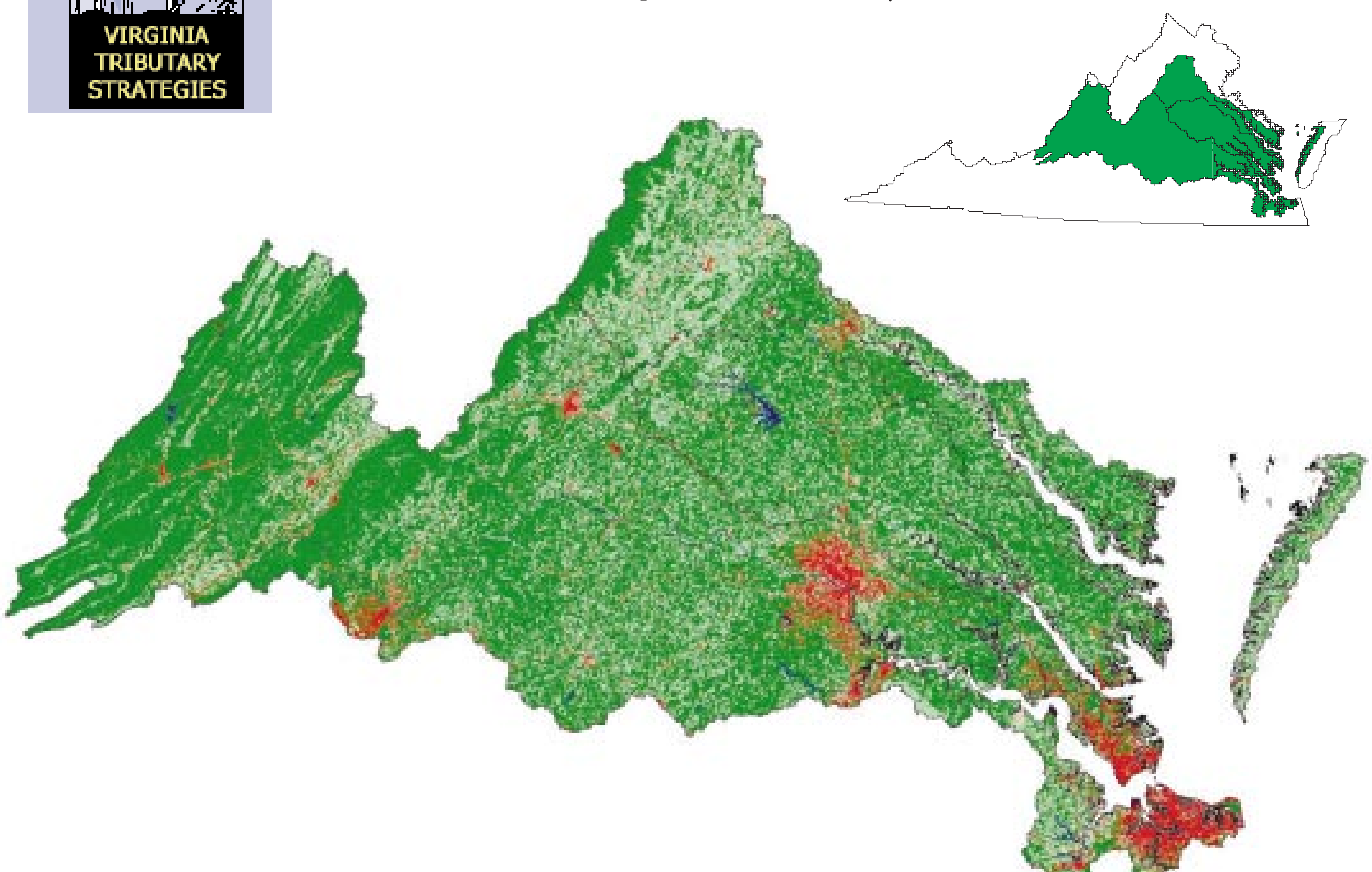
Technical Tools Used in the Development of Virginia's Tributary Strategies

VIRGINIA TRIBUTARY STRATEGIES

A Synthesis of Airshed, Watershed, and Estuary Model Results



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Technical Summary Report

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Introduction

Virginia is committed to setting nutrient reduction goals and developing tributary strategies for the lower Virginia tributaries by legislative statutes and directives of the Chesapeake Executive Council. To accomplish this Chesapeake Bay Program milestone, the best science, technical findings, and management tools are being used. The diverse regional and local stakeholders and partners involved in the goal-setting and tributary strategy development process were provided with in-depth information of direct relevance from the best data available to the Bay's scientific and technical community. This document is a synthesis of the overall findings from modeling results conducted during the assessment phase of Virginia's Tributary Strategy process.

To initiate the tributary strategy process, a workshop entitled the *Virginia Tributary Technical Synthesis Workshop* was held at the Virginia Institute of Marine Science on March 17-18, 1998. The objective of the workshop was to develop and reach consensus on status and trends information of various water quality and living resource changes in the lower Virginia Chesapeake Bay and tributary basins. Data from the first 12 years of Virginia's Chesapeake Bay Monitoring Program (1985-1996) for the Rappahannock, York, James, Western and Eastern Shore basins, and lower Chesapeake Bay were reviewed. A final report entitled *Virginia Tributary Basin Specific Profiles: Syntheses of the Underlying Technical Information Supporting Tributary Strategy Development* was printed in September, 1998.

A second workshop was held on November 20, 1998 to present preliminary model results from the Chesapeake Bay Estuary Model Package (CBEMP). Results from the first series of CBEMP ranging scenarios showed environmental responses for each of Virginia's tributaries under different levels of nutrient and sediment reductions. The model scenario workshop and subsequent additional scenarios provided Virginia's Tributary Strategy Technical Review Committee (TRC) members and interested stakeholders with information needed to set pollutant reduction goals.

This report contains a review of the overall modeling framework, as presented at the modeling workshop, as well as other models used in the tributary strategy process. In addition, it includes detailed descriptions of the scenarios, results, and interpretations of these modeling results. A unique feature of the Virginia Tributary Strategy development is that, for the first time, qualitative measures of key living resources and habitat needed to sustain these resources in the lower Bay tributaries, were addressed.

Results and products of the cross-media models of the airshed, watershed, and estuary were reviewed by Tributary Strategy workgroups of the Rappahannock, York, James, and Eastern Shore basins. These tributary teams consisted of citizens, local government leaders, environmental group representatives, and industry representatives. The workgroups assisted in the interpretation of model results and ultimately, developed tailored plans for the environmental protection of each tributary, taking into account the unique characteristics of each basin.

The plans adopted were innovative, ambitious, and practical. For the first time, air reductions in the deposition of nitrogen nutrients were considered in the development of nutrient reduction strategies. Effects of nutrient and sediment loads on key living resources like SAV were considered for the first time. Each of the lower tributary strategies contribute to environmental protection of the Chesapeake Bay through local environmental protection, principally directed at the environmental conditions in each of the tributaries of each of the lower tributaries.

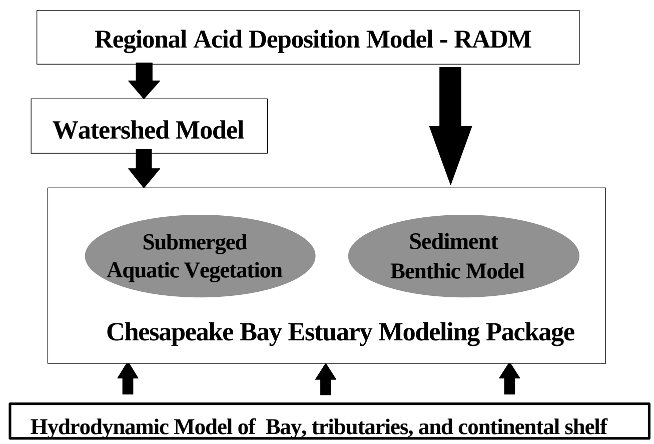
Additional information on the tributary strategies adopted by the basin workgroups can be found in each Tributary Strategy available on the web site of the Virginia Department of Environmental Quality.

Section 1: Overview of Airshed, Watershed, and Estuary Models

1.1 Background

The cross-media models used in this analysis consist of three models, an airshed model, a watershed model, and a model of the Chesapeake estuary (Figure 1.1). These models are linked together so that the output of one simulation provides input data for another. The simulation period is the ten-year interval from January 1, 1985 to December 31, 1994. These models have been used by the Chesapeake Bay Program for more than a decade and have been refined and upgraded several times. Application of the cross-media models assisted in determining tributary allocations for each of the four lower Virginia basins; the Rappahannock, York, James, and Eastern Shore.

Figure 1.1 **Cross-Media Models of the Chesapeake Bay**



A 1992 re-evaluation of pollutant loads and responses found that, taken as a group, the four lower basins had relatively little effect on Chesapeake Bay water quality. A 1992 version of the estuary model estimated only mainstem water quality. It could not simulate tributary water quality in sufficient detail for basin allocations in the lower four catchments. Prompted by the 1992 Executive Council Directive, the Chesapeake Bay Program and Virginia have worked together over the last six years to develop a detailed model of the lower Bay and its tributaries. Refinements to the hydrodynamic and water quality model have increased simulated spatial detail five-fold, mostly in Virginia waters. Capabilities of the model were expanded to include estimates of key water quality and habitat measurements and their response to changes in nutrient and sediment loads. As a result, the Virginia tributary teams were provided with water quality and habitat responses to these pollutant reductions that came from both within and outside the basin.

Further information on the entire suite of Chesapeake Bay Program models, their documentation and applications can be found at the following two Web sites:

1) http://www.chesapeakebay.net/info/model.cfm
2) http://www.chesapeakebay.net/search/subcommittee.cfm?GROUP_INIT=MODSC&GROUP_AFFIL=Modeling

1.2 Airshed Model

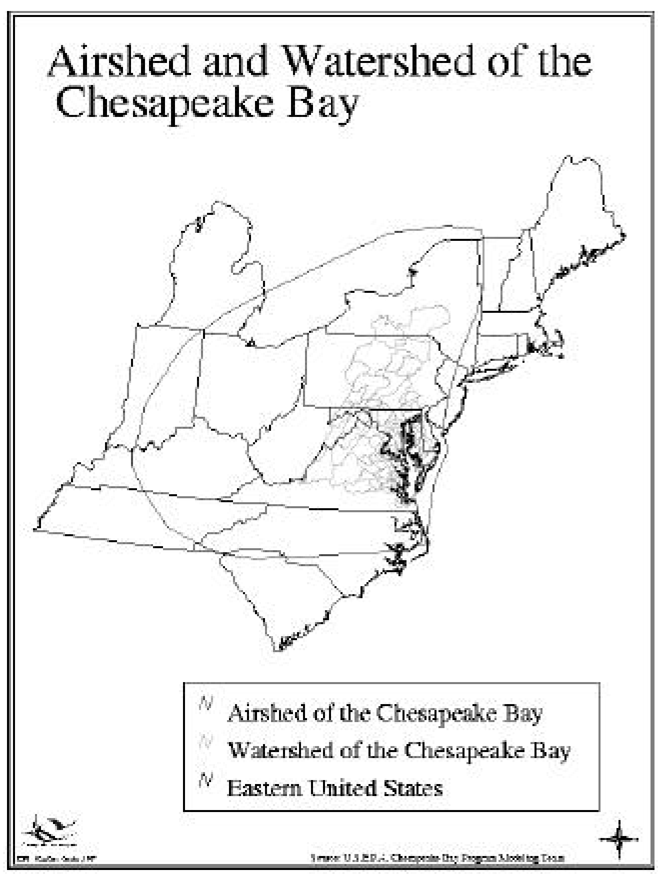
The Chesapeake Bay Program airshed model provides estimates of atmospheric deposition loads of nitrogen. A product of the EPA National Exposure Research Laboratory in Research Triangle Park, NC, RADM (pronounced "radum"), is an acronym for Regional Acid Deposition Model. RADM is a three dimensional model which tracks nutrient emissions across the eastern United States (Dennis, 1996). There are two RADM grids meeting various resolution needs. A larger grid scale, covering the entire RADM domain, contains about 20,000 square cells of 6400 square kilometers each. A finer grid scale covers the region of the Chesapeake Bay watershed and has 60,000 cells, each covering 400 square kilometers. The model domain in the vertical is 15 cells deep reaching from ground level to the top of the free troposphere. The depth of the cells increases with altitude. One of the findings of the RADM is that the Chesapeake Bay "airshed," defined as the area accounting for 75% of the watershed deposition, is approximately 5.5 times the size of the watershed. (Figure 1.2).

RADM is used to drive scenarios associated with reductions in atmospheric deposition of nitrogen. A base condition of deposition establishes a reference to which other atmospheric deposition reduction scenarios are compared. As precipitation is the primary forcing function in the Chesapeake Bay Watershed Model, great care is taken in developing this data base. The data set of daily 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 eleven years (1984-1994) of National Atmospheric Deposition Program (NADP) data from fifteen 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

Figure 1.2 **Chesapeake Bay Airshed Domain**



deposition of wet nitrate and ammonia. The average precipitation by segment is based on the spatial distribution of precipitation determined through the Thiessen polygon method. Data used in this method are from standard NOAA tape files of 178 precipitation stations in the Chesapeake watershed jurisdictions.

A rate of dry deposition of nitrate is determined for each model segment from average proportions of wet-to-dry deposition calculated by RADM. The RADM wet-to-dry ratios are applied to the average wet nitrate deposition of the base data set . The constant dry deposition and the variable wet deposition rates are input to each Watershed Model segment, including its non-tidal waters. Overall, dry nitrate deposition does not vary through the base simulation period of the Watershed Model for each segment, but varies among segments. Dry ammonia inputs are not accounted for in the model simulation since their magnitudes are unknown.

Atmospheric deposition of wet nitrate and ammonia to water surfaces of the estuary is determined by applying the same deposition calculated for certain below-fall line Watershed Model segments, to adjacent regions of the tidal Bay and tidal tributaries. Dry nitrate inputs to regions in the tidal Bay and tidal tributaries are determined by applying a wet-to-dry ratio of 3.33 to the average wet nitrate deposition for adjacent segments. This wet-to-dry ratio of nitrate is from monitoring data at an over-water site in the tidal Bay. The constant dry nitrate deposition rate for the below-fall line WSM segments is used as dry nitrate input to the nearby tidal waters. Overall, dry nitrate deposition to tidal regions does not vary through the simulation period for each region, but varies among regions. Dry ammonia is not included in the nitrogen flux to tidal waters.

Atmospheric deposition of wet organic nitrogen is simulated as a flux only to water surfaces because it is assumed that inputs and outputs on land surfaces are in balance. Seasonal averages of measured dissolved organic nitrogen concentrations are applied to the volume of precipitation for each WSM segment to ascertain deposition of this species to non-tidal waters. Dissolved organic nitrogen deposition to tidal water regions is the same as that to nearby below-fall line WSM segments. Dry organic nitrogen deposition is not accounted for in the model simulation since its magnitude is unknown.

The resultant daily atmospheric deposition to tidal surface waters is input to each cell of the Chesapeake Bay Estuary Model Package which simulates the hydrology and water and habitat quality parameters of the tidal Bay and tributaries. Atmospheric deposition to land surfaces and non-tidal waters of the Chesapeake is accounted for in Watershed Model delivered loads to the tidal Bay and tidal tributaries.

RADM scenarios account for emission controls and subsequent reduced atmospheric deposition. RADM determines percent reductions in wet nitrate deposition from the RADM reference, before 1990 Clean Air Act Amendment controls were in place. It is assumed that the RADM reference inputs are the same as the calculated base deposition. Seasonally-variable percent reductions are applied to the nitrate deposition rates of the base data set for each Watershed Model segment. Wet ammonia deposition remains the same as that of the base since RADM does not determine ammonia fluxes. Wet-to-dry nitrate ratios associated with the reduction scenarios are calculated by RADM for each Watershed Model segment. Dry deposition of nitrate is found by applying the ratios to the average wet deposition amounts of the scenario.

The RADM results prescribe the loads of wet and dry deposition to the Chesapeake watershed for the Virginia Tributary Strategy scenarios entitled Full Voluntary Program Implementation and Limit of Technology (Table 1.1). The established base condition atmospheric deposition loads were used for all other Virginia Tributary Strategy scenarios.

For the Full Voluntary Program Implementation scenario, atmospheric deposition assumes air emission controls associated with the "Annual 2010 812 Prospective Projection" air scenario. This air scenario reflects changes to atmospheric deposition resulting from annual emission controls on both stationary and mobile sources. Annual levels of emission control are placed on stationary sources in most of the 37-state RADM/RPM domain, resulting in emissions of no more than 0.15 lb/mm BTU from utility and large industrial sources. Emission controls placed annually on mobile sources for this scenario include 1) Tier 1 Light Duty Vehicle emission standards, 2) Heavy Duty Vehicle 2 gm standard, 3) Phase II Federal Reformulated Gasoline, 4) National Low Emission Vehicle program, and 5) High and Low Enhanced Inspection and Maintenance (I/M) and Basic I/M as specified by individual states.

Atmospheric deposition for the Current Limit of Technology scenario assumes that the maximum practical level of air emission controls are applied year-round in 37 states east of the Rocky Mountains through the simulation period. Seasonal controls are placed on stationary sources so that there are emissions of no more than 0.15 lb/mm BTU from utility and large industrial sources in 37 states or most of the RADM/RPM domain. Annual emission controls on mobile sources include 1) Tier 1 Light Duty Vehicle and Heavy Duty Vehicle emission standards, 2) Phase II Federal Reformulated Gasoline, 3) National Low Emission Vehicle (NLEV) program, and 4) High Enhanced Inspection and Maintenance and maximum Low Emission Vehicle benefits for all counties in the 37-state domain, regardless of ozone attainment.

Table 1.1 **Chesapeake Watershed Nitrogen Deposition under Varying Management Schemes for Controlling Emissions of Nitrogen Atmospheric Deposition Precursors**

Scenario	**TN Deposition (millions of kg/year)**
Base Condition	204
Full Voluntary Program Implementation/2010 812 Prospective Projection	178
Current Limit of Technology	128

Sources: Chesapeake Bay Program Phase IV Watershed Model and RADM

1.3 Watershed Model

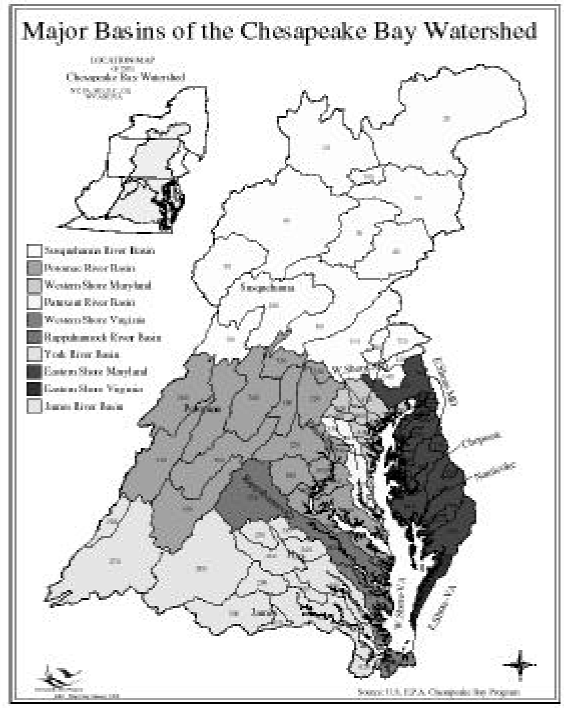
The Chesapeake Bay Watershed Model has been in continuous operation at the Chesapeake Bay Program since 1982, and has had many upgrades and refinements since that time. The version of the Watershed Model used in the Virginia Tributary strategy application, Phase 4.1, is a comprehensive package for the simulation of watershed hydrology, nutrient and sediment export from pervious and impervious land uses, and the transport of these loads in rivers and reservoirs. The model is based on a modular set of computer codes called Hydrologic Simulation Program - Fortran (HSPF). A slightly modified version of HSPF release 11.1 (Bicknell et al., 1996) is applied in the watershed simulation. Version 11 is a widely-used public-domain model supported by the U.S. Environmental Protection Agency (EPA), U.S. Geological Survey (USGS), and U.S. Army Corps of Engineers (Shenk et al., 1998).

The Watershed Model allows for the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interactions. The model takes into account watershed landuses and application of fertilizers and animal manure; loads from point sources, atmospheric deposition, onsite wastewater management systems; and best management practice reduction factors and delivery factors. Land uses, including cropland, pasture, urban areas, and forests, are simulated on an hourly time-step.

The Watershed Model is designed to simulate nutrient and sediment loads delivered to the Chesapeake Bay under different management scenarios (Donigian et al., 1994; Linker et al., 1996; Linker, 1996). The simulation is an overall mass balance of nitrogen and phosphorus in the basin, so that the ultimate fate of the input nutrients is incorporation into crop or forest plant material, incorporation into soil, or loss through river runoff. Nitrogen fates may also include volatilization into the atmosphere and denitrification. Sediment is simulated as eroded material washed off land surfaces and transported to the tidal Bay. Twelve calendar years (1984-1995) of varying hydrology are simulated by the Watershed Model although only ten of those years (1985-1994) are used in this study because of the more limited simulation period of the estuary model. Scenarios are run on a one-hour time step and results are often aggregated into ten-year-average annual loads for reporting and comparisons among scenarios. Watershed Model results in the form of daily flows and nutrient and sediment loads are used as input to the Chesapeake Bay Estuary Model Package (CBEMP).

To simulate the delivery of nutrients and sediment to the Bay, the watershed is divided into eighty-nine major model segments with an average area of 194,000 hectares (Figure 1.3). Segmentation, based on three tiers of criteria, partitions the watershed into regions of similar characteristics. The first criterion is segmentation of similar geographic and topographic areas, which are further delineated in terms of soil type, soil moisture holding capacity, infiltration rates, and uniformity of slope. The second criterion involves finer segmentation based on spatial patterns of rainfall. Each segment has a bank-full travel time of about 24-72 hours (Hartigan, 1983). The third criterion used to delineate segments is based on features of the river reach. River reaches containing a reservoir are separated into a reservoir simulation and a river simulation of the free-flowing river. For example, the James basin has eleven model segments including two that represent reservoirs on the James and Appomattox. Segmentation generally became finer with closer proximity to tidal waters.

Figure 1.3 **Watershed Model Segmentation**



Model segments are located so that segment outlets are as close as possible to monitoring stations. Water quality and discharge data are collected from federal and state agencies, universities, and other organizations that collect information at multiple and single land use sites (Langland et al., 1995; CBP, 1989). At the interface of the watershed and estuary model domains, model segments are further divided into 259 sub-segments to accurately deliver flow and nutrient and sediment loads to appropriate areas of the estuary. The division of basins into multiple segments as well as the use of hourly time-steps in the simulation greatly improved the accuracy of the model results. Scenario results are typically reported at the basin level and for ten-year-average annual loads. The use of this average annual load allows for a mix of wet, dry, and average hydrology years throughout the basin.

Nutrient loads from the following non-point sources are simulated: conventionally-tilled cropland, conservation-tilled cropland, cropland in hay, pasture, animal waste areas, forest, pervious urban land, impervious urban land, atmospheric deposition to non-tidal surface waters, septic systems, and a mixed-open category that is herbaceous but not part of an agricultural land use.

Sediment from all pervious land surfaces is simulated using an empirically-based module which represents sediment export as a function of the amount of detached sediment and the runoff intensity. Information on land slope and estimated erosion rates were provided by the National Resources Institute (NRI) database. Delivery of sediment from each land use was calibrated to the NRI estimates of annual edge-of-field sediment loads calculated by the Universal Soil Loss Equation.

HSPF 11 allows two types of nutrient export simulation from pervious land. One group of subroutines simulates nutrient cycling and export mechanistically, using storages of nutrients in the soil and plant mass and parameters to govern movement between the storages. Another group of subroutines uses an empirically-based approach, with potency factors for surface runoff and monthly specified concentrations in the subsurface. Soil characteristics for nutrient interactions and hydrology (percolation and reserve capacity) are obtained from the SCS Soil Interpretation Records (USDA).

Nitrogen cycling is simulated in forest using recent research of forest dynamics included in the mechanistic subroutines for HSPF 11 (Hunsaker, 1994). Forest phosphorus is simulated using the empirically-based group of subroutines. Crops are modeled using a yield-based nutrient uptake algorithm for both nitrogen and phosphorus to facilitate the direct simulation of nutrient management practices. State agricultural engineers provide fertilizer application rates and timing, crop rotations, and the timing of field operations.

Pasture and pervious urban categories use the mechanistic approach for nitrogen simulation and the empirically-based method for phosphorus. Impervious urban exports depend on nutrient storage that is incremented by a daily accumulation factor equal to atmospheric deposition. This storage is then washed off as a function of the rainfall intensity.

A Chesapeake Bay Program Land Use (CBPLU) database is compiled for the entire Chesapeake basin. This database is a combination of information from the EPA Environmental Monitoring and Assessment Program (EMAP), National Oceanic and Atmospheric Administration (NOAA) Coastal Change Assessment Program (C-CAP), and the USGS Geographic Information Retrieval and Analysis System (GIRAS). The 1990 EMAP database is the primary source of land use data.

Detailed information on agricultural lands is gathered from the U.S. Census Bureau series, Census of Agriculture for 1982, 1987, 1992, and 1997 (Volume 1, Geographic Area Series) published for each state. Tillage information on a county level is obtained for the conventional and conservation cropland distribution. Calculations and allocations of the agricultural land categories of high (conventional) tillage, low (conservation) tillage, pasture, and hay 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 resultant agricultural land acreage and the CBPLU database. Hopkins et al. (2000) describes these calculations and allocations in detail.

The final land use category of the Watershed Model is manure acres. This designation allows for the simulation of high nutrient content runoff from animal operations in unconfined (pasture) or confined areas. Manure acres are based on the population of different animal types in the watershed as given in the U.S. Agricultural Census data. The animal types include beef and dairy cattle, swine, and three categories of poultry; layers, broilers, and turkeys. The application rates of manure to agricultural lands are determined by a time-varying manure mass balance as described in *Tracking Best Management Practice Nutrient Reductions in the Chesapeake Bay Program* (1999).

Point source data for the simulation period are obtained from the National Pollution Discharge Elimination System (NPDES). If no state NPDES data are available, state and year-specific default data are calculated for each missing parameter and annual estimates of load are based on flow from the wastewater treatment plant. Septic system loads are also included in the Watershed Model simulation. Septic system data are compiled using census figures and methodology suggested in Maizel and Muehlbach (1995).

Each Watershed Model river reach is simulated as completely mixed waters of a fifth- to seventh- order river with all land uses considered to be in direct hydrologic connection. Of the 44 reaches simulated, the average length is 170 kilometers, the average drainage area is 1900 square kilometers, and the average time of travel is one day. Seven of the reaches are impounded by reservoirs.

The 1984-1995 time period is used for calibration of the Watershed Model where simulated results for stream flows, nutrient and sediment concentrations and loads, and other water quality parameters are compared to observed data from the tributaries. This calibration was reviewed and approved by Chesapeake Bay Program Modeling Subcommittee members which consists of recognized academic experts in the field of modeling and representatives from all Bay Agreement jurisdictions (PA, MD, VA, and the District of Columbia). Results for the hydrology and water quality calibration for the Virginia tributaries can be found in Appendices A and B, respectively, in *Chesapeake Bay Watershed Model Application & Calculation of Nutrient & Sediment Loadings*. The results are presented as plots and statistical tables of model results and monitoring data from calibration stations for the following parameters: flow, temperature, dissolved oxygen (DO), total suspended sediment, total phosphorus, organic and particulate phosphorus, phosphate, total nitrogen, nitrate, total ammonia, and organic nitrogen. The appendices also summarize the accuracy of the calibration.

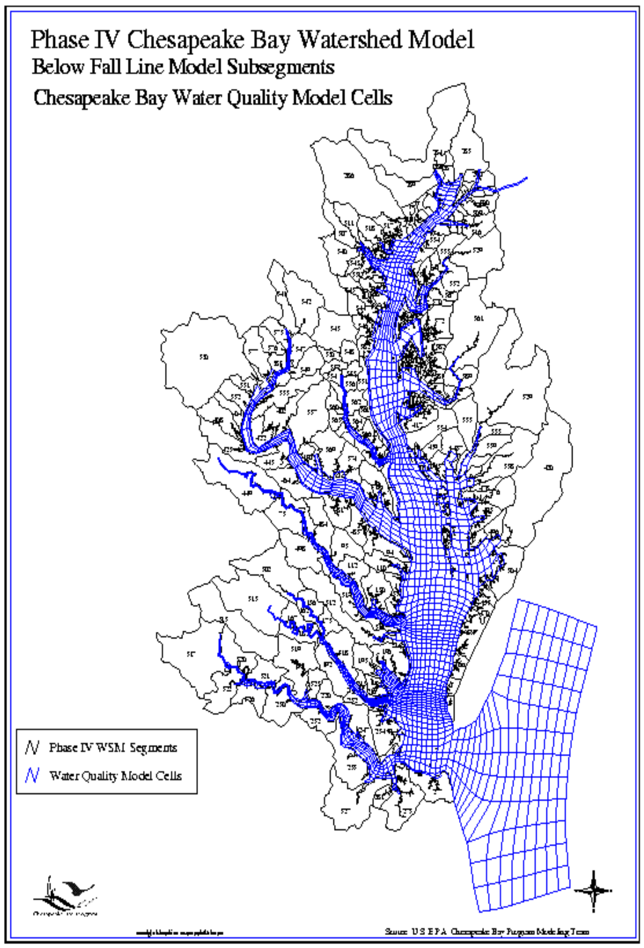
The Watershed Model provides input information for the Chesapeake Bay Estuary Model Package. In order to make a linkage between the two models, a more extensive segmentation of the below-fall line watershed model segments is developed using Geographic Information Systems (GIS) mapping technology. These sub-segments are wholly contained within the larger Watershed Model segments and adjoin estuary model grid cells. To accurately load the estuary model, sub-segment land uses are determined by allocating a calculated proportion of each segment land use to the sub-segments. After partitioning, the Watershed Model is run with the new segmentation and land use changes. The simulated flows and nutrient and sediment loads delivered to adjacent estuary model cells are the inputs to the CBEMP.

1.4 Estuary Model

The Chesapeake Bay Estuary Model Package (CBEMP) is actually a series of linked models. A hydrodynamic model simulates the hourly temperatures and movement of water in the Bay. A eutrophication or water quality model simulates the water and habitat quality response to nutrient and sediment loads. These loads are inputs from the watershed model as well as from direct atmospheric deposition to the surface of the Bay, pollutant loads from the ocean interface, and loads generated by a coupled bottom sediments model. The model package is applied in one continuous simulation period (1985-1994) to model transport, eutrophication processes, and sediment-water interactions under various management scenarios designed to analyze the water quality and living resource responses to load reductions at all points in the Bay. The details of the development of the hydrodynamic and water quality models and their calibration and sensitivity are presented in Cerco and Cole (1994), Wang and Johnson (2000), Cerco and Meyers (2000), Cerco (2000), and Cerco and Moore (2000).

The hydrodynamic and eutrophication models operate by dividing the spatial continuum of the Bay into a grid of discrete cells. The numerical grid contains 2100 cells (roughly 1.5 x 3 km) in the surface plane and one to twenty cells (1.5 to 2 m thick) in the vertical representing a maximum depth of 30.5 m. The total number of cells in the grid is about 10,400 (Figure 1.4). The estuary model has been refined by increasing the grid in the western tributaries and in shallow littoral areas and by extending the grid onto the continental shelf where input from a global tide model is employed. Other improvements involved an extension of the validation period to include the time frame of 1985-1994 and the incorporation of living resource parameters and processes. The new computations of zooplankton, submerged aquatic vegetation, and benthos compared successfully with observations aggregated over annual time scales and at spatial scales on the order of 100 km^2 (Cerco and Meyers, 2000). In addition, a preliminary investigation of fish bioenergetics

Figure 1.4 **Hydrodynamic and Water Quality Model Grid**



modeling is now possible with the CBEMP.

