Synthesis of U.S. Geological Survey Science for the Chesapeake Bay Ecosystem and Implications for Environmental Management

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Cover. Clockwise from upper left: [1] satellite image of Chesapeake Bay, [2] collection of sediment samples using the USGS hoverprobe, [3] storm event at the Conowingo Dam, and [4] osprey landing in nest. All photographs courtesy of USGS.
Inside Cover. The Minnie T. Phillips was built in Baltimore, Maryland in 1873. At 100 feet and 137 tons, she was primarily engaged in the coasting trade to the Bahamas. Photograph from Chesapeake Bay Schooners by Snediker and Jensen, 1992.

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Chesapeake Bay Bridge. Photograph by Jane Thomas, IAN Image Library (www.ian.umces.edu/imagelibrary/).

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Contents

Chapter 1: Introduction and Overview of Findings

By Scott W. Phillips

The U.S. Geological Survey (USGS), the science agency for the Department of the Interior (DOI), has the critical role of providing scientific information that is utilized to document and understand ecosystem condition and change in the Chesapeake Bay and its watershed. The findings are used by resource managers and policy makers to assess the effectiveness of restoration actions and adapt improved strategies for the future. The Chesapeake Bay, the Nation's largest estuary, has been affected by human-population increase resulting in degraded water quality, loss of habitat, and declines in populations of biological communities. Since the mid-1980s, the USGS has been a partner of the Chesapeake Bay Program (CBP), a multi-agency partnership working to restore the Bay ecosystem. The CBP created Chesapeake 2000, an agreement that established over 100 restoration commitments to be achieved during 2000–10. The major goals of the agreement are related to: (1) land use, (2) water quality, (3) vital habitats, (4) living resources, and (5) stewardship.

To support the expanded technical needs of the Chesapeake 2000 agreement, the USGS summarized its previous research (Phillips, 2002) and interacted with CBP partners to develop science goals for 2001–06:

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

The purpose of this report is to present a synthesis of the USGS Chesapeake Bay science related to the 2001–06 goals and provide implications for environmental management (fig. 1.1). The report provides USGS findings that address the science needs of the CBP restoration goals and includes summaries of: (1) land-use change; (2) water quality in the watershed, including nutrients, sediment, and contaminants; (3) long-term changes in estuarine water quality; (4) estuary habitats, focusing on submerged aquatic vegetation (SAV) and tidal wetlands; and (5) factors affecting fish and waterbird populations. A summary of the major CBP restoration goals and associated USGS scientific findings and their management implications is presented in table 1.

The USGS is also meeting the future needs of the CBP partners. In 2005, which represented the mid-point of the Chesapeake 2000 agreement, there was growing concern at all levels of government and by the public that ecological conditions in the Bay and its watershed had not significantly improved. The slow rate of improvement, coupled with the projected human-population increase in the Bay watershed, implied that many desired ecological conditions will not be achieved by 2010. The Government Accountability Office (2005) recommended that the CBP complete efforts for an integrated assessment approach of ecosystem conditions and developed a comprehensive, coordinated implementation strategy. To address these challenges, the CBP partners are writing a strategic implementation plan (SIP) to more accurately define the degree to which restoration goals can be achieved by 2010, and the most effective approach to achieve the goals. The USGS findings and their implications provide critical information that will be used by the CBP partners to prepare the SIP and develop improved management strategies.

Given the evolving needs of the CBP partners, the USGS revised its Chesapeake Bay Science Plan for 2006–11 (Phillips, 2005) to provide integrated science for effective ecosystem conservation and restoration, which are being addressed through four primary themes:

- The causes and consequences of land-use change;
- 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.

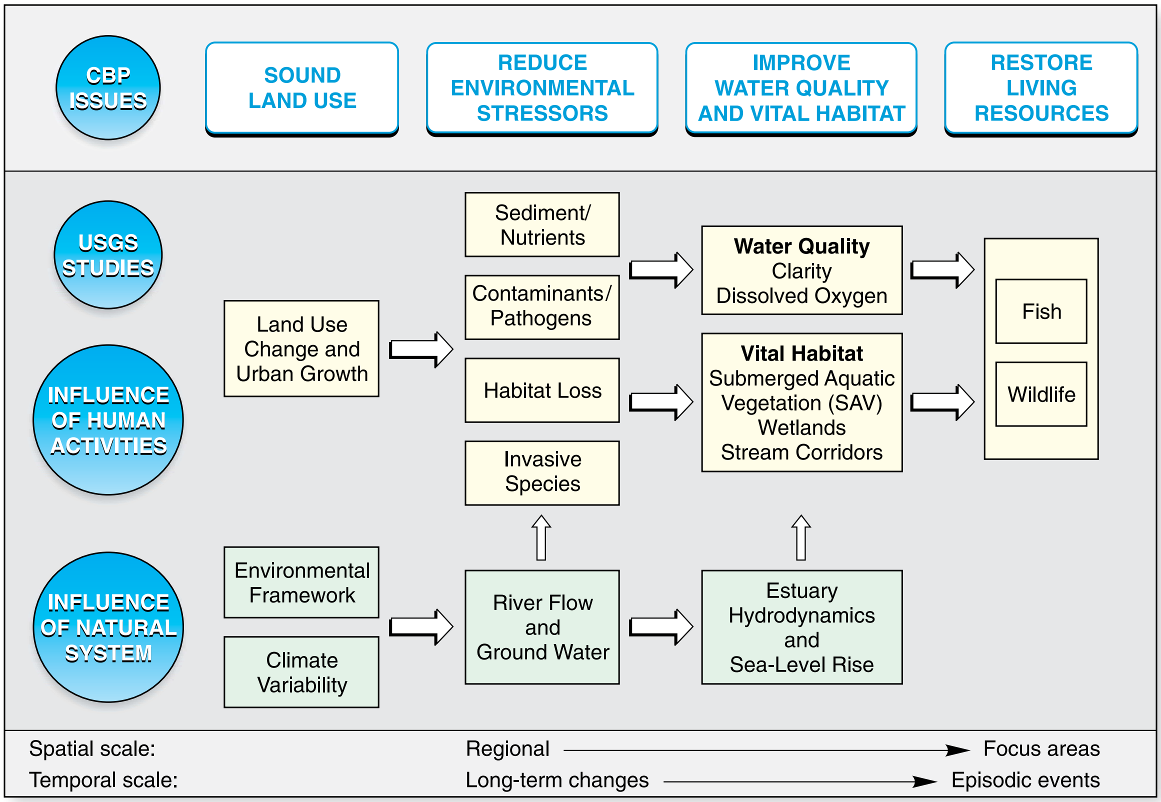

Figure 1.1. U.S. Geological Survey conceptual approach for studies of the Chesapeake Bay and its watershed during 2001–06 and relation to Chesapeake Bay Program issues.

The USGS has implemented projects to address each science theme through a combination of monitoring, modeling, research, assessment, and synthesis. The USGS is emphasizing an adaptive management approach for conducting its projects over the next 5 years so resource managers can use the findings to more effectively implement, assess, and adapt management actions in different landscape settings (fig. 1.2). The USGS results will:

- Provide an improved understanding of the ecosystem to better target implementation of conservation and restoration strategies;
- Assess ecosystem change to help evaluate the effectiveness of management activities;
- Forecast the potential impacts of population growth and climate change; and
- Provide implications and decision-support tools to help policy makers and resource managers adopt improved approaches for ecosystem assessment, conservation, and restoration.

Implementing USGS projects to address the science themes is achieved through collaboration between multiple USGS National Programs, Science Centers, and partners (Phillips, 2006). Projects are designed by scientists to meet the objectives of the USGS Chesapeake Bay science themes and missions of the collaborating USGS National Programs and partners. Appropriate Federal, State, local, and academic CBP partners work with USGS to jointly conduct monitoring, modeling, research, and assessment activities associated with each science theme. The USGS interacts with resource managers and policy makers to help them make informed decisions for conservation and restoration of the Chesapeake Bay and its watershed.

Table 1. Summary of U.S. Geological Survey (USGS) Chesapeake Bay findings and management implications.

CBP Management Goal and Information Need	USGS Scientific Findings	Management Implications
FINDINGS RELATED TO THE CHESAPEAKE BAY PROGRAM (CBP) CHESAPEAKE 2000 GOAL FOR SOUND LAND USE		
Goal: Reduce the rate of harmful sprawl in the watershed. **Need:** Develop methods to document and monitor harmful sprawl.	The USGS analyzed different indicators for harmful sprawl, recommended the CBP use impervious surface as an indicator, and analyzed changes in impervious surface. Analysis of impervious surface in the watershed showed impervious surface accounts for 21 percent of all urban lands in the watershed. Impervious surfaces increased 41 percent during the 1990s compared to an 8-percent increase in population. *(See Chapter 2)*	The rate of increase of impervious surface implies there will be a more rapid delivery of nutrients to streams and an increase in sediment erosion. State and local governments are using the results to conserve habitats to reduce runoff, increase implementation of stream-restoration actions, and develop policies to reduce impacts of impervious surfaces.
Goal: Preserve 20 percent of land in the watershed. **Need:** Identify high value lands to help guide preservation efforts.	USGS collaborated with CBP partners on the Resource Lands Assessment, which identified lands that have high ecological, water-quality, economic, and cultural value. The USGS conducted a vulnerability assessment to predict the risk of conversion of these high-value lands to urban areas by 2010. The results identified several areas under high development pressure including the Delmarva Peninsula, southern Pennsylvania, and the I-95 corridor. *(See Chapter 2)*	Land-use change due to population increase will continue to cause loss of high-value lands. State agencies and land-preservation organizations have used the methods from the vulnerability assessment to better target land acquisition and conservation programs.
Goal: Assess potential nutrient and sediment loads in the future due to population increase. **Need:** Forecasts of nutrient and sediment loads to the Bay.	The USGS began to develop a land-use change model to predict the impacts of population growth. The model will be linked with the CBP watershed model to provide scenarios of nutrient and sediment loading during 2010–30. *(See Chapter 2)*	The predictions of nutrient and sediment loads during 2010–30 will be used to formulate additional strategies needed to remove the Bay from the impaired waters list.
FINDINGS RELATED TO THE CBP CHESAPEAKE 2000 GOAL FOR WATER QUALITY – NUTRIENTS		
Goal: Implement the CBP tributary strategies to reduce nutrients to the Bay and improve water-quality conditions for living resources. **Need:** Better define the spatial distribution of the sources and transport of nutrients entering the Bay.	The USGS provided a better understanding of nutrient sources and their transport to streams and the estuary using a watershed model application know as SPAtially Referenced Regressions On Watershed attributes (SPARROW). The SPARROW model results have shown the spatial distribution of high priority nutrient sources (agriculture, urban lands, and point sources) and their delivery to the Bay. The SPARROW model results were also used to improve the spatial resolution of the CBP Phase V watershed model and to design the CBP nontidal water-quality network. *(see Chapter 3)*	Resource managers have identified several nutrient sources (agriculture, urban lands, and point sources) as a high priority for nutrient-reduction actions. The SPARROW model results are being used to identify priority areas for geographic targeting of management actions.
Goal: Reduce nutrients to remove the Bay from the impaired waters list by 2010. **Need:** Better define the transport time of nutrients being delivered to the Bay.	The USGS determined that on average, ground water was found to contribute about 50 percent of the water and nitrogen to the streams and rivers that enter the Bay. The highest concentration of nitrogen in ground water occurred in areas overlain by agricultural land. The age of ground water, which affects the time it takes for nitrogen to travel through shallow aquifers from the land to a stream, varies from modern to over 50 years old. About 50 percent of the total water to streams is modern, with 90 percent moving from its source to a stream in less than 15 years. *(See Chapter 4)*	The hydrologic pathways of nutrients in the watershed (surface water or ground water) will influence the lag time between implementing management actions and seeing a water-quality response. Watersheds with a higher percentage of the nitrogen transported through surface-water runoff will have more rapid improvements in water quality than those with a higher portion of nitrogen in ground water.
Goal: Reduce nutrient delivery to remove the Bay from the impaired waters list by 2010. **Need:** Improve monitoring and better define the factors affecting the delivery of nutrients entering the Bay.	The USGS worked with the U.S. Environmental Protection Agency (USEPA) and the six states in the Bay watershed to establish the CBP Nontidal Water-Quality Network. Data from the network are used to document water-quality change that is related to land use, implementation of management actions, and climate variability. The USGS has improved techniques to assess water-quality change in the Bay watershed and explain the factors affecting the change. Results from the analysis show streamflow variability has a large influence on the annual and seasonal loads in the watershed and their delivery to the Bay. When techniques are used to compensate for the effect of flow variability, there has been a decrease in nitrogen and phosphorus concentrations at a majority of the sites in the watershed. *(See Chapter 5)*	The watershed monitoring information was used to help assess progress in meeting goals to remove the Bay from the impaired waters list by 2010. Concentrations are not decreasing at a rate that would reduce nutrient loads sufficiently to remove the Bay from the impaired waters list by 2010. The USEPA has recently revised the timeline for delisting the Bay to beyond 2010.

Table 1. Summary of U.S. Geological Survey (USGS) Chesapeake Bay findings and management implications.—Continued

CBP Management Goal and Information Need	USGS Scientific Findings	Management Implications
FINDINGS RELATED TO THE CBP CHESAPEAKE 2000 GOAL FOR WATER QUALITY – SEDIMENT		
Goal: Reduce sediment to improve water clarity for submerged aquatic vegetation (SAV) and remove the Bay from the impaired waters list. **Need:** Understand the sources of sediment in the watershed and their delivery to the Bay.	USGS analysis of historical sediment data found the highest yields in the Piedmont, and lowest yields in the Coastal Plain. Based on results from three research studies, the portion of sediment from land erosion and stream corridor erosion varies in individual watersheds and needs to be defined for local areas. There is a significant amount of sediment and associated nutrients that are being stored in the forest and wetland assemblages on the Coastal Plain prior to their delivery to the estuary. Sediment is also being stored in stream corridors and in reservoirs. *(See Chapter 6)*	Sediment-reduction actions need to be implemented both in the watershed and in near-shore areas to improve stream and estuary conditions. In the watershed, practices should be emphasized in the Piedmont to decrease sediment to tidal-fresh areas of the estuary. Protecting and restoring forest and wetland assemblages in Coastal Plain stream corridors can be another effective approach to minimizing the transport of sediment to the estuary. Maintaining the sediment storage capacity of reservoirs and dams will also slow the delivery of sediment from the watershed to the estuary.
Goal: Reduce sediment to improve water clarity for SAV and remove the Bay from the impaired waters list. **Need:** Better document the sediment sources and factors affecting delivery to the Bay.	USGS synthesis of sediment information found that sediment sources to the Bay include watershed inputs, erosion of shorelines and wetlands, and ocean inputs. The relative importance of the sources varies in different regions of the Bay. Watershed sources affect the tidal fresh regions of the estuary. Below the estuarine turbidity maximum, which is the area of mixing between freshwater and saline water, erosion from shorelines is a primary source. The ocean and shoreline erosion are primary sources of sediment in the southern Bay. Sea-level rise is an important process affecting sediment erosion from low-lying shoreline areas. Sediment traveltimes from the watershed to the estuary may be decades to centuries. *(See Chapter 7)*	In addition to watershed management actions, practices to improve water clarity in the estuary should be focused at shoreline sources. Practices to address shoreline erosion must also consider the sediment erosion due to continued sea-level rise and climate warming.
FINDINGS RELATED TO THE CBP CHESAPEAKE 2000 GOAL FOR WATER QUALITY – CONTAMINANTS		
Goal: Have a "toxics free" Bay to improve conditions for aquatic-dependent wildlife. **Need:** Define the occurrence of contaminants in the Bay watershed.	Synthetic organic pesticides, along with certain degradation products, have been widely detected in ground water and streams in the Bay watershed. The most commonly detected pesticides are herbicides used on corn, soybeans, and small grains. Pesticides were also detected in urban areas, including insecticides and the herbicide prometon. Pesticides are present year round but changes in concentrations reflect application rates and properties affecting their movement. Emerging contaminants such as pharmaceuticals and hormones are also being detected in the Bay watershed, with the highest number being detected in municipal effluent. *(See Chapter 8)*	Pesticide occurrence is closely tied with nutrient land practices on agricultural and urban lands, so there is potential to better integrate management actions to reduce both nutrients and contaminants to the Bay. The occurrence of emerging contaminants and their environmental consequences needs to be better defined.
Goal: Have a "toxics free" Bay to improve conditions for aquatic-dependent wildlife. **Need:** Document the effect of contaminants on water birds and wildlife.	Concentrations of DDT and its breakdown products and other organochlorine pesticides have declined since their ban in the 1970s but PCB concentrations remain unchanged. Results from USGS and U.S. Fish and Wildlife Service studies indicate that pesticide concentrations are below thresholds that cause adverse reproductive effects for some water in the "toxic areas of concern" in the Bay watershed (Baltimore Harbor, Anacostia River, and Elizabeth River). *(See Chapter 9)*	Management actions in the 1970s and 1980s restricting the use of chlorinated pesticides have had several results for wildlife. The populations of many fish-eating birds, such as the bald eagle, have rebounded. However, other contaminants that are slow to break down remain a threat to wildlife.
FINDINGS RELATED TO THE CBP CHESAPEAKE 2000 GOAL FOR VITAL HABITATS – ESTUARY HABITATS		
Goal: Restore water-quality conditions to support fisheries. **Need:** Understand the effect of long-term changes in climate variability on estuary water quality.	The USGS found that climate variability over the past several thousand years has affected the salinity, temperature, and dissolved oxygen conditions in the Bay. Changes in these parameters show that the 20th century is characterized by anomalous climate variability when compared to the last 2,000 years. Water temperatures in the Bay during the late 19th and 20th centuries exhibited greater extremes than those of the previous 2,000 years. Hypoxia and anoxia were much more extensive and severe during the past four decades than at any time in the past 2,500 years. *(See Chapter 10)*	The results imply that management actions to address climate variability and associated global warming need to be incorporated into current strategies to restore the estuary. Management actions that address delivery of nutrient and sediment loads under varying river-flow conditions will need to be emphasized to help address the impacts of climate change and variability.

