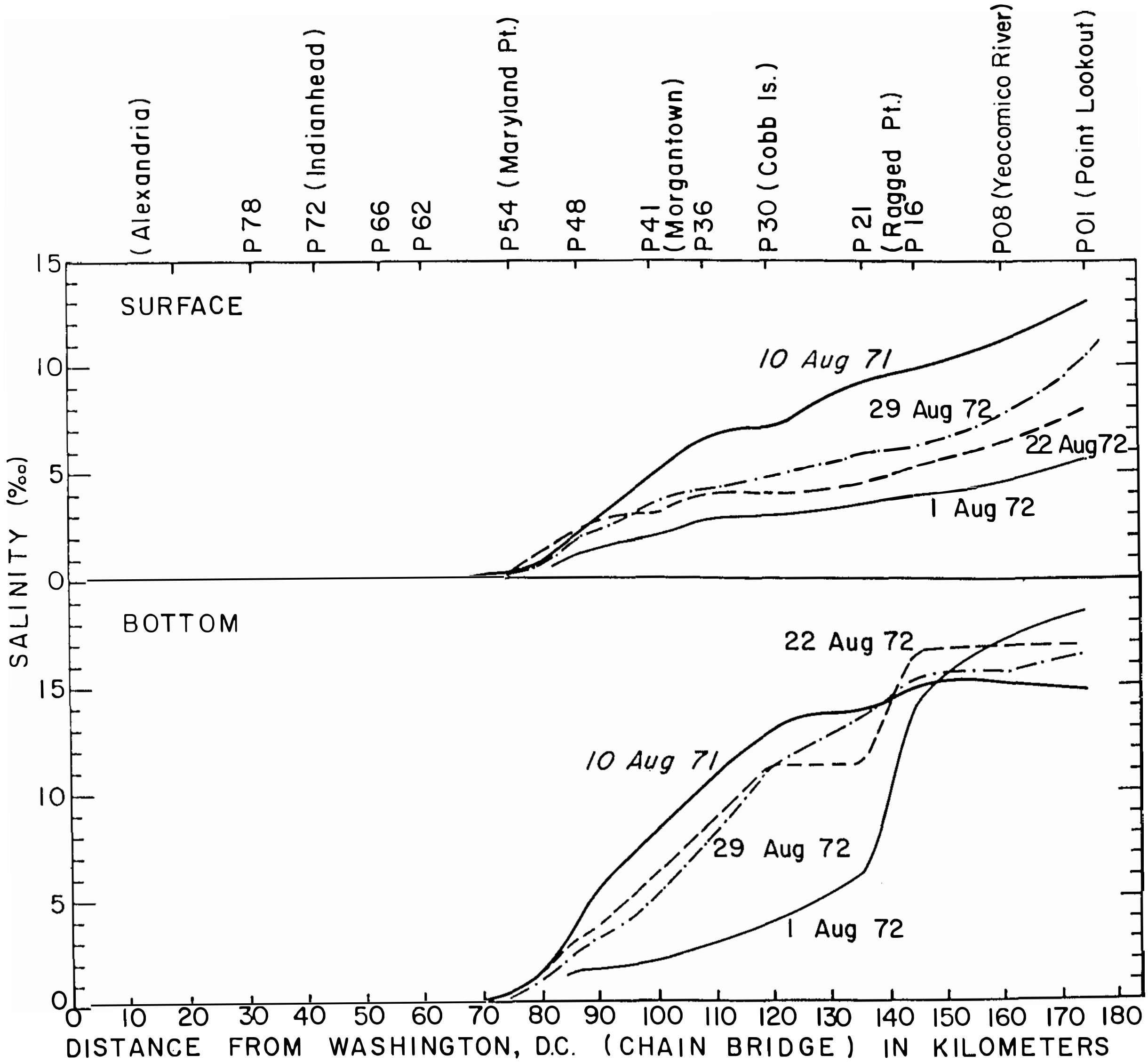


Figure 2.4. Variations in the surface and bottom salinities along the axis of the Potomac River estuary on specific dates following Agnes. Data from a more typical year are also shown for comparison. (C.B.I.)

River. For example, on the 31st of July at a point in the Bay just north of Point Lookout the surface salinity was 2.96‰ while at the bottom some 55 feet below the surface the salinity was 22.22‰.

Longitudinal distributions of temperature and salinity along the axis of the Potomac River estuary following Agnes are shown in Appendix II.

2.4 The Patuxent River Estuary

The Patuxent River estuary responded to the flood waters of Agnes much the same way as the Potomac did.

By 5 July the salinity was depressed far below normal (Figure 2.5). Whereas the average surface salinity at Solomons, Maryland in July is near 12‰ (Beavan, 1960), the highest daily salinity reading for July 1972 was 4.8‰ on 24 July, the lowest was 3.1% on 1 July. The salinity throughout the river, from Nottingham to the mouth, remained below 7‰ throughout July (Figure 2.6).

Most of the salinity data for the Patuxent still needs to be analyzed. But judging from the salinities taken at Solomons, the salinity started climbing upward in August and by October was only 1 or 2‰ below normal.

2.5 Virginia's Estuaries

Flood waters resulting from Tropical Storm Agnes crested at the fall line on 22 June in the Rappahannock River, on 23 June in the James River, and on 23, 25, and 26 June in the York River System. The flood waters affected the salinity structure of the estuaries associated with these rivers in similar fashions but to varying degrees.

A cursory examination of available data indicates that each estuary was subjected to an initial surge and rebound period similar to that resulting from passage of a solitary wave. This surge/rebound condition lasted a total of two to three days with the initial surge

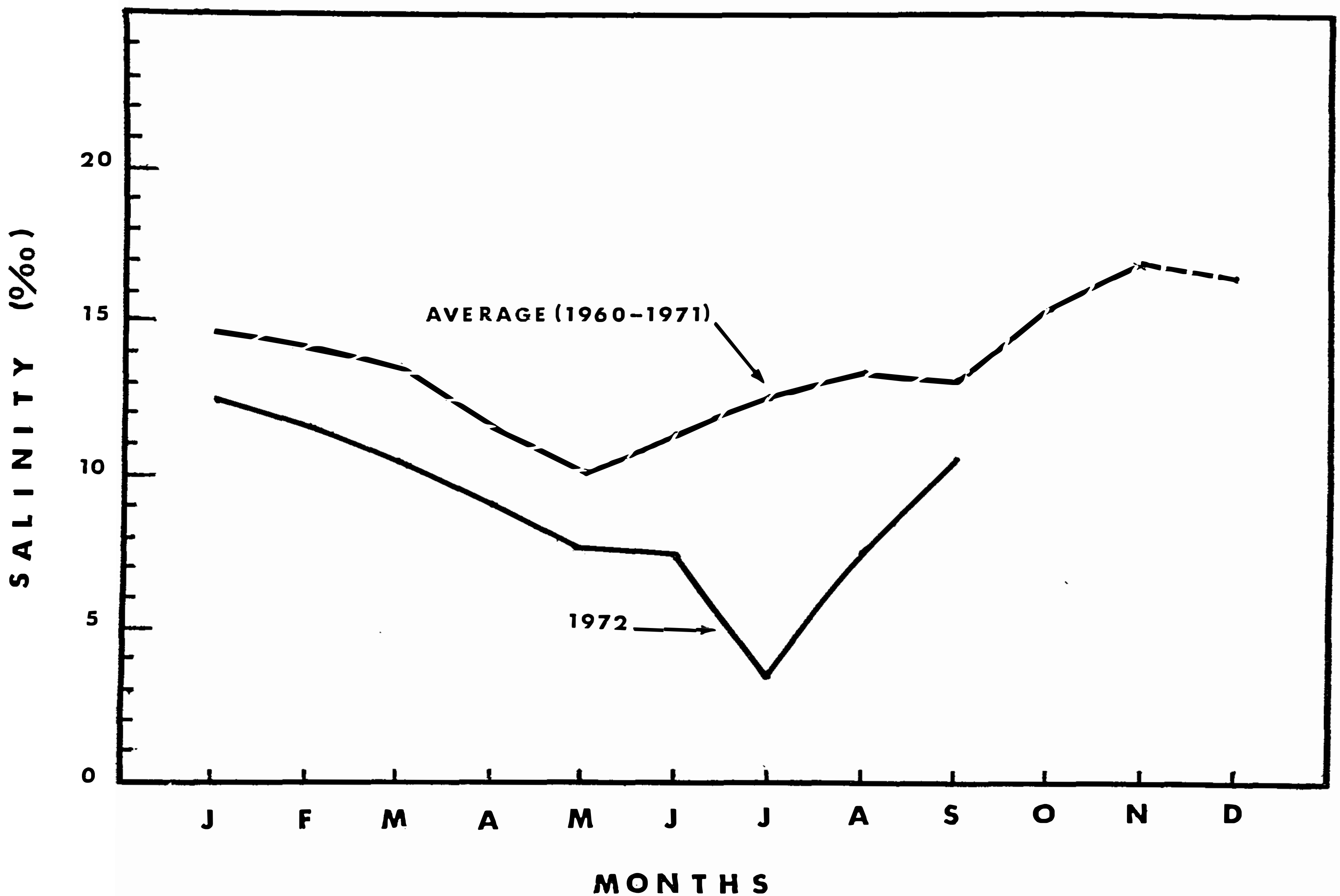


Figure 2.5. Monthly average salinities of the Patuxent River Solomons, Maryland for 1972, compared to monthly averages for the years 1960-1971. (C.B.L.)

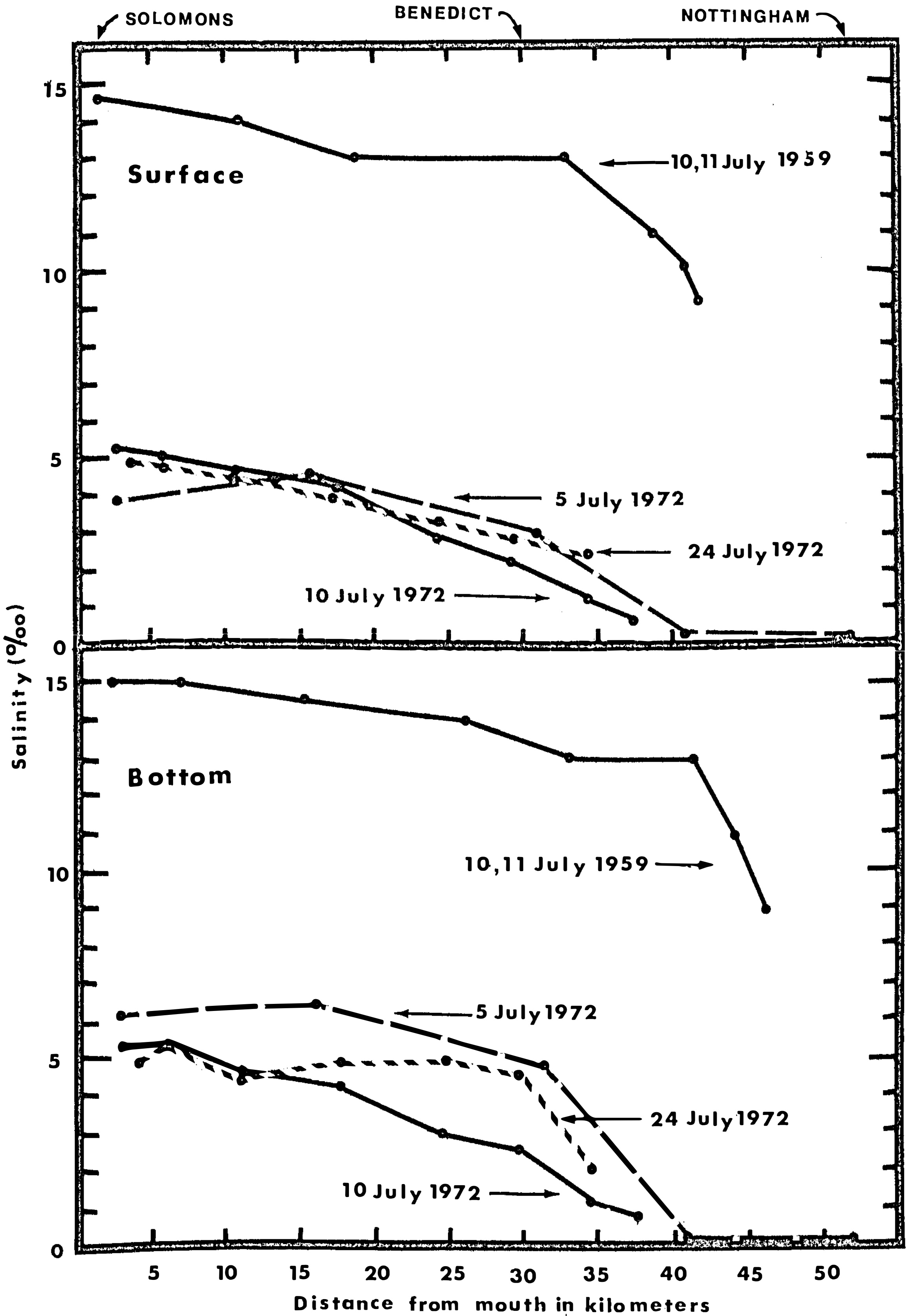


Figure 2.6. variations in the surface and bottom salinities along the axis of the Patuxent River from its mouth to Nottingham on specific dates following Agnes. Date from July 1959 are shown for comparison. (C.B.L.)

translating fresh water (with salinities less than 1‰) downstream to a point where channel depths were approximately 10 meters in the James and Rappahannock and 6 to 7 meters in the York. This resulted in salinities of 1‰ or less 46 km (25 nautical miles) upstream from the river mouth in the Rappahannock, and York Rivers and 55 km (30 nautical miles) in the James. Approximately 20 days prior to the flood, salinities at these locations averaged 8‰, 3.5‰, and 4‰ respectively in the three estuaries.

The initial flood surge resulted in a downstream displacement of the 1‰ isohaline of approximately 4 km in the James and Rappahannock rivers and 9 km in the York. The initial displacement occurred two days after the flood crest passed the fall line in the James and Rappahannock Rivers and approximately 8 days after crest passage in the York. Times of translation and position of the 1‰ isohaline provide sufficient information to calculate the celerity (speed) of the flood crest in each estuary; they are: 55 km per day in the James, 16 km per day in the York and 62 km per day in the Rappahannock. The calculated speeds are reasonably consistent with observations in the rivers because "chocolate" colored, debris-laden water was observed in the vicinity of deep water shoals on the James River on the evening of 24 June, one day after the flood crest passed Richmond 126 km upstream. (It should be noted that the James crested at Richmond on 23 June with a mean flow for the day of approximately 300,000 cfs whereas the mean flow one day earlier was 150,000 cfs; hence, the observed debris could have been material moved one day prior to the day of crest passage at Richmond.)

The initial rebound effect was similar in each estuary: an upstream encroachment of higher salinity bottom waters with little change in the surface salinity regime. The net result in each estuary was a layer 5 to 10 meters deep of extremely fresh water, a relatively strong halocline; and a "pool" of higher salinity water at the bottom near the mouth of each estuary. This rebound condition reached its maximum intensity (relative to crest passage at the fall line) at 5 to 6 days in the Rappahannock, 10 days in the York and 3 to 4 days in the James. The five to ten meter halocline was an identifiable feature in the river estuaries, in lower Chesapeake Bay and in coastal waters off Virginia Beach.

During the post-rebound period, the patterns of salinity in the three estuaries were different. The Rappahannock has a ten-meter sill at its mouth with a 20-meter-deep basin behind it. The sill prevented access of bottom waters from Chesapeake Bay to the lower Rappahannock. Surface salinities were further depressed as flood waters moved down and out the river. The strong halocline, which developed during the rebound period, deteriorated and the pool of saltier water at the mouth of the Rappahannock mixed with overlying waters to form what appeared to be a sectionally homogeneous estuary with a salinity of 8‰ at the mouth and 1‰ some 60 km upstream. This "worst case" condition occurred on 10 July, 18 days after flood crest passage at the fall line (Figure 2.7).

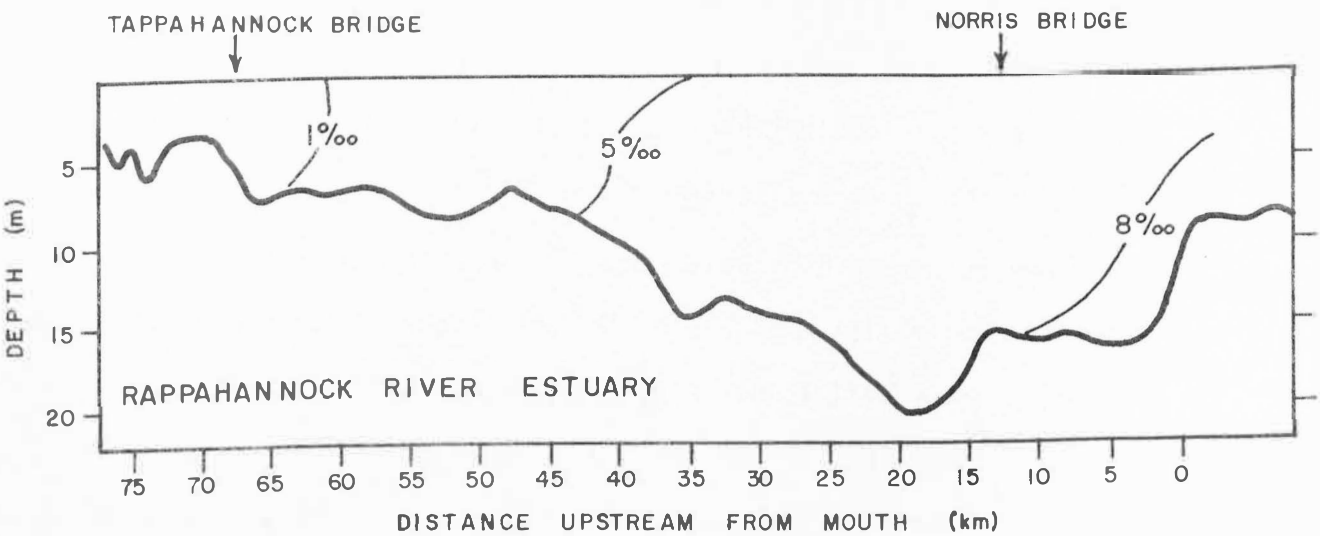


Figure 2.7 Salinity distribution in the Rappahannock Estuary on 10 July 1972, 18 days after flood waters from Tropical Storm Agnes crested at the fall line. (V.I.M.S.)

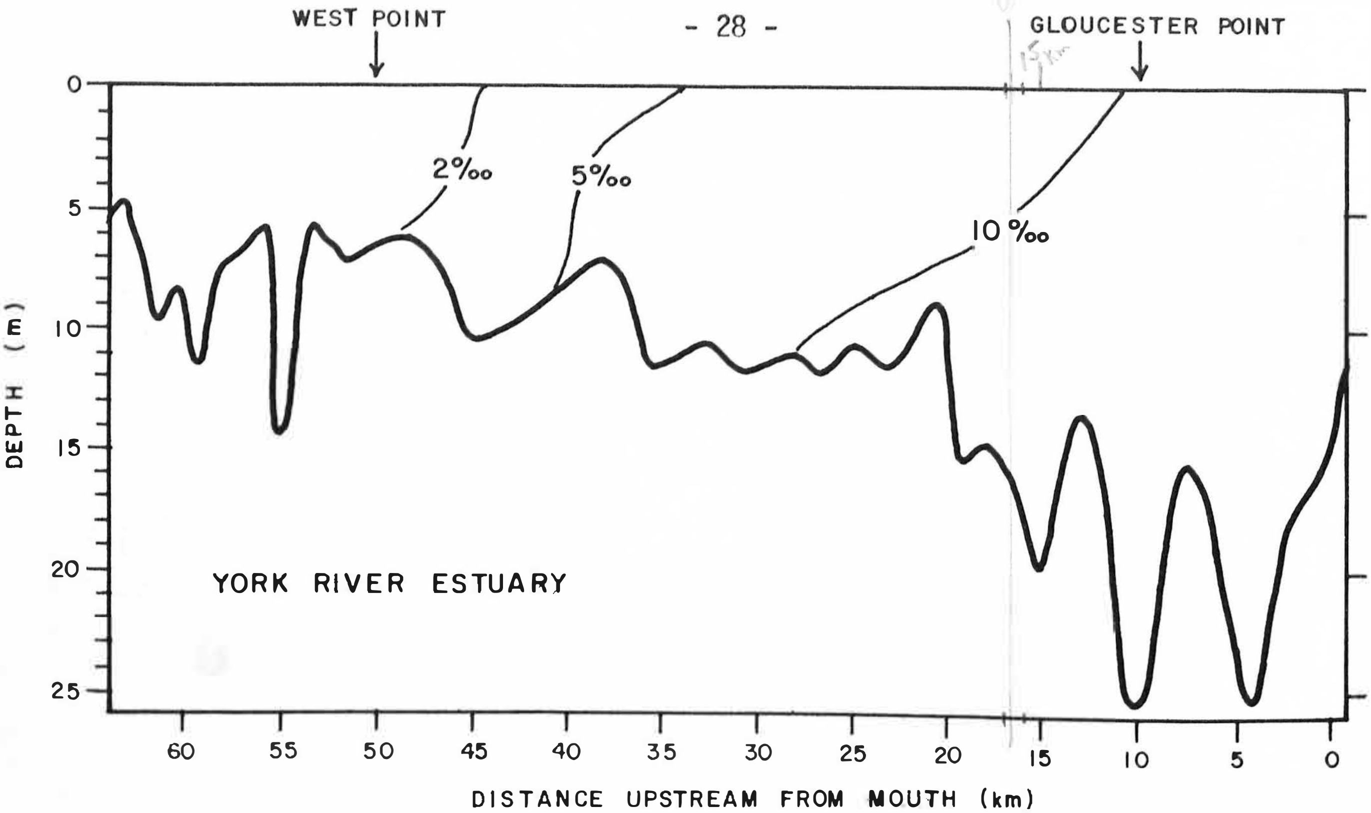


Figure 2.8 Salinity distribution in the York Estuary on 5 July 1972, 11 days after flood waters from Tropical Storm Agnes crested at the fall line. (V.I.M.S.)

Conditions in the York Estuary were similar to those in the Rappahannock but not as severe. The rebound effect, although evident, failed to produce a strong halocline. The worst-case situation in the York occurred on 5 July, eleven days after the flood crest passed the fall line (Figure 2.8). After that time, salinities increased slowly all along the York estuary but substantial vertical stratification was not evident until 24 July some 30 days after the flood (Figure 2.9).

The James Estuary exhibited the most rapid response to the flood with most depressed salinities measured on 28 June (Figure 2.10) 5 days after crest passage at the fall line. After this date, salinities increased with some consistency but strong vertical stratification was not evident until 19 July (Figure 2.11) at which time bottom salinities at the mouth were in excess of 25‰. This situation was relatively short lived for the strong vertical salinity gradient soon weakened resulting in an increase in surface and upstream salinities but a decrease in bottom downstream salinities. This trend persisted to conditions shown in Figure 2.12 where on 25 August no strong vertical gradient was evident and the estuary showed a tendency towards sectional homogeniety.

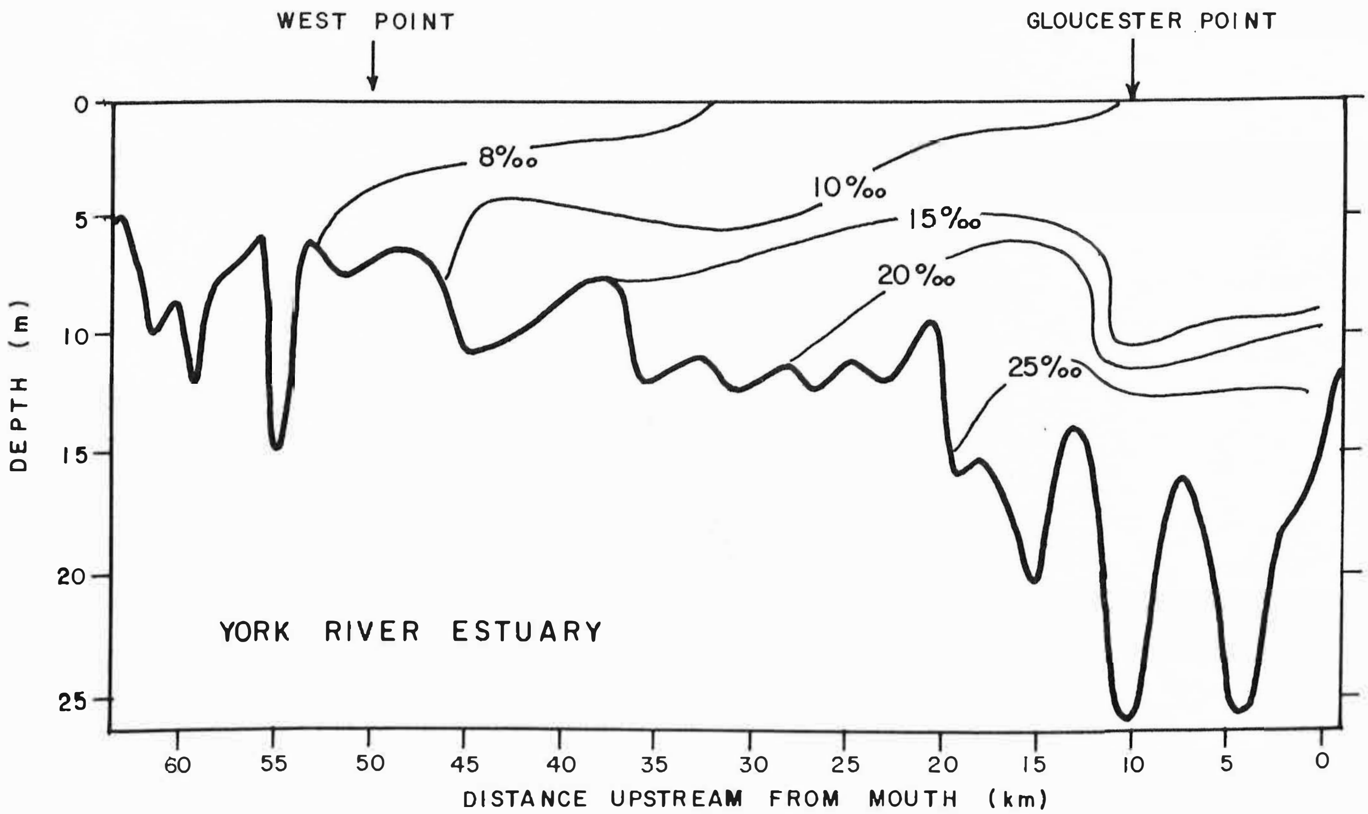


Figure 2.9. Salinity distribution in the York Estuary on 24 July 1972, 30 days after flood waters from Tropical Storm Agnes crested at the fall line. (V.I.M.S.)

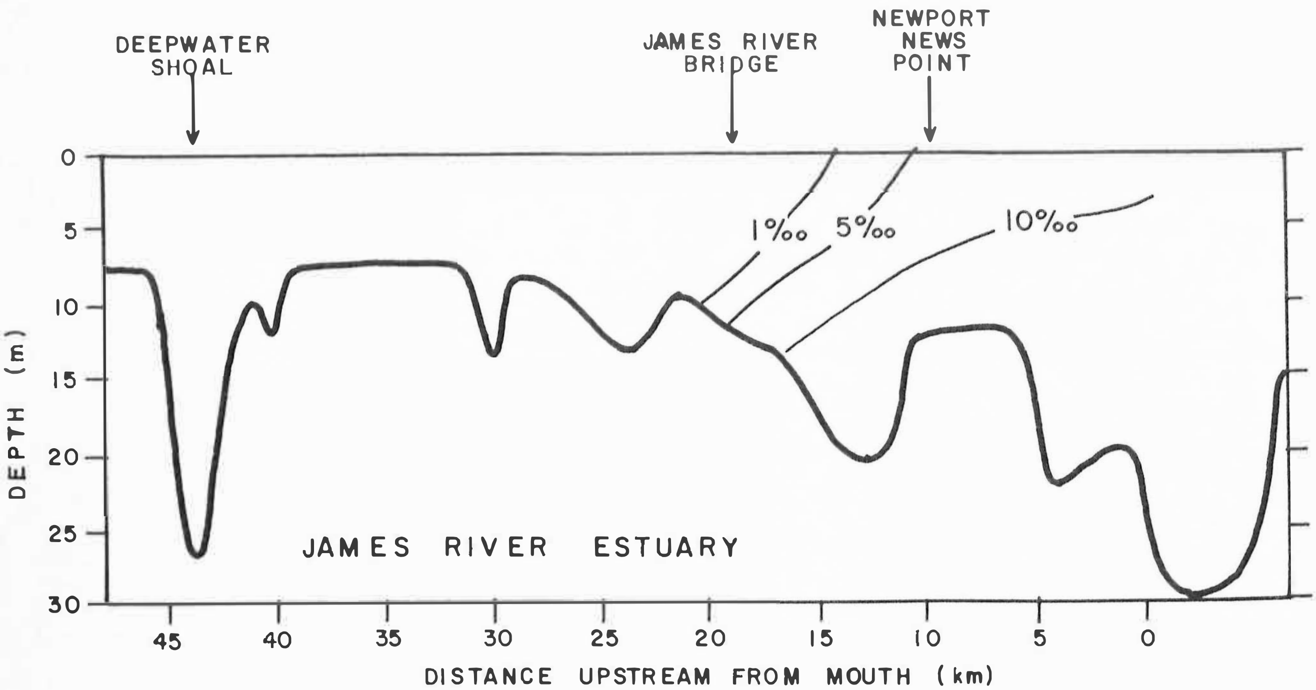


Figure 2.10. Salinity distribution in the James Estuary on 28 June 1972, 5 days after flood waters from Tropical Storm Agnes crested at the fall line. (V.I.M.S.)

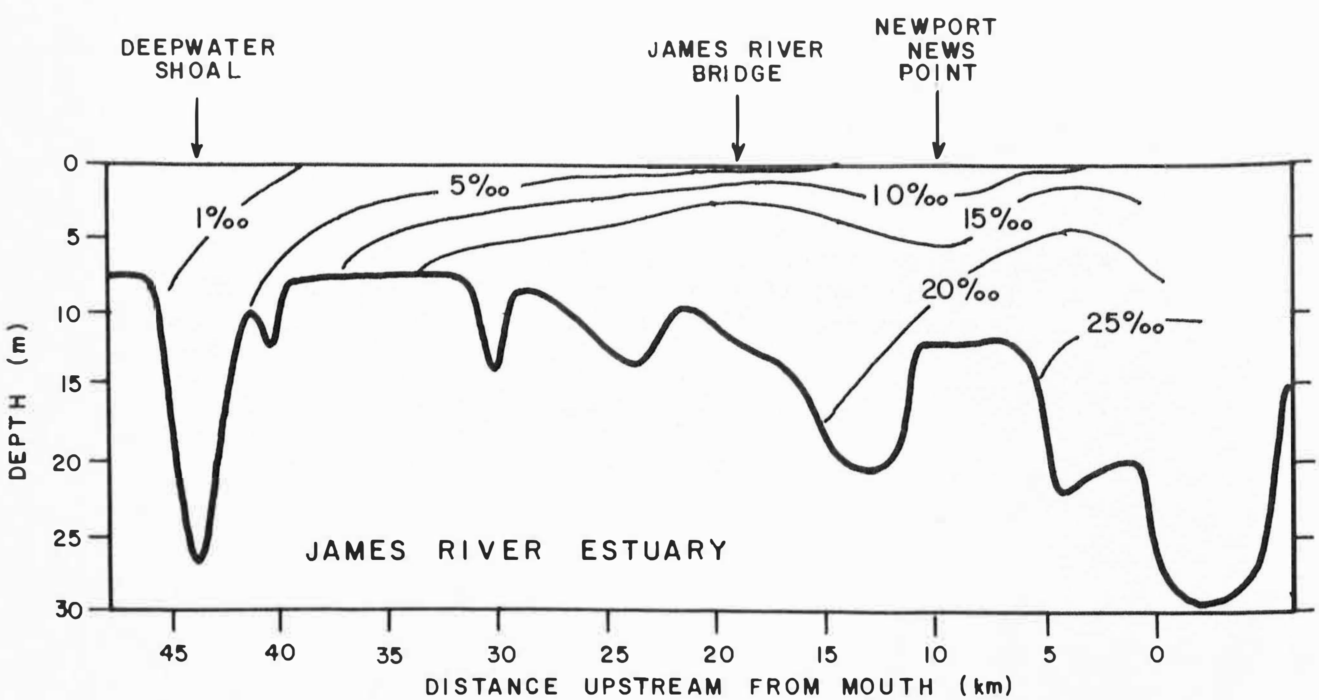


Figure 2.11. Salinity distribution in the James Estuary on 19 July 1972 26 days after flood waters from Tropical Storm Agnes crested at the fall line. (V.I.M.S.)

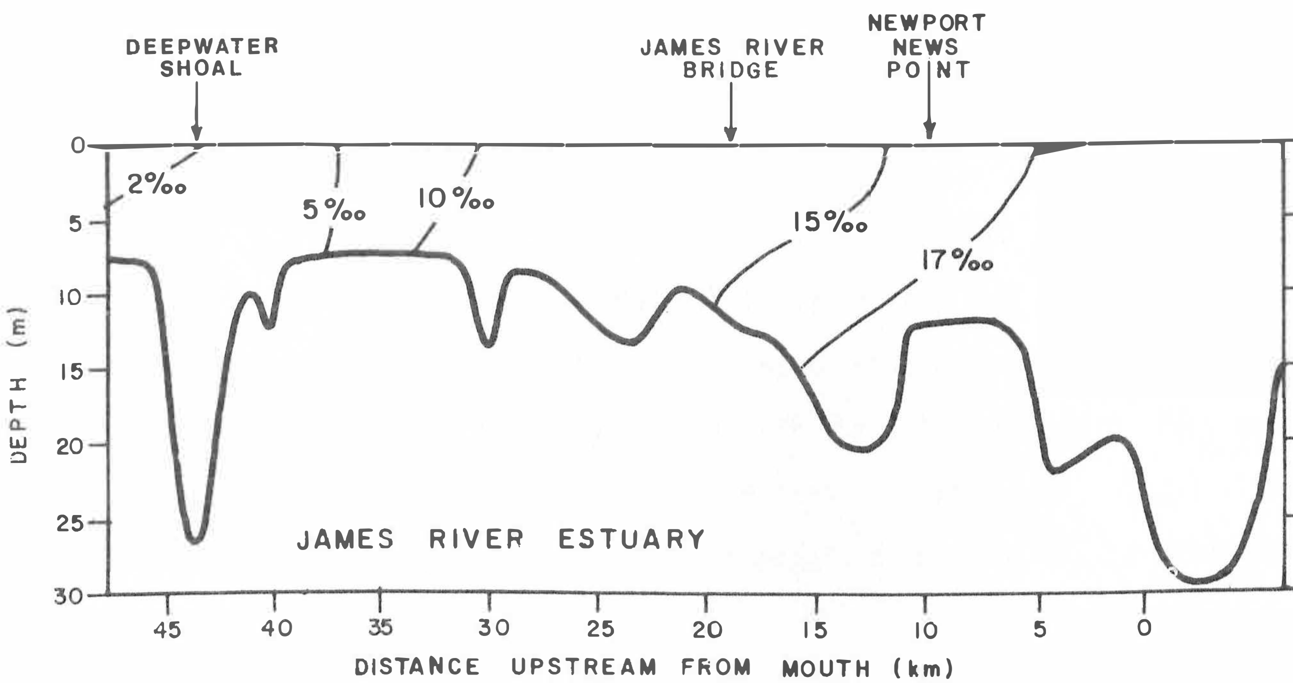


Figure 2.12. Salinity distribution in the James Estuary on 25 August 1972, 63 days after flood waters from Tropical Storm Agnes crested at the fall line. (V.I.M.S.)

2.6 The Lower Bay and The Continental Shelf

Three sets of synoptic surface salinity measurements were obtained in the lower Chesapeake Bay (below the Potomac) and over the adjacent Continental Shelf area on 29 June to 3 July (Figure 2.13), 10 to 14 July (Figure 2.14) and 17 to 19 July (Fig. 2.15). Approximately 120 surface salinity samples were obtained (by helicopter) for each set. The lowest salinities in these samples were found on 30 June, down-bay from the mouth of the Potomac River (Figure 2.13). No evidence is available to indicate the origin (Susquehanna or Potomac) of this freshened water.

It is evident that this surge of freshened water moved down the central portion of the bay and was approximately 10 meters thick. The situation of minimum bottom salinities and horizontal salinity gradients in the bay occurred on 13 July (Fig. 2.16). After this time, salinities of bottom waters increased while those of surface waters decreased until the highly stratified situation of 27 July (Fig. 2.17) resulted. As in the James estuary, the salinities of waters of lower Chesapeake Bay increased at the surface up-bay and decreased at the bottom in the lower reaches until the weak stratification of 31 August (Fig. 2.18) resulted.

Unlike the river estuaries, lower Chesapeake Bay was subjected to several pulses of fresh water entering at differing times and locations. The result was a more or less patchy distribution of surface salinities. Tidal influences were evidence in the lower bay and associated river estuaries but were greatly suppressed by water movement resulting from the flood pulses. This suppression did not persist as flood waters left the bay off Cape Henry.

Results from shelf cruises indicate that large-volume pulses of freshened surface water left the bay on the ebb tide and were separated from one

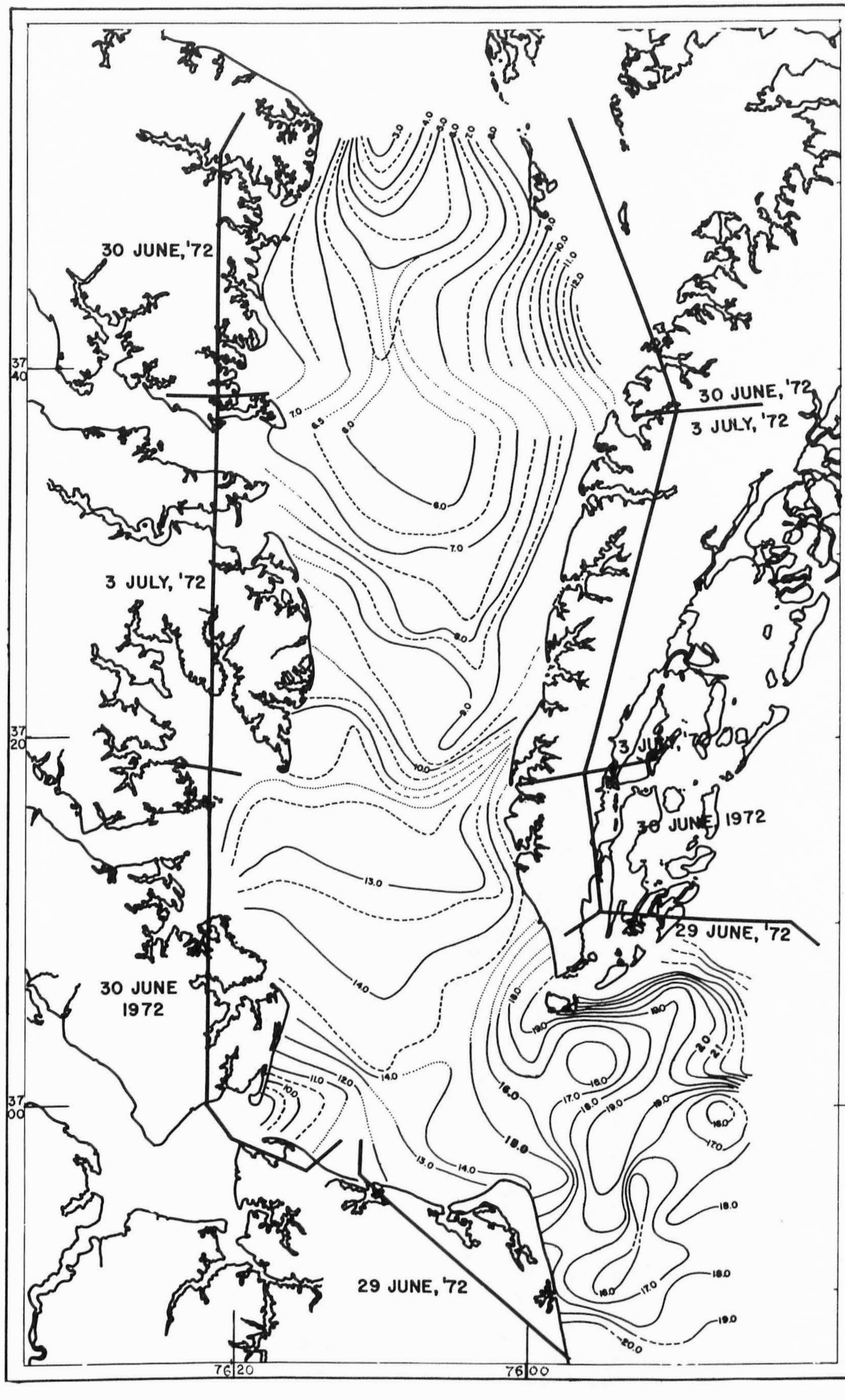


Figure 2.13. Surface salinities of lower Chesapeake Bay and nearshore shelf region based on samples collected on 29, 30 June and 3 July 1972. (V.I.M.S.)