Hydrodynamic Model

The three-dimensional numerical Hydrodynamic Model of the Chesapeake Bay, that provides transport or water movement to the three-dimensional water quality model, is called CH3D (Curvilinear Hydrodynamics in 3 Dimensions). It solves conservation equations for water mass, momentum, salinity, and heat on a boundary-fitted grid in the horizontal plane. The vertical grid is Cartesian. A finite difference solution scheme is employed such that vertically-averaged equations are first solved to yield the water surface elevations. These are then utilized in the computation of the baratropic portion of the horizontal pressure gradient in the internal model.

The Hydrodynamic Model uses a five-minute time step with computations made throughout a full year. Innovative techniques enable processing of the output to preserve all transport characteristics while allowing averaging over longer time periods. This technique is instrumental in allowing the 24-parameter water quality model to run time simulations of several decades on the bay and its tributaries.

Validation of the Hydrodynamic Model is accomplished by demonstrating its ability to reproduce observed data over time scales ranging from tidal to seasonal periods. After validation, the model is applied to simulate Bay hydrodynamics for ten years (1985-1994). These results are then used to drive the three-dimensional water quality model of the Chesapeake Bay.

Water Quality Model

The central issues in the water quality model (CE-QUAL-ICM) are computations of algal biomass and dissolved oxygen. Through primary production of carbon, algae provide the energy required by the ecosystem to function. Excessive primary production is detrimental; however, since its decomposition in the water and sediments consumes oxygen. Dissolved oxygen is necessary to support the life functions of higher organisms and is considered an indicator of the "health" of estuarine system. In order to compute algae and dissolved oxygen, a suite of twenty-four model state variables is necessary (Table1.2).

CE-QUAL-ICM treats each cell as a control volume which exchanges material with its adjacent cells. CE-QUAL-ICM solves, for each volume and for each state variable, a three-dimensional conservation of mass equation (Cerco and Cole, 1994). The numerous details of the kinetics portion of the mass-conservation equation for each state variable are described in Cerco and Cole (1994). In addition, this publication describes the characteristic eutrophication processes and the mechanisms that influence them. The processes and phenomena relevant to the water quality model simulation include 1) bottom-water hypoxia, 2) the spring phytoplankton bloom, 3) nutrient limitations, 4) sediment-water interactions, and 5) nitrogen and phosphorus budgets.

Table 1.2 **Water Quality State Variables Used in the CBEMP**

Temperature	Dissolved organic nitrogen
Salinity	Labile particulate organic nitrogen
Inorganic suspended solids	Refractory particulate organic nitrogen
Diatoms	Total phosphate
Cyanobacteria (blue-green algae)	Dissolved organic phosphorus
Other phytoplankton	Labile particulate organic phosphorus
Dissolved organic carbon	Refractory particulate organic phosphorus
Labile particulate organic carbon	Dissolved oxygen
Refractory particulate organic carbon	Chemical oxygen demand
Ammonium	Dissolved silica
Nitrate	Particulate biogenic silica
Microzooplankton	Mesozooplankton

Over seasonal time scales, sediments are a significant source of dissolved nutrients to the overlying water column. The role of sediments in the system-wide nutrient budget is especially important in summer when seasonal low flows diminish riverine nutrient input. In addition, warm temperatures enhance biological processes in the sediments creating greater sediment oxygen demand. Bay sediments retain a long-term nutrient load "memory" of several years. In other words, sediment nutrient fluxes to the water column are determined by organic nutrient inputs from several previous years. Therefore, the water quality model is coupled directly to a predictive benthic-sediment model (DiToro et al., 1993). These two models interact at each time step, with the water quality model delivering settled organic material to the sediment bed, and the benthic-sediment model calculating the flux of oxygen and nutrients to the water column.

The ultimate aim of eutrophication modeling is to preserve living resources. Usually, the modeling process involves the simulation of living resource parameters such as dissolved oxygen. Computed values are compared to living resource standards and a projection is made whether simulated conditions are beneficial to the resources of interest (e.g. fish, oysters, etc.).

SAV is an important living resource because it provides habitat for biota of economic importance and helps support the estuarine food chain. The direct simulation of SAV by the CBEMP accounts for the relationships among grass production, light, and nutrient availability, allowing for a measurement of the response of SAV to reductions in nutrient and sediment loads. A thin ribbon of model cells following the 2-meter contour is used to depict the littoral zone for SAV growth. The SAV component of the model builds upon the concepts established by Wetzel and Neckles (1986) and Madden and Kemp (1996).

Three state variables are modeled for SAV: shoots, (above-ground biomass), roots (below-ground biomass), and epiphytes (attached growth to leaves). In addition, three dominant SAV communities are incorporated in the estuary model based largely on salinity regimes (Moore et al., 1999). Within each community, a target species is selected: eelgrass *(Zostera marina*) for high salinity, widgeon grass (*Ruppia maritima)* for moderate salinity, and wild celery (*Vallisneria americana)* for tidal fresh. Since SAV production in the Bay and tributaries is largely determined by light availability (Orth and Moore, 1984; Kemp et al., 1983), a predictive representation of light attenuation is needed. The computation of light attenuation requires the addition of fixed solids, or suspended sediment, to the list of model state variables.

In addition to the simulation of SAV as a living resource, three phytoplankton groups are simulated while zooplankton are separated into two size classes for modeling purposes: microzooplankton (44-201 microns) and mesozooplankton (> 201 microns). Zooplankton are selected as a parameter because they are a valuable food source for finfish and to improve the computation of phytoplankton since zooplankton feed on phytoplankton, detritus, and each other.

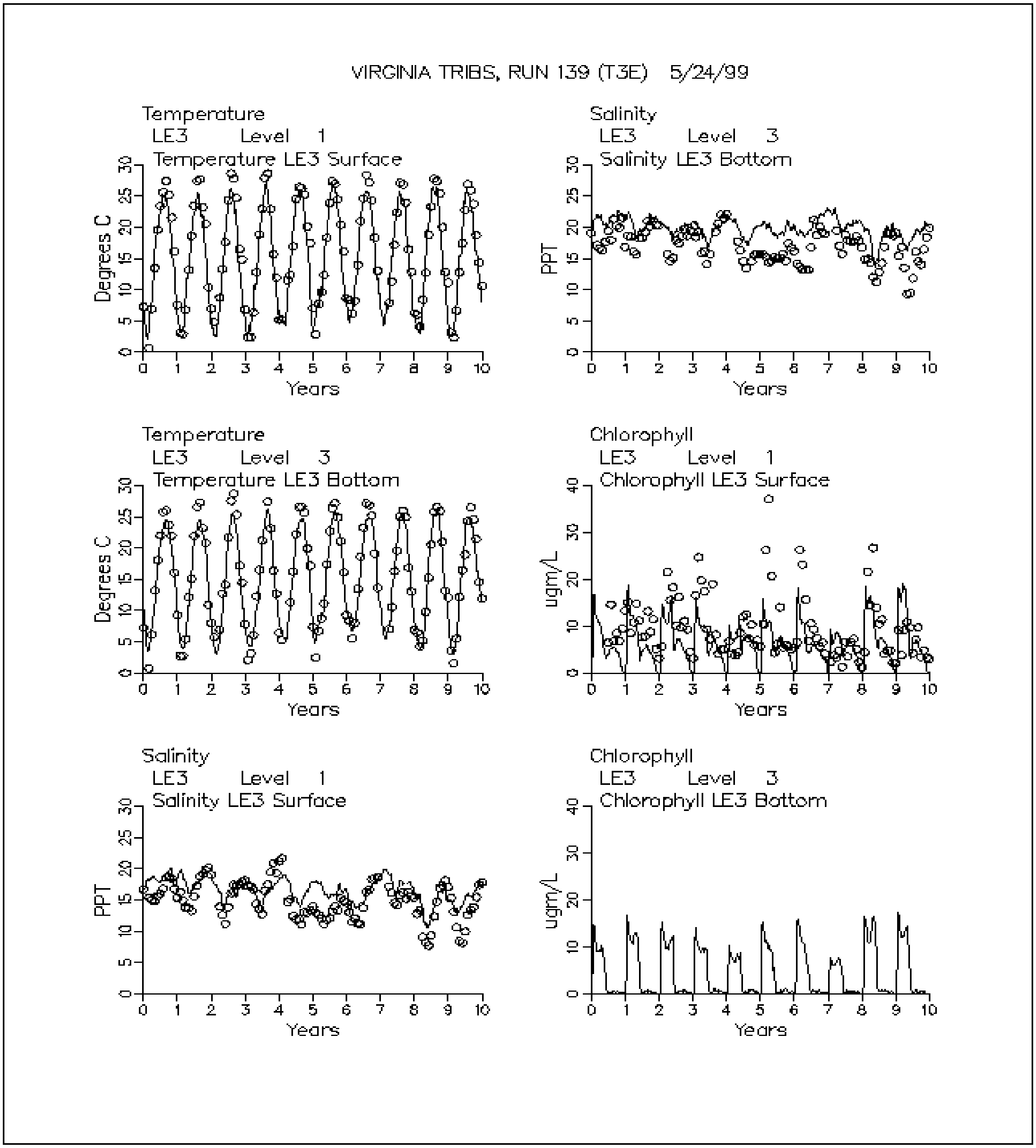
Benthos, or bottom-dwelling organisms, are included in the model because they are an important food source for crabs, finfish, and other economically significant biota and because they can exert a substantial influence on water quality through their filtering of overlying water (Cohen et al., 1984; Newell, 1988). Within the estuary model, benthos are divided into deposit feeders and filter feeders.

The Chesapeake Bay Monitoring Program provides the primary database for the estuary model calibration and performance evaluation. The program conducts about twenty surveys per year at approximately 90 stations in the mainstem and five major tributaries. In Virginia waters alone, over 5.5 million observations were processed for comparison with model results. Calibration is accomplished by comparing predicted and observed values over the ten years of simulation

A variety of output formats are used in the calibration assessment including several spatial and temporal scales. These include ten-year time series plots of water quality and sediment-water fluxes as shown in Figure 1.5. The monitoring station data represented in this figure is from the lower estuary of the Rappahannock River (CB Segment LE3). Level 1 represents the surface layer (or 1 meter below the surface) sample from the Chesapeake Bay Monitoring Program, and level 2 represents the bottom layer (or 1 meter above the bottom). Chlorophyll was not collected in the monitoring program from level 2; therefore, there are no bottom observations for this parameter for calibration or verification.

The CBEMP processes nutrient and sediment loads delivered from the Watershed Model and nutrient atmospheric deposition to tidal surface waters from the airshed model. In addition, loads from the ocean interface and from the linked bottom sediments model are incorporated in the model. The simulation of estuarine hydrology and water and habitat quality parameters and processes occurs on fifteen-minute time-steps with output generated each ten days. The entire simulation period is ten years (1985-1994). Seasonal averages for all water and habitat quality parameters are calculated for each year within this period. Estuary model results from management scenarios, designed to determine the impact of reduced nutrient and sediment loads, are often reported as a yearly or seasonal averages of the ten-year simulation.

Figure 1.5 **Calibration results from a monitoring station in the lower estuary Rappahannock River.**



1.5 Other Diagnostic Tools

While the linked Chesapeake Bay Program models are useful for tributary strategy development, limitations exist for both the Watershed Model and Estuary Model Package. For example, the CBEMP does not simulate small coastal basins such as those lining the Eastern Shore of the Bay and therefore, additional diagnostic tools were needed to estimate the response of SAV to pollutant loading reductions. The following sections describe these models and how they were applied.

Tidal Prism Modeling

In order to capture the spatial scales of small coastal basins, additional monitoring data and finer-scale modeling tools were employed on four target areas: the Piankatank and Poquoson Creeks on the Western Shore, and the Cherrystone and Hungars Creeks on the Eastern Shore. Existing monitoring data in these basins was used to test applications of the Tidal Prism Model (TPM) developed by the Virginia Institute of Marine Science. The modeling effort consisted of three tasks: 1) pre-calibration simulations to reference basins, 2) calibration/confirmation to monitoring data and assessment of TPM applications to other basins, and 3) conducting nutrient reduction scenarios for each of the four catchments. While the TPM did not contain the full ecosystem (biological) components as the larger CBEMP, it simulated all of the chemical and physical parameters of the Bay Program estuary model. Results of the TPM application to Virginia’s small coastal basins are described in section IV of this report.

Gallegos Model

The temporal and spatial scales of the CBEMP extend over broad salinity ranges during the growing season for SAV. A finer-scale tool was needed to define localized impacts of management pollutant reduction actions on SAV. The Gallegos optical model (1994) was used for this diagnostic application in Virginia's tributaries (EPA, 1999). It had the unique capability to compare light attenuation due to measured suspended solids and chlorophyll concentrations. In other words, the relative importance of these light-limiting parameters on SAV near any monitoring station was assessed.

Section 2: Scenarios

2.1 Overview

Models were employed to develop and test various lower tributary management options or strategies aimed at improving water quality through nutrient and sediment reductions. This section describes key scenarios used to assess the response of water and habitat quality and living resource to these load reductions. The major controllable nutrient and/or sediment loads include those from: 1) fall lines, 2) below-fall lines, 3) point sources, and 4) atmospheric deposition of nutrients to the tidal Bay water surfaces. All of the scenario results are based on a ten-year simulation period of varying hydrology in the Chesapeake watershed from 1985 to 1994, inclusive.

2.2 Scenario Descriptions

The CBEMP framework provided projections of expected water and habitat quality responses in the mainstem Bay and lower Virginia tributaries under a variety of management options. Five key scenarios provided the basis of analysis for the lower tributary allocations (Table 2.1). The full descriptions these and all scenarios can be found in Appendix B.

Table 2.1 **Key Scenarios**

KEY SCENARIO	DESCRIPTION
1985 Baseline Conditions	Represents the conditions of the entire Chesapeake Bay watershed in 1985 with respect to non-point source, point source, and atmospheric loads. ***Rationale***: Establishes a reference to which other scenarios will be compared. Also needed to compare status and trends monitoring data to model results for the Technical Synthesis.
1996 Progress	Represents the conditions of the entire Chesapeake Bay watershed in 1996 with respect to non-point source and point source loads. ***Rationale***: This scenario examines progress in reducing point source and non-point source nutrient and sediment loads from 1985 to 1996 and represents an estimate of the current water quality and living resource conditions in the lower tributaries**.**
Midpoint 1996 Progress – Full Voluntary Program Implementation	This is a derived scenario using point and non-point sources loads for all Chesapeake Bay basins midway between the *1996 Progress* scenario and *Full Voluntary Program Implementation.* Reductions vary by major basin. Atmospheric deposition for this scenario would assimilate these loads from both the *1996 Progress* and *FVPI* scenarios. ***Rationale***: This scenario examines tributary water quality and living resource response midway between a “no further action” management strategy (*1996 Progress*) and nutrient and sediment reductions estimated under a management strategy that achieves maximum reductions under a voluntary program (*FVPI*).

Full Voluntary Program Implementation - FVPI	***Rationale***: Projects loads under maximum feasible management implementation using a voluntary program throughout the Chesapeake Bay watershed. It is based on current technology, expanded program financing, and a maximum of 75% cost share by states. Time and availability of technical staff are not considered.
Current Limit of Technology – LOT	Estimates the maximum level of nutrient and sediment reductions given unlimited resources, unlimited cost share, and 100% landowner participation. A "do everything, everywhere" policy is applied using current available technologies. Time and availability of technical staff is not considered. ***Rationale***: This scenario examines the maximum load reductions of nitrogen, phosphorus, and sediment, and represents an estimate of the maximum improvement in water quality and living resource conditions in the lower tributaries.

These scenarios covered the range of nutrient and sediment loads from the maximum loads of the *1985 Baseline Conditions* scenario to the maximum possible controls under existing technologies estimated by the *Current Limit of Technology* scenario. Approximations of recent loads in the lower tributaries are represented by the *1996 Progress* scenario. The maximum level of nutrient and sediment control under a voluntary program is determined by the *Full Voluntary Program Implementation* scenario.

More specific management actions directed toward the lower Virginia tributaries were conducted through a series of five ranging scenarios (Table 2.2 and Appendix B). These scenarios changed loading conditions in the lower Virginia tributaries while those from the Potomac River basin and watersheds north of the Potomac were kept at levels established for their *Tributary Strategies*. Comparing these scenarios to the equivalent bay-wide scenarios allowed for the assessment of the impact of lower tributary nutrient and sediment reductions as compared to the impact from reductions made elsewhere. All of the scenario results are based on a ten-year simulation period of varying hydrology in the Chesapeake watershed from 1985 to 1994, inclusive. Unless otherwise noted, atmospheric deposition for the ranging scenarios is at *1985 Baseline Conditions*.

Table 2.2 **Ranging Scenarios**

RANGING SCENARIO	DESCRIPTION
VA 1996 Progress / Tributary Strategy Above	Represents non-point source and point source loads with respect to *1996 Progress* conditions for Virginia's lower tributaries while the northern Chesapeake Bay tributaries (Potomac and above) implement *Tributary Strategy* load reductions. ***Rationale***: This scenario determines an aspect of load reductions occurring at different levels in different basins. In this case, load reduction in the lower Virginia tributaries are relatively less than the load reductions in the tributaries of the Potomac and above. This scenario develops estimates of the affect *Tributary Strategy* load reductions from outside the lower Virginia tributaries have on water quality and living resources in Virginia waters.

VA BNR-BNR Equivalent / Tributary Strategy Above	This is a derived scenario where biological nutrient removal (BNR) is simulated at above- and below- fall line point sources in Virginia's lower tributaries. All of Virginia's lower tributaries are at *BNR* conditions for point sources except the Rappahannock with *BNR* only applied to >1 million gallon per day (mgd) facilities. Point source effluent concentrations of 8.0 mg/L TN and 2.0 mg/L TP are applied to flows projected to 2000 levels. For facilities with 1996 discharge TN concentrations less than 8.0 mg/l, the 1996 concentrations are used. Non-point source loads in the lower tributaries are reduced by basin to the same *(Equivalent)* PS:NPS load ratio prior to BNR removal. These non-point source loads are calculated using the following ratio and solving for BNR non-point source loads: $\frac{\textit{1996 Progress}\text{ PS loads - }\textit{BNR}\text{ PS loads}}{\textit{1996 Progress}\text{ PS loads – }\textit{FVPI}\text{ PS loads}} = \frac{\textit{1996 Progress}\text{ NPS loads – }\textit{BNR}\text{ NPS loads}}{\textit{1996 Progress}\text{ NPS loads – }\textit{FVPI}\text{ PS loads}}$ Solids are reduced to a non-point source phosphorus ratio. Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* load levels. The Watershed Model was not run for this scenario. Instead, point source delivered loads were calculated by using 1996 transport factors and the edge-of-stream BNR point sources described above. ***Rationale***: This scenario examines a moderate point source load reduction and a measure of an equivalent nutrient reduction from non-point sources.
VA Interim Bay Agreement / Tributary Strategy Above	Nutrient reductions in the lower Virginia tributaries at a 40% interim nutrient reduction goal while loads in the northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* levels. ***Rationale***: This scenario estimates water quality and ecosystem response to controllable loads in the lower Virginia tributaries set at 40% of *1985 Baseline Conditions*.
VA Full Voluntary Program Implementation / Tributary Strategy Above	Virginia's lower tributaries are at *Full Voluntary Program Implementation* load levels and the Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* amounts. Atmospheric deposition is at levels of *Full Voluntary Program Implementation* in the basins and tidal waters of the lower Virginia tributaries and at *1985 Baseline Conditions* for the Potomac River basin and watersheds above. ***Rationale***: This scenario determines an aspect of load reductions occurring at different levels in different basins. In this case, load reductions in the lower Virginia tributaries are relatively greater than the load reductions in the tributaries of the Potomac and above.

The final series of scenarios were directed toward reductions within geographic regions of a tributary or shoreline of the Bay (Table 2.3 and Appendix B). Loads from the Potomac River basin and tributaries to the north were at *Tributary Strategy* scenario levels while the lower Virginia tributaries, or portions of these major tributaries that were not included in the nutrient and sediment reductions, were held at *1996 Progress* amounts. Again, all of the scenario results are based on a ten-year simulation period of varying hydrology in the Chesapeake watershed from

1985 to 1994, inclusive. Unless otherwise noted, atmospheric deposition for the geographic management scenarios is at *1985 Baseline Conditions*.

Table 2.3 **Geographic Management Scenarios**

GEOGRAPHIC MANAGEMENT SCENARIO	DESCRIPTION
VA Eastern Shore FVPI / Tributary Strategy Above	Eastern Shore VA loads for point sources, non-point sources, and atmospheric deposition at *Full Voluntary Program Implementation* levels. All other lower VA basin loads (Rappahannock, York, James, and Western Shore VA) at *1996 Progress* amounts. Northern Chesapeake Bay tributaries (Potomac and above) at *Tributary Strategy* loads. ***Rationale***: This scenario determines an aspect of load reductions occurring at different levels in different basins. In this case, nutrient and sediment reductions in the Virginia Eastern Shore are relatively greater than load reductions in all other tributaries.
VA Western Shore FVPI / Tributary Strategy Above	Western Shore VA loads for point sources, non-point sources, and atmospheric deposition at *Full Voluntary Program Implementation* levels. All other lower VA basin loads (Rappahannock, York, James, and Eastern Shore VA) at *1996 Progress* amounts. Northern Chesapeake Bay tributaries (Potomac and above) at *Tributary Strategy* loads. ***Rationale***: This scenario determines an aspect of load reductions occurring at different levels in different basins. In this case, nutrient and sediment reductions in the Virginia Western Shore are relatively greater than load reductions in all other tributaries.
VA Current LOT Sediment / Tributary Strategy Above	Virginia's lower tributaries at *Current Limit of Technology* for total suspended solids (about 33% reduction from *1985 Baseline Conditions*). Loads from point sources, non-point source nutrients, and the atmosphere in the lower Virginia tributaries are at *1996 Progress* levels. Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* load levels. ***Rationale***: This sensitivity scenario examines the relative effect of the most stringent reductions of suspended sediment loads within the feasible region, with an estimate of the 1996 level of nitrogen and phosphorus controls.
VA Extreme Sediment Reduction / Tributary Strategy Above	Virginia's lower tributaries are at 40% load reduction of total suspended solids from *1985 Baseline Conditions.* (Pristine sediment load reduction is about 43% from the baseline). Loads from point sources, non-point source nutrients, and the atmosphere in the lower Virginia tributaries are at *1996 Progress* levels. Northern Chesapeake Bay tributaries (Potomac and above) at *Tributary Strategy* load levels. ***Rationale***: This sensitivity scenario examines the relative effect of sediment reductions outside the feasible region with an estimate of the current level of control for nitrogen and phosphorus to determine the impact suspended sediment loads have on lower tributary water quality and living resources.

York River 2010 Scenario	This is a Watershed Model scenario developed solely for the York basin. York point source effluent concentrations at BNR levels of 8.0 mg/l TN are applied to year 2000 flows. For facilities with 1996 TN discharge concentrations less than 8.0 mg/l and facilities less than 1 mgd, the 1996 concentrations are used. Point source TP loads in the York apply 1996 concentrations to projected 2000 flows. Year 2000 land uses, septic system loads and animal numbers are employed while atmospheric deposition is at *1985 Baseline Conditions*. The CBEMP was not run for this scenario. ***Rationale***: This scenario examines non-point source load reduction potential in 2010 with the implementation of BMPs assuming land uses, animal numbers, and septic system loads remain at 2000 levels and point source loads are capped at BNR levels. Non-point source loads in the York are simulated with 2010 projections of BMPs found in Appendix B.
James Above-Fall Line at BNR-BNR Equivalent / Tributary Strategy Above	Above-fall line James loads at *BNR-BNR Equivalent* or above-fall line James point sources at BNR concentrations for TN and TP and 2000 flows. For facilities in the above-fall line James with 1996 TN concentrations less than BNR concentrations, the 1996 concentrations are used. Non-point source loads for the above-fall line James are at a BNR equivalent levels of control. The Appomattox, below-fall line James, and other VA tributary loads at *1996 Progress*. Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* load levels. ***Rationale***: This scenario examines the water quality and living resource response to *BNR-BNR Equivalent* load reductions in the above-fall line James.
James Above-Fall Line, Appomattox, & Below-Fall Line Tidal Fresh James at BNR-BNR Equivalent / Tributary Strategy Above	Loads discharging into the tidal fresh James at levels of *BNR-BNR Equivalent*. For facilities discharging into the tidal fresh James with 1996 TN concentrations less than BNR concentrations, the 1996 concentrations are used. The James regions discharging below the tidal fresh portion of the James and other Virginia lower tributaries are set to *1996 Progress* loads. Northern Chesapeake Bay tributaries (Potomac and above) at *Tributary Strategy* load levels. ***Rationale***: This scenario examines the water quality and living resource response to *BNR-BNR Equivalent* load reductions in regions discharging to the tidal fresh James.
James Tidal Fresh at BNR-BNR Equivalent For Nitrogen / Tributary Strategy Above	Loads discharging into the tidal fresh James at levels of *BNR-BNR Equivalent* for nitrogen only. James discharging to the tidal fresh region at *1996 Progress* for phosphorus and sediment. For facilities discharging into the tidal fresh James with 1996 TN concentrations less than BNR concentrations, the 1996 concentrations are used. The James regions discharging below the tidal fresh portion of the James and other Virginia lower tributaries are set to *1996 Progress* loads. Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* load levels. ***Rationale***: This scenario examines the water quality and living resource response to *BNR-BNR Equivalent* load reductions for nitrogen only in regions discharging to the tidal fresh James. It quantifies the importance of nitrogen versus phosphorus controls.

Section 3 Tracer Analysis

3.1 Background

To better understand the hydrologic interactions of the different tributaries with the mainstem Bay, a series of tracer scenarios was performed. Tracer analyses are used to visualize the movement of conservative (or non-reactive) dissolved and particulate materials in the water. The conservative tracers, similar to non-reactive dyes used in observational studies, are carried and dispersed by water currents simulated by the Hydrodynamic Model. There are two types of traces. A dissolved tracer is assumed to be 100% soluble and is used to study the transport of a soluble pollutant such as nitrogen. A particulate tracer depicts an insoluble constituent, like suspended sediment or algae, and is associated with a specified settling velocity.

The tracer simulations used the Chesapeake Bay Estuary Model Package, setting all model constituents to a chemically and biologically non-reactive state. Similar to a dye test, a mass of tracer was loaded to an area such as a river's head-of-tide. Time-series outputs from the model showed changing tracer concentrations and movement of tracer particles to illustrate Bay hydrodynamics and provide information for pollution reduction management decisions. Caution must be used in the interpretation of tracer results since chemically and biologically active dissolved and particulate material will behave differently than the assumed inert material. Tracer analysis; however, allowed for the quantification of large-scale material transport in the Bay.

The dissolved tracers would represent the upper limit of tracer influence since they are non-settling or would transport further from their source. Particulate conservative tracers were input in the same manner, but particles had a settling rate of 0.1 m/day or 1.0 m/day, consistent with the simulated rate of settling for living suspended particles (algae) and inorganic particulate material, respectively. The particulate tracer with the higher settling velocity would represent the lower limit of tracer influence since it would transport the least distance from its source. Nutrients and sediments would most likely behave between the boundaries of the dissolved and particulate tracer influence.

Dissolved conservative tracers, simulating nutrients, were input continuously at an arbitrary load of 100,000 kg/year (274 kg/day) at the head-of-tide or fall line of each major basin including the Susquehanna, Potomac, Rappahannock, York, and James. Figure 3.1 depicts this input load using the Potomac as an example.

The Hydrodynamic Model uses a time step of five minutes, with an aggregated two-hour time step output as the driving force for the Water Quality Model. The tracer analyses in the Virginia tributary studies were conducted for the year 1987, a year of average hydrology. The CBEMP simulation ran until a steady-state condition existed after three years of repeated 1987 hydrodynamics. Daily concentrations of the tracer were then determined for each of the 10,196 model cells in the tidal Bay (Figure 3.2). Visualizations for the geographically-varying steady-state tracer concentrations were produced as still images for this report.

Figure 3.1 **Tracer loading of the Potomac River basin at the fall line**

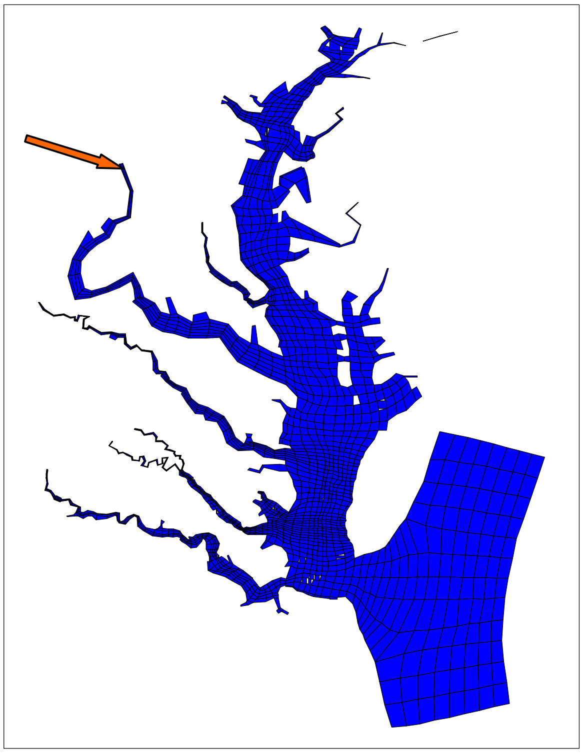
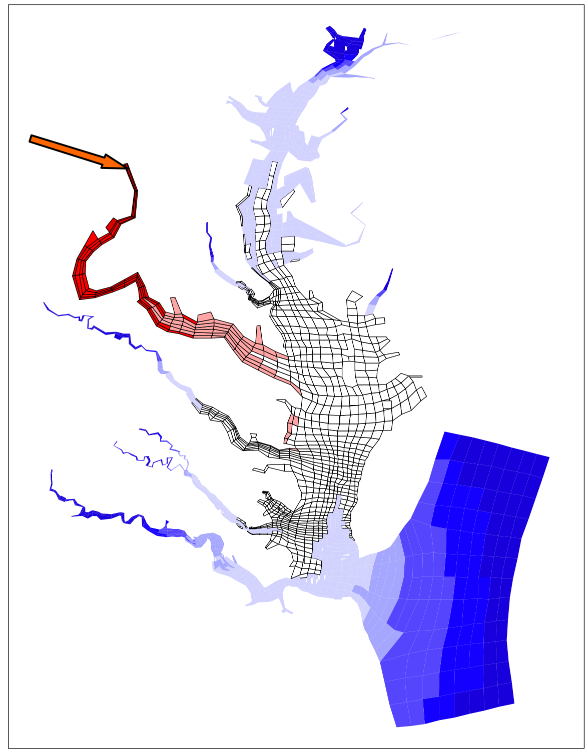
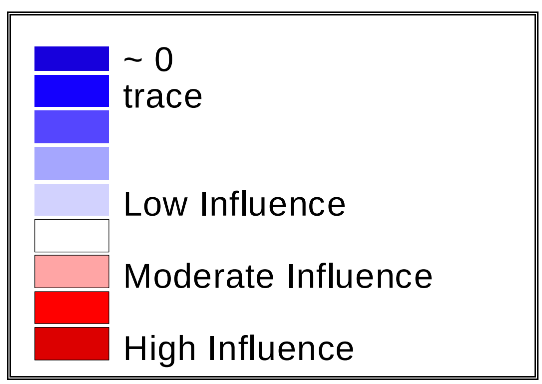


Figure 3.2 **Steady-state tracer concentrations after constant loading of the Potomac River fall line**



3.2 Response to Conservative Dissolved Tracer

Figure 3.3 **Dissolved Tracer Influence**



Tracer runs were carried out on five major Bay tributaries; the Susquehanna, Potomac, Rappahannock, York, and James. Figure 3.3 shows the range of possible tracer influence, or concentrations, on regions of the tidal Bay. The dark blue shading at the top of the legend indicates no influence or only trace concentrations are found in regions after the estuary model is run to steady-state. The concentrations at the bottom of the legend, designated in red, portray a high influence of the tracer.

