Scientific and Technical Needs for Fulfilling *Chesapeake 2000* Goals

2004 Update

Prepared by the Scientific and Technical Advisory Committee
Chesapeake Bay Program

Executive Summary

Chesapeake 2000 is an ambitious agenda for restoring the Bay's ecosystem through an array of watershed and estuarine activities that directly or indirectly alter water and air quality and living resources in the Bay and its watershed. The admirable plan provides specific completion dates for the activities with few details on the means or methods to meet the commitments, monitor progress (success/failure), or affect change at the local level where most decisions are made. Further, there are rapidly developing new technologies that could be applied in the effort that could aid in each of these three areas.

As the *Chesapeake 2000* agreement (C2K) is now the regional community's "Strategic Plan" for restoring the system, the Scientific and Technical Advisory Committee (STAC) of the Chesapeake Bay Program has drafted the following list of recommendations for undertaking the restoration. . The success of the restoration will be maximized if the effort selects the best available scientific approaches. Activities that are only weakly supported by our scientific understanding often are initially appealing but rapidly erode public sentiment when they fail.

Thus STAC provides the following suggestions for implementing the goals and commitments of *Chesapeake 2000*. Specific recommendations are provided to increase probable success for the five restoration goals of the agreement. These recommendations can be summarized as: conduct critical research (laboratory, field, and modeling) needed to undertake specific restoration commitments in each goal and distribute comprehensible information to local decision makers where, ultimately, Bay recovery rests.

STAC is providing this document as a first summary of needed activities. It should be viewed as a working document that will be updated as progress and achievements of the *Chesapeake 2000* Agreement move forward. The research needs identified in this document coupled with the three scenarios outlined in the STAC *Chesapeake Futures* report provide a foundation for progressively restoring the Bay and its watershed. STAC has dedicated itself to work with the Chesapeake Bay Program and its partners as they undertake the decadal restoration effort. Through a combination of good science and partner commitment and resources, many of the C2K commitments will likely succeed.

Introduction

As an historic next step in the recovery efforts undertaken in the Chesapeake Bay watershed, *Chesapeake 2000* (C2K) outlines specific restoration goals for the coming decade in the region's waters, lands, and air. The document provides accompanying research requirements in several areas, with projected completion dates through the decade. Its purpose is to provide a research compendium to the C2K agreement to help maximize the success of the restoration program.

The Scientific and Technical Advisory Committee (STAC) of the Chesapeake Bay Program (CBP) believes that initiation and decade-long support of restoration activities specific to *Chesapeake 2000* require immediate and continuous support for research and monitoring as well as incorporation of progressive new technologies. STAC strongly believes that undertaking the restoration activities in the watershed without consideration of the best scientific judgement possible, could result in unsuccessful restoration from potentially expensive outlays of money and labor. STAC is providing the following recommendations for research and monitoring that should be considered in implementing the restoration goals of *Chesapeake 2000*. Further, STAC is committed to assist the CBP and agreement signatories in identifying the appropriate members of the research community who could assist in monitoring the progress of implemented restoration activities, and implementing new technologies that could be employed to assist in evaluating and completing the proposed restoration.

Living Resources

Protection and restoration of living resources is at the center of the *Chesapeake 2000* agreement. Achieving the challenging goals require that the scientific community identify critical gaps in our understanding of living resources clearly articulate the research needed to enable informed management choices. These choices will span a wide range-from protection and conservation of some species and habitats to biological and ecological "engineering" designed to restore other species including the habitat, and ecological function. Inherent within this goal is the recognition that research efforts should lead to better management and new strategies for monitoring progress over short and long-term time scales.

Oyster Restoration

Priority needs

1. Develop understanding of the ecology of oyster reefs and beds to facilitate restoration and appropriate valuation.
2. Conduct the research required to evaluate potential risks and benefits of introducing a non-native oyster to Chesapeake Bay.

3. Advance husbandry technologies and management strategies in support of commercial fishery.

Background

Returning a sustainable, ecologically, and economically viable oyster population to Chesapeake Bay has been a commitment of federal and state governments and has enlisted researchers across the Bay community and beyond. This effort has now reached an important juncture as plans for large-scale restoration strategies are being developed. Recently, the proposed use of non-native oysters, especially *Crassostrea ariakensis*, has been advanced as a potential means to restore economic value as well as ecological function. That proposal has added further complication to an already daunting suite of issues and critical needs for research. As the Bay community contemplates major efforts in ecological engineering using either native or non-native oysters, there are a number of research priorities to be addressed.

The most critical, overarching research need that would be responsive to *C2K* requirements is the development of methodologies to successfully restore native oyster populations to Chesapeake Bay across a range of salinity regimes. Although large sums of money have been expended on placing shell and spat in Chesapeake Bay and its tributaries, only a small fraction of those funds have been devoted to systematic research designed to test and improve methods for oyster restoration. An experimental approach for testing restoration methods is critical because it will provide the greatest chance of success in future restoration efforts, while also providing scientifically defensible information on whether success is possible. Measures of success will depend on the goal of restoration efforts, which include provision of habitat, improving water quality, and sustaining a fishery. Both STAC and the National Sea Grant Program convened workshops within the past year that helped identify research questions relevant to native and non-native oyster management decisions. Another significant policy step is the agreement between Maryland, Virginia and the Federal government to conduct an Environmental Impact Study (EIS) on the proposed *C. ariakensis* introduction. The EIS was initiated in late 2003 and will apply new research findings in a decision- making framework. It is probable that the EIS will identify additional research needs as well. As a result of these activities, significant levels of new funding are becoming available for oyster research, although much of that funding is targeted to the evaluation of *C. ariakensis* and a limited number of other topics.

Recommendations

1) Reef Construction and Engineering: It is critical to develop a better understanding of how to site and construct oyster reefs to maximize recruitment, growth, and survival of oysters and associated communities. This requires an experimental approach to test restoration methodology, clearly defined measures of success appropriate for goals of particular restoration projects, and sufficient monitoring to determine relative success of restoration and control sites. Improved restoration methodology will require examining the relationship between engineering issues (reef design, construction, seeding methods, and type of seed to use) and oyster population dynamics, disease prevalence and intensity, and reef function.

