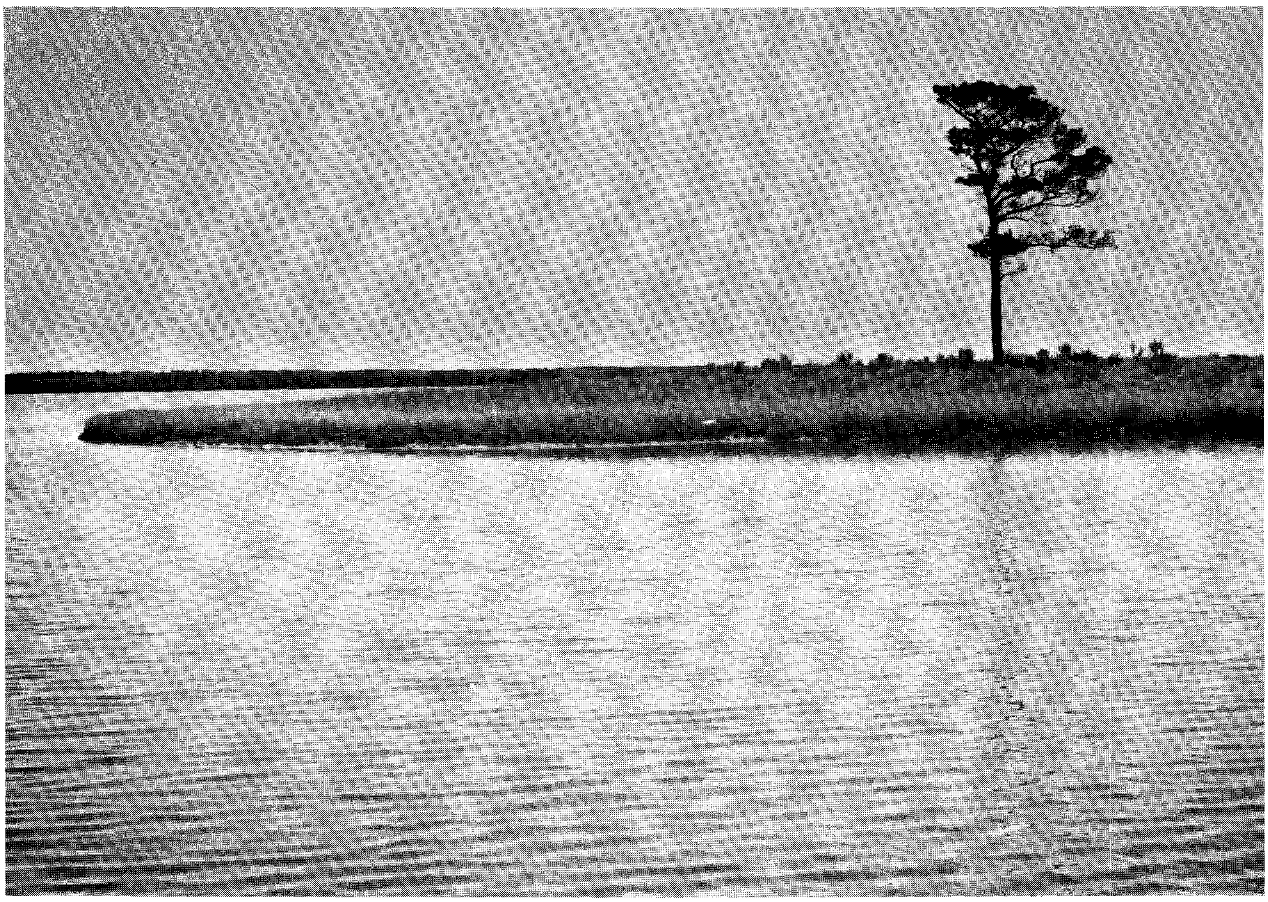
VIRGINIA DIVISION OF MINERAL RESOURCES PUBLICATION 56

EDEN IN PERIL: THE TROUBLED WATERS OF THE CHESAPEAKE BAY

S. O. Bird



COMMONWEALTH OF VIRGINIA

DEPARTMENT OF MINES, MINERALS AND ENERGY
DIVISION OF MINERAL RESOURCES
Robert C. Milici, Commissioner of Mineral Resources and State Geologist

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FRONT COVER: An unlikely tree stands alone in a salt marsh near the mouth of the York River estuary. Photographic print by T. M. Gathright, II.

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DEPARTMENT OF MINES,
MINERALS AND ENERGY

Richmond, Virginia

O. GENE DISHNER, Director

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF PURCHASE AND SUPPLY
RICHMOND

1985

Publication available from Virginia Division of Mineral Resources, Box 3667, Charlottesville, VA 22903.

Portions of this publication may be quoted if credit is given to the Virginia Division of Mineral Resources. It is recommened that reference to this report be made in the following form:
Bird, S.O., 1985, Eden in peril: The troubled waters of the Chespeake Bay: Virginia Division of Mineral Resources Publication 56, 27 p.

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EDEN IN PERIL: THE TROUBLED WATERS OF THE CHESAPEAKE BAY

S. O. Bird

ABSTRACT

The natural good health of the Chesapeake Bay is failing. Bits of garbage, abandoned tires, eroding beaches, a house undercut by relentless waves, a plot of gaping, seeded oysters, a prized fishing hole that no longer is productive—such is the stuff and substance of hearsay evidence. Hard facts are more subtle and more difficult to obtain, but, when assembled, more convincing. Hard data made available by the work of legions of research scientists show the following results. The volume of water in the Bay with an unnatural, and distinctly unhealthy, low level of oxygen has increased substantially over the last three decades; portions of the Bay's bottom are essentially sterile, though far from clean; discharges of chlorine from sewage treatment plants and from power plants cooled by Bay waters threaten aquatic life in, on, and above the bottom. Data from fisheries seem generally to indicate that the Bay is not well, but the nature of most of the accumulated information does not allow identification of the reasons for the decline or, indeed, determination of the truth or significance of it.

It is becoming clear that the chief reason for oxygen depletion in Bay waters is overproduction of algae; a state which in turn is caused by a man-made high level of the fertilizers phosphorus and nitrogen. Major sources are runoff from croplands and effluents from sewage treatment plants. Serious contamination of the Bay's sediments at urban centers and near the mouth of the Susquehanna River results from the accumulation of industrial discharges of heavy metals, organic compounds released from burned fuels, and pesticides. All these pollutants are concentrated in the mud-sized fraction of the sediment by the process of adsorption.

Virginia, Maryland, Pennsylvania, and the District of Columbia have begun an aggressive attack on the Bay's problems. The Initiatives passed by the Virginia General Assembly in 1984 include programs for limiting the input of fertilizers, chlorine, and pesticides to the Bay, tracing sources of heavy metals, and amassing data on Bay fisheries.

INTRODUCTION

The Chesapeake Bay, one of the world's largest estuaries, is perhaps the most studied and best known body of water in the world. It produces some $86 million in commercial fisheries annually, including 22 million pounds of shucked oysters, 59 million pounds of blue crabs, and 462 million pounds of finfish in 1980. Today, studies on the Bay are much before the public as well as the scientific community, for the welfare of its aquatic life and the quality of its waters are in serious decline.

Because of its beauty and mystique and because of its productivity and importance in trade, the Bay area has held a substantial population since colonial times. Growth now is very rapid, having doubled in the last 40 years. About 13 million people, representing some 5 percent of the Nation's population now live along the Bay and tidal portions of its tributaries, which together form over 7,000 miles of shoreline. The largest population centers are Baltimore, Washington, D. C., Richmond, and Norfolk. Many of the Bay's problems and much of the threat to its health come from this concentration of people, as well as from farming and industrial activities on lands whose waters drain into the Bay.

THE BAY'S HEALTH—AN ASSESSMENT

What has produced the current high level of interest in studies on the Bay?

Although scientific research has been going on in the Bay for much of this century, work intensified in the years following 1976, the year when the U. S. Congress directed the U. S. Environmental Protection Agency (EPA) to study the Bay's resources and water quality, and to develop related management strategies (1976, Public Law, P.L., 116). The studies lasted six years and about $30 million was spent in gathering data and writing reports—parts of which are summarized here.

Earlier activities that had a major effect on initiating system-wide studies of the Bay (Lynch, 1977?) were a report by the Federal Water Pollution Control Administration, Department of the Interior (1969); enactment of several laws, including the National Environmental Policy Act (1969, P. L. 91-90), the Federal Water Pollution Control Act Amendment of 1972 (P. L. 92-500) and its subsequent version the Clean Water Act (1977), the Coastal Zone Management Act (1972, P. L. 92-583), the Federal Environmental Pesticide Control Act (1972, P. L. 92-516); and the establishment of EPA (1970) and the Chesapeake Bay Consortium (1972). At the state level, interest was spurred by Governor Spiro Agnew's Conference on the Bay held in Maryland in 1968, and by Senator Charles Mathias' (R-MD) tour of the Bay in 1973. The tour and its findings were a major factor in the beginning of EPA's Chesapeake Bay Program. Other direct factors included the drastic decline in the production of oysters from the Bay in the early 1960's, a decline found to be caused by MSX (an organism) infestations in the oysters, and a general growing awareness of the importance of environmental quality on the productivity and recreational enjoyment of the Bay.

In 1980 Maryland and Virginia together formed a Chesapeake Bay Commission with offices in Annapolis, Maryland. The body, consisting of a staff of three and a board of 14 members, is an outgrowth of the Chesapeake Bay Legislative Advisory Commission created by the Virginia and Maryland General Assemblies in 1978. The existing Commission sponsored a Chesapeake Bay Conference entitled: "Choices for the Chesapeake: an Action Agenda" held at George Mason University in December 1983. Cooperating in the sponsorship were the Citizens Program for the Chesapeake Bay, Inc., the governors of Virginia, Maryland, and Pennsylvania, and the mayor of the District of Columbia. Results of this conference included the proposal of major Chesapeake Bay initiatives by Governor Charles Robb (Virginia), Governor Harry Hughes (Maryland), Lt. Governor William Scranton (Pennsylvania), and Mayor Marion Barry (District of Columbia). Other important developments were the establishment of the Chesapeake Bay Agreement, which included the formation of a Chesapeake Executive Council to assess and oversee various plans to improve the Bay's water quality and living resources, and the heightened awareness by citizens of the resolve of the several governments to accomplish their purpose (Chesapeake Bay Commission Annual Report, 1983). The initiatives adopted by the Virginia General Assembly in 1984 are presented later in this report.

Much of the research for EPA's Chesapeake Bay Program (see reference entries under U. S. EPA) was carried out by scientists at the member institutions of the Chesapeake Bay Consortium: the Virginia Institute of Marine Science of the College of William and Mary, the Chesapeake Bay Institute of the Johns Hopkins University, the Chesapeake Bay Laboratory of the University of Maryland, and the Smithsonian Institution. The first three named groups have been carrying out studies on the Bay for decades. Establishment of the Consortium enabled coordination of on-going activities and initiation of large-scale cooperative efforts. Dr. Maurice Lynch of the Virginia Institute of Marine Science (VIMS) is currently director of the Consortium. VIMS has long been a research leader on Bay problems, and Virginians can take pride in its past and present role in marine affairs.

Results of studies on the Bay are in several scientific and popular serials and books. Newsletters or magazines of general interest are published by VIMS (Gloucester Point, Va. 23062); Interstate Commission on the Potomac River Basin (1055 First Street, Rockville, Md. 20850); The Chesapeake Bay Foundation (11 South 12th St., Suite 314, Richmond, Va., 23219); the Citizens Program for the Chesapeake Bay (6600 York Road, Baltimore, Md. 21212); and EPA (Chesapeake Bay Program, 2083 West St., Annapolis, Md. 21401). Some references cited in this report are undated; these are denoted by a year and a question mark.

How did the Chesapeake Bay form?

A bay is generally defined as a major indentation along a coastline. The Chesapeake Bay is really a drowned river—an estuary. The ancient, drowned channel belonged to the Susquehanna River when sea level stood lower. Its tributaries, including the next two smaller streams, the Potomac and James, formerly emptied into the old channel of the Susquehanna, and each was drowned progressively as the melting ice of the last ice age raised sea level.

World-wide changes in sea level have occurred repeatedly in the last few million years—especially in the last two million years—as a result of the advances and retreat of the continental glaciers. The last major ice advance began about 300 thousand years ago; the last major retreat began 15 to 20 thousand years ago.

Radiocarbon dates and fossils show that some 12,000 years ago herds of mastodons, mammoths, tapirs, horses, musk oxen, and giant moose wandered through and around peat bogs that are now under more then 400 feet of water (Whitmore and others, 1967). Remains of the animals have been

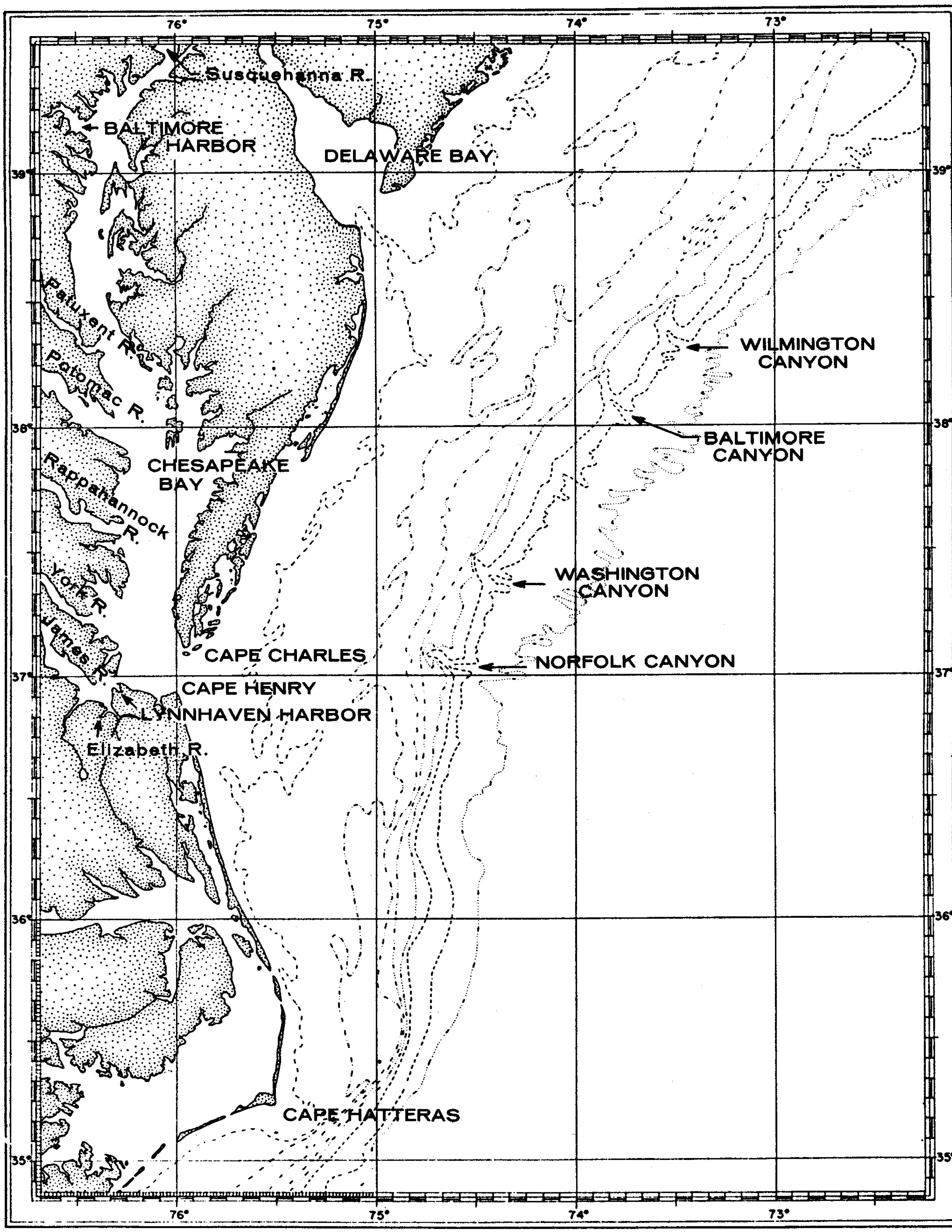

Figure 1. Map of Chesapeake Bay area.

