VIRGINIA CHESAPEAKE BAY WATER QUALITY AND LIVING RESOURCES MONITORING PROGRAMS

EXECUTIVE REPORT, 1985–1996

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JANUARY 15, 1998

This data reporting project was 44% funded by the Virginia Coastal Resources Management Program of the Dept. of Environmental Quality through Grant #NA57020561-01 of the National Oceanic and Atmospheric Administration, Office of Ocean and Coastal Resource Management, under the Coastal Zone Management Act of 1972, as amended. Other funding was provided by the USEPA and the Chesapeake Bay program of the Department of Environmental Quality. The total cost of the project was $114,686. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA, USEPA, or the Dept. of Environmental Quality.

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INTRODUCTION

This document represents a synthesis of the overall findings of water quality and living resources data generated over the first 12 years (1985 through 1996) of the Virginia Chesapeake Bay Monitoring Program. In this report, patterns of water quality and living resources for Virginia's tributaries and the Virginia Chesapeake Bay are examined. Patterns of nutrient loadings are examined for the entire watershed of each river; however, status and trends in water quality and living resources are presented only for the tidal portion of each river. The tidal portion of each river (also referred to as an estuary) represents that portion which is influenced by tides and by the mixing of saltwater from the ocean and freshwater from land runoff and groundwater. A series of more technical documents is also available which contain detailed statistical results that are the basis of this report.

Increasing nutrient levels, largely as a result of agricultural runoff and other non-point sources, have been associated with the over-stimulation of primary production (e.g., algal blooms) in many areas of the Bay. Excessive nutrient enrichment (eutrophication) may lead to major alterations of the living communities by promoting shifts in the composition of natural algal communities - the planktonic communities. Changes in the natural algal communities may then have a detrimental effect on early life stages of fishes that feed upon the plankton and on the commercially and recreationally important finfish stocks. Algal blooms and excessive runoff of suspended sediments decrease water clarity, reducing levels of seagrasses (submerged aquatic vegetation) on the bottom of the Bay. Seagrasses are important habitat for the early life stages of many finfish species and for the blue crab. The decline in seagrasses is a major indication of eutrophication of the Bay. In addition, eutrophication ultimately leads to low dissolved oxygen conditions when organic matter accumulates at rates faster than can be utilized by the decomposers in the system. Low dissolved oxygen conditions can lead to widespread degradation of organisms that live on the bottom of the Bay - the benthic communities.

Water quality, water clarity, plankton and benthic community parameters are monitored to measure progress in reducing levels of excess nutrients. The water quality and living resources monitoring programs are part of the commitment of the Commonwealth of Virginia to restoring the Chesapeake Bay to a healthy, balanced and productive ecosystem.

OVERVIEW

The patterns in trends for water quality and living resources were variable. Some areas showed improvements, many showed little or no change, and some regions are degrading, particularly the Middle and Lower regions of the York and Rappahannock rivers. This pattern reflected the amount of reduction in nutrient inputs into the watershed. Non-point source nutrient loads were reduced 2% and 3% for nitrogen and phosphorus, respectively, while point source loads of nutrients were reduced 11% and 53% for nitrogen and phosphorus, respectively, in the Virginia portion of the Chesapeake Bay watershed.

Between 1985 and 1996, there were several trends indicating improving water quality conditions in the James River, with decreasing trends in algal levels, algal growth rates, nitrogen concentrations and phosphorus concentrations. The York and Rappahannock rivers showed mixed patterns of some improvements, some deteriorations and many parameters unchanged. In the York River, nitrogen levels decreased in some regions, phosphorus increased in some regions and algal levels showed few trends. In the Rappahannock River, there were widespread declines in algal levels, some regions with decreased nitrogen concentrations, but widespread increases in phosphorous concentrations. Water clarity was generally poor in most regions of the tributaries and may affect the patterns seen in algal levels and algal growth rates more than reductions in nutrients due to light limitation of algal growth. The Virginia Chesapeake Bay showed mixed patterns of improving and deteriorating trends in phosphorus, degrading trends in water clarity and no changes in nitrogen and algal levels. Living resources generally followed the water quality patterns, with the best conditions in the James River and mixed patterns of concern in the York and Rappahannock rivers and the Virginia Chesapeake Bay.

Need to specifically identify these areas.

The results of this report confirm the ability of the Chesapeake Bay monitoring program to detect long-term trends in the reduction of eutrophication. Management actions that continue the reductions in nutrients are necessary to improve the current status of the living resources. The results of this report also indicate the need for further reduction of both nitrogen and phosphorus inputs to the Bay. Management actions to further reduce non-point source loads of nutrients (particularly nitrogen) and suspended solids will be required to significantly improve the status of the living resources of Virginia's tributaries.

Bottomline got to make stronger case for this!

Status

Status estimates are based upon the median value for each parameter for the three-year period from 1994-1996. The present status is compared to all historical data from 1985 through 1996. A status of *good* indicates that the median value fell within the lowest third of all data except for water clarity and dissolved oxygen for which the highest third represented the good portion of the data. A status of *fair* indicates that the median value fell within the middle third of all values. A status of *poor* indicated that the median value fell within the highest third of all values except for water clarity and dissolved oxygen for which the lowest third of all values represented the poor portion of the data. It is important that the reader remember that the status estimates are based on comparisons of data collected only within the Chesapeake Bay system. Characterizations of status based upon other criteria may alter the assessment and interpretation of status.

There were no large differences in algal levels and nutrients between the tributaries; however, Virginia's tributaries generally had lower algal levels and nutrients compared to Maryland's tributaries. The status for algal levels, nitrogen and phosphorus was fair or good at all locations in Virginia's tributaries and the Virginia Chesapeake Bay. The status for algal levels was good at all locations in Virginia's tributaries. Nitrogen status was good throughout Virginia's tributaries except in the Elizabeth River where it was fair. Phosphorus status was good throughout the upper regions of the tributaries; however, its status was fair through most of the York River, most of the Lower James River and fair in the Middle Rappahannock River.

Water clarity was the greatest water quality concern. Water clarity was poor throughout most of the James and York rivers and in the Middle Rappahannock River. Water clarity was fair in the Upper and Lower Rappahannock River. Total suspended sediments were poor in part of the York River and fair in much of the James River and the Rappahannock River. Poor water clarity controls rates of algal growth in the upper reaches of each tributary; however, nitrogen limitation is important in the lower regions of the tributaries, especially during the summer. Poor water clarity potentially limits the recovery of submerged aquatic vegetation throughout the tributaries.

The James River did not experience many low dissolved oxygen events. This is presumably due to its hydrographic characteristics that produce fairly rapid and unrestricted flow and to its proximity to oceanic sources of relatively high quality water inflows. On the other hand, the Rappahannock River had low dissolved oxygen events during the summer, particularly in the lower region where a sill restricts flow to the Bay. The York River did not display as severe low oxygen events, but moderately low oxygen concentrations (<5 mg/L) were frequently found.

The status of algal levels was good throughout all regions of the Virginia Chesapeake Bay. The status of both total nitrogen and dissolved inorganic nitrogen ranged from fair to good in all regions of the Virginia Chesapeake Bay. Status of both total phosphorus and dissolved inorganic phosphorus was good in all regions of the Virginia Chesapeake Bay. Status of water clarity was fair in all regions except Pocomoke Sound, which was characterized as poor. Status for dissolved oxygen was fair to good in all but the Upper Virginia Chesapeake Bay where the concentration of summer bottom dissolved oxygen over the past three years was less than 3.0 mg/L.

Trends

The tidal James River exhibited improving algal levels, with a reduction in the magnitude of seasonal peaks throughout the river. There were also widespread improvements in total nitrogen and dissolved inorganic nitrogen concentrations. The improvement in total nitrogen concentrations was most likely related to reductions in both point and non-point source loadings below the fall-line. Total phosphorus and dissolved inorganic phosphorus changed little, although there appeared to be a decline in dissolved inorganic phosphorus in the last seven years corresponding to the phosphate detergent ban. Degrading trends in suspended sediments were detected at two stations in the Upper James River. Improving trends in bottom dissolved oxygen were restricted to the Upper James River.

Few trends in algal levels were observed in the tidal York River. There were improving trends in nitrogen in the Upper Pamunkey and Mattaponi rivers and the Lower York River that tracked the 4% reduction in total nonpoint source loadings, even though point source loadings above the fall-line steadily increased from 1985 to 1995. No trends were detected in dissolved inorganic nitrogen below the fall-line. Both phosphorus and dissolved inorganic phosphorus increased in portions of the Pamunkey and Mattaponi rivers. There were no trends in dissolved oxygen. There was a single improving trend in water clarity in the Upper Mattaponi River. This improvement appears to have been caused by an increase in freshwater input from above the fall-line.

Improving overall trends in algal levels were detected throughout the tidal Rappahannock River except for the Mid-Upstream Rappahannock River. Improving trends in total nitrogen were limited to an overall trend in the Upper Rappahannock River and two season-specific trends in the Lower Rappahannock River. No improving trends in dissolved inorganic nitrogen were detected below the fall-line. Overall degrading trends in phosphorus were detected throughout the entire Rappahannock River. There was little change in dissolved inorganic phosphorus over 12 years which suggests that the increase in phosphorus was due to an increase in organic phosphorus compounds. The source of this organic enrichment did not appear to be anthropogenic, since both point and non-point source loadings decreased since 1985. Low values of dissolved inorganic phosphorus may be a reflection of the low point source loadings in this estuary. Water clarity did not improve in the Rappahannock River over the last 12 years. Deteriorating trends in dissolved oxygen were detected for some or all of the summer months in the Mid-Downstream and Lower Rappahannock River and the Corrotoman River. Plots of concentrations at these segments indicate that dissolved oxygen concentrations were approaching hypoxic levels (<2 mg/L) during most summers.

No improving trends in algal levels were detected in the Virginia Chesapeake Bay. There was no change in total nitrogen. Changes in inorganic nitrogen were limited to an improving trend in Pocomoke Sound and a degrading seasonal trend in the Upper Virginia Chesapeake Bay. Trends in phosphorus concentrations showed no consistent pattern between regions in the Lower Virginia Chesapeake Bay. An improving overall trend and a seasonal improving trend during the spring were detected in the Lower and Middle Virginia Chesapeake Bay, respectively. However, overall and seasonal deteriorating trends were detected in the Upper and Mid-Western Virginia Chesapeake Bay, respectively. There was little change in concentrations of dissolved inorganic phosphorus in the Virginia Chesapeake Bay. Water clarity was degrading in all regions of the Virginia Chesapeake Bay, except the Piankatank River and Mid-Western Virginia Chesapeake Bay. The lack of significant improving trends in summer dissolved oxygen concentrations in the Virginia Chesapeake Bay is probably of little ecological consequence in most regions. The only exception is the Upper Virginia Chesapeake Bay where the concentration of summer dissolved oxygen over the past three years was less than 3.0 mg/L.

Algal Growth Rate And Nutrient Limitation

Are the upriver light limitation conditions natural or anthropogenic in origin?

Status

Can these patterns be tied to light limitation differences across the rivers?

The tidal James River and the Southern Branch of the Elizabeth River had the highest rates of algal growth followed by the Rappahannock River, the York River and the lowest rates in the Virginia Chesapeake Bay. The Upper and Lower Pamunkey and Mattaponi rivers had the lowest algal growth rates. The status of algal growth rates in all regions of the Virginia tributaries and the Virginia Chesapeake Bay was good. Indeed, no areas of the Chesapeake Bay had algal growth rates that were considered poor, indicating that the highest rates of algal growth occurred prior to 1994-1996.

Rates of algal growth were generally light-limited in the upper regions of the tributaries, nitrogen-limited in summer and fall in the lower regions, and phosphorus-limited in the spring. The Upper James River was strongly light-limited and the Lower James River was nitrogen-limited with no phosphorus limitation. The Upper Pamunkey River was light-limited in the winter-spring and nitrogen-limited in the summer when most primary production occurs. The Middle York River was nitrogen-limited, while the Lower York River was phosphorus-limited in the spring and nitrogen-limited in the summer. The Upper Rappahannock River was light-limited and the Lower Rappahannock River was phosphorus-limited in the spring and nitrogen-limited in the summer and fall. The Virginia Chesapeake Bay was phosphorus-limited in the spring and nitrogen-limited in the summer and fall.

Trends

All trends in algal growth rates were improving (decreasing) trends and occurred in the upper and middle portions of all three tributaries. A decrease in algal growth rates was also found in the Middle Virginia Chesapeake Bay and Mid-Western Virginia Chesapeake Bay. There were no trends in rates of algal growth in the lower regions of any of the tributaries.

Need to explain why the upper rivers are responding when the lower rivers tend to holding steady in terms of algal growth rates

Status and Trends

Living resources in the tidal James River (phytoplankton, zooplankton, benthos) generally improved or achieved a good status. In the Upper James River, there were improving trends in the health of the phytoplankton and zooplankton. In the Lower James River, there was a deteriorating trend in zooplankton health. There were no improving or degrading trends in the health of the benthos. However, the health status of the benthic communities in the James River was the best in the Chesapeake Bay basin.

There were mixed patterns of living resource health in the tidal York River, with improving trends in the phytoplankton health in the Middle York River. The zooplankton community showed improving health in the Upper and Middle Pamunkey River and deteriorating health in the Lower York River. There was a deteriorating trend in the benthic health in the Middle York River and poor status throughout the river.

The tidal Rappahannock River exhibited mixed patterns in the health of the biotic communities, with some improving and deteriorating trends. The phytoplankton status was good throughout, with no trends in the health of the phytoplankton community. There were deteriorating trends of bloom producers and cyanobacteria in the Upper and Middle Rappahannock River and decreasing diatom concentrations in the Lower Rappahannock River. There were strong deteriorating trends in benthic health in the Middle York River and poor status throughout the river.