Development and testing disease-tolerant strains is critical, as is field-testing and modeling of the potential for outplanting of disease-tolerant strains to improve disease resistance in wild populations. The U.S. Army Corps of Engineers plans to conduct large-scale restoration projects in Virginia involving both reef construction and stock enhancement using selectively bred strains of the native oyster. Such initiatives (e.g., proposed for the Great Wicomico River, Virginia) represent important opportunities to conduct tributary-scale experiments to assess gene flow and rates of transfer of disease resistance to wild populations of oysters. A strong research and monitoring component should be supported and incorporated into these large-scale restoration activities.

Restoration research should also consider the potential contribution of non-engineering approaches to oyster restoration through the management of natural populations, including no-take zones for remnant oyster beds, which can serve as sources of seed. It is important to improve understanding of how to restore the ecological, as well as fishery value of oyster reefs, including knowledge of how spatial patterns of beds promote restoration or enhance interactions among restored oyster beds. Routine monitoring of restored beds is needed and expanded use of remote sensing technologies for monitoring shellfish habitat and ambient water quality near restoration sites is recommended. Mapping bottom conditions to distinguish sites with acceptable characteristics and sediment accumulation rates for restoration can contribute to the success of oyster restoration.

2) **Potential Risks and Benefits of Introducing *Crassostrea ariakensis* to Chesapeake Bay**. Both the 2004 STAC workshop report, and the 2003 NRC report describe research required to evaluate potential risks and benefits of introducing a non-native oyster to Chesapeake Bay. An introduction of diploid animals to the Bay, either intentionally or as a result of reversion of triploids, will likely be irreversible. Furthermore, successful establishment of *C. ariakensis* within Chesapeake Bay will almost inevitably result in its spread to other Atlantic Coast estuaries. Research is required to evaluate the consequences of taking such a step. Weighing the benefits against the risks requires research and modeling on the potential for *C. ariakensis* to become established throughout a range of Bay habitats, as well as the risks it poses to other Bay organisms through direct and indirect interactions (including disease). Because the species most at risk from an introduction of *C. ariakensis* is likely to be the native oyster, *C. virginica*, the potential for native oyster restoration is an important factor in evaluating risk of a non-native oyster introduction.

3) **Oyster Husbandry and Management:** Hatcheries have the potential to play a significant role in oyster restoration, sustainable fisheries, and aquaculture, whether native or non-native oyster species are used. Improved technology for production as well as development of disease-tolerant strains is needed. Biotechnological explorations, including molecular manipulations at the gene level, for disease resistant strains is a high priority. Research is also needed to understand the linkages between restoration and the management of natural populations (fisheries management and recruitment, stock-specific genetics and disease resistance, mortality, and dispersal). Further, there is a need

to develop understanding of cumulative effects of multiple anthropogenic and natural stressors on strategies to increase oyster populations in Chesapeake Bay. Of particular concern are improved understanding of harvests-disease interactions, and sustainable harvest levels. Finally, it is important to couple production of manipulated populations of native oysters with protected areas for grow out and seed source for disease-resistant strains; this might include exploring rack aquaculture and relocation to reduce exposures to salinity-dependent parasites.

4) **Ecological Value of Reef Ecosystems and Oyster Restoration:** Restoration of biogeochemical cycling, physical circulation, water clarity and associated species (planktonic, benthos, fish, SAV, etc.) in oyster reefs is critical. A better understanding of nutrient cycling on oyster reefs, as well as trophic and non-trophic species interactions, is needed to estimate ecosystem benefits of a restored oyster population. Such information should be used in statistical modeling, food web simulations, and the development and application of biophysical models, and will depend on continuing evaluation of reef impacts throughout the coming decade.

Additionally, there is an important need for better understanding of the socioeconomic impacts of large-scale oyster reef restoration efforts and oyster decline. Included are issues pertaining to balancing needs of conservation, traditional fisheries, aquaculture (including the potential of aquaculture to reduce harvest pressure), and the implications of multiple uses of habitat.

Exotic Species

Priority needs

1. Develop a fundamental understanding of the relationship between organism supply and invasion success.
2. Improve tracking of sources, establishment, and spread of exotic species.

Background

Chesapeake 2000 identifies Exotic Species as a priority area of concern, establishing a CBP Task Force in 2000 to rapidly advance knowledge and directed activities on the introduction and establishment of non-native species in the ecosystem. Invasions can (and presently do) undermine efforts to restore fisheries, preserve and restore critical habitats, and attain effective ecosystem management. The relationship between supply and establishment of invasives is poorly resolved, and there is an uneven picture of the extent and temporal pattern of invasions. Such gaps in information and understanding make it difficult to develop effective management and policy in this area.

Recommendations

1) **Sources, Supply, and Prevention of Invasive Organisms:** We need to develop a fundamental understanding of the relationship between organism supply and invasion success. A combination of laboratory experiments and field-based research can provide important insight and guide management decisions. CBP should support research, including agency partnering, on ballast tank cleansing processes to reduce introductions

of ship ballast biota. Microscopic invaders (viruses, bacteria, plankton, and specific disease causing taxa) likely pose the greatest threat and hence their elimination should be a priority. For example, the recent and unexpected identification of an oyster parasite from the genus *Bonamia* in North Carolina waters underscores the significance of this issue, particularly in light of proposals to introduce into Chesapeake Bay a non-native oyster susceptible to this parasite. By the same token, the introduction of non-native oysters may also be a vector for the introduction of herpes-like viruses which could affect other related species. An assessment of this risk should be undertaken.

2) **Monitoring and Tracking Invasions:** A tracking system must be developed to detect new invasions and probable sources. Screening should be included in the current monitoring programs of the CBP, providing long-term records of organism sources and subsequent establishment.

