

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

The Chesapeake Research Consortium, Inc.

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THE CHESAPEAKE RESEARCH CONSORTIUM, INC.

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November 1976

CRC Publication No. 54

*Published for The Chesapeake Research Consortium, Inc.,
by The Johns Hopkins University Press, Baltimore and London*

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Manufactured in the United States of America

The Johns Hopkins University Press, Baltimore, Maryland 21218
The Johns Hopkins Press Ltd., London

Library of Congress Catalog Card Number 76-47392
ISBN 0-8018-1945-8

Library of Congress Cataloging in Publication data
will be found on the last printed page of this book.

Preface

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

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

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

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

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

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

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

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

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

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

Jackson Davis
Project Coordinator

Acknowledgements

The Chesapeake Research Consortium, Inc. is indebted to the following groups for their logistic and/or financial aid to one or more of the consortium institutions in support of investigations into the effects of Tropical Storm Agnes.

U. S. Army

- Corps of Engineers, Baltimore District
- Corps of Engineers, Norfolk District
- Corps of Engineers, Philadelphia District
- Transportation Corps, Fort Eustis, Virginia

U. S. Navy

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

U. S. Coast Guard

- Reserve Training Center
- Coast Guard Station, Little Creek, Virginia
- Portsmouth Supply Depot
- Light Towers (Diamond Shoal, Five Fathom Bank, and Chesapeake)

National Oceanic and Atmospheric Administration

- National Marine Fisheries Service (Woods Hole, Massachusetts and Sandy Hook, New Jersey)

The National Science Foundation

Food and Drug Administration

Environmental Protection Agency

U. S. Office of Emergency Preparedness

State of Maryland, Department of Natural Resources

Commonwealth of Virginia, Office of Emergency Preparedness

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RESPONSE AND RECOVERY TO SEDIMENT INFLUX
IN THE RAPPAHANNOCK ESTUARY;
A SUMMARY¹

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Bruce Nelson³

ABSTRACT

Flooding from Tropical Storm Agnes produced unique hydrographic conditions for transport and dispersal of sediment in the Rappahannock and James estuaries. Analyses indicate two cycles of response and recovery to the shock of extreme freshwater and sediment influx; one cycle in response to Rappahannock inflow; the other to intense mixing within the estuary. Important stages in the sequence consist of: (1) an initial response and seaward surge of river water and sediment; (2) shock with downstream translation of the salt intrusion head with a near-bottom salinity front and high turbidity in surface and in bottom water; (3) rebound with intense stratification and formation of an enriched turbidity maximum; (4) partial recovery with salinity intrusion strengthened by upstream flow along the bottom; landward migration of the maximum; (5) full recovery and return to partly-mixed state with decay of turbidity maximum over a broad zone 30 days after flooding. Sediment was derived initially from lateral tributaries and then from the main river. The bulk of the load sedimented above the salt intrusion during the first three days of flooding. Sediment dispersed into the estuarine circulation system later was effectively trapped by upstream flow along the bottom. Over the entire event, 91% of the sediment load was trapped.

INTRODUCTION

Flooding caused a record influx of 0.1 megatons of sediment in the Rappahannock. Sediment was derived largely from the main river drainage basin. Clay minerals from the estuary, illite, chlorite and muscovite, indicate a Piedmont source. The chief question is, where does the sediment go? Is it either flushed through the estuary, trapped in suspension, or deposited on the channel floor?

The data analyzed consist of: (1) longitudinal sections of salinity and suspended sediment concentration observed daily near slack water along the estuary length; and (2) time distributions of salinity, current velocity, and suspended sediment concentration observed hourly at 3-4 depths from an anchor station in the lower estuary. The mass of data was reduced and evaluated to determine how the estuary responded to the 3-fold stress of freshwater inflow, sediment influx, and tide.

¹Contribution No. 758, Virginia Institute of Marine Science.