The distribution of constant dissolved tracer loads released from the two largest basins, the Susquehanna and Potomac, are shown in Figure 3.4 and Figure 3.5, respectively. Dissolved tracers from the head-of-tides of these basins were distributed and mixed throughout the Bay and portions of Virginia's lower tributaries. The analysis showed low to moderate influence in the lower salinity reaches of Virginia's three main tributaries. Among the Virginia estuaries, the greatest influence from tracers loaded to the Susquehanna and Potomac occurred in the mesohaline and polyhaline regions of the Rappahannock and York while the least effect was in the James. A high influence of the Potomac tracer is depicted in Virginia waters along the western shore between the mouths of the Potomac and Rappahannock (Figure 3.5).

Figure 3.4 **Influence of Susquehanna Constant Dissolved Tracer**

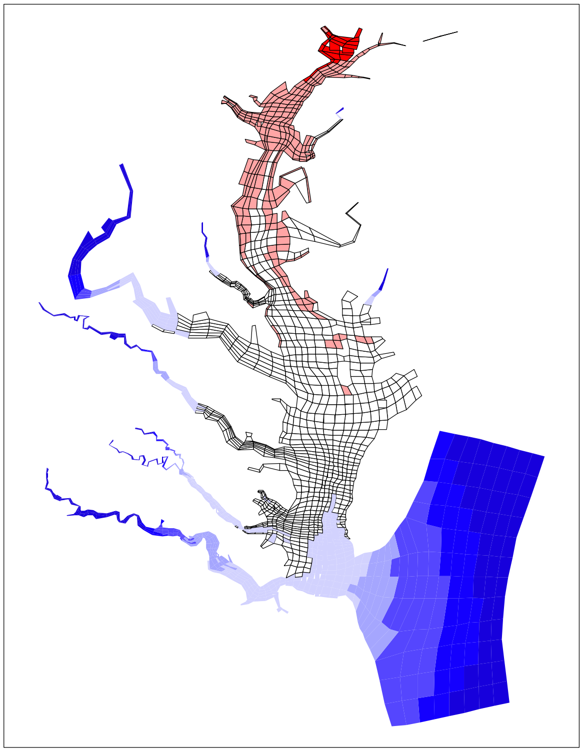
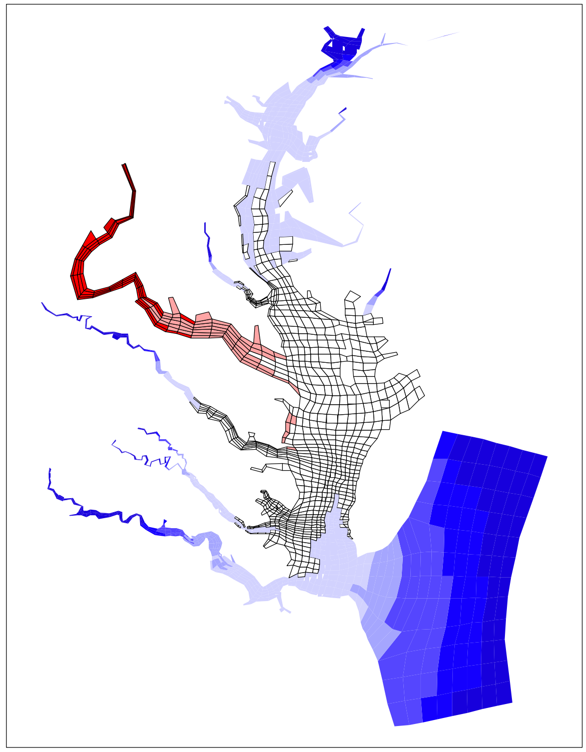


Figure 3.5 **Influence of Potomac Constant Dissolved Tracer**



Constant dissolved inputs from the fall line of the Rappahannock were mostly distributed throughout this tributary and the western portion of the lower Bay with some significant impact on Virginia's Eastern Shore (Figure 3.6). The overall influence on the mainstem was much less than that of the Susquehanna and Potomac tracers. For the York tracer, only trace concentrations were found in waters north of the York while a low to moderate influence was seen in the lower James and a high influence south of Mobjack Bay (Figure 3.7). Dissolved tracer inputs from the James fall line had a negligible impact on the mainstem Bay when compared to sources in the upper Bay and other Virginia tributaries (Figure 3.8). The mix of geography and Bay currents delivers most of the James tracer to the coastal ocean.

Figure 3.6 **Influence of Rappahannock Constant Dissolved Tracer**

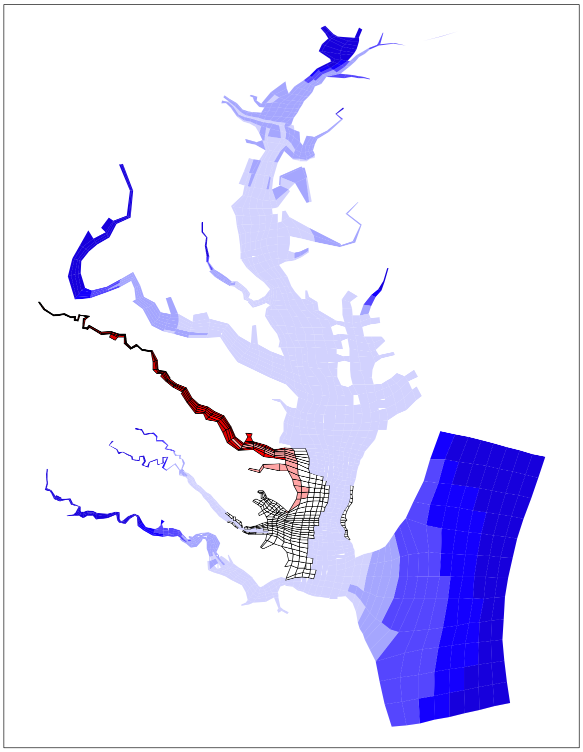


Figure 3.7 **Influence of York Constant Dissolved Tracer**

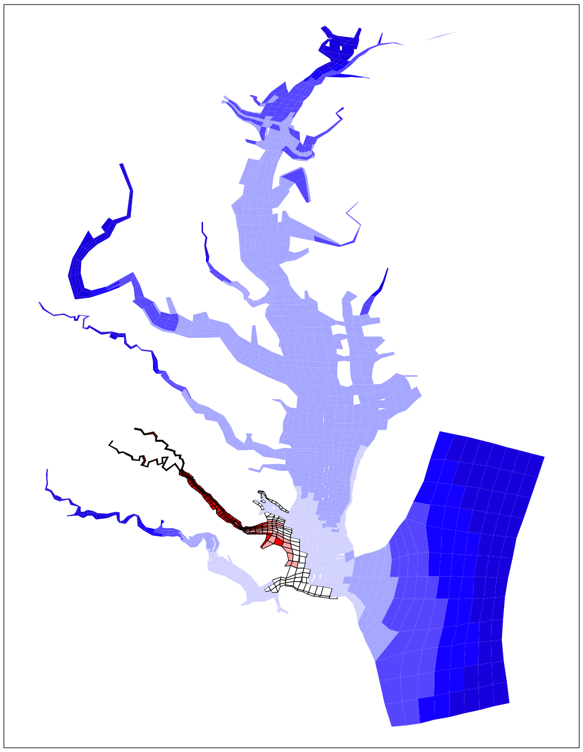
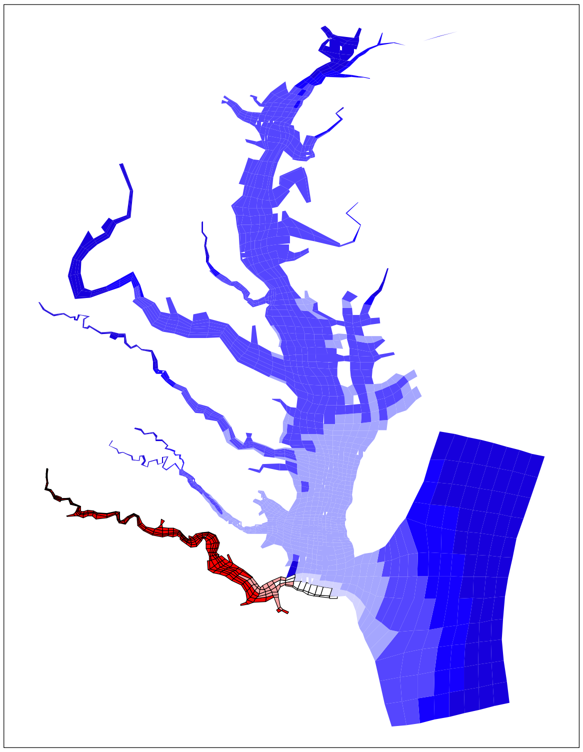


Figure 3.8 **Influence of James Constant Dissolved Tracer**



The relative influence of dissolved tracer loads from the five main tributaries on their tidal waters was examined. Again, the sources included fall line loads to the Susquehanna, Potomac, Rappahannock, York, and James River basins. Steady-state concentrations in the estuary model cells, that resulted from constant fall line loads, were proportionally adjusted according to relative 1987 total nitrogen loads for the different sources. These calculated concentrations were then compared to assign a percent influence from each source on the major regions of Virginia's tidal tributaries. With this type of tracer analysis, the influence of the main upper tributary sources on Virginia waters could be tested and compared to the influence of Virginia tributary sources, particularly the impacts on the lower portions of Virginia's tributaries. In other words, these influences generally reflected the overall impact of nitrogen loads from five main Chesapeake tributaries on water quality in Virginia's estuaries. A summary of the relative influence is found in Table 3.1 where the column headings indicate the source of the tracer load and the row headings are the areas of Virginia's tidal tributaries that were affected.

Table 3.1 **Dissolved tracer influence on Virginia's lower tributaries using a tracer load equivalent to the discharged load of nitrogen from each load source**

TIDAL REGION AFFECTED	SOURCE OF TRACER INPUT				
	Susquehanna	Potomac	Rappahannock	York	James
Rappahannock – Upper Tidal	1%	0%	99%	0%	0%
Rappahannock – Middle/Lower	36%	22%	41%	0%	1%
York – Upper Tidal	4%	2%	0%	94%	0%
York – Middle/Lower	27%	15%	2%	55%	1%
James – Upper Tidal	1%	0%	0%	0%	99%
James – Middle/Lower	15%	9%	1%	2%	73%

The greatest impact of tracer fall line loads at each of Virginia's tributaries was on the upper tidal regions of the respective tributary. For example, the Rappahannock tidal fresh region was almost entirely influenced by the tracer released in the Rappahannock. However, the lower tidal Rappahannock was affected by both in-stream inputs and mainstem Bay processes. In this lower region, the combined tracer contributions from the mainstem Bay and tributaries to the north was 58% while the effect of the fall line Rappahannock tracer on the lower area was 41%. The Rappahannock tracer had a slight influence on the lower regions of the York and James.

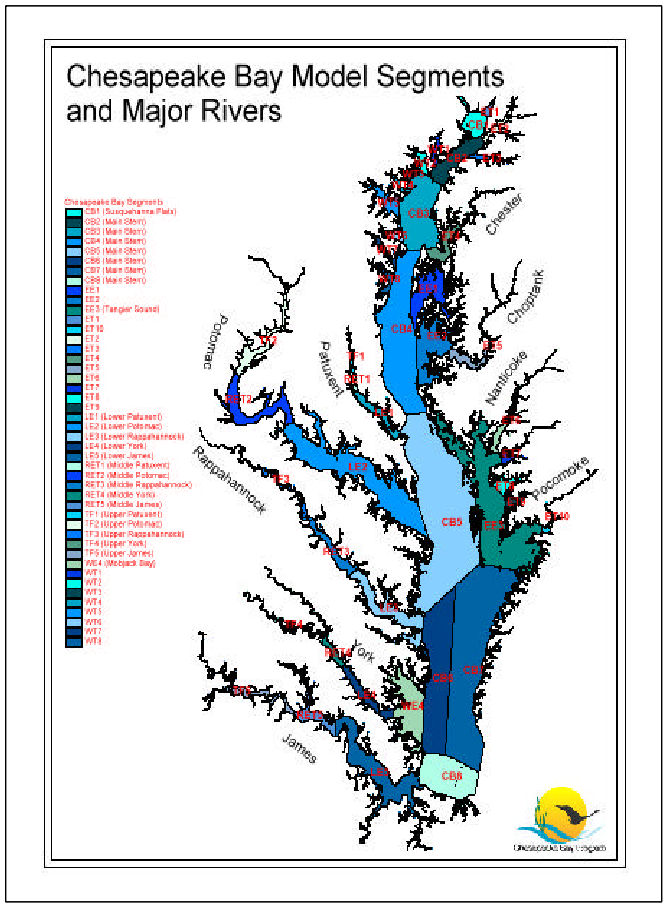
Throughout the York and in Mobjack Bay, tracer results indicated that loads from the York fall line had the greatest local influence. More than half of the tracer load impact in the lower York originated at its head-of-tide. However, loads from other regions, particularly the

Susquehanna and Potomac, were important as outside influences on the lower York and Mobjack Bay.

The James tidal fresh and mesohaline regions were heavily influenced by the James tracer. About 73% of the total tracer in the lower James was from the James fall line (Table 3.1). Among the lower areas of Virginia's tributaries, this region also showed the least impact from upper Bay loads.

Between the Patuxent River to the north and the Rappahannock River to the south, the Chesapeake region of CB5 straddles the boundary between the upper and lower Bays and includes the terminus of the southern end of the deep trench (Figure 3.9). The Susquehanna and Potomac sources predominated in CB5, but a slight influence from the lower tributaries, 4% of the total dissolved tracer load influence, was seen. This indicates that the lower tributaries have some impact on water quality of the mainstem Bay, but the predominate influence of nutrient reductions in the lower tributaries are in the lower tributaries themselves.

Figure 3.9 **Chesapeake Bay Estuary Model Segments**



To examine the relative influence of equivalent load reductions in different tributaries, a separate tracer analysis was performed. An equal mass of dissolved tracer load was discharged from each source to compare the water quality impact on a pound-per-pound basis. Assuming load reductions from each tracer source would be equivalent in cost, this analysis examined the relative cost effectiveness of equal load reductions. As can be seen in Table 3.2, the predominant influence of tracers from the five key tributaries on waters in Virginia's tributaries was estimated to be from local sources.

Table 3.2 **Dissolved tracer influence on Virginia's lower tributaries using an equal tracer load from each load source**

TIDAL REGION AFFECTED	SOURCE OF TRACER INPUT				
	Susquehanna	**Potomac**	**Rappahannock**	**York**	**James**
Rappahannock – Upper Tidal	0%	0%	100%	0%	0%
Rappahannock – Middle/Lower	5%	6%	87%	1%	0%
York – Upper Tidal	0%	0%	0%	100%	0%
York – Middle/Lower	3%	3%	3%	91%	0%
James – Upper Tidal	0%	0%	0%	0%	100%
James – Middle/Lower	4%	5%	5%	8%	78%

Overall, tracer loads from the Potomac basin and tributaries above generally mixed throughout the Bay. Tracer loads from the lower tributaries had little influence on the Bay, but had considerable local influence, both within the tributary where the tracer originates and on adjacent lower tributaries. The tidal fresh and mesohaline portions of each tributary were largely influenced by above-fall line sources and below-fall line sources that drain directly to the tidal fresh region. The lower Virginia estuaries were all influenced by loads from the Potomac and tributaries above, but the greatest single influence was from the basin's own tracer load. Due to the residual circulation of the Bay, tributaries to the north have a relatively greater influence on the tributaries to the south, so that the Rappahannock tracer is seen to have a relatively higher concentration in the lower York than in the lower Potomac.

3.3 Response to a Conservative Particulate Tracer

The influence of conservative particulate tracers were mostly local to the tracer origin. Particles with a 0.1 m/day settling rate, consistent with an algal settling rate, accumulated almost entirely within a two segment zone of their input. For example, for the fall line inputs, the particulate tracer would be found almost entirely within the tributary, with negligible influence on the mainstem of the Bay. Particles with a settling rate of 1.0 m/day, consistent with inorganic particulate material, settled primarily within the region of origin. For a fall line discharge, almost all of the particulate tracer would settle within the tidal fresh region of the tributary.

Section 4: Basin Descriptions with Nutrient and Sediment Loads

4.1 Basin Descriptions

Physical Description and Estuarine Characteristics

The lower Chesapeake Bay system consists of the mainstem Bay, three major tributaries on the western shore (James, York, and Rappahannock) and a number of lesser tributaries and embayments along the eastern and western shorelines (Figure 4.1). Virginia's lower tributary basins comprise about 22% of the watershed or about 15,500 square miles. The James/Appomattox basin represents about 15% of the total watershed and is the third largest source of freshwater to the Chesapeake Bay after the Susquehanna and Potomac Rivers. The Rappahannock River Basin covers only 4% of the Bay watershed while the York River Basin contributes another 3% and is represented by both the Pumunkey and the Mattaponi Rivers (2 and 1%, respectively). The remainder of Chesapeake Bay drainage area in Virginia consists of the Potomac River Basin and its tributaries, including the Shenandoah River, which are not discussed in this report.

Virginia's western shore tributaries are classified as partially-mixed coastal plain estuaries. The tidal range is reported as less than 2 meters. As a result, the tributaries are categorized as low-energy or microtidal. The depths along the river axes are generally less than 10 meters, but near the mouth of each river, there are natural deep areas or "holes" more than 20 meters deep.

Rappahannock River Basin

The Rappahannock River Basin is the second largest contributing stream to the Chesapeake Bay in Virginia, and represents about 7% (~2,600 square miles) of the Commonwealth (Table 4.1). Rappahannock waters flow from the eastern edge of the Blue Ridge physiographic province through the Piedmont and Coastal Plain physiographic provinces (Figure 4.2). Because of the high relief, the river produces rapid or "flashy" streamflow peaks during storm events. The river can carry large loads of sediments and nutrients relative to the size of the basin.

Table 4.1 **River Basin Areas**

River Basin	**Area (mi^2)**
Rappahannock	2,680
York	3,000
James	10,240
Eastern Shore	300

Source: Chesapeake Bay Program Phase IV Watershed Model

Figure 4.1

Lower Chesapeake Bay Basins

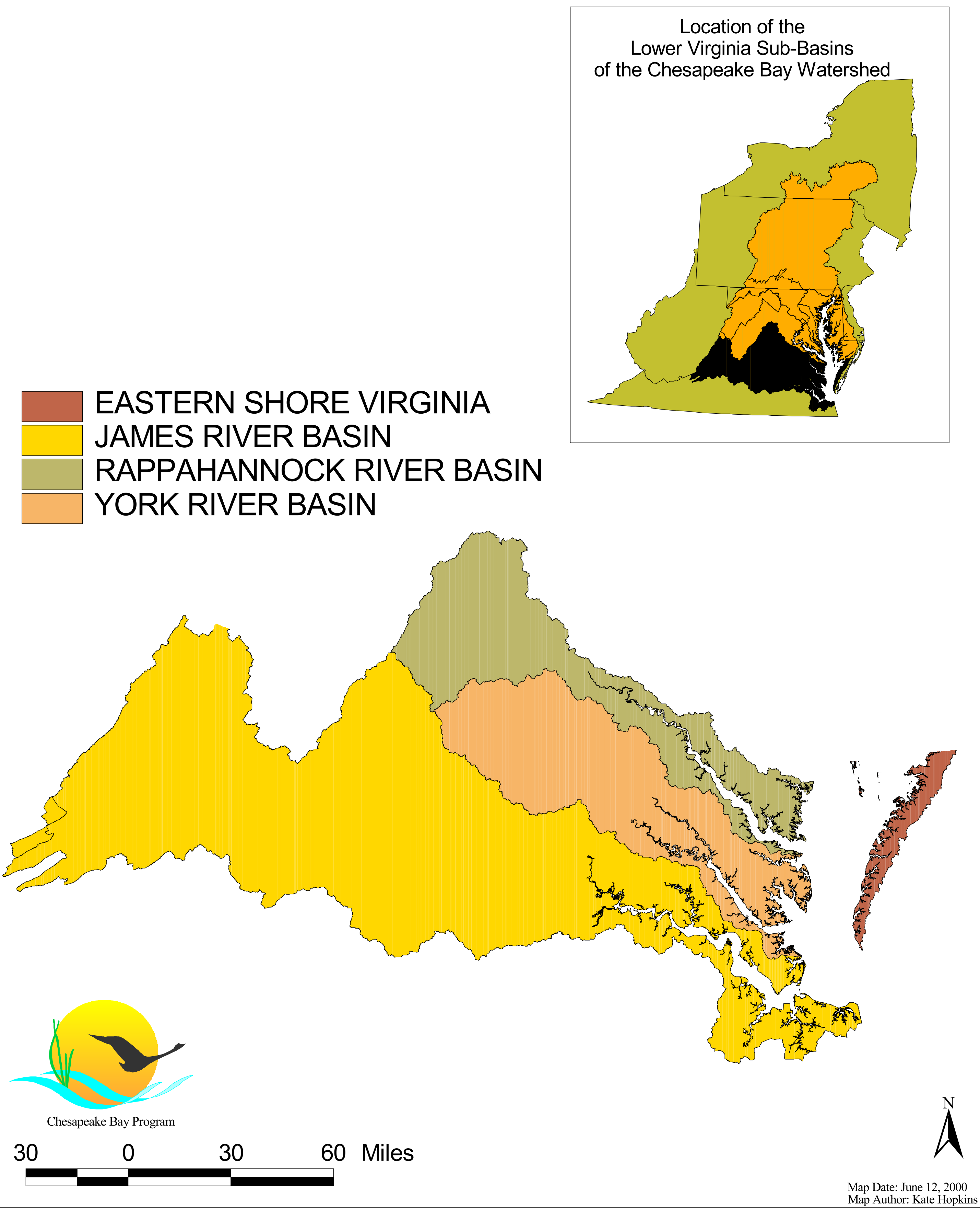
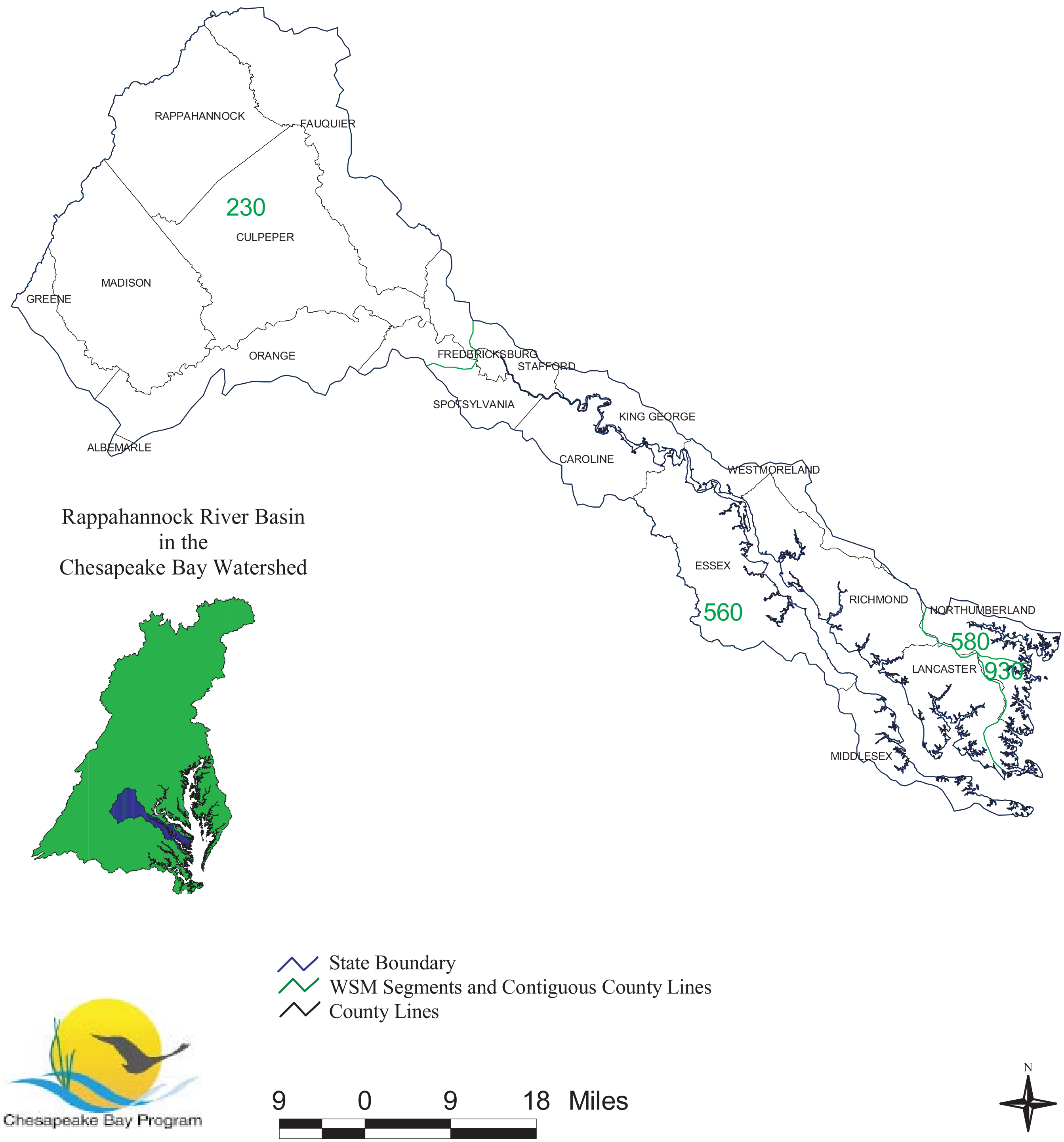


Figure 4.2

Rappahannock River Basin

Watershed Model Segments with State and County Boundaries



The Rappahannock River has a mean depth of 4.8 m (Table 4.2) with a deep channel flanked by shallow shoals of the estuary. There is a salinity gradient that causes tidal mixing along this stretch of the tidal river. The lower estuary experiences strong stratification during the summer months that restricts mixing between the low dissolved oxygen bottom waters and more oxygenated overlying surface waters. At the mouth, a shallow sill restricts the flow of bottom water from the river out into the Chesapeake Bay. Dissolved oxygen concentrations below 5 mg/L typically appear in deep waters in May or June when water temperatures exceed 20 ^{o}C. The anoxia/hypoxia is most pronounced in August. Among Virginia's tributaries, this water body has the longest water residence time of 53 days (Table 4.2).

Table 4.2 **Virginia Tidal River Characteristics**

Tidal River	**Surface Area (10^6 m^2)**	**Volume - mlw (10^6 m^3)**	**Mean Depth (m)**	**Mean Residence Time (days)**
James	658	2,399	3.3	31
York	256	909	4.3	35
Rappahannock	401	1,782	4.8	53

Sources: Cronin (1971); Hagy and Boynton (1999)

York River Basin

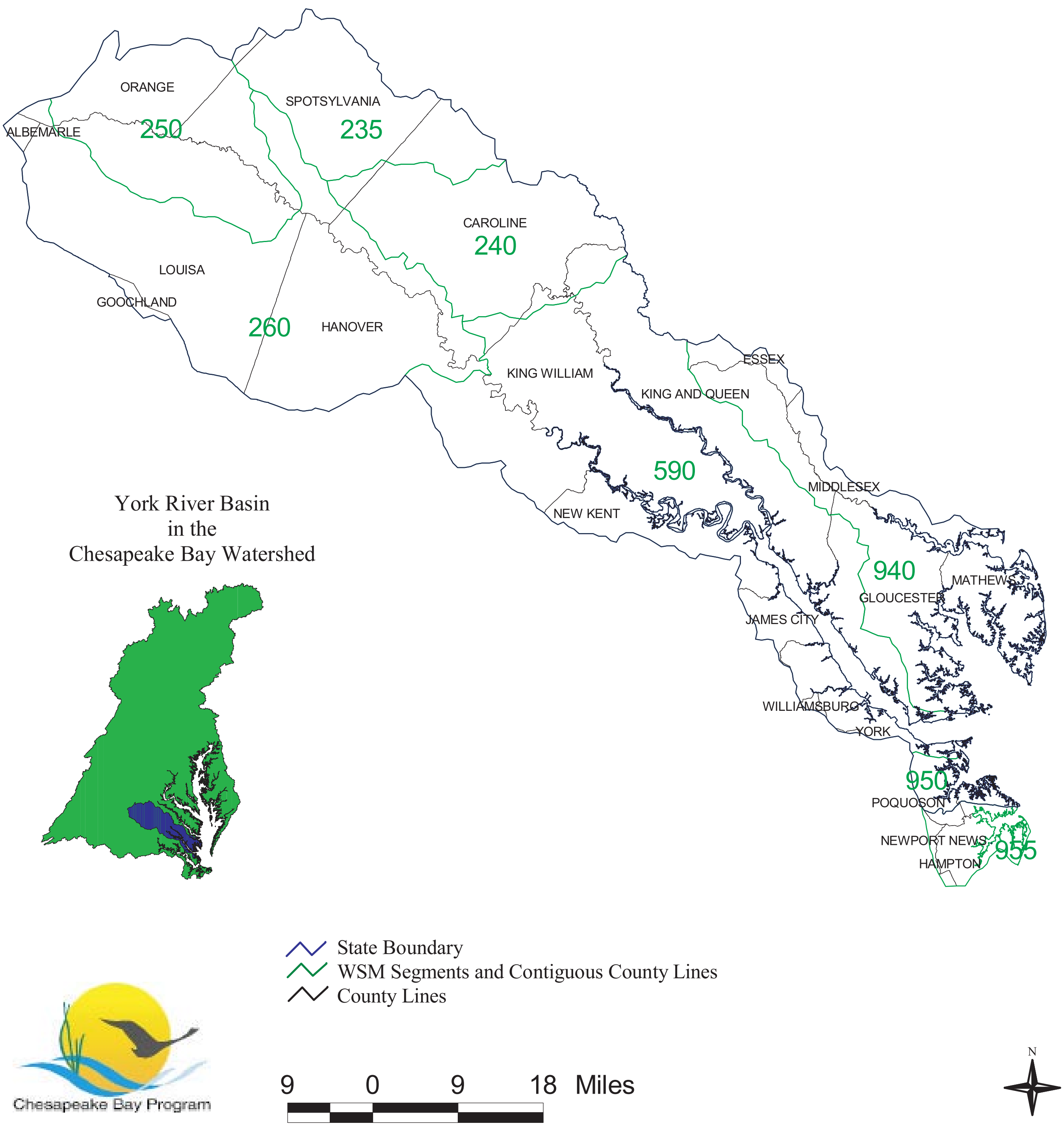
The York River Basin constitutes about 6.5% (~3,000 square miles) of the Commonwealth (Table 4.1). The basin is composed of the Pumunkey and Mattaponi Rivers and is located within the Piedmont and Coastal Plain physiographic province (Figure 4.3). Although the Pumunkey and Mattaponi rivers are often presented collectively as the York River Basin, each river has unique basin, discharge, and water-quality characteristics. The Pumunkey Basin is of low relief and relatively wide, and tends to produce storm flows that are slow to peak and recede. Lake Anna in the Pumunkey Basin also attenuates storm flow and loads. The Mattaponi Basin has relatively low relief and extensive wetland areas. It is the more northerly and smaller of the two rivers. Storm flows are even slower to peak and recede than the Pumunkey River. Nearly 70% of the York Basin is covered by forest and about 20% are classified as agricultural land. The basin as a whole contains significant percentages of barren land, open water, and wetlands.

The average depth of the York River is 4.3 m (Table 4.2) with hypoxia observed frequently in the deep waters. The York River is long and straight from West Point down to Gloucester Point. The tidal river has a deep channel running along its axis flanked by shallow shoals. There is a strong salinity gradient that causes a significant amount of tidal mixing along this stretch of the river. At the river mouth, a deep channel cuts across the shallow shoals of Mobjack Bay and the southern shore. This lower York area experiences strong stratification restricting mixing between the low dissolved oxygen bottom waters and more oxygenated overlying surface waters. During summer low river flows and with a water residence time of 35 days, conditions are favorable for depressed dissolved oxygen conditions in deeper waters.

Figure 4.3

York River Basin

Watershed Model Segments with State and County Boundaries



York River Basin
in the
Chesapeake Bay Watershed

Chesapeake Bay Program

James River Basin

The James River Basin includes about 25% of the Commonwealth of Virginia and encompasses nearly 10,200 square miles (Table 4.1). This basin extends from the eastern part of West Virginia through four physiographic provinces: Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain (Figure 4.4). As a result, this is the most varied basin in terms of geology and physiology. The James has a much greater portion in the Piedmont versus the Valley and Ridge compared to the Potomac and particularly the Susquehanna. Therefore, stream flows and sediment delivery within this basin are unique. Streamflow varies widely with time, depending on precipitation patterns that can result in either very localized or widespread storm flow events.