Table 1. Summary of U.S. Geological Survey (USGS) Chesapeake Bay findings and management implications.—Continued

CBP Management Goal and Information Need	USGS Scientific Findings	Management Implications
FINDINGS RELATED TO THE CBP CHESAPEAKE 2000 GOAL FOR VITAL HABITATS – ESTUARY HABITATS (Continued)		
Goal: Restore 185,000 acres of submerged aquatic vegetation (SAV) in the estuary. **Need:** Define the factors affecting water clarity and SAV.	Investigations showed that the factors affecting water clarity vary in different areas of the estuary. Total suspended solids, which include both organic matter and inorganic solids (clay, silt) are the primary factor affecting water clarity in the mid-channel sites in the estuary. At shallow water sites, organic solids were the primary factors affecting clarity during a low-flow year. Investigations revealed SAV has returned in some areas of the Potomac, including increases in both native and non-native species. *(See Chapter 11)*	The results imply that managers need to further define the primary cause of degraded water clarity to select the types of sediment- and nutrient-reduction strategies needed in different areas of the estuary.
Goal: Restore 25,000 acres of wetlands. **Need:** Define the factors affecting wetlands loss and restoration.	Sea-level rise, due to climate change, will impact tidal wetlands during the coming century. USGS forecasts of wetland change in the Blackwater National Wildlife Refuge reveal that marsh will continue to convert to open water for the next century. Additional factors influencing marsh loss include grazing of vegetation by nutria and waterfowl, altered flooding and salinity patterns, and annual prescribed burning of vegetation. *(See Chapter 12)*	Coastal wetland loss and landward migration will continue due to sea-level rise. Managers need to consider land-use policies that allow for landward migration of wetlands to help preserve and restore tidal wetlands.
Goal: Restore 25,000 acres of wetlands. **Need:** Science to support restoration and conservation.	The presence of an existing seed bank is important for wetland restoration. Tidal wetland creation from dredged sediments is an effective method for restoring wetland habitats when the proper intertidal soil elevations are established and maintained. Controlling competition and predation from non-desired species affects the function and structure of restored wetlands. *(See Chapter 12)*	The presence of an existing seed bank, and understanding the seed dispersal pathways, can increase success and reduce costs of wetland restoration projects. The success of the restoration efforts will also depend on controlling competition and predation from non-desired species, which also attempt to colonize a restored wetland.
FINDINGS RELATED TO THE CBP CHESAPEAKE 2000 GOAL FOR LIVING RESOURCES		
Goal: Restore, enhance and protect fisheries. **Need:** Define the factors affecting lesions on menhaden and relation to *Pfiesteria*.	The USGS and collaborators determined lesions on menhaden were caused by a fungal pathogen (*Aphanomyces invadans*). The same organism was demonstrated in menhaden from Delaware to South Carolina. It is now recognized that *A. invadans* is a serious pathogen of both estuarine and freshwater fishes worldwide. *(See Chapter 13)*	The USGS findings indicate that improving environmental conditions for menhaden, such as improved dissolved oxygen and lower contaminant concentrations, will make them less susceptible to *A. invadans* infections and other toxic algae.
Goal: Restore, enhance and protect fisheries. **Need:** Determine the cause of lesions in striped bass.	The USGS and collaborators identified the cause of the skin lesions in striped bass as mycobacteriosis, which are species of bacteria that can impact both marine and freshwater fish. The USGS co-hosted a workshop with the National Oceanic and Atmospheric Administration (NOAA) to summarize information about mycobacteriosis. Bacteria affect relatively high numbers of striped bass, with external lesions in up to 28 percent of the fish caught and internal lesions in more than 62 percent. *(See Chapter 13)*	The findings imply the resistance of striped bass populations to disease appears to have been lowered due to multiple environmental conditions including low dissolved oxygen, contaminant concentrations, and improper diet. Improving environmental conditions in the Bay could improve the ability of striped bass to resist the impact of mycobacteria.
Goal: Restore, enhance and protect fisheries. **Need:** Develop methods to assess fish health.	The USGS conducted tributary health assessments from 1998–2003 to understand fish health in the Bay and its tributaries. The assessments included developing new methods to document fish health and use the information to compare the "health" of various tributaries. Findings from the assessments showed the suppression of the white perch's immune system occurred in several tributaries and changed seasonally. *(See Chapter 13)*	The National Ocean Service of NOAA is implementing these methods in a program to monitor fish health in the Chesapeake Bay tributaries.
Goal: Restore, enhance and protect fisheries. **Need:** Assess cause of "intersex" conditions of fish in the Potomac Basin.	Since 2002, the USGS has been involved with numerous cooperators in examining potential causes for skin lesions and kills of various fish species in the watershed. During more comprehensive fish health assessments, the presence of testicular oocytes, a form of intersex, was noted in the male bass. Reproductive abnormalities in fish have been strongly linked with a variety of contaminants that have endocrine-modulating activity. *(See Chapter 13)*	Management agencies are awaiting the results from research to assess causes of intersex and fish kills in the watershed to begin to formulate actions and policies.

Table 1. Summary of U.S. Geological Survey (USGS) Chesapeake Bay findings and management implications.—Continued

CBP Management Goal and Information Need	USGS Scientific Findings	Management Implications
FINDINGS RELATED TO THE CBP CHESAPEAKE 2000 GOAL FOR LIVING RESOURCES (Continued)		
U.S. Department of the Interior (DOI) Goal: Manage populations of waterbirds. **Need:** Understand decline in waterfowl populations.	The USGS has focused on the factors affecting the declines in seaduck populations, which are a group of ducks not frequently seen by the public due to the fact that they feed in deep water in the Bay. USGS findings suggest these declines could be from changes in diversity and abundance of shellfish and other benthic foods. *(See Chapter 14)*	The findings imply that management efforts to increase oyster populations could also benefit seaduck populations.
DOI Goal: Manage populations of waterbirds. **Need:** Understand impacts of exotic species.	Food sources and habitats of waterbirds also are affected by exotic and invasive species. Although data on the reduction of SAV by nesting mute swans and their offspring during the spring and summer are limited, studies on their food habits show that mute swans rely heavily on SAV during these months. USGS findings revealed a major decline of wild rice in tidal marshes of the Patuxent River due to consumption by resident Canada geese. *(See Chapter 14)*	These findings imply a better understanding of factors affecting food sources and habitat of waterbirds will provide managers with more reliable information to manage and regulate populations.

View looking south along the mouth of the Elk River. In the foreground is recent development. Photograph by Jane Thomas, IAN Image Library (www.ian.umces.edu/imagelibrary/).

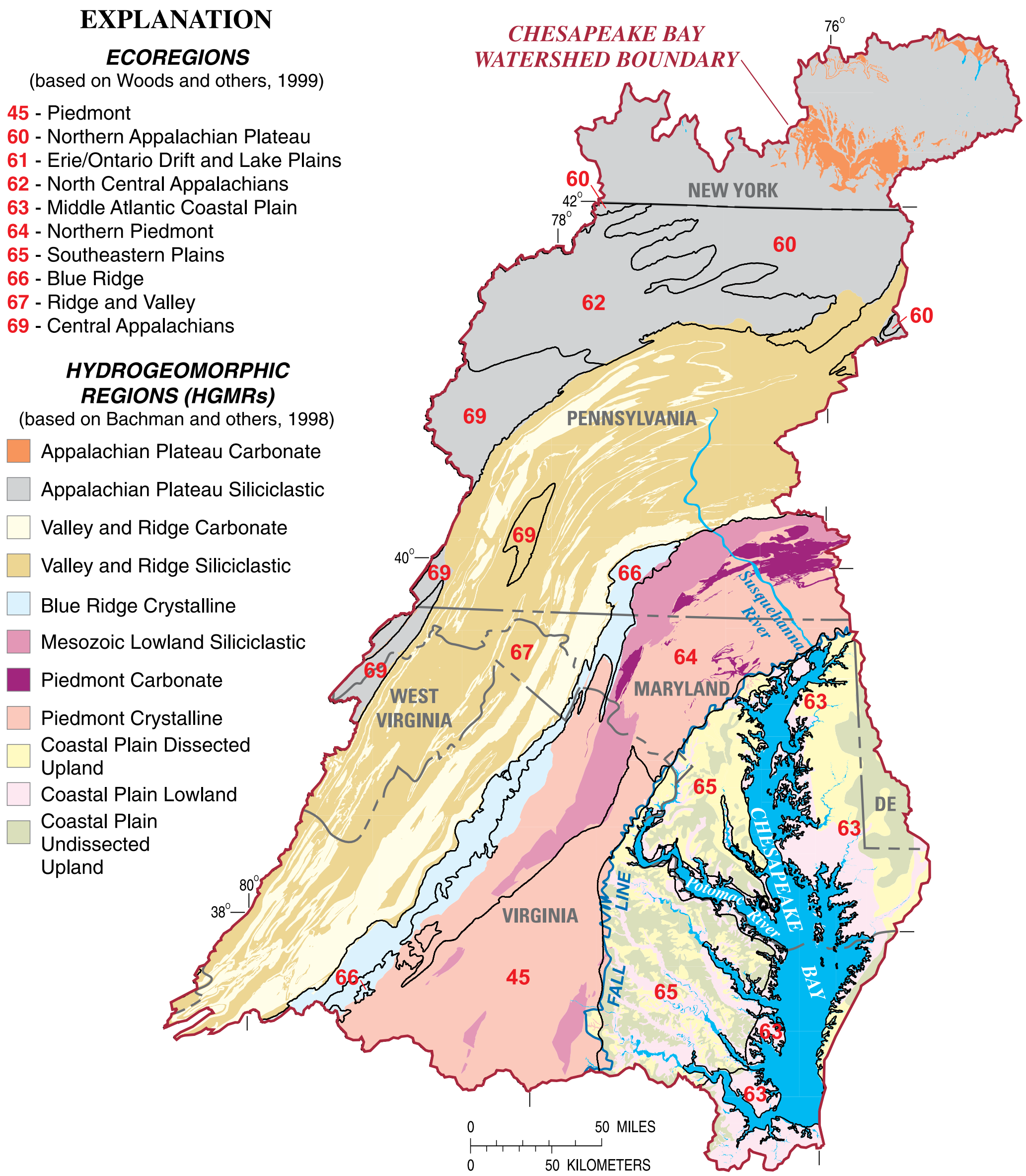

Figure 1.2. Different landscape settings in the Chesapeake Bay watershed (modified from Phillips, 2005). The movement of nutrients, sediment, and contaminants in the watershed and their delivery to the estuary are influenced by the different landscape settings, which have unique combinations of physical and biological characteristics. The USGS is providing a better understanding of the influence of landscape settings on water quality, habitat, and fish and bird populations to improve implementation and assessment of conservation and restoration activities. The USGS will conduct the majority of its activities in the watershed because (1) human-population growth and land-use change will continue to be the greatest threats to the ecosystem, and (2) the majority of conservation and restoration actions will be implemented on land. The USGS will work with partners to relate the changes in the watershed to the changes in the Bay and its tidal estuaries.

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Grassed waterways are an agricultural best management practice that helps slow down the flow of runoff and absorb nutrients before they reach streams or ground water. Photograph by Jane Thomas, IAN Image Library (www.ian.umces.edu/imagelibrary/)

Chapter 2: Human Population Growth and Land-Use Change

By Peter R. Claggett

Human activities and their associated impact on the landscape have significantly affected the condition of the Chesapeake Bay and its watershed. The Bay watershed is one of the most populous coastal estuaries in the United States and over the past 20 years has experienced the largest increase in population compared to all other coastal watersheds in the United States (Crossett and others, 2004). The population of the Chesapeake Bay watershed grew from 8.1 million in 1950 to almost 16 million in 2000, greatly expanding urban and suburban areas. To help address the impacts of population growth, the Chesapeake 2000 agreement includes a goal to "develop, promote, and achieve sound land-use practices which protect and restore watershed resources, maintain reduced pollutant loadings for the Bay and its tributaries, and restore and preserve aquatic living resources." Two specific restoration commitments for this goal include (1) by 2012, reduce the rate of urban sprawl by 30 percent, and (2) permanently preserve from development 20 percent of the land area in the watershed by 2010. To support these commitments, the USGS established a related goal during 2001–06 to improve watershed and land-use data and analysis. This chapter synthesizes the USGS findings about the rate of urban sprawl in the watershed and outcomes from a vulnerability assessment.

The USGS cooperated with the CBP partners to quantify the rate of urban land change as an approach to quantify the rate of urban sprawl. The USGS had previously conducted analysis that documented the increase of urban land use in the Baltimore-Washington area over the past 200 years and provided future projections (Acevedo, 1999). The USGS worked with the CBP partners to evaluate different methods to characterize urban sprawl and determined that impervious surface change would provide the best surrogate to track the rate of urban development. Analysis of land-cover information produced by the University of Maryland's Regional Earth Science Application Center (Goetz and others, 2004) revealed that during the 1990s, the expansion of suburban areas was a major contributing factor to a 41-percent increase in impervious surface in the Bay watershed compared to an 8-percent increase in population (U.S. Environmental Protection Agency, 2004). Some of the contributing factors to the dispersed pattern of growth were consumer preferences for houses on large lots and commercial preferences for less expensive office and retail space. Further USGS analysis of satellite imagery and road data indicates that impervious surfaces compose about 18 percent of all urban lands in the Bay watershed. The majority of impervious surfaces results from the construction of roads, buildings, and parking lots; driveways, sidewalks, and other sources typically make up less than 20 percent of the impervious surfaces in a watershed (Tilley and Slonecker, 2006).

The environmental consequences of impervious surfaces include increased water runoff from the land leading to higher peak streamflows, increased streambank and bed erosion, and downstream flooding (Konrad, 2003). Impervious surfaces also cause more rapid delivery of nutrients, sediment, and contaminants from the land to streams by routing runoff directly into streams and bypassing the filtration and retention services provided by wetlands and riparian forest buffers. Biological and chemical impairment of streams can occur when the proportion of impervious surfaces in a watershed exceeds 5 to 6 percent (Couch and Hamilton, 2002). The dispersed development patterns in the Bay watershed have resulted in a loss of forests and agricultural lands, which typically provide a combination of water quality, wildlife, and aesthetic benefits. State and local governments are using the data on development patterns to focus land conservation and restoration activities to reduce runoff and to develop policies that reduce the impacts of impervious surfaces.

State population projections indicate that population increases in suburban and exurban counties will continue to occur. Over the past 30 years, the population of the Bay watershed increased by over 1 million persons per decade, and if these trends continue through the year 2030, the area of developed land will increase by more than 60 percent (Boesch and Greer, 2003). As part the CBP Resource Lands Assessment (RLA), which was developed to help identify lands for preservation, the USGS conducted a vulnerability assessment (Claggett and Bisland, 2004). The vulnerability assessment evaluated the relative potential risk of future land conversion to urban areas by 2010 based on proximity to the urban growth areas of the 1990s (fig. 2.1). The findings from the assessment imply that land-use change will continue to impact valuable lands and habitats in the Bay watershed. The vulnerability assessment is useful for evaluating development patterns and has been used by State resource agencies, together with other information, to more strategically prioritize lands for protection. The USGS also began to develop approaches to link different land-use change models with the CBP watershed model to predict nutrient and sediment loads through the year 2030. The USGS will develop a Chesapeake Bay Land Change Model that will also be a prototype for a National Land Change Community Modeling system. The predictions of nutrient and sediment loads for the period 2010–30 will be used to formulate additional strategies needed to improve the Bay ecosystem.

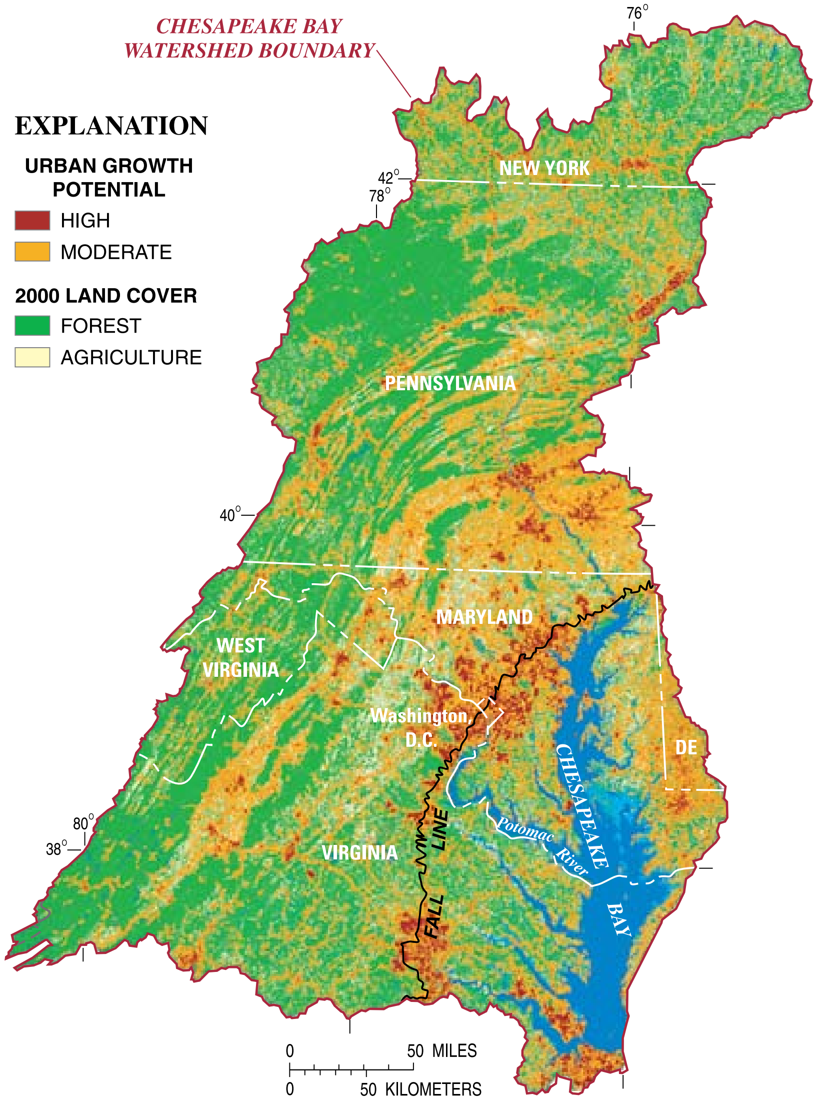

Figure 2.1. Potential urban land growth in the Chesapeake Bay watershed by 2010 (modified from Claggett and Bisland, 2004). The USGS conducted a vulnerability assessment to predict the risk of conversion of high value lands to urban areas by 2010. The results are being used to better target land acquisition and conservation programs.

View of the Patapsco River, Baltimore, including oil tank farms and the Patapsco Wastewater Treatment Plant. Curtis Creek is in the background. Photograph by Jane Thomas, IAN Image Library (www.ian.umces.edu/imagelibrary/).

Great Blue Heron fishes alongside road runoff culverts in Easton, Maryland. Photograph by Jane Hawkey, IAN Image Library (www.ian.umces.edu/imagelibrary/).

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Chapter 3: Factors Affecting the Distribution and Transport of Nutrients

By John W. Brakebill and Stephen D. Preston

In the Chesapeake 2000 agreement, the goal for water quality is to "achieve and maintain the water quality necessary to support aquatic living resources of the Bay and its tributaries and to protect human health." Related to this goal is a commitment to correct nutrient- and sediment-related problems in the Bay and its tributaries in order to remove the Bay from the impaired waters list by 2010. This chapter summarizes USGS efforts to better understand the distribution and transport of nutrients using a watershed modeling application, known as SPAtially Referenced Regressions On Watershed attributes (SPARROW).

SPARROW models use a nonlinear regression approach to define relations among nutrient sources, stream nutrient loads, and the environmental factors that potentially affect nutrient transport (Smith and others, 1997; Schwarz and others, 2006). Results from the SPARROW models provide (1) a statistical basis for estimating stream nutrient loads in unmonitored locations, and (2) the statistical significance of nutrient sources, environmental factors, and transport processes in explaining predicted nutrient loads.

The distribution and transport of nutrient sources in the Chesapeake Bay watershed have been evaluated by the USGS using the SPARROW methodology. Models of total nitrogen and total phosphorus were developed for the Chesapeake Bay watershed, estimating water-quality conditions for three snapshots in time: the late 1980s-Version 1.0 (Preston and Brakebill, 1999; Brakebill and Preston, 1999), the early 1990s-Version 2.0 (Brakebill and others, 2001), and the late 1990s-Version 3.0 (Brakebill and Preston, 2004). Spatial data representing nutrient source quantities for each specified time period were compiled and include: atmospheric deposition, point-source locations, septic systems (Version 2.0 only), land use, land cover, and agricultural sources including commercial fertilizer and manure applications. Environmental characteristics datasets representing factors that affect the transport of nutrients (land-to-water delivery) also were compiled.