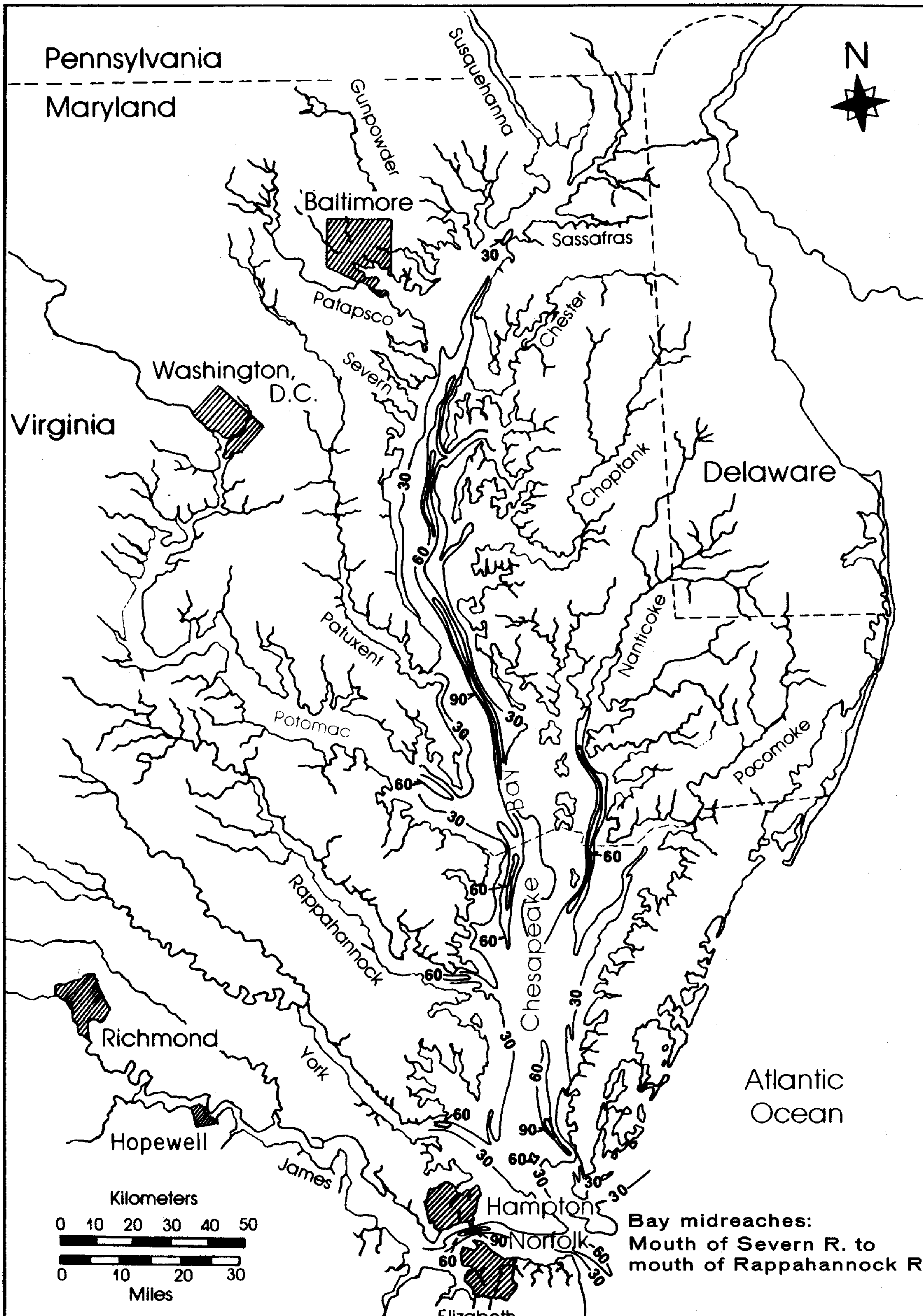

Figure 2. Chesapeake Bay bathymetry (in feet) after Folger (1972).

found from Newfoundland to Virginia up to 40 miles out to sea from the present coastline . Remnants of wave-cut terraces on the shelf also reflect the former low stand of the sea. In a few places channels of ancient streams can also be "seen" from detailed mapping of the topography below shelf waters. The upper part of the Norfolk Canyon (Figure 1) may mark the area of the former mouth of the Susquehanna River. Here mud and sand carried by the stream and deposited at its ancient mouth would have periodically been set in rapid motion down the continental slope as turbidity currents. Such currents would have cut the Canyon. This association of the River and the Canyon cannot now be found, for the connecting channel from the Bay's mouth to the Norfolk Canyon evidently has been filled.

The ancient channel of the Susquehanna is in places very evident within the Bay, where it locally is more than 120 feet below sea level (Figure 2). The average depth of the Bay is only 28 feet. It has largely been filled with sediment (Figure 3). Flooding by the sea ends at the Fall Line where sedimentary rocks of the Coastal Plain give way to the crystalline rocks of the Piedmont (Figure 4). Extensive and commercially important deposits of sand and gravel (Figures 5 and 6) and finer sediments frame the tributary estuaries in many places. These deposits locally represent a higher stand of the sea than the present one. It is generally held that these estuarine and fluvial sediments represent a warm-climate interval that preceded the onset of the last big advance of the ice sheets. Uranium-series dates on faunas in some of the younger, lower lying deposits range from about 60,000 to 350,000 years old (Mixon and others, 1982).

How far up the Bay does salt water extend?

Very extensive studies of the hydrography of the Bay have been carried out over the last 60 years, and several important volumes of data have been published (U. S. Coast and Geodetic Survey, 1930; Whaley and Hopkins, 1952; Cronin, 1971); hydrographic data was stored on computer tape at Johns

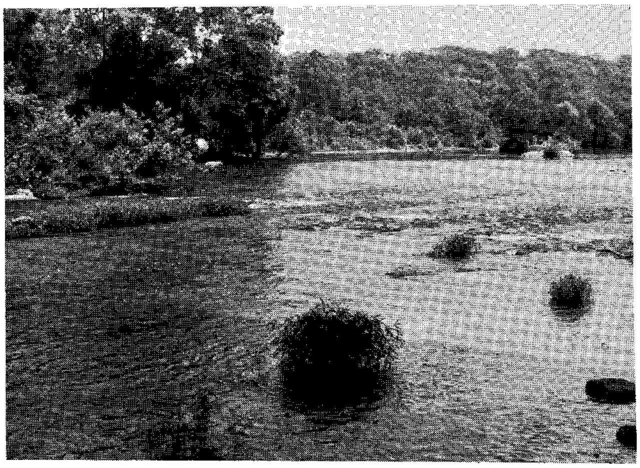

Figure 4. Riffles on submerged granite beside an island of sand on the Fall Line where the "river meets the sea" on the Rappahannock River.

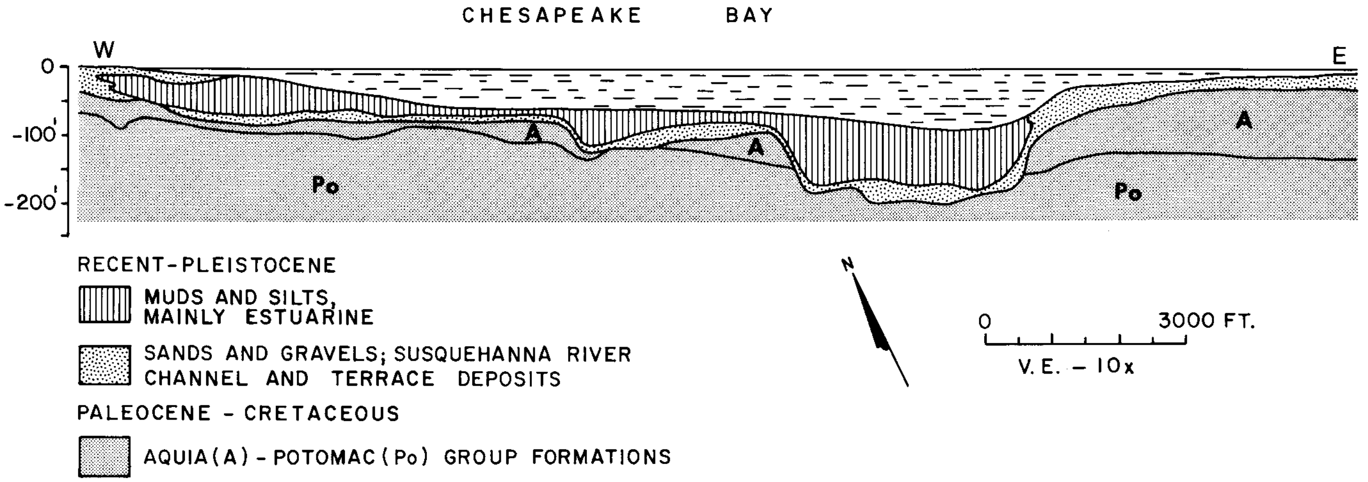

Figure 3. Geological cross-section at Bay bridge near Annapolis, Maryland (Figure 10). Coarse deposits of Pleistocene and Recent ages lie on eroded, much older strata. As the Bay was flooded during rising sea level, muds and silts filled the old Susquehanna channel, and buried its floodplain and terraces.

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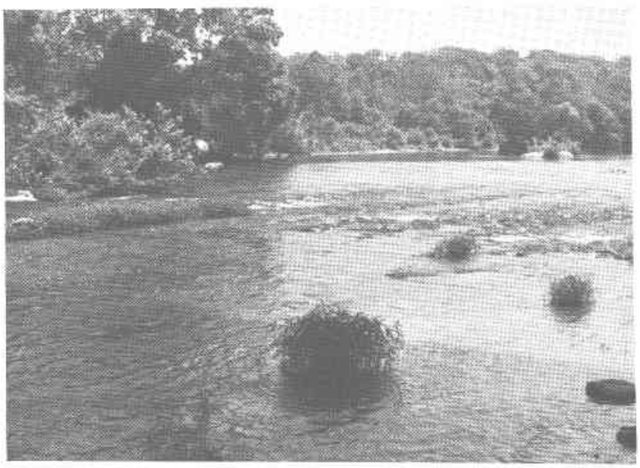

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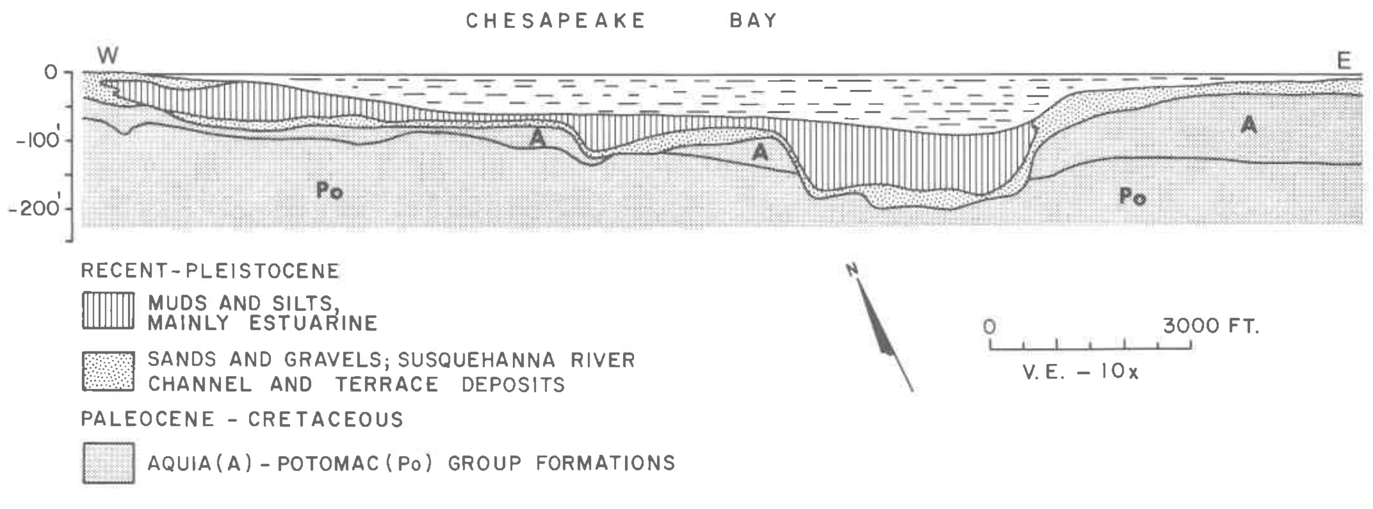

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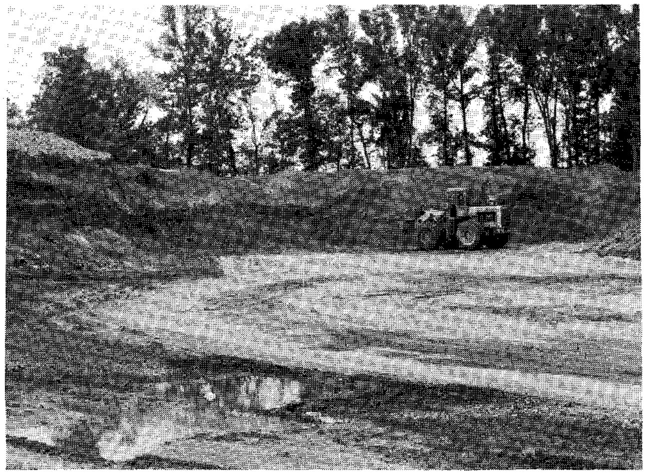

Figure 5. Excavation of fluvial and estuarine sand and gravel at a Caroline Sand and Gravel Company pit on the Rappahannock River floodplain about 10 miles below the Fall Line.

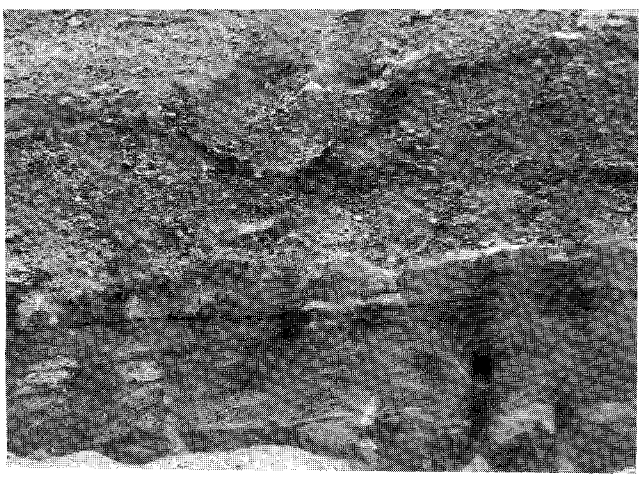

Figure 6. Coarse sand and gravel of Pleistocene age overlying cross-bedded Cretaceous sandstone. The limonite-lined channel is within the Pleistocene deposits. Total height of section is about 7 feet.

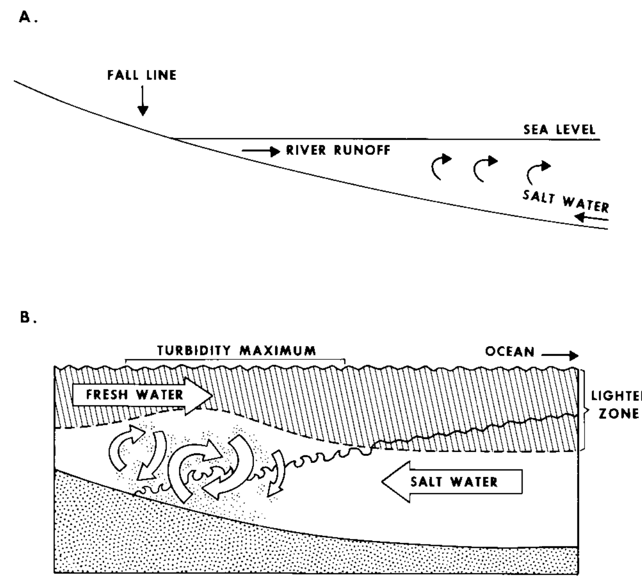

Figure 7. A. Diagram to show upstream flow initiated and maintained by entrainment of salt water. The upstream flow of ocean water is caused by entrainment of the salty water in the fresh; flow is augmented, but not caused, by flooding tides. B. Generalized circulation pattern near area of turbidity maximum.Less dense fresh water partly overlies and partly mixes with more dense salt water. The depth or thickness of the lighted zone depends on the turbidity of the water (after EPA, 1982b).

