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U.S. Geological Survey Chesapeake Bay Science Plan, 2006-2011

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Executive Summary

The Chesapeake Bay, the Nation's largest estuary, has been degraded due to the impact of human-population increase, which has doubled since 1950, resulting in degraded water quality, loss of habitat, and declines in populations of biological communities. Since the mid-1980s, the Chesapeake Bay Program (CBP), a multi-agency partnership which includes the Department of Interior (DOI), has worked to restore the Bay ecosystem. To enhance restoration efforts, the CBP created Chesapeake 2000, an Agreement that establishes restoration commitments for the next 10 years in the Bay and its watershed. In 2005, which is the mid-point for most of the restoration commitments in Chesapeake 2000 and marks over 20 years of restoration activities by the CBP, there is growing concern at all levels of government, and by the public, that ecological conditions in the Bay and its watershed have not significantly improved, and many desired ecological conditions will not be achieved by 2010. There is an acute need for enhanced science to better document the reasons for the lack of significant ecosystem improvement, assess the types and potential locations of restoration activities that will provide the greatest benefit, and forecast changes in human activities and their potential impact on the ecosystem so policy makers can adapt longer-term strategies to achieve ecologically sustainable development in the Bay watershed.

The scope of science and management activities needed to improve conservation and restoration of the Bay ecosystem is complex and comprehensive, but opportunities to meet these challenges exist between the CBP partners. The President's Executive Order to foster "cooperative conservation" is being emphasized by the CBP Federal partners as they recently signed a resolution to enhance cooperative conservation for the Chesapeake Bay restoration. The U.S. Geological Survey (USGS) will be a leader in coordinating science to meet the goals of the resolution and new challenges for restoration of the Bay ecosystem.

Since the beginning of the Chesapeake Bay restoration effort, the USGS has the critical role of providing unbiased scientific information that is utilized to document and understand ecosystem change to help assess the effectiveness of restoration strategies in the Bay and its watershed. The USGS is revising its Chesapeake Bay science plan for 2006-2011 to meet the science challenges for more effective conservation and restoration of the Bay and its watershed. The revised science plan will address the collective science needs of the CBP, DOI, and USGS with a **mission to provide integrated science to support effective ecosystem conservation and restoration**. The USGS science themes for this mission are:
-Impact of human activities on land use;
-Factors affecting water quality and quantity;
-Ability of habitat to support fish and bird populations; and
-Synthesis and forecasting to improve ecosystem assessment, conservation, and restoration.

Under each science theme, the USGS will use a combination of monitoring, modeling, research, and assessment to (a) provide an improved understanding of the ecosystem to better target implementation of current conservation and restoration strategies, (b) assess

ecosystem change to help evaluate the effectiveness of management activities, (c) forecast the potential impacts of increasing human population and climate variability, and (d) synthesize the findings and provide implications to help policy makers and resource managers adapt improved approaches for the conservation, restoration, and ecologically sustainable development of the ecosystem.

The primary objectives of the science theme "impact of human activities on land use" are:

- Enhance monitoring of, and further define the factors causing, the past and present land-use change patterns in the Bay watershed;
- Develop approaches to integrate land-use change findings and forecasts with water quality, quantity, and habitat models; and
- Synthesize findings and provide implications to conserve land that provide water quality and ecological benefit.

The primary objectives of the science theme "factors affecting water quality and quantity" are:

- Improve monitoring and simulation of, and further define the processes affecting, the occurrence, transport, residence time, and change of nutrients and sediment in the watershed;
- Better define the function of key habitats (forests, wetlands, stream corridors) to adsorb and store nutrients and sediment;
- Relate the delivery of nutrients and sediment from the watershed to water quality in the estuary; and
- Synthesize information and conduct forecasts to provide implications and tools for improved targeting and assessment of water-quality management activities.

The primary objectives for the science theme "ability of habitat to support fish and bird populations" are:

- Address the function of habitat to support the fish and bird populations in stream corridors and near-shore estuary environments;
- Identify the additional factors impacting the health of fish and bird populations; and
- Synthesize findings, and use forecasts of land-use change and water availability, to provide implications and improve tools for conservation and restoration of habitat.

The primary objectives of the science theme "synthesis and forecasting to improve ecosystem assessment, conservation, and forecasting" are:

- Enhance assessment by developing improved CBP environmental indicators and explanation of ecosystem condition and change;
- Improve approaches to integrate predictions of land use, water quality and quantity, and habitat to forecast potential changes of the ecosystem; and
- Synthesize findings and provide implications for improving implementation of ecosystem conservation and restoration strategies and developing new approaches for ecologically sustainable development.

The USGS's priority will be to focus the majority of its efforts to address the four science themes in the watershed because (a) the majority of conservation and restoration activities will be implemented in the watershed, (b) understanding the function of the

different hydrologic settings and habitats in the watershed in processing nutrients and sediment will provide a more cost-effective approach to implementing management actions, and (c) land-use change in the watershed will continue to be the greatest stress on the health of biological communities in the watershed and the Bay. The USGS will address the interaction of the watershed and estuary by focusing on the factors affecting water quality and habitat in the watershed and their relation to the estuary.

The USGS will prioritize science activities for each theme based on the ability to plan and implement studies between multiple USGS Programs, scientists, and partners. The USGS has a goal to have fewer, more integrated studies to increase interaction and synthesis of findings between scientists and partners. Overall, 2006 will be a transition year that will include completion of current studies, synthesis of their results, and analysis of existing data and interaction with partners to plan and begin to implement new studies (or modify existing efforts). The majority of field efforts for new studies will occur in 2007-2009, with final interpretations and publications in 2010 and 2011. Information from both the regional and focus area studies will be used to help the CBP partners evaluate and revise the effectiveness of restoration strategies in spring 2007, assess whether the desired ecosystem improvement is being achieved by 2010, and begin to consider new protection and restoration strategies for the future.

Introduction

Issues Facing the Restoration of the Nation's Largest Estuary

The Chesapeake Bay is the Nation's largest estuary, which historically supported one of the most productive fisheries in the world. The Bay serves as the spawning ground for 70 to 90 percent of the striped bass in the Atlantic Ocean (fig. 1). The 64,000-square-mile watershed of the Bay provides vital habitat for migratory birds using the Atlantic Flyway. In addition to supporting aquatic communities and wildlife, the Bay's watershed serves the economic and recreational needs of almost 16 million people. The impact of human-population increase, which has doubled since 1950, has caused the decline of the Bay ecosystem including degraded water quality, loss of habitat, and declines in populations of biological resources. Additionally, the Bay was listed as an "impaired water body" in 1999 under the Clean Water Act, due to excess nutrients and sediment, and must meet regulatory water-quality standards by 2010.

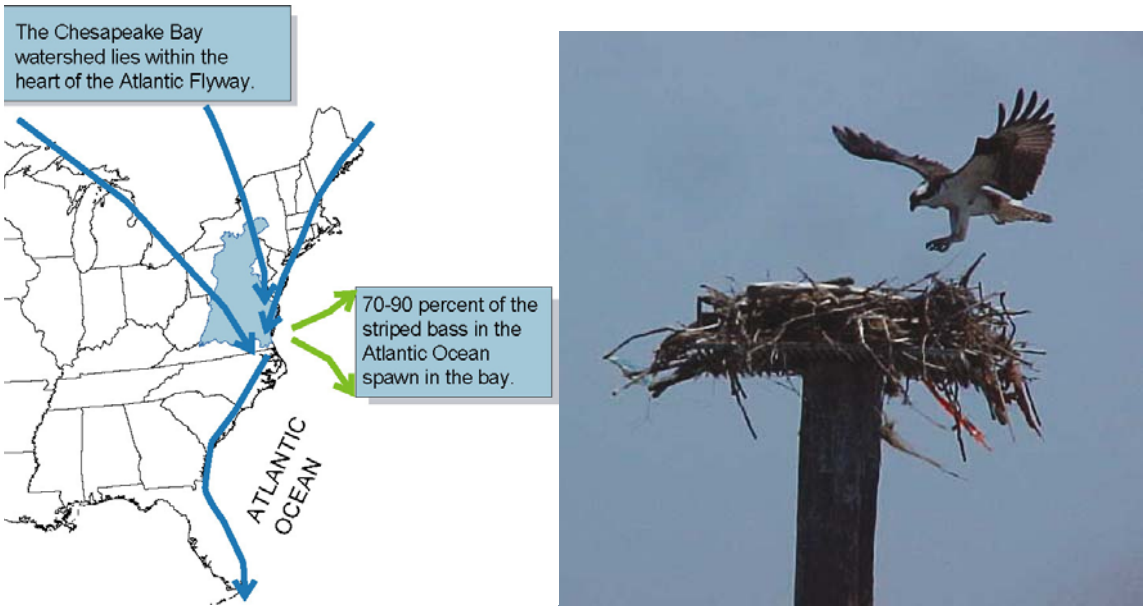

Figure 1-Location of the Chesapeake Bay watershed (modified from Phillips and others, 2002). The Chesapeake Bay and its watershed provides important habitat for both fish and bird populations and economic and recreational services for almost 16 million people. The impact of increasing human populations has lead to the estuary and streams in the watershed to be listed as "impaired" waters. Addressing the impacts of continued population growth and restoration of water quality and habitat to improve conditions for living resources is a primary focus for Chesapeake Bay Program. The U.S. Geological Survey has the critical role of providing unbiased scientific information that is utilized to document and understand ecosystem condition and change to help assess the effectiveness of conservation and restoration strategies in the Bay and its watershed.

Since the early 1980s, the CBP, which is a partnership between Maryland, Virginia, Pennsylvania, the District of Columbia, the Federal Government (including three DOI agencies), and the Chesapeake Bay Commission, has been formulating and implementing restoration goals to improve water quality and habitat to restore living resources. In 2000, the CBP recognized the need for an enhanced restoration effort and developed Chesapeake 2000, an Agreement that established over 100 restoration commitments for the next 10 years in the Bay and its watershed. The commitments were focused on achieving sound land use to reduce nutrient, sediment, and toxics and improve habitat to restore living resources in the Bay.

The technical needs for conservation and restoration of the Bay ecosystem have evolved since the signing of Chesapeake 2000 and include prioritization of the 100 restoration commitments into 10 "keystone" commitments. The keystone commitments have been organized into program areas including: (1) managing watersheds, which include commitments related to watershed planning, increasing land preservation, decreasing the rate of "harmful" sprawl; (2) managing for healthy waters, which includes the commitment to correct nutrient and sediment problems to remove the Bay from the impaired waters list, (3) managing habitats, which includes commitments for conserving forests along streams and shorelines and to restore wetlands and submerged aquatic vegetation (SAV); (4) managing fisheries, which includes commitments for multi-species

management of fisheries and restoration of oysters; and (5) fostering Chesapeake stewardship, which includes commitments for providing a meaningful Bay or stream experience for every school student and improving education and outreach.

In 2005, which is the mid-point for most of the restoration commitments in Chesapeake 2000 and marks over 20 years of restoration activities by the CBP, there is growing concern at all levels of government, and by the public, that ecological conditions in the Bay and its watershed have not significantly improved and many of the goals in Chesapeake 2000 will not be achieved by 2010. A recently released report by the Government Accountability Office (GAO) about the Bay restoration found that the Bay Program (1) has not yet developed an integrated approach for using individual measures to provide an overall assessment of progress in meeting the broad restoration goals of Chesapeake 2000, (2) the "State of the Bay" reports do not provide a clear and credible assessment of the condition of the Bay ecosystem, and (3) the Program lacks a comprehensive and coordinated implementation strategy to meet the goals of Chesapeake 2000 (Government Accountability Office, 2005). The GAO recommended the CBP (1) complete activities to provide an integrated assessment approach, (2) revise its reporting approach to provide effective and credible reports, and (3) develop a comprehensive and coordinated implementation strategy that takes into account available resources.

The science community through the CBP Scientific and Technical Advisory Committee (STAC) also addressed the challenges of restoring the Bay ecosystem in *Chesapeake Futures* (Boesch and Greer, 2003), which presented projections of the potential conditions in the Bay and its watershed in 2030. Potential future scenarios suggested that even if many of the commitments of Chesapeake 2000 could be met, increasing human population and associated land-use trends will result in only modest improvements in habitats and production of important Bay fisheries. The report suggests that alternative strategies and emerging technologies must be considered to improve the ecological and economic health of the Bay and its watershed.

There is a critical need to more effectively integrate science with implementation of conservation and restoration activities to (1) assess the types and potential locations of conservation and restoration activities that will provide the greatest benefit to the water quality and ecological health of the Bay and its watershed, and (2) provide a more integrated understanding and assessment of the factors affecting the status and change of ecosystem (the bay and its watershed) and response to restoration actions. Additionally, with continued population growth and the associated land-use trends in the Bay watershed, new science is needed to forecast potential changes that human activities will have on the ecosystem so policy makers can adapt longer-term strategies to achieve ecologically sustainable development in the Bay watershed. Ecologically sustainable development is the balance between population growth and the associated human activities (land-use changes and the use of natural resources), and the condition of the natural ecosystem (Marten, 2001). Further integration of science and management activities will help promote more of an "adaptive management" approach by having more integrated measurements of the ecosystem response to management activities, climate variability, and to use forecasting to help revise and develop new management approaches.

The Role of USGS and Need for a Revised Science Plan

The USGS has the critical role of providing unbiased scientific information that is utilized to document and understand ecosystem condition and change to help assess the effectiveness of conservation and restoration strategies in the Bay and its watershed. The USGS began research and monitoring studies in the late 1970s to document the amount and trends of nutrients entering the Bay, and the factors affecting the degradation of SAV. When the Bay Program was formed in 1983, the USGS was one of the original Federal partners and signed a Memorandum of Understanding (MOU) for providing science. Efforts increased significantly in the mid-1990s, when the USGS selected the Chesapeake Bay watershed as one of its priority ecosystems for study. At that time, the USGS began a multidisciplinary effort focused primarily on assessing the climatic and human factors affecting the sources, transport, and delivery of nutrients through the Bay watershed and determining the impact on selected environmental indicators of the Bay system (SAV). The studies were expanded to address fish and estuary health with the inclusion of the National Biological Service into the USGS in 1998.

To support the expanded technical needs of Chesapeake 2000, the USGS summarized existing studies and wrote a 5-year science plan (Phillips, 2002) with new science goals to help guide project directions and expand information delivery. The USGS science goals were closely related to Chesapeake 2000 and the needs of DOI agencies involved with the Chesapeake Bay and included:

Improve watershed and land-use data and analysis.
Understand the sources and impact of sediment on water clarity and biota.
Enhance the prediction, monitoring, and understanding of nutrient delivery to the Bay.
Assess the occurrence of toxic constituents and emerging contaminants.
Assess the factors affecting the health of fish and water birds.
Disseminate information and develop decision-support tools.

The goals were modified in 2003 to include wildlife to better reflect some of the information needs of DOI and also merge nutrient and contaminant issues. The USGS is conducting about 30 projects in the Chesapeake Bay and its watershed that address these goals and many of these projects will end in 2005 and 2006. Selected accomplishments for each of these goals are presented in Appendix A.