The fate and transport of nitrogen within a drainage catchment are influenced by watershed characteristics (such as slope, lithology, and geologic structure) and processes within the stream channel. Soil permeability (Version 1.0) and area within the Coastal Plain Physiographic Province (Versions 2.0 and 3.0) were identified in the SPARROW models as statistically significant watershed characteristics that affect the transport of nitrogen to streams. These factors may reflect the potential for nitrogen to flow through ground-water pathways that are slower and provide more potential for loss through denitrification (Brakebill and Preston, 2004). Additionally, the effect of in-stream loss processes, represented as a function of stream traveltime based on various streamflow classes and the presence of reservoirs, is a significant factor affecting the transport of nitrogen in streams (Brakebill and Preston, 2004; Preston and Brakebill, 1999). Smaller streams (those less than 200 cfs, or cubic feet per second), tend to have higher nitrogen loss than larger streams—those greater than 1,000 cfs. Smaller, shallower streams have more contact with bottom sediments and have a greater potential for total nitrogen loss due to biological processing and denitrification.

Resource managers have identified three nutrient sources—point sources, agriculture, and urban lands—as high priorities for nutrient-reduction actions. The spatial distribution of the amount of nitrogen delivered (expressed as yield) from each major source as it is transported to the Chesapeake Bay estuary is shown in figure 3.1. This information is being used to identify geographic areas where management actions designed to reduce nitrogen to the estuary should be implemented. The USGS also has provided the SPARROW model results for each of the tributary strategy basins, which are the geographic areas with specific nutrient and reduction goals, so resource managers can identify local areas with the highest delivery of nutrients to local streams and the estuary. An example of the SPARROW model results for the Shenandoah Valley tributary strategy basin is shown in figure 3.2. The amount of nitrogen that is generated locally and transported to streams ("incremental yield") is shown in figure 3.2*A*, and the amount of nitrogen that is generated locally and would be transported to the estuary ("delivered yield") is shown in figure 3.2*B*. The maps can be used together to better define areas where management actions may improve water quality both in local streams and the estuary. Information from the SPARROW models was also used to refine the segmentation for the CBP Phase V watershed model (Martucci and others, 2005), and to help design the CBP nontidal water-quality network (Brakebill and Preston, 2003). Results from the network for nutrient and sediment trends are provided in Chapter 5.

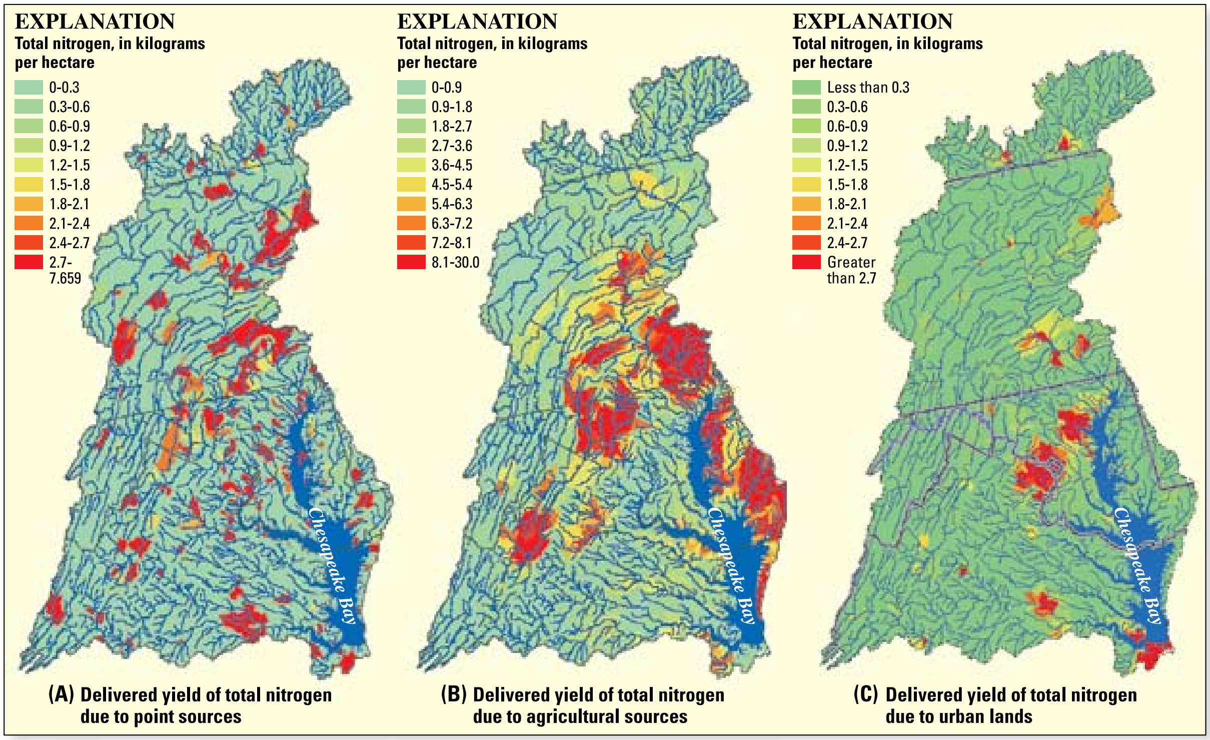


Figure 3.1. Distribution of nitrogen yields delivered to Chesapeake Bay from *(A)* point sources, *(B)* agricultural sources, and *(C)* urban lands (modified from Brakebill and Preston, 2004). The USGS developed watershed models (SPARROW models) that provide a finer resolution of nutrient sources and their transport to streams and to the estuary. The SPARROW model results are being used to identify priority areas for implementing management actions.

The Cambridge wastewater treatment plant, with downtown Cambridge in the background and the Choptank River Bridge on the right. Photograph by Jane Thomas, IAN Image Library (www.ian.umces.edu/imagelibrary/).

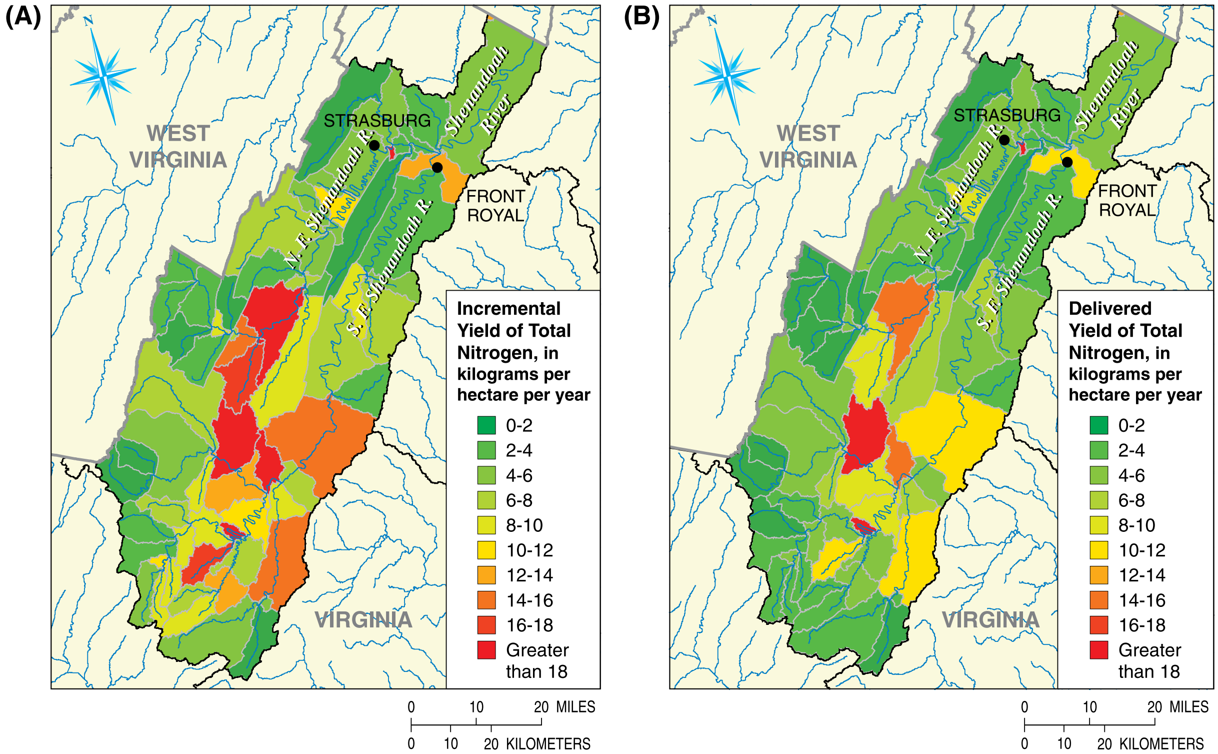
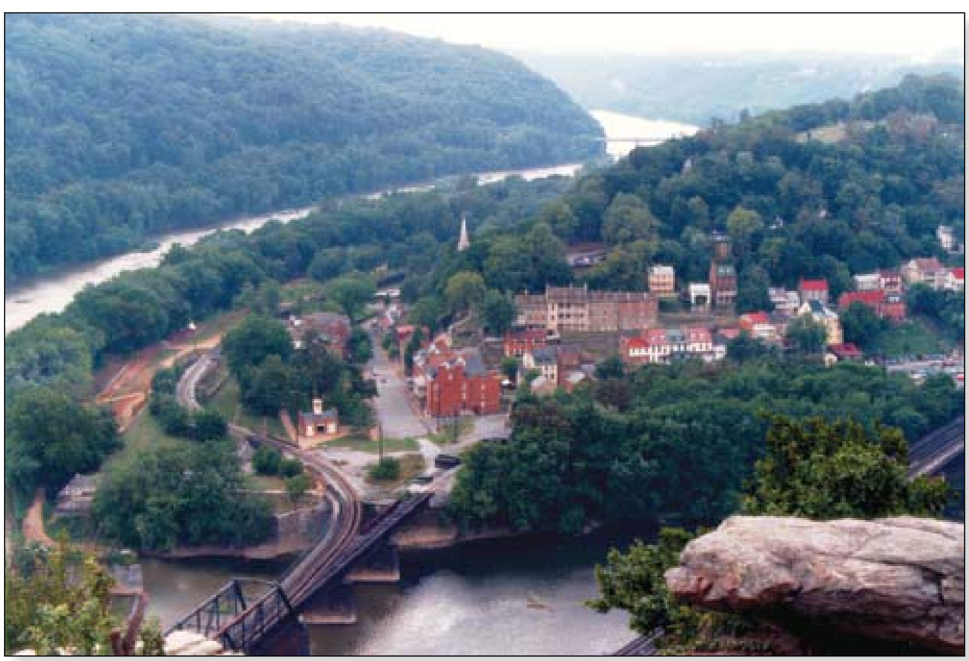


Figure 3.2. Distribution of total nitrogen yield in the Shenandoah Valley tributary strategy basin. *(A)* Incremental yield of total nitrogen is the amount generated in a local watershed and transported to a stream reach, and *(B)* delivered yield of total nitrogen is the amount that is generated in a local watershed and is reduced by instream loss as it is transported to the Bay. The results are being used to further delineate areas where management actions can benefit both the estuary and local water quality.



View of Harpers Ferry, West Virginia at the confluence of the Shenandoah and Potomac Rivers. Photograph by U.S. Geological Survey.

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Chapter 4: Transport of Nitrogen in Ground Water

By Scott W. Phillips

The hydrologic pathways for nutrients have important implications for the lag time between implementing management actions and detecting water-quality changes in surface water. Previous USGS studies documented that on average, just over 50 percent of the total volume of water in streams is from ground water, with a range of 16 to 92 percent for different streams (Bachman and others, 1998). Estimates of the amount of nitrogen delivered to a stream through ground water range from 17 to 80 percent, with an average of 48 percent (Bachman and others, 1998). Additional analysis by Sprague and others (2000) found similar percentages (15 to 65) of total nitrogen in streams from nitrate contributed through ground water. This chapter summarizes USGS findings about the factors affecting the occurrence and residence time of nitrogen in ground water and its discharge to streams.

The presence of nitrogen in ground water, which occurs mostly as nitrate, is related primarily to nutrient application in different land-cover settings and natural factors including rock type and denitrification that also influence the amount of nitrate occurring in ground water and its discharge to streams (Lindsey and others, 2003). Previous USGS studies determined that the average concentration of nitrate in ground water under different types of land cover ranged from about 5.0 mg/L (milligrams per liter) in agricultural areas, to 2.0 mg/L in urban areas, and less than 0.1 mg/L in forested areas (Ator and Ferrari, 1997). Results from USGS collaboration with USEPA to assess ground-water vulnerability to nitrogen (Greene and others, 2005) also were used to assess the spatial distribution of nitrate in ground water. The probability of nitrate concentrations exceeding 3 mg/L in the Mid-Atlantic area is shown in figure 4.1. The probability of nitrate exceeding 3 mg/L is greatest in parts of the Coastal Plain, in the northern part of the Piedmont Physiographic Province, and in the carbonate rocks of the Valley and Ridge. This information is useful for resource managers to better understand where ground-water discharge will more likely affect water-quality change in streams in response to management actions.

Once nitrate is in ground water, denitrification can be an important process in controlling the amount of nitrogen discharging to streams in some areas of the Bay watershed. In the Coastal Plain, areas with the highest potential denitrification correspond to poorly drained, impermeable soils with abundant organic matter (Ator and others, 2000, 2005). In much of the non-Coastal Plain areas of the watershed, Peper and others (2001) identified near-surface rock formations that contain high amounts of carbon and sulfur that promote denitrification. To better understand the relation between rock type and denitrification, the USGS studied four small watersheds in the major rock types within the Bay basin (Lindsey and others, 2003). Results from this study revealed that denitrification was occurring in the watersheds underlain by unconsolidated rocks (Coastal Plain) and sandstone, shale, and siltstone of the Valley and Ridge, but was not as common in crystalline (Piedmont) or carbonate rocks (Valley and Ridge). Further, the denitrification was significant in ground water with residence times greater than 20 years, but younger, more locally recharged water was not greatly affected by denitrification (Lindsey and others, 2003). Therefore, the influence of denitrification varies greatly throughout the watershed and has implications for management actions. In areas where denitrification is occurring in ground water, resource managers may focus actions to reduce nitrogen in overland runoff from reaching streams.

The age of waters being delivered to a stream will be influenced by the relative contribution of surface runoff, soil water, and ground water. Runoff and soil water both have very young ages (hours to months, respectively) and supply, on average, about half of the water to a stream (Phillips and Lindsey, 2003) (fig. 4.2). The remainder of the water supplied to a stream moves through the ground-water system and has a range of modern to over 50 years, with a median age of 10 years. The overall result is that about half of the water entering a typical stream in the Bay watershed can be considered modern, and about 90 percent is less than 15 years old. The relative contribution of surface water, soil water, and ground water will influence the response of the stream to changes in nutrient sources and management actions in a watershed.

The USGS prepared a ground-water model of the East Mahantango Creek watershed, a predominantly agricultural basin underlain by fractured rock, to predict the change in nitrate concentration in a stream over time (Lindsey and others, 2003). The model used information on the amount of nitrogen applied to the land surface over time in the basin, assumed a ground-water age of about 10 years, and estimated a response of the base-flow (the amount from ground water) nitrate concentrations in a stream (fig. 4.3). The model results indicate that the base-flow nitrate concentration of the stream increased during the last several decades (curve a in fig. 4.3) because of increases in the concentrations discharging from ground water. The increase in nitrogen sources used

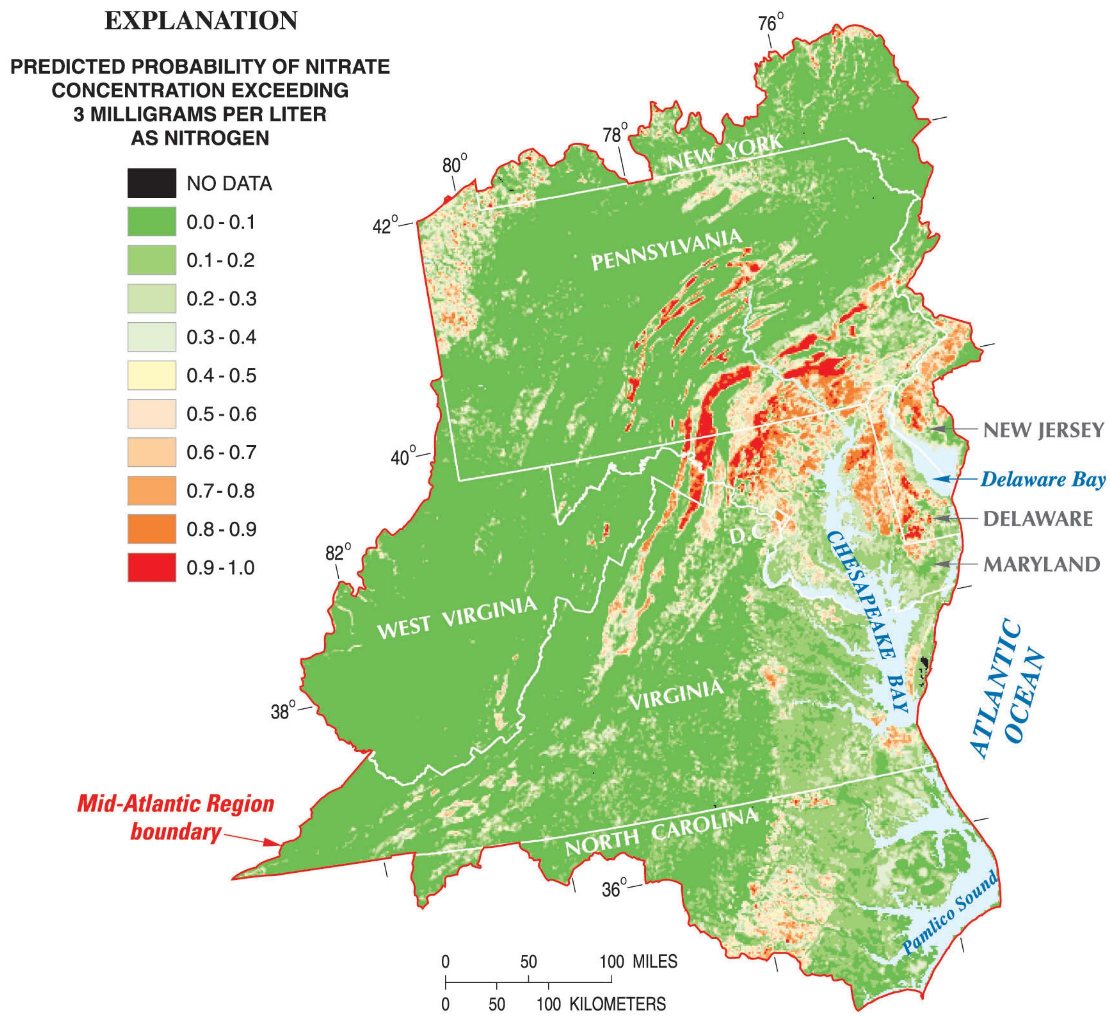

Figure 4.1 The probability of nitrate concentrations in ground water exceeding 3 miligrams per liter in the Mid-Atlantic region (modified from Greene and others, 2005). Having an understanding of nitrogen concentrations in ground water helps managers consider different options for implementing management actions to reduce nutrients to streams and the estuary.