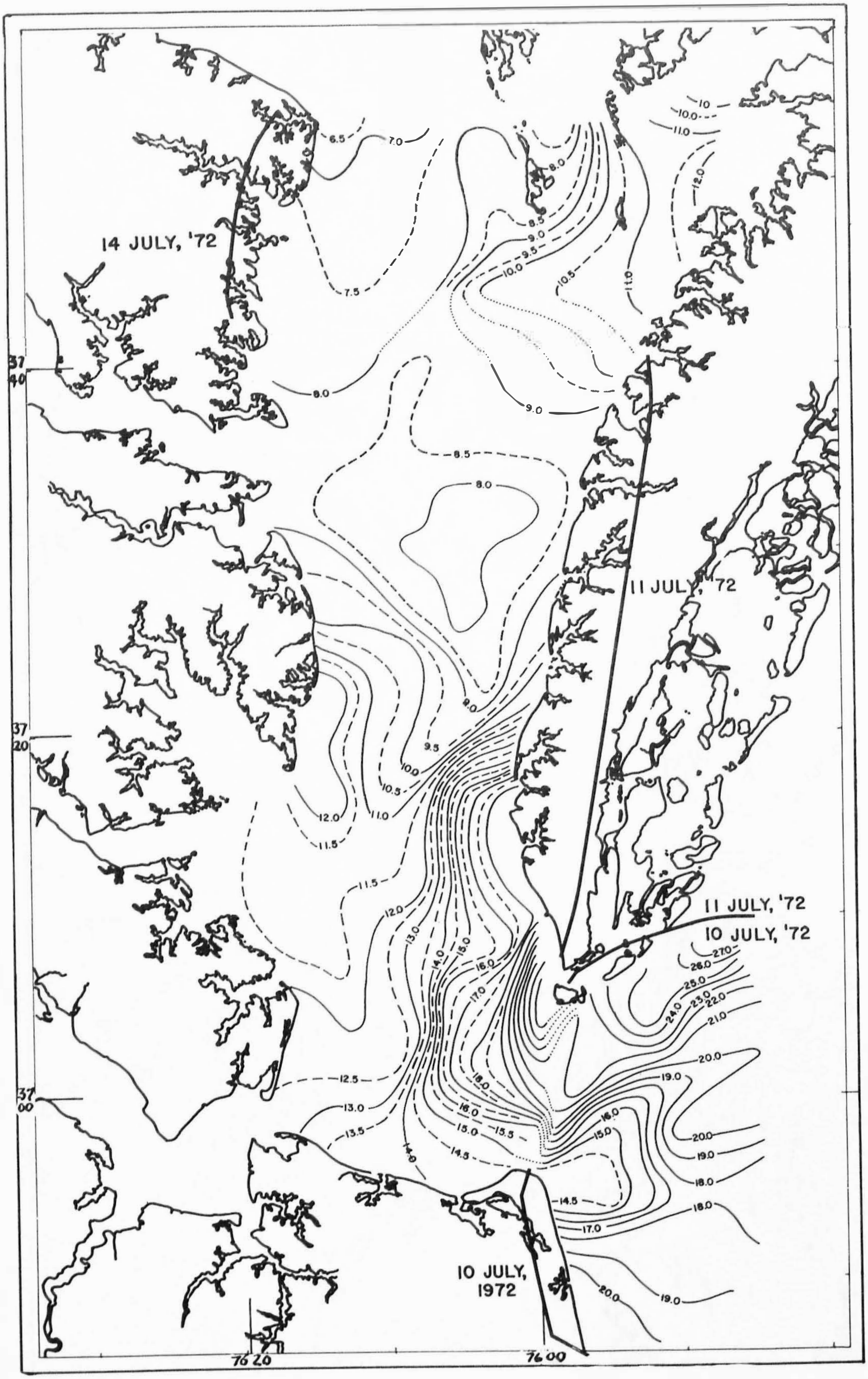


Figure 2.14. Surface salinities of lower Chesapeake Bay and nearshore shelf region based on samples collected on 10, 11 and 14 July 1972. (V.I.M.S.)

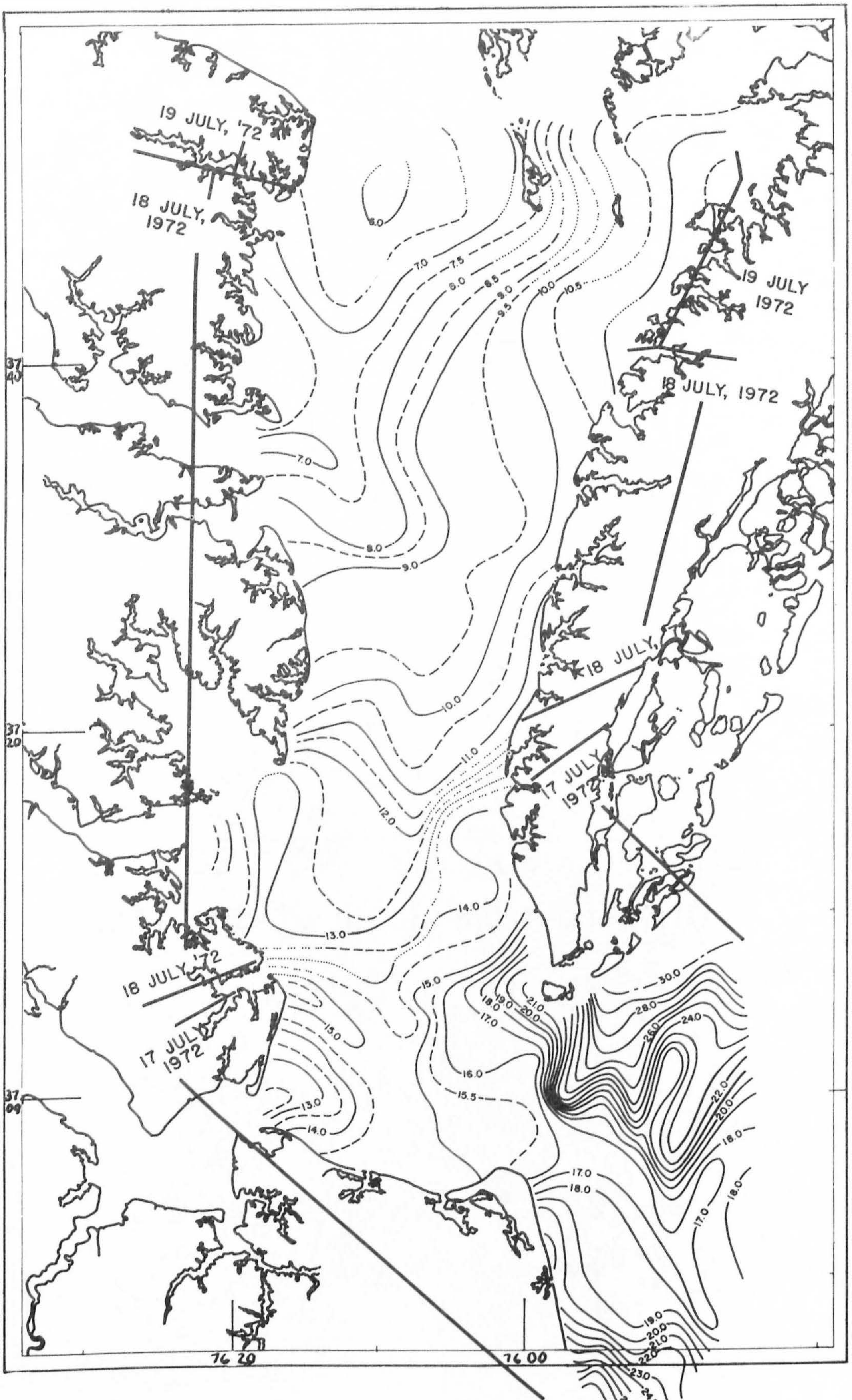


Figure 2.15. Surface salinities of lower Chesapeake Bay and nearshore shelf region based on samples collected on 17, 18 and 19 July 1972. (V.I.M.S.)

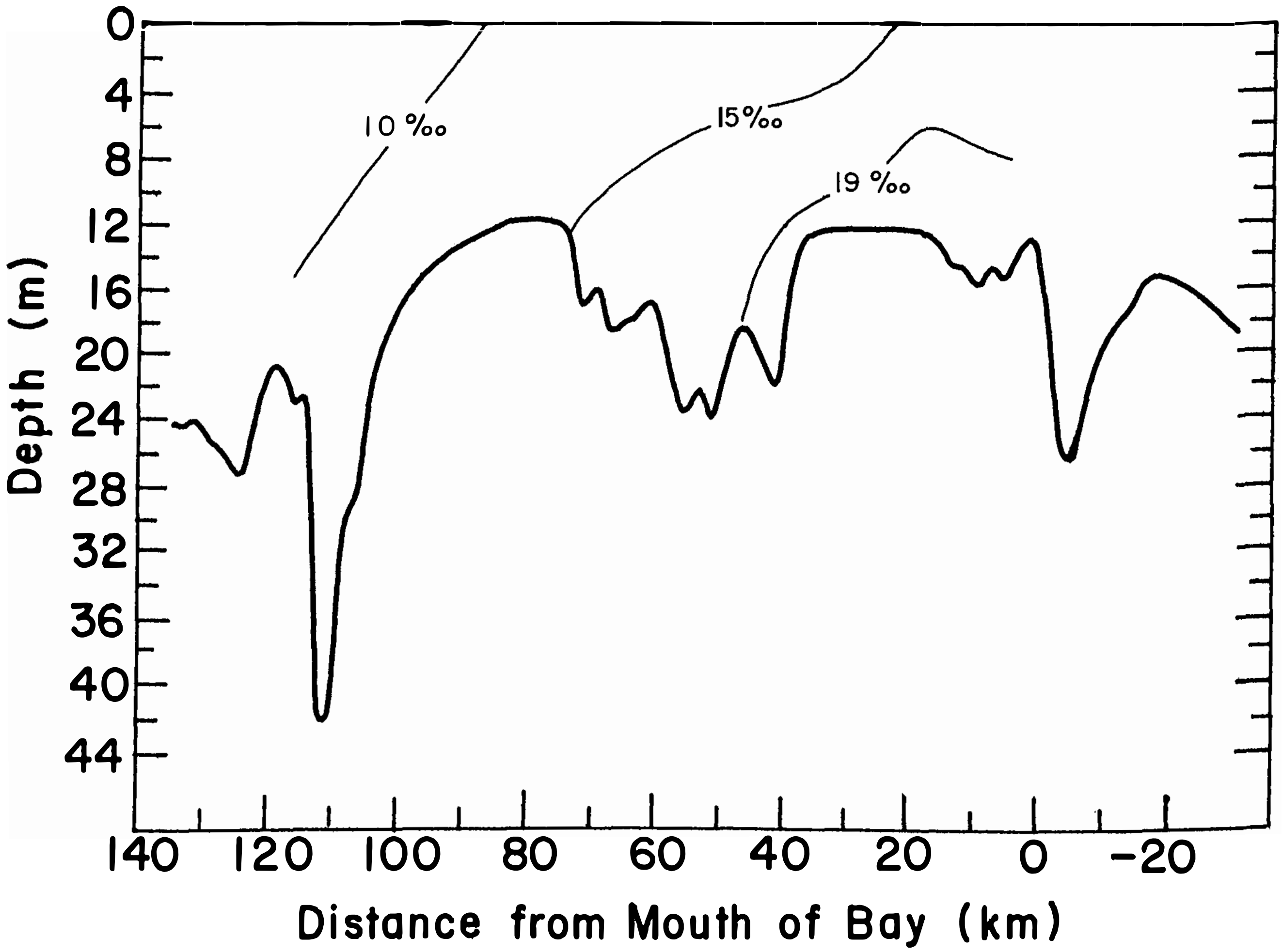


Figure 2.16. Salinity distribution along the axis of lower Chesapeake Bay on 13 July 1972. (V.I.M.S.)

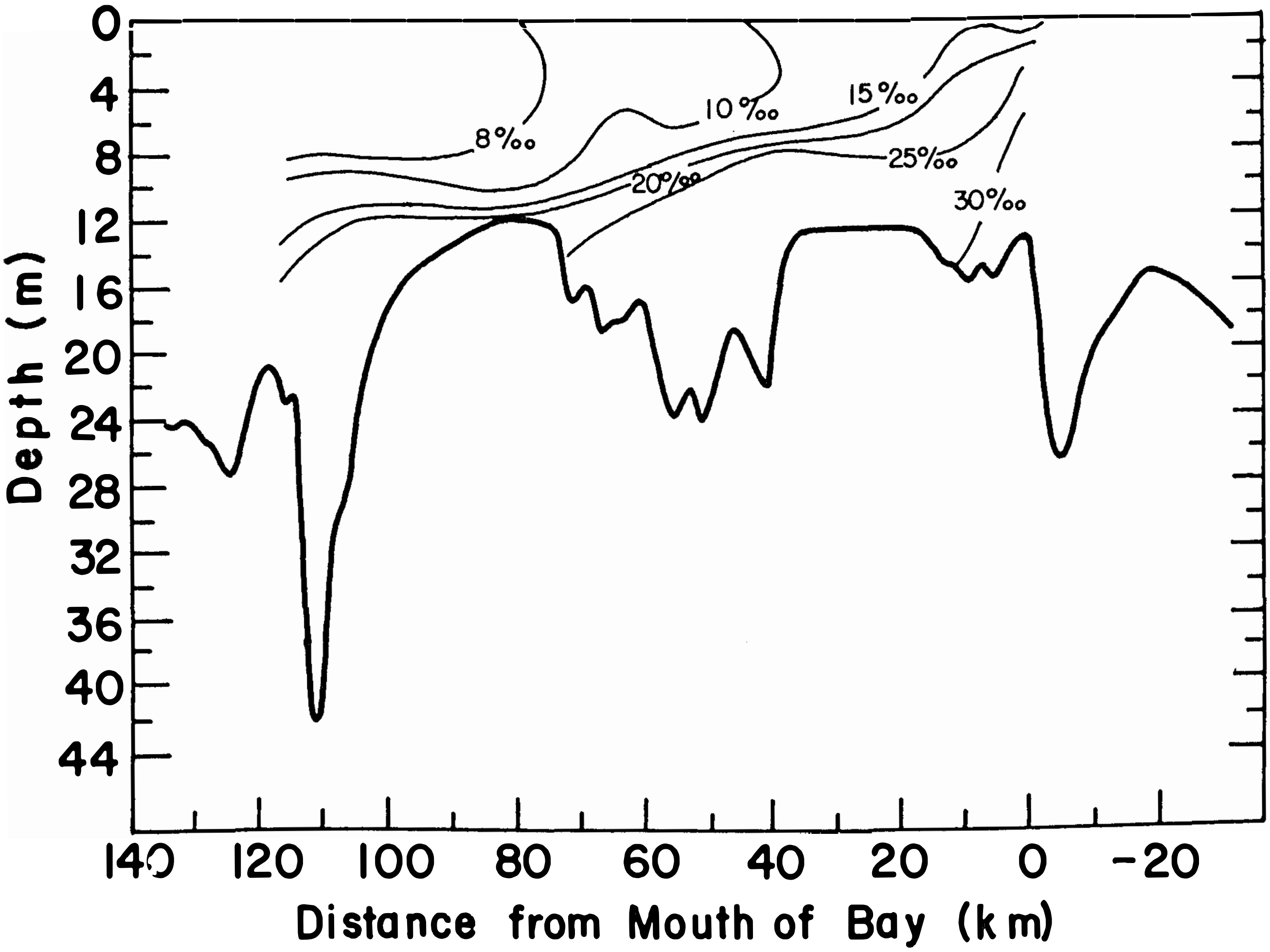


Figure 2.17. Salinity distribution along the axis of lower Chesapeake Bay on 27 July 1972. (V.I.M.S.)

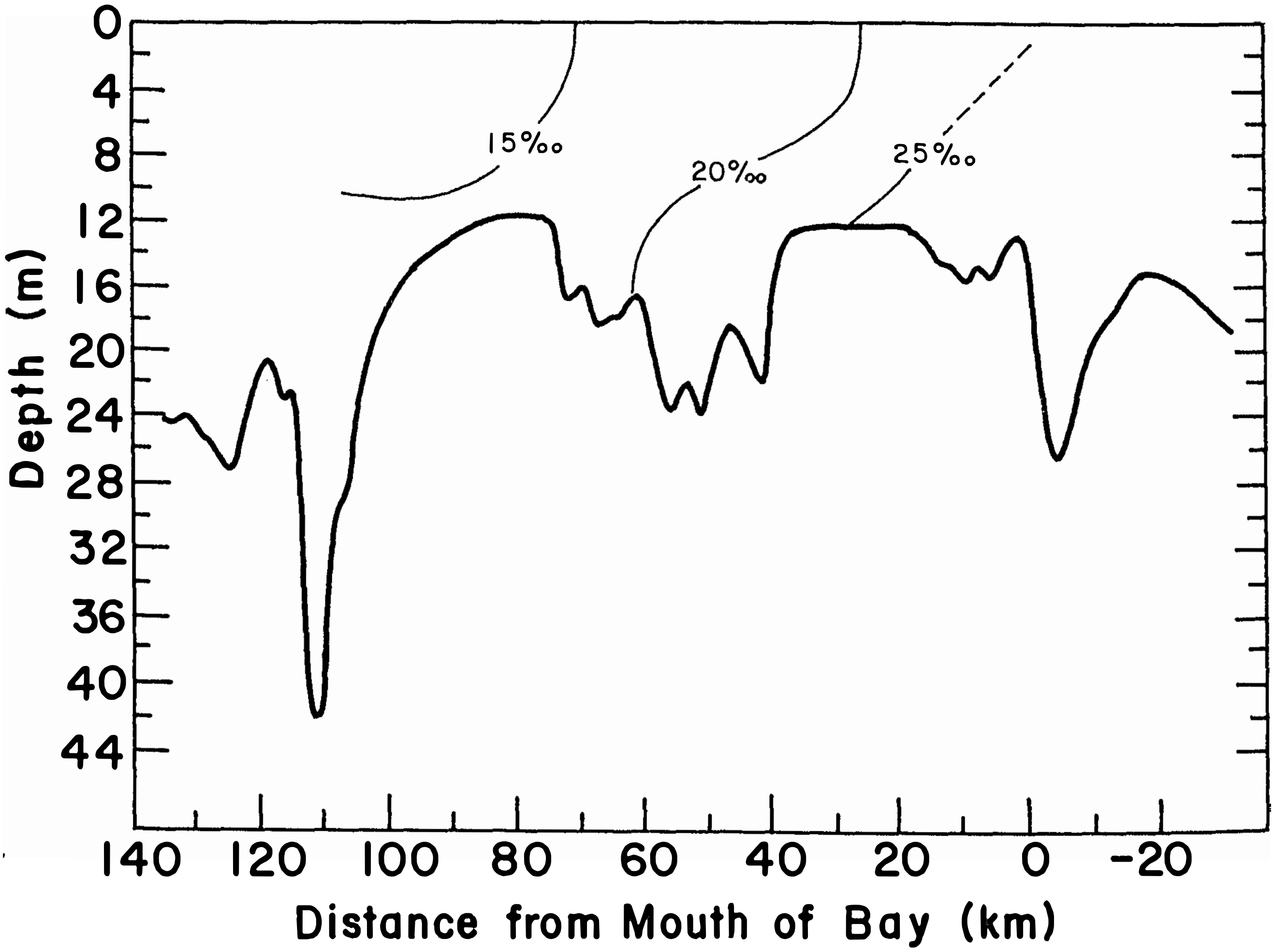


Figure 2.18. Salinity distribution along the axis of lower Chesapeake Bay on 31 August 1972. (V.I.M.S.)

another by intrusions of saltier, shelf-derived water on the flood tide. This feature is evident from data collected on 7-8 July (Fig. 2.19 and 2.20). These figures also indicate that the flood-derived waters remained in the upper 10 meters and tended to flow southward along the coast. The southward flow shows plainly in Figure 2.21, a map of surface salinities over the continental shelf between 28 June and 2 July 1972.

2.7 Present and Future Research

The temporal and spatial changes of the salinity distribution throughout the Chesapeake Bay estuarine system and in the waters overlying the adjacent continental shelf are being closely monitored. An intensive sampling program was initiated during the period of flooding. Sampling will be continued through at least one calendar year from the time of Agnes. This data will not only be useful in documenting the recovery of the Bay to normal salinity levels following such an event, but will also be useful for a number of other purposes. The data will be useful for verifying the hydraulic model. Verification that the model could reproduce the time-varying salinity distribution observed under conditions as unusual as those associated with Agnes would greatly increase confidence that the model could be used to predict the consequences of man's activities that fall outside the range of conditions used in the adjustment of the model. The data will also be valuable in verifying numerical models of the time-varying salinity distribution in the Chesapeake Bay and its tributaries. In addition, the physical data on temperature and salinity are essential in interpreting the sequence of biological changes that occurred following Agnes.

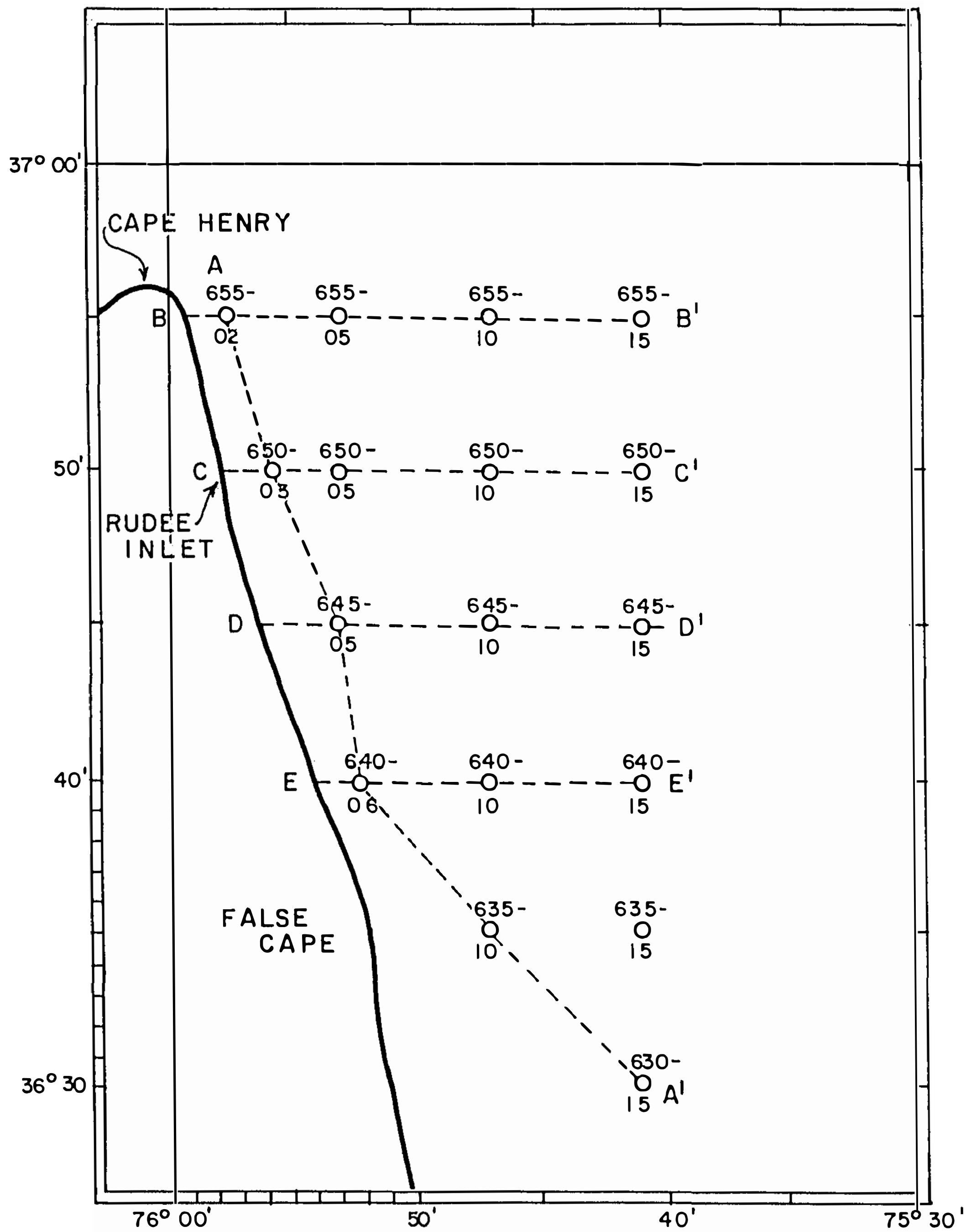


Figure 2.19. Chart showing positions and designation of stations occuped on VIMS Operation Agnes Cruise I, 7 and 8 July 1972. Dashed lines refer to salinity sections in figures 2.20A through 2.20E. (V.I.M.S.)

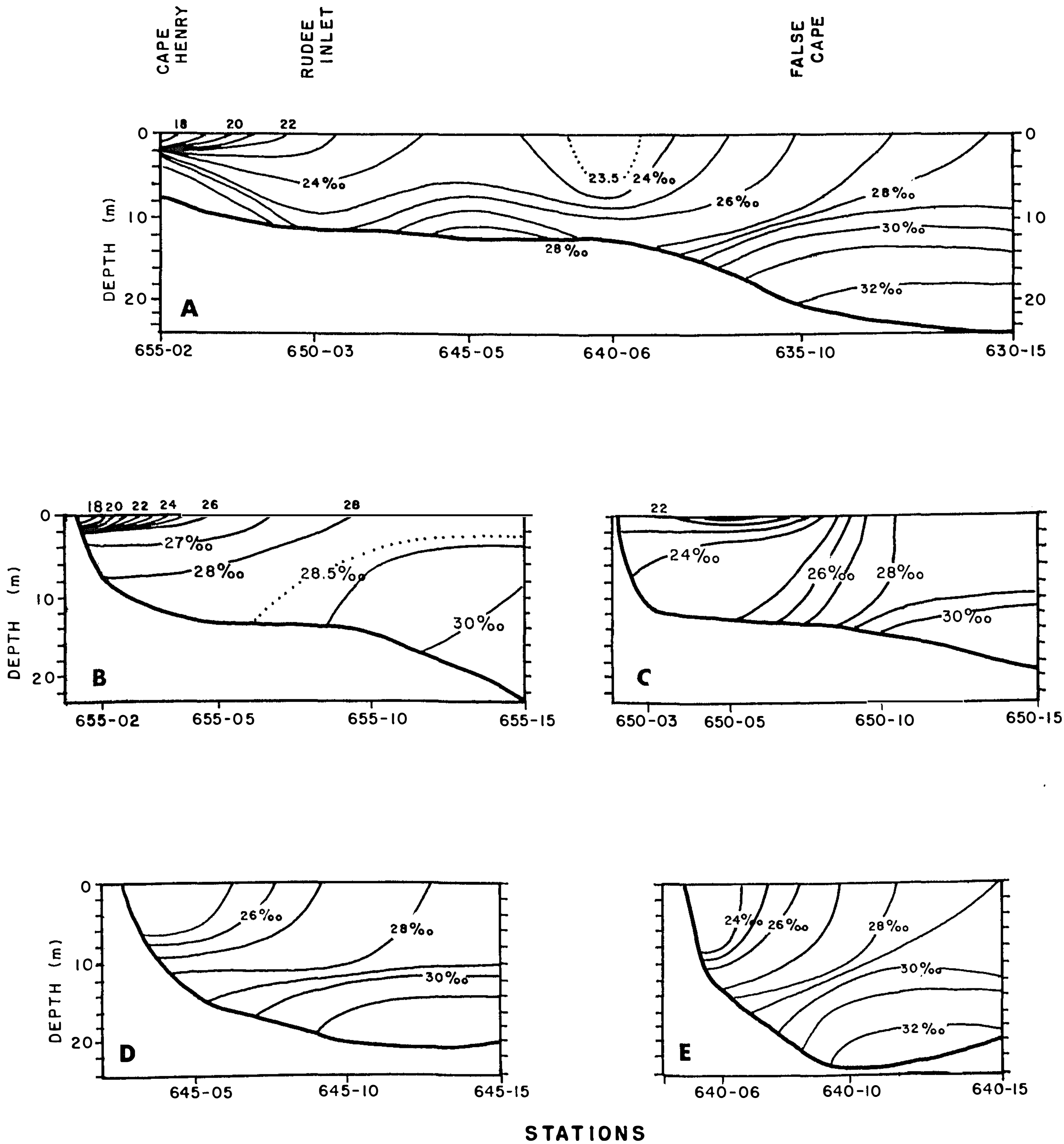


Figure 2.20. Salinity sections of nearshore shelf region showing effect of flood waters resulting from Tropical Storm Agnes. (V.I.M.S.)
a) Section along line A-A' of Figure 2.19.
b) Section along line B-B' of Figure 2.19.
c) Section along line C-C' of Figure 2.19.
d) Section along line D-D' of Figure 2.19.
e) Section along line E-E' of Figure 2.19.

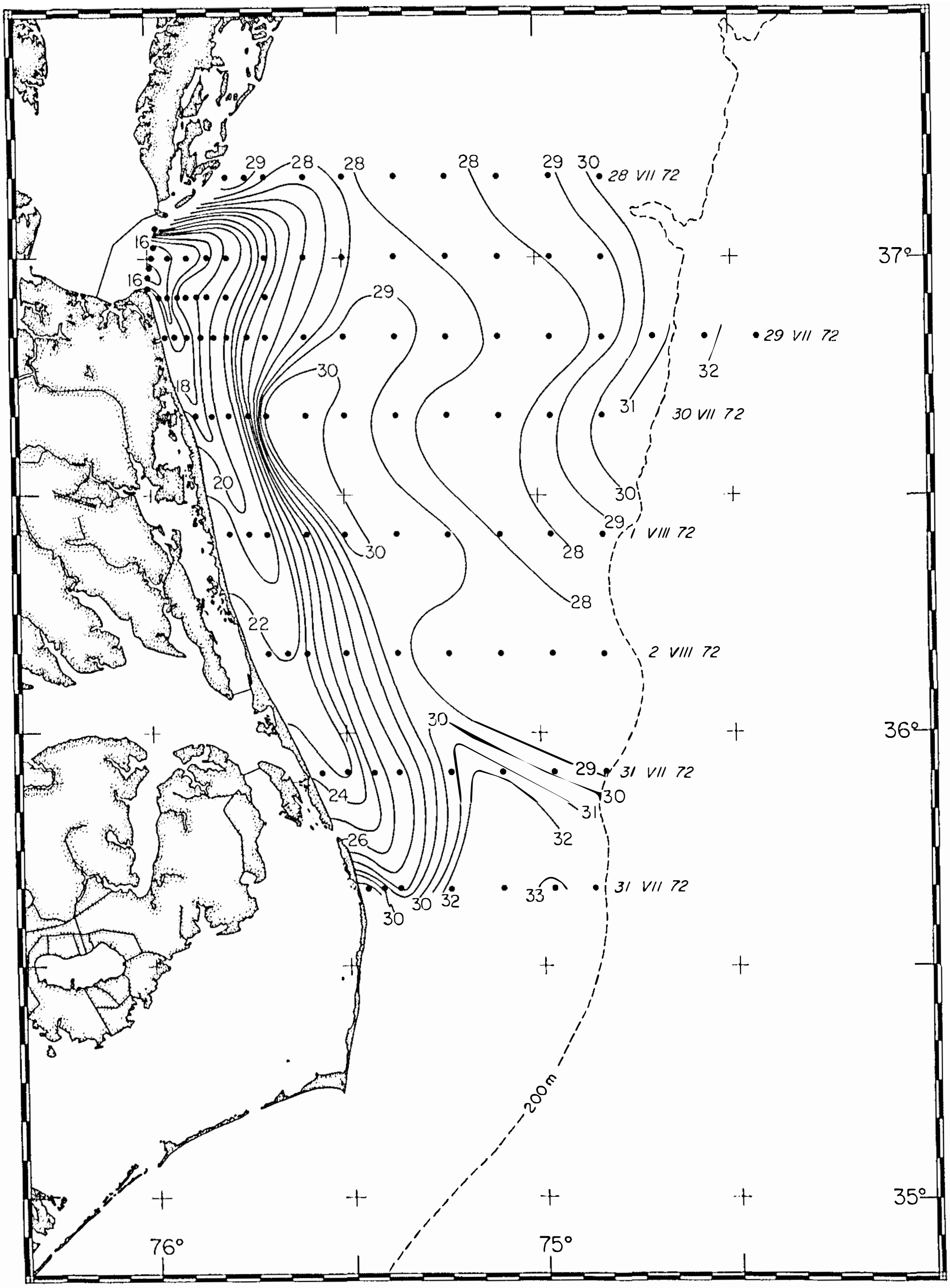


Figure 2.21. Map of surface salinity in the waters overlying the continental shelf off the mouth of Chesapeake Bay, 28 June to 2 July 1972. (C.B.I.)

2.8 Summary

The estuaries of the Potomac, Patuxent, James, York, and Rappahannock Rivers, and Chesapeake Bay proper responded somewhat similarly to the flood waters of Hurricane Agnes. In each case estuarine waters were initially translated downstream, with the surface waters being more affected than the bottom waters. The waters were then subjected to an upstream intrusion of more-saline bottom waters, resulting in strong vertical salinity stratification with a layer of fresh water(up to 10 meters thick) on the top. A second downstream translation of the estuarine waters created vertical mixing and tended to reduce the stratification. Finally the waters tended toward uniform salinities from top to bottom at any station, with the salinity of each estuary gradually increasing towards its mouth.

Early surface measurements in Chesapeake Bay indicate that flood waters traveled down the western and central portions of the bay bypassing higher salinity waters in adjacent embayments on the east side (e.g., the Choptank River and Pocomoke Sound) which were not immediately affected by Agnes.

Freshened bay water passing on to the continental shelf did so as pulses with some tidal association. These pulses of freshened water tended to travel southward along the coast.

A convenient table summarizing the sequence of salinity changes in the Bay gives the position of several isolines of salinity as a function of time (Table 2.1). Observed data have been interpolated to prepare this table, which lists the distance from the head of the Bay (at Havre de Grace) for the salinity values of 1‰, 5‰, 10‰, 15‰, and 20‰, for approximately uniform time intervals extending from some 15 days prior to the cresting of the fresh water inflow to the Bay to 30 August, 1972, some 68 days after the passage of Agnes. Lookout Point, at the mouth of the Potomac River, is 181 kilometers (98 nautical miles) below the head of the Bay at Havre de Grace. The mouth of the Chesapeake Bay at the Virginia Capes is 320 km (173 nautical miles) from the head of the Bay.

Table 2.1 shows that water having salinities of 5‰ or less moved down the Bay from about Love Point above the Bay Bridge just before Agnes to a position between Poplar Island and Plum Point by the 27th of June, about 3 days after the cresting of inflow from the Susquehanna. This represents a down-Bay movement of this salinity value of some 72 nautical miles. Note also that the 15‰ isoline of salinity moves out of the Bay and into the ocean during the interval from the 30 July through the 10th of August. Thus the minimum salinity at the mouth of the Bay was not reached until about 40 to 45 days after the passage of Agnes.

Table 2.1. Distances from the head of Chesapeake Bay (in nautical miles) for specific values of salinity, on specified dates. (C.B.I.)

	At the surface					On the Bottom				
Date, 1972	1‰	5‰	10‰	15‰	20‰	1‰	5‰	10‰	15‰	20‰
10 June	26	41	135	157	170	19	23	36	39	129
20 June	23	37	134	156	169	16	20	32	36	124
25 June	55	82	147	163	170	26	36	44	59	124
27 June	52	109	153	165	171	29	39	48	86	128
30 June	48	106	154	168	173	26	29	44	113	132
5 July	43	98	148	166	173	23	28	46	127	134
10 July	39	90	143	162	172	21	28	50	127	135
15 July	36	82	137	164	172	21	31	54	126	135
20 July	32	74	132	167	173	21	35	56	123	135
25 July	24	80	131	171	Ocean	19	27	42	89	114
30 July	23	70	147	Ocean	Ocean	18	21	30	50	79
5 August	25	36	162	Ocean	Ocean	17	20	24	30	44
10 August	23	30	150	Ocean	Ocean	15	20	28	32	45
15 August	19	28	125	164	173	12	19	33	34	60
20 August	17	28	104	151	166	12	19	33	36	64
25 August	17	29	98	145	163	14	20	31	37	63
30 August	18	31	98	143	160	16	22	29	36	62

SECTION 3. GEOLOGICAL EFFECTS

3.1 Suspended Sediments

3.1.a General

The flooding that accompanied the passage of tropical storm Agnes dumped large masses of sediment into the Chesapeake Bay estuarine system. Sediment is the archenemy and ultimate conqueror of every estuary. As an estuarine basin is filled with sediment the intruding sea is displaced seaward and the estuarine basin is gradually transformed back into a river valley system. For the past several years scientists have been monitoring the major inputs of sediment to the upper Chesapeake Bay and have been attempting to assess the relative contributions of the various sources to the sediment suspended in the waters of the Bay. Agnes presented these scientists with an unprecedented opportunity to document the relative importance of a catastrophic event in the geological life of an important estuary.

Sediments are introduced into the Bay by rivers, by shore erosion, and by primary productivity. The sources are thus external, marginal, and internal. In the upper Bay the external sources predominate, but in the rest of the main body of the Bay the marginal sources are probably the major contributors. The Susquehanna is the only river that debouches directly into the main body of the Bay; the other rivers flow into estuaries formed by the drowning of the lower reaches of these rivers.

3.1.b The Upper Bay

The Susquehanna, with an average sediment discharge of about 0.5 - 0.7 million tons per year, is the largest supplier of river-borne sediment to the main body of the Chesapeake Bay. The sediment discharge was considerably larger before construction of the reservoirs along the lower reaches of the river. The reservoirs trap nearly all of the coarse sediment load.

During most years, the bulk of each year's supply of new fluvial sediment is introduced during the spring freshet, the time when both river flow and the concentration of suspended sediment are normally the highest. In 1969, for example, more than 50% of the total sediment yield was discharged during the spring period of high runoff. Even during a freshet, suspended sediment concentrations greater than 200 mg/ℓ (=ppm) below Conowingo are unusual. In 1969 the highest value observed at Conowingo was only 57 mg/ℓ. In 1970 the highest concentration of suspended sediment was 253 mg/ℓ, and the concentration exceeded 100 mg/ℓ only 5 days during the entire year. In 1971 the highest concentration observed was 142 mg/ℓ, and it exceeded 100 mg/ℓ on only 4 days. During the spring freshet of 1972 in March when river flow exceeded 315,000 cfs the concentration of suspended sediment reached 190 mg/ℓ. Between 1 January 1972 and 21 June 1972 the concentration of suspended sediment exceeded 100 mg/ℓ on 4 days. During May and the first 20 days of June 1972 the concentration of suspended sediment at Conowingo was generally between 10 - 25 mg/ℓ being somewhat higher than normal for this time of year.

For contrast, look at the sediment loads caused by Agnes. On 22 June 1972 river flow rose rapidly as a result of the heavy rainfall accompanying the passage of Agnes, and the concentration of suspended sediment reached 400 mg/ℓ. On 23 June 1972 when river flow increased to 862,350 cfs at Conowingo the concentration of suspended sediment jumped to more than 10,000 mg/ℓ (10 grams/liter) --a concentration more than 40 times higher than any value we had ever observed in our daily sampling over the past 6 years. This was the concentration of suspended sediment on the downstream side of Conowingo; the concentration <u>after</u> the river had passed through the Safe Harbor, Holtwood, and Conowingo reservoirs. This value represents the concentration of suspended sediment in the flood water being discharged into the Chesapeake Bay. Unfortunately, no sample was collected on 24 June 1972, the day the river crested. The average flow on that day was more than 980,000 cfs. On 25 June 1972 the concentration of suspended sediment at Conowingo had fallen to 1456 mg/ℓ and the river flow to 814,734 cfs. By 30 June 1972 the concentration of suspended sediment was down to about 70 mg/ℓ and the river flow had subsided to 162,400 cfs.

