Exhibit 15

# SETTING AND ALLOCATING THE CHESAPEAKE BAY BASIN NUTRIENT AND SEDIMENT LOADS

## The Collaborative Process, Technical Tools and Innovative Approaches

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# chapter i
# Background

For the past twenty years, the Chesapeake Bay Program partners have been committed to achieving and maintaining water quality conditions necessary to support living resources throughout the Chesapeake Bay ecosystem. The *1983 Chesapeake Bay Agreement* set the stage for the collaborative multi-state and federal partnership, and the *1987 Chesapeake Bay Agreement* set the first quantitative nutrient reduction goals (Chesapeake Executive Council 1983, 1987). With the signing of the *Chesapeake 2000* agreement (Chesapeake Executive Council 2000), the Chesapeake Bay Program partners committed to:

> *Defining the water quality conditions necessary to protect aquatic living resources and then assigning load reductions for nitrogen and phosphorus to each major tributary;* and
>
> *Using a process parallel to that established for nutrients, determining the sediment load reductions necessary to achieve the water quality conditions that protect aquatic living resources, and assigning load reductions for sediment to each major tributary.*

Through a six-state memorandum of understanding, the headwater states of Delaware, West Virginia and New York joined Maryland, Virginia, Pennsylvania, the District of Columbia, the U.S. Environmental Protection Agency (EPA) and the Chesapeake Bay Commission in committing to restore Chesapeake Bay and river water quality through the adoption of new cap load allocations for nitrogen, phosphorus and sediment (Chesapeake Bay Watershed Partners 2001). All the watershed partners understood that these allocations represented loading caps that must be achieved and maintained, even in the face of increasing anthropogenic activities in the watershed.

Using the best scientific information available, Chesapeake Bay Program partners have agreed to nutrient and sediment cap loading allocations. On March 21, 2003 and April 15, 2003, the Chesapeake Bay Program Principals' Staff Committee and representatives of the headwater states convened to adopt the nutrient and sediment cap load allocations and submerged aquatic vegetation (SAV) restoration goals for the Chesapeake Bay (Appendix A). The cap loads, allocated by major tributary basin and by state jurisdiction, will serve as a basis for each state's tributary strategies that, when completed by April 2004, will describe local implementation actions necessary to meet the *Chesapeake 2000* nutrient and sediment cap load allocations by 2010.

This document describes the scientific and technical information and policy agreements that formed the basis for the important, comprehensive agreements that the Chesapeake Bay Program partners made with regard to cap load allocations for nitrogen, phosphorus and sediments, as well as new baywide and local SAV restoration goals. The assessment tools and techniques evolved significantly over the allocation decision-making process, therefore, it should be noted that this document is based on the most recent information and procedures used in support of the cap load allocation decisions that were made.

## FUNDAMENTALS OF DEVELOPING CAP LOAD ALLOCATIONS

Cap load allocations can be defined as cumulative pollutant loadings for all point and non-point sources established and assigned to different tributary basins within a larger watershed that, when achieved, will allow the receiving water body to attain the prescribed water quality goals. With the accelerated development of total maximum daily loads (TMDLs) over the recent years, the development of loading caps has become commonplace, but the size and complexity of the Chesapeake Bay watershed has made allocation of the nutrient and sediment cap loads similarly complex.

Typically, water quality goals are prescribed in state water quality standards. However, current state water quality standards addressing nutrient- and sediment-related impairments for the Chesapeake Bay and its tidal tributaries, which are based on national criteria first published in the 1960s for freshwater systems, only address dissolved oxygen. For this reason, the EPA, in direct consultation with the watershed states, developed comprehensive, Chesapeake Bay regional water quality criteria for dissolved oxygen, chlorophyll *a* and clarity, along with SAV restoration goals for each segment of the Chesapeake Bay and its tidal tributaries (U.S. EPA 2003a, 2003b). While at the time of publication of this document these criteria had not yet been adopted into state water quality standards, they were used as the water quality basis for setting and allocating the nutrient and sediment cap loads for the Chesapeake Bay watershed.

To determine the appropriate cap loads and allocate them to individual tributary basins, the pollutant sources must be related to impacts on water quality. It is important to quantify the loadings from all significant sources and to track the fate and transport of those pollutants from the source to the Bay's tidal waters. In the case of nutrients and sediments, the fate and transport mechanisms can be quite complex.

A complementary suite of models was employed to simulate the sources, transport, fate and ultimate impact on tidal Bay water quality conditions of nutrient and sediment loads. The airshed model was used to track air sources from the 350,000-

square-mile Chesapeake Bay airshed and the transport and deposition of atmospheric nitrogen loads to the Chesapeake Bay watershed and directly to tidal surface waters. The watershed model tracked all sources—point, non-point and air deposition—within the watershed and simulated the fate of those pollutants as they were transported through the free-flowing river systems of the watershed and delivered to the tidal Bay waters. The water quality model, which is actually a compilation of several models, then simulated the water quality impacts of those pollutants on the water quality of the Chesapeake Bay and its tidal tributaries.

Knowing the water quality goals through the water quality criteria as applied within the refined tidal-water designated uses and the reduced pollutant loading effects on water quality through the models, it was possible to develop defensible, equitable cap load allocations. However, good science was not enough to derive the cap load allocations. It was also important to blend the scientific understanding with policy input to derive cap load allocations that not only could achieve the stated water quality goals but also could gain considerable support from local stakeholders ultimately responsible for taking the actions necessary to reduce nutrient and sediment loadings.

Policy input to setting the cap load allocations was most important in determining an appropriate distribution of the allowable pollutant loads by major tributary basin and jurisdiction. 'Fair and equitable' were the basic principles used by the Chesapeake Bay Program partners in allocating the cap loads. Such subjective qualities do not readily lend themselves to technically based solutions without significant policy direction on how to achieve this desired result. Once the policy direction was established on distributing the cap loads 'fairly and equitably', a technical construct supporting these policy principles was developed.

## KEY PLAYERS IN DEVELOPING THE ALLOCATIONS

The Chesapeake Bay Program carries out its restoration and protection functions through an extensive committee structure led by the original Chesapeake Bay agreement signatories of Pennsylvania, Maryland, Virginia, the District of Columbia, the EPA and the Chesapeake Bay Commission (Figure I-1). For the development of water quality criteria, refined tidal-water designated use and cap load allocations, more than 500 individuals representing state, federal, regional and local government agencies, academic institutions, businesses, conservation organizations, community watershed organizations, many other nongovernmental organizations, as well as the headwater states of New York, West Virginia and Delaware joined as full partners. Point source representatives and environmental groups also were well-represented on the committees during this effort. An overview of the roles of each group and the interplay between groups is described below and illustrated in figures I-1 and I-2. A brief review of the primary groups is provided below.

### WATER QUALITY TECHNICAL WORKGROUP

This workgroup consisted of technical staff and mid-level managers from the states, the EPA and stakeholders from point source and environmental group interests and

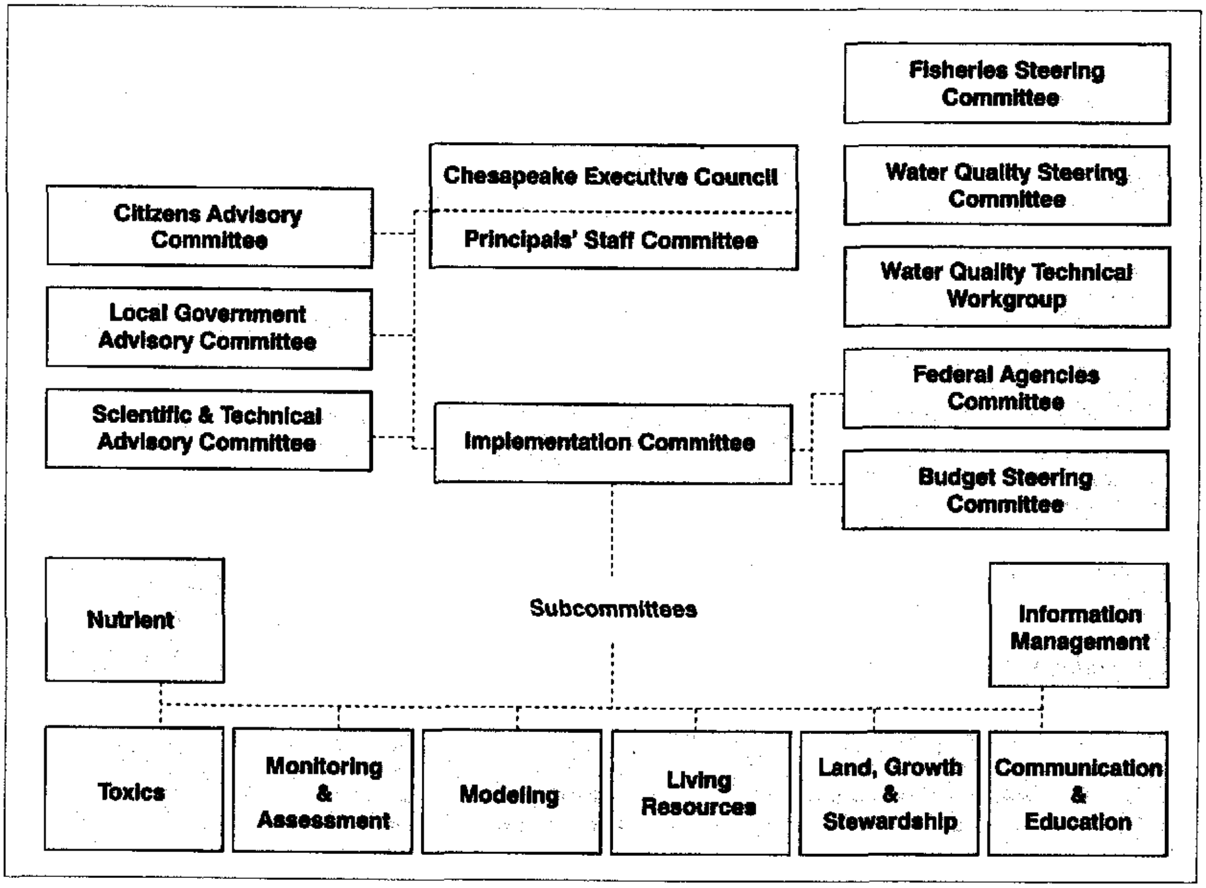


Figure I-1. Chesapeake Bay Program organizational structure.
Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

was expanded to include many of the modeling experts. Based on general policy direction given by the Water Quality Steering Committee, the Water Quality Technical Workgroup assessed modeling results, explored options, developed the allocation methodology and made recommendations to the Water Quality Steering Committee on technical issues with regard to the allocations. The workgroup's efforts were supported by several other groups:

- The Modeling Subcommittee maintained and updated the watershed and water quality models used in the allocation effort and provided for all modeling analyses, including an assessment of the relative impact of pollutant loadings from the major basins on Bay water quality; the impact of nitrogen versus phosphorus versus sediment inputs on Bay water quality; and all sensitivity and cap load allocation production runs leading up to the cap load allocations.
- The Nutrient Subcommittee developed the tiered scenarios and conducted an assessment of sediment reduction efficiencies for near shore sediment reduction best management practices.

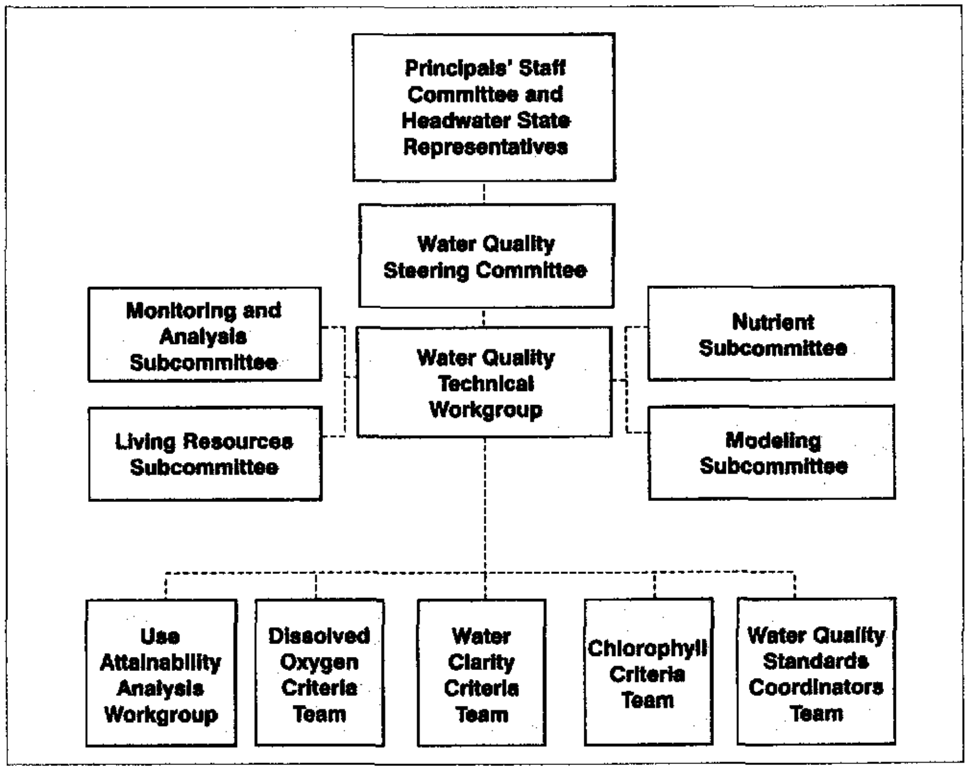


Figure I-2. Chesapeake Bay Program partner's organizational structure supporting the development and adoption of the Chesapeake Bay nutrient and sediment cap load allocations.

- The Living resources Subcommittee developed the baywide and local SAV restoration goals.
- The Monitoring and Analysis Subcommittee provided technical input and recommendations on monitoring-related issues, including using a three-year averaging period for all integrated monitoring and modeling results to determine attainability.
- The Dissolved Oxygen Criteria, Water Clarity Criteria, Chlorophyll Criteria and Water Quality Standards Coordinators teams derived the water quality criteria and refined tidal-water designated uses that were as the basis for setting and allocating the cap loads and developed the cumulative frequency distribution biological reference curve approach to determining criteria attainment.
- The Use Attainability Analysis Workgroup provided input on where to apply the criteria throughout the Bay tidal waters and provided input on feasibility and cost of options.

## WATER QUALITY STEERING COMMITTEE

This committee consisted of senior water program managers from all states in the Bay watershed, EPA Headquarters and regions II and III, the Chesapeake Bay Commission, the Susquehanna River Basin Commission and the Potomac River

Basin Commission. In addition, representatives from the point source and environmental group interests attended the meetings. The committee provided critical direction to the Water Quality Technical Workgroup, which explored policy and technical issues related to the restoring Bay water quality initiative. The issues explored included the derivation of the Bay water quality criteria, the refinement of the tidal-water designated uses, analysis of the attainability of current and the refined designated uses and the establishment and allocation of nutrient and sediment cap loads. The committee selected the baywide nutrient cap loads from various options that the workgroup forwarded. The Water Quality Steering Committee ultimately forwarded a full package of nutrient and sediment cap load allocation recommendations to the Principals' Staff Committee for review and formal adoption.

### PRINCIPALS' STAFF COMMITTEE

The Principals' Staff Committee (PSC) consists of the secretaries of the appropriate natural resource, agricultural, and regulatory pollution control agencies for the original signatory states of Pennsylvania, Maryland, Virginia, the District of Columbia, the Regional Administrator of EPA Region III and the Executive Director of the Chesapeake Bay Commission. While the headwater states of Delaware, New York and West Virginia were not members of the committee, representatives of these states attended PSC meetings and were directly involved in all decisions related to the cap load allocations. The committee was responsible for approving the allocations, but the PSC's involvement went well beyond approving the package recommended by the Water Quality Steering Committee. Since the recommendation of the Water Quality Steering Committee did not fully allocate the agreed-upon basinwide cap loads, the PSC and the headwater state representatives were called upon to negotiate the allocation of the additional 12 milion pounds per year of nitrogen reduction and 1 million pounds per year of phosphorus reduction necessary to achieve the baywide loading caps.

## REEVALUATING THE ALLOCATIONS

The nutrient and sediment cap load allocations adopted by the seven watershed jurisdictions and EPA are the best scientific estimates of the annual load reductions needed to attain proposed water quality criteria and tidal-water designated uses described in the *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and Its Tidal Tributaries (Regional Criteria Guidance)* published by the EPA (U.S. EPA 2003a). Over the next two years, Maryland, Virginia, Delaware and the District of Columbia will promulgate new water quality standards based on the regional guidance published by EPA.

Although the public process for adopting water quality standards varies among the states, each state's process will provide opportunities for considering and acquiring new information at the local level. States may choose to explore a number of issues during their adoption process, such as the economic impact of water quality standards and specific designated use boundaries.

While the allocations adopted at this time will provide the basis for tributary strategies, these allocations may need to be adjusted to reflect final state water quality standards. Furthermore, planned Bay model refinements, designed to estimate water quality benefits from filter feeding resources (such as oysters and menhaden) and improve understanding of the sources and effects of sediments, will increase the partners' understanding of the relationship between nutrient and sediment reductions and living resource responses in the Chesapeake Bay. For these reasons, the states and EPA agreed to a reevaluation of these cap load allocations by no later than 2007.

As partners, the jurisdictions committed to correcting the nutrient- and sediment-related problems in the Chesapeake Bay and its tidal tributaries enough to remove them from the list of impaired waters by 2010 under the Clean Water Act. The states recognize, however, that it will be difficult to meet projected water quality standards in all parts of the Chesapeake Bay tidal waters by that time. A key reason for this difficulty is that once nutrient and sediment reduction practices are installed and implemented, it may be years or even decades before the Chesapeake Bay benefits from these reductions. The jurisdictions intend to have programs in place and functioning by 2010. The Chesapeake Bay and its tidal tributaries are expected to become to be eligible for delisting when nutrient and sediment programs are fully implemented in the basin.

## SUPPORTING DOCUMENTS

In addition to recognizing the need for cap load allocations for nutrients and sediments, *Chesapeake 2000* also acknowledged the need for the development of scientifically sound water quality criteria for the protection of the Chesapeake Bay's living resources from nutrient- and sediment-related impacts. Through extensive scientific research, partner involvement and stakeholder and scientific review, the EPA has published regional water quality criteria for the Chesapeake Bay and its tidal tributaries for dissolved oxygen, water clarity and chlorophyll *a*. A full description of these water quality criteria can be found in the *Regional Criteria Guidance* (U.S. EPA 2003a).

To support the *Regional Criteria Guidance*, the EPA has published the *Technical Support Document for the Identification of Chesapeake Bay Designated Uses and Attainability* (*Technical Support Document*) (U.S. EPA 2003b). The purpose of the *Technical Support Document* is to identify new refined tidal habitat zones, or designated uses, to which the Chesapeake Bay criteria will apply. In addition, SAV restoration goals have been established by the Chesapeake Bay Program partners for segments throughout the Chesapeake Bay tidal waters. The *Technical Support Document* also delineates the boundaries of these designated uses and assesses their technological attainability. The EPA also has published a companion document entitled *Economic Analysis and Impacts of Nutrient and Sediment Reduction Actions* *to Restore Chesapeake Bay Water Quality*, which provides information on costs and impacts of various levels of nutrient and sediment technology and best management practices controls across the Chesapeake Bay watershed that may be necessary to meet the new criteria and designated uses (U.S. EPA 2003c).

Collectively, these three documents support the establishment of cap load allocations for nutrients and sediments by identifying attainable water quality and resource restoration goals for all habitats within the Chesapeake Bay and its tidal tributaries.

A memorandum from Secretary Tayloe Murphy (2003), Virginia Natural Resources Secretary, to the Principals' Staff Committee members and representatives of the Chesapeake Bay headwater states formally summarized the decisions regarding the nutrient and sediment cap load allocations and the new submerged aquatic vegetation restoration goals.

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## ORGANIZATION OF THE ALLOCATIONS DOCUMENT

The cap load allocations were based largely on a scientific understanding of what affects the water quality of the Chesapeake Bay and its tidal tributaries. Therefore, much of this document is dedicated to presenting the scientific tools and issues that were important to the development of the allocations. Accordingly, Chapter II reviews the primary tools used in developing the cap load allocations, including the loading scenarios. These scenarios were used to estimate the nutrient and sediment loads associated with increased levels of pollution control measures and to gain insight into the source loadings and associated impacts on water quality. In addition, this chapter provides a brief technical review of the various models used to simulate the source loads and their impact on the Bay's tidal water quality.

Chapter III reviews the major technical difficulties that arose and documents the innovative solutions created by the partners' technical staff. Included in this chapter are issues related to developing the methodology for determining attainment of the water quality criteria (e.g., applying biological reference curves), results of assessments on the impact of each major basin on the Bay's tidal water quality, results of assessments on the water quality impact from nitrogen versus phosphorus inputs to the Bay (e.g., analyzing relative effectiveness) and a brief technical review of the attainment simulations for the SAV acreage goals established for the Bay.

However, significant policy guidance was vital in order to arrive at cap load allocations with the highest probability of 'buy-in' and, therefore, the greatest assurance of implementation. Chapter IV describes how science informed the policy decisions applied during the cap load allocation process. It provides a detailed review of the methodologies, model results and policy decisions used to derive the cap load allocations for nutrients and sediments. Specifically, it presents the principles applied and approaches taken to derive baywide loading caps for nutrients and sediment and the two separate methodologies used to distribute the cap loads to the major tributary basins and then to jurisdictions within the Bay watershed for nutrients and sediments.

Finally, appendices A through F provide extensive model results and analyses in support of the allocations.

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# Contents

# Acknowledgments

Development of the nutrient and sediment allocations for the Chesapeake Bay involved sifting through a wealth of scientific data and information, constructing a technically sound decision making process and factoring in an array of policy considerations. The collaborative efforts, collective knowledge and applied expertise of the following committees, subcommittees, workgroups, and headwater representatives were contributed to the success of the process.

Development of the technical recommendations that met the diverse needs of the Chesapeake Bay Program partners would not have been possible without the understanding of water quality condition needs of the Bay, energy and enthusiasm, which was provided by members of and staff to the **Chesapeake Bay Program Water Quality Technical Workgroup:** Alan Pollock, Chair, Virginia Department of Environmental Quality; Richard Batiuk, U.S. EPA Chesapeake Bay Program Office; Victor Bierman, Jr., LimoTech Inc.; Michael Bowman, Virginia Department of Conservation & Recreation; Charles Lunsford, Virginia Department of Conservation & Recreation; William Brown, Pennsylvania Department of Environmental Protection; Arthur Butt, Virginia Department of Environmental Quality; John Kennedy, Virginia Department of Environmental Quality; James Collier, District of Columbia Department of Health; Carol Young, Pennsylvania Department of Environmental Protection; Richard Draper, New York State Department of Environmental Conservation; Richard Eskin, Maryland Department of Environment; Dave Montali, West Virginia Department of Environmental Protection; Will Hunley, Hampton Roads Sanitation District; Maggie Kerchner, NOAA Chesapeake Bay Office; Wendy Jastremski, U.S. EPA Chesapeake Bay Program Office; Robert Koroncai, U.S. EPA Chesapeake Bay Program Office; Norm LeBlanc, Hampton Roads Sanitation District; Lewis Linker, U.S. EPA Chesapeake Bay Program Office; Russel Mader, National Resources Conservation Service; Robert Magnien, Maryland Department of Natural Resources; Lee McDonnell, Pennsylvania Department of Environmental Protection; Mark Morris, U.S. EPA Office of Water; Scott Phillips, U.S. Geological Survey; Ana Pomales, U.S. EPA Region III; Christopher Pomeroy, AquaLaw PLC; John Schneider, Delaware Department of Natural Resources & Environmental Control; Gary Shenk, U.S. EPA Chesapeake Bay Program Office; Tom Simpson, University of Maryland; Tanya Spano, Metropolitan Washington Council of Governments; Peter Tango, Maryland Department of Natural Resources; Lyle Varnell, Virginia Institute of Marine Science; Lauren Wenzel, Maryland Department of Natural Resources; Allison Wiedeman, U.S. EPA Chesapeake Bay Program Office; Clyde Wilbur, Greeley & Hansen; and Kyle Zieba, U.S. EPA Chesapeake Bay Program Office.

Development of the nutrient and sediment cap load allocations would not have been possible without the ability to understand the water quality and living resource responses to pollutant loadings in the Bay. Such understanding is made possible through the Chesapeake Bay Airshed, Watershed and Water Quality models, which are ably managed, maintained, and continually enhanced by members of the Chesapeake Bay Program's **Modeling Subcommittee**: James Collier, Chair, District of Columbia Department of Health; Lowell Bahner, National Oceanic & Atmospheric Administration; Mark Bennett, U.S. Geological Survey; Peter Bergstrom, U.S. Fish & Wildlife Service; Michael Bowman, Virginia Department of Conservation & Recreation; William Brown, Pennsylvania Department of Environmental Protection; Arthur Butt, Virginia Department of Environmental Quality; Robin Dennis, National Oceanographic and Atmospheric Administration; Lewis Linker, U.S. EPA Chesapeake Bay Program Office; Charles Lunsford, Virginia Department of Conservation & Recreation; Robert Magnien, Maryland Department of Natural Resources; Ross Mandel, Interstate Commission on the Potomac River Basin; Timothy Murphy, Metropolitan Washington Council of Governments; Narendra Panday, Maryland Department of Environment; Kenn Pattison, Pennsylvania Department of Environmental Protection; Jeff Raffensperger, U.S. Geological Survey-Baltimore; Helen Stewart, Maryland Department of Natural Resources; Peter Tango, Maryland Department of Natural Resources; and Harry Wang, Virginia Institute of Marine Science.

While all of the Modeling Subcommittee members made important contributions, special recognition is appropriately due to Lewis Linker (EPA), Gary Shenk (EPA) and Jeff Sweeney (University of Maryland) for pioneering efforts in creating new approaches to difficult problems through relentless dedication to the task at hand. Special thanks and recognition to Ping Wang (University of Maryland) for his skill, expertise, and dedication in scenario operation and development on The National Environmental Super Computer Center, and to Kate Hopkins (University Of Maryland) for her expert application of GIS modeling support to the allocation analyses.

The sediment allocation recommendations were driven by the new Submerged Aquatic Vegetation (SAV) restoration goal. Without the close coordination between the Chesapeake Bay Program's **SAV Workgroup** and the Water Quality Technical Workgroup, linking the SAV resource to the sediment cap load allocations would not have been possible. Mike Naylor (Maryland Department of Natural Resources), Ken Moore (Virginia Institute of Marine Science), Frank Dawson (Maryland Department of Natural Resources) and Mike Fritz (EPA) in particular, led the effort to assure integration of the SAV restoration goal with efforts to derive water clarity criteria, set shallow-water designated use boundaries and establish the sediment cap load allocations.

The Chesapeake Bay Program's **Scientific and Technical Advisory Committee** (STAC) provided timely and important input to the allocation process during a critical juncture in the deliberations. Special thanks to Scott Phillips for his leadership in facilitating communication between STAC and the Water Quality Technical Workgroup.

Cap load allocations, especially as complex as that for the Chesapeake Bay, are a unique blend of science and policy. The Chesapeake Bay Program's **Water Quality Steering Committee** provided much needed direction to the Water Quality

Technical Workgroup on difficult matters of equity and process. Furthermore, it was the Water Quality Steering Committee that forwarded the cap load allocations to the Principals' Staff Committee for approval. The members were: Jon Capacasa, co-chair, U.S. EPA Region III; Rebecca Hanmer, co-chair, U.S. EPA Chesapeake Bay Program; Russell Baxter, Chesapeake Bay Commission; Jerusalem Bekele, District of Columbia Department of Health; Michael Bowman, Virginia Department of Conservation & Recreation; Edward Brezina, Pennsylvania Department of Environmental Protection; Patricia Buckley, Pennsylvania Department of Environmental Protection; William Brannon, West Virginia Department of Environmental Protection; James Collier, District of Columbia Department of Health; Melanie Davenport, Chesapeake Bay Commission; Kevin Donnelly, Delaware Department of Natural Resource and Environmental Control; Richard Draper, New York State Department of Environmental Conservation; Phillip M. DeGaetano, New York State Department of Environmental Conservation; Mario DelVicario, U.S. EPA Region II; Diana Esher, U.S. EPA Chesapeake Bay Program Office; Richard Eskin, Maryland Department of the Environment; Jack Frye, Virginia Department of Conservation and Recreation; Stuart Gansell, Pennsylvania Department of Environmental Protection; Carlton Haywood, Interstate Commission on the Potomac River Basin; David Heicher, Susquehanna River Basin Commission; James Keating, U.S. EPA Office of Water, Office of Science and Technology; Felix Locicero, U.S. EPA Region II; Steve Luckman, Maryland Department of the Environment; Robert Magnien, Maryland Department of Natural Resources; Chris Miller, U.S. EPA Office of Water, Office of Science and Technology; Matthew Monroe, West Virginia Department of Agriculture; Kenn Pattison, Pennsylvania Department of Environmental Protection; Alan Pollock, Virginia Department of Environmental Quality; John Schneider, Delaware Department of Natural Resources and Environmental Control; Thomas Simpson, University of Maryland; Robert Summers, Maryland Department of Environment; Ann Swanson, Chesapeake Bay Commission; Robert Yowell, Pennsylvania Department of Environmental Protection; and Robert Zimmerman, Delaware Department of Natural Resources and Environmental Control.

Without a unified commitment to restoring the Chesapeake Bay, agreement on allocating the last 12 million pounds of nitrogen and 1 million pounds of phosphorus that is necessary to achieve the basinwide cap loads would not have been possible. The Chesapeake Bay Program Principals' Staff Committee along with its new partner states of Delaware, New York, and West Virginia, provided the leadership that was necessary to approve the allocation recommendations and to allocate further remaining loads.

## Principals' Staff Committee

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# Executive Summary

The *Chesapeake 2000* agreement has been guiding Maryland, Pennsylvania, Virginia, the District of Columbia, the Chesapeake Bay Commission and the U.S. Environmental Protection Agency (EPA) in their combined efforts to restore and protect the Chesapeake Bay. It defined the goal to "achieve and maintain the water quality necessary to support the aquatic living resources of the Bay and its tributaries and to protect human health." Subsequently, Delaware, New York and West Virginia signed a Memorandum of Understanding committing to implement the Water Quality Protection and Restoration section of the agreement.

*Chesapeake 2000* committed its signatories to:

> *continue efforts to achieve and maintain the 40 percent nutrient reduction goal agreed to in 1987* and *correct the nutrient- and sediment-related problems in the Chesapeake Bay and its tidal tributaries sufficiently to remove the Bay and the tidal portions of its tributaries from the list of impaired waters under the Clean Water Act* by 2010.

Defining science-based loading caps for nutrients and sediment and allocating responsibility by major tributary basin to the jurisdictions were critical steps to fulfilling the water quality commitments. This document presents the collaborative process, technical tools and innovative approaches that made possible the successful allocation of nutrient and sediment cap loads to each jurisdiction by major tributary basin.

## NUTRIENT CAP LOAD ALLOCATIONS

Excessive nutrients in the Chesapeake Bay and its tidal tributaries promote a number of undesirable water quality conditions such as excessive algal growth, low dissolved oxygen and reduced water clarity. The effect of nutrient loads on water quality and living resources tends to vary considerably by season and region. Low dissolved oxygen problems tend to be more pronounced in the deeper parts of the upper bay region during the summer months. The allocations for nutrients were developed primarily to address this problem.

As a result, New York, Pennsylvania, Maryland, Delaware, Virginia, West Virginia, the District of Columbia and the U.S. Environmental Protection Agency agreed to cap annual nitrogen loads delivered to the Bay's tidal waters at 175 million pounds and annual phosphorus loads at 12.8 million pounds. It is estimated that these allocations will require reductions, from 2000 levels, in nitrogen pollution by 110 million pounds and phosphorus pollution by 6.3 million pounds.

The Chesapeake Bay Program partners agreed to these load reductions based upon Chesapeake Bay Water Quality Model projections of attainment of published Bay dissolved oxygen criteria applied to the refined tidal water designated uses. The model projects these load reductions will significantly reduce the persistent summer anoxic conditions in the deep bottom waters of the Chesapeake Bay and restore suitable habitat quality conditions throughout the tidal tributaries. Furthermore, these reductions are projected to eliminate excessive, sometimes harmful, algae conditions (measured as chlorophyll *a*) throughout the Chesapeake Bay and its tidal tributaries.

The jurisdictions agreed to distribute the basinwide cap loads for nitrogen and phosphorus by major tributary basin (Table 1) and jurisdiction (Table 2). This distribution of responsibility for load reductions was based on three basic principles:

1. Tributary basins with the highest impact on Chesapeake Bay tidal water quality would be allocated the highest reductions of nutrients.
2. States without tidal waters—Pennsylvania, New York and West Virginia—would be provided some relief from Principle 1 since they benefit less directly from improved water quality in the Chesapeake Bay and its tidal tributaries.
3. Nutrient reductions prior to 2000 would be credited towards achievement of the cap load allocations.

The nine major tributary basins were separated into three categories based upon their impact on Bay tidal water quality. Each basin within an individual category was assigned the same percent reduction of anthropogenic, or human-caused, load. Consequently, basins with the highest impact on tidal water quality were assigned the highest percentage reduction of anthropogenic load.

After completing the above calculations and applying Principle 2, New York, Pennsylvania and West Virginia allocations were set at the 'Tier 3' scenario nutrient load levels. The Tier 3 scenario is one of several tiers representing different implementation scenarios of nutrient reduction measures for the Chesapeake Bay watershed developed by the Chesapeake Bay Program partners. The Tier 3 scenario represented nutrient and sediment loads of 181 million pounds of nitrogen per year, 13.4 million pounds of phosphorus per year, 4.14 million tons of land-based sediment per year and included a 20 percent reduction in tidal shoreline erosion sediment loads. Additionally, allocations for Virginia's York and James River basins were set at previously established tributary strategy nutrient cap load levels since these two basins have a minimal impact on mainstem Bay water quality conditions, and their influence on tidal water quality is predominantly local.

Application of these rules resulted in shortfalls of 12 million pounds of nitrogen and 1 million pounds of phosphorus above the basinwide cap loads. However, the EPA committed to pursue the Clear Skies initiative, which is estimated to reduce the nitrogen load to Bay tidal waters by 8 million pounds per year. Furthermore, the Bay watershed states agreed to take responsibility for the remaining 4 million pounds of nitrogen and 1 million pounds of phosphorus. The nutrient cap load allocations in tables 1 and 2 reflect these agreements.

The cap load allocations for nitrogen and phosphorus were adopted as 'nitrogen equivalents'. Included was a commitment to explore how actions beyond traditional best management practices (BMPs) might help meet the Chesapeake Bay water quality restoration goals. A nitrogen equivalent is an action that results in the same water quality benefit as removing nitrogen. The Chesapeake Bay Program partners will evaluate how tidal water quality benefits from continued and expanded living resource restoration, such as oysters and menhaden, can be accounted for in offsetting the reductions of watershed-based nutrient and sediment loads. Seasonal fluctuations in implementation of biological nutrient removal, nutrient reduction from shoreline erosion control, implementation of enhanced nutrient removal technologies at large wastewater treatment plants, and trade-offs between nitrogen and phosphorus will also be evaluated.

Also, while the allocations adopted at this time will provide the basis for tributary strategies, these allocations may need to be adjusted to reflect final state water quality standards. If the final adopted state water quality standards are different than the criteria and designated use used to establish these cap load allocations, then the cap load allocations will need to be amended accordingly.

## SEDIMENT CAP LOAD ALLOCATIONS

Sediments suspended in the water column reduce the amount of light available to support healthy and extensive submerged aquatic vegetation (SAV), or underwater bay grass, communities. The relative contribution of suspended sediment and algae that cause poor light conditions varies with location in the Bay tidal waters. The Chesapeake Bay Program partners agreed that a primary reason for reducing sediment loads to the Bay tidal waters is to provide suitable habitat for restoring SAV. As a result, the cap load allocations for sediments are linked to the recommended water clarity criteria and the new SAV restoration goals and recognize that sediment load reductions are essential to SAV restoration. The jurisdictions also agreed that nutrient load reductions are critical for restoring SAV as well as improving oxygen levels.

To support the sediment cap load allocations, it became clear that updated SAV restoration goals were needed. The partners explored various methodologies for developing a baywide SAV acreage restoration target using the available historical record. The methodology selected used aerial photography from the 1930s to present to identify the best year of record (in terms of acres of SAV) for each Chesapeake Bay Program segment. The acreage determined to be the best year of record was designated as the SAV acreage goal for that segment. In aggregating all of the single best year results for each segment, a baywide SAV acreage restoration goal for the entire Bay of 185,000 acres was established. Table 3 provides the SAV acreage goal for each Bay segment while Table 4 provides the SAV acreage goal for each major tributary basin in the Chesapeake Bay watershed adopted by the Chesapeake Bay Program partners.

Unlike nutrients, where loads from virtually the entire Chesapeake Bay watershed affect mainstem Chesapeake Bay water quality, impacts from sediments are predominantly localized. For this reason, local, segment-specific SAV acreage goals have been established and the sediment cap load allocations are targeted towards achieving those restoration goals.

The partners recognize that the current understanding of sediment sources and their impact on the Chesapeake Bay is not yet complete. Currently, understanding of land-based sediments that are carried into local waterways through stream bank erosion and runoff is still basic. Knowledge about nearshore sediments that enter the Bay and its tidal rivers directly through shoreline erosion or shallow-water suspension is even more limited. Consequently, the sediment cap load allocations are currently focused on land-based sediment cap loads by major tributary basin (Table 1) and jurisdiction (Table 2).

Most land-based best management practices, which reduce nonpoint sources of phosphorus, will also reduce sediment runoff. Therefore, the partners agreed to land-based sediment allocations that represent the sediment load reductions likely to result from implementing management actions required for the allocated phosphorus reductions.

The sediment cap load allocations were set at the tier level for the phosphorus cap load allocation for each jurisdiction-basin. This designation is referred to as the 'phosphorus equivalent' land-based sediment reduction. If the 'phosphorus equivalent' land-based sediment reductions were found to be more than that which are necessary to achieve the local SAV restoration goals, then the land-based sediment cap load allocations were lowered to that level necessary to achieve the SAV restoration goal. The tidal-fresh Susquehanna Flats and tidal-fresh Potomac River are two examples where this modified approach was applied. If, in the development of their tributary strategies, tributary teams conclude that the land-based sediment allocations need revisions, the tributary teams may identify an alternate land-based allocation. For example, a jurisdiction may select different nonpoint source management actions than those prescribed in the tier approach to reach the phosphorus goal; the jurisdiction may adjust the sediment cap load allocation accordingly so long as SAV restoration and protection is not compromised. The tributary teams must work with all the jurisdictions within the affected basin in revising the sediment cap load allocations.

It is likely that reductions in nutrients and land-based sediments alone will not be sufficient to achieve the local SAV restoration goals for many areas of the Chesapeake Bay and its tidal tributaries. In these areas, tributary teams will be asked to further assess varied and innovative methods to achieve SAV establishment and growth. Such methods may include, but are not limited to SAV planting, offshore breakwaters, shore erosion controls, beach nourishment, establishment of oyster bars, and other actions as appropriate.

Table 1. Chesapeake Bay watershed nitrogen, phosphorus and sediment cap load allocations by major basin.

| Basin/Jurisdiction | Nitrogen Cap Load Allocation (million pounds/year) | Phosphorus Cap Load Allocation (million pounds/year) | Upland Sediment Cap Load Allocation (million tons/year) |
|---|---|---|---|
| **SUSQUEHANNA** | | | |
| PA | 67.58 | 1.90 | 0.793 |
| NY | 12.58 | 0.59 | 0.131 |
| MD | 0.83 | 0.03 | 0.037 |
| SUSQUEHANNA Total | 80.99 | 2.52 | 0.962 |
| **EASTERN SHORE - MD** | | | |
| MD | 10.89 | 0.81 | 0.116 |
| DE | 2.88 | 0.30 | 0.042 |
| PA | 0.27 | 0.03 | 0.004 |
| VA | 0.06 | 0.01 | 0.001 |
| EASTERN SHORE - MD Total | 14.10 | 1.14 | 0.163 |
| **WESTERN SHORE** | | | |
| MD | 11.27 | 0.84 | 0.100 |
| PA | 0.02 | 0.00 | 0.001 |
| WESTERN SHORE Total | 11.29 | 0.84 | 0.100 |
| **PATUXENT** | | | |
| MD | 2.46 | 0.21 | 0.095 |
| PATUXENT Total | 2.46 | 0.21 | 0.095 |
| **POTOMAC** | | | |
| VA | 12.84 | 1.40 | 0.617 |
| MD | 11.81 | 1.04 | 0.364 |
| WV | 4.71 | 0.36 | 0.311 |
| PA | 4.02 | 0.33 | 0.197 |
| DC | 2.40 | 0.34 | 0.006 |
| POTOMAC Total | 35.78 | 3.48 | 1.494 |
| **RAPPAHANNOCK** | | | |
| VA | 5.24 | 0.62 | 0.288 |
| RAPPAHANNOCK Total | 5.24 | 0.62 | 0.288 |
| **YORK** | | | |
| VA | 5.70 | 0.48 | 0.103 |
| YORK Total | 5.70 | 0.48 | 0.103 |
| **JAMES** | | | |
| VA | 26.40 | 3.41 | 0.925 |
| WV | 0.03 | 0.01 | 0.010 |
| JAMES Total | 26.43 | 3.42 | 0.935 |
| **EASTERN SHORE - VA** | | | |
| VA | 1.16 | 0.08 | 0.008 |
| EASTERN SHORE - VA Total | 1.16 | 0.08 | 0.008 |
| **SUBTOTAL** | 183 | 12.8 | 4.15 |
| **CLEAR SKIES REDUCTION** | -8 | | |
| BASINWIDE TOTAL | 175 | 12.8 | 4.15 |

Table 2. Chesapeake Bay watershed nitrogen, phosphorus and sediment cap load allocations by jurisdiction.

| Jurisdiction/Basin | Nitrogen Cap Load Allocation (million pounds/year) | Phosphorus Cap Load Allocation (million pounds/year) | Upland Sediment Cap Load Allocation (million tons/year) |
|---|---|---|---|
| **PENNSYLVANIA** | | | |
| Susquehanna | 67.58 | 1.90 | 0.793 |
| Potomac | 4.02 | 0.33 | 0.197 |
| Western Shore | 0.02 | 0.00 | 0.001 |
| Eastern Shore - MD | 0.27 | 0.03 | 0.004 |
| PA Total | 71.90 | 2.26 | 0.995 |
| **MARYLAND** | | | |
| Susquehanna | 0.83 | 0.03 | 0.037 |
| Patuxent | 2.46 | 0.21 | 0.095 |
| Potomac | 11.81 | 1.04 | 0.364 |
| Western Shore | 11.27 | 0.84 | 0.100 |
| Eastern Shore - MD | 10.89 | 0.81 | 0.116 |
| MD Total | 37.25 | 2.92 | 0.712 |
| **VIRGINIA** | | | |
| Potomac | 12.84 | 1.40 | 0.617 |
| Rappahannock | 5.24 | 0.62 | 0.288 |
| York | 5.70 | 0.48 | 0.103 |
| James | 26.40 | 3.41 | 0.925 |
| Eastern Shore - MD | 0.06 | 0.01 | 0.001 |
| Eastern Shore - VA | 1.16 | 0.08 | 0.008 |
| VA Total | 51.40 | 6.00 | 1.941 |
| **DISTRICT OF COLUMBIA** | | | |
| Potomac | 2.40 | 0.34 | 0.006 |
| DC Total | 2.40 | 0.34 | 0.006 |
| **NEW YORK** | | | |
| Susquehanna | 12.58 | 0.59 | 0.131 |
| NY Total | 12.58 | 0.59 | 0.131 |
| **DELAWARE** | | | |
| Eastern Shore - MD | 2.88 | 0.30 | 0.042 |
| DE Total | 2.88 | 0.30 | 0.042 |
| **WEST VIRGINIA** | | | |
| Potomac | 4.71 | 0.36 | 0.311 |
| James | 0.03 | 0.01 | 0.010 |
| WV Total | 4.75 | 0.37 | 0.320 |
| **SUBTOTAL** | **183** | **12.8** | **4.15** |
| **CLEAR SKIES REDUCTION** | **–8** | | |
| **BASINWIDE TOTAL** | **175** | **12.8** | **4.15** |

Table 3. Chesapeake Bay submerged aquatic vegetation (SAV) restoration goal acreage by Chesapeake Bay Program (CBP) segment based on the single best year of record from 1930 to present.

| CBP Segment Name | Segment | Acres |
|---|---|---|
| Northern Chesapeake Bay | CB1TF | 12,908 |
| Upper Chesapeake Bay | CB2OH | 302 |
| Upper Central Chesapeake Bay | CB3MH | 943 |
| Middle Central Chesapeake Bay | CB4MH | 2,511 |
| Lower Central Chesapeake Bay | CB5MH | 14,961 |
| Western Lower Chesapeake Bay | CB6PH | 980 |
| Eastern Lower Chesapeake Bay | CB7PH | 14,620 |
| Mouth of the Chesapeake Bay | CB8PH | 6 |
| Bush River | BSHOH | 158 |
| Gunpowder River | GUNOH | 2,254 |
| Middle River | MIDOH | 838 |
| Back River | BACOH | 0 |
| Patapsco River | PATMH | 298 |
| Magothy River | MAGMH | 545 |
| Severn River | SEVMH | 329 |
| South River | SOUMH | 459 |
| Rhode River | RHDMH | 48 |
| West River | WSTMH | 214 |
| Upper Patuxent River | PAXTF | 5 |
| Western Branch (Patuxent River) | WBRTF | 0 |
| Middle Patuxent River | PAXOH | 68 |
| Lower Patuxent River | PAXMH | 1,325 |
| Upper Potomac River | POTTF | 4,368 |
| Anacostia River | ANATF | 6 |
| Piscataway Creek | PISTF | 783 |
| Mattawoman Creek | MATTF | 276 |
| Middle Potomac River | POTOH | 3,721 |
| Lower Potomac River | POTMH | 10,173 |
| Upper Rappahannock River | RPPTF | 20 |
| Middle Rappahannock River | RPPOH | 0 |
| Lower Rappahannock River | RPPMH | 5,380 |
| Corrotoman River | CRRMH | 516 |
| Piankatank River | PIAMH | 3,256 |
| Upper Mattaponi River | MPNTF | 75 |
| Lower Mattaponi River | MPNOH | 0 |
| Upper Pamunkey River | PMKTF | 155 |
| Lower Pamunkey River | PMKOH | 0 |
| Middle York River | YRKMH | 176 |
| Lower York River | YRKPH | 2,272 |
| Mobjack Bay | MOBPH | 15,096 |

*continued*

Table 3. Chesapeake Bay submerged aquatic vegetation (SAV) restoration goal acreage by Chesapeake Bay Program (CBP) segment based on the single best year of record from 1930 to present *(cont.)*.

| **CBP Segment Name** | **Segment** | **Acres** |
|---|---|---|
| Upper James River | JMSTF | 1,600 |
| Appomattox River | APPTF | 319 |
| Middle James River | JMSOH | 7 |
| Chickahominy River | CHKOH | 348 |
| Lower James River | JMSMH | 531 |
| Mouth of the James River | JMSPH | 604 |
| Western Branch Elizabeth River | WBEMH | 0 |
| Southern Branch Elizabeth River | SBEMH | 0 |
| Eastern Branch Elizabeth River | EBEMH | 0 |
| Lafayette River | LAFMH | 0 |
| Mouth to mid-Elizabeth River | ELIPH | 0 |
| Lynnhaven River | LYNPH | 69 |
| Northeast River | NORTF | 88 |
| C&D Canal | C&DOH | 0 |
| Bohemia River | BOHOH | 97 |
| Elk River | ELKOH | 1,648 |
| Sassafras River | SASOH | 764 |
| Upper Chester River | CHSTF | 0 |
| Middle Chester River | CHSOH | 63 |
| Lower Chester River | CHSMH | 2,724 |
| Eastern Bay | EASMH | 6,108 |
| Upper Choptank River | CHOTF | 0 |
| Middle Choptank River | CHOOH | 63 |
| Lower Choptank River | CHOMH2 | 1,499 |
| Mouth of the Choptank River | CHOMH1 | 8,044 |
| Little Choptank River | LCHMH | 3,950 |
| Honga River | HNGMH | 7,686 |
| Fishing Bay | FSBMH | 193 |
| Upper Nanticoke River | NANTF | 0 |
| Middle Nanticoke River | NANOH | 3 |
| Lower Nanticoke River | NANMH | 3 |
| Wicomico River | WICMH | 3 |
| Manokin River | MANMH | 4,359 |
| Big Annemessex River | BIGMH | 2,014 |
| Upper Pocomoke River | POCTF | 0 |
| Middle Pocomoke River | POCOH | 0 |
| Lower Pocomoke River | POCMH | 4,092 |
| Tangier Sound | TANMH | 37,965 |
| **Total acres** | | **184,889** |

Table 4. Chesapeake Bay submerged aquatic vegetation (SAV) restoration goal acreage by major basin by jurisdiction.

| Basin/Jurisdiction | SAV Restoration Goal (Acres) |
|---|---|
| SUSQUEHANNA | 12,856 |
| EASTERN SHORE – MD | 76,193 |
| WESTERN SHORE – MD | 5,651 |
| PATUXENT | 1,420 |
| POTOMAC[1] | |
| MD | 12,747 |
| VA | 6,320 |
| DC | 384 |
| RAPPAHANNOCK | 12,798 |
| YORK | 21,823 |
| JAMES | 3,483 |
| EASTERN SHORE – VA | 31,215 |
| TOTAL | 184,889 |

[1] Breakdown of Potomac SAV restoration goals by jurisdictions are draft, pending confirmation of split between Maryland, Virginia and the District of Columbia along jurisdictional lines. Due to ongoing refinement, some numbers in this table differ from the April 25, 2003 version included in Appendix A and previous model estimates presented in tables III-3 and III-4.

chapter ii

# Overview of Technical Tools

Pollutant loading allocations must be based on credible science. It is important to understand and simulate the source loadings, as well as their impact on the water quality of the receiving water body. Because the Chesapeake Bay nutrient and sediment dynamics are so complex, establishing the scientific basis required the application of several coupled models of the Chesapeake Bay ecosystem:

- The Chesapeake Bay Airshed Model provided simulations of air sources of nutrients and air deposition onto the Chesapeake Bay watershed and the tidal surface waters;
- The Chesapeake Bay Watershed Model tracked loadings from all sources of nutrients and sediments in the watershed and simulated pollutant transport down to the Chesapeake Bay and its tidal tributaries;
- The Chesapeake Bay Water Quality Model is an aggregate of several models—hydrodynamic, water quality, bottom sediment, benthic community and SAV community—which combined effectively, simulated the effects of nutrient and sediment pollutant loadings on the water quality of the Chesapeake Bay and its tidal tributaries.

A brief review of these important tools is provided below. In addition, a description is provided of the development of management control scenarios, called 'tiers', which played a critical role in the process of developing allocations.

## TIERED MANAGEMENT IMPLEMENTATION SCENARIOS

A series of watershed model scenarios were designed to estimate the nutrient and sediment loads associated with increased implementation levels of best management practices (BMPs), wastewater treatment upgrades and/or other point or non-point control technologies. The resultant watershed model outputs—various combinations of nitrogen, phosphorus and sediment delivered loads to tidal Bay waters—were used as inputs to the Chesapeake Bay Water Quality Model to evaluate the relative response of key tidal water quality parameters (i.e. dissolved oxygen, water clarity and chlorophyll *a* concentrations) to these watershed loading levels. The range of water quality responses, in turn, helped define cause (nutrient and sediment loadings) and effect (tidal water quality) relationships and were used in assessing the attainability of current and refined designated uses (see *Tiered Scenario Estimated Nutrient and Sediment Loads*).

These tiered scenarios do not prescribe control measures necessary for the watershed jurisdictions to meet the *Chesapeake 2000* nutrient and sediment cap load allocations. Again, they were developed as a tool to assess relative water quality impacts from a range of load reductions. The scenarios are theoretical constructs of technological levels of effort and do not represent actual programs that jurisdictions must implement or required combinations of region-specific BMPs. Cost effective combinations of BMPs will be evaluated by the jurisdictions working directly with their tributary strategy teams, who will address real issues such as physical limitations and any potential adverse economic impacts from implementation.

The tiered scenarios characterize the Chesapeake Bay watershed's nutrient and sediment reduction potential in terms of types of BMPs, extent of implementation and performance of BMPs for both point and nonpoint sources (Appendix B). Tier definitions were designed to ensure each Tier went beyond the nutrient and sediment load reductions of the previous tier and, therefore, imply a 'level of effort'. The scenarios range from the Tier 1 scenario, representing extensions of current implementation rates throughout the watershed plus regulatory requirements in place by 2010, to everything, everywhere by everybody (E3 scenario), which goes beyond any previous Chesapeake Bay Program definition of 'limit of technology' (LOT). Two intermediate levels of implementation, the Tier 2 and Tier 3 scenarios, were also developed.

If the only objective of developing the tier scenarios was to relate tidal water quality response to nutrient and sediment load reductions, it would not have been necessary to define the scenarios in terms of increased implementation levels of BMPs and control technologies. This objective could have been accomplished by setting incremental loading reductions from all tributary basins in the Bay watershed. However, assessments of attainability of the current and refined tidal water designated uses required the association of load reductions to specific implementation levels of BMPs or control technologies, their nutrient and sediment reduction efficiencies, and their feasibility of implementation.

***Important Note:*** *Tiers are artificial constructs of technological levels of effort and were not meant to represent actual programs the jurisdictions will eventually implement to meet water quality standards. In addition, the tiers do not denote combinations of region-specific BMPs that would best reach the nitrogen, phosphorus and sediment cap loads allocated to each jurisdiction within each tributary. They were developed as an assessment tool to determine relative water quality impacts from a range of load reductions. Tier definitions were designed to ensure each Tier went beyond the nutrient and sediment load reductions of the previous Tier.*

Appendix A of the *Technical Support Document* describes the development of the tier scenarios and the pollutant control technologies represented in each tier (U.S. EPA 2003a). Both Appendix A and Chapter V of this document present the

Chesapeake Bay watershed model estimates of the nitrogen, phosphorus and sediment load reductions associated with each of the tier scenarios.

The tier scenarios were based primarily on BMPs and control technologies directed toward reductions in nitrogen and phosphorus loads. The model-simulated sediment reductions were incidental responses to the implementation of nutrient reduction BMPs. Other sediment reduction management practices are available and may, if implemented along with nutrient reduction efforts, afford additional water quality improvements (see Chapter III). This is especially true for BMPs applied in the near shore areas of the tidal Bay.

## DEVELOPMENT OF THE TIERED SCENARIOS

The tiered BMP implementation levels were initially defined by the 'source' workgroups of the Chesapeake Bay Program Nutrient Subcommittee. The Agricultural Nutrient Reduction, Forestry, Point Source and Urban Stormwater workgroups, which is comprised of representatives of Bay watershed jurisdictions and other technical experts, contributed expertise and information for their assigned 'source'. In some cases, the Nutrient Subcommittee's Tributary Strategy Workgroup edited the tier scenario definitions so that necessary input decks for the watershed model, which captured the essence of the definitions, could be developed.

### Projected 2010 Conditions

All tier scenarios were based on 2010 projections of land uses, human populations, agricultural animal populations, point source flows, and septic systems, as well as 2007/2010 or 2020 air emissions. Land use and human and animal population projections were developed from an array of national, regional, and state databases as described in *Chesapeake Bay Watershed Model Land Use and Model Linkages to the Airshed and Estuarine Models* (Hopkins et al. 2000).

Agricultural land uses were projected from agricultural census county information (1982, 1987, 1992 and 1997) according to methodologies chosen by individual states. The projected animal populations were also based on county agricultural census trends and information provided by state environmental and agricultural agencies.

Urban land uses for 2010 were projected from a methodology involving human population changes, as determined by the U.S. Census Bureau for 1990 and 2000, as well as by some individual state agencies. The population changes were related to 1990 high-resolution satellite imagery of the Chesapeake Bay watershed, which is the root source of urban and forest land acreages. In the case of Maryland, urban growth from 2000 to 2010 was determined by Maryland Department of Natural Resources and Maryland Department of Planning.

With urban and agricultural land use acreages fixed for 2010, the remaining land was divided between forest and mixed open in the same proportion that existed in 1990 for New York, Pennsylvania, Delaware, West Virginia, and the District of Columbia. The 2010 forest acreage was fixed for Maryland and Virginia following methodologies or data submitted by those states with the remaining acreage being mixed open.

## Tier Scenario Components

### Point Source

A multi-stakeholder Nutrient Reduction Technology Cost Task Force, which consisted of federal, state and local representatives as well as municipal authority representatives and expert consultants, was formed as a temporary extension of the Nutrient Subcommittee's Point Source Workgroup. The Task Force defined what would be logical tiers (break points) for incremental levels of point source control technology implementation (U.S. EPA 2002). Using wastewater flows projected for the year 2010, the tier scenarios range from the current (year 2000) treatment levels to the E3 scenario.