In the Virginia Chesapeake Bay there were phytoplankton trends indicating improving conditions, with decreases in picoplankton and increases in the ratio of total biomass to total abundance in all regions. Zooplankton trends indicated deteriorating conditions. There were no trends in the benthic community health and status of the benthos was the second best in the Chesapeake Bay.

There were some very modest increases in submerged aquatic vegetation (SAV) coverage in the Virginia tributaries over the past 12 years. The only substantial increase occurred in the Lower York River, where SAV coverage went from about 3,000 to 5,000 hectares from 1984 to 1993. No additional increases occurred in the Lower York River after 1993. In the Virginia Chesapeake Bay, all regions, except the Lower Virginia Chesapeake Bay, showed a fairly steady increase in SAV coverage from 1984 until 1993, followed by a drop in coverage during the last three years. The Lower Virginia Chesapeake Bay showed a steady decline in SAV coverage from about 1988 through 1993, followed by two peaks in 1994 and 1996. It is likely that the limited recovery of SAV in the Virginia tributaries and the apparent drop in SAV coverage in the Virginia Chesapeake Bay, is due primarily to the poor water clarity in these regions. Other violations of SAV habitat goals were noted in specific areas and probably adversely affected the success of SAV recruitment in the Virginia waters of Chesapeake Bay. Increased management controls of point and non-point source nutrient and suspended sediment loads will be required to assure continued improvement in SAV.

In August and September 1997, phytoplankton cells belonging to the *Pfiesteria* complex were identified in the Pocomoke, Rappahannock, and Great Wicomico rivers. These cells were in bloom concentrations and accompanied incidents of lesions in menhaden.

INTRODUCTION

The Chesapeake Bay is the largest estuary in the United States, yet the Mainstem of the Bay represents only a small fraction of a total drainage basin of approximately 64,000 square miles (165,760 km^2) (EPA, 1983). The Chesapeake Bay watershed comprises more than 150 rivers, streams and creeks covering portions of six states and the District of Columbia. Six major tributaries, the Susquehanna, Potomac, Rappahannock, James, York and Patuxent rivers, contribute almost 90% of the total freshwater input to the Bay (EPA, 1983). Historically, the Chesapeake Bay has supported some of the most productive commercial fisheries in the world. It also represents an important recreational center and supports a major tourism industry, particularly in the Virginia waters. Two of the nation's largest port complexes, Hampton Roads Harbor and Baltimore Harbor, are located on this estuary.

Environmental conditions in the Bay and its major tributaries have deteriorated significantly over the past 50 years. A variety of potentially toxic substances, primarily from industrial and municipal point sources, have been found in increasing concentrations in the water and sediments of the Bay. Increasing nutrient levels, largely as a result of agricultural runoff and other non-point sources, have been associated with the overstimulation of primary production (e.g., algal blooms) in many areas of the Bay. Excessive nutrient enrichment (eutrophication) may lead to major alterations of the food chain by promoting shifts in the composition of planktonic communities. These changes may then have a detrimental effect on the survival of sensitive early life stages of planktivorous fishes and on the long-term maintenance of commercially and recreationally important finfish stocks. In addition, eutrophication ultimately leads to low dissolved oxygen conditions when organic matter accumulates at rates faster than can be utilized by the decomposers in the system. The spatial and temporal extent of hypoxic and anoxic conditions in the Chesapeake Bay is not yet thoroughly understood, but low dissolved oxygen has been related to at least short-term declines in many of the Bay's biotic components and to widespread degradation of benthic communities (Dauer *et al.*, 1992; Ranasinghe *et al.*, 1994).

The Chesapeake Bay Program (CBP) began in 1976 when the U.S. Congress directed the Environmental Protection Agency (EPA) to initiate a comprehensive study of the Bay's environmental (water quality) conditions and living resources. The results of more than 50 research projects funded by the EPA to examine various abiotic and biotic aspects indicated several areas of concern within the Chesapeake Bay, all of which were related to trends of increasing concentrations of toxics and nutrients in the water and sediments and dramatic declines in the living resources. These observations stimulated the development of directives to better manage the Bay and its associated river systems. The strategy was to establish a cooperative agreement between state and federal agencies to address the current "State of the Bay." The Chesapeake Bay Agreements of 1983 and 1987 were implemented between the EPA, the State of Maryland, the Commonwealths of Pennsylvania and Virginia, and the District of Columbia to share the responsibilities for a comprehensive, long-term program to "revitalize" the Bay. The monitoring of environmental conditions is considered vital to assessing the progress of the Best Management Practices (BMPs) being implemented throughout the Bay and its tributaries.

A major focus in the monitoring program is the detection of natural and/or man-induced changes in environmental conditions over time. The Chesapeake Bay Agreements created a data base that will enable the federal and state authorities to discern long-term trends in the environmental conditions in the Bay. The Virginia Department of Environmental Quality (VDEQ), in cooperation with USEPA, recognized the need to begin to evaluate not only the patterns beginning to form in the environmental data sets, but also the effectiveness of the monitoring program for detecting long-term trends.

The Virginia CBP is a multipurpose program that includes the following programs conducted by Old Dominion University (ODU), the Virginia Institute of Marine Sciences (VIMS) and the Virginia Department of Environmental Quality (VDEQ): water quality monitoring (ODU and VDEQ); benthic biological monitoring (ODU and VIMS); and phytoplankton and zooplankton monitoring (ODU). The overall objectives of the program are to: 1) characterize spatio-temporal patterns in water quality conditions and biological communities in Virginian waters of the Chesapeake Bay and its tributaries; 2) evaluate long-term trends in data collected from major regions of the Virginia Chesapeake Bay and its tributaries; and 3) assess the relationships between water quality and living resources.

This document represents a synthesis of the overall findings of water quality and living resources data generated over the first 12 years of CBP monitoring in the Virginia Chesapeake Bay and its major tributaries. Major comparisons are made to the analysis of water quality and living resources trends from Alden *et al.* (1992a,b) and water quality trends from Alden (1997). A series of more technical documents will also be available which contain the detailed statistical results that are the basis of this report.

MONITORING PROGRAM DESCRIPTION

Water Quality

A marked decline in the water quality of the Chesapeake Bay has occurred over the past several decades. The disappearance of submerged aquatic vegetation in certain regions of the Bay, declines in the abundance of some commercially and recreationally important species, increases in the incidence of low dissolved oxygen events, changes in the Bay's food web, and other ecological problems have been related to the deteriorating water quality. The results of concentrated research efforts in the late 1970s and early 1980s stimulated the establishment of federal and state directives to better manage the Chesapeake Bay watershed. By way of the Chesapeake Bay Agreements of 1983 and 1987, the State of Maryland, the Commonwealths of Virginia and Pennsylvania, and the District of Columbia, agreed to share responsibilities for Bay cleanup efforts.

Monitoring of water quality conditions is considered vital to understanding potential environmental problems, to developing strategies for managing the Bay's resources, and to assessing progress of management practices implemented throughout the Bay and its associated tributaries. This report summarizes the results of statistical analyses conducted on surface measurements of total nitrogen, dissolved inorganic nitrogen, total phosphorus, dissolved inorganic phosphorus, chlorophyll *a*, secchi depth, total suspended solids and bottom measurements of dissolved oxygen. These parameters were analyzed because they are measures of water quality which can directly affect living resources.

The Chesapeake Bay is the largest estuary in the United States....the Chesapeake Bay watershed comprises more than 150 rivers, streams and creeks covering portions of six states and the District of Colombia. Historically, the Chesapeake Bay has supported some of the most productive fisheries in the world.

Nutrients such as total nitrogen and total phosphorus influence the growth of phytoplankton in the water column. Elevated concentrations of these nutrients can result in excessive phytoplankton production (algal growth rate). The consumption of the resulting surplus detrital material by bacteria during the summer may result in depressed levels of dissolved oxygen in bottom waters. Depressed oxygen levels (anoxic or hypoxic events) may cause fish kills and drastic declines in benthic shellfish communities.

Dissolved inorganic nitrogen and dissolved inorganic phosphorus (referred to as inorganic nitrogen and inorganic phosphorus) are the components of total nitrogen and total phosphorus that can be most readily assimilated by the phytoplankton. High concentrations of these two parameters are indicative of poor water quality. Increased inorganic nitrogen and phosphorus can indirectly affect the growth of SAV by increasing densities of phytoplankton in the water column and the densities of epiphytic phytoplankton on SAV leaf surfaces. High densities of both organisms can reduce the amount of light available to the SAV causing reduced productivity.

Chlorophyll *a* is a measure of the level of algal populations in the water column. In general, high chlorophyll *a* or algal levels are considered to be an indicator of deteriorating water quality.

Secchi depth (water clarity) is a measurement of the amount of light available to SAV. Poor or decreasing water clarity can be an indication that conditions within a water body are inadequate for the growth and maintenance of SAV.

Total suspended solids (referred to as suspended sediments) directly affect water clarity. In general, as suspended sediments increase, water clarity decreases. In addition, since suspended sediments can contain organic and mineral components consisting of nitrogen and phosphorus, increases in suspended sediments may result in an increase of nutrients.

SAV beds serve as refuges for juvenile fish, shellfish and other benthic organisms against predators, as well as, providing food for a variety of grazing organisms. As a result, any water quality parameters that affect SAV survival and growth will ultimately affect most, if not all, of the living resources in the Chesapeake Bay.

Virginia's water quality monitoring programs were conducted by Old Dominion University and the Virginia Institute of Marine Science in the Virginia Chesapeake Bay, and by the Virginia Department of Environmental Quality and the U.S. Geological Survey in the estuarine portion of the major tributaries.

Human activities directly affect water quality of the Chesapeake Bay. An attempt was made to describe potential human impacts on water quality and living resource conditions, including land-use patterns, human population levels, and estimates of point and non-point source nitrogen and phosphorus loadings. Human population levels presented in this report were provided by the United States Department of Commerce's Census

Bureau through the Environmental Protection Agency's Chesapeake Bay Program Office. Estimates of land use coverages and non-point source nitrogen and phosphorus loadings were provided by the Virginia Department of Conservation and Recreation. Point source discharge estimates were provided by the Virginia Department of Environmental Quality.

The data base produced by ongoing environmental monitoring programs enables researchers and regulatory managers to discern long-term natural and human-induced changes in water quality and living resource conditions.

Sample Collection and Processing

Water quality conditions were monitored from 18 to 20 times per year at 28 sites in the Virginia Chesapeake Bay and 28 sites in the James, York and Rappahannock rivers beginning in July 1985 (Table 1, Figure 1). Five additional stations were monitored on a monthly basis in the Elizabeth River beginning in February 1989. Field sampling procedures used in the project are discussed in detail in Alden *et al.*, 1992b. Specific laboratory procedures are described in the CBP Quality Assurance Project Plans of the participating agencies. Statistical analytical procedures used are described in (Lane *et al.*, 1998).

Phytoplankton Communities

Phytoplankton are microscopic plants (algae) that represent a ubiquitous and significant component in the waters of the Chesapeake Bay and its tributaries. These plants are the primary producers which support the major food webs within this ecosystem. This is a diverse community of more than 700 species that consist predominantly of unicellular and colonial forms (Marshall 1994). In addition to providing a food source to zooplankton, nekton and benthic species, the phytoplankton also generate oxygen for these same organisms. In contrast to this beneficial role, excessive phytoplankton growth may lead to algal "blooms", hypoxic (or anoxic) conditions and fish kills. More severe devastation to local fisheries can come from certain toxin-producing species if they reach high levels of abundance. For instance, in August 1997 there were fish kills and a high incidence of fish possessing lesions in the Pocomoke River. These events were associated with the presence of phytoplankton belonging to the *Pfiesteria* complex, of which at least one species was identified as a toxin producer. In September 1997, fish with lesions and cells from the *Pfiesteria* complex were found in the lower Rappahannock and Great Wicomico rivers.

The growth patterns of phytoplankton will fluctuate during the year in response to changing environmental conditions within the region, and perturbations to the local water quality (Marshall and Alden 1990;1997). A distinct subdivision within the phytoplankton is the autotrophic picoplankton, which is composed of cells ranging from 0.2 to 2.0 microns in size. The picoplankton and phytoplankton categories are the major producer communities that support the microbial and metazoan food webs, respectively, and that serve as oxygen sources within these waters (Marshall, 1995). Any major or lasting shifts in water quality conditions will directly alter the concentrations and balance that exist between these two producers and, subsequently, the stability of the higher trophic levels that depend upon each of these floral communities.

In general, a more favorable estuarine habitat and water quality status are associated with waters dominated by a diatom flora in contrast to high, or increasing, concentrations of cyanobacteria and autotrophic picoplankton. Rising algal concentrations, reduced species diversity, and increased algal growth rates are also not favorable conditions and are often associated with degrading habitat conditions. Similarly, a transition from cells with high biomass (diatoms) to smaller, more abundant cells (cyanobacteria, picoplankton) represent a degrading trend in the floral composition in the water column.

Sample Collection and Processing

Water column collections for phytoplankton in the Chesapeake Bay began July 1985 at seven stations, and in March 1986 six additional stations were added in the James, York, and Rappahannock rivers, with two more stations in the Elizabeth River included in February 1989 (Table 1, Figure 1). Picoplankton analysis and productivity (algal growth rates) were added at all stations in July 1989. For details concerning periods beyond monthly sampling efforts, see Marshall (1998). Field sampling and laboratory analytical procedures used in the phytoplankton program are discussed in detail in Alden *et al.* (1992b) and Marshall (1998).

Algal Growth Rate and Nutrient Limitation

Rates of algal growth were measured as the rates of primary productivity at each phytoplankton monitoring station using the C^{14} technique starting in July 1989 (Marshall and Nesius, 1993;1996).