Hopkins University as early as 1963, and the Chesapeake Bay Institute has published a large series of data reports since 1949.

The Bay is a partially mixed estuary (Pritchard, 1952; 1967). As shown in Figure 7, there is a *nontidal* upstream flow of ocean water into the Bay because of fresh-water runoff, differences in density between fresh and salt water, and partial mixing of the water masses. This circulation is effected by entrainment (advection) of salt water in fresh water. River runoff (surface water) moving downstream entrains the salt water which must be replaced by bottom water inflow. Pritchard worked out this concept using velocity observations at different levels in the water column of the James River. A rising tide increases the upstream flow.

At the heads of tributary estuaries, tidal amplitude is variable and may exceed by a factor of two the typical Bay regime (2 to 3 feet normally) and tidal currents upstream exceed 1 knot at the tidal headwaters of these streams. At the Fall Line, the tidal limit, the water is brackish or at times fresh, but generally unpotable. It is unstratified, too, and currents of the flood tide are in places directed upstream throughout the water column, as shown by current-meter measurements.

So salt water at the Bay mouth is constantly replenishing diluted salt water farther up the estuary. The volume of water coming in and going out changes with the tides, but heavy, salty water from the ocean moves ever upstream along the Bay's bottom. Thus the Bay is a complex mixing

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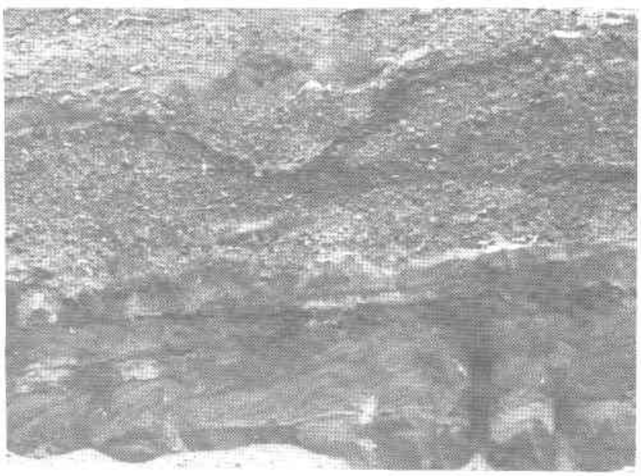

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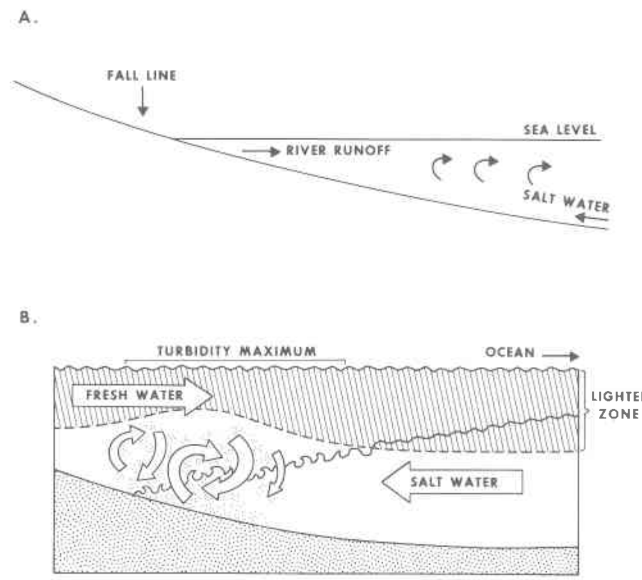

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So salt water at the Bay mouth is constantly replenishing diluted salt water farther up the estuary. The volume of water coming in and going out changes with the tides, but heavy, salty water from the ocean moves ever upstream along the Bay's bottom. Thus the Bay is a complex mixing bowl with an essentially constant volume of water: inflow of fresh water from rain through surface runoff and ground water recharge and discharge, and salt water from the ocean is equal to Bay outflow and evaporation.

What effect does this circulation pattern have on the distribution of sediments in the Bay and its tributaries?

The circulation has a pronounced effect on sediments near the mouth of the Bay and at the tidal headwaters and midreaches of the tributary estuaries downstream from the Fall Line. Sediments enter the Bay from the sea and from the rivers and are deposited there. All water, but little sediment, circulates through the Bay. Sediments and everything in or on them accumulate in this giant trap.

Surface tidal currents at the mouth of the Bay generally range from 1 to 2 knots maximum velocity during both ebb and flood tide. Calculated maximum velocities are as much as 3.4 knots (Ludwick, 1970). Net drift on the shelf near the Bay is inward toward it (Harrison and others, 1967). This and other considerations including the quantity, texture, and heavy mineral composition of the sediments at the Bay mouth illustrate an oceanic source for these sediments (Meisburger, 1972).

Bedding of sediments inside the Bay mouth generally slopes away from the northeast, indicating that the sediments came from that direction. Sediment particles moving southward along the Atlantic coast of Virginia north of the Bay mouth are swept into the Bay and consequently, beach areas immediately to the south, including Virginia Beach, are undernourished. Offshore drift is southward all along the eastern seaboard south to Cape Hatteras.

The sediments in the mouth of the Bay are chiefly fine quartz sand with coarser sands containing gravel lying in deeper channels where currents are relatively swift. These sediments rest on an erosion surface formed when sea level was lower (Figure 8). A buried peat deposit near the base of the Recent (or Holocene) sediments (those formed since the last glacial retreat) was dated at about 11,500 years old (Meisburger, 1972), and probably marks the edge of the advancing ocean for this time. As relative sea level rose, sediments partially filled the old Susquehanna channel and tributary channels, and locally covered its ancient banks and terraces some 100 feet above the channels (Figure 3). Constant tidal current action sorted and redistributed the surface particles of the accumulating sand. In some places terrace deposits of the old drainage system were reworked to become part of the modern sediments; in other places they were simply buried by sediments derived from other sources. Through time, relict

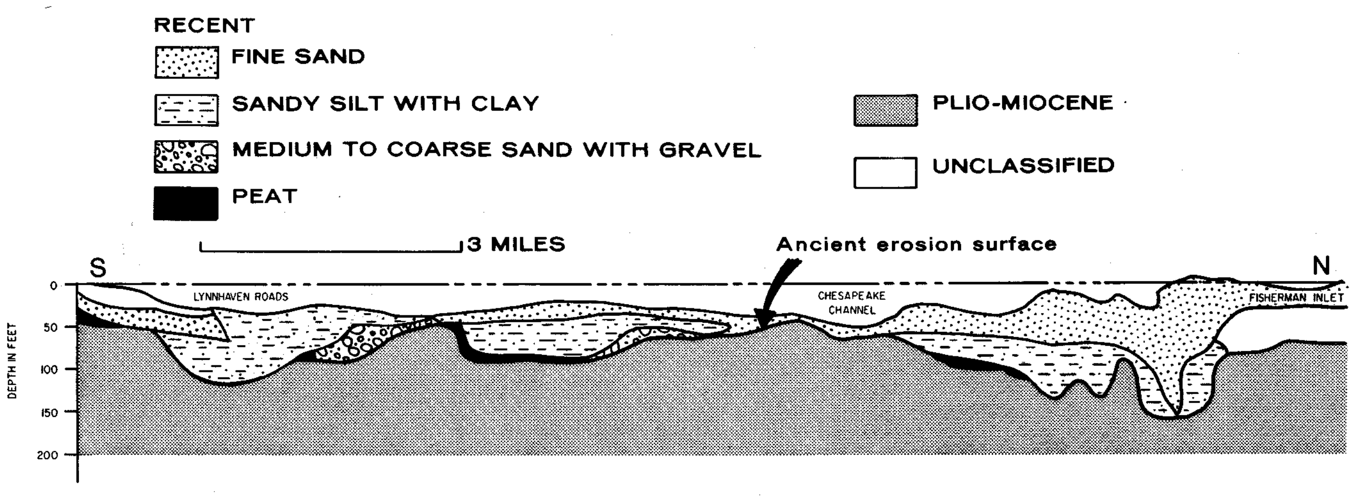

Figure 8. Geological cross-section at Chesapeake Bay mouth along the Bridge-tunnel route. Note post Pliocene/pre-Recent erosion surface. The Recent begins here with the peat, a fresh-water deposit, and includes the overlying fluvial, estuarine, and marine deposits (after Meisburger, 1972). Steep appearance of bottom topography results from vertical exaggeration.

sediments of the Bay were being buried as sea level continued to rise and as aggradation sought to keep pace.

Far up the Bay at heads of estuaries most sediments are dumped where the streams exit crystalline rock terrain to become part of the tidal system (Figure 4). Some sediment, that of colloidal size (less than 65 microns), continues downstream.

The rate of filling in the last 200 years or so along some tributary estuaries has been remarkable; thirty feet of sediment has accumulated locally in tidal creeks along the Rappahannock River (Wass and Wright, 1969), as navigable water has been turned to swamp marsh. The record of filling in parts of the upper Bay has been studied by Brush and Davis (1982), who used ragweed pollen and coal particles in cores to mark times of intense farming and the onset of industrialization in the Susquehanna and Potomac river valleys. Additional data on sediment rates are in Defries (1981). In the area of the Susquehanna Flats, some 12 inches of sediment have accumulated in the last 100 years. If this rate were the average for the Bay, it would be filled in 2800 years. The "average" Bay rate of sedimentation is about 0.2 inches/year.

Mud, containing primarily the clay minerals kaolinite, illite, montmorillonite, and chlorite (Lake and MacIntyre, 1977) and colloidal-sized quartz accumulate mainly in the midreaches of the tributary estuaries. In the zone below the tidal headwaters called the turbidity maximum (Schubel, 1968), where the difference in salinity between bottom and surface waters is sufficient to produce a vertical stratification of the water column, suspended sediment reaches a maximum concentration. Here suspended mud moving downstream overlies that moving up stream. The source of the sediment in both cases is upstream. Most of the mud entering the system through streams is deposited in this zone of turbidity, which migrates somewhat with the changing regimens of fresh and salt water: a flood of fresh water moves it bayward; a spring tide moves it landward. The turbidity maximum for the Susquehanna is in the main stem of the Bay and extends over some 20 miles of the upper Bay.

Along lower reaches of the tributary estuaries, Coastal Plain streams contribute mud, silt, and sand as does erosion of the cliffs along the streams, which in places are more than 100 feet high. Filling of these lower reaches has not progressed very far: maximum depths of the Potomac, James, and Rappahannock rivers are more than 70 feet below sea level.

In the Bay stem near Annapolis, the sediment fill consists of Ice Age channel, point bar, and terrace deposits—and also of more recent sediments, which are finer (Figure 3). The older part of the recent sediments is predominantly silt whereas the younger is black soupy mud and silt. The total thickness of the Ice Age and recent deposits, which overlie eroded marine deposits as much as 20 million years old, is up to 110 feet. They represent aggradation of the old stream channel and adjacent valley floor and terrace areas. As sea level rose and pushed the mouths of the Susquehanna and its tributaries ever more landward, the channel was progressively filled by sediments derived from land and sea.

In the Bay's midreaches, sand and silt, rather than mud, dominate the modern sediments (Byrne and others, 1982). The source of these sediments is headland erosion (Figure 9). Almost the entire Bay shoreline is undergoing intense erosion (Figure 10). Small promontories are attacked by waves from many directions and therefore furnish a disproportionately large amount of sediment—including much sand. More recessed (concave-bayward) or longer, straighter shorelines seem to be eroded less rapidly, but beach erosion depends on a number of factors including wave height and direction of attack, water depth and bottom configuration near shore, and beach materials. Very little of the Bay's shoreline is undergoing accretion (building of mass above mean low water).

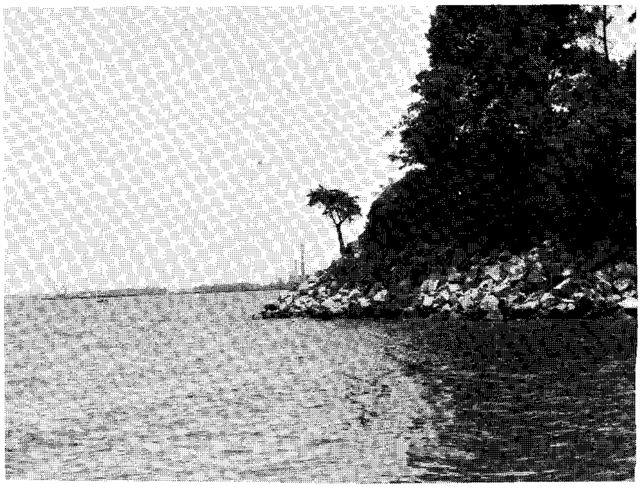

Figure 9. Steep, eroded bank of Yorktown Formation sandstone (Pliocene) near mouth of York River. Recently emplaced granite rip-rap is from the Fall Line on the Rappahannock River. Smoke stacks belong to VEPCO's steam electric plant and the tanks to its left to AMOCO oil refinery. View is downstream.

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Far up the Bay at heads of estuaries most sediments are dumped where the streams exit crystalline rock terrain to become part of the tidal system (Figure 4). Some sediment, that of colloidal size (less than 65 microns), continues downstream.

The rate of filling in the last 200 years or so along some tributary estuaries has been remarkable; thirty feet of sediment has accumulated locally in tidal creeks along the Rappahannock River (Wass and Wright, 1969), as navigable water has been turned to swamp marsh. The record of filling in parts of the upper Bay has been studied by Brush and Davis (1982), who used ragweed pollen and coal particles in cores to mark times of intense farming and the onset of industrialization in the Susquehanna and Potomac river valleys. Additional data on sediment rates are in Defries (1981). In the area of the Susquehanna Flats, some 12 inches of sediment have accumulated in the last 100 years. If this rate were the average for the Bay, it would be filled in 2800 years. The "average" Bay rate of sedimentation is about 0.2 inches/year.

Mud, containing primarily the clay minerals kaolinite, illite, montmorillonite, and chlorite (Lake and MacIntyre, 1977) and colloidal-sized quartz accumulate mainly in the midreaches of the tributary estuaries. In the zone below the tidal headwaters called the turbidity maximum (Schubel, 1968), where the difference in salinity between bottom and surface waters is sufficient to produce a vertical stratification of the water column, suspended sediment reaches a maximum concentration. Here suspended mud moving downstream overlies that moving up stream. The source of the sediment in both cases is upstream. Most of the mud entering the system through streams is deposited in this zone of turbidity, which migrates somewhat with the changing regimens of fresh and salt water: a flood of fresh water moves it bayward; a spring tide moves it landward. The turbidity maximum for the Susquehanna is in the main stem of the Bay and extends over some 20 miles of the upper Bay.

Along lower reaches of the tributary estuaries, Coastal Plain streams contribute mud, silt, and sand as does erosion of the cliffs along the streams, which in places are more than 100 feet high. Filling of these lower reaches has not progressed very far: maximum depths of the Potomac, James, and Rappahannock rivers are more than 70 feet below sea level.