The USGS is revising its Chesapeake Bay science plan for 2006-2011 to meet the science challenges for more effective conservation and restoration of the Bay and its watershed. The revised science plan will address the collective science needs of the CBP, DOI, and USGS. More specifically, the USGS science plan will better reflect the needs of the "keystone" commitments, have an increased emphasis on DOI needs, address national priorities of the USGS, and promote more emphasis on partnerships with other science institutions and resource-management agencies.

Overview of Need for Increased and More Integrated Science

There are several recent summaries that address the technical needs and future directions of the principal USGS partners in the Bay restoration that were used to help revise the science plan. The science community through the CBP STAC outlined the expanding science needs and research priorities to meet the challenges of Chesapeake 2000 and many of the associated keystone commitments (Scientific and Technical Advisory

Committee, 2005). STAC updates the science priorities annually to help guide science conducted by agencies and institutions involved with the Chesapeake Bay restoration effort. The appropriate technical needs and research priorities are listed in each USGS science theme.

Involvement in the Chesapeake Bay restoration effort by USGS, U.S. Fish and Wildlife Service (USFWS), and National Park Service (NPS) meets the National DOI mission areas and goals, which include resource protection, resource use, recreation, and serving communities (U.S. Department of Interior, 2003). The DOI science needs related to Chesapeake Bay have increased with the USFWS Chesapeake Bay Field Office report to Congress (U.S. Fish and Wildlife Service, 2003), expanded needs of the USFWS Chesapeake Bay/Susquehanna River Ecosystem Team, and the expansion of the NPS "Gateways Network". The USFWS has technical needs that match many of those in Chesapeake 2000, but also has an emphasis on migratory birds, threatened and endangered species, and their habitats. The NPS has been focused on explaining the history and cultural significance of the Bay through the Gateways Network, and is expanding more toward watershed planning and protection of NPS resources. On a National level, the USGS also has worked closely with USFWS to identify areas of future challenges that are relevant to both agencies. The four focus areas are: (1) global climate change, (2) biotechnology, (3) water for ecological needs, and (4) invasive species. All of these topics are relevant to the Chesapeake Bay restoration. The USGS is the principal science agency for DOI; therefore, increased science efforts are required to meet the collective needs of both the CBP and DOI agencies involved in the restoration of the Bay and its watershed.

There are increased science needs to meet the recommendations of the U.S. Commission on Ocean Policy (U.S. Commission on Ocean Policy, 2004) and the subsequent U.S. Ocean Action Plan. The Commission recommended that an ecosystem-based management approach is needed for managing oceans and coastal systems such as Chesapeake Bay. The Commission focused on several areas of change including strengthening science and generating high-quality, accessible information to inform decision makers. There is a need to improve the understanding of ocean and coastal environments and enhance the Nation's ability to observe, monitor, and forecast ocean and coastal conditions. In the Chesapeake Bay, this would include implementing a Chesapeake Bay Observing System (CBOS) as part of the regional networks that would comprise the National Integrated Ocean Observing System (IOOS).

The need for more integrated monitoring and modeling systems was also stressed during the 18th Biannual Conference of the Estuarine Research Federation. There was emphasis on the need to create integrated observing systems for watersheds and estuaries. Opportunities were identified to jointly plan and attempt to integrate some of the proposed efforts, which included linking land-based ecology observing systems with water-related observing systems to more effectively allow direct and rapid linking of receiving water responses to land- or watershed-based forcings (Sellner, 2005). The national scale observation systems would also need comprehensive modeling systems to integrate, assimilate, interpret, and disseminate data and derived projects (Gross and Hood, 2005).

There is also an increased need for science to improve ecological forecasting. Ecological forecasts predict the impacts of physical, chemical, biological, and human-induced change on ecosystems or their components (Committee on Environment and Natural Resources, 2001). Extreme natural events, climate change, land and resource use, pollution, and invasive species are five key drivers of ecosystem change. Most ecosystems are subjected to mixtures of these stresses and building the capacity to forecast the cumulative effects of multiple stresses is one of ecology's most significant research challenges (Valette-Silver and Scavia, 2003).

The scope of science and restoration activities needed to improve conservation and restoration of the Bay ecosystem is complex and comprehensive, but opportunities to meet these challenges exist in the CBP. The President's Executive Order to foster "Cooperative Conservation" is going to be emphasized by the CBP. The Federal partners, including DOI, USGS, USFWS, and NPS recently signed a resolution to enhance Federal cooperative conservation in the Chesapeake Bay Program. Federal, State, and academic partners are working to better integrate science efforts through coordination under STAC and the multiple partners are participating in the first annual comprehensive assessments which have been recommended by the General Accountability Office. There is a need and opportunity for enhanced scientific integration in the future that will benefit the Chesapeake Bay restoration efforts and have transferability to ecosystems in the United States and throughout the world.

Considerations for the Revised USGS Science Plan

The USGS has interacted with scientists, managers, and partners, and has established the Chesapeake Bay Executive Advisory Team (CBEAT) to provide guidance on the scope and priorities of the science plan. Based on the peer review comments of the CBEAT, interaction with other partners, outcomes from the USGS Chesapeake Bay Science workshop held in May 2005, and subsequent interaction with USGS scientists and managers, the following considerations were used to revise the science plan:

- The USGS Chesapeake Bay science themes should continue to be related to the CBP issues of concern (land use, water quality, habitat, and living resources), but be more focused, given the level of funding.
- Of these issues, science themes related to land use and water quality in the watershed should be the highest priority. The function of habitats in the biogeochemical cycling of nutrients and sediment in the watershed and implications for improving restoration of habitat would be an important complementary topic for water quality.
- Studies of living resources in the estuary are mostly being led by other agencies and institutions so the USGS should consider these as a lower priority that may be addressed by forming additional scientific partnerships.
- The USGS may want to focus more on the function and restoration of habitat conditions to support living resources in the watershed to complement the proposed focus on land use and water quality in the watershed. The impact of other stressors such as water availability for ecological needs and invasive species on the function of stream habitat should be considered. The health of fish and bird populations depending on the stream corridors could be an additional consideration for the science plan.

- Having a higher proportion of studies in the watershed than in the estuary since there is a significant need to understand the relation between changes in human activities, water quality in the watershed, and implementing restoration activities. However, there was strong agreement that an important component of the science themes would be to improve the understanding of the relation between the watershed and the estuary. Further study of the influence of the environmental framework (shallow geology and watershed characteristics) on the delivery of flow, nutrients, and sediment from the watershed to the estuary and its impact on water clarity was suggested as a continuing critical science need.
- The USGS should consider conducting the majority of its efforts to explain ecosystem conditions in major river basins and supplement these with process-oriented studies at more local scales. Local-scale studies should be conducted based on improving the understanding of regional conditions, models, and the ecosystem response to restoration activities. One or two "focus" areas should be identified to select locations to conduct the local-scale studies.
- Given the complexity of understanding and restoring the Bay and its watershed, the USGS should explore greater interaction with academic institutions in STAC, and additional partnerships with agencies and organizations conducting restoration activities to plan future studies.
- There needs to be a balance between monitoring, modeling, research, assessment and communication. The USGS should strengthen efforts in monitoring, assessment, and research to improve models. The uncertainty inherent in these models should be identified to help guide the type of process studies needed to improve the models.
- The synthesis of information to help resource managers and policy makers understand the implications of science findings for restoration should have high priority. The USGS should clearly articulate how efforts will be better integrated so that findings can be used to improve indicators of ecosystem condition, change, and restoration.
- The USGS should consider evolving from having a collection of individual studies to having fewer, more integrated studies focused on the highest priorities.

Additionally, some of the findings of the National Research Council (NRC) study (2001) of future directions for USGS apply to Chesapeake Bay. The NRC recommended the USGS place more emphasis on multi-scale, multidisciplinary, integrated projects that address priorities of National scale. The NRC also recommended USGS information management should shift from a passive role of study and analysis to one that seeks to convey information actively. Further, the USGS should provide National leadership and coordination in (1) monitoring, reporting, and where possible, forecasting critical phenomena (including seismicity, volcanic activity, streamflow, and ecological indicators), (2) assessing resources, and (3) providing geospatial information. These recommendations were also considered to help revise the USGS science plan for Chesapeake Bay.

Finally, the FY2006 Annual Guidance from the USGS Director lists four science thrusts for Interdisciplinary Science Priorities: (a) landslides/debris flows, (b) fire science, (c) water availability for ecological needs, and (d) integrated landscape modeling. Future USGS studies in the Chesapeake Bay, which was identified in the Director's Guidance as

an area for continuing active science, can contribute greatly to aspects of two USGS science thrusts: water availability for ecological needs and integrated landscape modeling. The annual guidance also recommends USGS studies and programs set priorities based on budget constraints so that we can conduct our work with excellence.

Revised USGS Chesapeake Bay Science Mission, Themes, and Approach

The revised mission for USGS Chesapeake Bay studies is to provide integrated science to support effective ecosystem conservation and restoration. To meet this mission, USGS Chesapeake Bay studies will address four science themes:
-Impact of human activities on land use;
-Factors affecting water quality and quantity;
-Ability of habitat to support fish and bird populations; and
-Synthesis and forecasting to improve ecosystem assessment, conservation, and restoration.

Under each science theme, the USGS will use a combination of monitoring, modeling, research, and assessment to (a) provide an improved understanding of the ecosystem to better target implementation of current conservation and restoration strategies, (b) assess ecosystem change to help evaluate the effectiveness of management activities, (c) forecast the potential impacts of increasing human population and climate variability, and (d) synthesize the findings and provide implications to help policy makers and resource managers adapt improved approaches for the conservation, restoration, and ecologically sustainable development of the ecosystem.

The USGS's priority will be to focus the majority of its efforts to address the four science themes in the watershed because (a) the majority of conservation and restoration activities will be implemented in the watershed, (b) understanding the function of the different hydrologic settings and habitats in the watershed in processing nutrients and sediment will provide a more cost-effective approach to implementing management actions, and (c) land-use change in the watershed will continue to be the greatest stress on the health of biological communities in Bay and its the watershed. The USGS will also address the interaction between the watershed and estuary by focusing on the factors affecting the water quality and habitat in the watershed and their relation to the estuary.

Current Understanding of the Chesapeake Bay Ecosystem

To better identify the potential scope for the revised USGS science themes, a conceptual diagram was used to present the current and potential future conditions of the Bay ecosystem (fig. 2). The conceptual diagram was originally prepared by the CBP and more recently modified (U.S. Environmental Protection Agency Chesapeake Bay Program and the Integration and Analysis Network at the University Of Maryland Center for Environmental Science, 2005). The USGS further modified the diagram to have more emphasis on watershed conditions and future population growth. The conceptual diagram represents the collective understanding of many scientists working on the Chesapeake Bay ecosystem so individual references are not listed for the following text.

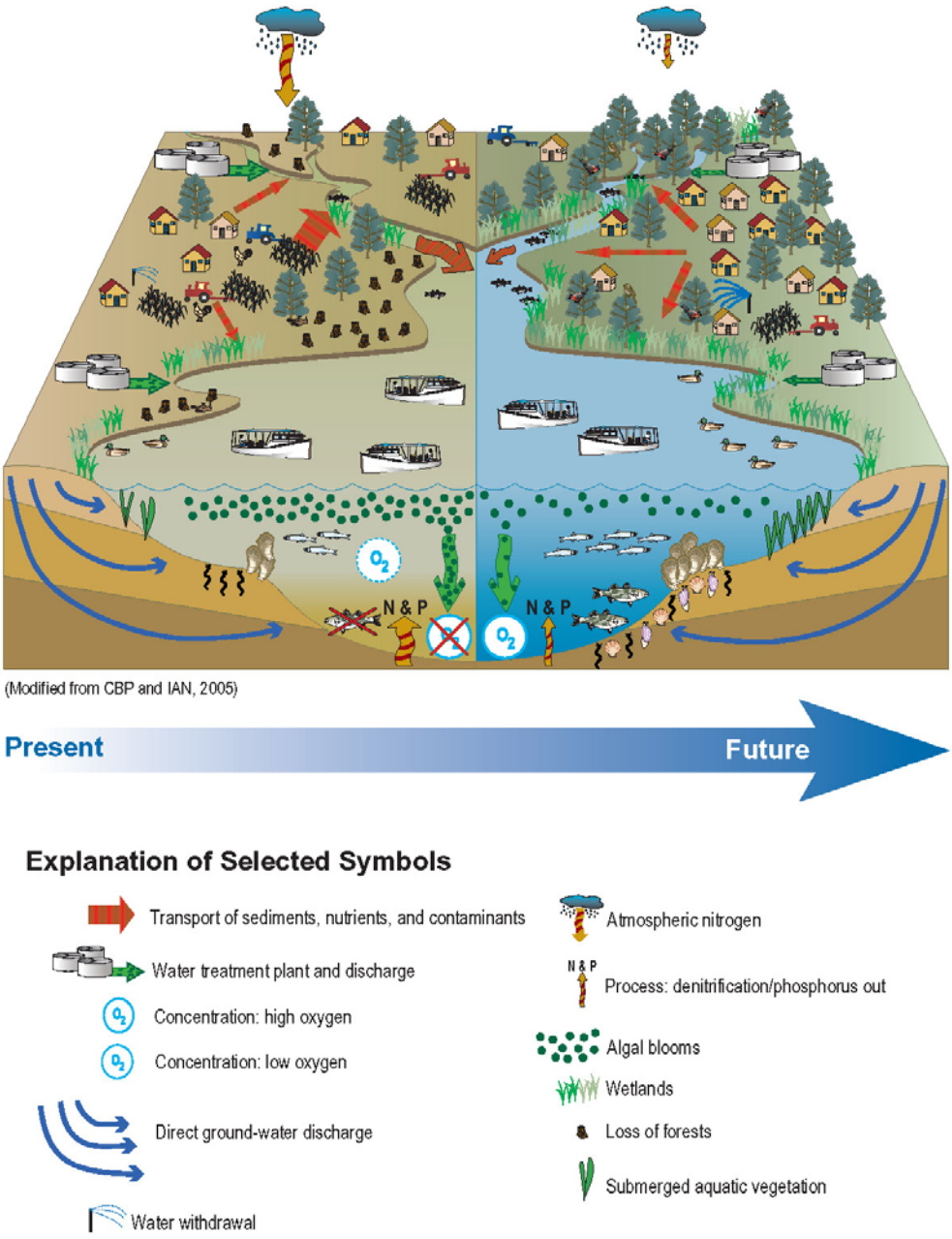

Figure 2. Conceptual diagram of current and potential future condition of the Chesapeake Bay ecosystem.

The conceptual diagram shows current and potential future conditions in the watershed and estuary. Future conditions in watershed will be further affected by human-population increase and the associated impact on land use, water quality, water availability, and habitat loss and fragmentation. All of these factors will continue to have negative impacts on habitats and biological communities in both the watershed and the estuary. The degree to which water-quality and ecological conditions improve in the future will likely depend on the degree of implementation and effectiveness of conservation and restoration actions. More integrated science can provide better targeting of management actions to provide the maximum water-quality and ecological benefit to the Bay and its watershed.