3) **Bay Health and Invasion Susceptibility:** It is important to evaluate effects of environmental conditions on establishment and consequences of exotic species introductions to Chesapeake Bay. Environmental conditions influence colonization and spread of exotic species; in some cases, factors such as habitat degradation and overfishing can increase susceptibility of ecosystems to invasions. These interacting factors must be included in research programs addressing invasive species.

4) **Ecological and Economic Impact of Invasions:** Continued evaluation of introduced species' impacts on critical habitats and resources, as well as food web and ecosystem impacts should be a high priority. Proactive modeling of potential impacts by invasive species can prepare resource managers to understand possible ecological or economic effects and for remedial actions before these species have a disruptive effect on the Bay.

Fisheries and Fish Management

Priority needs

1. Develop effective monitoring of distribution and abundance of fish resources, and distribution and quantity of harvest activities.
2. Advance knowledge of predator-prey relationships and species-habitat relationships to facilitate multi-species and ecosystem-based fisheries management.

Background

Ecosystem-based fisheries management incorporates knowledge of the interactions among exploited and non-exploited species, their habitats and stressors, to develop management plans. Success of this approach requires more than knowledge of individual species life histories and population dynamics. It remains critically important to conduct focused research on individual species such as the migratory fishes, now greatly reduced from historical levels in Chesapeake Bay and on iconic species such as the native oyster and blue crab to insure significant progress towards *Chesapeake 2000* goals. Several research, monitoring, and modeling approaches are recommended. The recently completed Fisheries Ecosystem Plan for Chesapeake Bay (*http://noaa.chesapeakebay.net/Fish'FEP_DRAFT.pdf*) will serve as a source document to identify needed research to support implementation of ecosystem-based fisheries management in the Bay.

Recommendations

1) **Monitoring and Assessing Fish Stocks:** Managing fisheries requires basic knowledge on stock size and trends in abundance. Spatial distributions of living resources and statistics on harvesting activities are needed for effective modeling, economic valuation, and management. Field experiments are required and analytical methods must be developed to estimate abundances of adult anadromous fishes upon their return to Chesapeake Bay to spawn. Conducting such research will assist in development of much-needed restoration targets for adult shads and river herrings. Further, monitoring will provide information on tributary-specific information on carrying capacity for young-of-the-year pre-recruits needed to judge restoration success. Monitoring and assessment of forage fish populations, especially Atlantic menhaden and bay anchovy, are important to provide information on these species needed in multispecies modeling. There is a need for assessment of declining American eel populations and evaluation of causes. Monitoring of fishes, especially striped bass, for disease and evaluation of its effects on stock productivity is an important need. Baywide surveys of fishes that were initiated recently (e.g. CHESFIMS and CHESMAP) are the monitoring tools that need support to provide assessment information for management.

2) **Multispecies and Trophic Analyses:** To meet mandates of *C2K*, we must increase knowledge of species interactions in food webs, especially predator-prey relationships. Such relationships are the 'trophic underpinnings' that sustain production of fisheries resources and include lower trophic levels (e.g., plankton and benthos), which are major prey of fishes. Predator-prey models of key interactions, e.g., striped bass/menhaden and blue crab/fish, should be developed.

3) **Fish-Habitat Relationships:** Research is needed to increase understanding of habitat (SAV, wetlands, shallow bottom, deep, cool oxygenated waters, hypoxia, oceanic impacts on migratory taxa) in relation to spatial distributions of fish species; this includes estimating effects of habitat restoration on food web interactions and habitat use. The interaction between habitat pattern and extent on food web functioning and predator-prey relationships needs to be studied, analyzed, and modeled. It is important to achieve a better understanding of how spatial heterogeneity of habitat and harvesting activities can be applied to improve management through Marine Protected Areas and other forms of spatially-explicit management. Experiments to evaluate performance and effectiveness of spatial management techniques and to define essential fish habitat must be conducted to design effective and efficient ecosystem-based fisheries management. Information onthe role of location and habitat with respect to fishing and behavior of fishers is needed to develop social and economic databases and models that define harvesting behavior.

4) Stock Enhancements: Restoration and management approaches increasingly involve stock enhancement of native fishery species (e.g., oysters, shad, sturgeon, and most recently blue crab) as well as plants (SAV and emergent wetland plants). In addition to uncertainties of success in such ventures related to trophic, habitat, and environmental factors, there are important genetic considerations when hatchery produced animals or cultivars are used for fishery enhancement or population and habitat restoration. Research is required to quantify and minimize genetic risks such as inbreeding and bottlenecking of populations, while developing protocols that maximize the chances of management success.

5) **Fisheries Models for Prediction and Assessment:** The development of new, and improvements of existing, multispecies and ecosystem-based fisheries stock-assessment models are required. Support is required to develop and employ a suite of multispecies, living resource models to evaluate impacts of manipulating water quality, prey, and fishing pressure on living resources. Analyzing and modeling effects of climate variability or change and sea level rise on anadromous fish population dynamics and recovery potentials also are critical to understand and manage recoveries in these taxa. Blue crab deserves particular attention. Blue crab assessment models and targets ultimately should be developed in the context of multispecies management in Chesapeake Bay. The same is true for forage fishes, such as Atlantic menhaden, that is both fished and serves as a major prey of piscivorous fishes. Development of food-web models for Chesapeake Bay should be initiated leading to more realistic trophic network models and dynamic food-web simulation models (e.g., the ECOPATH and ECOSIM modeling now underway, as well as other modeling approaches). Additionally, incorporation of environmental and multiple stressor effects, e.g., water quality, disease, and harvesting, into multispecies and ecosystem-based stock-assessment models is needed. For effective 'buy-in' by resource harvesters, developing models that lead to better understanding of the socioeconomics of multispecies fisheries is critical.

Vital Habitat Protection and Restoration

SAV and Wetland Preservation and Restoration

Priority need

1. Develop a fundamental understanding of the relationship between landscape pattern and ecosystem function with respect to critical plant communities (SAV and wetlands) and human alteration of the landscape.