In the Bay stem near Annapolis, the sediment fill consists of Ice Age channel, point bar, and terrace deposits—and also of more recent sediments, which are finer (Figure 3). The older part of the recent sediments is predominantly silt whereas the younger is black soupy mud and silt. The total thickness of the Ice Age and recent deposits, which overlie eroded marine deposits as much as 20 million years old, is up to 110 feet. They represent aggradation of the old stream channel and adjacent valley floor and terrace areas. As sea level rose and pushed the mouths of the Susquehanna and its tributaries ever more landward, the channel was progressively filled by sediments derived from land and sea.

In the Bay's midreaches, sand and silt, rather than mud, dominate the modern sediments (Byrne and others, 1982). The source of these sediments is headland erosion (Figure 9). Almost the entire Bay shoreline is undergoing intense erosion (Figure 10). Small promontories are attacked by waves from many directions and therefore furnish a disproportionately large amount of sediment—including much sand. More recessed (concave-bayward) or longer, straighter shorelines seem to be eroded less rapidly, but beach erosion depends on a number of factors including wave height and direction of attack, water depth and bottom configuration near shore, and beach materials. Very little of the Bay's shoreline is undergoing accretion (building of mass above mean low water).

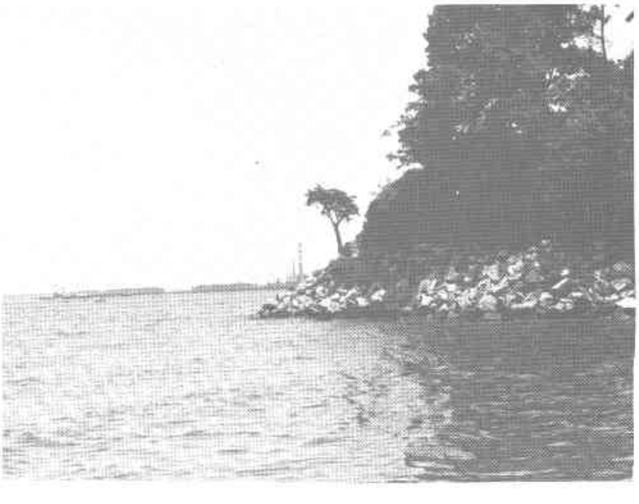


Figure 9. Steep, eroded bank of Yorktown Formation sandstone (Pliocene) near mouth of York River. Recently emplaced granite rip-rap is from the Fall Line on the Rappahannock River. Smoke stacks belong to VEPCO's steam electric plant and the tanks to its left to AMOCO oil refinery. View is downstream.

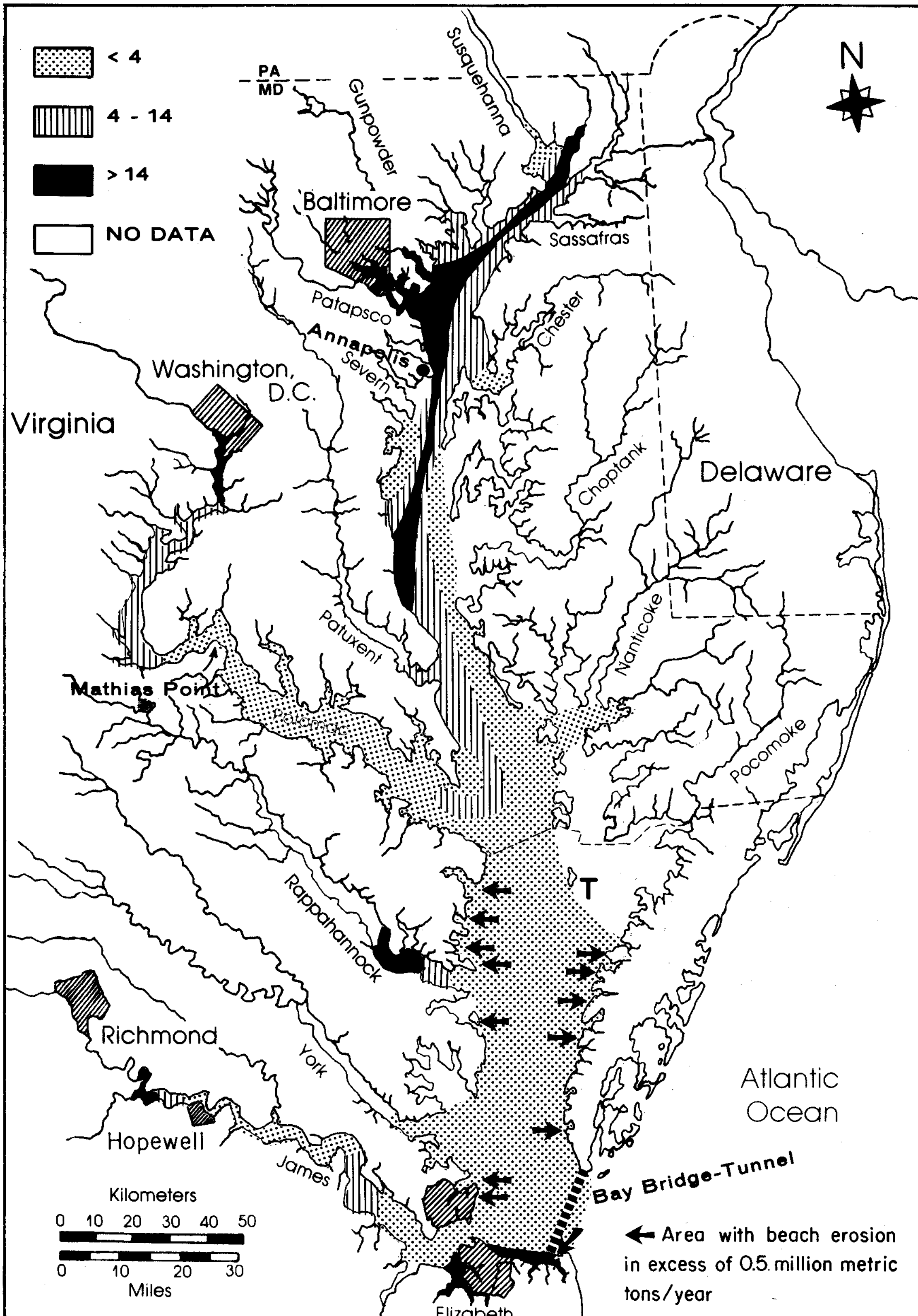


Figure 10. Shoreline erosion (arrows) and heavy metal contamination in Bay sediments. Numbers are factors above the combined natural background level of the metals. The western shore of Tangier Island, T, is undergoing intense erosion also. Figure modified from EPA (1983c); erosion data from Byrne and others (1982).

In summary, it may be said that heads of tributaries, the upper Bay and the lower Bay have undergone appreciable filling. The source of sediments for the lower Bay is the sea; upstream, it is the hinterland which includes parts of six states. The Bay midreaches are filled to a lesser extent. The major source of materials here is the sandy banks of the Bay margin, which in places are rapidly receding cliffs. The deep channel of the Bay contains mud and silt; the upper, more recent parts of these sediments are black, watery muds which in places are up to 6 feet thick in the Bay stem (Ryan, 1953).

What is happening to the Bay as an ecosystem?

An ecosystem is a self-contained, life-sustaining group of organisms and their physical (and chemical) environment. The concept includes an assumption of a balance in production and consumption of the life members and in the life-essential, physical (and chemical) components of the system. The system purifies and sustains itself as materials are recycled through the action of decay of organic "wastes."

A balanced aquarium theoretically can last "forever," that is, until the sun burns out, or until some failure in flow or flowrate within its biological or physical cycles. World oceans have a similar life expectancy, *but estuaries do not.* Natural death of these systems comes about as they are filled with sediments. Today there are many estuaries in the world because of the recent melting of the ice sheets. Sediment infilling may take a few thousand years, but local filling, especially in the tidal headwaters where runoff and erosion is aided by construction projects can be rapid. Unnatural death because of pollution can also come quickly.

Figure 11 from the work of Green (1978) is a graphic summary of an ecosystem. Shaded areas are potential or actual trouble spots. Man at the top of the heap can take too large a harvest and thereby threaten the future of a species; he also comes into the scene at the bottom of the system when he adds fertilizers. Bacteria (and fungi) can produce anoxic conditions (no oxygen) when decomposing excess phytoplankton (mainly floating, single-celled algae) as described below.

What is the major problem with the Bay's health?

In a word it is waste—waste waters from sewage treatment plants, runoff from croplands, and discharges from industries, especially those at and around the ports at Baltimore and Norfolk. The Bay is being overfertilized with soluble, plant-usable forms of nitrogen and phosphorus, and poisoned with pesticides (insecticides and herbicides) and other complex organic compounds and by heavy metals.

How can nutrients harm the Bay? Don't estuarine plants need these?

Just as overuse of fertilizers can damage a garden, it can lead to serious problems in a natural system. There are three broad ecological groups of plants in the Bay: those in the marshes which are periodically wetted by tidal waters, those that are anchored to the bottom and are largely or totally submerged, and those that live in the water column (Figure 12). The ones that live free in the water column, various types of algae, are central to a discussion of the Bay's health. The most important members of this group are the diatoms.

Algae populate the sunlit surface waters of the Bay throughout the year, but "typically" (under natural conditions) they go through two peaks of rapid reproduction and population growth. With the warming of waters in the Spring and the increased sunlight of the season, algal population growth begins. Soon the population is limited by the grazing of an expanded population of herbivores, mainly a group of Crustaceans known as copepods, and by the algae's depletion of nutrients in the water. During Summer, nutrients are scarce in the upper waters because of the stable stratification of the waters then. The cool, salty water from the ocean underlies the fresher, warmer water brought in by the rivers and there is little vertical mixing. In the Fall another algal bloom takes place when the surface waters are cooled and churned and mixed with those below by winds. Nutrients are thereby returned from the bottom to surface waters to support the Fall bloom. Later, in the shortened daylight hours of Winter, growth declines greatly. Under such natural conditions nutrients are resupplied to the water by the decay of organisms, mainly "left over" algae and copepods, at the bottom of the Bay and by the accumulated metabolic wastes of the Bay's natural populations.

Nitrogen and phosphorus are commonly and universally limiting factors in the environment, i.e., plant growth directly, and animal populations by way of the plants, can be restricted by the available quantity of these nutrients rather than by other limiting factors such as sulfur, oxygen, carbon

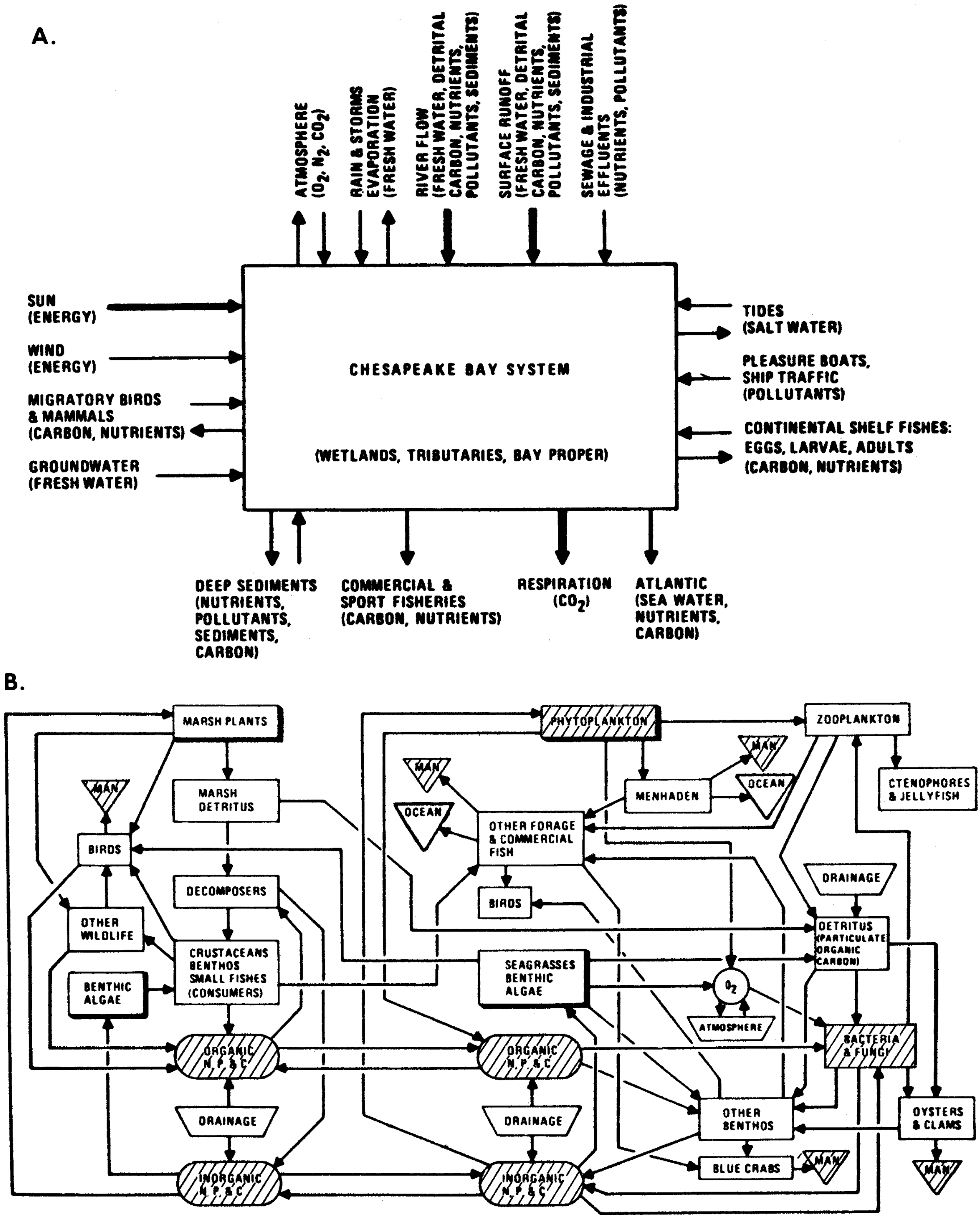


Figure 11. The Chesapeake Bay ecosystem. Diagram "A" shows extraneous influences; "B" shows the dynamics of the system, from Green (1978).

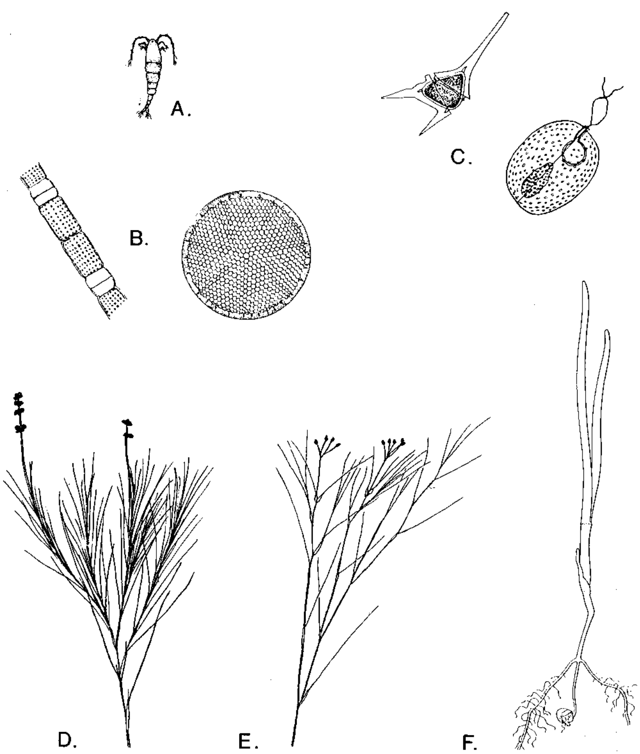


Figure 12. Copepod (A), diatoms (B), dinoflagellates (C), and three types of SAV—*Pomatogeton* sp.(D), *Ruppia maritina* (E), and *Zostera marina* (eelgrass)(F). Copepods, diatoms, and dinoflagellates are microscopic in size.

dioxide, temperature, light, space, and so on. When too much nitrogen and phosphorus are available in usable forms (including especially nitrates, nitrites, ammonia and orthophosphates and polyphosphates), algal growth and reproduction are apt to go on a rampage. This unbalanced growth can lead to disastrous results for other organisms and ultimately for the algae themselves. First by their very numbers, algae in a bloom block out the sunlight and impede growth in deeper parts of the water column or on the bottom. Numbers of algae may reach concentrations of 100 million per liter in fertilized waters; at such levels the liter volume is about 4 percent algae, and the water is difficult or impossible to see through, having the opacity of pea soup. Secondly, and more importantly, the overproduced algae may create a severe oxygen depletion. During their growth, the algae generate oxygen during daylight hours by photosynthesis and consume it at all times by respiration. When masses of them die, oxygen is taken up from the water and from sediments by their decay. The water's oxygen later can be replenished from the atmosphere, but the raining down of algal debris to the bottom can overwhelm the aerobic bacteria there. Consequently, conditions change from aerobic to anaerobic as the supply of organic material surpasses bacterial processing capacity. Now the bottom, and later the water in contact with the bottom, and still later possibly the whole water column, may become putrid and completely devoid of oxygen (anoxic).