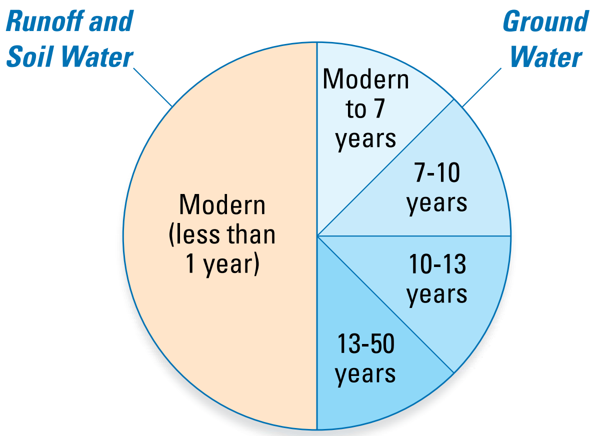

Figure 4.2. Distribution of ages from runoff, soil water, and ground water entering a typical stream in the Bay watershed (from Phillips and Lindsey, 2003). About 50 percent of the water contributed to streams is modern, with 90 percent of water moving to a stream in less than 15 years. The hydrologic pathways of nutrients in the watershed (surface water or ground water) will influence the lag time between implementing a management action and seeing a water-quality response. Watersheds with a higher percentage of the nitrogen transported through surface-water runoff will have more rapid improvements in water quality than those with a higher portion of nitrogen in ground water.

in the model is typical of many agricultural regions within the Chesapeake Bay watershed. Two future scenarios were examined with the model: (1) continuation of nitrogen applications at current levels, and (2) elimination of all nitrogen applications. The scenario with nitrogen applications at current levels results in a continued increase in concentration of base-flow nitrate in the stream over the next several decades (curve b in fig. 4.3). The scenario with complete elimination of nitrogen applications shows that a 50-percent reduction in nitrate base-flow concentrations could occur in the first 5 years, with a decrease likely to continue until 2040 (curve c in fig. 4.3). Base-flow nitrate concentrations over time in many streams in the Chesapeake Bay watershed likely will be bounded by these two scenarios depending on the amount of nonpoint-source reductions and the relative contribution and age of surface and ground water to a stream. The relative contribution of flows to a stream and their respective ages will influence the lag time between implementation of management actions and improvement in water quality. Streams with a higher portion of surface water and young ground water will have more rapid improvement than streams with higher proportions of ground water of older ages. Knowledge of these differences at local scales can be used to help choose the types of management actions needed and better assess their effectiveness.

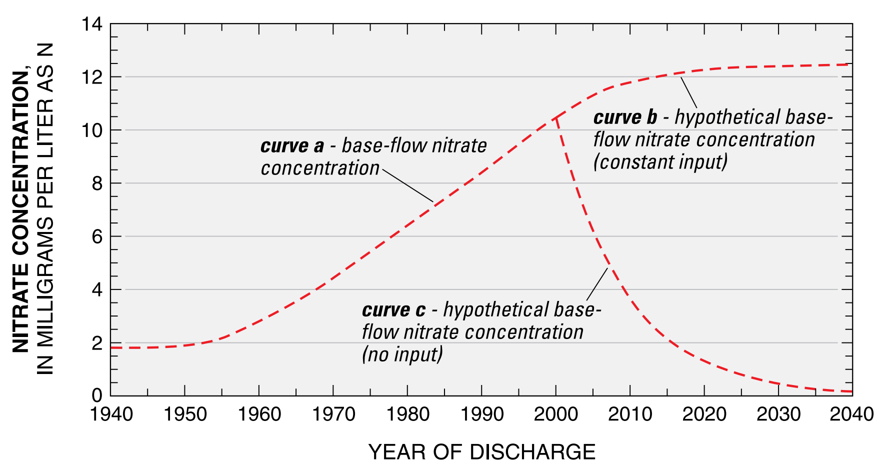

Figure 4.3. Predicted nitrate concentrations of base flow to a stream in the East Mahantango Creek watershed in Pennsylvania (from Phillips and Lindsey, 2003). A model was used to predict the stream concentrations based on nitrogen-source reductions and the influence of ground water in an agricultural watershed. The model results indicate that the base-flow nitrate concentration of the stream increased during the last several decades (curve a) because of increases in the concentrations discharging from ground water that are related to increases in nitrogen sources. Two future scenarios were examined with the model: (1) continuation of nitrogen applications at current levels, and (2) elimination of all nitrogen applications. Scenario (1) results in a continued increase in concentration of base-flow nitrate in the stream over the next several decades (curve b), while scenario (2) shows that a 50-percent reduction in nitrate base-flow concentrations could occur in about 5 years, with a decrease likely to continue until 2040 (curve c). Base-flow nitrate concentrations over time in many streams in the Chesapeake Bay watershed likely will be bounded by these two scenarios.

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Chapter 5: Assessing Changes in Streamflow and Nutrients

By Jeff P. Raffensperger and Michael J. Langland

Monitoring and assessing streamflow and nutrient concentrations in the watershed provide critical information toward evaluating the progress of management actions to reduce nutrient and sediment loads in the watershed and their delivery to the estuary. This chapter summarizes USGS findings related to change in streamflow and nutrients in the watershed and the factors affecting water-quality change.

Streamflow and water-quality monitoring in the watershed is conducted using three primary networks—the USGS stream-gaging network, the River-Input Monitoring (RIM) Program, and the CBP nontidal water-quality network. The stream-gaging network has multiple partners and purposes—computation of total river flow to the Bay and support of water-quality monitoring are the two primary applications for Chesapeake Bay studies. The USGS, in partnership with the Maryland Department of Natural Resources and the Virginia Department of Environmental Quality, began comprehensive water-quality monitoring in the 1980s through the RIM Program to estimate nutrient loads from the watershed to the estuary and assess concentration change over time. The RIM sites are at the head-of-tide on the nine major tributaries entering the Chesapeake Bay and collectively monitor approximately 80 percent of the Bay watershed (fig. 5.1). In 2004, the USGS partnered with USEPA and the six states in the watershed to establish the CBP Nontidal Water-Quality Network (fig. 5.1). The primary goal of the network is to identify the status and trends in water-quality conditions to help assess progress of the CBP tributary strategies to reduce nutrients and sediment to meet water-quality criteria in the estuary (U.S. Environmental Protection Agency, 2003). The partners in the network are using compatible sampling and analysis protocols to collect nutrient and sediment samples over a range of flow conditions at existing USGS stream-gaging sites. As of 2006, about one-third of the 200 proposed sites for the network had been fully implemented.

The USGS has developed (Cohn and others, 1989; Hirsch and others, 1991; Helsel and Hirsch, 1992) and enhanced techniques (Langland and others, 2000, 2004, 2006) to better document changes in streamflow and nutrient concentrations over time. The water-quality changes are affected by the natural variability in streamflow and the changes in nutrient sources over time. The natural variability in streamflow (fig. 5.2) has greatly impacted the transport of nutrients and sediment through the watershed and their delivery to the Bay (Langland and others, 2006). Between 1940 and 1959, the majority of annual river flow to the Bay was within the normal range (defined as the 25th to 75th percentile). A dry period occurred during the 1960s, followed by wetter conditions in the 1970s. The 15 years between 1990 and 2004 exhibited extreme variability. Since 1990, the annual nitrogen loads computed for the RIM stations have varied from 100 to over 350 million pounds with additional amounts of nitrogen being contributed from point sources and runoff from the areas not monitored at these stations (Langland and others, 2006). The combination of wetter conditions in the 1970s, along with increased nutrients and sediment from human activities, were two primary factors that caused the decline in water quality in the estuary that is still evident (Phillips and others, 2002). The findings indicate that even with reductions in nutrient and sediment concentrations, natural variability in streamflow will greatly influence the seasonal and annual delivery of loads to the estuary and influence its water quality. The CBP partners use a 3-year average of estuary water-quality data to assess attainment of water-quality standards to help address the influence of streamflow variability and loads on estuary water quality. The partners may also need to emphasize specific management actions to more effectively reduce nutrient and sediment loads from high-flow events. The flow-adjusted trend for a site is also estimated as a continuous percent change over time. Examples from three different sites are shown in figure 5.3. The pattern of change over time at a site can be used to further assess the influences of population growth and management actions in a watershed. Some watersheds continue to show downward trends in nutrients and sediment due to management actions, whereas other sites are starting to show increasing concentrations of nutrients and sediment due to continued population growth.

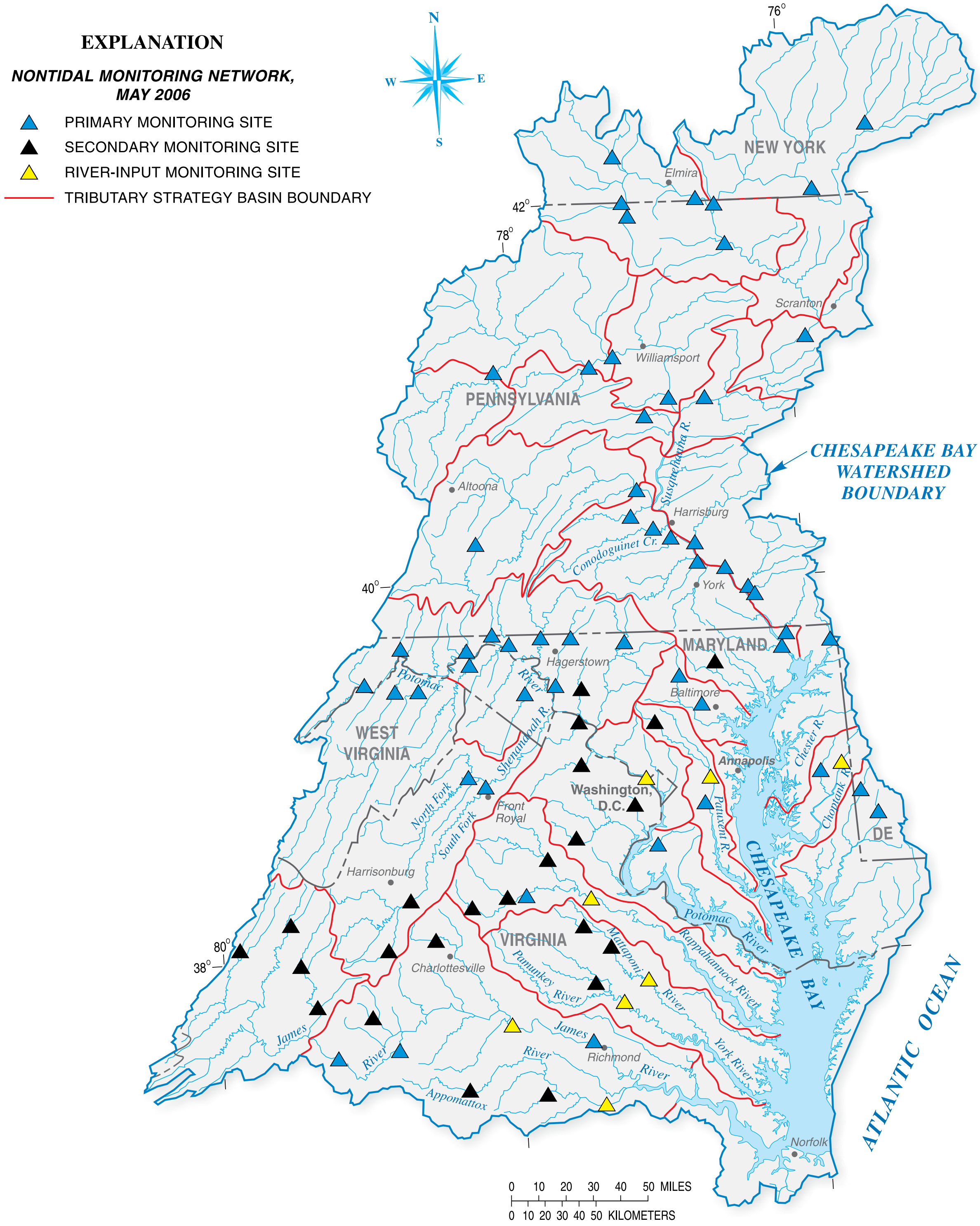

Figure 5.1. Monitoring sites of the Chesapeake Bay Program (CBP) Nontidal Water-Quality Network and River-Input monitoring sites. The USGS worked with the USEPA and the six states in the Bay watershed to establish the CBP Nontidal Water-Quality Network. Data from the network are used to document water-quality change that is related to land use, implementation of management actions, and climate variability.

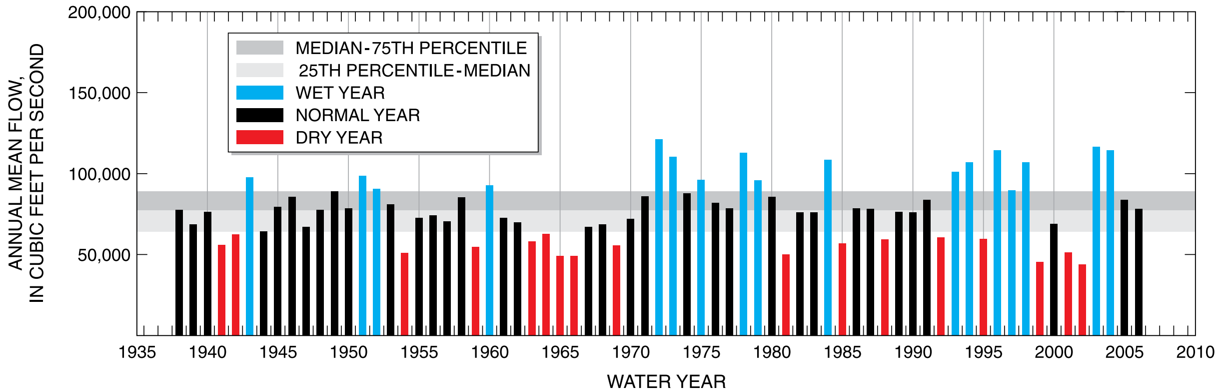

Figure 5.2. Annual total streamflow into the Chesapeake Bay, water years 1938–2006. Streamflow variability has increased since 1970 and has a large influence on the annual nutrient and sediment loads delivered to the Bay. Documenting the variability helps explain and forecast water-quality and ecological conditions in the estuary.

The USGS uses another approach, known as flow-adjusted trends, to provide an estimate of changes in nutrients due to human activities in the Bay watershed. This technique removes the influences associated with streamflow and seasonal variability to better estimate changes due to human activities. At sites where monitoring has been conducted since at least 1990, significant decreasing trends were detected at 72 percent of sites for total nitrogen (fig. 5.4), 81 percent of the sites for total phosphorous, and 43 percent of the sites for sediment (Langland and others, 2006). These results indicate that management actions are reducing the concentration of nutrients and sediment in parts of the watershed.

There are multiple factors affecting the occurrence and change of nutrients over time including the natural variability in streamflow, changes in nutrient sources and land use, influence of ground water, and implementation of management actions (Sprague and others, 2000; Phillips and others, 2006). More recent USGS analysis further documented the effect that the predominant land use and changes in land-use activities over time have on nutrient concentrations and trends throughout the Chesapeake Bay watershed between 1985 and 2005. Mean concentrations of total nitrogen and total phosphorus in stream water were highest in agricultural and urbanized basins, whereas lower concentrations occurred in streams draining areas dominated by forests, wetlands, and grasslands. Reductions in point-source loads of nitrogen and phosphorous, through the phosphate detergent ban and wastewater treatment plant improvements, contributed to improving water quality in some areas of the Bay watershed. In other areas, however, increasing urban or suburban population and other factors resulted in increased point-source loads and increasing trends of nutrients at some sites. Changes in nonpoint sources, including land-use changes, implementation of nutrient management plans, and changes in fertilizer and manure application rate, were also factors affecting nutrient loads and trends in surface water throughout the Bay watershed. The implication of these findings is that reducing nutrient and sediment loads to meet the water-quality criteria in the Bay by 2010 will not be achieved. The USEPA has used these findings, and other information on the rate of implementation of management actions, to revise the expectations for load reductions that will likely occur by 2010.

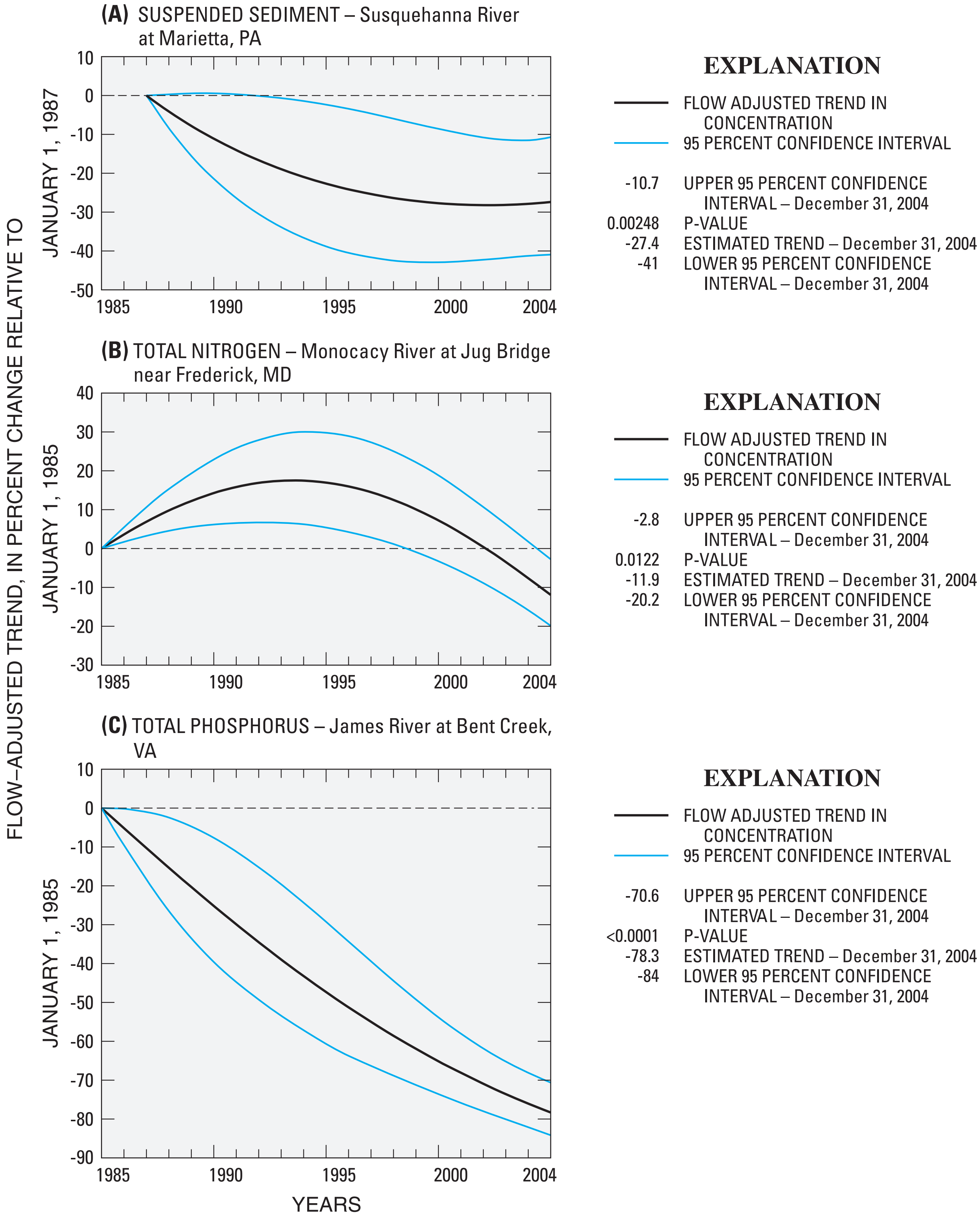

Figure 5.3. Examples of continuous flow-adjusted trend plots. The patterns of change over time at sites can be used to further assess the influences of population growth and management actions in a watershed. Some watersheds continue to show downward trends in nutrients and sediment due to management actions, whereas other sites are starting to show increasing concentrations of nutrients and sediment due to continued population growth.

