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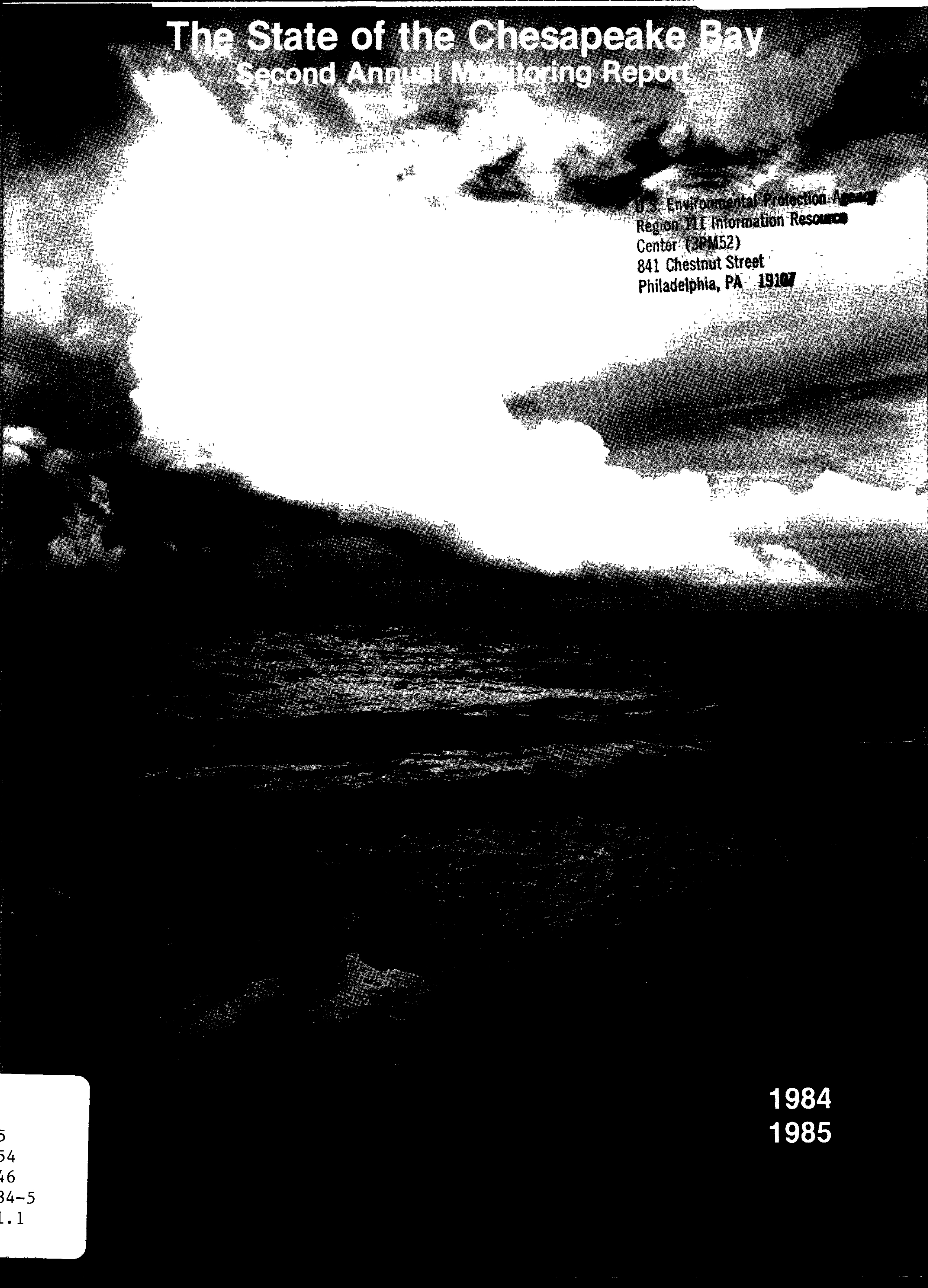
The State of the Chesapeake Bay
Second Annual Monitoring Report



1984
1985

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Monitoring is a key element in restoring the Chesapeake Bay. **Monitoring keeps managers, researchers, and citizens current on the health of the Bay, and measures the progress of control strategies. Under the Chesapeake Bay Agreement of 1983, the Implementation Committee established a Monitoring Subcommittee to develop and implement a Bay-wide coordinated monitoring program. The EPA/state cooperative program began in May, 1984 and a full sampling network was in place on the mainstem Chesapeake by July.**

The Chesapeake Bay Monitoring Network is a complex arrangement involving the federal government, three states (Virginia, Maryland, and Pennsylvania) plus the District of Columbia, three universities, seven private research institutions, and more than 125 individuals. The network is comprised of 167 stations that cover not only the mainstem Bay, but key portions of its 150 tributaries. Nineteen physical, chemical, and biological parameters are being monitored 20 times a year.

Monitoring data can provide a sound scientific basis for making important Bay program decisions. Monitoring data can serve environmental managers in a wide variety of Bay restoration programs--living resources, soil and land conservation, wastewater treatment, computer modeling--and in the legislative process.

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SYMBOLS

cfs	cubic feet per second
DO	dissolved oxygen
mgd	million gallons per day
mg/l	milligrams per liter (=ppm)
N	nitrogen
P	phosphorus
PAHs	polynuclear aromatic hydrocarbons
PCBs	polychlorinated biphenyls
ppb	parts per billion
ppm	parts per million
ppt	parts per thousand
SAV	submerged aquatic vegetation
STP	sewage treatment plant
TN	total nitrogen
TP	total phosphorus
TSS	total suspended solids
µg/l	micrograms per liter (=ppb)
µm	micrometer (=micron)
>	more than
<	less than

GLOSSARY

Algae Simplest of all aquatic plants. Most important Bay algae are the microscopic phytoplankton.

Bacteria Single-celled micro- organisms that usually lack chlorophyll.

Baseline In reference to data, the initial measurements against which later data are compared.

Benthos Plant and animal life whose habitat is the bottom of a sea, lake, or river.

Biomass Quantity (weight) of living matter

Estuary Highly productive bay and river ecosystems where fresh water meets salt water.

Fall line Zone where a major river changes from free-flowing (inland freshwater) to tidally affected (coastal).

Food chain Feeding sequence from plankton through higher predator organisms

Inorganic Combinations of elements (such as metals) that do not include organic carbon; generally non-volatile, not combustible, and not biodegradable.

Monitoring Observing, tracking, or measuring for a special purpose.

Nitrogen Essential nutrient; several forms organic and inorganic (ammonia, nitrate, nitrite); also atmospheric gas. Expressed in mg/l

Nonpoint Applied to pollution source· diffuse rather than point (pipe) discharge, i.e. farm runoff

Nutrient Primary element necessary for the growth of living organisms, generally applied to nitrogen and phosphorus, but also carbon and silicon. Excessive nutrient loads result in eutrophication.

pH Measure of acidity or alkalinity On a 0-14 scale, 7.0 denotes neutrality, less than 7 acidity and over 7 alkalinity.

Phosphorus Essential nutrient that occurs in various forms: inorganic (orthophosphate, pyrophosphate, tripoly- phosphate), and organic

Plankton Minute plants and animals that passively float or weakly swim in water.

Salinity The total amount of dissolved salts per 1,000 units of water (ppt).

Spat Newly attached juvenile oysters

Spawning Reproductive process in fish and other aquatic animals.

Tidal river River under tidal influence with a low saline and upper freshwater reach.

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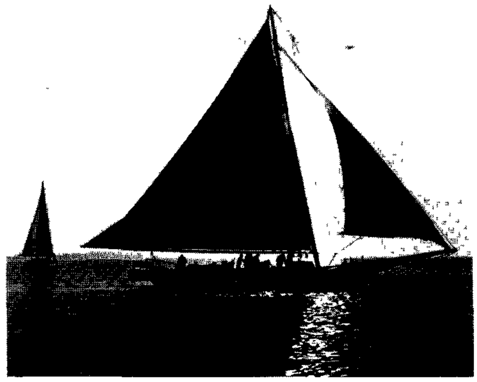


This second report from the Chesapeake Bay Program Monitoring Subcommittee summarizes data collected at over 165 stations Bay-wide for the new coordinated monitoring program from June 1984 through September 1985. This initial effort represents the groundwork of a large, complex, and rapidly growing store of information.

The challenge of the monitoring process should not be over simplified. Because the Bay is so large and complex, it will take an estimated three to five years to sift out the natural variability within a given year and between years in order to achieve a baseline characterization of the Bay, and to understand the slow and subtle changes resulting from management actions. Time and a consistent sampling program are essential to meet monitoring objectives. The major objectives are to determine long-term trends and the driving forces behind them, and to establish the link between water quality and the health of the Bay's living resources. The monitoring program should help to distinguish the effects on the Bay from natural events (like flows and salinities) from man-induced pollutants (such as excessive nutrients). Management actions will become increasingly focused as a result of this knowledge. The new program's comprehensive, in-depth information on Bay processes is already being used to design two water-quality models for the purpose of projecting how restoration programs can achieve improvements in the Bay.

The first part of this report focuses on the physical-chemical characteristics of the Bay: flows, salinity, dissolved oxygen, chlorophyll *a*, and nutrients (the water-quality base) plus sediments and toxics. The centerfold offers a broad capsulated picture of the monitoring network and the 1984-1985 Chesapeake. The second half of the publication covers the Chesapeake's living resources, from plankton, the important first link in the food chain, through submerged aquatic vegetation (SAV), and the Bay's finfish and shellfish harvests. The 1984-1985 data summary concludes with the early results of the citizen monitoring program and a look at the Patuxent River. Background boxes to help define and put the summary observations in context have been provided in each section. We suggest you read the boxes before the main text. Please note that in addition to this 28-page summary report, a more detailed compendium, composed of 19 chapters that focus on different aspects of the monitoring program, is available.

The 1984-1985 monitoring period comprised two very different years, and the Bay responded accordingly. Generally, 1984 was a wet year and 1985 a dry year. Streamflow in 1984 was 23% above average, while in 1985 it was substantially below average for the better part of the year. In November 1985, however, dry conditions were punctuated by tropical storm Juan. Juan's effects were confined, for the most part, to the lower Bay and had less impact than did "Agnes" in 1972. Flooding and sediment loadings were extensive in Virginia's major tributaries. The data indicate that there is some good news to report for SAV, waterfowl, and striped bass. SAV is one of the bellwethers that led to the conclusion that the Bay was in decline. A 26% increase in total SAV acreage from 1984 to 1985 is cause for optimism. This is a hopeful sign for living resources, including the many Bay waterfowl that use SAV as

food and habitat. Many waterfowl species remain in trouble, but the populations of a few species (mallard, bufflehead, and the Canada goose) have increased, presumably due to their finding food sources other than SAV. The Maryland striped bass ban and stringent harvest restrictions in Virginia, the Potomac River, and most coastal Atlantic states appear to be protecting the relatively strong 1982 "rockfish" year-class. When members of this year-class are adults and spawn (in 1988), it is hoped they will have better water quality and that healthier year-classes will result. Generally, during 1984 and 1985 shellfish were still under stress. While higher oyster spatfalls were observed in 1985, survival rates remained low. Harvests of the pugnacious blue-crab were gooc in both years. While mainstem benthic animals suffer as the number of areas with low summer oxygen levels increases, it is possible that wastewater treatment improvements are helping some tributary clams to have more stable populations.

The monitoring results underscore the uniqueness of patterns within each Bay sub-basin, and the importance of Bay-wide inter-relationships. Higher streamflows in 198 brought large pulses of nutrients, which triggered heavy plankton growth, particularly in the upper tidal-fresh reaches of the Potomac and Patuxent rivers. Dry 1985 brough higher salinities and, therefore, less clearly defined surface-to-bottom salinity differences and some improvement in deep-water oxygen conditions. High salinity, while conducive to better oyster spat production, encourages intrusion up-Bay of oyste diseases, MSX and Dermo, and the predatory oyster drill. Higher than usual plankton concentrations were noted during the monitoring period. High productivity appears to result in high levels of unconsumed plankton, which die and settle in deep water wher decomposition processes deplete oxygen. Both summers had periods of low oxygen and anoxia, but the severity and duration of these periods were substantially greater in 1984 than in 1985. Surveys in 1984 found oxygen-poor waters extending further into Virginia's Chesapeake than had been previously documented. Monitoring in both summers revealed that hypoxia and deep-water dissolved oxygen (DO) concentrations are more dynamic than previously expected, a finding that makes trend analysis of DC very difficult. Toxicants data contribute to our understanding of what toxic substance are where, and the relationship among toxicants, fine-grained sediments, and the benthic community. While there have been overall increases in toxics levels since 1979, there is less DDT. Future reports will benefit from a developing toxics strategy and ongoing work to monitor organics and metals.

Has progress been made? While it is still too early to document that our control programs are saving the Bay, it can be said that the 1984-1985 observations are valuable and represent a solid start toward establishing a base-line characterization. The first Bay-wide monitoring network, including nearly every tributary, is in place and is designed to link water-quality monitoring with important habitat and living resource monitoring. Communication and coordination now exist and have improved within and among agencies at all levels. So, while the Bay's problems are still with us, there is cause for modest optimism. Most important, there is a commitment to the Bay-wide goal of restoring the Chesapeake.

The Water Quality Base

Freshwater flows affect water quality because they influence circulation, stratification, and the loading of sediments, nutrients, and other pollutants to the Bay. River flows and stratification in the estuary have important implications for the habitats of living resources, nutrient dynamics, and phytoplankton growth.

Freshwater streamflows and seawater intrusion form two wedges of water going in opposite directions, the lighter (fresher) water flowing on top of the heavier (saltier) water. These wedges create a surface-to-bottom difference in salinity, or a stratification of the Bay.

High river flows increase stratification and inhibit mixing within the water column. Low river flows permit higher estuarine salinities as sea water intrudes further into the Bay system and stratification is reduced. Reduced stratification results in increased vertical mixing, which reoxygenates the water.

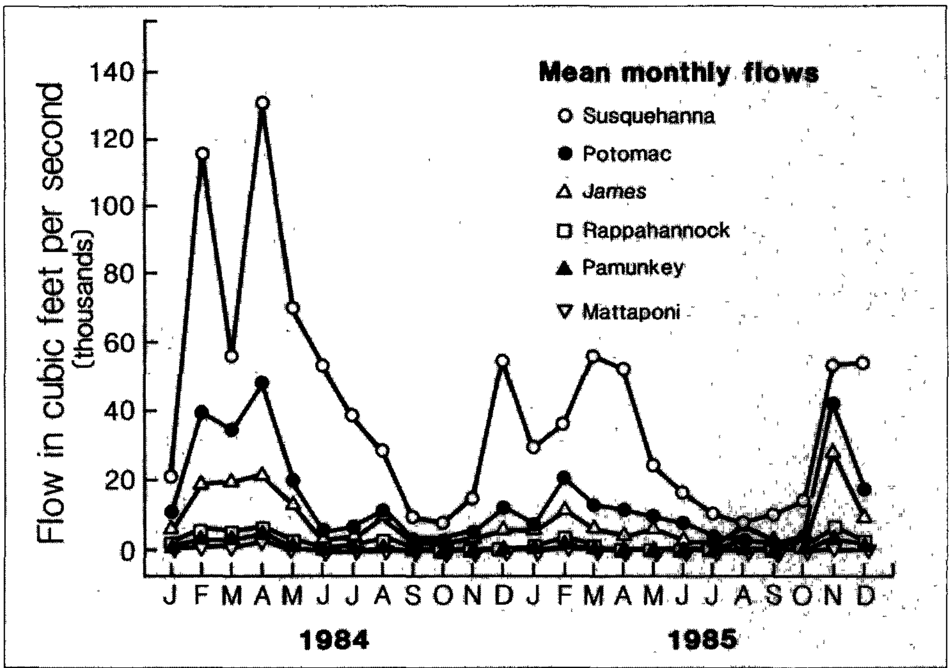
The Bay's living resources have different salinity tolerances. Salinity levels vary vertically and horizontally, and can range from 0 ppt at the head of tide to 25-30 ppt at the Bay's mouth. The waters along the Bay's eastern shore are saltier than western shore waters because of both the greater tributary flows on the western shore and the effect from the earth's rotation. Salinity generally reaches a yearly low in the spring when rainfall, groundwater, and melting snow cause increases in freshwater flows.

Oxygen is required by most living organisms for their basic metabolic processes. It enters the water from the atmosphere, and is also added as a byproduct of plankton and SAV photosynthesis. When dissolved oxygen (DO) levels in water fall below 3-5 mg/l, fish and many other organisms are stressed. Severe oxygen loss will cause mortalities. Hypoxia denotes low DO; anoxia denotes the total absence of DO.

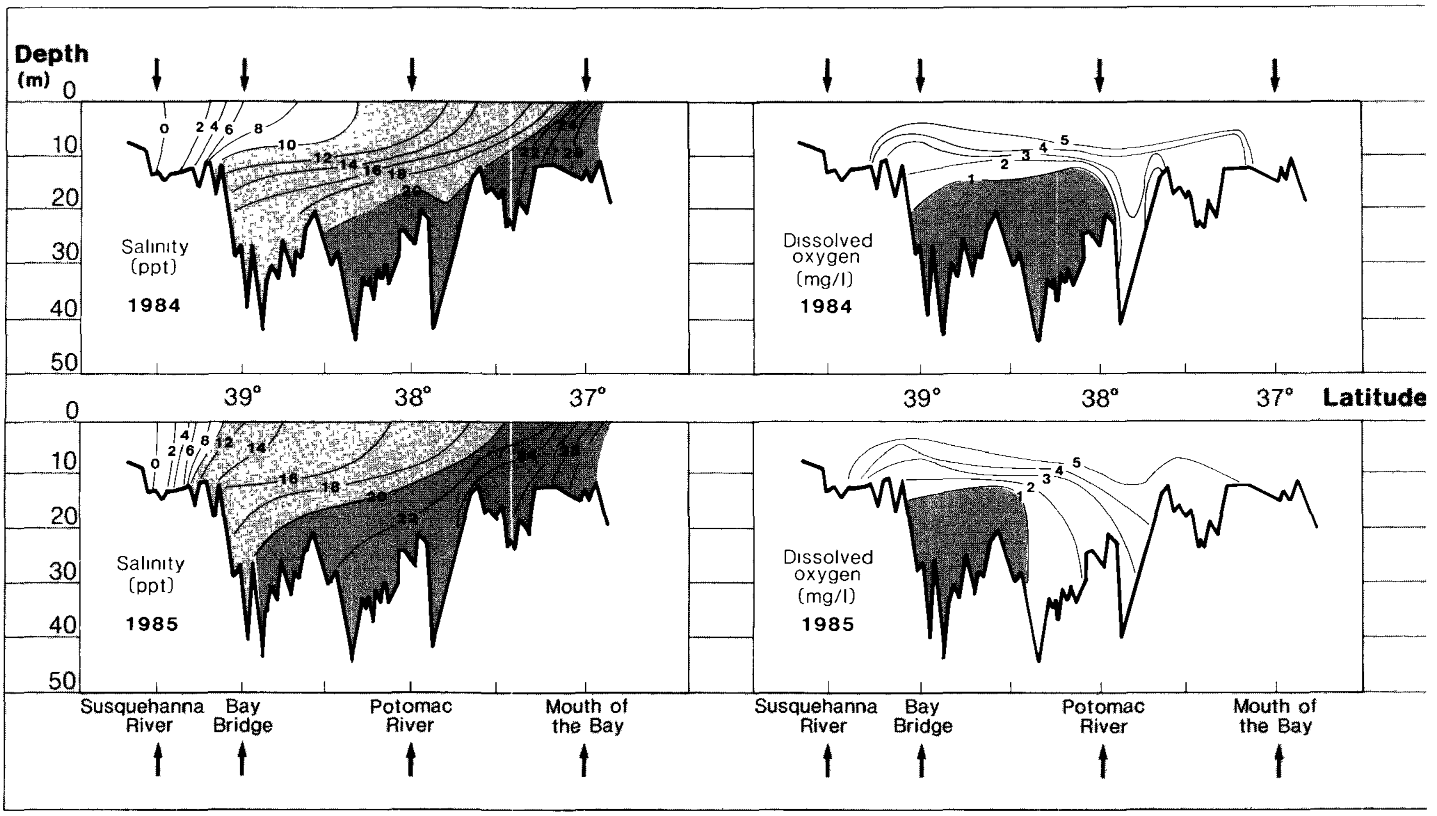
Flows of the major tributaries into the Bay have been monitored for many years by the U.S. Geological Survey. As an indication of the freshwater flow conditions during the first 15 months of the water quality monitoring program, the 1984-1985 flows can be compared to the long-term average flow for the Susquehanna River, which contributes 50% of the fresh water entering the Chesapeake Bay.