Preliminary estimates indicate that the mass of sediment discharged by the Susquehanna during the 7 day period from 22-28 June 1972 exceeded the total mass of sediment discharged during the past decade, and perhaps during the past half century. The bulk of this sediment was silt and clay-sized material, but a significant amount of fine sand was also discharged. The sediment discharges of the other rivers tributary to the Maryland portion of the Bay were also unusually high but there are few data on the concentrations of suspended sediment for any of these rivers.

The high discharges of suspended sediment by the Susquehanna and the other rivers produced anomalously high concentrations of suspended sediment throughout much of Chesapeake Bay and its tributaries.

In the upper Bay following Agnes there was a sharp downstream decline in suspended sediment. On 26 June 1972 the concentration of suspended sediment at the surface dropped from more than 700 mg/ℓ off Turkey Point at the head of the Bay to about 400 mg/ℓ at Tolchester and to approximately 175 mg/ℓ at the Bay Bridge off Annapolis, Figure 3.1. On the same day the concentration of suspended sediment at mid-depth showed the same distribution pattern. These concentrations were considerably higher than any previously recorded in the upper Bay. By 29 June 1972 the concentrations of suspended sediment had decreased considerably, primarily as a result of the settling out (sedimentation) of the fine particles, but the concentrations were still anomalously

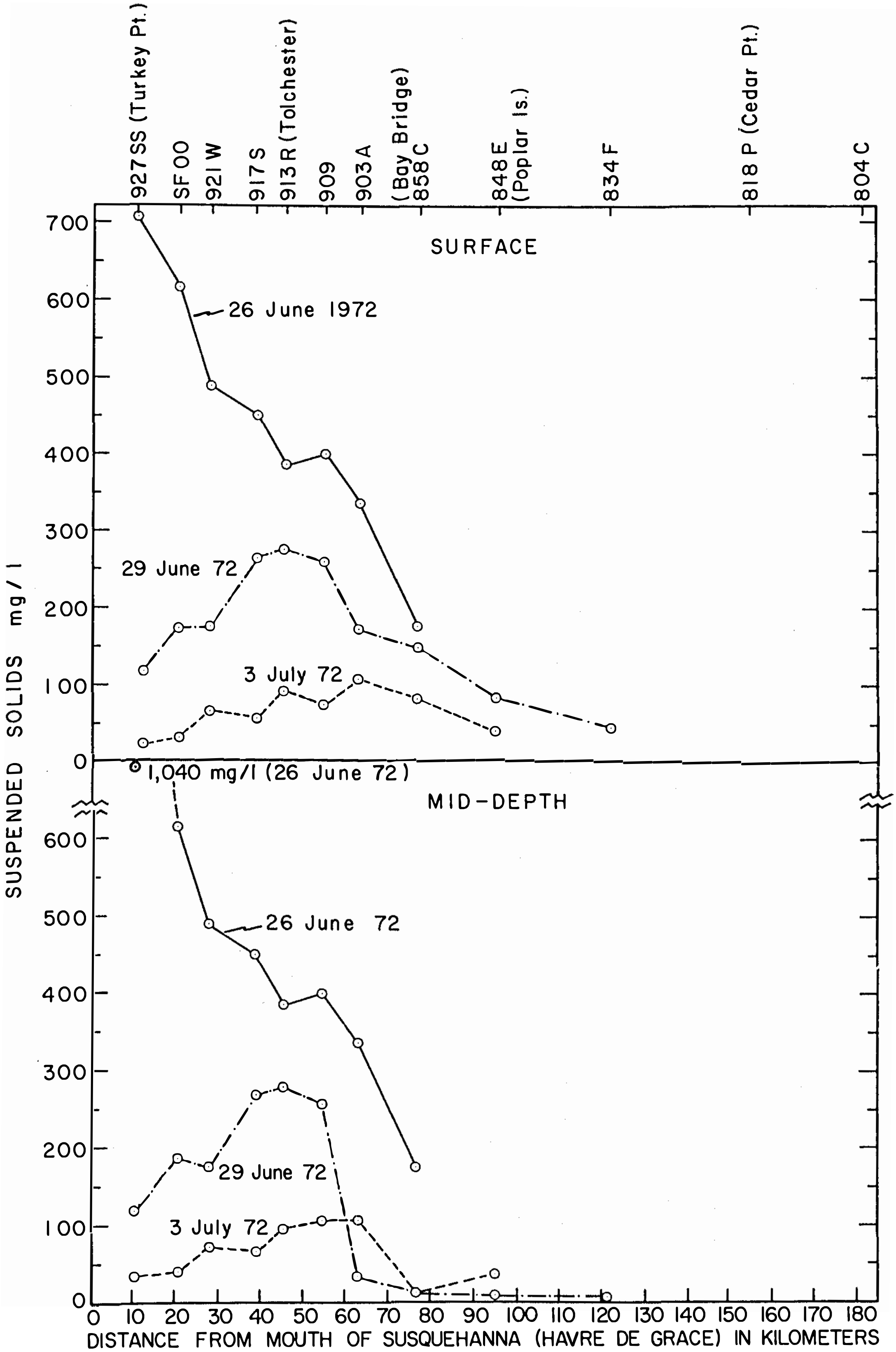


Figure 3.1. Longitudinal variations of the surface and mid-depth concentrations of suspended sediment along the axis of the upper Chesapeake Bay following Agnes. The Susquehanna River crested at 0200 on 24 June 1972 at Harrisburg, Pa. (C.B.I.)

high. The concentrations of suspended sediment remained abnormally high, particularly in the upper Bay, until the latter part of July, (Figure 3.2).

3.1.c Virginia's Estuaries and Lower Chesapeake Bay.

Detailed analysis of the effects of Agnes on sediments in the lower Chesapeake Bay and tributaries is not yet complete. Analysis is most advanced on Rappahannock River data, and some data for the mainstream of the Southern Bay has been summarized. In general, record amounts of sediment were brought into Virginia waters by Agnes. Fine particles appear to have been swept through the rivers into the mainstem of the Bay while large amounts of coarse particles sedimented by gravitation in the lower basins of the rivers.

Rappahannock River:

Agnes caused a record influx of more than 0.9 million tons of sediment to the Rappahannock River. More sediment was carried into this river during 15 days of flooding than during 6 years of average inflow. The high sediment influx temporarily overwhelmed the turbidity maximum that normally resides at the inner limit of salty water. Concentrations reached 300 to 400 mg/ℓ throughout the upper Rappahannock on June 24th. (Figure 3.3). Concentrations of 40 to 100 mg/ℓ persisted for two weeks. Size analyses of the suspensions indicate that most fine particles flushed through the Rappahannock mouth into Chesapeake Bay whereas coarse clay and silt particles sedimented by simple gravitational settling, rather than by floculation. A large amount of sediment must have accumulated in the lower Rappahannock basin by particle settling from the surface layer.

Recovery from major flooding was marked by increased salinity, first in the surface layer and later in the lower layer. The estuary slowly changed from a highly stratified to a partially mixed circulation system. The transition

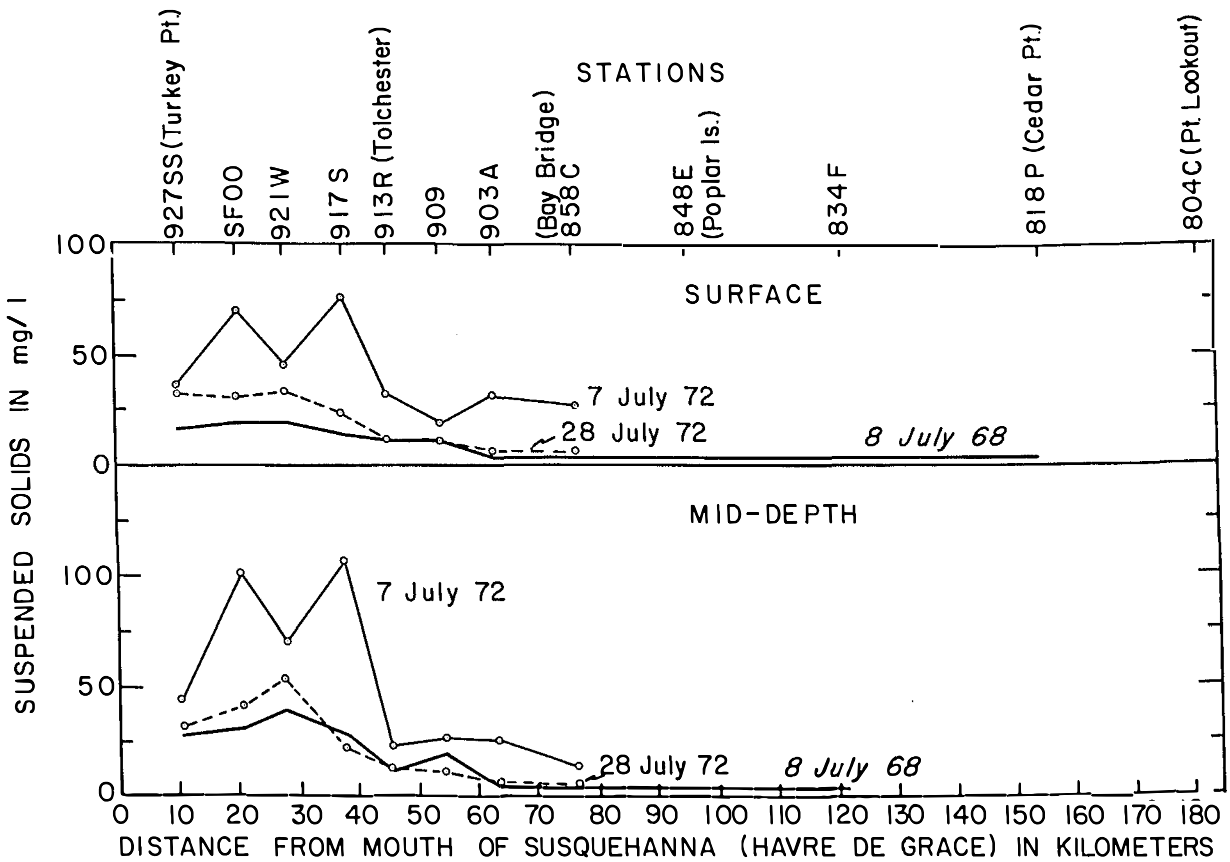


Figure 3.2. Longitudinal variations of the surface and mid-depth concentrations of suspended sediment along the axis of the upper Chesapeake Bay following Agnes. (C.B.I.)

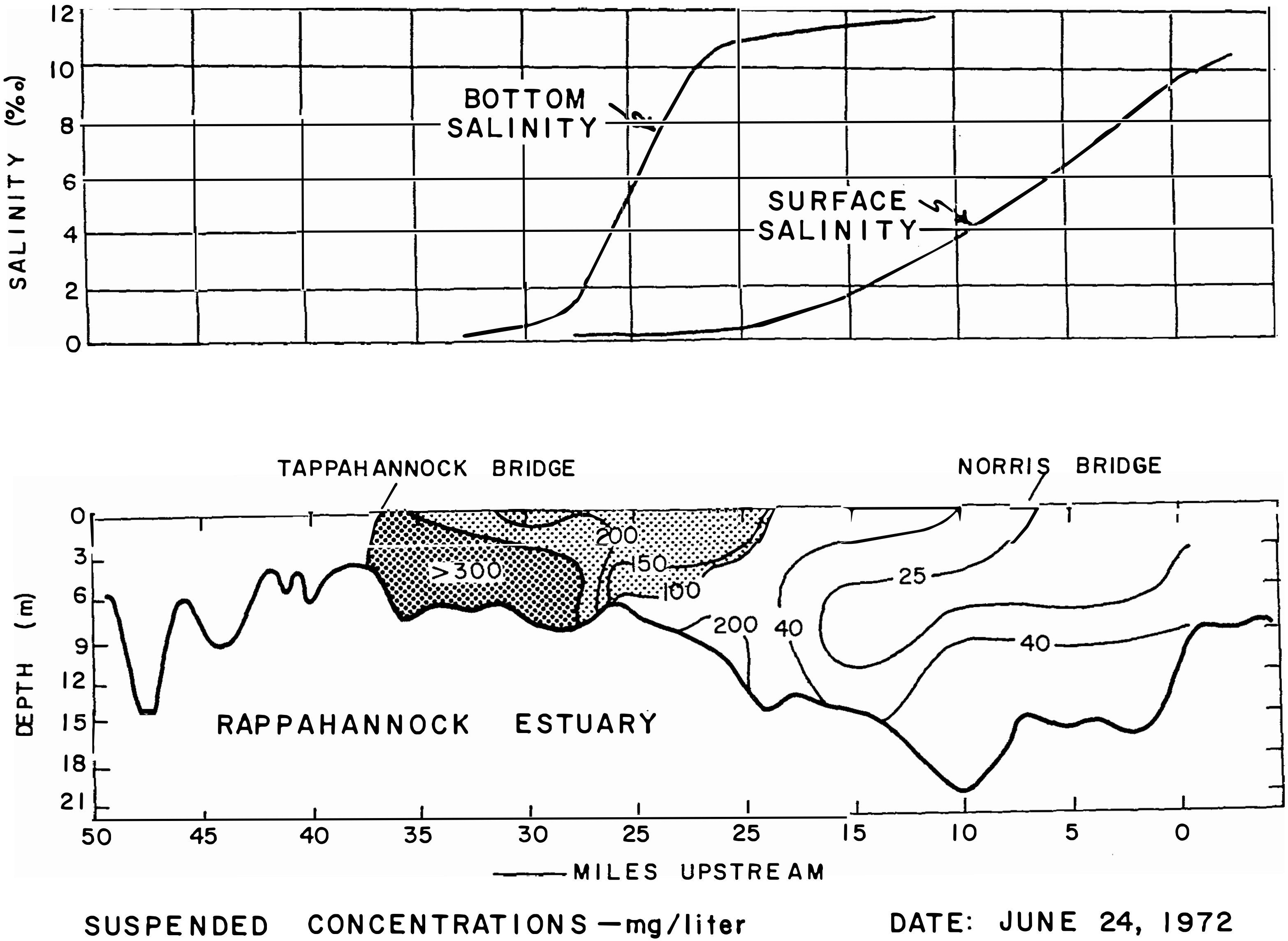


Figure 3.3. Distribution of total suspended sediment concentration in mg/l on June 24, 1972. Isopleth greater than 300 mg/l delineates maximum concentrations throughout water column just above the inner limit of salty water. (V.I.M.S.)

was accompanied by relocation of the turbidity maximum in the upper estuary. The sedimentary regime returned from essentially a bypassing to a trapping mode. The unique dynamic conditions provide a new insight into the processes of sediment transport and deposition.

The high freshwater discharge produced intense haline stratification with a low salinity surface layer 5 m thick. The normally partly mixed circulation system became a highly stratified system and upstream flows along the bottom were accelerated by 30 percent. The low salinity surface layer allowed seaward transport of sediment over shoals that normally are sites of deposition. However, the intense stratification trapped some sediment locally on the channel floor at the head of the salt intrusion.

Lower Chesapeake Bay:

Previous work on turbidity in the southern part of Chesapeake Bay is limited, but one study showed June-July turbidities in 1970 to be about 4.2 mg/l of suspended sediment in the vicinity of the northern section, and 3.1 mg/l near the southern section (Schubel, et al., 1970). Thirteen-hour average turbidity at the northern section on July 24, 1972 was 17.6 mg/l suspended sediment, and at the southern section on July 27, 1972, 37.4 mg/l. Thus, suspended sediment load was averaging 5-10 times greater than 1970. Also unusual is the abnormally high turbidity at the Bay Mouth; apparently due to local conditions and not due to the transport of a massive sediment plume down the Bay itself, as there was no such large sediment load passing through the northern section during the observation period. Table 3.1 shows spot-checked average turbidities at the two sections for all the sampling periods.

3.2. Sunlight Penetration

The high concentrations of fine-grained suspended sediment markedly limited the depth of penetration of sunlight and therefore the depth of the euphotic zone. In the upper Bay above Tolchester, less than 1% of the sunlight incident on the water surface reached a depth of 10 cm (=4 in) during the flooding period.

Table 3.1. Turbidities of lower Chesapeake Bay (mg/l suspended sediment). (V.I.M.S.)

Date	Northern Section	Southern Section
July 5, 1972	6.8	16.1
July 10	11.6	----
July 13	----	15.8
July 17	9.4	----
July 21	----	26.9
July 24	17.6	----
July 27	----	37.4
August 17	----	22.1

3.3 Erosion and Deposition

The important geological effects of Agnes on the Bay were depositional in character. There is little evidence of any erosion of the floor or shores of the Bay from the flood waters of tropical storm Agnes. Some erosion occurred in the upper reaches of some of the tributary estuaries, but most of the serious erosion occurred farther upstream. Large quantities of soil were stripped from the land and carried downstream by the rivers. The bulk of the material transported by the rivers was deposited in the upper reaches of their estuaries. Most of this material was fine-grained sediment, silt and clay, but significant amounts of sand were transported into the upper reaches of some of the tributaries.

Most of the coarse material carried by the Susquehanna was trapped in the reservoirs along the lower course of the river. The bulk of the sediment discharged by the Susquehanna past the most downstream reservoir at Conowingo was deposited in the upper Chesapeake Bay, north of Pooles Island. A number of small islands were formed on the Susquehanna flats below Havre de Grace during the floodings. These islands, formed of mud and fine sand discharged by the Susquehanna, are all of low relief and are being rapidly eroded. Not all of the sediment carried by the Susquehanna was deposited near the head of the Bay, however. Significant quantities of fine sediment were transported much farther down the Bay. A clearly identifiable layer of Susquehanna flood sediment was present south of the Bay Bridge at Annapolis.

A large number of cores were taken in the upper Chesapeake Bay to delineate the depositional patterns of the Agnes sediment. The thickness of the flood sediment is being determined in each core, and from these measurements a map will be made of the thickness of the new layer of sediment. The mass of Agnes sediment deposited in the upper Bay will be determined from these measurements and from measurements of the water content of the sediment. This mass will be compared with the estimate made of the mass of sediment discharged into the Chesapeake Bay by the Susquehanna. The latter estimate is based on measurements of water discharge and the concentration of suspended sediment at Conowingo. The analysis and interpretation of these data will take several months to complete but the results will provide valuable insight into the sedimentation processes that characterize "catastrophic" events, such as Agnes, and in assessing their relative importance in the development of the Bay. Although such an event occurs on the average at a frequency of only once every 100 - 200 years, the total number of such events in the lifetime of an estuary may be sufficiently large and their magnitudes sufficiently great that they may play a major role in determining the geological lifetime of an estuary.

3.4 Some Important Geological Questions

Other major floods have certainly occurred throughout the Bay's history, and it is interesting to ask whether any record of these events has been preserved. Until a few hundreds of years ago there was, of course, no man-made record and the Bay's history was recorded only in the sediments that blanket its floor. This sedimentary history is recorded in the kinds of sediments that accumulate--their physical and chemical characteristics--and in the fossils they contain. The extent to which we can determine the Bay's history depends upon how much of that history was recorded and preserved, and upon how clever we are at deciphering it. To aid us in understanding the Bay's past and in predicting its future, we study the present.

Will a record of the most recent flood, the flooding from tropical storm Agnes, be preserved in the sediments of the Chesapeake Bay? Will the layer of flood sediment be preserved as a discrete, identifiable sedimentary layer, or will it be destroyed by the normal processes, particularly by the activities of the burrowing organisms?

To answer these questions suites of cores were taken in the upper Chesapeake Bay and in the upper Gunpowder estuary. Some of the cores were examined visually to determine the thickness of the layer of new sediment. Other cores from the same locations were analyzed texturally to establish any differences in the size distributions of the flood sediment and the "normal" sediment accumulating in the Bay. Mineralogical determinations were also made and cores were examined by X-rays to reveal small-scale structural features, and to document the effects of burrowing organisms. These cores will be repeated at approximately monthly intervals to chronicle the persistence of the sedimentary evidence of tropical storm Agnes. This represents a major research effort.

SECTION 4. OTHER WATER QUALITY PARAMETERS

4.1 Bacteria

The Agnes floods inundated or caused physical destruction to numerous sewage treatment facilities around Chesapeake Bay and washed massive amounts of ran and partially-treated sewage into the bay.

A great number of water samples were collected and analyzed for bacteria, although little of the data from these samples is yet available. The levels of fecal coliform bacterial in upper Chesapeake Bay, however, were so great that the Maryland Department of Health and Mental Hygiene prohibited shellfish harvesting and water-contact sports. Virginia also closed its bay waters to shellfish harvesting.

4.1.a Maryland Waters

As part of an ongoing study of bacteria in the Patuxent River, water samples were collected from the Chesapeake Biological Laboratory pier at Solomons, Maryland. These samples were normally collected twice a week, on Monday and Friday, and innoculated into four media: (1) sea water agar for total bacteria, (2) lactose broth for estimating the most probable number of coliform bacteria, (3) purple dextrose for gram-negative, dextrose-fermenting, enteric bacteria, and (4) TCBS agar for cholera vibrios. The results are given in Table 4.1.

Hurricane Agnes shows its effects in the counts of total bacteria on sea water agar. Total bacteria counts were relatively low (200/ml) throughout April, May, and June; peaked on 3 July with a count of 3200/ml; and fluctuated throughout July, August, and September, with a gradual decline in numbers throughout these months (Figure 4.1).

Coliforms were relatively low throughout the spring and exhibited one peak early in May. Counts were exceptionally high (1600/100ml) throughout June and declined about the first week in July. Tidal fluctuations were evident through July, August, and September with a larger than usual count.

Table 4.1. Counts of bacteria from Patuxent River water collected from end of C.B.L. pier at Solomons, Maryland during 1972.

Date, 1972	Sea water agar Total bacteria (no./ml)	Lactose broth Coliformes (MPN/100 ml)	Purple destrose agar Gram-negative enterics (no./ml) (no./ml) Yellow	Other	TCBS agar Cholera Vibrios (no./ml) Green	Yellow
May 2	38	542	9	22	0	+[a]
16	170	9	30	8	0	13
23	21	0	0	7	0	0
June 13	126	1609	93	6	4	11
20	52	109	[b]	4[b]	3	11
27	223	1609	3	12	+	0
July 3	3200	27	11	30	2	3
6	630	14	42	24	0	0
7	490	7	126	270	1	+
11	290	25	[b]	194[b]	+	4
14	861	25	8	13	0	0
17	131	7	69	87	1	3
20	610	63	300	15600	3	12
25	1060	13	133	134	2	6
28	500	7	110	140	1	4
Aug. 1	370	27	290	300	3	5
4	686	21	137	270	9	6
7	152	33	107	97	0	0
11	830	30	12	87	1	2
14	348	141	260	940	4	11
18	677	26	137	1206	+	2
21	1013	9	83	1206	0	0
25	7	4	11	6	2	21
28	14	70	4	+	0	0
Sept. 1	360	7	2	91	2	2
5	26	9	2	111	0	0
8	43	11	14	32	0	0
11	190	49	100	200	32	30
15	840	14	45	633	8	4
18	563	8	460	176	10	5
22	348	340	53	270	6	2
25	240	11	10	29	4	6
29	286	49	21	140	0	0
Oct. 4	12	2	10	44	11	10

[a] + = less than 1.0/ml

[b] Counts not separated on these dates.

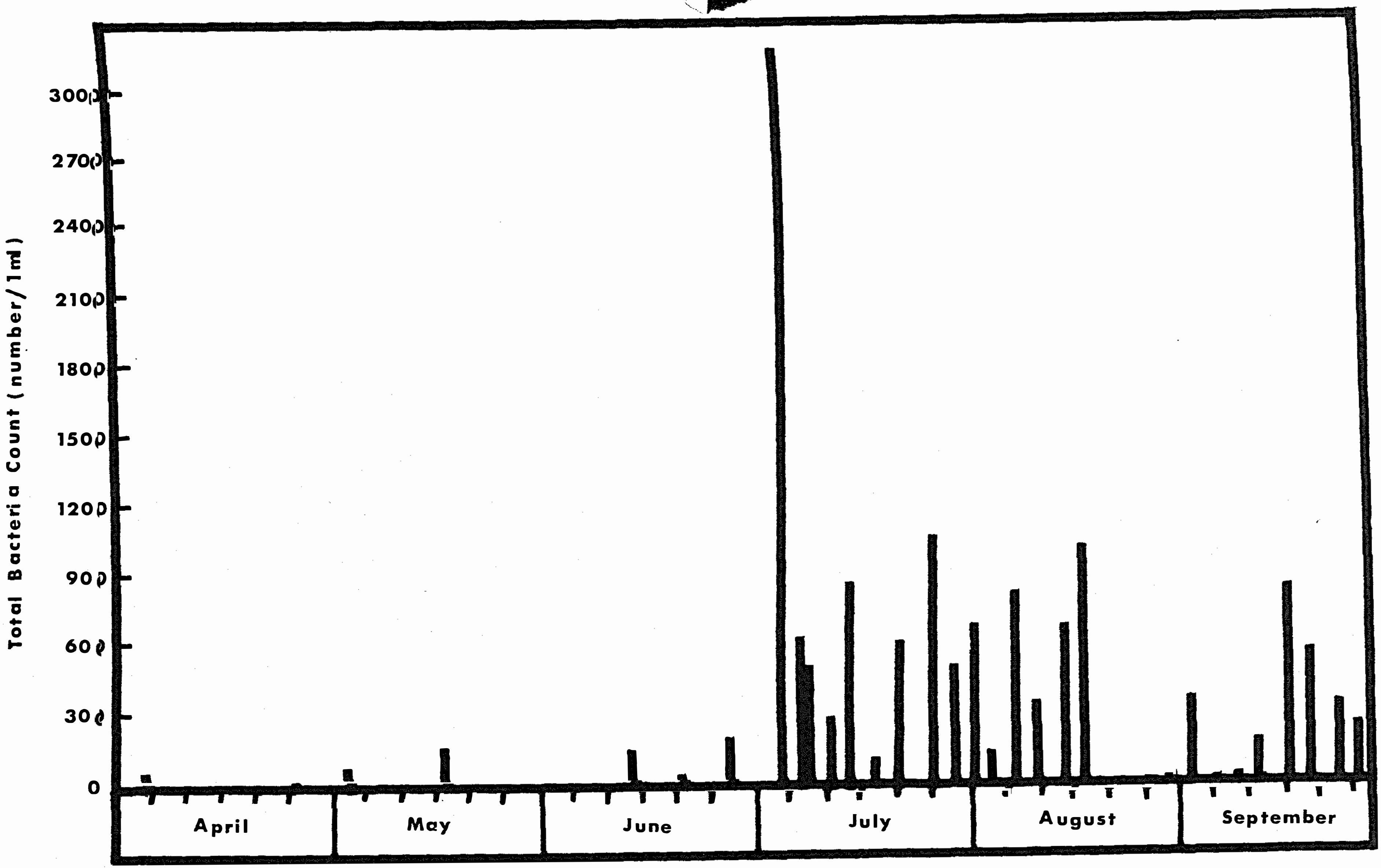


Figure 4.1. Counts of total bacteria (no./ml) on sea water agar from samples of Patuxent River water taken at the end of the C.B.L. pier at Solomons, Maryland. (C.B.L.)

Counts on purple dextrose agar were also moderate in the spring and exhibited three or four peaks throughout July and August. Gram-negative enteric bacilli (suggestive of fecal pollution) were exceptionally high throughout July, August, and September.

Counts on TCBS agar were relatively stable throughout the months of May-August showing normal increases and decreases with tidal fluctuations.

Closely related to bacterial contamination of the bay are illnesses caused by waterborne diseases. As shown in Figure 4.2., the reports of infectious hepatitis in Maryland hospitals increased sharply the first week in August (U.S.P.H.S, Center for Disease Control, 1972). Since the incubation period for infectious hepatitus is 4 to 6 weeks, the increase in the number of cases may be related to the Agnes floods.

4.1.b. Virginia Waters.

Detailed assessment of the bacteriological impact of Agnes in Virginia waters has not been completed. Threat of bacteriological loading resulted in immediate closing of all Virginia waters for taking of shellfish for direct consumption on 23 June 1972. Reopening of grounds closed as a result of Agnes began on 20 July in the lower part of the Bay including portions of the mouths of the James and York Rivers. All grounds closed as a result of Agnes were reopened on 5 October 1972. Although a rise in bacteriological indices occurred during the aftermath of Agnes, lack of appropriate seasonal baselines precludes assigning cause for all the rise to direct or indirect effects of Agnes at this time. Exchange of data with the Virginia Bureau of Shellfish Sanitation (VBSS) is providing the necessary background to further evaluate causal relationships between Agnes and bacteriological indices.

The preliminary evaluations presented below were developed from bacteriological reports received from the Virginia Bureau of Shellfish

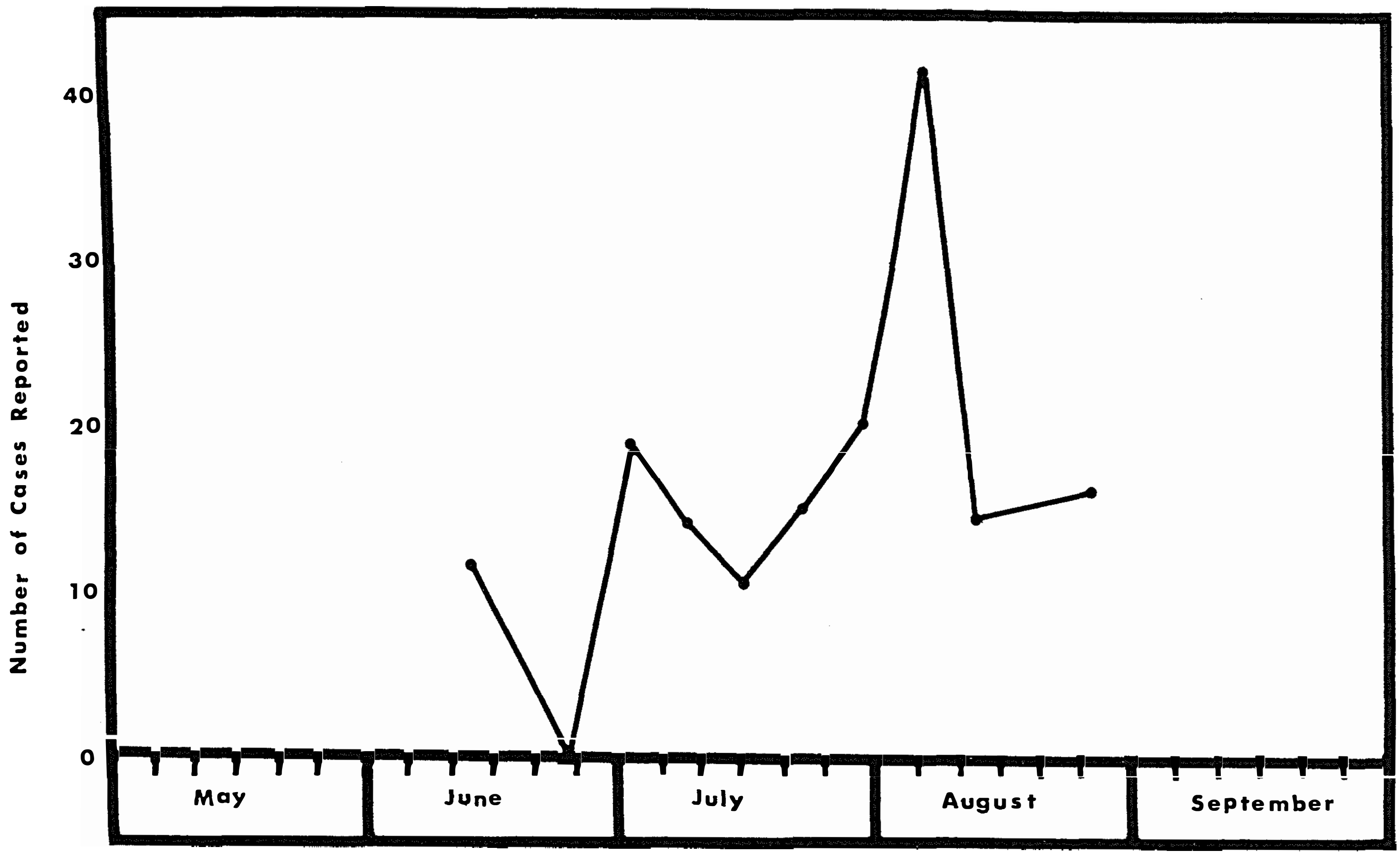


Figure 4.2. Number of infectious hepatitis cases reported in Maryland during the summer of 1972. (U.S.P.H.S., Center for Disease Control, 1972.)

Sanitation supplemented by some inhouse data from the VIMS Bacteriology Section. The data gathered by the VBSS was not designed to monitor the effects of Agnes, but to ensure that public health standards relative to shellfish harvest were being followed. As a result precise determination of Agnes direct and indirect effects on bacteriological populations must await analysis of VBSS and VIMS data in terms of hydrographic changes occurring during the flood and recovery. VBSS is cooperating by providing complete data both for the flood period and historical data from relevant areas. It must be emphasized that the interpretations presented here are preliminary and only those of VIMS personnel.

York River: Area 52-Goodwin Islands to Yorktown; A slight increase was noted at all stations except those nearest the shoreline of Goodwin Neck. A rise in the fecal MPN values were observed during the latter part of the week in July and into the second week. Station 15 which is east of the George P. Coleman Memorial Bridge was noted to have the highest number of fecal bacteria relative to all other stations in this area.

Area 46-Perrin River and Sarah Creek; Perrin River-Water samples collected from two stations in this area gave high fecal MPN values during the latter part of the first week in July and into the second week. High confirmed MPN values were also obtained on those dates with corresponding high fecal MPN's.

Sarah Creek Station 2, which is near the mouth of Sarah Creek showed both high fecal MPN's and corresponding confirmed MPN's during the latter part of the first week in July and into the second week. Fecal MPN's from water samples collected at Station 1 which is further out into the York River resulted in lower MPN values than those obtained at Station 2. The highest fecal MPN at Station 1 occurred in the second week of July.

Area 47-Gloucester Point to Allmondsville; The greatest number of fecal bacteria were recovered from each of three stations in this area at the end of the first week in July.

Although complete data is lacking with respect to the bacteriological events in the York River prior to Agnes, it apprears that our increase in fecal MPN values occurred after Agnes. Since the increase appeared first at upstream stations. Some of the increase can probably be attributed to the flood waters.

James River: Newport News to Deep Water Shoal; Generally, the fecal MPN values appeared to increase slightly during the first and second week of July. However, it must be noted that fecal MPN's of the same magnitude or greater occurred sporadically at previous dates in 1971 and 1972.

Warwick River; Slight rises in the number of fecal bacteria recovered from the mouth of the river were obtained during the second week in July. However, as discussed above, there were numberous fluctuations in fecal MPN values at previous time periods in 1971 and 1972. There was little if any apparent effect of Agnes on stations further upstream in the Warwick River. No significant effect could be seen in the Chuckatuck Creek, Batten Bay, and Nansemond River areas.

It is difficult to draw any valid conclusions from the available data for the James River and those rivers which flow into it. Slight increases were noted in only certain areas of the James River and at the mouth of the Warwick River. These rises in fecal bacteria may or may not reflect the influence of Hurricane Agnes. Data is available only for two periods in July, within four days of each other. It is possible that higher numbers of fecal and total coliform bacteria might have been found if more extensive sampling had been conducted.

Lower Bay: Old Point Comfort to Back River; During a four day sampling period in the second and third week of July, high numbers of fecal coliforms were recovered from Stations 019, B3, and B14.

Back River; During the second and third week of July the fecal MPN values in the Back River generally increased over those values obtained at earlier dates in 1971 and 1972. A simultaneous increase in the confirmed MPN values was also noted. A rise in the number of fecal coliforms was first observed at Station 16 which is upstream. Subsequent increases in fecal bacteria took place a couple of days later further downstream.

Poquoson River; Sufficient data prior to and following the flood was available for only Stations 1, 20, 27, 37, and 41. The results from Stations 20 and 37 showed slight increased in the fecal MPN values in the second week of July.

York River Mouth; Data obtained from samples collected at the York River mouth indicated that few fecal coliforms were present.

Potomac River; Sufficient bacteriological data during the time period prior to Agnes was not available and thus no true picture of the storm effects can be observed. However, of the five areas presented, Area 4 showed high fecal MPN's relative to other stations on the Potomac.

Eastern Shore; Data available for most areas of Eastern Shore, Areas 75, 77, 84, and 88, was characterized by fluctuating fecal MPN values during the month of July. There appeared to be no pattern to the increases and declines in the number of fecal coliforms with respect to time or events occurring at other stations within the same area. Data prior to Agnes was not available and thus no conclusions can be drawn as to the effects of Agnes.

Area Closings: All Virginia waters inland from a line closing Chesapeake Bay across its mouth were closed for the taking of shellfish for direct consumption on 23 June 1972. Various areas beginning with lower portion of the

Bay were reopened beginning on 20 July 1972. A list of closings and openings associated with Agnes is presented in Table 4.2. By 5 October 1972 all areas closed as a result of Agnes were reopened.

Table 4.2. History of closings and openings of Virginia Shellfish areas following bacterial contamination from the Hurricane Agnes floods.

Date	Action
23 June	All Virginia waters closed.
20 July	Lower Bay opened below New Point Comfort - Cape Charles City Range light line, except Mobjack Bay, York above Gloucester Point, and James (including an area south of the Old Point Comfort - Cape Henry Light line).
1 August	Mobjack Bay (except certain tributaries) and York to Bland Creek opened.
3 August	James and tributaries opened below a line north from Days Point except for areas normally closed. Bay opened below line from Cherry Point north east through southern tip of Tangier Island continuing to Md - Va. state line. Area south of Old Point Comfort - Cape Henry Light remains closed.
9 August	Remainder of Bay open except for south of Old Point Comfort - Cape Henry Light opened. Rappahannock River opened. Upper Piankatank and upper Great Wicomico remain closed.
5 October	All condemnation areas established due to Agnes opened. Normal condemnation areas remain in effect.

4.2 Nutrients

The heavy rainfall associated with tropical storm Agnes added not only large amounts of fresh water and sediment to the Chesapeake Bay estuarine system, but also large amounts of a number of other substances, including nutrients, heavy metals, pesticides, and herbicides. Many water samples have been collected, but few have been analyzed.

The set of samples for nutrient analysis will be of considerable value not only in assessing the impact of Agnes, but also in predicting the consequences of increased nutrient loading of the Bay from sewage treatment plant discharges.

4.2.a. Maryland Waters

The Chesapeake Bay Institute collected a large number of water samples from the Bay and selected tributaries for nutrient analysis. The samples were frozen, and only a few have been analyzed; but preliminary results indicate that following Agnes, nutrient concentrations in some areas were 5 to 10 times the "normal" levels for this time of year.

The Annapolis Field Office of the Environmental Protection Agency also collected water samples from the upper bay and the Potomac estuary for nutrient determinations. For July, EPA found that: (a) inorganic phosphorus values were slightly low, but not subnormal, with an average on the surface of about 0.05 ppm PO_4; (b) TKN (Kjeldahl nitrogen and ammonia) was approximately normal, values generally approximating 0.5 ppm N; (c) nitrate and nitrite (measured together, and presumably primarily nitrate) were extermely high at all stationa, normal values should be 0.05 to 0.4 ppm N, current values were approximately 1.0 ppm; and (d) ammonia values appeared to be normal, which ranges from 0.05 to 0.2 ppm N.

4.2.b. Virginia Waters.

Studies of the effects of Agnes on the nutrient budget of Virginia's waters were conducted in the mainstem of the Bay and on the adjacent continental shelf.

In the mainstem of the Bay, sampling stations were established along two transects of the Bay, a northern crosssection between Smith Point and Tangier Island, just south of the mouth of the Potomac River, and a southern cross section at the Bay Mouth, seaward of the Bay Bridge-Tunnel, between Cape Henry and Fisherman's Island (Figure 4.3). Sampling for dissolved and total nutrients and for turbidity was carried out at periodic intervals for up to seven weeks following the passage of the storm. Current meters were positioned at the section stations for calculations of nutrient and sediment fluxes. Salinity was measured on each sample.