At late stages in the progress of oxygen depletion, relatively complex organic compounds such as fatty acids accumulate in the sediments, whereas under oxygen-rich conditions these materials would be fully oxidized to water and carbon dioxide. After a time, if the bottom waters are not refreshed, all life except bacteria anaerobes perish, and an axle-grease-like mud accumulates. Such sediments, after burial and aging, become the sources of oil and gas of the geologic ages. Anaerobic decay is a slow, smelly process, and once its conditions are initiated, they tend to last.

Today's year-round high levels of nutrients in the upper Bay suggest that phosphorus and nitrogen are not limiting its phytoplanktonic growth (EPA, 1982a., p. 69)). Phosphorus levels are probably more critical as a limiting factor than nitrogen, even though phosphorus is needed in molecular quantities only one-sixteenth as great to sustain phytoplankton growth (N:P = 16:1). One reason for the continuous high levels of nutrients is the increased volume of sewage in many parts of the Bay. It is also becoming evident that phosphorus is being released from Bay sediments under anoxic conditions (Taft and others, 1980). The source of this phosphorus is the partially decayed algae accumulating in the black sediments. Thus, out-of-balance production accompanying unnaturally high levels of nutrients, causes both accumulation of nutrients in sediments and oxygen depletion. The conditions then cause phosphorus to be released to support continued high productivity when the phosphorus diffuses to sunlit parts of the water column. The result is a self-perpetuating cycle of less and less oxygen in the water and the underlying sediments.

What are the sources of the nutrients?

The Susquehanna River is the major single source of fresh water (some 50 percent), of nitrogen (about 70 percent), of phosphorus (about 56 percent) and of sediments (about 40 percent) entering the Bay through river sources. Point sources (principally sewage treatment plants) are the secondmost important suppliers of Bay nutrients (22 percent of all nitrogen and 35 percent of all phosphorus). Additional data on nutrient sources are in Table 1.

The biggest point source of nutrients on the Bay is the Blue Plains sewage treatment plant, located on the Maryland side of the Potomac River just below the District of Columbia. It now discharges some 317 million gallons of waste water per day. This Constitutes about 8 percent of the Summer fresh-water flow of the Potomac as measured above the City. Enough to float a battleship? Yes, about 22 *USS Iowas* in one day. Such volumes of waste water and the contained nutrients are sufficient to keep the level at or above the "bloom concentration" for some 15 miles downstream (Maryland Department of Natural Resources, 1980?, p. 65). Spring blooms here contain more than 100 million algal cells per liter. It is easy to see that at such numbers the algae could block out sunlight.

Are the problems of nutrient enrichment and its effects becoming worse?

In general they are, though some progress has been made by construction of advanced sewage treatment plants, especially on the Potomac River near Washington, D. C., where sewage has been a problem since the earliest days of the City, and on the upper James River estuary (EPA, 1983a). Records of nutrient levels for the Bay over the last two decades show increased concentrations of phosphorus and nitrogen, and a related growth of algae as seen by water clarity (turbidity) records. The upper Bay and areas downstream from Baltimore, Washington, D. C., and Richmond are heavily enriched with nutrients (Figures 13-15). An area of run-away enrichment is the Patuxent River, a small watershed with poor circulation and a heavy load of nutrients. It was first reported as a problem area in the 1940's (Boynton and others, 1980).

Perhaps the most alarming change is the increase in the quantity of oxygenless (anoxic) deep water (Officer and others, 1984), lying in and near the old Susquehanna channel from Baltimore to the mouth of the Potomac (Figure 16). The volume of anoxic water in the Bay observed in Summer increased by a factor of 12 or more from 1950 to 1977. Part of this degradation is caused by *Summer* blooms of algae in part fueled by phosphorus released from anoxic black muds of the deep waters. These Summer blooms are made up mainly of dinoflagellates, a food-poor group which impart an umber to orangish cast to the water (red tide). These motile forms are not attractive food for zooplankton, and thus their numbers amass on the bottom to a greater extent than diatoms and other algae that are selected as food. The overabundance of the dinoflagellates and their substitution for the generally more abundant diatoms, which are generally not motile, is in part because of their ability to migrate in the water column and thus escape conditions unfit for them.

The dissolved oxygen content of the deep water (that below 60 feet or so) is at a maximum in January and a minimum (to none) from May to September (Figure 17). The high, Winter values follow Fall mixing of the water caused by seasonal cooling of the water and the increased windiness typical of the season. In Spring, surface waters warm faster, and become increasing lighter, than the underlying waters, whose source is the ocean. This temperature stratification is augmented by the enhanced salinity layering brought about by the typically high Spring runoff. Stable stratification of Bay water continues through Summer into Fall.

Table 1. Material sources for Chesapeake Bay, in percents.

	Portion of riverine source:					Portion of total Bay input:				
Material	Susquehanna	Potomac	James	All Others	Total %	Rivers	STP's[3]	Sediment	Atmosphere	Total %
TN[1]	70	19	6	5	100	56	22	9	13	100
TP[1]	56	22	16	6	100	35	35	25	5	100
Sediment[1]	40	33	16	11	100	nd	nd	nd	nd	nd
Water[2]	49	18	16	17	100	nd	nd	nd	nd	nd

1 From EPA, 1982a; TN, total nitrogen; TP, total phosphorus; nd, not determined.
2 From Pritchard, 1952
3 Sewage treatment plants

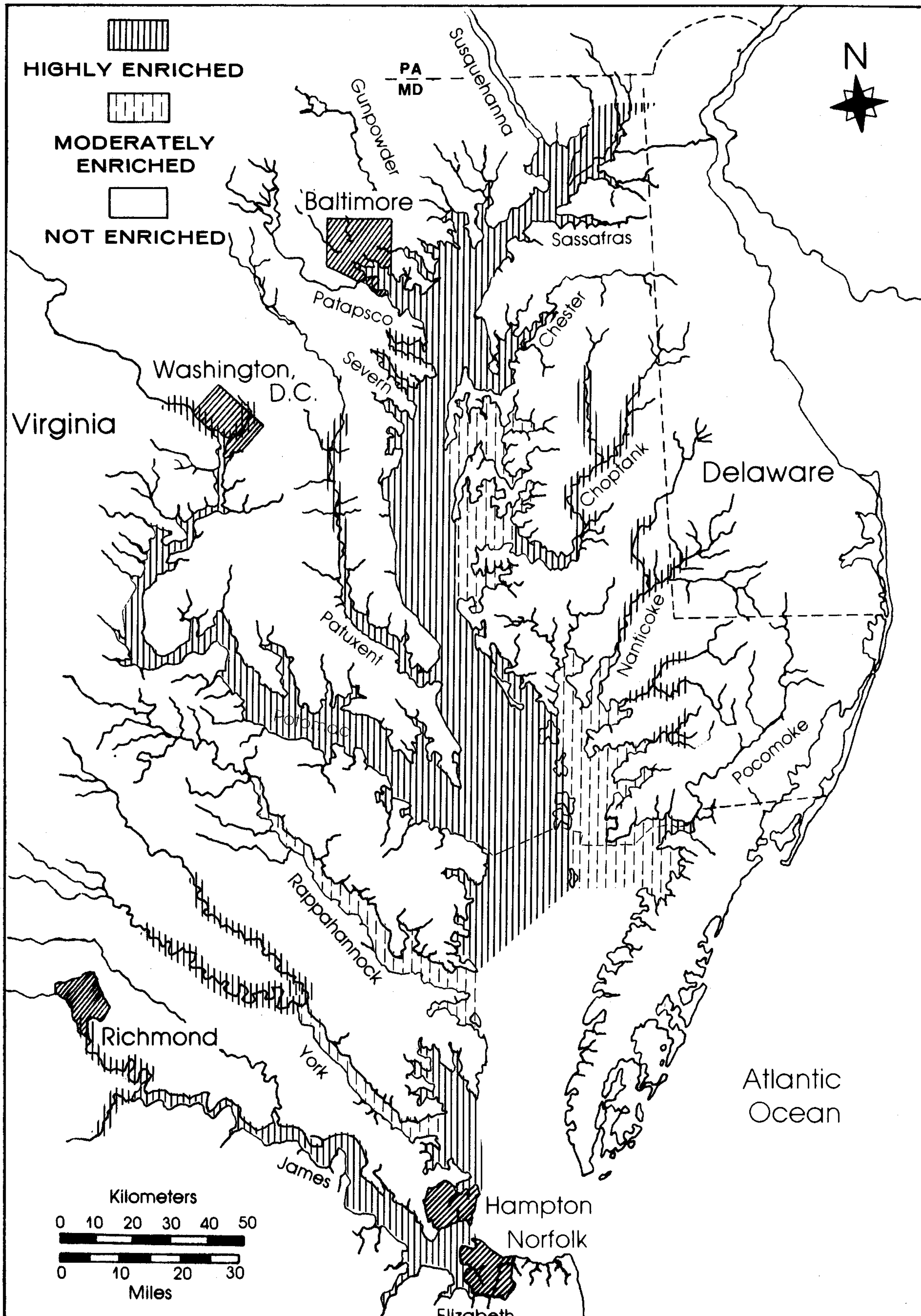


Figure 13. Enrichment of Bay waters with nitrogen and phosphorus, from EPA (1983c).

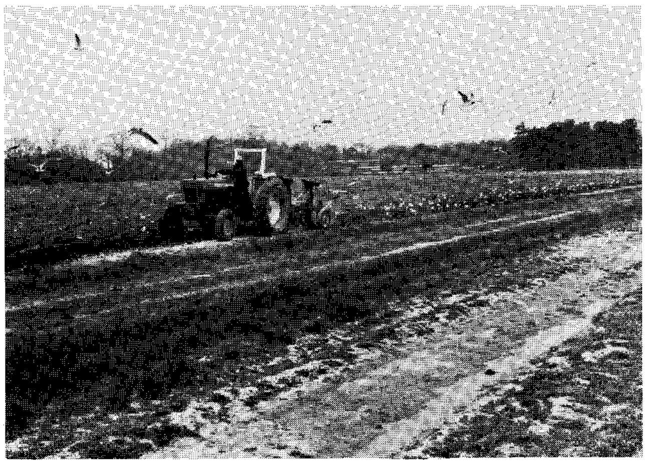


Figure 14. Nutrient sources: runoff of water containing fertilizers and animal wastes.

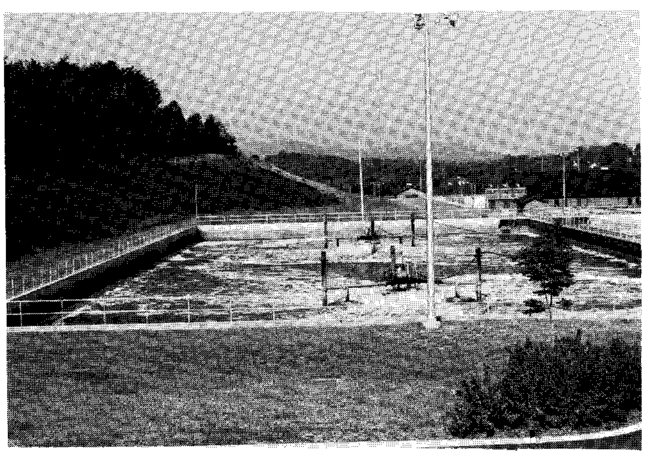


Figure 15. Nutrients and dissolved solids from waste treatment plants at Charlottesville (shown here) and from far beyond make their way into Bay waters.

What are the general warning signs of trouble throughout the Bay?

Some of the more obvious warning signs have been mentioned: high levels of nutrients, algal blooms, persistent low oxygen content of the water, and relatively high levels of toxic metals, pesticides, and other harmful organic compounds in fine-grained sediments. Trends such as persistent and progressive decreases of yields in commercial fisheries, decreases in number of species (diversity), and sudden appearances of new or rapid increase in numbers of previously inconspicuous species are other possible signs of stress. But these findings can reflect a wide variety of influences including overfishing, disease, hurricane damage, and so forth. Lack of repopulation may indicate more general problems such as disruption or annihilation of habitats. A brief review of the Bay's problems region-by-region is given in Table 2.

A look at the changes in river harvests for the Potomac estuary will be a useful example of general Bay problems. Records for the estuary have been summarized recently in a work published by the Maryland Department of Natural Resources (1980?). Fisheries along the tidal Potomac have been in general decline since the late 1800's. Oysters, once abundant and widely exploitable from Mathias Point to the mouth of the River, now are found only locally and in greatly reduced numbers. Because most of this reach has salinities below those required for MSX, this disease organism is not the direct cause of the decline. Production turned down to modern levels in the late 1960's, and the low salinities brought on by Hurricane Agnes (1972) produced such devastation that the area was closed to commercial fishing from 1972 until 1976. Today the area is being seeded with oyster spat.

Some commercial finfish have shown a recent abrupt decline. Among them are the alewife (the most abundantly caught fish in the river), croaker, spot, shad, and white perch. Meanwhile catches of menhaden and catfish have increased. The reported reasons for the changes include shifts in fishing preferences, unusually cold winter temperatures, Hurricane Agnes, and probably degradation of water quality and commensurate alterations of planktonic and rooted plant composition and production. It has not been demonstrated that declining water quality is chiefly responsible for the trends.

What is SAV and why is it important to the Bay's health?

The Potomac estuary has also lost large areas of desirable, i.e., food-rich, rooted aquatic vegetation. Native species of submerged aquatic vegetation (SAV) have been wiped out from areas up to 50 miles downstream from Washington, D. C. on the Virginia side and up to 25 miles down the Maryland side. Important species recently lost include various species of *Potamogeton*, and *Ruppia maritima* (widgeon grass, a favorite of ducks); in earlier times (1930's), eelgrass was lost from the Potomac and from the entire Bay, when it disappeared from bays of the eastern United States.