The overall geography of the James basin makes for a very effective sediment delivery system. The primary river channel of the James is much lower in elevation then the surrounding plateaus. Smaller creeks flow directly into the mainstem James River from steep-sloped gullies draining the surrounding lands. The underlying soils/substrate in the Piedmont have a much higher tendency to erode, leading to significant sediment runoff and re-distribution to the downstream river valleys. Most of this land erosion occurred in the eighteenth and nineteenth centuries. On a geological time scale, the headwaters region of the James basin is eroding about four times faster then the rest of the basin, thereby delivering more sediments across the fall line to the tidal river. In the Piedmont region of the James basin, the erosion rates are also elevated.

Of Virginia's three major tributaries, the James River has the largest surface area and volume (Table 4.2). Despite having the shallowest average depth (3.3 m) and the shortest mean residence time (31 days) among Virginia's estuaries, the James River has a second hole about 15 km from the hole at the mouth. The holes are connected by a dredged navigational channel about 14 m deep. The James has strong non-tidal circulation (Kuo and Neilson, 1987). Hypoxia (dissolved oxygen concentrations < 5 mg/L) is rarely reported from bottom waters of the James, but occurs more frequently in the Elizabeth River, a sub-tributary near its mouth.

Eastern Shore Basin

The Eastern Shore Basin is the smallest of the lower tributaries and is located within the Coastal Plain physiographic province. The area is characterized by a gently sloping land surface and dissected lowland with a series of ocean-cut inlets (Figure 4.5).

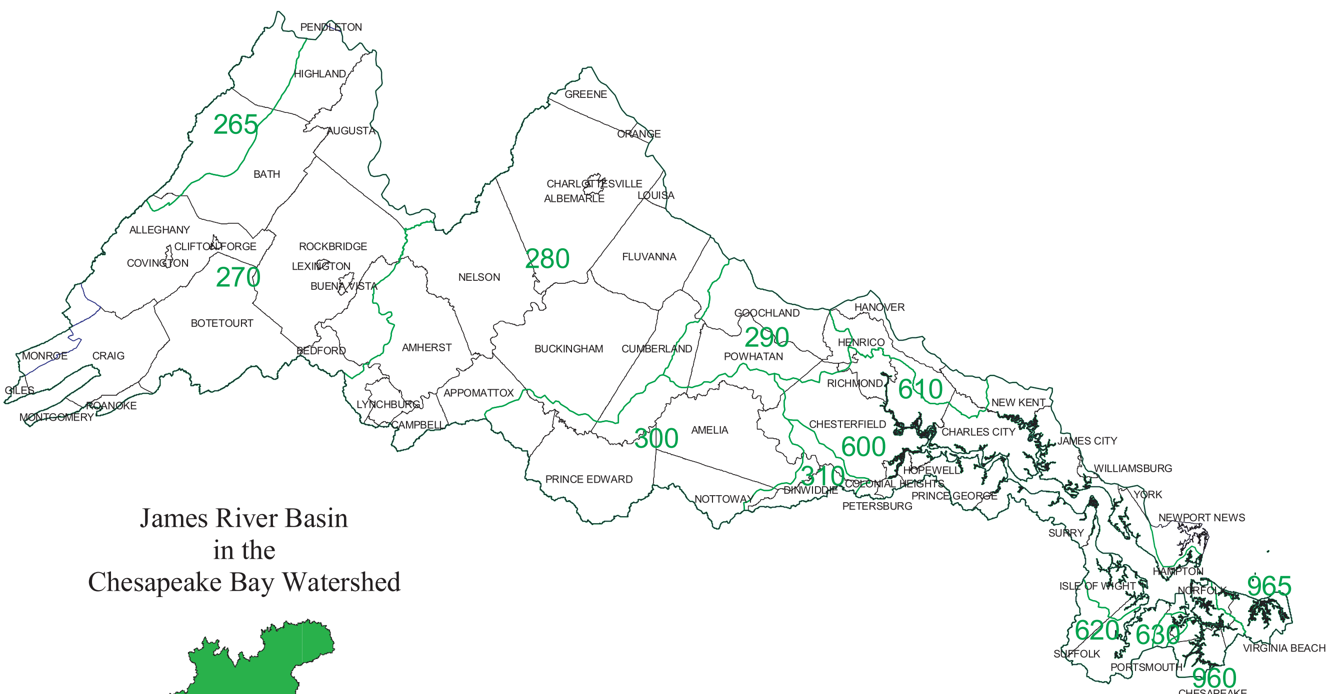
Hydrology

The primary freshwater flow to Chesapeake Bay is the Susquehanna River (~ 62% of total gauged freshwater flow) which empties into the northern portion of the Bay. Other major freshwater sources are the Potomac (~18%) and James (~11%) (Cerco, 1993). The Potomac empties midway down the Bay while James is the southern-most tributary. Between the Potomac and James, the York and Rappahannock each contribute about 3% of freshwater flow to the Bay. An annual runoff cycle exists in the major tributaries. Peak flows typically occur in March or April while minimum flows occur in August and September.

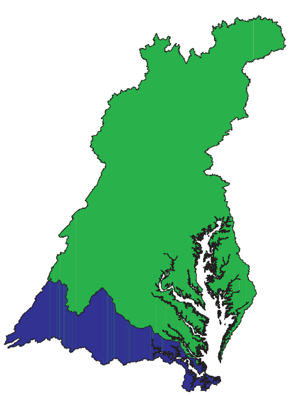
Figure 4.4

James River Basin

Watershed Model Segments with State and County Boundaries



James River Basin
in the
Chesapeake Bay Watershed



State Boundary
WSM Segments and Contiguous County Lines
County Lines

Chesapeake Bay Program

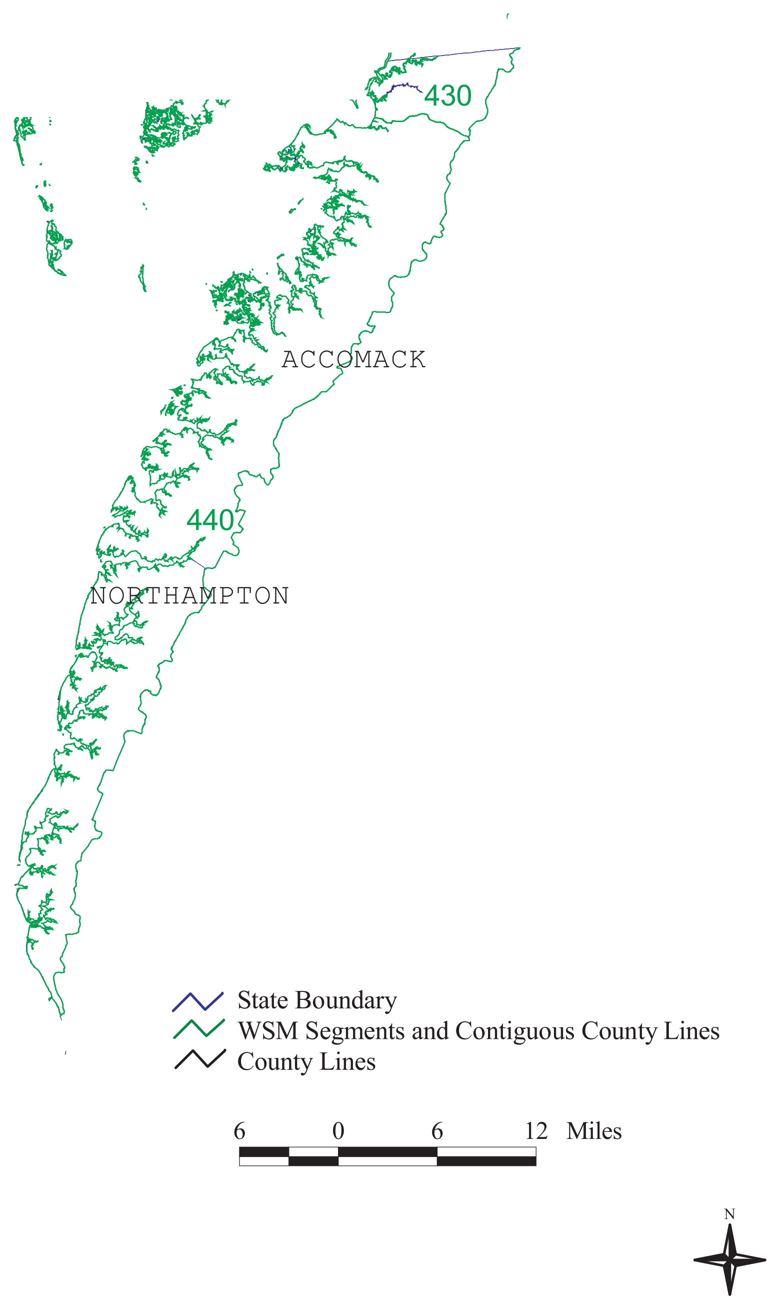
20 0 20 40 Miles

N

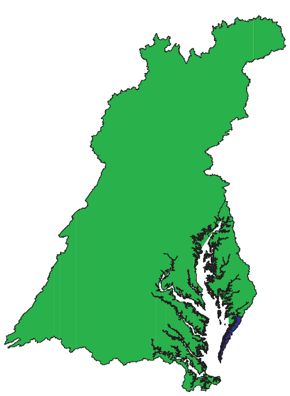
Figure 4.5

Eastern Shore Virginia

Watershed Model Segments with State and County Boundaries



Eastern Shore Virginia in the Chesapeake Bay Watershed



Chesapeake Bay Program

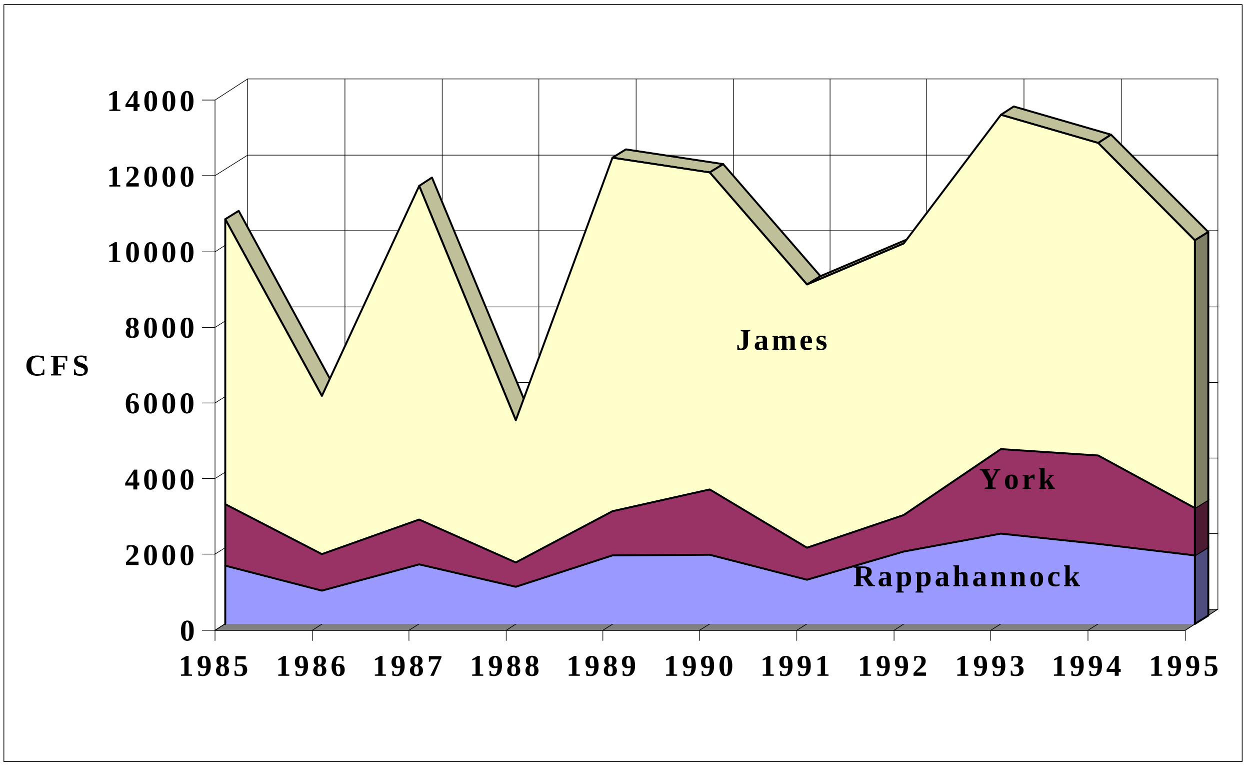
Based on mean annual discharge in cubic feet per second (cfs), Virginia's lower tributaries have modest flows compared to the Susquehanna, the Bay's largest tributary (Table 4.3). The James discharged just over 8,000 cfs (mean annual discharge James + Appomattox) while both the York (Mattaponi + Pumunkey) and Rappahannock were under 2,000 cfs (Figure 4.6). The basins also showed differing spatial and temporal discharges. While the York and Rappahannock basins had mean maximum annual mean discharges in 1993 and 1994 (as did the Susquehanna), the James and Potomac had maximum discharges in 1985. As shown below, annual average discharges for Virginia's three major tributaries varied greatly over the 1985-1995 period.

Table 4.3 **Annual Mean Discharge (cfs) from Seven Major Basins in the Chesapeake Bay**

Year	Susquehanna	Potomac	Rappahannock	Mattaponi	Pumunkey	Appomattox	James
1985	30,470	11,570	1,533	523	1,111	1,271	7,526
1986	41,240	8,133	879	335	621	760	4,195
1987	32,260	11,470	1,579	Nd	1,171	1,441	8,829
1988	27,160	8,712	974	Nd	648	732	3,757
1989	39,860	11,960	1,806	Nd	1,175	1,437	9,341
1990	48,310	10,450	1,823	600	1,128	1,125	8,379
1991	29,670	9,273	1,180	265	568	811	6,956
1992	35,500	9,771	1,906	342	633	820	7,173
1993	52,480	16,990	2,390	744	1,485	1,838	8,836
1994	51,700	16,680	2,117	769	1,553	1,445	8,275
1995	27,970	9,266	1,818	376	869	1,097	7,062
Average	37,870	11,298	1,637	494	997	1,162	7,303
Max.	467,000	293,000	51,500	7,780	20,400	14,100	199,000
MaxYear	1993	1985	1993	1994	1994	1985	1985
Min.	821	514	69	7	47	32	763
MinYear	1985	1991	1987	1991	1991	1993	1986

The mean minimum annual discharges were similar for the three largest Bay tributaries. Susquehanna, Potomac, and James had minimum annual discharges less than 1,000 cfs. Minimal annual averages for the York and Rappahannock were less than 100 cfs.

Figure 4.6 **Lower Chesapeake Bay Basin Discharges**



Loadings

Nutrient and sediment loads from above and below the fall lines within each tributary to the Bay were evaluated. The external loads were comprised of: (1) fall line loads, (2) below-fall line loads, (3) point source loads, and (4) atmospheric loads directly to the water surfaces of the Bay and tributaries. Fall line and below-fall line loadings were calculated from the Watershed Model. Point source loads were obtained from inventories provided by the Virginia Department of Environmental Quality and their Discharge Monitoring Reports. Atmospheric loadings were provided by RADM or by a regression of NADP data as described in Section 1.

Four reference loadings were used to establish the extent of reductions as comparisons: 1) 1985 Baseline Conditions, 2) 1996 Progress, 3) Full Voluntary Program Implementation, and 4) Current Limit of Technology. Refer to Section 2 for the complete scenario descriptions.

As noted previously in Section 2, these scenarios provided key simulations for comparisons to other, more specific, scenarios used to determine water quality and living resource responses over a wide range of possible management actions. The 1985 Baseline Conditions and the Limit of Technology scenarios were, respectively, the highest and lowest nutrient and sediment loads simulated of all the management scenarios. The 1996 Progress scenario provided a best estimate of current conditions and the Full Voluntary Program Implementation scenario estimated loads under application of a voluntary non-point source program to the fullest extent.

A matrix was developed for each tributary that contained information in three columns regarding scenarios, estimated loads, and estimated water and habitat quality measurements of living resource responses. Loads were determined for nitrogen for point sources, non-point sources, and total loads (in pounds); phosphorus for point sources, non-point sources, and total loads (in pounds), and total sediment loads (in tons).

Using the 1996 Progress scenario as an estimate of the current load conditions, the lower tributary load of nitrogen was 22% of the total Signatory State nitrogen load. The lower tributary phosphorus load was 37% of the total Signatory State load for this nutrient. The Signatory States are those that signed the 1983 Chesapeake Bay Agreement and include PA, MD, VA, and DC.

Sediment loads comprised eroded material from the watershed as well as from shoreline erosion along the tidal Bay and tributaries. The lower tributary sediment load was 40% of the total Signatory State sediment load for the 1996 Progress scenario. Shoreline erosion was largely uncontrollable and accounted for an estimated 7% of the total sediment loads to the lower tributaries.

Among the VA portions of the lower Bay tributaries, the James had the highest estimated loads of nutrients and sediment, comprising over 65% of the nitrogen, nearly 75% of the phosphorus, and 80% of the sediment loads from the major VA watersheds (Table 4.4). These results are for the 1996 Progress scenario. After the James, the highest loads of nitrogen, phosphorus and sediment came, in order, from the Rappahannock, York, and Eastern Shore basins.

Table 4.4 **Percentage of Total Virginia Loadings by Basin**

Basin	**Nitrogen**	**Phosphorus**	**Sediment**
Rappahannock	15 %	13 %	12 %
York	14 %	10 %	7 %
James	67 %	74 %	80 %
Eastern Shore	4 %	3 %	1 %

Source: Chesapeake Bay Program Phase IV Watershed Model 1996 Progress Scenario

For the 1996 Progress scenario and among all major Chesapeake Bay basins and regions, the James River basin accounted for the largest total phosphorus load delivered to the Bay on an average annual basis over the Watershed Model simulation period of 1985-1994 (Table 4.5). This load of 4.1 million lbs./year was greater than simulated results for the Potomac (3.9 million lbs./year) and the Susquehanna (3.5 million lbs./year).

Table 4.5 **Mean Annual Nutrient and Sediment Loads and Yields for the Major Basins and Regions of the Chesapeake Bay Watershed (1985-1994)**

Basin	**Total Nitrogen**		**Total Phosphorus**		**Sediment**	
	(10^6 lb/yr)	(lb/acre/yr)	(10^6 lb/yr)	(lb/ac/yr)	(10^6ton/yr)	(ton/ac/yr)
Susquehanna	116.8	6.7	3.5	0.2	0.97	0.06
Patuxent	5.6	9.6	0.4	0.7	0.18	0.30
Western Shore MD	18.9	22.6	0.8	1.0	0.12	0.15
Eastern Shore MD	32.9	11.4	2.6	0.9	0.55	0.19
Potomac	64.6	7.1	3.9	0.4	2.52	0.28
Rappahannock	9.0	5.2	0.7	0.4	0.30	0.17
York	8.0	4.2	0.5	0.3	0.16	0.08
James	39.0	6.0	4.1	0.6	2.00	0.31
Eastern Shore VA	2.4	11.5	0.2	0.9	0.04	0.18

Source: Chesapeake Bay Program Phase IV Watershed Model 1996 Progress Scenario

The James River basin load of nitrogen (39.0 million lbs./year) ranked third among major Chesapeake Bay watersheds and regions, behind the Susquehanna (116.8 million lbs./year) and Potomac (64.6 million lbs./year) loads (Table 4.5). The James annual mean sediment load for the 1996 Progress scenario (2.00 million tons/year) was second among the Bay's major basins. Only the Potomac River watershed had higher yearly sediment loads at 2.52 million tons/year.

The James had the highest sediment yield expressed as a unit weight per unit area (lb/acre) among all major Chesapeake Bay catchments (Table 4.5). Again for the 1996 Progress scenario, this average annual yield was 0.31 tons/acre for the James while the Patuxent ranked second with 0.30 tons/acre export of sediment. For both total nitrogen and total phosphorus, Eastern Shore VA ranked second among the Bay regions for export per unit area. The Western Shore MD area had the highest yields for these nutrients.

Limiting Nutrients

Management of an estuary or the rivers that flow into an estuary such as Chesapeake Bay are best accomplished over large time periods due to the wide variation in flows and loads. For this analysis, we looked at the nutrient(s) most limiting phytoplankton during the critical growing season (spring and summer). Each tributary was separated by salinity into upper (low salinity/tidal fresh), middle (moderate salinity/mesohaline) and lower (high salinity/polyhaline) regions.

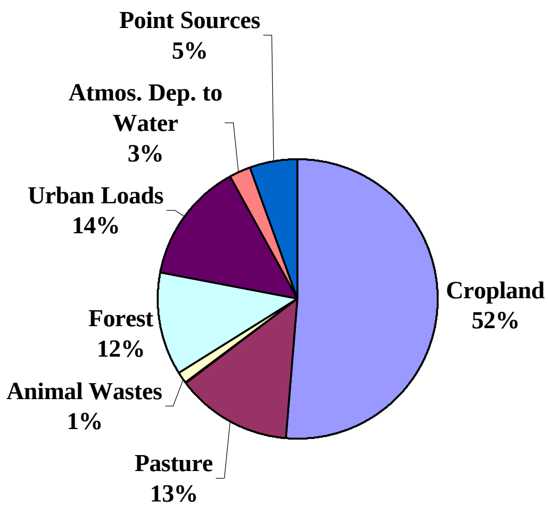
Many processes control the growth and accumulation of algae in aquatic systems (Fisher and Butt, 1994). Light is essential for photosynthesis and plant nutrients, like inorganic forms of nitrogen, phosphorus, and silicon, are required to sustain phytoplankton (algae) growth rates. Only dissolved inorganic forms of nitrogen and phosphorus are available to algae for primary production. Inorganic forms of nitrogen are either ammonia (NH_4) or nitrate (NO_3) with algae preferring the former. There is a single form of dissolved inorganic phosphorus (PO_4). The accumulation of algal biomass requires consideration of growth rates in conjunction with transport losses, grazing, sinking, and cell death. Both the Watershed Model and CBEMP simulate and characterize algal biomass accumulation.

Like most fresh water systems, non-tidal rivers (above the fall line) were phosphorus limited. The entire James River below Richmond was nitrogen limited during the spring and summer seasons. The tidal fresh regions of the Mattaponi and Pumunkey Rivers of the York basin were phosphorus limited during the spring. During the summer, the upper tidal reaches of these two rivers were phosphorus limited while the rest of the tidal York River was nitrogen limited. The Rappahannock River was phosphorus limited during the spring, but switched to nitrogen limitation during the summer. Also, the tidal fresh regions of the James, York, and Rappahannock were light limited, particularly after storm delivery of high sediment loads (Haas and Webb, 1998).

4.2 Rappahannock Basin Loads

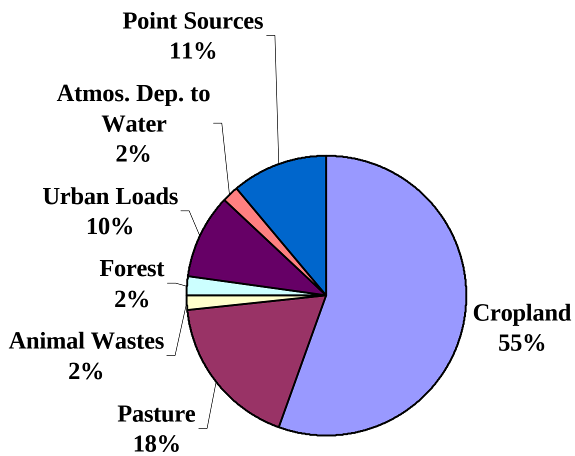
Nitrogen loads in the Rappahannock were primarily from agricultural sources with the estimated 1996 loads, from highest to lowest, being cropland, urban (including septic systems), pasture, forest, and point sources (Figure 4.7). The loading rate was a measure of nutrient and sediment loads coming off a unit area of land (such as an acre) over a unit of time (such as a year). Cropland often has a higher loading rate for nutrients and sediment than other sources, but other sources may cover more area in a basin and therefore, comprise a larger load.

Figure 4.7 **Rappahannock Nitrogen Loads By Source**



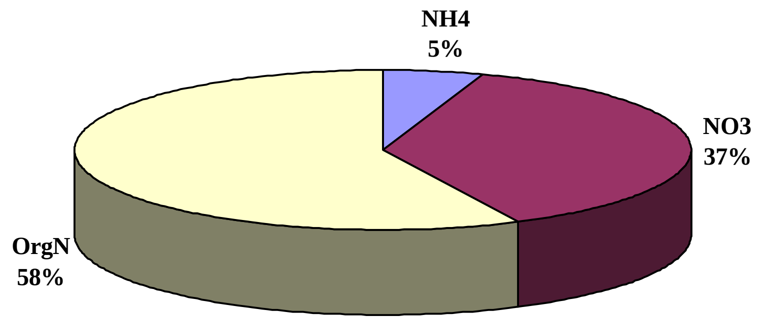
Estimated Rappahannock phosphorus loads were highest for agriculture, then pasture, point sources, and urban, followed by forest, animal wastes, and atmospheric deposition (Figure 4.8).

Figure 4.8 **Rappahannock Phosphorus Loads By Source**



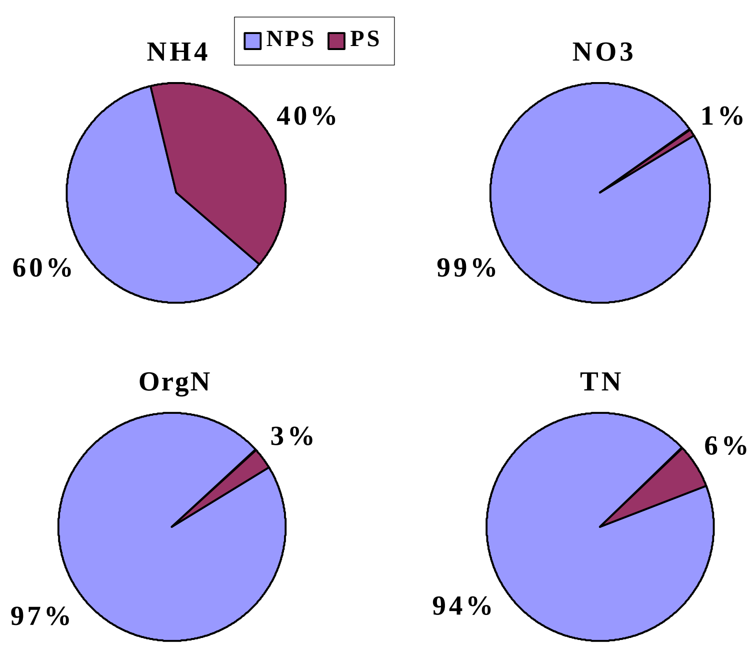
Nitrogen loadings were simulated as delivered to the tidal portions of the Rappahannock River in two forms: organic (58%) and inorganic nitrogen (42%) with inorganics in the species nitrate (37%) and ammonia (5%) (Figure 4.9). Estimated nitrogen loads were based on the Chesapeake Bay Watershed Model 1996 Progress scenario.

***Figure 4.9* Nitrogen Species Delivered to the Rappahannock River Fall Line**



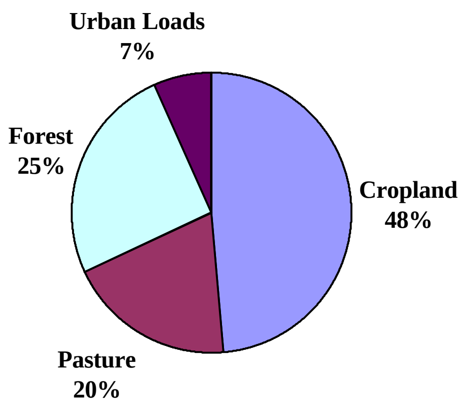
Estimated total nitrogen (TN) delivered below the fall line was from both non-point sources (94%) and point sources (6%) (Figure 4.10). These loads were in the same organic/inorganic forms. Most of the ammonia came from non-point sources (60%) while the nitrates and organic nitrogen came from agricultural sources (99% and 97%, respectively). In the nitrogen limited tidal waters, algae (phytoplankton) prefer dissolved forms of ammonia and uptake of nitrate occurs when the available ammonia has been depleted.

***Figure 4.10* Rappahannock Nitrogen Species Below Fall Line**



Estimated sediment loads have no point source component, but include shoreline erosion which amounted to 0.042 million tons/year. Cropland accounted for the largest source of sediment (48%) followed by forest (25%), pasture (20%), and urban lands (7%) (Figure 4.11).

Figure 4.11 **Rappahannock Sediment Loads By Source**



Along with the 1996 Progress loads, estimated loads for the Rappahannock scenario runs are shown in Table 4.6. Load estimates are a function of the loading rate from each source and the amount of land area in the basin covered by each source.

Table 4.6 **Tidal and Western Shore Rappahannock Loads by Scenario**

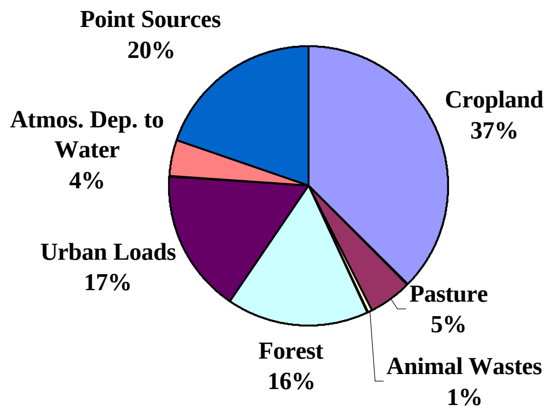
Scenario	Loads* (Nutrients in million lbs., Sediment in million tons)						
	Nitrogen			Phosphorus			Sediment
	PS	NPS	Total	PS	NPS	Total	Total
1985 Baseline Conditions	0.4	9.8	10.3	0.18	0.76	0.94	0.36
1996 Progress	0.5	8.5	9.0	0.08	0.62	0.69	0.30
1996 Progress/TS Above	0.5	8.5	9.0	0.08	0.62	0.69	0.30
BNR-BNR Equivalent/TS Above	0.3	6.7	6.9	0.07	0.60	0.66	0.29
Interim Bay Agreement Goal/TS Above			6.5			0.62	0.32
Midpoint 1996-Full Volun. Imp.	0.4	7.1	7.5	0.05	0.56	0.61	0.28
West Shore VA Full Volun. Imp./TS Above	0.5	8.3	8.8	0.08	0.61	0.68	0.30
Full Voluntary Imp./TS Above	0.2	5.8	6.0	0.02	0.51	0.53	0.27
Full Voluntary Implementation	0.2	5.8	6.0	0.02	0.51	0.53	0.27
Current Limit of Technology	0.1	5.0	5.1	0.00	0.43	0.43	0.24

*Includes loads for Western Shore Rappahannock which are 5.8% (TN), 4.3% (TP), and 3.6% (sediment) of the total Rappahannock load for 1985 Baseline Conditions. Sediment loads do not include 0.042 million tons of shoreline erosion load.

4.3 York Basin Loads

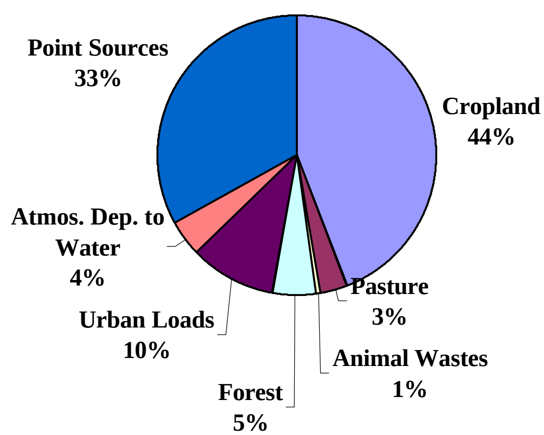
The York has more urban and forest land than the Rappahannock basin. Based on estimated 1996 conditions, agriculture dominated nitrogen loads with cropland, pasture, and animal wastes responsible for 37%, 5%, and 1% of the total delivered nitrogen load, respectively. Point sources were responsible for 20%, while urban (including septic) and forest were 17% and 16%, respectively (Figure 4.12).