The present conditions shown in the conceptual diagram (fig. 2) illustrate the impact of human activities on land use and different types of stressors on the ecosystem, including chemical stressors, alteration of habitat, and introduction of invasive species. The principal chemical stressors include nutrients (nitrogen and phosphorus) and sediment, with contaminants occurring in localized areas. Some of the major sources of nitrogen in the watershed include point- source discharges, and nonpoint sources from agricultural and developed lands, and atmospheric inputs. Phosphorus has similar sources except for a lack of atmospheric deposition, while sources of sediment in the watershed are mostly runoff from agricultural and developed lands and erosion of stream corridors. Alteration of habitat includes loss and fragmentation of forests and wetlands, and increases in impervious surface, which cause greater and more intense surface-water runoff and decrease ground-water flow to streams. Introduction of invasive species has altered structure and diversity of wetlands and other habitats.

The transport of chemical stressors through the watershed to streams, and ultimately the Bay, depends on the types and distribution of physical and biogeochemical processes in different landscape settings. The landscape settings are comprised of different combinations of physical and biological characteristics that occur in the watershed (fig. 3). Physical processes include climate variability and the environmental framework (topography, soil permeability, slope, stream geometry, and geologic framework) that influence stream- and ground-water flow regimes that control the transport of nutrients, sediment, and contaminants. The Bay watershed has different hydrogeomorphic settings, which are distinct combinations of topography, soils, and geology that influence the transport and residence time of nutrients and sediment through the watershed. These settings have been classified in slightly different ways by various investigators with one example based on Bachman and others (1998) shown in figure 3. Some of the major biogeochemical processes influencing the chemical stressors include (1) absorption onto sediment, (2) transformation by microbial processes in soils and shallow geologic materials, and (3) biotic uptake of nutrients in different habitats including forests, wetlands, and stream corridors. The type and function of different habitats varies in different ecoregions of the Bay watershed (shown in fig. 3). The water-quality function of habitats to absorb and store nutrients and sediment has been greatly compromised in the watershed due to land-use change, and can also differs depending on the hydrologic settings and ecoregions. There is also direct delivery of nutrients to the estuary through point-source discharge and direct ground-water discharge, and delivery of sediment from erosion of near-shore areas (fig. 2).

The combined impact of water-quality degradation, loss and fragmentation of forests and wetlands, impact of invasive species, changes in streamflow conditions, and blockages to fish migration have degraded stream corridors in the watershed and have also compromised their ability to support healthy fish and bird populations. Also, some chemical stressors, such as endocrine disruptors, have directly impacted the health of fish populations in some areas of the Bay watershed.

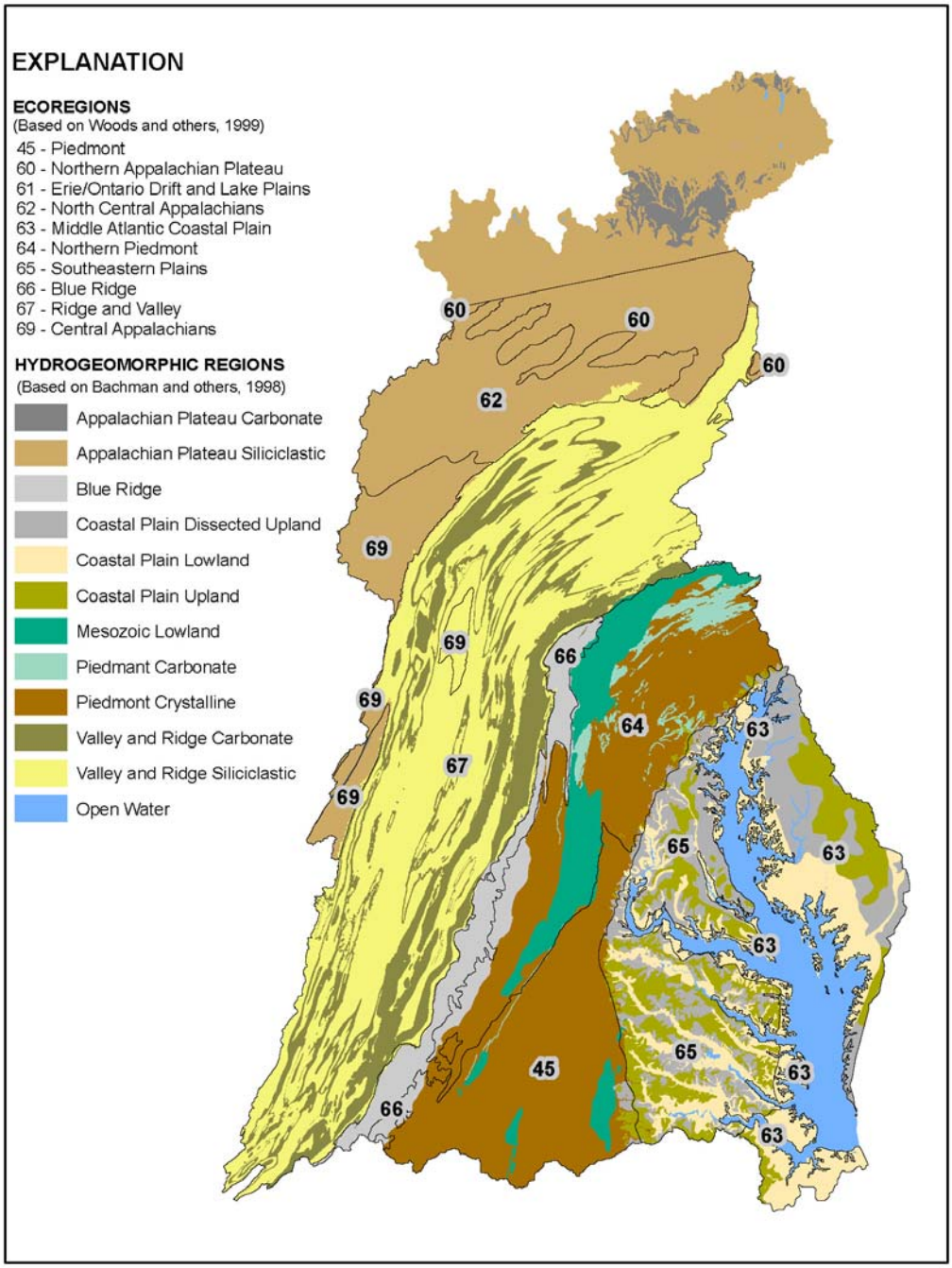

Figure 3-Different landscape settings in the Bay watershed.
The different combinations of physical and biological characteristics that occur in the watershed comprise unique landscape settings, which affect the transport of nutrients, sediment, and contaminants in the watershed and to the estuary. Developing a better understanding of the influence of landscape settings on water quality and habitat will improve implementation and assessment of conservation and restoration activities

The conceptual diagram also illustrates the important links (water quality and ecological) between the watershed and estuary. Present conditions reflect an overabundance of nutrients and sediment from the watershed, with their delivery influenced by natural variation in climate and river flow, that impact dissolved oxygen and water-clarity conditions in the tidal waters. Low dissolved-oxygen levels have degraded conditions important for fish spawning and resulted in fish kills. Poor water clarity, due to both nutrients and sediment, has resulted in a decline of the native SAV species. Some of the other key ecological linkages between the watershed and estuary include the (1) delivery of contaminants and pathogens that impact the health of fish and water-bird populations in the Bay, (2) improvement of fish migration from the estuary to spawning areas in the watershed through removal of blockages and construction of fish passages, and (3) the loss of habitat in near-shore areas that support water-bird populations. In addition to the watershed-estuary interactions, the biological communities in the estuary are impacted by harvest pressure, invasive species, and disease.

The conceptual diagram shows potential future conditions in the watershed and estuary. Conditions in watershed will be further affected by human-population increase and the associated impact on land use, water quality, water availability, and habitat loss and fragmentation. All of these factors will continue to have negative impacts on habitats and biological communities in both the watershed and the estuary. The degree to which water-quality and ecological conditions improve in the future will likely depend on (1) the degree of implementation and effectiveness of conservation and restoration actions, (2) improved land-use and resource planning decisions that promote ecologically sustainable development, and (3) impact of climate variability. Both improved land-use planning and implementation of conservation and restoration activities in the watershed can be better informed and implemented by a more integrated understanding of the influence of different landscape settings and habitats affecting nutrient, sediment, and contaminant transport to streams and delivery to tidal waters. Additionally, improved understanding of the complex ecosystem interactions between the habitats, and other factors affecting the health of fish and bird populations in stream corridors and near-shore estuary environments is needed to provide improved conservation and restoration of these habitats for the biological communities that depend on them. Finally, forecasts of future land-use conditions and climate scenarios with their potential impact on the watershed and Bay are needed to improve land-use and resource planning for ecologically sustainable development.

Integration of Activities and Study Scales to Address the Science Themes

The USGS approach to address the science themes will stress integration and refinement of USGS efforts and enhanced coordination with partners. “Integration” applies to both the programmatic and science approaches needed to achieve the mission statement. The programmatic integration needs to be achieved between multiple USGS programs supporting the Chesapeake projects and enhanced interaction with partners. The USGS portfolio of projects will evolve from a collection of studies addressing individual technical needs to having one project for each of the science themes. The projects will be integrated through joint planning between USGS scientists that will include having a core group of scientists (the Integrated Synthesis and Forecasting Team, or ISFT) working together to plan, execute, and synthesize findings from the projects. The USGS projects will also be coordinated with partners’ efforts to achieve an improved understanding of

the watershed and estuary conditions, and improve implementation and assessment of conservation and restoration activities.

To further integrate the science efforts between the four primary USGS themes, several key questions will be addressed that are critical to more effective conservation and restoration. Some of the key questions include:

- What is the impact of human-population growth on land use and resources in the Bay watershed?
- How can a more integrated understanding of the influence of landscape settings and habitats affecting the transport and residence time of nutrients and sediment be used to better implement and target management actions to improve water quality?
- How can enhanced integration of monitoring and modeling of water-quality changes be used to better assess the effectiveness of management actions?
- How can actions to improve water-quality conditions be better integrated with activities to conserve and restore habitats to improve the health of fish and bird populations?
- How can forecasts of human population growth be used with scenarios of climate variability to help develop future strategies for sustainable ecological development in the Bay watershed?

The science questions require a more integrated approach to monitoring, modeling, research, and assessment in the Bay watershed and estuary. The USGS will provide leadership and enhanced coordination between CBP partners to develop more integrated networks, modeling systems, and assessments for the watershed. More integrated watershed monitoring and modeling is required to address (a) land-use change, (b) surface-water quantity and quality, (c) ground-water quantity and quality, (d) habitat change, and (e) status and change of biological communities in the watershed. Currently, there are few integrated networks to address these monitoring needs but there are some existing networks, such as the CBP Nontidal Water-Quality Network, that can be enhanced to develop more integrated observation networks. Existing watershed modeling systems, such as the CBP Phase V model and USGS SPARROW (SPAtially Referenced Regressions On Watershed attributes) model (Preston and Brakebill, 1999), mostly focus on surface-water quality. The USGS will focus efforts to develop more integrated watershed models and conduct research to improve information about the water quality and ecological processes that are most needed for the models. The USGS will promote work with partners to further enhance the CBP environmental indicators and synthesize findings to improve assessments of the stressors impacting, and condition of, the watershed and the Bay. A summary of the monitoring, modeling systems, and assessments that will be the priorities of the USGS Chesapeake Bay science themes are listed in table 1. More detailed information for these activities is provided in the respective sections for each science theme.

Table 1—Summary of U.S. Geological Survey science themes and associated activities				
USGS Science Theme	Objectives	Monitoring/Modeling	Research/Assessment	Environmental Indicators/Applications
Impact of Human Activities on Land Use	-Enhance monitoring of, and further define the factors causing, past and present land-use change patterns. -Develop approaches to integrate land-use change findings and forecasts with water-quality, quantity, and environmental impact models. -Synthesize findings and provide implications for land conservation providing water quality and ecological benefit.	-Develop monitoring plan that addresses comparable data to assess land cover and habitat change. -Enhance land-use change forecasting models.	-Analysis of factors affecting land-use change patterns. -Relation of land-use change patterns to water quality and habitat. -Approaches to couple land-use change models with water quality and habitat models to provide forecasts.	-Indicators of land-cover change. -Enhance Resource Lands Assessment to improve targeting of land conservation.
Factors Affecting Water Quality and Quantity	-Improve monitoring and simulation of, and further define the processes affecting, the occurrence, transport, residence time, and changes of nutrient and sediment in the watershed. -Better define the function of key habitats to adsorb and store nutrients and sediment. -Relate the delivery of nutrients and sediment from the watershed to water clarity in the estuary. -Synthesize information and conduct forecasts to provide implications and tools for improved targeting and assessment of water quality.	-Enhance Nontidal Water-Quality Network to assess nutrients, sediment, streamflow, and ground water. -Enhance “Phase V” Watershed models and SPARROW nutrient and sediment models. -Develop ground-water models and couple with surface-water models to address water quality and availability in streams.	-Ground-water quantity, nitrogen, processes, and residence time. -Sediment and nutrient sources, transport, processes, and residence time. -Water-quality change over different time scales. -Approaches to couple land-growth forecasts and climate scenarios with water-quality and availability models to provide water-quality forecasts.	-Indicators of water-quality status, trends, and restoration progress. -Use to identify areas of high nutrient and sediment occurrence and delivery to target water-quality restoration. -Assess processes and restoration effectiveness in different landscape settings. -Help explain and forecast ecosystem changes over time due to natural and human influences.

USGS Science Theme (con't)	Objectives	Monitoring/Modeling	Research/Assessment	Environmental Indicators/Application
Ability of Habitat to Support Fish and Bird Populations	-Address the ability of habitat to support fish and bird populations in stream corridors and near-shore estuary environments. -Identify additional factors impacting the health of fish and bird populations. - Synthesize findings, and use forecasts of land-use change and water availability, to provide implications and improve tools for conservation and restoration of habitat.	-Monitoring of water quality and ecological function (physical change and fragmentation) of habitat to support fish and bird populations. -Utilize ground-water/surface-water models to assess ecological flows for streams. -Monitoring to assess the health of fish and bird populations. -Assess potential for ecosystem models for fish and bird population in stream corridors. -Enhance existing estuary models for water clarity, SAV, fisheries.	-Causes of compromised reproductive systems, lesions, and mortality of fisheries. -Causes of compromised habitat and potential restoration approaches. - Approaches to couple land-growth forecasts and with water-quality and availability models to predict impact on water availability to support ecological flows for streams.	-Enhance indicators of wetlands, riparian forest buffers, and SAV. -Develop indicators of health of fish and birds in the watershed and the Bay. -Assess if health of fish and bird populations responding to management actions. -Enhance Resource Lands Assessment to better target conservation and restoration of habitat.
Synthesis and Forecasting to Improve Ecosystem Assessment, Conservation, and Restoration	-Enhance assessment by developing improved CBP environmental indicators and explanation of ecosystem condition and change. -Improve approaches to integrate predictions of land use, water quality and quantity, and habitat to forecast potential changes of the ecosystem. -Synthesize findings, and provide implications for improving ecosystem conservation and restoration and new approaches for ecologically sustainable development.	-Use selected results from models and monitoring to enhance decision support tools. -Use coupled models to forecast future conditions.	-Integration of multiple approaches to assess ecosystem conditions and change.	-Identify areas where conservation and restoration would provide the highest water-quality and ecological benefit. -Help develop overall assessments of Bay ecosystem and effectiveness of restoration -Provide future conditions to help develop new conservation and restoration strategies.