Algal growth rates can be controlled by the amount of available nutrients or by the amount of available light (as indicated by water clarity). Nutrient-addition bioassays were conducted to determine if algal growth rates were controlled by nitrogen concentrations, phosphorus concentrations or by light availability. Nutrient-addition bioassays were conducted periodically in the Virginia Chesapeake Bay and its tributaries from 1989 through early 1993 (Haas and Webb, 1998).

Zooplankton Communities

The zooplankton have been systematically monitored since 1985. They represent the essential linkage between the food producing phytoplankton and the larger animals within the estuary. As phytoplankton react to nutrient loads, the zooplankton community consumes these primary producers. Zooplankton are, in turn, consumed by other levels such as larval and juvenile stages of fish and shellfish. Long-term trends in zooplankton allow us to understand the various food linkages. This insight will ultimately result in a more sound basis for making management decisions. Continued monitoring of zooplankton is particularly important because any major change in the composition and abundance of this community will have direct impact on the fisheries within Chesapeake Bay. The accumulation of zooplankton monitoring data has resulted in observable changes over space and time in a number of zooplankton community indicators that reflect environmental health. The most important of these is the number of species or diversity. Total zooplankton abundance and, to a lesser extent, biomass appear to be viable indicators. For instance, unfavorable trends would be associated with reduced numbers of and abundance of species. Other indicators specific to the tidal freshwater areas may also be good bioindicators but they did not show significant trends during the monitoring period.

Sample Collection and Processing

Mesozooplankton were monitored at seven stations in the Chesapeake Bay since July 1985, and in the James, York, and Rappahannock rivers since March 1986 (Table 1, Figure 1). Microzooplankton analysis began in January 1993. Field sampling and laboratory analytical procedures used in the zooplankton program are discussed in detail in Alden *et al.* (1992b) and Carpenter (1998).

Benthic Communities

The health of any aquatic system can be assessed using a variety of abiotic and biotic variables. Abiotic variables are generally direct physical or chemical parameters of water quality (dissolved oxygen, turbidity, nitrogen, phosphorus, heavy metals, chlorinated hydrocarbons, aromatic hydrocarbons, etc.). Measuring these variables is necessary to evaluate and detect sources of pollution and to provide means for evaluating the effectiveness of control or abatement measures. However, the ultimate evaluation of the health of any body of water must emphasize the condition of the living resources.

A wide variety of biotic variables can be measured. Estimates of the benthic macrofaunal community (organisms retained on a 0.5 mm screen) are often used to indicate environmental health because benthic animals (1) are relatively sedentary, (2) have relatively long life spans, (3) consist of different species that exhibit different tolerances to stress, (4) are economically important or are important food sources for economically or recreationally important species, and (5) have an important role in recycling nutrients and other chemicals between the sediments and the water column. Reviews of the rationale for pollution monitoring have confirmed the importance of benthic biological monitoring in meeting the primary objectives of most marine and estuarine monitoring programs (Bilyard, 1987).

Sedentary benthic organisms represent optimal indicator species because mobile species (such as fish) are able to leave or avoid stressed habitats. The relatively long life span of many macrobenthic species (compared to short-lived planktonic species) enables an evaluation of previous water quality conditions. The macrobenthic community is composed of species that vary from being extremely tolerant to extremely sensitive to changes in water quality. Comparisons of the relative proportions of these different species allow an evaluation of the amount of environmental stress.

The ecological role of benthic organisms is complex but includes activities that affect the exchange of materials across the sediment-water interface including potential toxicants (Aller, 1978; Berner, 1976; Swartz and Lee, 1980), and acting as an essential link to higher levels in the estuarine food web (Dauer *et al.*, 1982; Holland *et al.*, 1980; Virnstein, 1979). Benthic community condition has been significantly related to anthropogenic inputs and activities in the Chesapeake Bay watershed (Ranasinghe *et al.*, 1994). In addition, long-term trends in benthic communities have been successfully related to trends in water quality of the Chesapeake Bay (Dauer and Alden, 1995).

Sample Collection and Processing

Benthic communities of the Virginia Chesapeake Bay and its tributaries were sampled quarterly at 21 stations (Table 1, Figure 1). In 1996 the benthic monitoring program was modified with sampling at the fixed-point stations (Table 1) occurring in June and September and a probability-based sampling design initiated. In each of four strata (James River, York River, Rappahannock River and the Virginia Chesapeake Bay) 25 randomly selected locations were sampled. Probability-based sampling allows areas of each tributary with healthy or

Table 1.

Virginia Chesapeake Bay Program water quality, plankton and benthic monitoring program stations used in the 1997 Reevaluation analyses.

James River:

Station	Benthic	Plankton	Segment	Region
TF5.2			JMSTF1	Upper James River
TF5.3			JMSTF1	Upper James River
TF5.5	X	X	JMSTF1	Upper James River
TF5.6			JMSTF1	Upper James River
TF5.4			JMSTF2	Appomatox River
RET5.2	X	X	JMSOH1	Middle James River
LE5.1	X		JMSOH1	Middle James River
RET5.1			JMSOH2	Chickahominy River
LE5.2	X		JMSMH	Lower James River
LE5.3			JMSMH	Lower James River
LE5.4	X		JMSMH	Lower James River
LE5.5		X	JMSPH	Lower James River
LE5.6			JMSMH	Lower James River

Elizabeth River:

Station	Benthic	Plankton	Segment	Region
SBE2	X	X	WT10PH	Elizabeth River
SBE5	X	X	WT10PH	Elizabeth River
EBE1			WT10PH	Elizabeth River
WBE1			WT10PH	Elizabeth River
ELI2			WT10PH	Elizabeth River

York River:

Station	Benthic	Plankton	Segment	Region
TF4.4			YRKTF1	Upper Mattaponi River
TF4.2	X	X	YRKTF2	Upper Pamunkey River
RET4.2		X	YRKOH1	Lower Mattaponi River
RET4.1		X	YRKOH2	Lower Pamunkey River
RET4.3	X	X	YRKMH	Middle York River
LE4.1	X		YRKMH	Middle York River
LE4.2			YRKPH	Lower York River
LE4.3	X		YRKPH	Lower York River
WE4.2		X	WE4PH	Lower York River

Table 1.
Continued

Rappahannock River:

Station	Benthic	Plankton	Segment	Region
TF3.2			RAPTF	Upper Rappahannock River
TF3.3	X	X	RAPTF	Upper Rappahannock River
RET3.1	X	X	RAPOH	Mid-Upstream Rappahannock River
RET3.2			RAPOH	Mid-Upstream Rappahannock River
LE3.1			RAPMH1	Mid-Downstream Rappahannock River
LE3.2	X		RAPMH2	Lower Rappahannock River
LE3.4	X		RAPMH2	Lower Rappahannock River
LE3.6		X	RAPMH2	Lower Rappahannock River
LE3.3			RAPMH3	Corrotoman River

Chesapeake Bay Mainstem:

Station	Benthic	Plankton	Segment	Region
CB5.3			CB5MH	Upper Virginia Chesapeake Bay
CB5.5			CB5MH	Upper Virginia Chesapeake Bay
CB5.4	X		CB5MH	Upper Virginia Chesapeake Bay
CB5.4W			CB5MH	Upper Virginia Chesapeake Bay
CB6.1	X	X	CB6PH	Middle Virginia Chesapeake Bay
CB6.2			CB6PH	Middle Virginia Chesapeake Bay
CB6.3			CB6PH	Middle Virginia Chesapeake Bay
CB6.4	X	X	CB6PH	Middle Virginia Chesapeake Bay
CB7.1			CB7PH	Eastern Virginia Chesapeake Bay
CB7.1S			CB7PH	Eastern Virginia Chesapeake Bay
CB7.1N			CB7PH	Eastern Virginia Chesapeake Bay
CB7.2			CB7PH	Eastern Virginia Chesapeake Bay
CB7.2E			CB7PH	Eastern Virginia Chesapeake Bay
CB7.3			CB7PH	Eastern Virginia Chesapeake Bay
CB7.3E	X	X	CB7PH	Eastern Virginia Chesapeake Bay
CB7.4N			CB7PH	Eastern Virginia Chesapeake Bay
CB7.4		X	CB8PH	Lower Virginia Chesapeake Bay
CB8.1	X		CB8PH	Lower Virginia Chesapeake Bay
CB8.1E			CB8PH	Lower Virginia Chesapeake Bay
EE3.4			EE3MH	Pocomoke Sound
EE3.5			EE3MH	Pocomoke Sound
LE3.7			WT9PH	Piankatank River
WE4.1			WE4PH	Mid-Western Virginia Chesapeake Bay
WE4.3			WE4PH	Mid-Western Virginia Chesapeake Bay
WE4.4			WE4PH	Mid-Western Virginia Chesapeake Bay

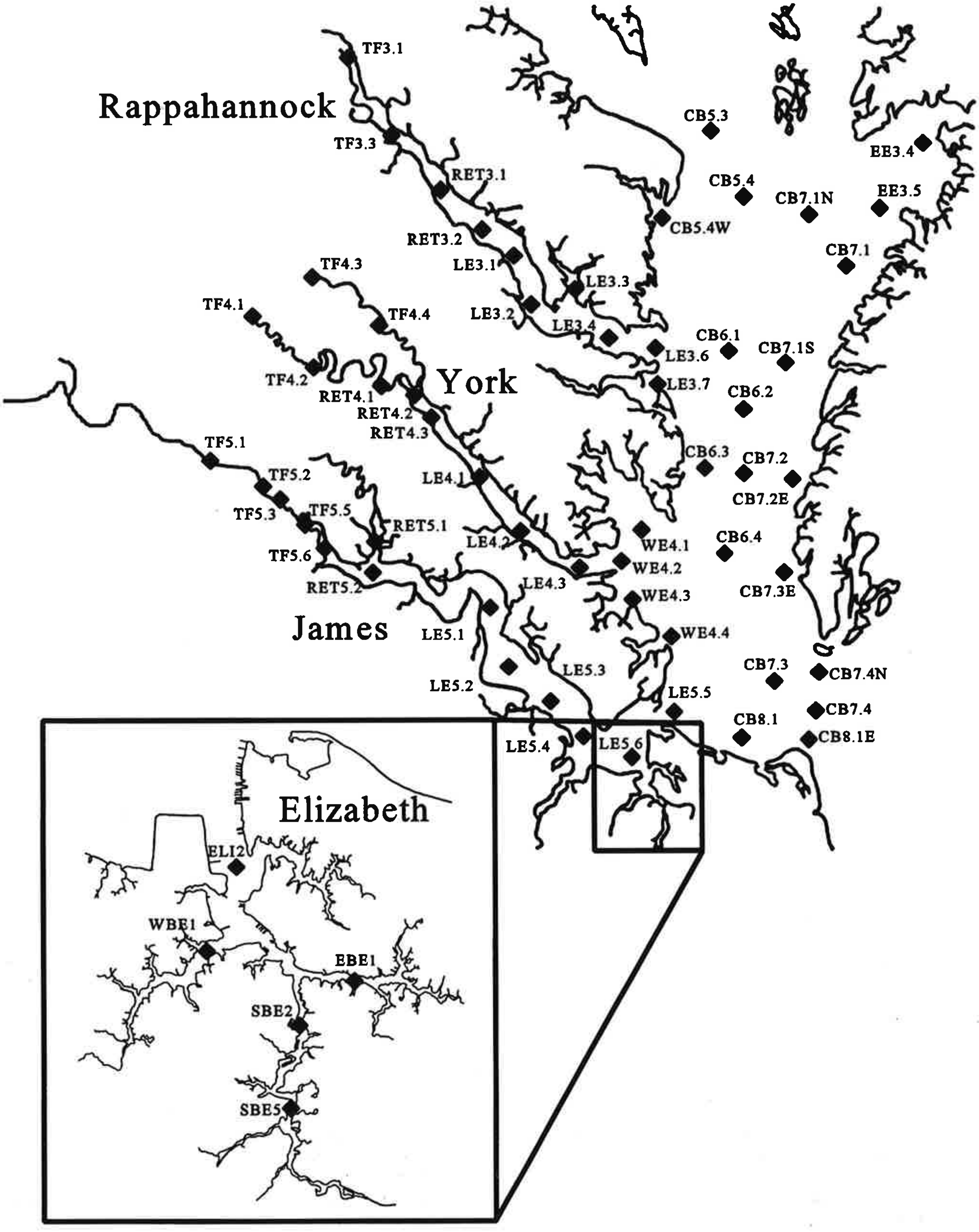


Figure 1. *Map of the Virginia Chesapeake Bay showing monitoring station locations.*

degraded benthic communities to be estimated with a known level of statistical confidence.

Field sampling and laboratory analytical procedures used in the benthic program are discussed in detail in Alden *et al.* (1992b) and Dauer (1997).

Health of the Living Resources

The health of the living resources of the Bay is summarized by an Index of Biotic Integrity (IBI). The IBI is based upon conditions for each community (phytoplankton, zooplankton and benthos) at reference sites that are considered to be minimally stressed by eutrophication and other human impacts. The zooplankton IBI was not considered reliable in its present form and the health of this community was determined by a species richness index, Margalef's Index (Carpenter, 1998), and the trend analysis results reported here reflect this index. However, the IBI was retained as a measure of status.