Figure 4.12 **York Nitrogen Loads By Source**



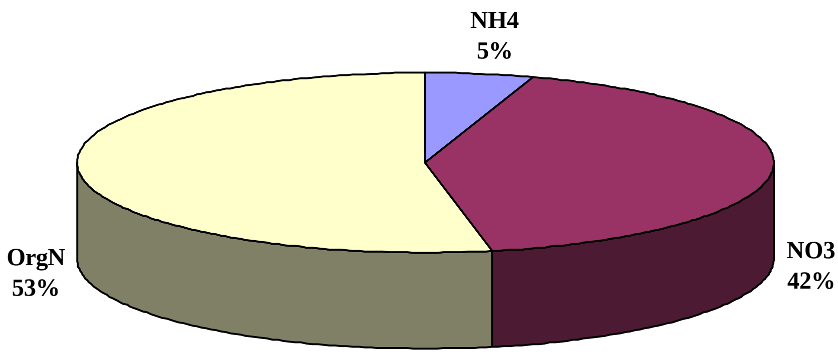
York phosphorus loads were highest for agriculture, point sources, and urban, followed by pasture, forest, atmospheric deposition, and animal waste (Figure 4.13).

Figure 4.13 **York Phorphorus Loads By Source**



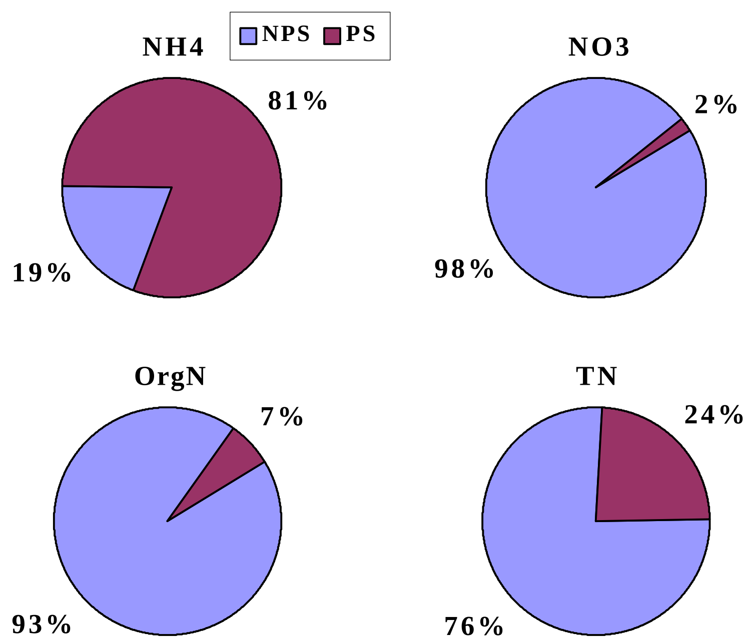
Nitrogen loads were delivered to the tidal portions of York in two forms: organic (53%) and inorganic nitrogen (47%) with inorganics in the species nitrate (42%) and ammonia (5%) (Figure 4.14). These estimates were based on the Watershed Model 1996 Progress run. Organic nitrogen from agricultural runoff is not available to algae as part of primary production, but accumulates in the sediments where it undergoes decay by bacteria.

Figure 4.14 **Nitrogen Species Delivered to the York River Fall Line**



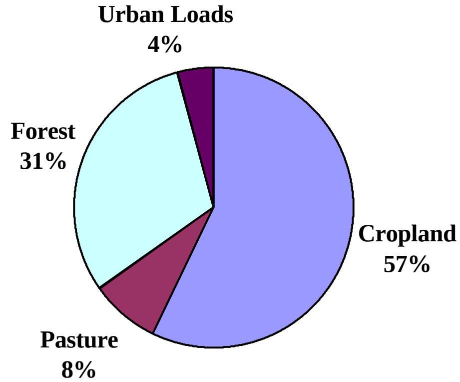
The total nitrogen (TN) delivered below the fall line was from both non-point sources (76%) and point sources (24%). These loads were in the same organic/inorganic forms, but their sources differed (Figure 4.15). Most of the ammonia came from point sources (81%) while the nitrates and organic nitrogen came from agricultural sources (98% & 93%, respectively). In the nitrogen limited tidal waters, algae (phytoplankton) prefer dissolved forms of ammonia and then nitrate when the available ammonia has been depleted.

Figure 4.15 **York Nitrogen Species Below Fall Line**



Estimated 1996 Progress scenario sediment loads in the York basin were slightly more than half that of those for the Rappahannock although shoreline erosion loads for the York were greater. Estimated sediment loads from shoreline erosion were 0.072 million tons/year which is the greatest among the Virginia tributaries. Cropland accounted for the largest source of sediment (57%) followed by forest (31%), pasture (8%), and urban lands (4%) (Figure 4.16).

Figure 4.16 **York Sediment Loads By Source**



Estimated loads for all scenario runs for the York tidal river are shown in Table 4.7. Load estimates are a function of the loading rate from each source and the amount of land area in the basin covered by each source.

Table 4.7 **Tidal and Western Shore York Loads by Scenario**

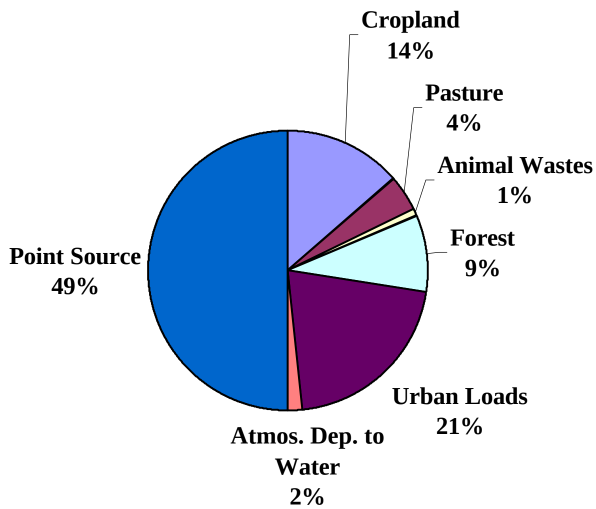
Scenario	**Loads*** (Nutrients in million lbs., Sediment in million tons)						
	Nitrogen			Phosphorus			Sediment
	PS	NPS	Total	PS	NPS	Total	Total
1985 Baseline Conditions	1.3	6.9	8.2	0.42	0.44	0.85	0.19
1996 Progress	1.6	6.4	8.0	0.18	0.36	0.54	0.16
1996 Progress/TS Above	1.6	6.4	8.0	0.18	0.36	0.54	0.16
BNR-BNR Equivalent/TS Above	0.8	5.1	5.9	0.15	0.36	0.5	0.16
Interim Bay Agreement Goal/TS Above			4.5			0.60	0.17
Midpoint 1996-Full Volun. Imp.	1.0	5.5	6.6	0.11	0.34	0.45	0.16
West Shore VA Full Volun. Imp./TS Above	1.6	6.2	7.8	0.18	0.36	0.54	0.16
Full Voluntary Imp./TS Above	0.5	4.6	5.1	0.05	0.32	0.37	0.15
Full Voluntary Implementation	0.5	4.6	5.1	0.05	0.32	0.37	0.15
Current Limit of Technology	0.3	4.0	4.3	0.01	0.26	0.27	0.13

*Includes loads for Western Shore York which are 18.3% (TN), 9.8% (TP), and 13.8% (sediment) of the total York load for the 1985 Baseline Conditions. Sediment loads do not include 0.072 million tons of shoreline erosion load.

4.4 James Basin Loads

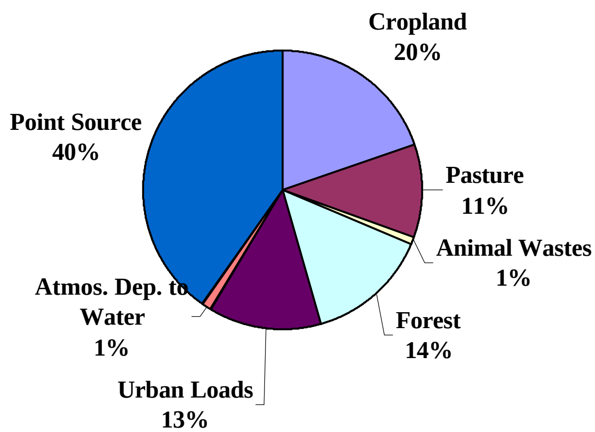
James basin loads, estimated by the 1996 Progress scenario, were dominated by point sources, followed by sources from urban land, cropland, forest, pasture, atmospheric deposition, and animal waste (Figure 4.17).

Figure 4.17 **James Nitrogen Loads By Source**



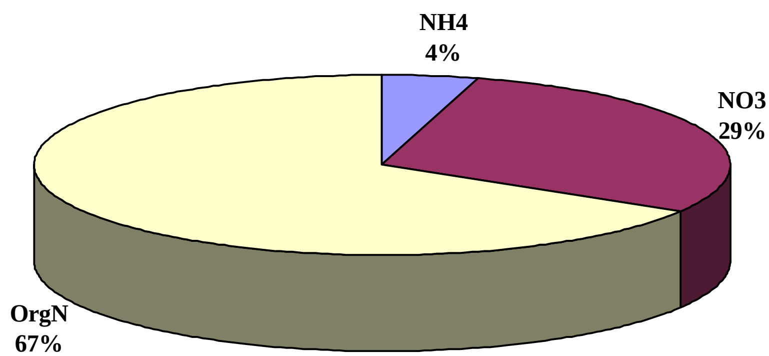
Phosphorus loads to the James were greatest from point sources, followed by cropland, forest, urban, and pasture. Animal waste and atmospheric deposition contributed the least to the total phosphorus load (Figure 4.18).

Figure 4.18 **James Phosphorus Loads By Source**



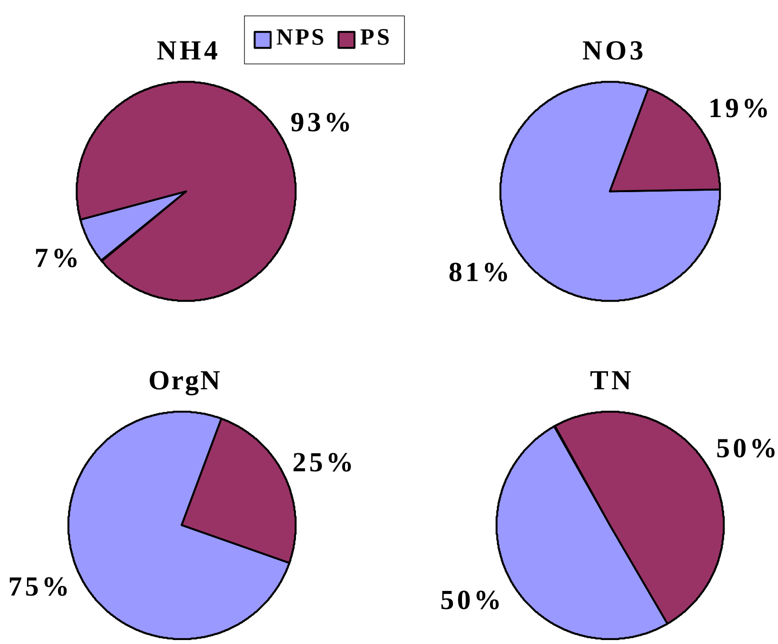
Nitrogen loads were delivered to the tidal portions of James River in two forms. Organic nitrogen accounted for two-thirds of the total nitrogen loads while inorganic nitrogen (in the species of nitrate and ammonia) represented the remaining 33% (Figure 4.19). Most of the organic nitrogen was from agricultural runoff.

Figure 4.19 **Nitrogen Species Delivered to the James River Fall Line**



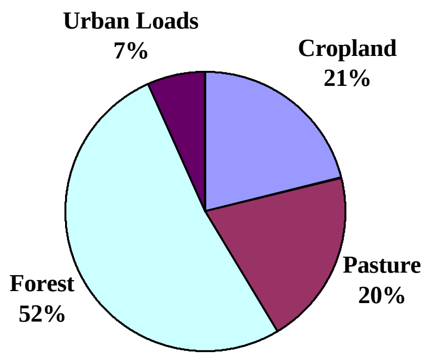
Estimated total nitrogen delivered below the fall line came equally from point and non-point sources (Figure 4.20). These loads were in organic and inorganic forms in varying source proportions. Most of the ammonia (93%) came from point sources while the nitrates and organic nitrogen came from agricultural sources (81% and 75%, respectively). In the nitrogen-limited tidal waters, algae (phytoplankton) prefer dissolved forms of ammonia and uptake of nitrate occurs when the available ammonia has been depleted.

Figure 4.20 **James Nitrogen Species Below Fall Line**



Estimated sediment loads were dominated by forest sources, followed by cropland, pasture, and urban source loads (Figure 4.21). Shoreline erosion for the James amounted to 0.051 million tons/year or about 3% of the total sediment load for the 1996 Progress scenario.

Figure 4.21 **James Sediment Loads By Source**



Along with the estimated 1996 Progress loads, results for the James tidal river are shown for all modeling scenarios in Table 4.8. Load estimates are a function of the loading rate from each source and the amount of land area in the basin covered by each source.

Table 4.8 **Tidal James River Loads by Scenario**

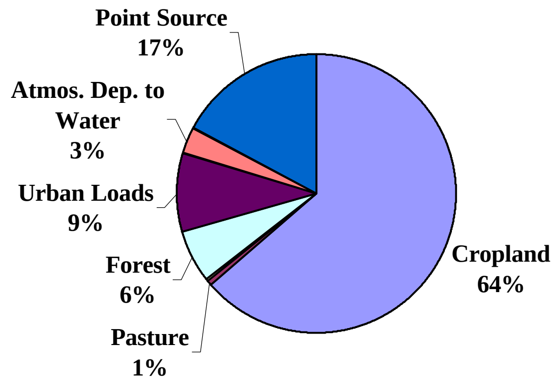
Scenario	Loads (Nutrients in million lbs., Sediment in million tons)						
	Nitrogen			Phosphorus			Sediment
	PS	NPS	Total	PS	NPS	Total	Total
1985 Baseline Conditions	22.1	19.1	41.2	3.58	2.54	6.12	2.0
1996 Progress	17.9	18.6	36.5	1.52	2.38	3.90	2.0
1996 Progress/TS Above	17.9	18.6	36.5	1.52	2.38	3.90	2.0
James AFL BNR Equiv./TS Above	17.4	17.5	34.9	1.46	2.36	3.82	1.9
James AFL, BFL TF & Appomattox BNR Equiv./TS Above	11.5	16.6	28.1	1.36	2.35	3.71	1.9
James TF BNR Equiv. For N/TS Above	11.5	16.6	28.1	1.52	2.38	3.90	2.0
BNR-BNR Equivalent/TS Above	8.3	15.4	23.7	1.34	2.34	3.68	1.9
Current LOT Sediment/TS Above	17.9	18.6	36.5	1.52	2.38	3.90	1.7
Extreme Sediment Reduction/TS Above	17.9	18.6	36.5	1.52	2.38	3.90	1.2
Interim Bay Agreement Goal/TS Above			29.4			3.95	1.9
Midpoint 1996-Full Volun. Imp.	12.1	16.6	28.7	1.01	2.25	3.25	1.9
Full Voluntary Imp./TS Above	6.2	14.6	20.8	0.49	2.11	2.60	1.8
Full Voluntary Implementation	6.2	14.6	20.8	0.49	2.11	2.60	1.8
Current Limit of Technology	3.7	12.3	16.0	0.10	1.77	1.87	1.7

Does not include loads for Western Shore James. Sediment loads do not include 0.051 million tons of shoreline erosion load.

4.5 Eastern Shore Basin Loads

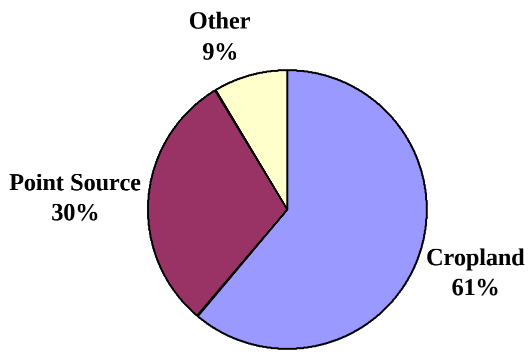
Eastern Shore basin loads were primarily from agricultural sources (Figure 4.22). Estimated nutrient loads for the 1996 Progress scenario have the unusual feature of increased point source loads for both nitrogen and phosphorus compared to the 1985 Baseline.

Figure 4.22 **Eastern Shore Nitrogen Loads By Source**



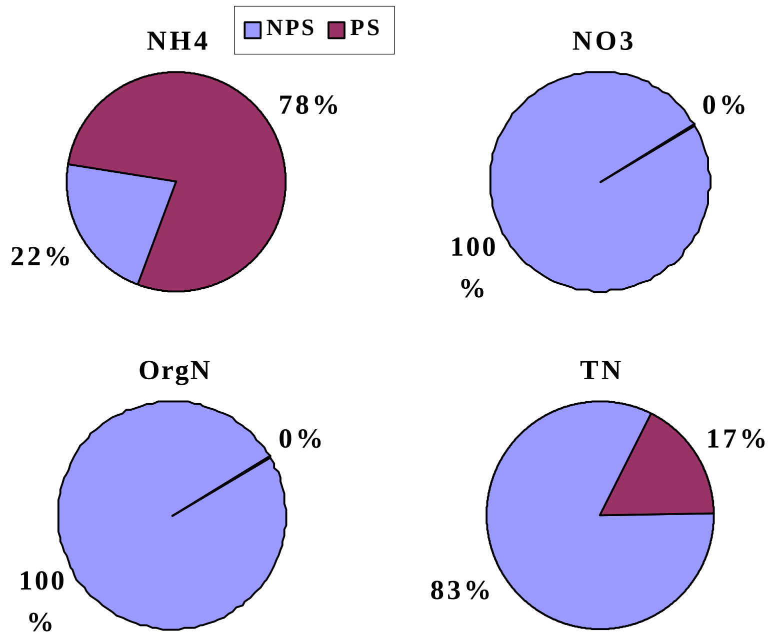
Sources of phosphorus loads from the Eastern Shore (in order from greatest to least) were cropland, point sources, and an "other" category comprising forest, urban, pasture, animal waste, and atmospheric deposition (Figure 4.23).

Figure 4.23 **Eastern Shore Phosphorus Loads By Source**



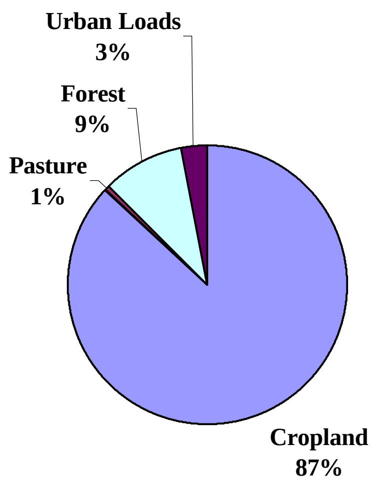
As seen in Figure 4.24 for the Watershed Model 1996 Progress run, point sources were 17% of the total delivered nitrogen loads from the Eastern Shore. While non-point sources represented almost 100% of the organic and nitrate fractions, the majority (77%) of ammonia originated from point sources.

***Figure 4.24* Eastern Shore Nitrogen Species Below Fall Line**



Eastern Shore sediment sources are depicted in Figure 4.25 and included, from greatest to least load, cropland, forest, urban, and pasture. Estimated sediment loads from shoreline erosion were 0.019 million tons, the lowest among major regions in Virginia.

***Figure 4.25* Eastern Shore Sediment Loads By Source**



Estimated loads for all scenario runs for the Eastern Shore are shown in Table 4.9. Load estimates are a function of the loading rate from each source and the amount of land area in the basin covered by each source.

***Table 4.9* Eastern Shore Virginia Loads by Scenario**

Scenario	Loads (Nutrients in million lbs., Sediment in million tons)						
	Nitrogen			Phosphorus			Sediment
	PS	NPS	Total	PS	NPS	Total	Total
1985 Baseline Conditions	0.287	2.398	2.685	0.006	0.193	0.199	0.049
1996 Progress	0.407	2.271	2.677	0.056	0.147	0.203	0.040
1996 Progress/TS Above*	0.407	2.271	2.677	0.056	0.147	0.203	0.040
Updated 1996 Progress/TS Above*	0.407	2.187	2.594	0.056	0.156	0.212	0.038
BNR-BNR Equivalent/TS Above	0.026	1.442	1.467	0.049	0.145	0.194	0.039
Interim Bay Agreement Goal/TS Above			1.776			0.093	0.036
Midpoint 1996-Full Volun. Imp.	0.212	1.840	2.052	0.029	0.139	0.167	0.036
East Shore VA Full Volun. Imp./TS Above	0.018	1.410	1.427	0.002	0.130	0.131	0.032
Full Voluntary Imp./TS Above	0.018	1.410	1.427	0.002	0.130	0.131	0.032
Full Voluntary Implementation	0.018	1.410	1.427	0.002	0.130	0.131	0.032
Current Limit of Technology	0.010	1.288	1.297	0.000	0.096	0.097	0.024

*These 1996 Progress simulated loads were used for the combined watershed and Chesapeake Bay model scenarios. Subsequent to this run, the Eastern Shore tributary team corrected the acres of conventionally tilled and conservation tilled cropland. The values for the adapted cropland 1996 scenario are reported under "Updated 1996 Progress/TS Above". The magnitude of the differences between the two 1996 Progress scenarios is slight and will have little effect on the water quality responses.

Section 5: Water Quality and Bay Grass Responses

5.1 Overview

Habitat Requirements for Chesapeake Bay Living Resources (CEC, 1988) published in response to the 1987 Chesapeake Bay Agreement provides "for the restoration and protection of the living resources, their habitats and ecological relationships". These water quality goals and requirements are considered from the point of view of maintenance, protection, and improvement of an aquatic ecosystem. The focus is on Bay fisheries and supporting aquatic life, including the benthic communities and submerged aquatic vegetation (SAV). Details on the development of water quality requirements are provided in Chesapeake Bay Program (1993), Dennison et al. (1993), Batiuk et al. (1992), Jordan et al. (1992), and Funderburk et al. (1991).

The principle water quality parameters included 1) dissolved oxygen (DO), 2) light attenuation affecting underwater Bay grasses, 3) chlorophyll a, 4) total suspended solids (TSS), and 5) dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP). Water quality and living resource goals unique to the conditions in each tributary were used as guidelines in the assessment of tributary nutrient and sediment reduction strategies.

Dissolved Oxygen

Dissolved oxygen is a major factor affecting the survival, distribution, and productivity of aquatic living resources. Because of natural fluctuations in dissolved oxygen and the sensitivity of the many key Bay species to low concentrations, dissolved oxygen habitat requirements are determined in three regions: 1) above the pycnocline, 2) below the pycnocline, and 3) in spawning areas. Living resource sensitivity to low oxygen concentrations depends upon life cycles, temperatures, salinity, duration of exposure, and other stress factors such as contaminants. By selecting conditions acceptable for the reproduction, growth, and survival of a variety of sensitive species, habitat requirements can be established that will also protect the Bay's other living resources.

Dissolved oxygen tolerance information was compiled and interpreted for fourteen target species of fish, mollusks, and crustaceans (Funderburk et al., 1991), including both commercial and recreational fish and shellfish. Exposure to low dissolved oxygen (less than 0.5-1.5 mg/L) was found to be lethal, during some life stages, to all of the target species for which exposure information was available. While many species can live in waters with severely depressed or hypoxic dissolved oxygen conditions (between 1.5 and 3.0 mg/L), deleterious effects on growth and reproduction occurred. The dissolved oxygen goals are summarized below in Table 5.1.

Table 5.1 **Summary of Dissolved Oxygen Goals**

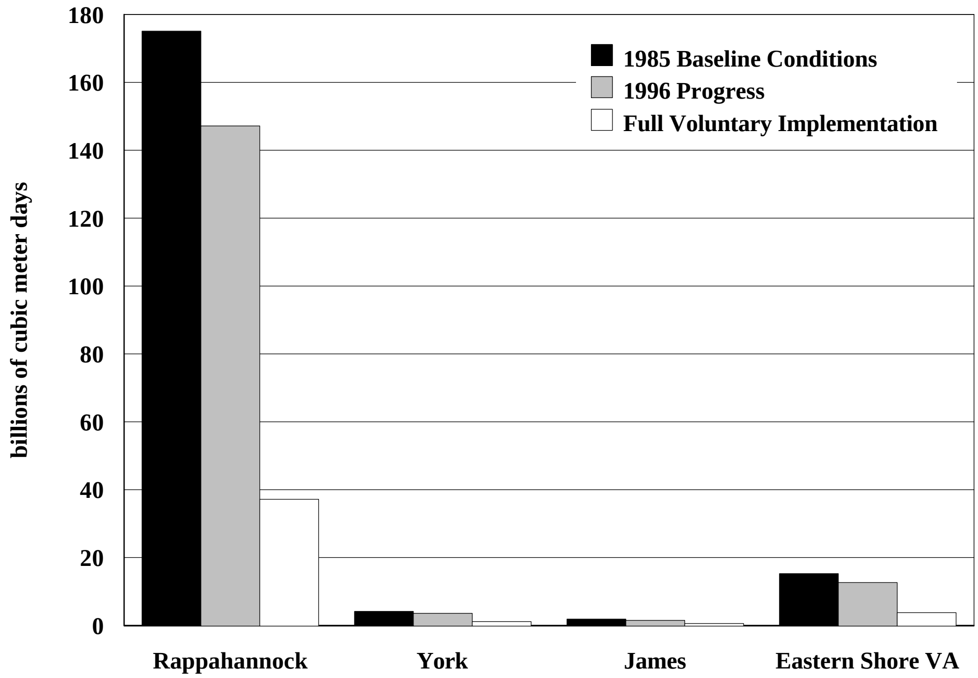
Dissolved Oxygen Goal	**Location & Other Specifications**
At least 1.0 mg/L at all times	Throughout the Bay and tidal tributaries, including sub-pycnocline waters
Less than 3.0 mg/L for less than 12 hours and intervals between excursions between 1.0 to 3.0 mg/L at least 48 hours	Throughout the Bay and tidal tributaries, including sub-pycnocline waters
Monthly mean of 5.0 mg/L or better at all times	All times throughout waters above the pycnocline
At least 5.0 mg/L at all times	Throughout the water above the pycnocline in spawning reaches, spawning rivers, and nursery areas.

Sources: Chesapeake Bay Program (1993); Jordan et al. (1992).

The model-calculated response of dissolved oxygen to nutrient load reductions was determined as seasonal (specifically summer) average concentrations as well as the extent and duration of dissolved oxygen concentrations under the thresholds of anoxia (<1.0 mg/L) and hypoxia (<3.0 mg/L). The two thresholds were assigned a quantity determined by calculating the volumetric and temporal extent of dissolved oxygen below their respective DO levels. These "anoxic volume-days" (AVD) and "hypoxic volume-days" (HVD) have units of m^3-days.

The model AVD and HVD output was tracked on a cell-by-cell basis over time and a sum of the volume less than the threshold concentration was accumulated over estuary model segments for each scenario. A ten-year total of volume-days was then computed. A summery of the anoxic volume-days for Virginia's lower tributaries for three key scenarios is provided in Figure 5.1. A matrix for each tributary describing the percent improvements from 1985 conditions for key water and habitat quality parameters associated with each scenario is also provided (Tables 5.3 – 5.6). Based on 1996 Progress scenario conditions, the Rappahannock accounted for 96% of anoxia in Virginia tributary waters.

Figure 5.1 **Virginia Total Amount Of Anoxic Water**



Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) refers to underwater vascular plants. These aquatic plants perform a number of valuable ecological roles. The plants are a major food source for waterfowl, provide habitat and shelter for a variety of fish and shellfish, and are habitat to many smaller organisms that serve as food to larger organisms, including valued commercial and recreational fishes. Historically, SAV has been abundant throughout Chesapeake Bay. However, today's populations are only a remnant of the once thick beds that provided shelter to the Bay's thriving seafood industry. The drastic decline of SAV, first noted in the 1970's, sparked the concern of Bay scientists and managers and prompted investigations into the cause for SAV loss and methods to restore this key resource.

The general consensus of Bay scientists is that the loss of SAV in Chesapeake Bay is due to decreased light penetration throughout the water column and bio-fouling of the plant leaf surfaces, caused by excessive loadings of nutrients and sediments from the watershed. Excessive nutrients and sediments decrease water clarity and therefore, reduce available light necessary for the plants to grow and reproduce. Habitat requirements most applicable to SAV are those water quality parameters that contribute to light attenuation, or extinction, and include 1) total suspended solids (TSS), 2) chlorophyll a, and 3) light attenuation by dissolved organic material. While light is the major parameter controlling SAV distribution, nutrients such as dissolved inorganic nitrogen (DIN) and dissolved inorganic phosphorus (DIP) indirectly contribute to light attenuation by stimulating growth of algae within the water column and on the leaves and stems of SAV. SAV habitat requirements are defined as the minimal water quality levels necessary for SAV survival.

The diversity of SAV communities, coupled with their wide salinity ranges, led to the establishment of separate requirements based on salinity for one-meter and two-meter depths. A summary of SAV habitat requirements is provided elsewhere (CBP, 1993; Dennison et al., 1993, Batiuk, 1992, Funderburk et al., 1991). To measure progress in SAV restoration, a tiered set of SAV distribution targets was established for the Chesapeake. Each tier represents an expansion in SAV distribution based on prior measurements of cover or on depth increments. As seen in Table 5.2, "Tier I" describes SAV restoration to areas currently or previously inhabited by SAV as mapped through regional and Bay-wide aerial surveys from 1971 through 1990. "Tier II" is restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat to the one-meter depth contour. "Tier III" is restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat down to the two-meter depth contour.

Table 5.2 **SAV Habitat Requirements**

TF=Tidal Fresh (<0.5 ppt salinity)
OL=Oligohaline (0.5 to 5.0 ppt salinity)
ME=Mesohaline (5.0 to 18.0 ppt salinity)
PO=Polyhaline (>18 ppt salinity)

One Meter Restoration

Water Quality Parameter	**Value**	**Other Specifications**
Light Attenuation (K_d) (m^{-1})	<2.0 <1.5	For TF[1] and OL[1] regions For ME[1] and PO[2]
Total Suspended Solids (mg/l)	<15	For TF[1], OL[1], and ME[1] regions and PO[2]
Chlorophyll a (ug/l)	<15	For TF[1], OL[1], and ME[1] regions and PO[2]
Dissolved Inorganic Nitrogen (mg/l)	<0.15	For ME[1] regions and PO[2]
Dissolved Inorganic Phosphorus (mg/l)	<0.02 <0.01	For TF[1], OL[1], and PO[2] For ME[1] and PO[2]

Two Meter Restoration

Light Attenuation (K_d)	<0.8	For TF[1], OL[1], and ME[1] regions and PO[2]

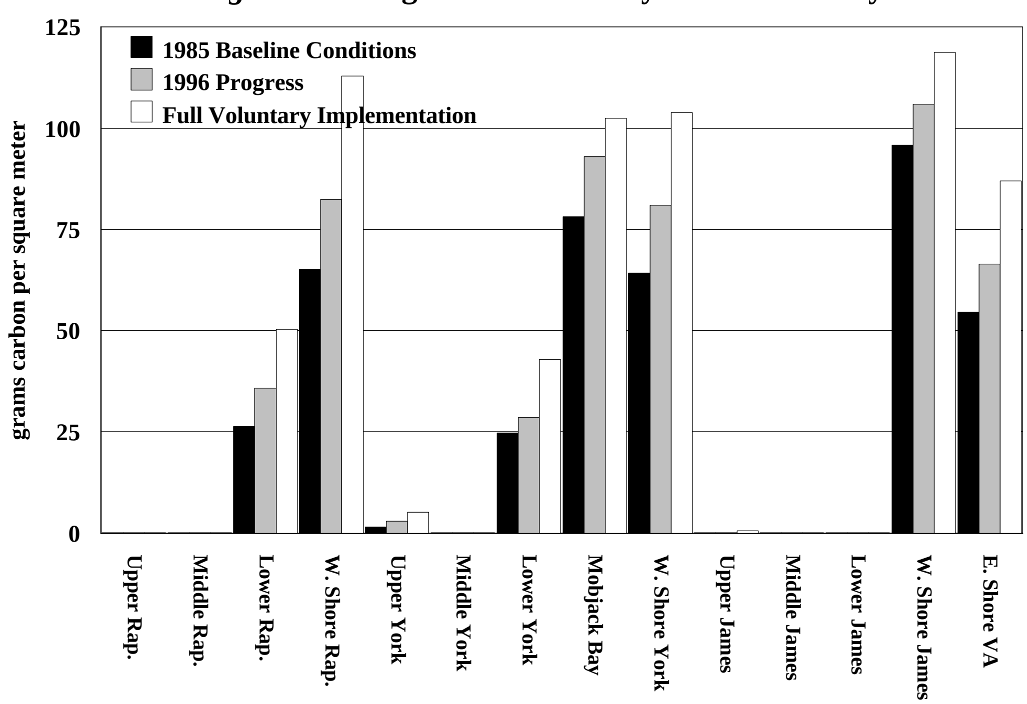
[1]Critical Life Period for SAV is April through October
[2]Critical Life Period for SAV is March through November

The Chesapeake Bay Estuary Model Package simulates three generalized species of SAV that are restricted to the littoral zone within the two-meter contour. In the model, the littoral zone is represented as having a constant mean depth of one meter. As described in Section 1, three additional state variables of shoots (above-ground biomass), roots (below-ground biomass), and epiphytes (attached growth to leaves) are modeled within this zone.