Over the past 18 years, the average flow of the Susquehanna River at Conowingo Dam has been 41,950 cfs. The average flows of the Susquehanna in 1984 were 19% above normal; in 1985 they were 27% below normal. There were major seasonal differences between these two years: the 1984 summer flows were much higher than those in 1985. The monthly average flows for the six largest Bay tributaries during 1984 and 1985 are shown below.

River flow patterns in each Bay tributary are unique because rainfall, topography, land use, and other factors differ between basins. For example, Patuxent River 1984 and 1985 flows differed from those of the Susquehanna. Patuxent River flows in 1984 were close to the long-term average as of that year (421 cfs), whereas 1985 flows were 50% below average. The James and Rappahannock rivers, however, experienced higher than normal flows during 1984 (34% and 54%, respectively) because of above-average winter and summer discharge. Between the fall of 1984 and the fall of 1985, the James and Rappahannock rivers experienced dry conditions, with flows 20% and 35% below normal, respectively. In November 1985, tropical storm Juan produced heavy rainfall in western and southern Bay watersheds. While the storm did not have much impact on the Susquehanna, the Potomac and James river basins were profoundly affected by major floods. Because the Bay is so large, a single broad characterization cannot describe the response of an individual sub-basin.



***Freshwater flows into the Bay from these six rivers** represent about 90% of all tributary inputs. Flows in 1984 were substantially higher than in 1985. (Source: Maryland Office of Environmental Programs [MD OEP] and Virginia State Water Control Board [VA SWCB]) Pamunkey and Mattaponi are tributaries to the York River*



Salinity and DO patterns differ from year to year. *The bold line represents the bottom of the mainstem, the thin lines represent either averaged salinity (ppt) or DO (mg/l) values at various depths. Salinity: the lower numbers in high-flow 1984 reveal that much of the Bay experienced lower salinities in 1984 than in 1985. Dissolved oxygen: low DO values were more extensive in high-flow 1984 and were further down-Bay. (Source: MD OEP and VA SWCB)*

Salinities were higher and the vertical salinity gradient was less pronounced in the lower-flow summer of 1985. In the deep-trough region of the mainstem, salinities were higher in 1985 than in 1984: surface salinities were approximately 6 ppt higher and bottom salinities were about 3 ppt higher. Similarly, in the Patuxent estuary, salinities were 4 to 7 ppt higher and stratification was reduced in 1985 compared to 1984. In the Rappahannock River, the same pattern of increased salinity and decreased stratification can be observed for 1985 relative to 1984. Stratification differences between the two summers are reflected in bottom-water oxygen concentrations.

Dissolved oxygen levels are high throughout much of the year, in months when water temperatures are low and the water column is well mixed. In the late spring and summer, however, high oxygen demand in the sediment and the rain of organics into the lower water column, coupled with limited downward mixing of oxygen, cause the depletion of oxygen in deeper waters.

Much has been written about the phenomenon of low dissolved oxygen in the Bay's deep waters. Recent research efforts by numerous investigators are likely to shed additional light on the complex processes that cause, sustain, and interrupt anoxic and hypoxic conditions in this region. The increased temporal and spatial sampling in the current monitoring program is making major contributions to understanding the Bay's oxygen.

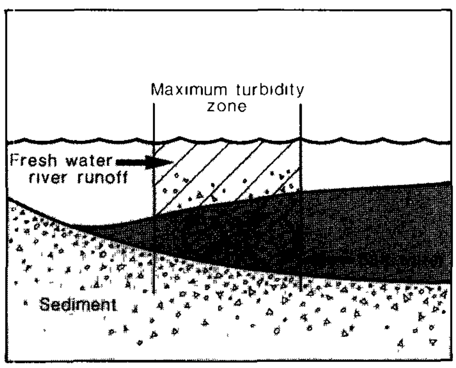
Strongly defined layers of water (stratification) have a significant influence on the DO characteristics of the estuary. Stratification inhibits the mixing of surface and bottom waters, and permits high oxygen demands from sediment and the water column to deplete oxygen in the isolated, deeper water. Higher than average flows resulted in more pronounced vertical salinity gradients in the mainstem in the summer of 1984 than in the summer of 1985.

Stratification *is the layering of the estuary waters: freshwater streamflows and seawater intrusion form two wedges of water going in opposite directions. The lighter (fresher) water flows on top of the heavier (saltier) water. These wedges create surface-to-bottom differences in salinity that significantly influence life and conditions in the Bay.*

Stratification is strongest where the two wedges meet, and when river flows are high. When stratification is strong, there is little mixing between surface and bottom waters.

Stratification is weakest at the sources of the wedges--the rivers and the ocean--and when flows are low. When stratification is weak, vertical mixing in the water column increases.

The maximum turbidity zone is an area where resuspension of bottom sediments is high. It is located at the upstream boundary of the saltwater wedge. (Source: MD OEP and VA SWCB)



Averaged longitudinal DO profiles for the summers of 1984 and 1985 (shown on page 4) demonstrate that high flow permits more extensive regions of low DO. Oxygen conditions for comparable salinity regions in the Bay's mainstem and its major tributaries were similar.

Mainstem

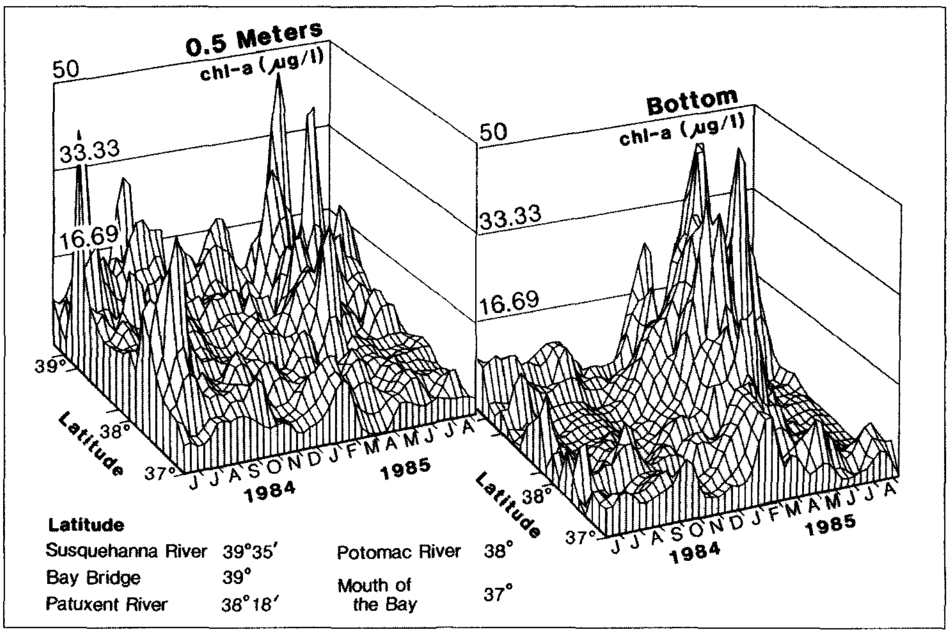
In the mainstem there were several differences between the two years, especially in the spatial extent of hypoxic waters (DO of <1.0 mg/l). In 1984 hypoxic water extended well into Virginia's portion of the Bay, reaching as far south as the mouth of the Rappahannock River. This did not happen in 1985, when winds and tides caused more frequent re-oxygenation events and reduced the duration of anoxic conditions that summer.

The summer 1984-1985 monitoring results have shown that mainstem deep-water dissolved oxygen concentrations are more dynamic than previously expected. Even during the summer of 1984, when density stratification was unusually strong, two major re-aeration events were documented in the deep-trough region, one in early July and one in early August. At least two re-aeration events were also documented during the summer of 1985. This means caution must be used when comparing current data with data from cruises in past years.

Tributaries

In the Rappahannock River the clearly defined stratification in the summer of 1984 appeared to have effects on bottom-water dissolved oxygen concentrations similar to those observed in the mainstem: summer DO depletion was severe and prolonged. In the Patuxent River, on the other hand, the effects on dissolved oxygen levels from the difference in stratification between the summers of 1984 and 1985 were not as clearcut as the effects on the mainstem. The observed differences between oxygen behavior of the Patuxent and that of the Bay indicate that factors other than salinity stratification influence DO conditions. Topography, localized storm events, periodic exchanges with mainstem waters, and the biological impacts of nutrient loadings--conditions unique to each basin--can also affect dissolved oxygen concentrations.

Chlorophylls are a group of green photosynthetic pigments that occur primarily within plant cells. Chlorophyll-*a* is the most important of the principal photosynthetic pigments. It is responsible for the green color in plants. Chlorophyll-*a* provides a measure of phytoplankton biomass levels, and is *expressed in micrograms per liter* (µg/l). Plankton and chlorophyll levels vary in the mainstem and tributaries; levels depend on season, nutrient availability, salinity range, and depth, and are influenced by external physical conditions such as river flow, sediment load, sunlight, and grazing of phytoplankton by zooplankton. As yet, there is no general agreement among scientists on target levels for chlorophyll-*a*. A chlorophyll-*a* level of 100 µg/l is usually cause for concern, however.



***Chlorophyll-a (chl-a) levels** indicate phytoplankton concentrations. These graphics show surface water chl-a peaks near the Bay Bridge and just below the Potomac's mouth during summer 1984 and February-May 1985. In bottom waters, chl-a levels were low in summer, but peaked in the winter/spring of 1985. (Source: MD OEP and VA SWCB)*

Chlorophyll is found at the highest levels in the tidal-fresh portions of the tributaries from spring to early fall. Plankton growth follows tributary enrichment by nutrient-laden spring flows. The mainstem's higher concentrations occur in the late winter and spring. The die-off and settling of this large pool of organic matter probably contributes to the spring oxygen demand in both the water column and sediments; this demand leads to the development of summer deep-trough hypoxia/anoxia in the mainstem.

Tributaries

Chlorophyll patterns in the tributaries were similar in 1984-1985. The highest chlorophyll levels in the tributaries were observed in the warmer seasons above the maximum turbidity zones; in the cooler months the higher chlorophyll levels were found below the maximum turbidity zone. Generally, the nutrient-rich upper reaches of the Patuxent and Potomac had higher chlorophyll concentrations than those of the James or Rappahannock. The Patuxent had the highest chlorophyll levels of all the major tributaries.

The lower Potomac estuary experienced average chlorophyll values of 40 mg/l during spring 1985, with a peak in May of over 90 µg/l. Summer 1985 chlorophyll levels peaked at unwelcome levels of 100 µg/l in the tidal-fresh reaches of both the Patuxent and Potomac rivers.

The peak chlorophyll concentrations in the tidal-fresh regions of the James and

Rappahannock were 20-50 µg/l and 20-40 µg/l, respectively, with levels decreasing downstream to below 10 µg/l near the river mouths.

Mainstem

In general, the upper Bay mainstem had higher chlorophyll levels than those found in the central and lower Bay mainstem; the lowest levels were found at the Bay's mouth. The higher upper mainstem levels are largely the result of the greater availability of nutrients from the Susquehanna River and other upper Bay loadings.

Chlorophyll levels had strong seasonal patterns with pronounced differences between mainstem surface and bottom waters. During the late winter of 1984-1985 and the spring of 1985, a large region of high chlorophyll (30-40 µg/l) was observed in bottom waters. During summer hypoxia, bottom chlorophyll was very low (under 5 µg/l). During summer sporadic peaks of surface phytoplankton growth (30-50 µg/l) could be seen, chiefly in the central and upper Bay. In the lower Bay toward the York River generally surface phytoplankton chlorophyll was low (5-15 µg/l).

Nutrients are a major focus of the Bay restoration program. While light, temperature, plankton grazing, and mixing in the water column play roles in plant productivity, the levels of nitrogen (N) and phosphorus (P) are the key elements in the undesirable Bay over-enrichment.

Nitrogen: Between July 1984 and September 1985, levels of total nitrogen (TN) in mainstem surface waters ranged between 1 and 2 mg/l at the head of the Bay, and from 0.4 to 0.7 mg/l in the lower Bay. The higher upper Bay levels reflect the strong influence of Susquehanna River inputs. In summer months, bottom-water concentrations of inorganic N (and P) are high but surface-water concentrations are generally low.

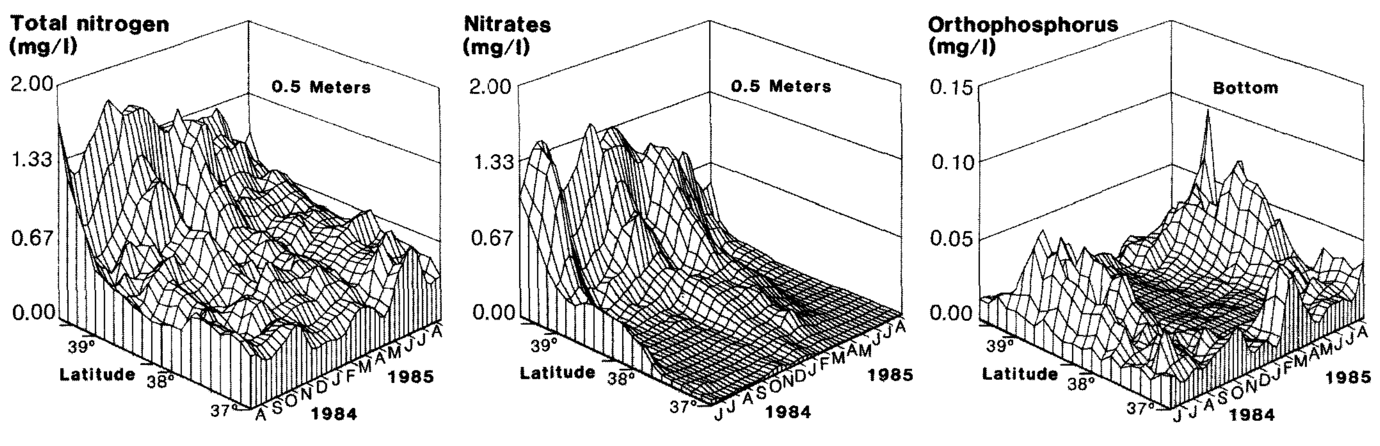
Values of TN were higher (generally at or above 2 mg/l) in the tidal-fresh regions of the Patuxent and Potomac rivers than in the upper Bay mainstem. In the tidal-fresh portions of the Rappahannock and James, however, TN levels were comparable to those found at the mainstem head. In all the tributaries, TN declined somewhat in the salinity transition zones, and declined further in the lower estuaries to levels around 0.5-1.0 mg/l.

The nitrogen enrichment found in the tidal-fresh regions of the tributaries is the result of both nonpoint and point-source impacts. Peaks in N during winter and

Nitrogen (N) and phosphorus (P) are essential to plant photosynthesis and growth. These nutrients are supplied to the Bay from land runoff, the atmosphere, fertilizers and STP discharges. Nonpoint sources supply significant amounts of N (and in some tributaries, P); point sources are the major sources of P.

The Bay and its living resources once assimilated additional nutrients from man's activities, but we have exceeded the Bay's capacity and now have undesirable phytoplankton levels in some areas. The death and decomposition of these algal plants contributes to dissolved-oxygen depletion. Over the last several decades, nutrient levels have increased in many parts of the Bay, particularly in the upper, low-salinity reaches of almost all western tributaries.

Sediment plays a significant role in nutrient transport and deposition, adsorbing both N and P, but primarily P. It is believed that there are large N and P reserves in bottom sediments and that, especially during the warmer months, substantial amounts of these nutrients are released from the sediments back into the water column. Such releases can contribute to algal growth.



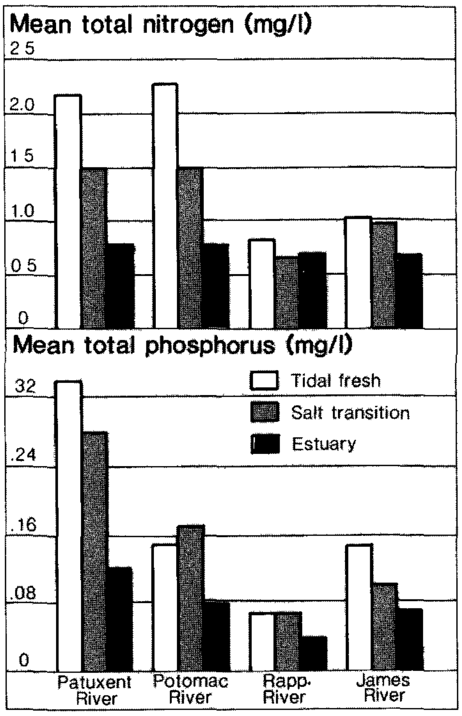
Latitude
Susquehanna River Mouth (39°35′), Bay Bridge (39°), Patuxent River Mouth (38°18′), Potomac River Mouth (38°) Mouth of the Bay (37°)

Nutrient levels *in the mainstem Bay in 1984-1985 are shown in these three graphics. The first two graphics look different, but are similar: the nitrate values shown in the middle make up a large portion of the total nitrogen values shown on the left. Highest nitrogen levels are up-Bay. Phosphate levels on the bottom of the Bay are generally low except during the warm months, when bottom waters become low in oxygen and phosphate is released from the sediments. (Source: MD OEP and VA SWCB)* spring high-flow periods can be attributed primarily to high nonpoint source loads.