The spatial and temporal scales needed to address the monitoring, modeling, research, and assessment for the USGS science themes were chosen based on consideration of several factors including: (1) scales of the physical, chemical, and biological processes being addressed, (2) scales of existing and desired monitoring and models, (3) scales of the planning and implementation of conservation and restoration activities, and (4) scales for assessments of water-quality and ecological conditions and trends. An assessment of the different scales needed to address these factors revealed several conclusions. The existing watershed monitoring and water-quality models are principally at regional scales (entire basins to hundred-square-mile watersheds). The scale for conservation and restoration planning for water quality is mostly at the scale of the tributary-strategy basins (several hundred to several thousand-square-mile areas); however, more local-scale information is needed for implementation of strategies within these areas. Conservation and restoration of habitats, such as improvement of stream corridors, is occurring at very local scales such as stream reaches and areas of several square miles. Watershed planning often occurs at the county level and smaller areas. Assessments of water-quality changes are occurring mostly in large river basins and their associated tidal waters and for the entire Bay. There are some assessments of smaller watersheds and tidal water bodies being conducted. The primary temporal scales include annual updates of long-term trends (since 1985) of ecosystem change, with focus on shorter periods of time to address annual changes in the ecosystem conditions and restoration progress. Temporal scales for forecasting include annual to decadal predictions.

Given the information needs at different scales, the USGS will conduct the majority of the science theme activities at regional scales, with complementary local-scale studies in two focus areas, which include the Potomac watershed and estuary and the mid-Delmarva Peninsula (fig. 4). The primary regional scales will be (a) the entire watershed, (b) the major drainage areas in the watershed, and (c) major landscape settings within the watershed. The major drainage areas in the watershed will focus on the River-Input sites that collectively represent 78 percent of the drainage into tidal waters and the Coastal Plain. The Coastal Plain drainage area, which is the area east of the Fall Line (fig. 4), is important because it contains the interface between nontidal and tidal waters, and 20 to 40 percent of the nutrient and sediment load to tidal waters is believed to originate there. The third regional scale will be major landscape settings, which will include a combination of different hydrologic settings and ecoregions (shown in figure 3), and major types of land cover (agricultural, urban, and forest) in the Bay watershed.

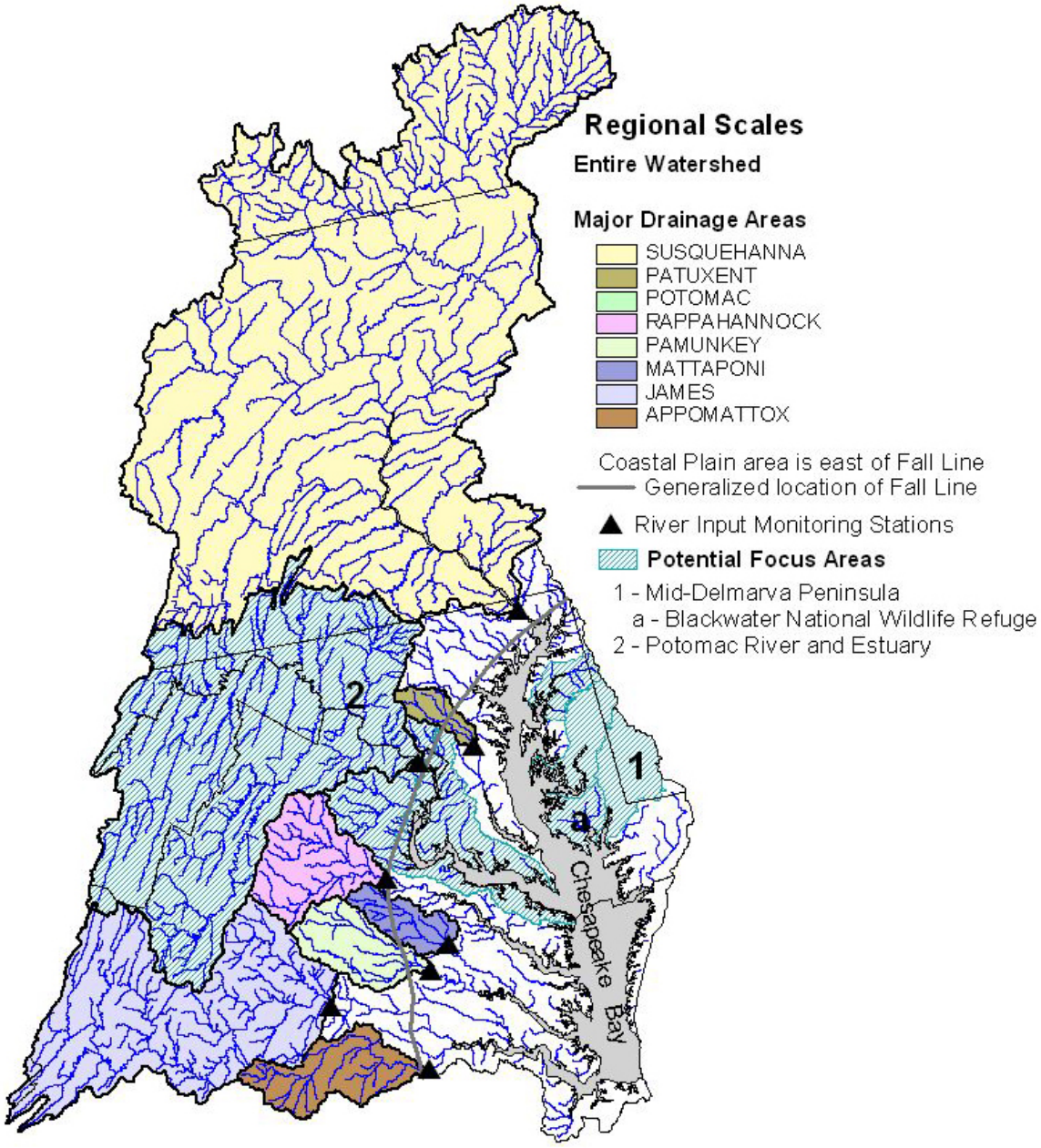

Figure 4—Regional study scales and focus areas for the USGS Chesapeake Bay studies. USGS will conduct the majority of the science theme activities at regional scales, with complementary local-scale studies in two focus areas, which include the Potomac watershed and estuary and the mid-Delmarva Peninsula. The primary regional scales will be (a) the entire watershed, (b) the major drainage areas in the watershed, and (c) major landscape settings.

The science themes addressing (1) the impact of human activities on land use, and (2) the factors affecting water quality and quantity will be conducted primarily at the regional scales with some local-scale studies in the focus areas. Addressing the water-quality and habitat interactions between the watershed and the estuary will also be conducted in the focus areas. The science theme addressing the ability of habitat to support fish and bird populations will be addressed mostly through local-scale studies in the focus areas. Synthesis and forecasting will be focused mostly on the regional scales with some complementary information from local-scale studies to provide an improved understanding of regional findings.

The three regional scales will provide different perspectives for improving the understanding of the ecosystem, explaining change, and forecasting future conditions. Analyzing and forecasting information for the entire watershed will provide assessments of conditions and trends of land use and water-quality conditions throughout the entire Bay watershed and help assess the collective impact on the health of the estuarine system. The major drainage areas will provide assessment of water-quality conditions and trends with regard to implementation of tributary strategies and comparison to tidal tributaries.
Addressing landscape settings will provide a greater understanding of processes controlling water quality and habitat at more local scales that will be useful in implementing and assessing management activities in the tributary strategy basins and county-level scales and improving models.

The USGS will explore using a more quantitative approach for classifying hydrologic landscapes in the Bay watershed that has been proposed by Winter (2001) and developed for the entire United States (Wolack, Winter, and McMahon, 2004). Hydrologic landscape units are defined on the basis of land-surface form, geology, and climate and have a complete hydrologic system consisting of surface runoff, ground-water flow, and interaction with atmospheric water. The USGS will also utilize findings from the landscape approach used by the CBP under the Resource Lands Assessment (RLA) (U.S. Environmental Protection Agency, 2004) to consider classifications of the Bay watershed. Once a classification has been developed, the USGS will conduct analysis to improve the understanding of how the biogeochemical and hydrological processes differ within these landscape settings within different land uses. The findings will be used to improve conceptual and quantitative models to help resource managers better target implementation and effectiveness of the conservation and restoration activities for water quality.

Local studies will be focused in two primary areas: the Mid-Delmarva Peninsula, and the Potomac Basin and Estuary (fig. 4). These areas would also be used to focus more local-scale studies for (a) addressing the processes influencing regional water-quality conditions in different landscape settings, (b) addressing the ability of habitat to support fish and bird populations, and (c) linking water quality and habitat of the watershed and estuary. These two focus areas contain the areas of the major landscape settings and habitats within the Bay watershed, so findings from the focus areas will have transferability to other areas of the Bay watershed. The USGS will work with partners to select specific locations and the potential scope of the local studies in the focus areas. The Potomac River and Estuary system was selected because it represents the second greatest freshwater flow to the Bay

and there is a significant impact of human population activities on land use, water quality and quantity, habitat, and living resources. The Potomac also has an ongoing study of water availability in the Great Valley that could be enhanced to address water quality and habitats. A multi-agency effort to address shallow water conditions is planned for the Potomac Estuary during FY2006-2008. The Mid-Delmarva Peninsula area represents high agricultural land use and also increasing urban development in the Coastal Plain. Additionally, it is an area that contains major DOI land holdings, including the Blackwater National Wildlife Refuge, and has an important land-preservation effort under the Delmarva Conservation Corridor. There are several planned restoration activities in these areas including Blackwater Refuge and the Choptank and Chester River Basins. There is also an effort underway to address water availability in the Coastal Plain of Maryland that would include both focus areas.

Timelines

Overall, FY2006 will be a transition year that will include completion of current studies, synthesis of their results, and analysis of existing data and interaction with partners to plan and begin to implement new studies (or modify existing efforts). Table 2 presents some of the major activities and timelines for all of the USGS Science Themes. The majority of field efforts for new studies will occur in FY2007-2009, with final interpretations and publications in FY2010 and FY2011. Information from both the regional and focus area studies will be used to help the CBP evaluate and revise the effectiveness of restoration strategies in spring 2007, assess whether the desired ecosystem improvement is being achieved by 2010, and begin to consider new protection and restoration strategies for the future. Selected reports and articles will be released each year and a carefully designed "launch strategy" will be prepared to identify project timelines and delivery mechanisms.

Table 2: Timelines and major activities for U.S. Geo logical Survey Chesapeake Bay Studies						
Major Activities	2006	2007	2008	2009	2010	2011
Prepare synthesis report of USGS studies, 2000-2005.	X					
Prepare integrated workplans for revised science themes, select analytical tools, and study locations.	X					
Conduct analysis of existing data and conduct selected field efforts.		X	X	X		
Prepare selected reports and journal articles. Prepare annual plans for “launch strategy” for product timelines and delivery mechanisms.	X	X	X	X	X	X
Participate in CBP Annual restoration and State of the Bay reports.	X	X	X	X	X	X
Participate in Re-evaluation of Water Quality.		X	X			
Participate in 2010 Evaluation of Water Quality and other Chesapeake 2000 goals.					X	
Synthesis report of USGS findings and future implications.					X	X

Science Theme: The Impact of Human Activities on Land Use.

Issues and Technical Needs

Increasing human populations and the associated land-use changes continue to be the primary factors causing water quality and habitat degradation in the Bay and its watershed. Human populations, and associated urban areas, are expected to grow to 19 million people by the year 2030 and will be the major factor impacting restoration of the ecosystem (Boesch and Greer, 2003). The CBP recognized this issue in Chesapeake 2000 and subsequently has identified three "keystone" commitments related to land use and watershed management: (a) by 2010, develop and implement watershed management plans in two-thirds of the Bay watershed to address protection, conservation, and restoration of stream corridors, riparian forest buffers, and wetlands for the purpose of improving habitat and water quality, (b) permanently preserve from development 20 percent of the land area in the watershed by 2010, and (c) by 2012, reduce the rate of harmful sprawl by 30 percent. DOI agencies also have priorities related to sound land use and land preservation. The USFWS has a goal to focus on long-term protection and/or acquisition of sufficient high-quality habitats to restore and maintain sustainable populations of fish and wildlife resources. The NPS recently completed a Special Resource Study that defined a larger role in watershed planning and protecting areas near NPS parks. Some of the technical needs associated with these issues are to (a) better document patterns of land-use change and their relation to changes in water quality, habitat, and living resources, (b) better document the socio-economic factors causing changes in the human activities that impact land use, (c) improve models to include socio-economic and other factors influencing human activities to forecast land-use change, and (d) better integrate land-use change models with water-quality, availability, and environmental impact models to better assess the potential for meeting restoration goals and promoting ecologically sustainable development.

Future Directions

In 2001, the USGS science theme for these issues was "improve land-use and watershed data and analysis to understand changes in water quality and living resources." One of the primary accomplishments for this theme was helping to design the RLA and apply forecasts of population growth to identify areas of vulnerability in the future (fig 5). This information is currently being used to help guide land conservation efforts in the Bay watershed. Additional USGS accomplishments for the theme are listed in Appendix A.

The USGS is revising the science theme to address the "impact of human activities on land use." The focus will be on the impact of, and factors affecting, human activities on land-use change patterns. The primary objectives for the theme will be to:

- Enhance monitoring of, and further define the factors causing, the past and present land-use change patterns in the Bay watershed;
- Develop approaches to integrate land-use change findings and forecasts with water quality, quantity, and habitat models; and
- Synthesize findings and provide implications to conserve land that provide water quality and ecological benefit.

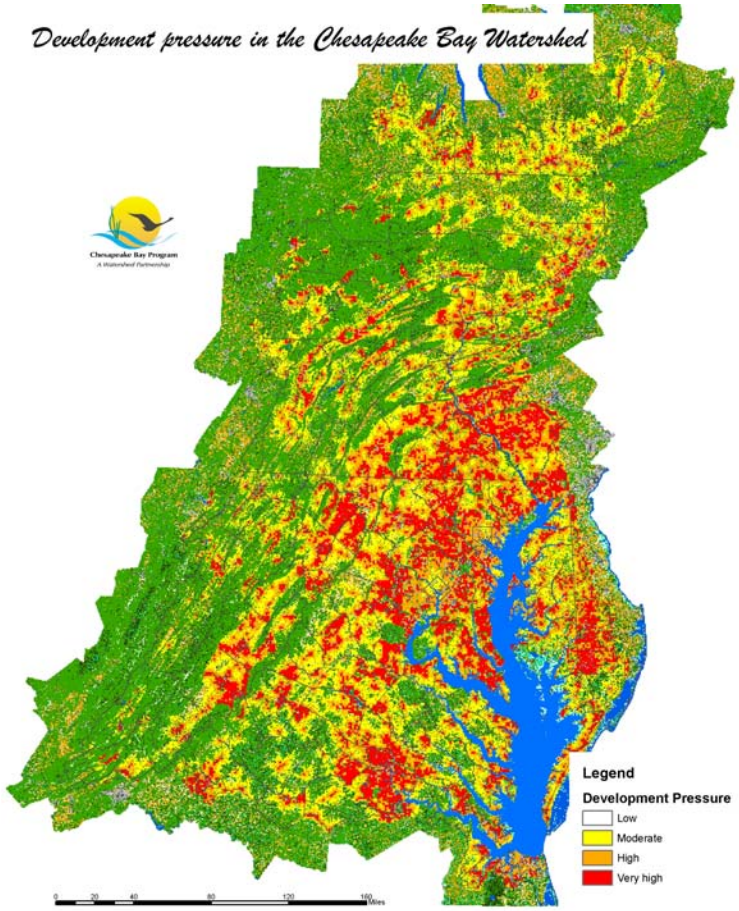

Figure 5: Potential future development pressure in the Chesapeake Bay watershed (from U.S. Environmental Protection Agency, 2004).
Human populations, and associated urban areas, are expected to grow to 19 million people by the year 2030 and will be the major factor impacting restoration of the ecosystem. As part of the CBP Resource Lands Assessment, the USGS helped develop projections of areas where development pressure will occur in the future. The information is being used to better target land-conservation efforts. The USGS will be enhancing studies addressing the impact of, and factors affecting, human activities on land-use change patterns.