Background

Preserving and restoring plant communities and associated habitats are acknowledged as a high priority for Bay restoration. The ambitious goals need to be addressed within the context of critical research needs. Efforts to address gaps will provide information that will greatly increase the likelihood of success in achieving restoration goals. Central to proposed research efforts is the viewpoint that effective restoration must be grounded in spatially-explicit “ecosystem-based management” of plant communities targeted to restoring abundance as well as functional, sustainable habitat. These concepts apply equally to submersed aquatic vegetation (SAV) and wetlands. For both cases priorities include the following.

<u>Recommendations</u>

1) **Critical Plant Communities:** Developing a fundamental understanding of the relationship between landscape pattern and ecosystem function with respect to critical plant communities (SAV and wetlands) is the highest priority. This effort should be directed to increase knowledge of spatially complex plant communities and interacting environments, and of their relative values as habitat and for biogeochemical processing in the Bay ecosystem.

2) **SAV Restoration Guides:** Research is needed to guide SAV and wetland restoration efforts and to optimize strategies for placement and design. This should include expanded remote sensing capabilities for shallow habitat conducive to SAV colonization and monitoring growing plants. Research to understand SAV and wetlands as a component of Bay habitat complexes should also be increased. From these measures, modeling to develop SAV site-specific forecasts should be explored. Further, there is a need to develop a wetlands function assessment to account for the relationships of landscape setting, speciation, physical structure, subsurface preferential flow pathways, and biogeochemical function in natural and restored wetlands. Recommended approaches include advanced imaging technologies, e.g., remote sensing, LIDAR (LIght Detection And Ranging), to estimate wetland acreage. Such approaches imply partnering with agencies such as NASA and NOAA.

Expanded research on SAV species growth requirements must be undertaken to identify appropriate taxa for site-specific restoration efforts. Strategies for co-restoration of multiple SAV species will provide options for changing environmental conditions (substrate, light and nutrient levels, salinity tolerances). Development of minimum size requirements of sites to achieve ecosystem function in wetlands and SAV beds, both biological and biogeochemical, is critical.

3) **Restoration Monitoring:** A commitment to long-term, research-based monitoring is needed to assess the underlying reasons for success or failure of restoration efforts, without which there will be no means to assess reasons for and conditions amenable to plant recovery.

4) **Climate Change and SAV:** Research is needed to understand the impact of climate change over short to long-term time frames and its implications for SAV and wetland restoration goals. Included are variations in water temperature and water depth, including sea level changes, and effects on light availability and sediment quality.

Terrestrial Systems: Watersheds and Forests

Priority need

1. Develop a fundamental understanding of the relationship between landscape pattern and ecosystem function with respect to forests and human alteration of the landscape.

Background

Aquatic health of streams and watersheds will be assured through jurisdiction-specific management plans. Forests as a large portion of the bay landscape are excellent nutrient sinks and serve as important natural nutrient-processing centers. Forest buffers in riparian buffer strips are now recommended features along our creeks, rivers, and Bay. Buffers reduce sediment erosion and sedimentation processes as well as limiting solar heating of adjacent creeks and the habitats they represent. Additionally, because not all forests are identical with respect to nutrient processing, nor as habitat for animal populations, due to differing species composition, rooting habitats, and canopy characteristics, some forests and forest lands may be more suitable than others for manipulation/logging/development. This knowledge needs to be collated and developed.

Streams throughout the watershed are important habitat for living resources and serve as effective nutrient-processing systems. In streams, because downstream nutrient delivery implies that export exceeds in-stream loss terms, innovative in-water measurements and predictive methods are needed to more accurately estimate loss terms and in-stream nutrient processing rates.

Recommendations

1) **New Technologies:** Newer chemical methods such as use of stable isotopes to assess *in-water* nutrient processing rates must be expanded to provide more realistic estimates of stream nutrient dynamics, including development of rate functions for modeling in-water processing to better quantify model predictions of watershed/stream export.

2) **Water Processing:** Manipulation of point source nutrient speciation to foster more in-water processing, e.g., denitrification, reducing nutrient export downstream might be explored in future CBP-supported planning.

3) **Remote Sensing:** Remote sensing technologies are routinely employed to determine forest acreage, location, and species and their use could be effectively expanded to determine encroachment of other land uses into forested area. Such approaches should be evaluated in CBP-sponsored activities.

4) **Forests as Nutrient and Sediment Retention Landscapes:** As forests represent large reservoirs of fixed nitrogen and effective sediment traps, research on managing forest growth/timbering to help reduce nitrogen and sediment loads should be pursued. Further, as forests become fragmented through development and altered land use, forest parcels are often heterogeneously distributed in a given region. The spatial and temporal variability in nutrient processing and sediment retention/erosion control in the fragmented forested landscapes must be evaluated particularly as it relates to historical land uses. Research is needed to determine forest acreage required for maintenance of biodiversity

in plants and animals, as refuges for endemic and migratory fowl, and as effective nutrient and sediment retention sites in catchments.

5) **Natural Buffering Models:** Modeling buffer roles in nutrient processing and animal habitat must be expanded. This includes innovative land use models that incorporate forests as nutrient buffering zones (function of root zone, buffer width, and depth of the water table, and effect of subsurface flows that bypass buffer zones) as well as essential habitat for valuable animal species. The models, in turn, should be routinely employed in developing master plans and county zoning maps.

6) **Local Model Application:** Zoning decisions are made at very local scales, far from the main stem of the Bay, and hence often not in local citizens' frames of reference for assisting the Bay's recovery. It is therefore critical to develop watershed models that incorporate land use decisions and predicted water quality, biological, and economic impacts for use by the local planning commissions. Without these tools, effective reductions in impacts from cumulative local zoning decisions cannot be achieved.