Due to the nature of the various analyses, only some data are available at this time. Computer programs for the plotting of the data are still in preparation. Total nutrient levels have not yet been analyzed. Only analyses for inorganic dissolved phosphate and dissolved nitrate-plus-nitrate concentrations have been completed.

The inorganic dissolved phosphate concentrations are uniformly low, with 13-hour average concentrations on 24 July 1972 of 0.34 mg-at/l PO_4^- at northern section and 0.52 mg-at/l PO_4^- at the southern section. Again little nutrient data are available for these parts of the Bay for comparison purposes. Total phosphorous concentration for the Bay, which should be greater than or equal to the inorganic dissolved phosphate concentrations, are normally between 1 and 2 mg-at/l P (Schubel, 1972).

There is considerable difference in the nitrate-plus-nitrate concentrations between the northern and southern sections. The 13-hr average concentrations of NO_3^- + NO_2^- for the northern section on 24 July 1972 were

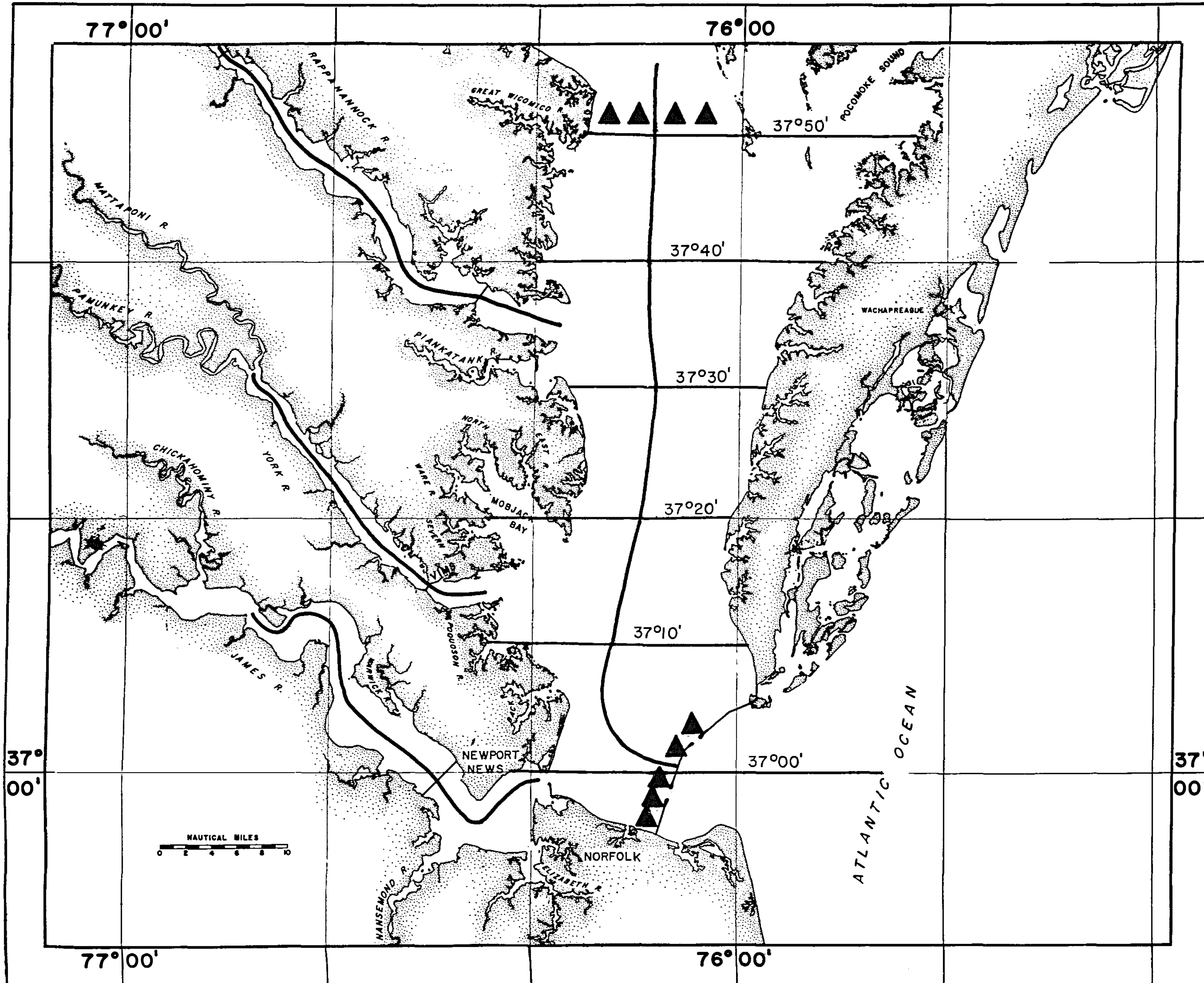


Figure 4.3. Locations of sampling stations for VIMS' nutrient studies.

26.6 mg-at N/l, and 1.4 mg-at N/l for the southern section on 27 July 1972. Normal nitrate concentrations in the Chesapeake Bay are very seasonal; they may range from as high as 45 mg-at N/l in early spring to less than 1 mg-at N/l in late summer. The nitrate influx to the Bay is derived mainly from agricultural area drainage via its tributaries, and is normally large during periods of high river flow. Thus, the high nitrate concentrations at the northern section reflect influx from the Upper Bay and its tributaries, and from the Potomac River. The nitrate concentrations at the southern section are low, and probably about normal for the time of year.

As data from current meter stations becomes available and as remaining chemical analyses are completed, we will be able to calculate the flux measurements at each section. We expect the first flux calculations for a section to be completed in January 1973.

In addition to the sections, nutrient levels were determined in conjunction with plankton sampling in lower Chesapeake Bay and the adjacent continental shelf in conjunction with plankton studies. Analysis of this data is not complete but preliminary assessment indicates seasonally low Phosphate and Nitrate-Nitrite were present in lower Bay waters. In the middle Bay values of Nitrate-Nitrite were higher than normal in late July. Phosphate in the mid-Bay by late July were essentially normal.

None of the shelf samples have been analyzed for nutrients yet.

4.2.c. Questions To Be Answered.

Throughout the bay, water samples for nutrient analysis are still being collected to document the time for recovery to "normal" levels. Some of the important questions scientists are attempting to answer are: (1) What was the additional input of nutrients to the Bay and its tributaries? (2) Will the high level of nutrients remain after the suspended sediment concentrations decrease to normal levels? (3) At what rate are the additional nutrients lost to the bottom in association with the settling suspended matter? (4) Will there be subsequent undesirable algal blooms and/or species changes?

4.3 Dissolved Oxygen

The nutrient loading following Agnes also had an effect on the dissolved oxygen content of the deeper layers of the Bay. Low oxygen zones are normal in the deeper layers of the Bay during the summer, but the extent and duration of these zones may have been increased as a result of Agnes. The biostimulation that resulted from the large additions of nutrients coupled with the reduction in the vertical mixing of the water because of increased salinity gradients during the recovery period may have led to a greater than normal deficit in the dissolved oxygen content of the lower layers. A large number of determinations have been made of the concentration of dissolved oxygen in the Bay and in selected tributaries. Because of the effort required for the intensive sampling programs, which are still being conducted, the analysis of the data has had to be deferred.

Documentation of the time-varying distribution of dissolved oxygen following Agnes will be useful not only in predicting the effects of future floods, but also in predicting the effects of future inputs of nutrients as a result of man's activities.

4.4. Heavy Metals

The high runoff into the Chesapeake Bay estuarine system introduced appreciable quantities of heavy metals in both particulate and soluble forms. These additions of heavy metals were largely from "natural" sources but many unknown substances from factories and warehouses were also swept into the bay (for example, see Myers, 1972).

4.4.a. Maryland Waters

No systematic heavy metals monitoring program was established in Maryland, however, one interesting related question concerning heavy metals is being investigated by the Chesapeake Bay Institute. It concerns the possible release of zinc from freshly deposited fluvial sediment following a period of very high riverflow.

Following the spring freshet in 1971 a rapid increase in the concentration of soluble zinc was observed in the waters of the upper Chesapeake Bay. This increase appeared after riverflow had subsided and it could not be explained by the source waters--the Susguehanna River and the "Bay" waters. It appears that zinc desorbes from the freshly deposited sediment as a result of cation exchange after the riverflow subsides and salty estuary water advects back into the region to displace the overlying fresh water. The samples collected in 1971 were spaced too far apart in time to establish the rate of this process.

Agnes presented an excellent opportunity for further investigation of the question. During July and August water samples were collected close to the bottom at a number of stations in the upper Bay every 10 - 14 days. The samples were frozen immediately after collection for analysis later. The analyses will be completed this winter.

4.4.b. Virginia Waters

Since the waters from Agnes changed the chemical characteristics of the overlying waters as well as washing in unknown amounts of heavy metals, VIMS initiated several research efforts designed to ascertain heavy metal concentration changes and the resulting effects on the biological community.

Before a change can be determined, baseline or background data must be obtained. Fortunately, four comprehensive studies on the heavy metals in Virginia's part of the Chesapeake Bay had been completed before Agnes flooded the system. The new programs, therefore, were designed to replicate the previous sampling locations, techniques, and methods of analysis as closely as possible. In this way we should be able to delineate and explain changes due to Agnes. At the present time some analyses are available for post-Agnes samples in the Rappahannock River. Little change was found between pre- and post-Agnes total noncrystallinic zinc concentrations, but total noncrystallinic copper concentrations were greatly elevated (Figure 4.4 and Figure 4.5).

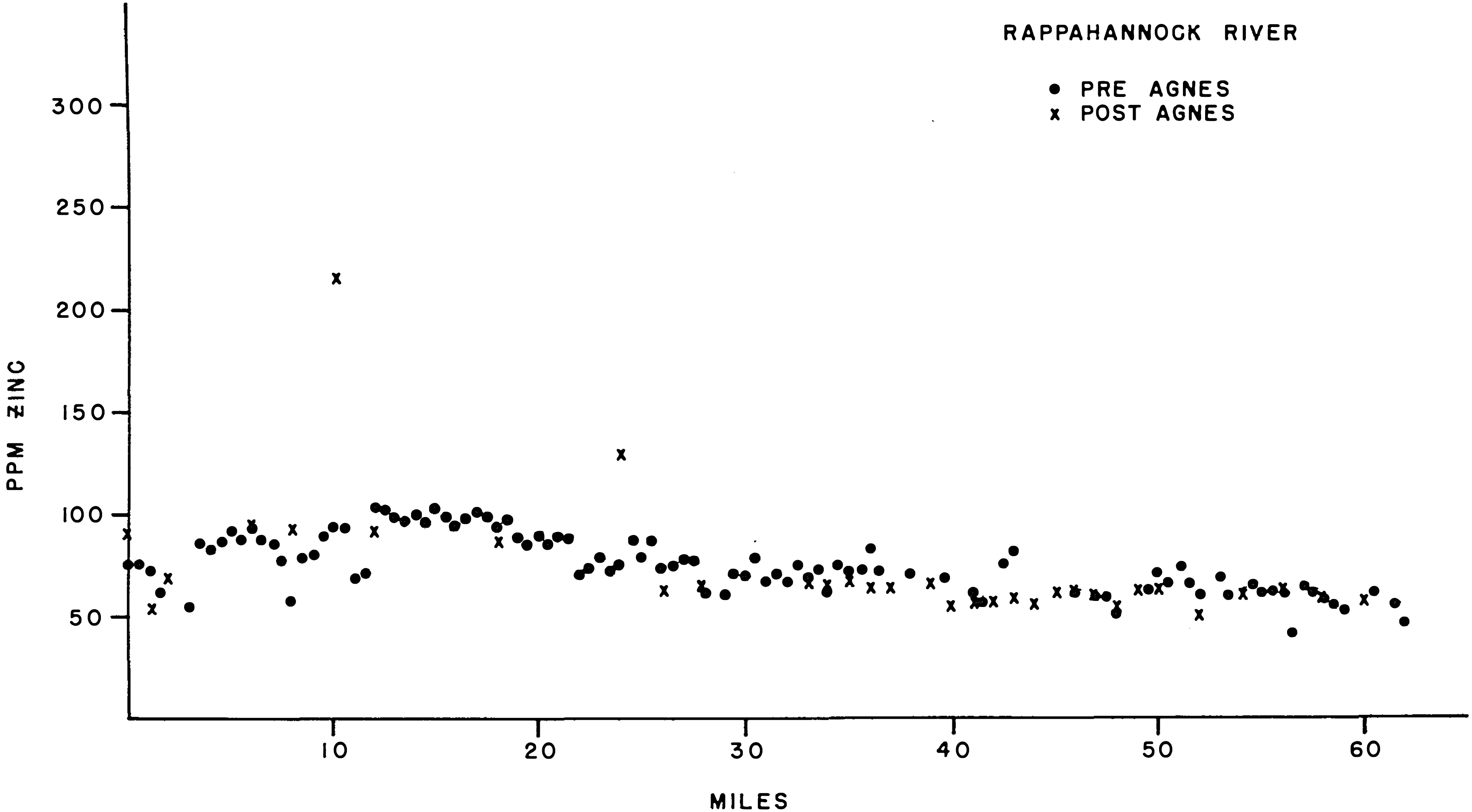


Figure 4.4. Levels of total, noncrystallinic zinc in Rappahannock River sediments before and after Hurricane Agnes (HNO_3 extracted). (V.I.M.S.)

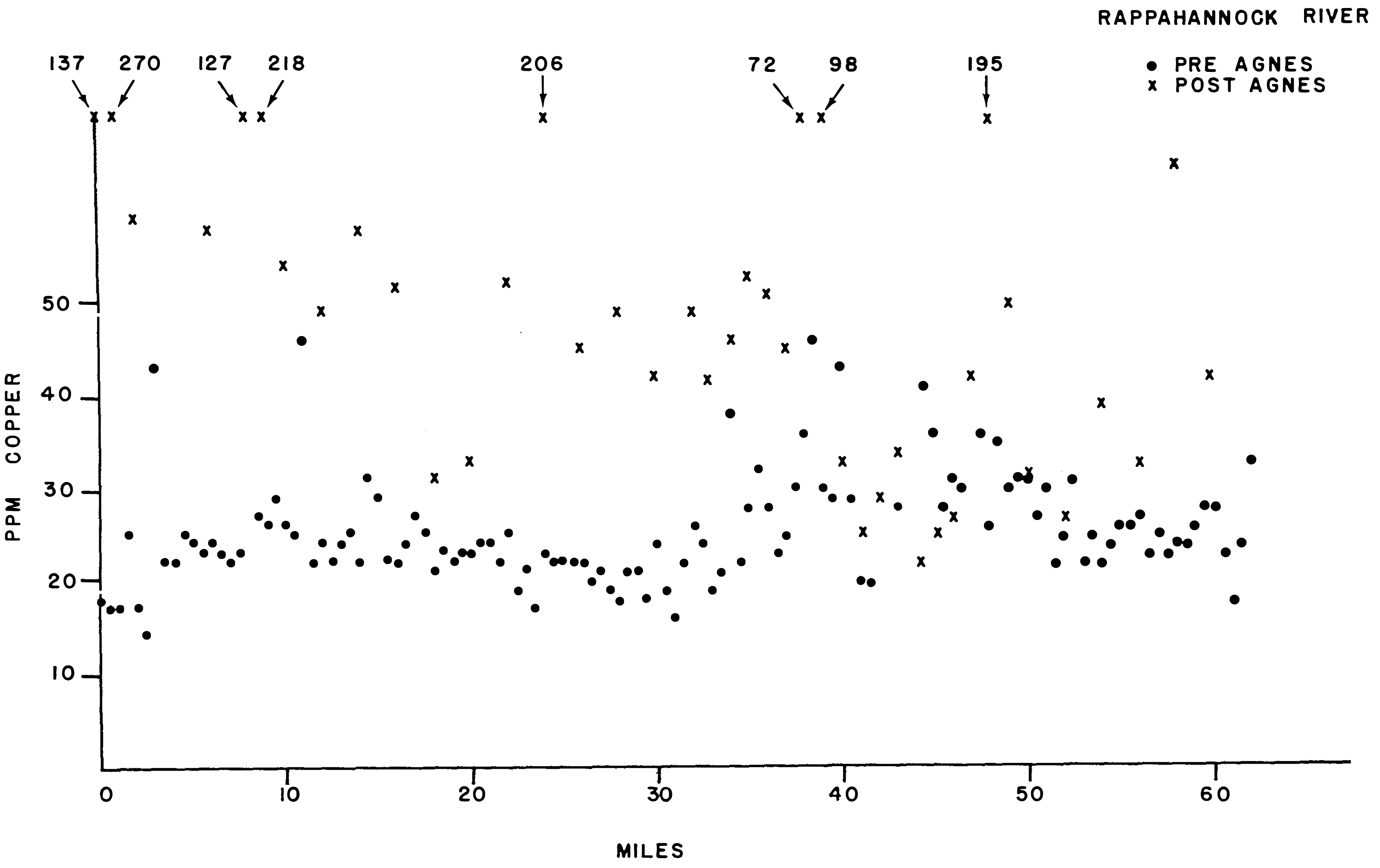


Figure 4.5. Levels of total, noncrystallinic copper in Rappahannock River sediments before and after Hurricane Agnes (HNO_3 extracted). (V.I.M.S.)

4.5. Pesticides

Agnes washed pesticides into the Bay. Although many agencies collected samples for pesticide analysis, only the data from VIMS is available.

Three species of shellfish were analyzed for chlorinated hydrocarbon pesticides and polychlorinated byphenyls (PCB's). Even though the use of chlorinated hydrocarbon pesticides has decreased in the past few years, their long half-lives make them potentially dangerous for years to come.

Samples of the eastern oyster (*Crassostrea virginica*), the hard clam (*Mercenaria mercenaria*), and the blue crab (*Callinectes sapidus*) were collected from various locations in the lower portion of Chesapeake Bay.

The method and procedure utilized in the analyses were essentially those of the Environmental Protection Agency (A.J. Wilson; Pesticide Analytical Manual for BCF contracting agencies; EPA Laboratory, Gulf Breeze, Florida). They consist of drying the blended sample with anhydrous sodium sulfate, soxhlet extraction with petroleum ether, sample cleanup with activated florisil, and analysis by gas chromotography.

The results of post-Agnes analysis are given in Table 4.3. Levels of the DDT-family of pesticides in the post-Agnes oyster samples are essentially the same as pre-Agnes levels. Polychlorinated biphenyls were present in oysters sampled prior to Agnes but were not detected in the post-Agnes samples. The levels of the DDT-family of pesticides in clams were less than 1 part per billion, indicating no accumulation in these animals. DDT-family pesticides were present in low levels in blue crabs but these levels are similar to pre-Agnes levels. No PCB's were detected in clams or blue crabs.

Agnes apparently had no effect on the chlorinated hydrocarbon budget in lower Chesapeake Bay. There is a possibility, however, that the flood might have temporarily flushed PCB's out of the system.

Table 4.3 Pesticides in edible portions of oysters, hard clams, and blue crabs from Virginia following Hurricane Agnes. (V.I.M.S.)

Organism	Location	DDT-Family [a] (ppm)	PCB(ppm)
Oysters	Lynnhaven Bay	0.002	ND[b]
	Cherrystone Inlet	0.024	"
	Old Plantation Creek	0.033	"
	Mouth of Poquoson River	0.001	"
	Pages Rock	0.001	"
	Bells Rock	0.015	"
Hard Clams	Elliots Ground	0.001	"
	Back River, Public Rock	0.001	"
	Back River Channel	0.001	"
	York River	0.001	"
	York River	0.001	"
	Goodwin Island	0.001	"
	Egg Island Bar	0.001	"
	Plumtree Bar	0.001	"
	Grand View	0.001	"
Blue Crabs	Accomac County	0.010	"
	Accomac County	0.003	"
	Accomac County	0.007	"
	Accomac County	0.020	"
	Accomac County	0.039	"

[a] DDT-family = DDT+DDE+DDD

[b] ND = nondetectable

SECTION 5. PLANKTON

5.1 General

Drifting about in Chesapeake Bay at the mercy of the water currents is a large number of small plants and animals, collectively called plankton. The minute drifting plants (including the diatoms, bacteria, and dinoflagellates) make up the phytoplankton. The small crustaceans (copepods, ostracods, mysids, and others), the arrowworms, the jellyfish, and the eggs and larvae of many fish and invertebrates make up the zooplankton.

None of these plankters is capable of much directed self-propulsion, they simply drift where the water currents take them. Thus a large intrusion of freshwater, sediment, and nutrients would be expected to seriously disrupt the normal plankton populations in the Bay. It could wash many of them into the ocean where they would perish, or by lowering the salinity or increasing the sediment level it could make much of the Bay unsuitable for the normal plankton. In contrast, the influx of nutrients would be expected to stimulate growth of some phytoplankters.

Two problems complicate an evaluation of the effects of Agnes on plankton. First, plankton studies are expensive, time-consuming, and require a high degree of expertise. Second, because of the first, there is little background data for comparisons.

5.2 Maryland Waters

Little quantitative data on plankton in the Maryland part of Chesapeake Bay is available yet. Apparently the flood-waters from Agnes washed many fish and invertebrate eggs and larvae from nursery areas, and perhaps out of the Bay, and the influx of nutrients stimulated phytoplankton production in some areas after the suspended sediments had settled.

A study of fish eggs and larvae by the Chesapeake Biological Laboratory was underway in the Elk River estuary and the Chesapeake and Delaware Canal when Agnes hit. The samples have not yet been processed.

At the Smithsonian's Chesapeake Bay Center for Ecological Studies on Rhode River, the distribution of plankton was reported changed because of the flood, and the nutrients stimulated those remaining to bloom. Also chlorophyll A, an index of the present abundance of phytoplankton, was 8 μg/L in Chesapeake Bay, but was much higher in Muddy Creek. The effect of Agnes on the species composition will be difficult to evaluate because the composition during the Spring of 1972 was different from that in other years.

"Mahogany tides" in several areas of Chesapeake Bay were reported after Agnes. These blooms of red phytoplankton were apparently stimulated by the high levels of nutrients, warm temperatures, and sunshine that followed the storm.

5.3 Virginia Waters.

Virginians were better able to access the effects of Agnes on Chesapeake Bay plankton. The zooplankton and plankton physiology projects within the NSF-RANN study of Chesapeake Bay (VIMS) had been conducting studies of the lower Bay and lower York River, respectively, for approximately one year prior to the arrival of Hurricane Agnes. The studies were cooperative and connected, with some identical stations in the mouth of the York River. They were, therefore, in a unique position to combine efforts in a study of the effects of Hurricane Agnes. A zooplankton survey was actually interrupted by the arrival of Agnes, thereby providing data immediately prior to flood conditions for comparisons.

Those measurements that had been routinely made by the plankton physiology group were added to zooplankton sampling over the lower Bay, thereby providing synoptic sampling of water temperature, salinity, dissolved oxygen, light transmission, dissolved nutrients, phytopigments, potential productivity and heterotrophy, phytoplankton identity and enumeration, zooplankton biomass, zooplankton identification and enumeration, and zooplankton biochemistry. The programs will continue to conduct monthly sampling over the lower Bay to monitor recovery.

In addition to the above efforts, zooplankton samples have been collected on the Rappahannock River with a Miller sampler for comparison with large-mesh nets used in assessment of effects on fish eggs and larvae.

Offshore collections were obtained on July 19-29 using Miller samplers and estimates of heterotrophic potential and hydrographic data were obtained during a CBI-Ridgely Warfield Cruise, 27 July-4 August.

Certain of the observations require much processing prior to use. This report is limited to potential productivity, heterotrophy and some zooplankton observations. Other data will be available at a later date.

Primary Productivity Potential: Primary productivity potential is defined by the methodology employed. We use the ^{14}C-$NaHCO_3$ fixation into particulate matter (that which does not pass a 0.45µ filter) by photosynthesizing organisms under controlled conditions of light intensity at ambient water temperature. Using the surface waters of York River mouth station as a reference, the range of values is usually between 40-80 mg $C/m^3/hr$ from May 1971 to August 1972. A trimodal distribution was noted during 1971 with peaks occurring in June (lowest), August (middle) and September-October (greatest). The September-October peak was characterized by several dinoflagellate blooms in 1971 with productivity potentials as great as 192 mg $C/m^3/hr$.

Immediately after Hurricane Agnes, 29-30 June, the productivity potential of the shallow waters of the western side of the lower bay were greater than 80 mg $C/m^3/hr$ with a large area of the Lower Bay having "normal" values of 40-60 mg $C/m^3/hr$. A rather similar condition was evident at the time of sampling one week later (6-7 July) but with a probable displacement of the surface water masses toward the bay mouth. By 13-14 July, most of the lower bay surface waters had productivity potential values greater than 80 mg $C/m^3/hr$ and at least 2 pockets greater than 100 mg $C/m^3/hr$. While the 80 mg $C/m^3/hr$ values appear to be at the upper range of "normal" values, the pockets of high productivity values may be considered excessive and caused in part by Hurricane Agnes. One of these pockets was located at the mouth of the James, whereas the other may be influenced by the shallower waters of the western shore. By 24-27 July, at least one pocket of highly productive waters (>100mg/$C.m^3/hr$) still persisted (probably influenced by the shallower waters of the Western Bay). Much of the lower Bay waters had productivities between 40-80 mg $C/m^3/hr$ which may be close to normal values for this time of year.

It is particularly noteworthy that the heterotrophic potential (see next section) was maximal at this time.

By 14-21 August, the upper and western reaches of the Lower Bay waters (the less saline regions) had high productivities (greater than 100 mg $C/m^3/hr$). These values are in excess of those measured during the previous year for the York River mouth Station.

By 12-14 September, the productivity potentials were in the range of 60-100 mg $C/m^3/hr$ which may be normal for this part of the year. No areas have productivity potentials greater than 100 mg/ $C/m^3/hr$ and no pockets of "Red Waters" were encountered.

Heterotrophic Potential of the Lower Chesapeake Bay: The potential heterotrophic activity of the estuarine plankton community was estimated using ^{14}C-labeled organic substrates incubated with natural water samples. The heterotrophic potential is a total response generally attributed to bacteria and other microscopic planktonic species.

Between June of 1971 and May of 1972, the heterotrophic potential of the water column at a station at the mouth of the York River was investigated weekly until September and then monthly from October to May. There were two high periods of heterotrophic potential: one in the spring (May-June) and one in the late summer (August-September). During the time of these measurements, the range for these numbers was 0.4 to 1.2 mg glucose/m^3/hr, with a few exceptions. The records for heterotrophic potential indicates a minimum of activity during the winter months while the waters are cool.

On 29-30 June, the first cruise in the lower Bay after Hurricane Agnes, the heterotrophic production at the 1-meter-deep level peaked in two ranges: 0.6-1.0 and 1.0-2.0 mg glucose/m^3/hr. The lower range approximates the seasonal norm (York River). The higher heterotrophic potential existed in the more shallow regions of both the Bay side of the Eastern Shore and the western side of the Bay.

By 6-7 July, the higher range values were still apparent along the shallow waters including one very dense value near Cape Charles.

By 13-14 July there were primarily three levels of concentration of heterotrophic potential. The areas of high heterotrophic potential appeared to have coalesced into a single large area in mid-bay. Intermediate potentials occurred in the waters of Mobjack, York River, and the lower Bay out to the Capes. The low potential waters occupied the area around the James River.

Near the end of July (Figure 5.1) the entire lower Bay had considerable heterotrophic potential. Precise interpretation is difficult because of limited background data from previous years. It is thought that these extremely high heterotrophic values are probably a summation of (1) the anticipated seasonal effect and (2) the contribution caused by Hurricane Agnes waters entering the Lower Bay. The high water temperatures (26-28°), lowered

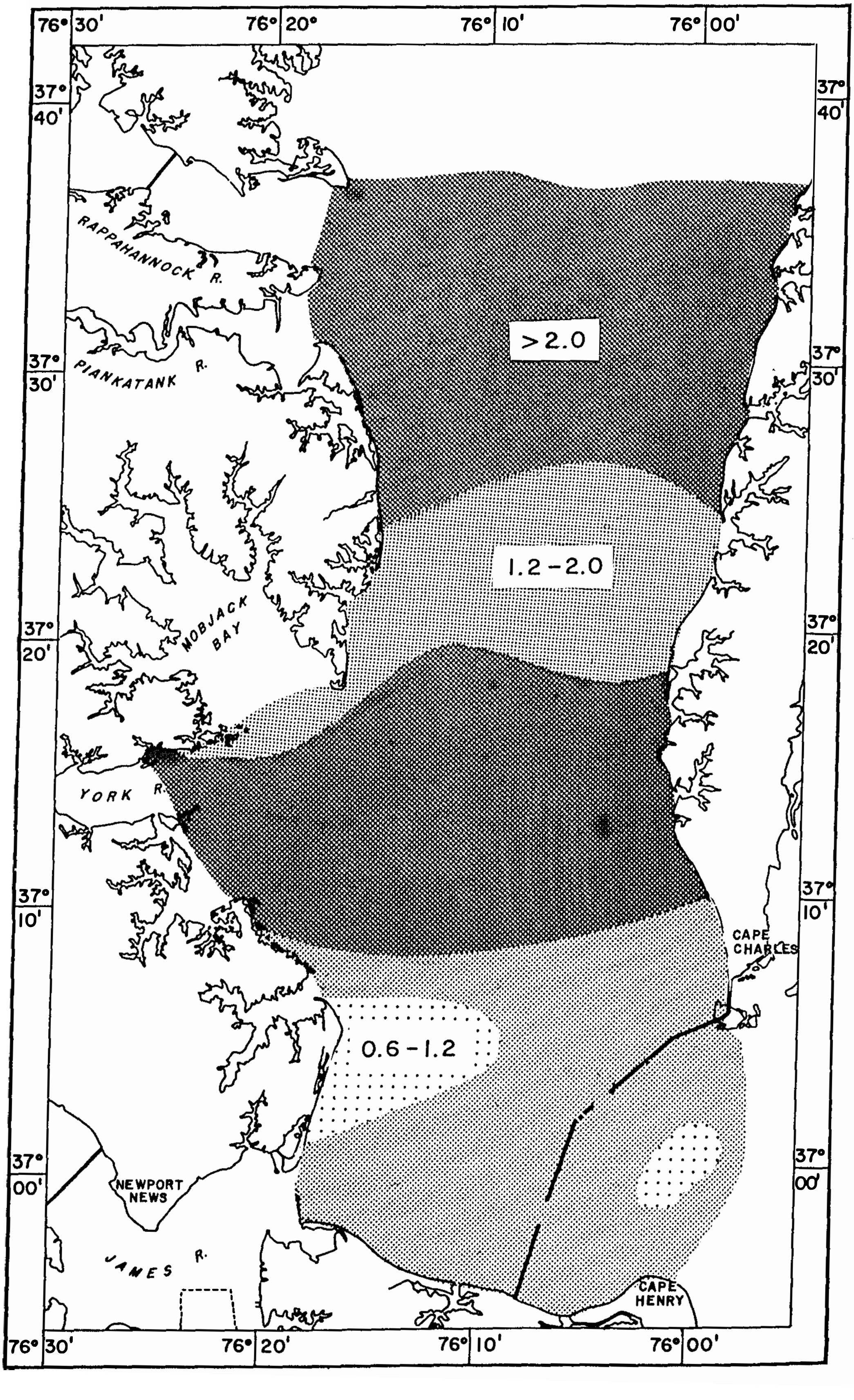


Figure 5.1. Heterotrophic Potential (Vmax glucose) of Surface Waters (at 1 meter depth) of the Lower Chesapeake Bay. (mg glucose/m^3/hr) 24-27 July 1972. (V.I.M.S.)

salinity, increased turbidity, and high silt load all probably contributed to these maximal heterotrophic potentials--the highest seen in the Lower Bay between May 1971 and September 1972.

Dominant Plankters: The following discussion is based on oblique zooplankton tows with 8 inch-diameter Bongo nets constructed of 202 micron mesh (Nitex), and vertical pump samples from depth to surface. The former provide two replicate samples from each station, one of which is preserved in 5% formalin for settled volume and taxonomic determinations. The duplicate sample is washed in distilled water to remove salt, then is freeze-dried for determiantions of dry weight and biochemical constituents. Vertical pump samples are passed through a final 35 micron filter and preserved in Lugol's iodine solution for phytoplankton identifications and counts.

Estimates of dry weight, shown as mean weight per cubic meter are still incomplete. The preliminary data demonstrate close correlation with measurements of settled volume, generally considered a less accurate measure of biomass. Dry weight data show a high biomass in August 1971, declining to a low in November, increasing to a second peak in March, dropping in April, then beginning to rise once again.

Very similar results are evident for settled volume (Figure 5.2) for the period. These data were obtained by settling preserved zooplankton in Imhoff cones for 24 hours, then calculating cruise averages. Seasonal peaks and trends are identical to those observed for dry weight. The immediate pre- and post-flood observations are shown in (Figure 5.3), with the insertion of the three weekly Agnes cruises. Much of the increase in the June 29-30 cruise was due to an abundance of Mnemiopsis leidyi and a bloom of Rhizosolenia calcar-avis. Biomass then declined (as did both Mnemiopsis and Rhizosolenia) until the 24-27 July cruise when some "recovery"

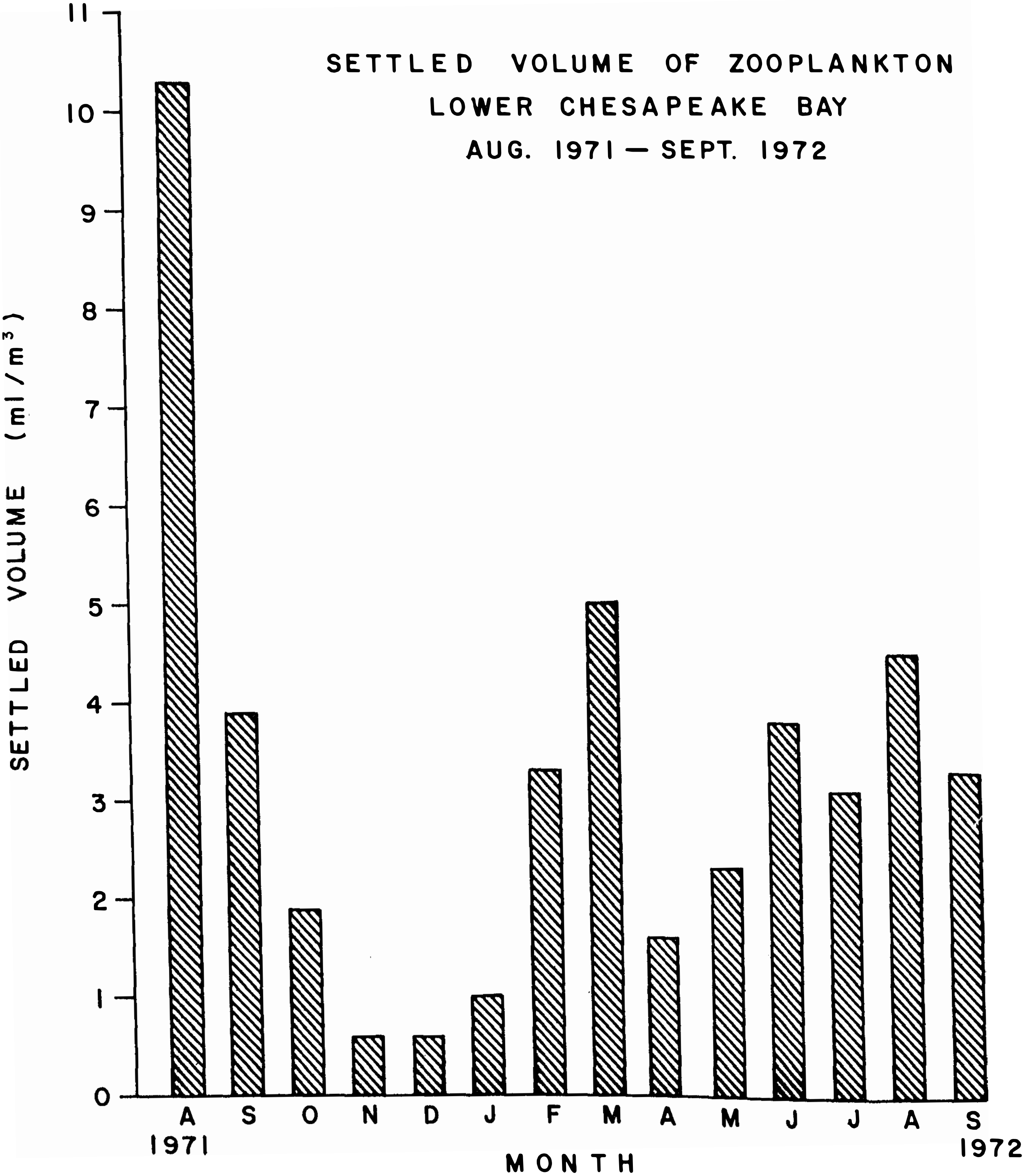


Figure 5.2. Mean settled volume in ml/m^3 of zooplankton in lower Chesapeake Bay, monthly cruises August 1971-September 1972. (V.I.M.S.)

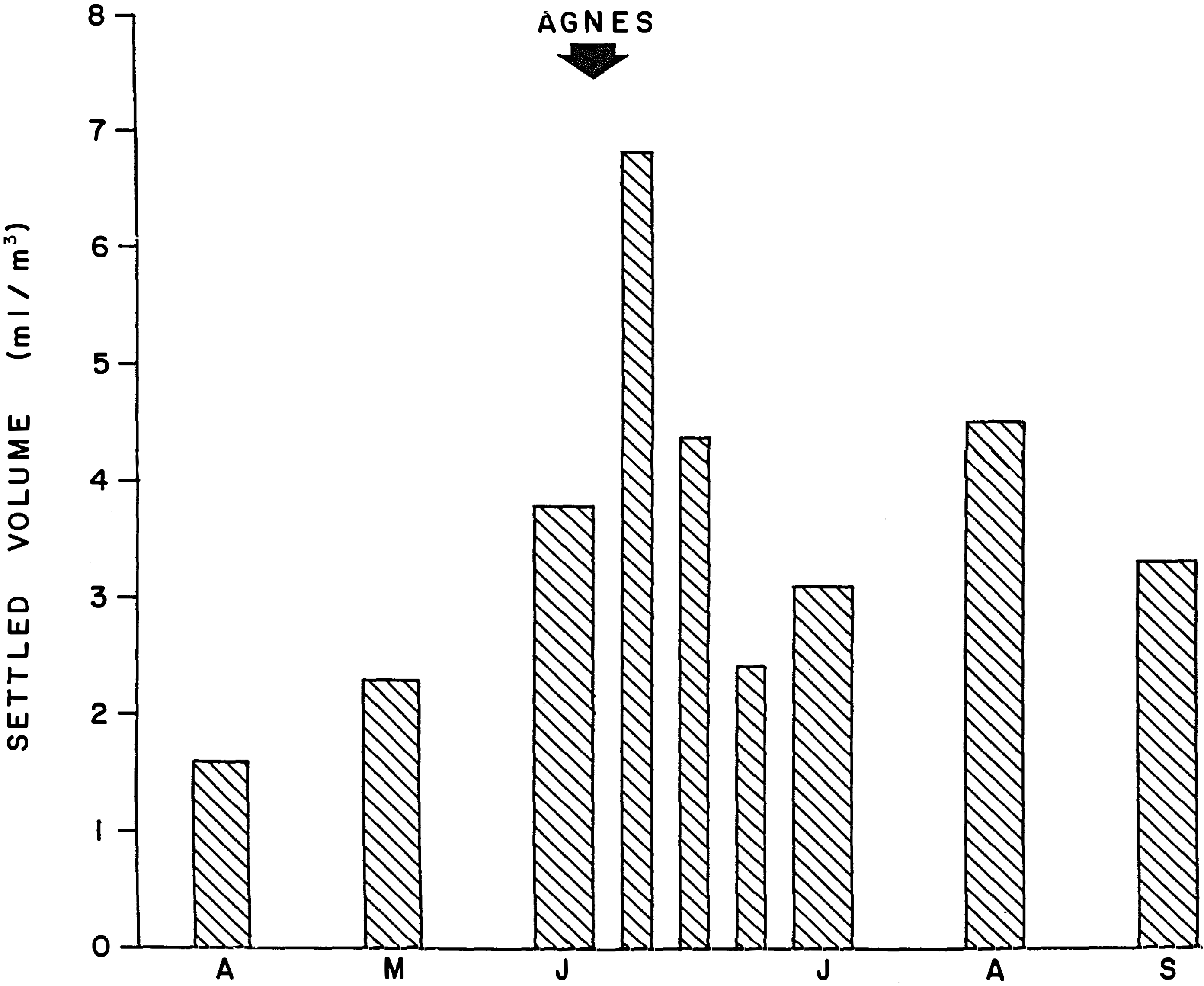


Figure 5.3. Mean settled volume during cruises of lower Chesapeake Bay immediately before and after Tropical Storm Agnes. Special weekly cruises have been inserted between regular June and July monthly cruises. (V.I.M.S.)

was noted. The seasonal peak in August 1972 was considerably lower than that observed one year earlier.