The activities associated with meeting these objectives will be conducted primarily at regional scales. Enhanced monitoring of, and addressing the factors affecting land-use change, is needed for the entire watershed, while addressing the impact on water quality is needed for the major drainage areas and their sub-watersheds. The relation of land-use change to habitat would be addressed in different landscapes in the focus areas. Some of the potential activities that would be conducted during FY 2006-2011 include:

- Further synthesize existing studies and potential approaches to prepare a work plan for the science theme;
- Lead assessment of land-cover/land-use monitoring needed to support analyses of land-use change patterns and promote more integrated monitoring and assessment of water quality and habitat change. Work with the CBP and partners to plan and implement a land-cover monitoring program;
- Improve analysis of existing land-use change information and the factors, including socio-economic influences, contributing to land-use change patterns;

- Enhance development and evaluation of models to forecast changes in future human activities and land-use patterns;
- Develop approaches to couple models of land-use change with environmental impact models (water-quality models and ecosystem models) to better assess current conditions and forecast potential changes in water quality and habitat conditions;
- Participate in development of CBP environmental indicators for land-use change and annual assessment reports; and
- Synthesize findings and provide implications for impacts of land-use change on water quality, quantity, and habitat. Enhance Geographic Information System (GIS)-based tools, such as the vulnerability model in the RLA (fig. 5), to help target implementation of land-conservation and restoration activities.

Some of the potential products for these activities include technical reports and papers, CBP environmental indicators of human activities and land-use change, CBP annual assessment reports, improved models for the RLA, and a monitoring plan for land cover and land use. The USGS expertise for these activities includes geographer(s) with experience in analysis of land-use change, analyzing factors affecting land-use change patterns, developing models for land-use change, and relating land-use change to water-quality and habitat change.

Partnerships

The USGS will continue to work directly with the CBP on this science theme by having a USGS employee serve as the Land Data Manager. The Land Data Manager has membership on the CBP Land Growth and Stewardship and Modeling Subcommittees and has been active in preparing the CBP RLA to better target critical lands for preservation. The USGS will increase interaction with USFWS and the NPS to apply the findings to help conserve habitats and lands supporting DOI resources. USGS will help support the development and improvement of land-use projection models by the Maryland Office of Planning and the Woods Hole Research Center. Additionally, there is potential for increased interaction with USEPA Region III and the USEPA Office of Research and Development (ORD) staff conducting the Mid-Atlantic Integrated Assessment (MAIA) to use results to develop improved tools to document the impact of human activities on land use and implication for improving water quality. Finally, enhanced partnerships will be explored with the Global Integrated Trends Network and the Multi-Resolution Land Consortium (MRLC) to provide land-cover information. State partners throughout the watershed have an interest in improving monitoring data of land-use change and academic partners, such as the University of Maryland, are potential collaborators for future research on the factors affecting land-use change.

Science Theme: Factors Affecting Water Quality and Quantity.

Issues and Technical Needs

Degradation of water-quality conditions due to excessive nutrients and sediment, and loss of habitat, continues to be the primary issue impacting the Bay ecosystem. In spite of 20 years of restoration efforts, there has been only modest improvement of water-quality conditions in some tidal tributaries of the Bay and the streams in the watershed. In 1999, the Chesapeake Bay was listed as an impaired water body under the Clean Water Act.

The CBP addressed water quality in the Chesapeake 2000 Agreement and subsequent "keystone" commitments: (a) by 2010, correct nutrient- and sediment-related problems in the Bay and tidal tributaries to remove them from the impaired waters list; and (2) by 2010, develop and implement watershed management plans in two-thirds of the Bay watershed to address protection, conservation, and restoration of stream corridors, riparian forest buffers, and wetlands for the purpose of improving habitat and water quality. In 2003, the CBP finalized criteria for dissolved oxygen, chlorophyll, and water clarity in the tidal waters and set "load allocations" for reduction of nutrients and sediment in tributary strategy basins for the watershed (shown on fig. 6). These load allocations are similar to a Total Maximum Daily Load (TMDL) that would be required in 2011 if the water-quality criteria are not met in the Bay. Jurisdictions are working to implement revised strategies to reduce nutrients and sediment between now and 2010, and there will be an assessment of progress during 2007-2008. The USFWS has very similar goals for the protection, improvement, and restoration of fish, wildlife, and their habitat from water-quality degradation and environmental contaminant impacts. However, the impact of toxic constituents is more localized in the Bay ecosystem and therefore is not considered as high a priority as nutrients and sediment.

The effort to implement the tributary strategies to improve water quality has a vast number of technical information needs. A STAC workshop on the lag time between implementation of management actions and response of the ecosystems (Scientific and Technical Advisory Committee, 2005) concluded that the water-quality criteria will likely not be met by 2010 and more integrated approaches to restoration were needed. Recommendations from the workshop included (a) improve the monitoring and study of ecosystem response to management actions, (b) improve the models simulating these processes, and (c) improve the targeting of management actions for maximum water-quality improvement. Other technical needs listed by STAC include: (a) better information and technologies for management practices and ecosystem response to these practices, (b) improve long-term monitoring of components of the ecosystem (land, atmosphere, and water) for model, trend, and ascertaining uncertainties, (c) improve the integration of modeling, monitoring, and encourage multiple models to better determine forces driving land-use changes, best management practices (BMPs), and economic sustainability of resource-dependent activities, and (d) improve interpretation of the relation between water quality and living resources. STAC has also listed the need for an improved understanding of the relation between landscape pattern and ecosystem function with respect to critical habitats and human alteration of the landscape in the watershed. Finally, recent findings from the National River Restoration Science Synthesis (Hassett and others, 2005) indicated since the performance of restoration activities can vary within landscape settings, tracking how restoration actions function in different locations is critical. They further state that monitoring the outcome of restoration efforts is the only way to identify the most effective strategies, given limited financial resources.

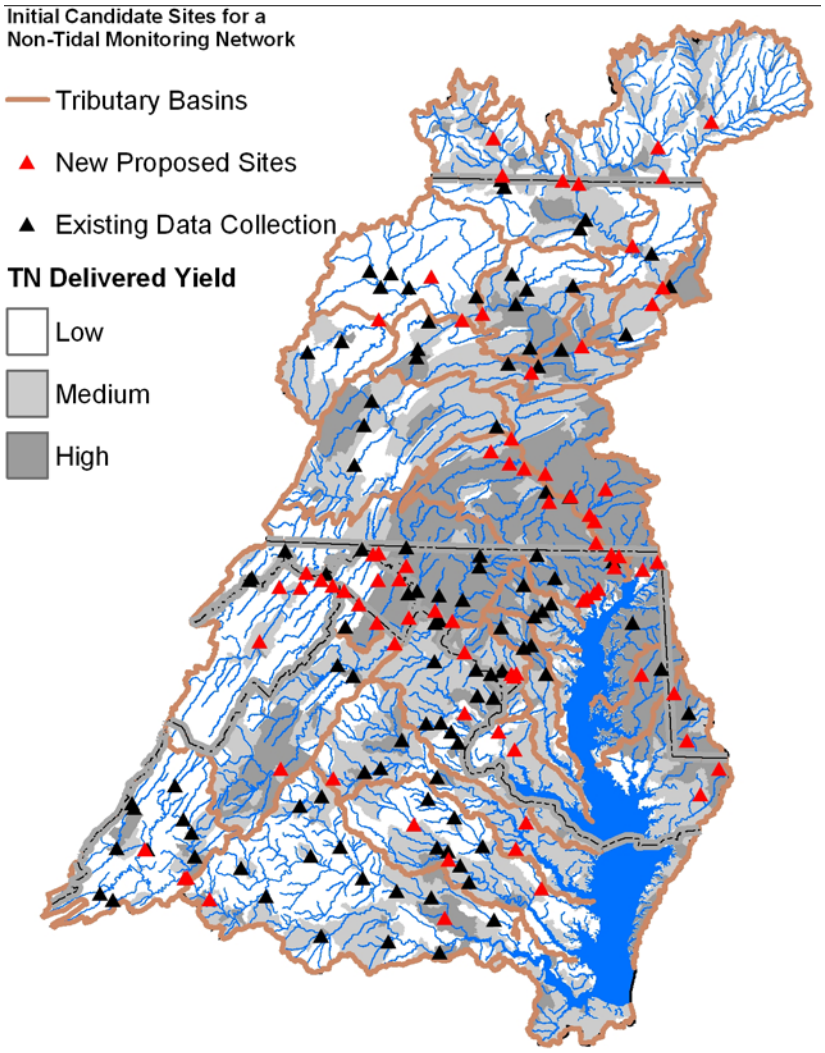

Figure 6-Tributary strategy basins and Chesapeake Bay Program Nontidal Water-Quality Network. Improved monitoring and assessment using the CBP Nontidal Water Quality Network will help determine the effectiveness of nutrient and sediment management actions being implemented in the tributary strategy basins. Of the nearly 200 candidate sites proposed for the network about 50 have been fully implemented in 2005. The distribution of total nitrogen yields, based on the USGS SPARROW model, were used to help select the site location and also to better target water-quality management actions in the watershed.

Future Directions

In 2001, the USGS developed three science themes related to water quality including (a) understand the sources and impact of sediment on water and biota, (b) enhance the prediction and monitoring of nutrient delivery to the Bay, and (c) assess the occurrence of toxic constituents and emerging contaminants. Some of the key USGS accomplishments include a synthesis of the information about processes affecting sediment in the Bay and its watershed, studies of sediment sources in the watershed and delivery to the tidal waters, and factors affecting trends of nutrients in the watershed including the influence of ground water (fig. 7). Additional USGS accomplishments are listed in Appendix A.

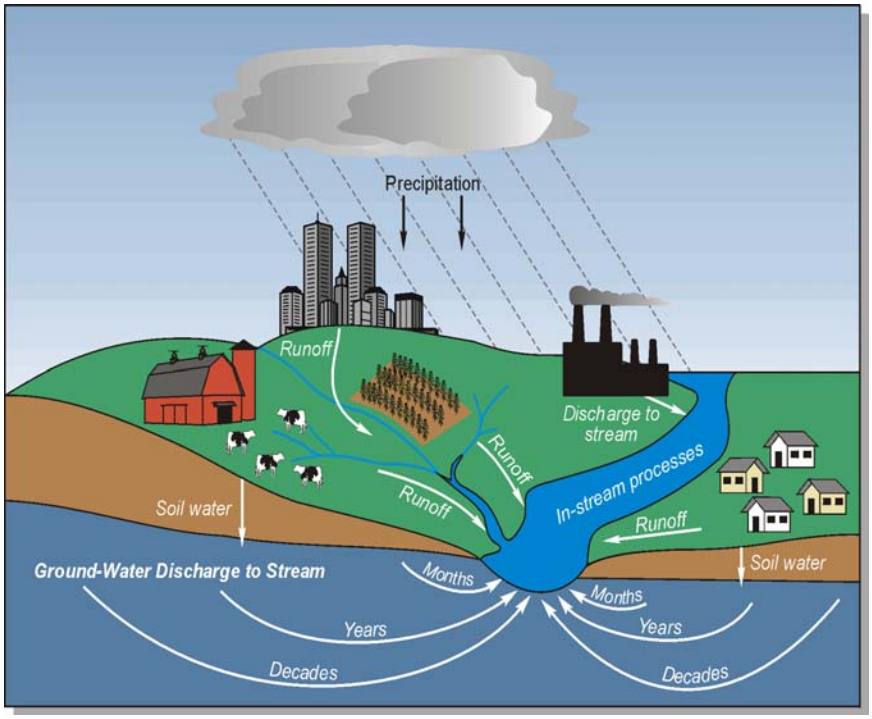

Figure 7: Conceptual diagram of nutrient and sediment sources and pathways in the Chesapeake Bay watershed (from Phillips and Lindsey, 2003).
The USGS will enhance efforts to address and simulate the multiple factors affecting nutrient and sediment transport in the watershed to improve targeting and assessment of nutrient and sediment reduction practices.

The USGS is going to merge its separate science themes for nutrients, sediment, and contaminants into one revised theme to address the "factors affecting water quality and quantity." Most of the focus will be on nutrients and sediment in the watershed to provide science for improved implementation and assessment of the tributary strategies. Studies will focus on the interrelation of the influence of (1) physical processes (watershed properties, shallow ground-water and geologic characteristics, water withdrawal, and climate variability), (2) geochemical processes (such as the carbon content in soils and aquifer materials), (3) biological processes (function and restoration of wetlands and riparian forest buffers), (4) water-quality response to restoration activities, and (5) the relation between nutrient and sediment delivery from the watershed on water quality in the estuary. Addressing contaminants will be focused on providing data to help access the factors affecting the health of fish and bird populations (see next science theme).

The primary objectives of the theme will be to:

- Improve monitoring and simulation of, and further define the processes affecting, the occurrence, transport, residence time, and change of nutrients and sediment in the watershed;
- Better define the function of key habitats (forests, wetlands, stream corridors) to adsorb and store nutrients and sediment;

- Relate the delivery of nutrients and sediment from the watershed to water quality in the estuary; and
- Synthesize information and conduct forecasts to provide implications and tools for improved targeting and assessment of water-quality management activities.

