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Enhanced Water Quality Monitoring of Virginia's Chesapeake Bay Tributaries

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**ENHANCED WATER QUALITY MONITORING OF VIRGINIA'S CHESAPEAKE
BAY TRIBUTARIES**

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EXECUTIVE SUMMARY

The Commonwealth of Virginia, through the collective efforts of stakeholders in the various watersheds and inter-agency teams under the Secretariat of Natural Resources, has developed strategies for the restoration of Virginia's Chesapeake Bay tributaries and coastal basins over the past several years. These strategies contain specific environmental improvement goals that the strategies are designed to achieve. However, new and enhanced monitoring activities will be required to track the progress and success of each tributary and coastal basin towards achieving these goals. This report summarizes the results of a study that reviewed the status and relevance of current long-term monitoring data collection activities for each tributary strategy, identified environmental monitoring needs, and specific monitoring requirements and approaches, as well as approximates costs to implement these enhanced monitoring activities.

Eastern Shore

The Eastern Shore Tributary Strategy long-term living resource goal is: *Increase the areas and density of Submerged Aquatic Vegetation throughout the Eastern Shore tidal creeks and embayments to historic levels to enable the return of abundant and diverse fish and shellfish populations which, in turn will help to sustain and improve local economies.* At this time the Eastern Shore Tributary Strategy does not include long-term nutrient and sediment reduction goals that would achieve its living resource goal. The objectives of this enhanced monitoring plan are to provide the additional long-term data necessary to evaluate the linkages between habitat conditions and existing SAV distributions and identify those factors that appear most limiting for SAV growth to historical levels. In addition, monitoring is suggested that will permit evaluation of differences in SAV habitat conditions that may be related to efforts to reduce watershed nutrient and sediment loadings.

The enhanced monitoring plan consists of several components. A *baseline*-monitoring program has been developed that focuses on measurements of specific physical and biological water quality characteristics (dissolved nutrients, phytoplankton chlorophyll a, suspended sediments, temperature, salinity, DO, pH, turbidity) that can be directly related to the evaluation of SAV habitat conditions. These data will be used to develop an understanding of the spatial and temporal patterns of water quality in selected creeks that are representative of a range of Eastern Shore bayside watershed conditions. Monitoring data can then be used in the future as input to "diagnostic" models developed by EPA to quantify limiting factors relative to SAV survival. The baseline monitoring should be continued for a period of at least three years at three sites per creek in order to evaluate the overall spatial and seasonal patterns of water quality in the creeks systems. Additionally the data can be used, along with improved water shed monitoring, to calibrate a tidal prism model for each creek system. To help select the creeks to be monitored a matrix was developed comparing historical SAV changes, availability of past water quality monitoring data, watershed land use, development pressure, presence of aquaculture and locations of point source discharges (NPDES permit). Based on the combination of these factors the following five creeks were selected: Chesconessex

Creek, Onancock Creek, Occohancock, Hungars Creek and Old Plantation Creek. Because of increased development pressure and to ease the timing constraints of logistically sampling each creek in one day within the same tidal phase, Cherrystone Creek was added to this list. For budgetary purposes the list has been divided into a southern creek group (Hungars Creek, Cherrystone Creek and Old Plantation Creek) and a northern creek group (Chesconessex Creek, Onancock Creek and Occohancock Creek).

A *pulsed event* sampling component of the monitoring has been proposed as episodic inputs of nutrients and sediments can be significant stressors affecting SAV recovery in this region. Rainwater-triggered sampling devices should be employed at least seasonally after rainfall events in an effort to quantify the magnitude and duration of pulsed inputs from surface run-off in each creek system at the principal headwater. Following a rainfall event, 24 sequential samples should be taken at programmed, 2 hr. intervals. Each of the parameters measured at the fixed stations should be measured. These data can then be used to evaluate the comprehensiveness of the baseline monitoring information as well as to quantify the duration and intensity of water quality conditions due to short-term events. Additionally these data can be used to compare the short-term responses of the different watershed/land use characteristics to episodic events. This monitoring should be undertaken for a minimum of two years in each of the creek systems.

Groundwater can be a significant component of nutrient input into the creek systems. While groundwater monitoring has been undertaken in some Eastern Shore watersheds most studies are site specific, therefore groundwater sampling in connection with the enhanced tidal creek water quality sampling should be undertaken. Two approaches should be employed to estimate groundwater contributions to nutrient loading in the creeks. One involves the use of land-based groundwater wells within the watersheds to determine groundwater water table heights and nutrient levels. This should begin in the Cherrystone Inlet watershed because of the existing wells established there. In the other two southern watersheds and the three northern creek watersheds nine wells should be established in each and sampled for water table height monthly and nutrients quarterly. The other approach estimates inputs directly through stream base flow into the creeks. Here nutrients in surface base flows should be measured throughout each of the watersheds at four to five locations at quarterly intervals at least 96 hours after a rainfall event.

Comprehensive aerial photography of the Eastern Shore watersheds should be undertaken to develop land use cover information for local planning. Currently SAV aerial mapping is undertaken in June of each year by VIMS as part of the bay wide SAV mapping program and the results including maps and summary information such as bed area and density classification are available in a web-based database (<http://www.vims.edu/bio/sav>). The photographic coverage of these over flights should be extended to include all of the Eastern Shore watersheds and the photographs provided in digital format.

As much as possible, citizen participation should be a component of the enhanced monitoring activities. This should involve assistance in watershed monitoring projects as

well measurements of potential epiphyte fouling on SAV. Epiphyte fouling of the leaves of SAV is an important factor affecting the light availability to the plants. In order to assess the light attenuation potential of epiphytic growth on the leaves of SAV, artificial substrata in the form of thin strips of Mylar® polyester plastic should be deployed by citizens at shallow (1 m MLW) water locations near the creek baseline water quality monitoring stations. The strips should be retrieved on at least bi-weekly intervals during the SAV growing season (April – November) and frozen until VIMS scientists remove the epiphyte accumulations for analysis. Epiphyte strip sampling should occur within 2 days before or after the Baseline water quality sampling dates.

James River

The James River in Virginia has been the focus of intense efforts from federal and state agencies, academic and research institutions such as VIMS and many bay partners, to develop and implement effective management strategies for the restoration of living resources such as SAV to former levels. The document, *Initial James River Basin Tributary Nutrient and Sediment Reduction Strategy* published in 1998 did not contain specific restoration goals. Following new model data generated by the Chesapeake Bay Water Quality Model, a James River basin Technical Review Committee subsequently met to define specific restoration goals. Although consensus restoration goals for nutrients and sediments were not realized, high sediment load in the tidal James and its effect on growth and recovery of SAV was identified as a critical problem. The *Initial James River Basin Tributary Nutrient and Sediment Reduction Strategy* (1998) emphasized restoration of water quality to “levels suitable for SAV survival and growth” in the lower tidal river.

Goals established for the James River were recently published in a document entitled *Tributary Strategy, Goals for Nutrient and Sediment Reduction in the James River Public Comment Draft January 2000*. These goals included annual reductions in nitrogen and phosphorus nutrient loadings and reduced sediment loading. Specifically, the document identifies a sediment reduction goal as “...9% sediment reduction from the levels that existed in 1985 for the entire basin by the year 2010.” This will be achieved by application of BMPs and sediment erosion prevention techniques.

During presentations and subsequent ad hoc discussions at the first James River Watershed Roundtable, both SAV restoration and the importance of water clarity were identified as important technical issues warranting enhanced monitoring and perhaps special studies. Water clarity in particular, and its contributing components was an issue of interest. Concerns related to the specific contributions of algal (chlorophyll *a*) and TSS inorganic materials to water clarity, the role of dynamic sediment re-suspension processes on water clarity, and the relationship between nutrients and water clarity in the lower James were mentioned. Most of these concerns cannot be addressed without enhanced monitoring/special studies.

The continuing development and implementation of the Commonwealth of Virginia Tributary Strategies, recent 303(d) listing of the Virginia region of the Chesapeake Bay

and its tributaries as degraded water, the development of water quality “Endpoints” for turbidity, chlorophyll *a*, and DO, as well as the potential for change in the CBP water quality monitoring program procedures have placed increased emphasis on accurate measurements of the temporal and spatial variability of water quality constituents. Temporally intensive water quality studies in vegetated and unvegetated shallows and adjacent channel areas in the bay have demonstrated that differences in water quality between the two can be significant. In addition, predictions of SAV transplant growth and survival using the closest available mid-channel, water quality monitoring data, can have poor success. Our understanding of the spatial variability of water quality constituents especially between channel and shoal regions and how this variability is related to SAV in the James River remains incomplete.

Accordingly, we have identified the following needs to support an enhanced monitoring program:

1. Establish a comprehensive monitoring program to assess the effectiveness of management efforts. This should include the addition of fixed shoal stations on each side of the existing mid-channel station in Hampton Roads, Chickahominy River and Hopewell region bay segments, as well as stations in the upper and lower Chickahominy.
2. Improve *spatial and temporal* coverage of important water quality parameters, e.g., chlorophyll *a*, turbidity/water clarity/TSS, physical/chemical data, through the establishment of new monitoring stations and the application of high frequency spatial and temporal monitoring using surface and subsurface water quality mapping systems on at least monthly intervals in the same three regions study regions as above. Moored buoys may be deployed at critical locations to provide continuous data.
3. Identify and continue to map existing SAV habitats to establish a baseline against which to measure restoration including yearly aerial monitoring along the entire James River. Ground survey monitoring should be augmented using citizen volunteers which are organized and trained by a group such as the Chesapeake Bay Foundation with assistance from VIMS and the results incorporated into the annual SAV report. Additionally, citizen can also be used to monitor epiphyte fouling in a manner similar to the Eastern Shore Tributary monitoring plan.
4. Evaluate current monitoring programs for effectiveness: station locations, methods and needs. Examine relationships between water quality parameters to assess validity of assumptions.
5. Establish a formal technical committee within the James River Watershed Roundtable composed of watershed stakeholders, regulatory and scientific personnel. Tasks for this committee could include the review of enhanced monitoring recommendations and approaches, providing guidance and recommendations to the Roundtable, and facilitating communication. This is a

critical need as there is currently no formal committee to discuss monitoring needs, results, consideration of special studies, and to identify and recommend (to the Round Table) needs worth of financial support.

York River

The York River Tributary Strategy Plan states that the goal of the strategy is to “reestablish York River habitat conditions, particularly dissolved oxygen and submerged aquatic vegetation, for the purposes of restoring fisheries and other living resources.” The strategy suggests that because non-point sources are the major contributors of nutrients and because the York River watershed displays low relief and long residence times, the aggressive implementation of non-point source Best Management Practices (BMP’s) is likely to be particularly useful for nutrient and sediment load reduction. The monitoring program for the York River includes several components that include: measuring water quality in the shallow as well as open water, deep water and deep channel designated-use habitats of the river; measurements of SAV abundance and distribution in the oligohaline and tidal fresh zones; monitoring of impaired watersheds; and citizen participation.

Measurements of water quality should be conducted at high frequency temporal and spatial intervals using new technologies. In the shallow water and open water designated-use habitats water quality constituents that can be used as a diagnostic to SAV growth and abundance (turbidity, phytoplankton fluorescence) as well as DO should be measured using a continuous surface mapping system with fixed stations used for calibration. This should be undertaken biweekly from April through October and monthly from November to March. Open water, deep water and deep channel habitats in the lower York where low DO has been observed below the pycnocline should be sampled at the same intervals as the surface mapping system using an undulating towed vehicle with similar sensors. Two fixed stations should be established using moored buoys for continuous monitoring of DA, salinity, and temperature at 1 m depth intervals at the mouth of the York River.

Because of the inherent difficulties in mapping SAV in tidal freshwater regions due to high turbidity and small size of the beds, ongoing annual aerial mapping of SAV should be augmented with extensive ground surveys by professionals, as well as trained citizens during each growing season. All the data should be tabulated by the organizing group such as the Chesapeake Bay Foundation and provided to VIMS for inclusion in the annual SAV report summaries.

Monitoring of additional sub-watersheds for nutrients, suspended sediments, DO and fecal coliforms, water flow, rainfall, should be performed using techniques similar to those used in the Polecat Creek Watershed Study. These include Plentiful Creek in Spotsylvania County and Mechupps and Matadequin creeks in Hanover County. Baseline flows (no rainfall for 3 days) and event-driven sampling should be undertaken at least quarterly. Citizen participation should be encouraged to assist in maintenance and

downloading of meteorological data loggers, collection of water samples and oversight of the monitoring equipment.

Rappahannock River

The Tributary Restoration Strategy for the Rappahannock River and Northern Neck Coastal Basins defined numerical endpoints to be attained by the year 2010 for both dissolved oxygen and submerged aquatic vegetation. In both instances, the desired endpoints were derived from results of the Chesapeake Bay Estuarine Modeling Package and are not indices or metrics that are presently measured by existing monitoring programs.

The dissolved oxygen restoration goal stipulated in the Rappahannock River strategy is “*to reduce by about 50% the annual volume of anoxic water in the Rappahannock River*”, the reduction to occur over the 25 year period, 1985-2010. Historically, low dissolved oxygen has occurred in the subpycnocline waters in the lower portion of the river. It is our recommendation that the attainment of this goal be determined by adapting and using the Chesapeake Bay Interpolator to calculate anoxic volume days (AVD) in the lower Rappahannock River using monitoring data for dissolved oxygen.

Options for monitoring the desired improvement in dissolved oxygen are proposed. Continued monitoring of dissolved oxygen where low DO is expected, using the standard protocols (i.e. four fixed stations, at 2 meter depth intervals once a month) has the advantage of providing a consistent AVD data set over the 25-year period of interest. However, the accuracy of the AVD determination from this scenario is compromised by the poor spatial and temporal resolution of the data collection. We recommend a series of options for increasing the spatial and temporal resolution of DO data collection. They are: (1) Add four additional fixed stations in the lower river along the mainstem and as many as 16 fixed stations lateral to the mainstem stations; increase spatial sampling frequency to one meter depth intervals and increase temporal frequency to biweekly; (2) implement a depth-variable, “continuous” recording towed vehicle to map the distribution of low dissolved oxygen in the lower Rappahannock River in three-dimensional space and increase sampling frequency by this method to biweekly; (3) install at least one fixed, multi-depth, continuously recording buoy in the lower Rappahannock River to monitor temporal changes in dissolved oxygen.