The model is parameterized to simulate a single species for each salinity regime: 1) wild celery (*Vallisneria americana)* for tidal fresh regions, 2) widgeon grass (*Ruppia maritima)* in regions of moderate salinity (mesohaline), and 3) eelgrass *(Zostera marina*) for high salinity (polyhaline) regions. The output is displayed as either area (hectares) of Bay grasses or Bay grass density in grams carbon per square meter (g C/m^2).

The summer Bay grass density for the lower tributaries is shown for three key scenarios in Figure 5.2. An important goal in SAV restoration is to achieve densities in and above a 25-50 g C/m^2 range. Densities in this range are capable of modifying local habitat and persist under pulses of poor water quality conditions (Moore, 1997).

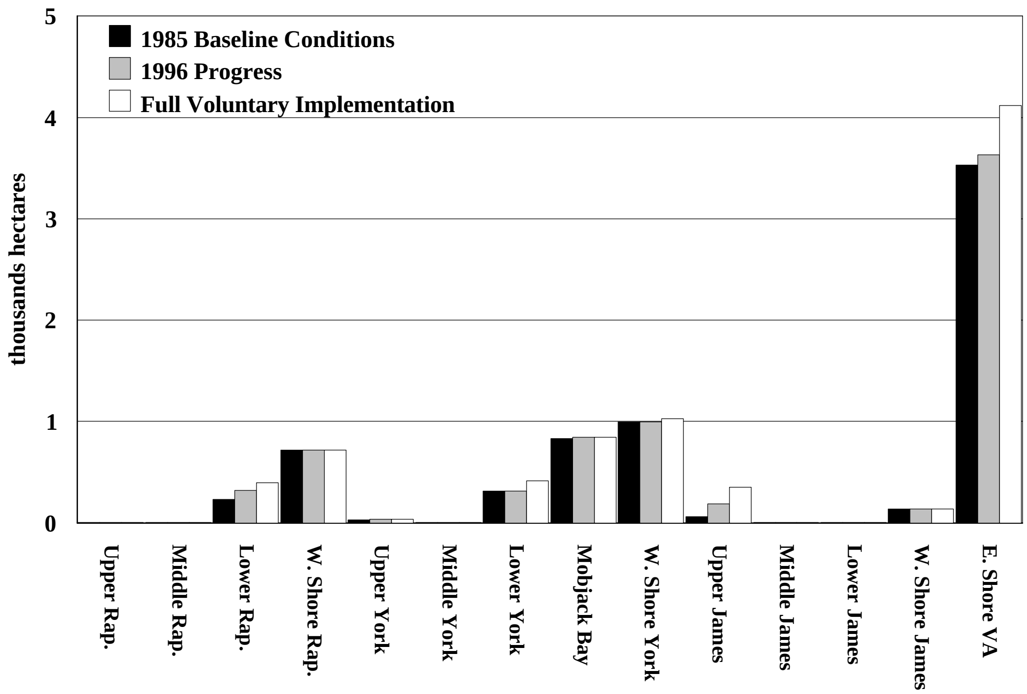
Figure 5.2 **Virginia Summer Bay Grasses Density**



All regions of Virginia's tributaries show improved densities with reductions in nutrient and sediment loads. For the lower regions and western shores of the Rappahannock and York, important regions of SAV in the lower Chesapeake, nutrient and sediment reductions beyond 1996 levels are estimated to be particularly beneficial to the grasses' ability to withstand pulses of poor water quality.

The area of SAV coverage is another indicator of SAV health. Figure 5.3 graphs the extent of SAV coverage in the lower tributaries. With the exception of the Lower Rappahannock, tidal fresh James, and the Eastern Shore, reductions in nutrient and sediment loads are estimated to have a greater influence on improved SAV density than expansion of SAV coverage.

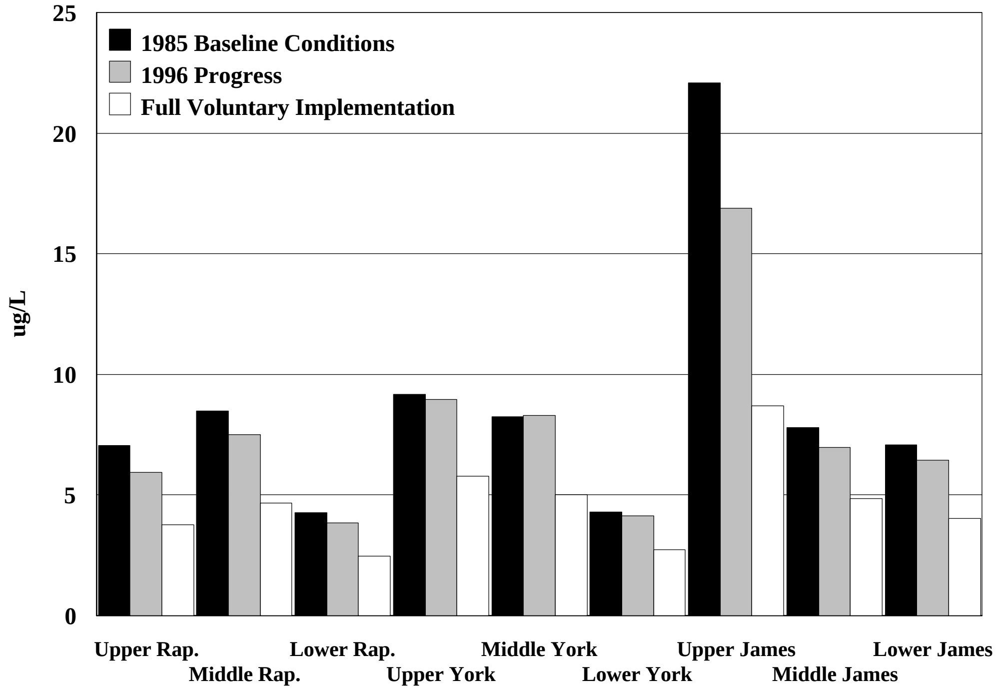
Figure 5.3 **Virginia Summer Bay Grasses Area**



Chlorophyll

Another water quality parameter used as an indicator of the Bay's health is chlorophyll. Chlorophyll concentrations, along with algae (or phytoplankton) growth rates, are employed to compare the relative health of an ecosystem, as measured by primary production or how much algae is being produced. While chlorophyll concentrations were not excessive in the Rappahannock and York Rivers, elevated concentrations were observed in the tidal fresh James (Figure 5.4). Chlorophyll concentrations greater than 10 ug/L in the tidal fresh regions are considered to be indicative of unhealthy algal levels. In more saline waters of the lower estuaries, concentrations greater than 5 ug/L designate unhealthy levels of algal growth.

Figure 5.4 **Virginia Summer Surface Chlorophyll Concentration**



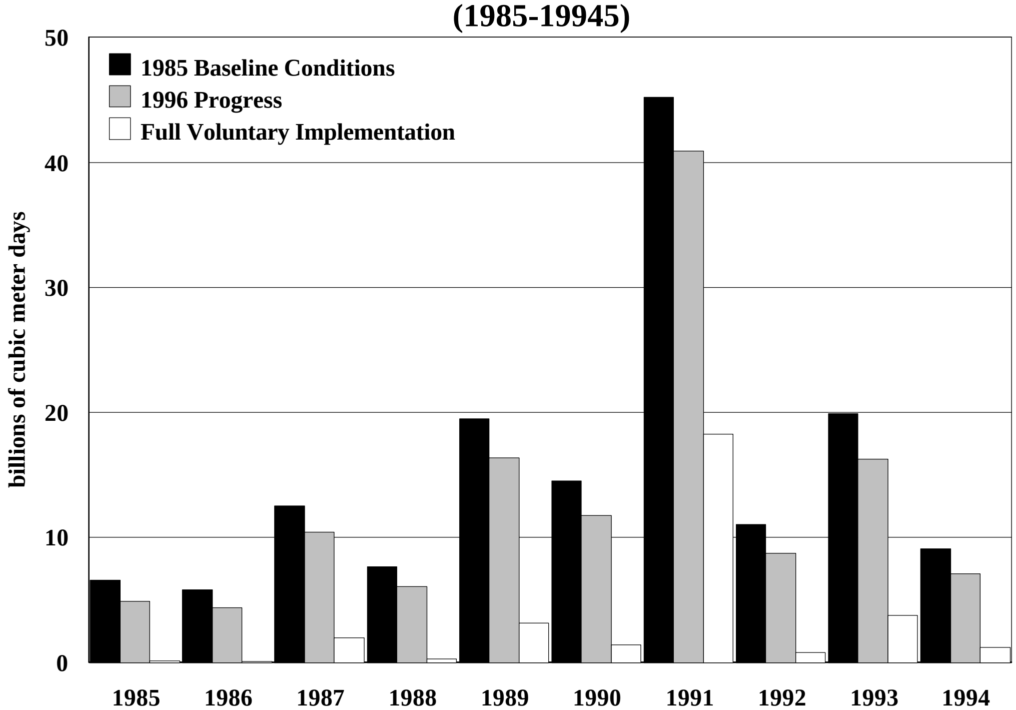
5.2 Rappahannock Basin Water and Habitat Quality

Dissolved Oxygen

Of Virginia's three largest tributaries, the Rappahannock had the most extensive areas of anoxia (Figure 5.1). Within the Rappahannock basin itself, the lower portion of the tidal tributary had the largest volume of anoxic water, followed by the Western Shore, and then the Middle Rappahannock. It should be noted that the Western Shore Rappahannock includes a portion of the Virginia mainstem Bay.

The estimated ten-year average AVD in the lower tidal Rappahannock was around 11 billion cubic meter-days under 1996 Progress conditions. However, when viewed on an annual basis with varying flows, most of the anoxic volume occurred in a single year (Figure 5.5). For the 1996 Progress scenario, the 1991 hydrology year had a total AVD of about 40 billion cubic meter-days while the 1986 hydrologic year estimate was as low as 4 billion cubic meter-days.

Figure 5.5 **Tidal Rappahannock Total Amount of Anoxic Water (1985-19945)**



According to the modeled responses for the 1996 Progress run, there was a 16% improvement in AVD in the Rappahannock resulting from nutrient management changes implemented since 1985 (Table 5.3). An additional 23% improvement in AVD was achieved with implementation of tributary strategies in the Potomac and basins further north of the Potomac. Full Voluntary Program Implementation in Virginia's lower tributaries provided an additional 10% improvement to dissolved oxygen conditions in this river. Full Voluntary Program Implementation throughout the entire Bay achieved nearly an 80% overall improvement and almost eliminated anoxia in the Rappahannock. This level of reduction nearly equated to the same level of response as the Limit of Technology controls applied throughout the entire Bay watershed.

Equivalent changes in the volume of hypoxic waters (<3.0 mg/L) were also seen. While significant benefits were calculated when greater load reductions were taken from the entire watershed, reductions of nutrients (and nitrogen, particular) within the Rappahannock were estimated to be more cost effective in improving Rappahannock low dissolved oxygen conditions than equivalent reductions outside the basin.

Submerged Aquatic Vegetation

The Western Shore Rappahannock maintained a relatively dense population of SAV under the estimated 1996 Progress scenario conditions (Figure 5.2). The densities were more than twice the estimates in the Lower Rappahannock. Both the Lower and Western Shore

Rappahannock had significant improvements in SAV density with nutrient and sediment reductions beyond 1996 conditions. In fact, SAV densities were sufficient to withstand periods of poor water quality conditions, like those during storm events.

Modeled results for the Rappahannock indicated that SAV responded to nutrient and sediment reductions by increasing the density and health within existing SAV areas with only a slight expansion of SAV area (Figure 5.3, Table 5.3).

Table 5.3 **Tidal and Western Shore Rappahannock Percent Improvements from 1985 Conditions for Key Water and Habitat Quality Measurements**

Scenario	**Loading Reductions**							**Water And Habitat Quality Improvements**			
	Nitrogen Reduction			Phosphorus Reduction			Sediment Reduction	Anoxic Water (<1 mg/L DO)	Habitat <3 mg/L DO	Bay Grasses Area	Bay Grasses Density
	PS	NPS	TOT	PS	NPS	TOT	TOT				
1996 Progress	-25*	13	13	56	18	27	17	16	11	9	28
1996 Progress/TS Above	-25*	13	13	56	18	27	17	39	27	9	47
BNR-BNR Equivalent/TS Above	26	32	33	62	22	29	20	45	31	9	52
Interim Bay Agreement Goal/TS Above			37			34	11	47	32	9	49
Midpoint 1996-Full Voluntary Implement.	0	28	27	72	26	35	22	50	35	9	57
West Shore VA Full Volunt. Imp./TS Above	-25*	15	15	56	20	28	17	39	27	9	52
Full Voluntary Imp./ TS Above	50	41	42	89	33	44	25	49	34	9	61
Full Voluntary Implementation	50	41	42	89	33	44	25	79	57	17	77
Current Limit of Technology	75	49	50	100	43	54	33	86	66	19	84

* Negative values indicate percent increase in nutrient loads over 1985 Baseline Condition loads.

There was almost a 30% improvement in Bay grass density between the 1985 Baseline and 1996 Progress runs and an additional 20% was achieved with implementation of tributary strategies in the Potomac and basins further north. An additional 5% to 15 % density increase was expected from nutrient and sediment controls within Virginia's tributaries up to Full

Voluntary Program Implementation controls in Virginia's lower tributaries. Full Voluntary Program Implementation throughout the entire Bay achieved nearly an 80% overall improvement in SAV density from the 1985 Baseline. This level of improvement nearly equated to the SAV response if Limit of Technology controls were applied throughout the entire Bay, reaching 84% increase in density over 1985 conditions. Changes in Rappahannock SAV density were estimated to be particularly responsive to nutrient and sediment reductions within the Rappahannock as compared to equivalent reductions outside the basin.

5.3 York Basin Water and Habitat Quality

Dissolved Oxygen

Under estimated 1996 conditions, the York had only 2% of the anoxic waters relative to the levels of anoxia in the Rappahannock (Figure 5.1), but reduced anoxia and hypoxia were modeled with reductions in nutrients, particularly nitrogen. According to the simulated responses, the 1996 Progress scenario indicated there was more than a 10% improvement in anoxic volume-days with nutrient management changes implemented since 1985 (Table 5.4). An additional 20% improvement was anticipated with implementation of tributary strategies in the Potomac and basins further north.

Full Voluntary Program Implementation in Virginia's lower tributaries provided an additional 15% improvement of dissolved oxygen conditions in the York. Full Voluntary Program Implementation throughout the entire Bay achieved more than a 20% further improvement. This 70% overall improvement from 1985 Baseline conditions would almost entirely eliminate York anoxia. The Full Voluntary Implementation level of anoxia reduction was just short of the estimated Limit of Technology improvement for the entire Bay, determined to be 80% overall when compared to the 1985 Baseline. Nutrient controls within Virginia's tributaries under both the BNR-BNR Equivalent and Interim Goal scenarios resulted in only a moderate improvement of 44%.

Submerged Aquatic Vegetation

The Lower York, Mobjack Bay, and Western Shore York maintained dense populations of SAV for the 1996 Progress run (Figure 5.2). Generally, SAV densities were comparable between the York and Rappahannock, but the area coverage of SAV in the York was more than twice that of the Rappahannock (Tables 5.3 and 5.4).

Table 5.4 **Tidal and Western Shore York Percent Improvements from 1985 Conditions for Key Water and Habitat Quality Measurements**

Scenario	**Loading Reductions**							**Water And Habitat Quality Improvements**			
	Nitrogen Reduction			Phosphorus Reduction			Sediment Reduction	Anoxic Water (<1 mg/L DO)	Habitat <3 mg/L DO	Bay Grasses Area	Bay Grasses Density
	PS	NPS	TOT	PS	NPS	TOT	TOT				
1996 Progress	-23*	7	2	57	18	36	16	13	10	1	22
1996 Progress/TS Above	-23*	7	2	57	18	36	16	34	27	3	31
BNR-BNR Equivalent/TS Above	38	26	28	65	19	41	15	44	34	4	36
Interim Bay Agreement Goal/TS Above			45			29	11	44	34	4	35
Midpoint 1996-Full Voluntary Implement.	23	20	20	74	23	47	16	46	37	4	38
West Shore VA Full Volunt. Imp./TS Above	-23*	10	5	57	18	36	16	38	28	3	33
Full Voluntary Imp./ TS Above	62	33	38	88	27	56	21	49	37	7	41
Full Voluntary Implementation	62	33	38	88	27	56	21	72	59	7	49
Current Limit of Technology	77	42	48	98	41	68	32	80	68	9	54

* Negative values indicate percent increase in nutrient loads over 1985 Baseline Condition loads.

According to optical model estimates (Gallegos, 1994; CBP, 1999), variations in chlorophyll concentrations were primarily responsible for the variability in light attenuation in some tidal tributaries while in other tributaries, total suspended solids dominated. For the Lower York and Mobjack Bay, estimates of the optical model found that habitat requirements for SAV were met for 0.5 meter and 1.0 meter at three monitoring stations in these regions. At another monitoring station in the Lower York (LE4.2 in Table 5.5), only the 0.5 meter requirements were met. Modest reductions in both chlorophyll and sediments (about 20%) were needed near this station to meet the 1.0 meter SAV habitat requirements (Table 5.5).

In order to reach the 2.0 meter requirements in Mobjack Bay, significant reductions in both total suspended solids and chlorophyll levels were essential (monitoring stations WE4.1 and WE4.3 in Table 5.5). Specifically, over 50% reductions were required for both parameters. In

Mobjack Bay, sediment reductions were the most feasible alternative to improving light attenuation for 1.0 meter; however, extreme reductions in both sediments and chlorophyll were needed to meet the 2.0 meter requirements.

Table 5.5 **SAV Habitat Requirements for Water Quality Attenuation in the York River: Percent reductions needed to meet SAV habitat requirements for 1.0 and 2.0 meters**

Station	**LE4.2 1.0 m**		**WE4.1 2.0 m**		**WE4.3 2.0 m**	
Parameter causing non-attainment of habitat	CHLA	TSS	CHLA	TSS	CHLA	TSS
Reductions needed to meet habitat requirements	20%	21%	63%	63%	62%	62%
TSS only reductions needed to meet habitat requirements	N/A	76%	N/A	70%	N/A	68%

There were positive responses of grass densities to nutrient reductions with over a 20% improvement in SAV density between the 1985 Baseline and 1996 Progress conditions (Table 5.4). An additional 10% was achieved with implementation of tributary strategies in the Potomac and basins further north of the Potomac. Up to an additional 10% improvement was estimated from nutrient and sediment controls within Virginia's tributaries. Full Voluntary Program Implementation throughout the entire Chesapeake basin achieved nearly a 50% improvement in SAV density over 1985 conditions. This increase was close to the estimated Limit of Technology SAV density improvement of 54%. Only a modest expansion of Bay grass areas was associated with progressive nutrient and sediment controls (Table 5.4).

Within the lower tributaries, the importance of controlling nutrient loads in order to improve SAV habitat was seen when comparing scenario results from 1996 Progress/Tributary Strategy Above, Full Voluntary Program Implementation/Tributary Strategy Above, and Full Voluntary Program Implementation scenarios (Table 5.6). The comparison was made between Chesapeake Bay basin-wide total nitrogen loads and the percent improvement in York SAV density to assess the impact of local versus Bay-wide controls. Using the 1996 Progress/Tributary Strategy Above scenario as the basis, reductions in nitrogen loads in the lower tributaries were about twice as effective in improving SAV density in the York than nitrogen load reductions in the entire Chesapeake basin. Specifically, there was a 4.7% improvement in York SAV density per 10 million pounds nitrogen removed in the lower tributaries compared to a 2.4% improvement in York SAV density per 10 million pounds nitrogen removed in the Chesapeake watershed.

Table 5.6 **Relative Improvements in York SAV Density to Nitrogen Load Reductions in the Lower Tributaries and in the Chesapeake Basin**

Scenario	**TN Loads**	**TN Reduction Relative to 1996 Progress/ Tributary Strategy Above Scenario**	**SAV Improvement Relative to 1996 Progress/ Tributary Strategy Above Scenario**	**Percent Improvement of SAV for 10 Million Pounds of Nitrogen Reduced**
1996 Progress/ Tributary Strategy Above	299.2	0	0	0
Full Voluntary Program Implementation/ Tributary Strategy Above	277.9	21.3	10%	4.7
Full Voluntary Program Implementation	225.6	73.6	18%	2.4

5.4 James Basin Water and Habitat Quality

Dissolved Oxygen

The James is an unusual Chesapeake basin in that the lower tidal James, generally, has sufficient oxygen levels for living resources. This may be due, in part, to this region's proximity to the Bay mouth which maintains relatively high oxygen concentrations in the bottom waters of the James. In addition, a high salinity gradient between the tidal fresh James and the mouth creates a relatively strong, gravity-driven circulation in the James, reducing bottom water residence time and exposure to sediment oxygen demand (Kuo and Neilson, 1987). There were few observations of dissolved oxygen concentrations less than 1 mg/L in the James. The exception was the Elizabeth River, a tributary located at the mouth of James. Model estimates of James anoxia are about 1% of the total anoxia in the lower tributaries (Figure 5.1).

Nevertheless, improvements in the slight amount of anoxia were calculated with reduced loadings. According to the modeled responses, the 1996 Progress run indicated there was a 20% improvement in hypoxic volume days (HVD, DO<3.0 mg/L) due to nutrient management changes implemented since 1985 (Table 5.7). A further 10% improvement in HVD would be anticipated with implementation of tributary strategies in the Potomac and basins further north. Nutrient reductions within the lower tributaries provided up to an additional 20% improvement to dissolved oxygen conditions in the James. Full Voluntary Program Implementation throughout the entire Bay would achieve an overall 67% improvement in hypoxia compared to 1985 Base conditions. This level of reduction was short of the estimated 75% improvement over 1985 Baseline conditions for the Limit of Technology scenario applied throughout the entire Bay.

Table 5.7 **Tidal James Percent Improvements from 1985 Conditions for Key Water and Habitat Quality Measurements**

Scenario	Loading Reductions							Water And Habitat Quality Improvements			
	Nitrogen Reduction			Phosphorus Reduction			Sediment Reduction	Anoxic Water (<1 mg/L DO)	Habitat <3 mg/L DO	Bay Grasses Area	Bay Grasses Density
	PS	NPS	TOT	PS	NPS	TOT	TOT				
1996 Progress	19	3	11	58	6	36	2	16	20	210	95
1996 Progress/TS Above	19	3	11	58	6	36	2	27	30	210	95
James AFL BNR Equivalent/TS Above	21	8	15	59	7	38	6		40	210	108
James AFL/BFL TF/App. BNR Equiv./TS Above	48	13	32	62	7	39	7		32	354	221
James TF BNR Equiv. For N/TS Above	48	13	32	58	6	36	2		40	354	200
BNR-BNR Equivalent/TS Above	62	19	42	63	8	40	7	47	51	354	217
Current LOT Sediment/TS Above	19	3	11	58	6	36	17	22	26	277	189
Extreme Sediment Reduction/TS Above	19	3	11	58	6	36	40	20	26	489	789
Interim Bay Agreement Goal/TS Above			29			35	3	41	44	242	90
Midpoint 1996-Full Voluntary Implement.	45	13	30	72	12	47	6	46	51	334	227
Full Voluntary Imp./ TS Above	72	24	50	86	17	58	9	52	57	486	410
Full Voluntary Implementation	72	24	50	86	17	58	9	62	67	486	411
Current Limit of Technology	83	36	61	97	30	69	17	72	75	741	1861

Submerged Aquatic Vegetation

Of the four lower Virginia tributaries excluding their western shores, the James had the lowest SAV densities and coverage under all scenario conditions (Figures 5.2 and 5.3). Western Shore James, an area along the Chesapeake shoreline just south of the York Basin, was the only region of the James with significant SAV density under the estimated 1996 Progress conditions (Figure 5.2). There is little modeled SAV response in the lower James, even at maximum nutrient and sediment reductions, but in the tidal fresh or upper James, there were beneficial responses in SAV and chlorophyll to these reductions. According to an optical model (Gallegos, 1994; CBP, 1999), habitat requirements for SAV were met for 0.5 meter under current conditions for all the tidal fresh (TF) stations. However, reductions in both total suspended solids and chlorophyll were needed to meet the 1.0 meter (Table 5.8) and 2.0 meter requirements.

Table 5.8 **SAV Habitat Requirements for Water Quality Attenuation in the Tidal Fresh James River: Percent reductions needed to meet SAV habitat requirements for 1.0 meter**

Station	**TF 5.5**		**TF 5.5A**		**TF 5.6**	
Parameter causing non-attainment of habitat	CHLA	TSS	CHLA	TSS	CHLA	TSS
Reductions needed to meet habitat requirements	37%	38%	42%	44%	10%	13%
Alternative reductions to meet habitat requirements	61%	33%	61%	40%	22%	11%
TSS only reductions needed to meet habitat requirements	N/A	46%	N/A	54%	N/A	15%
CHLA only reductions needed to meet habitat requirements	100%	N/A	100%	N/A	44%	N/A

According to CBEMP results, surface chlorophyll levels in the tidal fresh region would be reduced over 50% from the 1985 Baseline under various BNR runs (Table 5.9). These reductions would meet the 1.0 meter SAV requirements. Only modest sediment reductions (<10%) were achieved for most of the scenarios (Table 5.9). In fact, only the Limit of Technology and Extreme Sediment Reduction/Tributary Strategy Above scenarios produced significant sediment reductions of 16% and 40%, respectively. Therefore, chlorophyll reductions may offer the best management option to improve light penetration in this section of the river. Only TF 5.6 would approach the 1.0 meter requirements at Limit of Technology sediment reductions while TF 5.5 and 5.5A would need "extreme" sediment reductions to meet the 1.0 meter requirements.

Table 5.9 **Tidal Fresh James Percent Improvements from 1985 Conditions for Key Water and Habitat Quality Measurements**

Scenario	**Loading Reductions**							**Water And Habitat Quality Improvements**			
	Nitrogen Reduction			Phosphorus Reduction			Sediment Reduction	Surface Chlorophyll Conc.	Surface Light Atten.	Bay Grasses Area	Bay Grasses Density
	PS	NPS	TOT	PS	NPS	TOT	TOT				
1996 Progress	27	3	17	50	6	27	2	23	10	210	109
1996 Progress/TS Above	27	3	17	50	6	27	2	23	10	210	109
James AFL BNR Equivalent/TS Above	30	12	22	54	8	30	6	25	12	210	123
James AFL/BFL TF/App. BNR Equiv./TS Above	63	19	44	54	8	30	6	52	16	354	262
James TF BNR Equiv. For N/TS Above	63	19	44	50	6	27	2	52	15	354	237
BNR-BNR Equivalent/TS Above	63	19	44	54	8	30	6	52	16	354	253
Current LOT Sediment/TS Above	27	3	17	50	6	27	16	23	15	277	222
Extreme Sediment Reduction/TS Above	27	3	17	50	6	27	40	22	22	489	982
Interim Bay Agreement Goal/TS Above			32			47	3	28	9	242	101
Midpoint 1996-Full Voluntary Implement.	49	13	34	67	11	38	5	42	15	334	263
Full Voluntary Imp./ TS Above	71	23	50	83	16	49	8	61	20	486	485
Full Voluntary Implementation	71	23	50	83	16	49	8	61	20	486	485
Current Limit of Technology	82	34	61	96	29	62	16	72	25	641	2352

Chlorophyll

According to model simulations, chlorophyll a concentrations responded positively to nutrient reductions in the tidal fresh James. There was over a 20% improvement in chlorophyll levels between the estimated 1996 Progress and 1985 Base conditions. An additional 30% may be achieved with implementation of nitrogen controls at BNR levels. Model results showed that nutrient reductions within the watershed areas contributing to the tidal fresh region were most responsible for chlorophyll a reductions in the tidal fresh James. Further improvements in this parameter could be achieved with reductions associated with Full Voluntary Implementation (61% improvement over 1985 conditions).

5.5 Eastern Shore Basin Water and Habitat Quality

Dissolved Oxygen

Dissolved oxygen responses reported here refer to conditions in the eastern half of Virginia's mainstem, and not the shallow waters or small coastal basins isolated in the Eastern Shore of the Bay. As estimated by the 1996 Progress scenario, there was more than a 15% improvement in anoxic volume-days given the nutrient management changes implemented since 1985 (Table 5.10). A further 30% improvement could be anticipated with implementation of tributary strategies in the Potomac and basins further north. Full Voluntary Program Implementation in Virginia's lower tributaries would provide an additional 5% improvement to dissolved oxygen conditions in this region. Full Voluntary Program Implementation throughout the entire Bay would achieve nearly an overall 75% improvement from the estimated 1985 Base conditions and almost eliminate anoxia in this region. This level of reduction was just short of Limit of Technology scenario results with these conditions applied throughout the entire Bay. Nutrient controls within Virginia's tributaries at BNR-BNR equivalent levels and at VA interim goals resulted in only modest improvements in anoxia when compared to 1996 Progress conditions in Virginia.

Submerged Aquatic Vegetation

The Eastern Shore maintains a relatively dense and extensive coverage of SAV under estimated 1996 Progress scenario conditions (Figures 5.2 and 5.3). Of the four lower tributary basins, the Eastern Shore has the greatest area coverage. According to the modeled responses, the area of Bay grasses showed only modest improvements (< 10%) with nutrient controls up to Full Voluntary Implementation reductions throughout the entire Bay (Table 5.10). For this and the Limit of Technology scenarios, SAV area increases of 17% from the 1985 Baseline were estimated.

Improvements to grass densities showed more positive responses to nutrient reductions. There was more than a 20% improvement in Bay grass density between the estimated 1985 Base and 1996 Progress scenario conditions, and almost an additional 15% anticipated increase with implementation of tributary strategies in the Potomac and basins further north. Up to an additional 10 % improvement in SAV density would be expected from nutrient controls within Virginia's tributaries. Full Voluntary Program Implementation in the entire Bay watershed would provide for almost a 60% overall improvement to Bay grass densities as compared to the estimated 1985 Baseline. This level of density almost equates to the same response if Limit of

Technology reductions were applied throughout the entire Bay.