Future flow projections were developed either from population projections or information obtained directly from the municipal facility operators. The tier and E3 scenario flows for industrial dischargers remained at 2000 levels because these flows are not necessarily subject to population growth. The point source facilities analyzed in this effort include all significant facilities (including industrial) as defined by New York, Pennsylvania, Maryland, Virginia, Delaware, West Virginia and the District of Columbia.

### Nonpoint Source: Agriculture

In the Tier 1 scenario, nonpoint source agricultural BMP implementation rates between 1997 and 2000 were continued to the year 2010 with certain limitations. Since historic BMP data were not available from New York, Delaware and West Virginia, 2010 Tier 1 projections were determined from watershed-wide implementation rates from states that employed and tracked similar practices from 1997 through 2000.

The Tier 2 and Tier 3 scenario BMP implementation levels were generally determined by increasing BMP implementation by a fixed percentage of the remaining acreage between Tier 1 and E3 levels. The percentages were specific for each BMP and applied watershed-wide.

### Nonpoint Source: Urban

The Tier 1 scenario represents voluntary and regulatory storm water management programs that are or will be in place by 2010. These include both federal programs, such as the EPA's National Pollutant Discharge Elimination System Phase I and II storm water regulations, and state erosion control/storm water management programs. The Tier 2 and 3 scenarios represent progressively increasing levels of urban nonpoint source BMP implementation beyond Tier 1.

### Atmospheric Deposition

The Chesapeake Bay Program modeled four different nitrogen oxide ($NO_X$) emission reduction scenarios to estimate changes in atmospheric nitrate deposition and loading to the Chesapeake Bay watershed (U.S. EPA 2003a). The $NO_X$ emission reductions associated with Tier 1 and 2 scenarios are based on Clean Air Act regulations. In the Tier 3 and E3 scenarios, NOx emission reductions go beyond current regulations and include aggressive voluntary controls. All scenarios involve the combined $NO_X$ emission reductions from 37 states within the Chesapeake Bay airshed, well beyond the Chesapeake Bay watershed jurisdictions' boundaries.

### E3 Scenario

To estimate non-attainment caused by human-caused conditions that cannot be remedied, a boundary scenario had to be defined. In the past, the Chesapeake Bay Program partners defined this as the 'limit of technology'. The BMP levels and control technologies in the E3 scenario are believed by the Chesapeake Bay Program partners to be beyond feasible. Cost, physical limitations and social/economic impacts were *not* taken into account in order to eliminate subjectivity as much as possible from the E3 definitions.

The E3 scenario represents the *maximum* theoretical implementation of the *best combination* of BMPs or control technologies available to a land use or situation. It is assumed that nutrient and sediment reductions beyond this level represent "human-caused conditions that cannot be remedied." Generally, these are the best nutrient and sediment reductions possible with current technologies at maximum BMP implementation levels and include new technologies and management practices that are not currently part of jurisdictional pollutant control strategies or federal, state or local cost-share programs. Appendix A of the *Technical Support Document* details the assumptions and methodologies used to develop each control technology and BMP-based implementation level in the E3 scenario for all nutrient and sediment source categories and land uses (U.S. EPA 2003a).

## TIERED SCENARIO ESTIMATED NUTRIENT AND SEDIMENT LOADS

The estimated Watershed Model loads for nitrogen, phosphorus and sediment loads from simulated implementation of the tiered and E3 scenarios are described below and graphically summarized in figures II-1, II-2 and II-3, respectively.

These load estimates are compared with modeled 2000 Progress loads of 285 million pounds of nitrogen per year, 19 million pounds of phosphorus per year, and 5.04 million tons per year of land-based sediment.

### Tier 1

The nutrient and sediment loads associated with the Tier 1 scenario are 261 million pounds of nitrogen per year, 19.1 million pounds of phosphorus per year, and 4.64 million tons of land-based sediment per year. This represents an 8 percent reduction in nitrogen, a 1 percent reduction in phosphorus, and an 8 percent reduction in sediment loads to the Chesapeake Bay from 2000 progress levels.

### Tier 2

The nutrient and sediment loads associated with the Tier 2 scenario are 221 million pounds of nitrogen per year, 16.4 million pounds of phosphorus per year, and 4.14 million tons of land-based sediment per year. Compared to 2000 progress estimated loads, this represents a 22 percent reduction in nitrogen, a 14 percent reduction in phosphorus, and an 18 percent reduction in sediment loads.

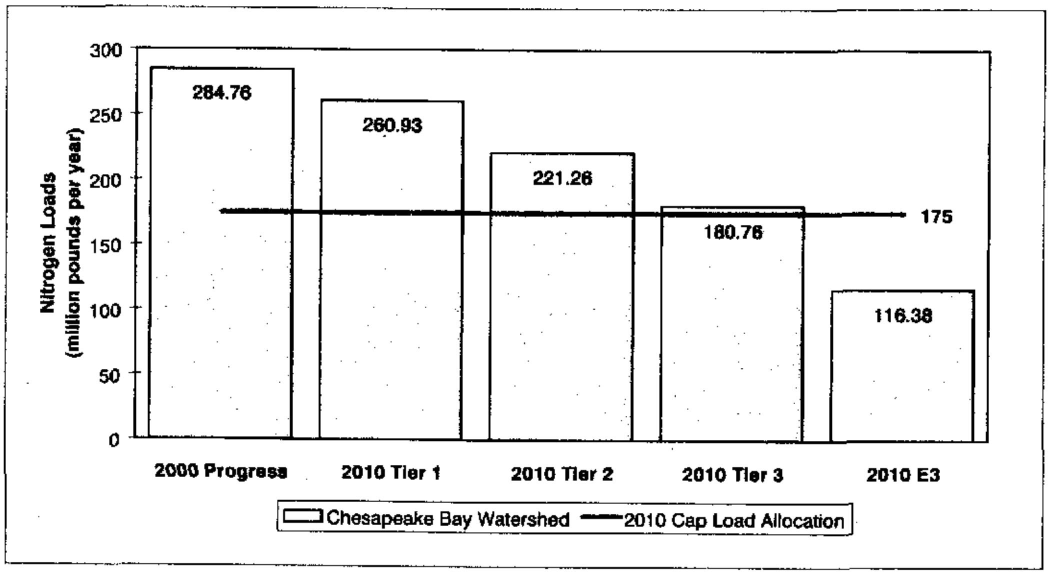


Figure II-1. Nitrogen loads delivered to the Chesapeake Bay and its tidal tributaries under the watershed model-simulated 2000 Progress, tiered and E3 scenarios.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

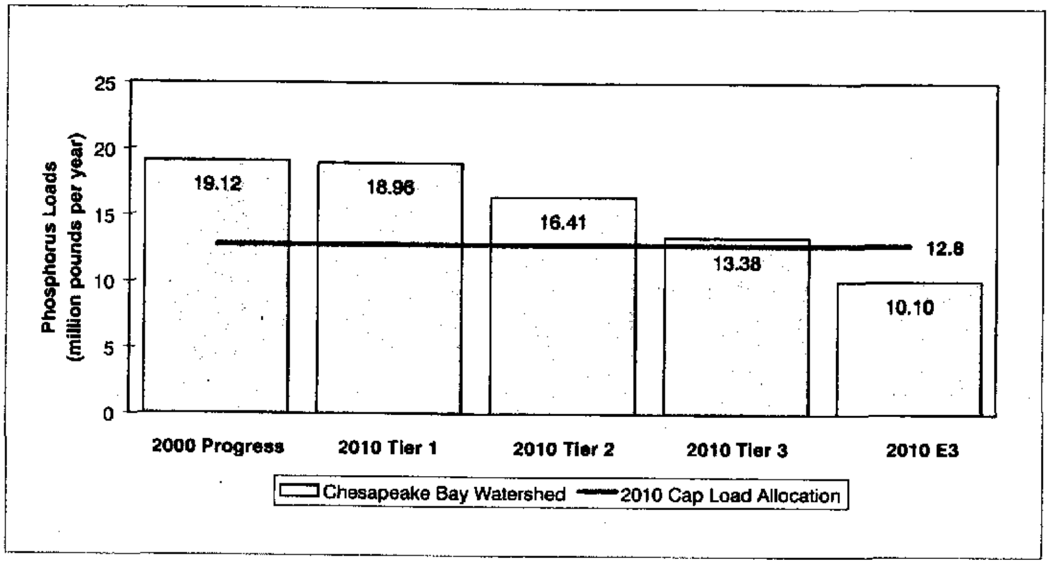


Figure II-2. Phosphorus loads delivered to the Chesapeake Bay and its tidal tributaries under the watershed model-simulated 2000 Progress, tiered and E3 scenarios.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

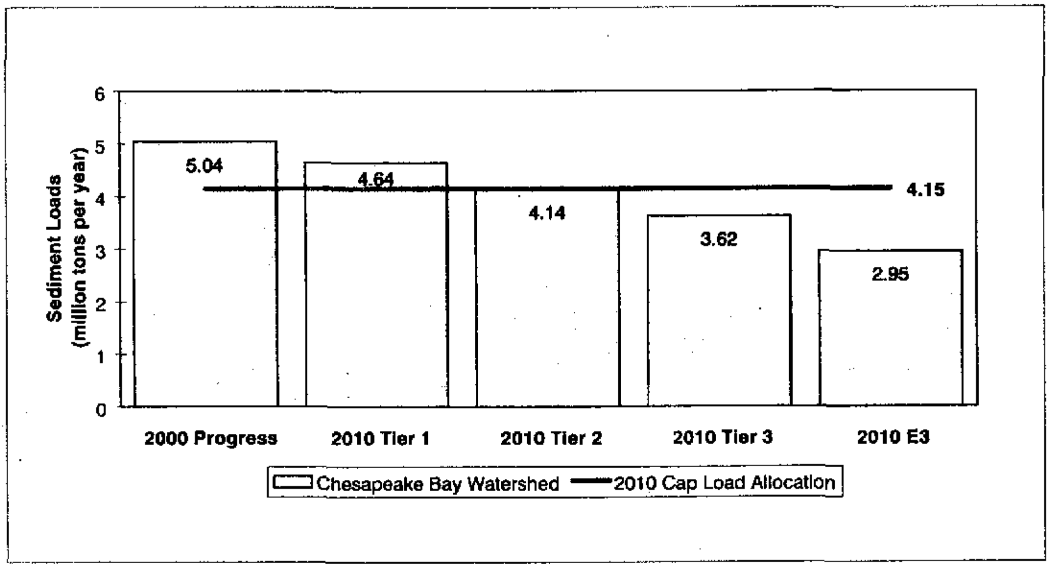


Figure II-3. Land-based sediment loads delivered to the Chesapeake Bay and its tidal tributaries under the watershed model-simulated 2000 Progress, tiered and E3 scenarios.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

## Tier 3

The nutrient and sediment loads associated with the Tier 3 scenario are 181 million pounds of nitrogen per year, 13.4 million pounds of phosphorus per year, and 3.62 million tons of land-based sediment per year. This represents a 37 percent reduction in nitrogen, a 30 percent reduction in phosphorus, and a 28 percent reduction in sediment loads from 2000 levels.

## E3

The combination of aggressive land and air nutrient controls resulted in E3 scenario loads of about 116 million pounds of nitrogen per year, 10.1 million pounds of phosphorus per year, and 2.95 million tons of land-based sediment per year. Compared to 2000 progress loads, this represents a 59 percent reduction in nitrogen, a 47 percent reduction in phosphorus, and a 41 percent reduction in land-based sediment loads.

# CHESAPEAKE BAY PROGRAM ENVIRONMENTAL MODELS

The Chesapeake Bay Program partners use a series of environmental models to project changes in the complex Bay ecosystem due to management actions. The Chesapeake Bay Program has developed what have become standard large watershed estuarine modeling tools, including an airshed model or Regional Acid Deposition Model (RADM) (Shin and Carmichael 1992; Appleton 1995, 1996), a watershed model (Donigian et al. 1994; Linker 1996; Linker et al. 2000), an estuarine hydrodynamic model (Wang and Johnson 2000), an estuarine water quality model (Cerco and Cole 1993, 1995a, 1995b; Thomann et al. 1994; Cerco and Meyers 2000; Cerco 2000; Cerco and Moore 2001; Cerco et al. 2002a), and an estuarine sediment diagenesis model (Di Toro and Fitzpatrick 2001). The Chesapeake Bay Program has used these environmental models for more than 18 years and has refined and upgraded each of the models several times. Figure II-4 portrays the interconnections among these cross-media models.

Results from the integrated airshed, watershed and estuarine models are used to elucidate complexities like eutrophication of the Chesapeake Bay or to closely examine sediment sources to assess their impacts on water quality and living resources in tidal waters. Together, these linked simulations provide a system to estimate dissolved oxygen, water clarity and chlorophyll *a* conditions in 35 major segments of the Chesapeake Bay and its tidal tributaries. The same criteria attainment assessment process applied to observed data is applied to integrated modeling/monitoring 'scenario' data to determine likely criteria attainment under management loading scenarios (U.S. EPA 2003b, Linker et al. 2002).

The watershed and airshed models are loading models. As such, they provide estimates of the impacts of management actions through air emission controls, agricultural and urban best management practices, and point source technologies

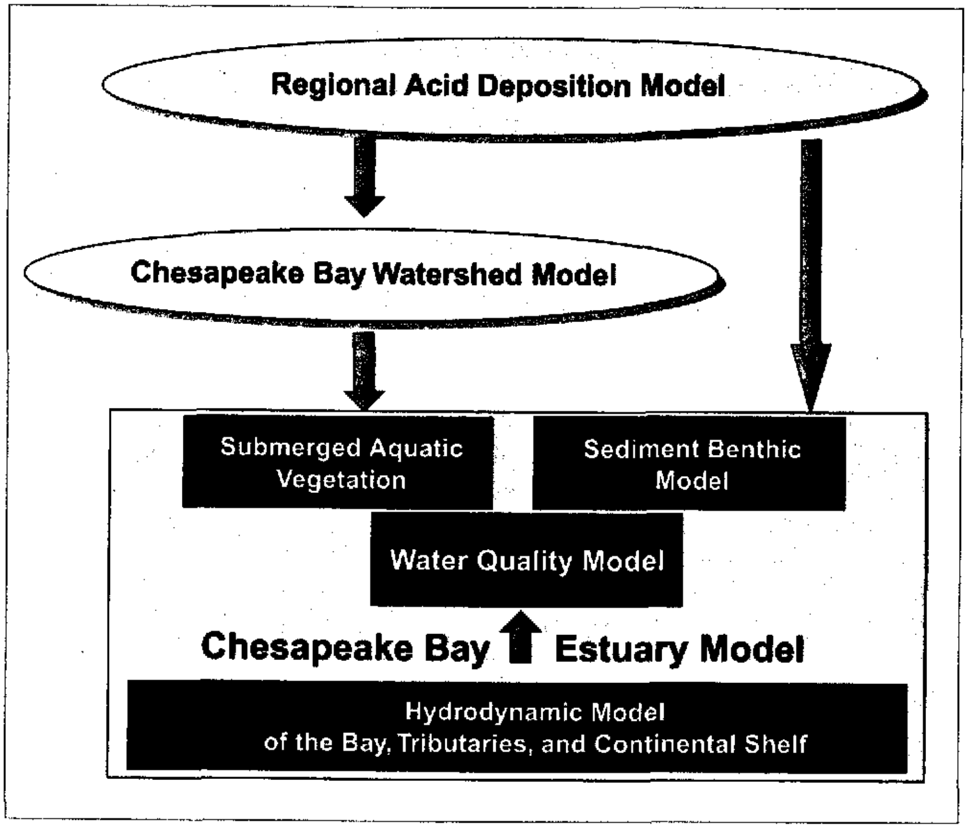


Figure II-4. Cross-media models of the Chesapeake Bay airshed, watershed and estuary.

Source: Chesapeake Bay Program website http://www.chesapeakebay.net.

that will reduce nutrient or sediment loads to the Chesapeake Bay tidal waters. The advantage of using loading models is that the full simulation through different hydrology periods (i.e., wet, dry and average) can be simulated on existing or hypothetical land use patterns. All of the Chesapeake Bay Program models used in this system simulate the same 10-year period from 1985 to 1994 (Linker et al. 2000).

The models are linked together so that the output of one simulation provides input data for another model. For example, the nitrogen output from RADM affects the nitrogen input from atmospheric deposition to the Watershed Model. The Watershed Model, in turn, transports the total nutrient and sediment loads, including the contributions from atmospheric deposition, to the Chesapeake Bay and its tidal tributaries through the boundary of the watershed and estuarine domains. The Water Quality Model examines the effects of the loads generated by the Watershed Model, as well as the effects of direct atmospheric deposition, on Bay water quality and living resources.

The models used by the Chesapeake Bay Program focus on quantifiable outcomes, such as reductions in estimated nutrient and sediment loads resulting from integrated point source, nonpoint source and air emission management actions, rather than a pollutant reduction strategy based on a single medium. For Chesapeake Bay Program decision-makers, model results are options to be examined, analyzed and further developed through an iterative process with the model practitioners. This was the process involved in determining cap load allocations (see section above titled *Tiered Management Implementation Scenarios*).

The models produce estimates, not perfect forecasts. Hence, they reduce, but do not eliminate, uncertainty in environmental decision making. Used properly, the models assist in developing nutrient and sediment reductions that are most protective of the environment, while being equitable and achievable.

## CHESAPEAKE BAY AIRSHED MODEL AND ATMOSPHERIC DEPOSITION

### Regional Acid Deposition Model

The Regional Acid Deposition Model, or RADM, is designed to provide estimates of atmospheric nitrogen deposition resulting from changes in precursor air emissions due to management actions or growth, and to predict the influence of source loads from one region on deposition in other regions (Chang et al. 1987). The current version of RADM, RADM 2.61, encompasses a geographic domain of 2,800 kilometers by 3,040 kilometers (Dennis 1996). Longitudinal coverage in the eastern United States is central Texas to Bermuda while latitudinal coverage is from south of James Bay, Canada to Florida, inclusive (Figure II-5). Grid cells are 80 kilometer by 80 kilometer with 15 vertically layered cells placed from ground level to the top of the troposphere, which equals an altitude of 16 kilometers. The total number of cells in the model domain is 19,950 (Chang et al. 1990). As shown in Figure II-5, over the regions of the mid-Atlantic states and the Chesapeake Bay watershed, the RADM contains a finer grid of 20 kilometer by 20 kilometer cells nested into the larger grid, allowing finer spatial distribution of nitrogen deposition.

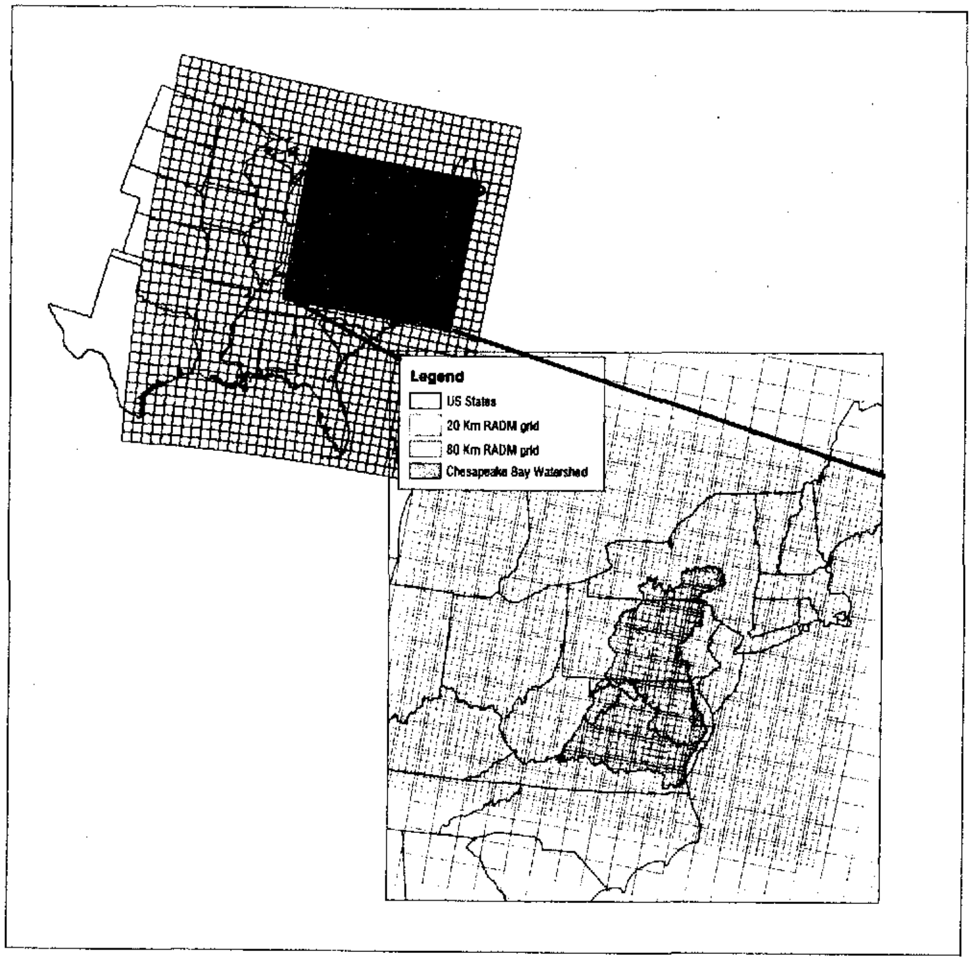


Figure II-5. Regional Acid Deposition Model domain grid and fine-scale nested grid for the Chesapeake Bay watershed.

Source: Dennis 1996.

The RADM has been used to estimate the area where nitrogen emission sources have the greatest potential in depositing nitrogen, both wet and dry, to a watershed. The area encompassing these sources is referred to as the 'principal airshed'. Figure II-6 shows the boundaries of the Chesapeake Bay watershed juxtaposed with the principle airsheds for both reduced (ammonia) and oxidized ($NO_X$) nitrogen. The Chesapeake Bay's ammonia airshed is about 688,000 square kilometers (266,000 square miles) in size. This is four times larger than the Chesapeake Bay's watershed and two-thirds the size of the $NO_X$ airshed which is 418,000 square miles (1,081,600 square kilometers) (Paerl et al. 2002).

Airsheds are not as firmly defined as watersheds in that there are no clear boundaries to the flow of chemicals in the atmosphere as there are for the flow of surface and ground waters in watersheds. The absolute influence that an emission source has on deposition to an area continuously diminishes with distance. Operationally, modelers

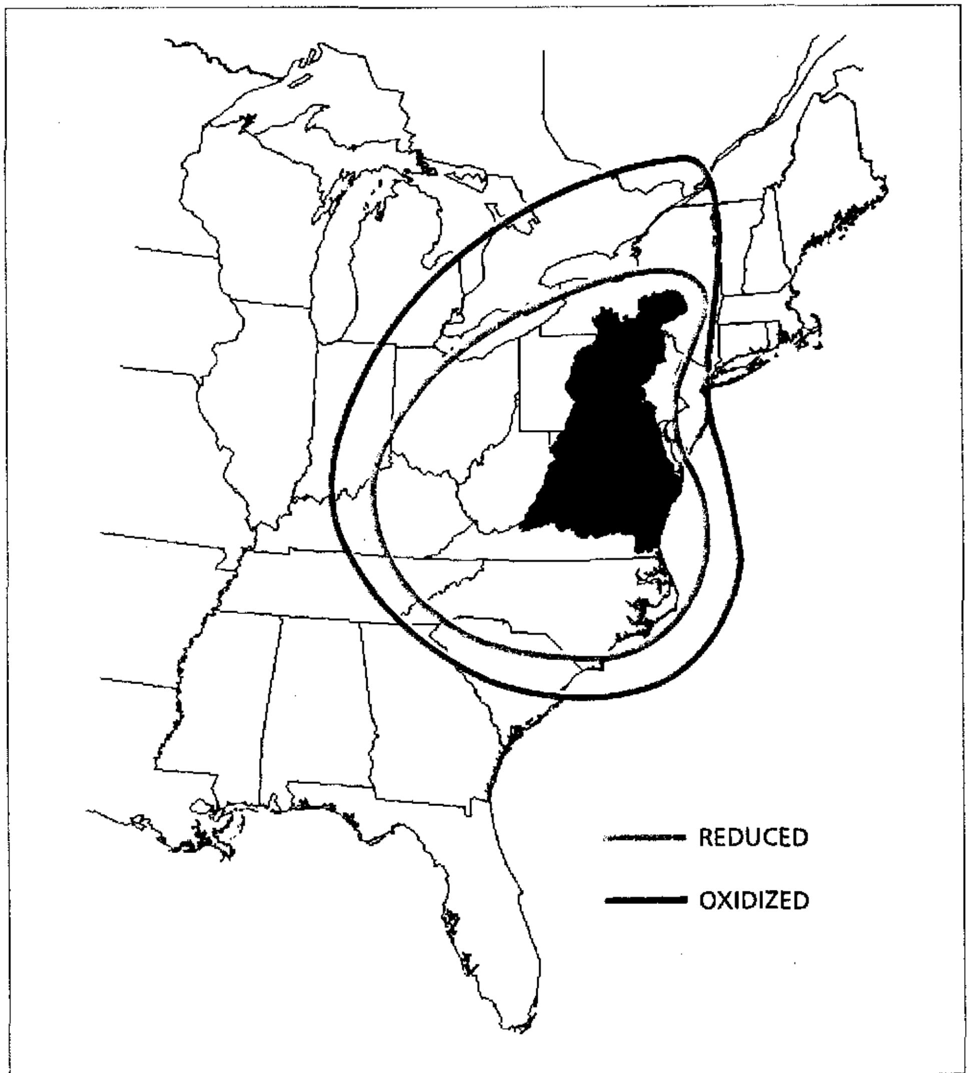


Figure II-6. Principle nitrogen airsheds for the Chesapeake Bay and its watershed.
Source: Chesapeake Bay Program website http://www.chesapeakebay.net/wqcmodeling.htm.

have found that a good distance of demarcation for setting the airshed boundary is the 65 percent contour of the normalized range of influence of a source region.

It is important to understand this concept of airsheds because the relationships between emissions and deposition, and subsequently atmospheric loadings into a water body, are not equal. For example, if 100 pounds of nitrogen were released into the air from a source, it will not all be deposited at once nor in one area. The annual deposition will be distributed over space and will be unevenly distributed in time. Just as emissions and deposition are not in a 1:1 ratio, neither are deposition and loadings to a water body. The terrestrial landscape will retain much of the deposited nitrogen. For example, current belief is that approximately 10 percent of nitrogen deposited to a typical forest ecosystem will be transported into receiving waters.

The three-dimensional RADM solves a series of conservation equations and considers a complex range of physical and chemical processes and their interactions. It is an Eulerian model in which the concentrations of gaseous and particulate species are calculated for the specific grid cells as a function of time. The calculation depends on emission input rates, as well as three-dimensional advective transport, dry deposition rates, turbulent transport, chemical transformations, scavenging and precipitation.

Meteorological fields used for advective transport and meteorological conditions for RADM chemistry are from the Pennsylvania State University National Center for Atmospheric Research Mesoscale Model (MM4). The MM4 is a weather model used to recreate detailed meteorology (Dennis et al. 1990; Brook et al. 1995a, b).

The chemistry that is simulated by the model consists of 140 reactions among 60 species. Photolysis and oxidant photochemistry is included in the simulation as are aqueous phase reactions which occur in clouds. Forty-one of the longer-lived chemical species are transported between model cells.

The key nitrogen species that are simulated and are of concern to coastal watersheds are: 1) particulate nitrate ($pNO_3^-$), nitric acid gas ($HNO_3$) and nitrate ($NO_3$) in precipitation, which all originate from $NO_X$ emissions; 2) particulate ammonium ($NH_4^+$), ammonia gas ($NH_3$) and ammonium in precipitation, which all originate from ammonia emissions; and 3) dissolved organic nitrogen (DON). Although the sources of DON are not well identified, it is believed to be a small fraction of the total nitrogen deposition.

The nitrogen oxide emissions that are accounted for in the RADM include those from anthropogenic fuel combustion, soil biological processes and ammonia. These emissions are input to the completely mixed grid cells of the model on an hourly time step. The simulation uses dynamically determined time steps of seconds to minutes to generate model output of wet and dry deposition on an hourly basis for each surface cell.

## Determination of Atmospheric Flux

While the RADM provides estimates of atmospheric deposition due to growth or management of atmospheric emissions, a base data set of atmospheric deposition is needed to provide a continuous 10-year time series of daily atmospheric deposition loads to the watershed and estuary models. This base condition of deposition establishes a reference to which other atmospheric deposition reduction scenarios are compared, quantifying the effects of managed reductions in emissions. The reduction scenarios are rooted in RADM results, represent changing levels of both regulatory and voluntary controls, and are simulated from utility, industrial and mobile sources.

Since precipitation is the primary forcing function in the Chesapeake Bay Watershed Model, great care is taken in developing the time-variable atmospheric flux. A data set of wet deposition of nitrate and ammonia is formed through concentration data from a regression model and precipitation data from gauging stations that are weighted according to a Thiessen polygon method.

The regression model uses National Atmospheric Deposition Program/National Trends Network data from monitoring stations in the Chesapeake watershed area to determine wet inorganic nitrogen concentrations. The regression calculates concentrations from measured precipitation amounts, the month of the year, and latitude. The concentrations are then applied to the volume of precipitation, for each model segment, to establish daily deposition of wet nitrate, ammonia, and organic nitrogen for the 10-year simulation period of the Watershed Model. A rate of dry deposition of nitrate is determined for each model segment from average proportions of wet-to-dry deposition calculated by RADM.

When used for scenarios that have reduced emissions and subsequent deposition in the Chesapeake watershed, RADM information on nitrogen emission reductions is applied to the Watershed Model through a proportioning method. It is assumed that the RADM reference inputs are the same as the calculated atmospheric flux. Fractional changes to the RADM reference deposition are related to the deposition database for each chemical species and both spatially and temporally. The results are revised fluxes to the watershed, tidal waters and their respective models that are used, in part, to determine the effects of emission controls on nutrient loads, water quality and living resources.

## CHESAPEAKE BAY WATERSHED MODEL

The Chesapeake Bay Watershed Model estimates the delivery of nutrients and sediment from all areas of the watershed to tidal waters under different management scenarios (Donigian et al. 1994; Linker et al. 1996; Linker 1996). The continuous, deterministic model has been in operation at the Chesapeake Bay Program since 1982. Since that time, many refinements to the simulation and data used in it have been made. Phase 4.3 of the Watershed Model, in conjunction with the airshed and estuarine models, was employed in the development of the nutrient and sediment cap load allocations.

The Chesapeake Bay Program's Watershed Model is based on a slightly modified version of Hydrologic Simulation Program-Fortran (HSPF) release 11 (Bicknell et al.1996), a widely used public domain model supported by the U.S. Environmental Protection Agency, U.S. Geological Survey, and U.S. Army Corps of Engineers. The system is run on personal computers with the Linux operating system. All supporting programs as well as HSPF are open source and written primarily in Fortran 77.

Nutrient simulation modules in the Watershed Model are detailed and flexible, and thus can be used to simulate a variety of land use types with associated applications of chemical fertilizers and animal manure. The model also takes into account loads from point sources, atmospheric deposition and onsite wastewater management systems. In addition, the simulation considers nutrient and sediment reductions due to BMP implementation as well as attenuation of chemical species as they travel through the river reaches to tidal waters of the Chesapeake Bay. The Watershed

Model simulates a period of ten years (1985-1994) on a one-hour time step and results are aggregated into daily loads and flows, to be used as input to the estuary model or into reported 10-year average loads for comparison among scenarios.

## Watershed Model Segmentation

To simulate the delivery of nutrients and sediment to the Chesapeake Bay, the 64,000 square mile Chesapeake Bay watershed is divided into 94 major hydrologic model segments that have an average segment area of 680 square miles (177,000 hectares) (Figure II-7). At the interface of the Watershed Model and Water Quality Model domains, below-fall-line model segments are further divided into sub-segments to deliver flow and nutrient and sediment loads to appropriate areas of the tidal waters (Hopkins et al. 2000).

Segmentation partitions the watershed into regions of similar characteristics based on criteria such as topographic areas with similar soil characteristics and slopes, or

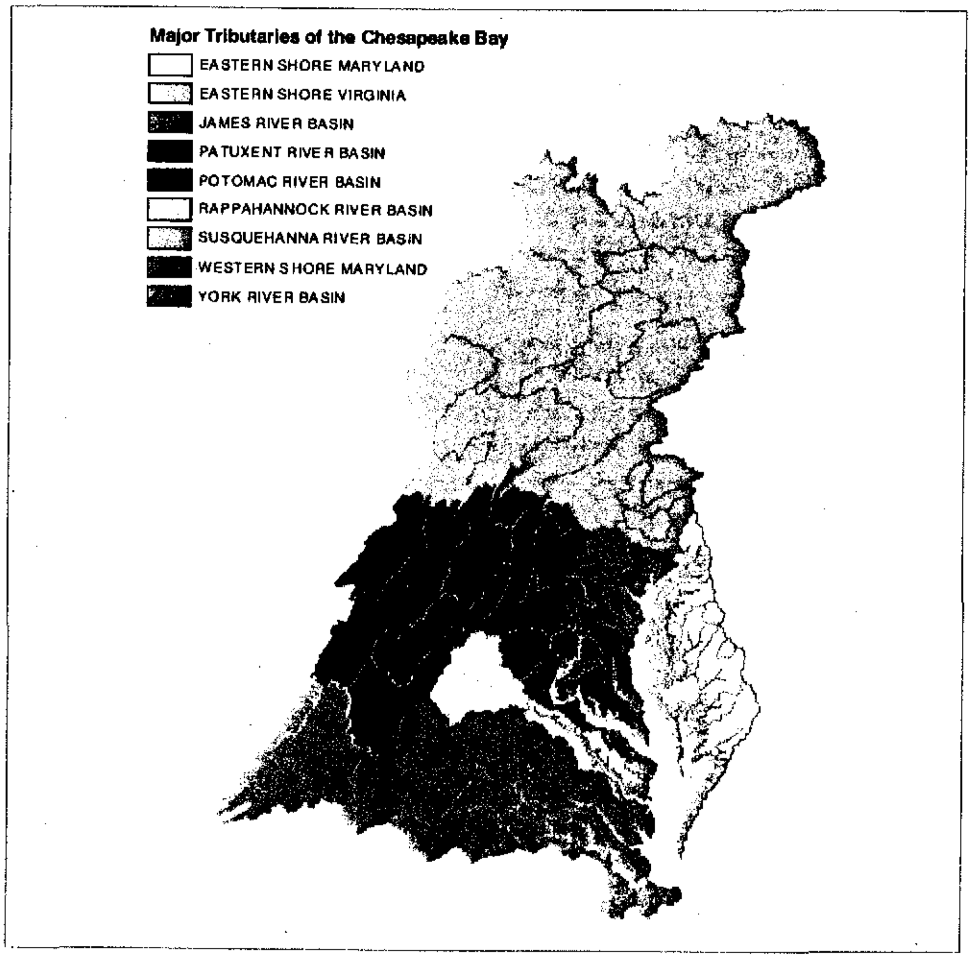


Figure II-7. Chesapeake Bay Watershed Model segmentation and major tributary basins.
Source: Linker et al. 2000.

similar travel times in river reaches (Hartigan 1983). Another consideration in defining model segments is the location of reservoirs or monitoring stations. Model segments are located so that segment outlets are as close as possible to monitoring stations that collect water quality and discharge data (Langland et al. 1995).

The proximity of monitoring stations to the outlet of model segments is important because the model is calibrated at the segment level. It is imperative to have the most accurate calibration of nutrient and total suspended sediment concentrations and flows in the river reaches so that the output loads of one segment accurately input the adjacent downstream segment.

Overall, the right size for segmentation weighs two factors. If a segment is too large, meaningful differences of many of the simulation parameters are missed. If a segment is too small, it could be difficult to acquire all the data for the simulation at that level, or the computing capacity of the model could be limited.

## Watershed Model Calibration

The Chesapeake Bay Program calibrates the Watershed Model over all available data and then uses the calibrated model to test management scenarios. In the Phase 4.3 version of the model, flow and water quality data from 1984-1997 were used for calibration. The calibration was reviewed and approved by Chesapeake Bay Program Modeling Subcommittee. The subcommittee members and quarterly review participants are recognized academic experts in the field of modeling and representatives from all Chesapeake Bay Agreement signatory jurisdictions—Pennsylvania, Maryland, Virginia and the District of Columbia.

For the calibration of land uses, simulated exports from land uses are compared to literature values and an analysis of the inputs. For example, the calibration of cropland considers the growth and nutrient uptake of estimated crop types—taking into account drought, heat stress, and the growing season—as well as considerations of the estimated nutrient inputs. The simulated cropland exports are, in turn, compared to export values published in peer-reviewed scientific literature and relevant model parameters are adjusted, if necessary, to achieve the best match.

For the calibration of river reaches, simulated results for stream flows, nutrient and sediment concentrations and loads, as well as other water quality parameters, are compared to observed data from in-stream monitoring sites. Results for the hydrology calibration of the Phase 4.3 Watershed Model can be found on the Chesapeake Bay Program Web site at http://www.chesapeakebay.net/pubs/113.pdf while water quality calibration information can be accessed at: http://www.chesapeakebay.net/pubs/238.pdf.

Calibration results are presented as plots and statistical tables of model information and monitoring data from calibration stations for the following parameters: flow, temperature, dissolved oxygen, total suspended sediment, total phosphorus, organic and particulate phosphorus, phosphate, total nitrogen, nitrate, total ammonia and organic nitrogen.

## Watershed Model Data Sources

Since precipitation, in a large part, drives loads to the tidal Bay water, much effort is spent developing this data base. For the 10-year simulation period of the Watershed Model, rainfall data from 147 monitoring stations are used. Typically, about six stations are used to develop the precipitation record for a model segment through a Thiessen polygon method for spatial distribution. In addition, temperature, solar radiation, wind speed, snow pack and dew-point temperature data are collected for the simulation from seven primary meteorological stations in the watershed (Wang et al. 1997).

A consistent land use dataset is compiled for the entire Chesapeake basin using a LANSAT-derived GIS land cover as a base (U.S. EPA 1994). The land cover is enhanced with detailed information on agricultural lands at the county level from the U.S. Census Bureau series, Census of Agriculture for 1982, 1987, 1992 and 1997 (Volume 1, Geographic Area Series). County tillage information is acquired for the conventional and conservation cropland distribution from the Conservation Technology Information Center (Palace et al. 1998). The land or source categories simulated in the Watershed Model are as follows:

- Conventional-tilled cropland;
- Conservation-tilled cropland;
- Cropland in hay;
- Pasture;
- Animal waste areas;
- Forest;
- Pervious urban;
- Impervious urban land;
- Non-agricultural herbaceous or mixed-open land; and
- Atmospheric deposition directly to water surfaces.

Calculations and allocations of the agricultural land categories follow methods described in *Chesapeake Bay Watershed Model Land Use and Model Linkages to the Airshed and Estuarine Models* (Hopkins et al. 2000). The non-agricultural land use classifications of 'forest', 'pervious' and 'impervious urban', 'mixed-open' and 'water' are generally developed through comparisons of the agricultural land acreage and the GIS land cover database and projections or interpolations of these. Hopkins et al. (2000) describes these calculations and allocations in detail.

For crop land, state agricultural engineers provide chemical fertilizer and manure application rates and timing of applications as well as information on crop rotations and the timing of field operations. The information on manure applications to cropland is part of a time-varying mass balance of manure nutrients developed through the Agricultural Census' animal populations and predominant manure handling practices (Palace et al. 1998).

Soil characteristics for both nutrient interactions and hydrology are obtained from the Soil Conservation Service Soil Interpretation Records (USDA 1984) with information on soil types and land slope from the National Resources Institute (NRI). Delivery of sediment from each land use is calibrated to the NRI estimates of annual edge-of-field sediment loads calculated by the Universal Soil Loss Equation (USLE).

For animal waste areas, the designation of a 'manure acre' allows for the simulation of high nutrient content runoff from animal operations. Manure acres are based on the population of different animal types in the watershed as given in Agricultural Census data. The animal types include beef and dairy cattle, swine and three categories of poultry (layers, broilers and turkeys). Nutrient export from animal waste storage areas is simulated as a concentration applied to the calculated runoff where the surface area of animal waste storages, or manure acres, changes with the number of animals and implementation of animal waste management systems.

Loads from point sources, combined sewer overflows (CSOs), and septic systems are input directly to river reaches. Point source inputs from municipal and industrial sources are developed from state National Pollution Discharge Elimination System (NPDES) records. If no state NPDES data are available, state and year-specific default data are calculated for each missing parameter and annual estimates of loads are based on flow from the wastewater treatment plant.

Several cities in the watershed have a sewer system with CSOs, including Washington, D.C., Richmond, Virginia and Harrisburg, Pennsylvania. Estimates of the average annual discharge from CSOs are only available for Washington, D.C. and the annual discharge is evenly distributed over the simulation period of the model.

Loads from septic systems are calculated using U.S. Census Bureau data of waste disposal systems associated with households, along with a methodology suggested in Maizel et al. (1995) where standard engineering assumptions of per capita nitrogen waste and attenuation of nitrogen are applied. Septic system loads are simulated as nitrate loads discharged to the river reaches.

## Watershed Model Simulation

Each Watershed Model segment contains information generated by a hydrologic sub-model, a nonpoint source sub-model, and a river or transport sub-model. The hydrologic sub-model uses rainfall, evaporation and meteorological data to calculate runoff and subsurface flow for land uses in each model segment.

The surface and subsurface flows ultimately drive the nonpoint source sub-model, which simulates soil erosion and pollutant loads from the land to the rivers using, in part, input data for atmospheric deposition, land use areas, nutrient applications, and BMP implementation and reduction efficiencies. A river sub-model routes flow and associated pollutant loads from the land through lakes, rivers and reservoirs to the Chesapeake Bay.

For nitrogen and phosphorus, the simulation represents a mass balance in the basin, so that the ultimate fate of the input nutrients is 1) incorporation into crops, forests, or other vegetation, 2) incorporation into soil, or 3) loss through river runoff or discharge directly to the Chesapeake Bay. Fate of nitrogen may also include volatilization to the atmosphere and denitrification.

Much of the nutrient simulation for pervious lands considers cycling and storages in the soil and plant mass as well as movement between the storages, thereby making these land use simulations sensitive to nutrient inputs. Crops are specifically modeled through a yield-based nutrient uptake algorithm allowing for the direct simulation of nutrient management practices since exports rely heavily on the nutrient levels above crop need. Nutrient exports from impervious urban land depend on storage, which accumulates by a factor equal to atmospheric deposition. Rainfall washes off this storage and the intensity of the rainfall determines how much is washed off.

Sediment is modeled as eroded material washed off pervious land surface, eroded from stream banks and transported to the tidal Bay waters. This simulation is performed through a module, which represents sediment export as a function of the amount of detached sediment and the runoff intensity.

The lumped-parameter HSPF model simulates each land use as an average for the entire segment. For example, conventionally-tilled cropland is modeled as an average crop rotation of corn, soybeans, and small grains in a segment with an average model-segment input of chemical fertilizer and manure loads, and with average slope, soil conditions, and nutrient cycling characteristics. The simulated single-acre land use, in turn, is multiplied by the acres of each land use draining to each river segment.

Each Watershed Model river reach is simulated as completely mixed waters with all land uses considered in direct hydrologic contact. Of the 44 reaches modeled, the average length is 106 miles (170 kilometers), the average drainage area is 730 square miles (1,900 square kilometers), and the average time of travel is one day. Seven of the reaches are impounded by reservoirs and are simulated as such.

The riverine simulation includes HSPF modules that consider, in part, sediment transport, oxygen transformations, ammonification, nitrification, and modeling of periphyton and phytoplankton. For areas close to the Chesapeake Bay and its tidal tributaries with a time of travel less than one day, a river reach is not modeled and terrestrial nutrient and sediment loads are directly loaded to the tidal estuary.

For all nutrient and sediment reduction scenarios, the Watershed Model is run for a 10-year hydrologic period, representing 1985 to 1994, inclusive. This time frame matches the years simulated in the Chesapeake Bay Estuary Model and provides a consistent 10-year hydrology, including wet, dry, and average periods of flow in each basin.

Nutrient and sediment loads from the Watershed Model are reported as the average annual load over this 10-year period to make comparisons among model scenarios without the influence of variable hydrology on loads. For example, any 2010 scenario has land uses, human and animal populations, point source discharges, and land management projected to the year 2010 but modeled using the same 1985–1994 hydrology used for all other Watershed Model scenarios. Assessing loads for an average-hydrology year shows how anthropogenic factors, such as changes in land use and management practice implementation, change average annual nutrient and sediment loads to the Chesapeake Bay over decadal periods of time.

## CHESAPEAKE BAY WATER QUALITY MODEL

The Chesapeake Bay Water Quality Model used to assist in developing the *Chesapeake 2000* nutrient and sediment cap load allocations is a linked hydrodynamic and water quality model which is coupled to a sediment processes, benthic infaunal community and submerged aquatic vegetation (SAV) model. The Chesapeake Bay water quality model is a 'third generation' model with two major refinements since its debut in 1992 when it was first used to develop the original nutrient cap load allocations committed to in the *1987 Chesapeake Bay Agreement* (Chesapeake Executive Council 1987; Thomann et al. 1994; Cerco and Cole 1993; Cerco et al. 2002a, 2002b). In 1998, the model grid was refined in the lower Virginia tidal tributaries and lower Chesapeake Bay mainstem with the new benthic infauna and SAV model. In 2002, the upper Chesapeake Bay mainstem and tidal tributaries grid was refined along with significant enhancements in the model simulation of primary productivity (Cerco et al. 2002a). During the 2002 model refinements, particular emphasis was placed on the calibration and analysis of dissolved oxygen, sediment, water clarity, SAV and chlorophyll *a*.

### HYDRODYNAMIC MODEL

The Chesapeake Bay Hydrodynamic, or CH3D (Curvilinear Hydrodynamics in 3 Dimensions), Model provides advective transport for dissolved and particulate material simulated in the Water Quality Model. The model grid covers the entire Chesapeake Bay, tidal tributaries and the adjacent ocean boundary with about 13,000 computation model cells.

The complex movement of water within the Chesapeake Bay, particularly the density driven vertical estuarine stratification, is simulated with a Chesapeake Bay hydrodynamic model of more than 13,000 cells (Wang and Johnson 2000). Three-dimensional equations of the intertidal physical system, including equations of continuity, momentum, salt balance and heat balance, are employed to provide the correct simulation of the movement, or the barriers to movement, of the water quality constituents of dissolved oxygen, water clarity and chlorophyll *a*. Correct formulation of vertical mixing, including the simulation of vertical eddy diffusion coefficients in the hydrodynamic model is particularly important for the dissolved oxygen criteria as the principal barrier to vertical movement of dissolved oxygen from surface waters to the deep water is the pycnocline simulated by the hydrodynamic model.

The Hydrodynamic Model was applied to generate a 10-year record of hydrodynamic transport for the Water Quality Model. The years that were simulated (1985–94) cover a wide hydrologic range. The years 1985, 1988 and 1992 are considered dry years; 1986, 1987, 1990 and 1991 are considered average years; and 1989, 1993 and 1994 are considered wet years. Although 1985 is considered a dry year overall, in November of that year the track of hurricane Juan swept over the upper Potomac and James basins and generated hundred-year-storm flows at the fall lines of these rivers.

As its name implies, the Hydrodynamic Model makes computations on a generalized curvilinear, or boundary-fitted, horizontal grid, i.e., the grid from the planar view follows the shape of the Bay's shoreline. However, to ensure that long-term stratification in the deep channels is maintained, the vertical grid, corresponding to depth, is Cartesian. Boundary-fitted grids in the horizontal plane allow for a better representation of the shoreline boundaries of the Chesapeake Bay, as well as internal features such as channels and islands (Figure II-8).

Mathematical simulations of all physical processes influencing circulation and mixing in water bodies such as Chesapeake Bay are included in the Hydrodynamic Model. These include freshwater inflows, tides, wind forcing, Coriolis forces,

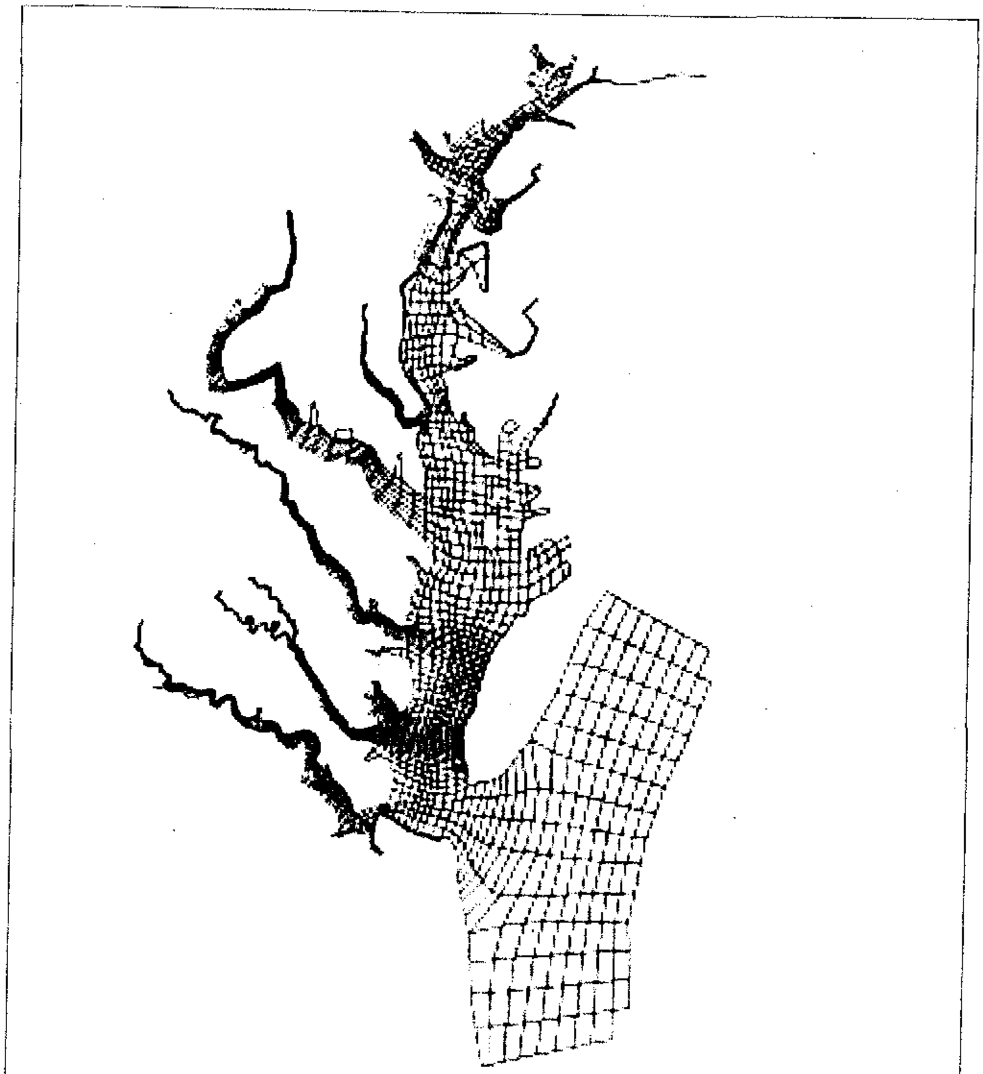

Figure II-8. Plan view of the Chesapeake Bay Hydrodynamic or CH3D Model boundary fitted grid.

Source: Cerco and Meyers 2000.

surface heat exchange and turbulence. The vertical turbulence closure model computes the eddy viscosity and diffusivity from the kinetic energy and dissipation of the turbulence. This type of closure model is known as a 'k-e turbulence model'. Turbulence is produced by wind stress at the surface, velocity shear in the water column and bottom friction. Density effects due to salinity and temperature are fully coupled with the developing flow field. Thus, advection/diffusion equations for the salinity and temperature are solved along with the conservation of mass and momentum equations for the flow field.

Complete documentation of the Hydrodynamic Model can be found in "Chapter 2: Validation and Application of the Second Generation Three-Dimensional Hydrodynamic Model of Chesapeake Bay" of *Tributary Refinements of the Chesapeake Bay Model* (Cerco et al. 2002a) available at: http://www.chesapeakebay.net/modsc.htm under the Documentation tab.

## WATER QUALITY MODEL

The Water Quality Model, based on the CE-QUAL-ICM code, is a three-dimensional, time-variable model of eutrophication processes in the water column and bottom sediments. As applied to the Chesapeake Bay and its tidal tributaries, the model is part of a package that includes the Chesapeake Bay Watershed Model and the Chesapeake Bay Airshed Model described previously.

The water quality model is linked to the hydrodynamic model and uses complex nonlinear equations describing 26 state variables relevant to the simulation of dissolved oxygen, water clarity and chlorophyll *a* (Cerco and Cole 1995a, 1995b, 2000; Thomann et al. 1994; Cerco and Meyers 2000). The state variables include the full suite of nitrogen parameters (ammonia, nitrate, total nitrogen, dissolved labile organic nitrogen, dissolved refractory organic nitrogen, particulate labile organic nitrogen and particulate refractory organic nitrogen) and the equivalent set of phosphorus and carbon parameters. Dissolved oxygen is simulated as the mass balance calculation of reaeration at the surface, respiration of algae, benthos and underwater bay grasses; photosynthesis of algae, benthic algae and underwater bay grasses; and the diagenesis, or decay of organics, by microbial processes in the water column and sediment. This mass balance calculation is made for each model cell and for associated sediment cells at each hourly time step, providing an estimate of dissolved oxygen from nutrient loads from the watershed and airshed to the waters of the 35 major segments of the Chesapeake Bay and its tidal tributaries. Water clarity is estimated from the daily input loads of sediment from the watershed and shoreline acted on by regionally-calibrated settling rates, as well as estimated advection due to hydrodynamics. Chlorophyll *a* is estimated based on Monod calculations of algal growth given resource constraints of light, nitrogen, phosphorous or silica.

Also, three basic phytoplankton groups, including greens, blue-greens and diatoms, are simulated. Algal limitation is simulated by Michaelis-Menton kinetics, with the resource in least supply providing the limitation to growth. Complete diagenesis is simulated between the water column and sediment as organics settle to the bottom, are incorporated in the sediment, undergo decomposition, and are ultimately simulated as a return flux of nutrients to the water column, or as deep burial (DiToro and

Fitzpatrick 1993). Lastly, simulation of SAV in shallow waters is coupled with the model (Cerco and Moore 2001).

Complete documentation of the Water Quality Model can be found in "Chapter 3: Tributary Refinements to the Chesapeake Bay Model" and "Chapter 4: Phytoplankton Kinetics in the Chesapeake Bay Eutrophication Model" of *Tributary Refinements of the Chesapeake Bay Model* (Cerco et al. 2002a) available at: http://www.chesapeakebay.net/modsc.htm under the Documentation tab. Further information on the model can be found at the same web site in the document *Three-Dimensional Eutrophication Model of the Chesapeake Bay* (Cerco and Cole 1994). Additional detailed documentation of this model is currently being developed and will be available at the above web site in Spring 2004.

## Wetland Sediment Oxygen Demand

During the most recent refinement and recalibration of the Water Quality Model, processes simulating the incorporation of oxygen demand by wetland sediment were built in. In some regions of the Chesapeake Bay tidal tributaries surface waters, a natural oxygen deficit below saturation levels is typically observed in the summer. These regions are found adjacent to extensive wetlands and contain comparatively small volumes of water. The tidal fresh and oligohaline regions of the Mattaponi (segments MPNTF and MPNOH) and Pamunkey (segments PMKTF and PMKOH) rivers, respectively, are two specific examples. On the other hand, regions of the Bay tidal waters where there are extensive tidal wetlands but are bordered by relatively large bodies of water, such as the Tangier Sound, have sufficient water volumes and mixing to mask the natural oxygen demand of adjacent wetland sediments.

In the segments with extensive tidal wetlands and small volumes of water, oxygen demand from wetland sediments is thought to influence surface water dissolved oxygen concentrations. Recent studies estimate wetland sediment oxygen demand to range from 1 - 5.3 g $O_2/m^2$-day (Neubauer et al. 2000; Cai et al. 1999). In the model, a uniform oxygen demand of 2g $O_2/m^2$-day was used. The wetland sediment oxygen demand is universally applied in the model based on GIS estimates of tidal wetland area (Cerco and Noel 2003).

## SAV Model

Three components are required for a systemwide SAV model. The first is a unit-level model of a plant. The second is a Water Quality Model (described above) that provides light, temperature, nutrient concentrations and other forcing functions to the plant component. The third is a coupling algorithm that links the systemwide environmental model to the local-scale plant model.

The unit-level plant model incorporates three state variables: shoots (above-ground biomass), roots (below-ground biomass), and epiphytes (attached growth). Epiphytes and shoots exchange nutrients with the water-column component of the eutrophication model while roots exchange nutrients with the diagenetic sediment component (DiToro and Fitzpatrick 1993). Light available to the shoots and epiphytes is computed via a series of sequential attenuations by color, fixed and organic solids in the water column, and self-shading of shoots and epiphytes. The selection of state variables and basic principles of the model were based on principles established by Wetzel and Neckles (1986) and Madden et al. (1996).