To meet the objectives, all three regional study scales will be addressed and complemented with local-scales studies in the Focus Areas. The entire watershed and the major drainage areas would be addressed with use of data from the CBP Nontidal Water-Quality Network (figure 6) and information from several models (such as the USGS SPARROW nutrient and sediment models). The USGS will also develop conceptual diagrams (such as the one shown in figure 7) to improve understanding of the influence of different landscape settings on nutrients and sediment transport. Implementation of local-scale studies in the two Focus Areas would be used to further address the processes in different landscape settings, assess water-quality response to restoration, integrate surface and ground-water models, and address the relation between water quality in the watershed and the estuary. Some of the potential activities during FY2006-2011 include:

- Further synthesize existing studies and potential approaches to prepare a work plan for the science theme;
- Summarize most recent modeling (the CBP Phase V WSM and USGS SPPARROW models) and monitoring information to prepare conceptual diagrams and identify areas and processes that will provide the most immediate water-quality benefit for implementing the tributary strategies. Also use the information and work with partners to select local watersheds for study of landscape settings and restoration effectiveness;
- Better define, map, and simulate the hydrologic processes and landscape settings controlling the amount and residence time of ground-water discharge to streams and direct discharge to the tidal waters. Assess the amount of nitrogen associated with ground water and identify and map factors controlling delivery to streams and tidal waters;
- Better define, map, and simulate the processes and landscape settings controlling sources, transport, and residence time of sediment and phosphorus in the watershed;
- Provide leadership for improved design and implementation of the nontidal water-quality monitoring network, including evaluating a more integrated approach for surface- and ground-water quality monitoring, and inclusion of land-use change monitoring;
- Continue to enhance techniques for load computations and trend analysis for nutrients and sediment over different time scales and explain the factors affecting change;
- Relate water-quality findings in the watershed with estuary conditions to further assess the primary factors and their sources (nutrient or sediment impairments) affecting water clarity for SAV in the Bay;
- Integrate modeling of human activities and land-use changes with improved water-quality and quantity models to forecast potential water-quality conditions in the future;
- Participate in development of CBP environmental indicators for water-quality change and annual assessment reports; and
- Synthesize information with other investigators to better assess factors affecting changes in water quality, link the information on delivery of nutrients and sediment from the watershed to the estuary to better identify source areas of impairments, and provide implications and improved tools (such as the water-quality model in the RLA) for

targeting conservation and restoration activities that provide the greatest water-quality benefit.

Potential products for these activities include technical reports and papers, enhanced CBP environmental indicators of water-quality conditions, CBP annual assessments, and improved models and tools (such as the models in the RLA) for targeting of conservation and restoration activities. The USGS expertise for these activities includes hydrologists with experience in (a) surface- and ground-water quality (nutrients and sediment) assessment and processes, (b) surface- and ground-water modeling, (c) statistical analysis of water-quality and flow data; geologists with experience in mapping the geologic framework and conditions that impact ground-water movement, addressing direct ground-water to estuaries, and the geomorphic characteristics and climate factors that impact generation and transport of sediment; and (d) geographers with expertise in analyzing the watershed and human factors affecting water quality.

Partnerships

The USGS will continue to coordinate with the CBP on this science theme by having a USGS employee serve as the CBP Monitoring Coordinator, having membership on the Nutrient, Modeling, and Monitoring and Analysis Subcommittees, and the appropriate workgroups. The USGS will continue to have active membership on the CBP Monitoring and Assessment Subcommittee (MASC) and associated workgroups that are integrating the factors affecting both nontidal and estuary water quality. The USGS will work with the CBP to consider improvements to water-quality models of the RLA to improve targeting of conservation and restoration activities to improve water quality. Additional interaction is planned with the USEPA MAIA and ORD efforts to explain the factors affecting water quality for assessing the effectiveness of restoration activities.

Interaction with DOI Bureaus and other Federal partners will be carried out to help the USFWS conserve and restore the health of stream corridors and wetlands, and with the NPS to improve watershed planning. Enhanced interaction will be explored with the U.S. Department of Agriculture including U.S. Forest Service (USFS), Agricultural Research Service (ARS), Natural Resources Conservation Service (NRCS), and Cooperative State Research, Education, Extension Service (CSREES) to improve nutrient and sediment source information and use USGS water-quality findings to help guide water-quality management activities. The USGS will examine opportunities to work with the National Oceanic and Atmospheric Administration (NOAA) to better integrate monitoring and assessment in the watershed and estuary, and to address recommendations of the U.S. Commission on Ocean Policy, such as including the Chesapeake Bay as part of the IOOS. The USGS will further explore interaction with the U.S. Army Corps of Engineers (USCOE) and NOAA to address sediment impacting the Bay and its watershed through development of a regional sediment management plan.

Partnerships with State agencies include continuing monitoring efforts for nutrients and sediment in nontidal rivers with the Maryland Department of Natural Resources (MD DNR) and the Virginia Department of Environmental Quality (VA DEQ) at River-Input Monitoring sites, and enhanced interaction with other State agencies to implement the nontidal monitoring water-quality network. Continued improvement of the CBP watershed model will be done in cooperation with the CBP modeling team, the Maryland

Department of the Environment (MDE), the Interstate Commission on the Potomac River Basin (ICPRB), and the Virginia Department of Conservation and Recreation. The USGS will continue its relationship with MD DNR, VA DEQ, and the University of Maryland Center for Environmental Science (UMCES), which collects water-quality data at SAV sites in the Potomac, and the Virginia Institute of Marine Sciences (VIMS) to address the relation of watershed impacts on near-shore water quality and SAV.

Additional efforts to improve partnerships with academic institutions will include exploring development of additional models with the Community Modeling Project, which is being overseen by the Chesapeake Research Consortium. The Smithsonian Environmental Research Center (SERC), Penn State University, and VIMS are potential academic partners to address development of water-quality indicators through the Atlantic Slope Consortium. Interaction with academic partners could also occur with other universities in the watershed if the Potomac or Susquehanna areas are selected for study by the Consortium of Universities for the Advancement of Hydrologic Science, Incorporated (CUAHSI).

Science Theme: The Ability of Habitat to Support Fish and Bird Populations.

Issues and Technical Needs

In addition to improving water-quality conditions, the CBP has recognized the need to improve conditions of streams because they interconnect the land, water, living resources, and human communities of the Bay watershed. The priority "keystone" commitment for this topic was: by 2010, develop and implement watershed management plans in two-thirds of the Bay watershed to address protection, conservation, and restoration of stream corridors, riparian forest buffers, and wetlands for the purpose of improving habitat and water quality. The CBP has two other "keystone" commitments related to this topic including (a) by 2010, restore 25,000 acres of tidal and nontidal wetland, and (b) conserve existing forests along all streams and shorelines. The need to integrate these goals to focus on stream corridor restoration was summarized in a STAC report (2004) that noted stream corridor restoration could integrate elements of restoring and maintaining passage for migratory and resident fish, and restoring riparian forest buffers and wetlands.

There have been multiple studies and substantial monitoring of the health of streams in the individual states, but integrating the information for the entire watershed has not been accomplished. The CBP has also conducted analysis of distribution of critical ecological habitats in the watershed through the RLA (fig. 8) but more focused information is still needed on the function of these habitats to support fish and bird populations. There are also concerns that as human population and water consumption increase in the watershed, there will be decreasing availability of water to support healthy stream ecosystems.

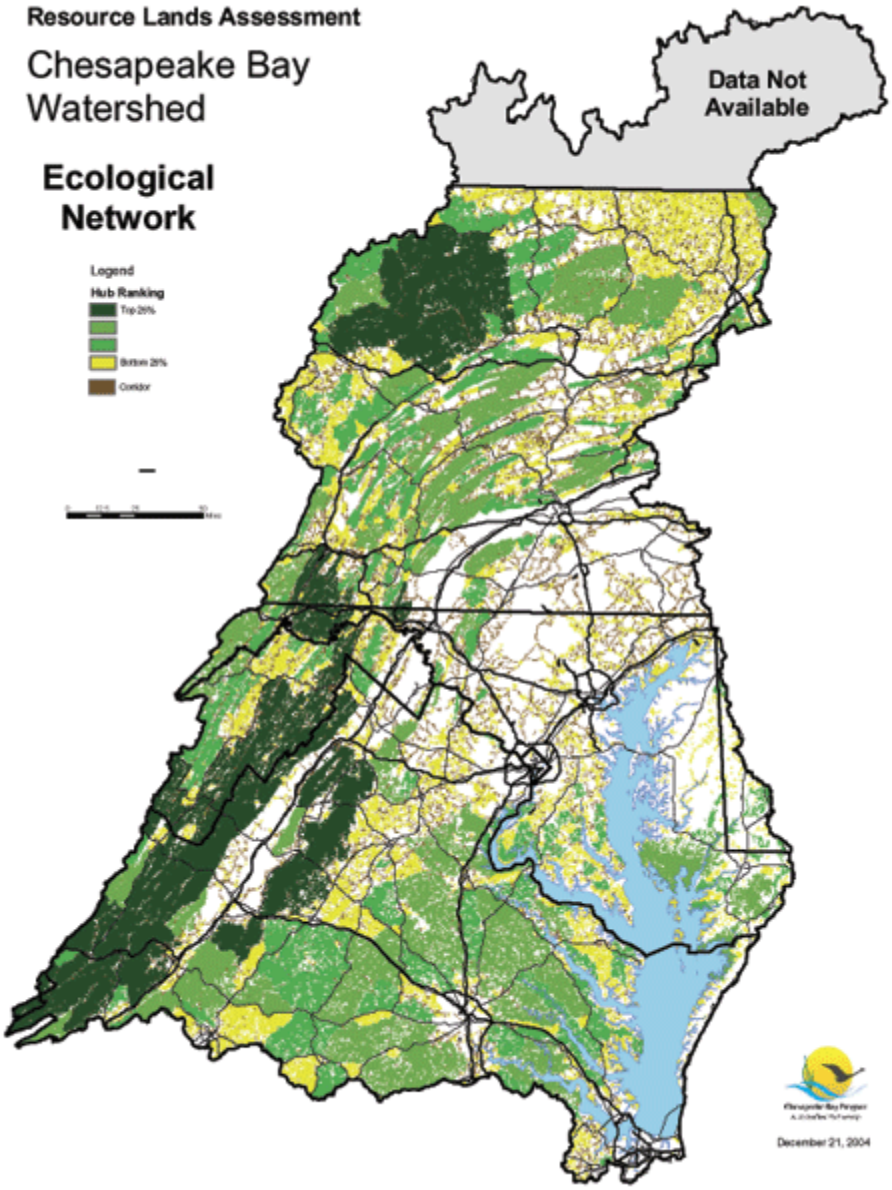

Figure 8-Ecological model from the Resource Lands Assessment (from U.S. Environmental Protection Agency, 2004).
Lands of high ecological value were identified for the RLA to help target lands for conservation. The USGS will be further addressing the factors affecting habitat supporting fish and bird populations in the watershed and near-shore estuary environments. The USGS will be working with the CBP partners to enhance approaches, such as the RLA, to identify areas for habitat conservation and restoration.

In addition to streams and habitats in the watershed, the CBP identified the restoration of several near-shore estuary habitats as "keystone" commitments, including: (a) by 2010, restore 25,000 acres of tidal and nontidal wetland; and (b) implement a strategy for protection and restoration of SAV. These habitats, and their ecological function, are being lost due to sea-level rise, land-use change, water-quality degradation, and invasive species. The CBP also has "keystone" commitments for living resources that depend on these habitats, including a commitment to develop (by 2005) and implement (by 2007)

multi-species management plans for fisheries, and to have a ten-fold increase in oysters by 2010.

The USFWS has similar goals to protect and restore essential aquatic habitats including wetlands, SAV, and stream corridors because of their use by fish, birds, and other wildlife. The USFWS also had specific technical needs related to fisheries, including providing data to restore, improve, or protect aquatic and riparian habitats of essential value to anadromous and other interjurisdictional fishes, through development of fish passages and removal of tributary blockages, and evaluating the impacts of disease on fish populations, including mycobacteriosis and striped bass. While migratory birds are not a "keystone" commitment of CBP, the Bay watershed is in the heart of the Atlantic Flyway and provides habitat for both domestic and migratory birds. The DOI and CBP are working to restore 20 species of water birds as obligated under the North American Waterfowl Management Plan. In a more recent report related to conservation of birds, the USFWS and other partners also identified priority breeding and non-breeding habitat patches in salt marsh and forested habitats as a high priority and determined there was a need for analyses on their rate and extent of loss. General issues identified for joint study between USGS and USFWS, which include (1) global climate change, (2) biotechnology, (3) water for ecological needs, and (4) invasive species, also apply to Chesapeake Bay.

To develop the strategies to conserve and restore the ecosystem, scientific information is needed to understand the function of habitat for supporting the health of fish and bird populations. Information is needed on the factors affecting the loss of function, and techniques for conservation and restoration, of these habitats. Finally, information is needed to address the additional factors, such as disease, affecting the health of fish and bird populations that depend on these habitats.

Future Directions

During 2001-2005, the USGS science theme addressed the "factors affecting the health of fish, wildlife, and their habitats". The USGS provided significant findings about the impact of disease on the health of key fish species in the Bay, migratory patterns of water birds, and the factors affecting the loss and restoration of the habitat they depend on (wetlands and SAV). Additional accomplishments are listed in Appendix A.

The USGS will revise its science theme to "ability of habitat to support fish and bird populations". The focus of this theme will be to address stream corridors and near-shore estuary habitats that support fish and bird populations. Some of the factors that will be addressed to understand the ability of habitats to support fish and bird populations include: (1) water quality, (2) water quantity and availability (3) habitat loss and fragmentation due to land-use change, and (4) the impact of invasive species. The USGS objectives for this theme will be to:

- Address the function of habitat to support the fish and bird populations in stream corridors and near-shore estuary environments;
- Identify the additional factors impacting the health of fish and bird populations; and
- Synthesize findings, and use forecasts of land-use change and water availability, to provide implications and improve tools for conservation and restoration of habitat.

The studies of habitats supporting fish and bird populations and their habitats will be concentrated in the two focus areas: the Potomac River and estuary and the Mid-Delmarva Peninsula. Potential activities and products include:

- Further synthesize existing studies and potential approaches to prepare work plan for the science theme;
- Conduct an assessment of fish health in the Bay watershed to better understand the condition of fisheries and the factors that have compromised reproductive systems, and caused lesions and mortality;
- Further investigate the loss of habitat functions causing degradation of fish health in the watershed including the water-quality (contaminants, pathogens), water quantity, and loss and fragmentation of habitat associated with stream corridors (riparian forest buffers and wetlands);
- Evaluate and begin to develop appropriate ecosystem models of fisheries and their habitat in stream corridors;
- Use surface- and ground-water models developed from the Science Theme addressing water quality and quantity to assess future scenarios of water availability to support the ecological health of streams;
- Provide forecasts of potential future impacts on habitat to help identify most critical stream corridors to conserve and restore habitats to support fish and bird populations;
- Further investigate the loss of habitat functions causing degradation of health of bird populations in the watershed and near-shore estuary environments, including water-quality (contaminants, pathogens, nutrients, and sediment), loss and fragmentation of habitat (due to land-use change and sea-level rise), and impact of invasive species;
- Participate in development of CBP environmental indicators using fisheries and birds as indicators of ecosystem health and annual assessments; and
- Synthesize information on the ability of habitats to support fish and water-bird populations and provide implications and enhance tools (such as the RLA) for conservation and restoration activities that provide the greatest ecological benefit.

Potential products for these activities include technical reports and papers, enhanced CBP environmental indicators of fish, birds and their habitat conditions, CBP annual assessments, and improved tools (such as the models in the RLA) for targeting of conservation and restoration activities. The USGS expertise for this theme includes ecologists to address habitat loss, change, and restoration; biologists to study the health of fish and bird populations, and hydrologists to address water quality and quantity conditions.