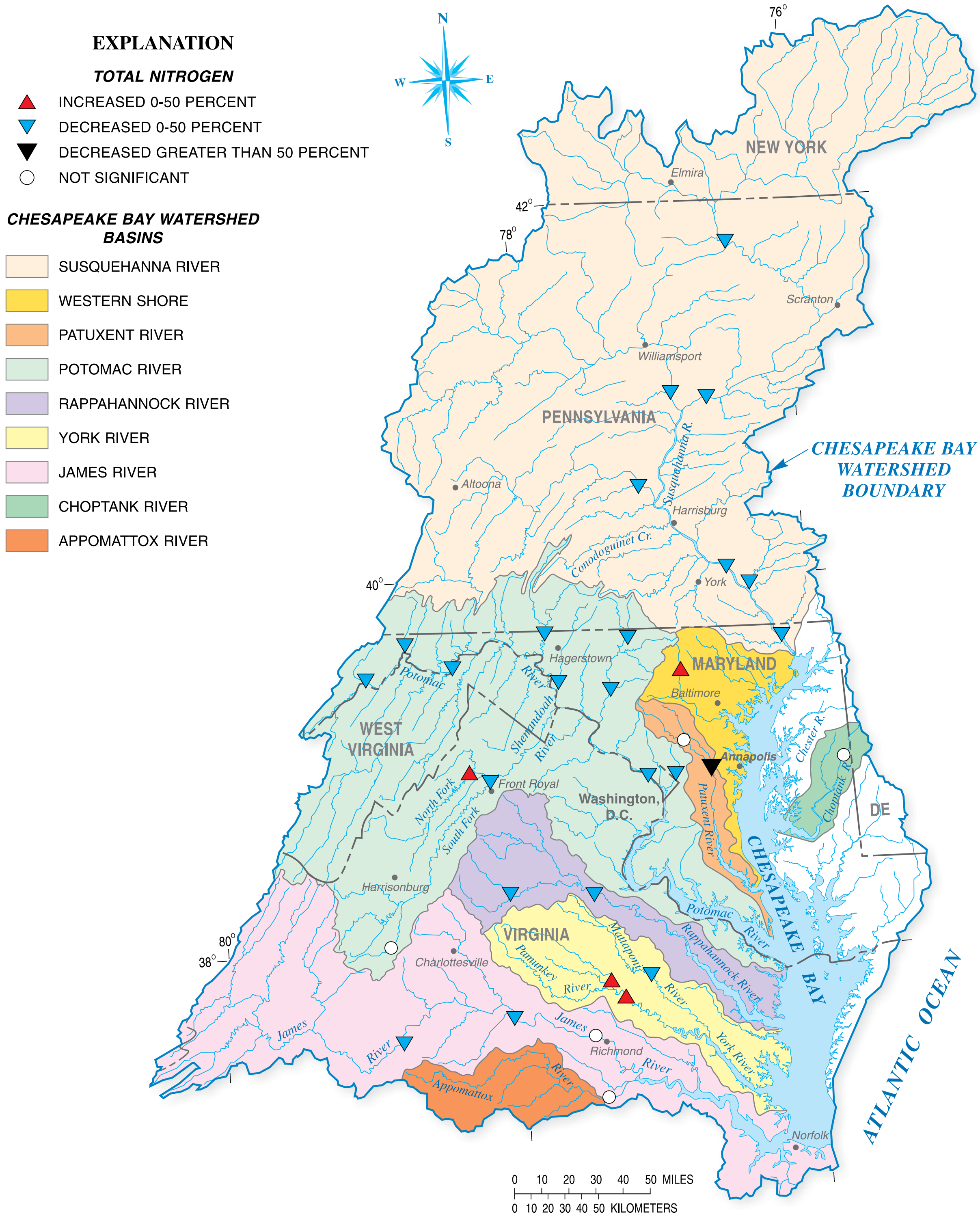

Figure 5.4. Change in flow-adjusted trends for total nitrogen in the Chesapeake Bay watershed (modified from Langland and others, 2006). There has been a decrease in nitrogen and phosphorus at a majority of sites in the watershed. However, concentrations are not decreasing at a rate that would reduce the nutrient loads sufficiently to remove the Bay from the impaired waters list by 2010.

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Chapter 6: Sources and Transport of Sediment in the Watershed

By Allen C. Gellis, Cliff R. Hupp, Jurate M. Landwehr, and Milan J. Pavich

Sediment has an adverse impact on the health of streams in the Bay watershed, SAV, and living resources in the estuary. The CBP partners have commitments to reduce sediment to the estuary to improve water-clarity conditions for SAV and conduct watershed planning to improve the health of streams. The USGS led a synthesis of sediment information by the CBP partners (Langland and Cronin, 2003) and conducted additional studies. This chapter provides a synthesis of USGS findings about sediment sources and transport in the watershed; the following chapter synthesizes sediment sources and deposition in the estuary.

The USGS used several methods to assess the sources of sediment in the watershed including (1) analyzing historical data to evaluate areas with the highest sediment loads, yields, and concentrations, (2) assessing the distribution of sediment erosion rates, and (3) using geochemical tracers to determine sediment sources. Gellis, Banks, and others (2004) examined historical annual suspended-sediment loads (tons per year), yields (tons per square mile per year), discharge-weighted concentrations (mg/L), and instantaneous suspended-sediment concentrations (mg/L) for 65 USGS sediment stations operating in the Chesapeake Bay watershed. The highest sediment loads entering the Bay were from the Potomac and Susquehanna River Basins. The sediment loads were highly correlated to drainage area and river discharge, so larger basins usually had larger sediment loads. Sediment yields, which are loads divided by basin area, are used for assessing and comparing sediment generation in different areas of the Bay watershed. The sediment yields ranged from just over 1,000 tons per square mile to under 10 tons per square mile for sediment stations operating from 1985–2001 (fig. 6.1). Some of the highest yields were in the Conestoga River, a tributary of the Susquehanna River. Agriculture is the predominant land use in the Conestoga watershed and therefore is probably an important contributing factor to the high amount of sediment in this watershed.

Sediment yields computed by Gellis, Banks, and others (2004) were further examined to assess the distribution of sediment erosion in the different physiographic regions in the watershed. The sites were classified to fall within six physiographic regions (Coastal Plain, Valley and Ridge, Piedmont, Mesozoic Lowlands, Blue Ridge, and Appalachian Plateau) in the Chesapeake Bay watershed. Watersheds that had a majority of their contributing areas draining the Piedmont had the highest sediment yields, whereas Coastal Plain sites had the lowest sediment yields. The amount of eroded sediment from any one area depends on multiple factors including geology, land use, climate variability, and vegetation. The Piedmont Physiographic Province has a high degree of land disturbance (urban and agricultural land use) and topographic relief that promotes erosion. While the Coastal Plain has similar land disturbance, it has much lower topographic relief (especially on the Eastern Shore) and therefore, less sediment erosion. These findings imply that management actions to reduce sediment to the upper reaches of the estuary would be most effective if they are implemented in the Piedmont Province.

These analyses of historical data are fairly consistent with another study approach that was first developed by Brown and others (1988) using a cosmogenic isotope ^{10}Beryllium (^{10}Be) to assess the relative disturbance and acceleration of erosion from upland soils. This technique was used to estimate erosion from 48 basins in the eastern United States, including 10 basins that drain to the Chesapeake Bay. The highest rates of erosion were observed in the Piedmont streams, and the lowest rates were observed in Coastal Plain streams. More recently, the USGS applied this technique to produce erosion indices based on ^{10}Be for selected watersheds in the Susquehanna River Basin (Gellis, Pavich, and others, 2004; Reuter and others, 2005). Many of the higher values indicating significant erosion are clustered in the lower Susquehanna Basin, including the Conestoga watershed. The Conestoga also had some of the higher sediment yields (fig. 6.1), indicating that the ^{10}Be approach is useful in assessing erosion rates in the Bay watershed.

The relative contribution of the erosion of sediment from the land surface rather than from stream corridors is not well understood in the Chesapeake Bay basin. The USGS conducted research in three watersheds using a "sediment fingerprinting" approach to identify the sources of fluvial sediment. Sediment fingerprinting approaches were developed by Walling (2005), and the USGS developed a new algorithm and made use of several geochemical tracers, namely the relative composition of total carbon, nitrogen, and phosphorous in a sample, the stable isotopes carbon 13, nitrogen 15, and two radionuclides (cesium 137, and lead 210) to better identify sources of sediment. Preliminary results show that samples from the Pocomoke watershed on the Eastern Shore of Maryland were found to have up to 75 percent of the sediment eroded from within stream corridors (Gellis and Landwehr, 2006). Land erosion appears to be a higher contributor in other watersheds. The implication of these

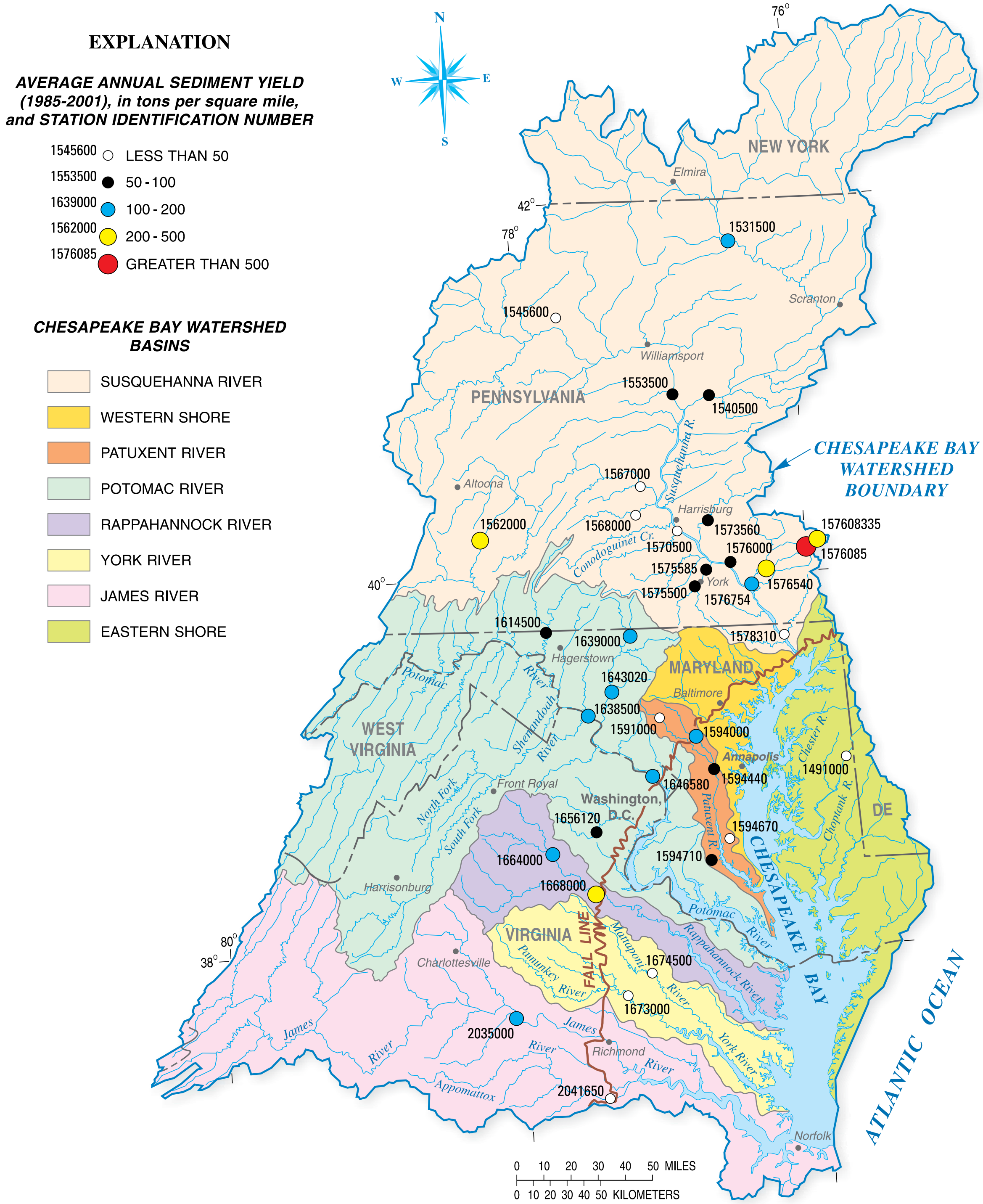

Figure 6.1. Distribution of sediment yields in the Chesapeake Bay watershed, 1985–2001 (from Gellis, Banks, and others, 2004). USGS analysis of historical sediment data found the highest yields in the Piedmont, with the lowest yields in the Coastal Plain, indicating that management actions to reduce sediment to tidal fresh areas should be targeted in the Piedmont. Protecting and restoring forest and wetland assemblages is another effective approach to minimize sediment transport to the estuary.

findings is that detailed information will be needed in local watersheds to identify the primary source of erosion (stream corridors or land erosion) to properly plan and implement sediment-reduction actions.

The time required to transport sediment from the watershed to the estuary depends on the amount of storage in different areas of the watershed. Sediment is stored and trapped in stream corridors, behind dams, and in Coastal Plain flood plains and wetlands adjacent to the estuary. The sediment stored in stream corridors includes a large amount of sediment eroded during land clearance in the 1700s and 1800s, known as "legacy" sediment (Langland and Cronin, 2003). Merritts and others (2004) proposed that impoundment of sediment behind tens of thousands of mill dams in the Mid-Atlantic Region was the dominant cause of sediment accumulation in stream-channel corridors. As these mill dams were breached or removed, sediment stored behind the dams was eroded and transported. Previous studies by the USGS revealed that dams on large rivers also store large amounts of sediment. Reservoirs on the lower Susquehanna River, for example, trap 70 percent of sediment being transported in the river (Langland and Hainly, 1997). The investigators also found that two of these dams have reached their sediment storage capacity and the lowermost reservoir (Conowingo) may fill in 20 to 25 years.

Coastal Plain flood plains and their bottomland hardwood systems remain a critical landscape element for the maintenance of water quality by trapping and storing large amounts of sediment and associated contaminants (Hupp, 2000). These flood plains are among the last places for sediment storage and natural biogeochemical remediation of nutrients and contaminants before entering critical estuarine nursery areas for fish and wildlife. Preliminary USGS results show large amounts of nitrogen and phosphorus are also trapped in sediment in the Chesapeake Bay Coastal Plain flood plains prior to entering tidal waters because of much lower stream gradients and a large amount of flood-plain area (Noe and Hupp, 2005). Therefore, maintaining the ability of the flood plains to retain sediment and associated nutrients is a critical management action for the CBP partners to consider.

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Plume of sediment-laden runoff, possibly from an adjacent construction area, near Annapolis, Maryland. Photograph by Jane Thomas, IAN Image Library (www.ian.umces.edu/imagelibrary/).

Chapter 7: Sediment Sources and Deposition in the Estuary

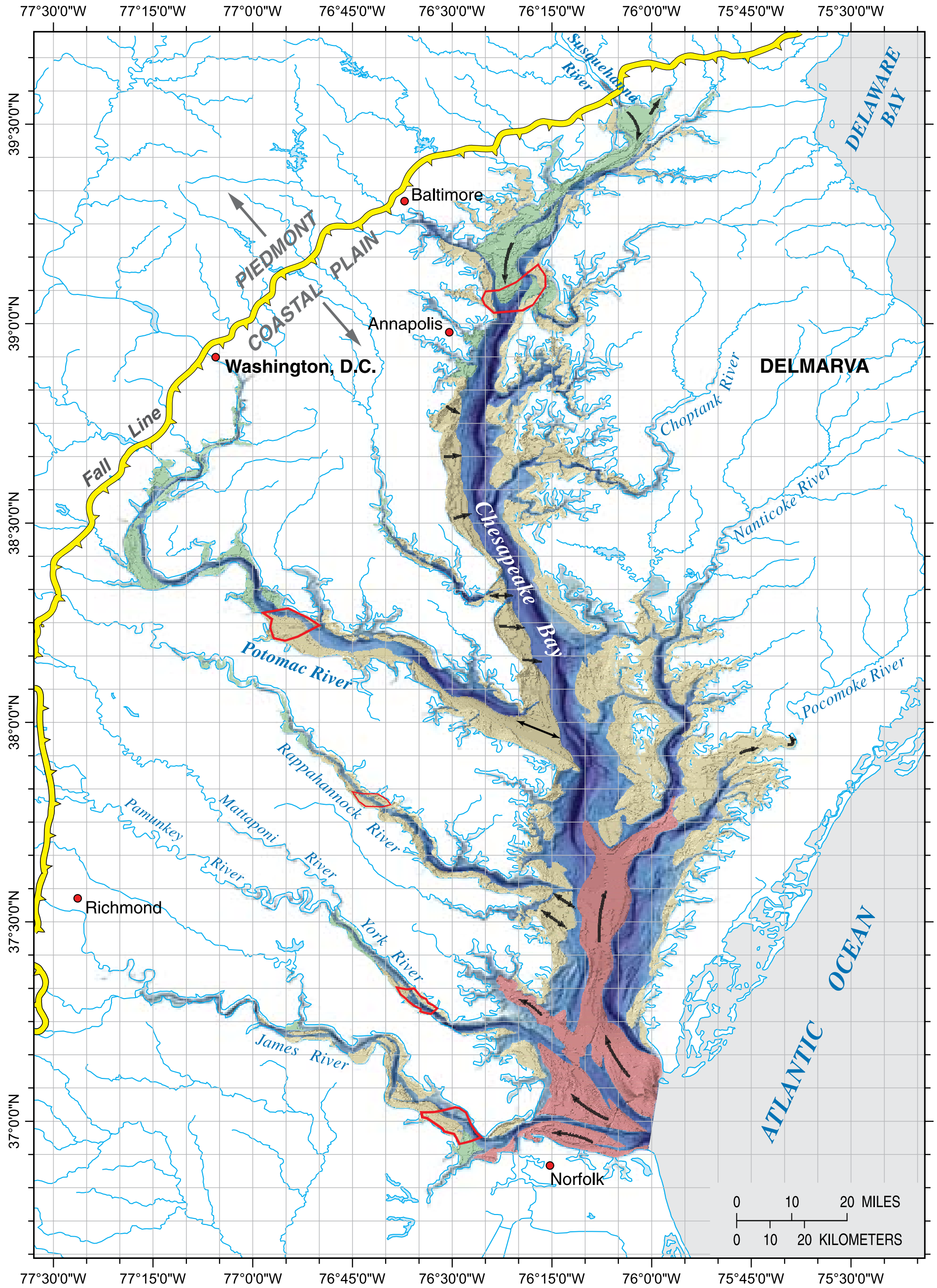
By Thomas M. Cronin

During the past 10 years, integrated studies of sediment in Chesapeake Bay and its tributaries have been carried out by a team of USGS scientists, in collaboration with researchers from several universities, the Maryland Geological Survey, the U.S. Naval Research laboratory, the USEPA, and other institutions. The USGS worked with these investigators to prepare a comprehensive review of sediment processes in the Bay and its watershed (Langland and Cronin, 2003). The current chapter, along with the chapter by Willard on the long-term water-quality changes in the Bay, summarizes the highlights of these studies.