In all instances in which revised, enhanced sampling protocols are utilized, it will be necessary to continue the historical sampling protocols for a minimum of 3-4 years so that DO metrics from the historical and enhanced protocols can be correlated. Information derived from the correlation will be used to “correct” the historical data so that a consistent data set spanning the 25 years of interest may be derived.

The submerged aquatic vegetation goal articulated in the River restoration strategy is “*to increase by approximately 50% the density of submerged grasses*”. In this instance, density is deemed to be synonymous with aboveground biomass of SAV in the beds (i.e. g C m^{-2}). Increased biomass within SAV beds is expected to enhance their resistance to

environmental perturbations that may eliminate less dense grass beds and to provide sufficiently lush beds that their own filtering action will reduce sediment concentrations sufficiently to improve light availability for SAV. Since the direct determination of a “density” metric for Rappahannock River SAV beds would require costly ground surveys of beds on an annual basis, two alternative options for monitoring SAV recovery are proposed.

The first is to continue the annual aerial surveys of Rappahannock River SAV beds and change the desired attainment endpoint from a biomass metric (g C m^{-2}) to an aerial metric (hectares). Thus, historic and future aerial photography would be similarly evaluated to determine the aerial extent of SAV coverage in the lower and middle Rappahannock region. Although a new numerical attainment goal may have to be determined, this option has the advantage of providing a consistent data set for determining attainment over the 25 years of interest. The second alternative is based on the existing capability to use aerial photographs to assign grass beds to one of four density classification types that can then be converted to percentage cover. The application of this technique to both future and historical aerial photographs can provide a consistent data set for quantifying improvement in this metric over the 25 years of interest. The close similarity of the proposed metric to metric identified in the strategy suggests that the numerical value of the goal may remain unchanged.

I. EASTERN SHORE TRIBUTARY ENHANCED MONITORING PLAN

Introduction

The Eastern Shore of Virginia is an 80-mile long peninsula that encompasses about 696 square miles of land area with approximately 50% of this land area draining into the Chesapeake Bay through numerous small watersheds that comprise a complex system of tidal creeks, guts and inlets. There are no rivers other than the Pocomoke, which lies primarily in Maryland, draining to the Bay from Virginia's Eastern Shore. The water quality within the creeks and basin of this region are largely controlled by inputs from groundwater, non-tidal base flow, runoff from pulsed or storm-related events and exchanges with Bay mainstem water (Kuo et al. 1998).

The Eastern Shore Tributary Strategy long-term living resource goal is: *Increase the areas and density of Submerged Aquatic Vegetation throughout the Eastern Shore tidal creeks and embayments to historic levels to enable the return of abundant and diverse fish and shellfish populations which, in turn will help to sustain and improve local economies.* At this time the Eastern Shore Tributary Strategy does not include long-term nutrient and sediment reduction goals that would achieve its living resource goal. The thrust of the Strategy is in gathering local water quality information through enhanced water quality monitoring and small watershed modeling to determine the existing water quality issues and concerns on which to base long-term nutrient and sediment reduction goals. The Eastern Shore Tributary Strategy Implementation Team did agree to work toward 2003 target reductions, which will be used in determining future long-term nutrient and sediment reduction goals. The Strategy will be re-evaluated in 2003, using information from the enhanced water quality monitoring and small watershed modeling efforts to develop long-term reduction goals.

There are over 60 named tidal creeks, guts, and branches in Virginia's Eastern Shore Bay watershed. The majority has little flow beyond the influence of tidal waters. Of these 60+ creeks monitoring occurs on 23 sites on 12 creeks. An evaluation of the results of these various monitoring projects is presented in the Eastern Shore Coastal Basin Tributary Nutrient Reduction Strategy Report (November 1999). Unfortunately, the conclusions drawn from the review of this monitoring data were that the available information was insufficient to allow a comprehensive analysis of current status and trends in water quality and that a comprehensive water quality monitoring program for the Eastern Shore be developed and implemented so that in the future, nutrient and sediment reduction efforts can best be target to address specific water quality problems. There are no Chesapeake Bay Tidal Tributary Water Quality Monitoring Stations located in any of the Eastern Shore tidal creeks.

The Chesapeake Bay Program Water Quality Model (WQM) has been found to have little applicability to the Eastern Shore tidal tributaries. The basins and creeks are small with shallow depths and their features fall below the resolution for the WQM simulations. A Tidal Prism Model developed by Dr. Kuo and others at VIMS (Kuo et al.

1998) was therefore applied to several small tidal tributaries including Cherrystone and Hungars Creeks on the Eastern Shore in 1997. This model is based upon tidal flushing, which is the primary factor in the dynamics of these small coastal basins and simulates nutrient and sediment loadings derived from land use types and amounts. As calibration for the Tidal Tributary model a total of 6 surveys of water quality measurements were made at three stations in each of the two creeks in 1997. These results indicated that water quality in the lower portions of the creeks is dominated by adjacent bay conditions but that the middle and upper portions of the creeks can be dominated by watershed loadings. The bi-monthly field data demonstrated inconsistent trends for nutrients although the concentrations of dissolved inorganic nitrogen and phosphorus were low on the sampling dates, however the data suggested that total suspended solids (TSS) might increase with distance landward. TSS concentrations typically exceeded the SAV requirements for growth to 1m depths in polyhaline areas and spatial distributions indicated that local sources, either from watershed runoff or shoreline erosion might be contributing to these high levels. Episodic or storm events may greatly increase the concentrations of both nutrients and TSS, yet little data is available to quantify this. The Tidal Prism Model does not yet have refined enough data on non-point source inputs (Land Use/land cover) as well as groundwater inputs to accurately characterize the effects of the individual watersheds on the tidal creeks and basin.

The principal living resource goal of the Eastern Shore Tributary Strategy has been to increase the abundance of SAV through the tidal creeks and embayments to historic levels. Analyses of historical photography for a few areas prior to the bay wide declines of SAV in the early 1970s (Orth and Moore 1983) indicated that SAV abundance in the region declined less than regions in the upper bay and western shore tributaries. However precise estimates of historical distribution and abundance prior to 1974 are not well known. Targets for SAV recovery have, however, been set based upon 1974-1991 measured abundances (Tier 1), growth to 1m depths (Tier 2) and growth to 2m (Tier 3). Both Tier 1 and 2 targets are estimates that generally do not include factors other than depth (such as substrate type, exposure, epiphyte loads, etc.) that may have limited SAV distribution historically. By June 2002 EPA CBP-funded analysis of aerial photography dating to the 1930s will be completed and this information will be used to set modified Tier 1 targets as part of a bay wide historical use analysis. These mapped distributions will provide useful goals to evaluate the potential for SAV recovery in the Eastern Shore tributaries.

Since the lack of SAV recovery to historical levels in the Chesapeake Bay system have been related to insufficient light available for plant growth and propagation (Orth and Moore 1983; Moore et al. 1996a, 1997), factors which directly or indirectly reduce available light have been the focus of management efforts. Watershed inputs of dissolved and particulate matter can directly reduce underwater light levels. Dissolved and particulate nutrient enrichment can promote the growth of algae and phytoplankton that can shade and smother rooted SAV. Therefore monitoring of the levels of these constituents at relevant spatial and temporal scales can provide insights as to both the specific factors that may be limiting SAV recovery and watershed management efforts that may be necessary to reduce these levels.

The objectives of this enhanced monitoring plan are to provide the additional long-term data necessary to evaluate the linkages between habitat conditions and existing SAV distributions and identify those factors that appear most limiting for SAV growth to historical levels. In addition, monitoring is suggested that will permit evaluation of differences in SAV habitat conditions that may be related to efforts to reduce watershed nutrient and sediment loadings.

Baseline Monitoring

A baseline-monitoring program has been developed that focuses on measurements of specific physical and biological water quality characteristics that can be directly related to the evaluation of submerged aquatic vegetation (SAV) water quality habitat conditions. This data will be used to develop an understanding of the spatial and temporal patterns of water quality in selected creeks that are representative of a range of Eastern Shore bayside watershed conditions. This monitoring data can then be used as input to “diagnostic” models developed by EPA to quantify limiting factors relative to SAV survival. The baseline monitoring should be continued for a period of at least three years in order to evaluate the overall spatial and seasonal patterns of water quality in the creeks systems. Additionally the data can be used, along with improved water shed monitoring, to calibrate a tidal prism model for each creek system. Based upon the results of the baseline monitoring it may be possible to reduce the sampling to fewer stations per creek system (including possibly existing DEQ WQ monitoring stations) that can serve as indexes of water quality throughout the individual systems.

Creek Selection

The Eastern Shore Tributary Strategy has set a goal of increasing monitoring at least 3 monitoring stations on five different creeks. Three stations per creek placed in the upper, middle and lower reaches would likely provide good measures of water quality conditions near the watershed inputs (upper), historical SAV limits (middle) and bay influenced areas (lower). To help select the creeks to be monitored a matrix was developed comparing historical SAV changes, availability of past water quality monitoring data, watershed land use, development pressure, presence of aquaculture and location of point source (NPDES permit). Based on the combination of these factors the following five creeks were selected: Chesconessex Creek, Onancock Creek, Occohancock, Hungars Creek and Old Plantation Creek. Because of increased development pressure and to ease the timing constraints of logistically sampling each creek in one day within the same tidal phase, Cherrystone Creek was added to this list. For budgetary purposes (Pers. Comm. E. Brown, DCR) the list has been divided into a southern creek group (Hungars Creek, Cherrystone Creek and Old Plantation Creek) and a northern creek group (Chesconessex Creek, Onancock Creek and Occohancock Creek). Monitoring should begin with the southern creek group due to its intense development pressure and expanded to include the northern creek group when additional funds become available. Monitoring should continue for a minimum of three calendar years.

This monitoring data should be analyzed to compare the concentrations of the various constituents across time and space using 2-way repeated measures ANOVA. Seasonal trends over time can be compared using Kendall's Rank correlation. Additionally, the nutrient, chlorophyll and TSS data should be used to predict the Percent Light through the Water (PLW) and Percent Light at the Leaf surface (PLL) that would be available for SAV growth (Batiuk et al. 2000). These values would then be compared with the defined habitat requirements for polyhaline SAV growth.

Station Specifications

- Nine fixed stations should be located on the southern creek group.
- Each creek should have three stations, one at the mouth, mid-length and head.

Sample Specifications

- Surface samples should be collected mid-channel during a three-hour period before flood tide. This will insure maximum watershed inputs.
- A minimum of two replicate samples per station should be collected during each sampling cycle.
- Bi-weekly samples should be collected during the polyhaline SAV growing season (March – November). Monthly samples should be collected December through February.
- If there is insufficient funding for sampling in all six creeks the northern group should be sampled quarterly at least one mid-length station in each creek until the more intensive sampling can be started.

Water quality parameters to be measured at the fixed stations.

- Dissolved nitrite + dissolved nitrate
- Dissolved inorganic phosphorus
- Dissolved ammonium
- Dissolved total nitrogen + phosphorus
- Phytoplankton (chlorophyll-a + phaeophytin)
- Suspended sediments

Water Constituents and Properties - determined at each site at time of sampling – ½ meter intervals to the bottom by Hydrolab Datasonde or equivalent

- Depth
- Temperature
- Salinity
- Dissolved oxygen
- pH
- Turbidity (secchi)

Pulsed Monitoring

As evidenced by the study of Kuo et al. 1998, the episodic inputs of nutrients and sediments can be significant stressors affecting SAV recovery in the Eastern Shore creek systems. Rainwater-triggered sampling devices (ISCO, Inc. or equivalent) should be deployed at least seasonally after rainfall events in an effort to quantify the magnitude and duration of pulsed inputs from surface run-off in each creek system at the principal headwater. Following a rainfall event, 24 sequential samples should be taken at pre-programmed, 2 hr. intervals. Each of the parameters measured at the fixed stations should be measured. These data can then be used to evaluate the comprehensiveness of the baseline monitoring as well as to quantify the duration and intensity of water quality conditions due to short-term events. Additionally these data can be used to compare the short-term responses of the different watershed/land use characteristics to episodic events. This monitoring should be undertaken for a minimum of two years in each of the creek systems.

Groundwater Monitoring

Groundwater can be a significant component of nutrient input into the creek systems. While some groundwater monitoring has been undertaken in some Eastern Shore watersheds most studies are site specific, therefore groundwater sampling in connection with the enhanced tidal creek water quality sampling should be undertaken. Two approaches should be employed to estimate groundwater contributions to nutrient loading in the creeks. One involves the use of land-based groundwater wells within the watersheds to determine groundwater heights and nutrient levels. The other attempts to estimate inputs directly through stream base flow into the creeks. Each approach has its limitations and the combination of the two provides the best estimate in the context of limitations of the monitoring program.

Groundwater Wells

Over 75 groundwater wells have previously been established in Cherrystone Inlet, but many will require servicing to get them functional. At least nine groundwater wells in each of the other watersheds should be developed. These wells should be monitored for water table height monthly and nutrient contents measured quarterly. In the Cherrystone Inlet watershed monitoring water table height should be measured in all of the wells should be undertaken, but only nine selected for nutrient monitoring. For the other two watersheds in the southern creek group (Old Plantation and Hungars) and eventually the three northern creek group watersheds (Chesconessex Creek, Onancock Creek and Occohancock Creek) nine wells should be established and sampled for water table height and water quality constituents as above.

Water quality parameters measured at groundwater stations.

- Dissolved Nitrite + dissolved nitrate
- Ammonia

- Dissolved total nitrogen + phosphorus
- Salinity (conductivity)
- Dissolved inorganic phosphorus
- PH

Base Flow

Surface base flow should be measured throughout each of the watersheds at four to five locations selected after review of surface water hydrology. At each location base flow water quality parameters listed below should be sampled quarterly at least 96 hours after a rainfall event.

Water quality parameters measured at base flow locations.