RESULTS AND DISCUSSION

JAMES RIVER

Basin Characteristics

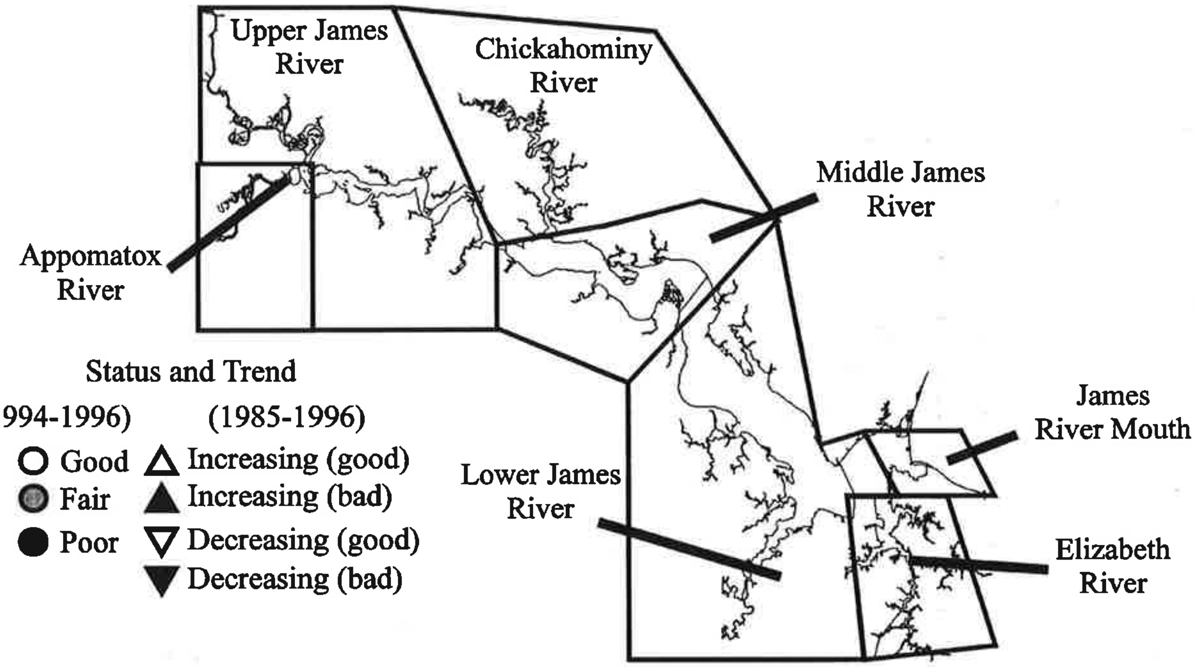
Approximately 66% of the basin is forested, 25% is agricultural croplands and the remaining 9% is urban residential and industrial land concentrated primarily in metropolitan areas such as Hampton Roads and Richmond. Only slight reductions in the percentages of forested and agricultural land-use occurred in the basin from 1985 to 1995. Population levels in the James River basin rose from one million to 1.5 million individuals from 1980 to 1996.

> ***The James River is the dominant tributary in Virginian waters of the Chesapeake Bay, with a typical flow rate 2-3 times greater than that of the York and Rappahannock rivers combined. The high flow and more urbanized nature of the James River watershed make it different in water quality characteristics from the other two major tributaries in Virginia. The James River had the highest concentrations of nutrients that stimulate the highest levels of primary production and because of its high flow rate, this tributary appears to be a major source of nutrients to the lower Chesapeake Bay. However, the rapid flow and proximity to clean ocean water of the James River generally prevent low oxygen events that are believed to produce the stress observed in the Virginia Chesapeake Bay and its tributaries.***

Estimates of total above and below fall-line non-point source nitrogen loadings decreased approximately 3% from 31.2 million lb/yr in 1985 to 30.3 million lb/yr in 1995. Estimates of total above and below fall-line non-point source phosphorus loadings decreased approximately 2% from 3.5 million in 1985 to 3.4 million lb/yr in 1995.

Point source loadings of total nitrogen above the fall-line showed little change from 1985 to 1995 with values for most years ranging from 2.3 million to 2.5 million lb/yr, with the exception of two peaks of 2.8 million lb/yr in 1988 and 3.2 million lb/yr in 1994. Point source loadings of total nitrogen below the fall-line increased from 21.1 million lb/yr in 1985 to 25.5 million lb/yr in 1988 and then decreased to 17.8 million lb/yr in 1995. Point source loadings of total phosphorus above the fall-line decreased from 538,000 lb/yr in 1987 to 341,000 lb/yr in 1992 and increased to 498,000 lb/yr in 1994. Point source loadings of total phosphorus below the fall-line showed a large decline

Figure 2. Map of the James River showing summaries of the status and trend analyses for each region at and below the fall-line. Station-specific trends are identified by a station designation found under the trend marker in any appropriate columns. Season-specific trends are indicated by a number under the triangle marker that identifies a trend. The number refers to the number of the month for the year. In cases where there are heterogeneous season-specific trends for a given parameter/region combination, there are two triangles in the appropriate column. Abbreviations for each parameter are: total nitrogen=STN; inorganic nitrogen=SDIN; total phosphorus=STP; inorganic phosphorus=SDIP; algal levels=SCHLA; water clarity=SECCHI; suspended sediments=STSS; dissolved oxygen=BDO; algal growth rate=C14; phytoplankton community health=P-IBI; zooplankton community health =Z-IBI; and benthic community health=B-IBI.



	STN	SDIN	STP	SDIP	SCHLA	SECCHI	STSS	BDO	C14	P-IBI	Z-IBI	B-IBI
Appomatox Fall-line	○ NS	NA	○ NS	○ ▲	NA	NA	○ NS	NA	NA	NA	NA	NA
James Fall-line	○ NS	○ NS	○ ▽	◍ ▽	NA	NA	○ NS	NA	NA	NA	NA	NA
Upper James	○ ▽	○ ▽	○ ▽ TF5.3	○ ▽ TF5.3 TF5.5	○ ▲ 12 ▽ 8	◍ △ TF5.3	◍ ▲ TF5.5 TF5.6	○ △	○ ▽	○ △	◍ △	NA
Appomatox	○ ▽	○ NS	○ NS	○ NS	○ ▲ 12 ▽ 3,6-9	● NS	◍ NS	○ NS	NA	NA	NA	NA
Middle James	○ ▽	○ ▽	○ ▲	○ NS	○ NS	● ▼	◍ NS	○ NS	○ ▽	○ NS	◍ NS	● NS
Chicka-hominy	○ NS	○ NS	○ NS	○ NS	○ NS	● NS	◍ NS	NA	NA	NA	NA	● NS
Lower James	○ ▽	○ ▽	◍ ▲ 7 ▽ 12	◍ NS	○ ▽	● NS	○ ▲ 1	○ NS	NA	NA	NA	○ NS
River Mouth	○ NS	○ NS	◍ NS	○ NS	○ NS	● NS	○ NS	○ NS	○ ▽	○ ▼	○ ▼	○ NS
Elizabeth	◍ NS	◍ ▽	◍ ▽	◍ ▲ 1,11 ▽ 2,8,10	○ NS	○ NS	○ NS	◍ △	○ NS	○ NS	○ ▼	○ NS

from 3.7 million lb/yr in 1986 to 1.2 million lb/yr in 1995.

Water Quality

Water quality conditions in the tidal James River either improved or remained relatively stable over the past 12 years (Figure 2). Although reductions in point and non-point source loadings are, in part, responsible for the changes seen, additional improvements in management practices could still be made, particularly with respect to water clarity.

__Summary Points__

- Greater dominance of point source loads compared to other Virginia tributaries.
- Point source loads improving.
- Fall-line nutrients improving.
- Below fall-line improvements in algal levels, total nitrogen and algal growth rate.
- Potential light limitation of the algal growth rate throughout the river.
- Living resources (phytoplankton, zooplankton, benthos) generally improving or in good health.
- Improving trends in phytoplankton and zooplankton community health in Upper James River.
- Deteriorating trend in zooplankton community health in the Lower James River.
- No trends in the benthic community health.
- Health of the benthic communities the best in the Chesapeake Bay.
- Concern for SAV potential recovery due to poor water clarity.
- Proximity to oceanic water and hydrodynamic mixing prevents dissolved oxygen problems.

Status of total nitrogen and inorganic nitrogen ranged from fair to good in all regions of the James River. In those regions with established SAV goals, inorganic nitrogen concentrations either met or marginally met the goal. In addition, widespread reductions in total nitrogen and inorganic nitrogen concentrations occurred that appear to be related to an effect other than freshwater input. The reductions in nitrogen concentration were most likely related to reductions in both point and non-point source loadings below the fall-line. Since these improvements appear to be related, at least in part, to point and non-point source reductions, additional controls in nitrogen loadings should result in further improvements in ambient nitrogen concentrations.

Status of total phosphorus and inorganic phosphorus ranged from fair to good in all regions of the James River; however, the SAV goals for inorganic phosphorus were either not met or only marginally met in most regions of the James River. Improving trends in total phosphorus concentrations were limited to a station-specific trend in the Upper James River and a season-specific trend in the Lower James River, while a degrading overall trend in total phosphorus was found in the Middle James River. Trends in inorganic phosphorus were limited to two station-specific trends in the Upper James River. Despite a lack of statistically significant trend results in most regions, an examination of plots of monthly values over time indicates that there was a general reduction in inorganic phosphorus throughout the James River over the past seven years that appears to coincide with the phosphate ban. Although the evidence for most regions is only circumstantial, improvements in phosphorus concentrations appear to have been made in the James River. The phosphate ban also had a significant impact on localized concentrations of phosphorus in the Richmond area (Hoffman and Bishop, 1994). As with nitrogen, additional controls of phosphorus loadings should result in additional improvements in ambient phosphorus concentrations.

Status for algal levels was fair to good throughout the James River and the SAV goal for this parameter was either met or marginally met in all regions of the James River. It should be noted that although algal levels are good overall in the Upper James, there are areas near Hopewell where algal levels were very high (VWCB, 1991). Improving season-specific trends in algal levels were detected in the Upper and Middle James River. In addition, there was a general reduction in the magnitude of seasonal peaks in algal levels throughout the river. Reductions in algal levels may be tied to the decreases in total nitrogen and total phosphorus. Alternatively, these reductions could be related to the poor water clarity in this tributary.

Status for water clarity was poor in all but the Upper James River where it was fair and SAV goals for water clarity were met or marginally met throughout the James River. An improving trend in water clarity occurred in the tidal fresh portion of the estuary which was related to a change in the flow regime. The poor status and lack of improving trends in water clarity in most regions may reduce the chance of improvements in SAV growth within the James River.

Need to make a better case for this!

What else would explain the improvements? Fall line results help?

Need to forge a tighter link w/ loading trends geographically

Does this show up in the 1985–1996 data record?

Does this show up in the 1985–96 data record?

Need to nail this down — was it decreases in TP, TN or decreases in water clarity?

Does the exact location of ~~point source~~ dischargers help explain these station specific trends?

Although the status for suspended sediments ranged from fair to good in all regions of the James River, the SAV goal for this parameter was met only in the Lower James River. Deteriorating trends in suspended sediments were detected at two stations in the Upper James River. Management controls of suspended sediments should help improve water clarity in the James River.

Improving trends in dissolved oxygen were restricted to the Upper James River; however, it is unlikely that this trend was of any ecological consequence since the status for dissolved oxygen was good in all regions of the James River and summer values rarely dropped below the Virginia state short-term dissolved oxygen standard of 4.0 mg/L.

Phytoplankton Communities

Phytoplankton communities of the James River were dominated by a favorable diatom composition with improving conditions as indicated by declining trends of less desirable cyanobacteria and autotrophic picoplankton. The status for the phytoplankton community health and algal levels was good for each region of the river. There were two trends in phytoplankton community health; a 17% increase in the Upper James River and a 13% reduction in the Lower James River. This indicates that general phytoplankton community health may be improving upstream but degrading downstream. The observation that conditions are improving in the Upper James River is supported by the decreasing trends observed in total phytoplankton abundance, cyanobacteria biomass, and the ratio of bloom-producing biomass to total phytoplankton biomass.

The algal growth rates were highest in the James River compared to the York and Rappahannock rivers. These rates were highest upstream and decreased downstream along with decreasing nutrient levels. There were improving trends in algal growth rates throughout the river. Improving trends in algal levels and algal growth rates were linked to overall improving trends in total nitrogen and inorganic nitrogen, and improving trends in total phosphorus and inorganic phosphorus upstream. In the Upper James River, the algal growth rate was strongly light-limited while the Lower James River was strongly nitrogen-limited. There was no seasonal phosphorus limitation. Status for the algal growth rate was good at all stations.

Although reductions in point and non–point source loadings are, in part, responsible for the changes seen, additional improvements in management practices could still be made. Results suggest that water quality conditions improved while living resources either improved or remained stable in the James River.

Based on these findings, the overall characterization of the phytoplankton community in the James River is favorable and shows signs of improving conditions.

Zooplankton Communities

Zooplankton communities showed a mixed pattern in the James River with an improving trend in health in the Upper James River but a degrading trend in the Lower James River. The improving zooplankton community health trend in the upper region suggests a linkage with the improving trends in both water quality and the phytoplankton community health. In the Lower James River, the decreasing trend in zooplankton community health suggested deteriorating environmental conditions as was also indicated by the deteriorating trend in phytoplankton community health. Status for the James River zooplankton community health was fair to good at all stations. Status of food availability for fish larvae ranged from poor to minimal.

Benthic Communities

There were no trends in the benthic community health. The benthic communities of the James River were the healthiest in the Chesapeake Bay with 84% of the benthos meeting the benthic restoration goals (Dauer, 1997). The health of benthic communities appears to be directly linked to the generally good and/or improving water quality conditions in the James River.

Summary

Widespread decreases in algal growth rates in the James River appear to be linked to improving water quality conditions indicated by reductions in nutrients. Reductions in algal growth rates in the Upper James River may be related to an increase in suspended sediments. Trends in the phytoplankton community parameters, the phytoplankton community health and zooplankton diversity indicate improvements in living resources occurred over the past 12 years in the upper reaches of the river. Although trends in benthic community health show no change over the past 12 years, current status indicates that benthic communities are in good health. These results suggest that water quality conditions improved while living resources either improved or remained stable in the James River.

ELIZABETH RIVER

Can the reasons behind this be explained given the lack of a chlorophyll a trend?