Flood effects on zooplankton can easily be confused with normal biological cycles in the bay waters. Previous studies have shown a close relationship of abundance among *Mnemiopsis leidyi, Beroe ovata,* and crustacean zooplankton (Burrell, 1968). *Mnemiopsis,* a tentaculate ctenophore that feeds on small crustacean zooplankton, reaches a peak of abundance in June in these waters. *Beroe,* a ctenophore without tentacles, appears in late June and July. *Mnemiopsis* severely reduces crustacean zooplankton at its seasonal peak, is preyed on by *Beroe* in early July, resulting in a decrease in *Mnemiopsis* and allowing recovery of crustacean zooplankton. This annual cycle occurred at the time of reduction and recovery of biomass shown above as possible flood effects.

If short term changes in biomass immediately before and after the flood are clouded by the *Mnemiopsis-Beroe*-crustacean-zooplankton cycle, one may have to resort to annual differences. The flood conditions could have contributed to the large decrease in biomass seen in a comparison of August 1971 with August 1972 levels. Table 5-1 lists the major components of zooplankton collections taken from subarea B during August cruises of 1971 and 1972. Counts of the listed groups show a general decrease in all taxa, but a very great decrease in cladocerans. The reduced biomass in 1972 may be attributed almost entirely to the relative scarcity of cladocerans. Preliminary specific identifications of cladocerans show, further, that the largest difference lies in a reduction of *Penilia avirostris,* a possible direct effect of flooding.

Table 5-1. Zooplankton composition, subarea B, August of 1971 and 1972.

	Numbers per Cubic Meter	
	1971	1972
Cladocera	145,000	795
Copepoda	11,700	4,840
Decapoda	571	82
Tunicata	318	282
Fish Eggs	52	29
Fish Larvae	14	9
Cirripedia	43	4
Mysidacea	20	1
Chaetognatha	16	2

Apparent effects of flood conditions can be summarized as an unusual bloom of Rhizosolenia, a decline in zooplankton for a period of about three weeks, then a gradual recovery to the seasonal August peak. The August peak, however, was considerably depressed compared with that of 1971.

The obvious difficulty in assessing flood effects by annual differences is that we are severely limited in point comparisons. Without a number of yearly observations, one cannot know whether 1971 or 1972 or either was an exceptional year.

Further analysis of collections would provide definition of qualitative differences, where they exist. The continued presence of freshened water in the lower Bay throughout the summer of 1972 most certainly would affect those species within sorted categories that have limited tolerance for reduced salinity. Species composition may have been significantly altered.

SECTION 6: FISHERIES

6.0. The Value of Chesapeake Bay's Fisheries.

World-famous for its seafood, the Chesapeake Bay produces more blue crabs (*Callinectes sapidus*), soft-shell clams (*Mya arenaria*), and striped bass (*Morone saxatilis*) than anywhere else in the world, and ranks high in the production of American or eastern oysters (*Crassostrea virginica*).

The commercial fisheries harvest at least 64 species of finfish and shellfish from Chesapeake Bay. In 1971, the preliminary figures on the landings of fishery products from the Chesapeake region totaled 562 million pounds and were valued at $40 million, dockside or exvessel price (National Marine Fisheries Service, 1972). In 1968, the last year with a complete compilation of U. S. fish landings, the blue crab catch of Chesapeake Bay accounted for 48% of the total U. S. catch, and the production of soft-shell clams was even more impressive, making up 54% of the U. S. catch (N.M.F.S., 1971). Chesapeake Bay production of American oysters follows only the Gulf States, accounting for 37% of the U.S. catch. Although unimpressive on a percentage basis, with only 10% of the total U.S. catch, the landings of finfish from Chesapeake Bay was worth $8 million, dockside. The striped bass, for which this bay is the greatest nursery as well as source, yielded 5.7 million pounds worth more than one million dollars to the fishermen. These commerical landings were produced by 15,418 Maryland and Virginia fishermen (Ibid.).

The exvessel price of $40 million for the commercial fisheries indicates only part of the worth of the catch to Chesapeake Bay because processers, distributors, and retailers also earn money from it; the retail price is a good measure of the full worth of the catch. The National Marine Fisheries

Service (N.M.F.S., 1972) estimates[4] that the retail price of domestic fisheries products is equivalent to 3.07 times the exvessel price. Thus, for Chesapeake Bay the full revenue from the commercial fisheries is about $122.8 million dollars ($40 million times 3.07). Commercial fishing in Chesapeake Bay is a big business.

The burgeoning recreational fishery is important too, but it is much harder to appraise. The catch of striped bass by sportsmen, for example, probably exceeds the commercial catch. Wallace, et al., (1972), estimated the annual economic value of Maryland's part of the Bay's recreational fishery at $145 million. The value of Virginia's recreational fishery is probably similar. Thus, the total revenue from recreational fishing is about $290 million.

The combined revenue from the commercial and recreational fisheries of Chesapeake Bay, therefore, comes to about $413 million.

An important point to recognize is that this revenue represents not the total value of the Bay's fisheries resources but, rather, the annual interest. The total value of these resources must be equated to a capital investment that would produce this annual interest at, say, a simple interest rate of 6%--or about $6.7 billion.

An analysis of the effects of a force, such as Hurricane Agnes, on the fisheries resources of the Bay is complicated by many factors. These resources are hidden from sight and must be evaluated indirectly by sampling. Also, the size of the bay and the rapid mobility of many organisms, like the crabs and fish, makes adequate sampling difficult or impractical. Further, organisms that die are rarely noticed since they sink to the bottom and are quickly disposed of by crabs, bacteria, and other scavengers. As a result of these and other complications, the effects of Hurricane Agnes on the Bay's fisheries

[4] "Estimated on the basis of actual and estimated weighted average mark-ups for each of the 17 most important species of fish and shellfish and an overall mark-up for the remaining species." (N.M.F.S., 1972).

may never be fully known. Many of the details can, however, be measured and assessed. The following subsections discuss what is now known about the effects of Hurricane Agnes on the fisheries resources and on the fisheries.

6.1. Oysters

6.1.a. Introduction

Oysters in Chesapeake Bay suffered through a bad year in 1972. The year started out with the salinity of the bay already depressed because of the above-average river flows of late 1971. The high inflow of fresh water continued through May. By April the lowered salinities (and rising water temperatures) were threatening to kill oysters in the upper parts of some rivers. The salinity of the Potomac River at Morgantown, Maryland, for example, had been below 5‰ since January. Prolonged exposure to low salinities is well-known as a cause of oyster mortalities and reproduction failures (for details, see the papers cited in Joyce's 1972 annotated bibliography). Then, in June, Agnes came along.

The first effect of Agnes on the oyster industry was felt when the levels of bacteria in oyster-growing waters exceeded the permissible levels for shellfish harvesting areas. Flood waters from Agnes had inundated sewage treatment plants in the drainage basins and washed the raw and partially treated sewage into Chesapeake Bay. The sewage bacteria probably did not affect the oysters directly, but the high number of bacteria in the water--and in the oysters--forced the state health departments to close all shellfish growing areas to harvesting. Even though the closure was temporary, the oyster harvesters, processors, and distributors suffered economic loss. In addition, many consumers, worried about contaminated seafood, quit eating oysters as well as other seafood. The main problem, however, was not polluted oysters, it was dead oysters.

Many Chesapeake Bay oysters died because of Hurricane Agnes. Although high sediment loads and low dissolved oxygen levels might have caused, or help cause, some deaths, experience coupled with frequent samplings of the oyster bars showed conclusively that the low salinities associated with Agnes was the primary cause of oyster deaths.

Immediately after the storm had passed, research vessels were dispatched to sample the oyster bars of Maryland and Virginia. These sampling trips continued throughout the summer and will continue into the summer of 1973.

The procedure for evaluating the effects of Agnes on oysters consists of dredging or tonging samples of oysters off the bars, then determining what percentage of those oysters were recently killed. A recently killed oyster (recent box) is one where the two shells are still attached at the hinge and the inner surfaces of the shells are clean. Records are also kept of dying (gaping) oysters; the condition of the live (small and market-sized) oysters; whether or not the adult oysters have spawned; salinity, temperature, and dissolved oxygen content of the water; and the abundance and condition of oyster pests and predators.

Figure 6.1 shows where major losses of oysters occurred.

6.1.b. <u>Maryland Oysters, Other Than Potomac River Oysters</u>

<u>Mortalities by Time and Place</u>

To date CBL has made three sampling trips to Maryland oyster bars. The first trip ran from 9 to 12 July, the second from 24 July to 1 August, and the third from 28 to 29 August. The results of these trips show increasing mortalities with time.

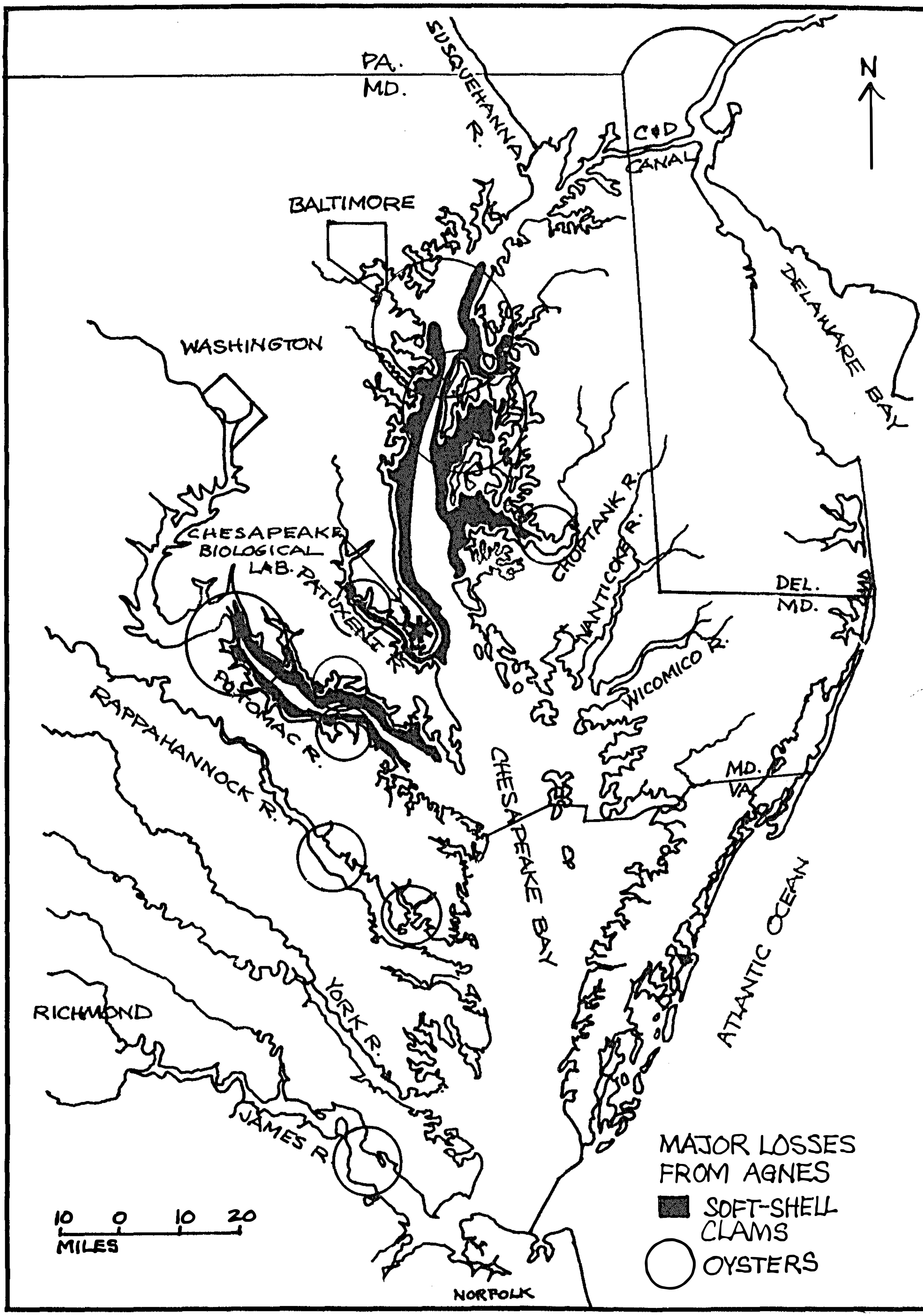


Figure 6.1. Map showing the areas with major losses of soft-shell clams and oysters from Hurricane Agnes. (C.B.L.)

The first trip (9-12 July) found few dead oysters. This trip sampled oyster bars above the Bay Bridge, in the Chester and Patuxent Rivers, and in Pocomoke and Tangier Sounds. Most samples contained all live oysters although some oysters were weak. Live oysters were found from Tolchester southward in the main part of the bay, in the Chester River, and in Pocomoke and Tangier Sounds. The only recent mortalities were found in the Patuxent River (0.8 to 33.3%) and in the upper bay above Tolchester (20.0%).

The highest mortality (33.3%) occurred above Benedict in the Patuxent River. Here, the salinity on the bottom of the river was 0.8‰, and the bar was heavily silted. Light mortalities (0.84 to 5.2%) were found in the lower part of the Patuxent River, where the salinities were above 4.0‰. Most Patuxent River oysters were ready to spawn; many appeared to have fed recently.

The dead oysters above Tolchester, in the upper Bay, appeared to have been buried. The live ones were weak and easily opened. The salinity was only 0.15‰.

At all the bars sampled on this first trip the dissolved oxygen levels and water temperatures were adequate for oyster survival.

The second trip (24 July to 1 August) resampled many of the bars visited on the first trip; but more attention was given to the bars in the main part of the bay, and Tangier Sound was bypassed.

High mortalities were found in the main part of the upper bay, 51.2% at Tolchester, 22.7% near Annapolis, and 13.4% eastward of Poplar Island. In the Patuxent, mortalities up to 15.4% were recorded. All along the lower eastern shore, from Eastern Bay to Pocomoke Sound, however, only a few recently dead oysters were found.

The third trip (28, 29 August) resampled oyster bars in the upper bay and the Choptank River. Above Swan Point accumulated mortalities exceeded 75%. Mortalities were also high in the upper Chester River (40%) and in the upper Choptank River (18%). In the main part of the bay, however, mortalities were less than 10%.

Prolonged exposure to low salinities frequently kills oysters. Generally, there will be few mortalities at salinities above 5‰; massive mortalities at salinities below 1‰, and variable mortalities between 1 and 5‰. The magnitude of mortalities in the critical range is determined by the length of exposure, the salinity level, the water temperature, and the genetic makeup of the oysters. Figure 6.2 shows the variation with time in the downstream location of the 1‰ and 5‰ isohalines for depths of 6 and 20 feet. From this figure it can be seen, for example, that at the Chesapeake Bay Bridge the salinity remained below 5‰ for about 6 weeks.

The Economic Loss to Maryland's Oyster Industry

The Maryland Department of Natural Resources estimated that the Maryland oyster industry will have lost 824,000 bushels of marketable oysters because of Hurricane Agnes. At a dockside value of $4.50/bushel, this loss amounts to $3,708,000. But more than the harvester's earnings are involved, and the loss to processers, packers, and retailers must also be considered. Seiling estimated that the total economic loss to the Maryland oyster industry for 1972 might amount to $14,835,500.

Future effects are exceptionally difficult to assess, since Agnes occurred when the oysters were spawning. The low salinities probably reduced or destroyed the new seed crop. Damage will certainly be felt over the next several years, and may be of serious importance for even longer. One of the direct effects of Agnes that cannot yet be evaluated is the increased exploitation of the surviving beds as oystermen crowd onto them.

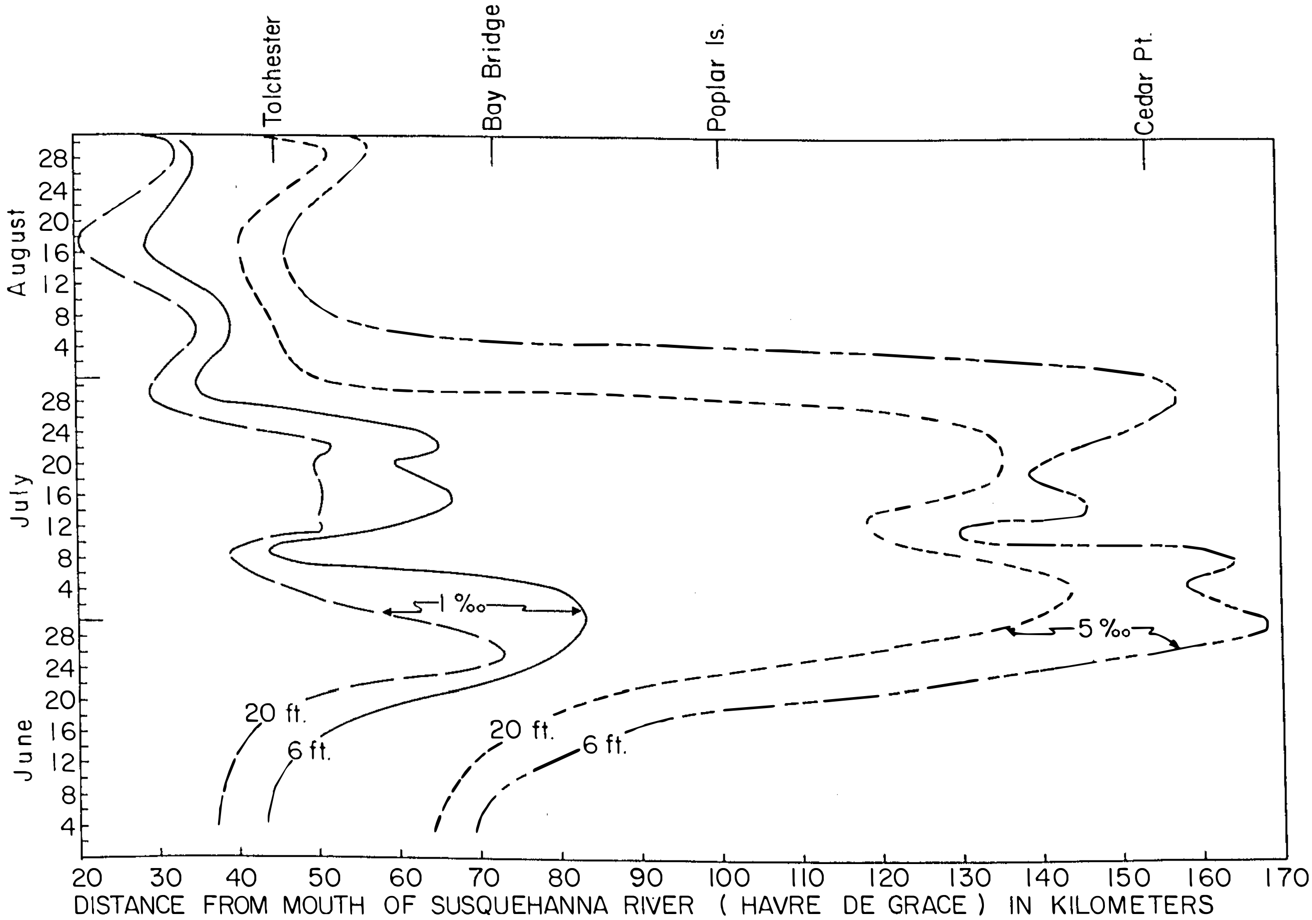


Figure 6.2. Temporal variation of the locations of the 1‰ and 5‰ isohalines at the 6 and 20 ft. levels along the axis of the Bay following Agnes. (C.B.I.)

6.1.c. Potomac River Oysters

The Potomac River estuary lies in Maryland but fishing rights are shared equally by Maryland and Virginia fishermen. The fisheries of the Potomac River are regulated by the interstate Potomac River Fisheries Commission.

Maryland and Virginia scientists have made 12 sampling trips to assay the effect of Agnes on Potomac River oysters and further sampling will be conducted.

Oysters in the upper Potomac River suffered heavy mortalities. Oysters upstream from a line connecting Cobb Island, Maryland to Popes Creek, Virginia had suffered about 10% mortality by mid-July. By the first of August these mortalities climbed to more than 70%. By the end of August nearly all of these oysters had died (89 to 100%). The salinity in this part of the Potomac was depressed before Agnes arrived, then Agnes came and kept the salinity below 5‰ until after the first of August.

Oysters in the Potomac downstream from the Cobb Island-Popes Creek line fared better. By mid-July no more than 6% of the oysters had died on any bar. More oysters had died by 25 July, but the highest mortality for any bar in the lower river was 12.6%. None had died near the mouth of the River. By the end of August some mortality had occurred to oysters living farther down the Potomac, e.g., 11% at Coles Point. The oysters on the bar at Bluff Point in St. Clement Bay, however, had 100% mortality. Overall, the oysters living in the lower potomac appeared to be in good condition by 1 September, most apparently had been feeding, and some had spawned.

In summary, oyster biologists estimate that about half of the marketable oysters in the Potomac River were killed by the low salinities brought on by Hurricane Agnes. A period of reduced catches is inevitable. On the brighter side, the large amount of nutrients brought down by the flood stimulated plankton production, which in turn permitted the surviving oysters to "fatten" in August, a month or so earlier than normal. So, even though there are few oysters to harvest, those that are harvested will have a high yield. If seed stocks of the proper types can be utilized and if environmental conditions are favorable the Potomac River oyster bars can eventually be restored to their former levels of productivity.

6.1.d Virginia Oysters

General

Estimates of damage to the Virginia oyster industry were based on extensive series of samples of bottom material collected from public oyster rocks and private oyster leases beginning on 24 June, 1972 and extending throughout the mortality period.

For public oyster rocks in Virginia and in the Potomac River, it was possible to obtain an estimate of what part of the total resource was damaged. This was done by relating our estimate of the percent mortality for the various areas, obtained during our surveys, to data on numbers of bushels of oysters produced by each river during the preceeding years. These data on catch have been obtained since 1963 for the Potomac by the Potomac River Fisheries Commission and losses are estimated in the preceeding section. For Virginia the data have been collected by the Virginia Marine Resources Commission.

Estimating the actual number of bushels of oysters killed on private leases, in respect to size of the resource, could not be accomplished directly since the state of Virginia does not require growers to report where oysters are cultured or how many are harvested. Only the grower knows where his oysters are growing and how many exist on his lease.

Even though this information is lacking certain generalizations can be made. It is possible to estimate (in respect to river systems) the percent of the oysters on private leases that was killed by Agnes.

For example, the general areas where private growers culture oysters are well known since they can only be grown on leased grounds. The location of these leased areas are clearly marked on charts on file at the Virginia Marine Resources Commission. Generally, they exist along the margins of the shore, since most of the public grounds are located in the central portions of the estuaries.

The region where private growers culture their crop is also outlined by environmental conditions. Low salinity effectively places an upriver limit to culture and this location is known so its approximate location in each river may be marked on a chart. The downriver limit to culture is also known, due to the occurrence of oyster diseases such as Dermocystidium and MSX and also predators such as the oyster drill Urosalpinx cinerea which make oyster culture impractical in these high salinity regions. For example, in the estuary of the Rappahannock River, where oyster mortality due to Agnes was highest for the state, almost all oysters are planted in the upper half, from Accaceek Point to Waterview. In the James, private beds are located along the shore of the system; few exist in deeper water, few, if any, are planted in the lower half. In the York River commercial plantings are concentrated in a 10-mile stretch in the upper third of the river from Bell Rock Light to Roane Point.

For this study, we based our estimates on the premise that oysters killed by Agnes on private leases in Virginia come from seed produced in Virginia; this is a reasonable assumption since the areas influenced by Agnes have little natural set. These values for seed production in bushels apportioned to various rivers were doubled to allow for the natural growth and multiplied by their dollar value of the bushel price at harvest.

The seed production from the James, Great Wicomico and Piankatank rivers (which were the sources of seed for the areas influenced by Agnes) was totaled for the past three years since it was recognized that three years are required for the seed to reach maturity. That is, seed planted in the 1969-70, 1970-71, and 1971-72 seasons was killed by Agnes. Next, on the basis of interviews with officials of the Virginia Marine Resources Commission and also on the basis of our knowledge and from interviews with growers, we estimated the percent of the total seed planted in each river. Therefore, it was possible to estimate the actual number of bushels of seed planted in each river for the period from 1969 to 1972. These values were multiplied by two since, on the average, in the upper Rappahannock and Potomac estuaries a return of two bushels of market oysters may be expected for every bushel of seed planted. Numbers of bushels were then multiplied by the expected bushel price. The results of these studies are summarized below by river system.

Mortalities by Time and Place

James River: Sampling in this system began on 24 June 1972 and continued at bi-weekly intervals through most of July. Surface and bottom salinities became quite low immediately after the 24th and the surface water had no measurable salt as far down stream as the James River Bridge during the first two weeks of sampling.

For public rocks, excessive damage was confined to the upper part of the system. The furthest rock upriver known as Deep Water Shoals, showed 67% mortality while Horsehead, the next bar down river, showed only 9%. Mulberry Swash (slightly down river from Horsehead) showed a 10% mortality. It was estimated that mortality for public rocks for the entire river was about 10%.

On private beds mortality was limited to a very narrow band in shallow water. On the East side the zone began at Jail Point just above the entrance to the Warwick River and extended upriver to Mulberry Point. In this region, mortalities collected on 8 September 1972 ranged from 46% at the lower end to 76% upriver. On the West side of the James many samples of oysters were collected from six separate leases in a region extending one-half mile above and below the James River Bridge. Here only a normal count for the season was noted (less than 10% recent boxes). No mortalities were reported for the vicinity of the Pagan River. However, our survey showed that a private lease located in from 4 to 6 feet (MLW) above Days Point showed from 23 to 60% mortality.

In summary it was evident that for the James, mortalities extended almost 4 miles further downriver along shore than they did toward the center of the river. Mortalities for the system were estimated at about 10% for private rocks and less than 5% for private leases.

York River: This system has been surveyed 10 times since 24 June 1972. Oyster mortality on public grounds were negligible and oyster mortality at Bells Rock in the upper part of the system was average for the season. Damage to oysters was largely confined to private leases in the upper river in the vicinity of Bells Rock. An estimated 2% of the oysters in the York River were killed as a result of Agnes. Flood-related mortalities were not found after late July.

Rappahannock River: This system has been surveyed 16 times since 24 June 1972.

Damage to oysters on public rocks in the Rappahannock was confined to Ross Rock in the upper river just below Tappahannock. Damage to oysters on private leases was extensive. Salinities in shallow water in the mortality area ranged from 0 to about 3‰ during the mortality period. Oysters began dying on 30 June with peak mortality occurring about 5 July. Flood-related mortalities were not found after 14 August. The area most seriously influenced extended on the south side of the river from 1-1/2 miles below to 3 miles above Bowler's Wharf (the upper limit of oyster culture). In this zone the good oyster bottoms are located in from 4 to 6 feet (MLW). Mortalities here range from 69 to 100%.

On the north side of the Rappahannock the mortality zone extends from Accoceek Point (about 5 miles below Tappahannock) to about 1 mile below Farnham Creek at depth of less than 6 feet (MLW). In this area mortalities ranged from about 48 to 86%. At depth ranging from 6 to 10 feet, mortalities were lower and ranged from about 19 to 74%. In deeper water, mortalities were still lower, but few oysters in this region are planted at depths greater than 14 feet (MLW).

Mortalities from fresh water were light to zero below Farnham Creek and 1-1/2 miles below Bowlers Wharf with the single exception of one bed in shallow water near Jones Point, and two beds in very shallow water at Butylo.

On 22 September 1972 a single survey was made of public and private oyster grounds in the Corrotoman River. Based upon numbers of recent boxes, mortalities in the upper-most portion of the river on private leases ranged from 20% at the Otterman Sharf Ferry Landing to 22% off John Creek. Public rocks from Shelton Bar in the upper river to Corrotoman Bar in the lower river all had less than 20% mortality.

An estimated 50% of the oysters on private leases in the Rappahannock were killed by Agnes.

Potomac River Tributaries (Virginia): Seven surveys have been made in this region. There was considerable damage to both public and private oyster beds in the Lower Machodoc Creek and in Nomini Creek. In Lower Machodoc Creek, up river from Narrows Point, from 68 to 75% of the oysters had died; by 28 July 1972 down river from Narrows Point mortalities ranged from 17 to 43%. Low oxygen conditions developed on 22 August, and caused further mortalities. In Nomini Creek mortalities ranged from 24 to 93% on 20 July 1972. Reports suggest that nearly all oysters are now dead due to a combination of low oxygen and fresh water.

The Economic Loss to Virginia's Oyster Fishery

In addition to the loss Virginia oystermen suffered from the destruction of the Potomac River oyster stocks, VIMS estimated the financial loss to Virginia oyster planters at $7.9 million.

This estimate is based primarily upon the amount of 1969, 1970, and 1971 seed planted in the various river basins (a three-year cycle is chosen because it takes approximately three years to produce market oysters from seed, and 1969, 1970 and 1971 seed were present on the oyster beds at the time of Agnes). Assumptions of the estimate are as follows:

(1) Seed oysters planted in the affected areas came from the James, Piankatank, and Great Wicomico Rivers.

(2) Of the total seed produced by these areas, the following percentages were placed in the rivers indicated:

James	5%
York	10%
Rappahannock	50%
Potomac Tributaries	25%

The remaining 10% was placed in unaffected areas.

(3) Oyster mortalities in the various rivers are based on field surveys by VIMS personnel as well as reports received from members of the industry. These mortalities are:

James	10%
York	2%
Rappahannock	50%
Potomac Tributaries	70%

(4) The natural increase is that normally expected in the affected areas, two bushels of market oysters harvested for each bushel of seed planted.

(5) The value assigned to a bushel of market oysters for 1971--$5.10--is based on information obtained from the Potomac River Fisheries Commission. The estimated rate of increase used in the calculations (20% per year) is believed to be a normal one. (The actual rate of increase will probably be higher due to a scarcity of oysters accompanied by an increase in price.)

(6) Areas which sustained the heaviest mortalities are in general poor setting areas, at the upper portion of the respective river basins. They are, however, good growing areas, free from pests, diseases, and predators, and are heavily planted with seed. Due to their upstream position, the major losses were sustained among these planted oysters.

The computations are as follows:

Computed Oyster Losses

River	Seed Produced (Bushels) * Year 1969	1970	1971
James	486,536	264,203	439,294
Piankatank	3,848	3,581	0
Great Wicomico	50,776	98,380	126,387
Totals	541,160	366,164	565,681

* All bushels are Virginia bushels (A Virginia bushel contains 3,000.9 cubic inches),

River	% of Total Seed Received	Seed Planted (Bushels) 1969	1970	1971
James	5%	27,058	18,308.2	28,284.1
York	10%	54,116	36,616.4	56,568.1
Rappahannock	50%	270,580	183,082.0	282,840.5
Potomac Tributaries	25%	135,290	91,541.0	141,420.3

Note: Unaffected areas received 10% of total seed planted.

River	% of Oysters Lost	Oysters Lost (Bushels) 1969	1970	1971
James	10%	2,705.8	1,830.8	2,828.5
York	2%	1,082.3	732.3	1,131.4
Rappahannock	50%	135,290.0	91,541.0	141,420.3
Potomac Tributaries	70%	94,703.0	64,078.7	98,994.4

River	Natural Growth from the Seed Planted (3 year cycle) Year (and Growth Factor) 69 (X2)	70 (X2)	71 (X2)
James	5,411.6	3,661.6	5,656.9
York	2,164.6	1,464.7	2,262.7
Rappahannock	270,580.0	183,082.0	282,840.5
Potomac Tributaries	189,406.0	128,157.4	197,968.7

Value Lost

River	Year (and value/bushel) 69 (5.10)	70 (6.12)	71 (7.34)	Total
James	27,599.2	22,409.2	41,521.7	91,530.1
York	11,039.6	8,963.7	16,608.4	36,611.7
Rappahannock	1,379,958.0	1,120,461.8	2,076,049.3	4,576,469.1
Potomac Tributaries	965,970.6	784,323.3	1,453,237.1	3,203,531.0
			Virginia Total	$7,908,141.9

It is believed that this estimate is a minimal figure for two reasons. First, estimates of losses based on seed planted are of course minimal since there is some natural set, even in the areas under discussion. Second, and perhaps more important, estimated losses based only on direct mortalities will not give a true picture of the economic damage. An example may clarify this. An oyster planter experiencing mortalities of 50% or more may find it uneconomical to harvest the survivors, i.e. the density of oysters on the bed may be too low to effectively harvest. Even if the bed is replanted and harvested later, some of the "carry-over" oysters will have been lost (mortalities due to old-age, predators, diseases, etc.). Therefore, taking the Potomac tributaries as an example where the estimated loss was 70%, it might be more realistic to count the remaining 30% as virtually lost and to apply a factor of 100% instead of the observed 70%.

The value estimate of 7.9 million dollars is only the primary market value. After processing this estimate would at least double (depending upon the pack); and, depending upon the choice of an appropriate multiplier, after retailing would be from three to five times the primary market value. Thus the total cost to the coastal economy would be considerably in excess of 7.9 million dollars.

6.1.e. Success of Oyster Reproduction in 1972.

Hurricane Agnes came into Chesapeake Bay just as the oysters were beginning to spawn. Many of the live oysters collected since Agnes had spawned to some extent.

In the American oyster, Crassostree virginica, the eggs are spawned into the water where fertilization takes place. The fertilized eggs are carried about by the water currents while they develop into free-swimming larvae. After a larval life lasting for two or three weeks the larvae cement themselves to objects on the bottom, such as oyster shells (a process called setting), and begin their life as sessile animals. The set is the seed of future oyster crops.

The success of setting in Maryland waters is unknown at this time.

In Virginia, oyster setting has been monitored at 57 stations since 19 June 1972. The results show that as of 1 October 1972 there has been an almost complete absence of set in almost all major river systems in Virginia with the exception of the Mobjack Bay region and the Seaside of the Eastern Shore. While cause and effect have not been demonstrated there is little doubt that the excessive fresh water run-off associated with Agnes is in some way associated with the absence of set. Note that of the three most important seed rivers of Virginia, the Great Wicomico and the Piankatank, have received no set, and the James only a very light set. This is most unfortunate since if no set occurs this year then the supply of seed in 1973 will be limited at the time when demand will be at an all time high.

6.1.f Oyster Predators

In oyster growing areas where the average salinity exceeds 15%, oyster predators seriously affect oyster production. Since most of Maryland's oysters grow in low-salinity waters they are relatively free of predators. Virginia's oysters, however, are not so lucky.

The most important effect of Agnes on shellfish communities in the bay, other than killing large number of clams and oysters, was the decimation of oyster drills. No statistics are yet available on Maryland or Potomac River drills, although biologists believe that the oyster drills in Tangier Sound should have been killed.

Virginia, however, has preliminary data from SCUBA surveys and trap catches; these data indicate a dramatic reduction in distribution and abundance of drills or screwborers. *Urosalpinx cinerea* and *Eupleura caudata* do not have pelagic larvae hence are slow to extend their distributions. Transplantation by oystermen and phoresis of newly hatched young are the major means of movement.

The usual "drill lines" are fairly well established by 25 years of fall surveys where live drills, egg cases and drilled spat were the criteria for abundance and distribution. These lines were about at Towles Point in the Rappahannock River, Claybank in the York River, and Brown Shoals, above the bridge in the James. The lines moved upriver a few miles during the drought years of the mid-1960's.

Drills appear to have been eradicated from the Rappahannock River, releasing thousands of acres of public oyster beds with light but regular oyster spatfalls for shell plantings and new production. Another year of monitoring will be necessary to confirm this conclusion and to determine if a buffer zone down to New Point Comfort has been established. The oyster-growing potential of this river is very great if protection and management activities are instituted promptly. The Rappahannock River has always been marginal for drill survival and reproduction, hence an elaborate plan for releasing fresh water in wet years for drill control has been proposed in connection with the Salem-Church Dam.

The York River at Gloucester Point is a much more favorable habitat for oyster drills; some field studies and many long-term observations provide background. In the past large numbers of drills were picked off the pilings at low tides and hundreds were trapped with trays of oysters or baited bags on the bottom. The abundance of drills on abandoned oyster beds above Gloucester Point, and away from piers and pilings, was most vividly demonstrated in the fall of 1971. A very heavy natural spatfall occurred in September 1971 in the lower York River with counts of hundreds of spat per shell on weekly test strings. Nearly 100 trays of oysters on the oyster ground also caught many spat. Within weeks, hundreds of drills had climbed into the trays, which were held one foot off the bottom by four iron legs, using algal and eel grass "bridges." The abundance of drills living on food other than oysters was dramatically demonstrated.

About a month after salinities below 10‰ had occurred from Agnes storm waters, a preliminary SCUBA survey around VIMS pier pilings revealed that drills were scarce. A series of traps baited with mussels and oyster spat has yielded about two drills per trap per week. Most of these are small drills of the 1971 year class, but both Urosalpinx and Eupleura are present. Egg cases have not been found. Nearly all the September 1971 oyster spatfall on natural bottom had been killed by drills before Agnes struck, hence there are not strongly competitive baits in the area. The timbers in the intertidal zone of VIMS piers are crowded with yearling oysters that are out of reach of drills. Above the Gloucester Point area, no drills have been caught yet. They were almost exterminated in this area which has usual annual salinity ranges of 15 to 25‰ and rarely drops to 10‰ even for a day.

In the James River, trapping and searching began at the Hampton Roads Bridge Tunnel and Hampton Bar. A few clusters of egg cases were found, most of which had hatched, and only a few drills have been caught in baited traps. Furthermore, several small 1972 oyster spat were seen on dredged shell which is not expected on Hampton Bar where drills formerly exhibited the highest abundance in Chesapeake Bay. It is most unfortunate, therefore, that oyster setting has failed--the most nearly complete spat failure throughout the western shore of Chesapeake Bay in Virginia for the 30 years of record.

Unfortunately, a flatworm predator (Stylochus) of newly-set oyster spat was not noticeably affected by Agnes at Gloucester Point. The small plankton-derived flatworms were as abundant as usual on test shells and effectively decimated barnacles in the summer of 1972. Other areas have not been monitored for this predator but it is more tolerant of low salinities than oyster drills.

6.2 Soft-shell Clams

6.2.a. General

The soft-shell clam (Mya arenaria) is a northern species, adapted to live in cool waters; Chesapeake Bay marks the southern end of its range. During the summer months Mya in Chesapeake Bay are living under a thermal stress--when the water temperatures become too high for too long, Mya die. These so-called "summer mortalities" occur frequently. Also, in recent years some unknown factor or factors has been depleting Mya populations in several areas of the bay, notably in the Potomac and Patuxent Rivers. Still, many soft-shell beds in the upper bay have remained highly productive.

When Hurricane Agnes hit, then, the soft-shell clams may have already been under a thermal stress. The additional stresses, including high turbidity, low salinity, and, perhaps, low dissolved oxygen, were expected to produce heavy mortalities.

6.2.b. Maryland

The first effect of Hurricane Agnes on the soft-shell clam industry was to pollute the bay waters and the clams with sewage. The bacterial levels in the bay quickly exceeded the permissible levels and forced the Health Department to stop the fishery.

Coinciding with the pollution was a severe drop in salinity and a slight increase in water temperature. Clams began to die.

The Maryland Department of Natural Resources (MDNR) immediately began to sample the major soft-shell clam beds to determine the extent of the mortalities and to collect clams for bacterial and pesticide studies. The MDNR research vessel, however, was only equipped to sample commercial-sized clams, not the smaller, seed clams. This sampling continued throughout the summer and sampled every major bed.

Although the data from the MDNR sampling has not been analyzed, it is apparent that market-sized soft-shell clams suffered heavy mortalities on every major bed, approaching 100% in some areas. Soft-shell clams began dying after 11 July. By 16 July the die-off was in full swing. Live clams were bloated and weak. Normally a temperature of 27 C (80 F) will stress Chesapeake Bay *Mya.* Three days before the peak mortality occurred the water temperature on the clam beds (at a depth of 3 m) reached 31.6 C (89 F), and averaged 30 C (85 F).