- Dissolved Nitrite + dissolved nitrate
- Ammonia
- Dissolved total nitrogen + phosphorus
- Dissolved inorganic phosphorus
- Salinity (conductivity)
- pH
- Flow velocity
- Cross-section of drainage basin

SAV Mapping and Surveys

Documenting a clear picture of past, existing and future SAV abundance is an important component necessary in assessing the living resource goals of increasing the areas and density of SAV throughout the Eastern Shore coastal basins. Additionally, comprehensive annual aerial photography of the bay watersheds is needed to develop land use cover information for local planning as well BasinSim and Tidal Prism modeling. Currently SAV aerial mapping is undertaken in June of each year by VIMS as part of the bay wide SAV mapping program and the results including maps and summary information such as bed area and density classification are available in a web-based database (see <http://www.vims.edu/bio/sav>). The photographic coverage of these over flights should be extended to include all of the Eastern Shore watersheds and the photographs provided in digital format. VIMS, Farm Service Agency (FSA) and the Eastern Shore Geographical Information Systems (GIS) committee should accomplish this through coordination of existing efforts. SAV ground survey information included in the annual surveys has been gathered bay wide for many years by a network of sources ranging from citizens to academic and governmental professionals. The Chesapeake Bay Foundation has provided training and field orientation of SAV ground surveys and these should be supported for the Eastern Shore region. For the most part, because of the relative high salinity waters in these creeks, only three species of the over 20 species that occur in the Chesapeake Bay are likely to be found in this region. Therefore, ground survey information are somewhat less important here than in other bay regions in defining SAV presence and community type.

Beginning in July 2001 historical (1930s to 1950s) photography will be reviewed and historical SAV bed areas quantified and provided in a digital format similar to the current annual SAV survey information. This project will be completed in June of 2002 and the results should be used to set revised interim goals for SAV recovery in the Eastern Shore coastal basin region.

Citizen Participation

One objective of the Tributary Strategy was to demonstrate that water quality in tidal creeks could be improved by integrating scientific research with community involvement through the cooperation and work of citizens and state and local agencies.

Access and Sampling

During the first year landowners adjacent to the creeks should be contacted informally to request their involvement with the monitoring project. When appropriate, landowners should be asked if they would be willing to:

1. Grant permission to access a sampling site from their property on a regular basis.
2. Record rainfall data on a regular basis.
3. Sample and document direct inputs to the creek after rainfall events.
4. Provide access for deployment of ISCO remote samplers for the collection of sequential samples timed to rainfall events.

Landowners' observations of inputs to the creek, storm water runoff and historical changes in land use or water quality are valuable at this stage. Throughout the monitoring project, staff carrying out the monitoring work should keep in contact with the landowners and insure that they have proper data sheets and sampling equipment.

Epiphyte Monitoring

Epiphyte fouling of the leaves of SAV is an important factor affecting the light availability to the plants. Growth of epiphytes, like phytoplankton in the water column can be related to excess nutrients in the system. In addition to nutrients, however, there are a number of factors that affect the accumulation of epiphytes on existing SAV, SAV seedlings or SAV transplant that are attempting growth in an area. These include: the availability and activity of invertebrate grazers such as snails and amphipods that remove the epiphytes, and the turbidity of the water, which reduces light for epiphyte growth. Currently there are several models (Batiuk et al. 2000) that are used to estimate the growth of epiphytes, but they are weakly calibrated. Monitoring data is needed to evaluate the actual fouling that is occurring in the creek systems and how this fouling relates to the nutrient availability and turbidity in the system.

In order to assess the light attenuation potential of epiphytic growth on the leaves of SAV, artificial substrata in the form of thin strips of Mylar® polyester plastic should be deployed at shallow (1 m MLW) water locations near the creek baseline water quality monitoring stations. The strips should be retrieved on at least bi-weekly intervals during the SAV growing season (April – November), placed in plastic Ziploc® bags, labeled, and frozen until the epiphyte accumulations are removed for analysis. Epiphyte strip sampling should occur within 2 days before or after the Baseline water quality sampling dates

The epiphyte fouling strips (2.5 x 51 x 0.7 cm in size) should be attached at one end to a submersed PVC collector frame filled with steel rebar to allow it to remain flush with the sediment surface. Small floats should be attached to the top of each strip to allow them to freely float vertically in the water column. Each frame will have 4 strips attached with 3 selected for sampling at each sampling interval. After removal and placement in Ziploc® bags all 4 strips will be replaced with new Mylar® and the frame replaced.

Mylar® strips collected should be measured for total suspended solids and total volatile solids. The individual strips should be scraped of all material and rinsed with distilled water. The scraped material should be diluted to a fixed volume (400-500 ml). This volume should be mixed thoroughly on a stir plate and a small aliquot (10-50 ml) extracted with a pipette and filtered through a pre-weighted 47 mm 0.7 um (GF/F) glass fiber filter. The filters + epiphyte should be dried at 50 °C, weighted and combusted at 550 °C.

To facilitate this phase of the study, citizen volunteers should be recruited to deploy and retrieve the Mylar® test strips. To assure QA/QC of the epiphyte monitoring project the volunteers should be trained and a methods manual developed following the established sampling and custody procedures.

Monitoring Plan Priorities of Tasks

Because of the availability of FY 2001 funding through DCR for limited monitoring the Eastern Shore Tributary Strategy Team met several times in 2001 and earlier drafts of this document were provided to them for discussion. Of the enhanced monitoring objectives the following was the priority assigned to the various tasks in order of rank.

- Task 1 Initiation of a bi-weekly Baseline Monitoring Program in the southern creek group for a minimum of three years with quarterly monitoring in the northern group.
- Task 2 Seasonal pulsed monitoring at headwater stations in each of the southern creek group.
- Task 3 Citizen involvement through epiphyte monitoring for the southern creek group.
- Task 4 Seasonal groundwater and surface monitoring for the southern creek group.

- Task 5 Expansion of 1, 2 and 3 for the northern creek group.
- Task 6 Data summarization, analysis and evaluation of enhanced monitoring data
- Task 7 Continuation of SAV mapping and historical surveys for all of the creeks systems including collection of ground survey information.
- Task 8 Expansion of aerial photography coverage for the watershed areas not covered in the annual SAV surveys.
- Task 9 Implementation of longer term (5-10 year) consolidated water quality monitoring stations within each of the creek systems.

Monitoring Plan Costs

A budget for monitoring tasks 1, 2, 3 and 4 has been developed and a study was initiated beginning in January 2001 by VIMS with. Costs were determined to be \$45,000 excluding indirect cost. Based upon these cost estimates as well as existing costs for the annual SAV aerial survey the following are annual estimates for the different tasks:

| | |
|---------------|--|
| Tasks 1, 2, 4 | \$40,000 |
| Task 3 | \$5,000 |
| Task 5 | \$50,000 |
| Task 6 | \$35,000 |
| Task 7 | \$10,000 (Includes 1 B&W print of each frame and ground survey) |
| Task 8 | \$3,500 (Includes 1 B& W print of each frame) |
| Task 9 | \$30,000 (costs dependent upon whether new or existing sampling sites can be used) |

II. JAMES RIVER TRIBUTARY ENHANCED MONITORING PLAN

Introduction

The James River in Virginia has been the focus of intense efforts from federal and state agencies, academic and research institutions such as VIMS and many bay partners, to develop and implement effective management strategies for the restoration of living resources such as SAV to former levels (Moore et al 1999). The James River basin's population in 1990 was nearly 2 million and expected to grow another 8 percent by the 2000. The basin's population comprises about 42 percent of Virginia's Chesapeake Bay watershed population, and roughly one-third of the state's total. Except for a small drainage area in West Virginia, the James River watershed is located almost entirely within Virginia. The river, which is 450 miles long, drains 10,102 square miles, one-fourth of the state's land base and 47 percent of Virginia's bay basin. Land use in the river's basin varies considerably from its headwaters to its mouth. Overall, about 71 percent of the land is forested, 23 percent is agricultural, and 6 percent is urban.

The document, *Initial James River Basin Tributary Nutrient and Sediment Reduction Strategy* published in 1998 did not contain specific restoration goals. Following new model data generated by the Chesapeake Bay Water Quality Model, a James River basin Technical Review Committee subsequently met for the purpose of defining specific restoration goals.

Although consensus restoration goals for nutrients and sediments were not realized, high sediment load in the tidal James and its effect on growth and recovery of SAV was identified as a critical problem. The *Initial James River Basin Tributary Nutrient and Sediment Reduction Strategy* (1998) emphasized restoration of water quality to "levels suitable for SAV survival and growth" in the lower tidal river. A special study conducted by VIMS indicated that historically SAV beds existed in the upper tidal portion of the river and in fact acreage recently identified in the Chickahominy in fact exceeded Tier 1 SAV goals (Moore et al. 1999). Although high suspended solids in the tidal portion of river may not be conducive to SAV recovery, reduced light penetration can be viewed as positive in the sense that algal production may be light limited. Compared to other tributaries low dissolved oxygen levels do not appear to be a problem in the James River. The James is not considered to suffer from "typical" water quality problems associated with nutrient enrichment.

Monitoring data to characterize water quality in the mainstem James River and its associated tributaries (Appomattox, Chickahominy, and Elizabeth Rivers) are collected at a total of 21 stations. Parameters include total nitrogen, dissolved inorganic nitrogen, total phosphorus, and dissolved inorganic phosphorus, chlorophyll *a*, total suspended solids, Secchi depth, and bottom dissolved oxygen. Samples are collected as grab samples at regular intervals at fixed locations.

Currently there are several ongoing SAV restoration projects in the James River ranging from formerly vegetated areas that have been planted with high salinity seagrass species

in Hampton Roads, to areas planted with freshwater submerged aquatics in the Hopewell region. In addition, beds of remaining native SAV have been observed in tributary creeks in the middle reaches of the tidal river in the vicinity of the Chickahominy River. Although, water quality parameters are monitored in mid-channel areas along the axis of the river as part of the Tributary Water Quality Monitoring Program as well as selected shallow water areas, the spatial distribution of SAV-related water quality constituents (water clarity and phytoplankton or chlorophyll *a* concentration) that have the greatest effect on SAV survival are poorly understood.

Goals established for the James River were recently published in a document entitled *Tributary Strategy, Goals for Nutrient and Sediment Reduction in the James River Public Comment Draft January 2000*. These goals included annual reductions in nitrogen and phosphorus nutrient loadings and reduced sediment loading. Specifically, the document identifies a sediment reduction goal as "...9% sediment reduction from the levels that existed in 1985 for the entire basin by the year 2010." This will be achieved by application of BMPs and sediment erosion prevention techniques.

Improved water quality may promote: (a) restoration of SAV, (b) a larger recreational fishery, (c) grass-stabilized shorelines, (d) grass-mediated nutrient removal, (e) reduced levels of algae, and (f) desirable fish species.

During presentations and subsequent ad hoc discussions at the first James River Watershed Roundtable, both SAV restoration and the importance of water clarity were identified as important technical issues warranting enhanced monitoring and perhaps special studies. Water clarity in particular, and its contributing components was an issue of particular interest. Concerns related to the specific contributions of algal (chlorophyll *a*) and TSS inorganic materials to water clarity, the role of dynamic sediment resuspension processes on water clarity, and the relationship between nutrients and water clarity in the lower James were mentioned. Most of these concerns cannot be addressed without enhanced monitoring/special studies.

The continuing development and implementation of the Commonwealth of Virginia Tributary Strategies, recent 303(d) listing of the Virginia region of the Chesapeake Bay and its tributaries as degraded water, the development of water quality "Endpoints" for turbidity, chlorophyll, and DO, as well as the potential for change in the CBP water quality monitoring program procedures have placed increased emphasis on accurate measurements of the temporal and spatial variability of water quality constituents. Temporally intensive water quality studies (e. g. Moore et al. 1995, 1996b) in vegetated and unvegetated shallows and adjacent channel areas in the bay have demonstrated that differences in water quality between the two can be significant. In addition, predictions of SAV transplant growth and survival using the closest available mid-channel, water quality monitoring data, can have poor success (Batiuk et al. 1992). Our understanding of the spatial variability of water quality constituents especially between channel and shoal regions and how this variability is related to SAV in the James remains incomplete.

Identification of enhanced monitoring needs

An important aspect of the James River tributary strategy implementation will be to develop long-term nutrient and sediment reduction goals. These goals will be implemented through the application and development of:

- Cost effective erosion control, sediment and water quality improvement plans
- Controls on point sources
- Land use regulations
- Citizen support

Enhanced monitoring will be needed to assess if these activities are eliciting corresponding improvements in SAV recovery and re-growth and water clarity. Current monitoring by “grab” or “snapshot” sampling using fixed main stem stations and monthly sampling regimens does not provide water quality data at sufficient spatial and/or temporal resolution to evaluate attainment of tributary strategy goals.

Present monitoring efforts provide insufficient data in shoal areas critical to assess SAV recovery. Main stem stations are inappropriate for this purpose because SAV do not grow in mid-channel locations and water quality measurements in the main stem channel can be quite different from that in the shoal littoral areas that are potential habitat for SAV (Batiuk et al. 1992, 2000). Recent surveys conducted by VIMS suggest SAV distributions in the Chickahominy are located along the entire axis of the tributary, but there can be significant variability in abundance for year-to-year (Orth et al. 2000). Therefore, a single water quality station at the mouth as currently exists is inadequate to assess relationships between water quality and Chickahominy SAV distributions. Two additional water quality stations should be added in the Chickahominy near the middle and at the headwater near the dam. Assuming that Chickahominy water quality represents conditions supportive of SAV growth, the additional station coverage could help identify and understand the nature of water quality characteristics supportive of SAV growth in the oligohaline James River. These additional longitudinal transect stations in the Chickahominy would also be useful to assess if the river is a source of nutrients to the James. Because water quality conditions in the Chickahominy support SAV growth, the James River Watershed roundtable may wish to propose the Chickahominy as a “SAV water quality reference area.” A focused effort to understand water quality conditions in the “water quality reference area” could disclose which water quality or associated factors promote SAV growth and survival.

Another important concern in the tidal reaches of the James relates to total suspended solids (TSS) and their effect on water clarity conditions essential for SAV. Turbidity has not been routinely monitored in the James River and the relationships between turbidity, chlorophyll a and TSS should be determined. Such information could potentially provide answers to the question of how water clarity is affected by re-suspension of sediment particles vs. phytoplankton. Data collected in an HRSD pilot SAV monitoring program in the lower James River (William Hunley, personal communication) have shown that

there are distinct differences between water clarity and the relationships between water clarity and the various water quality constituents that affect water clarity when shoal and mid-channel areas are compared. HRSD studies implicate re-suspension of sediment in shoal areas rather than chlorophyll *a* may be the dominant factor contributing to light attenuation there.