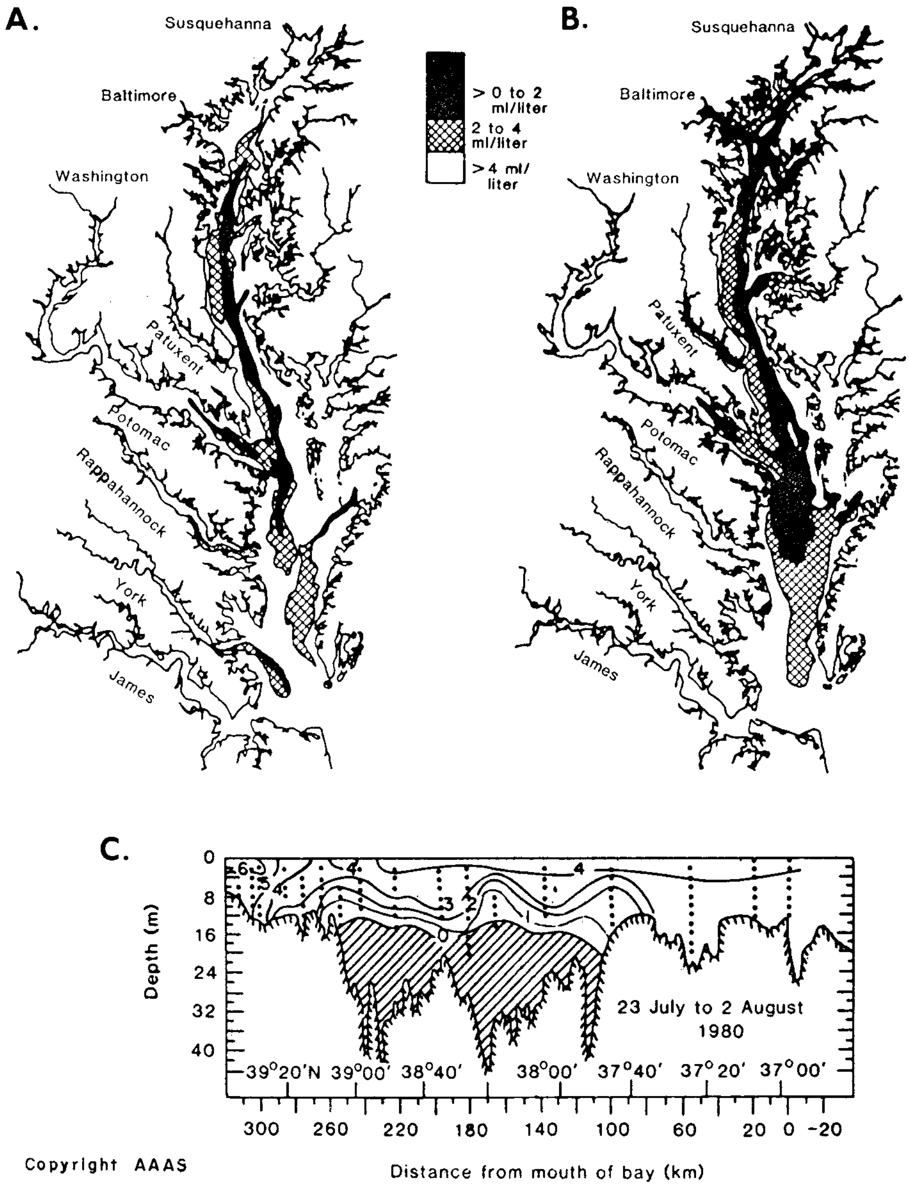
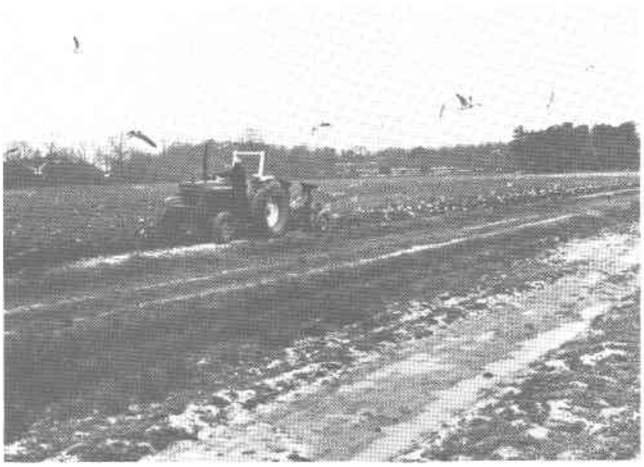


Figure 16. Changes in oxygen content of Bay waters from 1950(A) to 1980(B), and as seen from mouth to upper Bay(C). Oxygen content in milligrams per liter, after Officer and others (1984).



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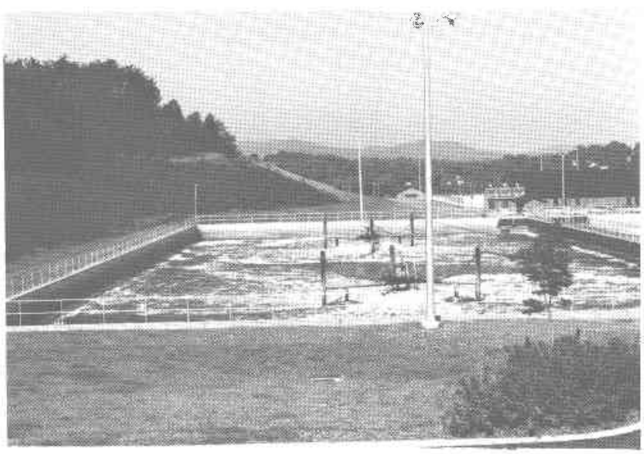

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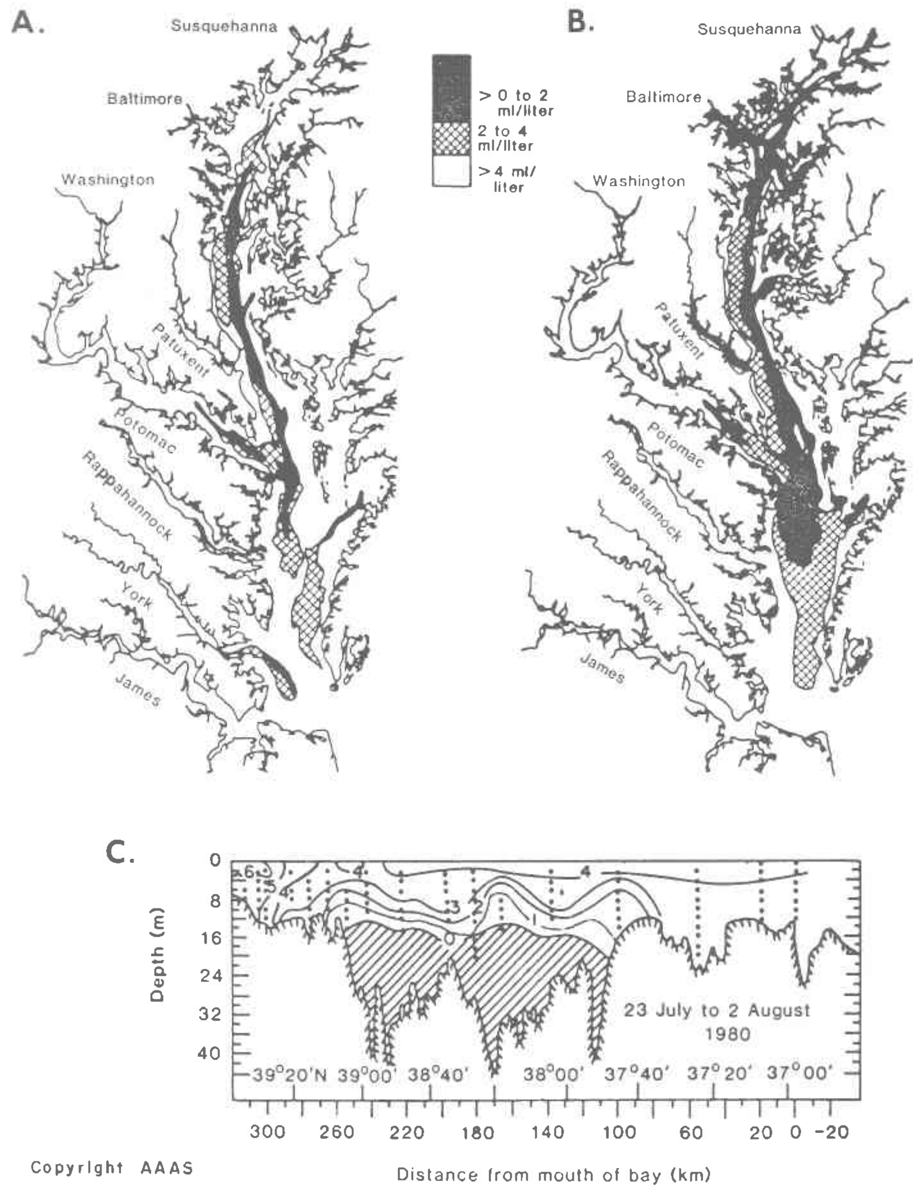

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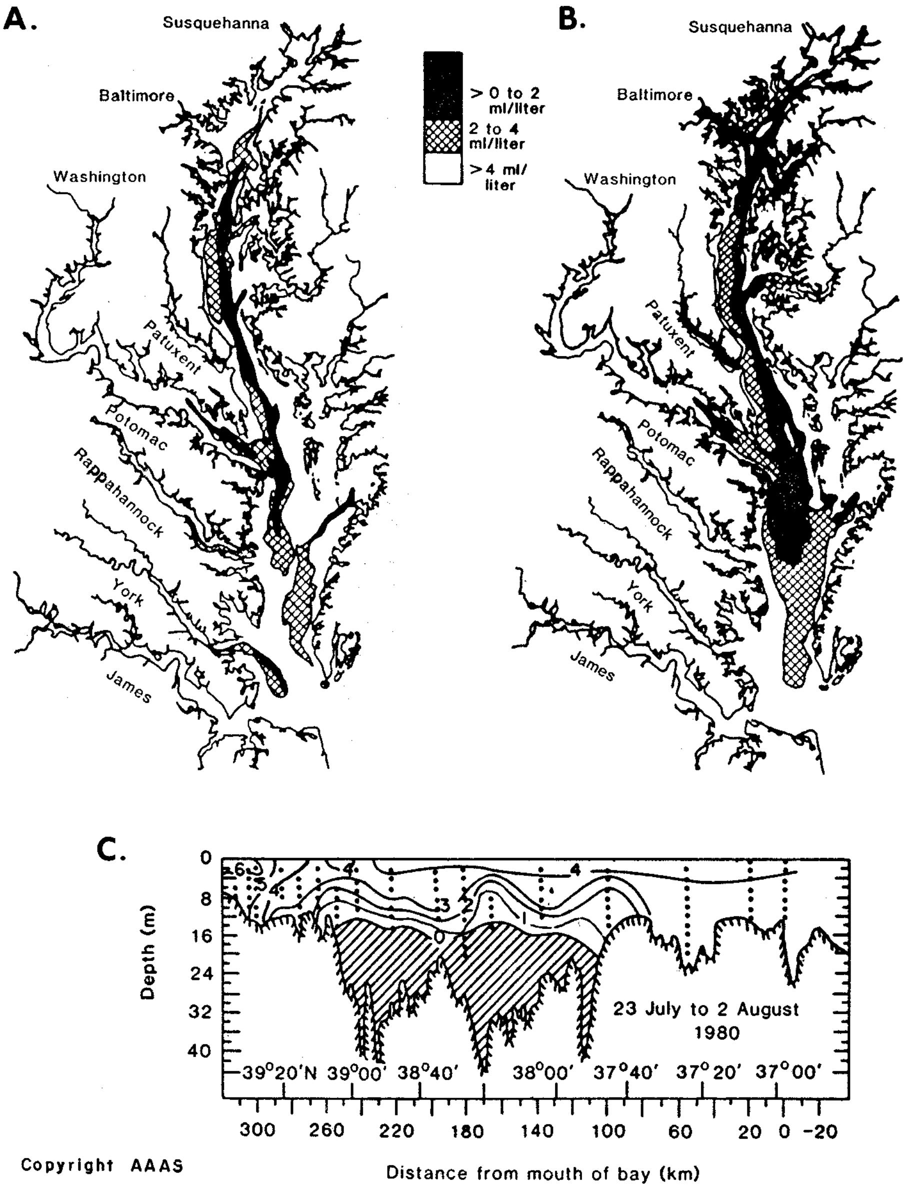

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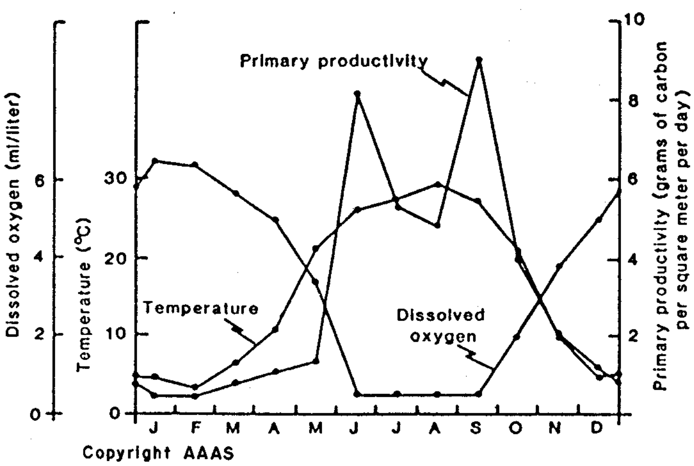

Figure 17. Seasonal changes in temperature, dissolved oxygen, and primary productivity for the Bay midreaches, from Officer and others (1984). The very high yearly production of carbon (the area under the primary productivity curve) results in large measure from the Summer algal peaks.

It has made a limited return locally in the Bay, but it is still absent from the Potomac. Eelgrass might better be called scallop grass, for Bay scallops are completely dependent on it, and production of the species went to zero when stands of the plant (a true grass) failed.

Much of the SAV habitat in the Potomac is today occupied by foreign species. The water chestnut, a food-poor species was introduced into the area in the early 1900's, and until the last few years it was a tenacious pest at former sites of native species. The Eurasian water milfoil, another submerged weed, has also been a major problem in the area. The water chestnut is now largely controlled by underwater mowing and improved water quality, and the milfoil was decimated by a virus in the 1960's, but threatens to return as a pest from tributaries where populations of it remain. In spite of tremendous reductions in these pests, native species have not repopulated the area. At this writing another SAV immigrant, *Hydrillia verticillata*, a species threatening to choke Florida waterways, is taking a strangle hold on areas of the Potomac. Plans to eradicate it are being rapidly made.

The "unprecedented" decline of SAV throughout the Bay is being taken as a major sign of failing health for the ecosystem. The decimation seems to have speeded up in 1972 (Orth and Moore, 1983). SAV is a food for ducks and other waterfowl and for some fishes, and it is a protective habitat for molting crabs and young fishes. It also provides food for a host of plants and animals as detritus, and it locally removes nutrients and sediments from Bay waters. Ten species make up the bulk of the SAV in the Bay—all of them in many places are in marked decline as shown by a number of surveys conducted from 1970 to 1981. Decreases in canvasback and redhead duck populations have been attributed to SAV decline.

The reasons for the progressive and generally severe reduction in SAV populations throughout the Bay are not known: it appears that light attenuation brought about by increases in phytoplankton populations, suspended mud and organic particles and the growth of other forms on the SAV (epiphytes) is a major cause. Increased quantities of nutrients in Bay waters likely affects the growth of the phytoplankton and epiphytes (Orth and Moore, 1983). Herbicide concentrations in Bay waters are thought to be too low to have produced the observed changes (EPA, 1982a, p. 556).

How has pollution affected fisheries in the Bay as a whole?

Finfish: According to a report by Rothschild and others (1981), catches are very much down for the following anadromous species (fresh- water spawners), American shad, river herring and striped bass; and also for two offshore spawners, Atlantic croaker and spot. Harvests were up for much of the 1970's for Atlantic menhaden and weakfish (both are offshore, or marine, spawners). The Bay is a nursery area for many fishes that spawn in the ocean, including the ones just mentioned.

To determine real changes in populations (not to say the reasons for the changes), one must have information on levels of fishing effort and alteration in methods. From available data on these factors, Rothschild and others (1981) and other workers estimate that striped bass stocks and those of the American shad are in a real decline. The decline may be caused by overfishing, climatic factors, and degradation of water quality.

Oysters: Oyster fisheries have been in sharp decline since the late 1800's. Beginning in 1960, MSX (*Minchinia nelsoni*) killed nearly all Bay oysters living in salinities of 15 parts per thousand or more, except for populations on the Eastern Shore. *Dermocystidium marinum*, a fungus, has long been present as an oyster killer in salinities

Table 2. Summary analysis of Bay problem areas. Data from EPA (1983a, p. 129ff; 1983b, Appendix C).