To improve the simulation of SAV, the computation model cell grid was extended into shallow, littoral zones of depth from 0-2 meters. Following Moore et al. 2000, three primary SAV communities were simulated: a freshwater community, a mesohaline *Ruppia* community, and a polyhaline *Zostera* community. The SAV simulation was further refined by adding an additional 'Tidal Fresh Potomac SAV' group to simulate the canopy-forming (as opposed to meadow-forming) SAV community of hydrilla (*Hydrilla verticillata*) and eurasian watermilfoil (*Myriophyllum spicatum*) in the tidal fresh Potomac (Cerco et al. 2002a).

Additional documentation of the SAV simulation can be found in "Chapter 5: Systemwide Submerged Aquatic Vegetation Model for Chesapeake Bay" of *Tributary Refinements of the Chesapeake Bay Model* (Cerco et al. 2002a) available at: http://www.chesapeakebay.net/modsc.htm under the Documentation tab.

As a part of the 26 state variables that the Water Quality Model simulates by computational model cell, estimates of dissolved oxygen, chlorophyll *a*, and water clarity are generated in ten minute time steps. To summarize model information into a manageable form, the standard output for dissolved oxygen, water clarity and chlorophyll *a* is presented as monthly averages for each designated use within each Chesapeake Bay Program segment. The percent attainment of the parameters is determined from the adjusted model output.

## ADJUSTMENT OF MODEL DISSOLVED OXYGEN, WATER CLARITY AND CHLOROPHYLL *A* ESTIMATES

To generate the modified data set for a particular scenario (e.g., 2010 Clean Air Act), the EPA compared the frequency distribution output from a scenario was compared with the frequency distribution output of the model calibration. Data were compared on a month-by-month basis. For example, Figure II-9 illustrates the hypothetical frequency distribution for dissolved oxygen concentration data in the deep-channel of Chesapeake Bay mainstem segment CB5MH. The deep-channel dissolved oxygen criterion is applied May 1 through September 30. From this graph one could infer that the model was estimating the observed data fairly well, since model-simulated output matches the mean, approximates the range and has the same characteristic shape as the frequency distribution of the observed data. However, despite the acceptable calibration, if the criterion had been set as 'dissolved oxygen concentration of < 2 mg liter$^{-1}$ no more than 10 percent of the time', the model would indicate a 'pass' while the observed data would indicate a 'fail'.

For each point along the frequency distribution where an observation exists during the 1985–1994 period, a mathematical relationship between the model scenario and the model calibration was established by regressing the 30 or so daily values for the month when the observation occurred in the water quality model cell that contains the observation. Figure II-10 compares the hypothetical output of a Water Quality

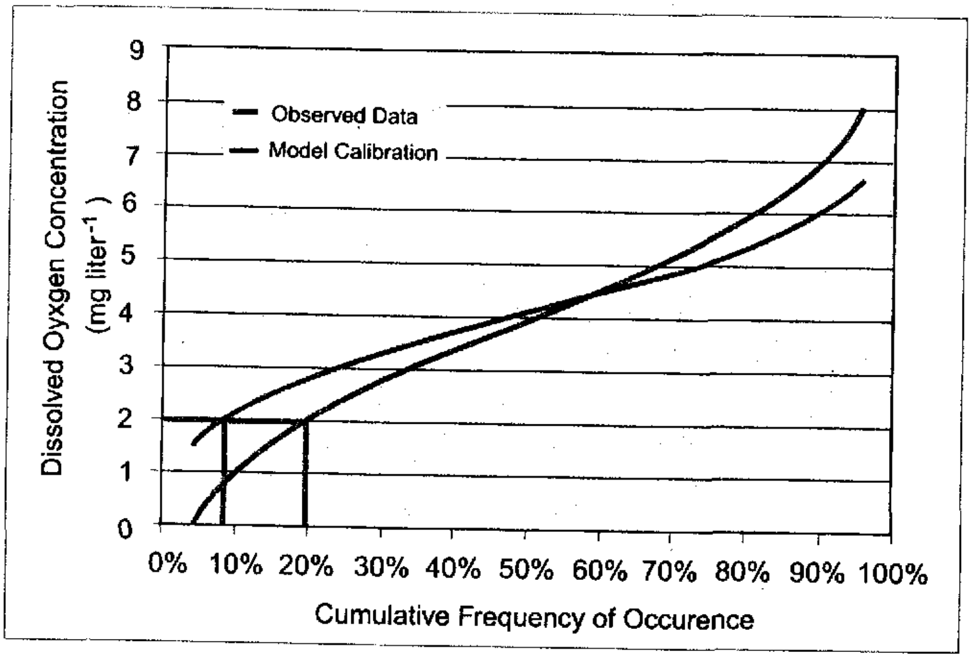


**Figure II-9.** Frequency distribution of hypothetical observed data and model calibration for a designated use.

Source: Linker et al. 2002.

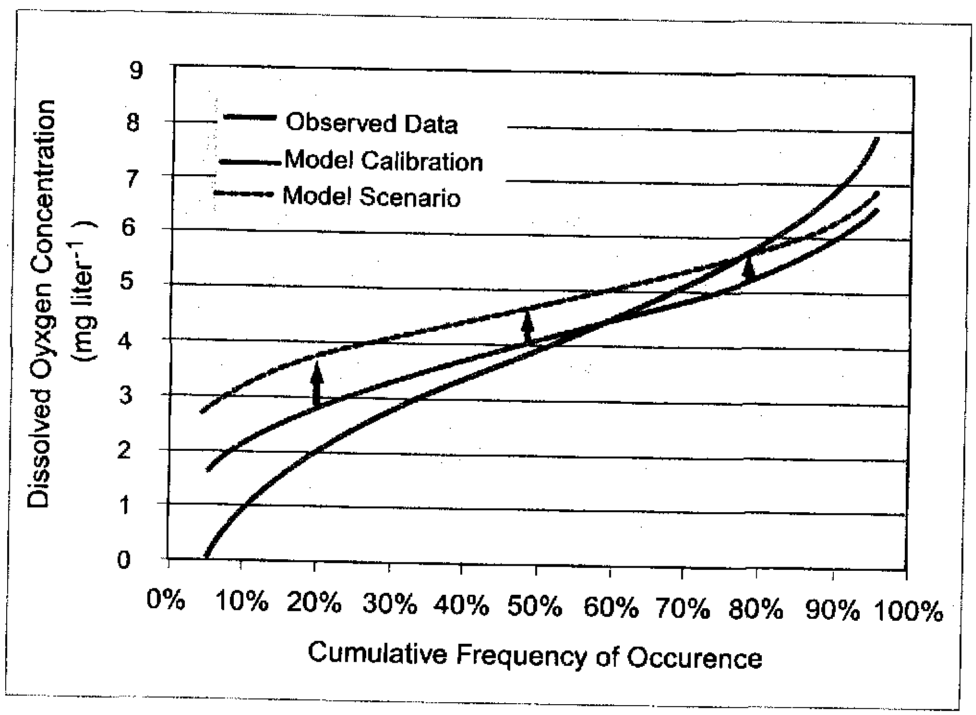


**Figure II-10.** Frequency distribution of hypothetical observed data, model calibration and model scenario for a designated use.

Source: Linker et al. 2002.

Model scenario based on a given load reduction to the Water Quality Model output calibration. These are shown on a frequency plot so that changes in the prediction of attainment can be seen along with the blue line of the observed data.

Figure II-11 shows the relationship between the calibration and scenario Water Quality Model output in more detail. By regressing the scenario output against the calibration output, one can find a relationship that can be used to transform the observed data set. The regression generates a unique equation for each point and month that transforms a calibration value to a scenario value. This relationship is then applied to the monitored observation as an estimate of what would have been observed had the Chesapeake Bay watershed been under the scenario management rather than the management that existed during 1985–1994.

Once the relationship between the calibration and any particular scenario is established, this relationship (applied as a regression equation illustrated in Figure II-12) is used to generate a 'scenario-modified' observed data set for the scenario. The 'scenario-modified' values represent an estimate of an observed data set under the conditions of nutrient and sediment management represented by the scenario. Each observed value for dissolved oxygen, chlorophyll *a* and light extinction in the 1985-1994 data set is replaced with a 'scenario-modified' value.

For a full discussion of this procedure, see *A Comparison of Chesapeake Bay Estuary Model Calibration With 1985-1994 Observed Data and Method of Application to Water Quality Criteria* (Linker et al. 2002) available at: http://www.chesapeakebay. net/modsc.htm under the 'Documentation' tab.

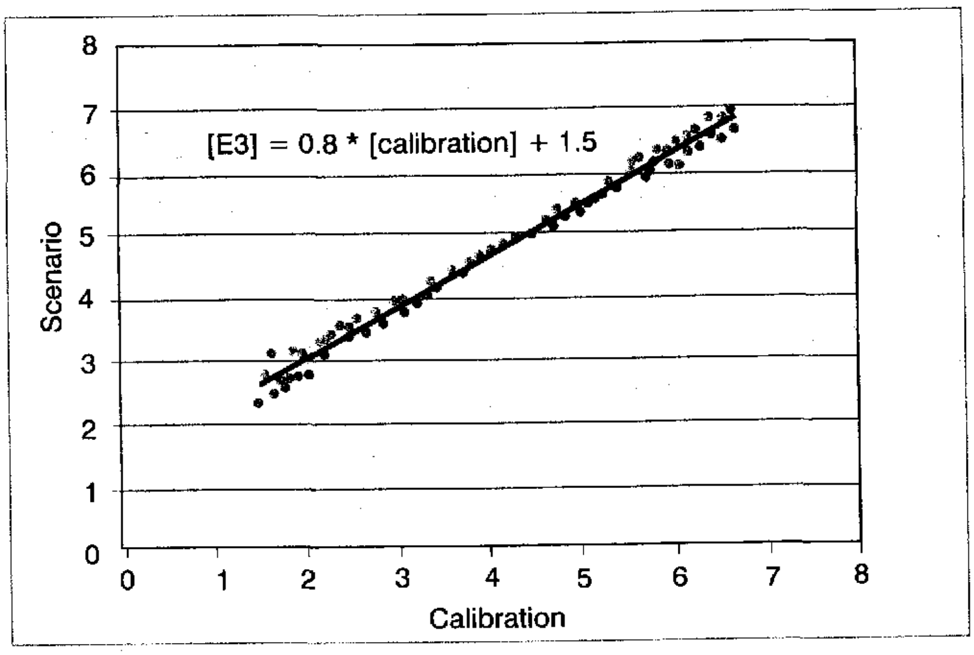


*Figure II-11. Example of a regression between model calibration and scenario data.*

Source: Linker et al. 2002.

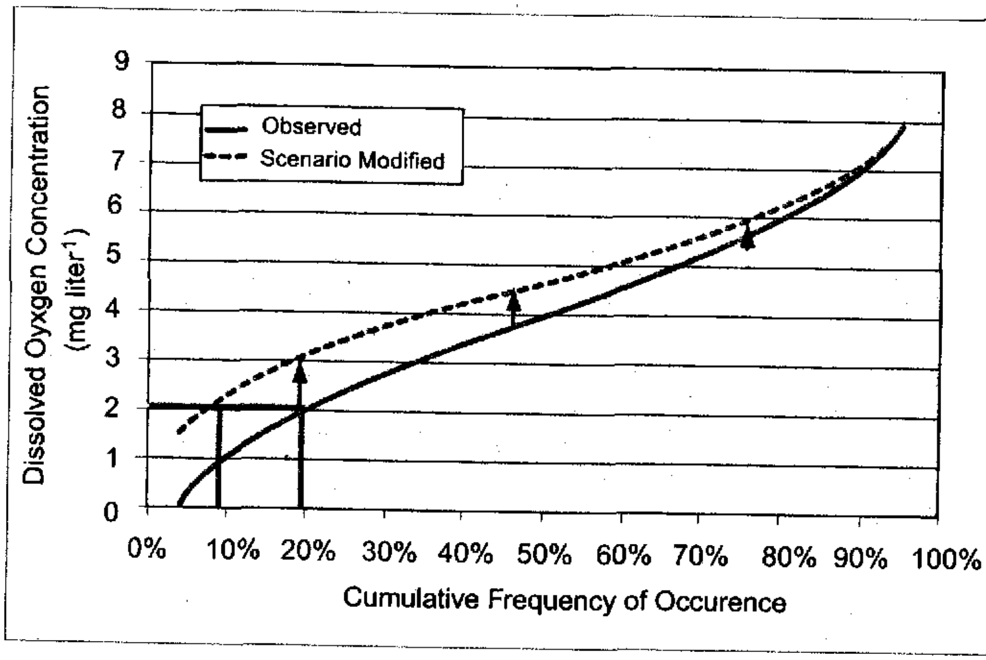


Figure II-12. Example of the regression equation applied to the observed.

Source: Linker et al. 2002.

## MANAGEMENT APPLICATION OF MODEL OUTPUTS

Apart from the adjusted model output that is used for assessing attainment of the three criteria, it is useful to examine the degree of model calibration in each designated use within each Chesapeake Bay Program segment where the water quality model will be applied to assess the quality/accuracy of the model calibration. For this purpose, a strict one-to-one comparison is made between the observed and simulated data. The comparisons are made for the same time (observed and simulated) and space (real and virtual).

A set of empirical decision rules were developed for the purpose of assessing the quality of the calibration for each Chesapeake Bay Program segment designated uses (Table II-1). The relative performance of the predicted metric (e.g., dissolved oxygen concentration) compared to the observed metric under the decision rules was rated as 'high certainty', 'moderate certainty', or 'low certainty' (Linker et al. 2002).

One comparison that was made was the central tendency, the mean or median, of the data. Another was the dispersion, or standard deviation. Range comparisons of the minimum or maximum were also employed, as well as examination of the frequency and scatter plots. A relative confidence estimate of model calibration was determined from the summary statistics and statistical plots of all the comparisons. Best professional judgement was used in cases where most, but not all, of the criteria were met. While the open-water dissolved oxygen criteria apply year-round, emphasis was on the periods critical for the living resources protected by the criteria. Evaluation of the migratory spawning and nursery dissolved oxygen criteria focused on the late winter

Table II-1. The relative confidence in model calibration findings were used directly by the Water Quality Technical Workgroup and Water Quality Steering Committee in making judgements as to exactly where the water quality model outputs could be used for setting the cap load allocations.

| | $R^2$ | Mean Difference | Standard Deviation | Best Professional Judgement |
|---|---|---|---|---|
| Dissolved Oxygen | >0.5 desirable | 1.0 mg liter$^{-1}$ (or roughly 10%); *minimum* concentrations do not differ by more than 2.0 mg liter$^{-1}$ | Do not differ by more than 0.5 | Yes |
| Chlorophyll a | >0.2 desirable | Not greater than two times the concentration; maximum concentration do not differ more than 20.0 mg liter$^{-1}$ | Do not differ by more than three times the observed standard deviation | Yes |
| Water Clarity | >0.2 desirable | Not greater than two times the concentration; maximum concentration do not differ by more than two times $K_e$ | Do not differ by more than two standard deviations | Yes |

Source: Linker et al. 2002.

to late spring period, while evaluation of the open-water, deep-water and deep-channel dissolved oxygen criteria focused on June through September.

A summary of the relative confidence in model calibration by Chesapeake Bay Program segment by designated use is provided in Table II-2. More detailed information on the Chesapeake Bay water quality model calibration is available at: http://www.chesapeakebay.net/modsc.htm under the publications tab and within the report *A Comparison of Chesapeake Bay Estuary Model Calibration With 1985–1994 Observed Data and Method of Application to Water Quality Criteria* (Linker et al. 2002).

Table II-2. Relative confidence in Chesapeake Bay water quality model calibration for 35 Chesapeake Bay Program segments for the three Chesapeake Bay water quality criteria by tidal water designated use.

| Chesapeake Bay Program Segment | Dissolved Oxygen | | | | Chlorophyll *a* | | |
|---|---|---|---|---|---|---|---|
| | Migratory Feb-June | Open Water All Year | Deep Water | Deep Channel | Spring | Summer | Water Clarity |
| CB1TF | a | NA | NA | NA | b | b | a |
| CB2OH | a | NA | b | NA | a | b | a |
| CB3MH | a | NA | b | a | a | c | a |
| CB4MH | NA | a | b | b | b | a | a |
| CB5MH | NA | a | c | c | a | b | a |
| CB6PH | NA | a | c | NA | b | b | a |
| CB7PH | NA | a | a | NA | b | a | a |
| CB8PH | NA | a | NA | NA | a | a | a |
| PAXTF | b | NA | NA | NA | a | c | b |
| PAXOH | b | NA | NA | NA | c | c | b |
| PAXMH | a | b | b | NA | a | b | a |
| POTTF | b | NA | NA | NA | a | b | b |
| POTOH | b | NA | NA | NA | b | c | a |
| POTMH | a | a | b | a | a | b | a |
| RPPTF | a | NA | NA | NA | c | c | a |
| RPPOH | b | NA | NA | NA | c | b | b |
| RPPMH | b | a | a | NA | b | a | b |
| MPNTF | c | NA | NA | NA | b | a | b |
| MPNOH | b | NA | NA | NA | a | b | b |
| PMKTF | a | NA | NA | NA | b | a | c |
| PMKOH | b | NA | NA | NA | b | c | b |
| YRKMH | a | a | NA | NA | a | b | a |
| YRKPH | NA | a | a | NA | b | a | a |
| PIAMH | NA | a | NA | NA | a | a | a |
| MOBPH | NA | a | a | NA | a | a | a |
| JMSTF | b | NA | NA | NA | a | b | b |
| JMSOH | a | NA | NA | NA | a | c | a |
| JMSMH | a | a | NA | NA | c | c | a |
| JMSPH | NA | a | NA | NA | b | a | a |
| EASMH | NA | a | a | NA | b | c | a |
| CHOOH | c | NA | NA | NA | b | c | a |
| CHOMH2 | a | NA | NA | NA | c | c | b |
| CHOMH1 | NA | a | NA | NA | b | b | a |
| TANMH | NA | b | NA | NA | a | a | a |
| POCMH | NA | a | NA | NA | b | a | b |

Key: a = High Certainty
b = Moderate Certainty
c = Low Certainty

Source: Linker et al. 2002.

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chapter iii

# Technical and Modeling Considerations for Setting the Cap Load Allocations

In calculating attainability under various loading scenarios using the Water Quality Model, it is necessary to apply innovative approaches to address various technical issues. The most important of these issues are described in this chapter, as follows: refining estimates of pycnocline depths; setting averaging periods for determining criteria attainment; defining allowable frequency and duration of criteria exceedances; establishing the geographic influence of loads on tidal water quality; establishing the tidal wetland influence on tidal-water dissolved oxygen; analysis of the isolation of individual pollutant effects on water quality; influence of sediment loads on dissolved oxygen; and the establishment and assessment of SAV restoration goals.

## REFINING ESTIMATES OF PYCNOCLINE DEPTHS

The pycnocline is usually characterized by strong gradients in chemical and biological properties and separates the deep, saltier waters from the less saline, well-mixed surface waters. In the Chesapeake Bay, another well-mixed layer forms on the bottom of the estuary due to bottom shear from estuary currents. Vertical stratification of the Chesapeake Bay has implications for use designations and, therefore, accurate estimates of the pycnocline are important for assessing attainment. The method for assessing upper and lower mixed layer depths is based on Fisher et al. (2003). This method differs from the standard field method in that it uses a measured density gradient based on salinity and temperature rather than on the surrogate, conductivity. Generally, the upper pycnocline depth is the shallowest occurrence of a density gradient of 0.1 $kg/m^4$ or greater and a lower mixed layer depth is the deepest occurrence of a density gradient of 0.2 $kg/m^4$, if a lower mixed layer exists.

Since pycnocline delineation is based on hydrodynamics and not bathymetry, the depth of the pycnocline and hence the boundaries of the designated uses changes on a monthly basis. Details are presented in Appendix D of the *Technical Support Document* (U.S. EPA 2003b). Since monitoring data is used to adjust model output as described previously in Chapter II, the upper and lower pycnocline boundary depths are determined on a monthly average period usually formed from two water quality monitoring sampling cruises each month over the assessment period. Consequently, only monthly average water quality criteria were assessed.

## AVERAGING PERIOD FOR DETERMINING CRITERIA ATTAINMENT

The method for determining attainment of the Chesapeake Bay dissolved oxygen, clarity and chlorophyll *a* criteria became an issue. Chesapeake Bay Program partners decided that the Bay modeling tools would be used to assist in allocating the nutrient and sediment cap loads, and the ambient tidal water quality monitoring data would be used to ultimately determine criteria attainment for listing and delisting purposes. This course of action required greater coordination between monitoring data and modeling output assessments and decisions on the method for analyzing monitoring data.

### ASSESSING MONITORING DATA

Monitoring criteria attainment requires reconciliation of dichotomous needs. Long averaging periods are needed to obtain the best assessment of criteria attainment through wet, dry and average years. Data from multiple years averages out other interannual variability, such as the timing of high flow and load events. The large nutrient and sediment load reductions called for in the *Chesapeake 2000* cap load allocations will occur in different places and at different rates, thereby adding more variability to interannual measurements of dissolved oxygen, clarity and chlorophyll *a*. All of these factors address assessing attainment with the longest monitoring period practicable.

On the other hand, responsive water quality management requires a reasonable assessment period, which requires a compromise on the quality of assessment. To best address the disparate needs of quality and responsiveness, a three-year averaging period was chosen. See Chapter 6 in the *Regional Criteria Guidance* for a detailed justification for the selection of this averaging period (U.S. EPA 2003a).

### ASSESSING MODELING DATA

Currently, Chesapeake Bay Water Quality Model output is available for 10 simulated years (1985–1994), which provides eight three-year running averages (1985-1987, 1986–1988, 1987–1989, etc.). To compare the standard 10-year assessment of the model outputs for dissolved oxygen, clarity and chlorophyll *a* to the three-year assessment of monitoring data, the model output was modified to provide estimates of the highest attainment of the eight three-year assessments, the lowest attainment of the eight three-year assessment and the average of the eight three-year running assessments. The modification allows for assessment of model estimated 'best' and 'worst' cases of attainment using a running three-year assessment period.

The deep waters of the middle mainstem Chesapeake Bay segments CB3MH, CB4MH and CB5MH, along with the deep waters of the lower Potomac River (POTMH) and Eastern Bay (EASMH) form a large contiguous region of deep water in close contact with the often anoxic waters of the deep channel. Attainment of the dissolved oxygen criteria for these deep waters is difficult, as Figure III-1 illustrates. Seven scenarios are shown: 1985–94 Observed, 2000 Progress, Tier 1, Tier 2, Tier 3,

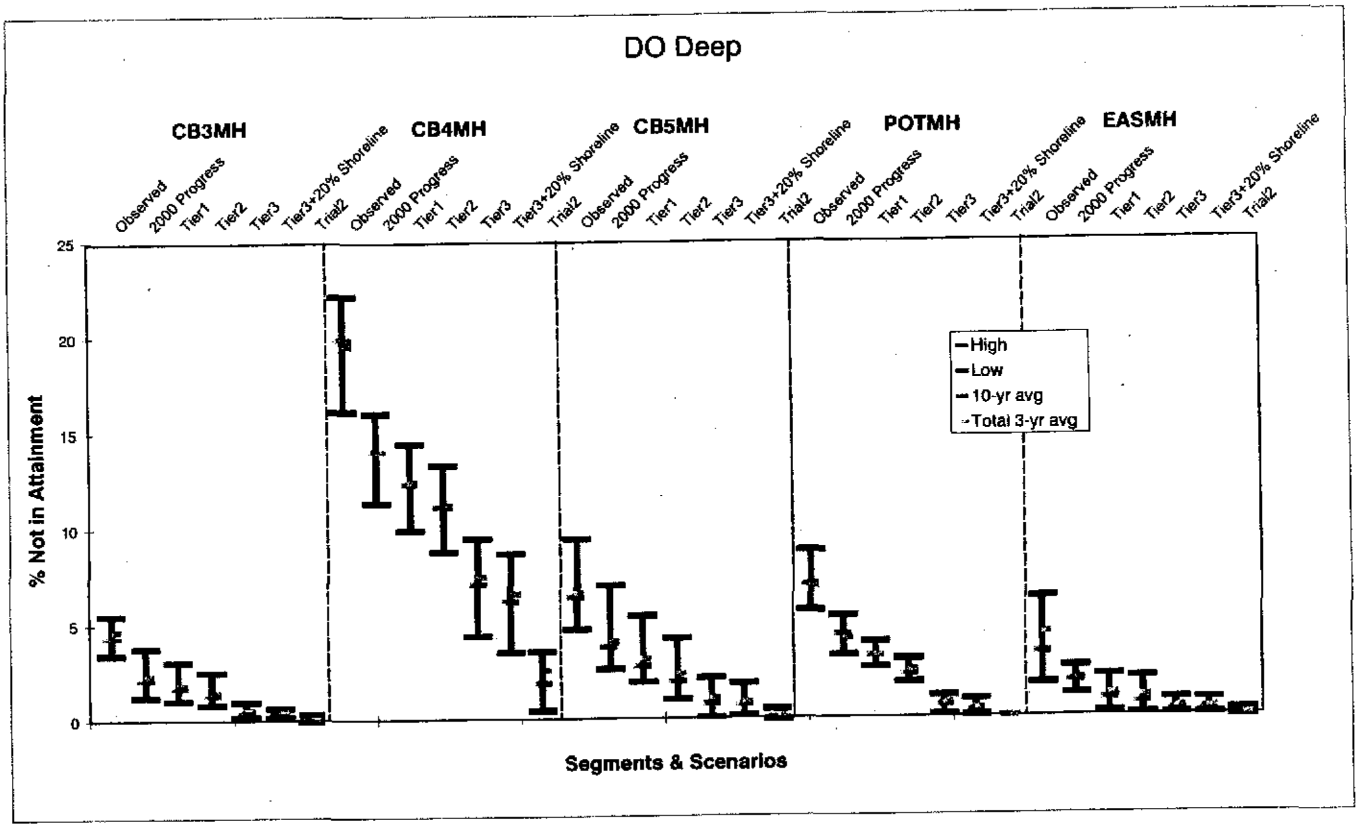


Figure III-1. Assessment of the range and mean of a three-year running average based on model estimates of dissolved oxygen criteria attainment for the deep waters of the contiguous region of CB3MH, CB4MH, CB5MH, POTMH and EASMH.

Tier 3+20% Shoreline Sediment Reduction, and Trial 2 (basinwide cap loads). The 10-year average of waters 'Not in Attainment' (labeled '10-yr avg') is approximated by the average of the eight three-year running averages (labeled 'Total 3-yr avg'). Moreover, as nutrient and sediment loads move toward the agreed-upon basinwide cap load values (Trial 2 scenario in Figure III-1), the 10-year average, the average of the eight three-year averages and the high and low three-year average begin to approach the same value.

The mainstem CB4MH segment, located in the middle of the deep-channel anoxia region of the Chesapeake Bay, has the greatest difficulty in attaining the deep-water dissolved oxygen criteria. Figure III-1 indicates that the 10-year average estimate of nonattainment (19 percent) is close to the average of the eight three-year running averages (18 percent) and that the worst three-year average period of nonattainment (23 percent) is, of course, greater than the best three-year average of nonattainment (16 percent). As the loads of nutrients and sediment are reduced, the levels of nonattainment decrease, and the range between 'best' and 'worst' three-year average nonattainment decreases. Model estimates of the range and average of the three-year averages of dissolved oxygen, clarity and chlorophyll *a* provide an estimate of what attainment may look like using a three-year running average of observations.

Given the findings that 10-year and 3-year averaging periods for determining attainment were very close at loading levels approaching the basinwide cap loads, the Chesapeake Bay Program partners decided the 10-year averaged modeling output could be used in making cap load allocation decisions.

## DEFINING ALLOWABLE FREQUENCY AND DURATION OF CRITERIA EXCEEDANCES

Water quality criteria are established as 'safe' levels necessary for the protection of aquatic life. Continued attainment of these levels should result in a healthy aquatic community. Typically, the EPA's national water quality criteria are further defined by magnitude, maximum duration and frequency of exceedances. Although it is well-established that exceedances of water quality criteria within limits still support a healthy aquatic community, the Chesapeake Bay Program identified the need to go beyond the simple time metrics of frequency and duration that are usually applied. An innovative approach was adopted based on allowable exceedances of time (percent of time exceeded with the criteria application period) and space (percent volume or surface area of the designated use within a Chesapeake Bay Program segment).

Monitoring for criteria attainment requires collection of data that are as fully representative as possible of the extent of space and time over which the assessment is to be performed, but resource limitations inevitably limit data collection. Therefore, an analytical framework is used to evaluate spatial and temporal criteria exceedance based on limited data.

As the monitoring program was being designed for criteria assessment, the scientists involved developed an analytical framework based on a cumulative frequency diagram (CFD) approach. Monitoring data collected at a limited number of locations were interpolated over a fixed three-dimensional grid. Criteria values were defined for each grid cell and combined with the data interpolation to provide a cell-by-cell estimate of criteria exceedance. Then, for each monitoring event, those grid-cell estimates were aggregated to provide a segment-wide estimate of 'percent of space' exceeding the criteria. Multiple monitoring events conducted over an assessment period provided a temporally defined collection of estimates of 'percent of space' exceeding the criteria. Those values were then plotted as a CFD using standard statistical procedures. The CFD generated using this approach reflects criteria in both space and time since 'percent of space' is represented on the horizontal axis and 'temporal frequency' is represented on the vertical axis (Figure III-2; see Chapter 6 of the *Regional Criteria Guidance* for more details) (U.S. EPA 2003a).

As the CFD approach was developed, it was recognized that some spatial and temporal criteria exceedance could occur at the same time that the overall segment was achieving its designated use. For example, some small tidal tributaries might chronically exceed the criteria simply because they are naturally poorly flushed. It was decided that these exceedances should be considered 'allowable' and should be accounted for in the CFD analytical framework.

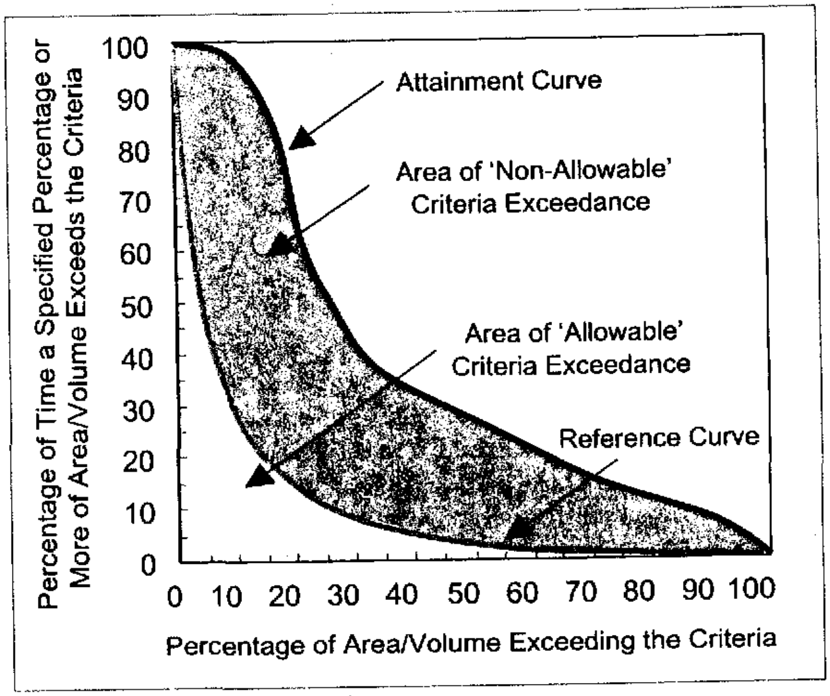


Figure III-2. Non-allowable exceedance illustrated in dark blue.

Source: U.S. EPA 2003a.

To account for 'allowable exceedances' in the CFD approach, multiple options were considered. Initially 10-percent of time and/or space was considered to be the best approach because it was consistent with past EPA guidance. However, strict adherence to a 10-percent rule almost always resulted in a violation because CFDs tend to exceed 10-percent of time or space at some location on the figure, even when there are few measured violations. A curved line is more consistent with the CFD and so a mathematically defined hyperbolic line was developed that encompassed 10-percent of the CFD plot area. This approach appeared to function well, but was considered arbitrary because it had no scientific basis with regard to actual achievement of a designated use. As a result, a third option was considered where a CFD was developed based on data from areas that were already achieving their designated use. That CFD was defined as a 'reference curve' that would be used as a benchmark against which other CFD assessment curves could be compared. The biologically-defined 'reference curve' was selected as the best alternative of those considered and adopted for routine use in criteria assessment (see Chapter 6 of the *Regional Criteria Guidance* for more details; U.S. EPA 2003a).

Exceedances in time and space for model were determined with cumulative frequency distributions (CFDs) and biological reference curves. As described in Chapter II, each model scenario was used to create a modified data set for that scenario. These results were then interpolated and used to create CFDs of spatial and temporal criteria exceedance for each segment and designated use. The CFD for the segment and scenario was compared to the appropriate biological reference curve that defines the biologically acceptable and protective combinations of frequency and spatial extent of criteria exceedances. The total area below the CFD for a segment, but above the biological reference curve represents the unallowable exceedance for that segment and scenario (Figure III-2). These calculations were automatically carried out by a system of computer programs available from the Chesapeake Bay Program Office. The development and application of CFDs is described in greater detail in Chapter 6 of the *Regional Criteria Guidance* (U.S. EPA 2003a).

## ESTABLISHING THE GEOGRAPHIC INFLUENCE OF LOADS ON TIDAL WATER QUALITY

In developing the cap load allocations, it was key to understand each major tributary's influence on tidal Bay water quality. To assist the Water Quality Steering Committee in isolating the effects of each of the nine major basins, the Chesapeake Bay Program ran a series of geographic isolation runs with the Water Quality Model. The model runs helped establish estimates of the influence of loads from each of the nine major tributary basins on water quality in each segment of the Bay's tidal waters. Specifically, isolation scenarios, in which the management controls were set at Tier 3 levels for the isolated basin and held at year 2000 levels for the rest of the watershed, were performed for each major basin. Issues in identifying the most affected segments and estimating the absolute and relative effects were addressed. Absolute effects were defined as the total effect of a basin on water quality, including loads, either large or small, and the geographic influence of a basin's position in the estuary (i.e., the Susquehanna, with the largest loads and a position at the head of the estuary, always had the highest estimated absolute effect). Relative loads were an estimate of the geographic effect alone, irrespective of the amount of the load, so that for upper Bay regions, the Western Shore and Patuxent were estimated to have about the same relative effect as the Susquehanna. The cap load allocation assessments took estimates of both the absolute and relative effects into account.

### FOCUSING ON MAINSTEM SEGMENTS CB3MH, CB4MH AND CB5MH

As described above, the Bay tidal-water area that requires the highest level of nutrient reduction to attain dissolved oxygen criteria is the deep-water and deep-channel designated use in the middle and central Chesapeake Bay (segment CB4MH). Hence, all other tidal Bay habitats that are not currently in attainment for dissolved oxygen would come into attainment before the CB4MH deep-water and deep-channel designated uses were fully in attainment. For this reason, the Water Quality Technical Workgroup focused on segment CB4MH when comparing the influence of different basins. This focus was later broadened to include segment CB3MH and segment CB5MH, respectively, since they were near segment CB4MH and also required higher levels of nutrient reduction to reach attainment.

### COMPARING ABSOLUTE VERSUS RELATIVE EFFECTIVENESS

Absolute effectiveness gives an indication of the total effectiveness of a particular basin in reducing nonattainment in a given segment by taking into account geography and total load, while relative effectiveness takes into account only geography.

Absolute effectiveness is the change in criteria nonattainment that results from a single basin changing from year 2000 level management to Tier 3 management. It is expressed in the same units as the CFD, which is percentage of space and time in nonattainment. For example, if the lower Potomac River segment POTMH moves from 35 percent nonattainment to 30 percent nonattainment from the implementation of Tier 3 in the Potomac basin, then the absolute effectiveness is 5 percent. Comparing the absolute effectiveness among basins helps to identify basins that can have the greatest total effect in correcting nonattainment. Figure III-3 shows the absolute effectiveness of each basin on reducing the deep-water dissolved oxygen criteria nonattainment in middle central Chesapeake Bay segment CB4MH.

Relative effectiveness is the absolute effectiveness divided by the total load reduction necessary to gain that water quality response. For example, if the load reduction in the Potomac basin was 5 million pounds of pollutant to get that 5 percent change in nonattainment, the relative effectiveness is 1 percent per million pounds. The relative effectiveness calculation is an attempt to isolate the effect of geography by normalizing by load. Comparing the relative effectiveness among basins shows the resulting gain in attainment from performing equal reductions among the nine major basins.

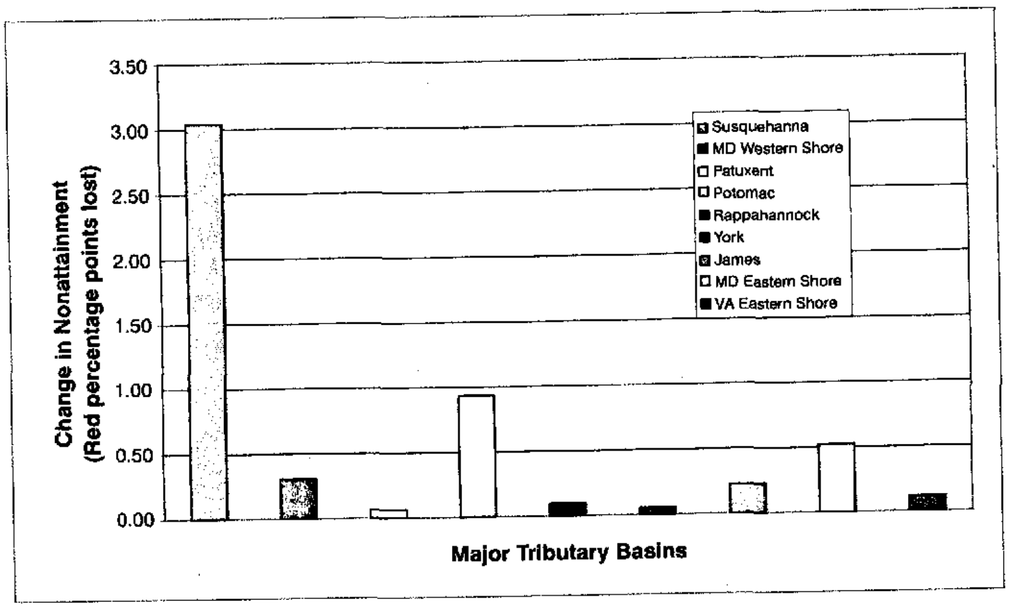


Figure III-3. Absolute effect of load reductions from the nine major basins on segment CB4MH deep-water dissolved oxygen concentrations.

## NORMALIZING FOR THE COMBINED NITROGEN AND PHOSPHORUS LOAD

Since the reductions that cause the absolute effect are taken across the board from nitrogen, phosphorus and sediment loads, one must determine the pollutant load type responsible for the increased attainment. The Chesapeake Bay is both nitrogen- and phosphorus-limited in different regions and seasons (D'Elia et al. 1986; Fisher et al. 1992, 1994, 1999, 2001; Boynton et al. 1995; Malone et al. 1996; Conley 1999). The spring algal bloom near the tidal-fresh and oligohaline regions is generally controlled by phosphorus. The summer algal bloom, primarily in the mesohaline regions, is controlled more by nitrogen. Low dissolved oxygen conditions in deep waters are caused by a combination of these seasonal blooms. Suspended sediment also has an effect on dissolved oxygen, but its effect is less than the nutrient effect (see *Influence of Sediment on Chesapeake Bay Dissolved Oxygen* below).

Since the effects of nitrogen and phosphorus are inherently connected in the Chesapeake Bay management control scenarios and cannot easily be isolated by separate management practices, the Water Quality Technical Workgroup agreed that the most appropriate divisor to convert absolute effectiveness to relative effectiveness is a combination of the two nutrients. Since nutrients are taken up by algae in roughly a 10:1 N:P ratio (by weight), this ratio was also used in the metric. Therefore, an algal unit is defined as 1 unit mass of phosphorus and 10 units mass of nitrogen. Figure III-4 shows the relative effectiveness of the nine different major basins on deep water in segment CB4MH, normalized by algal units.

To test if the water quality response was further separable by basin, the Susquehanna River basin was run with a reduction in phosphorus only, since the tidal-fresh waters that it empties into are typically phosphorus-limited. Figure III-5 shows the results of this test in the three mid-Bay segments. From this graph, it is clear that both nitrogen and phosphorus coming from the Susquehanna River basin both have large effects on water quality in the mid-Bay region.

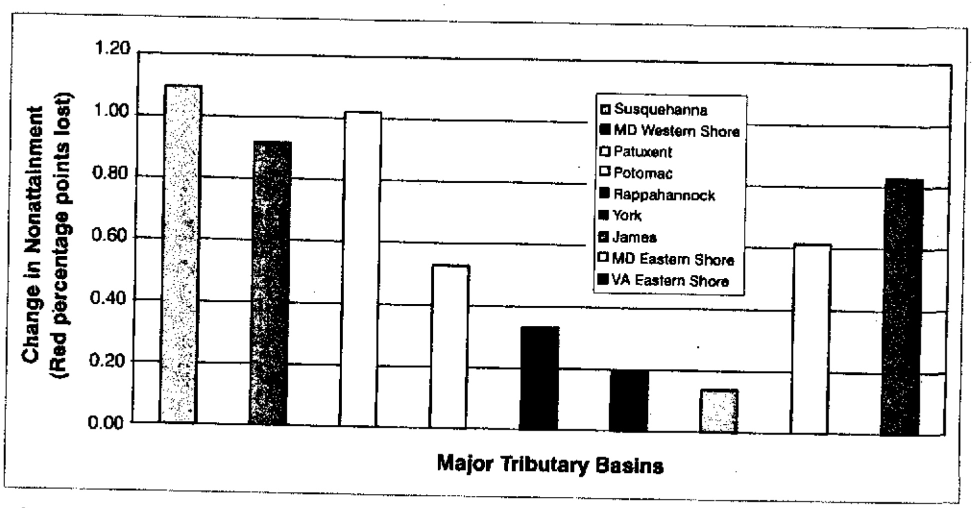


Figure III-4. Relative effect of load reductions from the nine major basins on segment CB4MH deep-water dissolved oxygen concentrations normalized by algal units.

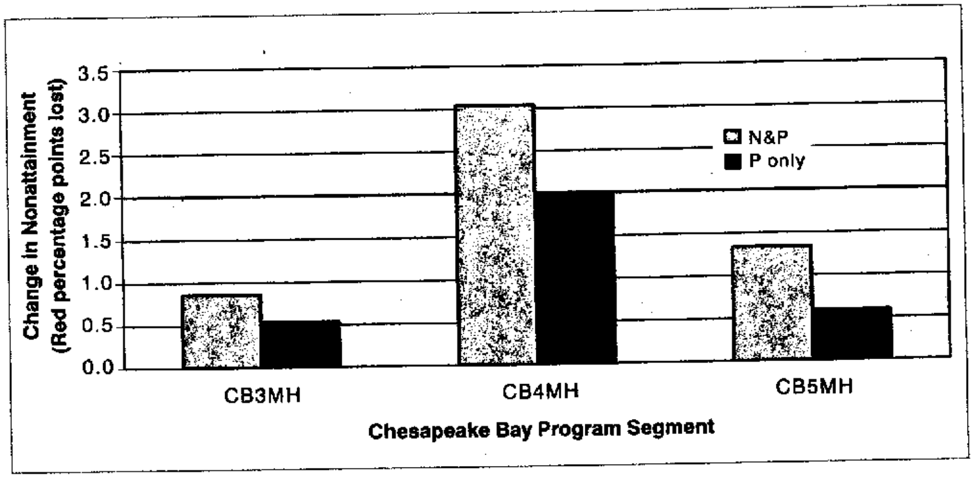


Figure III-5. Estimated absolute effectiveness of Susquehanna reductions of nitrogen and phosphorus loads (N&P) compared to reductions of the phosphorus load only (P only) on dissolved oxygen criteria attainment in the deep waters of mid-mainstem Chesapeake Bay segments CB3MH, CB4MH and CB5MH.

## GENERAL FINDINGS FROM THE GEOGRAPHIC ISOLATION RUNS

Figure III-6 shows the absolute and relative effectiveness of each major tributary basin on mainstem Chesapeake Bay segments CB3MH and CB5MH and suggests some generalizations. Northern tributary basins have a greater relative influence than southern tributary basins, due to the general circulation patterns of the Chesapeake Bay. Water and nutrients from the southern tributaries of the James and the York rivers have relatively less influence on the mainstem Bay due to their proximity to the mouth of the Bay, and the counter-clockwise circulation of the lower Bay also tends to wash nutrient loads from these southern tributaries out of the Bay mouth, since they are situated on the western side of the Bay. This same counter-clockwise circulation tends to sweep loads from the lower Eastern Shore northward.

Basins whose loads discharge directly to the mainstem Bay, like the Susquehanna, tend to have more impact on the mainstem Bay segments than basins with river estuaries (e.g., the Patuxent and Rappahannock), due to nutrient attenuation (burial and denitrification) within the river estuaries prior to the waters reaching the mainstem Chesapeake Bay. The size of a basin is uncorrelated to its relative influence, though larger basins, with larger loads, have a greater absolute effect. The upper tier of relative effect in the three mainstem segments includes the largest (Susquehanna) and the smallest (Eastern Shore Virginia) basins, both directly discharging into the Bay without intervening river estuaries to attenuate loads, and both 'up current' to the deep-channel region of the mainstem Chesapeake Bay (see Chapter IV).

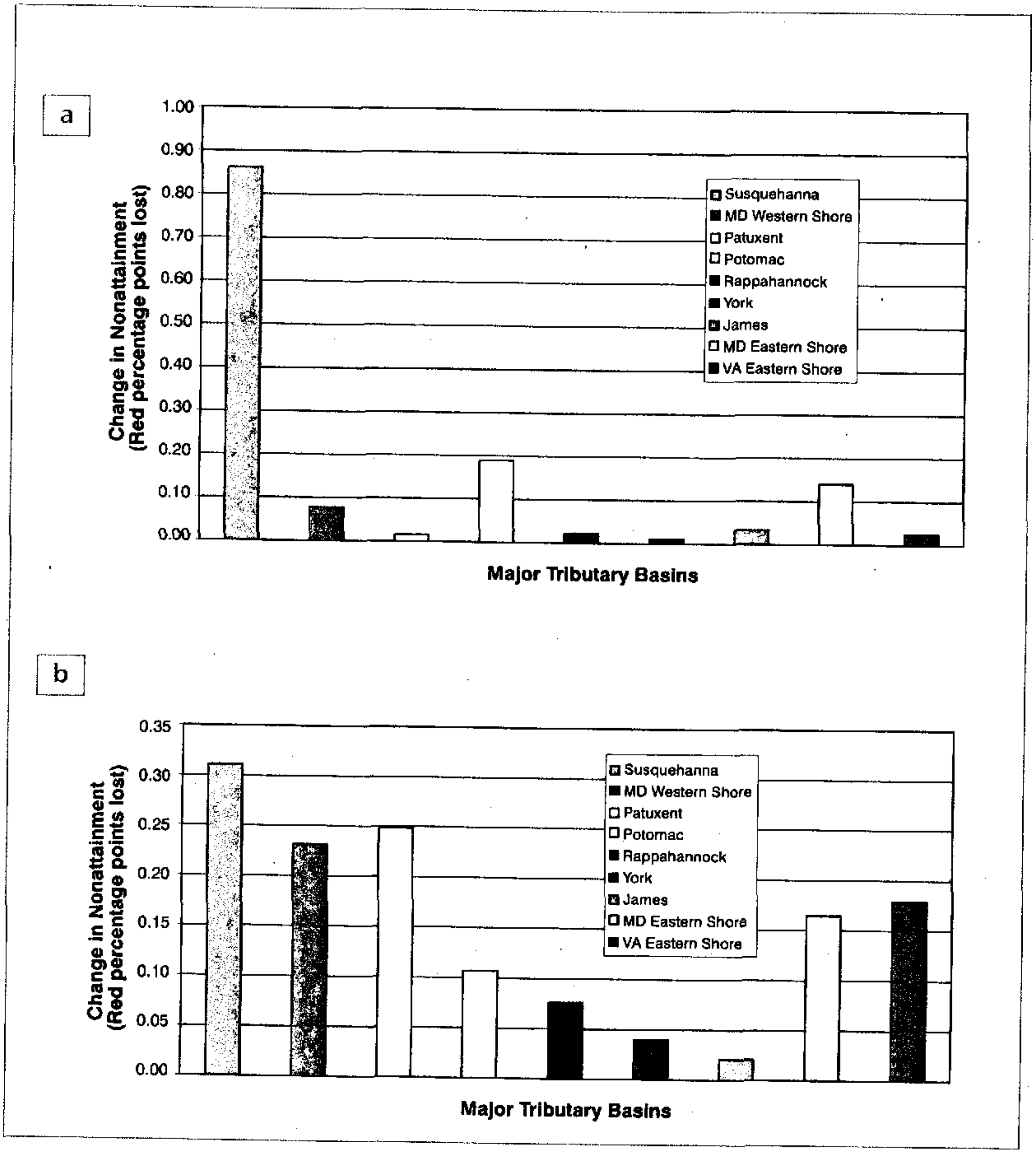


Figure III-6. Absolute (a, c) and relative (b, c) effect on mainstem Chesapeake Bay segments CB3MH and CB5MH deep water dissolved oxygen concentrations, respectively.

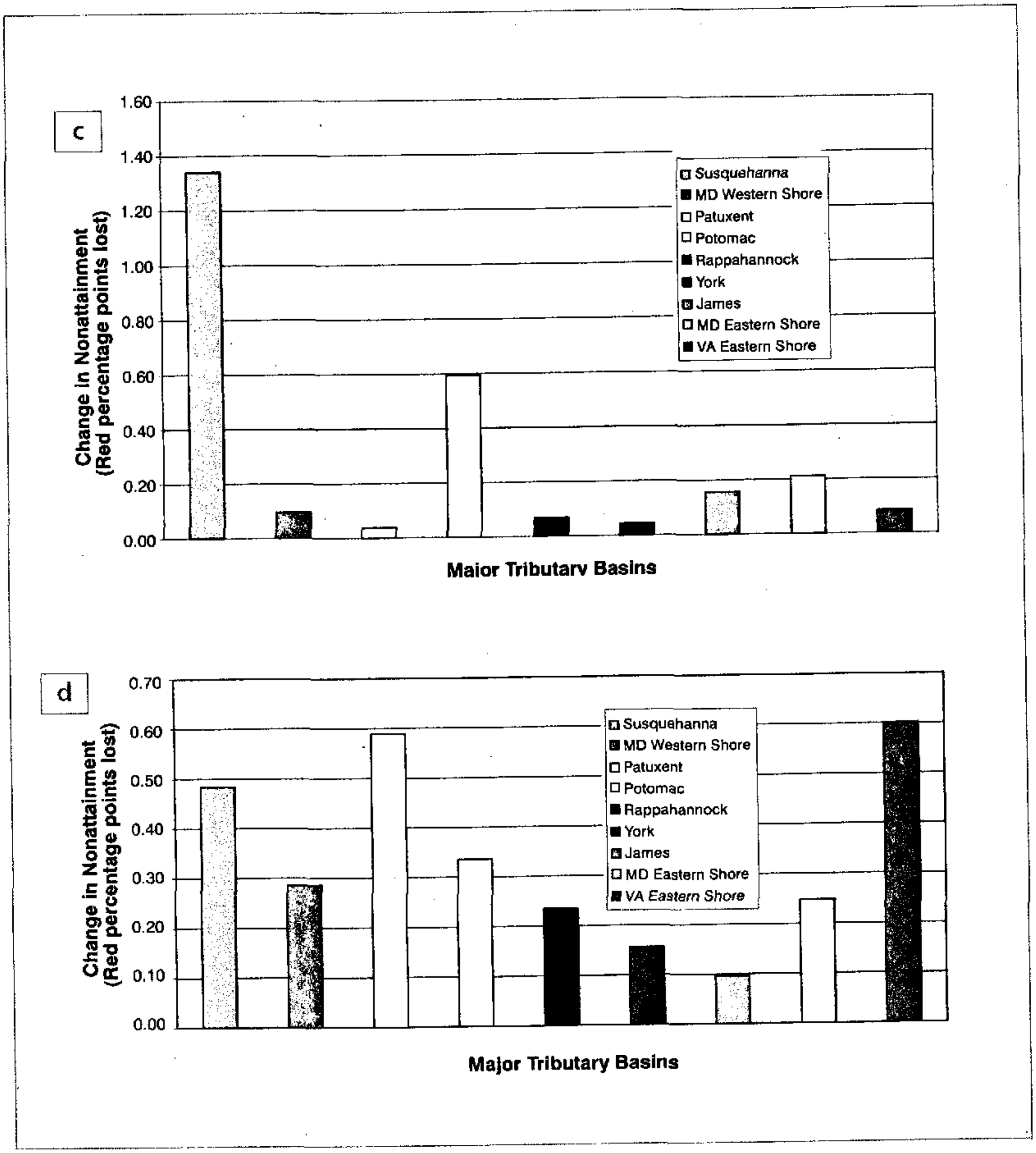


Figure III-6. (continued)

## ESTABLISHING WETLAND INFLUENCE ON TIDAL-WATER DISSOLVED OXYGEN CONCENTRATIONS

In some regions of the Chesapeake tidal tributaries in the surface waters in the summer, an oxygen deficit of several mg/L $O_2$ is typically observed. These regions are found adjacent to extensive tidal wetlands and contain comparatively small volumes of tidal waters. The tidal-fresh and oligohaline regions of the upper tidal York River is an example of relatively small volumes of waters fringed by extensive wetlands—Mattaponi (MPNTF, MPNOH) and Pammkey (PMKTF. PMKOH) rivers.

In these segments, oxygen demand from tidal wetland sediments is thought to influence surface water dissolved oxygen concentrations. Recent studies estimate wetland sediment oxygen demand to range from 1 - 5.3 g $O_2/m^2$-day (Neubauer et al. 2000; Cai et al. 1999). In the Chesapeake Bay Water Quality Model, a uniform oxygen demand of 2 g $O_2/m^2$-day was used as described in Chapter II. Regions of the Bay tidal waters where there are extensive tidal wetlands, but border relatively large bodies of water, such as in the Tangier Sound have sufficient volume and mixing to mask the oxygen demand of adjacent wetland sediments.

## WATER QUALITY MODEL RUNS ISOLATING INDIVIDUAL POLLUTANT EFFECTS ON WATER QUALITY

Allocations were developed for nitrogen, phosphorus and sediment loads for each basin. To achieve the water quality criteria, some reduction of each of the three loads is needed. Within limits, however, the mix of nitrogen, phosphorus and sediment load reductions can be altered and still achieve attainment of the criteria; for example, relatively fewer nitrogen reductions could be played against relatively more sediment reductions to achieve the same result. To examine these trade-offs, an analysis tool called a 'surface analysis' was used. While this tool was useful to examine the tradeoffs between reducing nitrogen, phosphorus and sediment loads, ultimately it will be most useful for tributary strategy development, where different load strategies that achieve the same level of water quality protection can be examined.

### SURFACE ANALYSIS PLOTS

In order to examine a particular water quality parameter, such as dissolved oxygen, with respect to different load inputs of nitrogen, phosphorus and sediment, a surface analysis was applied. Surface analysis is a statistical method that uses Water Quality Model output from multiple scenarios and produces three-dimensional plots called response surface plots. A response surface plot may be produced as a concentration of dissolved oxygen, or as the percent attainment of a dissolved oxygen criteria for a particular Chesapeake Bay Program segment or designated use over a particular attainment period (i.e., June through September for the segment CB4MH deep-water designated use). Response surface plots facilitate the understanding of interactions among nutrient and sediment loads in the Chesapeake Bay's ecosystem and in developing effective nutrient and sediment management strategies for improving water quality.

Figure III-7 examines the influence of nitrogen and phosphorus loads on the segment CB4MH deep-water dissolved oxygen concentrations. Note that the nutrient loads are expressed as a portion between 0.4 and 1.0 of the 2000 Progress Scenario loads for nitrogen and phosphorus. A 40 percent reduction in nitrogen and phosphorus loads, therefore, is represented by the grid position corresponding to 0.6 TN and 0.6 TP. The surface analysis estimate of the dissolved oxygen response in segment CB4MH deep water shows that a 40 percent reduction in either nitrogen or phosphorus alone would improve dissolved oxygen conditions, but reducing both nitrogen and phosphorus would bring about greater improvements.

In using this tool, it is important to examine the surface responses with respect to all the criteria—dissolved oxygen, water clarity and chlorophyll *a*—and in all regions or designated uses of the Chesapeake Bay and its tidal tributaries, while keeping in mind that the surface response plots are a statistical estimate of a series of model scenarios, which are also estimates of Chesapeake water quality.