Enhanced Monitoring Objectives

Given the discussion above the following objectives have been identified to support enhanced monitoring:

1. Establish a comprehensive monitoring program to assess the effectiveness of management efforts.
2. Improve *spatial and temporal* coverage of important water quality parameters, e.g., Chlorophyll *a*, Turbidity/water clarity/TSS, Physical/chemical data.
3. Identify and continue to map existing SAV habitats to establish a baseline in order to measure restoration.
4. Evaluate current monitoring programs for effectiveness: station locations, methods and needs.
5. Establish a formal technical committee within the James River Watershed Roundtable composed of watershed stakeholders, regulatory and scientific personnel. Tasks for this committee could include the review of enhanced monitoring recommendations and approaches, providing guidance and recommendations to the Roundtable, and facilitating communication. This is a *critical* need as there is currently no formal committee to discuss monitoring needs, results, consideration of special studies (such as HRSD), and to identify and recommend (to the Round Table) items for financial support.

Factors to Consider in Development of an Enhanced Monitoring Program

A program of enhanced monitoring for the James River should be designed to address both suspended sediment and SAV concerns as highlighted by the Technical Review Committee and the James River Watershed Roundtable. It is assumed that monitoring for nutrients and physical parameters will be continued as part of the overall monitoring program. Enhanced monitoring for SAV and sediment loading will focus on all regions of the tidal portion of the James.

Factors involved in development of enhanced monitoring should consider:

- a. Variability of water quality conditions in space and time- monthly interval grab samples is inadequate because the time scales of important biological, physical and chemical processes occur over shorter duration periods. Water quality

characteristics of mid-channel stations may not reflect water quality conditions in littoral zone where SAV grow.

b. Importance of short-lived or episodic events on water quality- severe weather or storm events can contribute very significantly to annual nutrient budgets, change physical conditions, alter biological communities and produce long-term environmental effects. Monitoring approaches must be capable of detecting episodic events.

c. Influence of selected water quality parameters, especially components of water clarity in shoal areas (<2m contour) on SAV habitat quality.

d. Factors other than water quality that can influence SAV status, e.g., sediment re-suspension, poor substrate (high organic content), poor recruitment and herbivory.

These requirements dictate increased station coverage as well as more frequent sampling. Both needs can be met using technologies that offer remote and continuous recording data buoys and vessel-based systems facilitating large areal coverages.

Proposed Enhanced Monitoring Program

Increase station coverage- The requirement for extended spatial and temporal coverage, especially in shoal regions should be met through the use of additional fixed stations located at strategic places chosen through an analysis of SAV distributions and proximity to sub-estuaries such as the Chickahominy or Pagan rivers.

a. Establish one shoal station on each side of existing mid-channel stations in each of the three regions of the tidal James River, i.e., Hampton Roads Region (segment JMSPH), Chickahominy River Region (segment CHKOH), Hopewell Region (segment JMSTF). These littoral zone stations will also anchor the river transects described below. Additional coverage can be obtained using the Surface Mapping System (SMS) described later in this document.

b. Establish two new stations in the Chickahominy River, one upstream and downstream of the existing station (RET 5.1A). These stations will provide points to measure gradients of water quality parameters in a region now supporting SAV. Gradient data also will be useful to assess if the Chickahominy is a source or sink of nutrients and sediments.

Depending on budget availability, these stations could be sampled using traditional grab sampling. For improved temporal resolution especially following episodic events, fixed continuous recording sondes such as those manufactured by Yellow Springs Instruments could be deployed at selected shoal stations and in the Chickahominy to continuously monitor temporal variations in chlorophyll *a*, turbidity, DO, °C, psu at multiple depths (diurnal, neap/spring cycles, episodic events) at selected locations. New YSI sensors are

now available to measure turbidity and chlorophyll *a*. High frequency turbidity measurements coupled with parameters such as wind speed and current movement would provide data to assess whether physical re-suspension is an important component of water clarity. Access to segment specific weather station data would be required and a weather station equipped to measure precipitation and wind speed should be deployed. Hybrid systems using sondes and buoys capable of vertical profiling can now provide remote data on water structure.

Remote sensing technologies could also be used at selected stations above the fall line where USGS or other gauging stations are located. For example, deployable automated buoys capable of measuring nitrate in situ are now available. Both USGS and DEQ should collaborate to determine if existing stations now capture dominant sources of nutrients.

Improve spatial coverage of surface shoal and mid-channel water quality data using a Surface Mapping System (SMS)

Until recently our capacity to measure, monitor, and evaluate water quality constituents in detail over ecologically relevant regions was limited. Currently Maryland, through the Chesapeake Biological Laboratory is employing a new state-of-the-art “Dataflow” surface water quality mapping system for high speed, high resolution mapping of surface water quality from small vessels capable of sampling shoal, littoral areas. Such a mapping system can have practical application in the analysis and interpretation of data from the ongoing Chesapeake Bay Program water quality monitoring program as well as the evaluating the results of ongoing SAV transplantation studies. Use of the SMS will allow us to ask how variable water clarity is in various regions of the tidal James.

- a. Assemble and validate a small vessel SMS designed to measure water quality parameters such as conductivity, turbidity, fluorescence, temperature, and DO.
- b. Assess instrument calibration and relationships between SMS turbidity and water clarity as determined by both Secchi depth and light attenuation (K_d).
- c. Establish a regular monitoring program along selected longitudinal and lateral transects, originating from shoal areas where SAV grow, using a ‘Dataflow’ system for maximum spatial coverage of water quality parameters. This system will allow for correlative analyses of SAV distribution with physical/chemical water quality characteristics. Variables measured would include fluorescence, turbidity, DO, and salinity. At selected locations along each transect discrete sampling for TSS, Secchi depth, and light attenuation will be performed.

At this time we propose one transect will be located in each of three regions of the tidal James River: Hampton Roads Region (segment JMSPH), Chickahominy River Region (segment CHKOH), Hopewell Region (segment JMSTF). Actual transect locations can change based on current data. Using the SMS transects are actually “saw tooth” shaped

and provide better coverage than linear transects. Transects should originate in the shallow littoral areas across the channel to the channel or to the opposite shore and then are repeated longitudinally. Transects should be initially run during the months of April through October at two week intervals and at monthly intervals from November through March. Sampling will be conducted using the SMS and sampled for DO, turbidity, fluorescence, salinity, temperature, and depth. Station locations will be determined and logged as GPS coordinates. In addition, during the spring, summer and fall repeated mappings should be taken under various climatic and tidal conditions. At a minimum 8 specific locations in mid-channel and shoal areas exhibiting a range of water clarity conditions should be sampled for chlorophyll *a*, Secchi depth, light attenuation, selected nutrients and TSS during each SMS run. Turbidity and in situ fluorescence measurements obtained using the SMS will be compared to grab sample data to assess how well SMS measurements predict grab sample data and to estimate the error if SMS measurements are interpolated across transects.

Water clarity should be measured with a Secchi disk as well as profiled using a Li-Cor 192-S downwelling sensor. The downwelling attenuation coefficient (K_d) can then be calculated according to Beer's Law. Total suspended solids should be determined by filtration, chlorophyll *a*, ammonium and orthophosphate by spectrophotometric methods, nitrate and nitrite by autoanalyser. Grab samples should be collected at intervals to evaluate relationships between turbidity and other parameters indicative of water clarity and to assess which parameters best predict water clarity.

There are other unique analytical and data analysis issues related to use of an SMS. These include methods of data reduction, establishing the validity of turbidity calibration curves when applied to natural water samples, and assessing whether turbidity can be used as a statistically significant surrogate of water clarity. Addressing these questions will require preliminary field surveys using the SMS or other advanced methods for high frequency data collection.

Examine the relationship between water clarity, suspended solids, and chlorophyll *a*

Total suspended solids have a primary direct affect on SAV growth through light attenuation (water clarity) in the water column and a secondary affect because epiphytes and suspended solids can foul leaf surfaces. Improved water clarity is essential to restoration and continued growth of SAV beds. A central question relates to identifying and understanding parameters affecting water clarity in the tidal James River. Is reduced water clarity the result of increased planktonic biomass or it is caused by river born sediments as well as channel erosion and re-suspension of bottom sediments? Or are both components biogenic and inorganic components important? And how do they vary over different time scales? Re-suspension can be driven by daily tidal currents or over time scales associated with high winds and episodic storm events. These questions can be addressed using an SMS and temporal relationships examined through deployment of continuous recording fixed datasondes.

- a. Install at selected shoal locations in each of the three tidal river segments continuous recording fixed datasondes equipped with sensors to record turbidity and chlorophyll *a* concentrations.
- b. In conjunction with SMS surveys collect grab samples at selected locations along transects to determine TSS and chlorophyll *a* concentrations.

By monitoring turbidity and chlorophyll *a* using remote high frequency data recorders at fixed locations it is possible to identify to extent to which transient physical factors contribute to water clarity and K_d . SMS turbidity values can be compared against actual turbidity, TSS, and chlorophyll *a* concentrations in selected grab samples collected over the transects described above and values of turbidity plotted vs. TSS and chlorophyll *a*, to evaluate the relative contribution of each parameter to water clarity (Secchi and K_d). High frequency recording datasondes will provide time-dependent records of turbidity and chlorophyll *a* concentrations. Turbidity values can be related to meteorological parameters such as precipitation and wind speed. A dedicated local weather station should be installed in the tidal portion of the James River to obtain the necessary local data.

Enhance SAV Monitoring and Assessment

Documenting a clear picture of past, existing and future SAV abundance is an important activity necessary in assessing the living resource goals of increasing the areas and density of SAV throughout the James River tributary. Currently SAV aerial mapping is undertaken in June of each year by VIMS as part of the bay wide SAV mapping program and the results including maps and summary information such as bed area and density classification are available in a web-based database (see <http://www.vims.edu/bio/sav>). Photographic coverage of these overflights should include all of the shoreline regions in the James that have been documented as historically supporting SAV growth. Recently a study by VIMS funded by EPA quantified and mapped the historical distribution of SAV in the James River region through the use of archival aerial photography (Moore et al. 1999). This study demonstrated that in the freshwater tidal regions of many of the small tributary creeks where SAV currently are growing, SAV beds are frequently too small and scattered to be evident from the small scale (high altitude, 1:24,000 scale) aerial photography used in the annual bay wide surveys. However, SAV ground survey information included as part of the annual SAV abundance reports (e. g., Orth et al. 1999) has been gathered bay-wide for many years by a network of sources ranging from citizens to academic and governmental professionals. The Chesapeake Bay Foundation (CBF) has provided training and field orientation of SAV ground surveys by citizen volunteers and these efforts should be supported for the James River regions. Such surveys are best accomplished using pre-organized, comprehensive plans for specific regions of the river system. Many times freshwater or low salinity SAV are not directly evident from the water surface and therefore raking of the bottom at regular intervals will provide both positive and negative information as to SAV presence. Species identifications should be made by trained individuals and voucher specimens collected for verification of species identification by professionals. Typically, data collected includes: GPS location, water

depth, bottom type, species identification, species abundance. Appropriate methodologies are described in Moore et al. (2000). These data should be collected and tabulated by the organizing group (e. g., CBF) and provided to VIMS for inclusion in the annual SAV report summaries. Finally, because of the availability of citizen assistance, it may be useful to incorporate epiphyte studies into these surveys through the use of monitoring films.

Prioritization of Recommended Monitoring Tasks

- | | |
|--------|--|
| Task 1 | Increased station coverage (continuous monitoring sondes at 3 shoal stations in each river segment and one Chickahominy location). |
| Task 2 | Examine the relationship between water clarity, suspended solids, and chlorophyll <i>a</i> (including weather station). |
| Task 3 | Improve spatial coverage of surface shoal and mid-channel water quality data using a Surface Mapping System (SMS). |
| Task 4 | Enhanced SAV monitoring and assessment. |
| Task 5 | Develop and test data analysis and interpolation methods (hire data analyst). |

Estimated Costs

- | | |
|--------|-----------------------------|
| Task 1 | \$40,000 |
| Task 2 | \$15,000 |
| Task 3 | \$26,000 + analytical costs |
| Task 4 | \$15,000 |
| Task 5 | \$50,000 |

III. YORK RIVER TRIBUTARY ENHANCED MONITORING PLAN

Introduction

The York River watershed encompasses 2662 mi² and is the fifth largest tributary basin to the Chesapeake Bay. The York River is formed by the confluence of the Pamunkey and Mattaponi Rivers. Both river sub-basins are located within the Piedmont and Coastal Plain physiographic provinces; however a larger percentage of the Mattaponi sub-basin is within the Coastal Plain. Both watersheds are characterized by low relief and by large inventories of freshwater marshes and lowland, hardwood swamps, which tend to buffer the rivers from human-induced disturbances (Sprague et al, 2000; Mills, 2000).

The predominant land use in the York watershed is forest, which as of 1996 ranged from 67 – 69% coverage of the watershed. The 2nd most common land use was agriculture, ranging from 23 – 24%. Urban area ranged from 5% in the lower York to 8% in the central York and 7% in the upper York regions (Va DCR, Va. DEQ, Va CBLAD, 2000). Because of its relative isolation from metropolitan areas the York remains one of the least impacted rivers on the east coast of the U.S. However, there are telltale signs that urban/suburban growth is infringing upon the watershed. In the upper York, along the shorelines of Lake Anna forested areas are being converted to residential lots. Some of the largest land use changes are occurring in the central York region in the vicinity of Fredericksburg and Ashland and along the Route 1 and I-95 corridors. In West Point at the confluence of the Pamunkey and Mattaponi plans to construct high-volume replacement bridges over the Pamunkey and Mattaponi rivers are likely to increase traffic flow and population density between the Richmond-Williamsburg and the Northern Neck areas. Land use changes in the lower York are likely to accelerate due to increasing population pressures from the counties of York, Gloucester, and James City, which are among the fastest growing in the state.

Non-point sources contribute the majority of the nitrogen and phosphorus loads to the York River system. Results of Chesapeake Bay Watershed Model (WSM) simulations indicate that in the Pamunkey river sub-basin during 1998 agriculture contributed approximately 38%, urban areas 32%, forested areas 16%, and point sources 10% of the total nitrogen budget. In the Mattaponi River agriculture contributed 39%, septic tanks 7%, urban areas 32%, and forested areas 20% whereas point sources contributed approximately 1% of the nitrogen budget. Sources of phosphorus to the Pamunkey River sub-basin were agriculture (61%), urban areas (19%), forested areas (8%) and point sources (9%). In the Mattaponi sub-basin phosphorus sources were agriculture (67%) urban areas (19%), forested areas (5%) and point sources 5% (Sprague et al, 2000; Mills, 2000).