Sediment input into the Chesapeake Bay comes from four main sources: riverine input, shoreline erosion, oceanic sediment, and *in situ* biological (biogenic) sources generated by organisms living in the bay (Langland and Cronin, 2003). The USGS used its understanding of geologic processes controlling sediment to map the probable locations of different sources of sediment entering the estuary (Newell and others, 2004). Although estimates of the relative contributions of different sediment sources vary, the rivers draining the Piedmont and Appalachian Physiographic Provinces are the main sources of sediment to the northern Bay and tidal fresh zones of the major tributaries (fig. 7.1). Shoreline and marsh erosion of Coastal Plain sediments are the primary sources in the central part of the Bay and below the zone of maximum turbidity in major tributaries. Both shoreline erosion and ocean input are major sources of sediment in the southern part of the Bay. Tidal re-suspension of existing sediment on the Bay floor through tides, currents, and waves also produces suspended material, especially in the turbidity maximum zones of the main stem and larger tidal tributaries. Among these sources and processes, sediments from the watershed and shoreline erosion have the greatest potential for reduction by management actions.

The USGS examined sediment cores to better understand the amount of sediment delivered from the watershed to the Bay. Analysis indicates a four-to-five fold increase in sediment accumulation in some parts of the Bay since the 1800s, whereas other areas showed no change in sediment rates (fig. 7.2) (Langland and Cronin, 2003). In general, evidence indicates that sediment transport from the watershed to the Bay is not uniform and varies according to local watershed characteristics, storage conditions, and climate variability. As mentioned in the previous chapter, sediment storage greatly influences the transport time in the watershed. Sediment transport from the watershed to the estuary can take decades to centuries (Langland and Cronin, 2003) and contributes to a substantial lag time between watershed erosion (and associated management controls) and improvements in water clarity in the estuary. As a result, the CBP partners are considering emphasizing land-based practices nearer the tidal parts of the Bay to improve water clarity.

Sediment erosion from shorelines also varies spatially and temporally because of multiple factors. The amount of sediment erosion from shorelines varies depending on climate conditions (wet or dry years), local geology, shoreline slope and geomorphology, offshore bathymetry, winds, and tides. The Western Shore of the Bay, for example, where headlands and large tidal tributaries draining the uplands are predominant, has different erosion processes than the Eastern Shore, where low-lying tidal marshes are extensive. Since sea level continues to rise in the Bay region at a rate of approximately 1.0 to 1.4 feet per century, and because the rate may be accelerated due to climate warming, shoreline erosion in response to rising sea level is an important process affecting low-lying areas (Langland and Cronin, 2003). The findings imply that, without management of coastal zones, a greater contribution of sediment to the Bay will come from shoreline erosion in the future. The states of Maryland and Virginia are considering sediment management of coastal areas as part of their tributary strategies. Overall, these findings imply that controlling sediment sources in the Piedmont Province of the watershed will be important to improve conditions for the tidal fresh regions of the estuary, and shoreline management actions will be needed to improve water clarity in more saline regions of the estuary.



EXPLANATION

SEDIMENT SOURCES AND DEPOSITIONAL ENVIRONMENTS

- **River Input Sediment** (deltas) from Piedmont and Appalachians (thickness range from 3 to 10 meters)
- **Coastal Erosion Sediment** from terraces, islands, and steep bluffs of Coastal Plain outcrops (thickness range from 3 to 10 meters)
- **Atlantic Sediment** from continental shelf and nearby coastal erosion (thickness range from 3 to 10 meters, may exceed 15 meters)
- **Thin Deposits** on Tertiary rock outcrops and buried Pleistocene channels; thick sediment stored in troughs along ancient thalweg (valley ways) of major rivers (as much as approximately 15 meters, locally may exceed 15 meters)

Map Unit Boundaries - The map units have no boundaries because the sediments are in flux in a dynamic environment. The top layers of Holocene sediments are moved by changing bottom currents driven by changes in salinity, temperature, and tidal cycling. Most of the shallow areas of the Bay are subject to resuspension above the wavebase during large storms and lunar tides.

- Prevailing movement of sediment from source
- 0 / -50 Bathymetry, in meters (from National Ocean Service, NOAA)
- Piedmont/Coastal Plain boundary (Fall Line)
- Zone of Maximum Turbidity (ZMT, approximately located; subject to seasonal migration)
- Towns

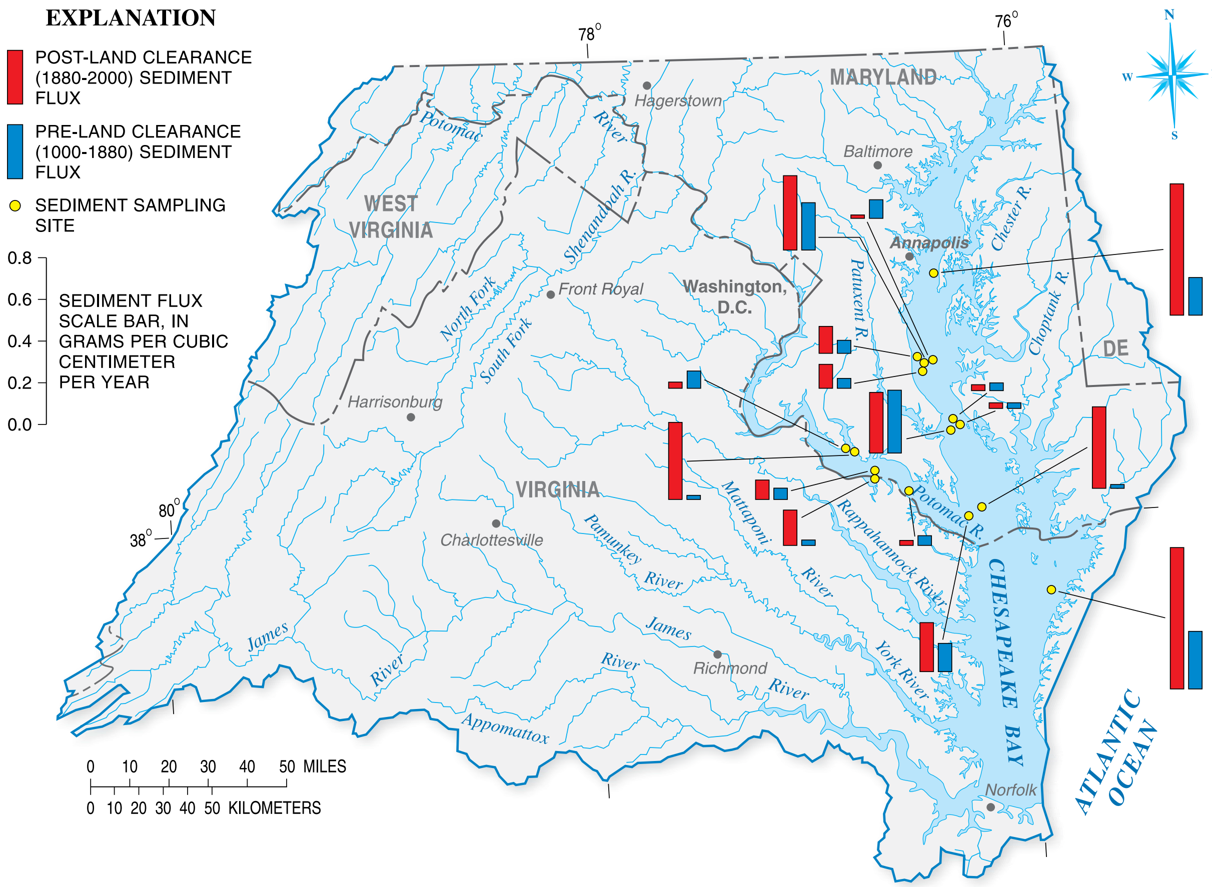


Figure 7.2. Rates of sediment deposition in the Chesapeake Bay estuary (modified from Langland and Cronin, 2003). Sediment deposition is influenced by land-based activities and factors affecting delivery of sediment from the watershed to the estuary. Sediment traveltimes from the watershed to the estuary may be decades to centuries. In general, sediment-reduction practices to improve water clarity in the estuary should be focused on sources that are closest to tidal waters. Practices to address shoreline erosion must also consider the sediment erosion due to continued sea-level rise and climate warming.

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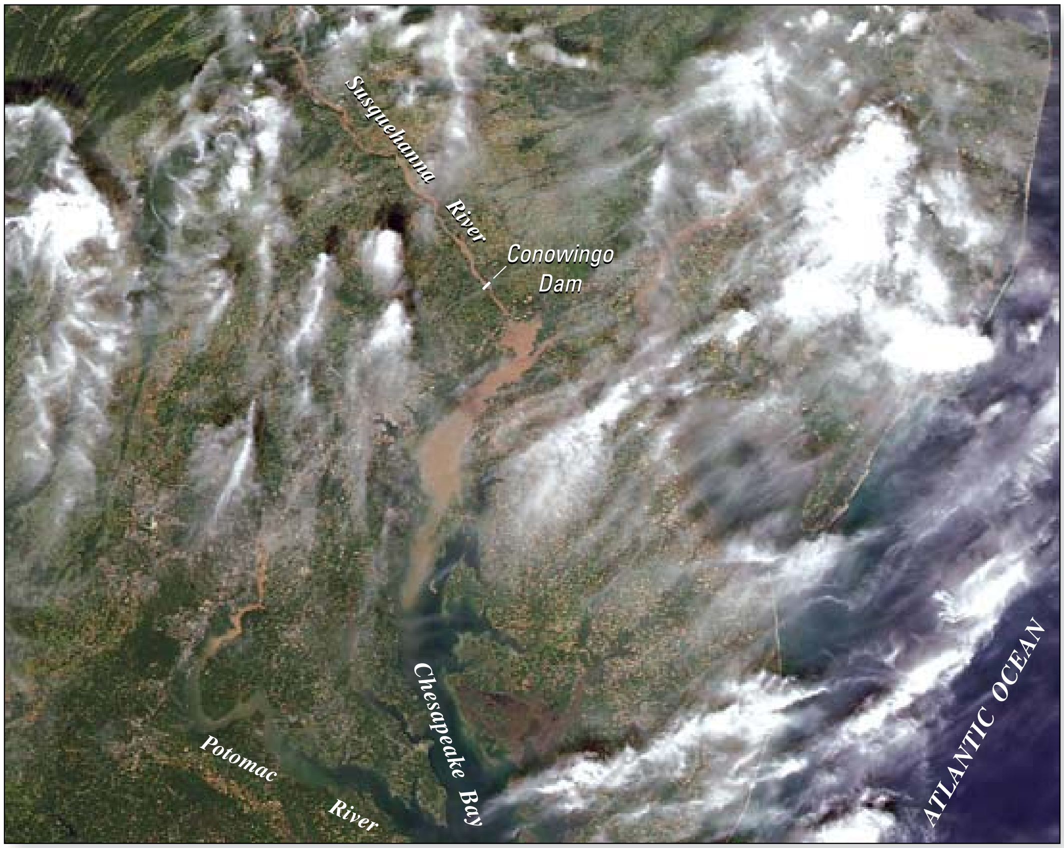


Photograph showing the high suspended-sediment concentrations caused by a large storm, Hurricane Ivan, which affected parts of the Chesapeake Bay Watershed from September 17–18, 2004. (NASA Terra satellite image of the Chesapeake Bay Watershed region taken on September 21, 2004, obtained from NASA Internet site *http://earthobservatory.nasa.gov/NaturalHazards/shownh.php3?img_id=12456*; accessed October 21, 2004). Note the brownish turbid waters of the Susquehanna and Potomac Rivers, and upper Chesapeake Bay. A sample collected at the Susquehanna River at Conowingo, Maryland on September 20, 2004 at 0900 yielded a suspended-sediment concentration of 3,685 milligrams per liter.

Chapter 8: The Occurrence of Pesticides in the Bay Watershed

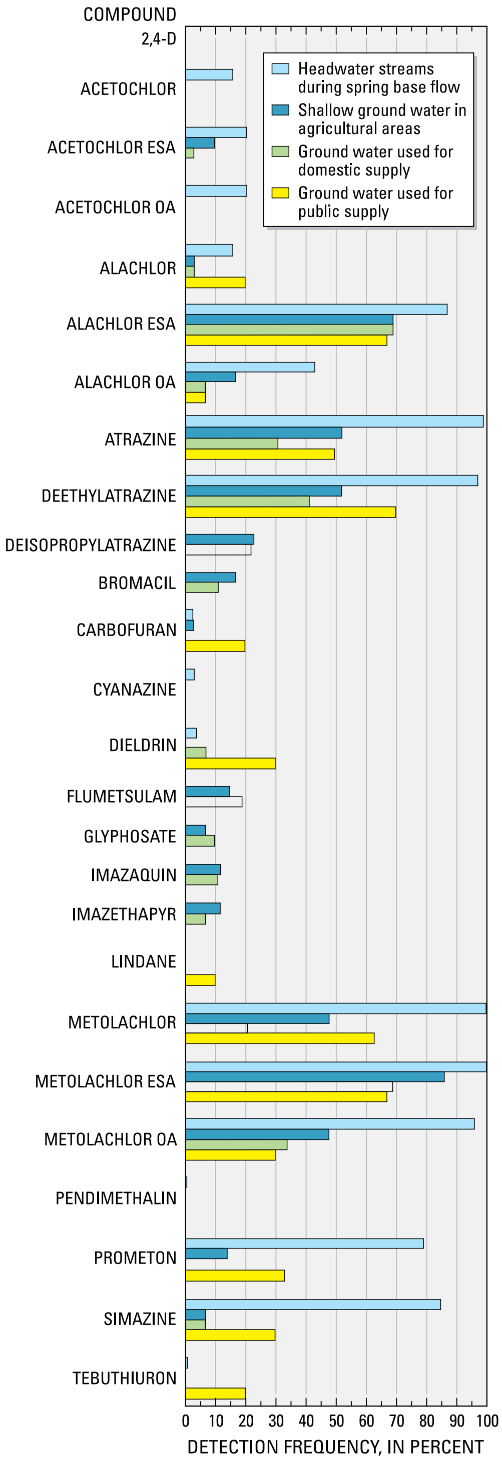
By Judith M. Denver and Scott W. Ator

One of the CBP's restoration goals is "to achieve and maintain the water quality necessary to support the aquatic living resources of the Bay and its tributaries and to protect human health." The CBP developed a toxics reduction strategy to address contaminants as part of this goal. Some of the information needs of the toxics reduction strategy include (1) documenting the sources and occurrence of contaminants, and (2) understanding the potential for contaminants to adversely impact aquatic-dependent wildlife. The USGS had a science goal in 2001–06 to address the occurrence of selected contaminants to provide information to the CBP and also to support DOI needs about the impact of contaminants on wildlife. The USGS science goal mainly addressed pesticide occurrence in surface and ground water in the watershed by utilizing results of the USGS National Water-Quality Assessment (NAWQA) Program studies that were conducted during 1992–2004. Additionally, more recent results from USGS studies of emerging contaminants are presented. The USGS goal also addressed the impacts of selected contaminants on waterbirds and wildlife species. This chapter summarizes findings about pesticides and some selected emerging contaminants in the watershed. It provides an overview of the occurrence of pesticides in ground water and surface water, their relation to land use and other factors, and changes over time, followed by a summary of emerging contaminants. The next chapter focuses on the impact of contaminants on waterbirds and wildlife.

Results from NAWQA studies in the Susquehanna River Basin (Lindsey and others, 1998), Potomac River Basin (Ator and others, 1998), and the Delmarva Peninsula (Denver and others, 2004) revealed that synthetic organic pesticides, along with certain degradation products, have been widely detected at low levels (typically less than 1 microgram per liter) in ground water and streams in the Chesapeake Bay watershed. Pesticides and their degradates are generally detected more frequently in streams than in ground water; an example from the Delmarva Peninsula is shown in figure 8.1. The most commonly detected pesticides are herbicides used on corn, soybean, and small grain crops. Atrazine, metolachlor, and simazine are the most commonly detected pesticides in surface water, whereas atrazine is the most commonly detected pesticide in ground water (Hainly and Kahn, 1996; Ator and Ferrari, 1997; Ferrari and others, 1997; Denver and others, 2004). Pesticides also are detected in urban areas, where the use and detection of insecticides—such as diazinon, carbaryl, and chlorpyrifos—and the herbicide prometon are more common. Herbicides common to agricultural areas have also been widely detected in urban areas, though typically at lower concentrations. Pesticides are less commonly detected in forested areas; infrequent, low-level detections in such areas may be attributable to local use or to atmospheric transport from agricultural or urban areas (Majewski and others, 1998). Degradation products of pesticides also are found in ground water and streams, often at concentrations higher than those of their corresponding parent compounds (Ator and others, 2005; Denver and others, 2004). The occurrence and distribution of pesticides in the Bay watershed reflect usage patterns, environmental conditions, and the chemical and physical properties of the pesticides. Given that pesticide occurrence is closely tied to nutrient practices on agricultural and urban lands, these results could be used by resource managers to better integrate actions to reduce nutrients and pesticides to improve water quality in the Bay and its watershed.

The occurrence and distribution of pesticides in ground water are related to natural geologic and soil conditions, as well as usage patterns. Where applied, pesticides usually occur at higher concentrations in ground water in areas underlain by permeable soils and aquifer material than in areas underlain by less permeable materials (Ator and Ferrari, 1997; Lindsey and others, 1998; Debrewer and others, 2007). Results from these studies showed that concentrations were generally higher in agricultural areas overlying limestone or fractured crystalline bedrock (such as in the Great Valley or parts of the Piedmont Physiographic Provinces) or sandy sediments in the Coastal Plain. Lower concentrations were found in agricultural areas overlying unfractured sandstone and shale of the Piedmont and Appalachian Mountains or in fine-grained sediments underlying fine-grained, organic-rich soil in the Coastal Plain. Once pesticide compounds enter ground water, they often take years to decades to be carried through the flow system and discharge to local streams and rivers.

Pesticides are present year round in streams of the Bay watershed, but the changes in pesticide concentrations over time generally reflect changes in application rates, as well as physical and chemical properties that control the movement of these compounds in the environment (Gilliom and others, 2006). Increasing or decreasing use of pesticides may cause relatively rapid corresponding changes in concentrations in overland runoff and streams during runoff periods. Changes in pesticide use will be more slowly reflected in ground water and,



Over-application of herbicides on farm fields can result in excess toxins and nutrients reaching the waterways. Photograph by Jane Hawkey, IAN Image Library (www.ian.umces.edu/imagelibrary/).

Figure 8.1. Pesticides detected in surface water and ground water in the Delmarva Peninsula, 1999–2001 (modified from Denver and others, 2004). Synthetic organic pesticides, along with certain degradation products, have been widely detected in ground water and streams in the Bay watershed. Pesticide occurrence is closely tied with nutrient land practices on agricultural and urban lands, so there is potential to better integrate management actions to reduce both nutrients and contaminants to the Bay.