Along the western shore, market-sized clams suffered heavy mortalities from Gibson Island (above Annapolis) to Herring Bay. Along the eastern shore mortalities were heavy from Kent Island to Bloody Point, in the Chester and Choptank Rivers, in Eastern Bay, and throughout Talbot County. Although not all of the market-sized clams died, too few remained to make fishing economical; survivors will serve as a breeding stock. Figure 6.1 shows the areas where major lesser of soft-shell clams occurred.

The Ocean Research Laboratory of the Westinghouse Electric Corporation was holding adult soft-shell clams in a laboratory near Annapolis when Agnes hit. All the clams died within a week after the salinity dropped.

Mortalities appeared to be less severe among the smaller, sub-commercial *Mya*. But how well they survived is not yet known. MDNR has equipped its vessel with a smaller-meshed dredge so that it can determine what numbers of seed clams are left. The Resource Evaluation Project of the National Marine Fisheries Service Laboratory at Oxford, Maryland (NMFS) used a small-mesh dredge to sample some *Mya* beds. NMFS found seed and some adults in the Miles and Choptank Rivers, in Eastern Bay near Kent Point, and around Poplar Island. The Chesapeake Biological Laboratory of the Natural Resources Institute (CBL) found some seed and a few adults in the lower Patuxent River, near Solomons. The CBL samples indicated that the clams had grown from 3 to 5 mm between 8 June and 21 August.

These seed clams if they continue to survive and grow will become commercial-sized by 1973. If they are abundant they could support a fishery. If few, they will serve as a spawning stock. At any rate, some *Mya* survived Agnes. The future of the Maryland soft-shell clam fishery may not be as grim as was first thought.

Detailed surveys of all areas where soft-shell clams usually occur are being conducted by state biologists and commercial clammers. These surveys will provide final assessments of damage and will form the basis for any rehabilitation efforts.

6.2.c. Virginia

Virginia has relatively small populations of soft-shell clams. No information is available concerning the effects of Agnes on these populations.

6.3. Hard Clams

Almost all of the hard clams harvested in Chesapeake Bay come from Virginia waters. In the Maryland part of the Bay, hard clams occur in significant numbers only on the lower eastern shore; nothing is known about the effect of Agnes on these clams.

In Virginia, the investigation of hard clam population was conducted on both private and public grounds. Mortalities were first reported by private ground holders, possibly because the dense concentration on their grounds and in their floats was an additional stress factor. Subsequent to these investigations public ground sampling began and is continuing.

Mortality on private grounds was determined from the sample ratio of live hard clams to recent "boxes" (valves still attached by the hinge). On public grounds, because of the time lapse in which valves could be separated or move shoreward by wind driven currents, the physical condition of live hard clams was evaluated. Clams in very poor condition, and possibly dying, were recognized by the dark and flaccid state of the mantle and gills. Furthermore, the valves of these clams were easily separated, an impossible feat in healthy clams.

Private Grounds: Estimates of damage were made on grounds of four commercial firms. One firm with holdings in the Perrin River (a tributary to the lower York) experienced 58% mortality of clams planted on the bottom and 82% mortality of clams held in floats. A firm located 8 miles above the mouth of the York River experienced 33% mortality among transplanted cherrystone and chowder size clams planted in water depths of 3-1/2 - 4 feet (MLW). Inshore in 2-3 foot depths (MLW) 100% mortality occurred among 1000 bushels of Littleneck clams. (This was the only planting where total number of bushels lost was known. This loss was estimated to be $25,000). Two other firms with grounds in the Poquoson area experienced 40-44% mortalities. The mortalities experienced during this period was far in excess of the 10% mortality normally realized in transplanting and holding operations. Total dollar value of hard clam loss on private grounds has not been estimated.

Public Grounds: All clams sampled from a depth of 20 feet or greater in the James River (MLW) appeared to be in healthy condition. All clams from the shoaler areas of the James, such as the Middle Ground and Newport News Bar, however, were weak. A high mortality would probably occur if these clams were to be harvested, transported and then replanted. (It is mostly Hampton Roads clams purchased since Agnes that are responsible for the high mortalities on the private grounds).

Hard clams from deep-water samples in the York River appeared to be in good condition. In shoal water, weak clams constituted as high as 70 percent in one sample at Yorktown, and, overall, for the area of Queen's Creek down to the Perrin River about 40 percent of the clams appeared weak and possibly dying.

Evaluation of Agnes effects on hard clam populations in the Chesapeake Bay from New Point Comfort to Wolf Trap is presently underway. Field work was completed by late October but an evaluation of the data is not available for this report.

6.4. Blue Crabs

Hurricane Agnes apparently caused little damage to blue crabs in Chesapeake Bay. Highly mobile, most crabs avoided the unfavorable environmental changes brought by Agnes, although a few died from silt, low dissolved oxygen levels, or red tide toxins. Reproduction may have been successful even though the storm destroyed some of the larvae hatched early in the summer.

6.4.a. Maryland

In Maryland, fewer crabs than normal were present before the storm. They were probably held in the lower bay by the lower than normal salinities and cooler water temperatures. Sampling by the Natural Resources Institute's Chesapeake Biological Laboratory in the Chesapeake and Delaware Canal and in the Patuxent River revealed very few crabs immediately after the storm. But the crabs soon came back, suggesting that they had moved away when the salinity dropped.

Commercial crab fishermen reported that some crabs died in their pots during and immediately after the storm but the total loss was not great. These mortalities were probably caused by heavy silt and low levels of dissolved oxygen. Also, after the storm the catches fell off for a while, possibly because the crabs were feeding on dead fish and oysters instead of being attracted to bait in the crab pots.

The storm hit during the crab spawning season. Possibly it destroyed the larvae released early because few small crabs were found in Maryland until October. The larvae released after the storm, however, may be adequate to sustain the population; evidence collected by Virginia biologists indicates that this is so.

6.4.b. Virginia

Blue crab stocks within the Chesapeake Bay and its tributaries in 1972 were made up of the 1969, 1970, 1971, and 1972 year classes. The effects of the storm appeared to differ with each yearclass, depending on the horizontal distribution of individuals before, during, and after the storm.

The 1969 yearclass supported the commercial hard crab fishery from September 1970 through August 1971. There would have been too few 3-year-old survivors in June 1972, less than five percent of the yearclass, to be considered in the appraisal of damage.

The 1970 hatch supported the hard crab fishery from September 1971 through August 1972. Most of the females of this yearclass matured in the fall of 1971 and spawned in the summer of 1972. Large catches of hard crabs were reported in the Potomac, Rappahannock, York and James rivers from April 1 until the storm occurred. Catch in the Potomac, lower Rappahannock, and lower York rivers remained good the following two weeks, while catch decreased in the upper York and in the James River and Hampton Roads. In the 2-week period following the storm, some fishermen caught too few crabs to justify the cost and effort of baiting and fishing pots.

Crabs moved downstream and to deeper water after the storm, and some time elapsed before fishermen relocated concentrations of hard crabs and reset their pots. The flood caused little mortality. Fishermen on the Potomac, Rappahannock, York and James rivers found a few dead crabs when pots were fished after the storm. Dissolved oxygen in the deeper waters of the river channels was reported to be below normal but rarely low enough, i.e. 2 ppm, to suffocate crabs. Landings of hard crabs in Virginia in July and August, as provisionally reported by the National Marine Fisheries Service, were about equal to those reported for the same months the two previous years despite the disruption of the fishery.

Crabs of the 1971 yearclass were located primarily in the Virginia tributaries and in Maryland waters of the upper bay before and during the storm. Size of these crabs ranged from one-half to three inches. Decreases in numbers of crabs of the 1971 yearclass in the Rappahannock and James rivers occurred in July and August. These decreases must be due in part to natural deaths unrelated to effects of the storm and to normal downriver displacement of females as growth continues and maturity is attained, and in part due to delayed effects of the storm. Oxygen sags occurred in various sections of the rivers at least through the end of August. Several crab kills were reported, for example along the southern shore of the lower end of the Potomac in late August, probably from a combination of oxygen deficiencies and the toxin produced by a naked dinoflagellate, Gymnodinium splendens. Crabs in the York River seemed least affected, probably because the river has a relatively small drainage area and freshwater flooding was less than in other rivers.

Reports from commercial soft and peeler crab fishermen and dealers of a decrease in numbers of crabs during the summer substantiate the results of trawl surveys. Catches of peelers (1971 yearclass) in middle and lower Rappahannock River and in mid-bay at Tangier in late April and May were better than average and shedding occurred with little accompanying mortality. Following the storm and throughout the remainder of the summer and early fall peelers were scarce, except for a brief small increase in mid-July.

Provisional landings reports of the National Marine Fisheries Service showed substantially lower than average peeler catch in July and August in Virginia.

Pushnet catches in shallow water at VIMS up to the end of August each year consist almost entirely of juvenile crabs hatched the previous year, but after early September the crabs are mainly young-of-the-year. Smaller numbers of juvenile crabs were caught in 1972 from April to August than in 1971, suggesting that the 1971 yearclass was smaller than that of 1970 (Table 6.1). Noteworthy is the decrease in numbers beginning in early July 1972, substantiating the results of trawl surveys and commercial fishermen's reports of a general decline soon after the flood.

Spawning of blue crabs began about mid-June, 1972, and eggs were hatching or about to hatch at the time Tropical Storm Agnes was passing through the Chesapeake Bay area.

Table 6.1. Pushnet samples of blue crabs at VIMS, York River in 1971 and 1972.

Date (approximate)	Number of Crabs 1971	1972
April 5	2	0
12	27	4
19	36	12
26	-	1
May 3	239	15
10	136	23
17	96	41
24	93	-
June 1	46	27
7	92	15
14	56	55
22	114	23
28	38	39
July 5	47	31
13	-	10
20	-	9
26	-	4
Aug 2	-	13
9	-	19
17	-	6
23	-	11
30	-	7
Sept 6	12	28
14	36	69
21	11	6
28	9	44
Oct 4	9	28
11	25	30
18	-	84

Hatching of crabs apparently continued throughout the summer and growth appears normal, judged from the presence of numerous crabs 9 to 36 mm wide in the latest samples of October 11 and 18. The 1972 yearclass appears to be of average size. Small crabs, 5 to 17 mm wide, appeared in pushnet samples by the first of September, in larger numbers than were caught on comparable dates in 1971 (Table 6.1). Samples of crabs from several sites on July 19 and 20 showed the presence of DDT and its metabolities in crab muscle was well below critical levels. High mortality among hard, soft and peeler crabs through the Chesapeake Bay in 1971 was attributed to a combination of low dissolved oxygen, high temperature and the presence of a bacterium *Vibrio parahaemolyticus.* This bacterium was unreported in 1972.

6.5. Finfish

6.5.a. Maryland

Little is known about the effects of Hurricane Agnes on fish in Maryland's part of the bay; and the long-term effects will probably not be evident for a year or more. The biggest effect was flushing out the nursery areas; the eggs, larvae, and post-larvae were swept away and probably destroyed, as were many of the food organisms. The loss of eggs and larvae was not measured, and the seriousness of the loss may never be known. The juveniles and adults of most fish species apparently moved down the bay to saltier water. Also some typically fresh-water fish, such as carp and pumpkinseed sunfish, were caught near Solomons in water that was nearly fresh but would normally have a salinity of 10 to 15‰. Few dead fish were reported.

6.5.b. Virginia

In Virginia, two programs designed to measure both direct and indirect effects of Agnes on finfish were mounted within a few days after Agnes rainfall. The first began June 24 and consisted of sampling the heavy runoff for planktonic fish larvae and fish food organisms in the Rappahannock River and the James River. The second program began June 28 and consisted of a bottom trawling program to determine the extent of displacement of larger fishes by the downstream runoff and subsequent salinity decrease. A follow-up trawl survey was made between August 8 and September 7 after the rivers had experienced some recovery.

Plankton Studies: During the early part of the survey for larvae and food organisms, all planktonic organisms in the water column were being carried out of the rivers and into the mainstem of Chesapeake Bay. No flood tides of any magnitude occurred for many days.

The fish larvae segment provided 268 quantitative samples of drifting larvae collected between 24 June and 7 July in the James and Rappahannock rivers. The collection has not been processed in detail but examination of four samples and visual observation of others discloses that tremendous number of young fish were swept out by the flood. Identification of the organisms in the samples is time-consuming. One sample represents only 10 minutes of fishing effort but required one day of processing effort. The following analysis of some samples should provide some idea of the mortality experienced.

The larvae catch for 10 minutes on June 27 at midnight in the Rappahannock was 247, and at 0100 on June 30 was 576. Gobies made up 99% and anchovies 1%. In the James River at 0100 on June 25, 62 larvae were captured and at 0125 on June 26, 110 larvae were captured. By principal taxa, gobies made up 64% and anchovies 30% of the catch. Young of other species, such as alewife and shad, were also captured but in small numbers. The effects of Agnes on Alosids were probably indirect, i.e., caused a food shortage, since by late June these fish have usually used up their yolk supply and are actively feeding.

Converting the fish catches per ten-minute sample to hourly values gave counts of 1482 and 3456. By using flow rate (which was measured by anchored current meters) we made preliminary calculations which show approximately 2,811,000 and 6,556,000 larvae passed out of the Rappahannock per hour on the times and dates indicated. As the larval samples are processed, more exact estimates of loss will be obtained.

The planktonic crustacea were also well represented in the plankton samples. These groups are extremely important as fish food. In the Rappahannock samples (above) there were 3872 mysids, 1344 Rithropanopeus, and 256 Acartia (a copepod) in the June 27 sample; and 5712 Rithropanopeus, 2112 Neomysis, and 240 Palaemonetes in the June 30 sample. In the James there were 5140 Leptodora and 785 Neomysis; and 5608 Neomysis and 896 Crangon for the respective two 10-minute samples.

Until the plankton samples are processed, absolute loss of larval fish and crustacea cannot be determined. The effects of the loss on future stocks will be difficult to estimate, particularly those taxa such as striped bass, gray trout, spot, and croaker that had young in the estuaries but were not actually swept out of the rivers. For them the loss of important food resources may have played an important role in population regulation in 1972.

Trawling Studies: The trawl survey conducted just after Agnes and again two months later demonstrated that the larger fishes moved downstream as the floodwaters reduced salinities in the estuaries. Our salinity profiles and species counts show the displacement was approximately 7-12 miles in the James, the same in the York, and 10-16 miles in the Rappahannock River. Bottom species such as spot and croaker were just as numerous after the flood as during. No dead fish were found on the bottom during our surveys. The dissolved oxygen (DO) on bottom was adequate and normal for the temperature encountered during both surveys. Since our survey only lasted two days on each river, it is very possible the extreme downstream displacement may have been missed, and the DO may have dropped to low levels later. In the Rappahannock low DO persisted for several days after the trawl survey had finished. Trawling was done in mainstream because of draft limitations of the vessel. From other Agnes work we know the salinities fell first on the upriver shoals and remained normal longest in the mainstream.

From our during-and-after trawl survey we can conclude, that the fish were moved downstream and off the shoals. We could detect no difference in population number and found no direct evidence of mortality of adults due to Agnes. As the freshet diminished, the larger fishes returned to their former distribution along the salinity gradient. Reproduction was not affected because the fishes had passed spawning time or were spawning elsewhere in late June. Growth may have been temporarily affected but this is doubtful. The trawl portion may be considered finished and the analysis completed. Detailed analysis is to be included in a report to be submitted to NMFS at a later date.

The displacement of fishes downstream and into deeper water disrupted the recreational fishery and the food fishery. The economic loss caused by the disruption has not been estimated.

A better assessment of the effects of Agnes on finfishes will be developed in retrospect as data accumulate on recruitment from the 1972 year classes. We know already that the 1972 year class of blueback herring, alewife, and shad was the lowest since 1969 on all rivers except the Rappahannock, but we are not ready to blame Agnes completely. As the young of other species mature we hope to census them and determine an unbiased index of population size which we can compare to later recruit indices. This should be included at least for the more important species not presently covered by existing VIMS programs.

SECTION 7. SEA NETTLES

The stinging sea nettle, Chrysaora quinquecirrha, is man's worse pest in Chesapeake Bay. The free-swimming medusa stage has interfered with commercial fishing and water-contact recreation since Colonial times. A medusa may grow to 9 inches in diameter and trail numerous stinging tentacles, each more than two feet long (Schultz and Cargo, 1971).

In recent years, Bay scientists have been studying the sea nettle, looking for some way to control it. A part of these studies consists of monitoring the bay for the medusa, ephyra, polyp, and cyst stages of sea nettles. Free swimming stages are captured by towing 1/2-meter plankton nets through the water. The sessile stages are monitored by examining the surfaces of oyster shells dredged from the bottom of the bay. The monitoring studies have shown that the troublesome medusa appear early in the year, reach the peak of abundance by July or August, and disappear by November. Furthermore, these studies showed that sea nettles live well and reproduce at salinities from 7‰ to 35‰, but that below 5‰ only the resistant cyst stage can survive.

Another study showed that sea nettle cysts held in water with salinities greater than 5‰ came out of their cysts (excysted) more rapidly as the salinity increased. For example, at a salinity of 6‰ they took 12 days to excyst, whereas at 12‰ they took only 2 days. Thus, the rate that the swimming forms reappear after a period of low salinity can be predicted by knowing how fast the salinity of the water increases.

7.1. Maryland

Hurricane Agnes made its influence felt on Chesapeake Bay just as the medusa stage was becoming abundant. By 1400 hours on 27 June the salinity at a sampling station in Mill Creek (near Solomons in Calvert County) had dropped to 3.1‰ and the sensitive stages (medusae, ephrae, and polyps) were being destroyed. During 23-24 June 1971, sampling for ephyrae over a 25-hour period yielded 2009 ephrae. During 27-28 June 1972, almost one year later and right after Agnes, a similar sampling effort collected only 18 ephyrae, about one one-hundredth of the previous year's catch. By 30 June only cysts remained. These did not begin excysting until the last half of July when the salinity had returned to 6%.

A similar pattern developed nearby at St. John Creek. Ephyrae were collected from 12 June until 26 June. The salinity during this period was 7‰ or greater. On 3 July the salinity had dropped to 3.1‰ and no ephyrae were found. None has been found since. During September a few medusae were found, but by then the salinity had risen to 10‰.

Bay-wide surveys of spawning sea nettles (medusae) also revealed the effects of Hurricane Agnes, although undramatically. Usually the medusae appear in numbers by late June. In 1971, however, the population was very low for some as yet unexplained reasons. Sampling revealed that this low population produced few larvae. Neverthless, cysts remained from previous years. These cysts should have produced medusae during the summer of 1972.

Sampling during 10-13 July throughout the upper Bay yielded only cysts, even in Tangier Sound where the storm's effects were mild. No medusae were observed at any time during this sampling. Appendix III contains a summary of this and the other CBL surveys for sea nettles during 1972. (For contrast, look at Appendix IV which shows the number of polyps per shell for 18 locations in November 1971. Note especially the number of shells with 50 or more polyps).

Later, on 24 July-2 August, when a partial recovery had taken place, the only localities where polyps were taken were the higher salinity stations where the effects of Agnes were the least marked. During this second survey, several large medusae, were sighted, two at Matapeake, near the Bay Bridge and one at McKeil Point in the Little Choptank River.

The third survey, in October, showed continued recovery. Polyps were more numerous but still confined mostly to the Tangier and Pocomoke Sound area. One shell from the St. Mary's River also bore some polyps. Salinities at this time were higher, although still well below the normal for this time of the year. Swimming medusae were noted at a number of stations at this time. Individual sea nettles, mostly very large (greater than 7 inches in diameter) were seen at two locations in the Patuxent River and in the Little Choptank River, Wye River, at Herring Bay and east of South Marsh Island. Off Parkers Creek about 20 miles north of Solomons, more than 25 medusae were seen during a 5 minute period. They were all large (greater than 6 inches) and appeared to be healthy and robust.

A sampling of the oyster bottoms in Virginia during 30 October to 2 November reiterated the shortage of sea nettle polyps. Only four samples taken in quiet coves opening directly into the bay showed live polyps. In one of these areas (Piankatank River) the polyps were quite abundant (up to 50 per shell).

These investigations made it evident that a major temporary effect was impressed upon the sea nettle population of Chesapeake Bay. Partial recovery was observed and will provide for some reinfestation in 1973. It appears, however, that there is little likelihood of an extra large population developing in 1972. In fact, the storm's effects may affect the sea nettle population for several years to come.

7.2. Virginia

Analysis of the effect of Hurricane Agnes on populations of *Chrysaora quinquecirrha* in lower Chesapeake Bay has to include data for several previous years. Medusa populations were unusually low in most of the lower Chesapeake Bay in 1970 and 1971. Therefore, data from the more normal years of 1968 and 1969 will serve as a basis for comparisons with the observations made in 1972.

Very few observations on medusa abundance had been made in 1972 prior to June 22. With the advent of Hurricane Agnes, we decided to concentrate on tributaries that were not affected by the freshet as rapidly as the major tributaries (the James and Rappahannock) were. However, observations made by VIMS personnel collecting other data in those rivers indicated a nearly complete absence of medusae at the time of the hurricane and thereafter.

Our observations showed that the jellyfish populations of those tributaries that empty directly into Chesapeake Bay or Mobjack Bay did not appear to be affected by Hurricane Agnes as seriously as the major tributaries. With the exception of the North River, medusae were present every time the rivers were visited, although the medusae numbers were low in comparison to those observed in 1969.

Ephyrae were present in most of the minor tributaries and in the tributaries of the James and York River near their mouths (Nansemond River and Hampton River in the James and Sarah Creek in the York) during July and August of 1972.

Polyp populations were determined by counting numbers of polyps on oyster shells from various areas in Virginia. Comparison with data collected in previous years and early in 1972 in the James and York rivers shows that Hurricane Agnes had a very harmful effect on polyp populations in the upper and middle estuaries of these rivers. We still were able, however, to find three polyps at Wreck Shoal, James River, on 8 August. These indicate that some polyps have survived the low salinities prevalent there. Samples from the Nansemond and Hampton rivers showed that polyp populations in tributaries of the James near the Chesapeake Bay were not affected as badly as those in the river proper. A relative abundance of polyps in Sarah Creek, a tributary to the lower York River, also indicates that tributaries close to the river mouth were not as greatly affected as up-river tributaries were.

The data collected in the Great Wicomico River show that medusa and polyp populations were found there in the spring and therefore suggest that substantial populations of both (at least of polyps, anyway) would be present through the summer. However, low salinities drastically reduced their numbers by August.

Observations made on one visit to the Eastern Shore together with comments from local watermen indicated that Chrysaora and Aurelia medusa populations were very small this summer.

Our observations may be summarized as follows. Medusae populations were absent from the major river tributaries of the bay and their polyp populations were almost wiped out. Tributaries of these rivers near the bay appeared to have escaped these extreme effects. Minor tributaries of the bay did not appear to be badly affected by Hurricane Agnes, except for a belated effect on the Great Wicomico River. Through the first part of August the Piankatank River was still supporting a moderate population of medusae. Of all tributaries studied, the North and Ware rivers supported the largest populations of medusae and substantial populations of polyps.

It should be emphasized that it is the high reproductive potential of existing polyps that poses the greatest problem. A polyp is capable of producing more polyps by a sectiorial reproduction through the formation of podocysts and buds. It is the polyp which gives rise to the medusa through the process of strobilation with as many as forty ephyrae being produced during the year. The ephyrae develop into the medusae. Although there is a limited number of polyps available at this time, the high potential for their reproduction and formation of cysts and medusae still exists for the coming year. The major effect of the storm has been to reduce the polyp populations and medusae populations but not to wipe them out entirely.

SECTION 8. FOULING ORGANISMS AND OTHER BENTHOS

8.1. Sponges

Four species of encrusting sponges are commonly present on oyster beds and piling in meso- and euryhaline waters. These species are *Microciona prolifera*, with the most low-salinity tolerant, persistent, and longest-lived colonies of the four; *Lissodendoryx isodictyalis*, the greenish-yellow "stinky" sponge; *Halichondria bowerbanki*, the common yellow "sun" sponge seen on pilings at low tide; and *Haliclona loosanoffi*, a delicate, soft, violet- or lavender-tinged "volcano" sponge. The latter three are casually referred to as "yellow" sponges in lower Chesapeake Bay although the colors are quite variable with state of health and growth, and also with regions. All four species are regular and common on trays of oysters and pilings at Gloucester Point although the yellow sponge colonies tend to vary in size with seasons. Yellow sponge "spots" representing new colonies from pelagic larvae are common in summer on weekly test plates and shells (new substrates each week).

The distributions of the encrusting sponges are determined more by the intensity of spring runoff (size of drainage basins) than by summer salinities. They usually persist where summer salinities are above 15‰, except in the James River where distribution is basically confined to Hampton Roads below the James River bridge. In the York, sponges extend almost to the head of the river, and in the Rappahannock River well above Towles Point (Urbanna) and often red sponges as far as Morattico bar.

Perhaps in no other phylum did species experience such drastic changes of distribution and abundance from Agnes runoff as in the sponges. In the Rappahannock River, no sponges could be found in mid-September 1972. Dead colonies of *Microciona* were intact and abundant but the other species had disintegrated and disappeared. No new encrusting colonies could be found on the Rappahannock River bridge pilings by SCUBA to 30-foot depths. The huge oyster bed at the mouth of the Corrotoman River called Drumming Ground, which probably comprises 1000 acres or more, was notorious for two decades for its massive growths of red and yellow sponges. It was nearly impossible to catch oysters and shells in late fall, even after spring shell plantings, because the dredge quickly filled with sponges and red algae (Agardhiella mostly). Dredging at shallor Corrotoman Point, where red algae always filled the dredge, revealed clean shells and no algae. Only sea anemones and encrusting bryozoans were abundant. Dredging in the Corrotoman River and as far down as Butlers Hole at the mouth of the Rappahannock River yielded nothing but dead colonies of Microciona.

In the York River near Gloucester Point, SCUBA diving on pilings and oyster beds revealed colonies of Microciona partly alive in very irregular patterns--not necessarily the tip or the base dead but spotty arrangements of dead and live tissue. New encrusting colonies increased in size and abundance between August and September surveys. Microciona is well on its way back at Gloucester Point as of September but branching colonies are small yet. Of the yellow sponges, only young Lissodendoryx colonies were found in low abundance on the York River bridge pilings. Yellow sponge "spots" occurred sparingly on monitoring substrates at VIMS Pier this summer but were not identified by genus. The usual massive growths of Halichrondia and Lissodendoryx on pilings, trays, and oyster beds are gone. Haliclona is fragile and usually less conspicuous and less persistent than the other yellow sponges. New growth was found on oysters in an old undisturbed tray at VIMS Pier on 10 October 1972.

Dredging and SCUBA surveys on Hampton Bar and the Hampton Roads bridge-tunnel pilings revealed only Microciona, apparently unharmed by low salinities but less massive and less abundant than expected. Yellow sponges, which regularly present cleaning problems in trays of oysters there for monitoring disease, were not found in three areas of the bridge-tunnel and Fort Wool complex, or on Hampton Bar.

One may predict that the vagile sponges with their rapid colonizing capabilities will be back in their usual distributions and abundances in a year or two. *Microciona* has an early start, but is slower growing, more tolerant of estuarine fluctuations, and may require longer to recoup substrate area than the yellow sponges. The Rappahannock River may be an exception to this prediction and may require more time.

Meanwhile, large areas of substrate on oyster beds have been released for oysters and short-lived opportunistic species to utilize. Unfortunately, oyster setting appears to be the poorest in decades on the Western Shore of Chesapeake Bay for current-year spat were quite rare. Intensive surviving spatfalls of the 1971 yearclass occurred on pilings of bridges in all three rivers in a zone about one foot wide near the low intertidal level.

It is difficult to assess the effects of Agnes on boring sponges in oysters. *Cliona celata,* the large-hole species, has conspicuous yellow papillae protruding from perforations of the shells. Boring sponges do not appear on oysters until about the third year unless spat are set on old shells containing active colonies or gemmules (resting stage). It is a regular practice at VIMS to immerse live oysters for five minutes in full brine solutions (saturated) to kill boring sponges, but this treatment usually kills only the outer layers, and in a couple of months, despite anaerobic blackening of the shells and holes, growth is resumed. Free oysters with no contact with old shell developed infestations of small-hole boring sponges in the third year in trays. Early infestations nearly always occur in the oldest shell near the hinge and most commonly on the cupped valve. The species that produce small holes are inconspicuous with papillae so small and retracted that live sponge is difficult to see without magnification or digging into the shell. Spicule preparations are required to identify the several species in Cheseapeake Bay. The distinction between large and small holes is clear and easy to make.

Boring sponge was not found in the Rappahannock River and it seemed scarce in Hampton Roads after breaking hole-filled shells. Most observations were made at Gloucester Point in trays of oysters. Freshwater exposure tends to kill sponge layers as does brine, but days of exposure are required. The boring sponges may have been damaged at Gloucester Point, but by 1 October 1972, Cliona celata was growing profusely in old oysters, and colonies of small-hole species were common in older oysters. C. celata tends to dominate on very old oysters (shell strike), but new infestations on free-spat-type oysters are usually small-hole species. Yet, earlier studies at VIMS showed a tendency for mixed infestations to be less common than expected by chance.

It appears that boring sponges have quite strong capabilities to resist unfavorable environments although further surveys may reveal that they have been eliminated temporarily from the Rappahannock River.

8.2. Hydroids and Other Coelenterates

The hydroids of Southern Chesapeake Bay have been studied intensively by Calder. In this report, however, only major conspicuous species will be mentioned. "Rope grass" is a familiar troublesome phenomenon to watermen, fouling nets and traps in the low-salinity, upriver reaches of Virginia estuaries. Post-Agnes salinity regimes permitted invasions of these hydroids to the mouths of each of the three major Virginia tributaries. Blue crabs were pushed down into the lower reaches of the rivers where crabbers followed them with pots. The rope grass became so heavy on crab pots that the traps were camouflaged and wouldn't catch crabs. Crabbers removed their pots for drying and brushing on shore. As late as mid-September, crabbers in the lower Rappahannock River were still pulling rope grass off their pots as they fished the crabs. Crabbers who had spent a lifetime fishing in the same river claimed they had never seen rope grass before in the lower Rappahannock River.

Rope grass in 1972 was comprised mostly of Garveia (Bimeria) franciscana which stretched out in arborescent colonies up to a foot long. This size exceeds the maximum reported by Calder, possibly because of the nutrient abundance following Agnes. Bougainvillia rugosa was also nearly always present on pilings and stakes but was much less abundant and not as luxuriant.

In the James River, Garveia did not become excessive on the Hampton Bar trays where the "white" bryozoan was dominant in August and sea squirts replaced it in September. At the James River Bridge (Brown Shoals), trays and oysters were excessively covered with rope grass. All stakes and pilings from Gloucester Point upriver to Bells Rock were heavily covered with the horny-stemmed hydroid. The bridge pilings in the York and Rappahannock rivers exhibited rope grass at the mean low tide level, and it increased in density to almost complete coverage at 20-foot depths. On the York River Bridge pilings, sea squirts increased similarly with depth although none were found on the Rappahannock River Bridge pilings. Only at the bridge-tunnel in the lower James did Bougainvillia approach the density of Garveia. Timing of observations was important, for rope grass and sea squirts tended to shift upriver in abundance as salinities increased. However, rope grass was still extremely abundant and vigorous at Gloucester Point in late September. Other species were probably affected but only the eruptive Garveia was conspicuously affected in abundance and distribution. Hydroids usually contribute little to fouling of oyster beds and trays except on shell bags in shallow low-salinity creeks. Rope grass is not usually found on oysters on the bottom. It accumulates in great abundance on trays, underwater lines and pilings. The bryozoan _Anguinella,_ which exhibits the arborescent habit of hydroids, was regularly present in moderate abundances on pilings at all stations visited in this fouling survey.

Sea anemones seemed to thrive on the salinity and nutrient changes produced by Agnes. At Gloucester Point on tray oysters, they seemed especially abundant and large. Many were survivors from 1971, hence rates of recruitment were obscured. At the bridge pilings in all three rivers, anemones appeared most abundant in the first two meters below low tide level, and individuals often extended out 1-1/2 inches from pilings. All anemones on oysters and bridge pilings were _Diadumene leucolena._

The purplish soft coral _Leptogorgia virgulata_ was never abundant in lower Chesapeake Bay but was usually seen on SCUBA dives in the lower York River and occurred fairly regularly in dredge hauls on oyster beds. The black "core" of colonies is very tough and persistent. Only dead colonies have been seen in all post-Agnes surveys including patent-tong rig clam catches in deep water at Gloucester Point where it is usually collected for classes.

8.3. _Tunicates_

Three species of tunicates foul oysters and trays at Gloucester Point. Perhaps the worst fouling organism in Virginia waters is the solitary sea squirt _Mogula manhattensis_ which grows to full size in 60 to 90 days. In typical years _Mogula_ covers all subtidal substrates off the bottom with layers of sea squirts up to one or two inches thick. The weight of a tray of oysters may be doubled or tripled in one month. Sea squirts have a long reproductive period from May to October in Virginia and a wide distribution in summer when salinities are favorable and maturity and reproduction are attained quickly.

In 1972 after Agnes, Mogula at Gloucester Point was suppressed by salinities fluctuating between 10 and 15‰ until August. Some 100 trays of oysters that were usually brushed clean every three weeks in summer had only a very few sea squirts as late as 10 August 1972. In early September a heavy coating of half-grown sea squirts was found on all trays. Diving revealed that all shells on the bottom in the vicinity of Gloucester Point were covered with Mogula, and on bridge pilings they increased in abundance with depth to a full mat at about 20 feet. Also in late August and early September, a state shell planting (one-quarter million bushels) inshore of Brown Shoals above the James River Bridge became coated, and coverage extended to Hampton Roads Bridge tunnel at the mouth of the river. Mogula is one of the species that is pushed downriver by low salinities but recovers its abundance and distribution quicly as salinities become favorable. A tray on Hampton Bar covered with an unrecognized bryozoan with stiff, erect, white fronds in early August was unbelievably loaded with sea squirts in early September. The full usual distribution had not been attained in the James River by mid-September and no sea squirts were found in the whole Rappahannock River, a favorable area in normal years.

The colonial ascidian Botryllus schlosseri has an interesting history in lower Chesapeake Bay. It requires higher salinities than Mogula and the sponges previously discussed. For nearly 20 years it was considered to be a rare inhabitant of deep waters near the mouth of Chesapeake Bay. It never occurred on oyster beds, even those planted in 20 to 30 feet of water on the western shore of Chesapeake Bay proper. During the drought years of the mid 1960's, Botryllus suddenly appeared at Gloucester Point on tray oysters and eventually erupted to cover nearly all tufts of eel grass and Ruppia in the lower York River and Mobjack Bay. It is a fast-growing pernicious pest in the cool months of spring and fall but barely survives hot summers in Virginia. It apparently requires a substrate off the bottom and out of heavy siltation for it was never observed on oyster beds, Botryllus was not vigorous in the wet year of 1971 but it was still present on trays of oysters in the spring of 1972. After Agnes it disappeared and no trace of it has been found at any fouling stations. Its second reproductive season for 1972 lies ahead but salinities probably are unfavorable this year and it may not recover its distribution of the 1960's until another series of drought years occurs.

The little greenish-yellow colonies of Perophora viridis are usually seen in late summer and fall at Gloucester Point, and they winter over in basal strands adhering closely to the substrate. They are more interesting than important as epifauna. None have been seen in 1972 for the first time in many years.

8.4. Bryozoans

Several common species of encrusting and arborescent bryozoans are adapted to low-salinity conditions, and Agnes provided clean surfaces and nutrients to enhance their abundance and distribution. The most striking event was the appearance of a dominant bryozoan noticed for the first time as a fouling organism after 22 years of handling trays. This species laced the tray frame and top with a network of rigid, white, compressed "fronds" that felt rough to the touch although fragile. This species appears to be an unusual growth form of Acanthodesia for colonies encrusting algal and hydroid stems were found with lateral frond branches without core or matrix. The tray was in the usually high-salinity area of Hampton Bar, but salinities were probably 13 to 15‰ when the bryozoan set and grew. The growth form almost disappeared from this tray (cleaned by brushing) but was later found in abundance on stakes covered with the hydroid Garveia franciscana off Aberdeen Creek in the York River and on the Rappahannock River Bridge pilings in the same association. Garveia was not noted on the Hampton Bar tray and certainly the bryozoan was growing directly attached to chicken-wire mesh of the tray top without hydrozoan substrate.

During July and August, the encrusting bryozoans Acanthodesia tenuis and Membranipora crustulenta were the most common organisms setting on fouling plates at Gloucester Point. SCUBA surveys of stakes, pilings and shells revealed that Acanthodesia was attempting to cover everything and throwing up frills and extensions in the process. All stations, regardless of salinities, exhibit heavy encrustations of this pest on oyster cultch but particularly in low-salinity areas such as the Rappahannock River. It is easily distinguished from the other common encrusting species M. crustulenta under SCUBA conditions by the shiny surface of colonies. Victorella pavida, a low-salinity species, does not seem to have exploited the areas of depressed salinities, but it commonly forms complete "felt cushions" on pilings and shells, particularly in shallow waters of creeks and in salinities as high as at Gloucester Point (15 to 25‰).

An arborescent species of bryozoan, Anguinella palamata, flexible, dirty, and masquerading as a hydroid was found in abundance on Hampton Roads and York River Bridge pilings in mid-September but most notably in Hampton Roads on shells lying on natural bottoms. It is well known in lower Chesapeake Bay as a fouling species. It was common on shells and pilings in September 1972 in Hampton Roads where Calder reported rare occurrence on test panels. Colonies were still common and active in mid-September. Bowerbankia gracilis which was common on pier structures in recent years has not been noted in 1972 but a definite search was not made. It was easily found previously on spider crabs but these are gone from trays now. Alcyonidium verrilli, a large, fleshy, conspicuous, long-lived bryozoan has long been present around piers and pilings at Gloucester Point and in the lower bay. Its abundance at VIMS piers was sharply reduced by Agnes but live colonies were found at the bases of pilings upon search. It thrives in Chesapeake Bay primarily on man-made, long-persistent piers and pilings but often survives as well on sandy and hard bottoms after being broken from its attachment surface, hence it is not uncommon in oyster bed dredge hauls. New colonies of *A. polyoum* have been seen at Gloucester Point since Agnes but it is inconspicuous and usually casual in occurrence in late summer.

8.5. Other Invertebrates

Many species commonly collected with patent-tongs from 20 to 30 feet of water near the York River Bridge were absent in September 1972. The echinoderms *Cucumaria pulcherrima, Thyone briareus, Amphiodia atra,* and *Ceriantheiopsis americanus* were absent although collected regularly in previous years. The three species of blood clams, *Noetia ponderosa, Anadara ovalis,* and *A. transversa,* which became extremely abundant during the drought years of the mid-1960's in patent-tong catches near the York River Bridge, are scarce or absent now, although most of these died two or three years ago from unknown causes. These echinoderms and molluscs are mesohaline species for which Gloucester Point represents about the upper limit of distribution.

SECTION 9. RECREATION AND WILDLIFE

Hurricane Agnes interfered only temporarily with recreational use of Chesapeake Bay, although the economic losses were considerable.

The immediate effect was a closure of parts of the bay to water-contact recreation because of sewage pollution. Boaters were warned to stay off the Bay because of the massive amounts of debris. The inclement weather and floods curtailed tourism. Although the immediate effects lasted only a few days they occurred during the Fourth-of-July holidays and caused marinas, motels, charter boats, restaurants, and tourist shops to lose business during this important vacation period.

The short-term effects include the displacement and destruction of aquatic vegetation, fish, and crabs. The Maryland Department of Natural Resources reports that up to two-thirds of the shallow-water vegetation on the Susquehanna River flats was destroyed by the flood; the loss of this vegetation will affect waterfowl distribution and abundance in the bay for some time. Sportfishing in the upper bay also declined after the storm perhaps because the fish moved down the bay into saltier water.

Longer-term effects include the changes in the bottom contours by scouring and filling and the loss of fish and shellfish. If the eggs and larvae of fish were decimated, the recreational sportfisheries may take several years to recover. Also, seafood restaurants, unable to obtain adequate supplies of fish and shellfish, will lose business. Coastal tourism could decline significantly without the "drawing cards" of good seafood restaurants and sportfishing. On the positive side, several new islands were formed near the mouth of the Susquehanna by the flood. The Maryland Department of Natural Resources plans to seed these islands with marsh grass so that the islands will stabilize and provide resting areas for waterfowl, as well as other wildlife and recreational use.