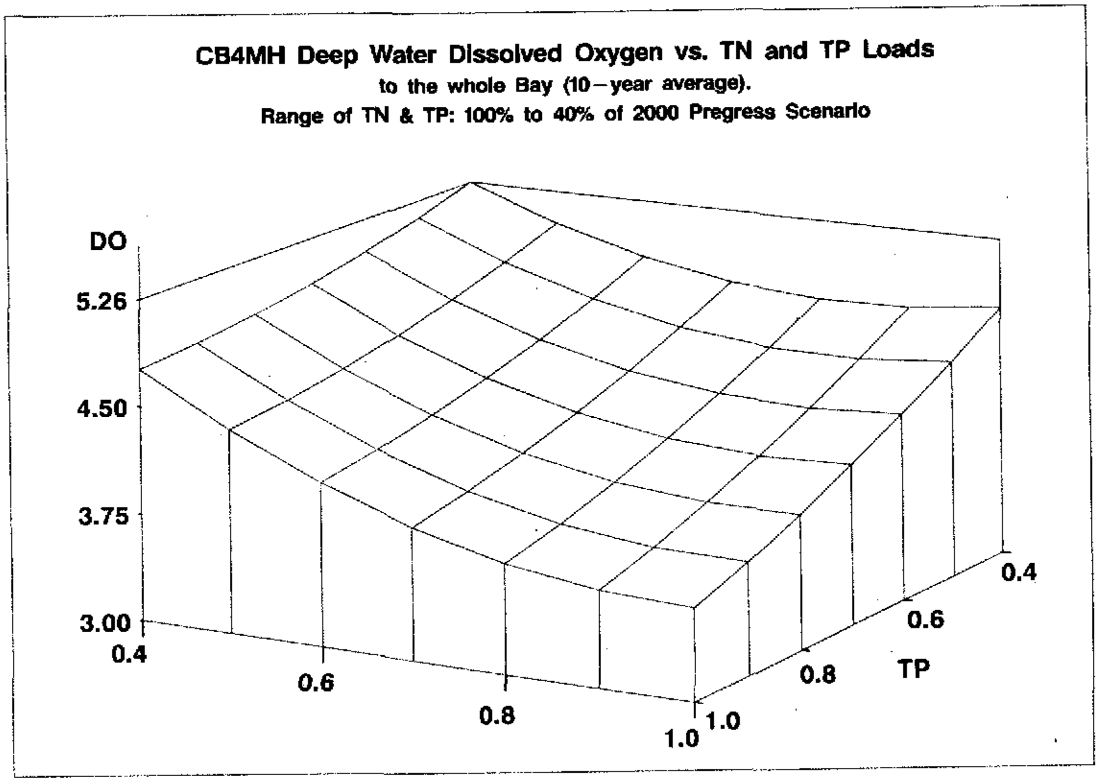


Figure III-7. Surface response of deep-water dissolved oxygen concentrations to nitrogen and phosphorus loads in segment CB4MH.

## SURFACE ANALYSIS UTILITY

Despite the fact that surface analysis is an 'estimate of an estimate' and the esoteric nature of three-dimensional regression plots, it remains a valuable tool. The utility of surface analysis is threefold. First, one can gain insight from the relative response of dissolved oxygen, clarity, SAV, chlorophyll *a* or any other water quality parameter, to any combination of nitrogen, phosphorus and sediment loads. Second, by interpolating scenario runs, the surface analysis provides an initial estimate of a water quality response without the need for exhaustive generation of numerous water quality scenarios. Third, and most important, surface analysis enables the tributary teams that are developing detailed implementation plans to achieve the nutrient and sediment cap load allocations to examine possible tradeoffs between nitrogen, phosphorus and sediment cap loads.

## INFLUENCE OF SEDIMENT ON CHESAPEAKE BAY DISSOLVED OXYGEN

In the Water Quality Model, decreases in sediment loads were accompanied by increases in water clarity, which resulted in simulated increases in shallow-water algae, benthic algae and SAV. Further examination of dissolved oxygen responses to sediment loads uncovered what initially seemed to be unusual simulation results. As sediment loads were decreased, deep-water dissolved oxygen concentration increased slightly. Further examination was necessary to explain this response.

Shallow waters of the Chesapeake Bay and its tidal tributaries occupy a region at the interface of the land and estuary. Higher sediment concentrations are generally observed in the shallow-water regions than in deeper open waters due to local watershed inputs, shore erosion and wave resuspension of sediment. As Figure III-8 illustrates, improved water clarity allows more processing of nutrients and organics in shallow-water regions. Effective interception of nutrients by benthic algae, SAV and phytoplankton in shallow, aerobic waters leads to nutrient diagenesis and loss in sediment through denitrification and phosphorus sequestration.

Additional sensitivity runs provided insight into the cascading effect of reducing sediment loads in shallow regions of the Chesapeake Bay on water quality in deep waters (Figures III-9 and III-10a-b). Figure III-9 shows the benthic algae summer biomass for the final calibration. The planar model grid shows benthic algae present in many of the shallow regions, but rarely exceeding 2 grams meter$^{-2}$ biomass. Figure III-10a is a sensitivity scenario that removes shoreline sediment loads and associated nutrient loads (SENS 146). A related sensitivity scenario (SENS 147) removed only the shoreline sediment loads, keeping the nutrients associated with the shoreline sediment loads unchanged (Figure III-10b). The pair of sensitivity scenarios (SENS 146 and 147) demonstrated that the reduced sediment load was the cause of the benthic algae increase. In reality, complete elimination of shoreline sediment loads is extreme and infeasible. However, reduced sediment loads will have a relative effect on nutrients and, ultimately, on dissolved oxygen concentrations.

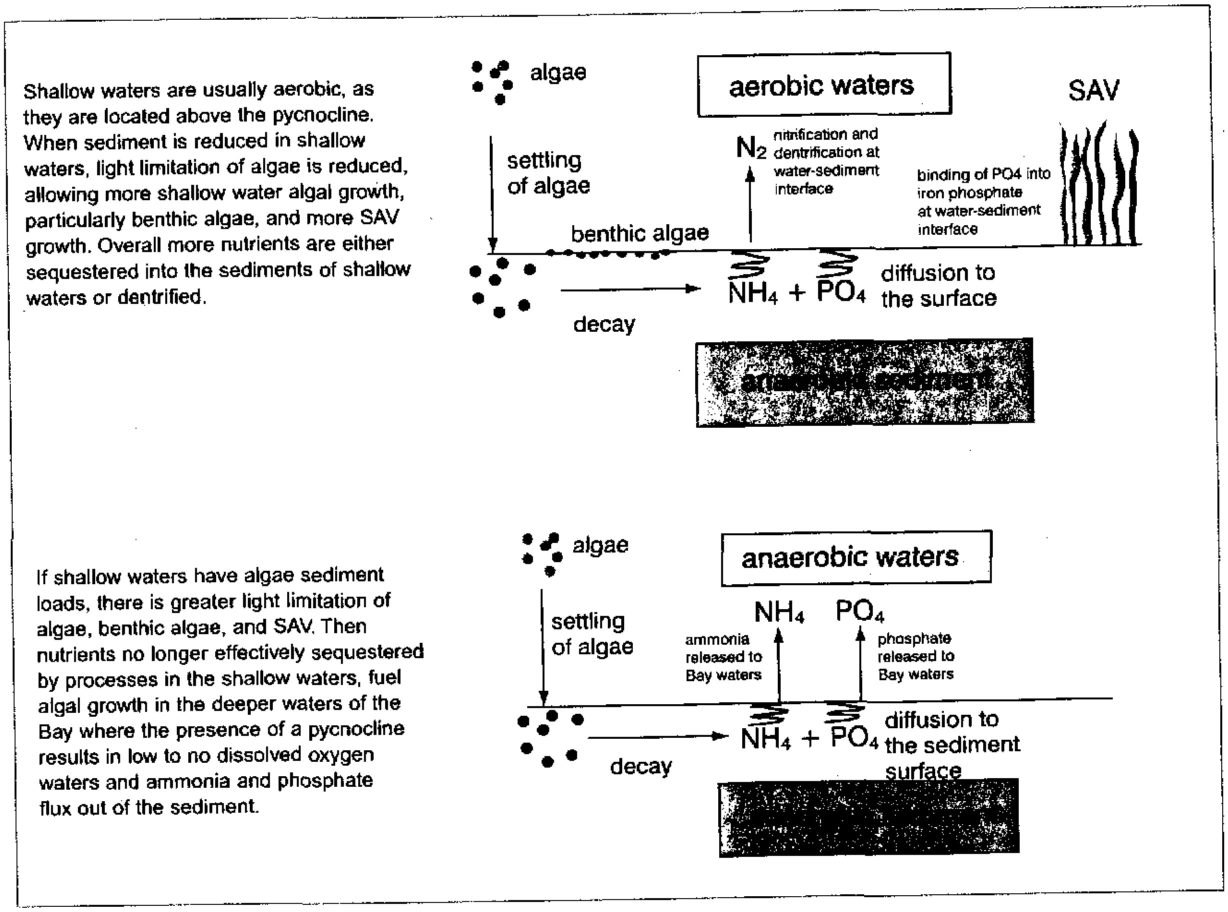


**Figure III-8.** Illustration of the influence sediment load has on shallow-water water quality and living resources.

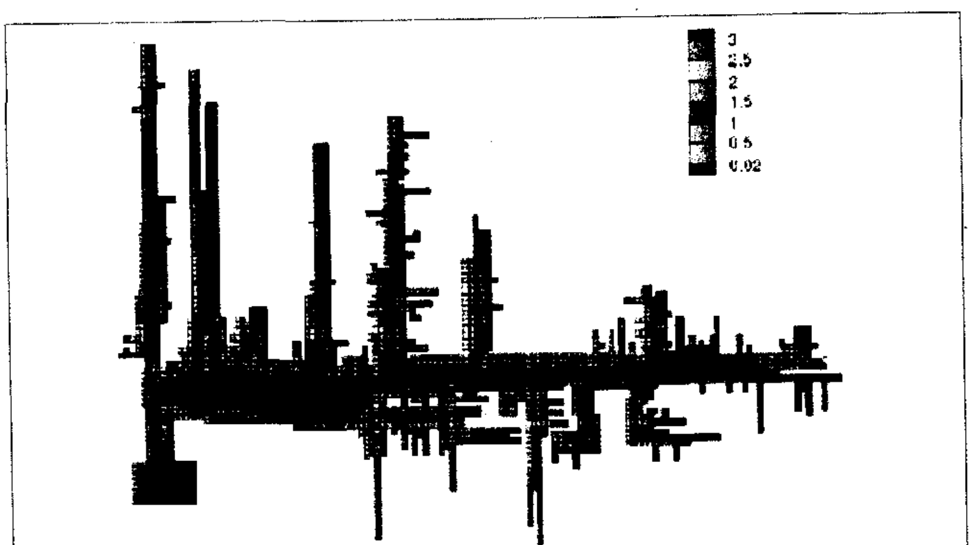


**Figure III-9.** Final calibration summer biomass of benthic algae. The units are in grams biomass meter$^{-2}$.

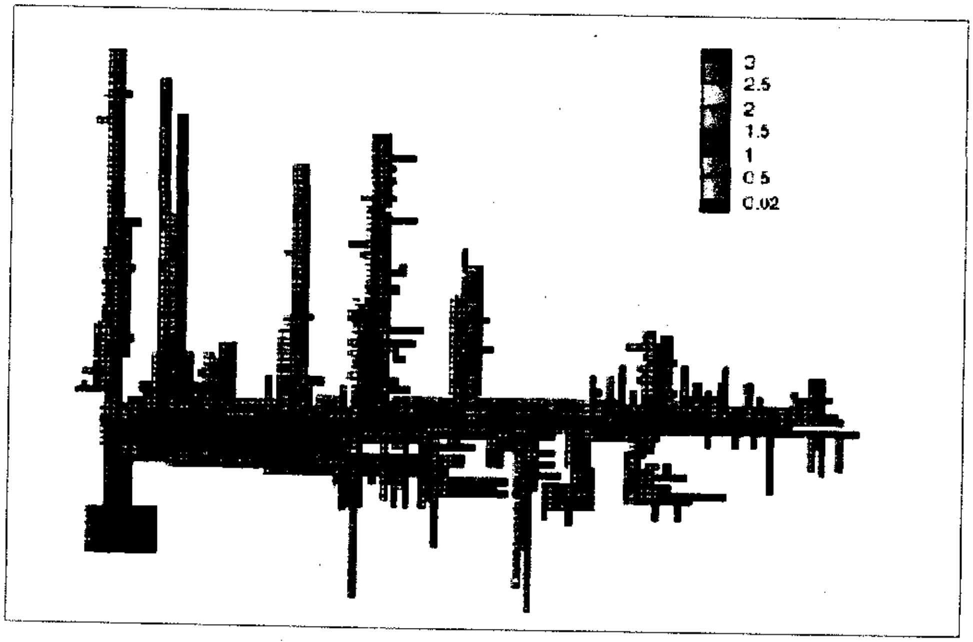


**Figure III-10a.** Sensitivity scenario of benthic algae summer biomass with no shoreline sediment or associated nutrient loads. The units are in grams biomass meter$^{-2}$.

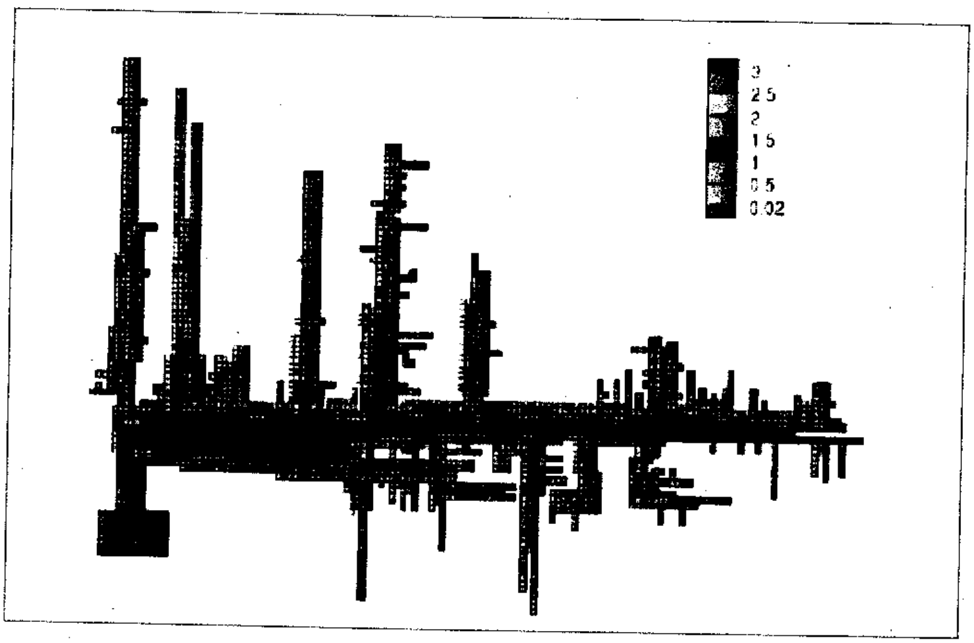


**Figure III-10b.** Sensitivity scenario of benthic algae summer biomass with no shoreline sediment, but associated shoreline sediment nutrient loads included. The units are in grams biomass meter$^{-2}$.

A modeling study of the Delaware inland bays demonstrated the importance of benthic algae on sediment diagenesis in shallow waters. Figure III-11 shows the simulated effect of the presence and absence of benthic algae on nutrient and oxygen (C. Cerco, unpublished data). The presence of benthic algae results in greater variation in nutrient and oxygen flux from the sediment (positive values out of the sediment, negative values into the sediment) but an overall net decrease of dissolved inorganic phosphorus and dissolved inorganic nitrogen flux out of the sediments. Model findings were substantiated by observed flux of oxygen and nutrients in Delaware Inland Bay sediments (S. Seitzinger, unpublished data), i.e., shallow waters with sufficient light for the growth of benthic algae demonstrated greater retention of nutrients.

In addition, researchers have shown the role of improved clarity on decreased level of nutrients. Using a STELLA modeling analysis, Kemp et al. (1994) explained that the interception of nutrients by "enhanced suspension feeding in the shallow waters of the Bay ... effect greater improvements for bottom oxygen than comparable action at deep sites". The interception of nutrients and increased nutrient processing was further examined by Newell et al. (2002), who described the potential for greater denitrification and sequestering of nutrients in aerobic shallow-water sediment. While these researchers specifically examined shallow-water oyster beds as the agent for greater interception and processing of nutrients in aerobic shallow waters,

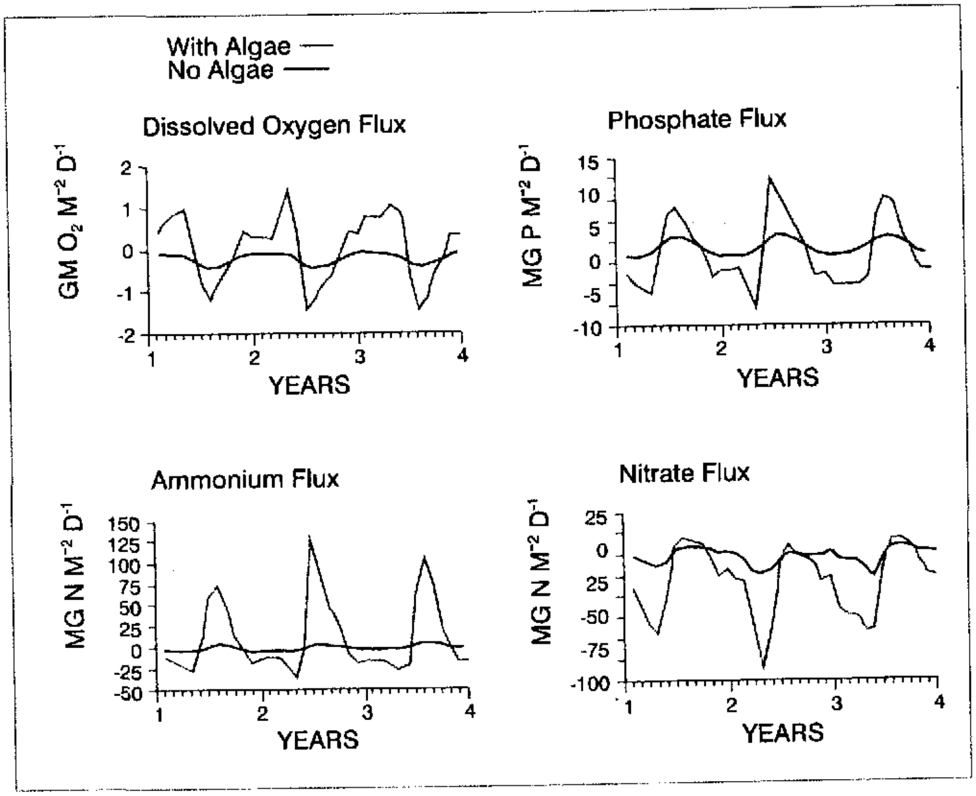


Figure II-11. Delaware Inland Bay study showing relative range of nutrient and dissolved oxygen flux resulting from the presence or absence of benthic algae.

decreased light attenuation was the principal factor in increasing nutrient interception in the model simulations.

Estimates of the influence that sediment loads, particularly to shallow waters, have on dissolved oxygen indicate an interesting synergy among nutrient/sediment loads and living resources, but care should be taken not to over-interpret these results. The current sediment simulation is the most refined model estimate of sediment loads, fate and effects, and considerable time was spent with the calibration. However, shoreline loads were approximated everywhere as a daily baywide average input, and sediment transport and wave resuspension were not simulated. Overall the influence of sediment loads on dissolved oxygen was found to be reasonable and consistent with current understanding of shallow-water processes, but also proved slight in its effect. A reduction of 20 percent of the loads from shoreline erosion and resuspension had the equivalent reduction in deep water dissolved oxygen as about a five million pound reduction in nitrogen. A 2003 review by the Chesapeake Bay Program's Scientific and Technical Advisory Committee (STAC) found that the ". . . mechanisms linking shoreline erosion reduction to improvements in deep-water dissolved oxygen through improved water clarity and increased shallow-water microphytobenthos production were plausible, but unproven" (STAC 2003). One concern the STAC review raised is the inability of the model structure and mechanisms to scour benthic algae, which may, after transport of organics to deep water, contribute, to deep-water oxygen demand.

The Water Quality Model is now being refined with a sediment transport simulation, refined spatial and temporal inputs of shoreline erosion loads and a simulation of wave resuspension with enhanced feedbacks between SAV and resuspended sediment. The influence of sediment load reductions on deep-water dissolved oxygen concentrations will be reexamined during the reevaluation of the nutrient and sediment allocations, which is planned for 2007.

## ESTABLISHING AND ASSESSING NEW SAV RESTORATION GOALS

During the development of the water clarity criteria, the shallow-water designated use and the associated sediment cap load allocations, the partners agreed to the alignment of the *Chesapeake 2000* commitment to establishing a new SAV restoration goal with the commitment to reducing sediment loads to "achieve the water quality conditions that protect living resources." *Chesapeake 2000* called for a recommitment to the long-standing 114,000-acre SAV goal and further called for more ambitious "SAV restoration goals and strategies to reflect historic abundance, measured as acreage and density from the 1930s to the present" including the specific levels of water clarity needed (Chesapeake Executive Council 2000).

Ultimately the SAV goal established to meet the *Chesapeake 2000* commitment was a 185,000-acre restoration goal, specified as baywide, tributary basin, and segment-specific restoration goals (Appendix A; Secretary Tayloe Murphy 2003). The sediment load allocation is closely aligned to this goal.

## DEVELOPING THE 185,000-ACRE SAV RESTORATION GOAL

The Chesapeake Bay Program has long committed to protecting and restoring SAV. In 2001, there were 85,415 acres of SAV in the Chesapeake Bay and its tributaries. The total potential shallow-water habitat available for SAV in the Chesapeake Bay out to 2-meters is 640,000 acres. SAV never covers 100 percent of the available habitat, but on average covers approximately 35 percent of it (U.S. EPA 2003b). On April 15, 2003, the Chesapeake Bay Program's Principals' Staff Committee and representatives of the headwater states approved the new Bay grass restoration goal of 185,000 acres by 2010. The partner states of the Bay Program have adopted the new goal, meeting the *Chesapeake 2000* commitment to:

> "*By 2002, revise SAV restoration goals and strategies to reflect historic abundance, measured as acreage and density from the 1930s to the present. The revised goals will include specific levels of water clarity that are to be met in 2010. Strategies to achieve these goals will address specific levels of water clarity, water quality and bottom disturbance*."

The following principles guided the development of the recommended new SAV goal:

- Use the best available data;
- Establish a direct link between the new goal and the new water quality criteria;
- Recognize that SAV should not be expected to cover all available shallow-water habitat;
- Areas expected to contribute to the goal should only include those that have demonstrated some minimal level of abundance or persistence in the past; and
- Provide segment-specific acreage goals for use by the tributary strategy teams.

The SAV abundance and distribution record includes interpreted historical aerial photography from the late 1930s to the 1960s, as well as the annual baywide aerial survey data from 1978 and 1984-2000. The single best year of SAV growth observed in each CBP segment from the entire record of aerial photographs (1938-2000) is the best available data on SAV occurrence over the long term. These same data were used to define, within each Chesapeake Bay segment, the depth to which the shallow-water Bay grass designated use should be considered. That depth is the maximum depth at which water clarity criteria would apply in the context of state water quality standards, and is, therefore, referred to as the 'application depth' for each segment (U.S. EPA 2003b). Table III-1 contains the derived segment-specific application depths.

As the first step to setting the SAV goal acreage out to the specific application depth was determined through bathymetry data and aerial photographs used to slice the single-best-year SAV acreage in each segment into three depth zones: 0–0.5 meters, 0.5–1.0 meters and 1–2 meters; and aerial photographs used to determine the depth to which SAV grew in each segment with either a minimum abundance or minimum persistence.

Next, the SAV goal for a segment is the portion of the single-best-year acreage that falls within this determined depth range, which, in turn, was established as follows:

> In all segments, the 0–0.5 meter depth interval will be designated for shallow-water Bay grass use. In addition, the shallow-water Bay grass use will be designated for deeper depths within a segment if either:
>
> - The single-best-year SAV distribution covered at least 20 percent of the potential habitat in a deeper depth zone; or
> - The single-best-year SAV covered at least 10 percent of the potential habitat in the segment-depth interval, *and* at least three of the four five-year periods of the record (1978-2000) show at least 10 percent SAV coverage of potential habitat in the segment-depth interval.

SAV restoration goals have been established in a manner consistent with the single-best-year method used to determine the application depths. Within each segment, the 2010 restoration goal for designated use attainment purposes is equal to the acreage of the single best year on record within the segment's application depth (U.S. EPA 2003b). These segment-specific SAV restoration goals are listed in Table III-1. New SAV acreage goals have been established on a segment-specific basis, a baywide basis and, between those two, a major tributary basin-specific basis (e.g., Potomac River; see Table III-2).

The new baywide SAV goal, 185,000 acres, is the sum of acreage targets for each of the 78 Chesapeake Bay segments based on the single-best-year acreage on record for each segment. The achievement of the baywide goal, as well as the local tributary basin and segment-specific restoration goals, will be based on the single-best-year SAV acreage within the most recent three-year record of survey results (U.S. EPA 2003a).

The Chesapeake Bay Program partners reached the following agreements on the implementation of the SAV restoration goals:

1. The tidal states of Delaware, Maryland and Virginia and the District of Columbia will adopt numerical water clarity criteria and consider the adoption of the SAV acreage restoration goals for each Chesapeake Bay Program segment into their Water Quality Standards.
2. The SAV acreage restoration goals will be used as the primary metric in the development and implementation of the tributary strategies with regard to sediment controls. If the SAV acreage restoration goal is achieved in a given segment, and if the state water quality standards allow, that segment will be considered as having achieved the shallow-water bay grass designated use even if the sediment loading caps were not met.
3. Virginia and Maryland will develop comprehensive SAV restoration strategies to meet the new SAV restoration goal.

Table III-1. The new Chesapeake Bay SAV acreage goal and current SAV acreages by Chesapeake Bay Program segment.

| Chesapeake Bay Program Segment Name | Shallow-water SAV Application Depth | 2001 SAV Acreage Out to Application Depth | SAV Restoration Goal |
|---|---|---|---|
| Northern Chesapeake Bay | 2 | 7,979 | 12,908 |
| Upper Chesapeake Bay | 0.5 | 203 | 302 |
| Upper Central Chesapeake Bay | 0.5 | 1 | 943 |
| Middle Central Chesapeake Bay | 2 | 112 | 2,511 |
| Lower Central Chesapeake Bay | 2 | 4,487 | 14,961 |
| Western Lower Chesapeake Bay | 1 | 715 | 980 |
| Eastern Lower Chesapeake Bay | 2 | 9,168 | 14,620 |
| Mouth of the Chesapeake Bay | 0.5 | 8 | 6 |
| Bush River | 0.5 | 3 | 158 |
| Gunpowder River | 2 | * | 2,254 |
| Middle River | 2 | * | 838 |
| Back River | 0.5 | * | 0 |
| Patapsco River | 1 | * | 298 |
| Magothy River | 1 | * | 545 |
| Severn River | 1 | 120 | 329 |
| South River | 1 | 27 | 459 |
| Rhode River | 0.5 | * | 48 |
| West River | 0.5 | * | 214 |
| Upper Patuxent River | 0.5 | 205 | 5 |
| Western Branch (Patuxent River) | 0.5 | * | 0 |
| Middle Patuxent River | 0.5 | 104 | 68 |
| Lower Patuxent River | 1 | 22 | 1,325 |
| Upper Potomac River | 2 | 1,964 | 4,368 |
| Anacostia River | 0.5 | 4 | 6 |
| Piscataway Creek | 2 | * | 783 |
| Mattawoman Creek | 1 | * | 276 |
| Middle Potomac River | 2 | 3,070 | 3,721 |
| Lower Potomac River | 1 | 1,739 | 10,173 |
| Upper Rappahannock River | 0.5 | 66 | 20 |
| Middle Rappahannock River | 0.5 | * | 0 |
| Lower Rappahannock River | 1 | 478 | 5,380 |
| Corrotoman River | 1 | 389 | 516 |
| Piankatank River | 2 | 539 | 3,256 |
| Upper Mattaponi River | 0.5 | * | 75 |
| Lower Mattaponi River | 0.5 | * | 0 |
| Upper Pamunkey River | 0.5 | 140 | 155 |
| Lower Pamunkey River | 0.5 | * | 0 |
| Middle York River | 0.5 | * | 176 |
| Lower York River | 1 | 801 | 2,272 |
| Mobjack Bay | 2 | 9,508 | 15,096 |
| Upper James River | 0.5 | 95 | 1,600 |
| Appomattox River | 0.5 | * | 319 |
| Middle James River | 0.5 | .15 | 7 |

*continued*

Table III-1. (continued)

| Chesapeake Bay Program Segment Name | Shallow-water SAV Application Depth | 2001 SAV Acreage Out to Application Depth | SAV Restoration Goal |
|---|---|---|---|
| Chickahominy River | 0.5 | 268 | 348 |
| Lower James River | 0.5 | 2 | 531 |
| Mouth of the James River | 1 | 232 | 604 |
| Western Branch Elizabeth River | * | * | 0 |
| Southern Branch Elizabeth River | * | * | 0 |
| Eastern Branch Elizabeth River | * | * | 0 |
| Lafayette River | * | * | 0 |
| Mouth of the Elizabeth River | * | * | 0 |
| Lynnhaven River | 0.5 | 43 | 69 |
| Northeast River | 0.5 | * | 88 |
| C&D Canal | 0.5 | 7 | 0 |
| Bohemia River | 0.5 | 354 | 97 |
| Elk River | 2 | 2,034 | 1,648 |
| Sassafras River | 1 | 1,169 | 764 |
| Upper Chester River | 0.5 | * | 0 |
| Middle Chester River | 0.5 | * | 63 |
| Lower Chester River | 1 | 205 | 2,724 |
| Eastern Bay | 2 | 2,886 | 6,108 |
| Upper Choptank River | * | * | 0 |
| Middle Choptank River | 0.5 | * | 63 |
| Lower Choptank River | 1 | 148 | 1,499 |
| Mouth of the Choptank River | 2 | 5,257 | 8,044 |
| Little Choptank River | 2 | 2,377 | 3,950 |
| Honga River | 2 | 4,945 | 7,686 |
| Fishing Bay | 0.5 | 6 | 193 |
| Upper Nanticoke River | * | * | 0 |
| Middle Nanticoke River | 0.5 | * | 3 |
| Lower Nanticoke River | 0.5 | * | 3 |
| Wicomico River | 0.5 | * | 3 |
| Manokin River | 2 | 404 | 4,359 |
| Big Annemessex River | 2 | 721 | 2,014 |
| Upper Pocomoke River | * | * | 0 |
| Middle Pocomoke River | 0.5 | * | 0 |
| Lower Pocomoke River | 1 | 1,528 | 4,092 |
| Tangier Sound | 2 | 13,310 | 37,965 |
| Totals | | 77,858 | 184,889 |
| | | +7,561 acres of SAV not included in the survey due to heightened security | |
| | | 85,419 | |

*Denotes no data available or no SAV present.

Source: U.S. EPA 2003b.

Table III-2. Chesapeake Bay SAV restoration goals by major tributary basin.

| Jurisdiction-Basin | SAV Restoration Goal (acres) |
|---|---|
| Susquehanna | 12,856 |
| Eastern Shore – MD | 76,193 |
| Western Shore – MD | 5,651 |
| Patuxent | 1,420 |
| Potomac | 19,450 |
| Rappahannock | 12,798 |
| York | 21,823 |
| James | 3,483 |
| Eastern Shore – VA | 31,215 |
| TOTAL | 184,894 |

## WATER CLARITY AND SAV

The water quality criteria distinguish two types of SAV communities with respect to light requirements (Batiuk et al. 2000; U.S. EPA 2003a). The tidal-fresh and oligohaline communities are estimated to require greater than 13 percent light-through-water while the more light-sensitive SAV communities of the mesohaline and polyhaline areas are estimated to require 22 percent light-through-water. These light requirements can also be expressed as light attenuation (variously symbolized as $K_d$ or $K_e$), which represents the rate of light lost through the water column.

Representing the equivalent light needs for the tidal-fresh/oligohaline and the mesohaline/polyhaline communities, Figure III-12 graphs the tradeoffs between light attenuation and depth. Light attenuation is a rate of light lost by passage through a water column, either by scattering through sediment, absorption by algal chlorophyll, or loss through absorption by dissolved organic material or water. For tidal-fresh or oligohaline SAV communities, a $K_d$ of 2.0 meter$^{-1}$ is equivalent to the 13 percent light-through-water light requirement at a 1-meter depth. As depth increases the light path, less light attenuation (greater water clarity) is required to achieve the same 13 percent light-through-water, so that at a 2 meter depth, light attenuation of no less than 1 meter$^{-1}$ is required to support SAV. At decreased depths more light attenuation is allowable for SAV, so that at 0.5 meters depth, a $K_d$ of 4.0 meter$^{-1}$ is still supportive of SAV growth.

To achieve the water clarity levels to support SAV, reductions in light attenuation by any of the various components (sediment, algae or color) may achieve the light requirements supportive of SAV, but for much of the Bay's tidal waters, reductions solely in nutrients and ultimately chlorophyll and epiphytic growth, are insufficient. A light attenuation model developed by Gallegos (2001) provides insight into the various components of light attenuation (see http://www.chesapeakebay.net/cims/index.htm under "Factors Contributing to Water-Column Light Attenuation: A Diagnostic Tool"). This model is applicable to any monitoring station data for any period of time. Figure III-13 represents estimated seasonal average light attenuation from the various components with color and attenuation due to water combined at the *monitoring* station EE3.2 in the Tangier Sound for the SAV season of April to October. At a 1-meter depth plotted here, only an estimated 1 year in 10 provides, on a seasonal average basis, the light required for a mesohaline SAV community of 22 percent light-through-water ($K_d$ of 1.5 meter$^{-1}$).

Reductions in light attenuation due to dissolved organic material and the base light attenuation rate of water are here depicted as '$K_d$ color' and are not possible as they

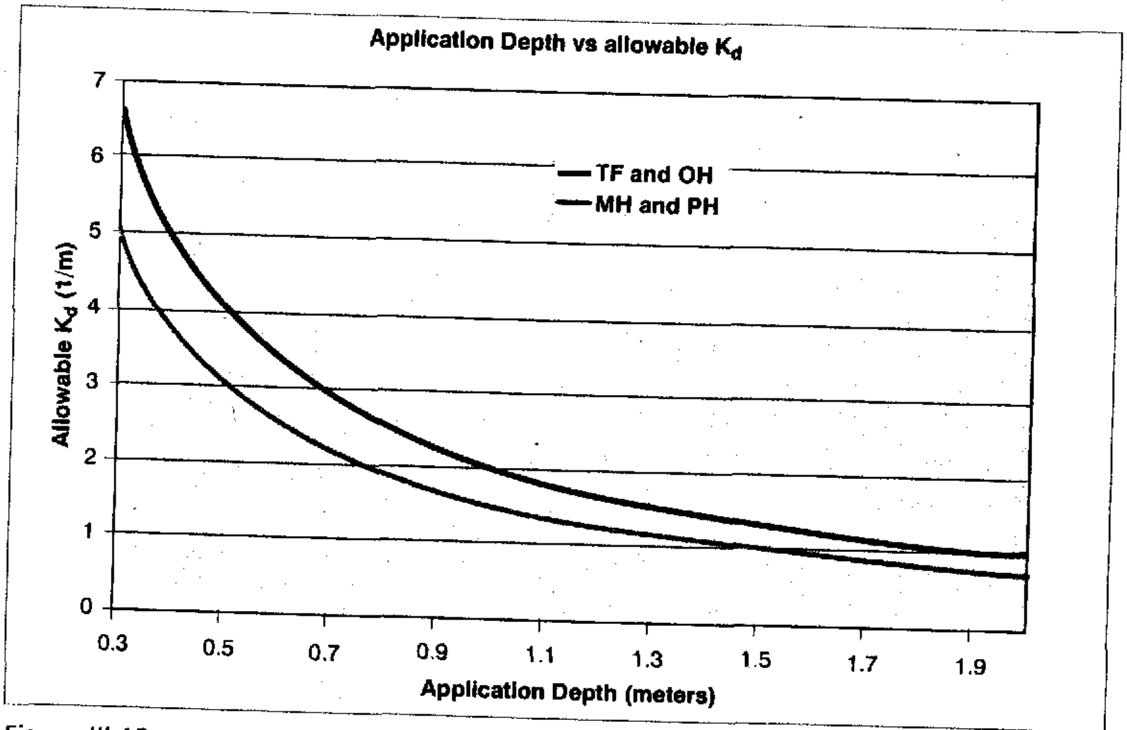


Figure III-12. Plots of equivalent 13 percent light-through-water for tidal-fresh (TF) and oligohaline (OH) SAV communities and 22 percent light-through-water for mesohaline (MH) and polyhaline (PH) SAV communities at depths between 0.3 and 2.0 meters expressed as light attenuation coefficient, or $K_d$.

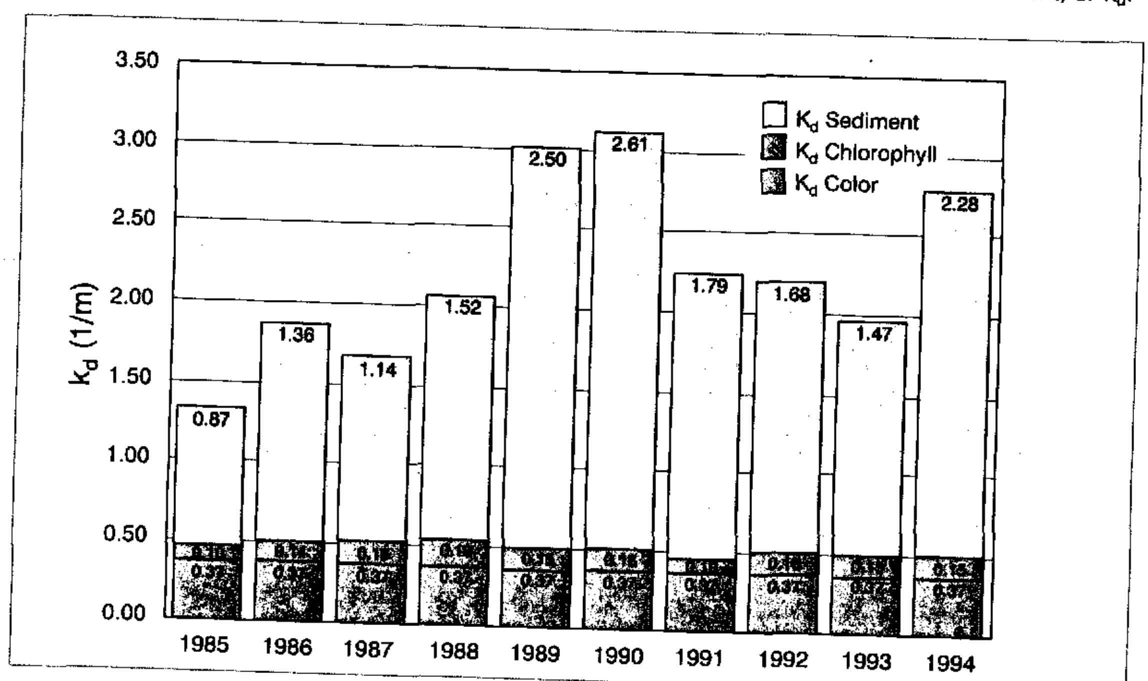


Figure III-13. Estimated average components of light attenuation ($K_d$) for the Tangier Sound monitoring station EE3.2 for the clarity criteria season (April-October) using a light attenuation model developed by Gallegos (2001).

Source: Chesapeake Bay water quality output http://www.chesapeakebay.net.

are natural conditions. Management reductions in reducing algal nutrients will reduce light attenuation from phytoplankton and epiphytes, but in Tangier Sound, as in many regions of the Bay's tidal waters, reductions in nutrients are estimated to be insufficient to improve water clarity to levels necessary to support SAV growth.

## SEDIMENT LOADS: LOCAL EFFECTS

Sediment loads and allocations are different from nutrient loads and allocations previously done by the Chesapeake Bay Program partners in that sediments are more local in their effect. Nutrient loads affect large regions of the Bay's tidal waters, as discussed above. Sediment loads in this water quality model simulation have a higher settling rate than organic material and, without simulated sediment transport, do not resuspend from the bottom.

Figure III-14 illustrates the local effect of sediment model behavior through the use of a simulated sediment load in a particular surface water quality model cell (#1720) in the Eastern Bay of the Chesapeake Bay. The simulated sediment tracer concentration was highest in the cell into which the tracer was loaded, with the concentration quickly dropping in adjacent cells. At a distance of 10 cells from the cell into which the tracer was loaded (about 10 kilometers), the tracer was no longer detectable.

These findings are consistent with monitoring and research findings of sediment behavior, with one important difference. With the current lack of a sediment transport model in the water quality simulation, once suspended sediment reaches

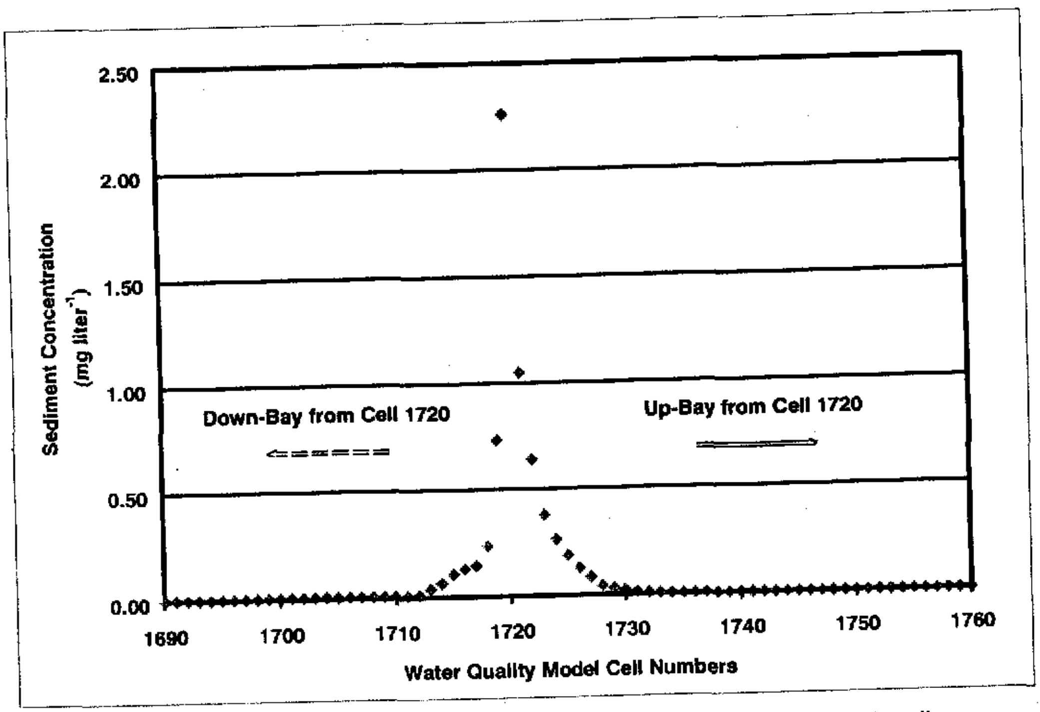


Figure III-14. Local effect of a conservative sediment tracer loaded to a single shoreline surface model cell (#1720) in Eastern Bay.

the bottom of the water column and is incorporated into the bottom sediments, it is lost from the system, as no resuspension is simulated. Work is under way to incorporate sediment transport into the simulation. A complete description of the Chesapeake Bay Water Quality Model's sediment simulation can be found in Cerco and Noel (2003).

## CALIBRATING THE WATER QUALITY MODEL FOR CLARITY

To support the development of the sediment cap load allocation, much attention was given to calibrating various components of light attenuation in the Water Quality Model. In the absence of a full sediment transport model, calibration entailed reconciling the daily Chesapeake Bay Watershed Model (Phase 4.3) sediment input loads with monitoring program estimates of suspended sediment concentrations by regionally adjusting the sediment settling rates. Further adjustment of the sediment concentrations, particularly useful for the calibration of sediment in bottom waters and in turbidity maximum zones, used differential settling rates in the water column and in the sediment bed. The settling rate of sediment in the water column was set at a higher rate than that of sediment bed incorporation to factor in the potential for resuspension of accumulated sediment in the bottom model cells. Figure III-15 is an example of the resulting calibration in upper Chesapeake Bay mainstem segment CB2OH surface waters and is representative of a single monitoring station calibration in comparison with model estimates of the few associated model cells at the monitoring station CB2.2 location. Full calibration results for sediment, chlorophyll and light attenuation are documented in Cerco and Noel (2003) and further documented in http://www.chesapeakebay.net/modsc.htm.

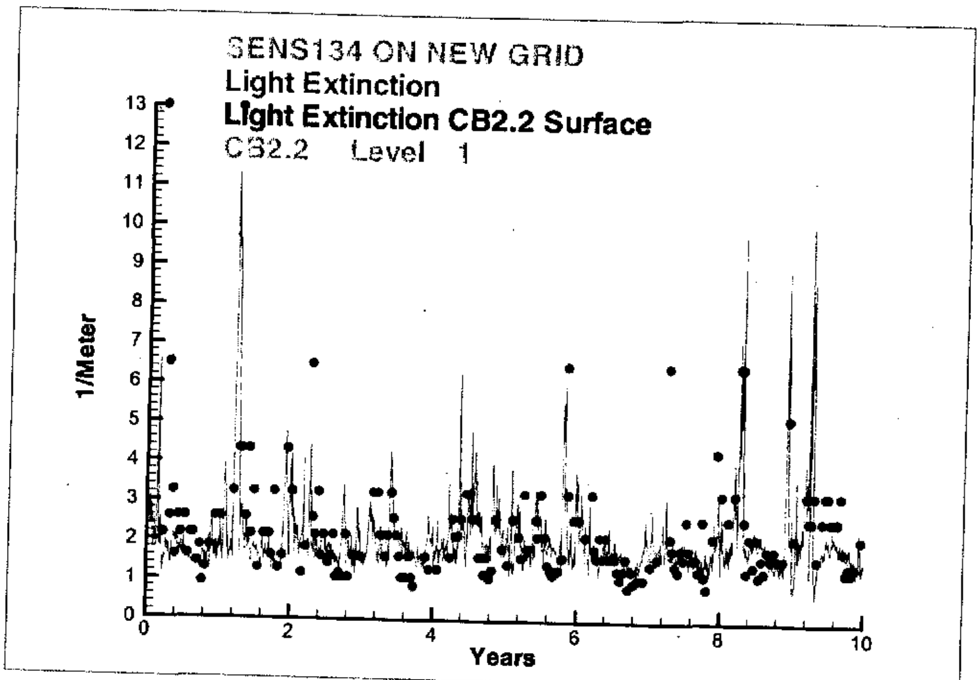


Figure III-15. Time series plot of model simulated light attenuation (solid line) and modeling program observed (circles) for a single monitoring station, CB2.2, compared to a single surface model cell. The time series extends from January 1985 to December 1994.

While calibration of light attenuation was necessarily at the location of the long-term monitoring stations, these stations are typically located in deeper waters and away from shallow-water SAV habitats. Shallow regions, located at the interface of the watershed and the tidal Bay, are at the 'point of discharge' of all sediment loads from the adjacent watershed, shore erosion and shallow-water resuspension and generally have less clarity than that found in the traditional deep-water monitoring stations. Figure III-16 shows the relative difference of $K_d$ model estimates for the shallows and deep waters of the Chesapeake Bay. Typically, the simulation estimates that the

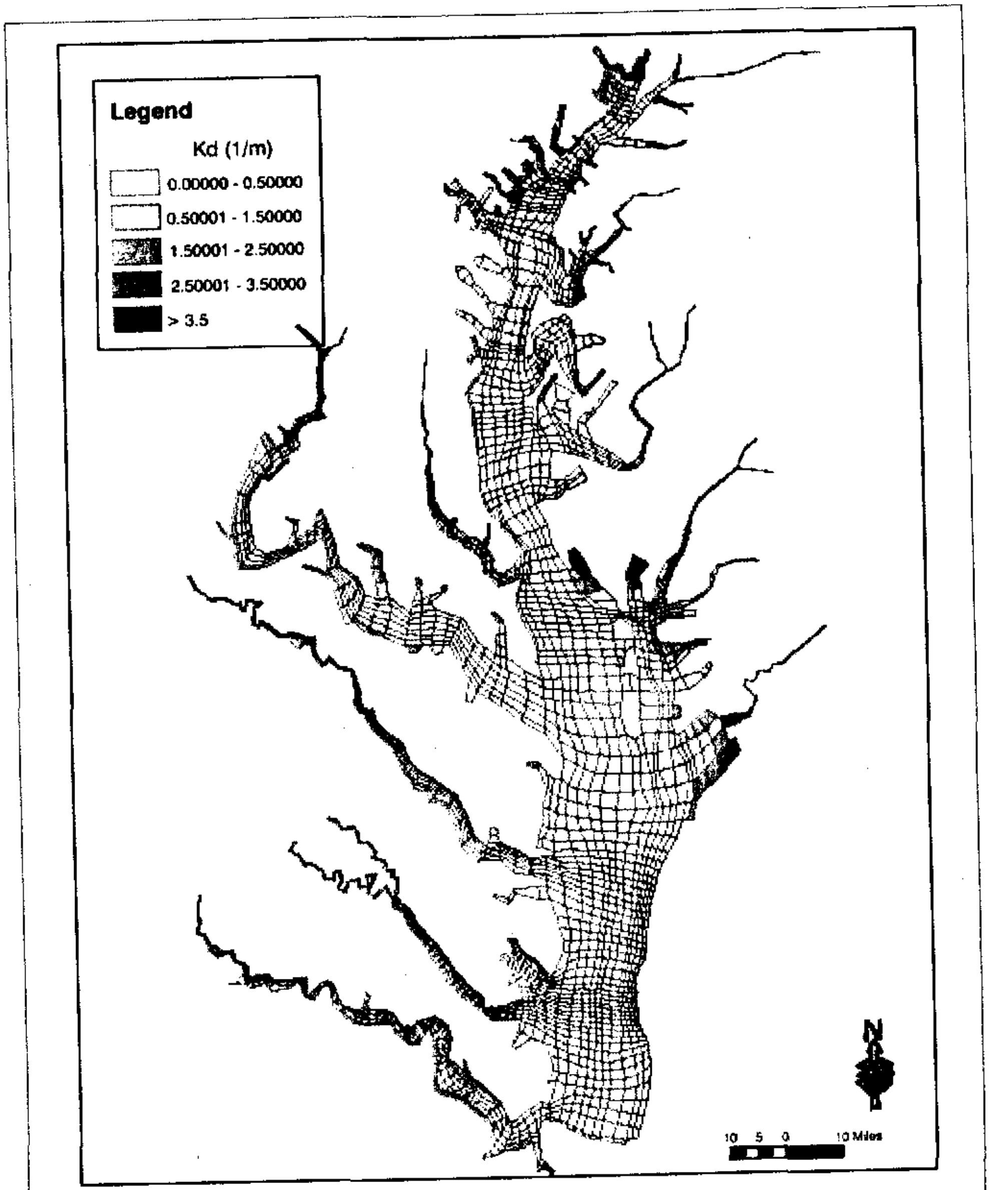


Figure III-16. Chesapeake Bay Water Quality Model estimated light attenuation ($K_d$) showing greater light attenuation in the shallows than in the deeper waters of the Chesapeake Bay and its tidal tributaries due to the local influence of sediment loads from the adjacent watershed and shoreline (units are meter$^{-1}$).

shallows have an attenuation rate two times greater than that of deeper waters, a finding consistent with monitoring program observations.

To address the difference between light attenuation estimates in shallow and deep waters, the monitoring program initiated a long-term shallow-water monitoring assessment in 2003. With information from new and existing monitoring assessments and research into sediment processes and transport, the Water Quality Model will be refined with an explicit sediment transport simulation by 2007, in time to support the reevaluation of the nutrient and sediment allocations.

## RELATING SAV BIOMASS TO ACREAGE

SAV abundance has been assessed by aerial surveys from 1984-2000, usually flown once annually at the time of estimated peak abundance (Moore et al. 2000). Area is related to abundance of SAV through density and biomass, that is, the area of SAV coverage increases as either density deceases or biomass increases, all else being the same. Further, changes in area may not be linear with changes in biomass. For these reasons, biomass has been described as a better measure of abundance than area, and biomass is the key SAV metric simulated by the Chesapeake Bay Water Quality Model. On the other hand, aerial surveys of SAV area are cost-effective, and the public goal of SAV restoration to an established acreage is a straightforward message to communicate to the public. For these reasons alone the aerial surveys of SAV have been, and will continue to be, the basis for abundance estimates of SAV in the Chesapeake Bay, augmented by associated estimates of SAV biomass.

The model structure of simulating a 'unit plant' of SAV within the larger water quality context of the Water Quality Model (Cerco et al. 2002; Cerco and Moore 2001) generates biomass estimates of SAV. Obviously, the first step in relating the SAV restoration goal and the sediment cap load allocations estimated in the model is the reconciliation of the acreage and biomass estimates. Fundamental to this reconciliation is the work done by Moore et al. (2000). Building on this approach, the Chesapeake Bay Program partners used the Water Quality Model estimates of SAV biomass to derive SAV acreage estimates (Cerco et al. 2003). The essence of using the model estimates of biomass relies on the simple assumption that SAV density does not change in the model scenarios. Then model estimates of SAV area can be determined by the simple relationship:

SAV Acres = (SAV biomass scenario/SAV biomass calibration) * acres SAV observed 1985-1994

As the calibration relates the SAV biomass to estimated SAV area over the 10-year period of 1985-1994, and further as the scenarios relate a relative change in SAV due to changes in nutrient or sediment loads, the relationship above provides a reasonable estimate of SAV area for any scenario.

SAV biomass varies over the growing season as shown in figures III-17 through III-19. Aerial estimates of SAV abundance are taken once during the year at about the time of peak biomass, generally in the late summer for oligohaline and mesohaline regions, and in the late spring or early summer for the polyhaline regions (Moore et al. 2000). To coordinate the observed peak abundance estimates with model-simulated estimates of SAV, July averaged simulated SAV biomass was used throughout, except

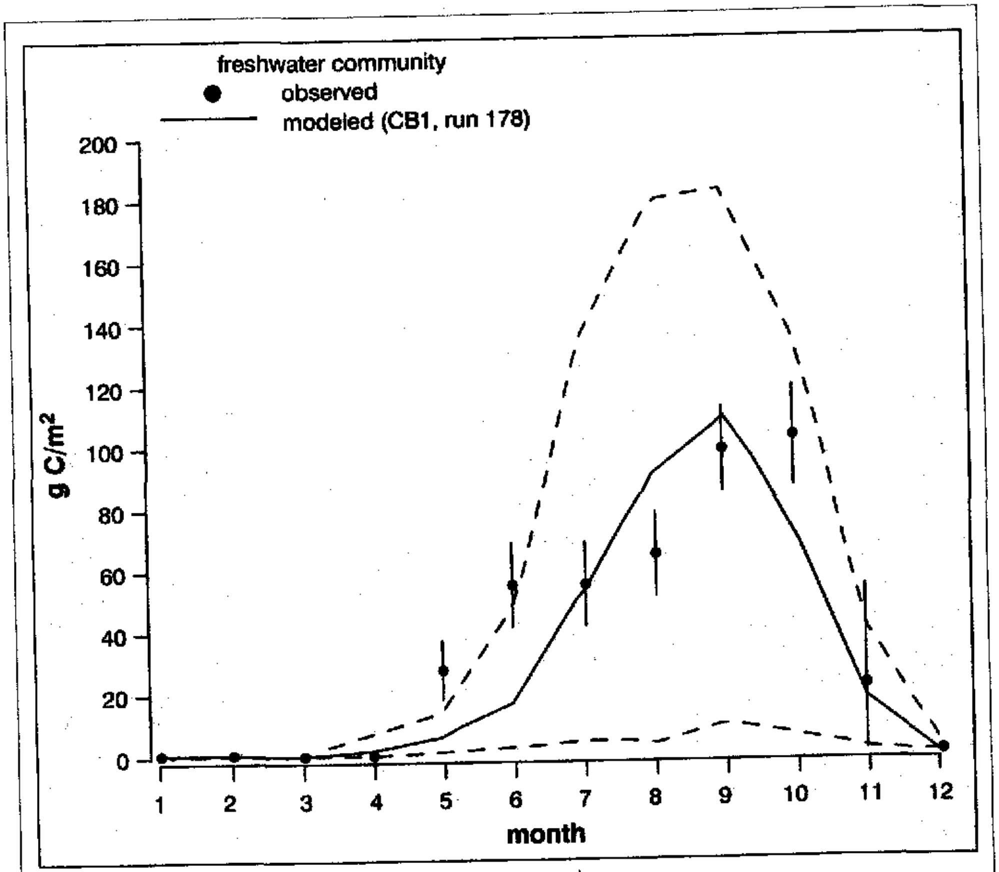


Figure III-17. Modeled (mean [solid line] and interval encompassing 95 percent of computations [dashed line]) and observed (mean [dot] and 95 percent confidence interval [vertical line through dot]) freshwater SAV community (above ground shoot biomass only). Observations from Moore et al. (2000). Model simulation from the Susquehanna Flats (Segment CB1TF) using the 10,000-cell 1998 version of the Water Quality Model.