During the period 1985 – 1998 there were no significant changes in either loads or flow-adjusted concentrations of nitrogen and phosphorus to the Pamunkey river sub-basin. Similarly in the Mattaponi sub-basin there were no significant changes in the loads of total nitrogen and phosphorus although there was a significant downward trend in flow-

adjusted concentrations of these nutrients (Sprague et al, 2000; Mills, 2000). USGS has noted that groundwater supplies a significant portion of the nitrate loads to both the Pamunkey (19%) and the Mattaponi rivers (17%). During the period 1985 to 1998 nitrate loads in groundwater to the Pamunkey increased by 71 – 194% whereas groundwater nitrate loads to the Mattaponi did not show a similar increase.

The York River Tributary Strategy Plan states that the goal of the strategy is to *“reestablish York River habitat conditions, particularly dissolved oxygen and submerged aquatic vegetation, for the purposes of restoring fisheries and other living resources.”* The strategy suggests that because non-point sources are the major contributors of nutrients and because the York River watershed displays low relief and long residence times, the aggressive implementation of non-point source Best Management Practices (BMP’s) is likely to be particularly useful for nutrient and sediment load reduction. The Strategy Plan further suggests that the York system is at a stage in overall system degradation where small improvements in nutrient or sediment loads may result in large improvements in habitat suitability.

Re-evaluation of the plan, which is scheduled for 2002, will address the environmental endpoints developed in cooperation with the Chesapeake Bay Program. Successful accomplishment of endpoint goals will result in a de-listing of the York River from the impaired waters (303d) list. As stated in the York River Tributary Strategy Plan, tracking the progress toward accomplishment of specified endpoint goals and tributary strategies is likely to require enhancement of present monitoring programs.

Goals of an Enhanced Monitoring Plan for the York River System and its Watershed

Test technologies for enhanced monitoring of dissolved oxygen (DO) at fine temporal and spatial scales in the lower York River.

- A major goal of the Tributary Strategy Plan for the York River is improvement in dissolved oxygen levels in the lower York. In addition, it is likely that implementation of environmental endpoint goals for the Chesapeake Bay tributaries, which will shortly be announced by EPA, will require monitoring of DO in 5 different “designated use habitats”. Such monitoring will require modification of the monitoring approach currently being used in Virginia. Lowest DO values are typically observed below the pycnocline during mid-summer at stations WE4.2, LE 4.3, and occasionally at LE 4.2. Dissolved oxygen is known to vary depending upon the degree of stratification, which varies between neap and spring tides in the lower York. Monitoring of DO, given the degree of variability across spatial and temporal scales, will require more automated methods than are currently used.

Extended aerial and ground mapping of SAV in the tidal fresh and low salinity portions of the York, Mattaponi and Pamunkey Rivers.

- A second major goal of the Tributary Strategy Plan for the York is “---restoration of the habitat quality necessary to allow for the return of the middle and lower salinity SAV species to the middle river’s shallow water habitats.” Documenting a clear picture of past, existing and future SAV abundance is an important component necessary in assessing the living resource goals of increasing the areas and density of SAV throughout the York River tributary.

Monitoring of small watersheds in the Upper York region to accomplish the following goals:

- Determine the effectiveness of BMP’s on water quality in “impaired” watersheds.
- Quantify the relative inputs of nutrients from groundwater sources (base flow) vs. surface water runoff;
- Determine changes in water quality during low-flow vs. high flow periods. Scientists studying the Polecat Creek watershed has suggested that during periods of low flow dissolved oxygen may sharply decrease in some watersheds (Crafton, personal communication).
- Set the stage for TMDL implementation for “impaired” watersheds.

The York River Tributary Strategies Plan states that in a system such as the York where non-point sources predominate, implementation of BMP’s in the watershed will be critical to improving downstream water quality. We suggest monitoring of the following watersheds: Plentiful Creek in Spotsylvania County (upper York region), designated impaired because of fecal coliform; Mechumps Creek and Matadequin Creek, both in Hanover County (central York region), designated “impaired” because of fecal coliform and low pH. The York Watershed Council is currently performing rapid bio-assessments on all 3 creeks. This activity has been approved by the Virginia Interagency TMDL workgroup. Following bio-assessment, the York Watershed Council plans to convene landowners in the watersheds to recommend a suite of BMP’s. The local Soil and Water Conservation Districts will then prioritize the recommended BMP’s. This provides an excellent opportunity to assess the effectiveness of selected BMP’s by monitoring these watersheds both prior to and after implementation of BMP’s.

We further suggest that monitoring of these “impaired” watersheds be closely coordinated with studies currently being performed in the Polecat Creek watershed. Selected, ‘unimpaired’ watersheds in the Polecat system will provide useful comparison with the “impaired” watersheds proposed for the enhanced monitoring program.

Historical Dissolved Oxygen Data Set

Observation of DO data from the historic dataset demonstrates some of the problems associated with previous monitoring techniques and data analysis. DO data are shown for stations WE4.2 and LE 4.1 in the York River (Figure 1). A look at data for WE4.2 might suggest to the casual observer that there has been an improvement in DO in bottom water; however, note that since 1996 there is no summer data for depths below 9 meters. Figure 2 shows the variation in data recorded as Bottom Depth for WE 4.2 suggesting

that the position at which measurements were made shifted between sampling dates. Finally Figure 3 shows the regression between average summer bottom depth and average summer DO for WE 4.3. As one might expect DO is inversely proportional to bottom depth; thus during years when the bottom sampling depth was shallower, DO appears to have improved. It is essential for status and trend analyses that the sampling depth is fixed. Monitoring methods described below will remove the inaccuracy due to inconsistent sampling position.

Recommended Monitoring Program

Water Quality in the Lower and Middle York

- **Spatial variability: shallow water habitats** – This zone will include the habitat where SAV are presently and have historically been found and will extend from the mouth of the York to the tidal fresh portions of the Pamunkey and Mattaponi Rivers. The zone studied will parallel those areas in which SAV abundance will also be monitored (see below). It is recognized that in the York system the habitat condition, which has the major influence on SAV distribution and abundance in areas historically, vegetated is water clarity.
 - a. Water Properties Monitored: DO, Chlorophyll fluorescence, turbidity, depth, temperature, salinity, pH, location (GPS)
 - b. Monitoring Technique: Continuous Surface Mapper – the Surface Mapper is similar to that currently employed by Maryland DNR and includes a YSI 6600 Datasonde fitted with fluorescence, DO, pH, conductivity, and temperature sensors, GPS unit, depth sensor, and data-logger/computer. Water will be pumped via a ‘ram’ tube and pump attached to the transom of a boat from a depth of 0.5 m through a bubble stripping unit and then into a chamber in which the Datasonde sensors are located. The mapping can be done at speeds of approximately 10 – 15 mph.
 - c. Sampling Intervals – From April through October sampling will be performed near mid-day bi-weekly during neap and spring tidal periods. From November through March sampling will be performed monthly during spring tides.
 - d. Calibration of Surface Mapper – all sensors will be calibrated at the beginning and end of each riverine sampling run using standard techniques. In addition, chlorophyll *a* vs. fluorescence regressions will be developed for the polyhaline, mesohaline, and oligohaline portions of the system at monthly intervals by taking triplicate grab samples at 8 stations evenly spaced along each sector for determination of chlorophyll *a*. Similarly, regressions of turbidity, as measured by the YSI Datasonde sensor vs. attenuation

coefficient, as measured at 2 depths with a LiCor PAR sensor will be performed at the same stations as for chlorophyll fluorescence.

- Spatial Variability: Open Water, Deep Water, and Deep Channel Habitats
 - a. Water Properties Monitored: DO, salinity/conductivity, temperature, chlorophyll fluorescence, depth, GPS position.
 - b. Monitoring Technique: A towed undulating vehicle similar to W.S. Ocean Systems U-tow or Chelsea Instruments Scanfish fitted with DO, salinity, temperature, and fluorescence sensors. Data from the undulating vehicle must be logged along with GPS position and depth. The Scanfish has been used by Dr. Walter Boynton of the University of Maryland, Horn Point Laboratory for 3 cruises per year for 6 – 7 years to determine water quality profiles on cross-Chesapeake Bay transects. Towed undulating vehicles allow collection of depth profiles of various water quality parameters at high resolution both in vertical and horizontal planes.
 - c. Sampling Locations and Interval – Sampling will be performed at the same time intervals as described for the surface mapper but will be restricted to the lower York River (between fixed stations WE 4.2 and LE4.2, where low DO has been observed below the pycnocline.
 - d. Calibration of Undulating Tow Sensors – Sensors will be calibrated as described for the Surface Mapper. Grab samples for development of a regression between fluorescence and chlorophyll *a* concentration will be taken at 8 stations even distributed between WE 4.2 and LE 4.2.
- Temporal Variability– Deep Water/Deep Channel
 - a. Stations and Monitoring Technique - Two fixed stations will be established using moored buoys for continuous monitoring (15 minute intervals) of DO, salinity, conductivity, temperature at 1 m depth intervals at the mouth of the York River and near Gloucester Point. VIMS currently has several continuous monitoring systems operating in the Great Wicomico River. We recommend that YSI 6600 datasondes coupled to Campbell data loggers be used to collect data. The datasonde sensors will be kept out of the water to reduce fouling. The data logger can also be used to control pumping and rinse cycles.
 - b. Calibration – The datasonde will be replaced with a lab-calibrated system weekly, enabling cleaning and careful calibration of the sensors. The DO sensor will be calibrated by the Winkler

technique in water, equilibrated with the atmosphere and at constant temperature (25⁰ C).

- Data Analyses of High Resolution Data

Analyses of the large datasets that will be accumulated by the automated techniques described above will require development of new techniques. We recommend that initially measurements at the current fixed stations be continued along with the enhanced monitoring. Interpolation techniques must be developed that allow use of the historic water quality dataset along with newly collected data. Use of an interpolation program such as that used by the Chesapeake Bay Program will require determination of the relationship between variance and distance from a fixed station for each of the parameters measured.

SAV Abundance and Distribution in the Oligohaline and Tidal Fresh Zones of the York River System

- Currently SAV aerial mapping is undertaken in June of each year by VIMS as part of the bay wide SAV mapping program and the results including maps and summary information such as bed area and density classification are available in a web-based database (see <http://www.vims.edu/bio/sav>). The photographic coverage of these over flights should include all of the shoreline regions that have been documented as historically supporting SAV growth. Currently a study by VIMS funded by EPA is quantifying and mapping the historical distribution of SAV in the York River region through the use of archival aerial photography. The results of this project will be available in the summer of 2001.
- In the freshwater tidal regions of the Mattaponi and Pamunkey Rivers SAV beds may be too small and scattered to be evident from the small scale (high altitude, 1:24,000 scale) aerial photography used in the annual bay wide surveys. However, SAV ground surveys, when combined with aerial surveys, will provide the necessary information on SAV abundance in the Pamunkey, Mattaponi, and their tributaries. Such information has been included as part of the annual SAV abundance reports (e.g. Orth et al. 2000), which have been gathered bay wide for many years by a network of sources ranging from citizens to academic and governmental professionals. The Chesapeake Bay Foundation (CBF) has provided training and field orientation of SAV ground surveys by citizen volunteers and these efforts should be supported for the York, Pamunkey and Mattaponi River regions. Although freshwater or low salinity SAV may not be directly evident from the water surface, raking of the bottom at regular intervals will provide both positive and negative information as to SAV presence. In summary:

- a. Perform aerial surveys of SAV at 1:24000 scale on transects from Claybank in the York River to the extent of tidal freshwater in the Pamunkey and Mattaponi Rivers
- b. Perform ground surveys at selected stations using raking techniques as described in Moore et al (2000). Stations will be selected based upon data from the aerial surveys. At stations where SAV are located, collect data on species diversity and abundance, GPS location, water depth (MLW), sediment type. Species identifications should be made by trained individuals and voucher specimens collected for verification of species identification by professionals.
- c. All data should be tabulated by the organizing group (e.g. CBF) and provided to VIMS for inclusion in the annual SAV report summaries.

Monitoring of “Impaired” Watersheds

Monitoring of “impaired” watersheds should be performed using techniques similar to those used in the Polecat Creek Watershed study. Monitoring of unimpaired sub-watersheds in the Polecat Creek area will provide useful comparison to measurements of “impaired” watersheds. In order to calculate loads of nutrients exported from watersheds, it is necessary to gauge the streams. Currently USGS has only one gauged stream above the fall line in Virginia. We recommend that the streams mentioned below be gauged. An additional goal of this study is to evaluate the relative importance of groundwater vs. surface water runoff inputs of nutrients to the York system. Although some information can be determined by measuring flows and nutrient concentrations during base flow vs. storm events, a more detailed understanding requires installation of groundwater well transects within the studied watersheds. Several such transects have been installed by USGS in the Polecat Creek watershed. We recommend installation of groundwater transects in the following “impaired” watersheds. These data will be critical to understanding the impact that BMP’s will have on downstream water quality.