Partnerships

The habitat associated with stream corridors and their link to the estuary is being studied by many Federal, State, and academic institutions. The USGS will build upon existing relationships, and form new, collaborative partnerships to address these issues. The USGS will increase membership on the Living Resources Subcommittee of the CBP and associated workgroups that are addressing both nontidal and near-shore habitats. The USGS will work closely with the USFWS to better integrate science findings with their efforts to achieve a comprehensive approach to watershed restoration and investigations on fish health. The USFWS CBFO has established the Comprehensive Habitat Assessment and Restoration Team (CHART) to help achieve this approach. The USGS will also address the water-quality and habitat function in the drainage area of the

Blackwater National Wildlife Refuge. The Refuge is threatened by changing land use near its property and loss of wetlands due to sea-level rise and changes in hydrologic patterns, and is planning a large multi-agency restoration effort. The USGS will continue partnerships with the USCOE to address the use of dredge spoil to restore wetlands including Poplar Island and determine whether similar potential exists at Blackwater Refuge. The USGS will also improve collaboration with NOAA to use information on habitat assessment and function to improve restoration activities and include findings on fish health for ecosystem management of fisheries. The USGS will work with States in the Potomac River Basin and ICPRB to better define the factors affecting the health of fisheries in streams. The USGS will work with academic partners, including SERC, to better assess the role of habitat to support fish and bird populations and provide water-quality benefit.

Science Theme: Synthesis and Forecasting for Improved Ecosystem Assessment, Conservation, and Restoration

Issues and Technical Needs

The CBP and DOI partners need improved information for ecosystem assessment and implementation of strategies to conserve and restore the Bay and its watershed. The need for improved assessment and coordinated restoration was emphasized by the GAO report that recommended the CBP (1) complete efforts to implement an integrated assessment approach, (2) revise its reporting approach to improve the effectiveness and credibility of its reports, and (3) develop a comprehensive, coordinated implementation strategy that takes into account available resources. The CBP consists of Federal (over 25 agencies and 3 from DOI), State (6 States and the District of Columbia), and local government partners. Science and restoration approaches for the Chesapeake Bay also have critical relevance for the conservation and restoration of ecosystems throughout the United States. Given the large array of information users, there is a need to improve synthesis of scientific findings at multiple scales to improve coordination, implementation, and assessment of conservation and restoration strategies and decision-support tools for improved targeting of those strategies. Additionally, with the continued population increase in the Bay watershed, there is a need to forecast potential impacts on the ecosystem so policy makers can begin to consider strategies to promote ecologically sustainable development in the Bay watershed.

Synthesis of scientific information can meet some of the technical needs to improve assessment, conservation, and restoration. Synthesis can provide a more integrated understanding of the factors affecting the condition and change of the ecosystem. This information is needed to enhance CBP efforts to improve development of environmental indicators and more integrated annual assessments of ecosystem condition and restoration activities (Fig. 9). While there has been progress on enhancing the indicators for the estuary, the CBP has not developed an approach to address the health of the watershed. There are approaches being developed by USEPA (Jackson and others, 2000) and between USEPA and academic institutions such as the Atlantic Slope Consortium (Brooks and others, 2005) that are working to develop ecological indicators for aquatic systems and other indexes for evaluating watersheds contributing to estuaries, whose methods can be utilized to help improve development of indicators for the watershed.

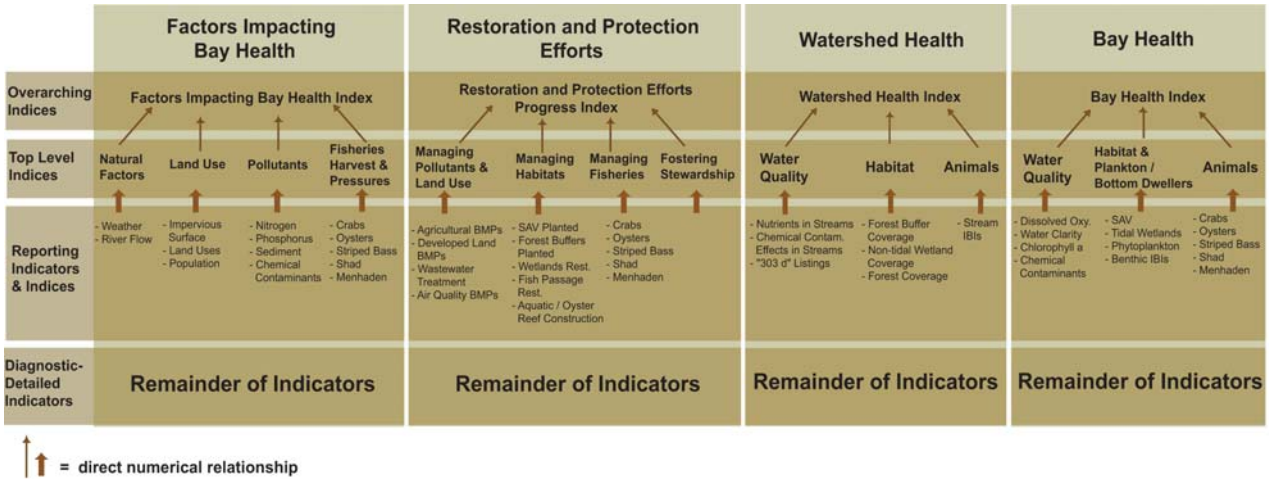

Figure 9-Framework of the Chesapeake Bay Program environmental indicators.
The CBP partners are developing a more integrated assessment of the condition and changes of the Bay and its watershed to better evaluation the condition of, and progress in restoring, the Bay ecosystem. The USGS will enhance synthesis and forecasting to help improve the assessments and support more effective ecosystem conservation and restoration.

Spatial and temporal forecasting is needed to improve assessment, conservation, and restoration. Spatial forecasting, through extrapolation of monitoring data and use of models, is needed to provide improved assessment of conditions in the watershed. Temporal forecasting is needed to predict the potential future impact of both natural (climate variability) and anthropogenic changes. Recently the CBP, under the leadership of the MASC and the University of Maryland began forecasting of summer dissolved oxygen, SAV, and Harmful Algal Blooms. Opportunities exist for other types of forecasting including impact of future land-use patterns and climate variability on nutrient and sediment loading, and habitat condition. The results from the synthesis and forecasting need to be further integrated to provide (a) a more integrated approach and improved tools to target conservation and restoration activities, (b) an improved assessment of ecosystem change to evaluate the effectiveness of these activities, and (c) the potential future impact of population growth on the ecosystem to help policy makers and resource managers adapt approaches to improve conservation and restoration of the ecosystem.

Future Directions

In 2001, the USGS had a goal to "disseminate information and enhance decision-support systems". As part of this goal, the USGS synthesized information and provided implications to many policy makers, resource managers, and other target audiences during 2001-2005 (Appendix A) including a synthesis report of studies from 1995-2000 (Phillips and others, 2002). In 2006, the USGS will be synthesizing findings from 2000-2005.

For the revised science plan, the USGS will increase its emphasis on integrated synthesis and forecasting through the revised science theme for "synthesis and forecasting for improved ecosystem assessment, conservation, and restoration." The USGS will have an Integrated Synthesis and Forecasting Team (ISFT), which will include lead investigators from each science theme to plan and conduct synthesis and forecasting of the findings. The

USGS will provide the implications and enhance decision tools for policy makers and resource managers who implement strategies to improve conservation and restoration of the Bay ecosystem (the Bay and its watershed). The ISFT will also integrate results of forecasting efforts under each science theme to provide implications to policy makers as they consider future strategies to promote more ecologically sustainable development as the human population continues to increase in the Bay watershed. The objectives of this theme include:

- Enhance assessment by developing improved CBP environmental indicators and explanation of ecosystem condition and change;
- Improve approaches to integrate predictions of land use, water quality and quantity, and habitat to forecast potential changes of the ecosystem; and
- Synthesize findings and provide implications for improving implementation of ecosystem conservation and restoration strategies and developing new approaches for ecologically sustainable development.

The synthesis and forecasting will be addressed at the three regional scales. The enhanced CBP assessment and improved environmental indicators are being developed mostly at the scale of the entire watershed and estuary, with more focus on major drainage areas in the future. Synthesis of the results for improved targeting of conservation and restoration activities will focus on the major drainage areas and different landscape settings within each area. The scale for forecasting will be dependent on the integration and models and will probably be conducted mostly in the two Focus Areas. Some of the potential activities in 2006-2011 include:

- Further synthesize existing studies and potential approaches to prepare a work plan for the science theme;
- Produce synthesis product(s) that would summarize findings of USGS studies conducted during 2001-2005;
- Based on synthesis of findings, prepare conceptual diagrams of major ecosystem processes in different landscape settings of the watershed to provide implications for conservation and restoration;
- Work with the CBP partners to improve the environmental indicators and assessments of conditions of the Bay, its watershed, and restoration activities;
- Evaluate opportunities and implement actions to improve spatial decision-support tools to target locations for maximum effectiveness of conservation and restoration activities;
- Examine opportunities to enhance applications the RLA to improve targeting for conservation and restoration of areas in the watershed that are most important for improve of water-quality conditions and habitat. Identify approaches to use results from existing models (CBP WSM, USGS SPARROW models); and additional data on hydrogeologic properties of the watershed in these tools;
- Enhance the USGS Chesapeake Bay Communication plan and include a “launch strategy” for products to better reach target audiences, and develop strategies for dissemination of information and implications through increased interactions with CBP subcommittees, workgroups, science meetings, and stakeholder workshops; and
- Synthesize scientific findings of USGS studies into a summary report in 2010 that will assess conditions and restoration progress and provide implications for further conservation and restoration of the Bay ecosystem.

Potential products will include a revised USGS Chesapeake Bay web site, development of decision-support tools, publication and presentation of scientific reports and articles, and technical workshops to increase interaction of resource managers and scientists in the CBP. The USGS expertise for this theme includes science writers, information technology specialists, geographers, and collective efforts of scientists working on all the USGS Science themes.

Partnerships

The USGS will work with the CBP partners, under the MASC, to improve environmental indicators to assess the current conditions and progress in restoring the Bay and its watershed. The USGS will enhance interaction with the CBP Communications Office to deliver information through their revised communication strategy and methods. The USGS will also enhance partnership with the IAN at the UMCES to improve conceptual models and indictors for the Bay and its watershed.

The USGS will continue to increase interaction with the policy makers and resource managers of the CBP and DOI (USFWS and NPS) to provide science to meet CBP "keystone commitments" and to conserve and restore DOI lands and trust resources. The USGS will increase interaction with the CBP to enhance the models in the RLA so they can be used for targeting both conservation and restoration activities in the watershed. The USGS will enhance interaction with the NPS to communicate findings through the "Chesapeake Gateways Network." Enhanced interaction will be explored with the USDA including USFS, ARS, NRCS, and CSREES to improve communication of sediment and nutrient results to help guide water-quality management activities and with NOAA to communicate the results.

Implementing the Revised USGS Chesapeake Bay Science Plan

The USGS's success in implementing projects to address the themes of the revised plan depends on collaboration of multiple USGS programs and partners. During 2001-2005, over 13 USGS programs funded approximately 30 projects at USGS Science Centers throughout the Bay watershed to address the science needs for the understanding and restoration of Chesapeake Bay. For the future, the USGS has a goal to evolve from having a collection of separate projects to fewer, more integrated projects. The goal will be to have one project to address each of the USGS Chesapeake Bay science themes. The projects will be closely coordinated through a core group of scientists (the ISFT) working to synthesize results and provide forecasts. The scope and funding for each project would depend on the involvement and collaboration of USGS Programs and Science Centers to fund scientists to conduct the activities within each project. The USGS will also increase interaction with other scientific organizations and resource management agencies to conduct the projects. The Chesapeake Bay Executive Advisory Team (CBEAT) will continue to provide guidance on integration of USGS and partner activities.

Measures of Success and Actions to Implement USGS Chesapeake Bay Studies

The ultimate measure of success for USGS Chesapeake Bay studies is to provide integrated science addressing the ecosystem to help resource managers and policy makers make more informed decisions for conservation and restoration activities, and consider future strategies to promote ecologically sustainable growth in the Bay and its watershed.

The USGS Chesapeake Bay Studies are designed to meet both the science needs related to Chesapeake Bay and the goals of participating USGS National Programs and Science Centers. The USGS will work vigorously to jointly plan and execute coordinated projects between USGS National Programs, Science Centers, scientists, and partners to enhance interdisciplinary investigations of the Chesapeake Bay and its watershed. Some of the proposed actions and tactics needed to meet the measure of success are:

(1) Develop a science plan that addresses collective science needs and priorities of the CBP, DOI, and USGS.

-Obtain input on issues and associated technical needs of the "keystone" commitments of Chesapeake 2000, DOI, and the USGS.
-Revise the USGS Chesapeake Bay science plan to meet the priority science needs and build on the strength of USGS capabilities.
-Have the USGS CBEAT provide continual feedback on the plan and implementation of potential projects to meet the goals of the plan.
-Interact with partners to assess opportunities to coordinate efforts to conduct projects to meet the goals of the science plan.

(2) Enhance coordination among all levels of USGS (Programs, Regions, Science Centers, and scientists) and partners.

-Improve joint planning of revised projects between USGS Programs, Science Centers, Region, and scientists.
-Include elements of the USGS Chesapeake Bay science themes into the 5-year plans of the USGS Programs and Science Centers.
-Increase interaction with other institutions and agencies to conduct joint studies.
-Promote a reward system for collaboration among USGS scientists and between the USGS and other agencies and academic institutions.
-Revise USGS science teams to help coordinate projects related to the revised USGS science themes. Have leaders as members of the USGS ISFT.
-Improve the function of the USGS ISFT, which is chaired by the USGS Chesapeake Bay Coordinator, to coordinate and integrate activities and synthesize findings among projects.
-Have the USGS Regional Executive and USGS Chesapeake Bay Coordinator increase engagement with USGS National Program Managers and Science Center managers to ensure projects meet the goals of all parties.
-Write and annually update a USGS Chesapeake Bay Operational Plan to reflect projects, funding amounts and accomplishments.

(3) Ensure that USGS information is used to help guide conservation and restoration of the Bay and its watershed.

-Improve USGS interaction with resource managers and policy makers to provide implications for conservation and restoration.
-Increase involvement of USGS scientists in CBP subcommittees, associated technical workgroups, and DOI agencies.
-Demonstrate how USGS information is being used to conserve and restore the Chesapeake Bay and its watershed, so it may be applied to other ecosystems in the Nation.

Role of USGS Programs and Science Centers

The USGS Chesapeake Bay Studies depend on the coordination of multiple USGS Programs and Science Centers that have a scientific interest in the Bay restoration. The missions of many USGS National Programs and their associated Science Centers can be met through their collaboration in the Chesapeake Bay Studies. Where possible, the USGS will plan and execute integrated efforts among USGS National Programs and Science Centers to enhance interdisciplinary approaches to technical issues. Some of the potential USGS National Programs that would meet their missions by collaborating to address the science themes in USGS Chesapeake Bay Science Plan are summarized in the following text.

Biology Discipline

Priority Ecosystem Science (PES): While not a formal line item Program, this activity coordinates USGS efforts to provide science for management and restoration of priority ecosystems in the Nation. The USGS Chesapeake Bay Studies coordinate with the different programs contributing to PES and also work with additional USGS National Programs to address collective priorities through investigations in Chesapeake Bay and its watershed.