SECTION 10. HISTORICAL SITES AND ARTIFACTS

Although Hurricane Agnes devastated many historical sites, structures, and artifacts along the rivers emptying into the Bay, we have received no reports of damage to historical sites or artifacts in the tidewater area of Chesapeake Bay. Knight (1972), for example, in his summary of Agnes' destruction makes no mention of damage to historical objects on Chesapeake Bay. Correspondence with local and national historical societies, e.g., The Maryland Historic Trust, the United States Capitol Historical Society, and the National Trust for Historic Preservation, confirmed Knight's summary. The damages to sites and structures along the rivers were caused by the flooding rivers. For historical sites and structures on the Bay the force and wetness of the flooding rivers had little effect and the moderate winds and surf presented no problems.

LITERATURE CITED

Beaven, G. Francis.
1960. "Temperature and salinity of surface water at Solomons, Maryland." Chesapeake Science 1 (1): 2-11.

Burrell, V. G., Jr.
1968. The Ecological Significance of a Ctenophore, Mnemiopsis leidyi (A. Agassiz), in a Fish Nursery Ground. M. A. Thesis, College of William and Mary, Williamsburg, Va. 61 p.

De Angelis, Richard M., and William T. Hodge.
1972. Preliminary Climatic Data Report: Hurricane Agnes, June 14-23, 1972. U.S. Dept. Commerce, N.O.A.A. Technical Memorandum EDS NCC-1. iv + 62 p.

Joyce, Edwin A., Jr.
1972. A Partial Bibliography of Oysters, with Annotations. Florida Department of Natural Resources, St. Petersburg, Florida. vi + 846 p.

Kammerer, J. C., H. D. Brice, E. W. Coffay, and L. C. Fleshmon.
1972. Water Resources Review for June 1972. U.S. Geological Survey, Washington, D.C. 17 p.

Knight, Carleton, III
1972. "Hurricane Agnes inundates East Coast." Preservation News, 12 (9): 1, 6.

Marasco, Richard J.
1972. The Chesapeake Bay Fisheries: An Economic Profile, Contribution No. 4526 of the Agri. Exp. Sta., Univ. of Maryland, College Park, Md. MP No. 802. ii + 203 p.

Myers, Marvin.
1972. "A picture report." Maryland Conservationist, 48(4): 14-17.

National Marine Fisheries Service.
1971. Fisheries Statistics of the United States, 1968. Statistical Digest No. 62. 578 p.

1972. Fisheries of the United States, 1971. Current Fisheries Statistics No. 5900. vi + 101 p.

Schubel, J. R.
1972. The Physical and Chemical Condition of Chesapeake Bay, An Evaluation. Chesapeake Bay Institute, The Johns Hopkins University, Baltimore, Maryland. Special Report 21.

Schubel, J. R., C. H. Morrow, W. B. Cronin, and A. Mason.
1970. Suspended Sediment Data Summary, August 1969-July 1970, Mouth to Head of Bay. Chesapeake Bay Institute, The Johns Hopkins University, Baltimore, Maryland. Special Report 18.

Schultz, Leonard P., and David G. Cargo.
1971. The Sea Nettle of Chesapeake Bay. Natural Resources Institute, Educational Series No. 93. 8 p.

Seiling, Fred W.
1972. Statement before the House Merchant Marine and Fisheries Committee, August 15, 1972. Maryland Department of Natural Resources, Annapolis, Md.

Taylor, Kenneth R.
1972. A summary of Peak Stages of Discharges in Maryland, Delaware, and District of Columbia for Flood of June 1972. U.S. Geological Survey, Water Resources Division, Open-file Report, Parkville, Maryland. 13 p.

U.S. Public Health Service, Center for Disease Control.
1972. Morbidity and Mortality Weekly Report, 21 (24-33). Public Health Service, Atlanta, Georgia.

Wallace, McHarg, Roberts, and Todd, Inc.
1972. Maryland Chesapeake Bay Study. A report to the Maryland Department of State Planning and the Chesapeake Bay Interagency Planning Committee. vi + 403 p.

APPENDIX I. Longitudinal distribution of temperature and salinity along the axis of Chesapeake Bay. (C.B.I.)

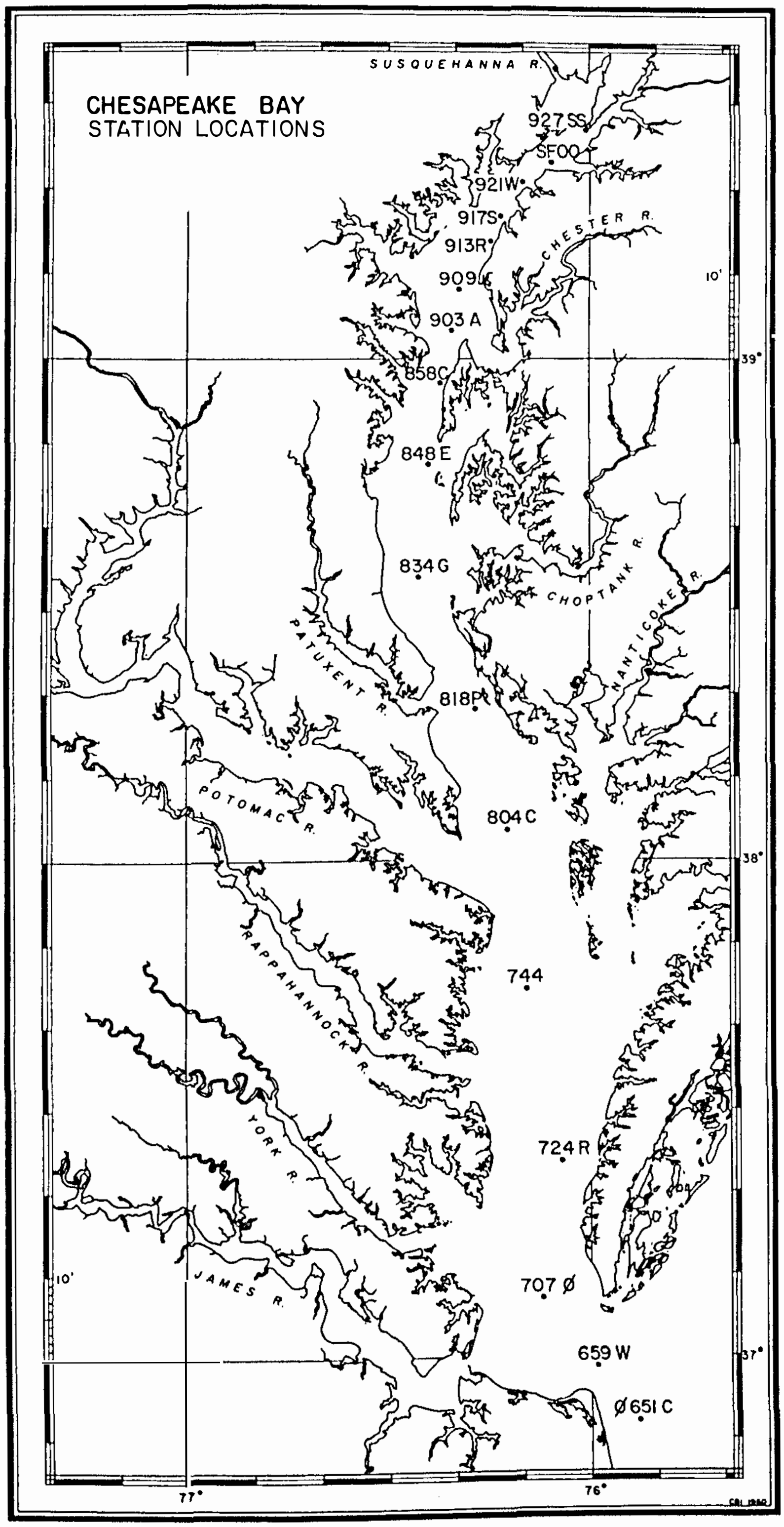


Figure A.I.1. Map of the Chesapeake Bay showing locations of stations used in Figures A.I.1 to A.I.6.

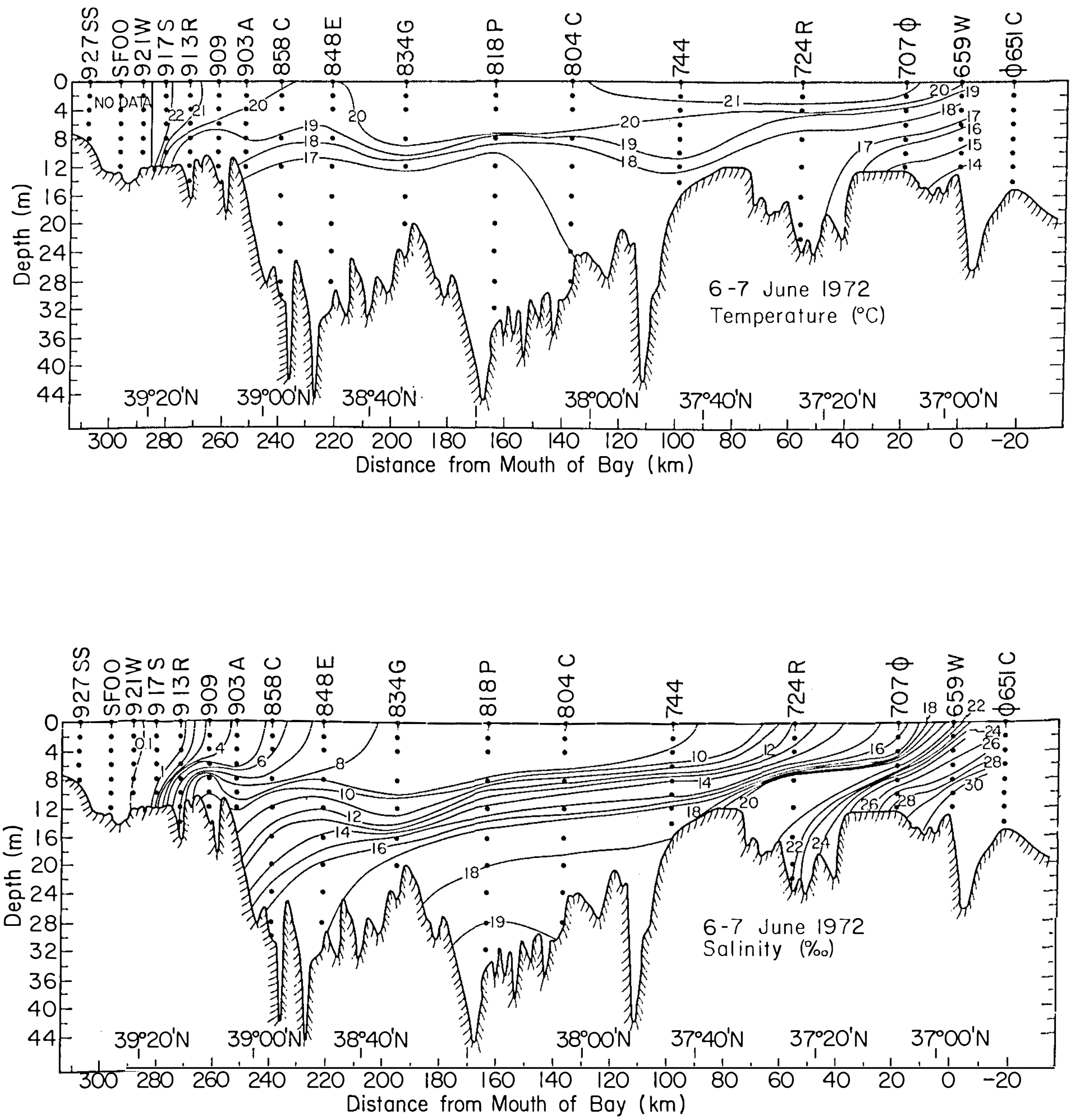


Figure A.I.2. Longitudinal distributions of temperature and salinity along the axis of the Bay on 6-7 June 1972.

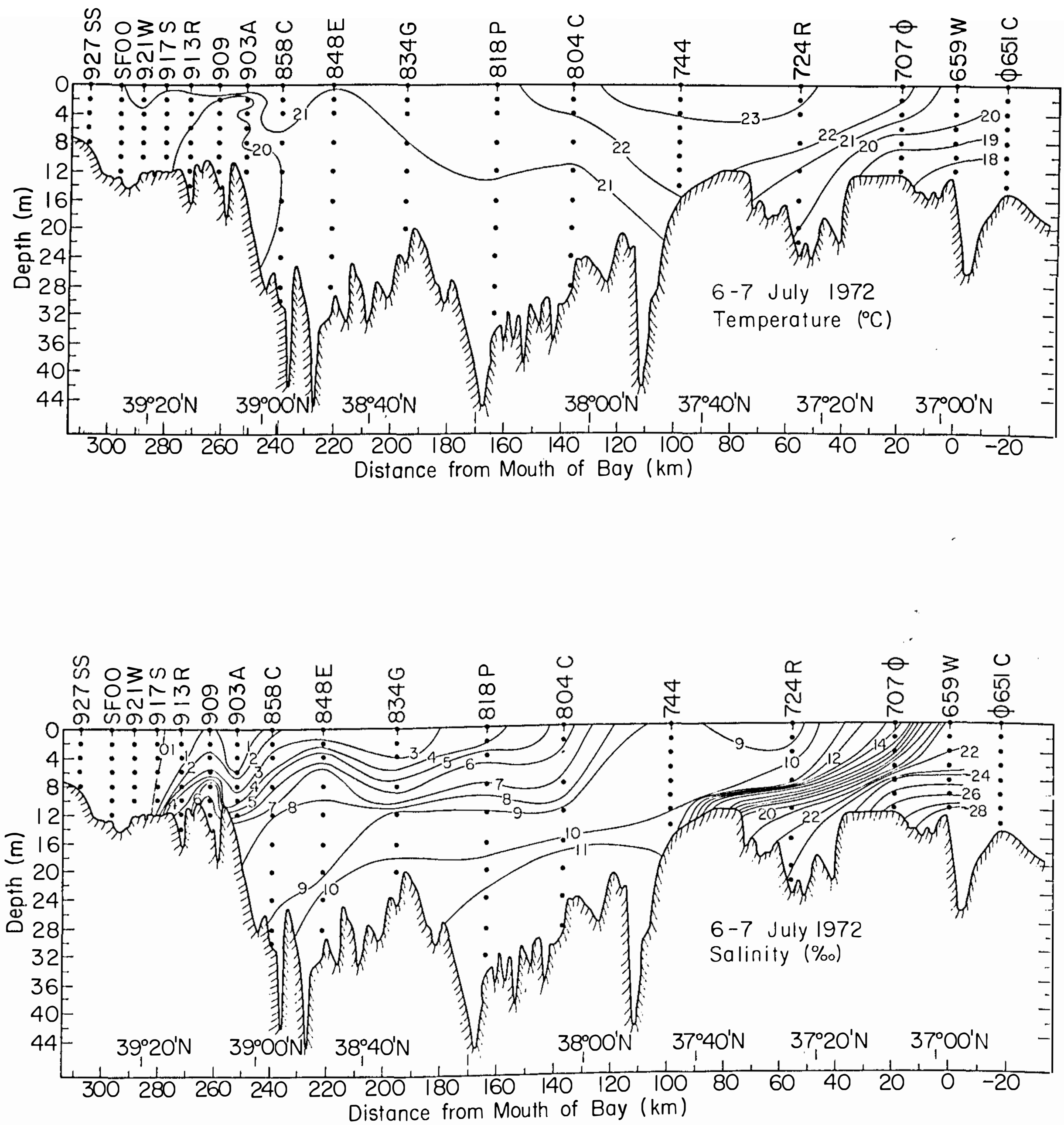


Figure A.I.3. Longitudinal distributions of temperature and salinity along the axis of the Bay on 6-7 July 1972.

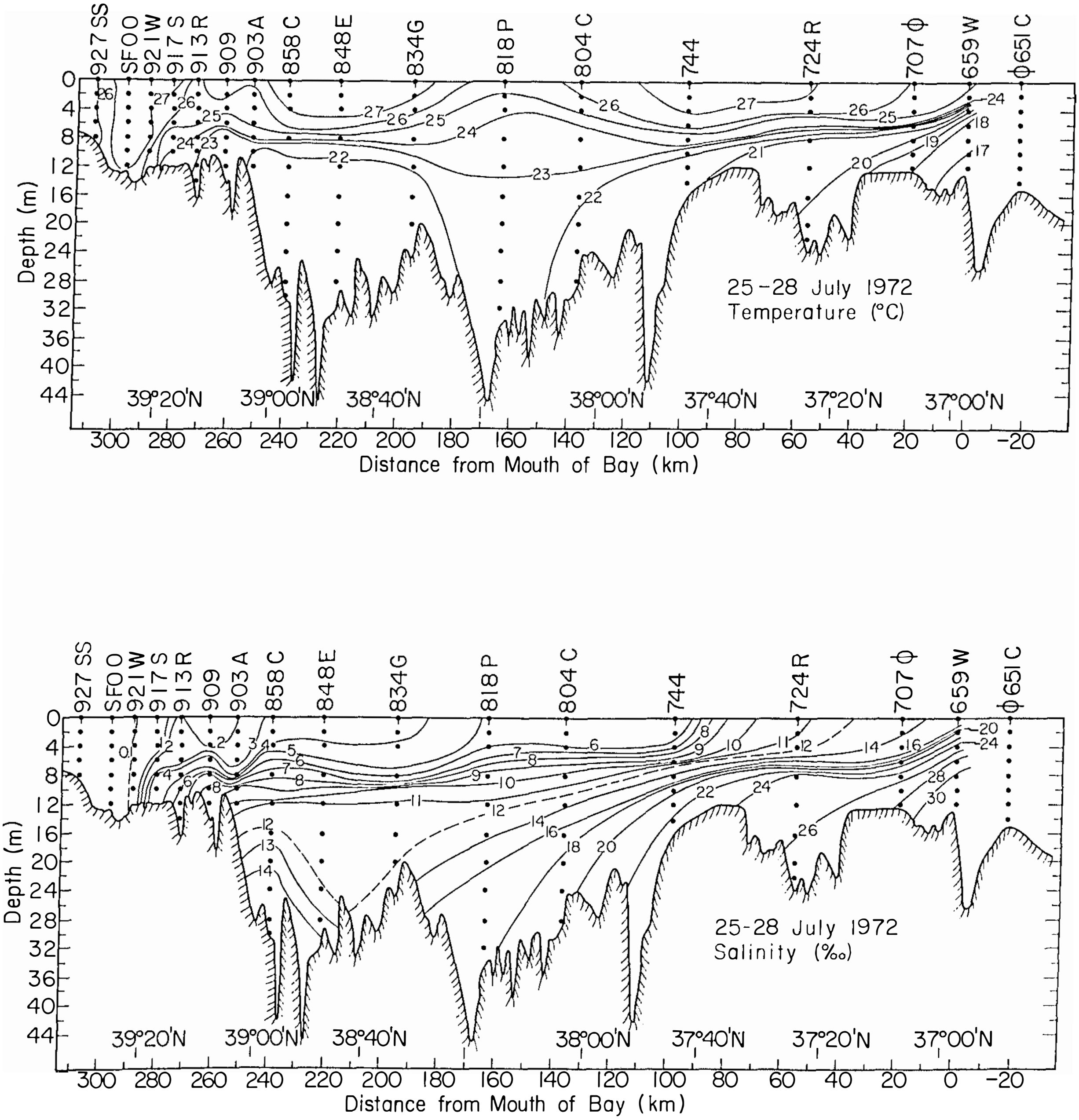


Figure A.I.4. Longitudinal distributions of temperature and salinity along the axis of the Bay on 25-28 July 1972.

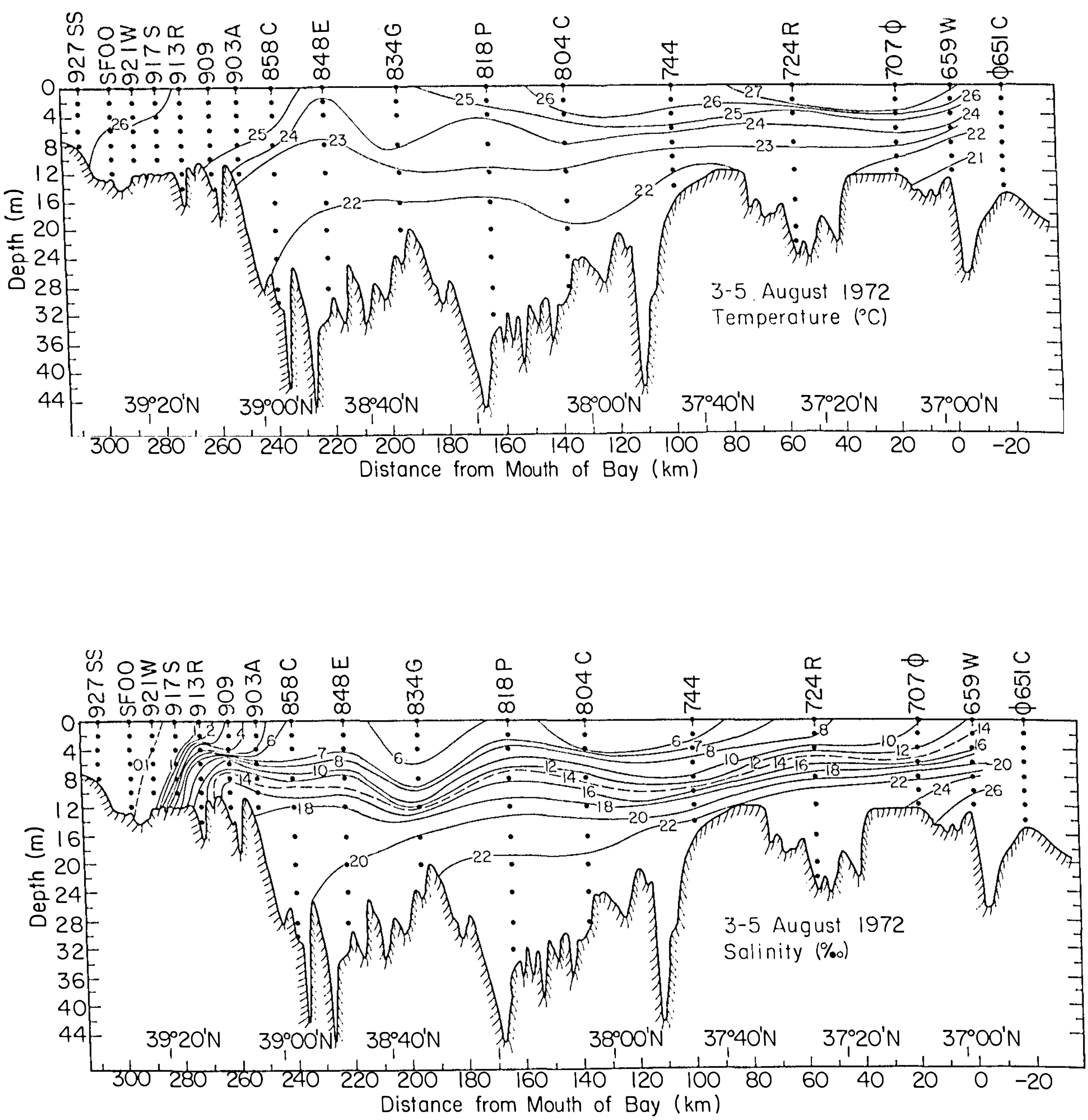


Figure A.I.5. Longitudinal distributions of temperature and salinity along the axis of the Bay on 3-5 August 1972.

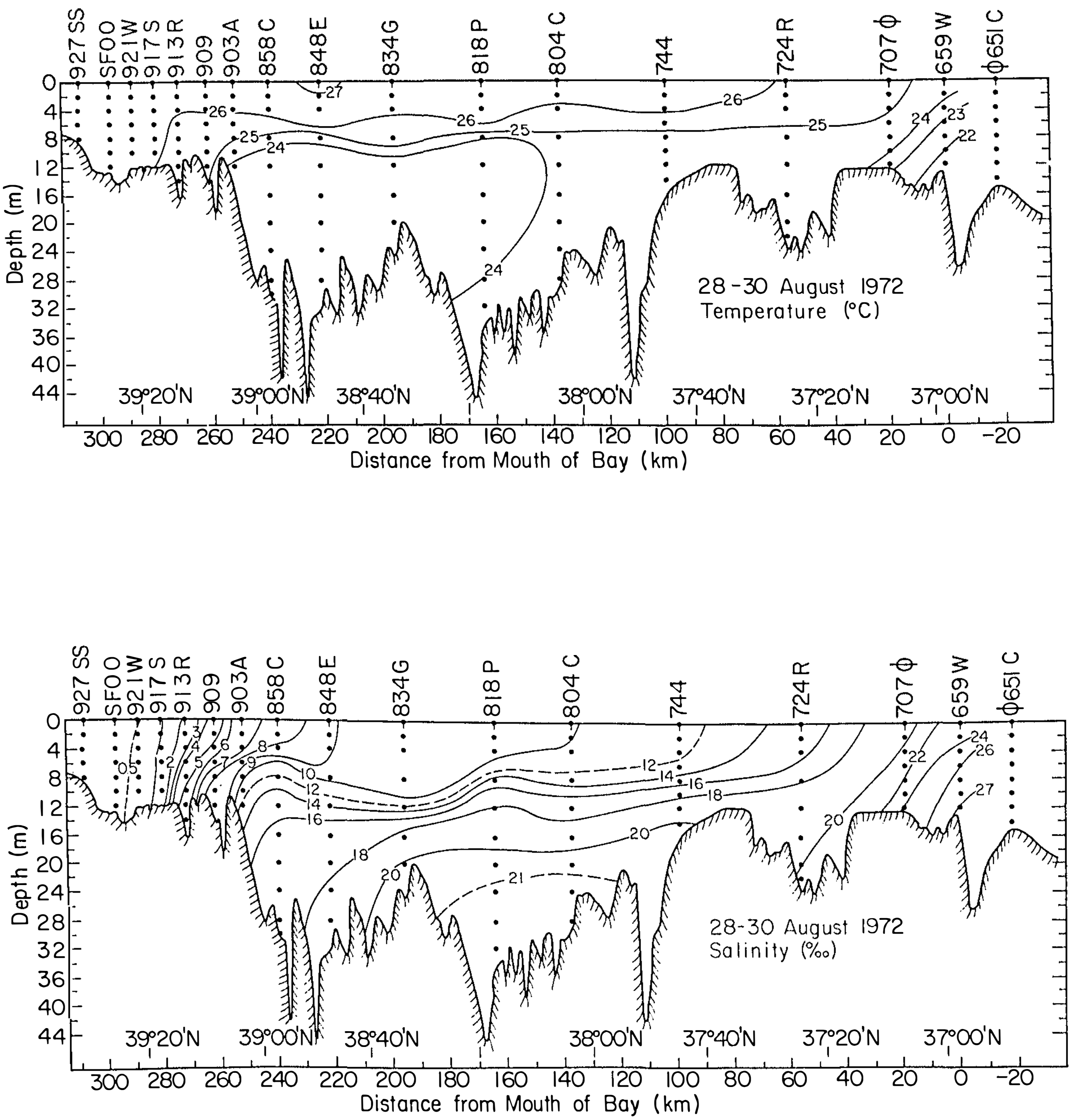
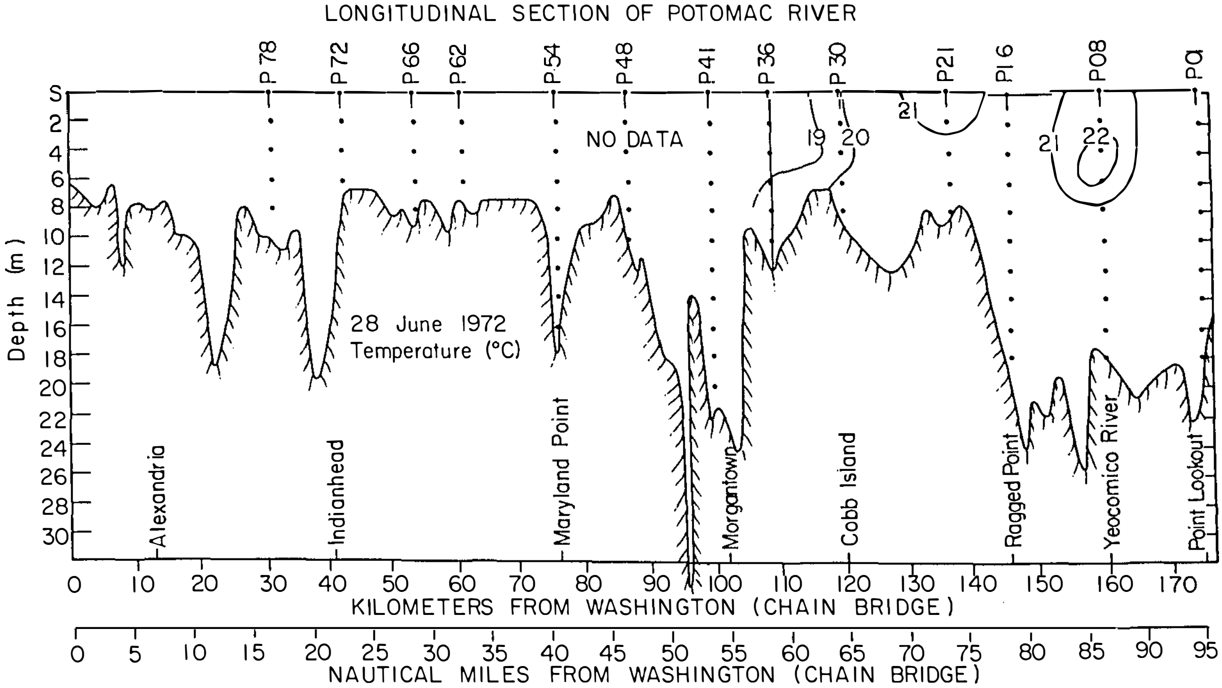


Figure A.I.6. Longitudinal distributions of temperature and salinity along the axis of the Bay on 28-30 August 1972.

APPENDIX II. Longitudinal distributions of temperature and salinity along the axis of the Potomac River estuary. (C.B.I.)



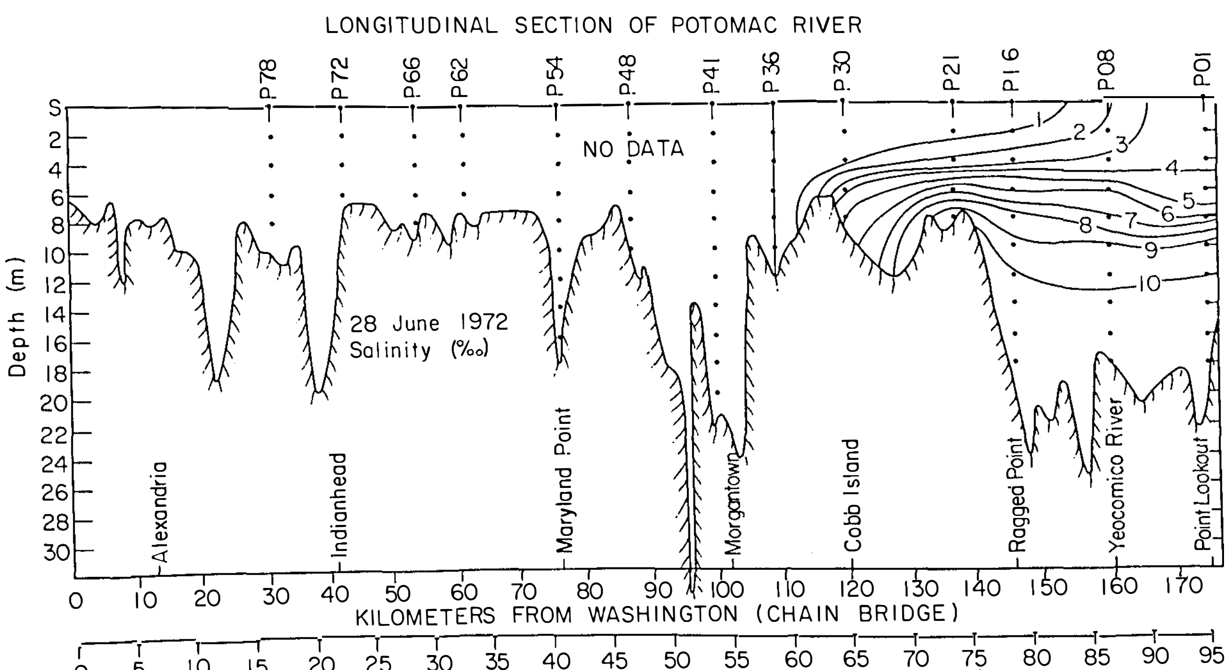
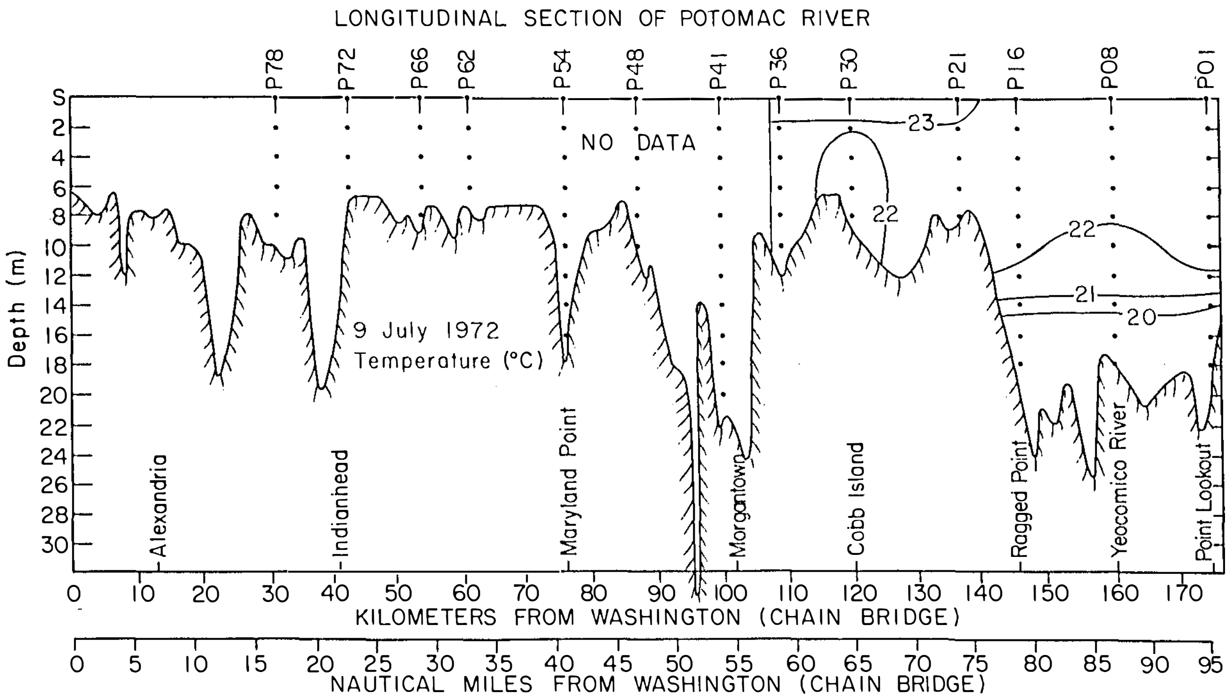


Figure A.II.1. Longitudinal distributions of temperature and salinity along the axis of the Potomac River estuary on 28 June 1972. (C.B.I.)



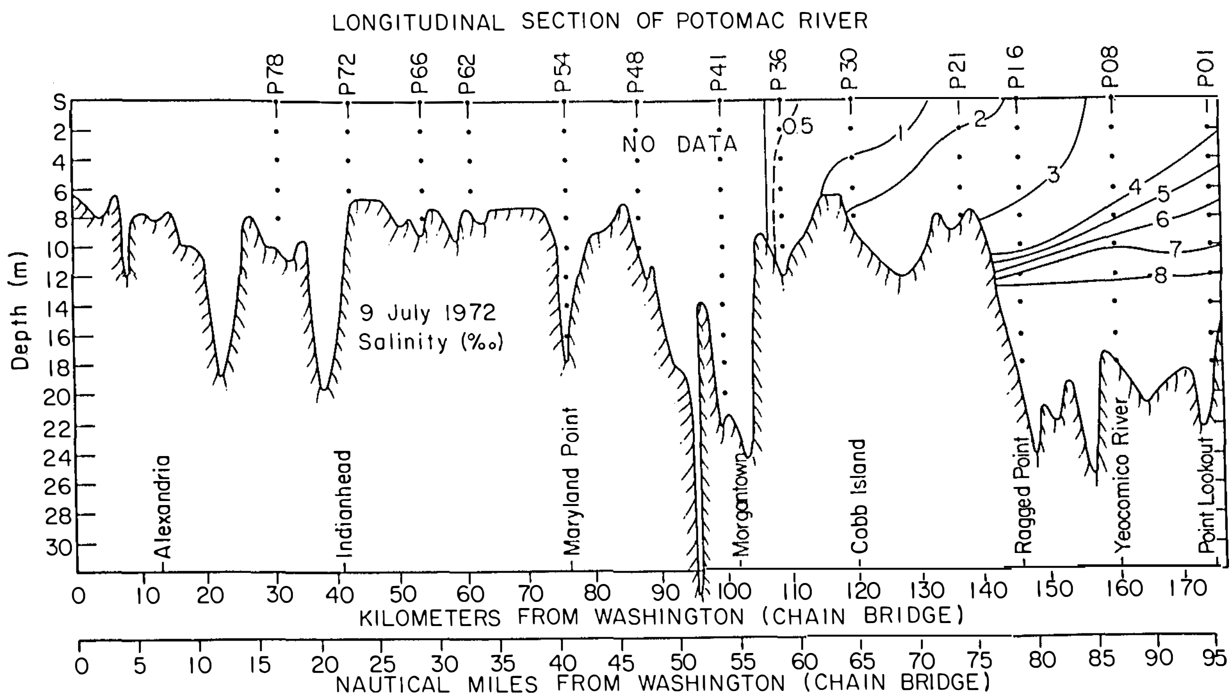
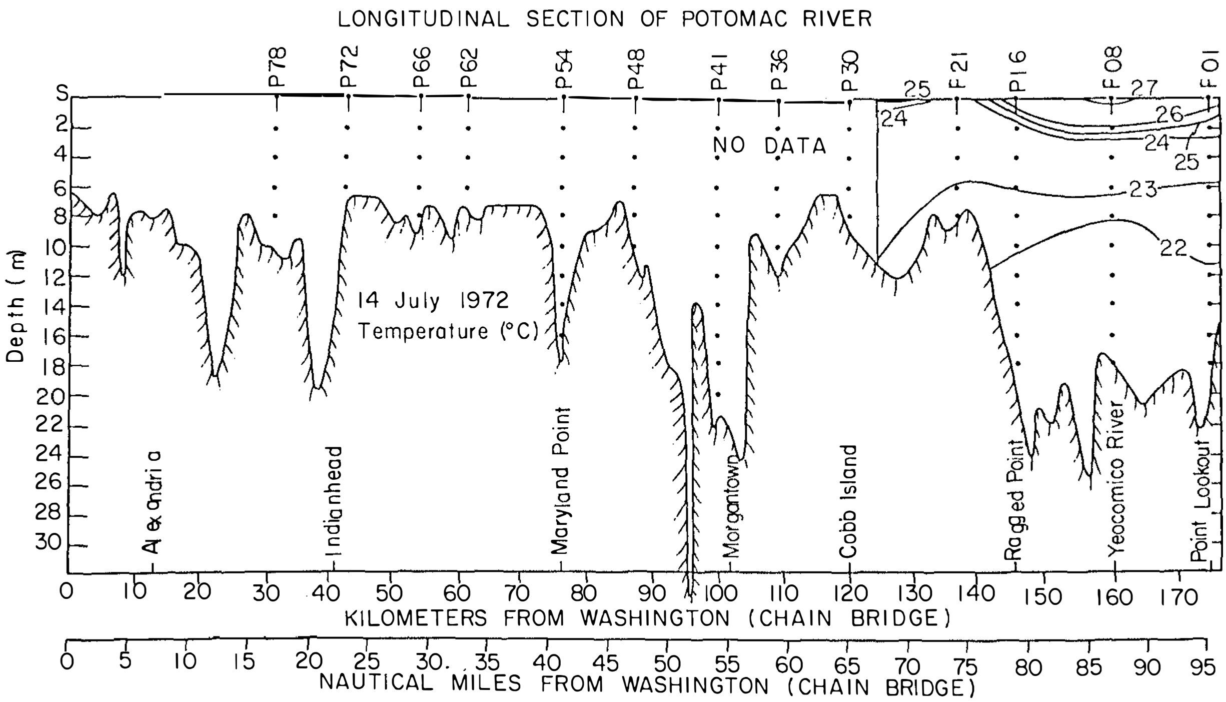


Figure A.II.2. Longitudinal distributions of temperature and salinity along the axis of the Potomac River estuary on 9 July 1972. (C.B.I.)