- Selected Watersheds
 - a. Plentiful Creek in Spotsylvania County
 - b. Mechumps Creek in Hanover County
 - c. Matadequin Creek in Hanover County
- Water Quality Parameters Measured
 - a. Total suspended solids – fixed and volatile
 - b. Nitrate + Nitrite
 - c. Total dissolved nitrogen
 - d. Ammonium
 - e. Total dissolved phosphate
 - f. Dissolved inorganic phosphorus

- g. Dissolved organic carbon
 - h. Dissolved oxygen
 - i. Conductivity
 - j. PH
 - k. Temperature
 - l. Fecal coliforms
- Hydrological and Meteorological Parameters
 - a. Water flow rate
 - b. Air temperature
 - c. Rainfall
- Sampling Intervals
 - a. Baseline: Grab samples for determinations of water chemistry will be taken monthly during periods of no rainfall (at least 3 days from the previous rain event).
 - b. Event-driven sampling: sampling will be performed using a rain event-driven autosampler such as manufactured by ISCO, coupled to a rain gauge. The autosampler will be programmed to respond following a rain event of 0.5 inches of rain.
- Monitoring Techniques
 - a. Meteorological data will be collected using data-logging temperature and rain gauges.
 - b. Physical water quality data (DO, temperature, pH, conductivity) will be collected using a YSI datasonde.
 - c. Event-driven water sampling will be performed using an ISCO autosampler. Samples will be preserved with sodium azide.
 - d. Water flow rates – this data is best collected using gauging stations. It is hoped that DEQ can partner with USGS for installation of gauging stations

Citizen Participation

- Citizen participation will be especially important for monitoring of “impaired” watersheds. Members of both the York Watershed Council and the Lake Anna Citizen Advisory Committee have expressed interest in volunteering help for watershed monitoring. Landowners within each of the sub watersheds will be contacted to request their involvement in the project. Volunteer participation will be valuable in:
 - a. Maintenance and downloading of meteorological data loggers
 - b. Collection of grab samples for determination of water chemistry

- c. Ensuring safety of monitoring equipment
- d. Providing information on land use within sub-watersheds

- Currently many of the ground surveys of SAV in the middle and upper York are performed by citizen volunteers trained by members of the Chesapeake Bay Foundation. We recommend that these surveys be continued with the help of the CBF and other interested environmental groups.

Monitoring Plan Prioritization

- Task 1 Pre- and post monitoring of BMP implementation in “impaired” watersheds.
- Task 2 Use of Surface Mapper for collection of water quality data in shallow habitats.
- Task 3 Development of data interpolation and other analytical tools for analyses of Surface Mapper and Towed Vehicle data.
- Task 4 Deployment of two continuous monitoring buoys for acquisition of data on temporal (spring/neap) scales.
- Task 5 Testing of towed, undulating vehicle for collection of profile data from open water habitats.
- Task 6 Aerial and ground surveys of SAV in oligohaline and tidal fresh water habitats.

Monitoring Plan Estimated Costs

| | | |
|--------|--|----------|
| Task 1 | Watershed Monitoring (per watershed) | \$15,000 |
| Task 2 | Surface Mapper Water Quality Data Collection - | \$25,000 |
| Task 3 | Data analysis and interpolation tools | \$50,000 |
| Task 4 | Continuous Monitoring Buoy (each) | \$20,000 |
| Task 5 | Towed Undulating Vehicle (with sensors) | \$75,000 |
| Task 6 | Aerial and ground surveys SAV | \$10,000 |

The above costs do not include technical help for maintenance, collection of samples and sample analyses where required. The data analysis cost is for one-year salary for a data analyst/statistician.

IV. THE RAPPAHANNOCK RIVER AND NORTHERN NECK COASTAL BASINS ENHANCED MONITORING PLAN

Introduction

In 1999 the VA Department of Environmental Quality (DEQ) published its nutrient and sediment reduction strategy designed to restore both water quality and essential living resources in the Rappahannock River (DEQ, 1999). The strategy differs from that of the other major tributaries in that it clearly articulates specific numerical goals as endpoints to be attained by the year 2010. These endpoints include improvements in dissolved oxygen (DO), an important water quality criterion, and submerged aquatic vegetation (SAV), an important living resource. In both instances the nature and value of the numerical endpoints are closely tied to results of the Chesapeake Bay Estuarine Model Package (CBEMP), which was used to assist development of Virginia's tributary strategies (Butt et al, 2000). The adoption of model output results as numerical restoration endpoints has significant implications for developing a viable monitoring program aimed at determining attainment of the Rappahannock River goals.

Dissolved Oxygen

The dissolved oxygen restoration goal stipulated in the Rappahannock River strategy is *"to reduce by about 50% (actual model prediction is 45%) the annual volume of anoxic water (water that has no dissolved oxygen) in the Rappahannock River"*. This goal was selected from among nine different nutrient reduction/water quality improvement scenarios evaluated by the CBEMP as being a practical and attainable goal (Table I). It should be noted that the Rappahannock River Restoration Strategy correctly defines anoxia as the absence of oxygen while the model scenario from which it is derived defines anoxic water as $< 1.0 \text{ mg l}^{-1}$ of dissolved oxygen. From an ecological perspective, the differences between anoxia and water with 0.99 mg l^{-1} are substantial. Anoxia greatly enhances the release of phosphorus from sediments and inhibits nitrification, thus reducing denitrification. Even small amounts of oxygen may both markedly reduce phosphorus release and promote denitrification, thus ultimately enhancing water quality.

CBEMP calculates anoxic volume days by dividing the Bay and tributary water volume into cells measuring approximately 1 km wide, 1.5 km long and 1.7 m deep and calculates a DO concentration for each cell at specific time steps. On this basis the model determines the volume (m^3) and duration (days) of dissolved oxygen less than a threshold for anoxia ($< 1.0 \text{ mg l}^{-1}$), and calculates the volumetric and temporal extent of anoxic water as "anoxic-volume days" (AVD, units of m^3 -days). Hypoxic or anoxic volume days are a useful DO parameter because it integrates environmental processes over large spatial and temporal scales and thus provides a single, annual, system-wide metric for analysis. The accuracy of an anoxic volume determination in the field is limited primarily by the data density used for its calculation.

Model predictions of AVD for the James, York and Rappahannock Rivers for three different nutrient reduction scenarios over the varying hydrography in the Chesapeake Bay watershed for a 10-year period (1985-1994) indicate that the Rappahannock River accounts for about 96% of the “anoxic” water that occurs seasonally in the Virginia tributary system (Fig. 1). Model predictions further illustrate that the interannual variability in AVD, over the 10-year hydrographic period used, is extreme, reaching nearly an order of magnitude (Fig. 2). Clearly there is a model prediction of a significant dissolved oxygen problem in the Rappahannock River, a conclusion that is confirmed by monitoring and other research results (Kuo et al., 1991). However, AVD are not routinely calculated from in situ, water quality monitoring data collected since 1985, so the various, specific predictions of the CBEMP for this particular metric (e.g. river-to-river comparisons, 1996 progress run, etc.) have not been compared to, or confirmed by environmental monitoring data.

The Rappahannock Restoration Strategy specifies the year 2010 as the time period by which the goals should be attained. Although not stated explicitly, it is assumed that the desired percentage reduction in AVD is to occur over the 25 year time period 1985-2010. This is based on the observation that nutrient reductions required to reach this water quality goal are based on reductions from the 1985 Baseline Nutrient Conditions. It is worth noting that the reductions in AVD predicted by the CBEMP are based on applying the 1985 “Baseline” nutrient loading conditions (i.e. land use/land cover conditions that existed in the Rappahannock basin in 1985) to the actual basin hydrology which occurred over a 10 year period (1985-1994), and comparing these results to other nutrient reduction scenarios applied over the same ten-year hydrology. The predicted reductions of AVD from the various scenarios, compared to the 1985 baseline loading data, are thus the cumulative or average effect over ten years of hydrology, and therefore have no specific date that can serve as a reference condition. Since there is no real-world corollary to this ten-year averaging scenario used by the model, our recommendation is to apply the standard CBP trend analyses to the 1985-2010 data set to determine if the desired 45% reduction in AVD has been attained.

Currently, and since 1985, there are six fixed, water quality-monitoring stations in the lower Rappahannock River where hypoxia/anoxia might be expected to occur (RET3.1, RET3.2, LE3.1, LE3.2, LE3.4, LE 3.6). Analysis of sixteen years of historical data (1985-2000) from these stations indicate that anoxia ($< 1.0 \text{ mg l}^{-1}$) was most commonly observed at the lower four stations (LE 3.1, 3.2, 3.4, 3.6), not observed at RET3.1 and observed in only one of 16 years at RET3.2, a single observation at 5 m (bottom) in 2000 (Table II). At those stations where anoxia is observed, it typically occurs within a few meters of the bottom (Table II), consistent with baywide observations that anoxia/hypoxia in the major tributaries where it occurs is usually restricted to subpycnocline depths. Anoxic years, anoxic depth (i.e. the depth at which 1.0 mg l^{-1} DO is first encountered) and station bottom depth are summarized for all six Rappahannock River stations in Table II.

We recommend that the Chesapeake Bay Tributary Interpolator be used to calculate anoxic volume in the mid-lower Rappahannock River for each date that data is collected.

AVD can then be calculated by summing the total days observed during the summer that are below the threshold value. The accuracy of applying this approach to historical data is limited by a lack of spatial resolution in the vertical (DO is measured at two-meter depth intervals and at one meter above bottom, except at station LE 3.6 where it is measured at 1 meter intervals to one meter above bottom), longitudinal (there are only four fixed stations along the 70-80 km mainstem of the Rappahannock River where hypoxia/anoxia occurs) and lateral (there are no stations to measure DO distribution laterally from the main channel) dimensions. Lack of temporal resolution will also reduce accuracy. For the most part, water quality data has been collected monthly and could miss short periods during the summer when DO exceeds the threshold. Spatial resolution can be enhanced by increasing the number of fixed stations (laterally and longitudinally) and increasing the vertical sampling frequency (i.e. one meter depth intervals) or by using a towed, undulating DO sensor that measures dissolved oxygen at short time intervals (i.e. seconds) while being towed through the water at varying depths. Sampling weekly or biweekly can increase temporal resolution during the period of expected hypoxia/anoxia, or by making continuous measurements of DO at fixed stations. Recommendations for enhancing spatial and temporal resolution using both fixed sample stations and continuous sampling are provided below.

Since it is unlikely that any changes in sampling protocols intended to increase the accuracy of determining AVD will be implemented in less than two years, enhanced monitoring data will be available for only the last six or seven years of the 25 year time span. This is about the minimum number of years required to detect a long-term trend if one is occurring, so it is necessary that the historical data set be utilized for trend detection. In order to utilize the entire historical data set on AVD, it will be necessary to have some period of overlap for the historical and enhanced protocols so that the two procedures can be co-correlated, ideally spanning years of divergent flows (i.e. 3-4 years minimum). Therefore, the historical protocols will likely need to be retained for the remainder of the 25-year period of interest.

Fixed Station DO Monitoring

The most direct approach to determining a change in AVD over the period of interest is to continue monitoring dissolved oxygen in the lower Rappahannock River using the protocols presently in use until the year 2010, and then apply a trend analysis to the annual AVD determined from the data. This approach has the advantage of using a consistent data set over the entire 25-year period, but suffers from lack of accuracy in the AVD determination stemming from poor spatial and temporal resolution in the dissolved oxygen data set.

At a minimum we recommend increasing the spatial and temporal frequency of fixed station sampling by increasing both the number of fixed stations (four to twenty additional stations) and the vertical sampling frequency (to one meter depth intervals) and increasing the temporal sampling frequency (to biweekly). We recommend a minimum of four additional stations along the mainstem located between each of the existing five lower stations, resulting in at least eight fixed stations where anoxia/hypoxia

may be expected to occur. The optimal station configuration would be to add lateral stations on each side of the mainstem stations (i.e. 16 additional stations). Sampling these additional lateral stations will not contribute to the anticipated increase in data density if they are too shallow to encounter anoxic water at depth. Their depth should probably equal or exceed the “anoxic depths” listed in Table II for their respective mainstem stations. Increasing the vertical sampling frequency to 1 m depth intervals at all stations is essential since accurate determination of anoxic volume is very sensitive to the initial depth at which the threshold value is observed. Increasing the sampling frequency to biweekly should also enhance the accuracy of the AVD calculation as it will allow more detailed evaluation of short periods of re-oxygenation which may occur periodically during the summer. The intention of this enhanced monitoring plan is that if sampling at each station is restricted only to temperature, salinity and DO, then the fixed station protocol should have the maximum number of stations that can reliably be sampled in one day.

We propose that the Chesapeake Bay Program Tributary Interpolator be used to calculate the anoxic volume for each day that DO data is collected at the fixed stations. The Interpolator has been recently revised by making smaller calculation cells in the tributaries and contains the required bathymetry for volume determinations in the Rappahannock River. Anoxic volume days can be calculated by integrating under the temporal curve generated from the daily data (biweekly). The Interpolator can accommodate any increased number of data points from fixed stations that result from enhanced monitoring.

The proposed enhanced monitoring retains the analytical methods in use since 1985 and because the protocols are unchanged (just more of them) the inter-comparison of historic and enhanced monitoring results is simplified. The Interpolator should be used to calculate AVD from historical DO data from the five existing fixed stations on an annual basis. These values should then be adjusted on the basis of a minimum of 3-4 years of inter-comparison between the historical and enhanced monitoring, to provide a consistent data set over the entire 25-year period of interest.

Summary of Fixed Station DO Monitoring

- Continue the historical data collection for dissolved oxygen until the year 2010 and determine the magnitude of change over the period 1985-2010 from annual determination of AVD using the Chesapeake Bay Interpolator.
- Add a minimum of four new fixed stations (mainstem) and a maximum of twenty new fixed stations (four mainstem and sixteen lateral) to the existing four stations where anoxia has historically been observed.
- Increase vertical sampling frequency to 1 m depth intervals and temporal frequency to biweekly.

- Use the Chesapeake Bay Tributary interpolator to calculate anoxic volume and interpolate under temporal curve to calculate anoxic volume days on an annual basis.
- On the basis of 3-4 years of inter-comparison between historical and enhanced data, correct the historical data to provide a coherent 25-year data set (1985-2010) for trend analyses.

Continuous DO Monitoring (Spatial)

An alternative means of greatly increasing the spatial sampling frequency is to employ a towed undulating vehicle, equipped with DO, salinity and temperature sensors. Such an instrument could be deployed from an appropriately sized vessel and used to map DO distributions, (logged along with GPS position and depth) in three-dimensional space over the relevant portion of the river. This protocol could greatly increase the spatial density of DO data, especially if the instrument were deployed only over those depth intervals where appropriate DO concentrations are expected to occur (i.e. near the pycnocline) rather than the entire water column. The accuracy of an anoxic volume determination is directly related to the extent that the location of the anoxic threshold value is determined. Locating DO values above and below the threshold are of less value. Results in Table II indicate that at 3 of the 4 current monitoring stations where anoxic water ($<1 \text{ mg l}^{-1}$ DO) may be expected to occur, the location of threshold values is likely to be within 1-2 m of the bottom. If a towed, continuously recording vehicle is not capable of reliably operating this close to the bottom, it may have limited utility with regards to increasing data density.