Phosphorus: The pattern of total phosphorus (TP) concentrations is similar to that for nitrogen, but not quite as clearly defined. In mainstem surface waters, TP peaked in the turbidity maximum region at about 0.05 to 0.08 mg/l and declined down-Bay to levels generally less than 0.04 mg/l.

During summer hypoxia in the deep-trough region, P fluxes from the sediments into the overlying waters (see pg. 18). As with the bottom-water accumulation of inorganic N, these higher P levels may nourish summer algal populations when and where vertical mixing occurs.

Tributary TP levels in 1984-1985 reveal differences between rivers. The Patuxent River had the highest TP levels of the four major tributaries, with levels in the tidal-fresh, transition, and lower estuarine zones approximately 0.30-0.35, 0.25, and 0.1 mg/l, respectively. The Potomac and James rivers had similar TP levels of approximately 0.15, 0.1-0.2, and 0.05-0.010 mg/l in tidal-fresh, transition, and lower estuarine reaches, respectively. The lowest TP values were found in the Rappahannock River, and were approximately 0.05-0.10, 0.05-0.10 and 0.03-0.05 mg/l in the tidal-fresh, transition, and lower estuarine zones, respectively. TP showed surprisingly little seasonal variation.

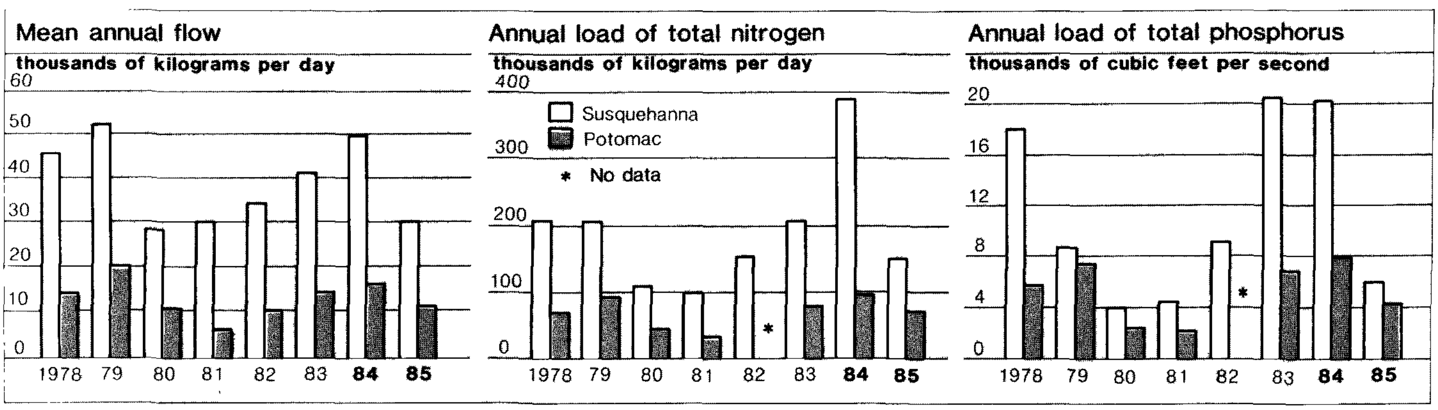


Average total nitrogen and phosphorus concentrations *in four important Bay tributaries, July 1984-September 1985. (Source: MD OEP and VA SWCB)*

The Susquehanna, Potomac and James rivers are the three largest rivers discharging to the Bay. Together these three rivers represent 84% of the freshwater flow. The exact proportion of the total river input load represented by these three rivers must be determined by extrapolation of the monitoring data to cover unmonitored portions of the Chesapeake Bay watershed. Methods of extrapolation range from simple flow-base techniques to sophisticated watershed computer models.

Based on the monitoring data, it is apparent that a simple flow-based extrapolation would not be very accurate. Considering only the flow and nutrient loads for 1984 and 1985 it is clear that, of these three rivers, the Susquehanna was the major contributor of flow and nutrients to the Bay. However, during the monitoring period, the Susquehanna's nutrient loadings (66% TN and 42% TP) were not in proportion to its flow (63%). If a simple flow-based extrapolation were used as an estimate for TP loads for the Susquehanna, a 21% over-estimate would result. Important factors unique to each watershed (topography, soils, land use, population density, etc.) also influence the magnitude of the loads delivered to the estuary and must be taken into account in order to produce an accurate estimate of nutrient loads.

Nevertheless, the strong influence of changing river flows on nutrient loads is clearly evident in both the long-term record of annual loads and in the seasonal loads calculated from the 1984-1985 monitoring data. In years and seasons when river flow is high, nutrient loads are also high. For example, approximately 80% of the flow and nutrient loads delivered to the estuary by the Susquehanna and Potomac in 1984 came in the winter and spring. □



Annual flows and nutrient loadings for the Susquehanna and Potomac rivers *between 1978-1985 are compared above. The Susquehanna is the largest Bay tributary. In 1984-1985, it contributed 63% of the freshwater flows to the Bay, and 66% of TN and 42% of TP. The Potomac's nutrient contributions are proportionately higher than its flows. Approximately 80% of the flows and nutrient loadings delivered to the Bay's mainstem by the Susquehanna and the Potomac in high-flow 1984 were delivered in the spring. (Source: MD OEP and VA SWCB)*

Sediments & Toxics

Measuring Turbidity, or determining the amount of suspended solids in the Bay's water column, is important. Turbidity can indicate conditions detrimental to aquatic life. Two methods used to measure turbidity are: (1) visibility measurement with a Secchi disk; (2) measurement of total suspended solids (TSS). *Higher Secchi depth readings mean lower turbidity; higher TSS values mean higher turbidity.* Measurements by Secchi disk are made by simply lowering the disk into the water and recording the limit of visibility. Bay Secchi depths generally range from over 3 meters (clearer waters in the winter) down to less than 1 meter (over-enriched waters, usually in the summer). In the tributaries and mainstem, Secchi readings can drop to as low as 0.1 meter following storms. TSS is determined by weighing the material filtered from a known volume of water. The American Fisheries Society has recommended a TSS criterion of 100 mg/l (maximum) for the prevention of mortality to fish, zooplankton, and benthic animals.

SEDIMENTS

Mainstem

Monitoring in 1984-1985 confirmed a strong north-to-south turbidity gradient in the mainstem. Generally, turbidity is high in the upper Bay because of the Susquehanna's heavy flows and the turbidity maximum zone; it decreases gradually toward the Potomac's mouth.

The maximum turbidity zone in the Bay proper occurs up-Bay of Baltimore near Aberdeen, Md. Monitoring of this area revealed typically low Secchi depths (between 0.2 and 0.5 meters) and high TSS values (between 15 and 25 mg/l). Turbidity decreases gradually down-Bay, to a point just above the Potomac's mouth. Here the Secchi depths were higher (from 1 to 3 meters) and the TSS values lower (from 5 to 10 mg/l).

In the central Bay, from the Potomac's mouth to that of the Rappahannock, there is sometimes an increase in turbidity. Here the Secchi depths in 1984-1985 were between 0.9 and 2.9, and the TSS values ranged from 10 to 40 mg/l.

From the Rappahannock to the Bay's mouth the waters again become clearer. Here Secchi disk readings ranged from 1 to 3 meters, and TSS values ranged from 5 to 15 mg/l. At the Bay's mouth turbidity is lowest.

Lower Bay western shore waters are generally more turbid than those along the eastern shore: the earth's rotation causes relatively clear oceanic water to be deflected eastward as tidal currents move up-Bay, and substantial quantities of more turbid water are added by the discharges from western Bay tributaries. These show up as localized peaks in the lower Bay in the Secchi depth graphic.

Tributaries

Between their turbidity maximum zones and their confluence with the Bay, the tributaries have turbidity and TSS patterns comparable to those in the Bay proper. Unlike the main Bay, however, tributaries like the Patuxent, Potomac, and James have large stretches of tidal freshwater, where extensive high-turbidity areas can result not only from re-suspended sediment but also from algal blooms.

The Susquehanna's sediment loadings (an average of 1.8 million tons annually) strongly track with river flow and are delivered directly into the mainstem. In wetter periods, typically winter and spring, sediment loads are much higher than in the summer and fall, when flows are generally lower. The Susquehanna is unusual because several reservoirs trap sediment, at least temporarily, and moderate loadings. The result is that the sediment contribution of the Susquehanna River to the Bay is often proportionately lower than its flows.

The Patuxent contributes only 0.5% of the Bay's freshwater flows, but its sediment loadings are proportionately higher than its flows. In the Patuxent's maximum turbidity zone (in the vicinity of Lower Marlboro), spring TSS peaks exceeded 80 mg/l. This high turbidity results not only from loadings, but also from the natural bottom-to-surface mixing in the water column. Secchi depths of 0.2 meters and less were observed in the 1984-85 monitoring period. In the lower Patuxent the waters become comparable to those of the mainstem at its confluence.

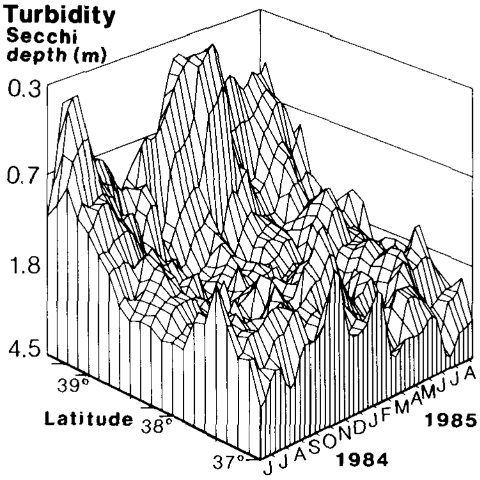
The Potomac is the second largest contributor of freshwater to the Bay but contributes *proportionately* the most sediment to the Chesapeake system. An estimated 1.5 million tons are discharged at the fall line in an average year. Most of this sediment remains in the upper and mid-estuary (there is a small net transport of 1% from the main Bay into the lower Potomac).

The Potomac's sediment loadings in 1984 and 1985 were 22% and 126% higher than average. The higher figure for 1985 reflects the effect of tropical storm Juan: approximately 1,134,000 tons of sediment was discharged from the upper Potomac basin in November alone.

The average Secchi disk readings for the Potomac in Washington, D.C. (where algal blooms also contribute to the river's turbidity), ranged from just over 1.1 meters down to 0.6 meters in 1985. Most of the heavily sediment-laden Anacostia within the District of Columbia had Secchi depth readings less than 0.3 meters.

The share of the total sediment loadings into the Bay from Virginia's James River is 16%. The upper reaches of both the James and the Rappahannock have comparable Secchi depths (0.6 m), and both show a steady decrease in turbidity from their tidal freshwater portions to their mouths. Their lower estuarine zones show a marked difference however. The James carries a heavier load of TSS than the Rappahannock (13.3 mg/l and 5.5 mg/l at the fall line, respectively), and tends to remain turbid longer. The average Secchi reading in the lower James ranges from 0.9 to 1.4 meters, while the readings in the lower Rappahannock generally range from 1.4 to 1.8 meters.

The James and the Rappahannock experienced higher than normal flows in 1984: 34% and 54%, respectively. Between the fall of 1984 and October 1985 both rivers experienced dry conditions. The flow of the James was 20% below normal; the Rappahannock flows were 35% below normal. The James was significantly affected by tropical storm Juan.



Latitude

Susquehanna River	39°35′	Potomac River	38°
Bay Bridge	39°	Mouth of the Bay	37°
Patuxent River	38° 18′		

Secchi depth readings can be converted to a relative measure of turbidity, *or a picture of the lack of water clarity in the Bay. Turbidity can indicate conditions detrimental to aquatic life. This graphic shows the turbidity profile in the Bay's mainstem in 1984 and 1985. The higher values in the graphic indicate higher turbidity (and lower Secchi depths). Shown is how spring high flows affect turbidity, especially in the upper mainstem. Most of the turbid water is near the Bay Bridge in the area of heavy inflows from the Susquehanna and other upper Bay tributaries. The highest turbidity was in the upper Bay during the summer of 1984 and the winter/spring of 1985 during periods of Susquehanna River high flows. (Source: MD OEP and VA SWCB)*

In their never-ending need to reach the sea, the Bay's rivers discharge an average of 2,000 cubic meters of water every second. Long after these waters have left the Bay, the fine-grained, mostly inorganic sediment particles (sand, silt, clay) that they have transported remain, suspended in the Chesapeake's water column or settled on the bottom. The original Bay channels are now roughly half-filled with sediment. Erosion and sedimentation are natural processes, but they have been accelerated by man's activities and now significantly affect the entire food chain.

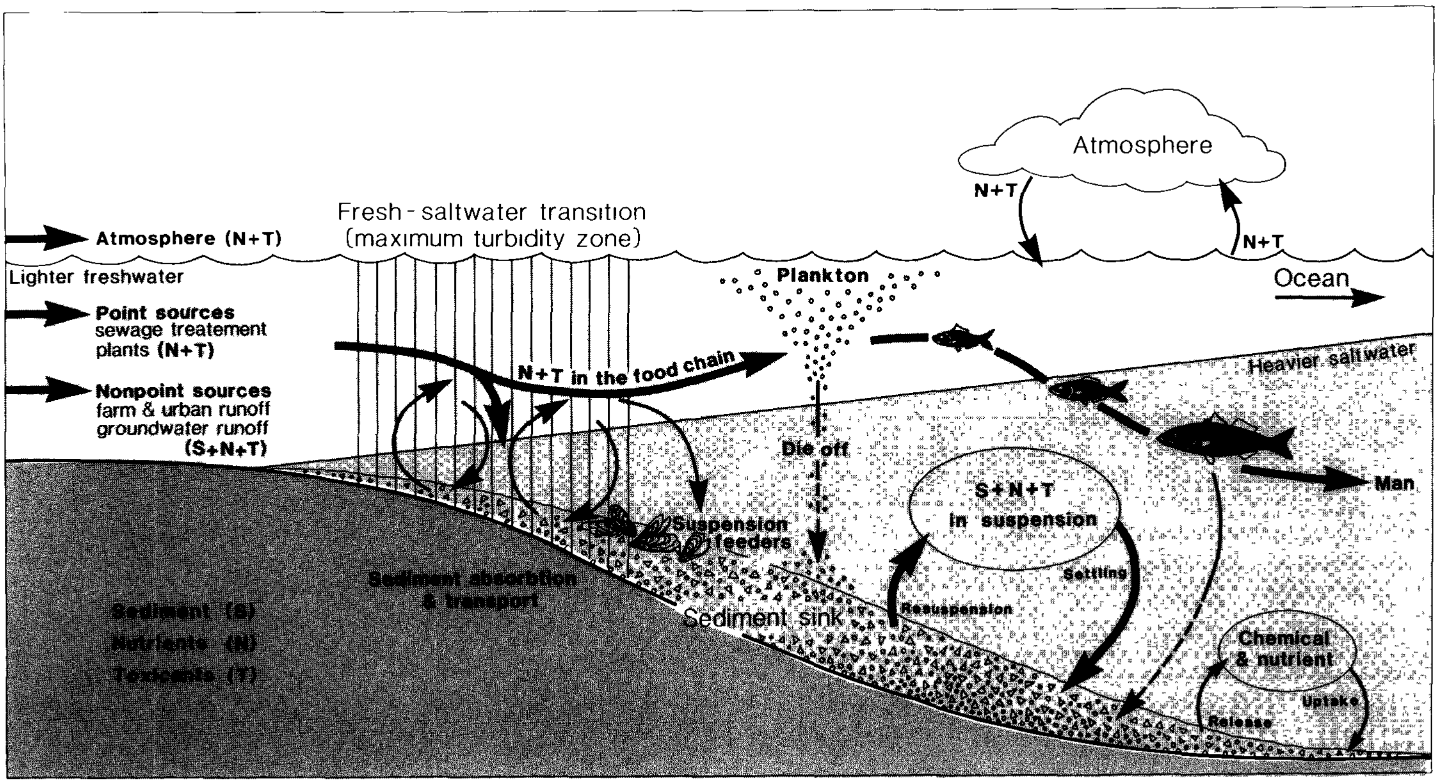
Sediment blocks the light needed for photosynthesis, changes the character of the bottom of the Bay, and carries unwelcome travelers such as excess nutrients and toxic materials.

As mentioned earlier, three tributaries, the Susquehanna, the Potomac, and the James, drain 84% of the total Chesapeake Bay drainage basin. The Susquehanna is the largest contributor of freshwater (50%) to the Bay; the Potomac is the second largest contributor (20%), followed by Virginia's James River (14%).

The annual sediment contributions (at the fall line) from the Susquehanna, Potomac, and James rivers are 40%, 33%, and 16%, respectively. These loadings reveal that the sediment contributions of the three rivers are not in the same proportion as their flows. For example, while the Potomac contributes 20% of the annual flow to the Bay, its sediment loading is 33%.

The flow pattern of each Bay tributary is unique; the sediment loadings of the tributaries vary due to differences in rainfall, topography, land use, and other factors.

Sediment deliveries to the Bay system are highly seasonal in nature. Most of the contributions are transported during high spring flows or tropical storm events. In 1984, for example, the Potomac's riverine sediment loadings were 85% higher from February through May than they were during the following four months. Sediment loadings are also episodic. The lowest recorded monthly sediment load discharged to the Potomac's estuary was 238 tons in the drought year of 1930, whereas 4,160,000 tons were discharged in one month during the 1936 flood.



The complex relationship between sediment, nutrients, and toxics and their pathways *is simplified in this illustration. The atmosphere contributes toxics to the Bay, but the majority of toxics are introduced into the Bay system along with nutrients from both point and nonpoint sources. Sediments, particularly fine-grained sediments, can adsorb, transport, store, and release both toxics and nutrients. Toxics and nutrients can pass up the food chain, be held in suspension, or be stored in bottom sediments for later release. (Source: NOAA/National Status and Trends, MD OEP, VA SWCB and Virginia Institute of Marine Science [VIMS])*

Some 66,000 chemicals are being used in the U.S., of which 60,000 have been classified by EPA as potentially if not definitely hazardous. It is not surprising, therefore, that toxic substances are found in Bay water and sediments. The Chesapeake Bay Program found the levels of both organic compounds and heavy metals to be unnaturally, sometimes alarmingly high, particularly around urban areas such as Baltimore and Norfolk/Hampton Roads. In Patapsco River (Baltimore) sediments, metal concentrations as high as 140 times natural background levels have been found.