Basin Characteristics

Nearly 75% of land use in the Elizabeth River basin is considered urban industrial or residential. There was an increase of 9% in urbanized land coverage in the Elizabeth River basin from 1985 to 1995. Population levels in the Elizabeth River basin rose from 630,000 to 780,000 individuals from 1980 to 1996. Estimates of non-point source total nitrogen and total phosphorus loadings increased 4.4% and 5.5%, respectively, from 1985 to 1995. Point source total nitrogen loadings remained fairly stable in the Elizabeth River generally ranging from 2.4 million lb/yr to 3.0 million lb/yr with a minimum of 1.8 million lb/yr in 1989. Point source total phosphorus loadings showed a dramatic decrease from 1.1 million lb/yr in 1987 to levels below 400,000 lb/yr from 1989 to 1995. These reductions are a result of the phosphate ban.

Water Quality

Although status for the majority of water quality parameters was either fair or poor, the Elizabeth River experienced some modest improvements (Figure 2).

Status for total nitrogen and inorganic nitrogen was fair, but concentrations of inorganic nitrogen violated the SAV goal. However, an overall decreasing trend in inorganic nitrogen was detected, indicating that conditions with respect to this nutrient are improving. Increased controls of point and non-point source nitrogen could help to continue improving conditions with respect to this nutrient.

Can this trend be tied to documented load reductions?

Although current conditions for both total phosphorus and inorganic phosphorus are characterized as fair and concentrations of inorganic phosphorus violated the SAV goal, an overall decreasing trend in total phosphorus and season-specific trends in inorganic phosphorus for the months of February, August and October were detected. These reductions appear to be related to the reduction in point source loadings caused by the phosphate ban.

Current algal levels in the Elizabeth River were characterized as good and marginally met the SAV goal for the parameter. No improvements were seen in this parameter over the past seven years.

Status for water clarity in the Elizabeth River for the last three years was poor and current water clarity levels are below the SAV goal for this parameter. However, water clarity improved in the Elizabeth River, as indicated by the increasing trend detected in this parameter.

Due to TSS given lack of a chlorophyll a trend?

Dissolved oxygen concentrations are improving as indicated by the overall increasing trend detected in this parameter. As a result of this trend, bottom dissolved oxygen concentrations increased to above 3 mg/L during the summer months causing the status of bottom dissolved oxygen to be characterized as fair.

Phytoplankton Communities

The status for phytoplankton community health was good, with no significant trends identified. Among the phytoplankton, diatoms and chlorophytes showed improving trends with improved water clarity. Improving trends in inorganic nitrogen and total phosphorus were linked to improving trends in autotrophic picoplankton and species diversity. The Elizabeth River also exhibited several unfavorable trends in the phytoplankton community. These trends included increased concentrations of bloom species and a decline in species diversity, with seasonal increases in cyanobacteria occurring in the lower strata upstream. Generally, phytoplankton concentrations improved moving downstream. This improvement was associated with increased diatoms and salinity and decreased picoplankton throughout the water column.

These phytoplankton populations were mainly dominated by flora similar to the Chesapeake Bay stations, with little influence coming from upstream flow. A good status was associated with these algal levels and their growth rate. However, phytoplankton community health and many of these rankings may be considered borderline to a less favorable condition. Improvement in this status will be influenced by further nutrient reductions and gains in water quality conditions.

Need to make this clearer given the mixed bag of trends above

Zooplankton Communities

Improving trends in mesozooplankton abundance were detected at both Elizabeth River stations. However, species diversity showed a deteriorating trend at one station. The increased abundance may be a result of generally improving water quality trends as evidenced by decreases in inorganic nitrogen and total phosphorus. The decrease in diversity may be indicative of some station-specific environmental disturbance that was not measured by this monitoring program. Status of zooplankton community health was good at both stations. Status of food availability for fish larvae was poor at both stations.

Benthic Communities

There was a significant trend of improving benthic community health at station SBE5 in the Southern Branch of the Elizabeth River. At SBE5 there were trends of increasing community biomass, species richness and abundance of individuals. Although there was improvement at SBE5, the status at that station remained poor and all benthic community parameters except abundance have 1994-1996 levels that are considered poor. Station SBE2 also was classified as poor with all benthic community parameters except abundance with levels considered poor or very poor. The poor benthic communities of the Elizabeth River are probably more related to levels of contaminants in the sediments than to water column parameters (Alden *et al.*, 1988; Dauer, 1993; Dauer *et al.*, 1993; Ranasinghe *et al.*, 1994).

YORK RIVER

Basin Characteristics

Approximately 64% of the basin is forested, 32% is agricultural croplands and the remaining 4% is urban land. Almost no change in land use percentages occurred in the basin from 1985 to 1995. Population levels in the York River basin rose from 123,000 to 182,000 individuals from 1980 to 1996.

Estimates of non-point source total nitrogen decreased 4% in the York River from 9.7 million in 1985 to 9.3 million lb/yr in 1995. Estimates of non-point source total phosphorus loadings decreased 6% in the York River from 800,000 to 750,000 lb/yr from 1985 to 1995.

Point source loadings of total nitrogen above the fall-line steadily increased from 83,000 lb/yr in 1985 to nearly 300,000 lb/yr in 1995. Point source loadings of total nitrogen below the fall-line fluctuated from 1985 to 1995. The loadings decreased from 1.25 million to 670,000 lb/yr from 1985 to 1988, increased to 1.23 million lb/yr in 1993 and then declined to 970,000 lb/yr in 1995. Point source loadings of total phosphorus above the fall-line increased from 23,000 lb/yr to 33,000 lb/yr from 1985 to 1989. Phosphorus loadings then decreased from 1989 to 1993 as a result of the phosphate detergent ban, but rose again to reach levels above 40,000 lb/yr in 1995. Point source loadings of total phosphorus below the fall-line decreased drastically from 1985 to 1989 from 400,000 lb/yr to less than 100,000 lb/yr. The loadings increased and stabilized at approximately 120,000 lb/yr over the past four years.

> *The York River displays some characteristics in common with those of both the Rappahannock River and the James River. The magnitude of freshwater flow into the York River is similar to that found in the Rappahannock River. Land use characteristics of the York River watershed are also similar to those of the rural Rappahannock River watershed, in contrast to the more urbanized James River basin. However, the York River does not have the same type of shallow sill that is found in the mouth of the Rappahannock River. Thus, like the James River, the flow of the York River is less restricted and its bottom waters exchange with those of the Bay much more freely than do those of the Rappahannock River.*

Need to talk in terms of further N, P reductions will likely result in what living resource response!

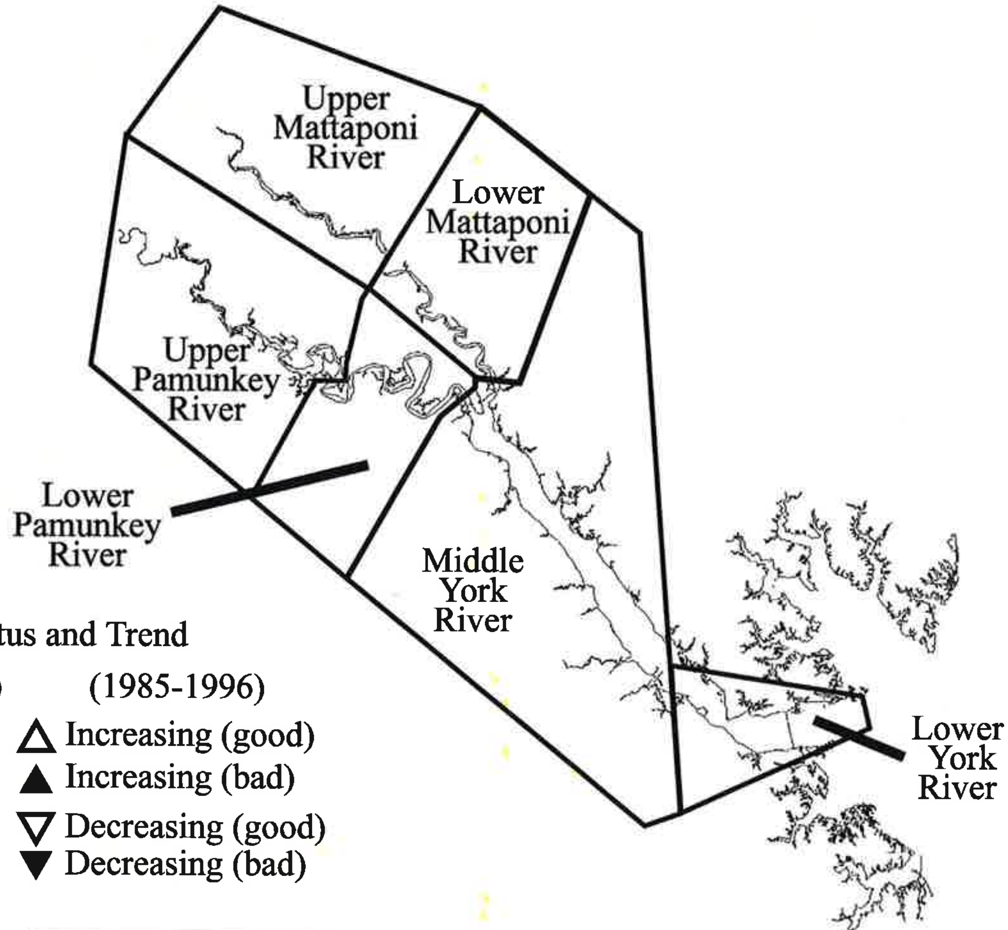
Water Quality

Got to lay out a better story for the York

Results of the status and trend analyses should be interpreted with caution. Although some improvements were indicated and the status of most parameters was good (Figure 3), the observed patterns seen do not necessarily reflect the results of management actions. In addition, some parameters exhibited trends indicative of degrading conditions.

Status of total nitrogen and inorganic nitrogen was good in all regions of the York River and in those regions with an established SAV goal, inorganic nitrogen concentrations were at levels which met that goal. Improving trends in total nitrogen occurred in the Upper Pamunkey and Mattaponi Rivers and Lower York River. Paradoxically, point source loadings above the fall-line steadily increased from 1985 to 1995, while concentrations of total nitrogen in both the Upper Pamunkey and Mattaponi Rivers showed a steady decline over the past 12 years. Plots of concentrations of total nitrogen in the Lower York River indicate a slight but steady increase from 1985 through 1993, followed by a decrease in concentration over the last three years. The drop in total nitrogen could reflect the drop in point source loads seen below the fall-line and/or the reduction in non-point source loadings. No trends were detected in inorganic nitrogen below the fall-line and plots of the concentrations of inorganic nitrogen show no apparent change over 12 years throughout the York River. Additional point and non-point source controls of nitrogen should result in reductions of ambient concentrations.

Status of total phosphorus and inorganic phosphorus was fair to good in all regions and the SAV goals for



Status and Trend

(1994-1996)
○ Good
◍ Fair
● Poor

(1985-1996)
△ Increasing (good)
▲ Increasing (bad)
▽ Decreasing (good)
▼ Decreasing (bad)

	STN	SDIN	STP	SDIP	SCHLA	SECCHI	STSS	BDO	C14	P-IBI	Z-IBI	B-IBI
Mattaponi Fall-line	○ ▽	○ ▽	○ ▽	○ ▲	NA	NA	○ NS	NA	NA	NA	NA	NA
Pamunkey Fall-line	○ NS	○ ▲	○ NS	○ ▲	NA	NA	○ NS	NA	NA	NA	NA	NA
Upper Mattaponi	○ ▽	○ NS	○ ▲	○ ▲	○ NS	◍ △ 2, 9 ▼ 3	○ NS	○ NS	NA	NA	NA	NA
Upper Pamunkey	○ ▽	○ NS	○ ▲	○ NS	○ NS	◍ NS	○ NS	○ NS	○ ▽	○ NS	◍ NS	NA
Lower Mattaponi	○ NS	○ NS	◍ ▲	◍ NS	○ NS	● NS	● ▲ 3 ▽ 5	○ NS	NA	NA	NA	NA
Lower Pamunkey	○ NS	○ NS	◍ NS	◍ ▲	○ NS	● NS	● NS	○ NS	NA	NA	NA	NA
Middle York	○ NS	○ NS	◍ NS	◍ NS	○ NS	● NS	● NS	○ NS	○ ▽	○ △	○ △	● ▼ RET4.3
Lower York	○ ▽	○ NS	◍ NS	○ NS	○ ▲ 10 ▽ 1, 8	● NS	○ NS	○ NS	○ ▽	○ NS	○ ▼	○ NS ● NS

inorganic phosphorus were met only in the Lower York River. Degrading trends were detected in total phosphorus and inorganic phosphorus in the Upper Mattaponi and Pamunkey rivers and the Lower Mattaponi River. Despite reductions in both point and non-point source loadings of phosphorus, ambient concentrations of these two parameters either increased or remained stable. Additional improvements in phosphorus controls may be required to produce a discernable change in these two parameters.

Although there was only a single season–specific improving trend in algal levels over the past 12 years, the status for this parameter was good and the SAV goals were met in all regions of the York River. However, the patterns in algal levels may be the result of the poor water clarity and not the result of any management actions.

Status of water clarity was poor except in the Upper Pamunkey and Mattaponi Rivers, where it was fair. The lack of improving trends in water clarity should be of concern to the management community since the SAV goal for this parameter was either not met or only marginally met in most regions of the York River. Water clarity was typically less than 1.0 m in most regions of the York River during the SAV growing season.

Improvements in total suspended sediments were limited to a single season-specific decreasing trend in March in the Middle York River. This improvement appears to have been caused by an increase in freshwater input from the fall-line. Suspended sediment concentrations goals were generally marginally met in the Upper Mattaponi and Pamunkey rivers and the Lower York River. The SAV habitat goals were met in the remainder of the York River. In addition, although no statistically significant trend was detected, peaks in total suspended sediment concentrations in the Lower York River appear to be steadily increasing.