Anoxic volume days derived from continuous monitoring would be calculated using the Chesapeake Bay Tidal Interpolator. The present version uses a UTM18 geographical coordination system that accommodates an Access database in which the location of parameter values is defined in three dimensions. In theory there is no limit to the number of data points entered if they are in the appropriate format. In its present configuration for use in the tributaries, the Interpolator utilizes a grid size of 100x100x1 m so that all entered values that fall within the same grid are averaged and placed at the centroid of the grid. Thus there is a limit at which increased data density is likely not to result in increased accuracy of the data output. The interpolator would have to be provided a higher resolution grid in order to optimize the output from a data set of sufficiently high data density. Since the proposed enhanced monitoring protocol is fundamentally different from the historic, fixed-station protocol, if an inter-comparison of the two protocols is desired, the historical sampling protocol (sampling at every other meter depth at four stations) would have to be continued in order to accomplish the inter-comparison noted above.

Summary of Continuous DO Monitoring (Spatial)

- Use a towed, depth-variable, “continuous” recording sensor to map DO associated with anoxia in the lower Rappahannock River in three-dimensional space.

- Increase sampling frequency to biweekly.
- Use the Chesapeake Bay Tributary interpolator to calculate anoxic volume and interpolate under temporal curve to calculate anoxic volume days on an annual basis.
- On the basis of 3-4 years of inter-comparison between historical and enhanced data, correct the historical data to provide a coherent 25-year data set (1985-2010) for trend analyses.

Continuous DO Monitoring (Temporal)

The ability to quantify short-term variability in the magnitude of anoxia/hypoxia in the Rappahannock River requires that fixed stations be established at which DO is measured continuously over the time period of interest. We recommend that at least one fixed buoy for continuous DO monitoring (15 minute intervals) is placed in the deep region of the lower river (i.e. vicinity of LE 3.2).

Submerged Aquatic Vegetation

The second major objective of the Rappahannock River restoration strategy is to improve the health of submerged aquatic vegetation in the mid and lower Rappahannock River and was articulated as “**to increase by approximately 50% (52% prediction) the density of submerged grasses**”. Like the DO objective, the SAV objective was derived from modeling scenarios which relate improvements in living resources, in this case SAV, to reductions in nutrient/sediment loadings. Furthermore, the Rappahannock River strategy chose the SAV objective that is predicted to occur as a result of the same nutrient reduction strategy associated with their DO objective (i.e. BNR-BNR Equivalent/Trib. Strat. Above; See Table I).

The CBEMP contains a predictive SAV model that can compute the spatial distribution and abundance of SAV species for various nutrient-loading scenarios (described in Cerco and Moore, 2001). Output from the SAV submodel is both as aerial coverage of SAV (i.e. hectares) and the aboveground biomass (i.e. $g\ C\ m^{-2}$) of SAV within the beds, which is termed “SAV density” in the Strategy. The model adequately predicts both the total SAV biomass and the relative abundance of three different SAV species for individual CB segments. The model less accurately portrays inter-annual variation or long-term trends in SAV aerial abundance within these segments (Cerco and Moore, 2001). The result of this limitation is evident in the model output depicted in Table I in which the impact of various nutrient reduction scenarios on SAV are predicted as percent changes from 1985 baseline loading conditions. The nine nutrient reduction scenarios evaluated have a wide range of effects on SAV biomass within existing beds (28 to 84% improvement) but have little impact on the aerial coverage of SAV beds (9 to 19% improvement) (Table I). This dichotomy likely has more to do with the way the SAV submodel is parameterized than a representation of realistic natural processes (Cerco and Moore, 2001)

The mesohaline portion of the Rappahannock River contains substantial beds of widgeon grass (*Ruppia maritima*), a species that tends to exhibit wide interannual variations in abundance in the absence of obvious habitat alteration. The more saline, lower River contains mixed beds of both *Ruppia sp.* and eelgrass (*Zostera marina*). The rationale for choosing an increase in SAV biomass as a desired endpoint is that attaining this objective would make the SAV less susceptible to stochastic environmental events that might eliminate less vigorous beds (Moore, 1997), and provide sufficiently lush beds that their own filtering action would further reduce sediment concentrations in the littoral zone and thus improve light availability generally for SAV (Moore, 1997).

Although the management objective of increasing the density of existing SAV beds may be well founded ecologically, it is based on a model output metric that is not routinely or readily measured by the existing monitoring program. SAV monitoring activities in the Chesapeake Bay use primarily aerial photography to annually quantify SAV aerial coverage. The output of these surveys is in hectares of SAV, and both baywide and segment restoration goals for SAV promulgated by the Chesapeake Bay Program are based on aerial coverage of SAV not on attainment of some level of SAV biomass within the beds. This dichotomy complicates the development of a monitoring program specifically directed at SAV biomass as an endpoint.

The direct determination of a biomass metric for the Rappahannock River SAV beds would require costly and time-consuming ground surveys of a representative number of SAV beds on an annual basis. However, routine aerial photography of SAV beds can be photo-interpreted and assigned to one of four density classes (Moore et al, 2000). In this case density refers to the percent of bottom that is actually covered by SAV, based on a percentage cover Crown Density Scale adapted from Paine (1981). The four density classes and the percentage range of coverage each represents are: Very Sparse, <10%; Sparse, 10-40%; Moderate, 40-70%; Dense, 70-100%. Given this capability, we propose two options for monitoring SAV recovery in the Rappahannock River, both based on routine, ongoing aerial photography

Aerial Coverage of SAV

The Rappahannock River SAV restoration goal could simply become an increase in aerial coverage of SAV, based on the premise that what is really desired from reduced nutrient and sediment loadings is more bottom covered by SAV regardless of the biomass of the grasses in the resulting beds. As one option, we propose that the annual photographic overflights and subsequent quantification of SAV aerial coverage continue for appropriate River segments. Attainment of a numerical goal is then determined over the 25-year period of observation (1985-2010). The advantage of this plan is that a consistent sampling protocol will have been used for the entire evaluation period. However, using the numerical endpoint of a c. 50% increase in SAV coverage based on 1985 levels (the percent improvement identified in the strategy for “density” improvement) is problematical since the original “density” metric and the proposed aerial coverage metric may have different impacts on ecosystem function and therefore may not

be numerically interchangeable. In all likelihood, a new aerial coverage numerical endpoint should be determined. Historical (i.e. pre-1971) SAV coverage in the mesohaline Rappahannock River is estimated at 3132 hectares and the Tier I SAV coverage goal is c. 1000 hectares. Figure 3 illustrates the temporal pattern of annual SAV aerial coverage in the mesohaline Rappahannock and is characterized by a peak in coverage in the late 1980's followed by a decrease after the wet years in the early 1990's with little indication of subsequent recovery or attainment of the Tier I goal.

Summary of Aerial Coverage of SAV

- Replace the “density attainment” goal with an “aerial attainment” goal and, if necessary, define a new numerical endpoint.
- Continue annual surveys of aerial SAV coverage in the mesohaline Rappahannock River.
- Utilize the consistent 25-year data set (1985-2010) to quantify the long-term trend in aerial coverage and determine attainment of numerical goal.

Density Classification of SAV

The ability to classify SAV beds into four different density classes from aerial photography provides an additional opportunity to develop and implement an SAV monitoring metric that attains the intent of the Rappahannock River strategy. Aerial photography annually during June-July, the period of maximum aboveground biomass for *Ruppia* and *Zostera*, provides the means for classifying each SAV bed or area into a density class which can be converted to a ground cover percentage (Moore et al, 2000). Aboveground biomass for each individual bed is then calculated as the product of the ground cover percentage, mean monthly biomass for an assigned community type, and bed area (Moore et al, 2000). Community type and biomass have been calculated from historical aerial photography (i.e. since 1985, none in 1988) for all Rappahannock River SAV beds through 1996. Subsequent historical photography could be similarly interpreted to provide a consistent data set for the 1985-2010 period. Maintaining the numerical goal proposed by the Rappahannock strategy of a c. 50% improvement over the 25 years of interest is reasonable, given the similarity between the original and proposed SAV metric. However, the extreme interannual variability evident in SAV density classification in the mesohaline Rappahannock (Fig. 4) makes it difficult to either choose an appropriate reference point from which to quantify an improvement or have confidence that a long-term trend in SAV condition, if occurring, can be discerned.

Summary of Density Classification of SAV

- Continue annual aerial photography of SAV in the Rappahannock River.
- Ground truth species composition in appropriate beds.

- On the basis of photo-interpretation, assign all observed SAV beds to one of four density classifications.
- Develop an area-weighted, mean biomass metric for relevant Rappahannock River segments.
- Re-interpret historical SAV aerial photography similarly to develop a consistent 25-year data set (1985-2010) for this biomass metric and to determine attainment of numerical endpoints.

Prioritization of Tasks

Dissolved Oxygen Monitoring Tasks

- Task 1 Use a continuously recording, variable-depth, towed instrument (Acrobat) to determine the dissolved oxygen distribution in the lower Rappahannock River biweekly during summer months (11 cruises). Using the CB Interpolator, calculate AVD on an annual basis. Inter-compare historical and enhanced methods and determine trend in AVD over the period 1985-2010.
- Task 2 Increase the number of fixed stations by adding 4 mainstem and 16 lateral stations. Sample all stations for DO, temperature and salinity biweekly at 1 m depth intervals throughout the summer months (11 cruises). Calculate anoxic volume from each cruise date using the CB Interpolator and determine an annual AVD. Inter-compare historical and enhanced methods and determine trend in AVD over the period 1985-2010.
- Task 3 Continue sampling 4-5 fixed stations with standard protocols and use CB Interpolator to calculate AVD for future and historical data and determine trend over the period 1985-2010.
- Task 4 Deploy a continuously recording, multiple-depth, fixed-station buoy to monitor dissolved oxygen in the lower Rappahannock River during the summer months (i.e. May-September). Use the temporal data on DO to calculate AVD in the lower River.

SAV Monitoring Tasks

- Task 1 Continue annual, aerial SAV survey. Ground survey appropriate sub-sample of Rappahannock River SAV beds and using photo-interpretation, assign all beds to density class and determine a biomass metric. Re-interpret historical SAV aerial photography to develop a 25-year biomass data set and perform trend analyses.

Task 2 Define a new SAV aerial attainment endpoint, continue annual surveys using standard protocols and determine the 25-year trend in aerial coverage.

Estimated Costs of Tasks

Dissolved Oxygen Monitoring Tasks

- Task 1 Acrobat - \$40,000
Vessel and manpower - \$2,000/cruise
Data management and trend analyses - \$10,000.
- Task 2 Datalogger and CTD with rapid response DO sensor - \$10,000
Vessel and manpower – \$2000/cruise;
Data management and trend analyses - \$10,000.
- Task 3 Management and trend analyses - \$7,500.
- Task 4 Buoy system to record DO at multiple depths - \$20,000
Manpower and vessels to deploy and retrieve buoy - \$5,000
Annual buoy maintenance - \$5,000
Data management (annual) - \$5,000.

SAV Monitoring Tasks

- Task 1 Ground surveying (annual) - \$2,000
Density assignments from aerial photography (annual) - \$3,000
Data management including historical re-interpretation and trend analyses - \$10,000.
- Task 2 Data management and trend analyses - \$5,000.

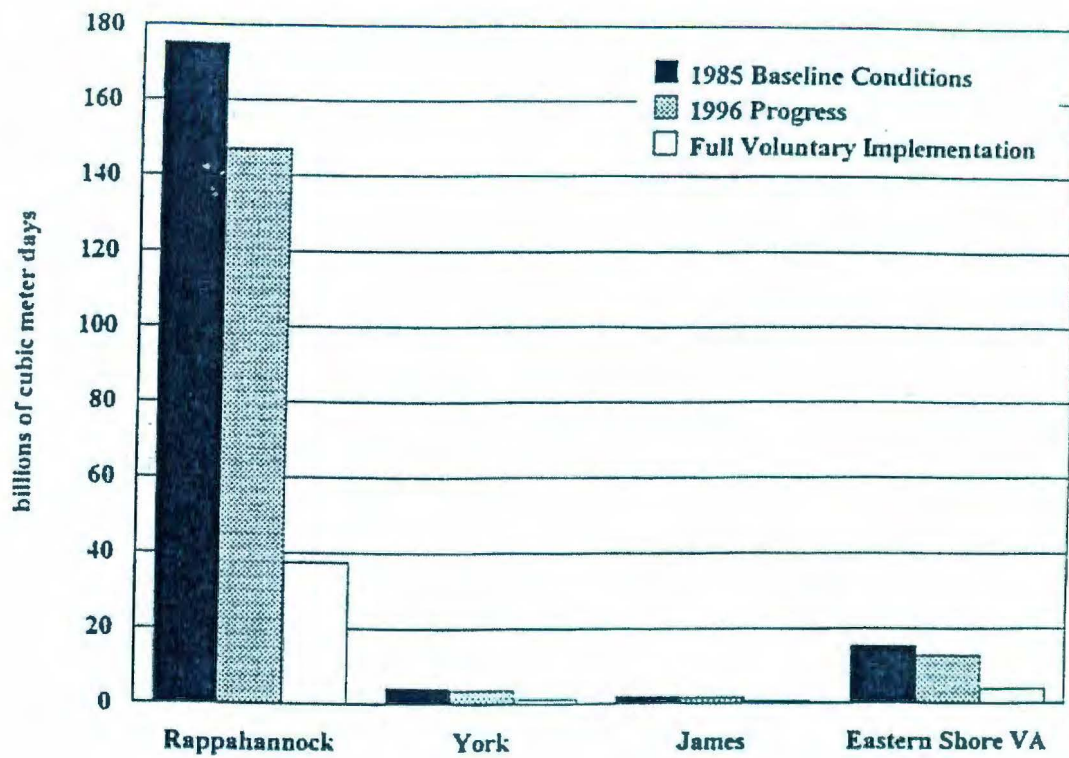


Figure 1. Total amount of anoxic water ($<1.0 \text{ mg l}^{-1} \text{ DO}$) predicted by the Chesapeake Bay Estuarine Model Package in Virginia tidal tributaries for three different nutrient reduction scenarios over the 1985-1994 hydrology. (Taken from Butt et al. 2000)