Source: Cerco et al. 2002.

for tidal-fresh regions, which use a September averaged biomass. The *monthly* peak average is typically about three times higher than the annual average biomass.

In relating the SAV restoration goal to the sediment cap load allocations, two factors needed to be considered in determining the scale at which SAV estimates will be made. In assessing SAV biomass: 1) sediment cap loads, like nutrients, are allocated at the major basin level; and 2) sediment is not transported far from its discharge point, which is usually a fall line or shoreline, due to relatively rapid settling. Accordingly, the tidal Bay shorelines and adjacent shallow-water habitats were apportioned into SAV regions associated with major tributary basins—the Susquehanna, Patuxent, Potomac, Rappahannock, York, James, Western Shore, Eastern Shore Maryland/Delaware and Eastern Shore Virginia. The Potomac basin was further divided into Maryland, Virginia and the District of Columbia. A major portion of the Susquehanna Flats (CB1TF) was assigned to the Susquehanna basin, which is considered the primary influence. The Northeast, Elk, Bohemia and

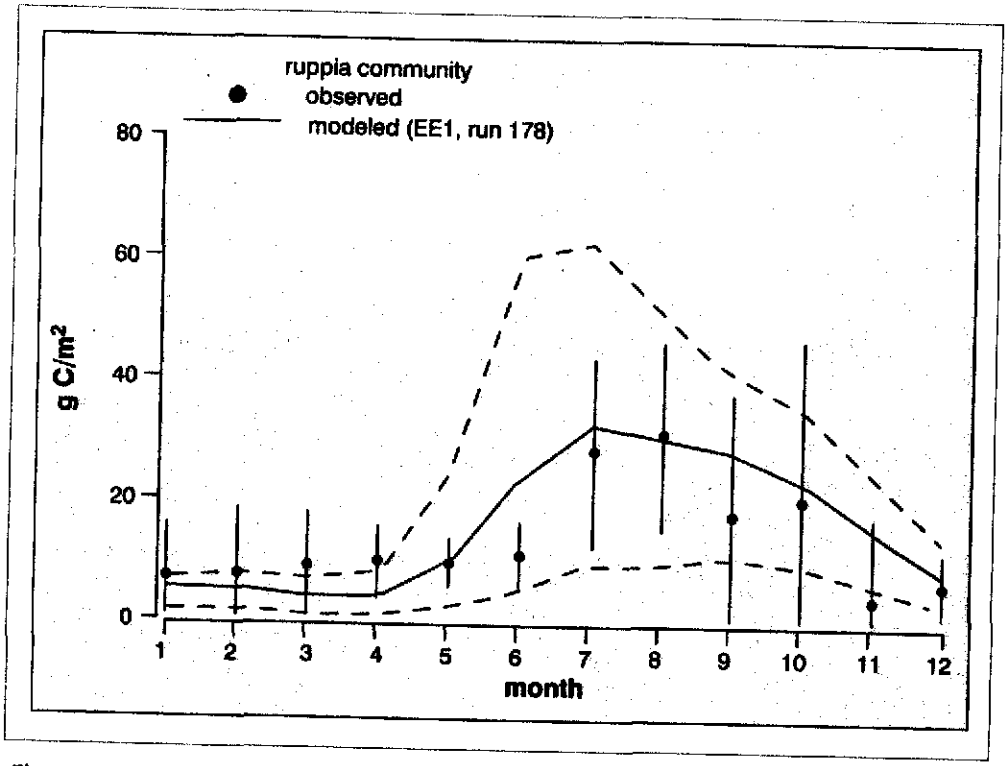


Figure III-18. Modeled (mean [solid line] and interval encompassing 95 percent of computations [dashed line]) and observed (mean [dot] and 95 percent confidence interval [vertical line through dot]) mesohaline SAV community (*Ruppia*, above ground shoot biomass only). Observations from Moore et al. (2000). Model simulation from Eastern Bay using the 10,000-cell 1998 version of the Chesapeake Bay Water Quality Model.

Source: Cerco et al. 2002.

Sassafras rivers, though part of CB1TF, were assigned to the Eastern Shore Maryland/Delaware basin (Figure III-20).

Model estimates of the SAV response under different management scenarios were estimated with two metrics, an SAV single-best-year estimate and an SAV running-three-year, single-best-year mean estimate. The single-best-year estimate is an estimate of the highest annual SAV biomass throughout the simulated hydrology period of the 1985-1994. The single-best-year estimate most closely resembles the new SAV restoration, in that the highest annual biomass is used for the entire simulation period. The SAV running-three-year, single-best-year mean estimate is a mean of the best year estimates of the eight three-year periods that the 1985-1994 simulation can be parsed into (1985-1987, 1986-1988, 1987-1989, etc.) The SAV running-three-year, single-best-year mean and standard deviation is the best *a priori* estimate of SAV biomass that will be ultimately be assessed through the monitoring program as described below. Taken together these two estimates provide an estimate of the greatest SAV response over a 10-year simulated hydrology and the estimated variation in SAV biomass over the period (tables III-3 and III-4). To further differentiate the SAV response in the major basins, the major fall line load regions where split into a tidal-fresh (TF) and a lower tidal river region. The Susquehanna SAV

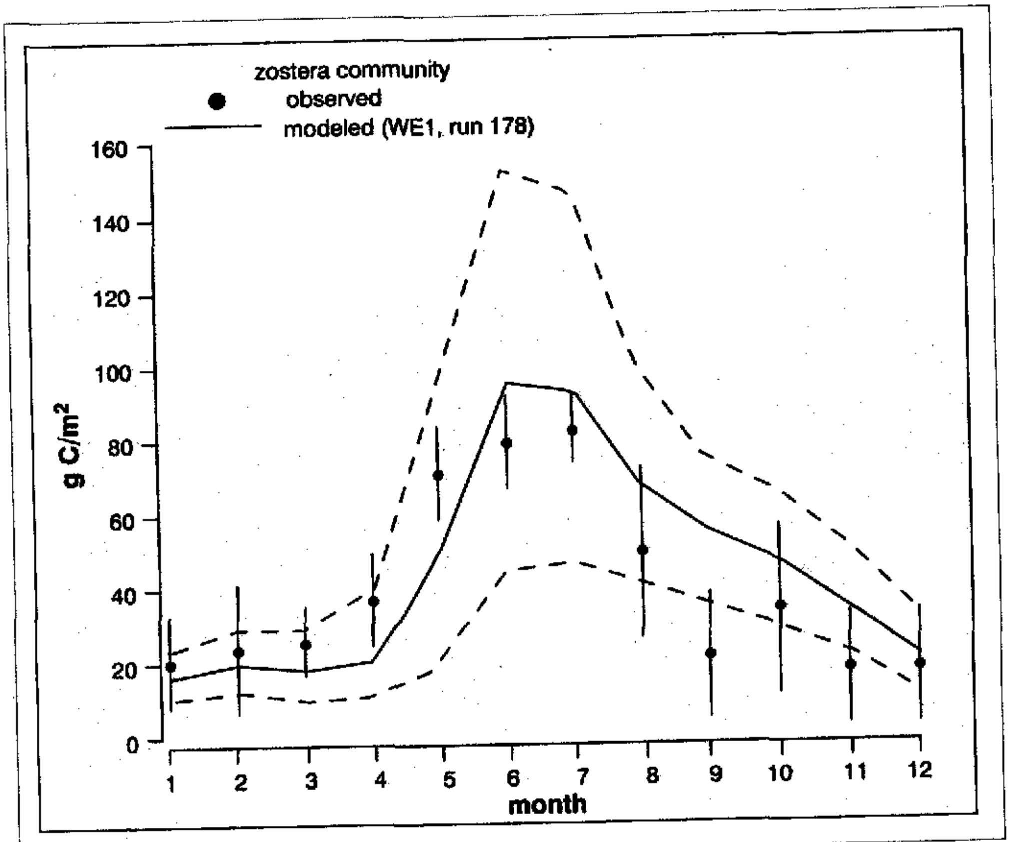


Figure III-19. Modeled (mean [solid line] and interval encompassing 95 percent of computations [dashed line]) and observed (mean [dot] and 95 percent confidence interval [vertical line through dot]) polyhaline SAV community (*Zostera* above ground shoot biomass only). Observations from Moore et al. (2000). Model simulation from the Mobjack Bay (segment MOBPH, formerly WE4) using the 10,000-cell 1998 version of the Chesapeake Bay Water Quality Model.

Source: Cerco et al. 2002.

response is represented as the SAV response of the Susquehanna Flats in the upper tidal-fresh Chesapeake Bay.

Under all scenarios, the lower Rappahannock and the tidal-fresh James rivers did not meet the C2K SAV acreage restoration goal, as the simulated SAV area in response to the scenario load reductions was much less than the estimates of SAV historic acreage that forms the basis of the 185,000-acre SAV restoration goal. The Patuxent and Rappahannock tidal-fresh estimates of SAV area show an initial drop in SAV acreage between the 2000 Progress and Tier 3 scenarios. In both cases this counter-intuitive response is due to a decrease in sediment loads causing an increase in light through the water column, resulting in greater algal biomass and a simulated poorer habitat for SAV. Further reductions past Tier 3 show increasing SAV response to decreasing loads. The standard deviation is in many cases greater than the mean, particularly in regions of the Bay where SAV acreage is sparse, indicating the high variability in year-to-year SAV area.

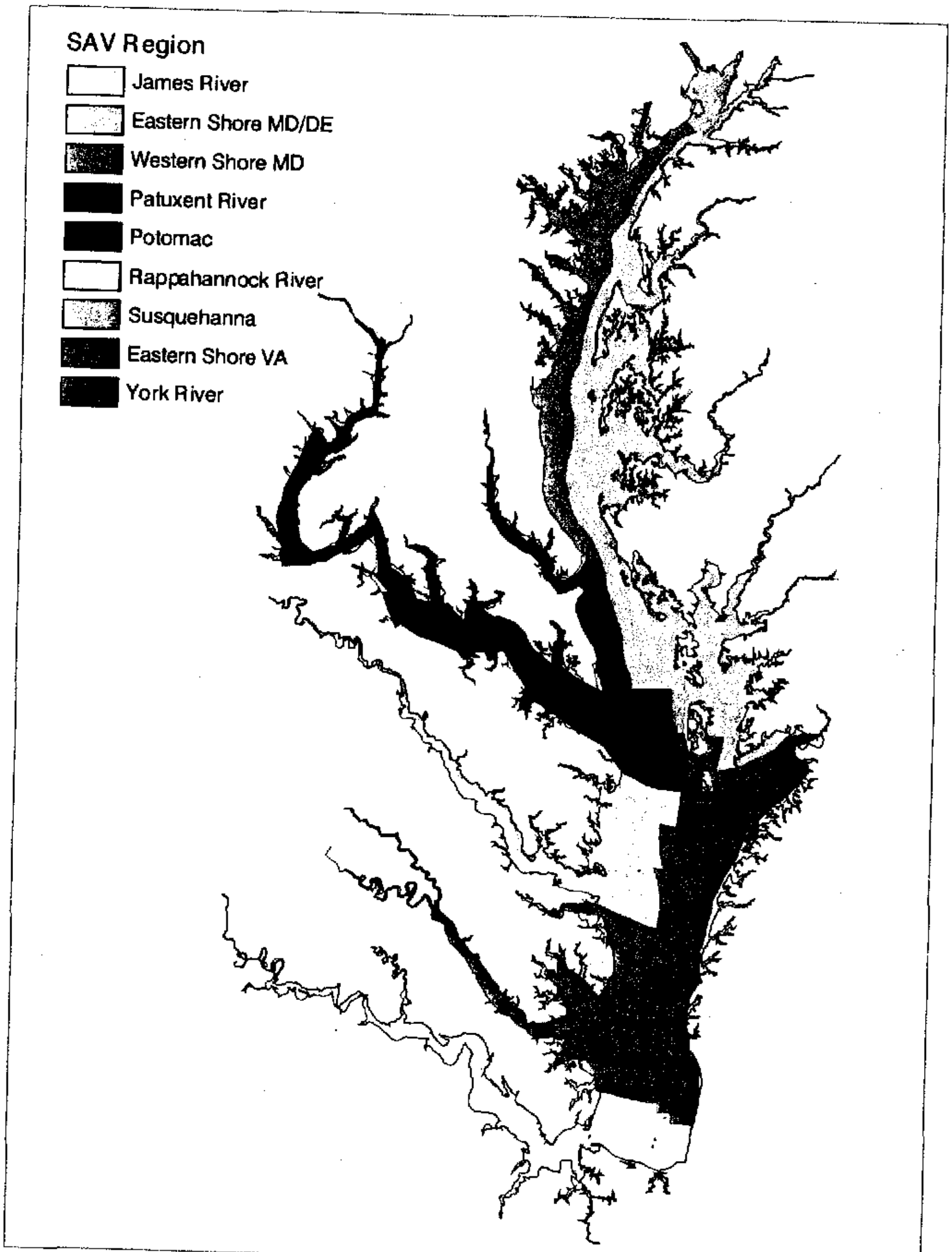


Figure III-20. SAV regions associated with the major Chesapeake Bay tributary basins.

## SPATIAL ANALYSIS OF EFFECTIVE SHORELINE LOAD REDUCTIONS

Sediment reductions from the watershed alone are estimated to be insufficient for full SAV recovery to the 185,000-acre SAV restoration goal. Additional reductions in shoreline loads including shoreline erosion loads and resuspension were simulated for key scenarios. In tables III-3 and III-4, two scenarios are simulated with an additional

Table III-3. Single-best-year estimate of SAV area under key management scenarios. Meets CBP goal = the original 1992 SAV restoration goal of 113,000 acres. Meets *Chesapeake 2000* goal = the new SAV restoration goal of 185,000 acres.

| | SAV Acreage | | | | | |
|---|---|---|---|---|---|---|
| | **2000 Progress** | **Tier 3** | **Tier 3 +20%** | **Scenario 175** | **CBP Goal** | **C2K Goal** |
| Susquehanna | 13171 | 20400 | 20400 | 20400 | 7620 | 12856 |
| Western Shore MD | 4522 | 4978 | 6453 | 6418 | 3710 | 5652 |
| Patuxent TF | 142 | 85 | 88 | 198 | 14 | 5 |
| Patuxent Lower | 209 | 276 | 745 | 772 | 451 | 1420 |
| Potomac TF | 6278 | 8768 | 12618 | 12842 | 7374 | 5438 |
| Potomac Lower | 7611 | 7976 | 10072 | 9751 | 5244 | 14017 |
| Rappahannock TF | 48 | 29 | 45 | 45 | 0 | 20 |
| Rappahannock Lower | 2927 | 3203 | 3539 | 3527 | 5376 | 12778 |
| York TF | 1734 | 2173 | 4298 | 4857 | 0 | 231 |
| York Lower | 15995 | 17848 | 20726 | 20408 | 18347 | 21592 |
| James TF | 136 | 313 | 580 | 552 | 0 | 1944 |
| James Lower | 656 | 746 | 983 | 838 | 441 | 1593 |
| Eastern Shore MD/DE | 33765 | 40970 | 54819 | 54475 | 42280 | 77706 |
| Eastern Shore VA | 21281 | 22747 | 26267 | 28518 | 22818 | 29702 |
| TOTAL | 108475 | 130512 | 161633 | 163601 | 113675 | 184954 |

Scenario 175 = nutrient and sediment cap load allocations

Scenario 175 meets original 1992 CBP SAV restoration goal

Scenario 175 meets *Chesapeake 2000* (C2K) SAV restoration goal

20 percent reduction in the base shoreline loads representing BMPs, which reduce shoreline erosion or sediment resuspension[1]. In many regions of the Chesapeake Bay, particularly those with extensive shorelines, the 20 percent shoreline load reduction resulted in a significant improvement in shallow-water water clarity and in SAV.

To further refine where the shoreline loads should be applied, an analysis was conducted to determine where any historical SAV occurred and map the adjacent shoreline. The identified shoreline was considered to be that where shoreline reductions would be effective for improving SAV habitat. An arbitrary 0.5-kilometer buffer was extended along the shoreline beyond the SAV areas as a further protection of SAV habitat. The combined shoreline adjacent to any historical SAV occurrence and the 0.5-kilometer buffer of shoreline was called the 'effective shoreline'.

The percent of effective shoreline varied from basin to basin ranging from a low of 16 percent in the James River to an effective shoreline of 73 percent in the Potomac River

[1]Information was presented to the partners that a 20 percent reduction in base shoreline loads may be beyond present technical feasibility. However, sufficient information was not available to reach a definitive conclusion at that time.

Table III-4. Mean and standard deviation of the estimated running-three-year, single-best-year SAV area under key management scenarios. Meets CBP goal = the original 1992 SAV restoration goal of 113,000 acres. Meets *Chesapeake 2000* goal = the new SAV restoration goal of 185,000 acres.

**SAV Acreage Calculation Using Running-Three-Year SBY Mean and Standard Deviation**

| | 2000 Progress | | Tier 3 | | T3+20% | | Scenario 175 | | Goals | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | Mean | Std. Dev. | CBP | C2K |
| Susquehanna | 10,149 | 1,546 | 20,400 | 4,777 | 20,400 | 5,348 | 20,400 | 5,507 | 7,620 | 12,856 |
| Western Shore MD | 1,375 | 1,509 | 1,514 | 1,661 | 1,962 | 2,153 | 1,951 | 2,141 | 3,710 | 5,652 |
| Patuxent TF | 66 | 65 | 40 | 39 | 41 | 40 | 92 | 91 | 14 | 5 |
| Patuxent Lower | 104 | 67 | 137 | 89 | 369 | 240 | 382 | 249 | 451 | 1,420 |
| Potomac TF | 4,750 | 1,197 | 6,633 | 1,672 | 9,546 | 2,406 | 9,716 | 2,449 | 7,374 | 5,438 |
| Potomac Lower | 5,027 | 1,697 | 5,268 | 1,778 | 6,652 | 2,245 | 6,440 | 2,173 | 5,244 | 14,017 |
| Rappahannock TF | 8 | 16 | 5 | 10 | 8 | 15 | 8 | 16 | - | 19.7 |
| Rappahannock Lower | 2,469 | 470 | 2,702 | 514 | 2,986 | 568 | 2,975 | 566 | 5,376 | 12,778 |
| York TF | 372 | 739 | 466 | 925 | 921 | 1,830 | 1,041 | 2,068 | 0 | 231 |
| York Lower | 14,271 | 1,902 | 15,925 | 2,122 | 18,493 | 2,465 | 18,209 | 2,427 | 18,347 | 21,592 |
| James TF | 29 | 58 | 67 | 133 | 124 | 247 | 118 | 235 | 0 | 1,943.60 |
| James Lower | 245 | 227 | 279 | 258 | 368 | 340 | 313 | 290 | 441 | 1,593 |
| Eastern Shore MD/DE | 28,284 | 4,304 | 34,320 | 5,222 | 45,921 | 6,988 | 45,633 | 6,944 | 42,280 | 77,706 |
| Eastern Shore VA | 18,667 | 1,951 | 19,953 | 2,085 | 23,041 | 2,408 | 25,015 | 2,614 | 22,818 | 29,702 |
| TOTAL | 85,816 | | 107,709 | | 130,832 | | 132,293 | | 113,675 | 184,953 |

Scenario 175 = nutrient and sediment cap load allocations

☐ Scenario 175 meets original 1992 CBP SAV restoration goal

☐ Scenario 175 meets *Chesapeake 2000* (C2K) SAV restoration goal

(Figure III-21). In scenarios in which reductions in the base shoreline loads were reduced, these reductions were universally applied to all base shoreline loads. Using the estimated effective shoreline estimates, the shoreline length to be considered for BMPs is considerably reduced (Figure III-22).

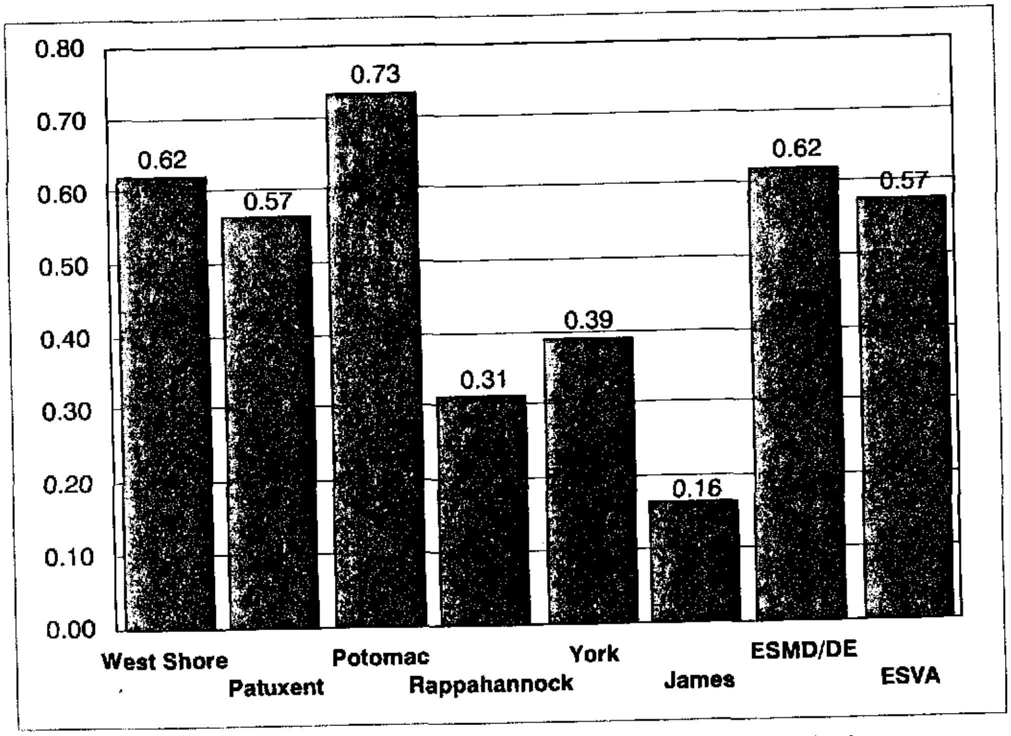


Figure III-21. Estimated effective shoreline for the major Chesapeake Bay basins.

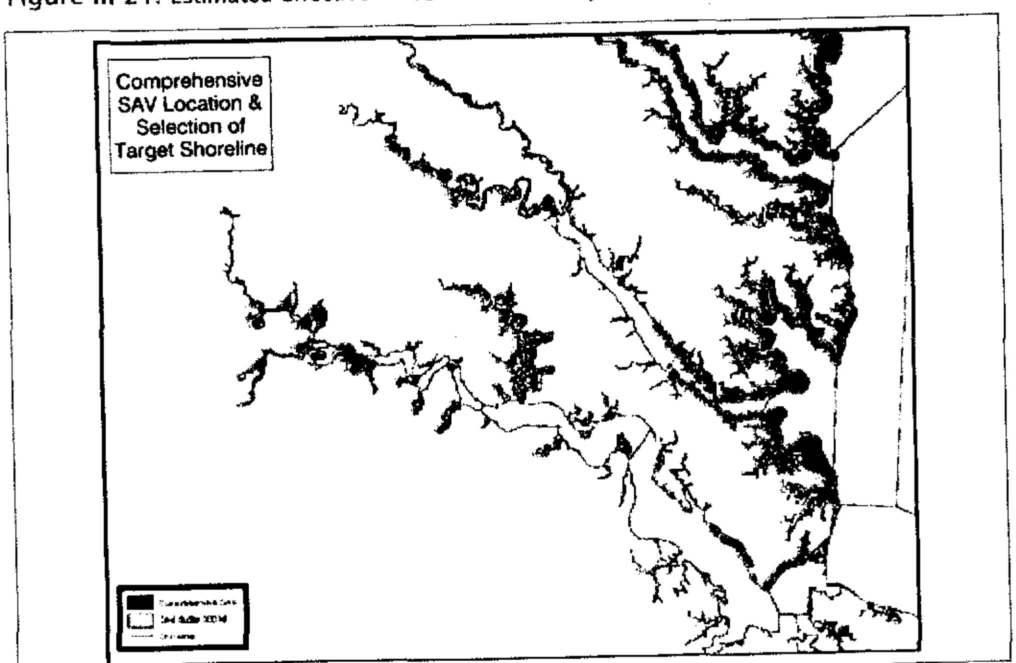


Figure III-22. Effective shoreline regions of the James, York and lower Rappahannock basins.

## MONITORING APPROACH

The Chesapeake Bay Program partners agreed to measure the achievement of the SAV restoration goal at the segment scale based on the single best year of a running three-year assessment to account for year-to-year fluctuations in water clarity due to changing hydrology and loads (U.S. EPA 2003a). To ensure consistency between metrics used to derive the cap load allocations and measure attainment, model-simulated SAV acreages were assessed using the single best year of a running three-year assessment period. The model estimates from the 10-year average estimate were matched with running three-year single-best-year estimates and formed the basis of the final model estimates of SAV under the different scenario assumptions as shown in tables III-3 and III-4.

## SEDIMENT CAP LOAD ALLOCATION PRINCIPLES

The principles applied in developing the sediment cap load allocations were as follows:

1. SAV habitat and the sediment allocation are linked and the primary reason for reducing sediment loads is to provide suitable habitat for SAV;
2. Sediment impacts, unlike those of nutrients, are local in their influence; and
3. The analysis and effects of nutrients on dissolved oxygen is well developed and understood, but the analysis of sediment loads and water quality effects is incomplete.

With these principals in mind, the Chesapeake Bay Program partners agreed to include the SAV goals into water quality standards. The local nature of the effects of sediment loads is reflected in the assignment of SAV goals to each Chesapeake Bay Program segment. It was decided that either the SAV acreage goal or the clarity goal would be used to assess attainment, through detailed monitoring assessments. If the SAV goal is not achieved with the nutrient and sediment allocations in place, additional innovative methods to achieve SAV regrowth, such as SAV planting, offshore breakwaters, shore erosion controls and other methods will be applied. The incomplete understanding of shoreline loads from shoreline erosion and resuspension led the partners to decide to allocate sediment load reductions to the land-based sediment loads.

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chapter iv

# Setting Nutrient and Sediment Allocations

This chapter describes the specific processes involved in deriving and allocating the cap loads for nutrients and sediments. While many alternative processes were explored, only the process ultimately agreed to and followed by the partners is described. The processes for deriving sediment and nutrient cap load allocations are distinct and are described separately in this chapter.

To establish cap load allocations for nutrients, the following steps were taken:

- A basinwide loading cap was established, which required identifying a baywide load that would meet the dissolved oxygen criteria throughout the Bay. The sections *Geographic Location and Criterion Driving the Allocation* and *Baywide Cap Loading Options* below, respectively, identifies the parts of the Bay's tidal waters and the criteria that were most critical to establishing a baywide allocation and presents the cap options that the Chesapeake Bay Water Quality Steering Committee explored.
- The baywide nutrient cap loads were distributed among the basins and jurisdictions. The section *Distributing Basinwide Allocations to Major Basins and Jurisdictions* below (page 91) describes the principles, decision rules and processes used to distribute the cap loading to the basins and jurisdictions.
- The initial process did not result in sufficient nutrient reductions to achieve the baywide cap loads. As described in the section *The PSC Completes the Allocation Process* below (page 99), it was necessary to have input from the Principals' Staff Committee and headwater state representatives to complete the allocations.
- The dissolved oxygen-based nutrient allocations were examined to ensure that they resolved any remaining chlorophyll *a* problems. The brief section *Cap Load Allocations to Achieve the Chlorophyll* a *Criteria* below (page 99) reviews the results of this analysis.

To establish allocations for sediments, the following steps were taken:

- SAV restoration goals were set and used to derive the sediment cap load allocations. The section *SAV Restoration as the Goal* below (page 103) explains why the SAV restoration goals were used in the sediment cap load allocation process.
- Sediment loadings were divided into two major source categories: upland loads (page 104) and near-shore loads (page 105).
- Sediment allocations were set. The section *SAV-Based Sediment Allocations* below (page 106) describes the scientific and policy bases for that process.

The mathematical models described in Chapter II were used to identify the sources of pollutant loadings and relate reductions in those loading sources to attainment of the Chesapeake Bay water quality criteria and restoration of underwater bay grasses, or SAV. While these models provided a good understanding of projected water quality effects from pollutant source reductions, policy decisions were necessary to derive an equitable distribution of the allocated load.

Chapter III describes many of the technical issues that had to be resolved before the allocations could be derived. The technical methods and policy decisions that led to the nutrient cap load allocations are discussed below. Because these methods and decisions differed from those used to develop sediment allocations, the processes for deriving each are described in separate sections.

## ESTABLISHING NUTRIENT CAP LOAD ALLOCATIONS

Three steps were involved in setting and allocating allowable caps on nutrient loads throughout the Chesapeake Bay watershed that, collectively, would restore Chesapeake Bay and tidal tributary water quality:

1. The basinwide caps on nitrogen and phosphorus loads necessary to attain the Bay criteria for dissolved oxygen through all tidal Bay habitats were determined;
2. The loading caps were distributed among the major tributary basins by jurisdiction; and
3. Care was taken to ensure that the dissolved oxygen-based nutrient cap load allocations would also bring the Chesapeake Bay and its tidal tributaries into attainment with the chlorophyll *a* criteria.

### GEOGRAPHIC LOCATION AND CRITERION DRIVING THE ALLOCATIONS

Early in the process of developing nutrient allocations, there was a question as to whether there was a geographic location in the Chesapeake Bay tidal waters and a criterion (dissolved oxygen or chlorophyll *a*) that would drive the nutrient cap load allocations. If such factors converged, then analyses could be focused on that location and that criterion in deriving nutrient cap load allocations. Also, if the cap load allocations eliminated the water quality impairment at that point, then they would likely eliminate all other impairments related to nutrients across all other tidal water habitats. To explore this issue, the modeled water quality predictions were reviewed (see Appendix D for modeled water quality results of various loading scenarios).

The water quality results from 'Tier 3 plus 20 percent near-shore reductions' were used in this analysis because they constituted the likeliest allocation scenario. The following observations can be made:

- For dissolved oxygen, the migratory spawning and nursery and open-water criteria have a high level of attainment under current observed conditions.
- For dissolved oxygen, significant nonattainment is shown for the Pamunkey and Mattaponi rivers. This nonattainment is observed under all loading scenarios

because it is due to natural conditions (extensive tidal wetlands resulting in natural oxygen consuming processes) and for this reason is not considered in establishing the allocations for nutrients. Chapter 5 of the *Technical Support Document* (U.S. EPA 2003b) addresses this issue in greater detail.

- For dissolved oxygen, nonattainment of the water quality criteria was highest in the deep-water portions of the middle Chesapeake Bay mainstem (segments CB3MH, CB4MH and CB5MH). It should be noted that the deep-water criteria only apply in summer, from June through September.
- For chlorophyll *a*, the Chesapeake Bay and its tidal tributaries achieve a set of numerical target concentrations except for a limited set of local areas.

These observations suggested that if the nutrient allocations were established to achieve the dissolved oxygen criteria in the deep-water portions of segments CB3MH, CB4MH and CB5MH, then all other impairments for dissolved oxygen and chlorophyll *a* would most likely be corrected (see Chapter III for details).

## BAYWIDE CAP LOADING OPTIONS

Having established the importance of correcting dissolved oxygen nonattainment in the deep-water portions of segments CB3MH, CB4MH and CB5MH, it was considered important to explore various baywide nutrient cap load options and their water quality effects on these segments.

Chapter III discusses the development of various management control scenarios, or tiers, that were used for deriving the cap load allocations. The tier scenarios were based on increasing point and nonpoint source controls throughout the Chesapeake Bay watershed. The loads delivered to tidal waters as a result of each of these control scenarios were then derived through the watershed model. This control scenario approach was considered superior to a straight percent reduction approach because:

- The tier scenarios provide a sense of the actual point and nonpoint technology necessary to achieve the loadings; and
- Costs for tier scenarios can be estimated for use in use attainability analyses.

### Five Options Explored

Ultimately, five bay nutrient cap load options, based largely on the tier approach, were explored. These options, and the model projections of the water quality response to them, are explained below and are further described in tables IV-1 and IV-2.

***Option 1: Nitrogen load capped at 160 million pounds per year, phosphorus load capped at 12.8 million pounds per year.*** This option was actually a model simulation that had been run and resulted in full attainment of the bay dissolved oxygen criteria.[1] Therefore it represented the lowest end of basinwide cap loads under consideration. While this option resulted in attainment, it was unknown at the time whether higher loading options would also result in attainment.

[1]The final water quality model results for Option 1 showed a small degree of nonattainment due to changes (agreed to by the partners) in how the deep-water and deep-channel dissolved oxygen criteria would be applied.

***Option 2: Nitrogen load capped at 175 million pounds per year, phosphorus load capped at 12.6 million pounds per year.*** This option, which considers all but the deep-water portion of segment CB4MH, was developed acknowledging that attainment of the dissolved oxygen criteria in deep-water portion of segment CB4MH is difficult. While the total loading under this option is not much different from Option 3 (5 million pounds nitrogen and 0.8 million pounds phosphorus less), the critical difference is the geographic distribution of the cap loadings. The cap loads for Option 3, compared with this Option, are higher for the northern tributaries (where additional reductions improve the Bay's water quality) with lower cap loads in the southern tributaries (where the impact of loads on Bay water quality is much less).

***Option 3: Nitrogen load capped at 181 million pounds per year, phosphorus load capped at 13.4 million pounds per year.*** This option represented the application of the Tier 3 level of controls across all major tributary basins. It was considered viable because it was perceived at the time as an equitable (all basins at Tier 3) and feasible allocation by the Water Quality Technical Workgroup and the Water Quality Steering Committee.

***Option 4: Nitrogen load capped at 188 million pounds per year, phosphorus load capped at 13.3 million pounds per year.*** This option was created as an alternative to Option 3, after recognizing that Virginia's lower western shore tidal tributary basins had a much lower effect on the dissolved oxygen depletion in the middle mainstem Chesapeake Bay than the Potomac, eastern shore and northern western shore tidal tributary basins. The nutrient cap loads for the Rappahannock, York and James basins were set to their existing tributary strategy levels of nutrient reductions. This option was established to determine if similar water quality results to Option 3 can be gained, despite the higher loading, at a lower cost to the lower western shore Virginia tributaries.

***Option 5: Nitrogen load capped at 198 million pounds per year, phosphorus load capped at 15.7 million pounds per year.*** Like Option 4, Option 5 is predominantly based on Tier 3 levels. However, the three lower Virginia western shore tributary basins' cap loads were increased to year 2000 progress levels. Again, this option was explored because it was known from previous Bay water quality model scenarios that these three tributary basins had less impact on the water quality of the Chesapeake Bay than the eastern shore and northern western shore tributaries. Like Option 4, the partners wanted to explore whether Option 5 would provide water quality results similar to Option 3, despite the higher loading, at less cost for the lower western shore Virginia tributaries.

Although the five options focused on assessing the effects of nutrient reductions on the Chesapeake Bay and its tidal tributaries, it was necessary for them to be applicable to subsequent sediment allocations as well. Therefore, each option included a 20 percent reduction in near-shore sediment loads.

The five options were intended to derive a basinwide loading cap for nutrients. At the same time, these options not only consisted of different basinwide cap loadings but also different geographical distributions of those nutrient cap loadings to the major tributary basins. For distributing the loading to individual basins, however, a more deliberate approach was necessary. Discussed later in this chapter, the approach was based on three underlying principles that sought to assure that the allocation process was both equitable and feasible.

Table IV-1. Basinwide nitrogen cap load options (million pounds per year) developed by the Water Quality Technical Workgroup, broken down by major tributary basin.

| Basin | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 |
|---|---|---|---|---|---|
| Susquehanna | 69.2 (T3.5) | 75.9 (T3.25) | 82.6 (T3) | 82.6 (T3) | 82.6 (T3) |
| Eastern Shore—MD/DE | 10.6 (T3.5) | 11.9 (T3.25) | 13.2 (T3) | 13.2 (T3) | 13.2 (T3) |
| Western Shore—MD | 8.0 (T3.5) | 9.25 (T3.25) | 10.5 (T3) | 10.5 (T3) | 10.5 (T3) |
| Patuxent | 2.5 (T3.5) | 2.8 (T3.25) | 3.1 (T3) | 3.1 (T3) | 3.1 (T3) |
| Potomac | 30.5 (T3.5) | 34.2 (T3.25) | 37.9 (T3) | 37.9 (T3) | 37.9 (T3) |
| Rappahannock | 5.0 (T3) | 5.0 (T3) | 5.0 (T3) | 5.0 (T3) | 5.0 (T3) |
| York | 5.7 (TS) | 5.7 (TS) | 5.1 (T3) | 5.7 (TS) | 8.0 (2000) |
| James | 28.1 (TS) | 28.1 (TS) | 22.3 (T3) | 28.1 (TS) | 35.6 (2000) |
| Eastern Shore—VA | 0.7 (T3.5) | 1.9 (TS) | 0.9 (T3) | 1.9 (TS) | 2.1 (2000) |
| **Total** | **160.4** | **174.8** | **180.8** | **188** | **198.1** |

Key: T3—Tier 3 scenario loading; T3.25—loading one quarter of the way between the Tier 3 and E3 scenarios; T3.5—loading halfway between Tier 3 and E3 scenarios; TS—tributary strategy loading; 2000—2000 progress scenario loading.

Table IV-2. Basinwide phosphorus cap load options (million pounds per year) developed by the Water Quality Technical Workgroup, broken down by major tributary basin.

| Basin | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 |
|---|---|---|---|---|---|
| Susquehanna | 2.54 (T3.5) | 2.69 (T3.25) | 2.83 (T3) | 2.83 (T3) | 2.83 (T3) |
| Eastern Shore—MD/DE | 1.29 (T3) | 1.2 (T3.25) | 1.29 (T3) | 1.29 (T3) | 1.29 (T3) |
| Western Shore—MD | 0.62 (T3.5) | 0.7 (T3.25) | 0.77 (T3) | 0.77 (T3) | 0.77 (T3) |
| Patuxent | 0.20 (T3.5) | 0.22 (T3.25) | 0.24 (T3) | 0.24 (T3) | 0.24 (T3) |
| Potomac | 3.18 (T.3) | 2.86 (T3.25) | 3.18 (T3) | 3.18 (T3) | 3.18 (T3) |
| Rappahannock | 0.66 (T3) | 0.66 (T3) | 0.66 (T3) | 0.66 (T3) | 0.66 (T3) |
| York | 0.48 (TS) | 0.48 (TS) | 0.54 (T3) | 0.48 (TS) | 0.79 (2000) |
| James | 3.71 (TS) | 3.71 (TS) | 3.77 (T3) | 3.71 (TS) | 5.70 (2000) |
| Eastern Shore—VA | 0.10 (T3.5) | 0.09 (TS) | 0.10 (T3) | 0.09 (TS) | 0.22 (2000) |
| **Total** | **12.78** | **12.61** | **13.38** | **13.25** | **15.68** |

Key: T3—Tier 3 scenario loading; T3.25—loading one quarter of the way between the Tier 3 and E3 scenarios; T3.5—loading halfway between Tier 3 and E3 scenarios; TS—tributary strategy loading; 2000—2000 progress scenario loading.

## Factors for Selecting the Basinwide Nutrient Cap Loads

In selecting the most appropriate basinwide cap loads from the five options considered above, the Water Quality Steering Committee considered three factors:

1. ***Basinwide nutrient cap loads should protect the living resources in the Chesapeake Bay and its tidal tributaries.*** The purpose of the allocation is to identify the cap loads necessary to achieve water quality standards that conform to the Chesapeake Bay criteria and refined tidal-water designated uses. This goal of protecting living resources by determining the necessary cap loads to do so is an important concept to keep in mind during the state-specific development and adoption of water quality standards.

2. ***Basinwide nutrient cap loads should be feasible to achieve.*** The Water Quality Steering Committee agreed that the Tier 3 loading levels were feasible to achieve while achieving the E3 loadings were infeasible. The water quality model results suggested that loads somewhere between the Tier 3 and E3 levels were necessary to protect the living resources of the Chesapeake Bay. Obviously, the closer the loading caps come to E3, the more concern exists as to their feasibility. As states work toward adopting water quality standards, the issue of feasibility will likely be subjected to further analysis and may become an important factor requiring further consideration.

3. ***Any nonattainment less than 1 percent is not considered significant.*** It is important to remember that the results reported here are model-simulated results and already factor in a defined level of allowable nonattainment. The Water Quality Steering Committee considered less than 1 percent nonattainment to be an artifact of the attainment determination methodology and, therefore, insignificant. This factor did not favor one of the options. Rather it was an important screening device to identify significant nonattainment in the complex and voluminous set of modeling results reviewed throughout the cap load allocation decision making process.

## Predicted Water Quality Response to the Five Basinwide Cap Load Options

Appendix D contains the predicted water quality response for the Chesapeake Bay and its tidal tributaries for many loading scenarios, including each of these options (presented as 'percent nonattainment'). Table IV-3 and figures IV-1 through IV-4, below, present the relevant information from Appendix D. Again, the nonattainment for dissolved oxygen in the Pamunkey and the Mattaponi rivers is not included because it is due to natural conditions (see Chapter II for details).

Table IV-3 provides an overview of the five options that were considered as possible baywide nutrient loading caps and a summary of water quality responses to each of the loading cap options.

As Table VI-3 indicates:

- The results of the various control options confirm that the nutrient loads of the Rappahannock, York and James basins do not have as significant an effect on the

Table IV-3. Modeled water quality responses to the five basinwide nutrient cap load options.[1]

| Modeled Responses | Option 1 | Option 2 | Option 3 | Option 4 | Option 5 |
|---|---|---|---|---|---|
| Nitrogen Loading (million pounds per year) | 160 | 175 | 181 | 188 | 198 |
| Phosphorus Loading (million pounds per year) | 12.8 | 12.6 | 13.4 | 13.3 | 15.7 |
| Potomac and north, Eastern Shore Tributary Basins | Tier 3.5 | Tier 3.25 | Tier 3 | Tier 3 | Tier 3 |
| Rappahannock, York and James Basins | Tributary Strategy | Tributary Strategy | Tier 3 | Tributary Strategy | 2000 Progress |
| Number of segments with >1% dissolved oxygen nonattainment (percent time volume) | 1 | 1 | 3 | 4 | 11 |
| CB4MH deep-water nonattainment (percent time volume) | 3.9 | 6.0 | 7.6 | 7.9 | 3.84 |
| Area of Bay bottom with dissolved oxygen concentrations <1 mg/L (percent bay bottom surface area) | 4 | 4 | 15 | 15 | 19 |
| Volume of bay in nonattainment for dissolved oxygen (percent bay volume) | 4 | 7 | 15 | 19 | 19 |
| Bay water surface area not meeting target chlorophyll *a* concentrations (percent surface area) | 1 | 15 | 23 | 24 | 25 |

[1]The dissolved oxygen response for these options includes a 20 percent reduction of shoreline erosion sediment loads. The dissolved oxygen nonattainment results do not include results from the tidal Mattaponi and Pamunkey rivers since the lower dissolved oxygen concentrations is a natural condition that was not remedied with nutrient loading reductions.

dissolved oxygen conditions of the mainstem Chesapeake Bay as the Potomac and Virginia Eastern Shore basins. Therefore, for all options but Option 3, the Potomac, western shore tributaries north of the Potomac and Eastern Shore basins have higher levels of nutrient load reductions than the Rappahannock, York and James basins.

- Water quality improves with each increasing level of baywide loading reduction.
- The bay water quality is good for most metrics below under options 1 and 2 but declines rapidly under options 3 through 5.
- Nonattainment of water quality criteria in the middle central Chesapeake Bay (segment CB4MH) does increase with increased loading but not dramatically so.
- The number of segments in nonattainment is less under options 1 and 2 (one segment impaired) than under the other options. However, note that only the deep-water portion of CB4MH is impaired under Option 1, while both the deep-water and the deep-channel portion of CB4MH is impaired under Option 2 (although the deep-channel impairment is marginal) (Table IV-3).

Figure IV-1 illustrates the percent of the Chesapeake Bay and its tidal tributaries in which the Bay bottom surface area is below 1 mg/L dissolved oxygen for various loading scenarios, including the five cap load allocation options. A low percentage of bottom surface area with less than 1 mg/L dissolved oxygen is a good indicator of

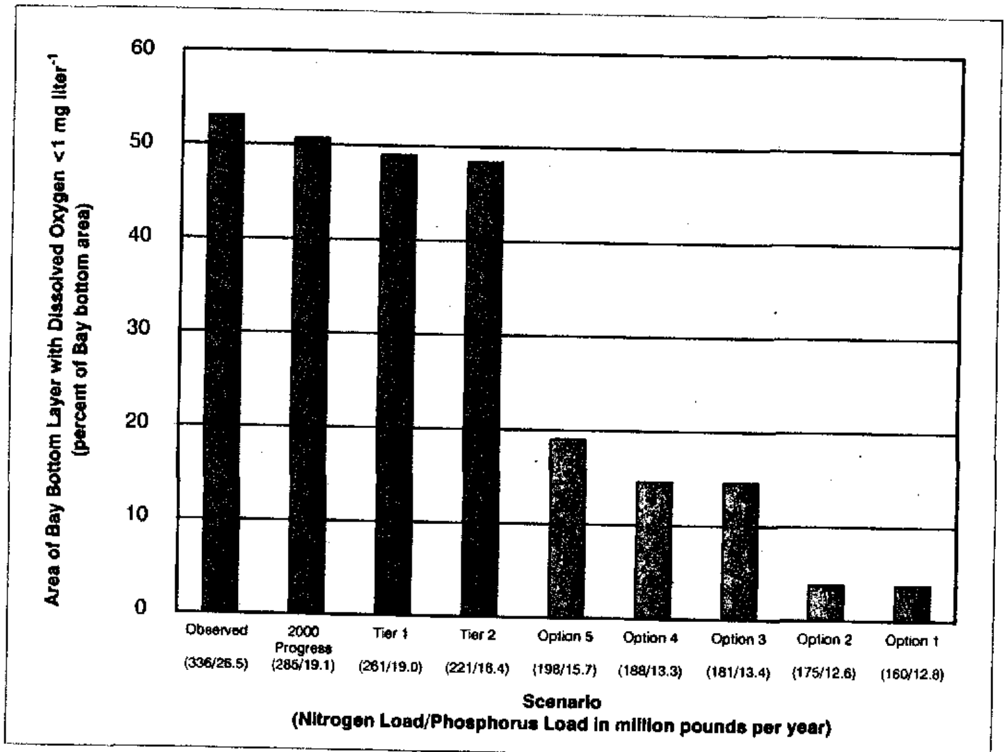


Figure IV-1. Nitrogen and phosphorus load versus percent of the Bay bottom surface area with dissolved oxygen concentrations less than 1 mg/L.

the extent to which the Bay may be habitable for bottom sediment dwelling worms and clams. Further, since phosphorus, and to some extent, nitrogen, are released from bottom sediments predominantly at dissolved oxygen levels below 1 mg/L, this analysis also indicates the potential for nutrient release from these sediments. Figure IV-1 shows that:

- Loading reductions represented by the observed through Tier 2 scenarios achieve little reduction in the percentage of the Bay bottom area that has dissolved oxygen concentrations of less than 1 mg/L. However, reductions beyond the Tier 2 scenario cause a dramatic reduction in the bottom area with dissolved oxygen concentrations of less than 1 mg/L.
- Implementation of options 1or 2 achieve dramatic improvement in low dissolved oxygen concentrations along the Bay bottom in comparison to Option 3. This improvement is due to the further nutrient reductions realized in the Potomac, northern western shore tidal tributaries and along the Eastern Shore. These basins are the ones that have the most impact on the dissolved oxygen levels of the Chesapeake Bay. Dissolved oxygen concentrations of less than 1 mg/L are almost eliminated with both options 1 and 2.

Figure IV-2 identifies the model-simulated volume of the Chesapeake Bay and its tidal tributaries, integrated over the 10-year simulation period, that do not attain the

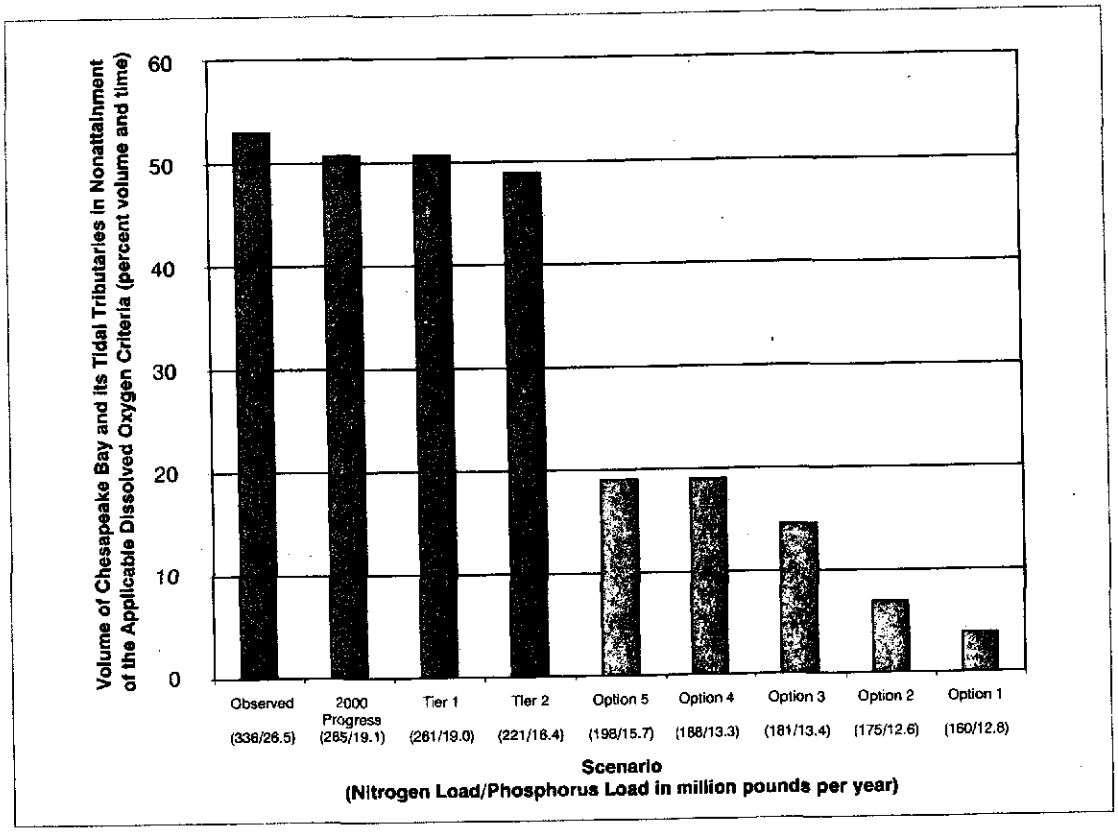


Figure IV-2. Percent volume of the Chesapeake Bay and its tidal tributaries in nonattainment for applicable dissolved oxygen criteria.

applicable dissolved oxygen criteria for numerous loading scenarios, including the five cap load allocation options. This metric shows the fraction of the water column that provides suitable habitat for living resources with respect to dissolved oxygen. Figure IV-2 shows that:

- Improvements in water column attainment of the dissolved oxygen criteria are not dramatic until loading reductions exceed Tier 2 levels. While water quality is improving with all loading reductions, these necessary nutrient reductions are not enough to bring many parts of the Chesapeake Bay and its tidal tributaries back into attainment.
- There is a dramatic improvement in attainment through all five basinwide cap load allocations stepwise from options 5 through 1.
- While the improvement in attainment of Option 1 over Option 2 looks significant, further review of the modeling results gives a better perspective. Nonattainment in the deep-channel portion of segment CB4MH for Option 2 is 1.02 percent, just barely over the established 1 percent threshold. It is this deep-channel nonattainment that brings the total water column volume nonattainment for Option 2 to 7 percent. Without this deep-channel nonattainment, Option 2 would have the same water column volume nonattainment as Option 1 (4 percent).

Figure IV-3 shows the model-simulated water surface area of the Chesapeake Bay and its tidal tributaries that do not meet a set of target chlorophyll *a* concentrations in spring (Appendix C). Spring algae concentrations and the timing of the spring algal blooms are closely linked to summer low dissolved oxygen levels. Figure IV-3 shows that:

- There are dramatic improvements in the water surface area of chlorophyll *a* achievement of target concentrations through the entire range of load reductions, from 2000 progress through to Option 1.
- The dramatic improvement in the water surface area of the Chesapeake Bay and its tidal tributaries in achieving the target chlorophyll *a* concentrations between options 2 and 3 requires closer review. That is, under Option 3, the lower Potomac estuary level of nonattainment is 1.53 percent, while it is less than 1 percent under Option 2. This small change in the level of achievement of the target concentrations in the Potomac River accounts for the difference in the baywide water surface area of nonattainment between options 2 and 3.
- The dramatic improvement between options 1 and 2 also needs closer review. That is, under Option 2, segment CB7PH is 1.52 percent, while it is less than 1 percent under Option 1. This small change in attainment accounts for the difference in baywide nonattainment between options 1 and 2.

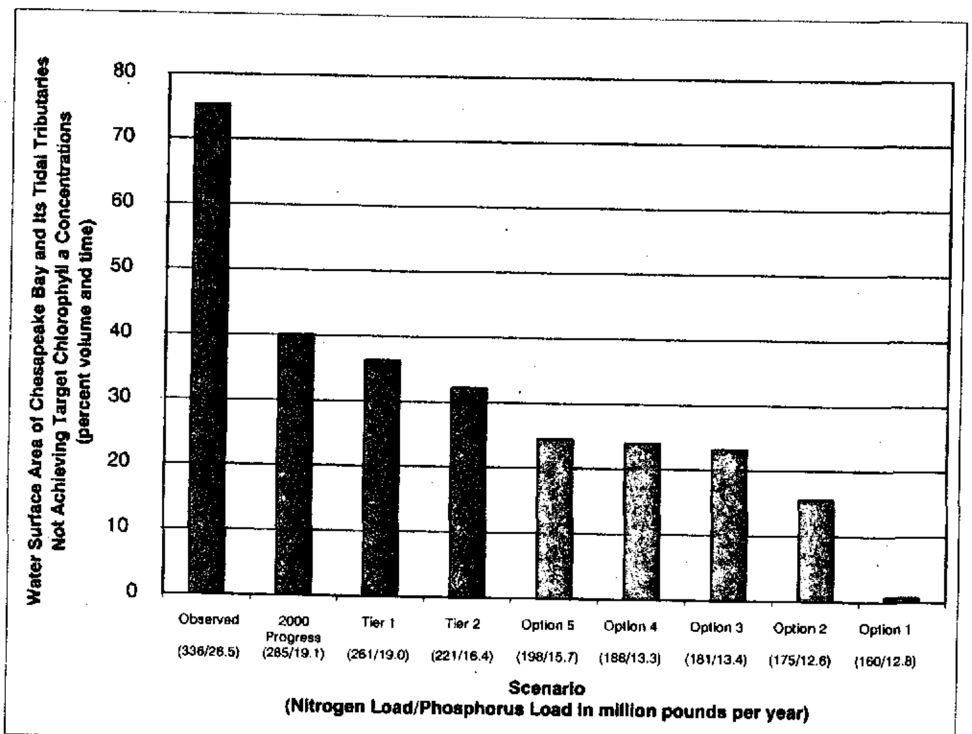


Figure IV-3. Percent of water surface area of the Chesapeake Bay and its tidal tributaries achieving target chlorophyll a concentrations in spring.

The Water Quality Steering Committee debated these five cap load allocation options at length and concluded that:

- Options 1 and 2 provide high protection against low (< 1 mg/L) dissolved oxygen waters along the Bay bottom and provide significantly better protection from these effects than options 3 through 5.
- Options 1 and 2 offer a similar level of water quality protection with respect to dissolved oxygen criteria, superior to that achieved under options 3 through 5. Although the Water Quality Model did not simulate full criteria attainment, and since the criteria and designated use will be subject to public review during the states' water quality standards adoption process, the marginal level of nonattainment remaining with these options was considered acceptable.
- As characterized by the target concentrations, model-simulated chlorophyll *a*-related water quality effects were largely addressed with the application of Tier 2 ???? loading reductions. While the chlorophyll *a* improvement through the five cap load allocation options is significant in Figure IV-2, caution should be taken not to overestimate the actual improvement, given the localized nature of algal-related impairments.
- Although the water quality response of Option 1 is similar to that for Option 2, Option 2 costs less and is more feasible.

Based on this information, the Water Quality Steering Committee recommended basinwide cap loadings of 175 million pounds of nitrogen per year and 12.8 million pounds of phosphorus per year. These cap loads combined the best Bay water quality and living resource protection and feasibility of all the potential options.

## DISTRIBUTING BASINWIDE ALLOCATIONS TO MAJOR BASINS AND JURISDICTIONS

Once these basinwide cap loads were identified, they needed to be allocated to the 20 major basins, by jurisdiction, in the watershed. To enable states and local stakeholders to develop tributary strategies, it was necessary to divide the basinwide nitrogen and phosphorus loads into cap loads for each of these 20 areas of the Bay watershed for which tributary strategies will be developed. States and local stakeholders will identify the actions necessary to achieve the nutrient and sediment cap load allocations.