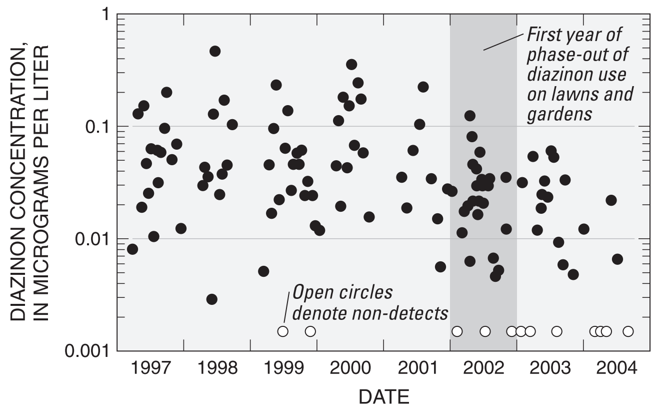


Figure 8.2. Changes in diazinon concentrations in Accotink Creek, a small urban stream near Washington, D.C., 1997–2004 (modified from Phillips and others, 2007). Pesticides are present year round, but changes in concentrations reflect application rates and properties affecting their movement.

therefore, in streams during base-flow periods, however. Diazinon concentrations decreased 39 percent between 1998 and 2004 in Accotink Creek, in an urban area near Washington, D.C., coincident with reductions in diazinon use (fig. 8.2) (Phillips and others, 2007). No trends were apparent, however, between 1993 and 2002 in concentrations of several commonly used herbicides (atrazine, metolachlor, prometon, and simazine) or desethylatrazine in ground water in agricultural areas of the Great Valley underlain by carbonate bedrock (Debrewer and others, 2007), which indicates that usage of these compounds did not change significantly during the corresponding ground-water recharge period. The implication of these findings is that there will be varying lag times between management practices to reduce pesticides and improvements in water quality. For pesticides in the dissolved phase that are transported in runoff directly from a field to a stream, a very short response time between management actions and water-quality improvements may be expected. There will be a longer response time if the compound has been transported through ground water. Pesticides associated with sediment will have the longest lag time between management actions and improvements in water quality.

In addition to pesticides, pharmaceuticals, hormones, and other organic wastewater compounds, are also of concern in the Bay watershed and the Nation. The USGS conducted a national study of emerging contaminants that included sites in the Bay watershed (Kolpin and others, 2002). During the study, samples were analyzed for 95 different emerging contaminants, including human and veterinary drugs, hormones, detergents, disinfectants, insecticides, and fire retardants. At least one of these contaminants was found in 80 percent of the Nation's streams, with mixtures of the chemicals occurring at 75 percent of the sites. The most common groups detected were steroids, nonprescription drugs, and insect repellent. Only 14 compounds have human or ecological health criteria, and measured levels rarely exceeded any of the standards or criteria. However, little is known about the majority of the compounds or their mixtures.

The USGS also published results of a study on pharmaceutical compounds having antibiotic resistance to bacteria and their relation to nutrient cycling in sediments (Simon, 2005). The antibiotic oxytetracycline (OTC) was found in bottom sediments in two streams that were studied on the Eastern Shore of the Chesapeake Bay. OTC can produce changes in antibiotic resistance of indigenous bacteria and change the reaction rates of nitrate oxidation by soil and sediment bacteria. These results indicate that OTC in sediments decreases the ability of bacteria to alter nitrogen and phosphorous, which could result in increased loads of nutrients being delivered to the estuary.

Studies have recently begun to document the potential relation between emerging contaminants and the disruption of the endocrine system of fish in parts of the Bay watershed. Reconnaissance sampling for emerging contaminants at several sites in the West Virginia part of the Potomac River Basin detected antibiotics in municipal wastewater, aquaculture, and poultry-processing effluent (Chambers and Leiker, 2006). The highest number and the greatest concentrations were found in municipal effluent. Previous results from USGS sampling of the Potomac Basin by the NAWQA Program detected chlordane, DDT, and PCBs in streambed sediment and aquatic tissues (Ator and others, 1998). Sediment from over one-half of the sites contained concentrations that may pose adverse effects on aquatic life. There is a limited amount of information on these contaminants in the Bay watershed and their impact on the stream ecosystems and fish populations, however. Therefore, the USGS is beginning a more extensive study of the issue in the Bay watershed. More information can be found in the chapter on fish health.

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Chapter 9: Contaminant Exposure and Impacts on Waterbirds and Selected Wildlife

By Barnett A. Rattner

The impact of selected contaminants on waterbirds and wildlife in the Chesapeake Bay ecosystem has been addressed with USGS studies and use of ecotoxicological information for wildlife that has been extracted from the Contaminant Exposure and Effects—Terrestrial Vertebrates (CEE-TV) database (Rattner and others, 2005). Currently, the CEE-TV database contains 839 data records (representing about 9,500 individuals) for the Chesapeake Bay region, with sample-collection dates ranging from 1966 to 2005. Contaminant exposure and effects data are available for 109 species of terrestrial vertebrates, with the majority of records from birds (79 percent) and mammals (12 percent). Exposure and effects data are available on 92 unique contaminants, with most information focused on legacy organochlorine contaminants (including DDT, chlordane, endrin, dieldrin, and polychlorinated biphenyls, or PCBs) and heavy metals (including lead, mercury, cadmium, and chromium).

Concentrations of *p,p*’-DDE (a metabolite of DDT that caused eggshell thinning and decimated populations of fish-eating birds) and other organochlorine pesticides and metabolites have declined since they were banned in the 1970s, whereas PCB values in eggs seem to have remained unchanged (fig. 9.1). One recent USGS study of ospreys documented their reproduction in the most highly polluted parts of the Bay (Rattner and others, 2004). In 2000 and 2001, a “sample egg” was collected from many osprey nests in or near the CBP “toxic regions of concern” (Baltimore Harbor, Anacostia River, Elizabeth River), and the fate of eggs remaining in each nest was monitored. Concentrations of organochlorine pesticides, total PCBs, and arylhydrocarbon receptor-active PCB congeners were often greater in sample eggs from regions of concern compared to the reference area (South, West, and Rhode Rivers). Productivity of ospreys in or near Baltimore Harbor and the Anacostia River was marginal (observed success less than 1 fledgling/active nest) for sustaining local populations. In addition, tumors in bullhead catfish have been found in these very same regions (Pickney, Harshberger, May, and Reichert 2004; Pickney, Harshberger, May, and Melancon, 2004). Overall, management actions in the 1970s and 1980s restricting the use of chlorinated compounds and some metals have had several results for wildlife. Decreased use of chlorinated pesticides contributed to improved conditions and population recovery of many fish-eating birds. Populations of many species, including the bald eagle, have rebounded to numbers observed before the advent and use of organochlorine pesticides. However, concentrations of other contaminants such as PCBs in wildlife appear unchanged and remain a concern.

Several emerging contaminants are being detected in Chesapeake Bay wildlife, but the associated threat to wildlife is not known at this time. Environmental concentrations of polybrominated diphenyl ether (PBDE) flame retardants (commonly used in polymers, textiles, and electronics) are increasing; on a global basis, some of the highest levels in bird eggs have been found in ospreys nesting in the Chesapeake (Hale and others, 2004). Since little is known about the toxicity thresholds of PBDEs in wildlife, it is difficult to predict the hazards they pose to biota in the Bay. USGS studies have been initiated to determine potential embryo-toxicity of these flame retardants using wild bird eggs. Other compounds of contemporary interest include alkylphenol, ethoxylate, and perfluorinated surfactants, pharmaceuticals, and personal care products. Finally, rising mercury concentrations in the environment and widespread fish consumption advisories are of national concern (U.S. Geological Survey, 2006). Although fish consumption advisories due to mercury contamination are widespread, adverse effects have not been documented in wildlife associated with the estuary. Data from the CEE-TV database show that mercury concentrations in bird eggs, and in livers and kidneys of terrestrial vertebrates collected in the Chesapeake estuary, are generally well below known adverse effect levels.

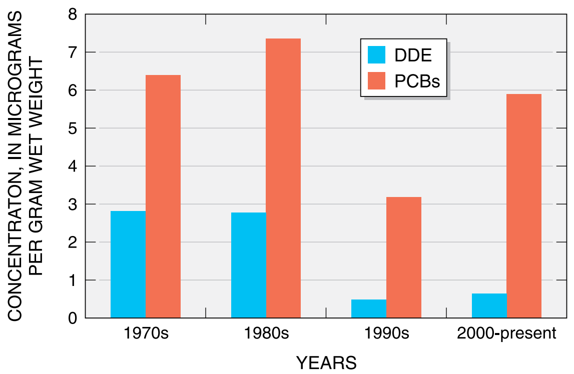

Figure 9.1. Changes in DDE and PCB concentrations in the Bay ecosystem from the 1970s to present day. Concentrations of DDT and its breakdown products have declined since their ban in the 1970s, but PCB concentrations remained unchanged. The populations of many fish-eating birds, such as the bald eagle, have rebounded with the decline in DDT and DDE. However, other contaminants that are slow to break down remain a threat to wildlife.

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Osprey nest atop channel marker in the Tred Avon River in Easton, Maryland. Photograph by Jane Hawkey, IAN Image Library (www.ian.umces.edu/imagelibrary/).

Chapter 10: Long-Term Changes in Climate and Water Quality

By Debra A. Willard

The CBP has restoration goals to increase dissolved oxygen and water clarity in the Bay to improve water-quality conditions for fisheries and SAV. Because land-use practices in the Chesapeake Bay watershed have a great influence on estuarine water quality and its biota, most of the restoration actions focus on changing land-use practices to reduce nutrient and sediment loads. Regional climate variability also has a significant impact on water quality. Precipitation and river flow into the Bay directly affect salinity stratification within the estuary, which in turn influences the timing and extent of seasonal hypoxia, independent of nutrient loads. Likewise, a climatically induced fluctuation in river flow to the Bay affects the amount of suspended sediment in the water column. Therefore, the proposed management strategies to improve estuarine water quality need to consider the impacts of natural climatic fluctuations on nutrient and sediment loads. The USGS has summarized results from a series of integrated studies designed to document the long-term variability of Chesapeake Bay water quality (salinity, temperature, and dissolved oxygen).

The Chesapeake Bay is underlain by a thick sequence of sediments that provide an archive of past ecosystem response to a series of climatic and land-use changes. These sediments have been deposited continuously throughout the approximately 7,000-year history of the modern Bay, and previously when the paleo-Susquehanna River flowed through the valley that ultimately was flooded by sea-level rise to form the modern Chesapeake Bay. Biological and geochemical indicators are analyzed from sediment cores, which serve as proxies for environmental parameters (temperature, salinity, and dissolved oxygen), to assess water-quality changes during the past several thousand years. Age models of the cores are developed using radiogenic isotope methods (carbon 14, lead 210, cesium 137) and pollen biostratigraphy (see Willard and others, 2003, for a complete discussion). Reconstruction of the history of temperature, salinity, and dissolved oxygen in the Bay is based on quantitative analysis of microfossils of pollen, ostracodes, foraminifers, mollusks, dinoflagellates, diatoms, and sediment geochemistry.

An understanding of the natural variability in river flow, which is strongly influenced by precipitation, is important for developing sustainable management plans to limit nutrient and sediment loads in the Bay. The relation among rainfall, river flow, and Chesapeake Bay salinity over the past 175 years was quantified by USGS researchers using instrumental records, and established foraminiferal and ostracode indicators for salinity made it possible to reconstruct past variability in salinity and river flow during the last 7,000 years (Cronin and others, 2000). Examination of the sediment records reveals a significant difference between Chesapeake salinities of the early Holocene (7,200 to 5,000 years before present, or yrBP), when mean was 28 ppt (parts per thousand) and the last 2,000 years, when salinity averaged 20 ppt (Cronin and others, 2005). The persistent occurrence of multidecadal salinity and temperature oscillations (every 20–40 years) during the entire history of the Bay indicates that climate variability is an inherent component of the North Atlantic climate system (Cronin and others, 2005). Over a shorter time scale, detailed records spanning the last 1,500 years document both extended periods of drier than average conditions (during the Medieval Warm Period ranging from 1200–600 yrBP), and wetter than average conditions during the Little Ice Age (from 500–100 yrBP). The 20th century is characterized by a series of precipitation extremes that indicate anomalous behavior of the climate system. The occurrence of such extreme variability in river flow over annual to decadal periods can have a much greater influence on delivery of nutrient and sediment loads to the estuary than the management actions designed to reduce these loads. The results imply that managers need to better account for natural variability when assessing progress in reducing nutrient and sediment loads to the estuary and assessing attainment of water-quality standards.

Seasonal and interannual temperatures of Chesapeake Bay surface waters are influenced both by inflowing waters from the continental shelf and regional atmospheric temperatures. The potential for 21st century warming related to greenhouse gas concentrations also is likely to affect estuarine temperatures. Using magnesium/calcium ratios from ostracode shells from sediment cores, USGS researchers, in collaboration with colleagues at Duke University, reconstructed long-term, estuarine surface-water temperatures over the past 2,000 years. These records indicate that surface-water temperature maxima occurred approximately every 70 years during the interval between 2200 yrBP and 250 yr (fig. 10.1*A*). This pattern indicates the long-term persistence of multi-decadal processes such as the North Atlantic Oscillation (Cronin and others, 2000; Cronin and Vann, 2003). Temperatures during the late 19th and 20th centuries exhibited greater extremes (fig. 10.1*B*) than those observed during the previous 2,000 years, including the relatively warm Medieval Warm Period (MWP) and cooler Little Ice Age (LIA)

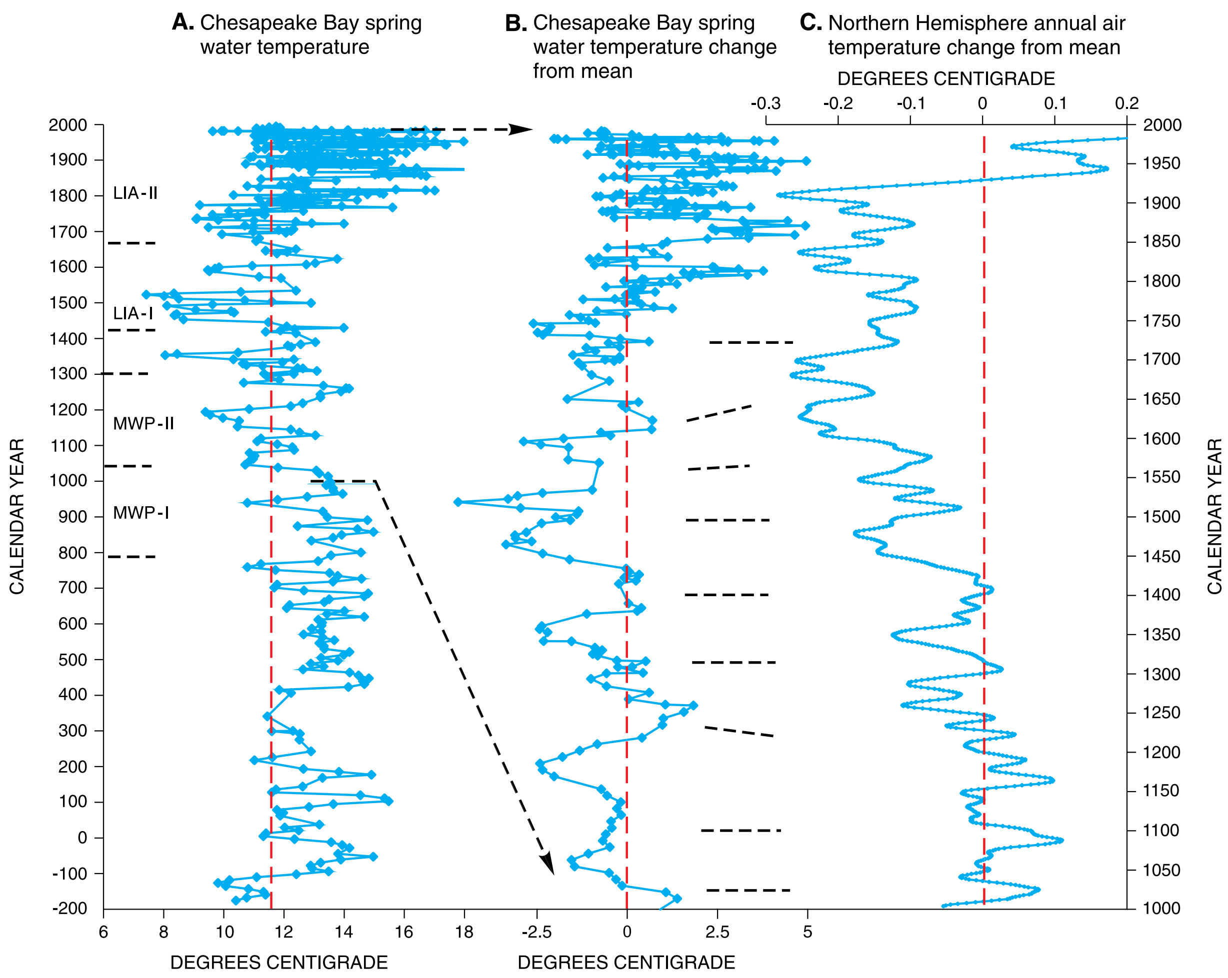

Figure 10.1. *(A)* Water temperature patterns for Chesapeake Bay, and *(B)* change from long-term mean compared with *(C)* Northern Hemisphere atmospheric temperature changes from long-term mean. Water temperatures in the Bay during the late 19th and 20th centuries exhibited greater extremes than those of the previous 2000 years. The results imply that management actions to address climate variability and associated global warming need to be developed to restore the estuary.

(fig. 10.1*A*). These results are consistent with other studies in the North Atlantic region that indicate anomalous 20th century climate variability when compared to the past 2,000 years (fig. 10.1*C*). The implications of these findings are that long-term changes in climate, due to both natural variability and increasing greenhouse gases from human sources, and changes in land-use practices have to be addressed to improve water-quality conditions in the Bay.

Seasonal oxygen depletion in waters of the Chesapeake Bay has been documented for much of the 20th century by a number of research efforts. Research by USGS scientists has focused on reconstruction of dissolved oxygen trends in Chesapeake Bay during the past 2,500 years (Bratton and others, 2003; Cronin and Vann, 2003; Karlsen and others, 2000; Willard and others, 2003) and indicates that the deep channel of the Bay may have been briefly hypoxic (concentrations less than 2 mg/L) during relatively wet periods prior to European colonization (prior to 1600 AD). Seasonal anoxia (a lack of dissolved oxygen lasting weeks to months) probably occurred periodically during the relatively wet periods between 1600 AD and 1960 AD, and became more frequent after 1970 (fig. 10.2). These findings, together with earlier research, clearly indicate that hypoxia and anoxia were much more severe and extensive in Chesapeake Bay and its tributaries during the past four decades than at any time in the past 500–2,500 years.

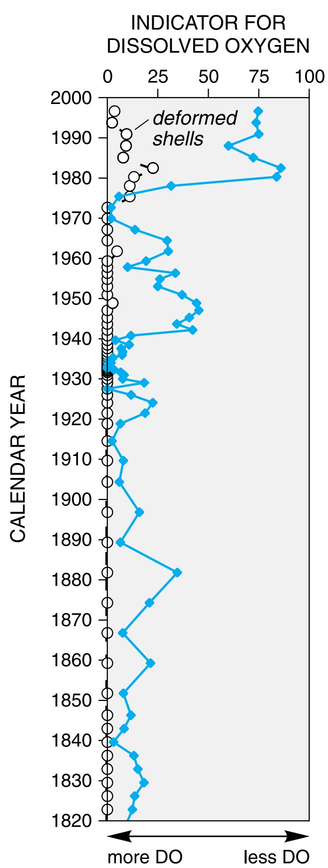

Figure 10.2. Long-term changes in dissolved oxygen (DO) conditions in Chesapeake Bay. Since the 1970s, both population growth and a period of extreme climate variability contributed to dissolved oxygen occurring at the worst levels of the past 500–2,500 years. Management actions that address delivery of nutrient and sediment loads under varying river flow conditions will need to be emphasized to help address climate variability.