Drainage Basin or Bay Region	Major Problems	Polluting Sources	Recommended Methods of Mitigation
Susquehanna River 27,100 mi²	Loss of, habitat for anadromes, SAV[1], soft crabs, oysters in upper Bay from discharge of toxic substances and nutrients to Bay, especially from the lower basin.	Chiefly cropland runoff: N85%; P60% of areal total.	Apply BMP's[1] to reduce runoff waters containing crop fertilizers; remove or limit phosphorus effluent of new STP's[1].
West Chesapeake area 2,058 mi²	Changes in bottom communities in Patapsco and Back rivers resulting from accumulations of toxicants, and overabundance of nutrients.	Industrial burning of coal and release of waste waters from industrial and municipal sources.	Limit phosphorus discharge from STP's; identify sources of toxicants being discharged; control storm overflows of STP's; other measures.
Eastern shore area 3821 mi²	Some decline in anadromes and SAV because of overabundance of nutrients.	Cropland runoff	Apply BMP's to reduce runoff of waters containing crop fertilizers
Patuxent River 884 mi²	Loss of SAV and changes in bottom communities because of overabundance of nutrients.	STP's	Limit phosphorous and nitrogen discharges from STP's
Potomac River 14,134 mi²	Loss of SAV from upper reaches of estuary and of oysters from lower salinity habitats; swelling growth of nuisance and weed plants and low oxygen levels in water resulting from overabundance of nutrients.	STP's and cropland runoff	Stem phosphorus and nitrogen discharge from STP's and from croplands; prevent storm overflow; other measures.
Rappahannock River 2,631 mi²	Some declines in fish, oysters and SAV populations. Probably not directly related to pollution.	Some signs of nutrient buildup from croplands.	Limit nutrient input of future STP's, and initiate BMP for agricultural lands.
York River 2,986 mi²	Decline of anadromes; some loss of SAV. Probably not directly related to pollution.	Some phosphorus enrichment from croplands and industrial discharges.	Upgrade all primary STP's to secondary systems; insure containment of storm overflow of STP's.
James River 10,195 mi²	Decline of anadromes prior to fishing ban of 1975, of oysters and crabs resulting from accumulations of toxicants including Kepone and heavy metals in the James and PNA's[1] and heavy metals in Elizabeth rivers, and from overabundance of nutrients.	Municipal and industrial discharges.	Construct new STP's and upgrade existing ones, including changing all primary to secondary treatment, identify sources of toxicants being discharged; monitor storm water overflow of STP's; apply BMP to croplands; limit phosphorus discharges.

[1]Abbreviations:
- SAV - submerged aquatic vegetation
- BMP - best management practice; includes use of animal-waste controls, conservation tillage, buffer strips, and diversion of runoff water
- STP - sewage treatment plant
- PNA - polynuclear aromatics

between 12 and 15 ppt. In salinities below about 8 ppt, oysters do not do well and they cannot live at those below 5 ppt; at salinities above about 15 ppt they fall victim to oyster drills and other predators.

The oyster fishery in the Bay is not healthy. A major decline has taken place in Virginia waters since 1960, but production records for Virginia have been fairly constant over this time because of imports from Maryland and the Gulf Coast (Haven and others, 1978); about one-half of the total comes from Maryland where the industry is heavily subsidized. At Virginia processing plants the oysters are shucked, packaged, and shipped north to market. Oystermen buy seed oysters grown in the lower James River from the Commonwealth of Virginia. These are transported to favorable sites leased from the State on the Rappahannock, York, and other rivers of the Bay to be planted and later harvested. The cost of obtaining, transporting, planting, and harvesting the oysters is substantial, and so are the risks. Disease and fresh-water runoff pose the biggest threats to a profitable venture (Figures 18-20). Many oyster producers process crabs and finfish in order to hedge their risks on oysters.

Crabs: The catch of the Bay blue crab (Figure 21) has been rather high since the record year of 1965 but a large sag came in 1977. Catches per unit of effort for crabpots and trotlines are down, but dredge returns are up. Biggs (*in* Officer and others, 1984), in citing crab fishermen, reports that before 1965 there were abundant crabs in waters with depths in excess of 65 feet in areas of the Bay's midreaches; now there are few in waters of that depth. No crabs were caught in some areas where water was deeper than about 15 feet in 1982. Crabs that once hibernated in deep water muds now do so in shallow water sediments—probably because of lowered oxygen content in the deeper waters. There has been no observed declines in crab populations, however.

Rothschild and others (1981) conclude that there are insufficient data to determine the relative and absolute effects of pollution, human population growth or fishing on the status of Bay stocks. Until good data are available on catch per unit effort, it will be difficult to evaluate the possible causes for declining yields, and management policies should be on the conservative side.

Are heavy metals in Bay sediments a major threat to the health of the Bay?

Several lines of evidence indicate that Bay sediments north of Baltimore and near it, and in parts of the Potomac, Rappahannock, and James river estuaries are enriched with regard to several heavy metals known to be toxic to various organisms (Figure 10). The Elizabeth River is also heavily contaminated. The metals include especially arsenic, cadmium, chromium, copper, manganese, nickel, lead, tin, and zinc. Sources of these metals are assuredly from industrial and municipal waste waters. Similarity of ratios between metals, lead to iron, for example, from various stations throughout the upper Bay has been used by Harris and others (1980) to show source of metals and migration of sediments containing them in the area of Baltimore Harbor. Sinex and Helz (1981) showed

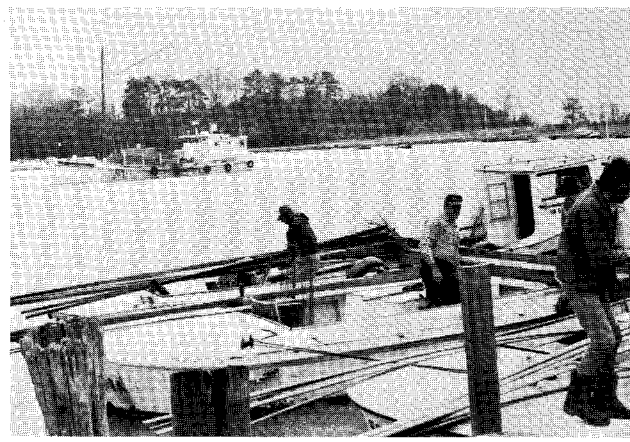

Figure 18. Seed oysters coming in from the lower James River estuary to the State dock on Deep Creek in Newport News. Oyster tongers harvest seed oysters on State-owned grounds. The seed are then sold to private concerns and are planted on lands leased from the State. Mature oysters are harvested two or three years later.

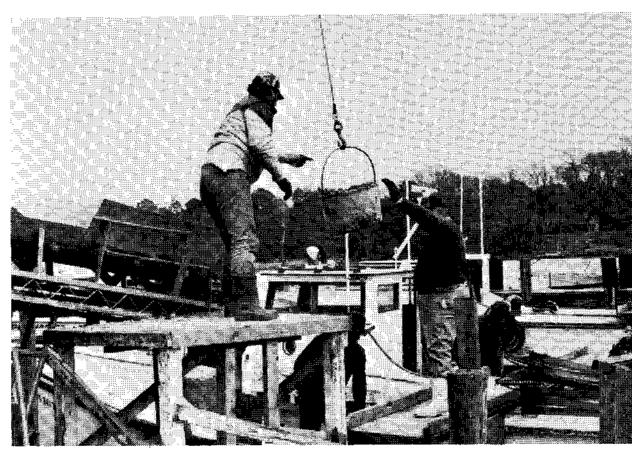

Figure 19. "Soup oysters" being loaded into refrigerated trucks at Deep Creek. Their destination is mainly local processing plants.

the Susquehanna River to be a source of abnormal concentrations of metals. Cores of bottom sediments show that contamination began as early as 1890 as indicated by analyses of mud lying some 20 inches below the top of the cored sediment.

The method of ensnarement of these metals by sediments is not fully known, and the process is complicated by the mutual association of mud, naturally occurring organic materials, and metals (Lu and Chen, 1977, and Knezevic and Chen, 1977). Metals dissolved in the water may be adsorbed or otherwise attached to clay minerals in contact with of Virginia. These are transported to favorable sites leased from the State on the Rappahannock, York, and other rivers of the Bay to be planted and later harvested. The cost of obtaining, transporting, planting, and harvesting the oysters is substantial, and so are the risks. Disease and fresh-water runoff pose the biggest threats to a profitable venture (Figures 18-20). Many oyster producers process crabs and finfish in order to hedge their risks on oysters.

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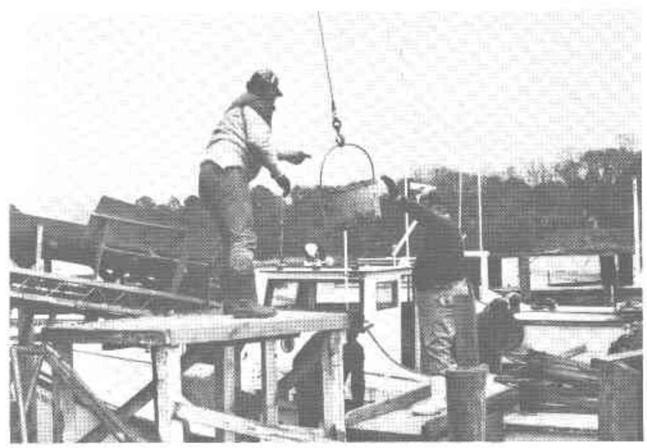

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Figure 20. Two Virginia Marine Resources Commission patrol vessels. Virginia regulates its commercial fishing industries, licences commercial harvesting, and enforces the laws relating to fisheries and habitat management.

Figure 21. Bushels of blue crabs at the mouth of the York River being loaded on trucks for market in Baltimore.

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Not much is known about release of the metals from the sediments, including the organic detritus. The water column above or adjacent to areas with sediments containing relatively high metal contents generally is not enriched in dissolved metals. The exchange between sediments and water depends greatly on the chemistry of contacting waters. It is certain that phosphorus is released from black, anoxic sediments in the Bay during Summer months (Taft and others, 1980).

Detailed analyses of the changing rates of accumulation of metals in Bay sediments have not been made. Locally, rates of sedimentation are know from determination of lead-210 content, which has a "constant" atmospheric source (Schubel and Hirschberg, 1977). Lead-210 has a half life of 21 years—short enough to date historic times. This dating method is only good where the sediments have not been mixed or turned over by burrowing worms or other biological or physical processes. This limits application of the method to black muds. Not many samples have thus far been analyzed.

Because man-made or man-concentrated organic compounds are also attached to clay minerals and to organic detritus, their distributions are similar to that of heavy metals (Figure 10). Polynuclear aromatic compounds (PNA's) which are formed and released during the burning of coal, wood, oil and gas, are the most widespread and most concentrated organic materials in the Bay (EPA, 1982a, p. 314). The combined effect of the metals and synthetic organic compounds can be devastating to many species of benthic life. Laboratory studies (bioassays) on amphipods (Crustaceans) in contaminated sediments from the Bay showed 90 percent mortality for the species in samples from the Patapsco and Elizabeth rivers, and from the upper Bay from Baltimore north to the mouth of the Susquehanna River (EPA, 1982a, p. 342). The Patapsco River is a major source of PNA's, as is the Susquehanna. The Patapsco and Baltimore Harbor are very much contaminated with these compounds. The general observation that the number of benthic species is very low in areas of highly contaminated sediment is also evidence of the damage to life of extraneous substances.

In recent studies, Bieri and others (1982) used gas chromatography and the mass spectrometer to identify 310 artificial organic compounds in surface sediments of the Elizabeth River. About 40 percent of the total weight of the organics was contributed by polynuclear aromatics (PNA's), whose major source is the burning of coal and hydrocarbons. A headward source for the contaminants is indicated.

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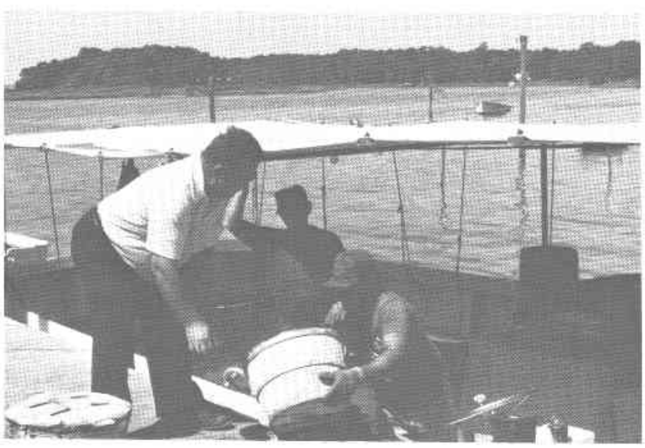

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The Elizabeth River is seriously contaminated by sewage and industrial outfall; heavy metals are abundant in the River's sediments. Shellfish harvesting for direct marketing (without placing them in pure water for self cleansing of coliform bacteria) in the River has been closed since 1925. Bioassays using the grass shrimp have shown the sediments to be lethally contaminated (Gilinsky and others, 1983).

Are organic contaminants a threat to the Bay?

Not much appears to have been done on pesticides in Bay waters or sediments. Herbicides were once thought to be an active agent in causing the decline of SAV in the Bay, but other factors including changes in available light are now judged to be more significant (EPA, 1982a).

Some pesticides, including the chlorinated hydrocarbons such as DDT and aldrin are quite insoluble in water and tend to accumulate in muddy sediments. Many herbicides are highly soluble in water and organophosphate insecticides are somewhat soluble; both of these types of compounds are also adsorbed on clay particles (Li, 1977?, p. 453). DDT and aldrin are among the most widespread synthetic organic materials in the aqueous environment. These, and most other insecticides, all of which are poisons, may be greatly concentrated as they move toward the top of the ecological pyramid—from herbivore to grazer and from prey to predator. Algae will concentrate dieldrin (a derivative of aldrin) to 30,000 times its value in their water (Li, 1977?, p. 459).

The bitter story of Kepone contamination in the James River estuary is well known. A recent survey of the water and sediments of the zone showed that contamination is still a serious threat to aquatic life there (Lunsford and others, 1980). Some hundred tons of Kepone, an insecticide manufactured at Hopewell from 1966 to 1975, were released to the environment. Much of it is in the sediments of the James River; most is in the area of the estuary from the source near Hopewell to the lower part of the turbidity maximum at Jamestown Island. Water column concentrations of the substance are relatively low. Kepone is immiscible with water, and concentrations in bottom waters are not significantly higher than in surface waters. Concentrations from Hopewell to the River mouth are 0.02 micrograms per liter or more. Maximum concentration in the water is reached from July to September, evidently as the result of assimilation in phytoplankton. When these algae are filtered from the water before chemical testing, recorded concentrations are lower than when the water is not so treated.

All commercial and sport fishing in the affected part of the River has been banned since 1975, except for oysters, shad, herring, and catfish. Female blue crabs also can be taken. All these animals, except oysters, spend a part of each year in offshore waters.

Kepone is somewhat associated with silt and clay and strongly associated with organic content of sediments (Lunsford and others, 1980; Nichols and Cutshall, 1981). The contaminant is detectable as far down stream as the Hampton Roads Bridge-Tunnel. The highest concentrations in the sediments are from 30-48 miles above the mouth of the River at the turbidity maximum. Most is in the upper 7-8 inches of sediment.

What are some other pollutants in the Bay?

Chlorine is certainly a major concern. It is used as a disinfectant at sewage treatment plants and as an antifouling agent in cooling water conduits in electric power generators on the Bay. Free chlorine (an oxidant) reacts with water to form another oxidant, hypochlorous acid (HOCl), and with organic compounds to form toxic and long lasting chloramines. Because chlorine is a disinfectant, it is not surprising that its use reduces productivity in treated waters. Items in the *Chesapeake Bay Foundation News* (1982a, 1982b) called for lower tolerances in sewage treatment discharge waters entering the Bay. The current range in Virginia is 1.5 to 2.5 mg/l residual chlorine in shellfish waters. Large fish kills in the James River estuary in 1973 were attributed to chlorine and associated compounds fed in by municipal waste water (Davis and Middaugh, 1977?). Chlorine is implicated in or known to cause many large fish kills (Kelly, 1974). Kelly reviewed alternatives to chlorine disinfection including the use of ozone and ultraviolet radiation.