While not currently a serious threat, toxicants are being found in the tissue of the Chesapeake's living resources. The compounds of greatest concern are metals such as cadmium, chromium, copper, zinc, lead, nickel; complex organic chemicals such as polychlorinated biphenyls (PCBs), chlordane, Kepone, polyaromatic hydrocarbons (PAHs), and DDT; and other chemicals such as chlorine. Limited studies of ambient levels of highly toxic tributyltin (used in boat anti-fouling paint) began in 1985 at several harbor sites Bay-wide; results are expected by spring of 1987.

Low concentrations of these toxic compounds may have little immediate effect on organisms, but long-term low-dosage exposure is not well understood. Increasingly higher concentrations of toxic compounds cause reduced fish reproduction, deformities, and abnormal behavior; they may exacerbate disease effects and cause eventual mortalities. Toxicants can cause an imbalance in species; they can be accumulated by organisms that reach the family dinner table.

Toxic materials enter the Bay system from a variety of sources–point sources (industrial facilities, sewage treatment, and power plants), and nonpoint sources (urban and agricultural runoff, dump sites, and the atmosphere). The major toxicant "hotspots" in the Bay system are the Elizabeth River and Baltimore Harbor (Patapsco River). The major tributaries also contribute toxic loadings.

The CBP estimated that over 800,000 metric tons of 13 metals enter the Bay from the major tributaries in an average year. The loadings of organic compounds have not been quantified as yet, but over 300 organic compounds have been found in the mainstem Bay. All but a few of these are toxic in some concentration.

TOXICS

Progress has been made in our understanding of the broad distribution of toxic contaminants in the Bay system. The following results from the 1984-1985 benthic monitoring contributed significantly toward that understanding.

Upper Bay Sampling

A total of 26 organic pollutants were detected in sediments and biota (clams and worms) in 1985. Polynuclear aromatic hydrocarbons (PAHs) were the most prominent organic contaminants detected, ranging from 10,000 ppb in Baltimore Harbor to less than 1 ppb at the mouth of the Potomac. The majority of these PAHs were produced by the combustion of carbonaceous fuels. Pesticides were detected in sediments and biota at four of the eight stations sampled. PCBs were detected only in the sediments of Baltimore Harbor.

The average concentrations of the four most abundant trace metals (zinc, chromium, copper, and lead) in sediments and clams in 1985 (and 1986) were analyzed. The analysis revealed that, although high metal concentrations were seen in sediments associated with Baltimore's industrial area, the relationships between sediment/metal and biota/metal concentrations were not consistent. The results showed that in clams some metals varied considerably over the course of the year. Metals such as zinc and copper tended to be higher in clams than in sediments. On the other hand, lead and chromium were higher in sediments than in tissue.

Both clams and worms living in relatively sandy sediments (with low organic carbon) had lower body burdens of organic chemicals than those animals living in sediments low in sand (and high in organic carbon). Since the latter sediments had higher toxicant concentrations, especially in areas near heavy industrial activity, it appears that bioaccumulation depends on both the organic content in sediment and the grain size.

A preliminary picture of how much toxic material exists in the Bay was obtained during the Bay Program's research phase. The new sampling efforts will expand this picture. The ability to interpret long-term trends, and the reason for the deposition of Bay toxicants at various levels, will require understanding of all the other variables that affect levels of pollutants, particularly seasonal and localized variability.

Lower Bay Results

Virginia sampled and examined sediments for organic chemicals at eight stations in the lower Bay in the 1984 and 1985 period. Virginia's approach is to scan for a wide range of possible hyrocarbon toxicants. Hundreds of compounds were detected in some of the samples. As in the upper Bay, the most abundant toxic compounds found were PAHs, but the total PAH concentrations were not excessively high.

The spatial distribution of concentrations appears to reflect both the particle size distribution in the sediments and input from rivers. Coarse-grained sediments found near the mouth of the Bay (CB7.3E, CB8.1E on map) contained low PAH levels. The PAH concentrations were generally higher near river mouths than in the mainstem.

Drawing conclusions for the lower Bay based on a comparison of 1979 and 1984-85 sampling is difficult: (1) the sampling stations, while comparable, are not identical; (2) there are too few stations for an area the size of the lower Bay. However, at this point we can say:

- The 1984-1985 samples show increases in overall toxics concentrations when compared to 1979 samples (detection methods have improved also).
- There is a slight but statistically insignificant decrease in total concentrations in 1985 from 1984 (inferences are guarded since transport of sediment and associated pollutants is dependent upon several variables).
- At Hampton Roads, total PAHs increased about four-fold from 1984 to 1985, a change possibly due to a decrease in sediment size that would increase toxicant adsorption.

The NOAA Status & Trends (NS&T) Program

The National Oceanic & Atmospheric Administration (NOAA) studies the bioaccumulation of toxics in coastal regions nationwide. In the Bay, NOAA focuses on contaminants in sediments and in Atlantic croaker livers and oysters. Preliminary observations follow.

DDT: General use of DDT declined significantly during the late 1960s and was ultimately banned in 1972. Analysis of historical data reflects this decline; oyster body burdens of DDT and DDT metabolites declined steadily from 1965 to 1977. In fish, it is known that many environmental and physiological factors can affect bioaccumulation of DDT. NS&T results indicate sediment DDT concentrations are highly correlated with liver concentrations for Bay Atlantic croaker, which eat benthic animals.

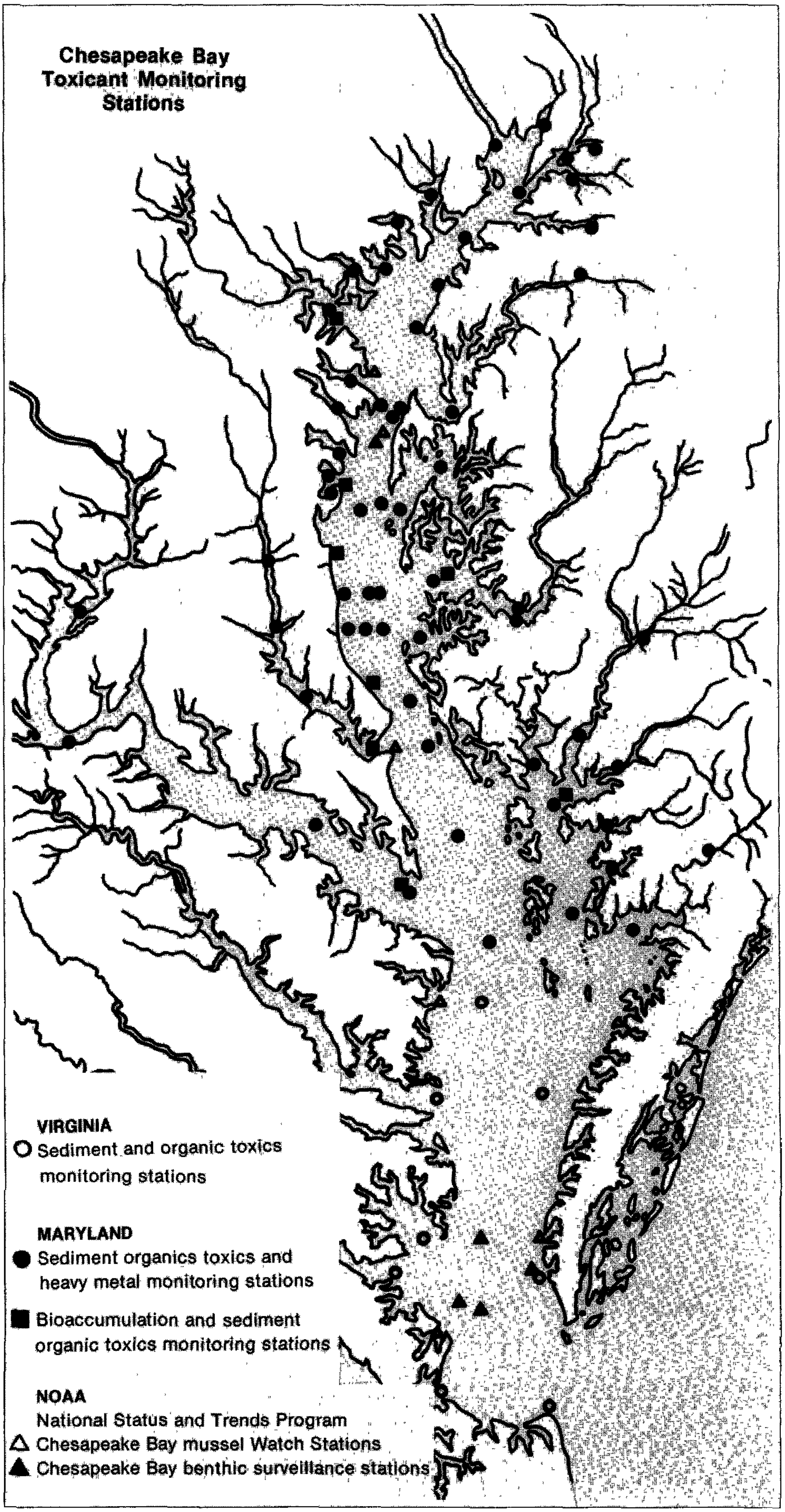
Polynuclear aromatic hydrocarbons (PAHs): Studies elsewhere have associated sediment contamination by PAHs with occurrences of serious histopathological cancers such as cancerous lesions in fish. Although disorders of this kind were not observed in Bay croaker and spot, occurrences of other types of lesions were correlated with concentrations of total PAHs in sediment.

Metals: Sample sites in the upper Bay yielded consistently higher levels of metals in oyster tissue than sites in the central and lower Bay. The relative roles of contamination and natural processes (availability of metals increases in fresh water) have not been determined. □

Sediments bind metals and organics just as they do nutrients, *transporting them to the* Bay system from the rivers and land runoff, and then retaining them on the bottom of the Bay. More than 60% of the total input into the Bay of iron, manganese, nickel, lead, and zinc is held in the bed sediments.

The ability of sediment to bind and store chemicals is related to the size of sediment particles. Fine-grained sediments have a relatively higher surface area per unit mass than do more coarse-grained ones. Therefore, with all other factors being equal, those chemicals that associate with surfaces will be more concentrated in fine-grained sediments. Fine-grained sediments usually contain a higher proportion of naturally occurring organic matter. Thus, chemicals that combine with these natural organics are more abundant in fine-grained sediments. Also, fine-grained sediments have higher concentrations of metals.

The natural variability of the contaminants in the system, seasonal cycling of pollutants within sediments, and the pathways by which these toxics go from sediment to the Bay's living resources are processes not fully understood.



***Monitoring for toxicants** has been conducted at 87 stations along the mainstem of the Chesapeake Bay and in the Maryland tributaries. (Sources: VIMS, MD OEP, and NOAA)*

CHESAP

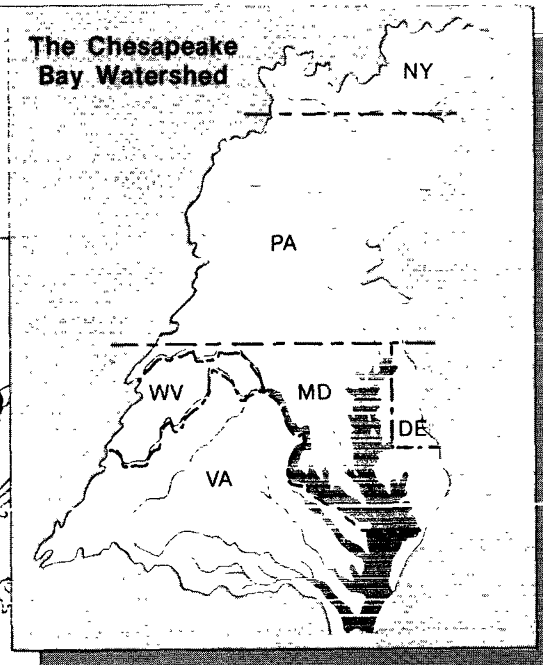
In 1976, Congress directed the Environmental Protection Agency (EPA) to conduct a study of the Chesapeake Bay. Completed in 1983, the study found:

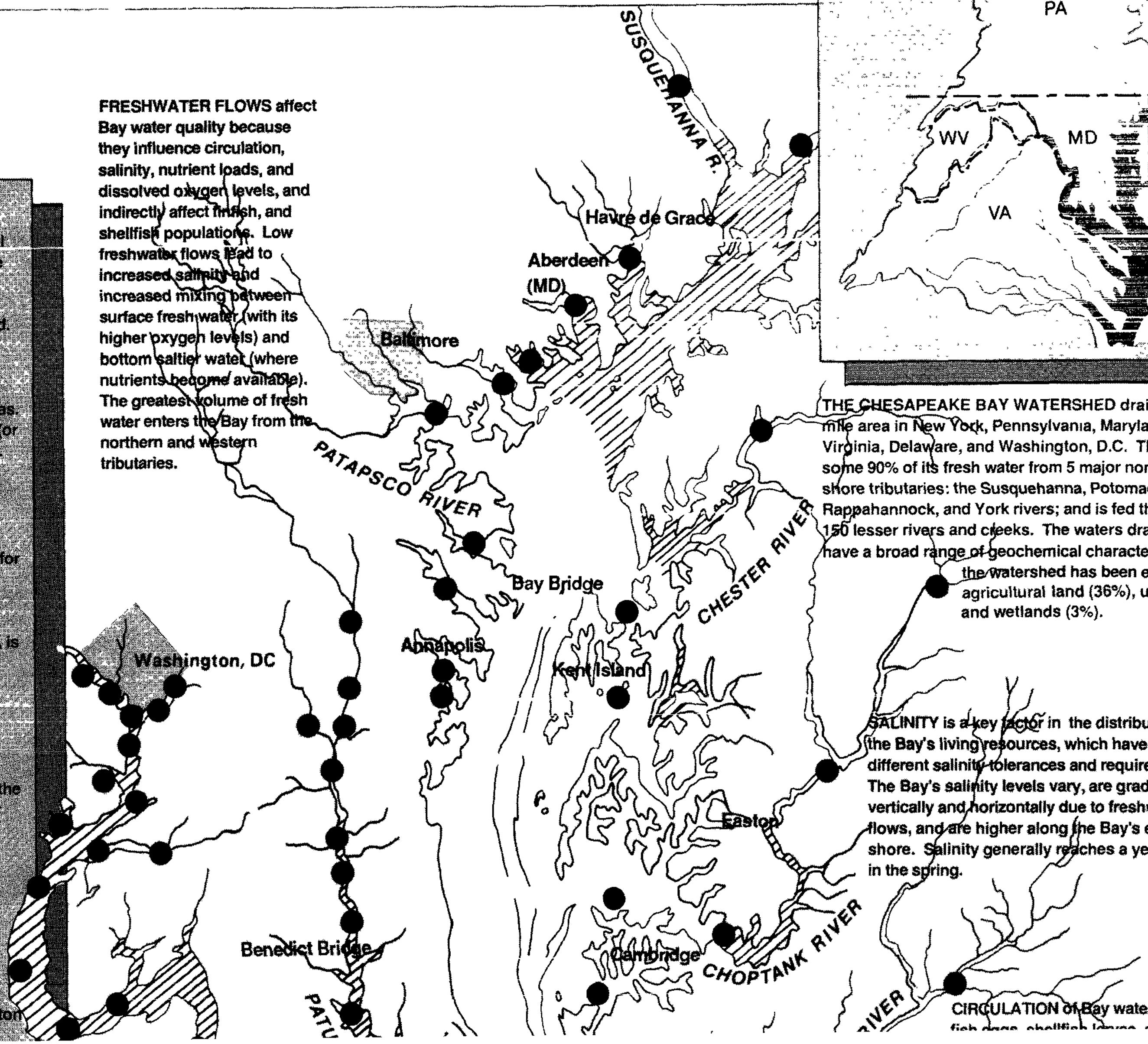
- Bay submerged aquatic vegetation had declined.
- Oyster spat set had declined.
- Landings of freshwater- spawning fish had decreased.
- Levels of nutrients were increasing in many areas.
- The amount of summer Bay water showing low (or no) dissolved oxygen had increased significantly.
- High levels of heavy metals and toxic organic compounds had accumulated in Bay water and sediments.

Bay monitoring collects comprehensive data for a current description of the Bay. Collected over time, monitoring data may reveal trends. The Chesapeake Bay Monitoring Program, begun in 1984 by the Chesapeake Bay Executive Council, is a Bay-wide EPA/state cooperative effort. Comprising over 165 stations, the program combines efforts of Maryland, Pennsylvania, Virginia, the District of Columbia, several federal agencies, 10 institutions, and over 30 scientists. Nineteen physical, chemical, and biological characteristics are monitored 20 times a year in the mainstem Bay and many tributaries. A volunteer citizen monitoring program was started in the summer of 1985.

The following are monitored because they are key indicators of the Bay's health:

NUTRIENTS are a major focus of the Bay restoration program. Levels of nitrogen and phosphorus are the key to excessive phytoplankton growth and decomposition, which depletes





FRESHWATER FLOWS affect Bay water quality because they influence circulation, salinity, nutrient loads, and dissolved oxygen levels, and indirectly affect finfish, and shellfish populations. Low freshwater flows lead to increased salinity and increased mixing between surface freshwater (with its higher oxygen levels) and bottom saltier water (where nutrients become available). The greatest volume of fresh water enters the Bay from the northern and western tributaries.

THE CHESAPEAKE BAY WATERSHED drains a 64,000 square-mile area in New York, Pennsylvania, Maryland, Virginia, West Virginia, Delaware, and Washington, D.C. The Bay receives some 90% of its fresh water from 5 major northern and western shore tributaries: the Susquehanna, Potomac, James, Rappahannock, and York rivers; and is fed the balance by about 150 lesser rivers and creeks. The waters drained by the basin have a broad range of geochemical characteristics. Land use in the watershed has been estimated: forests (54%), agricultural land (36%), urban land (7%), and wetlands (3%).

SALINITY is a key factor in the distribution of the Bay's living resources, which have different salinity tolerances and requirements. The Bay's salinity levels vary, are graduated vertically and horizontally due to freshwater flows, and are higher along the Bay's eastern shore. Salinity generally reaches a yearly low in the spring.

CIRCULATION of Bay waters transports plankton, sediments sink to the bottom, they change the character of the Bay's floor. Sediment is significant in nutrient and toxic transport, deposition, and recyling: sediments adsorb nutrients and bind metals and organics. Sediment deliveries to the Bay system are highly seasonal and unique to each tributary.