Water Quality Protection and Restoration

The Water Quality Protection and Restoration section of the *Chesapeake 2000* Agreement has the overall goal to achieve and maintain the water quality necessary to support the aquatic living resources of the Bay and its tributaries and to protect human health. The primary commitments to meet this goal include correcting nutrient and sediment related problems in the Bay by 2010, and having a Bay "free of toxics" (no toxic or bioaccumulative impact on living resources). Enhanced scientific information is needed to better understand the sources and effectiveness of remediation practices for nutrients, sediment, and contaminants as well as, their transport and fate. There is an immediate need to quantify what further reductions in nutrient loadings can be gained from existing BMPs, and which new BMPs can be implemented in the short-term. The scientific information to meet these needs must include improved predictive modeling, enhanced integration of watershed and estuary monitoring, and research.

Controlling Inputs from Watershed and Air

Priority Needs

1. Continue development of low cost, robust, effective technologies for pollutant reduction.
2. Improve understanding of lag time between BMP implementation and measurable improvements.
3. Undertake long-term targeted studies of the impacts of BMPs on sediment, nutrient, and contaminant movement through the watershed to the Bay.

Background

Nutrient enrichment (and to a lesser degree sediment loadings) is the major problem facing the Chesapeake Bay and its tributaries, threatening living resources, altering water quality, and posing greater and greater threats to sustainable Bay-related industries. It is therefore critical to expand our understanding of the loads to the system, from the air and land. Our accomplishments to date have been modest considering the focus on nutrient reductions over the last decade. The following recommendations are proposed in support of the goal to reduce loads in the system.

Recommendations

1. **Recovery and Control Practices:** Water and nutrient recovery and re-use from point sources are innovative practices that are being explored in Western Europe, Japan, and elsewhere. These practices should be investigated to see whether they are practical and efficient for the C2K reduction program. For example, phosphorus and ammonium recovery through precipitation with magnesium cations is a possible alternative for reducing loadings and encouraging reuse of these macronutrients. The development and application of diffuse-source controls and evaluation of their effectiveness remains one of the most important scientific challenges in the restoration and protection of water quality in the Chesapeake Bay.

2. **Agriculture:** As the major source of nutrients to the watershed, agriculture requires considerable attention in reducing nutrient loads to the water resources. Better data on feed, fertilizer, and manure use are needed. Sales of fertilizer are not decreasing in many areas of the Bay watershed. Is this due to non-changing applications on agricultural lands or a shift in the fertilizer use from agricultural to suburban lands? For animal manure, there is a need to determine the opportunities to manage the concentration of increasing animal production in the watershed, to control animal nutrient intake and excretion, and to reduce the resulting nutrient loading in the watershed. Studies should be supported to evaluate the effectiveness of different agricultural management practices to reduce landscape losses based on site-specific conditions, including soil, tillage, cropping conditions, etc. Economically sustainable soil, crop, and animal management practices, supportive policies, and effective means to encourage their utilization should be developed. Associated studies can evaluate the effectiveness of new approaches in nutrient-loss reduction strategies in agriculture, including yield reserve incentives to reduce over-fertilization, application of phosphorus indices, etc.

3. **Suburban Runoff:** The increasing development pressure around the watershed requires that research focus on the effects of the changing landscape. The effects of suburban water management practices on water flow, water quality, and the ecology of receiving streams needs to be better quantified.

4. **Air:** Atmospheric deposition is one of the largest sources of non-point pollution impacting the Bay. The quantification of dry and wet deposition of nutrients and pollutants still remains a problem: New technologies must be developed to provide better estimates of dry (and wet) deposition and for assessing their fate in nutrient processing in

the watershed. However, specific source-receptor relationships are not well understood nor are the contributions from local point and area sources (transportation, animal husbandry, industry, etc.) Additional research is needed to identify and quantify local versus long-range inputs. This is particularly important with respect to nitrate and ammonium deposition.

5. **Research on Spatial Controls for Nutrients, Sediments, and Contaminants:** Research is needed to improve estimates and locations of nutrient, sediment, and contaminant sources, transport pathways, and sinks in the watershed, starting with the synthesis of existing data and metadata. The effects of watershed storage and associated time lags, e.g. groundwater inputs, should be evaluated. Further, because chemical contaminants are delivered through air and water, air trajectory and deposition technologies are critical to future Bay efforts. Air shed modeling for volatiles from urban and rural sources needs to be quantified.

6. **Evaluations of Control Options:** Develop an accurate inventory of implemented BMPs and conduct long-term targeted studies of the impacts of BMPs on sediment, nutrient, and contaminant movement through the watershed to the Bay. It has been noted repeatedly that benthic organisms also alter fluxes of nutrients and resuspension susceptibility. Thus, the potential influences of biotic factors should be considered in future CBP activities. Further, the interactions of contaminants and sediments, including the effectiveness of source controls (e.g. urban runoff), sedimentation, and the degree of subsequent release from sediments versus long-term burial, should be investigated further.

7. **Sediment Loading:** Stream-bank erosion, its controlling factors, estimates of loadings from the watershed, and its impact on aquatic resources, must be quantified. These are critical in order to update sediment mass balance estimates and understand the potential effects and response lags of sediment management practices. Research is also needed to improve understanding of internal and external sediment sources and sediment transport dynamics in the Bay, and to better understand the relative importance of these sources for suspended sediment levels, turbidity, and sediment accumulation. The first step is to synthesize existing data, identify additional data needs, and identify poorly understood but critical processes.

Watershed and Estuarine Monitoring

<u>Priority Needs</u>

1. Perform strategic monitoring to validate the model and maintain the land use, atmospheric, and water quality monitoring programs for a period of sufficient length to distinguish longer-term trends, with the objective of improving estimates of uncertainties and variances in atmospheric deposition and impacts on water quality.
2. Improve sediment monitoring to identify sources, and determine impacts on water clarity.
3. Improve monitoring methodologies.

Background

Development of *Chesapeake 2000* followed analyses suggesting that the previous 40% reduction goal for nutrients had not translated to significant nutrient and chlorophyll reductions nor alleviated the low DO problem. It is absolutely critical to implement rigorous monitoring programs in the current decade, designed specifically to assess effectiveness of those management programs implemented to fulfill *Chesapeake 2000* goals.