Figure IV-4 delineates each of the major basins in the watershed and identifies the various jurisdictions for each major basin. In some cases (for example, the Susquehanna River Basin in Pennsylvania), states have chosen to further subdivide their allocated cap load into smaller watersheds for which tributary strategies will be developed.

### Guiding Principles of Allocation Decisions

The discussions and analyses of options for equitable allocation of the basinwide cap loads were extensive. The policy decisions for allocating the basinwide cap loads were driven by an overall desire for equity and achievability. Achieving equity is a complex and somewhat subjective undertaking. In addition to equity, the Chesapeake

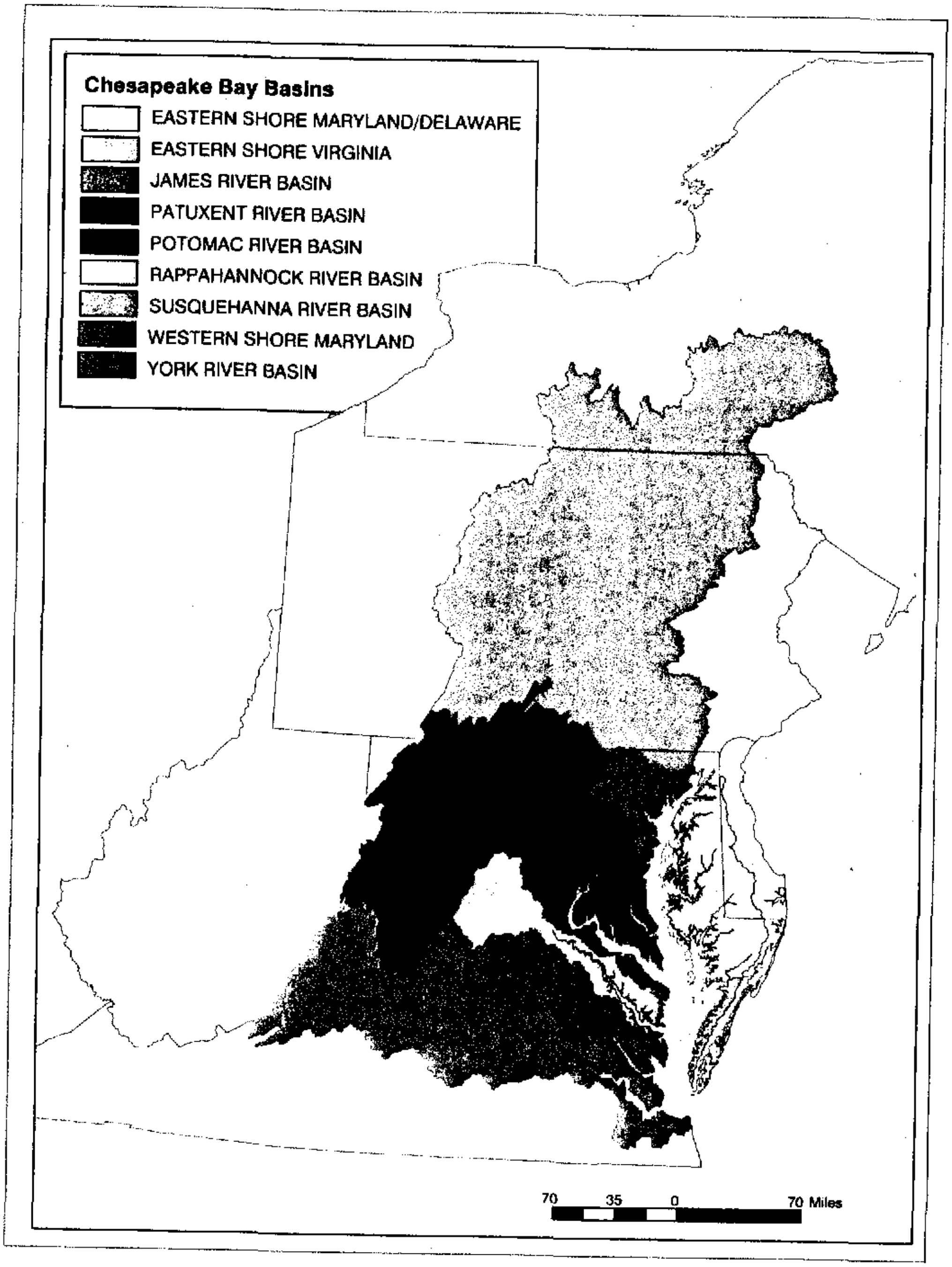


Figure IV-4. The major tributary basins and jurisdictions in the Chesapeake Bay watershed.

Bay Program partners factored in the feasibility of achieving reductions when distributing the cap loadings. All the partners agreed that the E3 scenario was not feasible. Similarly, the partners agreed that Tier 3 was feasible. Hence, the Chesapeake Bay Program partners limited allocations options to below E3.

The Chesapeake Bay Program partners succeeded in framing an equitable and feasible approach by applying three underlying principles to the allocation process. The specific process that was used to distribute the allocation based upon these principles is provided later in this chapter. The underlying principles were:

1. *Basins that contribute the most to the problem must do the most to resolve the problem.* The Chesapeake Bay water quality model allowed the partners to determine the relative impact of each tributary basin on the dissolved oxygen problems experienced in the middle mainstem Bay and lower tidal Potomac River. Figure IV-5 shows the relative influence from each basin. Basins that have the greatest influence on the Bay water quality will generally be required to achieve the highest percent reduction of nutrient loads.[2]
2. *States that benefit most from the Chesapeake Bay recovery must do more.* States that encompass the Chesapeake Bay and its tidal tributaries in its state boundaries, e.g., Maryland, Virginia, Delaware and the District of Columbia, will realize greater benefits, such as tourism dollars, than others. This principle was applied by capping the reductions for nontidal states (New York, Pennsylvania and West Virginia) at a lower level than reduction targets suggested through application of Principle 1.
3. ***All** reductions in nutrient loads are credited toward achieving final assigned loads.* This principle was adopted to avoid penalizing states that have achieved significant nutrient reductions. It was applied by establishing a 'baseline' load using 2010 land use and population, but no point or nonpoint source treatment in place (2010 anthropogenic load). Since all reductions were from this baseline, all past and existing best management practices and treatment upgrades were credited toward the needed reductions.

The above principles guided the Water Quality Technical Workgroup in allocating the loadings among the major tributary basins, but a more detailed approach was needed in order to divide the load among the major basins by jurisdiction. After exploring alternatives to allocating the basinwide cap loads based on these principles, the Water Quality Technical Workgroup recommended a more detailed approach to the Water Quality Steering Committee. The Chesapeake Bay Program partners agreed to the following decision rules for dividing the cap load allocation:

1. *Basins with the greatest impact on the Bay must achieve the highest controls.* Although segment CB4MH was considered the critical area of focus relative to dissolved oxygen in establishing the basinwide nutrient cap loads, a broader look at water quality effects than the original focus on CB4MH was preferred for determining which tributary basins has the greatest impact on the Bay water quality. To

[2]Earlier modeling studies indicated ocean inputs were responsible for 29 to 36 percent of the total nitrogen loading (approximately 131 million pounds per year) to the Chesapeake Bay (Thomann et al. 1994). These ocean loads were a constant factor in the model-based analysis of relative impact on water illustrated in Figure IV-5.

avoid an overly narrow assessment, basin impacts on water quality conditions in segments CB3MH, CB4MH and CB5MH were assessed.

'Relative impact' (i.e., comparative water quality impact of the major basins) was used to determine the impact on the Bay (see Chapter III for more details). To derive the 'relative impact' of each basin the water quality model was run with all basins but one (isolated) basin set at their existing loading (2000 progress). The isolated basin was set at the Tier 3 level of controls. The water quality model was run nine times, thereby 'isolating' each of the nine major basins. In this way, the water quality improvement from reductions from each basin could be modeled. 'Relative impact' was chosen over 'absolute impact' because the latter, which measures the impact of the total loading and the hydrologic proximity of the basin with the depressed dissolved oxygen concentrations in the middle Bay, was determined to be arbitrary and unfair to the larger basins and subsequently dismissed. To calculate 'relative impact', 'absolute impact' was 'normalized' by dividing it by the nitrogen and phosphorus loading for each basin. Hence, the approach measures the impact from each basin for each unit of nutrient load delivered to the Bay's tidal waters and approximates only the hydrologic proximity of each basin. Figure IV-5 shows the relative influence, determined from a 'normalized' impact assessment, of each basin on the dissolved oxygen concentrations of Bay segments CB3MH through CB5MH.

Using the Chesapeake Bay water quality model, basins were grouped based on their relative influence (per pound nutrient loading) on the dissolved oxygen concentration in the identified segments of the mainstem Chesapeake Bay. In this analysis, the Chesapeake Bay Program partners decided to assess the combined nitrogen and phosphorus load impacts on the middle mainstem Chesapeake Bay (CB3MH through CB5MH). These loads were 'normalized' by assuming that 10 pounds of nitrogen had the impact of 1 pound of phosphorus. The potential load impacts from both nitrogen and phosphorus were thus combined into the term 'algal units' (see Chapter III for more details).

Finally, basins were grouped based on their influence on improving the dissolved oxygen concentrations in segments CB3MH through CB5MH (Figure IV-6). The Virginia Eastern Shore, Susquehanna River, Patuxent River and Maryland Western Shore were found to have the greatest influence on the dissolved oxygen levels of the middle mainstem Chesapeake Bay and, therefore, grouped as basins having high impact on the Bay tidal water quality. The Potomac River and the Maryland/Delaware Eastern Shore basins were found to have moderate impact on the middle mainstem Chesapeake Bay water quality. The Rappahannock, York and James river basins were found to have a low impact on the middle mainstem Chesapake Bay water quality.

2. *An 'equal percent reduction' of the 2010 'anthropogenic load' would be used as a baseline.* Using the grouping of basins identified above, the Chesapeake Bay Program partners agreed that load reductions would be based on an equal percent reduction of anthropogenic load for all basins within a single group.

   Using 2010 population and land use estimates and assuming no point or nonpoint controls in place, watershed model runs were conducted to calculate the total loading delivered to Bay tidal waters from each basin. The watershed model was

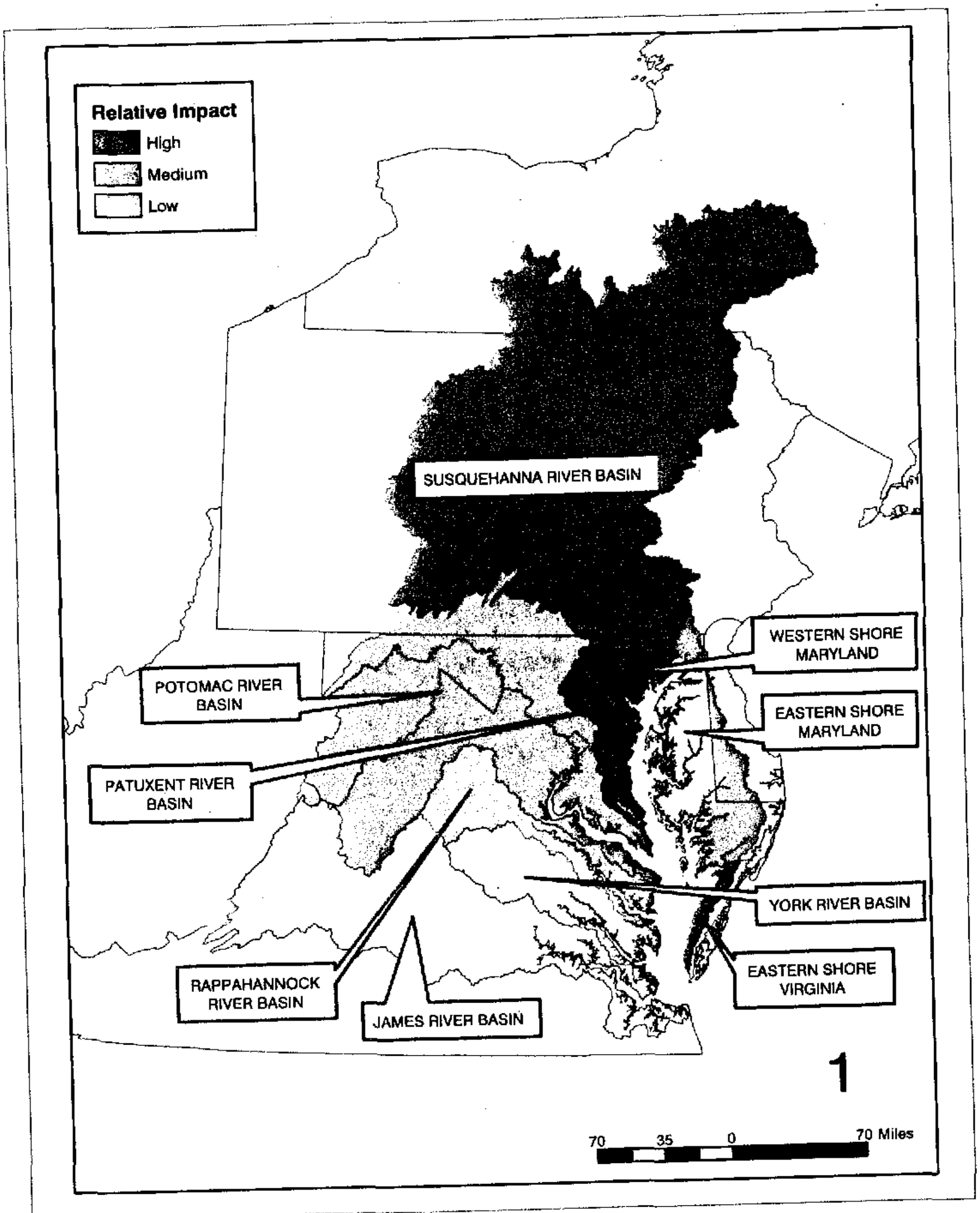


Figure IV-5. Relative impact of major tributary basins on the dissolved oxygen concentration in the mainstem Chesapeake Bay that was considered when allocating the basinwide nutrient cap loads.

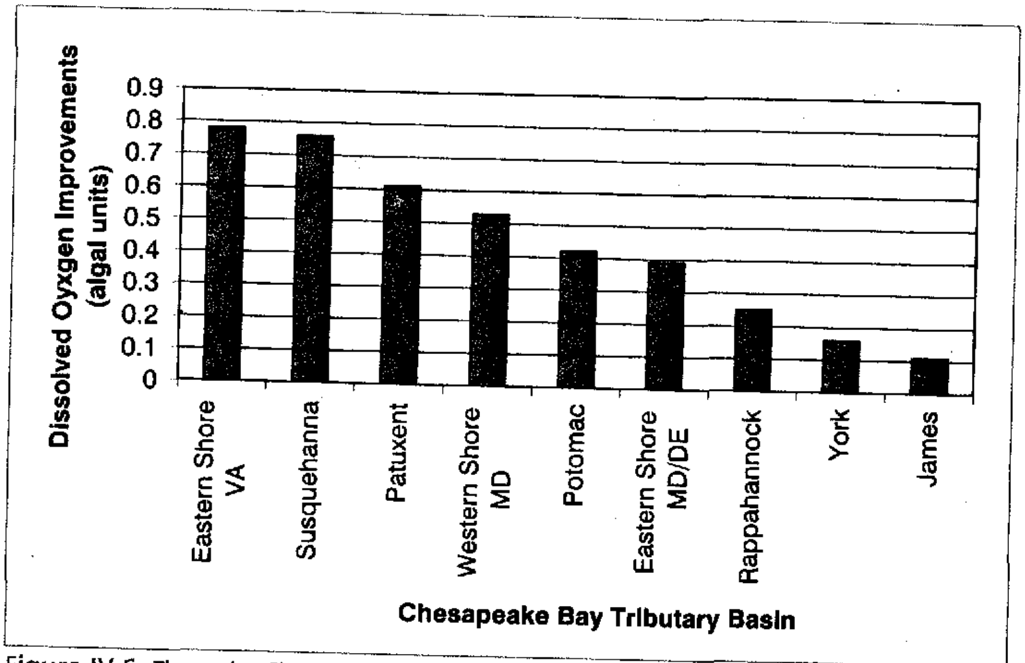


Figure IV-6. The major Chesapeake Bay tributary basins grouped according to their relative influence on dissolved oxygen concentrations in segments CB3MH, CB4MH and CB5MH.

also used to calculate the 'forested' loads. The difference between these loads became the anthropogenic load. That is:

**Anthropogenic load (2010) = Loadings without controls (2010) - Forest Load (2010)**

The Bay partners agreed to equal percent reduction of the anthropogenic load as the best expression of equity. It is important to reiterate that the basins had been grouped as to their impact on the Bay water quality. Therefore, to implement the first principle above, the basins within each group were required to achieve the same percent reduction of their anthropogenic load.

After exploring options for dividing the reductions among the three basin groups, Bay Program partners agreed that while the percent reduction of loading within each group was the same, there would necessarily be a smaller percent reduction required for basins that had less impact on Bay water quality. The issue then focused on how much smaller a reduction between groups was appropriate. A difference in percent reduction between groups of 3 percent and 5 percent was examined. For example, if the group of tributary basins that affected the Bay the most was required to achieve a 70 percent reduction in anthropogenic load, should the group of basins that had the next highest impact be required to reduce their anthropogenic load by 67 percent or 65 percent, or some other reduction? After exploring these and other options, the partners selected a difference of 3 percent between the basin groups. This option kept reductions for all basins within a more feasible range. That is, the 5 percent option, which was considered, placed a higher burden, necessitated high reductions bordering on infeasible, for the most impacting basins.

To achieve the basinwide target load of 175 million pounds of nitrogen and 12.8 million pounds of phosphorus, the 3-percent difference needed to be translated into actual percent reduction for each jurisdictional basin. The resulting percent reductions for nitrogen and phosphorus are shown in Figure IV-6.

Based on application of the "basins with the greatest impact on the Bay need to achieve the highest controls" and the "equal percent reduction" decision rules above, preliminary allocations were developed using the equation:

**Preliminary Load Allocation** = **2010 Anthropogenic Load * [(100 – basin group percent reduction)/100] + Forest Land**

Table IV-4 summarizes the results of this analysis.

The above decision rules were applicable to principles 1 and 3. The Chesapeake Bay Program partners agreed that further decision rules were necessary to better address Principle 1 and Principle 2. After applying the above decision rules, the Bay partners agreed to the following additional decision rules.

3. *The Virginia tributary basins of the York and James rivers would be set at their current tributary strategy cap loads.* The York River and James River tributary strategies called for loading targets that were slightly higher for nitrogen and slightly lower for phosphorus than the cap loads proposed in Table IV-4. Because the differences are small and offset each other, the Bay Program partners agreed that the current tributary strategy cap load goals for nitrogen and phosphorus for the York River and the James River basins would be applied in the proposed cap load allocations.

4. *All nontidal states with nitrogen or phosphorus reductions greater than Tier 3 from decision rules 1 and 2 above would be adjusted to a Tier 3 levels.* As further expression of equity, the Chesapeake Bay Program partners agreed that the states that benefited most directly from the recovery of the Bay would take on a greater burden for the cleanup. Obviously, the jurisdictions with Bay tidal waters benefit most from nutrient reductions directed toward Bay water quality restoration. Hence, they agreed to limit the loading reductions of the nontidal states—New York, Pennsylvania and West Virginia—to Tier 3 levels for nitrogen and phosphorus.

5. *For phosphorus, any tidal jurisdiction with an allocation of reductions greater than Tier 3.4 would be adjusted to a Tier 3.4 level.* When decision rules 1 and 2 were applied for phosphorus, the resultant cap loads allocated to several basins—Eastern Shore (VA), Susquehanna (MD), Eastern Shore (MD) and Rappahannock (VA)—were at or beyond E3 levels. The partners expressed concern that such high levels of controls were not achievable. Therefore, the allocations for these basins would be set at a Tier 3.4 level, which is a loading equal to Tier 3 plus 40 percent (0.4) of the difference between the Tier 3 and the E3 loadings. In this way the tidal states were 'capped' at a greater loading reduction (Tier 3.4) than the nontidal states (Tier 3), thus requiring greater reductions for those states that benefit more from the reductions.

Table IV-4. Preliminary nitrogen and phosphorus cap load allocations based on the application of decision rules 1 and 2 with jurisdictional-basins grouped according to their relative influence on mainstem Chesapeake Bay water quality.

| | NITROGEN (Million pounds per year) | | | | PHOSPHORUS (Million pounds per year) | | | |
|---|---|---|---|---|---|---|---|---|
| **Jurisdiction-Basin** | **2010 No BMPs** | **2010 All-Forest** | **2010 Anthropogenic** | **Preliminary Load Distribution** | **2010 No BMPs** | **2010 All-Forest** | **2010 Anthropogenic** | **Preliminary Load Distribution** |
| Eastern Shore VA - VA | 2.84 | 0.24 | 2.61 | 1.16 | 0.29 | 0.01 | 0.29 | 0.08 |
| Susquehanna - MD<br>0.00295 | 1.80 | 0.32 | 1.48 | 0.85 | 0.1021 | 0.0046 | 0.0975 | |
| Susquehanna - PA | 117.19 | 30.35 | 86.85 | 61.06 | 4.89 | 0.28 | 4.62 | 1.46 |
| Susquehanna - NY | 16.99 | 7.64 | 9.35 | 10.95 | 0.91 | 0.08 | 0.83 | 0.29 |
| Western Shore MD - MD | 30.52 | 1.05 | 29.47 | 11.47 | 3.61 | 0.02 | 3.59 | 0.94 |
| Western Shore MD - PA | 0.05 | 0.00 | 0.04 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| Patuxent - MD | 6.07 | 0.55 | 5.53 | 2.50 | 0.84 | 0.02 | 0.82 | 0.23 |
| HIGH IMPACT BASINS LOADING | 175.47 | 40.14 | 135.32 | 88.00 | 10.64 | 0.41 | 10.24 | 3.03 |
| Eastern Shore MD - MD | 24.86 | 2.45 | 22.41 | 11.05 | 2.96 | 0.05 | 2.90 | 0.88 |
| Eastern Shore MD - VA | 0.14 | 0.02 | 0.12 | 0.06 | 0.02 | 0.00 | 0.02 | 0.01 |
| Eastern Shore MD - DE | 6.64 | 0.53 | 6.11 | 2.88 | 1.20 | 0.01 | 1.19 | 0.35 |
| Eastern Shore MD - PA | 0.54 | 0.05 | 0.49 | 0.24 | 0.05 | 0.00 | 0.05 | 0.01 |
| Potomac - D.C. | 7.22 | 0.05 | 7.18 | 2.80 | 1.38 | 0.00 | 1.37 | 0.39 |
| Potomac - MD | 27.63 | 2.26 | 25.37 | 11.99 | 3.79 | 0.08 | 3.71 | 1.14 |
| Potomac - VA | 28.68 | 2.98 | 25.69 | 12.84 | 4.64 | 0.10 | 4.54 | 1.4 |
| Potomac - PA | 8.09 | 1.02 | 7.08 | 3.73 | 0.66 | 0.04 | 0.62 | 0.21 |
| Potomac - WV | 7.97 | 1.83 | 6.14 | 4.18 | 0.63 | 0.09 | 0.54 | 0.24 |
| MODERATE IMPACT BASINS LOADING | 111.77 | 11.18 | 100.60 | 49.77 | 15.32 | 0.38 | 14.94 | 4.65 |
| Rappahannock - VA | 9.87 | 1.98 | 7.89 | 5.24 | 1.40 | 0.05 | 1.34 | 0.48 |
| York - VA | 10.16 | 1.66 | 8.50 | 5.18 | 2.03 | 0.05 | 1.98 | 0.6791 |
| James - VA | 56.83 | 5.59 | 51.24 | 26.79 | 11.89 | 0.25 | 11.64 | 3.9228 |
| James - WV | 0.04 | 0.02 | 0.01 | 0.03 | 0.01 | 0.00 | 0.01 | 0.0055 |
| LOW IMPACT BASINS LOADING | 76.90 | 9.26 | 67.64 | 37.23 | 15.33 | 0.36 | 14.97 | 5.08 |
| **BASINWIDE TOTAL** | **364.13** | **60.58** | **303.56** | **175.00** | **41.29** | **1.14** | **40.15** | **12.76** |

Notes: 2010 No BMPs = 2010 land use, no BMPs or wastewater treatment controls; 2010 All-Forest = fully forested watershed; 2010 Anthropogenic = 2010 All-Forest – 2010 No BMPs.

The preliminary allocations presented in Table IV-4 were modified to reflect decision rules 3 through 5. Table IV-5 shows the allocations that the Water Quality Steering Committee presented to the Chesapeake Bay Program's Principals Staff Committee and headwater state representatives. Note that the basinwide cap loads of 187 million pounds for nitrogen and 13.8 million pounds for phosphorus after rules 3 through 5 were applied. Specifically, the Water Quality Steering Committee's cap load *allocations* fell short of the agreed upon basinwide cap loads of 175 and 12.8 million pounds by 12 million pounds of nitrogen and 1 million pounds of phosphorus, respectively. These shortfalls were called 'orphaned loads'.

## THE PSC COMPLETES THE ALLOCATION PROCESS

In the spring of 2003, the Principals' Staff Committee and the headwater state representatives promptly approved the basinwide cap loadings of 175 million pounds per year of nitrogen and 12.8 million pounds per year of phosphorus, which the Water Quality Steering Committee had recommended. However, as Table IV-5 shows, recommended jurisdiction-basin allocations fell short of the nutrient reductions needed. Twelve million pounds of nitrogen reductions and 1 million pounds of phosphorus reductions still needed to be assigned to the jurisdiction-basins. The Principals' Staff Committee and headwater state representatives succeeded in addressing the 'orphaned loads' by sharing the burden. The EPA committed to the pursuit of adopting the proposed Clear Skies initiative, which is estimated to bring about an 8 million pound reduction of nitrogen loads delivered to the Chesapeake Bay and its tidal tributaries per year beyond the Clean Air Act controls. In a genuine gesture of partnership to restore Bay water quality, Pennsylvania, Virginia, Maryland, Delaware and the District of Columbia promptly accepted further reductions in their respective nitrogen and/or phosphorus cap loads. These additional reductions in individual basin/jurisdiction cap loads were sufficient to achieve the nutrient basinwide cap loads. These cap load allocations are presented in Table IV-6 by major tributary basin by jurisdiction and in Table IV-7 by jurisdiction.

## CAP LOAD ALLOCATIONS TO ACHIEVE THE CHLOROPHYLL *A* CRITERIA

As the previous discussion demonstrates, nutrients not only depress the amount of dissolved oxygen in the water but also promote excessive algae growth. Therefore, along with numeric criteria for dissolved oxygen for the Chesapeake Bay, the EPA also recommended narrative chlorophyll *a* criteria to protect against excessive algal growth (U.S. EPA 2003a). Early in the process of developing the cap load allocations, it appeared likely that nutrient controls designed to achieve the dissolved oxygen criteria would also be adequate to achieve the chlorophyll *a* criteria. Therefore, the analysis of nutrient allocations for chlorophyll *a* was secondary to that of nutrient allocations for dissolved oxygen.

After developing the nutrient cap load allocations, the resulting chlorophyll *a* concentrations were assessed to determine if further reductions were necessary. After reviewing the model-simulated chlorophyll *a* concentrations under the cap load allocation scenario (see Appendix C), further adjustments to the nutrient cap load allocations were deemed unnecessary.

Table IV-5. The revised draft nitrogen and phosphorus cap load allocations based on application of decision rules 1 through 5 that the Water Quality Steering Committee presented to the Principals' Staff Committee and headwater state representatives.

| | NITROGEN (Million pounds per year) | | | | PHOSPORUS (Million pounds per year) | | | |
|---|---|---|---|---|---|---|---|---|
| **Jurisdiction-Basin** | **Preliminary Load Distribution (from Table IV-4)** | **Allocation** | **Percent Reduction of Anthropogenic Load** | **Tiers** | **Preliminary Load Distribution (from Table IV-4)** | **Allocation** | **Percent Reduction of Anthropogenic Load** | **Tiers** |
| Eastern Shore VA - VA | 1.16 | 1.16 | 64.6 | 2.40 | 0.08 | 0.08 | 74.42 | 3.40 |
| Susquehanna - MD | 0.85 | 0.85 | 64.6 | 3.30 | 0.0295 | 0.03 | 74.42 | 3.40 |
| Susquehanna - PA | 61.06 | **69.08** | **55.4** | **3.00** | 1.46 | **2.20** | **58.25** | **3.00** |
| Susquehanna - NY | 10.95 | **12.58** | **47.2** | **3.00** | 0.29 | **0.59** | **39.11** | **3.00** |
| Western Shore MD - MD | 11.47 | 11.47 | 64.6 | 2.90 | 0.94 | 0.94 | 74.42 | 2.40 |
| Western Shore MD - PA | 0.02 | 0.0192 | 64.6 | n/a | 0.00 | 0.0000 | n/a | n/a |
| Patuxent - MD | 2.50 | 2.50 | 64.6 | 3.55 | 0.23 | 0.23 | 74.42 | 3.10 |
| TOTAL BASIN LOADING | 88.00 | 97.65 | – | – | 3.03 | 4.06 | – | – |
| Eastern Shore MD - MD | 11.05 | 11.05 | 61.6 | 2.60 | 0.88 | 0.88 | 71.42 | 3.40 |
| Eastern Shore MD - VA | 0.06 | 0.0642 | 61.6 | 3.10 | 0.01 | 0.0100 | 71.42 | 3.10 |
| Eastern Shore MD - DE | 2.88 | 2.88 | 61.6 | 3.00 | 0.35 | 0.35 | 71.42 | 1.00 |
| Eastern Shore MD - PA | 0.24 | **0.27** | **54.5** | **3.00** | 0.01 | **0.03** | **49.93** | **3.00** |
| Potomac - D.C. | 2.80 | 2.80 | 61.6 | 2.90 | 0.39 | 0.39 | 71.42 | 2000 Progress |
| Potomac - MD | 11.99 | 11.99 | 61.6 | 3.20 | 1.14 | 1.14 | 71.42 | 1.90 |
| Potomac - VA | 12.84 | 12.84 | 61.6 | 3.20 | 1.40 | 1.40 | 71.42 | 3.00 |
| Potomac - PA | 3.73 | **4.02** | **57.5** | **3.00** | 0.21 | **0.33** | **52.80** | **3.00** |
| Potomac - WV | 4.18 | **4.71** | **53.0** | **3.00** | 0.24 | **0.36** | **49.29** | **3.00** |
| TOTAL BASIN LOADING | 49.77 | 50.62 | – | – | 4.65 | 4.90 | – | – |
| Rappahannock - VA | 5.24 | 5.24 | 58.6 | 2.70 | 0.48 | **0.62** | **57.79** | **3.40** |
| York - VA | 5.18 | **5.70** | **52.5** | **TS/2.4** | 0.6791 | **0.48** | **78.47** | **TS/3.5** |
| James - VA | 26.79 | **27.90** | **56.5** | **TS/2.0** | 3.9228 | **3.71** | **70.25** | **TS/3.0** |
| James - WV | 0.03 | **0.03** | **31.1** | **3.00** | 0.0055 | **0.01** | **n/a** | **n/a** |
| TOTAL BASIN LOADING | 37.23 | 38.87 | – | – | 5.08 | 4.82 | – | – |
| BASINWIDE TOTAL | 175.00 | 187.15 | – | – | 12.76 | 13.78 | – | – |

Note: Bolded numbers in this table resulted from application of decision rules 3 through 5 to Table IV-4.

Table IV-6. The final *Chesapeake 2000* nitrogen and phosphorus cap load allocations by major tributary basin and jurisdiction.

| | NITROGEN (Million pounds per year) | | | | | PHOSPORUS (Million pounds per year) | | |
|---|---|---|---|---|---|---|---|---|
| **Jurisdiction-Basin** | **WQSC Recommendation** | **PSC Reduction** | **Cap Load** | **Clear Skies To 2010** | **Delivered Load** | **WQSC Recommendation** | **PSC Reduction** | **Cap Load** |
| Eastern Shore VA - VA | 1.16 | 0.00 | 1.16 | 0.05 | 1.11 | 0.08 | 0.00 | 0.08 |
| Susquehanna - MD | 0.85 | 0.02 | 0.83 | 0.03 | 0.80 | 0.03 | 0.00 | 0.03 |
| Susquehanna - PA | 69.08 | 1.50 | 67.58 | 3.91 | 63.67 | 2.20 | 0.30 | 1.90 |
| Susquehanna - NY | 12.58 | 0.00 | 12.58 | 0.80 | 11.78 | 0.59 | 0.00 | 0.59 |
| Western Shore MD - MD | 11.47 | 0.20 | 11.27 | 0.19 | 11.08 | 0.94 | 0.10 | 0.84 |
| Western Shore MD - PA | 0.02 | 0.00 | 0.02 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 |
| Patuxent - MD | 2.50 | 0.04 | 2.46 | 0.09 | 2.38 | 0.23 | 0.02 | 0.21 |
| TOTAL BASIN LOADING | 97.7 | 1.8 | 95.9 | 5.1 | 90.8 | 4.1 | 0.4 | 3.6 |
| Eastern Shore MD - MD | 11.05 | 0.16 | 10.89 | 0.30 | 10.58 | 0.88 | 0.08 | 0.81 |
| Eastern Shore MD - VA | 0.06 | 0.00 | 0.06 | 0.00 | 0.06 | 0.01 | 0.00 | 0.01 |
| Eastern Shore MD - DE | 2.88 | 0.00 | 2.88 | 0.11 | 2.77 | 0.35 | 0.05 | 0.30 |
| Eastern Shore MD - PA | 0.27 | 0.00 | 0.27 | 0.01 | 0.27 | 0.03 | 0.00 | 0.03 |
| Potomac - D.C. | 2.80 | 0.40 | 2.40 | 0.02 | 2.38 | 0.39 | 0.05 | 0.34 |
| Potomac - MD | 11.99 | 0.18 | 11.81 | 0.38 | 11.42 | 1.14 | 0.10 | 1.04 |
| Potomac - VA | 12.84 | 0.00 | 12.84 | 0.52 | 12.32 | 1.40 | 0.00 | 1.40 |
| Potomac - PA | 4.02 | 0.00 | 4.02 | 0.19 | 3.83 | 0.33 | 0.00 | 0.33 |
| Potomac - WV | 4.71 | 0.00 | 4.71 | 0.35 | 4.37 | 0.36 | 0.00 | 0.36 |
| TOTAL BASIN LOADING | 50.6 | 0.7 | 49.9 | 1.9 | 48.0 | 4.9 | 0.3 | 4.6 |
| Rappahannock - VA | 5.24 | 0.00 | 5.24 | 0.19 | 5.05 | 0.62 | 0.00 | 0.62 |
| York - VA | 5.70 | 0.00 | 5.70 | 0.19 | 5.51 | 0.48 | 0.00 | 0.48 |
| James - VA | 27.90 | 1.50 | 26.40 | 0.69 | 25.71 | 3.71 | 0.30 | 3.41 |
| James - WV | 0.03 | 0.00 | 0.03 | 0.00 | 0.03 | 0.01 | 0.00 | 0.01 |
| TOTAL BASIN LOADING | 38.9 | 1.5 | 37.4 | 1.1 | 36.3 | 4.8 | 0.3 | 4.5 |
| **BASINWIDE TOTAL** | **187** | **4** | **183** | **8** | **175** | **13.8** | **1.0** | **12.8** |
| Target Load | 175 | | 175 | | 175 | 12.8 | | 12.8 |
| **Orphaned Load** | **12** | | **8** | | **0** | **1.0** | | **0.0** |

WQSC – Water Quality Steering Committee; PSC – Principals' Staff Committee.

Table IV-7. The final *Chesapeake 2000* nitrogen and phosphorus cap load allocations by jurisdiction.

| | NITROGEN (Million pounds per year) | | | | | PHOSPORUS (Million pounds per year) | | |
|---|---|---|---|---|---|---|---|---|
| **Jurisdiction-Basin** | **WQSC Recommendation** | **PSC Reduction** | **Cap Load** | **Clear Skies To 2010** | **Delivered Load** | **WQSC Recommendation** | **PSC Reduction** | **Cap Load** |
| Pennsylvania | 73.40 | 1.50 | 71.90 | 4.10 | 67.79 | 2.56 | 0.30 | 2.26 |
| Maryland | 37.85 | 0.60 | 37.25 | 0.99 | 36.26 | 3.22 | 0.30 | 2.92 |
| Virginia | 52.90 | 1.50 | 51.40 | 1.64 | 49.76 | 6.30 | 0.30 | 6.00 |
| District of Columbia | 2.80 | 0.40 | 2.40 | 0.02 | 2.38 | 0.39 | 0.05 | 0.34 |
| New York | 12.58 | 0.00 | 12.58 | 0.80 | 11.78 | 0.59 | 0.00 | 0.59 |
| Delaware | 2.88 | 0.00 | 2.88 | 0.11 | 2.77 | 0.35 | 0.05 | 0.30 |
| West Virginia | 4.75 | 0.00 | 4.75 | 0.35 | 4.40 | 0.37 | 0.00 | 0.37 |
| TOTAL | 187 | 4 | 183 | 8 | 175 | 13.8 | 1.0 | 12.8 |

WQSC—Water Quality Steering Committee; PSC—Principals' Staff Committee.

Target concentrations of chlorophyll *a* by season and salinity regime were drawn from the technical information published in the *Regional Criteria Guidance* (U.S. EPA 2003a) (see Appendix C). Comparing these target chlorophyll *a* concentrations with the cap load allocations 'confirmation' scenario simulated chlorophyll *a* concentration yielded the following findings:

- Chlorophyll *a* levels relative to the target concentrations were very similar between the 'confirmation' scenario and Option 1, indicating additional nutrient reductions down to the Option 1 level would not yield large chlorophyll *a* concentration reductions at the Chesapeake Bay Program-wide segment scale.
- Only in very localized tidal habitats were the target chlorophyll *a* concentrations not achieved under the 'confirmation' scenario.

### ADDITIONAL ALLOCATION CONSIDERATIONS

Recognizing that nutrient effects could be lessened either by reducing nitrogen or phosphorus, or by other management controls that would alleviate low dissolved oxygen concentrations in the Bay's tidal waters, the Chesapeake Bay Program partners agreed to keep the nutrient allocations flexible (Secretary Tayloe Murphy 2003).

Any jurisdiction can exchange loading for a nutrient from one major tributary basin to another as long as the basins were in the same grouping of relative effectiveness (see Figure IV-6).

A jurisdiction may exchange or credit nitrogen reductions for phosphorus reductions. It is important to note that both nitrogen and phosphorus have an adverse, but exchangeable, effect on the water quality of the Chesapeake Bay, so the nutrient allocations could be viewed as 'nitrogen equivalents'. 'Nitrogen equivalent' means any management action (e.g., phosphorus control, oyster or underwater bay grass restoration, etc.) that has the similar water quality effect of reducing a known quantity of nitrogen loading.

## ESTABLISHING SEDIMENT CAP LOAD ALLOCATIONS

### SAV RESTORATION AS THE GOAL

The cap load allocation process for sediments originally focused on achieving the water clarity water quality criteria. However, good reasons existed for focusing management plans and even the establishment of the sediment cap load allocations on the recovery of the underwater bay grass or SAV beds. This was a positive shift in emphasis, for the following reasons:

- It directly measures the health of the underwater bay grass living resource;
- Annual aerial surveys enable the partners to record and measure the SAV beds, whereas, sparse water clarity data exists for Bay tidal- and shallow-water habitats;
- The Chesapeake Bay water quality model cannot at present reliably simulate reductions in sediment loads or water clarity responses in Bay tidal- and shallow-water habitats at the desired geographic scale with sufficient accuracy; and
- It accommodates the transient nature of SAV growth, which the historical record clearly documents, whereas water clarity criteria necessitated rigid boundaries.

While acres of SAV have become the dominant measure to direct management controls of sediment within the tributary strategies, water clarity still plays an important role. The EPA has published water clarity criteria for the protection of the SAV in the *Regional Criteria Guidance* (U.S. EPA 2003a). In the *Technical Support Document* the EPA also identified SAV restoration goals for the Chesapeake Bay and its tidal tributaries (U.S. EPA 2003b). Currently, sediments are discharged into the Bay's tidal waters in quantities that cause exceedance of the water clarity criteria and prevent achievement of the SAV restoration goals. In response, sediment cap load allocations have been developed along with the SAV restoration goals for each tributary basin. Sediment loads that affect water clarity and SAV growth in the Bay and its tidal tributaries come from two major areas:

1. Land-based loads originate from land erosion, are discharged in runoff and include stream bank erosion; and
2. Near-shore erosion is attributable to tidal shoreline erosion and includes resuspension of sediment material from the shoreline.

Model results have indicated that sediments tend to affect areas in the Chesapeake Bay and its tidal tributaries close to where they are introduced (see Chapter III for details). For this reason, the Bay and its tidal tributaries were divided into discrete sections representing areas affected by the local sediment loads that had little to no impact on other areas (see Figure III-20). These areas roughly correspond with the nine major tributary basins of the Bay.

## LAND-BASED (UPLAND) SEDIMENT ALLOCATION

As the previous section points out, the Water Quality Model is not capable of providing a reliable understanding of the sediment loads' effect on water clarity. Therefore, it was necessary to derive and agree on reasonable sediment cap load allocations without a similar level of quantitative support from the Water Quality Model as was used in establishing the nutrient cap load allocations.

Since no reliable modeling tool existed, neither water clarity criteria attainment nor SAV-based sediment cap load allocations could be developed. Sediment cap load allocations, therefore, were based on sediment loads (reductions) that would likely result from implementing the land-based phosphorus controls necessary to achieve the dissolved oxygen-based phosphorus cap load allocations.

It is well-known that for nonpoint sources, most BMPs that reduce phosphorus do so by reducing the sediment that carries the phosphorus to the stream. Thus, phosphorus and sediment controls for nonpoint sources are closely related. Figure IV-7 illustrates the strong correlation between phosphorus and sediment load reductions from BMPs.

The methodology used to determine the 'phosphorus equivalent' sediment loads was relatively straightforward. Since increasing control scenarios were already defined (e.g., Tier 1 through E3), the first step involved identifying the tier level represented by the phosphorus cap load allocations already established to achieve the dissolved oxygen and chlorophyll *a* criteria for each major tributary basin. If the phosphorus cap load allocation was between two loading levels (i.e., two tiers), the exact tier was

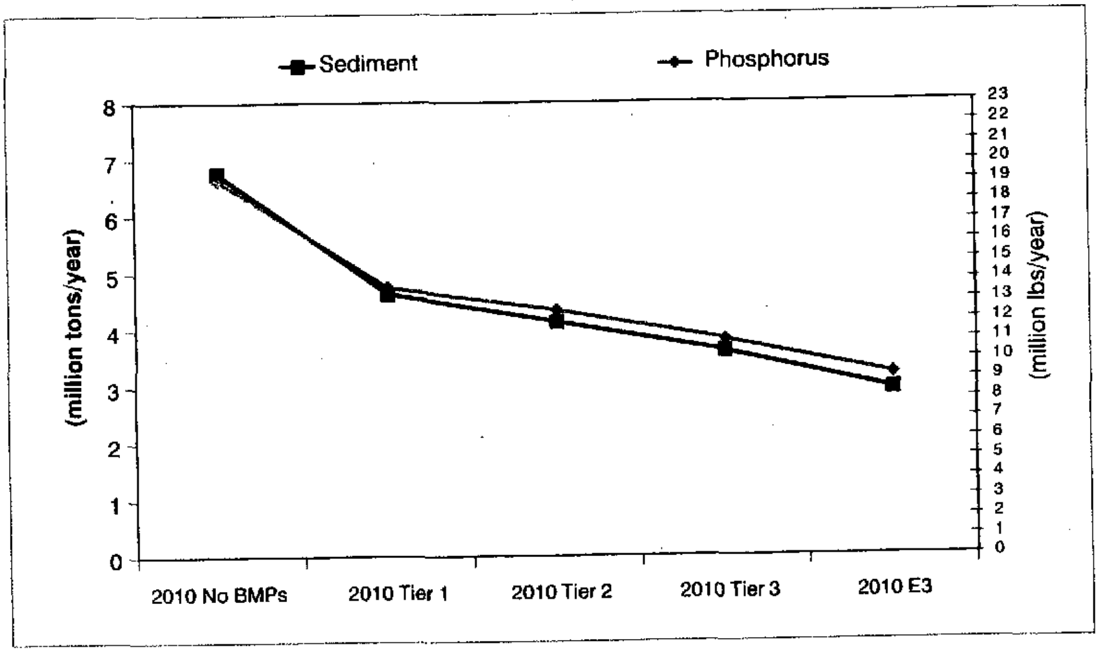


Figure IV-7. Chesapeake Bay Watershed Model simulated relationship between sediment and nonpoint source phosphorus loads.

interpolated. Once the tier for the phosphorus allocation was identified, the sediment cap load allocation was determined by calculating the corresponding sediment load for that tier. It is important to recognize the tentative nature of these allocations, which are driven by the anticipated sediment loads after the phosphorus controls are in place. The tributary teams were, therefore, given latitude in identifying alternate land-based sediment allocations if it could be shown to be more appropriate for achieving the SAV restoration goals for that particular tributary basin.

After the 'phosphorus equivalent' sediment loads were established, these land-based sediment cap load allocations were modified for several major tributary basins (e.g., Potomac tidal-fresh and Susquehanna) because the Chesapeake Bay Water Quality Model and existing data suggested the previously determined land-based sediment allocations were greater than necessary to achieve the SAV restoration goal for that particular major tributary basin. For these basins, the sediment cap load allocations were relaxed to levels estimated to be appropriate for that basin. Table IV-8 provides the resulting allocations.

## ESTABLISHING THE NEAR-SHORE SEDIMENT ALLOCATION

Due to an insufficient technical understanding of near-shore sediment fate and transport, no specific recommendation for near-shore sediment load reductions was recommended when the land-based sediment cap load allocations were established. Tributary teams should acquire local knowledge of near-shore erosion problem areas and make specific recommendations on reductions in those sediment loadings.

## SAV-BASED SEDIMENT CAP LOAD ALLOCATIONS

Scientific understanding of the quantitative relationship between sediment reductions and SAV recovery is less broad than the current understanding of the relationship between nutrient loads and dissolved oxygen on Bay tidal waters. Thus, the tributary teams should note the following when establishing their sediment/SAV related components of the tributary strategies:

1. ***The local SAV goal should serve as the primary goal in establishing sediment control measures by the tributary teams.*** Attaining more SAV acreage is the most direct measure of the status of this living resource and can be measured directly. Therefore, if all management actions prescribed in the tributary strategy are taken, yet the SAV restoration goal is not attained, further measures should be employed. Conversely, if the SAV restoration goal is achieved, yet all sediment reduction measures have not been implemented, then further management actions may not be necessary.
2. ***Based on a comprehensive SAV recovery plan by the tributary teams, revisions to the upland sediment cap load allocations may be recommended to the Principals' Staff Committee, where appropriate.*** As noted, the 'upland' allocations are tentative. That is, the sediment cap load allocations represent the sediment load likely to result from implementing the phosphorus cap load allocations that have been established by the Principals' Staff Committee and headwater state partners. Obviously, these upland sediment loads have only a qualitative relationship to SAV recovery. Thus, these upland sediment allocations should be used as a basis for sediment controls unless the tributary teams, based on the tributary strategy development process, conclude that the recommended upland sediment controls are not appropriate. In such cases, the tributary team shall identify the upland sediment cap load allocations that are appropriate and also identify the management actions necessary to achieve those allocations.
3. ***The tributary teams should explore a comprehensive suite of management actions to achieve the local SAV restoration goal.*** It is apparent that upland sediment controls alone will be insufficient to achieve the local SAV restoration goals in some areas. The tributary teams should assess varied and innovative methods to achieve SAV regrowth in such areas. Methods could include, but not be limited to, streambank stabilization, SAV planting and near-shore erosion control, where appropriate.

## SUMMARY OF NUTRIENT AND SEDIMENT CAP LOAD ALLOCATIONS

Through extensive modeling and an intricate interplay of technical and policy decisions, the Chesapeake Bay Program partners agreed to load allocations for nitrogen, phosphorus and sediment for each of the 20 areas of the Chesapeake Bay watershed delineated by major basin and jurisdiction. These nutrient and sediment cap load allocations are based on achieving the Chesapeake Bay water quality criteria for dissolved oxygen, chlorophyll *a* and water clarity, and the baywide and local SAV acreage restoration goals. Tables IV-9 and IV-10 provide a full tabulation of the nutrient and sediment cap load allocations by major tributary basin and jurisdiction, respectively.

Table IV-8. Land-based 'phosphorus equivalent' sediment cap load allocation by major tributary basin, by jurisdiction.

| Basin | Jurisdiction | Land-Based Sediment Allocation (Million tons per year)* |
|---|---|---|
| SUSQUEHANNA | PA | 0.793 |
| | NY | 0.131 |
| | MD | 0.037 |
| Basin Total | | 0.962 |
| EASTERN SHORE – MD | MD | 0.116 |
| | DE | 0.042 |
| | PA | 0.004 |
| | VA | 0.001 |
| Basin Total | | 0.163 |
| WESTERN SHORE | MD | 0.100 |
| | PA | 0.001 |
| Basin Total | | 0.100 |
| PATUXENT | MD | 0.095 |
| Basin Total | | 0.095 |
| POTOMAC | VA | 0.617 |
| | MD | 0.364 |
| | WV | 0.311 |
| | PA | 0.197 |
| | DC | 0.006 |
| Basin Total | | 1.494 |
| RAPPAHANNOCK | VA | 0.288 |
| Basin Total | | 0.288 |
| YORK | VA | 0.103 |
| Basin Total | | 0.103 |
| JAMES | VA | 0.925 |
| | WV | 0.010 |
| Basin Total | | 0.935 |
| EASTERN SHORE – VA | VA | 0.008 |
| Basin Total | | 0.008 |
| SUBTOTAL | | 4.15 |
| BASINWIDE TOTAL | | 4.15 |

*The tributary teams will assess these upland sediment allocations and, if necessary, revise them as part of a comprehensive strategy of management actions necessary to achieve the local SAV restoration goals.

Table IV-9. Chesapeake Bay watershed nitrogen, phosphorus and sediment cap load allocations by major tributary basin.

| Basin/Jurisdiction | Nitrogen Cap Load Allocation (million pounds/year) | Phosphorus Cap Load Allocation (million pounds/year) | Upland Sediment Cap Load Allocation (million tons/year) |
|---|---|---|---|
| **SUSQUEHANNA** | | | |
| PA | 67.58 | 1.90 | 0.793 |
| NY | 12.58 | 0.59 | 0.131 |
| MD | 0.83 | 0.03 | 0.037 |
| SUSQUEHANNA Total | 80.99 | 2.52 | 0.962 |
| **EASTERN SHORE - MD** | | | |
| MD | 10.89 | 0.81 | 0.116 |
| DE | 2.88 | 0.30 | 0.042 |
| PA | 0.27 | 0.03 | 0.004 |
| VA | 0.06 | 0.01 | 0.001 |
| EASTERN SHORE - MD Total | 14.10 | 1.14 | 0.163 |
| **WESTERN SHORE** | | | |
| MD | 11.27 | 0.84 | 0.100 |
| PA | 0.02 | 0.00 | 0.001 |
| WESTERN SHORE Total | 11.29 | 0.84 | 0.100 |
| **PATUXENT** | | | |
| MD | 2.46 | 0.21 | 0.095 |
| PATUXENT Total | 2.46 | 0.21 | 0.095 |
| **POTOMAC** | | | |
| VA | 12.84 | 1.40 | 0.617 |
| MD | 11.81 | 1.04 | 0.364 |
| WV | 4.71 | 0.36 | 0.311 |
| PA | 4.02 | 0.33 | 0.197 |
| DC | 2.40 | 0.34 | 0.006 |
| POTOMAC Total | 35.78 | 3.48 | 1.494 |
| **RAPPAHANNOCK** | | | |
| VA | 5.24 | 0.62 | 0.288 |
| RAPPAHANNOCK Total | 5.24 | 0.62 | 0.288 |
| **YORK** | | | |
| VA | 5.70 | 0.48 | 0.103 |
| YORK Total | 5.70 | 0.48 | 0.103 |
| **JAMES** | | | |
| VA | 26.40 | 3.41 | 0.925 |
| WV | 0.03 | 0.01 | 0.010 |
| JAMES Total | 26.43 | 3.42 | 0.935 |
| **EASTERN SHORE - VA** | | | |
| VA | 1.16 | 0.08 | 0.008 |
| EASTERN SHORE - VA Total | 1.16 | 0.08 | 0.008 |
| **SUBTOTAL** | 183 | 12.8 | 4.15 |
| **CLEAR SKIES REDUCTION** | -8 | | |
| BASINWIDE TOTAL | 175 | 12.8 | 4.15 |

Table IV-10. Chesapeake Bay watershed nitrogen, phosphorus and sediment cap load allocations by jurisdiction.

| Jurisdiction/Basin | Nitrogen Cap Load Allocation (million pounds/year) | Phosphorus Cap Load Allocation (million pounds/year) | Upland Sediment Cap Load Allocation (million tons/year) |
|---|---|---|---|
| **PENNSYLVANIA** | | | |
| Susquehanna | 67.58 | 1.90 | 0.793 |
| Potomac | 4.02 | 0.33 | 0.197 |
| Western Shore | 0.02 | 0.00 | 0.001 |
| Eastern Shore - MD | 0.27 | 0.03 | 0.004 |
| PA Total | 71.90 | 2.26 | 0.995 |
| **MARYLAND** | | | |
| Susquehanna | 0.83 | 0.03 | 0.037 |
| Patuxent | 2.46 | 0.21 | 0.095 |
| Potomac | 11.81 | 1.04 | 0.364 |
| Western Shore | 11.27 | 0.84 | 0.100 |
| Eastern Shore - MD | 10.89 | 0.81 | 0.116 |
| MD Total | 37.25 | 2.92 | 0.712 |
| **VIRGINIA** | | | |
| Potomac | 12.84 | 1.40 | 0.617 |
| Rappahannock | 5.24 | 0.62 | 0.288 |
| York | 5.70 | 0.48 | 0.103 |
| James | 26.40 | 3.41 | 0.925 |
| Eastern Shore - MD | 0.06 | 0.01 | 0.001 |
| Eastern Shore - VA | 1.16 | 0.08 | 0.008 |
| VA Total | 51.40 | 6.00 | 1.941 |
| **DISTRICT OF COLUMBIA** | | | |
| Potomac | 2.40 | 0.34 | 0.006 |
| DC Total | 2.40 | 0.34 | 0.006 |
| **NEW YORK** | | | |
| Susquehanna | 12.58 | 0.59 | 0.131 |
| NY Total | 12.58 | 0.59 | 0.131 |
| **DELAWARE** | | | |
| Eastern Shore - MD | 2.88 | 0.30 | 0.042 |
| DE Total | 2.88 | 0.30 | 0.042 |
| **WEST VIRGINIA** | | | |
| Potomac | 4.71 | 0.36 | 0.311 |
| James | 0.03 | 0.01 | 0.010 |
| WV Total | 4.75 | 0.37 | 0.320 |
| **SUBTOTAL** | **183** | **12.8** | **4.15** |
| **CLEAR SKIES REDUCTION** | **–8** | | |
| BASINWIDE TOTAL | 175 | 12.8 | 4.15 |

Nutrient and sediment cap load allocations were established based on the EPA's recently published *Regional Criteria Guidance* (U.S. EPA 2003a), which is specific to the Chesapeake Bay. Therefore, the states will be modifying their water quality standards based upon the published Bay criteria as well as the refined tidal-water designated uses. If the final adopted state water quality standards do not rely on the criteria and designated uses employed to establish these cap load allocations, then the allocations will need to be amended accordingly.

It will be difficult to achieve these cap load allocations. States will develop tributary strategies for each of the 20 areas by April 30, 2004. Some states may choose further to subdivide their tributaries into smaller watershed for the development of tributary strategies. These tributary strategies will identify specific actions needed to achieve the cap load nutrient and sediment cap load allocations.

## LITERATURE CITED

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appendix A

# Summary of Decisions Regarding Nutrient and Sediment Load Allocations and New Submerged Aquatic Vegetation (SAV) Restoration Goals

## Memorandum from W. Tayloe Murphy, Jr.,
*Chair, Chesapeake Bay Program Principals' Staff Committee,*
**to the Principals' Staff Committee Members and Representatives of Chesapeake Bay "Headwater" States**

A2

# COMMONWEALTH of VIRGINIA

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To: Principal Staff Committee Members and Representatives of Chesapeake Bay "Headwater" States

From: W. Tayloe Murphy, Jr., Chair
Chesapeake Bay Program Principals' Staff Committee

Date: April 28, 2003

Subject: Summary of Decisions Regarding Nutrient and Sediment Load Allocations and New Submerged Aquatic Vegetation (SAV) Restoration Goals

For the past twenty years, the Chesapeake Bay partners have been committed to achieving and maintaining water quality conditions necessary to support living resources throughout the Chesapeake Bay ecosystem. In the past month, Chesapeake Bay Program partners (Maryland, Virginia, Pennsylvania, the District of Columbia, the Environmental Protection Agency and the Chesapeake Bay Commission) have expanded our efforts by working with the headwater states of Delaware, West Virginia and New York to adopt new cap load allocations for nitrogen, phosphorus and sediment.