TOXICANTS (both organic compounds and heavy metals) have been found in Bay water and sediments at high levels. While not an acute threat, toxicants are present in the tissue of the Bay's living resources. *Toxicants enter the Bay system from a* variety of sources–point sources (industrial facilities, sewage treatment, and power plants), and nonpoint sources (urban and agricultural runoff, dumpsites, and the atmosphere).

PLANKTON are the mostly microscopic plants (phytoplankton) and animals (zooplankton) that drift with the Bay's currents. Phytoplankton are the first link in the food chain, but an overabundance causes imbalances. Zooplankton are usually the prime consumers of phytoplankton and are often critical food for larval, juvenile, and some adult fishes.

BENTHOS, collectively the millions of animals (like worms, oysters, and clams) that live on or burrow in the bottom of the Bay, are good indicators of water quality and are important in the food chain.

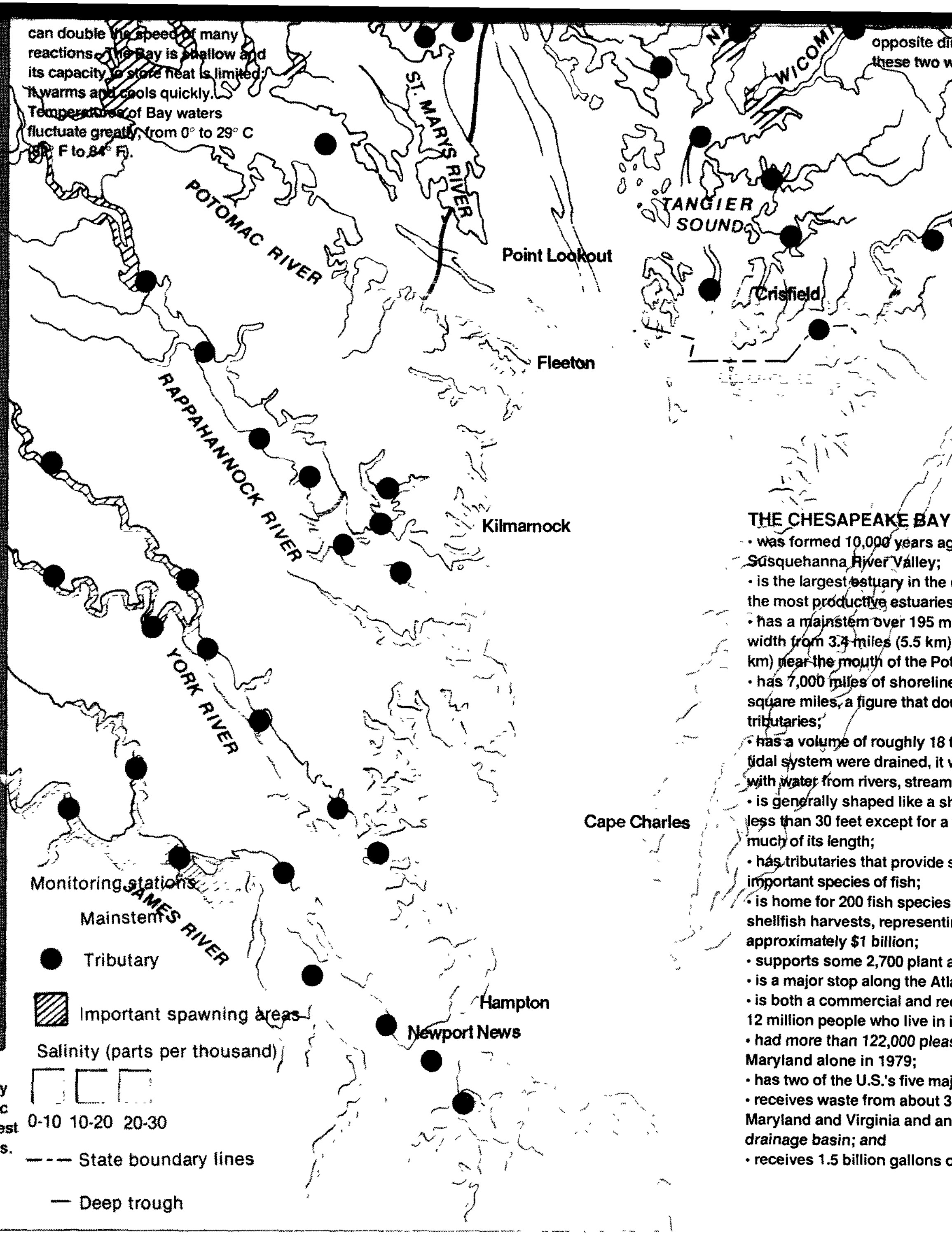
FINFISH AND SHELLFISH are crucial to the Bay ecosystem. Numbers of harvestable anadromous fish have decreased, with continued poor spawning and low abundances of juveniles. Harvests of marine-spawning fish, which depend on the ocean rather than the Bay, are relatively good. Shellfish harvests remain at all-time lows due to poor reproduction and larval survival rates, plus increased demand and harvesting, weather, and disease. Crab harvests remain variable but high.

SUBMERGED AQUATIC VEGETATION (SAV) is a Bay restoration priority due to its place in the food chain (particularly as a food source for waterfowl) and its significance as a habitat and nursery area. The steep SAV decline since the 1960s is believed to be related to man's activities.

can double the speed of many reactions. The Bay is shallow and its capacity to store heat is limited; it warms and cools quickly. Temperatures of Bay waters fluctuate greatly, from 0° to 29° C (32° F to 84° F).

opposite directions. The opposing movement of these two wedges affects circulation.

OXYGEN is required by most living organisms. It enters Bay waters from the atmosphere and as a byproduct of plankton and aquatic plant photosynthesis. Low oxygen (hypoxia) or no dissolved oxygen (anoxia) will stress or kill fish and other organisms. Surface water is at or near saturation all year, while deep bottom waters go from saturation to nearly zero.



THE CHESAPEAKE BAY:

- was formed 10,000 years ago when melting glaciers flooded the Susquehanna River Valley;
- is the largest estuary in the contiguous United States and one of the most productive estuaries in the world;
- has a mainstem over 195 miles (314 km) long, which ranges in width from 3.4 miles (5.5 km) near Aberdeen, MD. to 35 miles (56 km) near the mouth of the Potomac River;
- has 7,000 miles of shoreline and a surface area of over 2,200 square miles, a figure that doubles with the inclusion of its tributaries;
- has a volume of roughly 18 trillion gallons of water; if its entire tidal system were drained, it would take more than a year to refill with water from rivers, streams, and runoff;
- is generally shaped like a shallow tray with an average depth of less than 30 feet except for a few deep troughs running along much of its length;
- has tributaries that provide spawning and nursery sites for several important species of fish;
- is home for 200 fish species and boasts extensive finfish and shellfish harvests, representing an annual commercial value of approximately $1 billion;
- supports some 2,700 plant and animal species;
- is a major stop along the Atlantic Migratory Bird Flyway;
- is both a commercial and recreational resource for the more than 12 million people who live in its basin;
- had more than 122,000 *pleasure craft registered in the state of* Maryland alone in 1979;
- has two of the U.S.'s five major North Atlantic ports;
- receives waste from about 3,000 point-source dischargers in Maryland and Virginia and another 2,000 dischargers in its upper *drainage basin; and*
- receives 1.5 billion gallons of treated sewage effluent per day.

THE FALL LINE forms the geological boundary between the Piedmont Plateau and the Atlantic *Coastal Plain. Ranging from 15 to 90 miles west* of the Bay, it is marked by waterfalls and rapids.

Plankton & The Food Chain

They form a vast array of several hundred species with such unfamiliar names as dinoflagellates, rotifers, and cladocerans. They are plankton--those important and mostly microscopic plants and animals that drift with the Bay's currents. They can be as small as 1 micrometer (µm)--a pinhead measures 2,000 µm across--and invisible to the unaided eye, or as large as a jellyfish. Millions of them can be present in a liter of water. These primary producers, consumers, and decomposers form the first link of the Chesapeake's complex and interdependent food chain, and are critical in assessing the state of the Bay.

The phytoplankton (algae) are plants and are the first link of the food chain. Phytoplankton are the primary producers that conduct photosynthesis: they use sunlight, carbon dioxide, water, dissolved nutrients, and their own chlorophyll to produce the carbohydrates on which all life depends. Most phytoplankton serve as an important food source, take up carbon dioxide, and add oxygen to the water column. Problems develop when an overabundance of phytoplankton causes an imbalance with one or only a few species dominating, and a depletion of oxygen as they die and decompose. Minute phytoplankton tentatively identified as cyanobacteria appear to be the most abundant phytoplankters in Chesapeake Bay.

Zooplankton are the animal forms of plankton. Like phytoplankton, they are generally grouped according to size, from the smallest to the largest: microzooplankton (smaller than 200 µm), mesozooplankton, (larger than 200 µm) and macrozooplankton (larger than 500 µm). They are usually the prime consumers of phytoplankton.

Zooplankton include certain types of protozoans, rotifers, crustaceans, jellyfishes, and the eggs and larvae of fish and shellfish. These usually microscopic animals are often critical food for larval and juvenile (and some adult) fishes. Many fishes (including striped bass) depend on zooplankton for food in their early developmental stages. Salinity, temperature, food, and predation influence zooplankton distribution and abundance.

Plankton and benthic monitoring for the new cooperative Bay-wide program was initiated in 1984-1985. This program is an important advance toward understanding the Chesapeake Bay. Plankton were collected at 23 Bay stations simultaneously with water-quality data, allowing biological and water-quality data to be examined together. Benthic samples are collected at 86 stations.

Phytoplankton

The Bay is one of the most productive estuaries in the world. It is not surprising, therefore, that the 1984-1985 sampling revealed a continuous supply of phytoplankton. Phytoplankton activity is greater in the freshwater and transition (0.5-5.0 ppt) zones of the Bay and its tributaries where there are high nutrient concentrations.

Maryland's 12-month sampling revealed high productivity in the upper freshwater portions of the Potomac and Patuxent. The upper two freshwater and transition stations in the mainstem Bay, however, showed the lowest productivity. This low production was at the mouth of the Susquehanna, where high potential productivity is inhibited by high turbidity. The highest productivity in Maryland's part of the Bay was found in the mainstem (mesohaline zone, 5-18 ppt) near the Chesapeake Bay Bridge.

The seasonal pattern of phytoplankton productivity in 1984-1985 was typical: high late-summer productivity due to longer days and warm waters; a fall peak followed by low winter productivity; a major spring peak following an influx of nutrients with the spring freshwater inflows.

Productivity and seasonal patterns for the Potomac and Patuxent were similar. The Patuxent, however, had higher and more frequent peaks of productivity than any other area sampled. Patuxent River carbon fixation rates (a measure of organic production) were 40% higher than Bay rates, and chlorophyll-*a* values (a measure of biomass) were 50%-200% higher.

In terms of composition, diatoms were dominant during the late-winter/spring and fall blooms. Small coccoid green cells (possibly cyanobacteria) were numerically dominant in the Bay in Maryland the rest of the year. During 1984-1985, large quantities of phytoplankton settled into deeper Bay waters, where their decomposition would further deplete oxygen in bottom water.

Virginia sampling of the mainstem was limited to the three-month period July-September 1985. The data indicate: diverse population patterns with distinct differences in phytoplankton composition and concentrations between the central and lower Bay; significantly greater abundances and diversity in the deeper water layer; a greater diversity and concentration of species near the Bay's mouth.

Zooplankton

During 1984-1985, microzooplankton were sampled in Maryland's portion of the Bay, and mesozooplankton were sampled in both Maryland and Virginia. As with phytoplankton, higher zooplankton biomass was found in the upper freshwater and transition zones. Maryland sampling revealed nothing surprising in species composition, abundance, or distribution: shrimp-like crustacean copepods, *Acartia* and *Eurytemora,* were the dominant zooplankters. In Virginia's lower Bay, isolated and unexpected high concentrations of copepods were found.

Zooplankton seasonal peaks occurred. Coupled with phytoplankton growth, there were spring and fall peaks, which

Species of phytoplankton (left border) and zooplankton (right border) accompany other Bay inhabitants (center) whose life cycles include both benthic and planktonic forms. Complete life cycles are shown for the blue crab *(Callinectes sapidus)* and sea nettle *(Chrysaora quinquecirrha)*. Other species shown include:

Phytoplankton

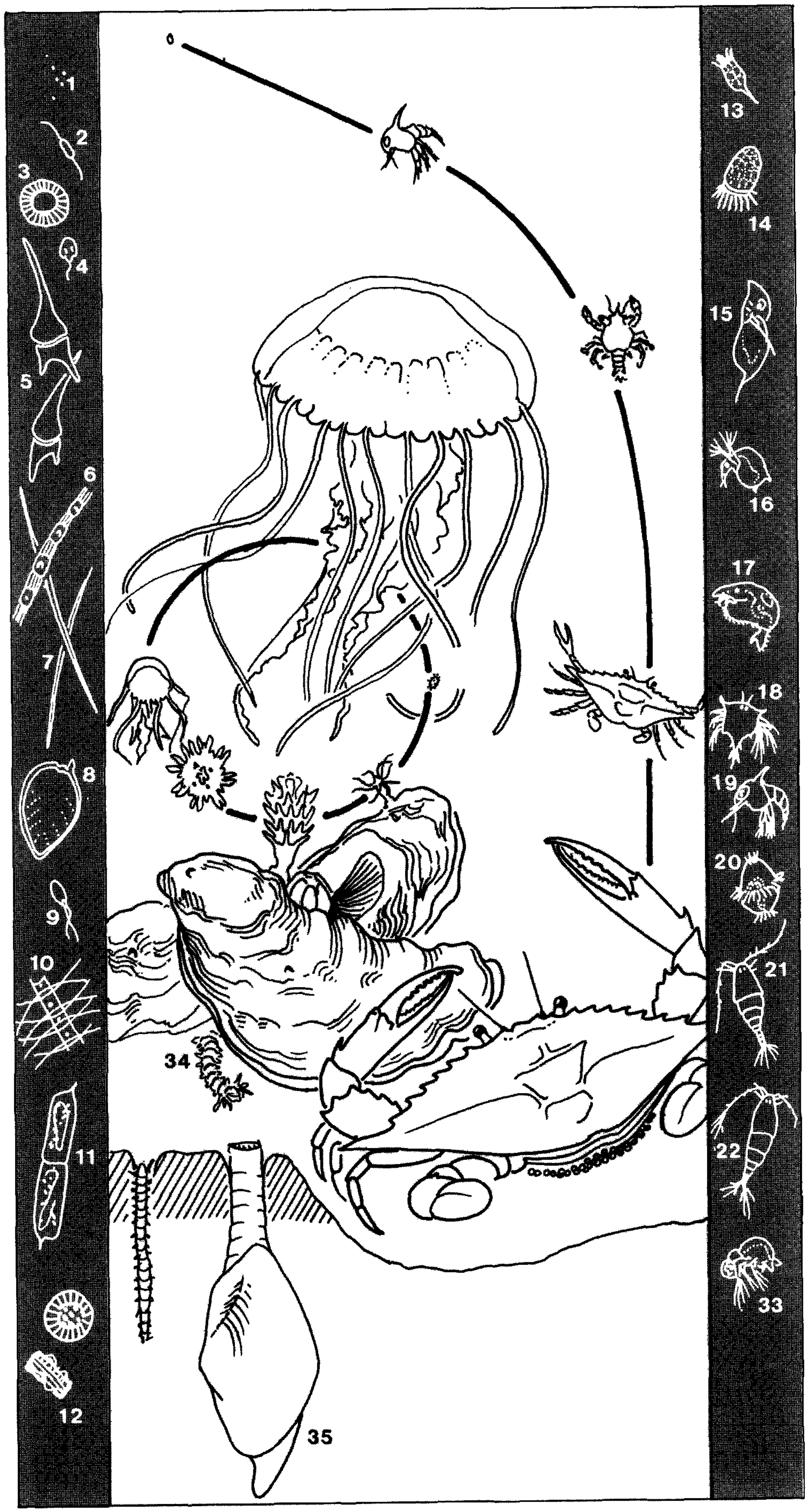
1	*Cyanobacteria*
2	*Cylindrotheca closterium*
3	*Cyclotella meneghiana*
4	*Katodinium rotundatum*
5	*Ceratium lineatum*
6	*Skeletonema costatum*
7	*Rhizosolenia alata*
8	*Prorocentrum micans*
9	*Cryptomonas sp*
10	*Chaetoceros decipiens*
11	*Rhizosolenia fragilissima*
12	*Cyclotella striata*

Zooplankton

13	*Keratella cochlearis*
14	Trochophore larva of oyster
15	*Daphnia retrocurva* (rare)
16	*Bosmina longirostris*
17	*Alona affinis*
18	*Barnacle nauplius*
19	Blue crab zoea
20	Trochophore larva of polychaete
21	*Acartia clausi*
22	*Acartia tonsa*
23	*Podon polyphemoides*

Benthos

24	*Nereis succinea*
25	*Mya arenaria*



Millions of animals live on or burrow in the bottom of Chesapeake Bay. They are known collectively as the "benthos." Because of their limited mobility (worms, clams, shrimp, and snails) or lack of mobility (oysters and mussels), they are good indicators of localized water quality. Some, such as oysters, crabs, and clams, are commercially valuable. The less familiar worms, small crustaceans, snails, and anemones are also important. Benthic organisms form one of the major intermediate links between the primary producers (phytoplankton) and the higher trophic levels such as fish and waterfowl. Their burrowing and feeding activities are also important in the nutrient cycles that control the Bay's productivity. The benthic community is not uniformly distributed over the bottom. Salinity, sediment type, and dissolved oxygen are the major determinants in their distribution. Currents, pollutants, diseases, and predation further shape their distribution and abundance. The greatest benthic variety (some 150 species) occurs in the saltier waters of the lower Bay.

were more pronounced in the less saline waters. The monitoring results support the concept of "coupling" between phytoplankton and zooplankton: the seasonal microzooplankton peaks coincided with or followed by one month the phytoplankton peaks; the mesozooplankton peaks coincided with the phytoplankton peaks during the spring bloom, but at other times tracked more closely microzooplankton abundance. This phenomenon also suggests that microzooplankton is an important link between phytoplankton and the larger mesozooplankton in the food chain for much of the year.

Benthos

Over the last several decades, the duration and extent of low dissolved-oxygen episodes in Bay bottom waters during summer months have increased. With decreasing oxygen levels, the abundance of short-lived benthic species that are less suitable prey for finfish and crabs has increased, while the availability of preferred longer-lived benthic prey for fish and crabs has decreased. The lowest standing stocks and abundance of benthic biomass were found in the deepwater mu(habitats where summer hypoxia/anoxia (low/no dissolved oxygen) occurs.

The deep central portion of the Bay in Maryland, the lower half of the Potomac River, and the upper Bay in Virginia support the lowest benthic biomass; the greatest benthic biomass is in the brackish and low-salinity habitats.