Recommendations

1. **Monitoring Data:** Field observations must be made for all activities undertaken to meet *Chesapeake 2000* goals, implying pre- and post-management observations through time. These data include all relevant water quality parameters at sampling frequencies needed for determining ecosystem health and recovery. At a minimum, the water quality criteria parameters DO, chlorophyll, and water clarity are mandatory. Note: similar data collections through time are also needed for other valued *Chesapeake 2000* priorities including living resources such as oysters, exotics, SAV, fish and crab stocks, etc.). When possible, real time data collection should be encouraged for data assimilation modeling (see below) and remote sensing capabilities should be incorporated into standard monitoring activities of the CBP.

Event-driven sediment and nutrient loadings can dramatically overwhelm background average conditions. Monitoring programs must include event-based sampling to resolve background levels that can dramatically alter the system's long-term nutrient and sediment 'memory'. *In-water* sensors for nutrients (wet and dry chemistry, laser and solid state electronics) and pollutants (mass spectrometers, high performance liquid chromatography) are now available and can be routinely employed. Adequate on-ground surveys must be conducted to determine causative factors influencing the large-scale land use changes occurring in the watersheds. Atmospheric monitoring stations and networks should be established in critical areas to measure nutrient fluxes.

Land use, atmospheric, and water quality monitoring programs should be maintained for a period sufficient to distinguish longer-term trends from short-term pulses thereby improving estimates of the uncertainties and variances in basic atmospheric and water quality.

2. **Sediments:** The role of sediments in water clarity and burial of native oyster populations is acknowledged throughout the Bay. However, the sources of sediments remain unclear. Data are required in routine collections to determine fall line sediment loadings, open boundary loadings, shoreline erosion contributions, and resuspension loads. Susceptibility of sediment to erosion from bioturbation, biodeposition, and presence/absence of SAV must be quantified and georeferenced. Monitoring and modeling of stream-banks as a potential source of sediment to downstream water bodies should be investigated. Currently there is no model available to evaluate the effects of different buffer types on bank stability and erosion.

3. **Management Practice Evaluation:** Evaluation of the effectiveness of diffuse source controls and best management practices through rigorous monitoring is a critical need, through synthesizing existing studies of small watersheds and by conducting future studies coupling modeling and monitoring in selected small watersheds.

Predictive Modeling of Inputs, Transport, and Ecological Responses

Priority Needs

1. Couple existing predictive models and monitoring observations to improve development and refinement of models.
2. Develop a comprehensive sediment transport modeling capability for the watershed and its estuary, supported and informed by appropriate research on processes and patterns.
3. Encourage the development and/or implementation of alternative and innovative modeling approaches.
4. Determine the forces driving land use changes, best management practice implementation, and economic sustainability of resource-dependent activities.

Background

Modeling of pollutant (nutrients, sediments, and contaminants) sources, transport, and effects and monitoring of inputs, water quality, and biological responses have been keystone technical tools for the Chesapeake Bay Program, and must remain central to future activities in the decade. Data transfer, assimilation, and analysis tools are sorely needed as the volume of data delivered in the future may outstrip the resources available to interpret the data.

Recommendations

1. **Modeling Predictions:** Continued improvements in modeling and as recommended above, monitoring, are required. Predictions from existing models and observations from monitoring must be more effectively coupled, including the development and routine use of data assimilation models where real-time data can provide for better approximations of real-world observations.

2. **Sediment Transport Modeling:** Development of a comprehensive sediment transport modeling capability for the estuary, supported and informed by appropriate research on processes and patterns, is necessary. A set of models should be built into the framework of the several hydrodynamic models, but they should incorporate new forcings (e.g., surface waves), additional inputs (fall line sediment loadings, open boundary loadings, and shoreline erosion), and an explicit sediment bed to account for changes in erodibility and sediment sequestration. The set should include multiple sediment particle classes (e.g., sand, slowly settling fine particles, and rapidly settling flocs), consider potential interactions between these classes, and be open to inclusion of

biological feedbacks such as changes in sediment erodibility due to bioturbation, biodeposition, or SAV bed development. Both shallow and deep subenvironments should be modeled, the former for their potential importance as SAV and oyster habitat and the latter for their importance as zones of particle accumulation and recycling.

3. **Multiple Modeling Approaches:** Encourage the development and /or implementation of alternative and innovative modeling approaches. The development of *multiple* modeling approaches should be encouraged, rather than reliance on single models. Although using multiple modeling approaches may produce different answers regarding outcomes or consequences, the variability provides some measure of confidence and a more realistic understanding of uncertainties for managers and policy-makers. Exchange programs should be implemented for scientists and program managers between institutions developing and using models.

4. **Implementation and Sustainability:** The forces driving land use changes, best management practice implementation, and economic sustainability of resource-dependent activities in the Bay and its watershed should be determined. For example, both agricultural and suburban diffuse sources must be considered in their longer-term socio-economic contexts. Potential changes in input stressors that result from socio-economic forces, e.g., governing animal production and intensification, atmospheric deposition, population growth and development, must be considered. Complementary policy education should be based on these outcomes. Many forces drive change in the Bay and its watershed. Guided change must acknowledge these forces and influence those that will contribute to Bay and watershed restoration.

5. **Integrated Models:** Development/improvement of integrated models of watershed nutrient, sediment, and contaminant transport within the framework of the watershed model, to better understand connections between land-based management controls and Bay loadings, is necessary. This effort should link upland water quality models and in-stream models to enhance our ability to evaluate the impact of control measures on aquatic resources.

6. **Epidemiological Modeling:** State-of-the-art epidemiological modeling should be applied to the region to identify likely areas for greater potential health impacts from historically higher air and water contaminants. In turn, the results should focus health care and increased evaluations for indicators of exposure that might be useful in future assessments in other areas.