Using the best scientific information available, Bay Program partners have agreed to allocations that are intended to meet the needs of the plants and animals that call the Chesapeake home. The allocations will serve as a basis for each state's tributary strategies that, when completed by April 2004, will describe local implementation actions necessary to meet the *Chesapeake 2000* nutrient and sediment loading goals by 2010.

This memorandum summarizes the important, comprehensive agreements made by Bay watershed partners with regard to cap load allocations for nitrogen, phosphorus and sediments, as well as new baywide and local SAV restoration goals.

***Nutrient Allocations***

Excessive nutrients in the Chesapeake Bay and its tidal tributaries promote undesirable algal growth, and thereby, prohibit light from reaching underwater bay grasses (submerged aquatic vegetation or SAV) and depress the dissolved oxygen levels of the deeper waters of the Bay.

As a result, Bay watershed states and the District of Columbia, with the concurrence of EPA, agreed to cap annual nitrogen loads delivered to the Bay's tidal waters at 175 million pounds and annual phosphorus loads at 12.8 million pounds. It is estimated that these allocations will require a reduction, from 2000 levels, of nitrogen pollution by 110 million pounds and phosphorus pollution by 6.3 million pounds annually.

The partners agreed upon these load reductions based upon Bay Water Quality Model projections of attainment of proposed water quality criteria for dissolved oxygen. The model projects these load reductions will eliminate the persistent summer anoxic conditions in the deep bottom waters of the Bay. Furthermore, these reductions are projected to eliminate excessive algae conditions (measured as chlorophyll *a*) throughout the Bay and its tidal tributaries.

The jurisdictions agreed to distribute the baywide cap load for nitrogen and phosphorus by major tributary basin (Table 1) and jurisdiction (Table 2). This distribution of responsibility for load reductions was based on three basic principles:

1. Tributary basins with the highest impact on Bay water quality would have the highest reductions of nutrients.

2. States without tidal waters – Pennsylvania, New York and West Virginia – would be provided some relief from Principle 1 since they do not benefit as directly from improved water quality in the Bay and its tidal tributaries.

3. Previous nutrient reductions would be credited towards achievement of the cap load allocations.

The nine major tributary basins were separated into three categories based upon their impact on water quality in the Bay. Each basin within a category was assigned the same percent reduction of anthropogenic load. Basins with the highest impact on tidal water quality were assigned the highest percentage reduction of anthropogenic load.

After applying the above calculations and Principle 2, New York, Pennsylvania and West Virginia allocations were set at "Tier 3" nutrient load levels. Additionally, allocations for Virginia's York and James River basins were set at previously established tributary strategy nutrient cap load levels since each basin has minimal impact on mainstem Bay water quality conditions, and their influence on tidal water quality is predominantly local.

These rules resulted in shortfalls to the baywide cap load allocation of 12 million pounds of nitrogen and 1 million pounds of phosphorus. EPA committed to pursue the Clear Skies initiative which is estimated to reduce the nitrogen load to Bay tidal waters by 8 million pounds per year. Bay watershed states agreed to take responsibility for the remaining 4 million pounds of nitrogen and 1 million pounds of phosphorus. The nutrient cap load allocations in tables 1 and 2 reflect these agreements.

The allocations for nitrogen and phosphorus were adopted with the concept of "nitrogen equivalents" and a commitment to explore how actions beyond traditional best management practices might help meet Bay restoration goals. A nitrogen equivalent is an action that results in the same water quality benefit as removing nitrogen. The Chesapeake Bay Program will evaluate how to account for tidal water quality benefits from continued and expanded living resource restoration, such as oysters and menhaden, to offset the reductions of watershed based nutrient and sediment loads. Seasonal fluctuations for biological nutrient removal implementation, nutrient reduction benefits from shoreline erosion reductions, implementation of enhanced nutrient removal at large wastewater treatment plants, and trade-offs between nitrogen and phosphorus will also be evaluated.

***Baywide SAV Restoration Goal***

To set new SAV restoration goals, scientists and resource managers from state and federal agencies agreed to use data from the single best year of observed SAV growth to estimate the historical longterm bay grass coverage in Chesapeake Bay. Data were collected from aerial photographs taken between 1938 and 2000. From 3-4 years in the 1938 -1964 period, and more than 20 years of data since 1978, new baywide SAV restoration goal acreage was determined by totaling the single best year acreage from each Chesapeake Bay Program segment.

The states have adopted 185,000 acres as the new baywide SAV restoration goal to be achieved by 2010 – consistent with the goals of *Chesapeake 2000*. The achievement of the baywide goal, as well as the local tributary basin and segment specific restoration goals summarized in Table 3, will be based on the single best year SAV acreage within the most recent three-year record of survey results. This new acreage goal has been added to the recently adopted strategy to accelerate the protection and restoration of SAV in the Chesapeake Bay; and Maryland and Virginia have agreed to develop an implementation plan for this strategy by April 2004.

***Sediment Allocations***

Sediments suspended in the water column reduce the amount of light available to support healthy and extensive SAV communities. With regard to the sediment allocations, the partners agreed that a primary reason for reducing sediment loads to the Bay is to provide suitable habitat for restoring SAV. The jurisdictions also agreed that nutrient load reductions are critical for SAV restoration as well as improving oxygen levels. As a result, the states linked the establishment of sediment cap load allocations to the proposed water clarity criteria and to the new SAV restoration goals.

Unlike nutrients - where loads from virtually all parts of the Bay watershed affect Bay mainstem water quality - impacts from sediments are predominantly seen at the local level. For this reason, local SAV acreage goals have been established and sediment allocations are targeted towards achieving those restoration goals.

The partners recognize that the current understanding of sediment sources and their impact on the Bay is not yet complete. We have only a basic understanding of land-based sediments that are carried into local waterways through stream bank erosion and runoff, but a more limited knowledge about near shore sediments that enter the Bay and its tidal rivers directly through shoreline erosion or shallowwater resuspension. Consequently, sediment allocations are currently focused on land-based sediment cap loads by major tributary basin (Table 1) and jurisdiction (Table 2).

Most land-based best management practices which reduce nonpoint sources of phosphorus will also reduce sediment runoff. Therefore, the jurisdictions agreed to land-based sediment allocations that represent the sediment loading likely to result from implementation management actions required to achieve the phosphorus cap load allocations.

The sediment allocation was set equal to the tier level for phosphorus allocation for each jurisdictionbasin. This is referred to as the 'phosphorus equivalent' land-based sediment reduction. If the 'phosphorus equivalent' land-based sediment reductions were found to be more than necessary to achieve the local SAV acreage goals, then the land-based sediment allocations were raised to that necessary to achieve the SAV goal. The tidal fresh Susquehanna Flats and tidal fresh Potomac River are two examples where this modified approach was applied. If, in the development of their tributary strategies, tributary teams conclude that the land-based sediment allocations need revisions, the tributary teams may identify an alternate land-based allocation working with all the jurisdictions within the effected basin. For example, a jurisdiction may select different nonpoint source management actions than those prescribed in the tier approach to reach the phosphorus goal; the jurisdiction may adjust the sediment goal accordingly so long as SAV restoration and protection is not compromised.

It is likely that reduction in nutrients and land-based sediments alone will not be sufficient to achieve the local SAV goals for many areas of the Bay. In these areas, tributary teams will be asked to further assess varied and innovative methods to achieve SAV re-growth. Such methods may include, but are not limited to SAV planting, offshore breakwaters, shore erosion controls, beach nourishment, establishment of oyster bars, and other actions as appropriate.

***Support to State Tributary Strategies***

The partners have agreed to complete their nutrient and sediment reduction strategies by April 2004. To assist in the development of tributary strategies, the Chesapeake Bay Program Office will provide an array of technical analyses, water quality and watershed modeling, cost-effectiveness and economic assessment support to the tributary strategy teams through the states.

The jurisdictions agreed that it is critical to work together to assure the aggregate of control actions recommended within the nutrient and sediment strategies yield the load reductions and the Bay and tidal tributary water quality improvements desired.

***Reevaluation of the Allocations***

The nutrient and sediment cap load allocations adopted by the jurisdictions are the best scientific estimates of what will be needed to attain proposed water quality criteria and tidal water designated uses described in guidance published by EPA. Over the next two years, Maryland, Virginia, Delaware and the District of Columbia will promulgate new water quality standards based on the guidance published by EPA. Although the public process for adopting water quality standards varies among the states, each state's process will provide opportunities for considering and acquiring new information at the local level. States may choose to explore a number of issues during their adoption process, such as the economic impact of water quality standards and specific designated use boundaries.

While the allocations adopted at this time will provide the basis for tributary strategies, these allocations may need to be adjusted to reflect final state water quality standards. Furthermore, planned Bay model refinements - directed towards estimating water quality benefits from filter feeding resources (e.g., oysters and menhaden) and better understanding the sources and effects of sediments - will increase our understanding of the relationship between nutrient and sediment reductions and living resource responses in the Bay. For these reasons, the states agreed to a reevaluation of these allocations no later than 2007.

As partners, the jurisdictions committed to correcting the nutrient and sediment related problems in the Bay and its tidal tributaries sufficiently to remove them from the list of impaired waters under the Clean Water Act. Although the states agreed to do their utmost to remove the Bay from the federal list of impaired waters by 2010, they recognize that it will be difficult to meet projected water quality standards in all parts of the Bay by that time. A key reason for this difficulty is that once nutrient reduction practices are installed, it may be years or even decades before the Bay benefits from these reductions. The jurisdictions intend to have programs in place and functioning by 2010 such that when fully implemented all parts of the Bay are expected to become eligible for delisting.

I would like to express my appreciation to all the partners in this effort for their hard work and commitment to restoration of the Chesapeake Bay. We have agreed to nutrient and sediment reductions which will result in profound improvements in the water quality, habitat and living resources of the Bay.

Table A-1. Chesapeake Bay watershed nitrogen, phosphorus and sediment cap load allocations by major basin.

| Basin/Jurisdiction | Nitrogen Cap Load Allocation (million pounds/year) | Phosphorus Cap Load Allocation (million pounds/year) | Upland Sediment Cap Load Allocation (million tons/year) |
|---|---|---|---|
| **SUSQUEHANNA** | | | |
| PA | 67.58 | 1.90 | 0.793 |
| NY | 12.58 | 0.59 | 0.131 |
| MD | 0.83 | 0.03 | 0.037 |
| SUSQUEHANNA Total | 80.99 | 2.52 | 0.962 |
| **EASTERN SHORE - MD** | | | |
| MD | 10.89 | 0.81 | 0.116 |
| DE | 2.88 | 0.30 | 0.042 |
| PA | 0.27 | 0.03 | 0.004 |
| VA | 0.06 | 0.01 | 0.001 |
| EASTERN SHORE - MD Total | 14.10 | 1.14 | 0.163 |
| **WESTERN SHORE** | | | |
| MD | 11.27 | 0.84 | 0.100 |
| PA | 0.02 | 0.00 | 0.001 |
| WESTERN SHORE Total | 11.29 | 0.84 | 0.100 |
| **PATUXENT** | | | |
| MD | 2.46 | 0.21 | 0.095 |
| PATUXENT Total | 2.46 | 0.21 | 0.095 |
| **POTOMAC** | | | |
| VA | 12.84 | 1.40 | 0.617 |
| MD | 11.81 | 1.04 | 0.364 |
| WV | 4.71 | 0.36 | 0.311 |
| PA | 4.02 | 0.33 | 0.197 |
| DC | 2.40 | 0.34 | 0.006 |
| POTOMAC Total | 35.78 | 3.48 | 1.494 |
| **RAPPAHANNOCK** | | | |
| VA | 5.24 | 0.62 | 0.288 |
| RAPPAHANNOCK Total | 5.24 | 0.62 | 0.288 |
| **YORK** | | | |
| VA | 5.70 | 0.48 | 0.103 |
| YORK Total | 5.70 | 0.48 | 0.103 |
| **JAMES** | | | |
| VA | 26.40 | 3.41 | 0.925 |
| WV | 0.03 | 0.01 | 0.010 |
| JAMES Total | 26.43 | 3.42 | 0.935 |
| **EASTERN SHORE - VA** | | | |
| VA | 1.16 | 0.08 | 0.008 |
| EASTERN SHORE - VA Total | 1.16 | 0.08 | 0.008 |
| **SUBTOTAL** | 183 | 12.8 | 4.15 |
| **CLEAR SKIES REDUCTION** | -8 | | |
| **BASINWIDE TOTAL** | 175 | 12.8 | 4.15 |

Table A-2. Chesapeake Bay watershed nitrogen, phosphorus and sediment cap load allocations by jurisdiction.

| Jurisdiction/Basin | Nitrogen Cap Load Allocation (million pounds/year) | Phosphorus Cap Load Allocation (million pounds/year) | Upland Sediment Cap Load Allocation (million tons/year) |
|---|---|---|---|
| **PENNSYLVANIA** | | | |
| Susquehanna | 67.58 | 1.90 | 0.793 |
| Potomac | 4.02 | 0.33 | 0.197 |
| Western Shore | 0.02 | 0.00 | 0.001 |
| Eastern Shore - MD | 0.27 | 0.03 | 0.004 |
| PA Total | 71.90 | 2.26 | 0.995 |
| **MARYLAND** | | | |
| Susquehanna | 0.83 | 0.03 | 0.037 |
| Patuxent | 2.46 | 0.21 | 0.095 |
| Potomac | 11.81 | 1.04 | 0.364 |
| Western Shore | 11.27 | 0.84 | 0.100 |
| Eastern Shore - MD | 10.89 | 0.81 | 0.116 |
| MD Total | 37.25 | 2.92 | 0.712 |
| **VIRGINIA** | | | |
| Potomac | 12.84 | 1.40 | 0.617 |
| Rappahannock | 5.24 | 0.62 | 0.288 |
| York | 5.70 | 0.48 | 0.103 |
| James | 26.40 | 3.41 | 0.925 |
| Eastern Shore - MD | 0.06 | 0.01 | 0.001 |
| Eastern Shore - VA | 1.16 | 0.08 | 0.008 |
| VA Total | 51.40 | 6.00 | 1.941 |
| **DISTRICT OF COLUMBIA** | | | |
| Potomac | 2.40 | 0.34 | 0.006 |
| DC Total | 2.40 | 0.34 | 0.006 |
| **NEW YORK** | | | |
| Susquehanna | 12.58 | 0.59 | 0.131 |
| NY Total | 12.58 | 0.59 | 0.131 |
| **DELAWARE** | | | |
| Eastern Shore - MD | 2.88 | 0.30 | 0.042 |
| DE Total | 2.88 | 0.30 | 0.042 |
| **WEST VIRGINIA** | | | |
| Potomac | 4.71 | 0.36 | 0.311 |
| James | 0.03 | 0.01 | 0.010 |
| WV Total | 4.75 | 0.37 | 0.320 |
| **SUBTOTAL** | **183** | **12.8** | **4.15** |
| **CLEAR SKIES REDUCTION** | **–8** | | |
| BASINWIDE TOTAL | 175 | 12.8 | 4.15 |

Table A-3. Chesapeake Bay submerged aquatic (SAV) restoration goal acreage by Chesapeake Bay Program (CBP) segment based on the single best year of record from 1930 to present.

| Segment Name | Segment | Acres |
|---|---|---|
| Northern Chesapeake Bay | CB1TF | 12,908 |
| Upper Chesapeake Bay | CB2OH | 302 |
| Upper Central Chesapeake Bay | CB3MH | 943 |
| Middle Central Chesapeake Bay | CB4MH | 2,511 |
| Lower Central Chesapeake Bay | CB5MH | 14,961 |
| Western Lower Chesapeake Bay | CB6PH | 980 |
| Eastern Lower Chesapeake Bay | CB7PH | 14,620 |
| Mouth of the Chesapeake Bay | CB8PH | 6 |
| Bush River | BSHOH | 158 |
| Gunpowder River | GUNOH | 2,254 |
| Middle River | MIDOH | 838 |
| Back River | BACOH | 0 |
| Patapsco River | PATMH | 298 |
| Magothy River | MAGMH | 545 |
| Severn River | SEVMH | 329 |
| South River | SOUMH | 459 |
| Rhode River | RHDMH | 48 |
| West River | WSTMH | 214 |
| Upper Patuxent River | PAXTF | 5 |
| Western Branch (Patuxent River) | WBRTF | 0 |
| Middle Patuxent River | PAXOH | 68 |
| Lower Patuxent River | PAXMH | 1,325 |
| Upper Potomac River | POTTF | 4,368 |
| Anacostia River | ANATF | 6 |
| Piscataway Creek | PISTF | 783 |
| Mattawoman Creek | MATTF | 276 |
| Middle Potomac River | POTOH | 3,721 |
| Lower Potomac River | POTMH | 10,173 |
| Upper Rappahannock River | RPPTF | 20 |
| Middle Rappahannock River | RPPOH | 0 |
| Lower Rappahannock River | RPPMH | 5,380 |
| Corrotoman River | CRRMH | 516 |
| Piankatank River | PIAMH | 3,256 |
| Upper Mattaponi River | MPNTF | 75 |
| Lower Mattaponi River | MPNOH | 0 |
| Upper Pamunkey River | PMKTF | 155 |
| Lower Pamunkey River | PMKOH | 0 |
| Middle York River | YRKMH | 176 |
| Lower York River | YRKPH | 2,272 |
| Mobjack Bay | MOBPH | 15,096 |

*continued*

Table A-3. Chesapeake Bay submerged aquatic (SAV) restoration goal acreage by Chesapeake Bay Program (CBP) segment based on the single best year of record from 1930 to present. *(cont.)*.

| Segment Name | Segment | Acres |
|---|---|---|
| Upper James River | JMSTF | 1,600 |
| Appomattox River | APPTF | 319 |
| Middle James River | JMSOH | 7 |
| Chickahominy River | CHKOH | 348 |
| Lower James River | JMSMH | 531 |
| Mouth of the James River | JMSPH | 604 |
| Western Branch Elizabeth River | WBEMH | 0 |
| Southern Branch Elizabeth River | SBEMH | 0 |
| Eastern Branch Elizabeth River | EBEMH | 0 |
| Lafayette River | LAFMH | 0 |
| Mouth to mid-Elizabeth River | ELIPH | 0 |
| Lynnhaven River | LYNPH | 69 |
| Northeast River | NORTF | 88 |
| C&D Canal | C&DOH | 0 |
| Bohemia River | BOHOH | 97 |
| Elk River | ELKOH | 1,648 |
| Sassafras River | SASOH | 764 |
| Upper Chester River | CHSTF | 0 |
| Middle Chester River | CHSOH | 63 |
| Lower Chester River | CHSMH | 2,724 |
| Eastern Bay | EASMH | 6,108 |
| Upper Choptank River | CHOTF | 0 |
| Middle Choptank River | CHOOH | 63 |
| Lower Choptank River | CHOMH2 | 1,499 |
| Mouth of the Choptank River | CHOMH1 | 8,044 |
| Little Choptank River | LCHMH | 3,950 |
| Honga River | HNGMH | 7,686 |
| Fishing Bay | FSBMH | 193 |
| Upper Nanticoke River | NANTF | 0 |
| Middle Nanticoke River | NANOH | 3 |
| Lower Nanticoke River | NANMH | 3 |
| Wicomico River | WICMH | 3 |
| Manokin River | MANMH | 4,359 |
| Big Annemessex River | BIGMH | 2,014 |
| Upper Pocomoke River | POCTF | 0 |
| Middle Pocomoke River | POCOH | 0 |
| Lower Pocomoke River | POCMH | 4,092 |
| Tangier Sound | TANMH | 37,965 |
| Total acres | | 184,889 |

[1]Breakdown of Potomac SAV restoration goals by jurisdictions are draft, pending confirmation of split between Maryland, Virginia and the District of Columbia along jurisdictional lines. Due to ongoing refinement, some numbers in this table differ from the April 25, 2003, version included in Appendix A and previous model estimates presented in tables III-3 and III-4.

Table A-4. Chesapeake Bay submerged aquatic vegetation (SAV) restoration goal acreage by major basin by jurisdiction.

| Basin/Jurisdiction | SAV Restoration Goal (Acres) |
|---|---|
| SUSQUEHANNA | 12,856 |
| EASTERN SHORE – MD | 76,193 |
| WESTERN SHORE – MD | 5,651 |
| PATUXENT | 1,420 |
| POTOMAC[1] | |
| MD | 12,747 |
| VA | 6,320 |
| DC | 384 |
| RAPPAHANNOCK | 12,798 |
| YORK | 21,823 |
| JAMES | 3,483 |
| EASTERN SHORE – VA | 31,215 |
| **TOTAL** | **184,889** |

[1]Breakdown of Potomac SAV restoration goals by jurisdictions are draft, pending confirmation of split between Maryland, Virginia and the District of Columbia along jurisdictional lines. Due to ongoing refinement, some numbers in this table differ from the April 25, 2003, version included in Appendix A and previous model estimates presented in tables III-3 and III-4.

# appendix B
# Chesapeake Bay Living Resource-Based Refined Designated Uses and Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll *a*

To better reflect the desired and attainable Chesapeake Bay water quality conditions called for in the *Chesapeake 2000* agreement, Chesapeake Bay Program watershed partners determined that the underlying tidal-water designated uses needed to be refined. The Chesapeake Bay watershed partners, thus, proposed five *refined sub-categories* of the current broad aquatic life designated uses contained in the existing state water quality standards of the four jurisdictions bordering directly on Chesapeake Bay and its tidal tributaries.

Four of the refined designated uses were derived largely to address seasonally distinct habitats and living resource communities with widely varying dissolved oxygen requirements:

- Migratory fish spawning and nursery;
- Open-water fish and shellfish;
- Deep-water seasonal fish and shellfish; and
- Deep-channel seasonal refuge.

The fifth refined designated use, the shallow-water bay grass designated use, is a seasonal overlay on that part of the year-round open-water use which borders the land along the tidal portions of the Chesapeake Bay and its tributaries.

Table B-1 provides general descriptions of the five designated uses and the aquatic communities they were established to protect[1], while Table B-2 provides the proposed designated uses for each Chesapeake Bay Program segment. See the *Technical Support Document for Identification of Chesapeake Bay Designated uses and Attainability* (U.S. EPA 2003b) for more detailed explanation of the five refined designated uses.

[1]Note that for brevity, these refined designated uses may be referred to as migratory spawning and nursery, shallow-water, open-water, deep-water and deep-channel.

Table B-1. General descriptions of the five proposed Chesapeake Bay tidal-water designated uses.

**Migratory Fish Spawning and Nursery Designated Use:** Aims to protect migratory finfish during the late winter/spring spawning and nursery season in tidal freshwater to low-salinity habitats. This habitat zone is primarily found in the upper reaches of many Bay tidal rivers and creeks and the upper mainstem Chesapeake Bay and will benefit several species including striped bass, perch, shad, herring and sturgeon.

**Shallow-Water Bay Grass Designated Use:** Designed to protect underwater bay grasses and the many fish and crab species that depend on the shallow-water habitat provided by grass beds.

**Open-Water Fish and Shellfish Designated Use:** Designed to protect water quality in the surface water habitats within tidal creeks, rivers, embayments and the mainstem Chesapeake Bay year-round. This use aims to protect diverse populations of sportfish, including striped bass, bluefish, mackerel and seatrout, bait fish such as menhaden and silversides, as well as the listed shortnose sturgeon.

**Deep-Water Seasonal Fish and Shellfish Designated Use:** Aims to protect living resources inhabiting the deeper transitional water column and bottom habitats between the well-mixed surface waters and the very deep channels during the summer months. This use protects many bottom-feeding fish, crabs and oysters, as well as other important species, including the bay anchovy.

**Deep-Channel Seasonal Refuge Designated Use:** Designed to protect bottom sediment-dwelling worms and small clams that act as food for bottom-feeding fish and crabs in the very deep channel in summer. The deep-channel designated use recognizes that low dissolved oxygen conditions prevail in the deepest portions of this habitat zone and will naturally have very low to no oxygen during the summer.

Source: U.S. EPA 2003b.

The five tidal-water designated uses, in turn, provided the context for deriving dissolved oxygen, water clarity and chlorophyll *a* water quality criteria for the Chesapeake Bay and its tidal tributaries. These criteria, derived to protect each of the five refined designated uses, were based on effects data from a wide array of biological communities to capture the range of sensitivity of the thousands of aquatic species inhabiting the Chesapeake Bay and tidal tributary estuarine habitats. See *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll* a *for the Chesapeake Bay and Its Tidal Tributaries* for more detailed explanation of the Chesapeake Bay water quality criteria (U.S. EPA 2003a). As presented in Table B-3, the Chesapeake Bay dissolved oxygen criteria have been defined for each of the five designated uses. Table B-4 presents the water clarity criteria applicable to the shallow-water designated use. The narrative chlorophyll *a* criteria, which is recommended for all Chesapeake Bay and tidal tributaries, is presented in Table B-5.

Table B-2. Recommended tidal-water designated uses by Chesapeake Bay Program segment.

| Chesapeake Bay Program (CBP) Segment Name | CBP Segment | Migratory Spawning and Nursery (2/1–5/31) | Open-Water (Year-Round) | Deep-Water (6/1–9/30) | Deep-Channel (6/1–9/30) | Shallow-Water (4/1–10/30) |
|---|---|---|---|---|---|---|
| Northern Chesapeake Bay | CB1TF | x | x | | | x |
| Upper Chesapeake Bay | CB2OH | x | x | | | x |
| Upper Central Chesapeake Bay | CB3MH | x | x | x | x | x |
| Middle Central Chesapeake Bay | CB4MH | x | x | x | x | x |
| Lower Central Chesapeake Bay | CB5MH | | x | x | x | x |
| Western Lower Chesapeake Bay | CB6PH | | x | x | | x |
| Eastern Lower Chesapeake Bay | CB7PH | | x | x | | x |
| Mouth of the Chesapeake Bay | CB8PH | | x | | | x |
| Bush River | BSHOH | x | x | | | x |
| Gunpowder River | GUNOH | x | x | | | x |
| Middle River | MIDOH | x | x | | | x |
| Back River | BACOH | x | x | | | x |
| Patapsco River | PATMH | x | x | x | | x |
| Magothy River | MAGMH | x | x | | | x |
| Severn River | SEVMH | x | x | | | x |
| South River | SOUMH | x | x | | | x |
| Rhode River | RHDMH | x | x | | | x |
| West River | WSTMH | x | x | | | x |
| Upper Patuxent River | PAXTF | x | x | | | x |
| Western Branch (Patuxent River) | WBRTF | x | x | | | x |
| Middle Patuxent River | PAXOH | x | x | | | x |
| Lower Patuxent River | PAXMH | x | x | x | | x |
| Upper Potomac River | POTTF | x | x | | | x |
| Anacostia River | ANATF | x | x | | | x |
| Piscataway Creek | PISTF | x | x | | | x |
| Mattawoman Creek | MATTF | x | x | | | x |
| Middle Potomac River | POTOH | x | x | | | x |
| Lower Potomac River | POTMH | x | x | x | x | x |
| Upper Rappahannock River | RPPTF | x | x | | | x |
| Middle Rappahannock River | RPPOH | x | x | | | x |
| Lower Rappahannock River | RPPMH | x | x | x | x | x |
| Corrotoman River | CRRMH | x | x | | | x |
| Piankatank River | PIAMH | x | x | | | x |
| Upper Mattaponi River | MPNTF | x | x | | | x |
| Lower Mattaponi River | MPNOH | x | x | | | x |
| Upper Pamunkey River | PMKTF | x | x | | | x |
| Lower Pamunkey River | PMKOH | x | x | | | x |
| Middle York River | YRKMH | x | x | | | x |
| Lower York River | YRKPH | | x | x | | x |

*continued*

Table B-2. Recommended tidal-water designated uses by Chesapeake Bay Program segment *(cont.)*.

| Chesapeake Bay Program (CBP) Segment Name | CBP Segment | Migratory Spawning and Nursery (2/1–5/31) | Open-Water (Year-Round) | Deep-Water (6/1–9/30) | Deep-Channel (6/1–9/30) | Shallow-Water (4/1–10/30) |
|---|---|---|---|---|---|---|
| Mobjack Bay | MOBPH | | x | x | | x |
| Upper James River | JMSTF | x | x | | | x |
| Appomattox River | APPTF | x | x | | | x |
| Middle James River | JMSOH | x | x | | | x |
| Chickahominy River | CHKOH | x | x | | | x |
| Lower James River | JMSMH | x | x | | | x |
| Mouth of the James River | JMSPH | | x | | | x |
| Western Branch Elizabeth River | WBEMH | | x | | | |
| Southern Branch Elizabeth River | SBEMH | | x | | | |
| Eastern Branch Elizabeth River | EBEMH | | x | | | |
| Lafayette River | LAFMH | | x | | | |
| Mouth to mid-Elizabeth River | ELIPH | | x | x | x | |
| Lynnhaven River | LYNPH | | x | | | x |
| Northeast River | NORTF | x | x | | | x |
| C&D Canal | C&DOH | x | x | | | x |
| Bohemia River | BOHOH | x | x | | | x |
| Elk River | ELKOH | x | x | | | x |
| Sassafras River | SASOH | x | x | | | x |
| Upper Chester River | CHSTF | x | x | | | x |
| Middle Chester River | CHSOH | x | x | | | x |
| Lower Chester River | CHSMH | x | x | x | x | x |
| Eastern Bay | EASMH | | x | x | x | x |
| Upper Choptank River | CHOTF | x | x | | | |
| Middle Choptank River | CHOOH | x | x | | | x |
| Lower Choptank River | CHOMH2 | x | x | | | x |
| Mouth of the Choptank River | CHOMH1 | x | x | | | x |
| Little Choptank River | LCHMH | | x | | | x |
| Honga River | HNGMH | | x | | | x |
| Fishing Bay | FSBMH | x | x | | | x |
| Upper Nanticoke River | NANTF | x | x | | | x |
| Middle Nanticoke River | NANOH | x | x | | | x |
| Lower Nanticoke River | NANMH | x | x | | | x |
| Wicomico River | WICMH | x | x | | | x |
| Manokin River | MANMH | x | x | | | x |
| Big Annemessex River | BIGMH | x | x | | | x |
| Upper Pocomoke River | POCTF | x | x | | | |
| Middle Pocomoke River | POCOH | x | x | | | x |
| Lower Pocomoke River | POCMH | x | x | | | x |
| Tangier Sound | TANMH | | x | | | x |

Source: U.S. EPA 2003b.

Table B-3. Chesapeake Bay dissolved oxygen criteria.

| Designated Use | Criteria Concentration/Duration | Protection Provided | Temporal Application |
|---|---|---|---|
| Migratory fish spawning and nursery use | 7-day mean $\geq$ 6 mg $liter^{-1}$ (tidal habitats with 0-0.5 ppt salinity) | Survival/growth of larval/juvenile tidal-fresh resident fish; protective of threatened/endangered species. | February 1 - May 31 |
| | Instantaneous minimum $\geq$ 5 mg $liter^{-1}$ | Survival and growth of larval/juvenile migratory fish; protective of threatened/endangered species. | |
| | Open-water fish and shellfish designated use criteria apply | | June 1 - January 31 |
| Shallow-water bay grass use | Open-water fish and shellfish designated use criteria apply | | Year-round |
| Open-water fish and shellfish use | 30-day mean $\geq$ 5.5 mg $liter^{-1}$ (tidal habitats with 0-0.5 ppt salinity) | Growth of tidal-fresh juvenile and adult fish; protective of threatened/endangered species. | Year-round |
| | 30-day mean $\geq$ 5 mg $liter^{-1}$ (tidal habitats with >0.5 ppt salinity) | Growth of larval, juvenile and adult fish and shellfish; protective of threatened/endangered species. | |
| | 7-day mean $\geq$ 4 mg $liter^{-1}$ | Survival of open-water fish larvae. | |
| | Instantaneous minimum $\geq$ 3.2 mg $liter^{-1}$ | Survival of threatened/endangered sturgeon species.[1] | |
| Deep-water seasonal fish and shellfish use | 30-day mean $\geq$ 3 mg $liter^{-1}$ | Survival and recruitment of bay anchovy eggs and larvae. | June 1 - September 30 |
| | 1-day mean $\geq$ 2.3 mg $liter^{-1}$ | Survival of open-water juvenile and adult fish. | |
| | Instantaneous minimum $\geq$ 1.7 mg $liter^{-1}$ | Survival of bay anchovy eggs and larvae. | |
| | Open-water fish and shellfish designated-use criteria apply | | October 1 - May 31 |
| Deep-channel seasonal refuge use | Instantaneous minimum $\geq$ 1 mg $liter^{-1}$ | Survival of bottom-dwelling worms and clams. | June 1 - September 30 |
| | Open-water fish and shellfish designated use criteria apply | | October 1 - May 31 |

[1]At temperatures considered stressful to shortnose sturgeon (>29°C), dissolved oxygen concentrations above an instantaneous minimum 4.3 mg $liter^{-1}$ will protect survival of this listed sturgeon species.

Source: U.S. EPA 2003a.

Table B-4. Summary of Chesapeake Bay water clarity criteria for application to shallow-water bay grass designated use habitats.

| Salinity Regime | Water Clarity Criteria as Percent Light-through-Water (PLW) | Water Clarity Criteria as Secchi Depth[1] | | | | | | | | Temporal Application |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Water Clarity Criteria Application Depths | | | | | | | | |
| | | 0.25 | 0.5 | 0.75 | 1.0 | 1.25 | 1.5 | 1.75 | 2.0 | |
| | | Secchi Depth (meters) for Above Criteria Application Depth | | | | | | | | |
| Tidal fresh | 13% | 0.2 | 0.4 | 0.5 | 0.7 | 0.9 | 1.1 | 1.2 | 1.4 | April 1 - October 31 |
| Oligohaline | 13% | 0.2 | 0.4 | 0.5 | 0.7 | 0.9 | 1.1 | 1.2 | 1.4 | April 1 - October 31 |
| Mesohaline | 22% | 0.2 | 0.5 | 0.7 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | April 1 - October 31 |
| Polyhaline | 22% | 0.2 | 0.5 | 0.7 | 1.0 | 1.2 | 1.4 | 1.7 | 1.9 | March 1 - May 31, September 1 - November 30 |

[1]Based on application of the equation, PLW = 100exp($-K_dZ$), the appropriate PLW criterion value and the selected application depth are inserted and the equation is solved for $K_d$. The generated $K_d$ value is then converted to Secchi depth (in meters) using the conversion factor $K_d$ = 1.45/Secchi depth.

Source: U.S. EPA 2003a.

Table B-5. Recommended Chesapeake Bay chlorophyll *a* narrative criteria.

Concentrations of chlorophyll *a* in free-floating microscopic aquatic plants (algae) shall not exceed levels that result in ecologically undesirable consequences—such as reduced water clarity, low dissolved oxygen, food supply imbalances, proliferation of species deemed potentially harmful to aquatic life or humans or aesthetically objectionable conditions—or otherwise render tidal waters unsuitable for designated uses.

Source: U.S. EPA 2003b.

## LITERATURE CITED

U.S. Environmental Protection Agency. 2003a. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity, and Chlorophyll* a *for Chesapeake Bay and its Tidal Tributaries*. EPA 903-R-03-002. Chesapeake Bay Program Office, Annapolis, Maryland.

U.S. EPA. 2003b. *Technical Support Document for Identification of Chesapeake Bay Designated Uses and Attainability*. EPA 903-R-03-004. Chesapeake Bay Program Office, Annapolis, Maryland.

# appendix C
# Summary of Watershed Model Results for All Loading Scenarios

This appendix describes general assumptions and methodologies applied for several model scenario used in the cap load allocation process including the 2010 Tiers, 2010 "Everything, Everywhere, by Everyone" (E3), 2010 No-BMPs and All-Forest scenarios.

## LEVEL-OF-EFFORT AND E3 SCENARIOS

As described in Chapter 4, the Tier and E3 scenarios were developed by the Chesapeake Bay Program Nutrient Subcommittee's Workgroups to provide reference points of increasing load reductions of nutrients and sediment that could be associated with increasing levels of BMP implementation for both point and non-point sources in the Chesapeake Bay watershed.

The series of ranging scenarios were simulated by the Chesapeake Bay Program's Phase 4.3 Watershed Model and the resultant loads for nitrogen, phosphorus and sediment were used as inputs to the Chesapeake Bay Estuary Model. Evaluation of water clarity, dissolved oxygen and chlorophyll *a* concentrations from the Estuary Model, in turn, provided a sense of the response of key water quality parameters to the various loading levels. For the Tier and E3 scenarios, best management practices (BMP) implementation levels, the resultant modeled loads and the measured responses in tidal water quality are informational. They are not intended to prescribe control measures to meet *Chesapeake 2000* nutrient and sediment loading caps.

Implementation levels in all of the Tiers and E3 scenarios are not cost effective. The most cost effective combinations of BMPs will be evaluated by jurisdictions and their tributary or watershed teams as their tributary strategies are developed. In addition, and as noted in Chapter 4, E3 levels of BMP implementation are theoretical since the scenario, generally, did not account for physical limitations or participation levels in its design.

The Tier and E3 BMP implementation levels were mostly deliberated and set by the "source" workgroups of the Chesapeake Bay Program's Nutrient Subcommittee. These workgroups are made up of representatives of Chesapeake Bay watershed jurisdictions and Chesapeake Bay Program Office personnel. The specific workgroups that decided BMP implementation levels included the Agricultural Nutrient Reduction Workgroup, the Forestry Workgroup, the Point Source Workgroup and the Urban Stormwater Workgroup. The Tributary Strategy Workgroup and Nutrient Subcommittee finalized the E3 scenario definitions after review and further deliberation.

To conform to *Chesapeake 2000* goals, all of the Tier and E3 scenarios were rooted in 2010 projections of landuses, animals, point source flows and septic systems as well as 2007/2010 or 2020 air emission controls. Landuses and animal populations in the Chesapeake Bay Program Watershed Model are developed from an array of national, regional and state databases as described in *Chesapeake Bay Watershed Model Land Use and Model Linkages to the Airshed and Estuarine Models* (CBPO, 2000). The modeled landuses include the following categories:

- Forest
- Conventional-Tilled (High-Till)
- Conservation-Tilled (Low-Till)
- Hay
- Pasture
- Manure Acres (model accounting of runoff from animal feeding operations)
- Pervious Urban
- Impervious Urban
- Mixed Open

2010 agricultural landuses were projected from Agricultural Census information (1982, 1987, 1992 and 1997) by county and according to methodologies chosen by individual states. Projected animal populations, to estimate manure applications, were rooted in county Agricultural Census trends and information from state environmental and agricultural agencies.

2010 urban landuses were mostly projected from a methodology involving human population changes as determined by the U.S. Census Bureau for 1990 and 2000 and by individual state agencies for 2010. The population changes were related to 1990 high-resolution satellite imagery of the Chesapeake Bay watershed which is the root source of urban and forest acreage. In the case of Maryland, urban growth from 2000 to 2010 was determined by Maryland Department of Natural Resources and the Department of Planning.

For all jurisdictions except Maryland and Virginia, 2010 forest and mixed open landuses were determined by proportioning the net change between 2010 and 1990 agricultural and urban land to 1990 mixed open and 1990 forest. Maryland and Virginia forest acreage changes followed methodologies or data submitted by these states.

Estimates of the number of septic systems in the watershed in 2010 were derived from human population projections and people per septic system ratios from the 1990 U.S. Census Bureau survey.

Point sources were divided into categories which included: 1) significant municipal wastewater treatment facilities—discharging flows greater than or equal to 0.5 million gallon per day; 2) significant industrial facilities—discharging flows greater than or equal to 0.5 million gallon per day; and 3) non-significant municipal wastewater treatment facilities—discharging flows less than 0.5 million gallon per day and limited to facilities in Maryland and Virginia due to availability of data.

Point source nitrogen and phosphorus loads from significant and non-significant municipal wastewater treatment facilities were determined using flows projected for the year 2010 for facilities located in all jurisdictions of the Chesapeake Bay watershed. These future flows were developed mostly from population projections. Tier and E3 scenario flows for industrial dischargers remained at 2000 levels.

Treatment technologies for municipal facilities varied among the Tier scenarios to reach and maintain concentrations defined under each Tier scenario description. The treatment technologies included extended aeration processes and denitrification zones, chemical additions, additional clarification tanks, deep bed denitrification filters and micro-filtration. For industrial dischargers, site specific information on reductions by facility was obtained via phone contacts or site visits.

Atmospheric deposition to the Chesapeake Bay watershed and tidal surface waters for all Tier and E3 scenarios employed deposition data from the Regional Acid Deposition Model (RADM), which also provides deposition estimates representing current conditions used for Progress model runs.

## 2010 TIER 1 SCENARIO

2010 Tier 1 BMP implementation levels were generally determined by continuing current levels of effort and cost-share in each Chesapeake Bay watershed jurisdiction. In addition, expected regulatory measures, jurisdictional programs and construction schedules between 2000 and 2010 were included.

### 2010 TIER 1 NON-POINT SOURCE BMPs

For most non-point source BMPs, implementation rates between 1997 and 2000 were continued to the year 2010 with limits that levels could not exceed the available or E3 land area to apply the BMPs to. The scale of the calculations is a county-segment or the intersection of a county political boundary and a Chesapeake Bay watershed model hydrologic segment. This is the same scale that most jurisdictions report BMP implementation levels to the Bay Program office.

Every effort was made to include BMPs submitted by the jurisdictions for progress model runs into Tier 1. Since historic BMP data was not available from New York, Delaware and West Virginia, 2010 Tier 1 projections were determined from watershed-wide implementation rates in states which employ and track the practice.

2010 Tier 1 BMPs were extrapolated from recent implementation rates by the landuse types submitted by the states for each BMP. For example, if a jurisdiction submits data for nutrient management on crop land, 2010 Tier 1 crop land was projected and then split among high-till, low-till and hay according to relative percentages. If a jurisdiction submits data as nutrient management on high-till, low-till and hay individually, projections were done for each of these landuse categories.

The 2010 Tier 1 scenario does not include tree planting on tilled land, forest conservation and forest harvesting practices. These practices are tracked by some jurisdictions and credited in the Watershed Model for progress scenarios, but are not part of the Tiers and E3. For forest harvesting practices and erosion and sediment control, the watershed model simulation does not account for additional loads from disturbed forest and construction areas, respectively. For forest conservation, planting above what is removed during development is accounted for in the 2010 urban and forest projections. Tree planting on agricultural land is included in Tier 1 for pasture as forest buffers since this BMP is also part of the Tier scenarios and E3 and pasture tree planting and pasture buffers are treated the same in the model.

Table C-1 shows Tier 1 watershed-wide BMP implementation levels for all nonpoint source BMPs. The table designates the unit of measure for each BMP and the relevant model landuses that BMPs are applied to by four major categories: agricultural, urban and mixed open, forestry and septic. As references, 2000 nonpoint source BMP implementation levels are listed as well.

## 2010 TIER 1 POINT SOURCE TREATMENT TECHNOLOGIES

- Tier 1 significant municipal wastewater treatment facilities
  - Nitrogen—Existing municipal facilities with nutrient-removal technologies (NRT) and those planned to go to NRT by 2010 are at 2010 projected flows and 8 mg/L total nitrogen effluent concentrations (annual average). All remaining significant facilities are at 2010 projected flows and 2000 total nitrogen effluent concentrations.
  - Phosphorus—2010 projected flows and 2000 total phosphorus effluent concentrations except those targeted in VA which are at 1.5 mg/L total phosphorus effluent concentrations (annual average).
- Tier 1 significant industrial dischargers
  - 2000 flows and 2000 levels of effluent concentrations for total nitrogen and total phosphorus or the permit limit effluent concentration, whichever is less.
- Tier 1 Non-significant municipal wastewater treatment facilities
  - 2000 total nitrogen and total phosphorus effluent concentrations applied to 2010 projected flows.

Table C-1. Chesapeake Bay watershed-wide nonpoint source best management practice implementation levels for 2000, Tier and E3.

| | Unit of Measure | Applicable Landuse | 2000 Progress | 2010 Tier 1 | 2010 Tier 2 | 2010 Tier 3 | 2010 E3 |
|---|---|---|---|---|---|---|---|
| **AGRICULTURAL BMPs** | | | | | | | |
| Conservation Tillage | Acres | Low-Till | 1,994,745 | 1,962,824 | 2,340,908 | 2,300,093 | 2,312,209 |
| Riparian Forest Buffers | Acres | Row Crop, Hay | 9,054 | 30,588 | 133,772 | 206,663 | 494,450 |
| Riparian Forest Buffers | 1-side stream miles, 100 foot width | Row Crop, Hay | 747 | 2,524 | 11,036 | 17,050 | 40,792 |
| Wetland Restoration | Acres | Row Crop, Hay | 1,277 | 2,862 | 10,260 | 17,659 | 25,282 |
| Land Retirement | Acres | Row Crop, Hay | 87,488 | 128,510 | 500,452 | 742,695 | 1,090,540 |
| Grass Buffers | Acres | Row Crop | 4,294 | 15,036 | 71,985 | 113,800 | 0 |
| Tree Planting | Acres | Row Crop, Pasture | 8,568 | 4,142 | 0 | 0 | 0 |
| Riparian Forest Buffers | Acres | Pasture | 0 | 0 | 46,732 | 63,851 | 184,081 |
| Riparian Forest Buffers | 1 side stream miles, 100 foot width | Pasture | 0 | 0 | 3,855 | 5,268 | 15,187 |
| Carbon Sequestration/ Bio Energy | Acres | Row Crop | 0 | 0 | 0 | 509,431 | 770,736 |
| Standard Nutrient Management Plan Implementation | Acres | Row Crop, Hay | 2,283,426 | 3,023,742 | 3,850,244 | 2,967,870 | 0 |
| Yield Reserve Implementation | Acres | Row Crop, Hay | 0 | 0 | 0 | 1,271,944 | 4,830,817 |
| Total Nutrient Management Plan Implementation | Acres | Row Crop, Hay | 2,283,426 | 3,023,742 | 3,850,244 | 4,239,814 | 4,830,817 |
| Farm Plans | Acres | Agriculture | 3,666,165 | 5,075,549 | 5,860,003 | 6,854,953 | 7,202,280 |
| Cover Crops | Acres | Row Crop | 220,134 | 152,766 | 1,544,635 | 2,203,196 | 2,312,209 |
| Stream Protection With Fencing | Acres | Pasture | 40,744 | 69,257 | 171,739 | 580,365 | 712,302 |
| Stream Protection Without Fencing | Acres | Pasture | 26,166 | 27,979 | 83,584 | 63,583 | 0 |
| Grazing Land Protection | Acres | Pasture | 134,327 | 304,868 | 853,863 | 1,394,909 | 2,371,463 |
| Animal Waste Management | Acres | Manure Acres | 4,886 | 6,425 | 6,953 | 7,692 | 8,537 |
| | Animal Units | Manure Acres | 708,498 | 931,677 | 1,008,208 | 1,115,351 | 1,237,801 |
| Manure Excess | Wet Tons As Excreted | N/A | 1,270,139 | 1,927,899 | 2,145,277 | 1,870,085 | 8,856,825 |

*continued*

Table C-1. Chesapeake Bay watershed-wide nonpoint source best management practice implementation levels for 2000, Tier and E3. *(cont)*

| | Unit of Measure | Applicable Landuse | 2000 Progress | 2010 Tier 1 | 2010 Tier 2 | 2010 Tier 3 | 2010 E3 |
|---|---|---|---|---|---|---|---|
| **URBAN AND MIXED OPEN BMPs** | | | | | | | |
| Abandoned Mine Reclamation | Acres | Urban/Exposed | 6,062 | 0 | 0 | 0 | 0 |
| Urban Growth Reduction | Acres | Urban | 38,787 | 0 | 26,096 | 52,192 | 78,288 |
| Riparian Forest Buffers | Acres | Pervious Urban | 0 | 364 | 9,808 | 28,522 | 93,643 |
| | 1 side stream miles, 50 foot width | Pervious Urban | 0 | 60 | 1,618 | 4,706 | 15,451 |
| Grass Buffers | Acres | Pervious Urban | 0 | 95,022 | 84,997 | 65,702 | 0 |
| Storm Water Management on New Development | Acres | Urban | 0 | 153,157 | 207,705 | 183,440 | 159,560 |
| Storm Water Management on Recent Development | Acres | Urban | 165,040 | 374,357 | 373,817 | 373,236 | 0 |
| Storm Water Management on Recent and Old Development | Acres | Urban | 0 | 29,959 | 187,185 | 748,488 | 3,740,806 |
| Total Storm Water Management | Acres | Urban | 165,040 | 557,474 | 768,707 | 1,305,164 | 3,900,366 |
| Erosion and Sediment Control | Acres | Urban | 25,911 | 0 | 0 | 0 | 0 |
| Urban Nutrient Management | Acres | Pervious Urban | 6,608 | 28,630 | 1,055,077 | 1,964,784 | 2,601,733 |
| Tree Planting | Acres | Mixed Open | 22,596 | 44,280 | 0 | 0 | 0 |
| Riparian Forest Buffers | Acres | Mixed Open | 0 | 0 | 54,702 | 73,757 | 413,922 |
| | 1 side stream miles, 100 ft. width | Mixed Open | 0 | 0 | 4,513 | 6,085 | 34,149 |
| Mixed Open Nutrient | Acres | Mixed Open | 0 | 60,791 | 1,997,497 | 3,870,252 | 4,950,621 |

*continued*

Table C-1. Chesapeake Bay watershed-wide nonpoint source best management practice implementation levels for 2000, Tier and E3. *(cont)*

| | Unit of Measure | Applicable Landuse | 2000 Progress | 2010 Tier 1 | 2010 Tier 2 | 2010 Tier 3 | 2010 E3 |
|---|---|---|---|---|---|---|---|
| **FORESTRY BMPs** | | | | | | | |
| Forest Harvesting Practices | Acres | Forest | 67,448 | 0 | 0 | 0 | 0 |
| **SEPTIC BMPs** | | | | | | | |
| Septic Connections | Systems | Septic | 31,514 | 31,514 | 31,514 | 31,514 | 31,514 |
| Septic Pumping | Systems | Septic | 2,954 | N/A | N/A | N/A | N/A |
| Septic Denitrification | Systems | Septic | 312 | 312 | N/A | N/A | N/A |
| Septic Denitrification/Pumping on New and Existing Systems | Systems | Septic | N/A | N/A | 8,305 | 93,014 | 1,357,026 |

## 2010 TIER 1 ATMOSPHERIC DEPOSITION SOURCE CONTROLS

Tier 1 atmospheric deposition assumes implementation of the 1990 Clean Air Act projected for the year 2010 with existing regulations. Air emission source controls for the Tier 1 scenario include the following:

- 2007 non-utility (industrial) point source and area source emissions.
- 2007 mobile source emissions with "Tier II" tail pipe standards on light duty vehicles.
- 2010 utility emissions with Title IV (Acid Rain Program) fully implemented and 20-state nitrogen oxides (NOx) state implementation plan (SIP) call reductions at 0.15 lbs/MMbtu during the May to September ozone season only.

The impacts of Tier 1 emissions and deposition to the Chesapeake Bay watershed's land area and non-tidal waters are part of the reported nutrient loads from the individual landuse source categories, i.e., agriculture, urban, mixed open, forest and non-tidal surface waters). The reported Chesapeake Bay Watershed Model loads; however, usually do not include contributions from atmospheric deposition to tidal waters although the water quality responses, as measured by the Chesapeake Bay Estuary Model, account for this source at levels prescribed by Tier 1.

# 2010 TIER 2 SCENARIO

In the design of the Tier 2 scenario, considerations of the costs of BMP implementation, participation levels and physical limitations are very limited. Tier 2 BMP levels are considered technically possible and generally described below for each of the major source category.

## 2010 TIER 2 NON-POINT SOURCE BMPs

2010 Tier 2 BMP implementation levels for non-point sources were generally determined by increasing levels above Tier 1 by a percentage of the difference between Tier 1 and E3 levels for each BMP with the percentages being lower than those used in Tier 3. These percentages were mostly prescribed by individual source workgroups in the Chesapeake Bay Program Nutrient Subcommittee and were applied watershed-wide by county-segments or the intersections of county political boundaries and the Watershed Model's segments.

Table C-1 shows Tier 2 watershed-wide BMP implementation levels for all nonpoint source BMPs. The table designates the unit of measure for each BMP, the relevant model landuses BMPs are applied to by four major categories: agricultural, urban and mixed open, forestry and septic.

## 2010 TIER 2 POINT SOURCE TREATMENT TECHNOLOGIES

For Tier 2 point source municipal facilities, technologies to achieve 8 mg/L total nitrogen effluent concentration included extended aeration processes and denitrification zones, along with chemical addition to achieve a total phosphorus effluent concentration of 1.0 mg/L where facilities are not already achieving these levels.

- Tier 2 significant municipal wastewater treatment facilities
  - Nitrogen—All significant municipal facilities are at 2010 projected flows and reach and maintain effluent concentrations of 8 mg/L (annual average) including those facilities that planned to go to NRT by 2010.
  - Phosphorus—All significant municipal facilities are at 2010 projected flows and reach and maintain total phosphorus effluent concentrations of 1.0 mg/L (annual average) or the permit limit, whichever is less.
- Tier 2 significant industrial dischargers
  - 2000 flows and generally maintain total nitrogen and phosphorus effluent concentrations that are 50 percent less than those in Tier 1 or the permit limit, whichever is less.
- Tier 2 non-significant municipal wastewater treatment facilities
  - 2000 total nitrogen and total phosphorus effluent concentrations are applied to 2010 projected flows.

## 2010 TIER 2 ATMOSPHERIC DEPOSITION SOURCE CONTROLS

Tier 2 atmospheric deposition assumes implementation of the 1990 Clean Air Act projected for the year 2020 with mobile source controls beyond those in Tier 1. Air emission source controls for the Tier 2 scenario include the following:

- 2020 non-utility (industrial) point source and area source emissions with no additional controls than Tier 1.
- 2020 mobile source emissions with 2020 mobile source emissions with Tier II tail pipe standards on light duty vehicles that are more effective than those in the Tier 1 scenario, as well as heavy duty diesel standards to further reduce NOx emissions.
- 2020 utility emissions with Title IV (Acid Rain Program) fully implemented and 20-state NOx SIP call reductions at 0.15 lbs/MMbtu during the May to September ozone season only—same as Tier 1 controls.

The impacts of Tier 2 emissions and resultant atmospheric deposition to the Chesapeake Bay watershed's land area and non-tidal waters are part of the reported nutrient loads from the individual landuse source categories, i.e., agriculture, urban, mixed open, forest and non-tidal surface waters). The reported Chesapeake Bay Watershed Model loads, however, usually do not include contributions from atmospheric deposition to tidal waters although the water quality responses, as measured by the Chesapeake Bay Estuary Model, account for this source at levels prescribed by Tier 2.

## 2010 TIER 3 SCENARIO

In the Tier 3 scenario, considerations of the costs of BMP implementation, participation levels and physical limitations are very limited. Tier 3 BMP levels are considered technically possible and are generally described below for each of the major source categories.

### 2010 TIER 3 NON-POINT SOURCE BMPs

2010 Tier 3 BMP implementation levels for non-point sources were generally determined by increasing levels above Tier 1 by a percentage of the difference between Tier 1 and E3 levels with the percentages being higher than those used in Tier 2. As with Tier 2, the levels of nonpoint source control were applied watershed-wide by county-segments or the intersections of county political boundaries and the Chesapeake Bay Watershed Model's segments.

Table C-1 shows Tier 3 watershed-wide BMP implementation levels for all nonpoint source BMPs. The table designates the unit of measure for each BMP, the relevant model landuses BMPs are applied to by four major categories: agricultural, urban and mixed open, forestry and septic.

### 2010 TIER 3 POINT SOURCE TREATMENT TECHNOLOGIES

For Tier 3 municipal point source facilities, treatment technologies to achieve 5 mg/L total nitrogen effluent concentration included extended aeration processes beyond those in Tier 2, a secondary anoxic zone plus methanol addition, additional clarification tanks and additional chemicals to achieve a phosphorus effluent concentration of 0.5 mg/L total phosphorus.

- Tier 3 significant municipal wastewater treatment facilities
  - Nitrogen—All significant municipal facilities are at 2010 projected flows and reach and maintain effluent concentrations of 5 mg/L total nitrogen (annual average) including those facilities that planned to go to NRT by 2010.
  - Phosphorus—All significant municipal facilities are at 2010 projected flows and reach and maintain effluent concentrations of 0.5 mg/L total phosphorus effluent concentration (annual average) or the permit limit, whichever is less.
- Tier 3 significant industrial dischargers
  - 2000 flows and generally maintain total nitrogen and phosphorus effluent concentrations that are 80 percent less than those in Tier 1 or the permit limit, whichever is less.
- Tier 3 non-significant municipal wastewater treatment facilities
  - 2000 total nitrogen and total phosphorus effluent concentrations are applied to 2010 projected flows.