Spills of petroleum and its products are a potential threat because of the substantial traffic of tankers at Baltimore and Hampton Roads. A major oil spill occurred in the Bay in 1976 when a barge sank near the mouth of the Potomac River. The barge was being towed from a refinery at the mouth of the York River to Baltimore. Some 250,000 gallons of No. 6 oil were released. Damage to waterfowl was substantial, but because of the cleanup, other damage to wild life, including salt marshes, was judged to be minor (Roland and others, 1977 and Hershner and Moore, 1977).

Recently, a reported 1500 gallons of crude oil were spilled into the James River, serving as a reminder of this constant threat to the Bay area.

What effect does dredging have on the Bay? How about power plants?

The major problems with channel deepening in estuaries are technical ones: where to put the spoil and how to keep the channel from refilling. Methods of spoil disposal include piling it alongside the channel (with or without dikes to keep it there), or piling it on land or taking it offshore. Materials dredged from Lynnhaven Harbor near Norfolk are being trucked south to Virginia Beach as one of several measures being used to replenish the eroding beach there. Burial of organisms by spoil and release of material from spoil plumes are not generally considered to have large environmental impacts. Concentrations of suspended sediments in disposal areas may not be much greater than those occurring naturally during storms or tidal excusions (Schubel and Meade, 1977?). Disposal in deep Bay water is perhaps the best solution (U. S. Army Corps of Engineers, 1981, p. K24). Scattering of highly contaminated sediments could conceivably cause problems and so could reentry of the polluting substances into the water mass. Some study has been done on leaching of the contaminated sediments. The effects of leaching are not large (U. S. Army Corps of Engineers, 1981, p. K. 2). Certainly, dredged sediments should not be piled atop plants in productive salt marshes.

Increased water depth in the channel results in a lowered base level of deposition which causes filling by sediments. Materials along the channel sides are subject to more vigorous current and wave action than they were before dredging. Attack on shorelines and cliffs could become more pronounced as a consequence of bottom reshaping—a response to the shifting sands at work to fill the dredged channel. In addition, the saltwater front will move further upstream in response to the deepening, and bottom filling will begin at its head. As filling proceeds, the turbidity maximum will move seaward and rapid filling follows its path (Schubel and Meade, 1977?). Generally, much of the fill material is that which was dredged. In short, dredging is expensive and its effects temporary; it needs to be continuous to be effective. Salt marshes and SAV tend to slow down general erosion.

Channel deepening could possibly have ill effects on groundwater: it could lead to salt water ingression, and it could lead to fresh-water drawdown in aquifers exposed by dredging. Either or both, in the sequence drawdown-ingression, could result from intersection of an aquifer. Increased exchange in either direction would depend on hydrostatic head. In the proposed deepening of the Chesapeake Bay by the U. S. Army Corps of Engineers as authorized by Congress (1970 River and Harbor Act, P. L. 91-611), the possibility of saltwater ingression is considered; they conclude that little additional ingression would result from the project (U. S. Army Corps of Engineers, 1981, p. K30, K31).

The Corps' plans for deepening shipping channels in the Bay are set forward in its publication, *Main Report and Environmental Statement, Baltimore Harbor and Channels, Maryland and Virginia, 1981.* The project calls for dredging about 54 miles of the Bay (29 miles in Virginia) to reach a depth of 50 feet below sea level. Proposed widths of channels range from 600 to 1800 feet. Cost is estimated at $301.5 million. Even the newly constructed Dominion Terminal in Newport News, which began operation in March 1984, cannot accommodate today's largest colliers. At present Japanese supertransport ships, for example, must top off their loads in South Africa. The 45-foot-deep channel of the lower Bay, which is the dredged depth, is too shallow to allow a fully loaded coal ship to pass.

There were 22 power plants using Bay water for cooling and thereby for condensing steam in 1972 (U. S. Army Corps of Engineers, 1978?). Potential harm to organisms from this operation includes injury from their entrainment in the intake water, their being poisoned by chlorine used to keep pipes free from fouling, their being overheated by discharge waters, and possibly their being poisoned by contaminants released by the chlorine-induced oxidation of polluted sediments (Mihursky, 1977?). Thermal effects of discharged water in once-through plants are not considered to be serious (Jensen, 1977?). General effects on biota are measurable but not large. Changes in types and numbers of species were observed to occur as far as 1300 feet beyond the discharge point of water issuing from the Yorktown steam electric generating station on the York River estuary (Warinner and Brehmer, 1966). And whereas the impacts of such operations are local and not generally significant at present, increased demands for electricity could enlarge the combined effect. This trend resulting from population growth is offset by better plant designs (Mihursky, 1977?), and the possibility of the discontinuance of the use of chlorine in them.

What are the immediate plans of the State for attacking the Bay's problems?

The Virginia General Assembly in its 1984 session appropriated $10.4 million toward improving the condition of the Bay for the 1984-86 biennium, $4.4 million more than was proposed by Governor Robb (Table 3). These initiatives establish projects to stem the inflow of sediments from agricultural lands and of nutrients from agricultural lands and sewage treatment plants (STP's), to decrease or eliminate the discharge of chlorine, toxic metals, and pesticides, to continue the gathering of data on all parts of the Bay ecosystem including its fisheries, and to educate the State's citizens on the Bay's problems and the progress of the State's programs in dealing with these problems. In addition $2.9 million was appropriated for increasing activities in Bay related programs. A ten-year Virginia plan for the Bay calls for spending an additional $150 million to "save" the Bay.

SUMMARY

The Chesapeake Bay with a length of 200 miles and a surface area of 4,410 square miles is one of the world's largest estuaries. The Bay is the home of two of the world's busiest ports, Hamptom Roads and Baltimore Harbor. Hampton Roads is mainly an export center, and it ranked first in the United States in export tonnage in 1982. The marine terminals are at Newport News (James River mouth) and at Norfolk, Portsmouth, and Chesapeake (all adjacent to the Elizabeth River). Virginia ports account for some 8.8 percent of all United States foreign trade tonnage; the State's export was 69 million tons in 1982. Major exports are bituminous coal, for which Virginia leads the nation, and agricultural products, chiefly corn, wheat, soybeans, and tobacco leaf. Imports are mainly petroleum products, gypsum, lumber and wood products, and chemicals.

Baltimore Harbor, on the Patapsco River, is largely the site of imports, which include iron and other metallic ores and concentrates, petroleum and petroleum products, gypsum, sugar, salt, iron and steel products, and motor vehicles. Its main exports are coal and grains.

The bustling activity along the Bay's shores and its tributaries, coupled with the concentration of people necessary for carrying out the commerce, has led to the major problems of the Bay. The worst problem is waste water. It comes to the Bay from far away croplands and nearby urban centers. The volume of man-made materials in the waste water entering the Bay is sufficient to make it behave as an aquarium in the sense that its fate is controlled by the people "attending it." In a real sense the Bay is an overly enriched garden, and it is becoming weedy.

Analyses of water uses for the Bay in 1970 (U. S. Army Corps of Engineers, 1978?) showed that industrial (60 percent) and municipal facilities accounted for 95 percent of the use. Among industries, the top ranking ones for gross water use among manufacturers were primarily metals (42 percent), paper (24 percent), chemicals (15 percent), and petroleum (0.1 percent). The total manufacturing use was about 2600 million gallons per day (mgd). Utilities were not treated separately in the report, but figures for 1972 show that power plants withdraw 12,660 million gallons per day, or nearly five times as much as the combined use of the 1970 rate for manufacturers. Little of this was potable water. The concentration of heavy industry on the Bay is evident, as is a concentration of heavy metals (Figure 10).

The volume of municipal waste water increases in proportion to population increase. The population in the Bay area grew from about 7.9 million in 1970 to over 12 million in 1983, an average increase of about 315,000 people per year. The volume of waste water from publicly owned sewage treatment plants on the Bay in Virginia and Maryland was some 787 mgd in 1975. This quantity approaches, and may exceed, the late Summer flow of the James and Potomac rivers, the sites of most of the waste water discharge. Over supply of nutrients and accompanying growth of unwanted, food-poor weed species of phytoplakton and rooted vegetation and the development of oxygen-poor water results from the conditions of concentrated effluent.

It is difficult to assess the changes in production of Bay fisheries in the last 20 years because of alterations in methods of fishing, in the effort expended, and because of shifts in targets of fisherman in part arising from changes in fish populations. Rapid, short term aberrations can result from natural environmental catastrophe (such as hurricanes), from large artificial help (such as planting seed oysters), or from epidemics.

The oyster catch has been in decline since the 1880's and it took a drastic turn downward after 1960 largely because of the onset of MSX disease (Haven and others, 1978). The trend for the period

Table 3. Major Virginia Chesapeake Bay Initiatives for 1984-86 approved by General Assembly in 1984, from draft report of Sept. 9, 1983 by Council on the Environment and from report entitled "Overview of the Chesapeake Bay Plan."

Problem or need	Abatement or Study Process	Effect	Management Program and Lead Agencies	Total 1984-86 Cost
A. Nutrients: Point and Non Point Sources				
1. Runoff carrying nutrients and pesticides from agricultural lands.	Establish buffer zones between crop-growing areas and waterways. Other best management practices.	Slow down eutrophication of Bay waters; decrease quantity of toxic wastes entering Bay.	Grants to 1000 individual farmers (50,350 acres) through Va. Soil and Water Conservation Commission. Educational programs.	$2,500,000[2]
2. a) Discharge of nutrients and microbes from sewer lines, sewage treatment plant overflow and from b) private residences on Bay.	a) Repair sewer lines and interceptor systems[4]; b) install new septic tanks and repair old ones.	Slow rate of eutrophication; prevent closing of oyster grounds.	a) Loans or grants from Va. State Water Control Board (SWCB) to selected facilities on lower James River, and b) loans to some 50 individuals to meet State health regulations in and near lower Rappahannock River and embayment areas of eastern shore.	a) 450,000[1] b) 300,000[1]
3. Discharges of improperly treated sewage from municipalities.	Construct STP's.	As above.	Grants to municipalities from SWCB.	225,000[3]
B. Toxic Compounds				
1. Chlorine discharge by municipal sewage treatment plants (STP's).	Dechlorinate effluents from STP's.	Protect anadromous fish larvae and oyster spat and larvae.	Grants from SWCB to dechlorinate waste water from major STP's on York and Rapphannock rivers and on lower Potomac; dechlorinate 82% of STP effluent on upper James and 25% of Va. input on upper Potomac.	1,700,000[2]
2. Discharge of toxic metals and organic compounds.	Obtain samples of industrial and municipal waste waters to determine content of effluents and compare results to analyses of sediments.[4]	Get information on amount and type of cleanup needed.	Detailed chemical analyses of samples, especially from James and Elizabeth river areas; SWCB is responsible agency.	$350,000[1]
3. Kepone in James River.	a) Study on health effects b) Continue monitoring program.	a) Determine tolerance levels and effects. b) Keep track of movement of the pesticide in the physical and biological systems.	a) Observations on occupationally exposed persons; work on test animals. b) Sample sediment, finfish, and groundwater. SWCB is responsible agency for both programs.	a) 300,000[1] b) 150,000[1]
C. Improved Water Quality				
1. Runoff carrying sediments, nutrients, and toxics.	Establish and implement best management practices to control urban runoff.	Improve water quality.	Grants to municipalities from Va. Soil and Conservation Commission.	750,000[1]
2. Declining water quality, habitats, and resources of Bay.	Continue monitoring of the Bay.	Provide data for assessing changes in Bay ecosystem.	Additional monitoring programs. Responsible agencies are SWCB, Va. Marine Resources Commission, various research institutions, State Health Department.	300,000[1]
3. Declining water quality of James River.	Continue monitoring of stream.	Assess changes and prevent decline.	Additional monitoring by SWCB.	400,000[3]
D. Education				
1. Improve citizen awareness of the Bay and its resources.	Supply information.	Secure future of Bay and wise use of its resources.	a) Grants to private and public institutions to develop educational programs through the Council on the Environment. b) Public announcements by Dept. of Conservation and Economic Development.	a) 250,000[1] b) 40,000[3]
E. Other Programs				
1. Bay management programs.	Fund general research on controls of oyster and finfish populations. Emphasis on toxicants and James and Elizabeth rivers.	Increase biologic populations.	Grants to VIMS through Virginia Sea Grant Consortium. The Council on the Environment is the lead agency.	$1,700,000[3]
2. Coordinated data base for ecosystem.	Continue and add to data base established by EPA.	Facilitate quantitative studies on Bay; reduce overlap in efforts.	Funds to SWCB and to other agencies and to research institutions for equipment, personnel, training.	$300,000[1]
3. Clean-up of selected sites on Bay margins.	Remove trash from salt marshes, etc.	Increase aesthetics and production of areas.	Grants to Youth Conservation Corps from Department of Conservation and Economic Development.	$300,000[3]
4. Continuous fisheries data.	Supply statistics on finfish, shellfish, and bluecrabs and associated fisheries industries.	Wise use of fisheries resources; prevention of over exploitation.	Data compilation and storage by Va. Marine Resources Commission.	$200,000[1]
5. Decline in SAV.	Replant SAV in selected areas on Rappahannock River[4].	Curb sediment movement, and provide food and shelter for various animals.	Funds to Va. Institute of Marine Science (VIMS).	$150,000[2]
6. Synthesis of data.	Assess trends in ecosystem.	Provide guidance for future Bay programs.	Funds to Council on the Environment.	$75,000[1]
			TOTAL	$10,440,000

[1] Governor's initiative unchanged by legislative body
[2] Governor's initiative increased by legislative body
[3] Legislative initiative
[4] Pilot program

1962-1980 is definitely down. Oysters are sedentary and are highly susceptible to untoward conditions of siltation, low oxygen, and toxicants. Yields of blue crabs for the Bay fluctuate widely; catches generally increased from the late 1800's until about 1970. The trend was downward for the 1970's (EPA, 1983a, p. 100) but the catch for 1982 and 1983 were up significantly (Paul Aninnos, personal communication, 1984).

The dockside value of Virginia's fisheries (finfish and shellfish) from the Bay in 1983 was about $28.4 million. Comparisons of Virginia's industries as reported in *Virginia Facts and Figures* (1984) shows the following values: manufacturing—$35.9 billion (1981), tourism—$3 billion, agriculture—$1.8 billion (1983), mineral production—$1.72 billion (1982), forest harvest—$110 million (1982). EPA (1983a) estimates of Baywide harvests for 1980 were (a) shucked oysters—22 million pounds (this figure includes oysters imported, mainly from the Gulf coast, and shucked at Bay processing plants), blue crabs—59 million pounds, finfish—462 million pounds. Menhaden accounted for 96 percent of the finfish catch by weight. By contrast, the industrial catch for an earlier time, 1966-1970, was only 83 percent of the total finfish yield (U. S. Army Corps of Engineers, 1978?, p. 93). In general, fresh-water spawning (anadromous) fish, which include most edible fishes taken in the Bay, have declined.

The great and remarkable resources of the Chesapeake Bay are recognized by us all, and the people of Virginia in concert with those of Maryland and Pennsylvania are hurrying to secure its immediate and long term future as a multipurpose resource. The successful completion of the Virginia initiatives and additional measures over the next several years are required to keep the beauty of the surface waters from becoming the beast below them.

ACKNOWLEDGEMENTS

The following people have been most helpful in my acquiring information and references, and I here extend my warm thanks to them: Susan Barrick and Kay Stubblefield of Virginia Institute of Marine Science; Frances Flanigan, Citizens Program for the Chesapeake Bay, Inc.; Claiborne Jones of the Chesapeake Bay Commission; Larry Minnock and Robert Crooenberghs of the Council on the Environment; Paul Anninos, Virginia Marine Resources Commission; Robert Ellison, University of Virginia, and William Horne, Director, of the Chesapeake Bay Program of the U. S. Environmental Protection Agency. I thank especially Mr. Anninos and Rick Berquist, Virginia Division of Mineral Resources, for reviewing parts of the manuscript.

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