A summary of the more notable findings from 1984-1985 benthic sampling:

- Effects of anoxia are most apparent in deep waters just downstream of the Ba' Bridge where anoxia is generally most severe and of the greatest duration. Stres: from hypoxia/anoxia events also appears to have affected benthic communities at two Virginia stations--in the deepwater mainstem Bay and in the lower Rappahannock.
- Areas not experiencing anoxia confirm that year-to-year fluctuations in salinity are a major factor influencing long-term benthic trends.
- In the Patuxent River, populations of a clam *(Macoma balthica)* dependent o organic-rich sediment deposits have declined since 1980. This suggests that secondary sewage treatment and sediment controls are having a beneficial effect. □

Nutrients are used and re-used in the Bay. Nutrients such as nitrogen (N) and phosphorus (P) are the essential building blocks needed for growth in the elaborate Bay food chain that begins with phytoplankton (microscopic algae). Generally, plants use the two nutrients in a ratio of 16 parts N to 1 part P. Nutrients "fertilize" Chesapeake phytoplankton and the larger aquatic plants just as they do crops and gardens on land.

In order to conduct photosynthesis, phytoplankton depend on several forms of inorganic N and P: ammonia (N), nitrate (N), and phosphate (P). These nutrients enter the Bay's estuaries from many different sources: agricultural and urban runoff, sewage treatment plants, and rainfall. A large portion of these dissolved nutrients are transported along with sediment in the high spring flows (sediments adsorb both nutrients, but primarily P). The major use of these fertilizers is by phytoplankton in surface waters where there is enough light to support plant growth. When Bay waters are over-enriched by nutrients, growth explosions or "blooms" result.

In land ecosystems nutrients tend to be washed away, never to return. In estuaries such as the Chesapeake, however, nutrients tend to be retained because of the unique patterns of water movement (circulation) and used again and again because of recycling (similar to processes occurring in a compost pile) in both Bay waters and sediments. The algae flow toward the ocean in the lighter (and fresher) waters. When these microscopic plants die, they sink to the bottom and decompose (using oxygen in the process) in the sediments.

Nutrients are released back into the water column under a variety of physical and chemical conditions not completely understood. Nutrient release occurs particularly in areas with low oxygen levels. Higher water temperatures and alkalinity, along with physical perturbation of the sediments (due to water turbulence or movement of benthic organisms) can also increase release rates. Overturn mixing events transfer nutrients into upper waters where they can be re-used by new algal generations. This recycling process implies that some portion of the nutrients stored in sediments will get back into the system.

Citizen Monitoring

How Citizens Can Get Involved

- Join the annual hunt for submerged aquatic vegetation;
- Learn how individuals can reduce their contribution to pollution;
- Participate in activities to restore and protect the Bay;
- As a member of an organization, set up a water-quality monitoring project for a local watershed.

CONTACT: Citizens Program for the Chesapeake Bay, Inc., 6600 York Road, Baltimore, MD 21212; or Kathleen Ellett, Citizen Monitoring Coordinator, Chesapeake Bay Program, 410 Severn Avenue, Annapolis, MD 21403.

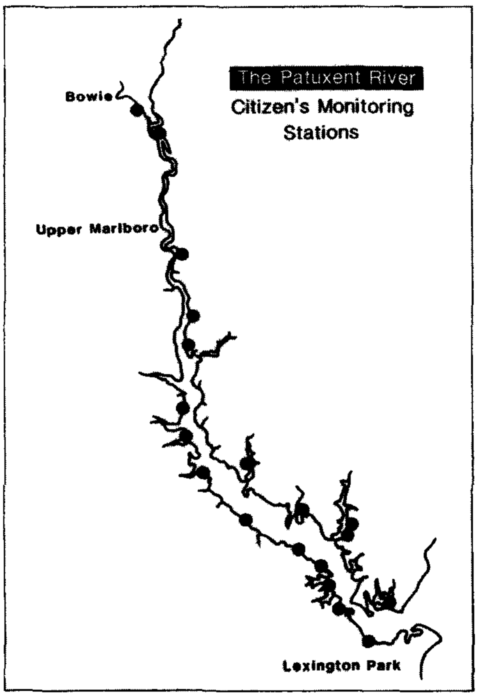
A citizen volunteer monitoring program was started in the summer of 1985 by the Citizens Program for the Chesapeake Bay, Inc. (CPCB). The program monitors the near-shore waters of two major Chesapeake Bay tributaries, the Patuxent and the James. The purpose of this program is to demonstrate that volunteers can collect reliable water-quality data that will help managers detect and assess long-term Bay ecological trends for the near-shore habitat. This pilot project will determine the appropriateness of a larger, permanent program.

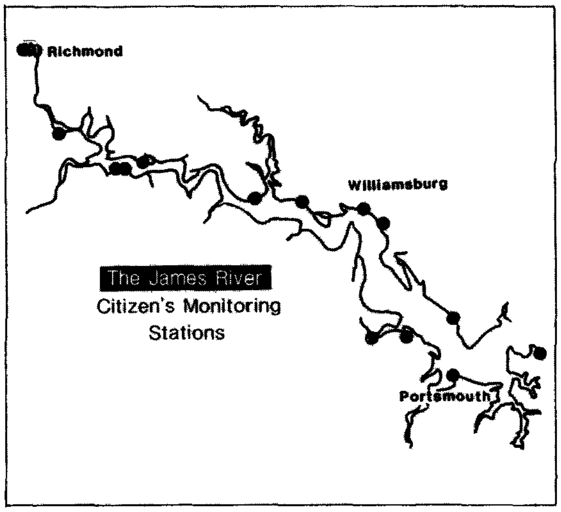
Data are being collected at 19 sites on the Patuxent and 16 sites on the James, from the head of tide to the mouth. Five surface water-quality factors are measured weekly at each site: water temperature; pH (using a color comparator kit); turbidity (using a Secchi disk); dissolved oxygen (using a micro-Winkler titration), and salinity (using an hydrometer). In addition, monitors record weather and general ecological observations about the site on the Data Collection Form. They send this data to the program coordinator at the Chesapeake Bay Program Liaison Office for entry into the Bay Program computer and subsequent periodic analysis.

There are 37 participants in the program. Of those who originally started in the program, 81% are still monitoring. The citizen monitors come from a variety of backgrounds and professions--farmers, students, housewives, teachers, scientists, bureaucrats, retired military, and medical professionals are monitors. All volunteers attend a training session and an annual workshop; they receive computer printouts and plots of their data, plus a newsletter. The newsletter, *River Trends,* contains monitoring results, informative articles, and sampling tips.

Results obtained so far indicate that trained volunteers can collect quality-controlled data. A comparison of citizen data with data collected by the Virginia Water Control Board on the James River and by Maryland's Office of Environmental Programs on the Patuxent River shows similar results.

The first comparison was made for four stations on each river where the state had a station close to a citizen monitoring site. The results of the comparison showed that dissolved oxygen and Secchi disk readings were in close agreement; pH values were similar. Water temperatures showed differences only during extraordinarily hot weather when the





shallower waters of the volunteer monitoring stations warmed significantly. Salinity values were comparable, although the hydrometers consistently read about 3 ppt higher than the conductivity meters used by the state agencies.

Volunteers have demonstrated their ability and willingness to collect data on short notice during and after such tropical storms as Gloria and Juan, when state and federal programs were less able to respond quickly. Secchi disk depths recorded by volunteers along the James River clearly showed the increased river turbidity following those two storms. In late 1985, citizens reported hypoxic/anoxic conditions in the bottom waters of St. Leonard's Creek, a tributary of the Patuxent River. The main channel of the Patuxent is known to have low dissolved-oxygen levels in late summer, but low D.O. levels had not been reported previously in water as shallow as St. Leonard's Creek (3-4 meters). The extent and duration of this phenomenon was to be explored in 1986.

CPCB began sponsoring a similar program on the Conestoga River in Lancaster County, *Pennsylvania in the* fall of 1986. Similar projects have been started in Maryland with the help of CPCB: on Back Creek in Annapolis, West River in Anne Arundel County, and on the Choptank River on the Eastern Shore.

SAV Habitat & Nursery

The restoration of submerged aquatic vegetation (SAV) is a Bay cleanup priority for several reasons. One reason is its high primary productivity--its high rate of biomass accumulation. In addition, aquatic plants form an important link in the food chain, between nutrients in the water column and sediment, and the animals. Many waterfowl are particularly dependent on SAV for food. Aquatic plants are also significant in the Bay's ecosystem as habitat and nursery areas for many species of commercially important fish and invertebrates. These plants effectively aid erosion control as they dampen wave action and trap light-reducing sediment running off the land. SAV acts as a nutrient buffer by accumulating large quantities of nitrogen and phosphorus. Seasonally, SAV provides an important source of dissolved oxygen for the Bay.

The Chesapeake Bay, with its broad salinity range, supports approximately 20 species of SAV, 10 of which historically have been abundant. These Bay "grasses" vary in their salinity tolerance.

The recent precipitous decline in submerged aquatic plants, beginning in the 1960s, is believed to be related to man's activities. SAV loss was first observed in the late 1960s in the upper Bay and some tributaries. The period from 1965 to 1980 showed an unprecedented decline of Bay SAV, with an acceleration between 1972 and 1974. The decline was most dramatic in the upper Bay and western shore tributaries. The reason for the decline is not fully understood; light reduction from sediment and algal turbidity and the fouling of SAV leaves by organism growth are believed to be the principal causes. Storm damage and grazing pressure are additional factors. The effects of agricultural herbicides appear to be less important and more localized.

While the increases in SAV in the mid-1980s have been relatively small overall, the resurgence of this integral component of the Bay system is a hopeful sign.

Chesapeake Bay submerged aquatic vegetation (SAV), in severe decline from the late 1960s until 1984, showed an overall increase of 26% (47,893 acres) from 1984 to 1985. The largest increase was found mid-Bay, along the Eastern Shore. There was a slight decrease in the upper Bay, and little change was observed in the distribution and abundance of SAV in the lower Bay. There has been some slight improvement in the declining numbers of migratory waterfowl, especially in SAV-resurgent areas.

Upper Bay

There was a slight decrease of 4.5% (7,472 acres) in the abundance of SAV in the upper Bay zone, with declines revealed in three of the four sections studied. There was a 142% increase (259 acres) in the sparsely vegetated Eastern Shore section, principally along the Elk and Sassafras rivers. More than half (66%) of this zone's SAV is in the Susquehanna Flats area, and this zone is dominated by wildcelery, Eurasian watermilfoil, and hydrilla. Redhead grass and widgeongrass dominate in the Eastern Shore area.

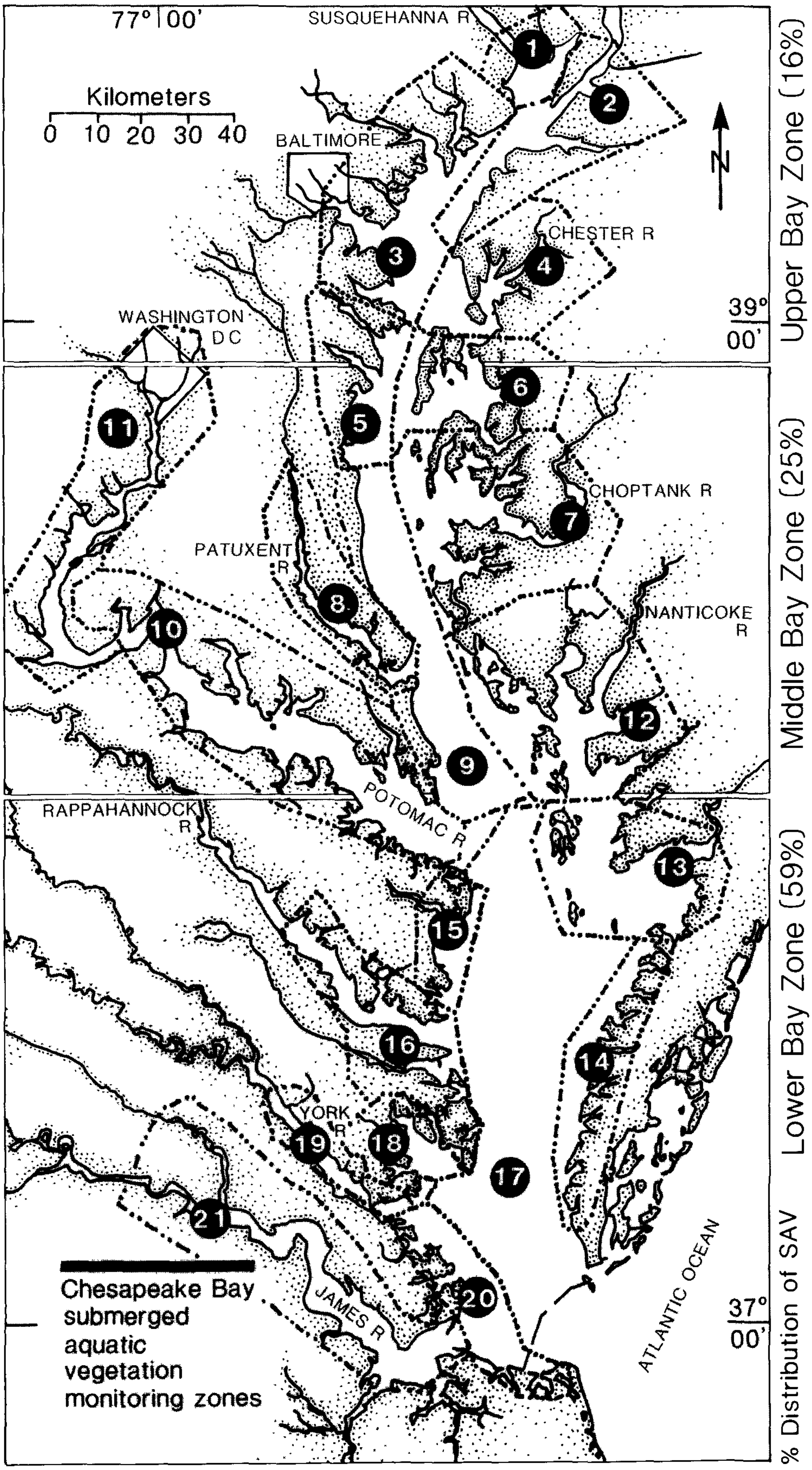
Middle Bay

The 1985 SAV "good news" was the increase in grasses in all sections of the middle Bay zone over the previous year, resulting in a 389% increase (12,315 acres) for the entire zone. Even the Patuxent River, while still sparsely vegetated, showed a 401% increase (22 acres in 1984 to 109 acres in 1985). In the Potomac River, increases were seen in both the upper and lower sections, 140% (3,557 acres) and 59% (941 acres) respectively. Ten species of Bay grasses were found in the upper Potomac section, with Eurasian watermilfoil and hydrilla the most prevalent. Widgeongrass was found to be the dominant aquatic plant in the mainstem of the middle Bay zone.

Lower Bay

There were no major changes in SAV in the nine sections of the lower Bay zone between 1984 and 1985. The largest change occurred in the Reedville section, where the 1985 survey revealed a decrease of 34% (425 acres) in SAV distribution from 1984. Most of the Bay's grasses (59%) are in the lower Bay zone, with 68% of this zone's vegetation located along the Eastern Shore bayside. Bay grasses are still absent in two of the six areas of historical abundance in the lower bay. Widgeongrass and eelgrass are the dominant SAV in the lower Bay. □

Analysis of surveys of Bay waterfowl over 39 years (1948-1986) by the U.S. Fish & Wildlife Service reveals that the overall long-term average population of Bay waterfowl during January is 1 million birds. The average for the 1980s is also 1 million birds, but the species composition reflects major changes. Of the thirteen species of waterfowl studied, only three had higher population averages in the 1980s than in the 1948-1979 period. The mallard and bufflehead have shown population increases of 16% and 17%, respectively. Canada goose populations have shown a more dramatic increase of 75% (apparently due to their finding food sources other than SAV). All other species, however, have shown significant declines. The declines in canvasback and redhead duck populations appear to be directly related to the degradation of waterfowl habitat in the Bay. A balanced mix of waterfowl species is not likely unless the Bay's SAV beds recover.


77° 00'
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YORK R
JAMES R
ATLANTIC OCEAN
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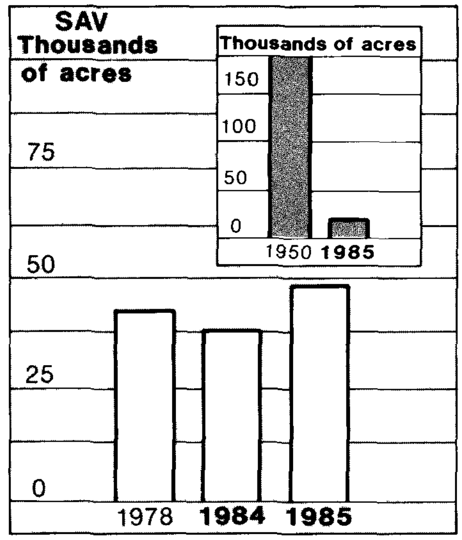
Chesapeake Bay submerged aquatic vegetation monitoring zones
Upper Bay Zone (16%)
Middle Bay Zone (25%)
Lower Bay Zone (59%)
% Distribution of SAV
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21


SAV Thousands of acres
75
50
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Thousands of acres
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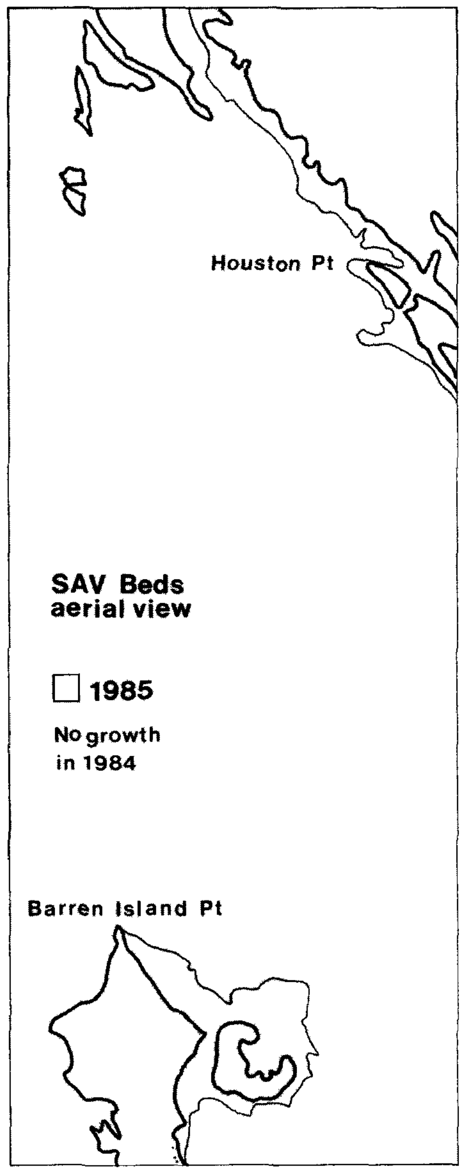

Houston Pt
SAV Beds aerial view
1985
No growth in 1984
Barren Island Pt

The Harvest: Finfish

The esteemed striped bass, or "rockfish," can live more than 30 years and can grow to a great size While the usual maximum size has been 60 pounds in recent years, rockfish weighing over 100 pounds were recorded in the late 1800s, and have been occasionally reported in recent years.