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STRESS AND RESPONSE

Freshwater inflow, which reached a peak of 2,382 m³ per sec, June 22, 1972 at Fredericksburg on the fall line, receded gradually over a 15-day period from June 22 to July 6, 1972, except for a slight increase on June 30. Sediment inflow reached an estimated 56,680 tons per day at Fredericksburg and, except for the "second surge", diminished with recession of inflow. Tidal heights at Tappanhook reached a maximum during late stages of the storm, June 21, and high waters gradually diminished over the 15-day period. At the same time the tide range increased from neap to spring, thus acting to increase tidal currents and haline mixing during the progress of flooding.

Suspended sediment concentrations in surface water of the lower estuary reached a maximum 5 days after peak flooding on the fall line. As shown in Fig. 1, the magnitude and direction of net velocity varied through a sequence of phases from "initial response" to "shock", "rebound", "reversal", "second shock", "homogeneity", and "recovery". Despite fluctuating sediment loads and diminishing concentrations after the 6th day, sediment transport follows the time-trends of net velocity. A similar sequence of changes occurred at depth in the lower layer. However, they are smaller than in the upper layer and the net current is directed mainly upstream except for a short period of reversal. Thus, the two-layered estuarine circulation responded quickly to flooding and prevented escape of most sediment from the estuary.

The complete sequence of stress and response consists of 7 stages (grouped chronologically by days after peak flooding on the fall line):

1) *Initial response* (+1 to +2 day). Flooding began with increasing inflow and sediment influx from lower tributary creeks. Storm tides flooded and the combined force of storm surge, wind-waves and tidal currents intensely stirred the estuary floor. Freshwater inflow pushed the salt intrusion downstream and transformed it into a salt wedge. Therefore, currents in the upper estuary reversed from upstream to downstream and allowed river-borne suspended sediment to pass into the upper estuary. The high sediment influx overwhelmed the turbidity maximum that normally resides in the upper estuary (+2 day).

2) *Shock* (+3 to +4 day). As the main surge from mainstream drainage entered the estuary it freshened near-surface water, lowered the halocline and created a salt wedge with high stratification. The high hydrostatic head created a near-surface gravitational current that carried part of the sediment load seaward through the upper layer into the lower estuary. But seaward transport below mid-depth was arrested by the salt wedge. The main load of sediment accumulated landward of the convergence and created a high longitudinal concentration gradient (+4 day).

3) *Rebound* (+4 to +5 day). As the main surge diminished the salt wedge penetrated landward into the upper estuary channel (+5 day). Stratification became intense and the convergence strengthened. Enriched turbid aureoles, a turbidity maximum, formed just landward of the near-bottom convergence. At the same time the estuarine circulation was maintained in the lower estuary and net currents returned to near-normal speeds. The suspended sediment "minimum" at mid-depth disintegrated as tidal resuspension diminished and as sediment settled from the upper layer.

4) *Reversal* (+6 to +7 day). Freshening of Chesapeake Bay temporarily created an inverse salinity gradient in the lower estuary and resulted in a reversal of the estuarine circulation. At the same time the salt wedge penetrated farther landward and the turbidity maximum shifted upstream.

5) *Second shock* (+8 through +11 day). A second surge of mainstream flooding again depressed the salt wedge. It freshened the upper layer, increased stratification and strengthened the estuarine circulation. The turbidity maximum became larger and shifted downstream. The second shock was less intense than the first shock but it persisted longer.

6) *Haline homogeneity* (+12 to +22 day). As the second surge diminished, bottom water continued to freshen as spring tides weakened stratification and mixed near-surface water downward. The estuarine circulation persisted but net current was very weak. Sediment influx from the bay and intense mixing maintained the turbidity maximum.

7) *Recovery* (+22 to +60 day). As river inflow subsided, and as Bay water regained normal salinity, the estuary returned to its normal partly-mixed state. The salt intrusion stabilized in the upper estuary and the turbidity maximum decayed over a broad zone (e.g. +30 day).