Table 5.10 **Tidal Eastern Shore Virginia Percent Improvements from 1985 Conditions for Key Water and Habitat Quality Measurements**

Scenario	**Loading Reductions**							**Water And Habitat Quality Improvements**			
	Nitrogen Reduction			Phosphorus Reduction			Sediment Reduction	Anoxic Water (<1 mg/L DO)	Habitat <3 mg/L DO	Bay Grasses Area	Bay Grasses Density
	PS	NPS	TOT	PS	NPS	TOT	TOT				
1996 Progress	-41	5	0	-815	24	-2	19	17	15	3	22
1996 Progress/TS Above	-41	5	0	-815	24	-2	19	44	36	8	36
Updated 1996 Progress/TS Above	-41	9	3	-815	19	-6	21				
BNR-BNR Equivalent/TS Above	91	40	45	-698	25	3	20	47	38	8	42
Interim Bay Agreement Goal/TS Above			34			53	27	47	38	8	41
Midpoint 1996-Full Voluntary Implement.	26	23	24	-370	28	16	27	55	43	8	46
East Shore VA Full Volun. Imp./TS Above	94	41	47	74	33	34	35	45	36	8	41
Full Voluntary Imp./ TS Above	94	41	47	74	33	34	35	49	40	8	45
Full Voluntary Implementation	94	41	47	74	33	34	35	74	65	17	59
Current Limit of Technology	97	46	52	97	50	52	50	81	72	17	64

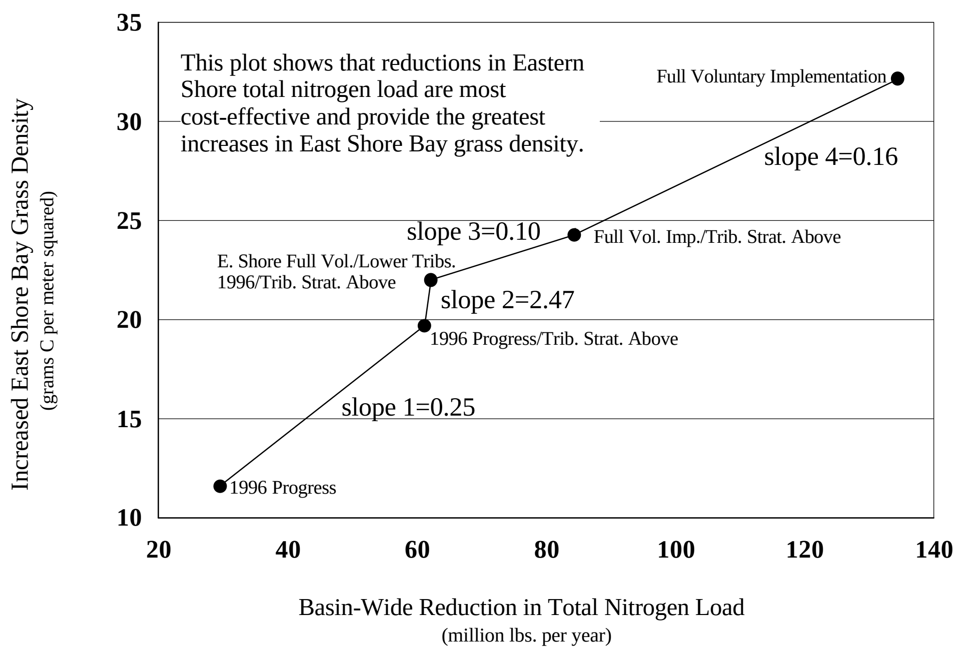
* Negative values indicate percent increase in nutrient loads over 1985 Baseline Condition loads.

The effect of nutrient reductions in different regions of the Bay on Eastern Shore SAV densities can be seen in Figure 5.6. For five scenarios, nitrogen load reductions relative to the 1985 Base are plotted against estimated increases in SAV densities, again relative to 1985 conditions. Each of the scenarios represents, incrementally, greater nitrogen reductions from different regions of the Bay, first for estimated 1996 conditions throughout the Bay, then for estimated 1996 conditions in the lower tributaries and Tributary Strategy loads in the basins of the

Potomac and above. The third scenario is the estimated Full Voluntary Program conditions in the Eastern Shore only, with 1996 conditions in the Rappahannock, York, and James and Tributary Strategy conditions in the basins of the Potomac and above. The final two scenarios are the estimated Full Voluntary Program Implementation conditions in all of the lower tributaries with Tributary Strategy levels in the Potomac and above, and finally, Full Voluntary Program Implementation conditions throughout the Chesapeake watershed. Note that the value of the slope, or the rise of the graph line divided by the run of the line, changes in Figure 5.6.

The slope represents, in large part, the relative improvement in Eastern Shore SAV density to reductions in nitrogen from different regions. An examination of slope 2 in Figure 5.6 shows that even a slight decrease in nitrogen loads in the Eastern Shore is estimated to result in large relative improvements in Eastern Shore SAV density. Eastern Shore nitrogen controls associated with Full Voluntary Implementation are estimated to be up to 25 times more effective in increasing SAV density than the same amount of nitrogen reductions taken in other regions of the Bay.

Figure 5.6 **Relative Load Reduction Effectiveness for Eastern Shore VA SAV Density Improvements**



5.6 Conclusions and Findings

Dissolved Oxygen

Of Virginia's tributaries, the Rappahannock had the most anoxic and hypoxic waters. The Rappahannock has a deep channel running the length of the tributary with a shallow sill just off the mouth, which prevents the deeper, low-oxygen water of the Rappahannock from exchanging with open Bay waters. Most of the Rappahannock anoxic events began in the spring and extended throughout the summer months. Low dissolved oxygen conditions in the Rappahannock responded favorably to nutrient reductions, particularly for nitrogen, in the Potomac and basins in the upper Bay region as well as controls within the basin. Nutrient reductions within the Rappahannock are estimated to be more cost effective in the reduction of anoxia and hypoxia than equivalent reductions outside the basin.

Anoxia in the York River was limited to just the high-salinity regions near the mouth. Compared to the Rappahannock, low oxygen conditions were less severe in spatial extend and duration. According to monitoring studies, the onset of anoxia in the York was caused by stratification of the water column most prevalent during Spring-Neap tides. Improvements in low dissolved oxygen are seen with nutrient reductions in the Potomac and basins in the upper Bay region, as well as controls within the York.

There were few observations of dissolved oxygen concentrations less than 1 mg/L in the James River except for the Elizabeth River, a tributary located at the mouth of James River. Unlike other basins, low dissolved oxygen responded almost solely to controls within James River. For dissolved oxygen levels, Virginia’s mainstem Eastern Shore region responded favorably to nutrient reductions in the Potomac and basins in the upper Bay region while local controls caused little effect.

Submerged Aquatic Vegetation

Since SAV habitat requirements are defined as the minimal water quality levels necessary for SAV survival, SAV requirements for healthy grass beds were expected to be less than required to establish new beds. Therefore, higher or cleaner water quality conditions would be necessary for re-establishment of new beds. For example, eelgrass *(Zostera marina*) would only re-colonize after more hardy forms were established and SAV responses to nutrient and sediment reductions in the model should be considered conservative.

Model results showed that SAV responded favorably to both sediment and nutrient controls in Virginia’s tributaries. While most of the improvements were located in the lower estuaries of the York, Rappahannock, and Eastern Shore, some improvements were modeled in the tidal fresh James, but these were very modest (<5 gm C/m^2). Historical photographs of the James River showed SAV along shallow flats (<1 meter) in the tidal fresh area and extending out to 1 meter in the lower estuary/western shore region.

The Western Shore Rappahannock, Western Shore York, Lower York, Mobjack Bay, and the Eastern Shore maintain some of the healthiest grass beds in Virginia’s waters. While the area of Bay grasses showed modest improvements with nutrient controls, there were positive responses for grass densities. Grass densities improved with implementation of tributary strategies in the Potomac and basins further north as the regions of SAV coverage in the lower tributaries were influenced by water quality conditions of the lower mainstem Bay, but local reductions of nutrients and sediment were more effective in improving SAV densities than equivalent reductions from outside the basin.

The area of Bay grasses on the Eastern Shore showed only modest improvements with nutrient controls until Full Voluntary Implementation was simulated throughout the entire Bay. Improvements in SAV density; however, were more positive. There was a predicted 14% improvement through implementation of tributary strategies in the Potomac and basins further north. An additional 6% to 10% would be expected from nutrient controls within Virginia's tributaries. Full Voluntary Program Implementation in the entire Bay watershed would provide almost a 60% improvement in Eastern Shore Bay grass density.

Chlorophyll

Elevated chlorophyll concentrations have been reported in the tidal fresh portions of James River. Observations often exceeded 30 ug/L at and below Hopewell, VA. Concentrations greater than 10 ug/L in tidal fresh estuaries are considered ecologically unhealthy. Of 40 tidal systems analyzed worldwide, the James River had one of the highest reported levels of chlorophyll (Monbet, 1992). The other two estuaries with similar high levels were the Potomac and Patuxent rivers that are both point-source dominated. All of the Chesapeake Bay and its tributaries were classified as low-energy or microtidal systems making them more sensitive to dissolved nitrogen concentrations (Monbet, 1992).

While Virginia's three major tributaries showed surface dissolved inorganic nitrogen above 0.4 mg/L during winter and spring, only the James River had elevated concentrations year-round (above 0.5 mg/L in the tidal fresh region). In fact, of all the microtidal estuaries investigated by Monbet, dissolved inorganic nitrogen levels were highest in the James and Potomac rivers.

Among Virginia's tributaries, algal turnover or growth rates, were highest in the James (Dauer et al., 1998). While these rates may be controlled by either available nutrients or the amount of available light, it was determined that the tidal fresh James was light-limited (Haas and Webb, 1998; Lung, 1986) and therefore, sediment inputs could be limiting algal growth here. However, if light limitation was removed or reduced through sediment reductions, there would be sufficient nutrients in the form of dissolved inorganic nitrogen (DIN) to support higher algal populations. This suggests that any improvements in water clarity through sediment controls would have to include further reductions in dissolved inorganic nitrogen; otherwise, removing light limitation alone could cause further increases in chlorophyll concentrations.

Section 6: Small Coastal Basin Monitoring and Modeling

6.1 Background:

Virginia's small coastal basins are located in the high salinity waters of the lower Chesapeake Bay. While fresh water and associated nutrient and sediment loads pour into the Bay from the major river systems, the lower Bay is mostly influenced by coastal ocean waters. The highest salinity waters are along the Virginia Eastern Shore. This portion of the Bay is influenced by coastal waters that enter through the Bay mouth and flow northward along the Eastern Shore. Water along the Western Shore is more of a mix of riverine freshwater and oceanic salt water.

Much of the lower Bay, its tributaries, and small basins are shallow except for a few deep channels. Salinity and water temperatures fluctuate depending on depth and season. This environment provides a unique and challenging habitat for a number of important living resources. Microscopic phytoplankton and zooplankton inhabit the water column, utilize the abundant nutrients, and also provide food for numerous fish species.

Submerged aquatic vegetation (SAV) areas are a unique habitat and a valuable indicator of water quality. SAV covers the shallows of many small basins, including Mobjack Bay, Eastern Shore, and Tangier Island, with relatively high densities. Environmental status and trends information for these portions of the Bay are found in *"Basin-Specific Characterizations of Chesapeake Bay Living Resources Status"* (September, 1994) and *"First Annual Report on the Development and Implementation of Nutrient Reduction Strategies for Virginia's Tributaries to the Chesapeake Bay"* (1996 Report of the Secretary of Natural Resources – November, 1996).

Unfortunately, there are few monitoring stations in the small coastal basins aside from the Virginia shellfish bacteriological monitoring program and a few citizen monitors. It was determined that the Chesapeake Bay Estuary Program Model (CBEMP) would have limited use in targeting nutrient reductions in the coastal basins of the Eastern and Western Shores because this large Bay model does not have the spatial or temporal resolution needed for small areas.

The Watershed Model Phase 4.1 (Section 1.3) provided estimates of nitrogen and phosphorus loads from simulated land uses to the small coastal basins from six below-fall line model segments (Figure 6.1, Table 6.1). Landuses used to estimate loads were determined by the Environmental Monitoring and Assessment Program (EMAP) using remote sensing data on a scale of 660 square meters or 0.165 acres (See: *Chesapeake Bay Watershed Model Land Use and Model Linkages to the Airshed and Estuarine Models* at http://www.chesapeakebay.net/ model.htm).

Figure E.2.11

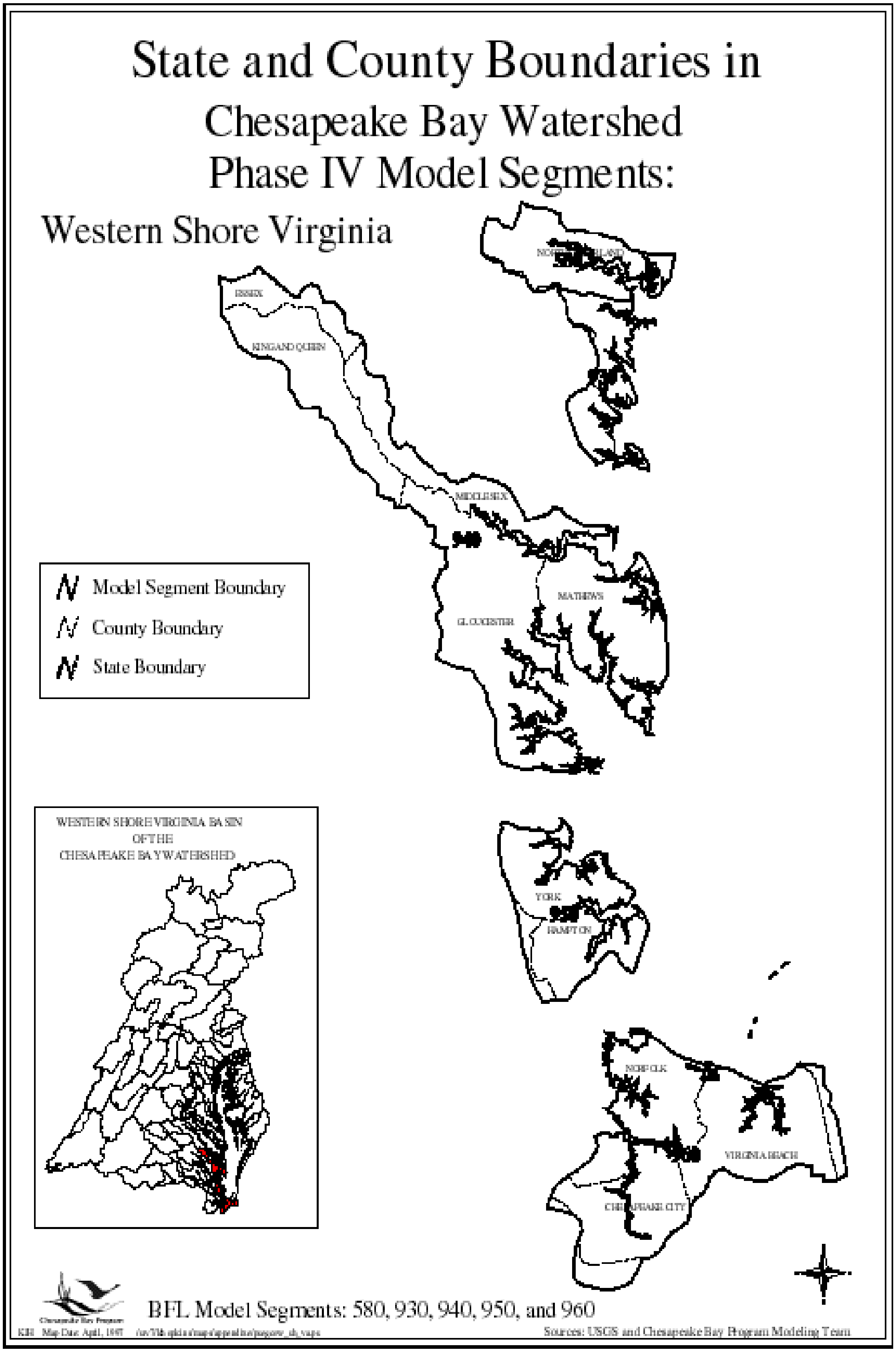

State and County Boundaries in
Chesapeake Bay Watershed
Phase IV Model Segments:
Western Shore Virginia
Model Segment Boundary
County Boundary
State Boundary
ESSEX
KING AND QUEEN
MIDDLESEX
MATHEWS
GLOUCESTER
YORK
HAMPTON
NORFOLK
VIRGINIA BEACH
WESTERN SHORE VIRGINIA BASIN
OF THE
CHESAPEAKE BAY WATERSHED
BFL Model Segments: 580, 930, 940, 950, and 960
Sources: USGS and Chesapeake Bay Program Modeling Team

Figure E.2.12

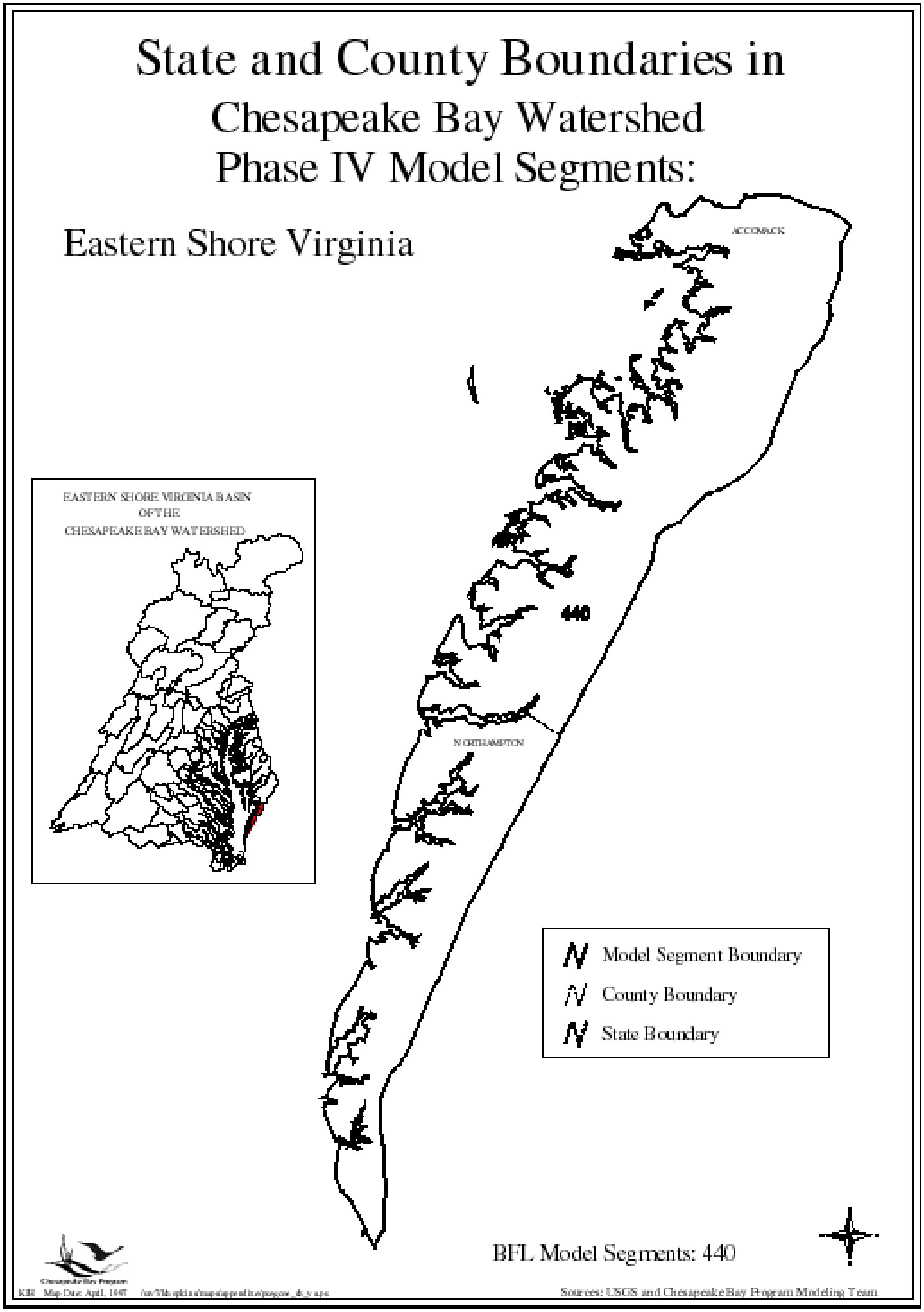

State and County Boundaries in
Chesapeake Bay Watershed
Phase IV Model Segments:
Eastern Shore Virginia
ACCOMACK
440
NORTHAMPTON
EASTERN SHORE VIRGINIA BASIN
OF THE
CHESAPEAKE BAY WATERSHED
Model Segment Boundary
County Boundary
State Boundary
BFL Model Segments: 440
Sources: USGS and Chesapeake Bay Program Modeling Team

Table 6.1 **Watershed Model Segments and Counties**

Phase IV Model	Segments	County
Western Shore	580 & 930 940 950 960	Northumberland (580 & 930) Lanchaster (930) Gloucester, Mathews & Middlesex York, Hampton & Newport News Norfolk, Chesapeake and VA Beach
Eastern Shore	440	Accomack & Northhampton

While the relatively small scale of the Watershed Model segments used for small coastal basin loads allowed for a comparison of loads under different management alternatives, it was determined that this model was also not appropriate for small coastal basin management and additional monitoring and modeling were needed.

6.2 Small Coastal Basin Monitoring and Modeling

Realizing the limitations of the Chesapeake Bay Program's watershed and water quality models, small coastal basin monitoring and modeling was conducted to further guide nutrient reduction efforts in support of the Tributary Strategies. It was determined that it was neither practical nor feasible to monitor and model all the small coastal basins of Virginia. In order to support Virginia's tributary strategy development, an effort was directed towards targeted monitoring and modeling.

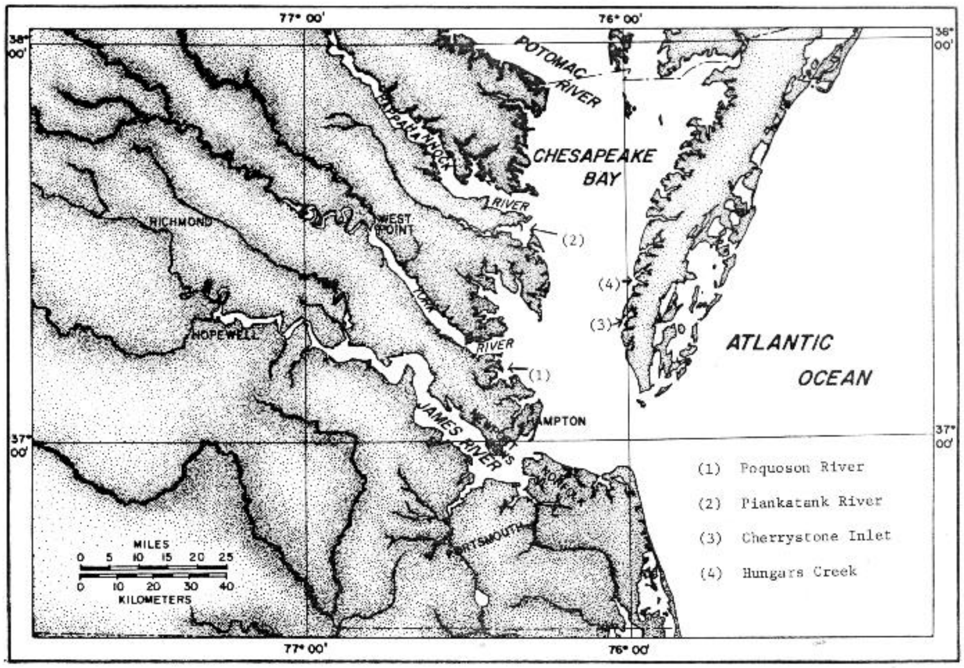
The first stage included water quality monitoring needed to calibrate a small coastal basin. It was decided to test a model developed for Lynnhaven Inlet. The Tidal Prism Model (TPM) of the Lynnhaven Inlet was developed by scientists from the Virginia Institute of Marine Science under a Virginia Coastal Resources Management Program Grant in 1993-1994.

In order to determine the extent of application of TPM to other small coastal basins in Virginia, four target basins were selected: 1) Piankatank and 2) Poquoson Creeks on the Western Shore, 3) Cherrystone and 4) Hungars Creeks on the Eastern Shore (Figure 6.2).

Monitoring data was used to test modeling applications in these four basins to determine the extent of TMP application to other small basins. A year-long water quality monitoring program in the target tributaries began in January of 1997. Results from the study provided data to calibrate and assess the full capabilities of TPM (Table 6.2)

The modeling effort consisted of three tasks: 1) pre-calibration simulations to reference basins; 2) calibration/confirmation to monitoring data and assess TPM applications to other basins; and 3) conduct nutrient reduction scenarios for each of the four basins. While the TPM did not contain the full ecosystem or biological components as the larger CBEMP (Section 1.4), it simulated most of the important chemical and physical parameters for the Bay and tributaries

Figure 6.2 **Virginia Target Coastal Basins**



6.3 Summary and Conclusions

Most of the nutrient inputs to these small coastal basins were associated with non-point sources. Therefore, water quality along the shorelines and upper portions of the basins characterized as tidal fresh were influenced by runoff while the higher salinity regions were influenced more by bay/ocean water quality (Kuo et al., 1998).

Observed concentrations of dissolved inorganic nitrogen and phosphorus were all very low while high chlorophyll a concentrations were observed in all basins in late winter and early spring. Spatial distributions suggested that the winter-spring algal blooms originated from the Bay. Summer algal growth was mostly in the shallow landward end of the basins except for Hungars Creek. There, chlorophyll a concentrations were low and did not exhibit a distinct spatial pattern.

Dissolved oxygen concentrations were generally above 5.0 mg/L except for several observation from Piankatank River where it was low (>3 mg/L) and restricted to the bottom waters during the summer months. Total suspended sediment (TSS) concentrations exceeded SAV requirements in all four basins and in all seasons. Except for Hungars Creek, spatial distributions indicated that local sources, either from watershed runoff or shoreline erosion, had significant contributions to the excessive TSS levels.

Salinity distributions were simulated well by the TPM in all four basins (Kuo et al, 1998). However, it was determined that better characterization of non-point source loadings was required prior to usage of the TPM for scenario runs. Model simulations and field data provided an overall characterization of the small coastal basins and uncovered unique features of the basins investigated.

Water quality in the lower portions of the small basins was dominated by the conditions at the mouth of each basin. Water quality data at the mouth would be required for any further model applications. These data could be obtained through monitoring or the three-dimensional water quality model of the Bay and major tributaries. Non-point source loadings during and immediately following runoff events dominated the tidal fresh portions of the basins. The use of a more sophisticated watershed model to generate loading inputs will be required for any further simulations.

Table 6.2 **Number of Data Points Failing to Meet SAV Requirements (Kuo et al., 1998)**
( ) indicates observed values

Month		Feb.	April	June	Aug.	Oct.	Dec.
Poquoson River (5 stations, 6 data points)	Chlorophyll	6	1	0	2	0	0
	DIN	0	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	2	2	4	5	1	0
	DO<5	0	0	0	0	0	0
Piankatank River (4 stations, 5 data points)	Chlorophyll	1	4	1	2	0	0
	DIN	4*	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	3	3	2	1	2	0
	DO<5**	0	0	3(>3.9)	3(>2.8)	1(>4.7)	0
Cherrystone Inlet (4 stations, 5 data points)	Chlorophyll	3	3	0	1	0	0
	DIN	0	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	3	5	3	2	5	2
	DO<5**	0	0	1(4.9)	0	0	0
Hungars Creek (3 stations, 4 data points)	Chlorophyll	3/3	4	1	0	0	0
	DIN	0	0	0	0	0	0
	PO_4	0	0	0	0	0	0
	TSS	3/3	0	1	0	4	2
	DO<5	0	0	0	0	0	0

* Mostly nitrite-nitrate nitrogen, ~0.15 mg/l ** Occurred only from bottom waters
Chlorophyll <15 mg/m^3; DIN <0.15 mg/L; DIP <0.01 mg/L (mesohaline), <0.02 (polyhaline);
TSS <15 mg/L

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Appendix A: Phase IV Chesapeake Bay Watershed Model Documentation

Phase IV Chesapeake Bay Watershed Model Application & Calculation of Nutrient & Sediment Loadings

Complete copies of the Chesapeake Bay Watershed Model Appendices can be obtained at: http://www.chesapeakebay.net/search/pub_action.cfm?SubjectCriteria=MODSC&STARTROW=1&MAXROWS=10&SEARCH_TYPE=SUBCOMMITTEE&GROUP_AFFIL=Modeling&GROUP_INIT=MODSC&BOOLEANOP=AND

Appendix A: Hydrology Calibration Results, *Technical Report CBP/TRS 196/98 and EPA 903-R-98-004*, U.S. EPA Chesapeake Bay Program, Annapolis, MD.

Appendix A documents in detail the Phase IV Watershed Model hydrology calibration. The results are presented as plots and statistical tables that compare the simulated and observed flows for the 8 years of calibration (1984-1991) for 17 flow calibration stations of the Chesapeake Bay. Specifically, this appendix includes the following plots: (1) observed and simulated flows; (2) actual error of the low; (3) observed and simulated cumulative flows; (4) actual error versus percentile sample population; (5) paired frequency distribution of simulated and observed data versus percentile of population; and (6) scatter plot and regression of simulated versus observed with ideal line. The appendix also contains the following statistical tables: (1) comparison of annual total observed and simulated flows; (2) comparison of daily and average monthly total flow observed and simulated regressions; and (3) average seasonal regressions. Regression statistics include r-squared, intercept, and slope statistics for the entire data set, on an annual basis and on a seasonal basis.

The daily observed and simulated flow plots generally show good to excellent agreement between the model and data. The differences are mainly attributable to storm events and high-flow, snowmelt events of the spring freshet. The observed and simulated cumulative flows versus time show both under- and over-estimation relative to the observed flow, but no particular bias for any of these stations. The actual error plots generally display a flat curve around 0 cubic feet per second (cfs) and a sigmoidal shape indicating the errors are normally distributed. A sigmoidal plot centered on 50% of the population indicates a lack of bias in the simulation.

The frequency distribution of paired simulated and observed flow plotted against percentile of sample population show good agreement, with the greatest differences between simulated and observed occurring during very high flows (95^{th} percentile or higher) or very low flows (5^{th} percentile or lower). In the scatter plots, the ideal line (slope = 1, intercept = 0) is drawn as a point of reference for the flow data and the flow regression statistics are displayed. As a point of comparison, the tabular regression statistics are for the log flow regression and the regression statistics displayed on the scatter plot are for untransformed flow data.

Appendix B: Water Quality Calibration Results, *Technical Report CBP/TRS 196/98 and EPA 903-R-98-003*, U.S. EPA Chesapeake Bay Program, Annapolis, MD.

Appendix B documents the water quality calibration of the Phase IV Watershed Model. Simulated and observed concentrations are compared for 8 years of calibration (1984-1991) at 15 water quality stations. Calibration data is shown for temperature, dissolved oxygen, total suspended sediment, total phosphorus, organic and particulate phosphorus, phosphate, total nitrogen, nitrate, total ammonia, and organic nitrogen.

The following plots are completed for each constituent: (1) observed and simulated concentrations; (2) observed and simulated loads (temperature loads are not calculated); (3) scatter plot and regression of simulated versus observed concentrations; (4) observed and simulated actual error of paired data (simulated concentration – observed concentration); (5) frequency distribution of paired simulated and observed data, i.e. coincident observed and simulated concentrations, and (6) frequency distribution of all simulated and observed data.

The daily observed and simulated concentration plots generally show good to excellent agreement between the model and data for temperature, dissolved oxygen, and total suspended sediment and fair to good agreement on other water quality constituents. Generally, as the number of water quality observations at a station increases, the calibration improves.

The simulated and observed load plots are developed from the observed mean daily flow and concentration compared to model estimated loads. Overall, the load comparisons range from fair to excellent depending, in different cases, on the simulation of flow or the simulation of concentration.

Scatter plots of observed and simulated concentrations are shown with the ideal line (slope = 1, intercept = 0) drawn to assist interpretation of the plots with changing x and y axis scales. The actual regression line slope, intercept, correlation coefficient, standard error of the slope, standard error of the intercept, and the number of observation are shown in the plot legend.

The actual error plot is calculated as the difference of the simulated and observed concentrations plotted against time and is useful for indicating calibration bias and the actual magnitude of errors. The two frequency distribution plots are useful for examining the differences between the observed and simulated concentrations with respect to concentration magnitude and frequency of occurrence. Generally, calibration is best in the central area of the data and calibration performance is least in the tails, particularly the 10^{th} and 90^{th} percentiles.

Appendix D: Precipitation & Meteorological Data Development & Atmospheric Nutrient Deposition, *Technical Report CBP/TRS 181/97 and EPA 903-R-97-022*, U.S. EPA Chesapeake Bay Program, Annapolis, MD.