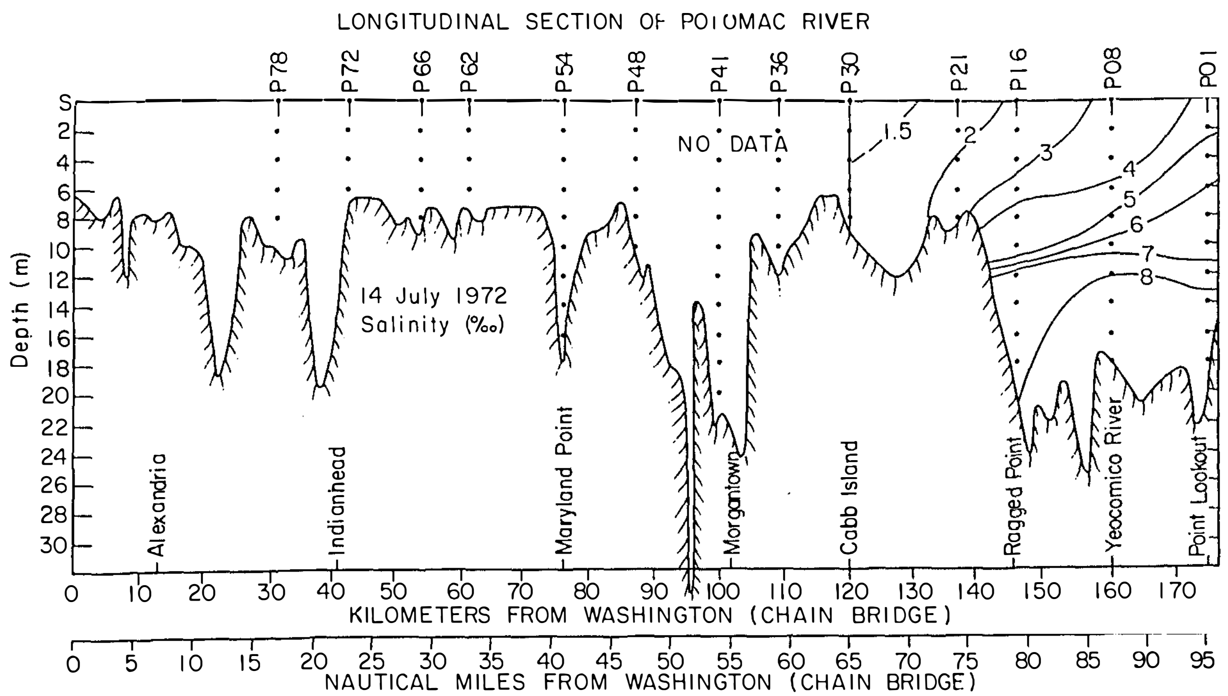
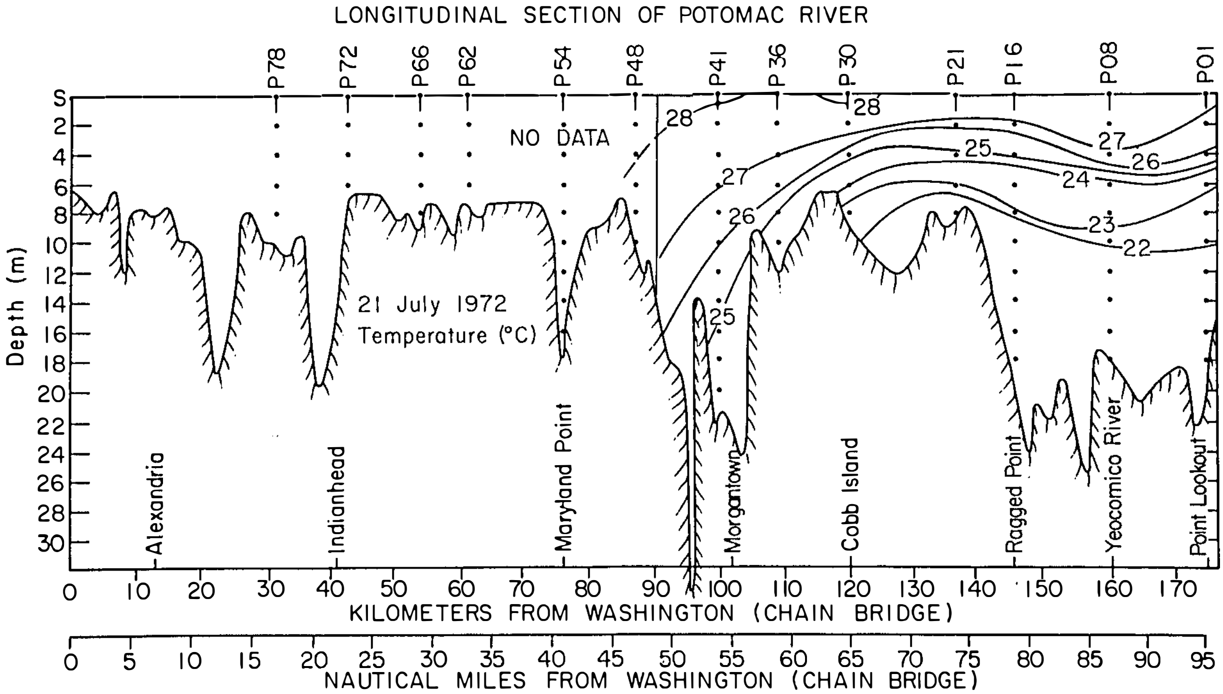


Figure A.II.3. Longitudinal distributions of temperature and salinity along the axis of the Potomac River estuary on 14 July 1972. (C.B.I.)



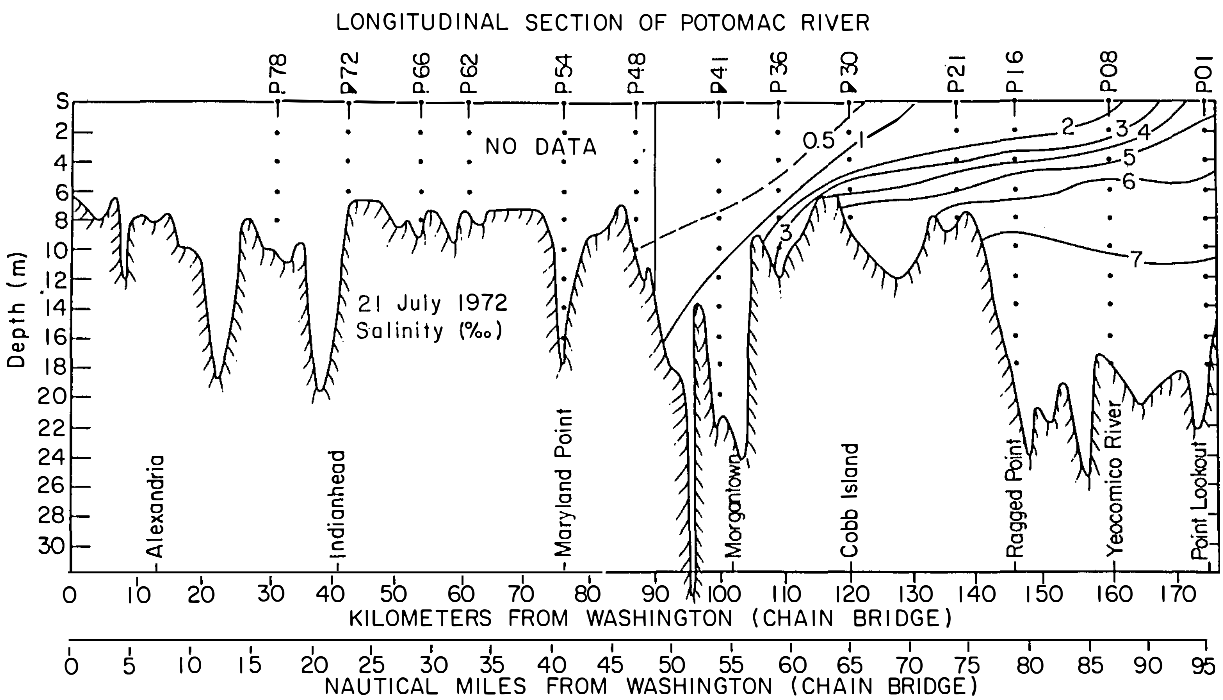
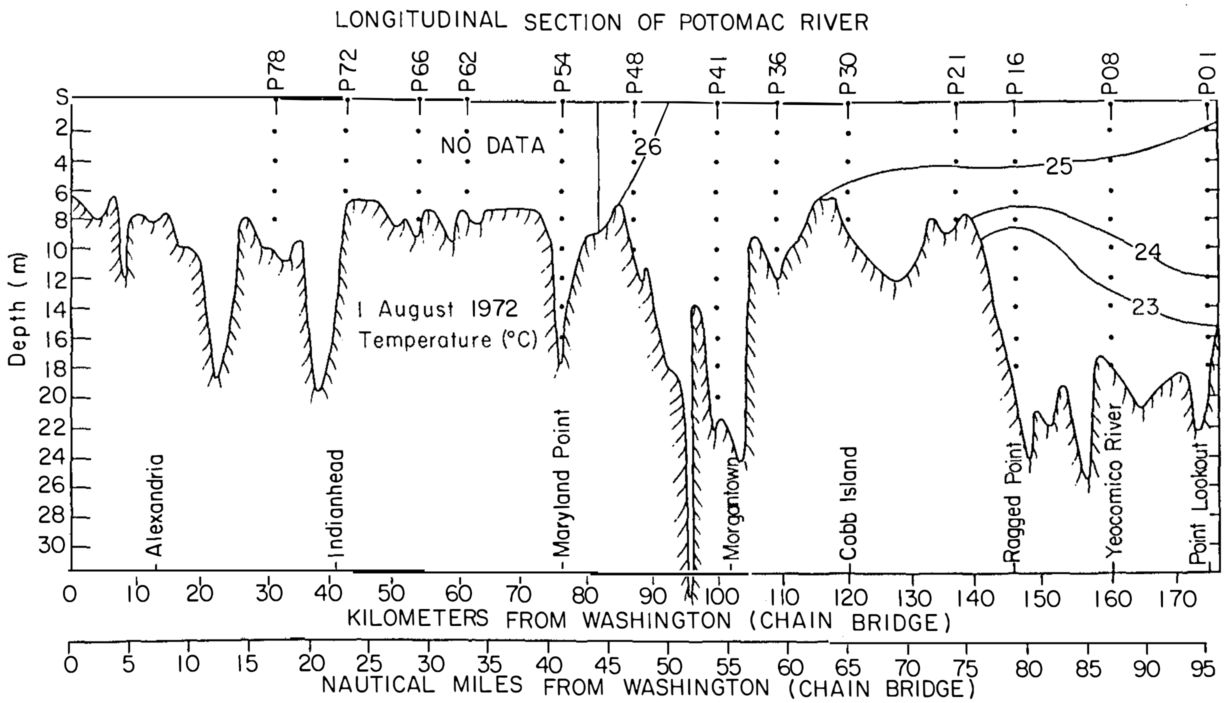


Figure A.II.4. Longitudinal distributions of temperature and salinity along the axis of the Potomac River estuary on 21 July 1972. (C.B.I.)



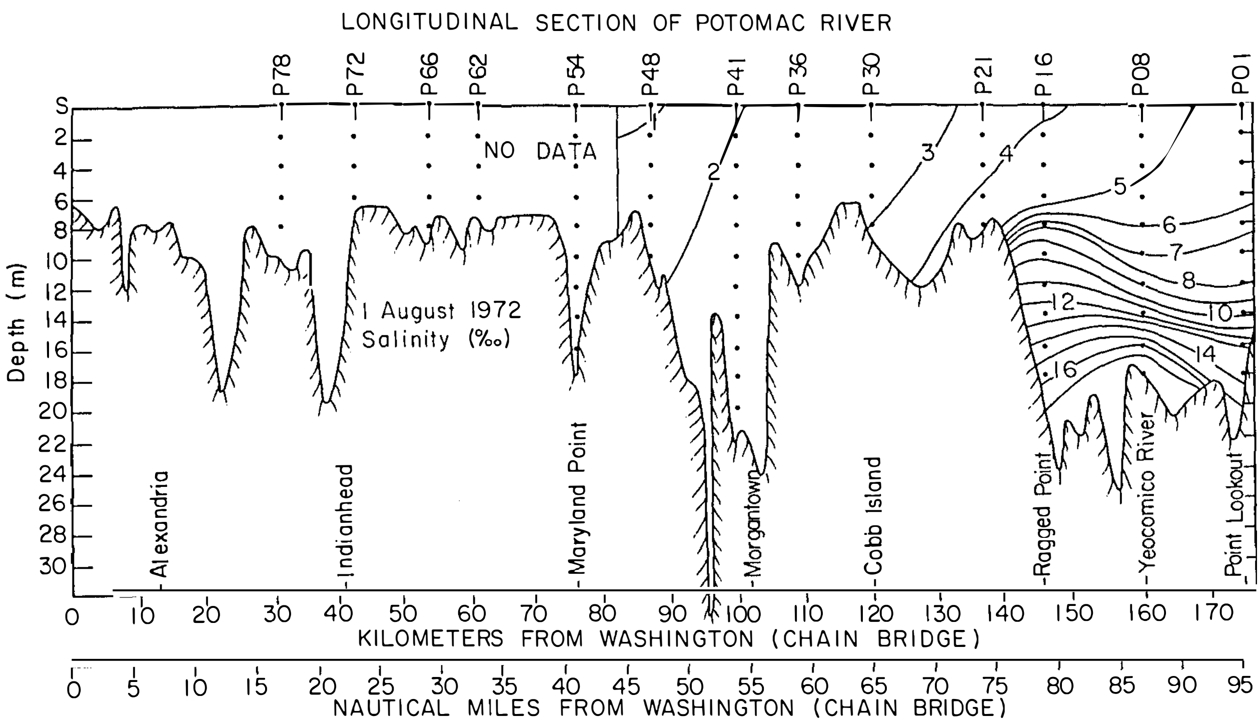
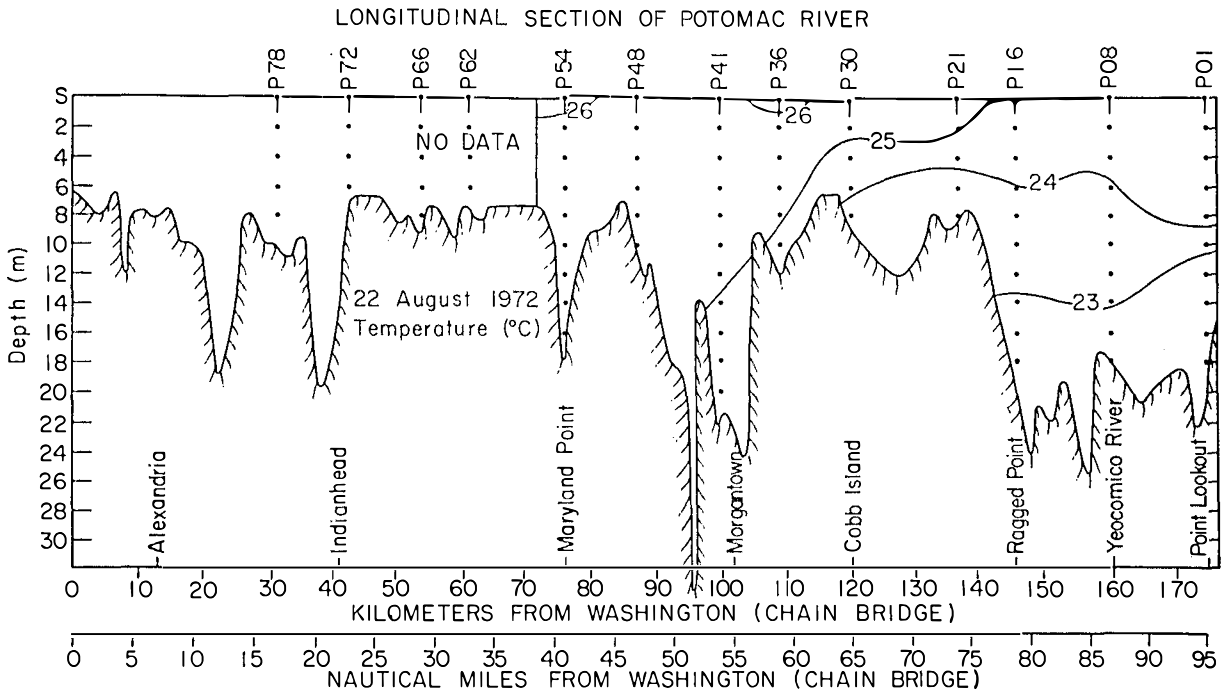


Figure A.II.5. Longitudinal distributions of temperature and salinity along the axis of the Potomac River estuary on 1 August 1972. (C.B.I.)



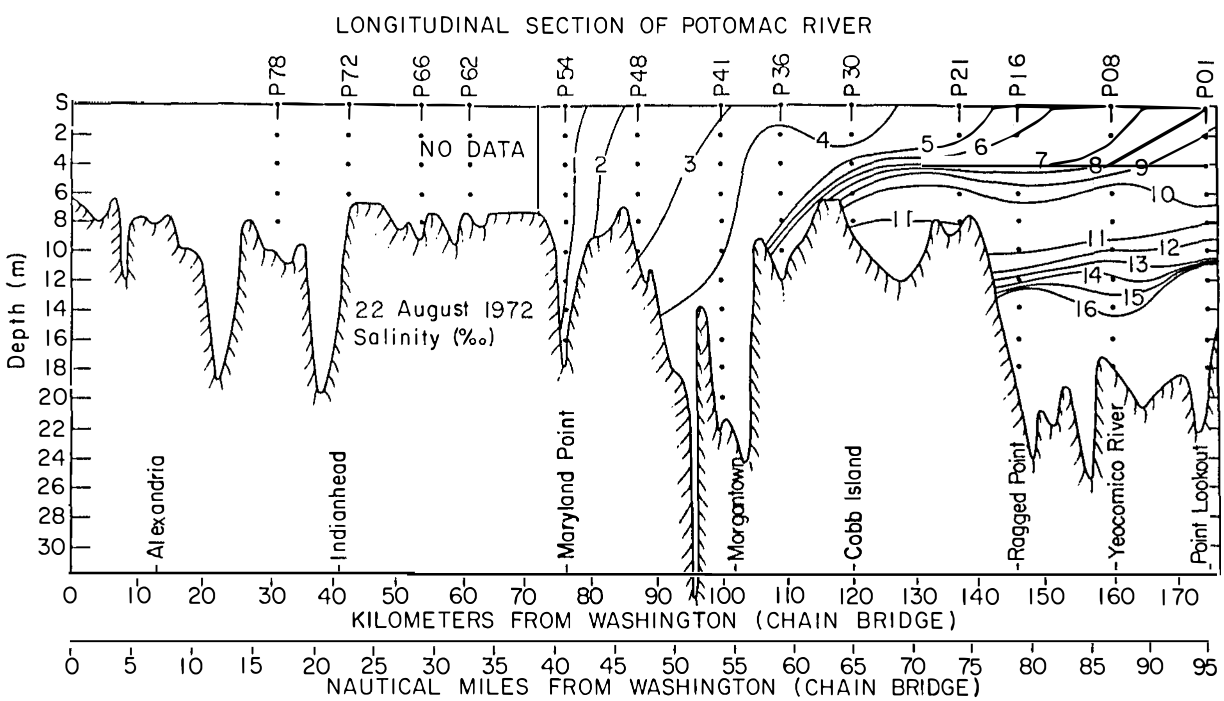
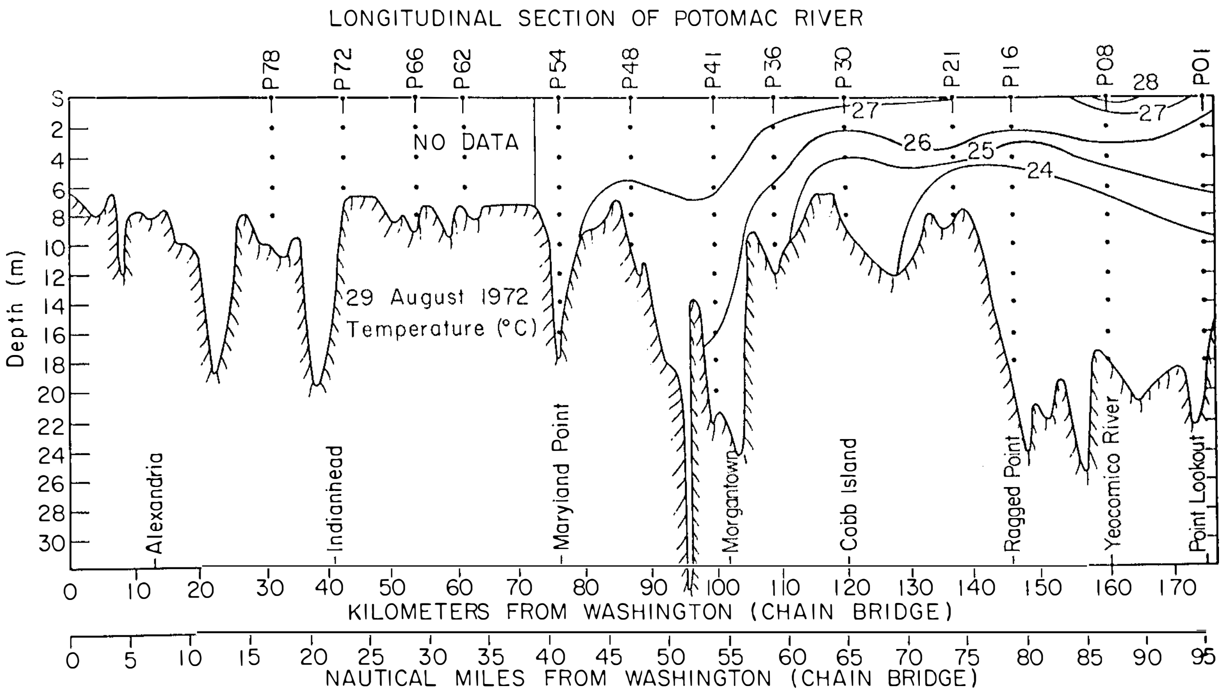


Figure A.II.6. Longitudinal distribution of temperature and salinity along the axis of the Potomac River estuary on 22 August 1972.



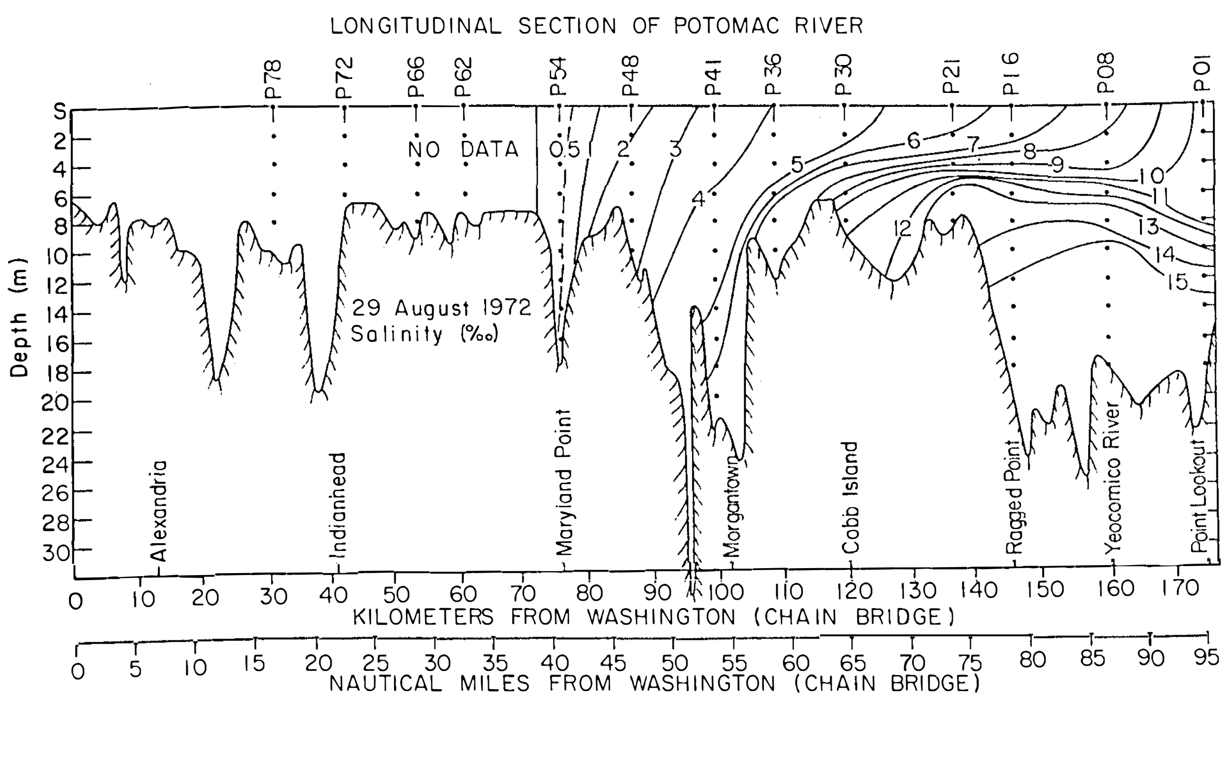


Figure A.II.7. Longitudinal distributions of temperature and salinity along the axis of the Potomac River estuary on 29 August 1972.

APPENDIX III. Frequency of sea nettle polyps and cysts on oyster shells from selected sampling areas in Chesapeake Bay. (C.B.L.)

A.III.1: SURVEY OF 5-7 JUNE 1972

Location	Number of blank shells	Number of polyps per shell			Number of cysts per shell		
		1-10	11-50	50+	1-10	11-50	50+
Little Choptank at Beacon	28	5	0	0	0	0	0
Choptank R. at Howell Pt.	26	0	0	0	0	0	0
Broad Creek	15	6	1	0	0	0	0
Tilghmann Island at Bar Neck	14	0	0	0	0	0	0
Eastern Bay at Bloody Pt.	21	0	0	0	0	0	0
Wye River	24	0	0	0	0	0	0
Miles R. at N-12 Buoy	15	2	0	0	0	0	0
Parsons Island	20	0	0	0	0	0	0
Chester R. at Cedar Pt.	27	0	0	0	0	0	0
Chester R. at Corsica	17	0	0	0	0	0	0
Swan Point	21	0	0	0	0	0	0
Tolchester	17	0	0	0	0	0	0
Still Pond	21	0	0	0	0	0	0
Bodkin Point	23	0	0	0	0	0	0
Hackett Point	22	0	0	0	0	0	0
Saunders Point	11	0	0	0	0	0	0
Rhode River	23	0	0	0	0	0	0
Herring Bay	29	0	0	0	0	0	0
Parkers Creek	19	0	0	0	0	0	0

Location	Number of blank shells	Number of polyps per shell			Number of cysts per shell		
		1-10	11-50	50+	1-10	11-50	50+
Calvert Cliffs at power plant	14	0	0	0	0	0	0
Little Cove Point	17	0	0	0	0	0	0
Honga R. at mouth	16	0	0	0	0	0	0
Sharfkin Shoal	21	0	0	0	0	0	0
Halls Point	17	1	0	0	0	0	0
Potomac R. at Popes Cr.	26	0	0	0	0	0	0
Potomac R. at Hawks Neck	26	0	0	0	0	0	0

A.III.2: SURVEY OF 10-13 JULY 1972

Location	Number of blank shells	Number of polyps per shell			Number of cysts per shell		
		1-10	11-50	50+	1-10	11-50	50+
Patuxent R. at Gatton Bar	20	0	0	0	0	0	0
Patuxent R. at Buzzard Island	20	0	0	0	0	0	0
Patuxent R. at Farmers Bar	20	0	0	0	0	0	0
Patuxent R. at Hog Island	19	0	0	0	1	0	0
Swan Point	20	0	0	0	0	0	0
Tolchester	20	0	0	0	0	0	0
Miles River	20	0	0	0	0	0	0
James Island Point	3	0	0	0	0	0	0
Potomac R. at Ragged Point	17	0	0	0	0	0	0
Potomac R. at Old Farm	16	0	0	0	0	0	0
Potomac R. at Beacon Bar	20	0	0	0	0	0	0
Chesapeake Bay at SW Middlegrounds	20	0	0	0	0	0	0
Kedges Straight	20	0	0	0	0	0	0
Marumsco	20	0	0	0	0	1	0
Piney Island East	20	0	0	0	0	0	0
Mud Rock	20	0	0	0	0	0	0
Lambstrom	20	0	0	0	0	0	0
Hooper Straight at Normans	20	0	0	0	0	0	0
Little Choptank at Ragged Pt.	21	0	0	0	1	1	0

Location	Number of blank shells	Number of polyps per shell			Number of cysts per shell		
		1-10	11-50	50+	1-10	11-50	50+
Broad Creek	13	0	0	0	0	0	0
Tred Avon at Pecks	10	0	0	0	1	0	0
Choptank R. at LeCompte	7	0	0	0	0	1	0
Wye River	17	0	0	0	0	0	0
Bloody Point	6	0	0	0	0	0	0
Patuxent R. at Spencers	20	0	0	0	0	0	0

A.III.3: SURVEY OF 24-26 JULY 1972

Location	Number of blank shells	Number of polyps per shell			Number of cysts per shell		
		1-10	11-50	50+	1-10	11-50	50+
Patuxent at Gatton Bar	19	0	0	0	0	0	0
Patuxent at Spencers Bar	20	0	0	0	0	0	0
Patuxent at Green Holly	22	0	0	0	0	1	0
Patuxent at Hog Island	22	0	0	0	1	1	0
Potomac at Ragged Pt.	12	0	0	0	0	0	0
St. Mary's R. at Horseshoe Pt.	19	0	0	0	0	0	0
St. Mary's R. at Windmill Pt.	16	0	0	0	1	1	0
St. Mary's R. at Cherryfield Pt.	20	0	0	0	0	0	0
Miles R. at N-12 Buoy	18	0	0	0	2	0	0
Hacketts Point	20	0	0	0	0	0	0
Saunders Point	12	0	0	0	1	0	0
Drum Point	9	0	0	0	0	0	0
Punch Island	16	0	0	0	2	0	0
Little Choptank at Ragged Pt.	15	0	0	0	0	0	0
Broad Creek	15	0	0	0	1	0	0
Herring Bay	17	0	0	0	0	0	0
Marumsco	17	1	0	0	0	0	0
Piney Island East	19	1	0	0	0	1	0
Nanticoke R. at mouth	19	0	0	0	0	1	0

Location	Number of blank shells	Number of polyps per shell			Number of cysts per shell		
		1-10	11-50	50+	1-10	11-50	50+
Upper Wicomico	17	0	0	0	0	0	0
Lambstrom	20	0	0	0	0	0	0
Honga R. at Normans	19	0	0	0	0	0	0
Little Cove Point	16	0	0	0	0	0	0
Tolchester	20	0	0	0	0	0	0

A.III.4: SURVEYS OF 24-26 JULY and 31 JULY-2 AUGUST 1972

Location	Number of blank shells	Number of polyps per shell			Cysts Only
		1-10	11-50	50+	
Patuxent at Gatton Bar	19	0	0	0	0
Patuxent at Spencers Bar	20	0	0	0	0
Patuxent at Green Holly	22	0	0	0	1
Patuxent at Hog Island	22	0	0	0	2
Potomac at Ragged Pt.	12	0	0	0	0
St. Mary's at Horseshoe Pt.	19	0	0	0	0
St. Mary's at Windmill Pt.	16	0	0	0	2
St. Mary's at Cherryfield Pt.	20	0	0	0	0
Miles R. at N-12 Buoy	18	0	0	0	2
Hacketts Point	20	0	0	0	0
Saunders Point	12	0	0	0	1
Drum Point	9	0	0	0	0
Punch Island	16	0	0	0	2
Little Choptank at Ragged Pt.	15	0	0	0	0
Broad Creek	15	0	0	0	1
Herring Bay	17	0	0	0	0
Marumsco	17	1	0	0	0
Piney Island East	19	1	0	0	1

Location	Number of blank shells	Number of polyps per shell			Cysts Only
		1-10	11-50	50+	
Nanticoke R. at mouth	19	0	0	0	1
Upper Wicomico	17	0	0	0	0
Lamstrom	20	0	0	0	0
Honga R. at Normans	19	0	0	0	0
Little Cove Point	16	0	0	0	0
Tolchester	20	0	0	0	0

A.III.5: SURVEY OF 23-27 OCTOBER 1972

Location	Number of blank shells	Number of polyps per shell 1-10	11-50	50+	Cysts Only
Still Pond	17	0	0	0	0
Tolchester Beach	13	0	0	0	0
Swan Point	10	0	0	0	0
Patapsco R. at Bodkin Pt.	10	0	0	0	0
Magothy R. at Adams Pt.	13	0	0	0	0
Hackett Point	16	0	0	0	0
Chester R. at Cedar Pt.	9	0	0	0	0
Saunders Point	10	0	0	0	0
Rhode River	10	0	0	0	0
Bloody Point	10	0	0	0	0
Eastern Bay at Prospect Bay	12	0	0	0	0
Wye River	10	0	0	0	0
Miles R., N. of St. Michaels	14	0	0	0	0
Herring Bay	15	0	0	0	0
Knapps Narrows (Tilghman Isl.)	10	0	0	0	0
Broad Creek	15	0	0	0	0
Little Choptank at Ragged Point	12	0	0	0	0
Parkers Creek	9	0	0	0	0
Little Cove Point	15	0	0	0	0
Hog Island	10	0	0	0	0

Location	Number of blank shells	Number of polyps per shell 1-10	11-50	50+	Cysts Only
Patuxent R. at Green Holly	13	0	0	0	0
Patuxent R. at Hellens Cr.	13	0	0	0	0
Patuxent R. at Broomes Is.	11	0	0	0	0
Patuxent R. at Queentree Landing	11	0	0	0	0
Honga R. at Dutch Point Cove	13	1	0	0	0
Hooper Straits Sharkfin Shoal	9	3	0	0	0
Tangier Sound at Hanes Point	10	2	0	0	0
Tangier Sound E. of South Marsh Is.	11	2	0	0	0
Tangier Sound at Flatcap Point	10	0	0	0	0
Wicomico R. at Chaptico	10	0	0	0	0
Potomac R. at Breton Bay	10	0	0	0	0
Potomac R. at Ragged Point	10	0	0	0	0
Potomac R. at St. George Is.	12	0	0	0	0
St. Marys R. at Windmill Pt.	11	1	0	0	1
Potomac R. at Cornfield Harbor	10	0	0	0	0
Pocomoke Sound at Marumsco	9	3	0	0	0

A.III.6: SURVEY OF 30 OCTOBER to 2 NOVEMBER 1972

Location	Number of blank shells	Number of polyps per shell			Cysts Only
		1-10	11-50	50+	
Great Wicomico at Sandy Pt.	13	1	0	0	1
Fleets Point	10	0	0	0	0
Fleets Bay	14	0	0	0	0
Rappahannock R. at Parrot Is.	10	0	0	0	0
Rappahannock R. at Towles Pt.	10	0	0	0	0
Rappahannock R. at Lagrange Cr.	11	0	0	0	0
Rappahannock R. at Tarpley Pt.	10	0	0	0	0
Piankatank R. at Ginney Pt.	11	1	3	0	1
Piankatank R. at Godfrey Bay	6	8	6	0	0
Stingray Point	10	0	0	0	0
Mobjack Bay at Mobjack	10	0	0	0	0
Mobjack Bay at Ware Neck	17	2	2	0	0
York R. at Clay Bank	12	0	0	0	0
York R. at Bells Rock	11	0	0	0	0
York R. at Purtan Is.	7	0	0	0	0
Plumtree Pt.	12	0	0	0	0
James R. at Hampton	10	0	0	0	0

Location	Number of blank shells	Number of polyps per shell			Cysts Only
		1-10	11-50	50+	
James R. at Newport News	14	0	0	0	0
James R. at Blunt Pt.	14	0	0	0	0
James R. at Mulberry Pt.	11	0	0	0	0
Willoughby Bank	10	0	0	0	0
Old Plantation Flats	10	0	0	0	0
Powells Bluff	-	-	-	-	-
Onancock Creek	-	-	-	-	-
Watts Island	10	0	0	0	0

APPENDIX IV. Frequency of sea nettle polyps on oyster shells from selected sampling areas in Chesapeake Bay. November 1971. (C.B.L.).

Location	Number of polyps per shell			
	0	1-10	11-50	50+
Little Cove Pt.	7	0	2	0
Calvert Cliffs Power Plant	12	0	0	0
Herring Bay	11	2	3	1
Black Can- South River	3	6	3	2
Mouth South River	14	4	1	0
Off Hackett Pt.	3	7	6	0
Off Tolchester Pier	12	0	0	1
Swan Pt.- Chester River	17	0	1	0
Eastern Neck - Chester River	6	5	3	0
Prospect Bay	2	4	4	3
Grace Creek- Broad Creek	5	4	4	0
Brookes Creek- Little Choptank	5	6	3	0
Mouth Honga River	7	2	1	1
Fishing Bay	11	0	2	0
Off Deale Island	12	2	0	0
Frenchtown- Manokin River	11	0	0	0
N. Entrance Canal	10	0	0	0
Entrance Broad Creek	7	0	0	0

APPENDIX V. LOGISTIC SUPPORT PROVIDED BY VARIOUS AGENCIES (STATE AND FEDERAL) TO THE VIRGINIA INSTITUTE OF MARINE SCIENCE DURING OPERATION AGNES

Agency	Support	Utilization
U.S. Navy		
Naval Ordinance Laboratory Solomons, Maryland	Vessels	Anchor stations mid-Bay Transect, 3 and 7 July 1972.
Coastal River Squadron Two Little Creek, Virginia	PT Boats	Spine of the Bay, slack runs from Bay mouth to Potomac River, 10 runs in July and August.
Assault Craft Unit Two Little Creek, Virginia	LCU's	Anchor stations in Bay mouth transects, 6 periods, July and August.
Explosive Ordinance Disposal Unit Two, Fort Story, Va.	Divers	Equipment Recovery (two occasions).
Naval Ordinance Laboratory White Oak, Maryland	Magnetometer Boon	Equipment Recovery
U.S. Coast Guard		
Reserve Training Center	Cutter CUYAHOGA	Anchor stations, mid-Bay transect, 4 periods during July.

Agency	Support	Utilization
U.S. Coast Guard		
Coast Guard Station Little Creek, Virginia	Cutter POINT MARTIN	Equipment Recovery 13 and 14 July.
Portsmouth Supply Depot	Buoy Tender RED CEDAR and buoy boat.	Reset current meter arrays.
Light Towers		
Diamond Shoal Five Fathom Bank Chesapeake	Personnel	Hydrographic Observations July - August
U.S. Army		
Transportation Corps Fort Eustis, Virginia	Tugs	James River slack runs and anchor station. June - July 1972. 2 weeks.
National Marine Fisheries Service		
Woods Hole, Massachusetts	R/V ALBATROSS	Shelf Hydrographic Stations
Sandy Hook, New Jersey	Vessel and Personnel	Hydrographic Observations Shelf
NASA		
Langley Research Center	Helicopters and Personnel	Bay-surface Hydrographic Observations
	Instrumentation Personnel	Bay-mouth Hydrographic Studies

Agency	Support	Utilization
NASA		
Wallops Island	Aircraft	Remote Sensing
National Ocean Survey	Research Vessel WHITING	Set current meter arrays in Bay mouth, Smith Point-Tangier Island Transect 29-30 June 1972.
Virginia Marine Resources Commission	Vessels	Sampling and transportation throughout study.
Virginia Pilots Association	Vessel support	Bay-mouth Hydrographic Studies (2 weeks)
Chesapeake Bay Institute	R/V RIDGLEY WARFIELD	Shell Hydrographic Studies