7. **Uncertainties Exploration:** Continued exploration of uncertainties in model predictions is necessary. A stochastic approach should be adopted, adding model components where necessary, to more realistically reflect uncertainties by expressing predictions in terms of probabilities. Further, the use of estimates stated in terms of statistical probability should be considered, allowing improved estimation of the time required before the effects of nutrient and pollutant management practices can be meaningfully measured.

8. **Cost-Benefit Analyses:** The decade-long implementation of restoration practices should be rigorously evaluated for the likely cost versus benefits from the planned management. The gains of some proposed restoration activities, although highly endorsed by watershed inhabitants, may be prohibitively expensive for the value derived in undertaking the activity.

9. **Local Application:** User-friendly models that permit scenario runs for different land uses in a region are important tools to be distributed with training to the smallest planning bodies. These include land uses, exports, and economic valuations that ultimately decide adoption of one zoning versus another.

Ecosystem Responses to Input Reductions

Priority needs

1. Investigate nutrient equivalency.
2. Determine the relationships between inputs and living resources.

Background

The final, and in some ways most important, need is to understand the likely responses of the Chesapeake Bay ecosystem to pollutant reduction through an integrated analysis of load reduction impacts that are dependent on physical, chemical, and biological characteristics of the system. As has been shown on several occasions, altering one parameter for a system, e.g., loadings per year, often does not express itself linearly nor predictably through the system, as there are multiple interactions between chemistries, organisms present or absent from a locale, and water movements through space (horizontal and vertical) and time (e.g., seasonal temperature optima for a population). For example, as discussed in the Living Resource section, we must improve our ability to monitor, understand, and simulate the factors (water clarity and availability of propagules) that are affecting SAV recovery in different areas of the Bay and its tidal tributaries. This information is needed to improve restoration and increase SAV acreage but will have dramatic feedbacks on biodiversity and nutrient processing. And as noted in the same section, we must understand the influences of oyster restoration on water quality (and water clarity) in the Bay; increasing oysters could remove more nutrients, plankton, and sediments and perhaps reduce pelagic forage fish needed for pelagial production in higher trophic levels. Lowered cultural eutrophication will have huge impacts and it is critical to quantify responses expected from the strong restoration effort in the watershed.

Recommendations

1. **Investigate Nutrient Equivalency:** The issue of whether or not nitrogen removal can be traded for phosphorus removal, and vice versa, needs to be resolved as soon as possible.

2. **Relationship between Inputs and Living Resources:** This knowledge is critically needed for the development of restoration strategies.

3. **Harmful Algal Blooms:** As one indicator of coastal eutrophication in some systems, increases in frequencies and impacts of blooms of harmful algae provide good indications of system imbalance. We must improve our understanding of the factors causing harmful algal blooms and how nutrient and circulation/hydrology (residence times) affect algal communities.

4. **Temporal Heterogeneity in Forcing Functions and System Responses:** We must better define the relationship between the rate and timing of pollutant delivery to the Bay and the responses of water quality and living-resources in the Bay and its tidal tributaries; this includes identifying and quantifying base and event flow import. *In water* and field-team focused event sampling for nutrients, salt, and sediment should be routine, with event-based data incorporated into all load estimates.

5. **Toxics and Biota:** We must further define the effects of contaminants on the living resources of the Bay and its watershed, as chronic exposures likely alter populations subtly, therefore making food web impacts difficult to identify. Synergistic impacts of classical pollutants and emerging contaminants on Bay living resources and the public must be assayed. Chronic low-level exposures to water- and air-borne suites of materials can result in far greater threats than exposures to single compounds. A much-expanded assessment of the impacts of multiple compound exposures under the air and water environments of the region has to be incorporated into monitoring plans for the coming years. This might include expanded EPA partnerships with various agencies, e.g., NIH, CDC, to develop bioindicators of exposure, for both low level single compounds to mixtures of many compounds and the variety of water and atmospheric conditions inherent to the area.

Sustainable Development and Landscape Management

It has long been recognized that land use has serious implications for water quality and habitat preservation. Many water quality problems and habitat losses can be attributable to urban and suburban development that in many cases occurred before there was even rudimentary stormwater management. With a population of 14,000,000 in the Bay watershed and a rapid growth rate, the challenge is to correct the problems of the past and prevent the recurrence of similar problems in the future.

Only recently have land use planning and site design begun to address these concerns. An innovative aspect of the *Chesapeake 2000* agreement is the formal recognition of the linkage between land use and water quality. Accordingly, many of the *Chesapeake 2000* commitments are designed to ensure that “sound land use” encompasses water quality and habitat concerns. In fact, many of the *Chesapeake 2000* commitments depend on the effective use of development and land management practices.

One of STAC's objectives is to "provide knowledge on techniques and tools to manage land-based resources through land use planning, site development, land use conservation, and on-site property management." Accordingly, STAC has systematically examined the agreement commitments and identified the important scientific and technical needs that should be addressed to meet these commitments.

While the common focus is on managing what happens on the land, it involves a range of disciplines including engineering, biology, urban planning, modeling, monitoring, economics, and education.

Modeling and Analytical Tools

Priority need

1. Make a wide variety of analytical tools and techniques readily accessible to facilitate widespread application of Environmentally Sensitive Site Design (ESSD) and Low Impact Development (LID) practices.

Background

As agricultural lands shift to more intensive practices or move into suburbanization, dramatic alterations in flows off and under the land occurs. Those remaining undeveloped or in easements (or under other protective modes) require economic assessments to encourage continued protection, as best intentions can be offset by economic realities. The movements of water, nutrients, sediments, and toxics from the altered lands to the tributaries and Bay must be recognized at the lowest planning levels as this is where decisions on land use and hence delivery of these materials are made. For the lands developed, there is a demonstrated a linkage between imperviousness and poor water quality and habitat. ESD/LID (Environmental Sensitive Site Design/Low Impact Development) technology and practices offer excellent prospects for restoration of watersheds impacted by development and protection of undeveloped watersheds as new development occurs.