Status for dissolved oxygen was good in all regions of the York River. The lack of significant increasing trends in summer dissolved oxygen concentrations in the York River is probably of little ecological consequence at most segments since summer concentrations in these areas have rarely dropped below 4.0 mg/L. The only exception was the Lower York River where concentrations of bottom dissolved oxygen typically dropped to or below the Virginia state short-term goal during at least one summer month. These violations of the goal constitute a management concern since they will adversely affect living resources in this region of the York River.

Phytoplankton Communities

In the York River, there were improving trends in the algal growth rate. Algal growth rates in the Upper Pamunkey River were limited by light in the winter-spring time period and nitrogen in the summer, the period of greatest phytoplankton abundance at this station. In the Middle York River, the magnitude and period of summer nitrogen-limitation was increased. In the Lower York River there was no light-limitation but phosphorus-limitation was apparent in the spring, while the summer remained nitrogen-limited. There was no evidence of silica-limitation in the York River system.

An improving trend in phytoplankton community health was detected in the Middle York River. The status of phytoplankton community health and algal growth rates was good throughout the river. There were increasing bloom-producers in the tidal freshwater region where total phosphorus increased and total nitrogen decreased. Downstream reaches of the river had recurring summer and early fall blooms of dinoflagellates, some of which extended into the Virginia Chesapeake Bay.

These data indicate mixed spatial and seasonal responses among the phytoplankton to conditions in the York River. Although the general trends and several indices are favorable, the continuation of improved phytoplankton levels will depend on nutrient control practices. These actions will influence the composition and abundance of these algae throughout the river.

Zooplankton Communities

There were no significant trends in species diversity in the Upper Pamunkey River. Zooplankton diversity showed an improving trend in the Middle York River and a degrading trend in the Lower York River. Status of the zooplankton community health was fair to good, while status of food availability for fish larvae ranged from poor to below minimum. The lack of trends in the Upper Pamunkey River, improving trends in the Middle York and deteriorating trends in the lower region suggest an overall mixed environmental situation in the York River.

Figure 3. Map of the York River showing summaries of the status and trend analyses for each region at and below the fall-line. Station-specific trends are identified by a station designation found under the trend marker in any appropriate columns. Season-specific trends are indicated by a number under the triangle marker that identifies a trend. The number refers to the number of the month for the year. In cases where there are heterogeneous season-specific trends for a given parameter/region combination, there are two triangles in the appropriate column. Abbreviations for each parameter are: total nitrogen=STN; inorganic nitrogen=SDIN; total phosphorus=STP; inorganic phosphorus=SDIP; algal levels=SCHLA; water clarity=SECCHI; suspended sediments=STSS; dissolved oxygen=BDO; algal growth rate=C14; phytoplankton community health=P-IBI; zooplankton community health =Z-IBI; and benthic community health=B-IBI.

If it's not low DO, then what conditions have changed over the 1985-96 timeframe that could of caused these declining trends?

Benthic Communities

The random station sampling approach in the York River characterized only 26% of the bottom as having a good rating, the worst benthic condition in the Chesapeake Bay. Low bottom dissolved oxygen does not seem to be a contributing factor in explaining the poor status of the York River benthos. There was a strong decreasing trend (47% decline) in the benthic community health in the Middle York River. Both community biomass and species richness declined (66% and 54%, respectively) in the Middle York River and abundance declined over 99% in the Lower York River.

Summary

There were decreases in algal growth rate at both sampling locations in the York River, but few regions with declines in algal levels. Nitrogen decreased in the Upper Pamunkey and Mattaponi rivers and in a portion of the Lower York River while inorganic nitrogen showed no trends. Phosphorus increased in the upper Pamunkey and Mattaponi rivers, as well as in a portion of the Middle York River. There were improving trends in phytoplankton and zooplankton community health in the Middle York River with a deteriorating trend in zooplankton health in the Lower York River. There were deteriorating trends in benthic community health in the Middle York River and the status of the benthic communities was poor throughout the river and poorest among all rivers in the Chesapeake Bay. These results suggest that water quality conditions improved little while living resources show patterns of concern, with little improvement and some indications of further deterioration in status.

Summary Points

- Point source loads showed little change.
- Fall-line nutrients with mixed trends.
- Improvements in algal levels in Upper and Middle York River (Initial values low - little ecological significance).
- Improvements in nitrogen in Upper York River.
- Degrading trends in nitrogen in the Lower York River and phosphorus in the Upper and Middle York.
- Status of water clarity poor in Middle York River.
- Status of dissolved oxygen good except the Lower York River where it was fair.
- Among Virginia tributaries lowest algal levels and nutrients in Upper and Middle York River.
- Improving trends in phytoplankton and zooplankton health in the Middle York River.
- Deteriorating trend in zooplankton health in Lower York River.
- Deteriorating trends in benthos in Middle York River and poor status throughout.

RAPPAHANNOCK RIVER

Basin Characteristics

Land use coverage in the Rappahannock River basin is 55% forested, 40% agricultural and 5% urbanized. No change in land use coverage occurred from 1985 to 1995. Population levels in the Rappahannock River basin rose from 151,000 to 228,000 individuals from 1980 to 1996.

Estimates of non-point source total nitrogen and total phosphate loadings decreased approximately 5% and 9%, respectively, from 1985 to 1995.

Point source loadings of total nitrogen above the fall-line increased from 157,000 lb/yr in 1985 to 226,000 lb/yr in 1995. Point source loadings of total nitrogen below the fall-line increased from 330,000 lb/yr in 1985 to 469,000 lb/yr in 1989 but then decreased to 257,000 lb/yr in 1995. Point source loadings of total phosphorus above the fall-line exhibited a substantial decline from 157,000 lb/yr in 1985 to 33,000 lb/yr in 1995. Point source loadings of total phosphorus below the fall-line showed a similar decline from 116,000 lb/yr in 1985 to 37,000 lb/yr in 1995. The decline in phosphorus loads both above and below the fall-line was probably caused in part by the phosphate ban.

Water Quality

The Rappahannock River displayed a pattern similar to the York River. Although the status of most parameters was good, there were only limited improvements in some water quality parameters and degradations in others (Figure 4). The observed improvements do not necessarily reflect management actions.

Status for total nitrogen and inorganic nitrogen was good at all segments and SAV goals for inorganic nitrogen were met in all regions with an established goal. Improvements in total nitrogen were limited to an overall decreasing trend in the Upper Rappahannock River and a season-specific decreasing trend in the Lower Rappahannock River. No improving trends in inorganic nitrogen were detected below the fall-line.

Status of total phosphorus and inorganic phosphorus was fair to good in all regions and the SAV goal for inorganic phosphorus was met or marginally met in all regions. Overall degrading trends in total phosphorus were detected in all regions of the Rappahannock River. Plots of concentrations at all segments confirmed a pattern of increasing total phosphorus throughout the Rappahannock River. There was little change in inorganic phosphorus over 12 years which suggests that the increase in total phosphorus is due to an increase in organic phosphorus compounds. The source of this organic enrichment does not appear to be anthropogenic, since both point and non-point source loadings decreased since 1985. Perhaps the reductions in phosphorus loadings were not sizeable enough to affect ambient concentrations of phosphorus. Although no improving trends in inorganic phosphorus were detected, concentrations of this parameter were generally below the SAV goal in all regions. Low values of inorganic phosphorus may be a reflection of the low point source loadings in this tributary.

Status for algal levels was good at all regions and the SAV goal for this parameter was met in all regions of the Rappahannock River. Improving overall trends in algal levels were detected in all but the Mid-Upstream Rappahannock River. Plots of algal level concentrations confirmed the results of the trend analyses. The status and trends obtained for algal levels may be attributable to the reductions in nitrogen. Alternatively, these results may be due to the poor water clarity in this tributary.

The flow of the Rappahannock River is similar in magnitude to that of the York River. Like the York River, its watershed is primarily rural in nature. However, the shallow sill at its mouth restricts flow and exchange of bottom waters with the Bay. This characteristic produces low oxygen conditions in the lower reaches of the Rappahannock River.

Status for water clarity ranged from fair to poor but the SAV goal was met in most regions. Although no significant trends in water clarity were detected, plots of water clarity showed a general decrease during the last two to five years in all regions. As with the other tributaries, water clarity should be a priority for environmental managers since poor water clarity will adversely affect the success of SAV.

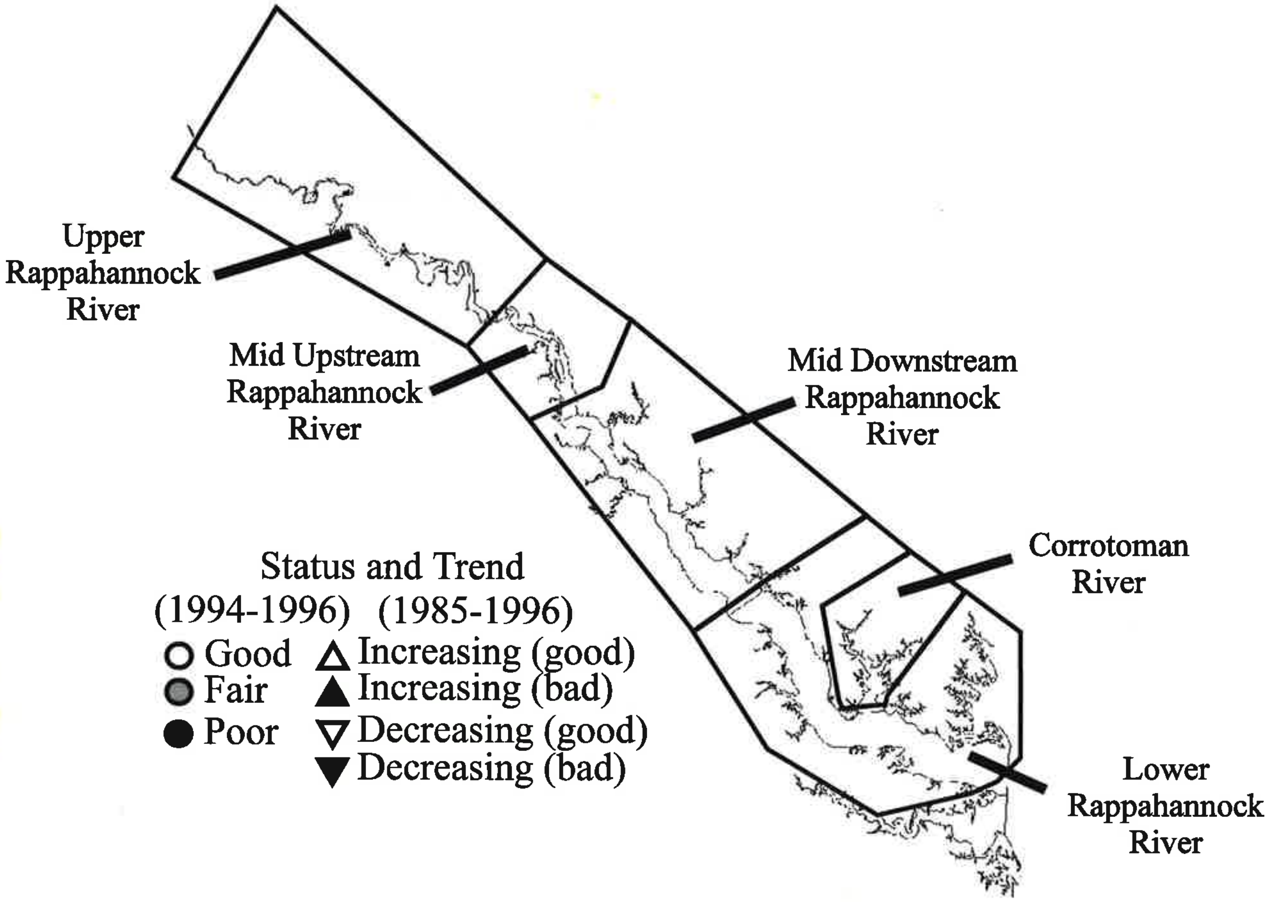
Status of total suspended solids ranged from fair to good in all regions of the Rappahannock River. In the Upper, Mid-Upstream and Mid-Downstream Rappahannock River, total suspended sediment concentrations exceeded the SAV habitat goal. Little or no change occurred in suspended sediments over the past 12 years. Improvements in suspended solids will be required before any improvements in water clarity can be expected.

Status for dissolved oxygen ranged from good at the upper and middle regions to fair at the lower region of the Rappahannock River. Degrading trends in dissolved oxygen were detected for some or all of the summer months in the Mid-Downstream Rappahannock, the Lower Rappahannock, and the Corrotoman rivers. Plots of concentrations at this region indicate dissolved oxygen concentrations violated the Virginia short-term dissolved oxygen standard and also reached hypoxic levels (<2.0 mg/L) during the summer months.

Phytoplankton Community

Status in phytoplankton community health was good at all stations and no trends in phytoplankton community health were detected. Although the general health status of the phytoplankton is classified as good, there were several patterns in these segments that are generally degrading. These include deteriorating trends of the bloom-producers and cyanobacteria in the Upper and Mid-Upstream portions of the river and decreasing diatom concentrations in the Lower Rappahannock River.