DISPERSAL AND DEPOSITION

Sediment was initially transported through the main channel of the upper estuary and later through the upper layer of the salt intrusion in both the channel and over bordering shoals. However, the sediment transport budget indicates 91% of the total river-borne input was trapped. It was partly retained for a while in the turbidity maximum upstream of the salt intrusion and gradually deposited as the maximum shifted landward during recovery. For another part, suspended sediment was progressively diluted with distance downstream and deposited by simple gravitational settling rather than by flocculation. Thus the flood-borne load was spread out on the channel floor of the upper and middle estuary from 7.5 to 2mm thick (estimated by Huggett, this volume). This deposition, which amounts to one-third of the annual average deposition, is part of a long-term trend of sedimentary and seaward shifting of the locus of shoaling. Unless existing channel depths are maintained by dredging, shoaling will shift the head of navigation seaward, reduce salinity in the estuary, and shift the circulation pattern from a type B to a type C (Pritchard 1955). Thus, deposition will change the hydraulic regime from a trapping mode to an escape mode.

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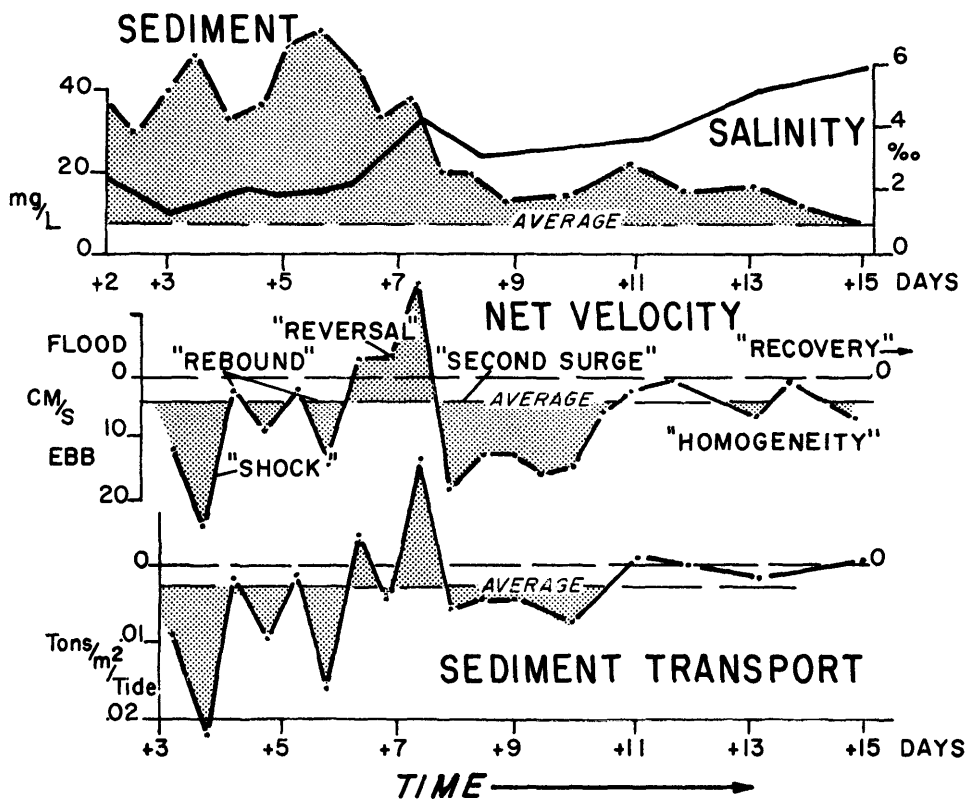


Figure 1. Time-variations of total suspended matter (sediment), salinity (top), net velocity (middle), and sediment transport (bottom) in surface water of the lower Rappahannock Estuary near Urbanna between June 24 (+ 2 day) and July 7 (+ 15 day) 1972. Sequence of events, defined mainly by net velocity response, are labeled "shock", "rebound", etc. Deviation from average values in this reach of the estuary, shaded.