Recommendations

1) **Modeling:** It is very important to actively expand the use of computer modeling in land use planning. Therefore, it is recommended that the development and enhancement of computer models to better assess water quality, habitat, and economic impacts (costs and revenues) of development and redevelopment be a high priority within the CBP. Such tools and others (e.g., computer-based engineering, environmental, and economic models and the supporting analysis to ensure their validity) could be an indispensable adjunct to land use, zoning, and site planning decisions via the ability to project potential land use changes resulting from anticipated development pressure and the ability to assess the impact of alternative development scenarios. The integration of ESSD/LID in site plans for both new and retrofit development creates a need for new computer-based models available to site designers and site plan reviewers.

2) **Large Scale Land Use Characterization:** Assessing all land use in the watershed can only be accomplished with a large spatial scale tool, such as aerial or satellite remote sensing. New sensors and analytical tools for data derived from the sensors need to become routine portions of the CBP, for quantifying potential transported nutrient and sediment.

3) **Economic Valuation:** There is a need to better understand and assign a value to resource lands potentially targeted for protection through acquisition or other conservation techniques. Ideally, such mechanisms should reflect sound science and economics and also be readily accessible for agencies, land trusts, and others involved in land acquisition and preservation.

Stormwater Management

Priority need

1. Improve design and siting of best management practices to control nutrients, sediments, bacteria and toxics, and to approximate predevelopment hydrology.

Background

Water quality problems are particularly challenging for managing stormwater on the urban/suburban landscape. Although the sources and impacts were intensively studied and documented more than two decades ago, until fairly recently urban stormwater has been viewed by the general public as largely a drainage problem, with little regard for downstream effects. Only in the last decade or so has there been a concentrated effort to address water quality conditions. Equally challenging are the problems of controlling runoff from rural areas where nutrients, sediment, pesticides, and herbicides are of concern.

Recommendation

1) **Testing/Evaluating Stormwater Management Strategies:** Technological innovation is needed in all aspects of runoff control, including approximating the ideal of replicating pre-development hydrology, and controlling nutrients, sediment, bacteria, and toxics. Substantial research and development, including field-testing, is needed in terms of improving the technology of stormwater management. The focus should be on both separate “BMPs” and also on integration of controls into the development landscape.

Stream Corridor Protection

Priority need

1. Develop economical and cost-effective approaches to protection of biological integrity in streams.

Background
The aquatic and terrestrial habitats of stream corridors are particularly vulnerable to the impacts of development. From sediment deposition to streambank erosion to excessive paving to pollution runoff, special attention is needed on the science and technology of stream corridor restoration and protection.

Recommendation
1) **Stream Corridor Restoration & Approaches:** The restoration of stream corridor habitat is essential to the restoration of biological integrity. As existing technology and practices are often prohibitively expensive, a major focus should address cost-effective approaches.

Stewardship and Community Engagement

Citizen involvement is critical to Bay restoration, and hence distribution of information and engagement of the watershed's population is essential. Local populations receive and digest information which in turn, is passed to local officials to guide local-county decisions that ultimately control loads to the Bay. Therefore, *Chesapeake 2000* emphasizes this need for communication to the citizens. The effort can succeed through preparation and distribution of reference documents reflecting current state-of-the-art; development of protocols for prioritizing projects; assessment of tax codes or regulatory requirements; publication of case studies; workshops targeting specific topics; or areas where additional research is needed.

Background
Distributing information and tools to the citizens, planners, and local governments is critical to familiarizing these individuals and organizations with relevant materials. However, implementing restoration of the Chesapeake bay watershed requires specific training and application in the users' hands and staffs.

Recommendations
1) **Bay-Specific User Friendly Software and Training:** Data distribution and user friendly public software and training in its use must become part of core education programs for K-12 populations, as engaging older citizens has proven effective for only a small portion of the regional population. Bay-centric efforts for understanding the links between air, land use, and the Bay must become routine through schools so that a decade from now, these trained young adults can better digest newly acquired information from one sector of our ecosystem and know potential impacts on others.

2) **Land Use Tool Distribution:** Success in achieving environmentally sensitive site design depends on outreach efforts and tools that are accessible to land development practitioners. These include landscape architects, land use planners, site designers, developers, site plan reviewers, and builders. There are significant needs for developing such tools.

3) **Data Information Transfer System:** The transfer of GIS referenced data, graphics, and interpreted information to local decision makers must be eased, expanded, and made cheaper. A simplified data and information transfer system must be created and implemented, and training provided for use of the distributed information. Further, the implementation of local stormwater, erosion control, and other water resource protection approaches should include local community access to air born monitoring and interpretation and access to and training in water re-use technologies for small contained developments.

4) **Model Applications at the Local Level:** Land use decisions in most locales are economically-based decisions with environment a lower level priority. Socio-economic modeling should be integral to all watershed modeling efforts, with the focus on township to county application and training. Models, for land use and economics, should permit local involvement and exploration. For assessment of impacts, expanded modeling capabilities, linking water quality, habitat, and economic costs and revenues for development and redevelopment could be an indispensable adjunct to land use, zoning, and site planning decisions.

5) **Education System for New Approaches for Reducing Local Loads:** Local community focusing on innovative wastewater treatment options should include exposure to nutrient reducing septic systems, passive and energy requiring demonstration projects such as vacuum systems for feces, and provide results from R&D on performance and improvements in new technologies as they become available.

6) **Transportation and Planning:** Transportation is a major air-born pollutant source. New urban center planning (e.g., new urbanism) and use of new automotive technologies (Freedom car, gas-electric and ethanol-biodiesel hybrids) must be encouraged with modeled emissions and savings (pollutants, fuels, etc.) estimated for local and regional jurisdictions. Similarly, as a major polluter, petroleum-product powered vehicles continue to increase as part of our societal fabric. Most urban areas cannot accommodate the costs for mass transit to populated but distant suburban areas. Hence, alternative fuel options are a priority for a cleaner Bay.

4) **Distribution of Management Procedures:** For most effective incorporation of science-based technologies, the CBP should develop a specific capacity for direct transfer and training of implementation procedures for planning/management at the lowest levels of public government in the watershed.