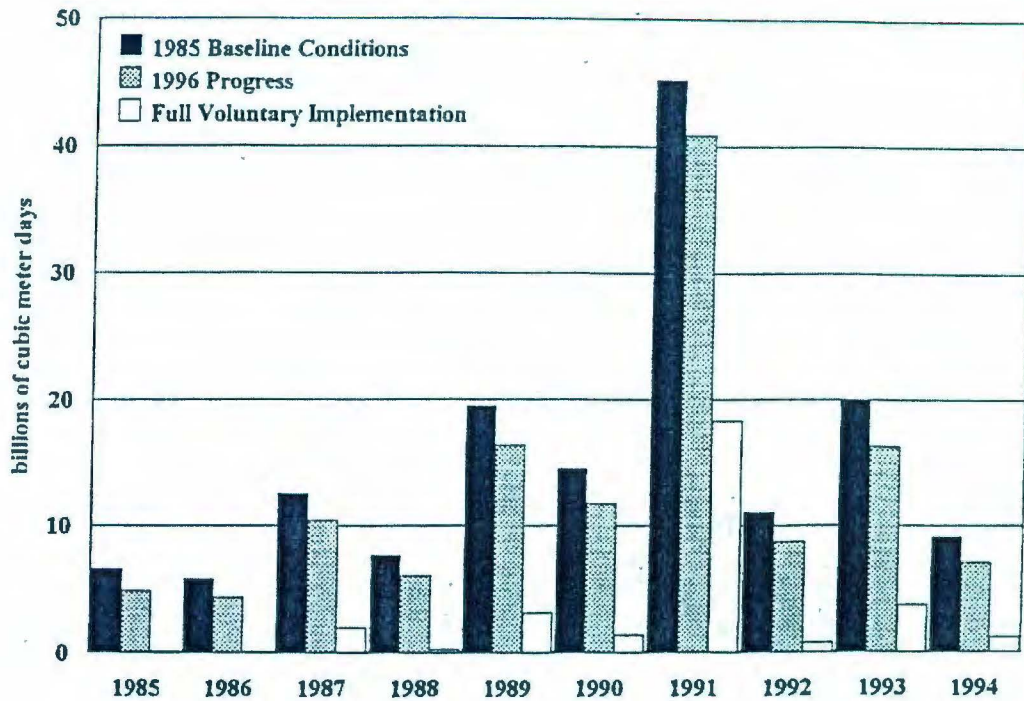


Figure 2. Total annual volume of anoxic water ($<1.0 \text{ mg l}^{-1} \text{ DO}$) predicted by the Chesapeake Bay Estuarine Model Package for the tidal Rappahannock River for three different nutrient reduction scenarios for each year of the 1985-1994 hydrology. (From Butt et al. 2000)

Fig. 3 Rappahannock River Mesohaline SAV Annual Aerial Coverage, 1984-2000

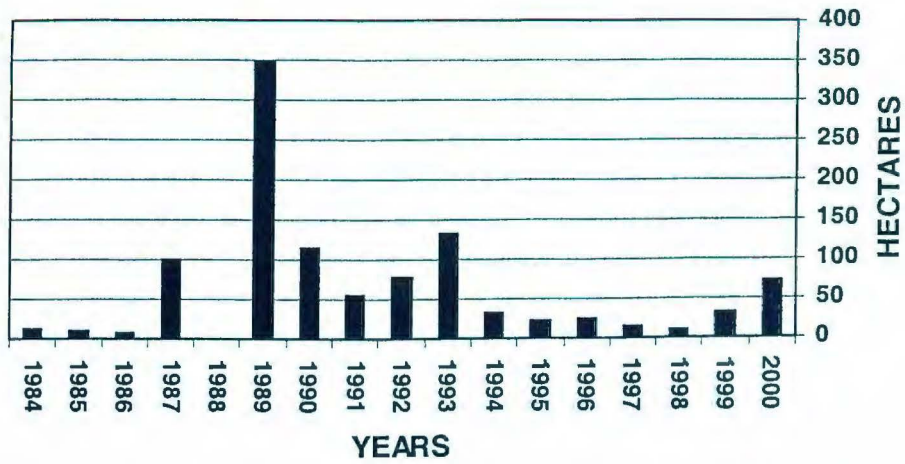


Fig. 4 Rappahannock River Mesohaline SAV Density Classification, 1985-2000

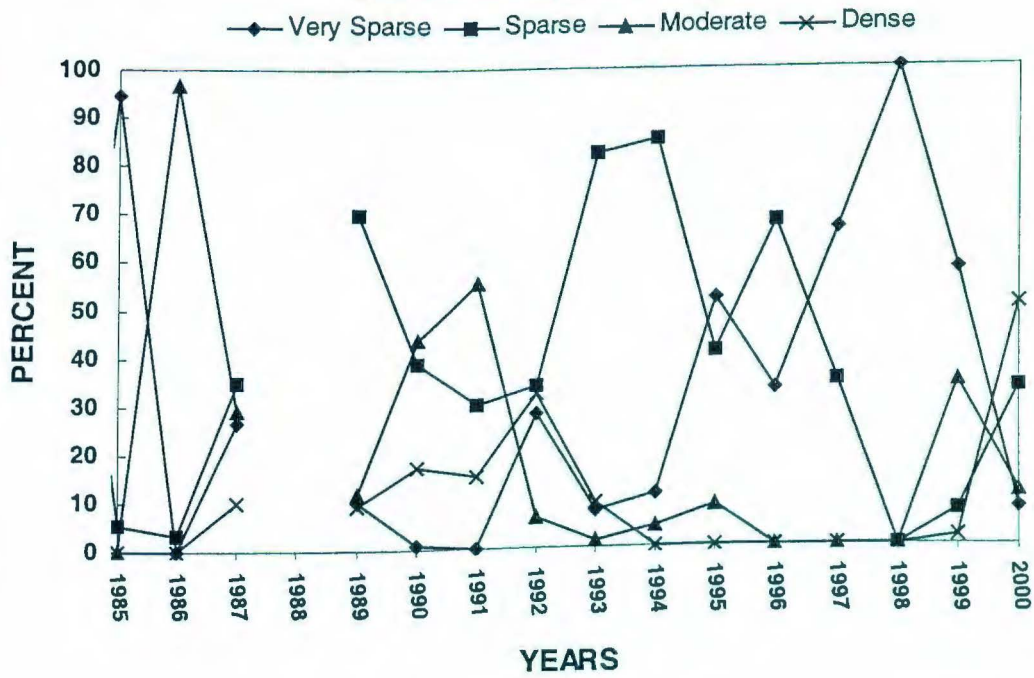


Table 1. Tidal Rappahannock River percent improvement from 1985 watershed baseline conditions for loads and key water and habitat quality measurements predicted by the Chesapeake Bay Estuarine Modeling Package for various load reduction scenarios. (From Butt et al., 2000).

| Scenario | Loading Reductions | | | | | | Water And Habitat Quality Improvements | | | | |
|---|--------------------|-----|-------|----------------------|-----|-------|--|--------------|------------|-------------|-------------|
| | Nitrogen Reduction | | | Phosphorus Reduction | | | Sediment Reduction | Anoxic Water | Habitat | Bay Grasses | Bay Grasses |
| | PS | NPS | Total | PS | NPS | Total | Total | (<1 mg/L DO) | <3 mg/L DO | Area | Density |
| 1996 Progress | -25 | 13 | 13 | 56 | 18 | 27 | 17 | 16 | 11 | 9 | 28 |
| 1996 Progress/Trib. Strat. Above | -25 | 13 | 13 | 56 | 18 | 27 | 17 | 39 | 27 | 9 | 47 |
| BNR-BNR Equivalent/Trib. Strat. Above | 26 | 32 | 33 | 62 | 22 | 29 | 20 | 45 | 31 | 9 | 52 |
| Interim Bay Agreement Goal/Trib. Strat. Above | | | 37 | | | 34 | 11 | 47 | 32 | 9 | 49 |
| Midpoint 1996-Full Volun. Imp. . | 0 | 28 | 27 | 72 | 26 | 35 | 22 | 50 | 35 | 9 | 57 |
| West Shore VA Full Volun. Imp./Trib. Strat. Above | -25 | 15 | 15 | 56 | 20 | 28 | 17 | 39 | 27 | 9 | 52 |
| Full Voluntary Imp./Trib. Strat. 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 |

Table II. "Anoxic" conditions in lower Rappahannock River for the years 1985-2000.

| Station ¹ | "Anoxic" Years ² | "Anoxic" Depth ³ | Bottom Depth ⁴ | Anoxic Layer Thickness ⁵ (m above bottom) |
|----------------------|-----------------------------|-----------------------------|---------------------------|---|
| RET 3.1 | 0/16 | N.A. | N.A. | N.A. |
| RET 3.2 | 1/16 | 5 m (1 depth) | 4-5 m | 1 m |
| LE 3.1 | 6/16 | 5-7 m | 5-7 m | 1 m |
| LE 3.2 | 15/16 | 9-13 m (2 yrs. At 7 m) | 13-15 m | 5 m |
| LE 3.4 | 13/16 | 9-23 m (None at 7 m) | 9-11 m | 2 m |
| LE 3.6 | 3/16 | 8-9 m | 8-9 m | 1 m |

1. Chesapeake Bay Program water quality stations in lower Rappahannock River.
2. Number of years out of 16 (1985-2000) that "anoxic" water ($< 1.0 \text{ mg l}^{-1} \text{ DO}$) observed at each station.
3. Depth from the surface (m) that "anoxic" water ($< 1 \text{ mg l}^{-1} \text{ DO}$) typically first observed.
4. Typical bottom depth (m) observed at each station.
5. Typical "thickness" (m) of bottom "anoxic" water ($< 1 \text{ mg l}^{-1} \text{ DO}$).

V. DATA MANAGEMENT AND QA/QC

All data should be managed and stored in Microsoft Access software. The data should be formatted in Access according to the data base dictionary provided by the Department of Environmental (DEQ). Monitoring staff should perform a Quality Performance Check once a year before submitting data to Chesapeake Information Management System (CIMS), Virginia Institute of Marine Science (VIMS), Department of Conservation and Recreation (DCR), DEQ and Eastern Shore Soil and Water Conservation District (ESSWCD).

The quality assurance objectives are to ensure that:

- (1) The quality of data generated is known.
- (2) The data quality always meets the QA/QC objectives of the section.
- (3) The data quality objectives for specific projects are met.

Accordingly, the policy of the section is for all field and laboratory efforts to conform to quality assurance and quality control procedures, as embodied in manuals of standard operating practices in each arena. Thus, the precision and accuracy of the data will be known, and the precision and accuracy will meet the agreed upon standards.

Quality of Sampling Activities

- (1) Precision is assessed through field replicate measurements/analyses and is expressed as coefficient of variation (CV). For the Water Quality Monitoring Sampling: Precision <20%
- (2) Accuracy is assessed through field spike analyses and is expressed as percent recovery. For the water quality monitoring: accuracy is 80-120%
- (3) Sampling completeness is calculated based on the ratio of samples collected to samples that were planned, and is expressed as percent completeness. For the water quality monitoring sampling: Completeness shall exceed >90%

Quality of Field Measurements

- (1) Accuracy, expressed as percent of reference value, is calculated based on reference materials (where available) and calibrating reference techniques.
- (2) Completeness is calculated based on the ratio of measurements made to measurements planned.

Quality of Field Measurements is as follows:

| PARAMETER | COMPLETENESS | MDL |
|-------------------|--------------|--------------------------------|
| pH | 90 % | 0.1 pH |
| D.O. | 90 % | 0.2 mg/L |
| Secchi Disk | 90 % | 0.1 m |
| Conductivity | 90 % | 1.5 umho/cm |
| Salinity | 90 % | 0.15 ppt |
| PAR | 90 % | 1 μ mol/sec/m ² |
| Light Attenuation | 90 % | 0.5 % @ 100 % light |
| Water Temperature | 90 % | 0.1 C |
| Depth | 90 % | 0.1 m |
| Epiphyte Mass | 90 % | 0.1 g/m ² |

Quality of Analytical Data

- (1) Comparability is a measure of confidence with which one data set can be compared with another.
- (2) Precision, expressed as coefficient of variation is calculated based on replicate analyses.
- (3) Accuracy, expressed as percent recovery, is calculated based on the analysis of spiked samples and reference materials.
- (4) Completeness is calculated based on the ratio of samples that are analyzed to the number of samples collected.
- (5) Method Detection Limits are determined for all parameters.

Quality of Analytical Data is as follows:

| ANALYTE | PRECISION | ACCURACY | COMPLETE | MDL |
|----------------------------------|-----------|----------|----------|----------------|
| O-PO ₄ -F | < 20 % | 80-120 % | 90 % | 0.0006 mg/L |
| NO ₂ | < 20 % | 80-120 % | 90 % | 0.0002 mg/L |
| NO ₂ /NO ₃ | < 20 % | 80-120 % | 90 % | 0.0008 mg/L |
| NH ₄ | < 20 % | 80-120 % | 90 % | 0.0015 mg/L |
| TN | < 20 % | N/A | 90 % | 0.0015 mg/L |
| TP | < 20 % | N/A | 90 % | 0.0006 mg/L |
| Chlorophyll | < 20 % | N/A | 90 % | 0.95 μ g/L |
| TSS, MSS | < 20 % | N/A | 90 % | 2 mg/L |
| Color (<i>g₄₄₀</i>) | < 20 % | 80-120 % | 90 % | 0.001/m |

Field data should be analyzed for differences among stations using ANOVA. Residual analysis is to be used to check model assumption with appropriate transformations, where necessary, to preserve normality and heteroscedasticity (Zar 1996). Means are compared using multiple comparison tests with a family confidence coefficient of 0.95. Non-parametric ANOVA comparisons may be made using Kruskal-Wallis procedure (Zar

1996) if assumptions for parametric comparisons cannot be met. Trends analyses can be determined using Kendall's Rank correlation.

Water Quality Data submitted to CIMS must meet the data dictionary standards, documentation requirements, conform to the data set formats described in "Water Quality Database; June 1998" and "Chesapeake Bay Program Relational Water Quality Database: Primary Table Descriptions And File Submission Format, June 17, 1998" or the most current versions of these documents.

SAV Aerial and Ground Surveys

All aerial and ground surveys will follow protocols and QA/QC procedures established for the Annual CBP SAV surveys (see Orth et al. 2000).

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