Contaminants Biology Program: The Program investigates the effects and exposure of environmental contaminants to the Nation's living resources, particularly those under the stewardship of the DOI. In collaboration with USGS Chesapeake Bay Studies, the goal of the Program would be addressed through study of the potential role of emerging contaminants and other stressors affecting the reproductive system of fish in the Bay watershed and birds in watershed and estuary environments.

Fisheries: Aquatic and Endangered Resources Program (FAER): The FAER Program focuses on the study of fish, fisheries, fish diseases and parasites, aquatic organisms, and their water-based and water-dependent habitat. The Program's research on the diversity, natural history, health, and habitat requirements of fish and other aquatic organisms is carried out to support the management, conservation, and restoration of our Nation's aquatic resources. Through collaboration with USGS Chesapeake Bay Studies, the FAER mission would be met through focus on several research areas including identifying the factors (disease, contaminants, and change of habitat) affecting the health of fish populations in the Bay and its watershed, providing an improved understanding and models of the habitat-species relationships, and providing science to help identify the optimal areas to restore habitat to improve the health of fish populations.

Invasive Species Program: The mission of the Program is to provide management-oriented research and deliver information needed to prevent, detect, control, and eradicate invasive

species. In collaboration with USGS Chesapeake Bay Studies, the mission of the Program would be met through study on the impact of invasive species on stream and estuary habitats.

Status and Trends of Biological Resources Program: The mission of this Program is to measure, predict, assess, and report the status and trends of the Nation's biological resources. In collaboration with USGS Chesapeake Bay Studies, the Program mission and several goals would be met by establishing a pilot monitoring network to assess the status and trends of key fish and bird populations and their habitats in selected locations of the Chesapeake Bay watershed and estuary habitats.

Terrestrial, Freshwater, and Marine Ecosystems Program: This Program focuses on understanding the factors that control ecosystem structure, function, conditions, and provision of goods and services. Information from ecosystem research guides the design and evaluation of scientifically based strategies to manage and restore ecosystems and landscapes. Through collaboration with USGS Chesapeake Bay Studies, the goals of this Program would be met by addressing the factors controlling the function of stream ecosystems and estuary habitats, and evaluation of strategies for conservation and restoration.

Wildlife: Terrestrial and Endangered Species Program: The Program conducts research on waterfowl, songbirds, large mammals, terrestrial plants, amphibians, and their habitats. Results complement and support the conservation and management efforts of Federal and State wildlife agencies, non-governmental organizations, and International treaties. The mission of the Program would be met by research on factors affecting the decline, and potential approaches for restoration of selected bird populations and their habitats.

Geography Discipline

Geographic Analysis and Monitoring Program: The mission of this Program is to bring focus to the Nation's urgent environmental, natural resource, and economic issues through scientific assessments that provide a national and global perspective on land-surface change. Through collaboration in USGS Chesapeake Bay Studies, the Program mission would be met by research to understand and forecast the impact of human activities on the land surface including the impact on water quality and habitat in the Bay watershed, and development and enhancement of decision-support tools for resource managers.

Land Remote Sensing (LRS) Program: The fundamental goal of the LRS Program is to provide the Federal Government and the public with a primary source of remotely sensed data and applications and be a leader in defining the future of land remote sensing, nationally and internationally. Through collaboration with USGS Chesapeake Bay Studies, the goal of the LRS Program could be met by participating in development and implementation of a land-use monitoring program for the Bay watershed.

Science Impact Program: The mission of this Program is to increase the use and value of USGS science in decision making through three principal activities: synthesis, applications, and evaluations. Through collaboration with the USGS Chesapeake Bay studies, the mission of Science Impact could be meet through enhancing the synthesis, application, and dissemination of

USGS Chesapeake Bay science to help decision makers improve ecosystem management in the Chesapeake Bay and other ecosystems in the Nation.

Geospatial Information Office

Cooperative Topographic Mapping (CTM) Program: The mission of this Program is to provide the Nation with access to current, accurate, and consistent base geographic data and derivative products including topographic maps. The Program is accomplishing this mission by deemphasizing data production in order to focus on partnerships for data sharing that can be used as content for *The National Map.* Through collaboration with USGS Chesapeake Bay Studies, the mission of CTM Program can be met through data-sharing agreements between Federal, State, and local partners involved with the Chesapeake Bay Program. Potential also exists to improve Web access to *The National Map* data and other USGS data sets that are critical to the Chesapeake Bay watershed.

Geology Discipline

Earth Surface Dynamics (ESD) Program: Activities of the ESD Program focus on documenting, analyzing, and modeling the character of past and present environments and the geologic, biological, hydrologic, and geochemical processes involved in environmental change so that future environmental changes and impacts can be anticipated. Through collaboration with USGS Chesapeake Bay Studies, the mission of ESD would be met through research on effects of land-cover change and climate variability on water quality in the Bay watershed and estuary.

Coastal and Marine Geology (C&M) Program: The goal of this Program is to describe the geology of coastal and marine systems. Through collaboration with USGS Chesapeake Bay Studies, the C&M Program theme to address environmental quality and preservation would be met through research on direct ground-water delivery of nutrients to the estuarine waters of the Bay and using remote sensing to address sediment sources and dynamics affecting water clarity and SAV.

National Cooperative Geologic Mapping Program (NCGMP): The mission of this Program is to provide accurate geologic maps and three-dimensional frameworks that contribute to sustaining and improving the quality of life and economic vitality of the Nation and mitigating geologic hazardous events and conditions. Through collaboration with USGS Chesapeake Bay studies, an important objective of this Program would be met through creation of three-dimensional geologic frameworks to support models to understand ground-water discharge to streams and coastal areas and the impact on the health of ecosystems.

Water Discipline

Cooperative Water Program: The mission of the Program is to provide reliable, impartial, and timely information needed to understand the Nation's water resources through a program of shared efforts and funding. The Program has several high priority issues that match issues in Chesapeake Bay (water quality, data networks, water availability and use, wetlands and estuaries, and water resources in coastal zones). Through collaboration with USGS Chesapeake Bay Studies, the Program mission would be met through enhanced surface-water monitoring, analysis, and modeling to document the occurrence, transport, and trends of sediment and nutrients in the streams of the Bay watershed and their delivery

to the estuary. Additional opportunities exist to address flow requirements, water quality, and habitat conditions needed to support key fish and bird species in the Bay watershed.

The Ground-Water Resources Program (GWRP): The GWRP is one of eight Water Resources Investigations Programs funded by Congress to identify, measure, and assess the Nation's water resources. Future priorities for the Program include regional and national water overview, scientific assessments of critical ground-water issues, field measurement and model development, and improved access to ground-water data. There is opportunity for enhanced collaboration between GWRP and USGS Chesapeake Bay studies to address the simulation of ground water delivery of nitrogen to streams and tidal waters, and ground-water delivery to support the ecological health of streams.

Hydrologic Networks and Analysis (HNA) Program: The HNA Program provides for the collection and analysis of hydrologic data to support needs of the Nation. Through collaboration with USGS Chesapeake Bay Studies, the HNA mission would be met through collection and analysis of streamflow, ground-water, and water-quality information.
National Research Program (NRP) in the Hydrologic Sciences: The mission of the NRP includes the development of new information, theories, and techniques to understand, anticipate, and solve water-resource problems facing managers of Federal lands and the Nation. Through collaboration with USGS Chesapeake Bay Studies, the NRP mission would be met through research of the sources, fate, and transport of sediment and nutrients in selected watersheds and development and application of integrating ground- and surface-water models. Research on the relation of water-clarity conditions between the watershed and estuary would also meet the NRP mission.

The National Streamflow Information Program (NSIP): NSIP is designed to improve monitoring of streamflow and it will provide a backbone for enhanced water-quality monitoring because meaningful water-quality monitoring requires flow information to determine loads of chemicals. The information delivery system being implemented by NSIP will provide for better delivery and archiving of water-quality data as well as streamflow data. There is opportunity for enhanced collaboration between NSIP and USGS Chesapeake Bay studies as a nontidal and tidal water-quality monitoring networks are enhanced in the Bay and its watershed.

National Water-Quality Assessment (NAWQA) Program: The goal of the NAWQA Program is to develop long-term consistent and comparable information on streams, ground water, and aquatic ecosystems to support sound management and policy decisions. Through collaboration with USGS Chesapeake Bay Studies, the goal of the Program mission would be met through work developing techniques for trend analysis and simulation of nutrients and sediment and interaction with regional teams and the Potomac/Delmarva study to understand nutrient and contaminant relation to land use and processes affecting streams in the Bay watershed.

Toxics Substances Hydrology Program: The Program provides objective scientific information to improve characterization and management of contaminated sites, to protect human health, and reduce potential future contamination problems. Through collaboration with USGS Chesapeake Bay studies, the goal of the Program would be met

through study of the occurrence and fate of emerging contaminants that are impacting the reproductive system of fish and birds.

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Appendix A—Selected accomplishments of USGS Chesapeake Bay Studies, 2001-2005

The USGS had five science goals to address needs of the CBP during 2001-2005. Selected accomplishments of the goals have been organized by the revised science themes to summarize existing findings.

Science Theme: The Impact of Human Activities on Land Use

In 2001, the USGS science theme for these issues was "improve land-use and watershed data and analysis to understand changes in water quality and living resources."
Some of the USGS accomplishments toward this theme included:

-Producing data on land cover and hydrography for the Bay watershed,
-Generating information on land cover and watershed characteristics to improve the two primary predictive models of nutrient and sediment sources and transport in the Bay watershed. An enhanced database of the information is near completion.
-Generating information on the land-cover change and watershed characteristics to better interpret the sources of sediment in the lower Susquehanna Basin.
-Establishing the CBP/USGS Land Data Manager, who oversees and guides data compilation and analysis at the CBO office.
-Helping to develop the Resource Lands Assessment, which identified critically important economic and ecological lands in the Bay watershed.
-Beginning to develop and test models to forecast land-use change.

Science Theme*: *Factors Affecting Water Quality and Quantity

In 2001, the USGS developed three science themes related to water quality including (a) understand the sources and impact of sediment on water and biota, (b) enhance the prediction and monitoring of nutrient delivery to the Bay, and (c) assess the occurrence of toxic constituents and emerging contaminants. The USGS is going to merge its separate science themes for nutrients, sediment, and contaminants into one revised theme to address the "factors affecting water quality in the watershed and relation to the estuary."
The USGS has significant accomplishments for this theme including:

-Developed partnerships with the CBP to have USGS employees serve as Monitoring Coordinator and Quality-Assurance Officer.
-Provided study results and participated in development of water-clarity and dissolved oxygen criteria for the Bay.
-Led the CBP sediment workgroup in completion of a report that summarized existing sediment information for the Bay and its watershed. Findings from the report were used to help develop an approach for assessing sediment-reduction strategies and begin improvement of predictive models.
-Developed techniques to fingerprint the sources and erosion of sediment, and use the results with historical monitoring data to identify areas of high sediment generation.
-Conducted investigations to further identify sediment sources to the estuary that will help formulate improved sediment-reduction strategies by 2007.
-Conducted interpretation of the relation between river flow, sediment loads, and changes in water clarity and occurrence of SAV in the major tributaries of the Bay. USGS also continued work in the Potomac and Pocomoke Rivers during 2003 to understand the importance of light transmittance, water quality, propagule availability, sediment quality, and other biotic and abiotic factors on SAV. These findings were used to help set the water-clarity criteria for the Bay.

-Began to determine the relative contributions of TSS (inorganic and organic material), chlorophyll, and other components affecting water clarity in shallow water zones of the Potomac Estuary, and continued study of factors affecting growth of SAV. These results will help to guide the balance of nutrient and sediment controls in different areas of the Bay.
-Used the results from the USGS SPARROW model to help states develop revised nutrient-reduction strategies.
-Led the design of a nontidal water-quality network that will be used to help assess progress for reducing nutrients and sediment.
-Summarized the factors affecting nutrients and sediment in the watershed including results on the discharge, nitrogen, and residence time of ground water to help understand the implications for implementing nutrient-reduction strategies and improving simulation in water-quality models.
-Identified the occurrence of arsenic, pesticides, and antibiotics in bottom sediments of some systems that can impact the microbial populations that affect the cycling of nutrients.

Science Theme: The Ability of Habitat to Support Fish and Bird Populations

In 2001, the USGS had two science themes related to habitats and living resources including (a) the relation between sediment, water clarity, and biota, and (b) assessing the factors affecting the health of fish and water birds. The second goal was refined in 2003 to include fish, wildlife, and their habitats in an attempt to better reflect the needs of the USFWS and on-going studies by USGS.

Some of the accomplishments related to these goals include:

-Monitored and analyzed habitat loss and displacement due to sea-level rise and other factors at the USFWS Blackwater National Wildlife Refuge, which showed that wetland loss is being impacted by both sea-level rise and subsidence of the land surface. The information is being used to help plan wetland restoration.
- Conducted investigations of wetland and near-shore restoration at Poplar Island and the Anacostia watershed to help determine approaches and suitability of using dredge materials for reconstructed wetlands. Additionally, techniques were developed to assess exposure to, and effects of, organic and inorganic contaminants in reconstructed wetlands on wildlife.
-Improved the understanding of the factors affecting the population of seaducks that winter in the Chesapeake Bay including study of the movement, habitat use, and feeding ecology of seaducks to better assess the potential degradation of feeding habitat in Chesapeake Bay.
-Conducted an assessment of the distribution of the Diamondback Terrapin, which is the only brackish water turtle species in the United States. Over 1,500 terrapins were tagged in the Chesapeake Bay to establish baseline monitoring of the population, and help develop options for protection and conservation.
-Completed a study with the USFWS to determine the cause of the decline in night heron populations in Baltimore Harbor, and identify potential effects of environmental contaminants on reproduction of osprey nesting in the regions of concern in the Bay watershed (Baltimore Harbor, Anacostia River, and the Elizabeth River). The USGS also completed an assessment of the available contaminant data to determine impacts on wildlife near Chesapeake Bay.

-Conducted studies to better understand the causes of the numerous outbreaks of fish lesions/disease and fish kills in the Chesapeake Bay and its tributaries. Studies included (1) assessment of *Pfiesteria* (a toxic dinoflagellate)-related fish kills and *Aphanomyces* (an invasive fungal pathogen) in menhaden, (2) *Mycobacteria* (a systemic bacterial infection) in striped bass, and (3) a comprehensive health assessment of white perch in five tributaries.

Science Theme: Synthesis and Forecasting to Improve Ecosystem Assessment, Conservation, and Restoration.

Since 2001, the USGS has conducted activities to deliver information for assessment of restoration on the Bay ecosystem. Some accomplishments include:

-Continued participation in CBP subcommittees, workgroups, and STAC Chesapeake Bay workshops.

-Prepared several synthesis products to help the CBP develop the strategies to reduce nutrients and sediment improved water-quality criteria can be achieved.

-Increased emphasis on presentations to the USFWS Chesapeake Bay Ecosystem Team. Based on the presentations, the USFWS requested that USGS become members of the team to increase interaction between the two agencies.

-Presentations at numerous National meetings including the World Watershed Summit, National Conference on Ecosystem Restoration, and the American Association for the Advancement of Science (AAAS).

-Continued progress on development of web-based decision-support tools that focused on delivering information from the USGS SPARROW models and water-quality monitoring data.