Precipitation and meteorological input data are the primary forcing functions of the Watershed Model. Flow, non-point source loads, and reaction rates all primarily depend on the continuous time series of input precipitation, temperature, evaporation, and solar radiation. Appendix D documents the development of precipitation, meteorological, and atmospheric deposition data.

Chesapeake Bay Watershed Model Land Use and Model Linkages to the Airshed and Estuarine Models, U.S. EPA Chesapeake Bay Program, Annapolis, MD.

This document replaces the older Appendix E and contains the methods for determining both the Chesapeake Bay Program Land Use and the Phase IV Watershed Model Landuse. Land use is developed from several sources including the GIS coverages of EMAP, GIRAS, and CCAP, augmented by information from the Agricultural Census, the National Tillage Information Center (NTIC), and other Federal and State sources. This publication documents the steps used to construct the land use data used in the Watershed Model including the methodology for hind-casting and forecasting of model land uses and the development of model segmentation and model linkages.

Appendix F: Point Source Loadings, *Technical Report CBP/TRS 207/98 and EPA 903-R-98-014*, U.S. EPA Chesapeake Bay Program, Annapolis, MD.

Appendix F documents, in detail, the Phase IV Chesapeake Bay Watershed Model point source nutrient data assimilation process for the facilities located in signatory and non-signatory jurisdictions of the Chesapeake Bay Watershed. This document includes a description of the data sources, the methods of assimilation, types of analysis performed to determine nutrient reduction estimates, and trends in nutrient loadings discharged to the Chesapeake Bay Watershed. The Phase IV Watershed Model Point Source Database includes information for approximately 612 (the exact number varying depending on the year) active industrial, municipal, and federal facilities discharging directly to surface waters within the Chesapeake Bay watershed from all signatory and non-jurisdictions including: New York, Pennsylvania, Maryland, Delaware, District of Columbia, Virginia and West Virginia. Facility information, and flow and loading data are included for each of the 612 facilities for the years 1985 through 1996, 2000, Tributary Strategy Implementation (which is expected to occur after the year 2000) and additional nutrient reduction scenarios. The following flow and loading parameters are included: flow, total nitrogen, nitrate, organic nitrogen, total phosphorous, phosphate, organic phosphorous, biochemical oxygen demand, and dissolved oxygen.

The nutrient point source loading data are presented in both loads discharged at end of pipe and loads delivered to the Chesapeake Bay. To determine delivered loads, delivery factors were applied to the discharged loads to estimate attenuation as loads travel down the tributaries to the mainstem of the Chesapeake Bay. The total nitrogen load delivered to the Chesapeake Bay has decreased by 14 percent from 1985 to 1996, and is expected to decrease 27 percent from 1985 to 2000, and 33 percent from 1985 and Tributary Strategy Implementation (after 2000). These reductions are primarily due to facilities implementing biological nitrogen removal. The total phosphorous load delivered to the Chesapeake Bay has decreased 50 percent from 1985 to 1996, and is expected to decrease 55 percent from 1985 to 2000.

<u>Appendix H: Tracking Best Management Practice Nutrient Reductions in the Chesapeake Bay Program</u>, *Technical Report CBP/TRS 201/98 and EPA 903-R-98-009*, U.S. EPA Chesapeake Bay Program, Annapolis, MD.

Appendix H documents the work of the Chesapeake Bay Program Nutrient Subcommittee and the Tributary Strategy Workgroup. The Tributary Strategy Workgroup is made up of Chesapeake Bay Program scientists, engineers, and managers who work closely with the Chesapeake Bay Watershed Model in estimating the progress toward Chesapeake Bay nutrient reduction goals. Appendix H provides a summary of the methodologies used in tracking nutrient reduction goals with the Phase IV Watershed Model and outlines the data management procedures used for BMP tracking within each state. Information on nutrient application rates, land use conversions, and the application of land use-based BMP efficiency rates within the Phase IV Watershed Model is presented.

<u>Appendix I: Operations Manual</u>, *Technical Report CBP/TRS 209/98 and EPA 903-R-98-016*, U.S. EPA Chesapeake Bay Program, Annapolis, MD.

Appendix I discusses the Chesapeake Bay Phase IV Watershed Model operating procedures. The Phase IV Watershed Model is a comprehensive package for simulation of watershed hydrology and water quality based on the Hydrological Simulation Program - FORTRAN (HSPF) code. The Phase IV Watershed Model allows the integrated simulation of land and soil contaminant runoff processes with in-stream hydraulic and sediment-chemical interaction. The Phase IV Watershed Model partitions the Chesapeake Bay into 86 segments. Each segment is further divided into nine land uses which are: conventionally tilled cropland, conservation tilled cropland, hayland, pasture, forest, pervious urban, impervious urban, animal waste, atmospheric deposition to water surfaces. The model generates daily non-point source edge-of-stream (EOS) nutrient loads for each land use on a unit area basis and daily nutrient loads delivered to the Bay. The simulation of the entire Chesapeake Bay Basin necessitates the running of 29 separate input decks. Each input deck, as it is currently designed, can simulate up to 3 segments of the basin. The simulation period is 12 years and spans from January, 1984 to December, 1995.

Each model run produces a history of the runoff flow rate, nutrient and sediment loads and concentrations, along with a history of water quantity and quality at any designated point in the watershed. The Chesapeake Bay Watershed Model generates edge-of-stream loads for the land uses simulated, as well as nutrient concentrations and loads in each segment.

Appendix B: Scenario Descriptions

Key Scenarios

SCENARIO	DESCRIPTION
1985 Baseline Conditions	Represents the conditions of the entire Chesapeake Bay watershed in 1985 with respect to non-point source, point source, and atmospheric loads. ***Rationale***: Establishes a reference to which other scenarios will be compared. Also needed to compare status and trends monitoring data to model results for the Technical Synthesis. ➢ 1985 land uses are generally back-projected from 1990 Environmental Monitoring and Assessment Program (EMAP) land use data with the incorporation of 1982 and 1987 Agricultural Census estimates. ➢ Septic system loads and animal waste loads are estimated using 1985 watershed human population and animal population estimates, respectively. ➢ Best Management Practice (BMP) implementation is also at 1985 levels. ➢ Atmospheric wet deposition of nitrate and ammonia are based on a regression of National Atmospheric Deposition Program (NADP) data. Dry deposition of nitrate is determined from average proportions of wet and dry deposition calculated by the Regional Acid Deposition Model (RADM). Atmospheric deposition of nitrate and ammonia are input to both land and water surfaces. Atmospherically deposited phosphorus and organic nitrogen are input only to water surfaces.
1996 Progress	Represents the conditions of the entire Chesapeake Bay watershed in 1996 with respect to non-point source and point source loads. ***Rationale***: This scenario examines progress in reducing point source and non-point source nutrient and sediment loads from 1985 to 1996 and represents an estimate of the current water quality and living resource conditions in the lower tributaries**.** ➢ 1996 land uses are generally forward-projected from 1990 Environmental Monitoring and Assessment Program (EMAP) land use data with the incorporation of 1992 and 1997 Agricultural Census estimates.. ➢ Septic system loads and animal waste loads are estimated using 1996 watershed human population and animal population estimates, respectively. ➢ Best Management Practice (BMP) implementation is at levels of *1985 Baseline Conditions.* ➢ Atmospheric deposition is at levels of *1985 Baseline Conditions.*
Midpoint 1996 Progress – Full Voluntary Program Implementation	This is a derived scenario using point and non-point sources loads for all Chesapeake Bay basins midway between the *1996 Progress* scenario and *Full Voluntary Program Implementation.* Reductions vary by major basin. Atmospheric deposition for this scenario would assimilate these loads from both the *1996 Progress* and *FVPI* scenarios. ***Rationale***: This scenario examines tributary water quality and living resource response midway between a "no further action" management strategy (*1996 Progress*) and nutrient and sediment reductions estimated under a management strategy that achieves maximum reductions under a voluntary program (*FVPI*).

<table>
<tr>
<td>Full Voluntary Program Implementation - FVPI</td>
<td>
Rationale: Projects loads under maximum feasible management implementation using a voluntary program throughout the Chesapeake Bay watershed. It is based on current technology, expanded program financing, and a maximum of 75% cost share by states. Time and availability of technical staff are not considered.
The following agriculture, urban, and atmospheric deposition methodologies apply to the Full Voluntary Program Implementation scenario basin-wide unless otherwise specified. Nutrient reductions are given for nitrogen and phosphorus as percent reduced or pounds per acre. Phosphorus reductions are based on TSS reduction percentages. The base year for land use is the year 2000.
<u>AGRICULTURE:</u>
➢ NON-POINT SOURCE:
<u>Land use changes:</u>

75% conservation tilled acres.
25% conventionally tilled acres.
Retirement of highly erodible cropland: 1% of the total conventional till, conservation till, and hayland in all geographic areas. Defined as all future state/federal programs designed to take cropland out of production for extended periods of time which is not counted as part of another nutrient reduction program, such as forest buffers. It is assumed that retired acreage is maintained in an unfertilized unharvested permanent grass. Note: Federal/state programs prior to 1998 are included within Phase IV of the Watershed Model for all years and scenarios.

BMP 18 – Forest Buffers

Implemented on both sides of the stream.
35 feet in width.
10% of the unbuffered stream miles in conventional till, conservation till, and hayland converted to forest buffers.
10% of existing grass buffers in conventional till, conservation till, and hayland converted to forest buffers.
Pasture is not buffered (addressed under BMP 7 - Streambank Protection).
Two up-gradient acres receive a nutrient reduction benefit. The nutrient reduction varies with model segment and land use.

BMP 17 – Grass Buffers

10% of the unbuffered stream miles in cropland are converted to grass buffers.
Two up-gradient acres receive a nutrient reduction benefit. The nutrient reduction varies by model segment.

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<tr>
<td>Full Voluntary Program Implementation – FVPI (continued)</td>
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BMP 1 – Soil and Water Quality Conservation Plan (SWQCP) Cropland/Hayland

80% of the conventional till, conservation till, and hayland acres.
Nutrient reductions vary with land use:

<table>
<tr><th></th><th>N</th><th>P</th></tr>
<tr><td>Conventional Till</td><td>10%</td><td>40%</td></tr>
<tr><td>Conservation Till</td><td>4%</td><td>8%</td></tr>
<tr><td>Hayland</td><td>4%</td><td>8%</td></tr>
</table>
BMP 2 – Soil and Water Quality Conservation Plan (SWQCP) Pasture

80% of pasture acres.
Reduction rate: N = 20% and P = 14%.

BMP 3 – Cover Crop

80% of the conservation till, conventional till, and hayland acreage in the Coastal Plain, Potomac River basin and south.
80% of the silage corn acreage above the Potomac. Silage acreage is defined a 20% of the total conservation till and conventional till acres (80% of the 20%).
Nutrient reductions vary with model segment. The range is N = 34-51% and P = 10-20%.

BMP 4 – Animal Waste Management and Runoff Control

Applied to 80% of total manure acres. Converted acres go into pasture.

BMP 7 – Streambank Protection w/ Fencing

Implementation assumes fencing on both sides of stream.
15% of the unprotected stream miles in pasture.
The area affected is determined by adding the stream miles w/o fencing on one side of the stream + (2 times) stream miles w/o fencing on both sides of the stream.
Nutrient reduction of N = 75% and P = 75% is applied to 51 acres/stream mile.

BMP 19 – Streambank Protection w/o Fencing

Implementation assumes fencing on both sides of stream.
15% of the unprotected stream miles in pasture.
The area affected is determined by adding the stream miles w/o fencing on one side of the stream + (2 times) stream miles w/o fencing on both sides of the stream.
Nutrient reduction of N = 40% and P = 40% is applied to 51 acres/stream mile.

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Full Voluntary Program Implementation – FVPI (continued)	**BMP 8 – Nutrient Management Planning** • Applied to conventional till, conservation till, and hayland acres at the following rates: 95% in MD, 75% in VA, PA, and non-signatory states. • Reduction varies with model segment with an N and P range of 5-39% and 5-35% respectively. **BMP 9 – Grazing Land Protection** • 30% of the pasture land. • Reduction rates: N = 50% and P = 25%. URBAN: ➢ POINT SOURCE: **Sewage Treatment Plants (STPs):** • BNR or equivalent technology at all major municipal and industrial treatment plants basin-wide. Apply concentrations of N = 5.5 mg/L and P = 0.18 mg/L. STPs reporting concentrations below these levels will use reported figures. **Combined Sewer Overflows (CSOs):** • 30% of flow routed through a collection facility. • 10% connected to BNR-based STPs and 60% uncontrolled. • Applies to DC only. ➢ NON-POINT SOURCE: **Septic Systems:** **BMP 15 – Septic Connections** • 1% of the existing septic systems. Connections assumed going to a treatment plant using BNR or equivalent technology. Base year is 1997. This BMP does not apply to non-signatory states. • Reduction rate: N = 80% and P = 0% **BMP 14 – Septic Denitrification** • 100% of new systems and 50% of replacement systems not connected to a STP. Replacements are estimated to be 5% of total systems. Base year is 1997. This BMP does not apply to non-signatory states. • Reduction rate: N = 50% and P = 0% **BMP 13 – Septic System Pumping** • Applied to 50% of the septic systems not connected to a STP. Based on a 5-year cycle, assumed that proper maintenance provides benefits throughout the 5-year cycle and that all systems have been pumped at least once. This BMP does not apply to non-signatory states. • Reduction rate: N = 5% and P = 0%

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<td>Full Voluntary Program Implementation – FVPI (continued)</td>
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<u>Urban Pervious:</u>

BMP 16 – Urban Nutrient Management

N and P will be applied to the same percentage of urban pervious acres as in LOT but at a reduced rate (50%).
30% of the acreage receives fertilizer at a reduced rate.
N and P reduction rates are N = 8.5% and P = 11%.
Remaining acreage (70%) receives no fertilizer.

BMP 11 – Erosion and Sediment Control

Applied to 85% of the disturbed area. The number of disturbed acres is defined as all new urban pervious and impervious acres after 1997. Non-signatory states are not included in this BMP.
Reduction rates: N = 33% and P = 50%.

BMP – Forest and Grass Buffers

Implement a 35-foot forest buffer and 35-foot grass buffer on 10% (each) of the urban pervious stream miles not currently in forest buffers.
Grass buffers do not receive fertilizer.
Both buffer types receive nutrient reduction benefits on two up-gradient acres. The nutrient reduction varies by segment.

<u>Urban Impervious:</u>

BMP 12 – SWM Ponds

Up through 1990, 5% urban impervious acreage is considered serviced by SWM retrofits. Apply wet pond efficiencies of N = 32% and P = 46%.
All new (after 1990) urban impervious acreage is considered serviced due to SWM regulations. Apply dry pond efficiencies of N = 27% and P = 47%.

<u>OTHER:</u>

Reductions Activities Outside the WSM:

➢ Marine Pump-outs
➢ Shoreline Protection (tidal):

Structural
Nonstructural

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Full Voluntary Program Implementation – FVPI (continued)	ATMOSPERIC DEPOSITION: Atmospheric deposition assumes air emission controls associated with the Annual 2010 812 Prospective Projection air scenario. ➢ Stationary Sources (annual controls) • Emissions of no more than 0.15 lb./mm BTU from utility and large industrial sources in 37 states or most of the RADM/RPM domain. ➢ Mobile Sources (annual controls) • Tier 1 Light Duty Vehicle emission standards • Heavy Duty Vehicle 2 gm standard • Phase II Federal Reformulated Gasoline • National Low Emission Vehicle (NLEV) program • High and Low Enhanced Inspection and Maintenance (I/M) and Basic I/M as specified by individual states.

Current Limit of Technology – LOT	Estimates the maximum level of nutrient and sediment reductions given unlimited resources, unlimited cost share, and 100% landowner participation. A "do everything, everywhere" policy is applied using current available technologies. Time and availability of technical staff is not considered. ***Rationale***: This scenario examines the maximum load reductions of nitrogen, phosphorus, and sediment, and represents an estimate of the maximum improvement in water quality and living resource conditions in the lower tributaries. The following agriculture, urban, and atmospheric deposition methodologies apply to the *Current Limit of Technology* scenario basin-wide unless otherwise specified. Nutrient reductions are given for nitrogen and phosphorus as percent reduced or pounds per acre. Phosphorus reductions are based on TSS reduction percentages. The base year for land use is the year 2005. <u>AGRICULTURE:</u> ➢ NON-POINT SOURCE: **<u>Land use changes:</u>** • 75% conservation tilled acres. • 25% conventionally tilled acres. • It is assumed that crops are grown within the Chesapeake Bay Basin that cannot be planted using conservation tillage methods and that the distribution of those crops is uniform throughout the basin. Retirement of highly erodible cropland through CRP • CRP acreage cannot exceed 25% of the total cropland acres within a county. • Total cropland acres is the sum of all conventional till, conservation till, and hayland acreage within a specified geographic area. • CRP acreage is calculated by taking (25% * total cropland acres) – (the combined acreage from all state and federal programs designed to take cropland out of production for extended periods of time, such as forest buffers). • Assumed that at least 25% of the total cropland within a county meets CRP requirements. • It is assumed that retired acreage is maintained in an unfertilized unharvested permanent grass. **BMP 18 – Forest Buffers** • Implemented on both sides of the stream. • 100 feet in width on both sides of stream. • 100% of the unbuffered stream miles in conventional till, conservation till, and hayland converted to forest buffers. • Pasture is not buffered (addressed under BMP 7 - Streambank Protection). • Two up-gradient acres receive a nutrient reduction benefit.

Current Limit of Technology – LOT (continued)	**BMP 17 – Grass Buffers** • None **BMP 1 – Soil and Water Quality Conservation Plan (SWQCP) Cropland/Hayland** • 100% of the conventional till and conservation till. • Nutrient reductions vary with land use: N / P Conventional Till: 10% / 40% Conservation Till: 4% / 8% Hayland: 4% / 8% **BMP 2 – Soil and Water Quality Conservation Plan (SWQCP) Pasture** • 100% of pasture acres. • Reduction rate: N = 20% and P = 14%. **BMP 3 – Cover Crop** • 100% of the conservation till, conventional till, and hayland acreage in the Coastal Plain, Potomac River basin and south. • 100% of the silage corn acreage above the Potomac. Silage acreage is defined a 20% of the total conservation till and conventional till acres (100% of the 20%). • Nutrient reductions vary with model segment. The range is N = 34-51% and P = 10-20%. **BMP 4 – Animal Waste Management and Runoff Control** Applied to 100% of total manure acres. Converted acres go into pasture. **BMP 7 – Streambank Protection w/ Fencing** • Implementation assumes fencing on both sides of stream. • 100% of the unprotected stream miles in pasture. • The area affected is determined by adding the stream miles w/o fencing on one side of the stream + (2 times) stream miles w/o fencing on both sides of the stream. • Nutrient reduction of N = 75% and P = 75% is applied to 51 acres/stream mile. **BMP 19 – Streambank Protection w/o Fencing** • None **BMP 8 – Nutrient Management Planning** • Applied to 100% of the conventional till, conservation till, and hayland acres. • Reduction varies with model segment with an N and P range of 5-39% and 5-35% respectively.

Current Limit of Technology – LOT (continued)	**BMP 9 – Grazing Land Protection** • 100% of the pasture land. • Reduction rates: N = 50% and P = 25%. URBAN: ➢ POINT SOURCE: **Sewage Treatment Plants (STPs):** • BNR or equivalent technology at all major municipal and industrial treatment plants basin-wide. Apply concentrations of N = 3.0 mg/L and P = 0.075 mg/L. **Combined Sewer Overflows (CSOs):** • 50% of flow routed through a collection facility. • 30% connected to BNR-based STPs and 20% uncontrolled. • Applies to DC only. ➢ NON-POINT SOURCE: **Septic Systems:** **BMP 15 – Septic Connections** • 2% of the existing septic systems. Connections assumed going to a treatment plant using BNR or equivalent technology. Base year is 2000. This BMP does not apply to non-signatory states. • Reduction rate: N = 80% and P = 0% **BMP 14 – Septic Denitrification** • 100% of new systems and 50% of replacement systems not connected to a STP. Replacements are estimated to be 5% of total systems. Base year is 1997. This BMP does not apply to non-signatory states. • Reduction rate: N = 50% and P = 0% **BMP 13 – Septic System Pumping** • Applied to 100% of the septic systems not connected to a STP. Based on a 5-year cycle, assumed that proper maintenance provides benefits throughout the 5-year cycle and that all systems have been pumped at least once. This BMP does not apply to non-signatory states. • Reduction rate: N = 5% and P = 0%

Current Limit of Technology – LOT (continued)	<u>**Urban Pervious:**</u> **BMP 16 – Urban Nutrient Management** • 30% of the acreage receives fertilizer at a reduced rate. • N and P reduction rates are N = 17% and P = 22%. • Remaining acreage (70%) receives no fertilizer. **BMP 11 – Erosion and Sediment Control** • Applied to 100% of the disturbed area. The number of disturbed acres is defined as all new urban pervious and impervious acres after 2000. Non-signatory states are not included in this BMP. • Reduction rates: N = 33% and P = 50%. **BMP – Forest and Grass Buffers** • Install a 35-foot forest buffer on both sides of stream on 50% of the urban pervious stream miles not currently in forest buffers. • The remaining 50% is considered in grass buffers. • Both buffer types receive nutrient reduction benefits on two up-gradient acres. <u>**Urban Impervious:**</u> **BMP 12 – SWM Ponds** • Up through 1990, 50% urban impervious acreage is considered serviced by SWM retrofits. Apply wet pond efficiencies of N = 32% and P = 46%. • All new (after 1990) urban impervious acreage is considered serviced due to SWM regulations. Apply dry pond efficiencies of N = 27% and P = 47%. <u>**Mixed-Open:**</u> **BMP 16 – Urban Nutrient Management** • Acreage receives no fertilizer. **BMP 11 – Erosion and Sediment Control** • No BMPs installed, no reductions taken (edge-of-field load should be minimal due to assumed cover and no additional nutrient source loads). **BMP 12 – SWM Ponds** • None installed. **BMP – Forest Buffers** • Forest buffer (100-feet per stream side) installed along all streams not currently in forest. **BMP – Grass Buffers** • None installed.

Current Limit of Technology – LOT (continued)	OTHER: Potential Reductions Outside the WSM: ➢ Marine Pump-outs ➢ Shoreline Protection (tidal): ➢ Forest Conservation ➢ Tree Planting ATMOSPERIC DEPOSITION: Atmospheric deposition assumes the maximum practical level of air emission controls are applied year-round in 37 states east of the Rocky Mountains through the simulation period. ➢ Stationary Sources (seasonal controls) • Emissions of no more than 0.15 lb./mm BTU from utility and large industrial sources in 37 states or most of the RADM/RPM domain. ➢ Mobile Sources (annual controls) • High Mobile Sources (annual controls) • Tier 1 Light Duty Vehicle and Heavy Duty Vehicle emission standards • Phase II Federal Reformulated Gasoline • National Low Emission Vehicle (NLEV) program • High Enhanced Inspection and Maintenance and maximum Low Emission Vehicle benefits for all counties in the 37-state domain, regardless of ozone attainment.

Ranging Scenarios

SCENARIO	DESCRIPTION
VA 1996 Progress / Tributary Strategy Above	Represents non-point source and point source loads with respect to *1996 Progress* conditions for Virginia's lower tributaries while the northern Chesapeake Bay tributaries (Potomac and above) implement *Tributary Strategy* load reductions. ***Rationale***: This scenario determines an aspect of load reductions occurring at different levels in different basins. In this case, load reduction in the lower Virginia tributaries are relatively less than the load reductions in the tributaries of the Potomac and above. This scenario develops estimates of the affect *Tributary Strategy* load reductions from outside the lower Virginia tributaries have on water quality and living resources in Virginia waters.
VA BNR-BNR Equivalent / Tributary Strategy Above	This is a derived scenario where biological nutrient removal (BNR) is simulated at above- and below- fall line point sources in Virginia's lower tributaries. All of Virginia's lower tributaries are at *BNR* conditions for point sources except the Rappahannock with *BNR* only applied to >1 million gallon per day (mgd) facilities. Point source effluent concentrations of 8.0 mg/L TN and 2.0 mg/L TP are applied to flows projected to 2000 levels. For facilities with 1996 discharge TN concentrations less than 8.0 mg/l, the 1996 concentrations are used. Non-point source loads in the lower tributaries are reduced by basin to the same *(Equivalent)* PS:NPS load ratio prior to BNR removal. These non-point source loads are calculated using the following ratio and solving for BNR non-point source loads: $\frac{\textit{1996 Progress}\text{ PS loads} - \textit{BNR}\text{ PS loads}}{\textit{1996 Progress}\text{ PS loads} - \textit{FVPI}\text{ PS loads}} = \frac{\textit{1996 Progress}\text{ NPS loads} - \textit{BNR}\text{ NPS loads}}{\textit{1996 Progress}\text{ NPS loads} - \textit{FVPI}\text{ PS loads}}$ Solids are reduced to a non-point source phosphorus ratio. Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* load levels. The Watershed Model was not run for this scenario. Instead, point source delivered loads were calculated by using 1996 transport factors and the edge-of-stream BNR point sources described above. ***Rationale***: This scenario examines a moderate point source load reduction and a measure of an equivalent nutrient reduction from non-point sources.
VA Interim Bay Agreement / Tributary Strategy Above	Nutrient reductions in the lower Virginia tributaries at a 40% interim nutrient reduction goal while loads in the northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* levels. ***Rationale***: This scenario estimates water quality and ecosystem response to controllable loads in the lower Virginia tributaries set at 40% of *1985 Baseline Conditions*.

VA Full Voluntary Program Implementation / Tributary Strategy Above	Virginia's lower tributaries are at *Full Voluntary Program Implementation* load levels and the Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* amounts. Atmospheric deposition is at levels of *Full Voluntary Program Implementation* in the basins and tidal waters of the lower Virginia tributaries and at *1985 Baseline Conditions* for the Potomac River basin and watersheds above. ***Rationale***: This scenario determines an aspect of load reductions occurring at different levels in different basins. In this case, load reductions in the lower Virginia tributaries are relatively greater than the load reductions in the tributaries of the Potomac and above.

Geographic Management Scenarios

SCENARIO	DESCRIPTION
VA Eastern Shore FVPI / Tributary Strategy Above	Eastern Shore VA loads for point sources, non-point sources, and atmospheric deposition at *Full Voluntary Program Implementation* levels. All other lower VA basin loads (Rappahannock, York, James, and Western Shore VA) at *1996 Progress* amounts. Northern Chesapeake Bay tributaries (Potomac and above) at *Tributary Strategy* loads. ***Rationale***: This scenario determines an aspect of load reductions occurring at different levels in different basins. In this case, nutrient and sediment reductions in the Virginia Eastern Shore are relatively greater than load reductions in all other tributaries.
VA Western Shore FVPI / Tributary Strategy Above	Western Shore VA loads for point sources, non-point sources, and atmospheric deposition at *Full Voluntary Program Implementation* levels. All other lower VA basin loads (Rappahannock, York, James, and Eastern Shore VA) at *1996 Progress* amounts. Northern Chesapeake Bay tributaries (Potomac and above) at *Tributary Strategy* loads. ***Rationale***: This scenario determines an aspect of load reductions occurring at different levels in different basins. In this case, nutrient and sediment reductions in the Virginia Western Shore are relatively greater than load reductions in all other tributaries.
VA Current LOT Sediment / Tributary Strategy Above	Virginia's lower tributaries at *Current Limit of Technology* for total suspended solids (about 33% reduction from *1985 Baseline Conditions*). Loads from point sources, non-point source nutrients, and the atmosphere in the lower Virginia tributaries are at *1996 Progress* levels. Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* load levels. ***Rationale***: This sensitivity scenario examines the relative effect of the most stringent reductions of suspended sediment loads within the feasible region, with an estimate of the 1996 level of nitrogen and phosphorus controls.
VA Extreme Sediment Reduction / Tributary Strategy Above	Virginia's lower tributaries are at 40% load reduction of total suspended solids from *1985 Baseline Conditions.* (Pristine sediment load reduction is about 43% from the baseline). Loads from point sources, non-point source nutrients, and the atmosphere in the lower Virginia tributaries are at *1996 Progress* levels. Northern Chesapeake Bay tributaries (Potomac and above) at *Tributary Strategy* load levels. ***Rationale***: This sensitivity scenario examines the relative effect of sediment reductions outside the feasible region with an estimate of the current level of control for nitrogen and phosphorus to determine the impact suspended sediment loads have on lower tributary water quality and living resources.

York River 2010 Scenario	This is a Watershed Model scenario developed solely for the York basin. York point source effluent concentrations at BNR levels of 8.0 mg/l TN are applied to year 2000 flows. For facilities with 1996 TN discharge concentrations less than 8.0 mg/l and facilities less than 1 mgd, the 1996 concentrations are used. Point source TP loads in the York apply 1996 concentrations to projected 2000 flows. Year 2000 land uses, septic system loads and animal numbers are employed while atmospheric deposition is at *1985 Baseline Conditions*. The CBEMP was not run for this scenario. ***Rationale***: This scenario examines non-point source load reduction potential in 2010 with the implementation of BMPs assuming land uses, animal numbers, and septic system loads remain at 2000 levels and point source loads are capped at BNR levels. Non-point source loads in the York are simulated with the following 2010 projection of BMPs: Farm Plans 304,605 acres Nutrient Management 185,749 acres Agricultural Land Retirement 37,763 acres Grazing Land Protection 7,907 acres Stream Protection 384 acres Cover Crops 39,641 acres Grass Filter Strips 990 acres Woodland Buffer Filter Area 101 acres Forest Harvesting 11,965 acres Animal Waste Control Facilities 14 systems Poultry Waste Control Facilities 9 systems Loafing Lot Management 0 systems Erosion and Sediment Control 2,556 acres Urban SWM/BMP Retrofits 17,497 acres Urban Nutrient Management 500 acres Septic Pumping 0 systems Shoreline Erosion Protection: nitrogen reduction 35,266 pounds phosphorus reduction 23,128 pounds sediment reduction 735 tons

James Above-Fall Line at BNR-BNR Equivalent / Tributary Strategy Above	Above-fall line James loads at *BNR-BNR Equivalent* or above-fall line James point sources at BNR concentrations for TN and TP and 2000 flows. For facilities in the above-fall line James with 1996 TN concentrations less than BNR concentrations, the 1996 concentrations are used. Non-point source loads for the above-fall line James are at a BNR equivalent levels of control. The Appomattox, below-fall line James, and other VA tributary loads at *1996 Progress*. Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* load levels. ***Rationale***: This scenario examines the water quality and living resource response to *BNR-BNR Equivalent* load reductions in the above-fall line James.
James Above-Fall Line, Appomattox, & Below-Fall Line Tidal Fresh James at BNR-BNR Equivalent / Tributary Strategy Above	Loads discharging into the tidal fresh James at levels of *BNR-BNR Equivalent*. For facilities discharging into the tidal fresh James with 1996 TN concentrations less than BNR concentrations, the 1996 concentrations are used. The James regions discharging below the tidal fresh portion of the James and other Virginia lower tributaries are set to *1996 Progress* loads. Northern Chesapeake Bay tributaries (Potomac and above) at *Tributary Strategy* load levels. ***Rationale***: This scenario examines the water quality and living resource response to *BNR-BNR Equivalent* load reductions in regions discharging to the tidal fresh James.
James Tidal Fresh at BNR-BNR Equivalent For Nitrogen / Tributary Strategy Above	Loads discharging into the tidal fresh James at levels of *BNR-BNR Equivalent* for nitrogen only. James discharging to the tidal fresh region at *1996 Progress* for phosphorus and sediment. For facilities discharging into the tidal fresh James with 1996 TN concentrations less than BNR concentrations, the 1996 concentrations are used. The James regions discharging below the tidal fresh portion of the James and other Virginia lower tributaries are set to *1996 Progress* loads. Northern Chesapeake Bay tributaries (Potomac and above) are at *Tributary Strategy* load levels. ***Rationale***: This scenario examines the water quality and living resource response to *BNR-BNR Equivalent* load reductions for nitrogen only in regions discharging to the tidal fresh James. It quantifies the importance of nitrogen versus phosphorus controls.