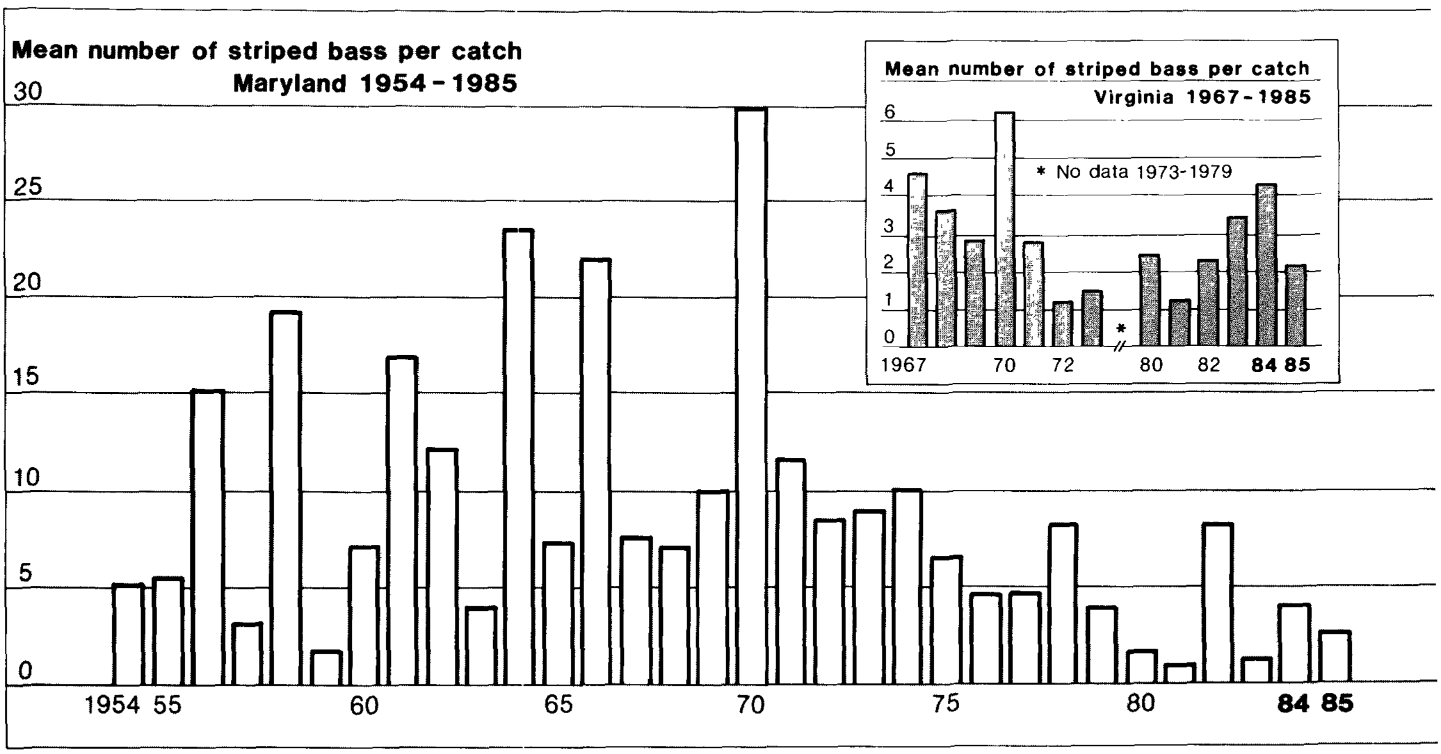
In its native range along the Atlantic Coast, the striped bass spawns from February through July. In the Chesapeake, spawning generally occurs from late April through May. Rockfish spawn in fresh or nearly fresh water, normally in the upper tidal reaches of all major Bay tributaries. The Chesapeake is regarded as the center of abundance for the species, and historically its migratory stocks have been considered the major source for the Atlantic Coast harvests. In the 1970s, when rockfish stocks were larger, it was estimated that the Chesapeake stock contributed 90% to the Atlantic Coast striped bass harvests. With reduced Bay stocks, the current contribution would appear to average between 50% and 70% Abundance, health, and conditions of Chesapeake stocks are therefore critical to the entire Atlantic fishery.

The trend of decreasing numbers of harvestable anadromous fish (estuarine or marine fish that spawn in freshwater), showed no change in 1984-1985. Anadromous fish spawning results remain poor, and abundance of juveniles low. There is some optimism, however: the most important anadromous fish, the striped bass, or "rockfish," appears to be benefiting from recent protective regulations, and hatchery-release programs have been initiated. Also, more data about striped bass are now being collected in the upper Potomac River, a significant striped bass spawning ground. An excellent intermittent data base exists on striped bass spawning in the upper Potomac. There has been a lack of information, however, on juveniles and adult fish in the river's reach in the nation's capital. The new data collection program initiated by the District of Columbia in 1985 will rectify this. Also, the states are standardizing the available Chesapeake Bay commercial catch information on the most important Bay fisheries.

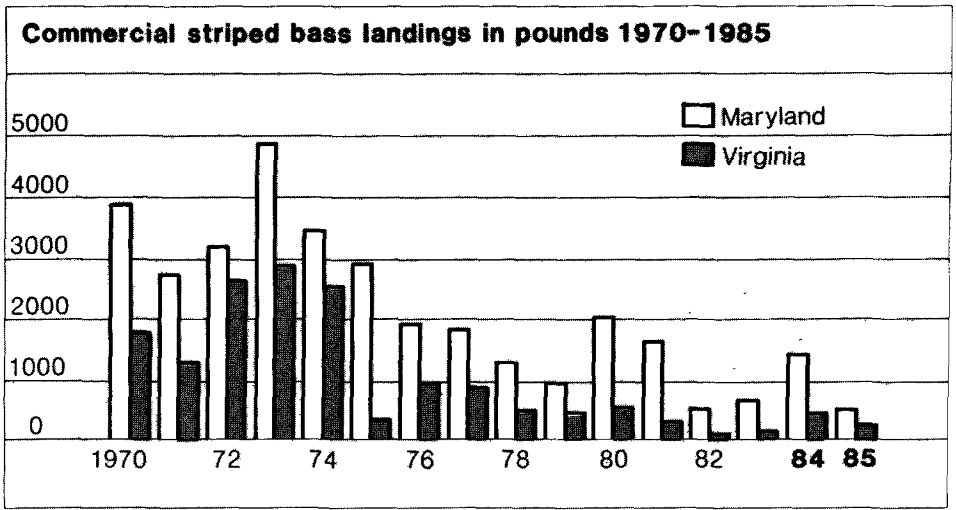
The health of the striped bass remains a high-priority concern. Research efforts focus on stock assessments, young-of-year analyses, larval abundance and transport studies, related habitat investigations, hatchery restocking programs, and laboratory toxicity studies.

It appears that the striped bass harvesting moratorium in Maryland and the partial ban in Virginia are protecting the important 1982 year-class as intended. The marked increase in striped bass observed in Virginia since 1981, and the large numbers of young stripers caught in unregulated D.C. waters in 1985, are believed to be a result of the bans.

In 1985, Maryland banned harvesting of striped bass because of the drastic declines in commercial rockfish landings since the mid-1970s. Declines in commercial fishery landings for both the Chesapeake and the Atlantic reveal poor recruitment into the fishery since the 1970 "super" year-class. The 1982 year-class of rockfish, which will not spawn until 1988, is the object of protection because its abundance offers considerable



Striped bass young-of-year indices (abundance) show great variability. Due to differences in habitat and capture method, the indices of the two states are similar, but not identical. The unusually high 1970 index dominates in both states. Virginia's indices increased steadily from 1981 through 1984, but dropped in 1985. Maryland's indices have been very low since 1978, with the larger 1982 year-class the object of state protection. (Source: MD Department of Natural Resources [DNR] and VA Marine Resources Commission)



Commercial striped bass landings in Maryland and Virginia 1970-1985. (Source: NOAA/National Marine Fisheries Service [NMFS])

potential for increasing the spawning stock.

While Virginia is optimistic about the number of rockfish in its waters, recent stock assessment work has confirmed that the 1982 year-class is the only reasonably abundant one in Maryland. Data reveal very few fish older than the 1981 year-class in the Potomac, and a very low ratio of females--the egg layers on which good year-classes depend--to males. The Potomac pattern appears to be the general case for Maryland's portion of the Bay.

Maryland striped bass spawning stocks have been low; they were lowest in 1982 and 1983, and slightly higher in 1984 and 1985, largely due to the protected 1982 year-class males. Striper egg and larval abundance also continues to be low. Intensive Maryland habitat studies, which seek to relate water quality and other habitat factors to larval abundance, are currently under way. A combination of low pH, which tends to mobilize naturally high levels of aluminum (which impairs larval gill function), and low hardness found in some Eastern Shore rivers such as the Choptank, may be causing significant larval mortalities.

Fishery biologists recognize that there is a high mortality rate (over 99%) in early life history stages of striped bass; the mortality rate declines considerably, however, when individuals reach the juvenile or "fingerling" (2 to 5 months old) stage. Juvenile or young-of-year abundance firmly establishes the strength of the newly recruited year-class, and allows projections of its contribution to the commercial fishery in subsequent years.

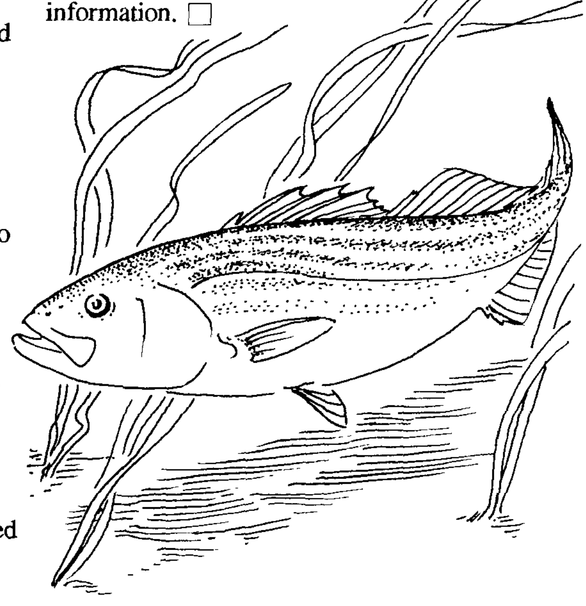
Both Maryland and Virginia survey juvenile striped bass annually. Young fish are trapped either by seine net (Md.) or by seining and trawling (Va.). The young stripers are counted and the totals averaged. Due to differences in habitat and capture method, Maryland and Virginia juvenile indices are similar but not identical. Maryland's more shallow shoreline allows for more extensive seining and higher young-of-year catches than is possible along Virginia's deeper shores. The Maryland indices, therefore, will be higher than those in Virginia.

In Maryland, a juvenile index of 8 has been considered the minimum desirable index because historically, year-classes with an index of 8 or better have apparently supported a commercial fishery of 2 million pounds of stripers annually. Since the 1970 year-class with a very high index of 30, however, Maryland juvenile indices have been alarmingly low. The 1982 index of 8.4 was followed by low indices of 1.4 (1983), 4.2 (1984), and 2.9 (1985). In the District of Columbia, recent young-of-year averages (not available prior to 1984) were also low: 2.4 (1984) and 3.9 (1985). The Virginia young-of-year indices, however, show a steady increase from 1.6 (1981) to 4.4 (1984). The 1984 index was the highest number of juveniles recorded in Virginia since the record 1970 year-class with an index of 6.4. The 1985 juvenile year-class index of 2.3 was only average.

Since mortality of striped bass in the wild is greatest from the fertilized egg through the fingerling stage, hatchery rearing may be a bridge to an improved fishery. Striped bass are now being reared in U.S. Fish & Wildlife Service and Maryland hatcheries until the fall, when they are less vulnerable and big enough to be tagged and released into selected Bay areas. Experimental tagging and tag recovery programs were initiated in both Maryland and Virginia in late 1985. The expectation is for a release of 3.5 million fish in Maryland alone by the end of the program in 1989. What has been learned: a large number of striped bass can be raised in hatcheries, tagged, and released into Bay tributaries successfully. The next step is to determine the program's impact.

Stocks of other anadromous fish such as shad, river herrings, and yellow perch remain at all-time lows. White perch numbers are also low. Abundance estimates of the harvest-banned shad from 1980 through 1985 indicate a trend of generally increasing stocks, but numbers of young-of-year and adults remain extremely low. Harvests of marine-spawning fish, dependent on oceanic rather than Bay conditions, are relatively good. Ocean-spawning menhaden, sea trout, spot, and bluefish harvests remained stable or increased during 1984-1985.

The first preliminary comprehensive assessment on thirteen Bay species (including striped bass) represents progress in bringing together the available commercial catch data in a uniform manner. Assessments of six additional species are scheduled. While the assessments are based on those fish reported (as opposed to those which may actually have been caught), and while no complete set of information exists for any one of the Bay fisheries, the value of this preliminary effort is that it will more clearly reveal important missing information. □



The Harvest: Shellfish

With oyster reproduction and survival declining seriously over the last decade, the higher spatfall in both Maryland and Virginia in 1985 was good news. Over the 1984-1985 monitoring period, however, spat survival rates remained low and still unexplained. No changes were noted in the dismal picture for soft-shell clams, but the blue crab fishery remains healthy, if unpredictable.

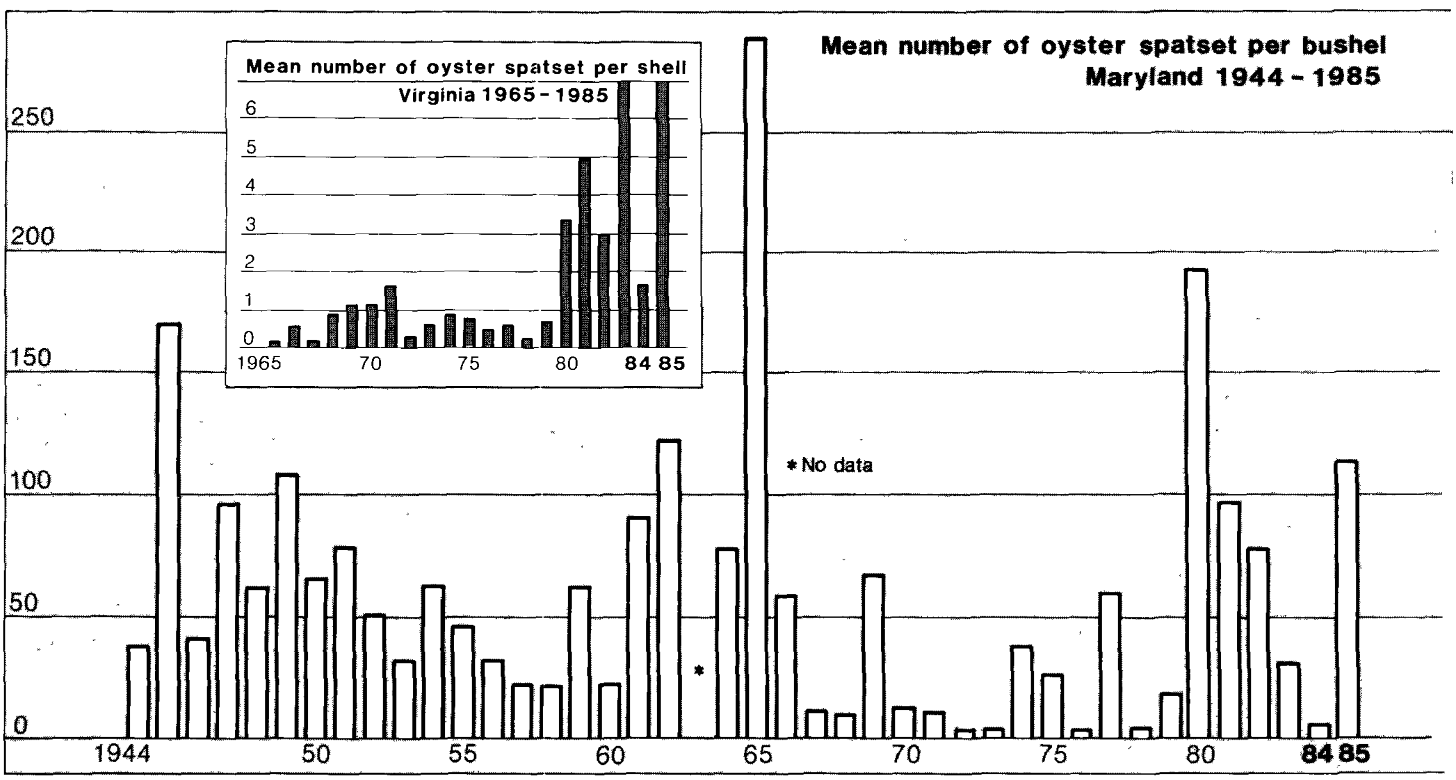
Rainfall and temperature are key variables that determine oyster harvests. A strong correlation has been found between high salinity and good oyster reproduction. Dry summers, for example, may provide the oyster with highly saline waters and good feeding and growing conditions as a result. This same kind of weather, however, can encourage oyster diseases. The significant effect of rainfall and temperature on the productivity and health of the Bay's resources is evident when one examines the condition of the Bay's shellfish, particularly in 1984 and 1985.

While there has been no long-term trend in rainfall/salinity, there has been a distinct trend toward warmer falls and winters over the last 10 years. The spring of 1985, with below-normal rainfall, was followed by one of the three warmest autumns in 30 years (which extended into the winter). The drier and warmer fall of 1985 resulted in a considerably longer spawning season than that of 1984; the oyster spawning season extended beyond the normal June-September period into late October.