## 2010 TIER 3 ATMOSPHERIC DEPOSITION SOURCE CONTROLS

Atmospheric deposition under the Tier 3 scenario reflects existing regulatory nitrogen oxide emissions controls under the 1990 Clean Air Act, as well as more aggressive but voluntary emissions controls on the utility sector, projected for the year 2020. Estimated changes in deposition for the Tier 3 scenario reflect the following controls on nitrogen oxide emissions:

- 2020 non-utility (industrial) point source and area source emissions with no additional controls than Tiers 1 and 2.
- 2020 mobile source emissions with the effect of the Tier II tail pipe standards on light duty vehicles being felt, and the implementation of the heavy duty diesel standards to further reduce $NO_x$ emissions. Same as Tier 2 controls.
- 2020 utility emissions with major (90 percent) reductions in $SO_2$ and aggressive 20-state $NO_x$ SIP call reductions through utilities going to 0.10 lbs/MMbtu for the entire year—no longer just seasonal.

The impacts of emissions and deposition to the Chesapeake Bay watershed's land area and non-tidal waters under the Tier 3 scenario are part of the reported nutrient loads from the individual landuse source categories (i.e., agriculture, urban, mixed open, forest, and non-tidal surface waters). The reported loads, however, usually do not include contributions from atmospheric deposition to tidal waters although the water quality responses, as measured by the Water Quality Model, account for this source at levels prescribed by the Tier 3 scenario.

## 2010 E3 SCENARIO

BMP implementation levels in the Tier scenarios were bounded by levels of E3, which is specifically designed to take out most of the subjectivity surrounding what can or cannot be achieved in control measures. The particular definitions of E3 BMP implementation levels are, in part, rooted in earlier work of the Chesapeake Bay Program when a limit-of-technology condition was assessed by the Tributary Strategy Workgroup. However, E3 is less subjective than the previous limit-of-technology scenarios in its determinations of maximum implementation levels.

The BMP levels in E3 are theoretical. There are no cost and few physical limitations to implementing BMPs for point and non-point sources. As discussed in Chapter 4, E3 implementation levels and their associated reductions in nutrients and sediment could not be achieved for many BMPs when considering physical limitations and participation levels. However, there are some control measures in E3 that physically could be more aggressive. The E3 conditions for these BMPs were established because a theoretical maximum implementation level would have been entirely subjective. Finally, E3 includes new BMP technologies and programs that are not currently part of jurisdictional pollutant control strategies. BMP implementation levels for the E3 scenario are generally described below for nonpoint and point source categories.

## 2010 E3 NON-POINT SOURCE BMPs

For most non-point source BMPs, it is assumed that the load from every available acre of the relevant land area is being controlled by a full suite of existing or innovative practices. In addition, management programs convert landuses from those with high-yielding nutrient and sediment loads to those with lower yields. Table C-1 shows E3 watershed-wide BMP implementation levels for all nonpoint source BMPs. The table designates the unit of measure for each BMP and the relevant model landuses that BMPs are applied to by four major categories: agricultural, urban and mixed open, forestry and septic.

## 2010 E3 POINT SOURCE TREATMENT TECHNOLOGIES

For point sources in E3, municipal wastewater treatment facilities reach and maintain effluent concentrations of 3 mg/L total nitrogen and at least 0.1 mg/L total phosphorus through technologies such as deep bed denitrification filters and micro-filtration.

- E3 significant municipal wastewater treatment facilities
  - Nitrogen—Significant municipal facilities are at 2010 projected flows and reach and maintain total nitrogen effluent concentrations of 3 mg/L (annual average) including those facilities that planned to go to NRT by 2010.
  - Phosphorus—Significant municipal facilities are at 2010 projected flows and reach and maintain total phosphorus effluent concentrations of 0.1 mg/L (annual average).
- E3 significant industrial dischargers
  - Nitrogen—2000 flows and total nitrogen effluent concentrations of 3 mg/L (annual average).
  - Phosphorus—2000 flows and total phosphorus effluent concentrations of 0.1 mg/L (annual average) or the permit limit, whichever is less.
- E3 non-significant municipal wastewater treatment facilities
  - Nitrogen—Non-significant municipal facilities are at 2010 projected flows and reach and maintain total nitrogen effluent concentrations of 8 mg/L (annual average).
  - Phosphorus—Non-significant municipal facilities are at 2010 projected flows and reach and maintain total phosphorus effluent concentrations of 2.0 mg/L (annual average) or 2000 concentrations, whichever is less.

## 2010 E3 ATMOSPHERIC DEPOSITION SOURCE CONTROLS

E3 atmospheric deposition assumes implementation of the 1990 Clean Air Act projected for the year 2020 with aggressive controls on utilities, industry and mobile sources. Air emission source controls for the E3 scenario include the following:

- 2020 non-utility (industrial) point source emissions cut almost in half for both $SO_2$ and NOx.
- 2020 area source emissions that are the same as Tiers 1-3.

- 2020 mobile source emissions assuming super ultra-low emissions for light duty vehicles and heavy duty diesel standards to further reduce NOx emissions beyond Tier 2 and Tier 3.
- 2020 utility emissions with major (90 percent) reductions in $SO_2$ and aggressive 20-state NOx SIP call reductions through utilities going to 0.10 lbs/MMbtu for the entire year—same as Tier 3 controls.

The impacts of E3 emissions and resultant atmospheric deposition to the Chesapeake Bay watershed's land area and non-tidal waters are part of the reported nutrient loads from the individual landuse source categories, i.e., agriculture, urban, mixed open, forest and non-tidal surface waters. The reported Chesapeake Bay Watershed Model loads, however, usually do not include contributions from atmospheric deposition to tidal waters although the water quality responses, as measured by the Chesapeake Bay Estuary Model, account for this source at levels prescribed by E3.

## BASINWIDE LOADS FOR 2000, TIERS 1-3 AND E3

Figures C-1 through C-3 depict Chesapeake Bay watershed modeled basinwide nutrient and sediment loads delivered to the Chesapeake Bay and its tidal tributaries by major source category for each of the Tier scenarios as well as E3. As references, the model estimated loads for the year 2000 are also portrayed.

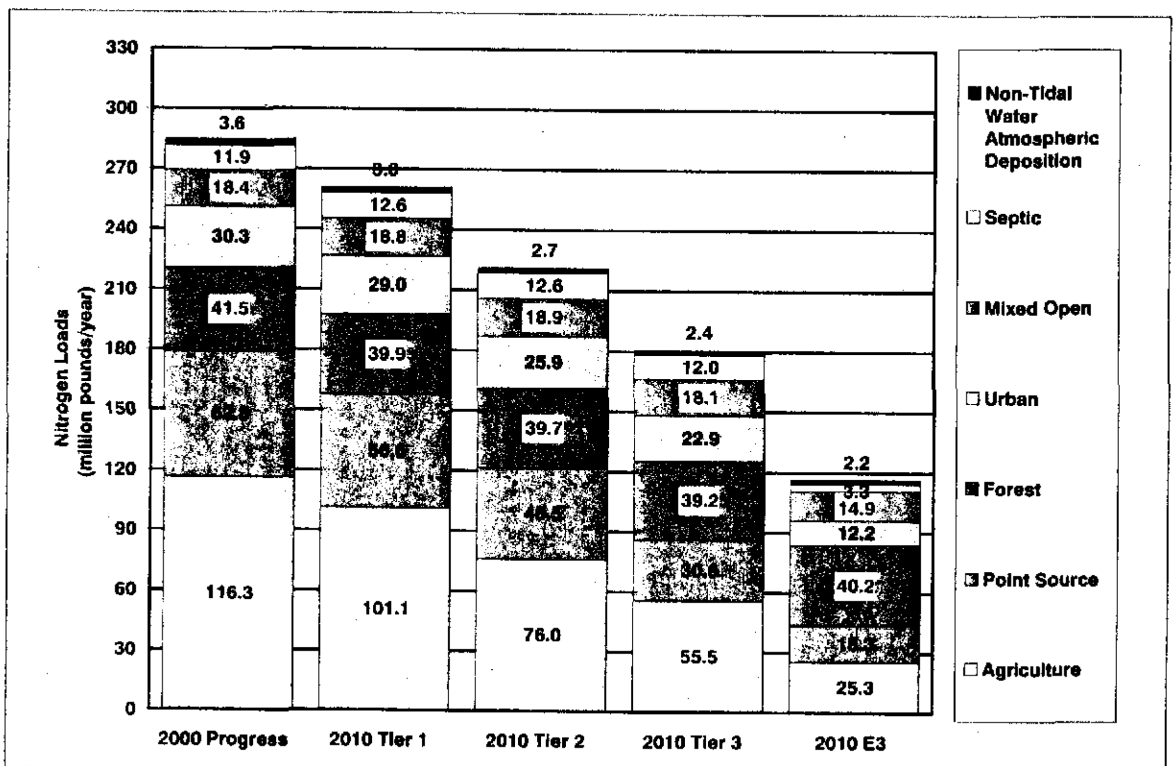


Figure C-1. Chesapeake Bay Watershed Model-estimated nitrogen loads delivered to the Chesapeake Bay and its tidal tributaries by source.

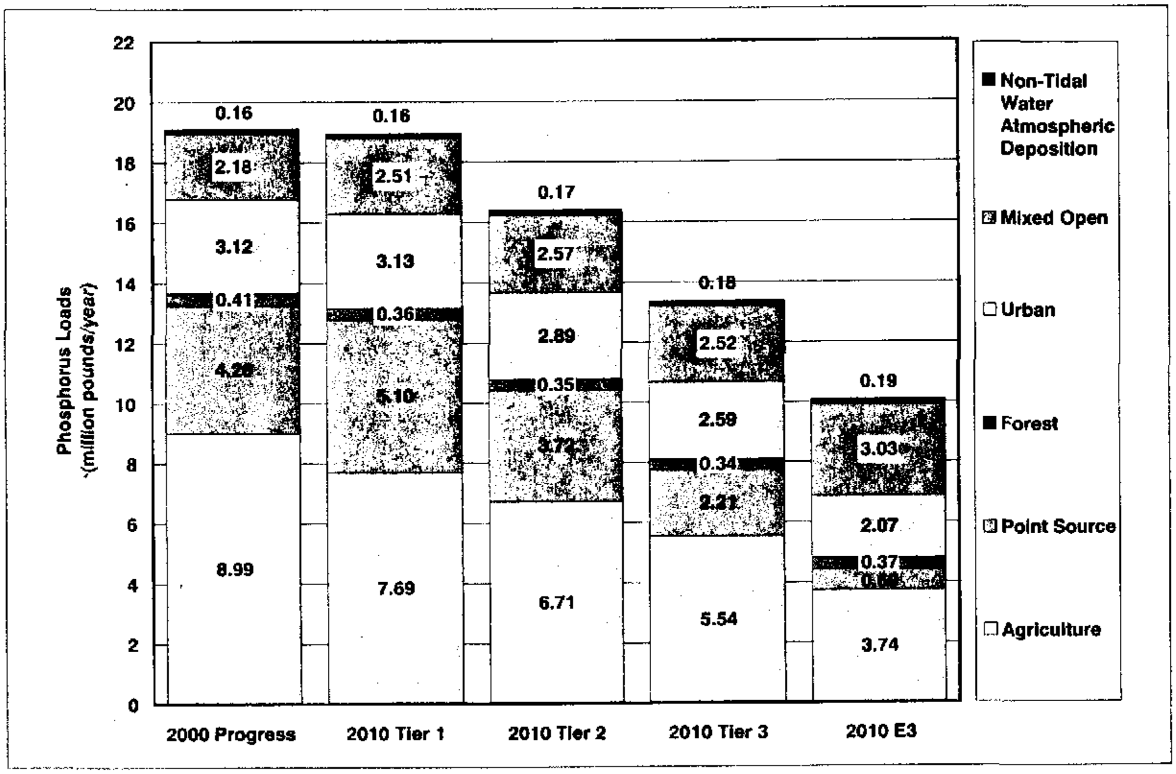


Figure C-2. Chesapeake Bay Watershed Model-estimated phosphorus loads delivered to the Chesapeake Bay and its tidal tributaries by source.

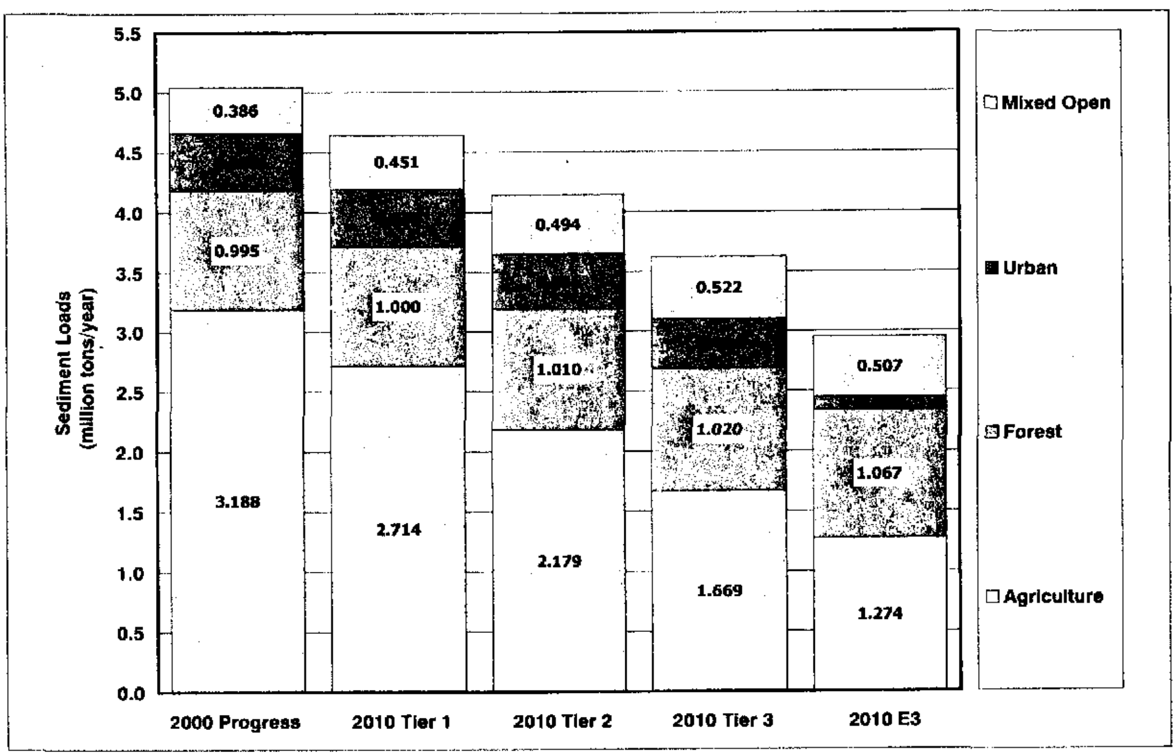


Figure C-3. Chesapeake Bay Watershed Model-estimated land-based sediment loads delivered to the Chesapeake Bay and its tidal tributaries by source.

As is common for reporting purposes, the model-estimated delivered loads are a yearly average of loads simulated over a 10-year period (1985-1994). This removes considerations of the effects of variable precipitation levels or flows on loads. Also, nutrient loads are reported in units of million pounds per year while sediment fluxes are in million tons per year.

Load reductions through the Tiers to E3 show the impact of most point and non-point source BMPs employed in the design of the scenarios. For nonpoint sources, the influence of generally increasing BMPs listed in Table C-1 is depicted in the nutrient and sediment load reductions for the three relevant source categories: agriculture, urban and mixed open and septic. For point sources, the impact of lower effluent concentrations through the Tier to E3 yields the point source reductions shown in Figures C-1 and C-2.

Atmospheric deposition to the Chesapeake Bay watershed's land area and non-tidal surface waters are part of the reported loads but the loads do not include contributions from atmospheric deposition direct to tidal surface waters. In addition, the reported loads do not reflect shoreline erosion controls employed in the scenarios. The water quality responses as measured by the Chesapeake Bay Estuary Model, however, account for both atmospheric deposition to tidal waters and shoreline erosion at levels prescribed for the Tiers and E3.

It is important to note that landuses and animal populations change considerably between 2000 Progress and the Tiers and E3, which are rooted in projected 2010 landuses and populations. Therefore, nutrient applications to agricultural land change considerably over the decade. Also, the number of septic systems and the flows from municipal wastewater treatment facilities shift dramatically from 2000 to 2010 based on an increasing population. For example, point source phosphorus loads increase from 2000 to 2010 Tier 1 because of increases in municipal facility flows which, unlike nitrogen, are not offset by technologies to reduce this nutrient in effluents.

In addition to changes between 2000 and the 2010 Tier and E3 scenarios, it is imperative to consider landuse changes among the Tiers and E3 due to increasing non-point source BMP implementation levels. For example, sediment loads from forested land increase through the Tiers to E3 because the land area increases as, for example, more and more riparian buffers are planted on agricultural and urban land. In addition, increases in loads from mixed open land is attributable to greater acreage in this category as, for example, agricultural land is retired.

## INFLUENCE OF AIR EMISSION CONTROLS AND ATMOSPHERIC DEPOSITION ON LOADS

The impacts of emission controls and the resultant lower atmospheric deposition to the Chesapeake Bay watershed's land area and non-tidal surface waters are part of the reported nutrient loads from the individual landuse source categories in the Tiers and E3, i.e., agriculture, urban, mixed open, forest and non-tidal surface waters. As mentioned previously, the reported loads; however, usually do not include contributions from atmospheric deposition to tidal surface waters although the water quality responses account for this source.

To estimate the effects of only the Tier and E3 emission controls, i.e., without the influences of other point and non-point source BMPs, the histograms in Figure C-4 show changes in atmospheric deposition of nitrogen to the watershed's land area and non-tidal surface waters and the response in delivered loads. In this model study, all landuses, fertilizer applications, point sources, septic loads and BMP implementation levels were held constant at 2000 conditions. Only atmospheric deposition varied.

What the deposition scenarios say, for example, is "If projected emission and deposition reductions associated with the Tiers and E3 were realized today (2000), loads to the Chesapeake Bay and its tidal tributaries are estimated to be the following." For references, reported Tier 1 and Tier 2 loads from the watershed are also shown in the graphics.

As can be seen in Figure C-4, atmospheric deposition to the watershed progressively declines from 2000 through the Tiers to E3 as more air emission controls are included in the model simulation. Loads from the watershed land area and non-tidal surface waters respond to these progressive emission and deposition reductions, but to a much smaller degree.

The most significant reason for the dampened response is that the Chesapeake Bay watershed is about 57 percent forested, or 57 percent of atmospheric deposition falls on forests. Among landuses, forests have the greatest potential to uptake nitrogen as, generally, forests in the Bay basin are not nitrogen-sensitive.

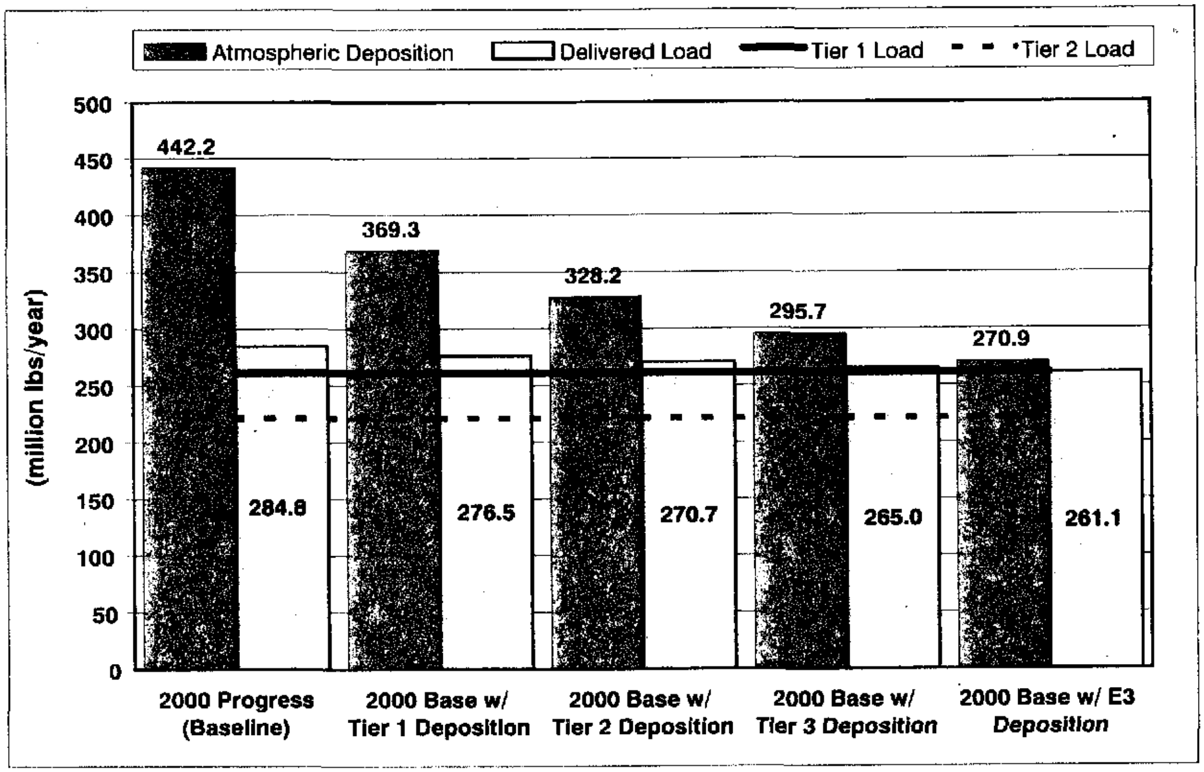


Figure C-4. Chesapeake Bay Watershed Model-estimated nitrogen deposition versus delivered loads—2000 baseline with Tier and E3 emission controls.

It is the impacts of emission controls on delivered loads that are important in the establishment of tributary strategies—rather than the contribution to loads from atmospheric deposition. Understanding the loading responses to changes in deposition better addresses to what degree the loads can be controlled. The proportion of the loads attributed to atmospheric deposition changes dramatically from 2000 through the Tiers and E3 because of both variable air emission controls and changes in landuses that the atmospheric flux is deposited to.

In the most dramatic case, atmospheric deposition of nitrogen to the watershed decreases 171 million lbs/year from 2000 to 2010 E3. If this reduction in deposition were realized today, (i.e., deposition was to 2000 landuses with all other present conditions), nitrogen loads to the Chesapeake Bay and its tidal tributaries would decrease 21 million lbs/year or would be at levels associated with the Tier 1 scenario.

It is important to note that E3 levels of emission controls are considered to be the current limits of technology with aggressive controls on all major sources of technology with aggressive controls on all major sources utilities, mobile and industrial. E3 emission controls are voluntary, as opposed to regulatory and follow the format of defining other E3 point and nonpoint source BMPs in that implementation levels did not consider physical limitations, participation rates and costs. As has been described previously, the intent of the Tiers is not to establish what can and cannot be done through management actions, either regulatory or voluntary, as this is the responsibility of Bay watershed jurisdictions.

## LITERATURE CITED

Chesapeake Bay Program Office (CBPO). 2000. *Chesapeake Bay Watershed Model Land Use and Model Linkages to the Airshed and Estuarine Models*. Prepared by the Chesapeake Bay Program Modeling Subcommittee. Annapolis, Maryland.

# appendix D
# Summary of Key Water Quality Attainment Scenarios

Table D-1. Key scenario descriptions.

| | |
|---|---|
| Observed | 1984–1994 Chesapeake Bay water quality monitored conditions. |
| Progress 2000 | *Model estimated conditions* resulting from implementation of BMPs and treatment technologies in place in 2000 |
| Tier 1 | Model estimated conditions resulting from implementation of Tier 1 BMPs and treatment technology implementation levels. |
| Tier 2 | Model estimated conditions resulting from implementation of Tier 2 BMPs and treatment technology implementation levels. |
| Tier 3 | Model estimated conditions resulting from implementation of Tier 3 BMPs and treatment technology implementation levels; same as Option 3 cap load allocation. |
| Tier 3 + 20% | Tier 3 model estimated conditions plus a 20 percent reduction in shoreline/nearshore sediment loads. |
| Tier 3 + 50% | Tier 3 model estimated conditions plus a 50 percent reduction in shoreline/nearshore sediment loads. |
| Option 4 | Option 4 cap load allocation model estimated conditions. |
| Confirm | Confirmation of agreed to nutrient and sediment cap load allocations model estimated conditions. |
| Confirm + 10 | Confirmation *scenario model estimated* conditions plus a 10 percent reduction in shoreline/nearshore sediment loads. |
| Confirm + 20 | Confirmation scenario model estimated conditions plus a 20 percent reduction in shoreline/nearshore sediment loads. |
| Allocation | Selected cap load allocation option (175 million pounds nitrogen/12.8 million pounds phosphorus) model estimated conditions. |
| Option 1 | Option 1 cap load allocation model estimated conditions. |
| Option 5 | Option 5 cap load allocation model estimated conditions. |
| E3 | E3 scenario model estimated conditions. |
| All Forest | All forested watershed scenario model estimated conditions. |
| Pristine | Pristine watershed scenario model estimated conditions. |

Table D-2. Key scenario summary of dissolved oxygen criteria attainment.*

| Segment | DU | Observed | Progress 2000 | Tier 1 | Tier 2 | Tier 3 (181) | Tier 3 + 20% | Tier 3 + 50% | Opt4 (188) | Confirm (175) | Confirm + 10 | Confirm + 20 | Allocation (175) | Opt1 (160) | Opt5 (198) | E3 | All Forest | Pristine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mainstem Upper Bay (CB1TF) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Upper Bay (CB2OH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 1.92 | 0.88 | 0.68 | 0.43 | 0.17 | 0.13 | 0.07 | 0.14 | 0.12 | 0.10 | 0.10 | 0.08 | 0.04 | 0.14 | A | A | A |
| Mainstem Upper Bay (CB3MH) | MIG | 0.19 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | DW | 4.18 | 2.52 | 2.24 | 1.61 | 0.73 | 0.54 | 0.37 | 0.61 | 0.54 | 0.44 | 0.40 | 0.38 | 0.17 | 0.67 | A | A | A |
| | DC | 13.52 | 8.16 | 7.21 | 5.03 | 1.84 | 1.24 | 0.11 | 1.46 | 0.67 | 0.31 | 0.22 | 0.12 | A | 1.68 | A | A | A |
| Mainstem Mid-Bay (CB4MH) | OW | 0.05 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | DW | 19.64 | 15.28 | 14.28 | 12.05 | 8.51 | 7.57 | 5.62 | 7.89 | 7.08 | 6.68 | 6.32 | 5.96 | 3.90 | 8.24 | 0.69 | A | A |
| | DC | 45.19 | 32.75 | 28.94 | 18.81 | 3.93 | 2.69 | 1.00 | 3.17 | 1.79 | 1.44 | 1.24 | 1.02 | 0.33 | 3.84 | A | A | A |
| Mainstem Mid-Bay (CB5MH) | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | DW | 6.16 | 4.38 | 3.75 | 2.58 | 1.08 | 1.00 | 0.72 | 1.10 | 0.82 | 0.80 | 0.76 | 0.72 | 0.31 | 1.17 | A | A | A |
| | DC | 13.79 | 7.76 | 6.00 | 2.59 | 0.15 | 0.14 | 0.11 | 0.24 | 0.09 | 0.09 | 0.09 | 0.08 | 0.01 | 0.32 | A | A | A |
| Mainstem Lower Bay (CB6PH) | OW | 5.87 | 4.26 | 3.68 | 2.71 | 1.30 | 1.23 | 0.99 | 1.39 | 1.07 | 1.05 | 1.01 | 0.97 | 0.51 | 1.58 | 0.01 | A | A |
| | DW | 0.36 | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB7PH) | OW | 4.55 | 3.31 | 2.81 | 1.82 | 0.74 | 0.66 | 0.49 | 0.78 | 0.57 | 0.55 | 0.52 | 0.50 | 0.22 | 0.93 | A | A | A |
| | DW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB8PH) | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Patuxent Tidal Fresh (PAXTF) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | 0.01 | 0.03 |
| | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | 0.38 | 15.14 | 19.13 |
| Patuxent Mid-Estuary (PAXOH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 9.79 | 1.56 | 1.84 | 1.62 | 0.86 | 0.36 | 0.11 | 0.36 | 0.06 | 0.05 | 0.03 | 0.09 | 0.01 | 0.38 | A | A | 0.15 |
| Patuxent Lower Estuary (PAXMH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A A | |
| | OW | 7.40 | 1.59 | 1.69 | 1.04 | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A |
| | DW | 5.52 | 0.85 | 0.82 | 0.50 | 0.07 | 0.02 | A | 0.02 | A | A | A | A | A | 0.03 | A | A | A |
| Potomac Tidal Fresh (POTTF) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Potomac Mid-Estuary (POTOH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 2.10 | 1.36 | 1.08 | 0.63 | 0.31 | 0.30 | 0.25 | 0.31 | 0.24 | 0.17 | 0.15 | 0.18 | 0.08 | 0.32 | 0.01 | A | A |
| Potomac Lower Estuary (POTMH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 0.78 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | DW | 6.90 | 5.03 | 4.53 | 3.11 | 1.12 | 0.70 | 0.15 | 0.87 | 0.67 | 0.40 | 0.33 | 0.26 | A | 0.95 | A | A | A |
| | DC | 18.89 | 11.39 | 8.64 | 5.07 | 0.19 | 0.17 | 0.16 | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 | 0.11 | 0.17 | A | A | A |
| Rappahannock Tidal Fresh (RPPTF) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Rappahannock Mid-Estuary (RPPOH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Rappahanock Lower Estuary (RPPMH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 0.44 | 0.27 | 0.10 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | DW | 5.58 | 2.61 | 1.09 | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | DC | 6.39 | 5.20 | 3.38 | 1.65 | A | A | A | A | A | A | A | A | A | A | A | A | A |

*continued*

| Segment | DU | Observed | Progress 2000 | Tier 1 | Tier 2 | Tier 3 (181) | Tier 3 + 20% | Tier 3 + 50% | Opt4 (188) | Confirm (175) | Confirm + 10 | Confirm + 20 | Allocation (175) | Opt1 (160) | Opt5 (198) | E3 | All Forest | Pristine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| York Lower Estuary Piankatank (PIAMH) | OW | 0.12 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Tidal Fresh Mattaponi (MPNTF) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 33.26 | 27.37 | 25.87 | 27.23 | 33.73 | 32.44 | 30.50 | 34.44 | 40.58 | 39.64 | 36.53 | 34.44 | 34.44 | 22.51 | 52.14 | 63.65 | 64.72 |
| York Mid-Estuary Mattaponi (MPNOH) | MIG | A | A | A | 1.72 | 2.78 | 2.40 | 1.79 | 1.34 | 2.34 | 2.34 | 2.34 | 1.34 | 1.34 | A | 6.08 | 4.77 | 3.98 |
| | OW | 46.88 | 31.00 | 28.95 | 31.86 | 28.99 | 26.88 | 19.11 | 24.25 | 29.83 | 29.85 | 29.36 | 24.17 | 23.72 | 22.63 | 48.11 | 56.07 | 58.52 |
| York Tidal Fresh Pamunkey (PMKTF) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | 0.10 | 4.28 | 4.28 |
| | OW | 62.25 | 49.53 | 42.07 | 30.35 | 32.94 | 21.16 | 10.32 | 21.77 | 36.67 | 29.48 | 25.80 | 21.77 | 21.77 | 28.81 | 54.50 | 81.08 | 80.84 |
| York Mid-Estuary Pamunkey (PMKOH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 42.15 | 15.22 | 12.66 | 13.86 | 10.32 | 4.52 | 1.06 | 4.96 | 11.32 | 10.21 | 9.73 | 4.92 | 4.88 | 6.21 | 11.39 | 24.27 | 32.26 |
| York Lower Estuary (YRKMH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 18.08 | 4.85 | 3.31 | 2.32 | 0.42 | 0.23 | 0.03 | 0.42 | 0.21 | 0.20 | 0.20 | 0.15 | A | 0.29 | A | A | A |
| York Lower Estuary (YRKPH) | OW | 1.48 | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | DW | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary Mobjack (MOBPH) | OW | 2.30 | 1.78 | 1.60 | 1.10 | 0.34 | 0.29 | 0.23 | 0.38 | 0.27 | 0.26 | 0.25 | 0.25 | 0.16 | 0.56 | A | A | A |
| James Tidal Fresh (JMSTF) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 0.66 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Mid-Estuary (JMSOH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Lower Estuary (JMSMH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Lower Estuary (JMSPH) | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Eastern Bay (EASMH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | DW | 3.26 | 2.18 | 2.00 | 0.90 | 0.36 | 0.32 | 0.20 | 0.32 | 0.29 | 0.27 | 0.28 | 0.27 | 0.14 | 0.34 | A | A | A |
| | DC | 20.23 | 12.87 | 11.26 | 6.49 | 0.67 | 0.10 | 0.01 | 0.18 | 0.20 | 0.08 | 0.02 | 0.02 | A | 0.22 | A | A | A |
| Choptank Mid-Estuary (CHOOH) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 0.14 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Choptank Lower Estuary (CHOMH1) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 2.27 | 1.83 | 1.78 | 1.51 | 1.08 | 0.92 | 0.74 | 0.97 | 0.94 | 0.88 | 0.83 | 0.78 | 0.65 | 1.00 | 0.43 | A | A |
| Choptank Lower Estuary (CHOMH2) | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 0.33 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Tangier Sound (TANMH) | OW | 0.15 | 0.06 | 0.06 | 0.05 | 0.36 | 0.31 | 0.84 | 0.33 | 0.31 | 0.29 | 0.29 | 0.31 | 0.28 | 0.35 | 0.22 | 0.20 | 0.35 |
| Pocomoke (POCMH) | OW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Chester Lower (CHSMH)** | MIG | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | OW | 5.67 | 4.71 | 4.56 | 3.56 | 2.54 | 2.42 | 1.69 | 2.42 | 2.13 | 2.06 | 1.90 | 1.74 | 1.42 | 2.42 | 0.86 | A | A |
| | DW | 0.85 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | DC | 11.80 | 3.98 | 2.89 | 0.85 | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Elizabeth River (ELIPH)** | OW | 3.05 | A | A | A | A | A | A | A | A | A | A | A | A | A | A | 2.22 | 6.48 |
| | DW | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| South Branch Elizabeth (SBEMH)** | OW | 59.51 | 58.86 | 58.67 | 60.37 | 57.71 | 56.71 | 56.39 | 56.81 | 58.67 | 58.58 | 58.47 | 56.80 | 56.80 | 60.73 | 56.20 | 50.31 | 53.63 |

* 4/1/03, Version 15 — Changes since version 12: SAV Re-calibration, Wetlands Oxygen Demand, No Seasonal Anoxic Zone

** for information purposes only, model not sufficiently calibrated for these areas

D4

Table D-3. Key scenario summary of chlorophyll a criteria attainment.*

| Segment | Season | Observed | Progress 2000 | Tier 1 | Tier 2 | Tier 3 (181) | Tier 3 + 20% | Tier 3 + 50% | Opt4 (188) | Confirm (175) | Confirm + 10 | Confirm + 20 | Allocation (175) | Opt1 (160) | E3 | Pristine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mainstem Upper Bay (CB1TF) | Spring | 2.51 | 0.88 | 0.21/ | A/ | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 0.39 | 0.36 | 0.39 | 0.37 | 0.35 | 0.37 | 0.41 | 0.37 | 0.38 | 0.40 | 0.40 | 0.36 | 0.30 | A | A |
| Mainstem Upper Bay (CB2OH) | Spring | 0.70 | 0.54 | 0.57 | 0.51 | 0.29 | 0.02 | A | 0.02 | 0.23 | 0.10 | 0.01 | A | A | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Upper Bay (CB3MH) | Spring | 1.13 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 5.71 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Mid-Bay (CB4MH) | Spring | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 3.09 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Mid-Bay (CB5MH) | Spring | 4.35 | 0.16 | 0.13 | 0.07 | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB6PH) | Spring | 10.38 | 6.97 | 5.50 | 3.18 | 0.40 | 0.22 | A | 0.30 | 0.31 | 0.24 | 0.14 | A | A | A | A |
| | Summer | 0.47 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB7PH) | Spring | 7.81 | 6.62 | 5.31 | 3.31 | 2.06 | 1.79 | 0.18 | 1.94 | 1.87 | 1.75 | 1.62 | 1.52 | 0.03 | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB8PH) | Spring | 9.28 | 4.16 | 3.45 | 0.01 | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Patuxent Tidal Fresh (PAXTF) | Spring | 3.61 | 3.35 | 3.15 | 3.78 | 3.84 | 4.26 | 3.62 | 4.26 | 3.35 | 3.57 | 3.59 | 4.01 | 3.62 | 0.73 | A |
| | Summer | 47.01 | 42.60 | 42.90 | 46.93 | 44.09 | 48.26 | 47.20 | 48.26 | 44.06 | 45.93 | 47.55 | 47.02 | 45.49 | 29.78 | A |
| Patuxent Mid-Estuary (PAXOH) | Spring | 0.43 | 0.93 | 1.57 | 1.17 | 0.92 | 1.55 | 0.35 | 1.56 | 0.24 | 0.46 | 0.63 | 1.10 | 0.48 | 0.09 | A |
| | Summer | 18.49 | 20.92 | 20.98 | 21.32 | 20.12 | 23.88 | 22.04 | 23.90 | 19.51 | 20.74 | 21.56 | 22.88 | 22.15 | 12.98 | A |
| Patuxent Lower Estuary (PAXMH) | Spring | 2.93 | 0.17 | 0.57 | 0.21 | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 11.79 | 5.36 | 5.24 | 2.60 | 1.06 | 0.20 | A | 0.22 | A | A | A | A | A | A | A |
| Potomac Tidal Fresh (POTTF) | Spring | 0.55 | 0.54 | 0.55 | 0.56 | 0.55 | 0.54 | 0.53 | 0.54 | 0.55 | 0.55 | 0.55 | 0.53 | 0.53 | A | A |
| | Summer | 16.76 | 11.41 | 8.76 | 7.11 | 1.76 | A | A | A | 10.87 | 5.14 | 1.82 | A | A | 0.97 | A |
| Potomac Mid-Estuary (POTOH) | Spring | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 0.09 | 0.04 | 0.07 | 0.05 | A | A | A | A | 0.01 | 0.01 | A | A | A | A | A |
| Potomac Lower Estuary (POTMH) | Spring | 7.96 | 4.20 | 4.12 | 3.14 | 1.53 | 1.53 | 0.58 | 1.53 | 0.70 | 0.66 | 0.62 | 0.65 | A | A | A |
| | Summer | 3.11 | 1.58 | 0.49 | 0.06 | A | A | A | A | A | A | A | A | A | A | A |
| Rappahannock Tidal Fresh (RPPTF) | Spring | 0.66 | 0.54 | 0.07 | 0.12 | 0.24 | 0.22 | 0.10 | 0.22 | 0.25 | 0.25 | 0.25 | 0.22 | 0.22 | A | A |
| | Summer | 36.03 | 16.06 | 11.04 | 2.73 | A | A | A | A | A | A | A | A | A | A | A |
| Rappahannock Mid-Estuary (RPPOH) | Spring | 0.61 | A | A | A | A | A | A | A | A | A | A | A | A | A | 0.43 |
| | Summer | 2.01 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Rappahanock Lower Estuary (RPPMH) | Spring | 0.70 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary Piankatank (PIAMH) | Spring | 4.72 | 0.49 | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 2.37 | 0.49 | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Tidal Fresh Mattaponi (MPNTF) | Spring | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 0.49 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |

*continued*

| Segment | Season | Observed | Progress 2000 | Tier 1 | Tier 2 | Tier 3 (181) | Tier 3 + 20% | Tier 3 + 50% | Opt4 (188) | Confirm (175) | Confirm + 10 | Confirm + 20 | Allocation (175) | Opt1 (160) | E3 | Pristine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| York Mid-Estuary Mattaponi (MPNOH) | Spring | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Tidal Fresh Pamunkey (PMKTF) | Spring | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Mid-Estuary Pamunkey (PMKOH) | Spring | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary (YRKMH) | Spring | 1.99 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 2.06 | 0.50 | 0.14 | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary (YRKPH) | Spring | 12.36 | 2.05 | 0.70 | 0.32 | 0.01 | A | A | 0.04 | 0.06 | 0.03 | 0.01 | 0.01 | 0.01 | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary Mobjack (MOBPH) | Spring | 4.86 | 2.29 | 0.96 | 0.03 | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 0.17 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Tidal Fresh (JMSTF) | Spring | 18.40 | 4.28 | 5.03 | 1.37 | A | A | A | 0.25 | 0.06 | 0.03 | 0.02 | 0.25 | 0.25 | A | A |
| | Summer | 44.31 | 19.80 | 28.86 | 8.88 | A | A | A | 3.40 | 1.45 | 0.90 | 0.38 | 3.40 | 3.40 | A | A |
| James Mid-Estuary (JMSOH) | Spring | 10.13 | 0.54 | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 0.33 | 0.38 | 0.39 | 0.31 | A | A | A | 0.24 | 0.19 | 0.18 | 0.18 | 0.24 | 0.24 | A A | |
| James Lower Estuary (JMSMH) | Spring | 5.20 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Lower Estuary (JMSPH) | Spring | 26.27 | 18.87 | 16.83 | 8.55 | 0.07 | A | A | 5.89 | 2.25 | 1.92 | 1.58 | 2.78 | 2.67 | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Eastern Bay (EASMH) | Spring | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 9.37 | 0.71 | 0.43 | 0.17 | 0.05 | A | A | A | A | A | A | A | A | A | A |
| Choptank Mid-Estuary (CHOOH) | Spring | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 14.34 | 13.91 | 11.88 | 9.30 | 7.54 | 7.62 | 3.21 | 7.71 | 7.52 | 7.43 | 7.27 | 6.13 | 4.87 | 1.94 | A |
| Choptank Lower Estuary (CHOMH2) | Spring | 1.01 | 0.03 | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 9.56 | 3.02 | 0.40 | 0.13 | A | A | A | A | A | A | A | A | A | A | A |
| Choptank Lower Estuary (CHOMH1) | Spring | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 0.30 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Tangier Sound (TANMH) | Spring | 2.05 | 0.03 | 0.02 | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Pocomoke (POCMH) | Spring | 0.23 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| | Summer | 3.15 | 0.30 | 0.18 | A | A | A | A | A | A | A | A | A | A | A | A |

* 4/1/03, Version 15 — Changes since version 12: SAV Re-calibration, Wetlands Oxygen Demand, No Seasonal Anoxic Zone

Table D-4. Key scenario summary of water clarity criteria attainment at maximum depths.*

| Segment | Observed | Progress 2000 | Tier 1 | Tier 2 | Tier 3 (181) | Tier 3 + 20% | Tier 3 + 50% | Opt4 (188) | Confirm (175) | Confirm + 10 | Confirm + 20 | Allocation (175) | Opt1 (160) | E3 | Pristine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mainstem Upper Bay (CB1TF) | 75.37 | 75.32 | 75.31 | 74.18 | 65.08 | 54.87 | 41.09 | 54.87 | 73.19 | 68.43 | 64.05 | 52.58 | 50.16 | 58.05 | 0.07 |
| Mainstem Upper Bay (CB2OH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Upper Bay (CB3MH) | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Mid-Bay (CB4MH) | 72.64 | 57.26 | 54.58 | 49.45 | 40.38 | 26.26 | 6.86 | 26.37 | 42.45 | 35.89 | 29.94 | 23.20 | 19.97 | 25.98 | A |
| Mainstem Mid-Bay (CB5MH) | 60.81 | 39.64 | 37.34 | 31.81 | 24.69 | 11.18 | 0.01 | 11.26 | 24.18 | 17.57 | 11.67 | 9.18 | 6.91 | 11.33 | A |
| Mainstem Lower Bay (CB6PH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB7PH) | 43.87 | 36.46 | 35.13 | 32.23 | 29.06 | 12.08 | 0.10 | 10.97 | 28.52 | 20.83 | 14.03 | 10.13 | 11.12 | 24.44 | A |
| Mainstem Lower Bay (CB8PH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Patuxent Tidal Fresh (PAXTF) | 25.77 | 11.04 | 14.33 | 26.15 | 9.94 | 2.00 | A | 2.00 | 11.66 | 6.71 | 2.56 | 1.13 | 0.64 | 4.21 | A |
| Patuxent Mid-Estuary (PAXOH) | 20.51 | 7.41 | 7.18 | 7.19 | 6.15 | A | A | A | 6.67 | 2.97 | A | A | A | 5.02 | A |
| Patuxent Lower Estuary (PAXMH) | 36.87 | 30.29 | 29.03 | 27.16 | 25.57 | 18.81 | 6.78 | 18.87 | 25.19 | 21.75 | 18.60 | 18.39 | 17.86 | 22.20 | A |
| Potomac Tidal Fresh (POTTF) | 75.37 | 75.29 | 75.29 | 74.79 | 71.30 | 46.62 | 18.54 | 46.61 | 75.28 | 74.80 | 70.29 | 44.25 | 53.46 | 65.17 | 0.01 |
| Potomac Mid-Estuary (POTOH) | 75.37 | 74.42 | 74.20 | 73.22 | 72.46 | 53.29 | 30.86 | 53.25 | 74.89 | 73.36 | 68.84 | 53.43 | 62.23 | 75.20 | 5.13 |
| Potomac Lower Estuary (POTMH) | 21.31 | 10.49 | 9.84 | 6.62 | 6.21 | 2.13 | 0.42 | 2.13 | 8.09 | 4.89 | 3.67 | 2.10 | 2.85 | 7.92 | A |
| Rappahannock Tidal Fresh (RPPTF) | 1.59 | 0.02 | 0.02 | 0.01 | 0.01 | A | A | A | 0.01 | 0.01 | 0.01 | A | A | A | A |
| Rappahannock Mid-Estuary (RPPOH) | 8.66 | 0.69 | 0.69 | 0.19 | 0.04 | 0.02 | A | 0.02 | 0.08 | 0.04 | 0.04 | 0.02 | 0.02 | 0.03 | A |
| Rappahanock Lower Estuary (RPPMH) | 39.74 | 34.67 | 33.49 | 32.44 | 31.11 | 24.62 | 7.85 | 24.67 | 30.94 | 29.75 | 28.07 | 24.48 | 24.30 | 28.82 | A |
| York Lower Estuary Piankatank (PIAMH) | 70.67 | 45.30 | 39.33 | 20.78 | 13.17 | 6.76 | 2.60 | 7.72 | 10.88 | 8.73 | 6.76 | 5.83 | 4.10 | 1.35 A | |
| York Tidal Fresh Mattaponi (MPNTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Mid-Estuary Mattaponi (MPNOH) | 11.34 | 0.77 | 0.26 | 0.26 | 0.14 | 0.02 | A | 0.02 | 0.26 | 0.26 | 0.26 | 0.02 | 0.02 | 0.08 | A |
| York Tidal Fresh Pamunkey (PMKTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Mid-Estuary Pamunkey (PMKOH) | 17.63 | 3.48 | 2.67 | 1.94 | 0.96 | A | A | A | 2.20 | 1.39 | 0.67 | A | A | 0.30 | A |
| York Lower Estuary (YRKMH) | 17.09 | 7.60 | 6.54 | 5.42 | 3.57 | A | A | A | 4.32 | 2.92 | 1.83 | A | A | 1.60 | A |
| York Lower Estuary (YRKPH) | 9.10 | 4.06 | 3.37 | 2.69 | 2.11 | 0.01 | A | 0.05 | 2.31 | 1.70 | 1.23 | 0.03 | 0.02 | 1.22 | A |
| York Lower Estuary Mobjack (MOBPH) | 62.96 | 53.25 | 51.58 | 48.73 | 45.18 | 33.89 | 10.62 | 34.31 | 45.02 | 40.19 | 35.19 | 33.55 | 32.61 | 40.34 | A |
| James Tidal Fresh (JMSTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Mid-Estuary (JMSOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Lower Estuary (JMSMH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Lower Estuary (JMSPH) | 4.95 | 0.70 | 0.36 | 0.02 | A | A | A | A | A | A | A | A | A | A | A |
| Eastern Bay (EASMH) | 65.24 | 35.47 | 32.16 | 25.01 | 9.70 | 2.03 | 0.42 | 2.03 | 9.43 | 3.79 | 2.10 | 1.96 | 1.84 | 2.87 | A |
| Choptank Mid-Estuary (CHOOH) | 5.47 | 2.27 | 2.18 | 1.92 | 1.63 | 0.15 | A | 0.15 | 1.63 | 1.28 | 1.03 | 0.15 | 0.15 | 1.22 | A |
| Choptank Lower Estuary (CHOMH2) | 33.64 | 8.53 | 5.10 | 1.46 | A | A | A | A | A | A | A | A | A | A | A |
| Choptank Lower Estuary (CHOMH1) | 67.17 | 49.00 | 45.46 | 39.17 | 32.68 | 14.89 | 1.33 | 15.13 | 33.24 | 26.34 | 16.45 | 12.04 | 9.25 | 17.62 | A |
| Tangier Sound (TANMH) | 74.55 | 71.19 | 70.37 | 68.17 | 65.11 | 46.54 | 3.44 | 46.06 | 64.80 | 58.65 | 49.61 | 45.20 | 45.08 | 60.55 | A |
| Pocomoke (POCMH) | 41.96 | 22.15 | 20.19 | 14.46 | 10.02 | 0.02 | A | 0.01 | 9.25 | 1.43 | 0.35 | 0.01 | 0.02 | 20.24 | A |

* 4/1/03, Version 15 — Changes since version 12: SAV Re-calibration, Wetlands Oxygen Demand, No Seasonal Anoxic Zone

Table D-5. Key scenario summary of water clarity criteria attainment at mid depths.*

| Segment | Observed | Progress 2000 | Tier 1 | Tier 2 | Tier 3 (181) | Tier 3 + 20% | Tier 3 + 50% | Opt4 (188) | Confirm (175) | Confirm + 10 | Confirm + 20 | Allocation (175) | Opt1 (160) | E3 | Pristine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mainstem Upper Bay (CB1TF) | 71.62 | 55.46 | 50.88 | 40.18 | 23.13 | 16.03 | 10.03 | 16.03 | 35.95 | 31.08 | 26.85 | 14.43 | 12.69 | 13.42 | 0.01 |
| Mainstem Upper Bay (CB2OH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Upper Bay (CB3MH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Mid-Bay (CB4MH) | 37.20 | 16.20 | 12.48 | 7.19 | 2.78 | 0.30 | 0.01 | 0.32 | 3.78 | 2.15 | 1.08 | 0.04 | 0.01 | 0.38 | A |
| Mainstem Mid-Bay (CB5MH) | 16.07 | 0.01 | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB6PH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB7PH) | 8.13 | 1.99 | 1.33 | 0.09 | 0.01 | A | A | A | 0.01 | 0.01 | A | A | A | A | A |
| Mainstem Lower Bay (CB8PH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Patuxent Tidal Fresh (PAXTF) | 0.20 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Patuxent Mid-Estuary (PAXOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Patuxent Lower Estuary (PAXMH) | 17.55 | 13.63 | 13.46 | 12.88 | 11.77 | 5.55 | A | 5.56 | 11.01 | 8.58 | 5.26 | 4.80 | 3.69 | 8.71 | A |
| Potomac Tidal Fresh (POTTF) | 74.97 | 73.15 | 73.03 | 68.56 | 55.27 | 25.35 | 1.25 | 25.35 | 72.82 | 68.13 | 50.02 | 23.35 | 29.40 | 42.39 | A |
| Potomac Mid-Estuary (POTOH) | 73.51 | 64.27 | 63.04 | 54.36 | 49.75 | 31.74 | 19.24 | 31.70 | 65.41 | 52.99 | 40.17 | 31.81 | 35.88 | 67.30 | A |
| Potomac Lower Estuary (POTMH) | 4.53 | 1.02 | 0.98 | 0.23 | 0.09 | 0.09 | A | 0.09 | 0.61 | 0.09 | 0.09 | 0.03 | 0.03 | 0.20 | A |
| Rappahannock Tidal Fresh (RPPTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Rappahannock Mid-Estuary (RPPOH) | 0.03 | 0.01 | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A |
| Rappahannock Lower Estuary (RPPMH) | 27.17 | 17.92 | 16.50 | 15.60 | 14.41 | 6.64 | A | 6.69 | 14.43 | 13.30 | 12.22 | 6.60 | 6.49 | 12.79 | A |
| York Lower Estuary Piankatank (PIAMH) | 29.01 | 9.78 | 3.33 | 0.87 | 0.20 | 0.20 | 0.06 | 0.20 | 0.20 | 0.20 | 0.20 | 0.20 | 0.06 | 0.06 | A |
| York Tidal Fresh Mattaponi (MPNTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Mid-Estuary Mattaponi (MPNOH) | 0.02 | A | A | A | A | A | A | A | A | A | A | A | A | 0.01 | A |
| York Tidal Fresh Pamunkey (PMKTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Mid-Estuary Pamunkey (PMKOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary (YRKMH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary (YRKPH) | 0.61 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary Mobjack (MOBPH) | 32.89 | 17.42 | 14.74 | 12.07 | 8.83 | 0.34 | A | 0.41 | 8.18 | 3.74 | 0.70 | 0.27 | 0.22 | 3.30 | A |
| James Tidal Fresh (JMSTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Mid-Estuary (JMSOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Lower Estuary (JMSMH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Lower Estuary (JMSPH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Eastern Bay (EASMH) | 24.96 | 2.61 | 1.91 | 0.54 | A | 0.01 | 0.01 | 0.01 | 0.07 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | A |
| Choptank Mid-Estuary (CHOOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Choptank Lower Estuary (CHOMH2) | 0.24 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Choptank Lower Estuary (CHOMH1) | 30.84 | 11.80 | 8.79 | 2.58 | 0.07 | 0.01 | 0.01 | 0.01 | 0.57 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | A |
| Tangier Sound (TANMH) | 49.18 | 38.38 | 36.38 | 32.93 | 28.44 | 11.18 | A | 11.27 | 28.34 | 20.62 | 13.23 | 11.03 | 10.45 | 23.04 | A |
| Pocomoke (POCMH) | 7.41 | 0.43 | 0.18 | A | A | A | A | A | A | A | A | A | A | A | A |

* 4/1/03, Version 15 — Changes since version 12: SAV Re-calibration, Wetlands Oxygen Demand, No Seasonal Anoxic Zone

Table D-6. Key scenario summary of water clarity criteria attainment at low depths.*

| Segment | Observed | Progress 2000 | Tier 1 | Tier 2 | Tier 3 (181) | Tier 3 + 20% | Tier 3 + 50% | Opt4 (188) | Confirm (175) | Confirm + 10 | Confirm + 20 | Allocation (175) | Opt1 (160) | E3 | Pristine |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mainstem Upper Bay (CB1TF) | 21.88 | 11.93 | 8.43 | 1.74 | 0.04 | 0.04 | 0.04 | 0.04 | 0.70 | 0.16 | 0.07 | 0.03 | 0.02 | 0.01 | A |
| Mainstem Upper Bay (CB2OH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Upper Bay (CB3MH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Mid-Bay (CB4MH) | 0.07 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Mid-Bay (CB5MH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB6PH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB7PH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Mainstem Lower Bay (CB8PH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Patuxent Tidal Fresh (PAXTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Patuxent Mid-Estuary (PAXOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Patuxent Lower Estuary (PAXMH) | 0.02 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Potomac Tidal Fresh (POTTF) | 54.15 | 30.87 | 29.00 | 11.69 | 3.97 | 0.01 | 0.01 | 0.01 | 18.35 | 6.17 | 2.39 | 0.01 | 0.01 | 0.02 | A |
| Potomac Mid-Estuary (POTOH) | 40.89 | 26.46 | 25.09 | 20.64 | 17.30 | 8.73 | 2.07 | 8.75 | 23.85 | 17.83 | 10.82 | 6.64 | 7.97 | 14.73 | A |
| Potomac Lower Estuary (POTMH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Rappahannock Tidal Fresh (RPPTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Rappahannock Mid-Estuary (RPPOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Rappahanock Lower Estuary (RPPMH) | 2.98 | 0.13 | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary Piankatank (PIAMH) | 0.87 | 0.01 | 0.01 | 0.01 | 0.01 | A | A | A | A | A | A | A | A | A | A |
| York Tidal Fresh Mattaponi (MPNTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Mid-Estuary Mattaponi (MPNOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Tidal Fresh Pamunkey (PMKTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Mid-Estuary Pamunkey (PMKOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary (YRKMH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary (YRKPH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| York Lower Estuary Mobjack (MOBPH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Tidal Fresh (JMSTF) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Mid-Estuary (JMSOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Lower Estuary (JMSMH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| James Lower Estuary (JMSPH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Eastern Bay (EASMH) | 0.06 | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Choptank Mid-Estuary (CHOOH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Choptank Lower Estuary (CHOMH2) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Choptank Lower Estuary (CHOMH1) | 0.01 | A | A | A | A | A | A | A | A | A | A | A | A | A | A |
| Tangier Sound (TANMH) | 4.53 | 1.86 | 1.32 | 0.59 | 0.41 | A | A | A | 0.41 | A | A | A | A | A | A |
| Pocomoke (POCMH) | A | A | A | A | A | A | A | A | A | A | A | A | A | A | A |

* 4/1/03, Version 15 — Changes since version 12: SAV Re-calibration, Wetlands Oxygen Demand, No Seasonal Anoxic Zone