There were no significant trends in the algal growth rate and the status for all regions of the Rappahannock River was good. Results of the algal growth limitation experiments indicate the tidal freshwater Rappahannock River is light-limited throughout the year, but there was some indication of a slight limitation of the algal growth



	STN	SDIN	STP	SDIP	SCHLA	SECCHI	STSS	BDO	C14	P-IBI	Z-IBI	B-IBI
Fall-line	○ ▽	○ NS	○ ▽	○ NS	NA	NA	○ ▽	NA	NA	NA	NA	NA
Upper	○ ▽	○ NS	○ ▲	○ NS	○ ▽	◍ NS	◍ NS	○ NS	NA	NA	NA	NA
Upstream	○ NS	○ NS	○ ▲	○ NS	○ NS	● NS	◍ NS	○ △	○ NS	○ NS	○ △	● ▼
Downstream	○ NS	○ NS	◍ ▲	○ NS	○ ▽	● NS	◍ ▽ 7	○ ▼ RET3.2	NA	NA	NA	○ NS
Lower	○ ▽ 10, 11	○ ▲ 4	○ ▲	○ NS	○ ▽	◍ NS	○ ▲ 2 ▽ 7, 9	◍ ▼ 2, 3, 4	○ NS	○ NS	○ ▼	● NS ●▽ NS
Corrotoman	○ NS	○ NS	○ ▲	○ NS	○ ▽	◍ NS	○ NS	◍ ▼	NA	NA	NA	NA

rate due to phosphorus concentrations. The lower portion of the estuary exhibits nitrogen-limitation in the summer and fall, and phosphorus-limitation in the spring. There was no response to silicate enrichment or light-limitation in the lower portion of the Rappahannock River.

The Lower Rappahannock River was the location where members of the dinoflagellate *Pfiesteria* complex were recorded in September 1997. There were no fish kills at this time, but there was a high prevalence of menhaden with lesions in these waters. This event emphasizes the ability of specific components in the phytoplankton community to respond to conditions favorable to their growth. Overall, the phytoplankton composition and trends are favorable, but several of the negative patterns indicate the necessity for maintaining and improving water quality conditions for this river.

Zooplankton Communities

Zooplankton community health showed an improving trend in the Mid-Upstream Rappahannock River but a deteriorating trend in the Lower Rappahannock River. The status for zooplankton community health was good throughout the river. Status of food availability for fish larvae based on zooplankton data was below minimum for all regions. The zooplankton communities of the Rappahannock River showed a mixed pattern of regions of improvement and regions of concern. As in both the York and James rivers the region of concern was the lower region of each tributary.

Benthic Communities

Benthic communities were deteriorating in the Mid-Upstream Rappahannock River but improving slightly in the Lower Rappahannock River. Status of the benthic communities was considered good at only 25% of the fixed point sampling stations and 38% of the randomly allocated sampling stations.

In the face of declining D.O. trends what's happening.

Summary

Water quality and living resources results in the Rappahannock River do not present a clear picture. Trends in the living resources do not appear to be tied to trends in water quality. In addition, trends in reduced rates of algal growth are accompanied by increasing trends in phytoplankton community biomass. Mixed results were obtained for both the zooplankton and benthic communities.

Got to lay out a better story line for the Rappahannock

Summary Points

- •Point source nutrient loads improving since 1989.
- •Fall-Line nitrogen, phosphorus, and suspended sediments improved.
- •Improvements in algal levels, algal growth rate, nitrogen and dissolved inorganic nitrogen.
- •Degradation in phosphorus except in the Upper Rappahannock River.
- •Degradation in dissolved oxygen in portions of the Rappahannock River of potential concern.
- •Mixed patterns in living resources with some improving and deteriorating trends.
- •Phytoplankton status good throughout with no trends in health and algal growth rates.
- •Deteriorating trends of the bloom producers and cyanobacteria in the upper and middle regions of the river and decreasing diatom concentrations in the lower region.
- •Mixed trends in zooplankton health with an improving trend in the upper region and a deteriorating trend in the lower region.
- •Deteriorating trends in benthic communities in middle region and poor status throughout river.

Figure 4. *Map of the Rappahannock River showing summaries of the status and trend analyses for each region at and below the fall-line. Station-specific trends are identified by a station designation found under the trend marker in any appropriate columns. Season-specific trends are indicated by a number under the triangle marker that identifies a trend. The number refers to the number of the month for the year. In cases where there are heterogeneous season-specific trends for a given parameter/region combination, there are two triangles in the appropriate column. Abbreviations for each parameter are: total nitrogen=STN; inorganic nitrogen=SDIN; total phosphorus=STP; inorganic phosphorus=SDIP; algal levels=SCHLA; water clarity=SECCHI; suspended sediments=STSS; dissolved oxygen=BDO; algal growth rate=C14; phytoplankton community health=P-IBI; zooplankton community health =Z-IBI; and benthic community health=B-IBI.*

VIRGINIA CHESAPEAKE BAY

Basin Characteristics

Estimates of non-point source loadings of total nitrogen and total phosphorus from the Virginia portion of the Chesapeake Bay watershed showed modest decreases of 2% and 3%, respectively, from 1985 to 1995. Population levels in the Virginia portion of the Chesapeake Bay watershed increased 24% from approximately 2.5 million in 1980 to 3 million in 1995. Point source loadings of total nitrogen for the Virginia Chesapeake Bay watershed increased from 26.7 million lb/yr in 1985 to 31.3 million lb/yr in 1988. Point source loadings of total nitrogen then declined to 23.8 million lb/yr in 1995. The total decrease in point source loadings of total nitrogen over 10 years was approximately 11%. Point source loadings of total phosphorus for the Virginia Chesapeake Bay watershed decreased from 4.5 million to 2.1 million lb/yr, for a total decrease of 53%.

Water Quality

Status of total nitrogen and inorganic nitrogen ranged from fair to good in all regions of the Virginia Chesapeake Bay and the SAV goals for inorganic nitrogen were met or marginally met in all regions (Figure 5). There were no changes in total nitrogen in the Virginia Chesapeake Bay and Piankatank River. Improvements in inorganic nitrogen were limited to a decreasing overall trend in the Piankatank River and a season-specific decreasing trend during the summer in the Lower Virginia Chesapeake Bay. The Upper Virginia Chesapeake Bay experienced a season-specific degrading trend in inorganic nitrogen.

Status of total phosphorus and inorganic phosphorus was good throughout the Virginia Chesapeake Bay. SAV goals for inorganic phosphorus were met in all regions. Trends in total phosphorus concentrations showed no consistent patterns between regions in the Virginia Chesapeake Bay. A decreasing overall trend in the Lower Virginia Chesapeake Bay and a seasonal decreasing trend during the spring in the Middle Virginia Chesapeake Bay indicate that total phosphorus concentrations are improving. However, overall increasing trends in the Upper and Mid-Western Virginia Chesapeake Bay and an overall increasing trend in the Piankatank River indicate conditions were degrading with respect to total phosphorus. There were overall increasing trends in concentrations of inorganic phosphorus in the Upper Virginia Chesapeake Bay, Pocomoke Sound, and the Piankatank River indicating conditions are degrading with respect to this parameter. An improving trend in inorganic phosphorus was detected in the Lower Virginia Chesapeake Bay.

Status of algal levels was good and the SAV goals for this parameter were met in all regions of the Virginia Chesapeake Bay. Algal levels showed no significant changes in any region. The lack of any widespread reductions in nutrients suggests that the status obtained for algal levels may be related to water clarity.

Status of water clarity was fair except in the Pocomoke River, which was characterized as poor, but the SAV goals were met for this parameter in all regions of the Virginia Chesapeake Bay. Water clarity was degrading in most of the Virginia Chesapeake Bay, as indicated by the decreasing overall trends found in all but two of the seven regions. Trends in water clarity are probably related to the increasing trends in suspended sediments.

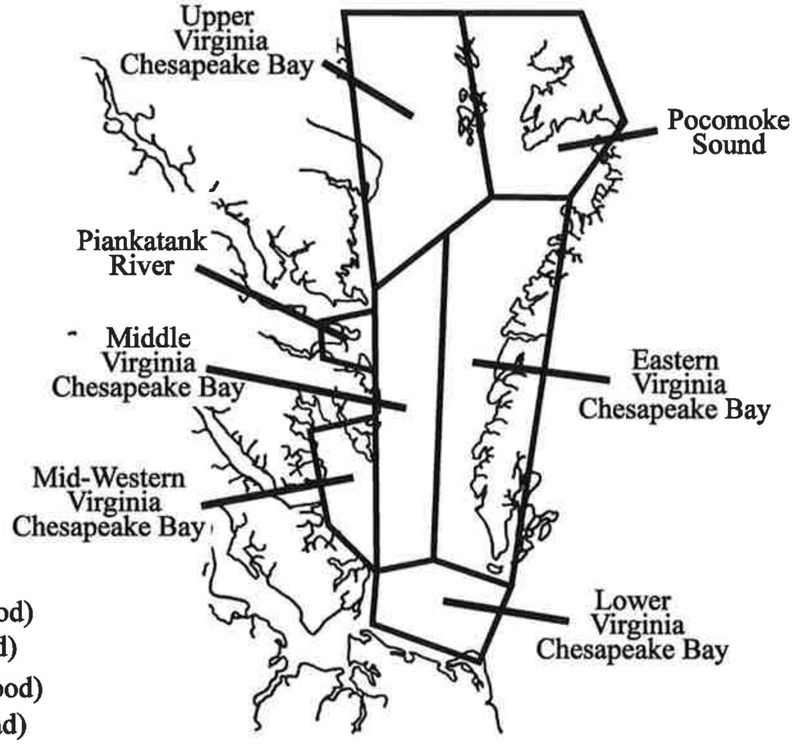
Status for total suspended sediments was good in most segments and the SAV goals for this parameter were met or marginally met throughout the Virginia Chesapeake Bay. There were significant degrading trends in this parameter in all but the Upper and Middle Virginia Chesapeake Bay. In order to ensure continued improvements in SAV recovery, it will be necessary to implement additional management controls of suspended sediments. Although current status is good, the degrading trends could result in a change of status for this parameter.

Status for dissolved oxygen was fair to good in all regions of the Virginia Chesapeake Bay, except the Upper Virginia Chesapeake Bay where it was poor. The lack of significant improving trends in summer dissolved oxygen concentrations in the Virginia Chesapeake Bay is probably of little ecological consequence in most regions. The only exception is the Upper Virginia Chesapeake Bay, in which the concentrations of dissolved oxygen typically violate the Virginia short-term dissolved oxygen standard, with concentrations sometimes dropping below 3.0 mg/L.

Phytoplankton Communities

The phytoplankton community health status was good throughout the Virginia Chesapeake Bay, with no significant trends indicated. The status of algal levels was good, with no trends present. The algal growth rate status was good throughout the Virginia Chesapeake Bay, with an improving trend in the Upper Virginia Chesapeake Bay.

Trends in phytoplankton community parameters do not indicate any consistent change with respect to the health of these communities although current status ranged from fair to good. Increases in bloom-producers with decreases in species diversity were unfavorable trends



Status (1994-1996)	Trend (1985-1996)
○ Good	△ Increasing (good)
◍ Fair	▲ Increasing (bad)
● Poor	▽ Decreasing (good)
Ⓥ Very Poor	▼ Decreasing (bad)

	STN	SDIN	STP	SDIP	SCHLA	SECCHI	STSS	BDO	C14	P-IBI	Z-IBI	B-IBI
Upper	○ NS	○ ▲ Sp	○ ▲	○ ▲	○ NS	◍ ▼	○ NS	● NS	NA	NA	NA	Ⓥ NS
Pocomoke	◍ NS	○ ▽	○ NS	○ ▲	○ NS	● ▼	○ ▲	○ NS	NA	NA	NA	NA
Middle	○ NS	○ NS	○ ▽ Sp	○ NS	○ NS	◍ ▼	○ NS	◍ NS	○ ▽	○ NS	○ NS	● ○
Piankatank	○ NS	○ NS	○ ▲	○ ▲	○ NS	◍ NS	● ▲	○ NS	NA	NA	NA	NA
Eastern	○ NS	○ NS	○ NS	○ NS	○ NS	◍ ▼	○ ▲	○ NS	○ NS	○ NS	○ NS	○ NS
Mid-western	○ NS	○ NS	○ ▲	○ NS	○ NS	◍ NS	○ ▲	○ NS	NA	NA	NA	NA NA
Lower	○ NS	○ ▽ Su	○ ▽	○ ▽	○ NS	◍ ▼	○ ▲	○ NS	○ NS	○ NS	○ NS	○ NS

Figure 5. Map of the Virginia Chesapeake Bay showing summaries of the status and trend analyses for each region. Station-specific trends are identified by a station designation found under the trend marker in any appropriate columns. Season-specific trends are indicated by a number under the triangle marker that identifies a trend. The number refers to the number of the month for the year. In cases where there are heterogeneous season-specific trends for a given parameter/region combination, there are two triangles in the appropriate column. Abbreviations for each parameter are: total nitrogen=STN; inorganic nitrogen=SDIN; total phosphorus=STP; inorganic phosphorus=SDIP; algal levels=SCHLA; water clarity=SECCHI; suspended sediments=STSS; dissolved oxygen=BDO; algal growth rate=C14; phytoplankton community health=P-IBI; zooplankton community healthn =Z-IBI; and benthic community health=B-IBI.

in the Middle and Lower Virginia Chesapeake Bay. Conversely, decreases in picoplankton and increases in the ratio of total biomass to total abundance in all regions suggest that conditions may be improving.

The algal growth rate in the Virginia Chesapeake Bay is primarily nitrogen-limited during the summer and fall and phosphorus-limited during the spring. Phosphorus-limitation decreases and nitrogen limitation increases toward the Lower Virginia Chesapeake Bay. There was a strong silicate-limitation at one Mainstem station during the spring.

Phytoplankton composition in the Virginia Chesapeake Bay was dominated by diatoms common to the estuary, with additional entries of various neritic species through the Bay entrance in sub-surface waters. This represents a healthy phytoplankton status subject to seasonal patterns of dominance by several algal groups. Nutrient limitation to growth is a major controlling factor to the abundance and composition of this flora. This healthy status is enhanced by the dynamic flushing action of waters within the Bay and its estuaries to reduce the residency time of species at these sites and their exposure to any nutrient enrichment. Actions influencing nutrient and sediment loads in the Bay river systems will subsequently impact the presence of algal populations within the Virginia Chesapeake Bay.