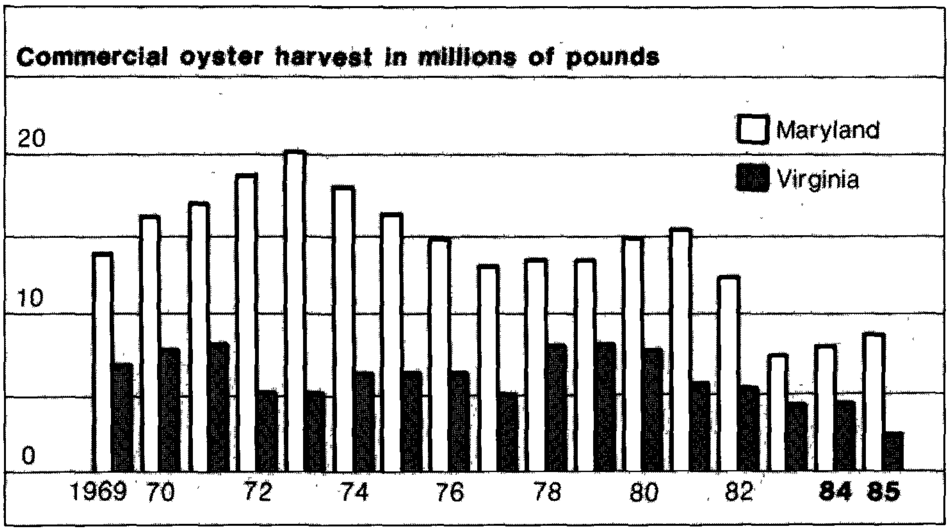
Both Maryland and Virginia had high spatfall as a result. Virginia's spatfall was moderate to heavy in the 1984 and 1985 spawning seasons. The heavier spat sets generally occurred in 1985, particularly on the James River seed beds. There was considerable temporal and spatial variability in the spatfall. The occurrence of heavy spatfalls, despite low brood stock, underscored the importance of local weather and climate in the determination of year-class strength.

Although its 1984 spatfall (2.4 spat per bushel) continued a downward trend, Maryland found high numbers of spat on its 55 key oyster bars in 1985. The Maryland spatfall average in 1985 exceeded 100 spat per bushel. The higher spatfall was welcome, but it was limited mainly to the mouth of the Potomac River and Maryland's Eastern Shore tributaries. This area is greatly reduced compared with that area where high spat sets were recorded between 1938 and 1965.

The survival of spat to yearling continues to be of prime concern. In this regard, unfortunately, 1984 and 1985 were not exceptions. In Virginia, the state-wide poor survival of spat to yearling was evident in the oyster bar surveys that



Oyster spat set for Maryland (1944-1985) and Virginia's James River (1965-1985). The density of the annual spat set is a measure of oyster reproductive success. Spat set is measured annually but with different methods by the two states. Maryland measures the number of spat per bushel; Virginia measures spat per shell. Shown here is the great variability of spat set in both states. The relatively higher sets for the two states in 1985 was good news. (Source: MD DNR and VIMS)



Commercial oyster harvests. Since the turn of the century, the trend has been one of decreasing harvests of smaller oysters. Even though management practices such as shell and seed planting have helped to stabilized the harvests since the 1960s, the current Bay-wide landings average around 2.6 million bushels (U.S.) annually. It has been estimated that the sustainable yield of Maryland oysters is 2-3 million bushels annually. Virginia's oyster industry has not recovered from the disease attack of the late 1950s. (Source: NOAA/NMFS)

followed the heavy 1985 spawning season (predation by the abundant blue crab may play an important role). Bay biologists point out that the success of the oyster fishery depends on a number of consecutive years of above-average spat set, as well as the absence of threats from harvest pressure, disease, and lack of dissolved oxygen.

MSX and Dermo can pose serious disease threats to the oyster industry. MSX attacks adult oysters (the peak period of infection is June), flourishing in the same saline conditions that favor oyster production. Virginia's oyster industry has been threatened by MSX since 1959. The organism has been a problem in Maryland waters since 1963. Maryland's high spat sets in the early 1980s were offset by an extensive outbreak of MSX in the 1982-1983 season.

While conditions in 1984 and 1985 were not conducive to the spread of MSX in Virginia, Maryland's lower Bay waters experienced some Dermo mortalities and conditions conducive to MSX infestation in 1985. Mortalities resulting from the latter would be seen in 1986.

The stocks of Maryland's soft-shell clams continue to be low; 1984 and 1985 harvests were each only about 1 million pounds. The crab fishery remains the one source of "good news" for the Bay's fisheries, however. While historically crab harvests have fluctuated wildly, the fishery appears to be unthreatened. Both 1984 and 1985 were good years for crabs. Bay-wide crab harvests were 59 million pounds and 46 million pounds in 1984 and 1985 respectively.

One reason for the lack of concern about this crop (the Bay's second most valuable), is because crab year-classes are believed to depend more on the environmental conditions and hydrological effects associated with the Bay's mouth than other factors. The higher salinity of the Bay's mouth is also essential for crab spawning and larval growth. The circulation pattern at and outside the mouth of the Bay can transport crab larvae into the up-Bay water currents of the deeper, saltier water layers, or can carry them into ocean currents and permanently offshore. □

The American oyster has been important to the Bay's economy since the mid-1880s, when the average annual yield for Maryland alone was about 12 million bushels. Since the turn of the century, the trend has been decreasing harvests of smaller oysters. Even though management practices, such as shell and seed planting, have helped to stabilize the harvests since the 1960s, current Bay-wide landings average around 2.6 million bushels (U.S.) annually.

The density of the annual oyster spat set is a measure of oyster reproduction success. Free-swimming oyster larvae (2 to 4 weeks old) drop to the bottom to set; they attach to suitably clean and firm substrate (usually oyster shell) in order to grow. These spatfalls are measured annually by Virginia and Maryland, and monitored carefully since, in spite of improvement in Virginia's spat sets since 1980, there has been an overall Bay-wide decline in spatfall for more than ten years. Setting patterns and survival rates have varied widely. Spat set has long been considered a reasonable indicator of subsequent harvests, but its predictive value has been reduced over the last couple of decades because of poor spat survival.

In addition to low reproduction and larval survival rates, increased demand, and harvesting, oysters have been affected by weather and disease. Oysters require a salinity range of 5-35 ppt. Freshwater inflow, therefore, is a key variable affecting reproduction and mortality.

The oyster diseases known as Dermo *(Perkinsus marinus)* and MSX *(Haplosporidium nelsoni)* have taken their periodic tolls on the oyster fishery. These organisms are associated with higher salinities (above 15 ppt), and are far more regularly a threat in the saltier waters of Virginia and lower Maryland. Their attacks on middle and upper Maryland Bay shellfish are less frequent but can be devastating.

The naturally fluctuating harvests of the economically important soft-shell clam have dwindled. The reason for the soft-shell clam decline is not apparent, although low-oxygen areas, disease, and heavy harvesting are suspect.

Crab harvests are variable but high, and the fishery appears unstressed. The fishery is controlled primarily by the better environmental factors near the Bay's mouth, where crabs spawn.

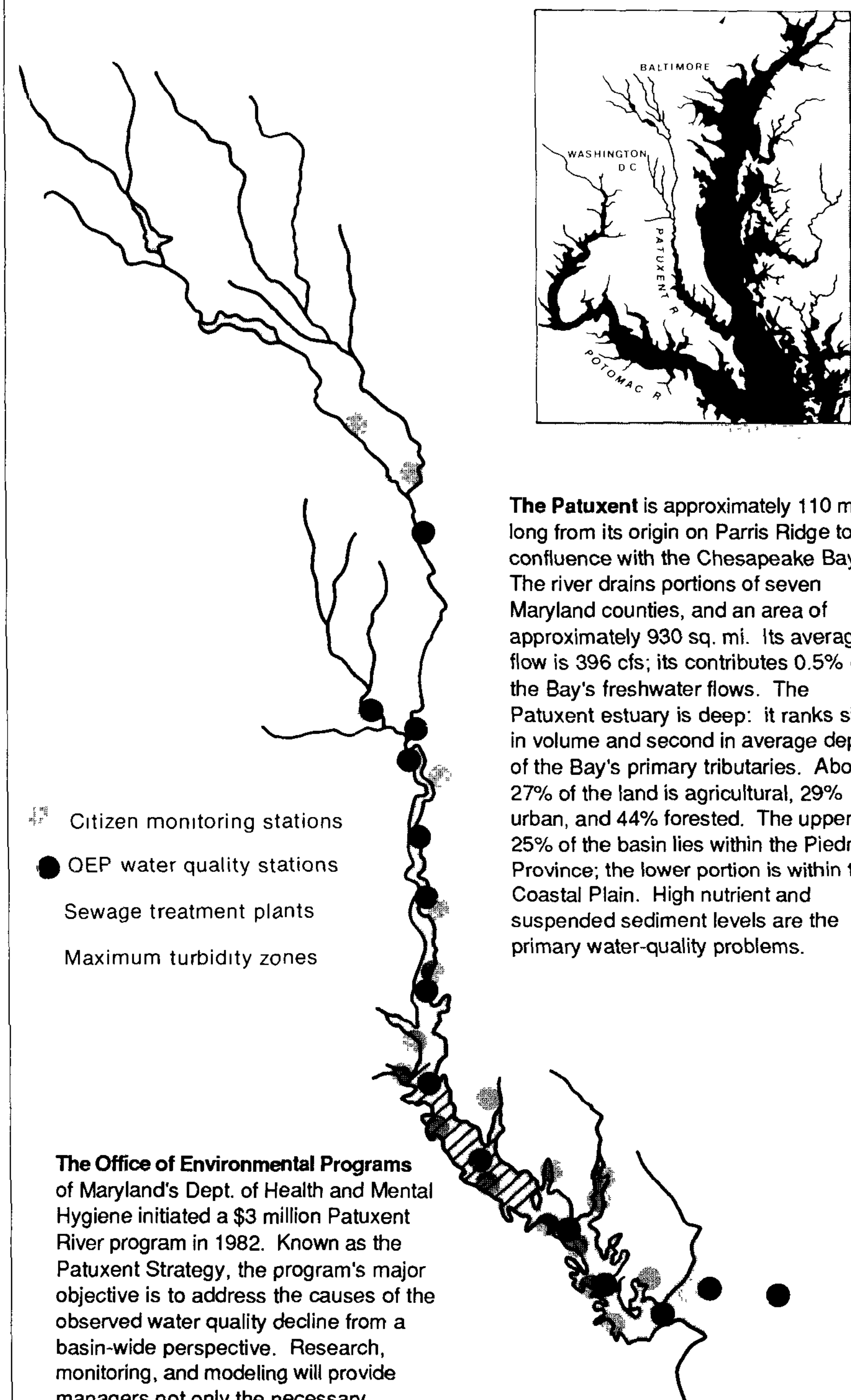
A Case Study: The Patuxent

The Patuxent River is the longest intrastate river in Maryland, and its watershed is the only major sub-basin that drains entirely within the state. Five decades of research, monitoring, and modeling have adequately addressed localized environmental concerns. The current goal for the Patuxent, however, is to employ a system-wide approach in order to achieve a return to the good water-quality conditions of the 1950s.

Consistent with Northeast trends over the last few decades, there has been an increase in urbanization within the Patuxent watershed. The human population has increased: from 62,000 in 1920, to 248,210 in 1970, and to 352,860 in 1980. The amount of developed land increased more than 27% between 1973 and 1981. These population increases and changes in land use have coincided with both a "greening" (from excessive phytoplankton) and "browning" (from excessive sediment) of the estuary. The deterioration of the Patuxent was evident by the 1960s.

Reconstruction of 50-year patterns within the watershed (see p. 27) has revealed increased nutrient enrichment due to point source (STP discharge) and non-point source (land run-off) loadings. STP loadings, which contribute nutrients in their effluent, went from 3 mgd in 1963 to 34.5 mgd in 1985. The nutrient increase has led to excessive algal (microscopic plant) growth. The over-production of algal growth has been linked to lowered dissolved oxygen levels in the deeper waters of the Patuxent estuary: the decomposition of dead organic matter increases the demand for oxygen.

Additional ecological changes have also been noted, such as drastic loss of submerged aquatic vegetation and declines in typical native, estuarine-dependent commercial and recreational finfish and shellfish. Today's Patuxent oyster industry is a fraction of what it was in the 1960s.

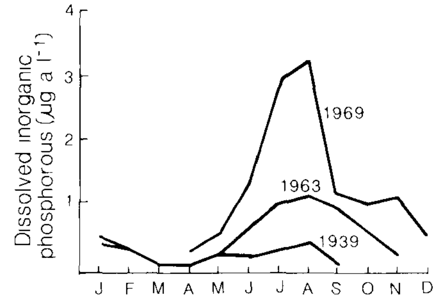


The Patuxent is approximately 110 mi long from its origin on Parris Ridge to its confluence with the Chesapeake Bay. The river drains portions of seven Maryland counties, and an area of approximately 930 sq. mi. Its average flow is 396 cfs; its contributes 0.5% of the Bay's freshwater flows. The Patuxent estuary is deep: it ranks sixth in volume and second in average depth of the Bay's primary tributaries. About 27% of the land is agricultural, 29% urban, and 44% forested. The upper 25% of the basin lies within the Piedmont Province; the lower portion is within the Coastal Plain. High nutrient and suspended sediment levels are the primary water-quality problems.

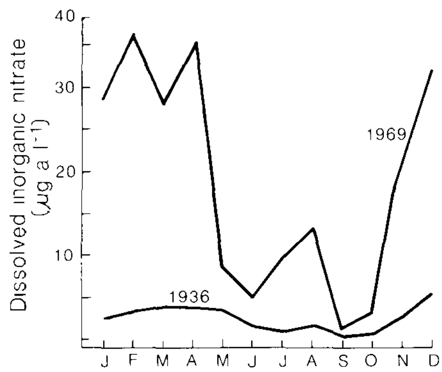
The Office of Environmental Programs of Maryland's Dept. of Health and Mental Hygiene initiated a $3 million Patuxent River program in 1982. Known as the Patuxent Strategy, the program's major objective is to address the causes of the observed water quality decline from a basin-wide perspective. Research, monitoring, and modeling will provide managers not only the necessary information to understand better the processes affecting water quality, but also the means to evaluate the effectiveness of various management options. (Source: EPA, MD OEP)

Historical data reveal the long-term undesirable trend of increased nutrient enrichment and decreased dissolved oxygen levels in the Patuxent River.

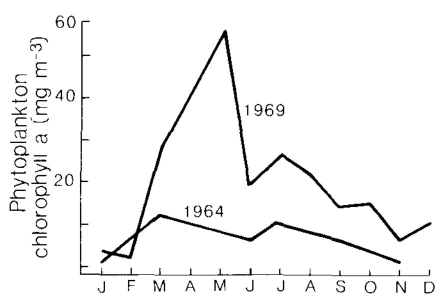
PHOSPHORUS Two types of phosphorus (P) are commonly reported: dissolved inorganic P (DIP) and total P (TP). The Patuxent's longest nutrient record is that for DIP. DIP data collected at Broomes Island in 1939, 1963, and 1969 reveal significant increases in DIP levels. Values of DIP near the mouth of the estuary have also increased over the years. The estimated annual loadings of TP from upstream sources to the Patuxent estuary for 1965: 180,779 lbs; 1970: 341,717 lbs; 1975: 608,476 lbs; and 1985: 216,500 lbs. During the 1984-1985 monitoring period, the Patuxent River had the highest TP levels of the tributaries monitored. The Patuxent River TP concentrations in the tidal-fresh, transition, and lower estuarine zones were approximately 0.30-0.35, 0.25, and 0.1 mg/l, respectively.



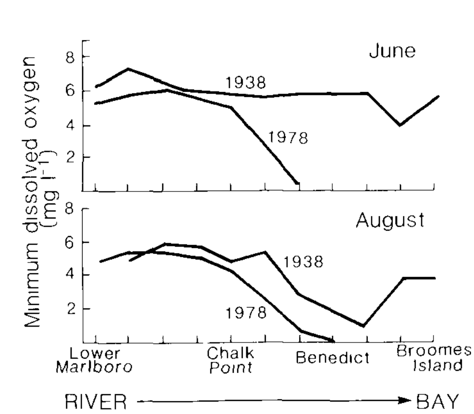
NITROGEN Of the nitrogen forms that are routinely measured, only nitrate was measured in the Patuxent prior to major STP construction. Shown at right is the profile of nitrate values for Lower Marlboro in the low-salinity reach of the Patuxent. The data reveal a clear seasonal pattern of nitrate concentration, with high values in winter throughout the estuary, and low values in the summer and fall. Nitrate values tend to be strongly correlated with river flows. The graph shows increases in nitrate levels after winter periods in both 1936 and 1963, with a major increase in the latter. Lower Marlboro winter values in 1969 were 8 times higher than those reported in 1963, and 20 times higher than those reported in 1936. The estimated annual total loadings of TN from upstream sources to the Patuxent River estuary for 1965: 509,268 lbs; 1975: 2,462,563 lbs; and for 1985: 1,900,000 lbs. The 1984-1985 values of TN were generally at or above 2 mg/l in the tidal-fresh river.



CHLOROPHYLL-*a* Chlorophyll-*a* values have increased over the years as shown in the graph. The data collected at Benedict Bridge, Md., at the lower end of the turbidity maximum region and in the mesohaline segment of the estuary, show that maximum observed late-winter and spring values increased by over 100% between 1964 and 1969. Excessive phytoplankton growth from the increased levels of phosphorus and nitrogen was becoming apparent in the early 1970s. In 1984-1985, the highest concentrations of chlorophyll-*a* during the warmer seasons were found in the upper Patuxent estuary. Chlorophyll levels peaked at 100 ug/l in the tidal-fresh reach of the Patuxent in the summer of 1985.



DISSOLVED OXYGEN The lowest DO levels generally occur in the deeper bottom waters during warm seasons. A comparison of the June and August low DO values in the lower Patuxent estuary's bottom waters in 1938 and 1978 is shown to the right. The comparison reveals 1978 minimum DO levels substantially lower than those observed in 1938, beginning at Benedict and continuing downstream. No zero values were found in 1938, while zero levels were common in 1978. In the summers of 1984 and 1985, the DO levels ranged between 5.0 and 9.5 mg/l in surface waters, and between 0 and 8.0 mg/l in bottom waters. CPCB monitoring program volunteers reported hypoxic/anoxic conditions in the bottom waters of shallow St. Leonard's Creek in the summer of 1985. While the main channel of the Patuxent is known to have low dissolved oxygen levels in late summer, low DO levels have only occasionally been reported in water as shallow as St. Leonard's Creek (3-4 meters). (Source: Chesapeake Biological Laboratory, University of MD)



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The coordinated monitoring network, created on behalf of the Chesapeake Bay Program, has drawn upon government resources at federal, state, and local levels, and their contractors, and major university research institutions throughout the Chesapeake basin. Their coordinated efforts and dedication to the common goal of restoring and protecting the Chesapeake Bay have made this report possible. This report was assembled by the Monitoring Subcommittee by authority of the Chesapeake Bay Executive Council, the Implementation Committee, the Citizens Advisory Committee, and the Scientific and Technical Advisory Committee.

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