Zooplankton Communities

Trends in zooplankton community parameters indicated that zooplankton communities are degrading. In the Lower Virginia Chesapeake Bay there was a 40% reduction in the species diversity index. In the Eastern Virginia Chesapeake Bay there was a 42% reduction in total zooplankton abundance and a 35% reduction in the species diversity index. The Middle Virginia Chesapeake Bay exhibited a 39% reduction in total zooplankton abundance and season specific reductions in species diversity.

Got to lay out one or several explanations for these trends.

Benthic Communities

Benthic conditions in the Virginia Chesapeake Bay appear to have remained stable for the past 12 years as evidenced by the lack of trends in benthic community health. Status assessments of the benthic community health ranged from poor in the Upper Virginia Chesapeake Bay to good in the Middle, Eastern and Lower Virginia Chesapeake Bay regions. Poor status in benthic communities in the Upper Virginia Chesapeake Bay is probably linked to the poor status obtained for dissolved oxygen in the same region. Status estimates for the benthos based upon the randomly allocated samples indicated that 68% of the Virginia Chesapeake Bay benthos were in good health. This percentage of good area is exceeded only by the James River.

Summary

In general, the Virginia Chesapeake Bay appeared to have mixed water quality conditions. Status of all parameters except water clarity was good in most regions; however, there were some deteriorating trends in phosphorus and water clarity in some regions and deteriorating trends in suspended sediments in all but one region. There were no trends in the health of any of the biotic communities (phytoplankton, zooplankton, benthos). Status for living resources was generally good except in the Upper Virginia Chesapeake Bay. Improving conditions were associated with decreases in picoplankton at all segments and increases in the ratio of total biomass to total abundance at all segments. However, there were some deteriorating trends of bloom-producing phytoplankton, zooplankton species diversity and zooplankton abundance indicating some concern. The status of the benthos as indicated by the probability-based sampling was the second best in the entire Chesapeake Bay watershed.

Summary Points

- No changes in algal levels and total nitrogen.
- Mixed trends for phosphorus.
- Degrading trends in some regions for dissolved inorganic phosphorus.
- Degrading trends for suspended sediments in most regions.
- No trends in dissolved oxygen.
- Phytoplankton trends indicate that conditions are improving.
- Zooplankton trends indicate that conditions are deteriorating.
- No trends in benthic communities but status estimates indicated the second best benthic community health in the entire Chesapeake Bay system.

BAYWIDE PATTERNS, WATERSHED ACTIVITIES AND CONDITION OF THE LIVING RESOURCES

Non-point source loadings of nitrogen and phosphorus declined in each basin of the James, York and Rappahannock rivers from 3-5% for nitrogen and 2-9% for phosphorus. Point source loads for phosphorus generally declined both above and below the fall-line, probably due to the phosphate detergent ban. The only exception was an increase above the fall-line in the James River basin from 1992 to 1994, but these loads were still below the 1987 value. Point source loads of nitrogen show a mixed pattern, with above fall-line increases in the York River and Rappahannock River and little change in the James River. Below the fall-line, point source loadings of nitrogen showed recent declines in the James River, a fluctuating pattern in the York River and increases in the Rappahannock River. For the entire Chesapeake Bay watershed point source loadings of nitrogen declined 11% over the last 10 years.

Figure 6 summarizes the present status estimates (1994-1996) for algal levels, total nitrogen and total phosphorus comparing the Virginia tributaries to the Potomac River, Patuxent River and the Choptank River. In general, algal levels and nitrogen levels are lower in the Virginia tributaries (Figure 6A,B) while phosphorus patterns show the highest levels in the Patuxent and Choptank rivers (Figure 6C). This pattern appears to be related to the different land-use patterns of the tributaries. The following patterns were reported by Ranasinghe et al. (1994). The Potomac River and the Patuxent River have high population densities (two to five times greater) and a greater percentage of Urban Land Use Area (particularly below the fall-line) compared to the other tributaries. The Choptank River watershed, although a relatively small one, had a higher percentage of Urban Land Use Area than any of the Virginia tributaries and is comparable to the Potomac River. The Choptank River watershed had by far the largest percentage of Agricultural Land Use Area (> 50%), with the Potomac and Rappahannock rivers having intermediate values (approximately 30%) and the York and James rivers having the lowest values (approximately 20%). The Virginia tributaries have the highest percentages of Forested Land Use Area (all exceeding 60%), the Potomac and Patuxent rivers have intermediate levels (40-55%) and the Choptank River has the lowest value (approximately 35%).

Ranasinghe et al. (1994) examined the relationships between (1) the condition of the benthic communities of Chesapeake Bay (as indicated by the benthic IBI), (2) water column measures of eutrophication (algal levels, nitrogen concentrations and phosphorus concentrations) and sediment-borne contaminants that alter the benthic condition, and (3) measures of anthropogenic activity that lead to changes in eutrophication and contamination. The measures of anthropogenic activities included population density, point and non-point source loadings of nitrogen and phosphorus and land use patterns (percentages of watershed that was forested, agricultural or urbanized). They found significant correlations between the condition of the benthic communities and frequency of low dissolved oxygen events ($r = -0.61$) and levels of contaminants ($r = -0.33$), but no relationship to algal levels, total nitrogen and total phosphorus. Benthic communities impacted by sediment contaminants were found in only a few locations (e.g. the Southern Branch of the Elizabeth River and the Back River) while benthic communities impacted by low dissolved oxygen were widespread. When the widespread effect of dissolved oxygen was removed, benthic condition was weakly (r values from - 0.30 to - 0.39) but significantly correlated with algal levels, total nitrogen and total phosphorus concentrations. Finally, Ranasinghe et al. (1994) found significant correlations between the condition of the benthic communities and measures of anthropogenic activity. Benthic condition was weakly ($p = 0.05$) but positively correlated ($r = 0.62$) with % Forested Land Use Area, negatively correlated with population density ($r = -0.70$; $p = 0.02$), negatively correlated with point source loadings of nitrogen and point source loadings of phosphorus ($r = -0.70$; $p = 0.02$ for both parameters) and negatively correlated with total point source and non-point source loadings of nitrogen ($r = -0.68$; $p = 0.03$). Interestingly, there were no correlations with non-point source loadings at any level (above the fall-line, below the fall-line, or total watershed). The results of Ranasinghe et al., (1994) and this report are consistent in indicating that future reductions in nitrogen loads are necessary to significantly improve the living resources of the Virginia tributaries. In addition, improvements in water clarity are required to allow improvements in the status of submerged aquatic vegetation. The regional improvements in water quality and living resources of this study indicate that with significant reductions in nitrogen loads and improvement in water clarity, the living resources are expected to respond with significant improvements in status.

Finally, Table 2 compares the pattern of trends detected for concentrations of algal levels, total nitrogen and total phosphorus after five years (Alden et al., 1992),

LITERATURE CITED

Alden, R.W. III 1997. Dynamics of an estuarine ecosystem -The Chesapeake Bay experience: statistical approaches and water quality patterns. *Oceanologica Acta.* **20**: 55-69.

Alden, R.W. III, R.S. Birdsong, D.M. Dauer, H.G. Marshall and R.M. Ewing. 1992a. Virginia Chesapeake Bay Water Quality and Living Resources Monitoring Programs: Executive Report, 1985-89. Final report to Virginia Water Control Board. AMRL Report No. 849 33 pp.

Alden, R.W. III, R.S. Birdsong, D.M. Dauer, H.G. Marshall and R.M. Ewing. 1992b. Virginia Chesapeake Bay Water Quality and Living Resources Monitoring Programs: Comprehensive Technical Report, 1985-89. Final report to Virginia Water Control Board. 366 pp.

Alden, R.W. III, A.S. Gordon, E.F. Stillwell, R.K. Everton and M.F. Helmstetter. 1988. An evaluation of toxicants/mutagens in the Elizabeth River, Virginia in relation to land use activities. Report to the Virginia Water Control Board under VWCB Contract No. 12-01-02-21, 190 pp.

Aller, R.C. 1978. The effects of animal-sediment interactions on geochemical processes near the sediment-water interface, pp. 157-172, IN: M. Wiley (ed.), *Estuarine Processes.* Academic Press, New York, NY.

Berner, R. 1976. The benthic boundary layer from the viewpoint of a geochemist. pp. 33-35, IN: J. McCave (ed.), *The Benthic Boundary Layer.* Plenum Press, New York, NY.

Bilyard, G.R. 1987. The value of benthic infauna in marine pollution monitoring studies. *Marine Pollution Bulletin,* **18**: 581-585.

Bradley, B. P. and M. H. Roberts. 1987. Effects of contaminants on estuarine zooplankton. IN: *Contaminant Problems and Management of Living Chesapeake Bay Resources.* Pennsylvania Academy of Sciences, 417-441.

Carpenter, K.E.. 1998. Virginia Chesapeake Bay Water Quality and Living Resources Monitoring Programs 1985-1996: Zooplankton Communities. In press.

Dauer, D.M. 1991. Long-term trends in the benthos of the lower Chesapeake Bay. IN: J. Mihursky and A. Chaney (eds.), *New Perspectives in the Chesapeake Bay System: A Research and Management Partnership. Proceedings of the 1990 Chesapeake Research Conference, Baltimore, MD, Dec. 1990.* pp. 527-536.

Dauer, D.M. 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. *Marine Pollution Bulletin* **26**: 249-257.

Dauer, D.M. 1997. Virginia Chesapeake Bay Water Quality and Living Resources Monitoring Programs 1985-1996: Benthic Communities. Final Report to the Virginia Department of Environmental Quality. 92pp.

Dauer, D.M. and R.W. Alden III. 1995 Long-term trends in the macrobenthic communities of the lower Chesapeake Bay (1985-1991). *Marine Pollution Bulletin* **30**: 840-850.

Dauer, D.M., R.M. Ewing, G.H. Tourtellotte, W.T. Harlan, J.W. Sourbeer and H.R. Barker, Jr. 1982. Predator pressure, resource limitation and the structure of benthic infaunal communities. *Int. Revue ges. Hydrobiol.* **67**: 477-489.

Dauer, D.M., M. W. Luckenbach and A.J. Rodi, Jr. 1993. Abundance biomass comparison (ABC method): effects of an estuarine gradient, anoxic/hypoxic events and contaminated sediments. *Marine Biology* **116**: 507-518.

Dauer, D.M., J.A. Ranasinghe and A.J. Rodi, Jr. 1992. Effects of low dissolved oxygen levels on the macrobenthos of the lower Chesapeake Bay. *Estuaries.* **15**: 384-391.

EPA, 1983. Chesapeake Bay: A Profile of Environmental Change. U.S. Environmental Protection Agency. Philadelphia, PA. 200 pp.

Haas, L.W. and K.L. Webb. 1998. Resource limitation of phytoplankton in the Virginia Chesapeake Bay and tributaries using nutrient-addition bioassays. In press.

Hoffman, F.A. and J.W. Bishop. 1994. Impacts of a phosphate detergent ban on concentrations of phosphorus in the James River, Virginia. *Water Research*, **28**:1239-1240.

Holland, A.F., N.K. Mountford, M.H. Hiegel, K.R. Kaumeyer and J.A. Mihursky. 1980. Influence of predation on infaunal abundance in upper Chesapeake Bay. *Marine Biology*, **57**: 221-235.

Kuo, A.Y. and M.Z. Moustafa. 1989. Hypoxia in the lower Rappahannock estuary. *Special Report in Marine Science and Ocean Engineering. No. 302.* Virginia Institute of Marine Science, College of William and Mary. 75 pp.

Lane, M.F., A.W. Messing and R.W. Alden III. 1998. Virginia Chesapeake Bay Water Quality and Living Resources Monitoring Programs 1985-1996: Water Quality. In press.

Marshall, H.G. 1994. Chesapeake Bay phytoplankton: I. Composition. *Proceedings of the Biological Society of Washington.* **107**: 573-585.

Marshall, H.G. 1995. Autotrophic picoplankton distribution and abundance in the Chesapeake Bay, U.S.A. *Marine Nature*, 4:33-42.

Marshall, H.G. 1998. Virginia Chesapeake Bay Water Quality and Living Resources Monitoring Programs 1985-1996: Phytoplankton Communities. In press.

Marshall, H.G. and R.W. Alden III. 1990. A comparison of phytoplankton assemblages and environmental relationships in three estuarine rivers of the lower Chesapeake Bay. *Estuaries.* **13**: 287-300.

Marshall, H.G. and R.W. Alden III. 1997. Dynamics of an estuarine ecosystem: the influence of flow patterns on phytoplankton trends in the Chesapeake Bay. *Oceanologica Acta,* **20**:109-117.

Marshall, H.G. and N.K. Nesius. 1993. Seasonal relationships between phytoplankton composition, abundance, and primary productivity in three tidal rivers of the lower Chesapeake Bay. *Journal of Elisha Mitchell Science Society.* **109**:141-151.

Marshall, H.G. and N.K. Nesius. 1996. Phytoplankton composition in relation to primary production in Chesapeake Bay. *Marine Biology*, **125**:611-617.

Ranasinghe, J.A., S.B. Weisberg, J. Gerritsen, D.M. Dauer. 1994. Assessment of Chesapeake Bay benthic macroinvertebrate resource condition in relation to water quality and watershed stressors. Report prepared for the Governor's Council on Chesapeake Bay Research Fund and the Maryland Department of Natural Resources. 60 pp.

Swartz, R.C. and H. Lee II. 1980. Biological processes affecting the distribution of pollutants in marine sediments. Part I. Accumulation, trophic transfer, biodegradation and migration, pp. 533-554, IN: *Contaminants* *and sediments, Vol. 2, Analysis, Chemistry, Biology* (R.A. Baker, ed.), Ann Arbor Science, Ann Arbor, MI.

Virnstein, R.W. 1979. Predation on estuarine infauna: response patterns of component species. *Estuaries* 2: 69-86.

VWCB, 1991. Tributary Water Quality 1988 Characterization Report. Chesapeake Bay Office, Virginia Water Control Board.

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