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The USGS Hoverprobe is used to collect sediment cores to study long-term ecosystem history. Photograph by Daniel J. Phelan, U.S. Geological Survey

Chapter 11: Submerged Aquatic Vegetation and Water Clarity

By Nancy B. Rybicki and Jurate M. Landwehr

Underwater grasses, known as submerged aquatic vegetation (SAV), provide food for waterfowl populations as well as vital habitat for juvenile fish and shellfish. Historically, the Chesapeake Bay supported a diverse and abundant community of SAV; however, the acreage has declined substantially since the 1960s. The decline has been linked to poor water clarity due to a combination of increased suspended sediment and persistent algal blooms. The CBP has a goal to double the number of SAV acres by 2012. The USGS summarized its findings related to (1) water clarity, and (2) the influence of exotic species on SAV acreage.

USGS research on SAV minimum light requirements has identified the water-clarity conditions needed to support SAV in different salinity zones of the Bay. The minimum light requirements, defined as the amount of surface light reaching the bottom, are 13 percent for the freshwater SAV community and 22 percent for the more brackish waters (Carter and others 2000; Kemp and others, 2004). Many fluctuating factors, such as quantity of river flow and suspended matter in the water column, contribute to the variability in water clarity (fig. 11.1). To determine which water column constituents best explain variation in water clarity during the SAV growing season (April to October), the USGS analyzed factors influencing water clarity at 63 mid-channel water-quality-monitoring stations (fig. 11.2) throughout the Chesapeake Bay (Landwehr, 2005). The analysis indicated that the most important factor affecting water clarity is total suspended solids (TSS), which includes organic matter (phytoplankton, other planktonic organisms, bacteria, and organic detritus) and inorganic solids (clay, silt, and sand). For the Potomac River and the eight major tributaries, TSS was the primary explanatory variable for water clarity at 54 of the 63 stations. At eight stations in the more saline portions of the York, Rappahannock, Patuxent, and Choptank Rivers (fig. 11.2), chlorophyll-*a* concentration (an indicator of phytoplankton biomass) was the primary explanatory variable. Assuming that the inorganic component of TSS is greater than the organic component

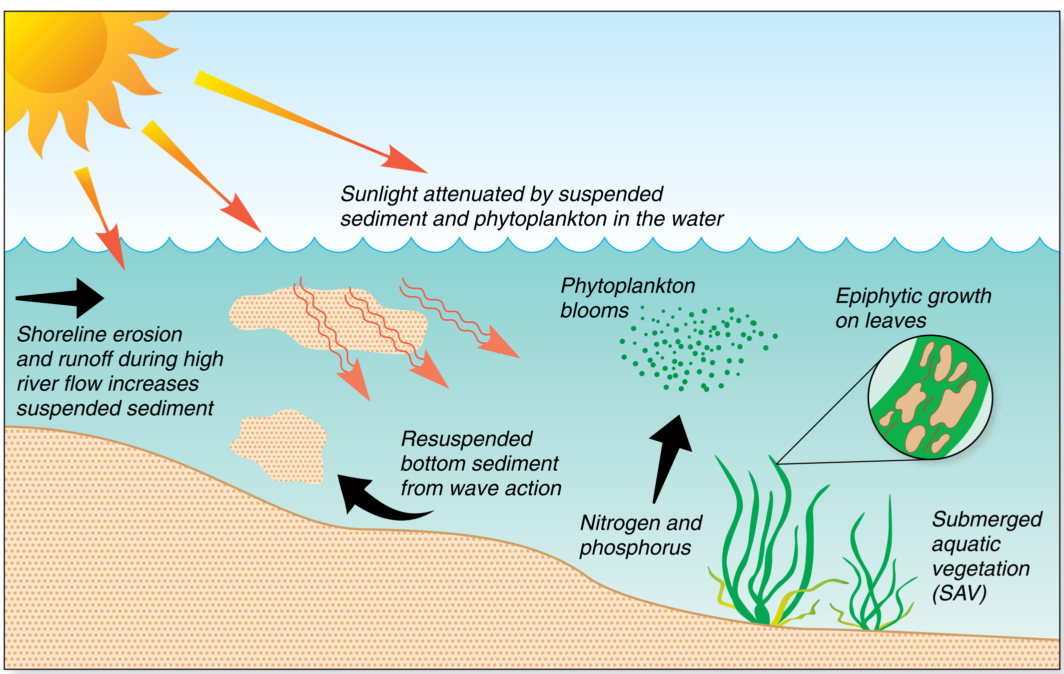

Figure 11.1. Conceptual diagram of factors affecting water clarity. Impacts of sediment, nutrients, algal blooms, and epiphytic growth on submerged aquatic vegetation (SAV) can affect the amount of sunlight reaching the plants. USGS research on the light requirements for SAV in different salinity zones was used to help set the water-quality standards in the estuary.

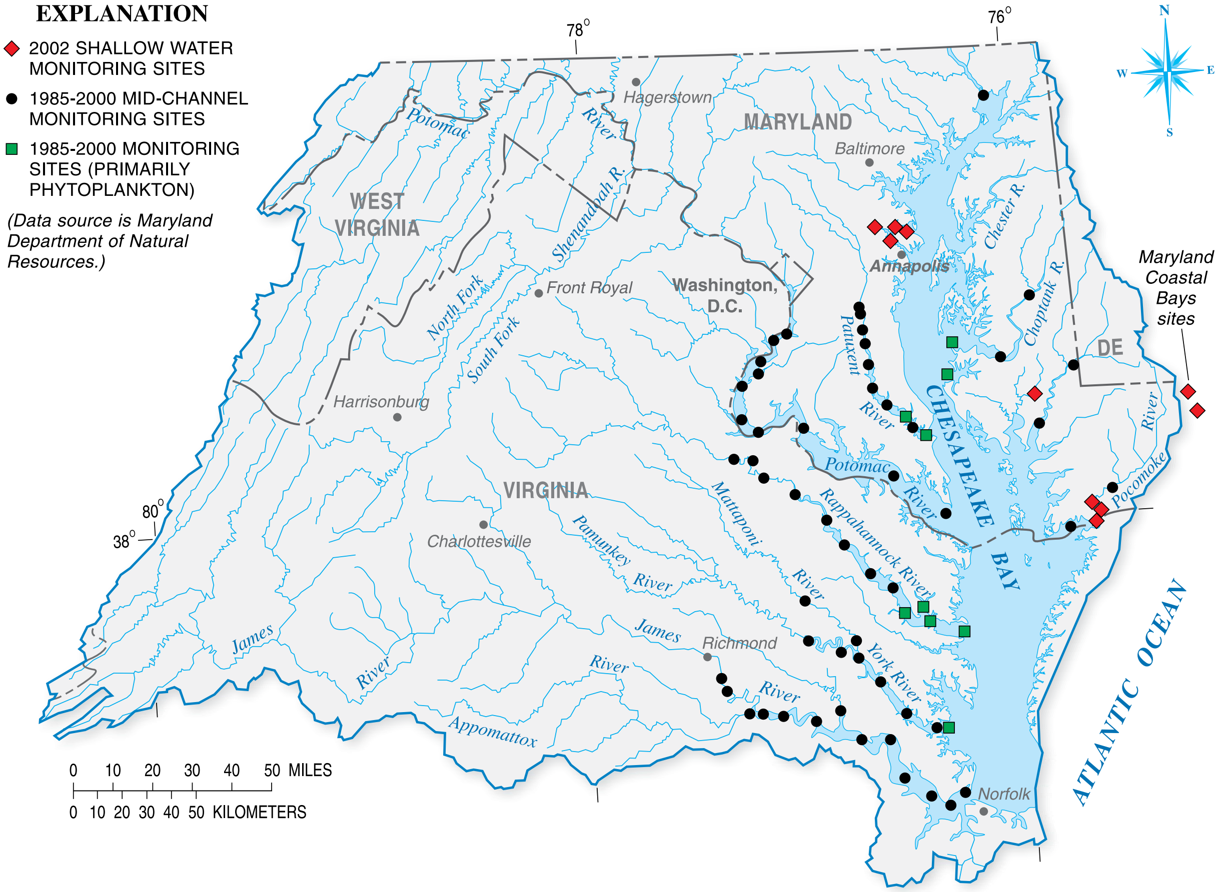

Figure 11.2. Water-clarity monitoring sites in the Chesapeake Bay estuary. Investigations have shown that factors affecting water clarity vary in different areas of the estuary. The results indicate that managers need to further utilize information about the primary cause of degraded water clarity to better focus sediment- and nutrient-reduction strategies.

in most regions of the Bay and that the attenuation from inorganic solids exceeds attenuation from organic solids (Cerco and Moore, 2001), these results indicate that strategies to reduce sediment loads could improve water clarity more than strategies to reduce nutrient loads in most locations. At the other eight locations, these data would indicate that water clarity could improve with nutrient reduction and subsequent reduction in phytoplankton.

The USGS also analyzed information from both shallow water sites (nearer the shoreline) and mid-channel sites (further from the shoreline) to assess factors affecting water clarity in these different areas. In 2002, the Maryland Department of Natural Resources (MD DNR), in partnership with the USGS, measured water quality at 10 shallow water sites within the Chesapeake and Maryland Coastal Bays (fig. 11.2). Regression analysis showed that in 2002, a dry and low-flow year, nutrients and organic suspended solids best explained light attenuation at the shallow water monitoring sites (Baldizar and Rybicki, 2006). These results indicate that nutrient reduction and subsequent reduction of organic solids would have a greater impact on water clarity than reduction of sediments (inorganic solids) during low-flow conditions. The regression analysis of the mid-channel data from the nine Bay tributaries showed a different result. The results of mid-channel analysis indicate that TSS is the dominant factor impacting water clarity at most sites in the estuary. Given these results, managers should remain focused on both sediment- and nutrient-reduction strategies to improve water clarity in the estuary. The results also indicate that additional data analysis is needed to evaluate factors affecting water clarity during other flow conditions.

The USGS also addressed the occurrence of invasive aquatic plants in the estuary (Rybicki and Landwehr, 2007). Exotics are expanding their range annually, yet few studies have summarized the conditions and impacts of this expansion within the context of water-quality restoration efforts. Hydrilla, the dominant exotic species in the upper tidal Potomac River, occurs in rivers, lakes, and estuaries throughout the world. The USGS conducted a long-term, quantitative study of SAV diversity following the colonization of hydrilla to the fresh and upper oligohaline part of the Potomac Estuary between Washington, D.C. and Maryland Point. Using information from annual field surveys and aerial photographs, USGS scientists created a database to document which species occurred in SAV beds in different sections of the Potomac River system. They recorded the percentage of total coverage and biomass each species attained annually. In comparing species coverage with water-quality composition, they discovered that, with the reduction of nitrogen concentration, hydrilla coverage expanded but so did the diversity of plant species. Hydrilla did not crowd out native species; indeed, native species increased. In addition, hydrilla is a good winter food source for waterfowl communities, which have increased significantly over this period.

Seagrass in Round Bay in the Severn River, Annapolis, Maryland. Photograph by Jane Thomas, IAN Image Library (www.ian.umces.edu/imagelibrary/).

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Floating mats of green algae and horned pondweed on the North Fork of the Tred Avon River in Easton, Maryland. Photograph by Jane Hawkey, IAN Image Library (www.ian.umces.edu/imagelibrary/).

Chapter 12: Factors Affecting Coastal Wetland Loss and Restoration

By Donald R. Cahoon

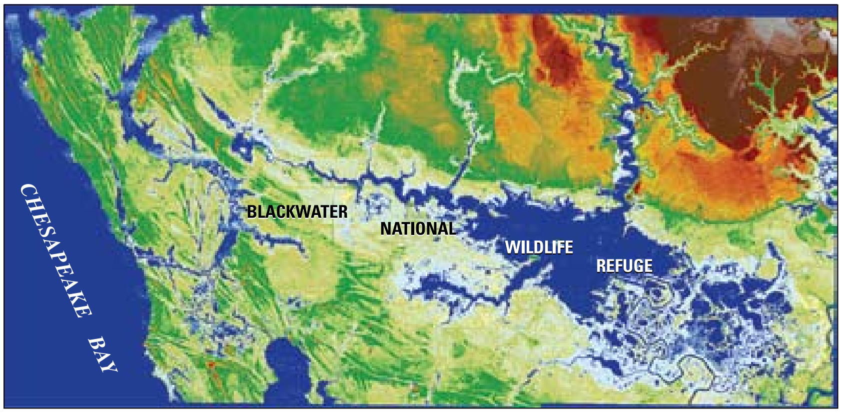
Tidal and nontidal wetlands in the Chesapeake Bay watershed provide vital hydrologic, water-quality, and ecological functions. Situated at the interface of land and water, these valuable habitats are vulnerable to alteration and loss by human activities including direct conversion to non-wetland habitat by dredge-and-fill activities from land development, and to the effects of excessive nutrients, altered hydrology and runoff, contaminants, prescribed fire management, and invasive species. Processes such as sea-level rise and climate change also impact wetlands. Although local, State, and Federal regulations provide for protection of wetland resources, the conversion and loss of wetland habitats continue in the Bay watershed. Given the critical values of wetlands, the Chesapeake 2000 Agreement has a goal to achieve a net gain in wetlands by restoring 25,000 acres of tidal and nontidal wetlands by 2010. The USGS has synthesized findings on three topics: (1) sea-level rise and wetland loss, (2) wetland restoration, and (3) factors affecting wetland diversity.

Chesapeake Bay is a drowned-river-valley estuary where emergent tidal wetlands migrate landward (upslope) in response to sea-level rise through the accumulation of mineral sediments and plant matter. Wetlands convert to shallow, open-water habitat (such as ponds) through interior marsh breakup if they do not build vertically at a pace equal to sea-level rise, which is currently about 3 mm/yr (millimeters per year) in the Bay (Douglas, 2001). The majority of tidal marsh in Chesapeake Bay is in the lower part of Maryland's Eastern Shore. Extensive areas of submerged upland marshes in the Blackwater River-Fishing Bay region of Dorchester County, Maryland have converted to open water over the past century, particularly those marshes at Blackwater National Wildlife Refuge (BNWR).

The rate of sea-level rise is predicted to increase two- to four-fold during the next century (Church and others, 2001). To determine what impact this sea-level change would have on wetland resources and to improve land-use planning within the immediate vicinity of BNWR for the next century, USGS scientists developed a digital elevation model (DEM) of BNWR land surfaces from LIDAR (Light Detection And Ranging) data collected in March 2002 (fig. 12.1*A*) (Larsen and others, 2004). DEM simulations using current sea-level rise rates (approximately 3 mm/yr) reveal that high marsh will convert to low marsh and low marsh will continue to convert to open water for the next century, assuming 2002 surface elevations remain unchanged (fig. 12.1*B*). Marsh loss rates will be higher, and the area impacted larger, for predicted future rates of sea-level rise (about 6 mm/yr) (fig. 12.1*C*). Measurements of marsh vertical accretion, marsh-surface elevation change, and shallow soil subsidence made by USGS scientists over 5 consecutive years reveal that marsh-surface elevations are not static but are actually decreasing at most sampling stations at BNWR (G. Guntenspergen, U.S. Geological Survey, written commun., 2007). The declining marsh surface elevations at BNWR indicate that the DEM projections likely underestimate the extent of future marsh loss.

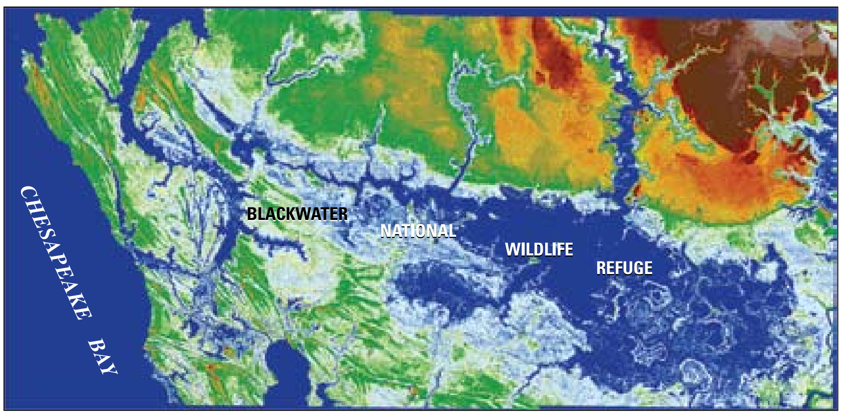
The BNWR marsh system is characterized by low mineral sediment supply. Although major storms, such as Hurricane Isabel in 2003, deposit mineral sediments on the marsh every few decades, the increase in marsh elevation is often minimal. This soil organic matter accumulation comprised mostly of plant roots plays an important role in vertical soil development. Several factors affect the ability of the marshes at BNWR to build vertically through soil matter accumulation and therefore likely influence the rate of ongoing interior marsh breakup. These factors include grazing of vegetation by muskrat and nutria, altered flooding and salinity patterns, annual prescribed burning of vegetation, overabundance of nutrients, subsidence, and changes in the rate of sea-level rise (fig. 12.2). For example, intense grazing of marsh vegetation by nutria, an exotic species introduced to the United States from South America, severely reduced plant production at BNWR. Following the removal of more than 9,000 nutria from the region between 2002 and 2004, there has been strong recovery of marsh vegetation (M. Haramis, U.S. Geological Survey, written commun., 2007). These findings imply that the combination of sea-level rise and factors affecting sediment accumulation rates will govern the rate of wetland loss along the estuary. Thus, resource managers will have to fully understand the combination of factors affecting marsh loss at a particular site for successful wetland restoration.

Sediments dredged from Chesapeake Bay navigation channels are being used to restore degraded wetland habitats within the Bay. During the past decade, several wetland restoration projects using dredged sediments have been undertaken, including Poplar Island, Anacostia River, and Barren Island. USGS investigations at Poplar Island brackish marshes in the central Bay (Erwin and others, 2003) and Kenilworth and Kingman tidal freshwater marshes in the Anacostia River, Washington, D.C. (Hammerschlag and others, 2006), revealed some

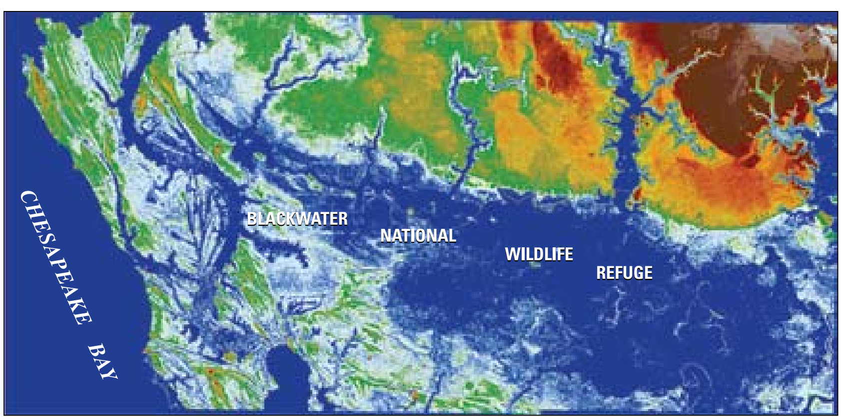


(A)
Year 2002

Healthy marshes (green) and stressed marshes (brown) in Blackwater National Wildlife Refuge, June 2006. Photograph by Jane Thomas, IAN Image Library (www.ian.umces.edu/imagelibrary/) (Marsh colors refer to this photo only.)



(B)
Year 2100,
assuming a 3-millimeter-per-year rise in sea level



(C)
Year 2100,
assuming a 6.2-millimeter-per-year rise in sea level

Location of Blackwater National Wildlife Refuge, Dorchester County, Maryland.

Figure 12.1. Digital elevation model (DEM) forecasts of sea-level rise at Blackwater National Wildlife Refuge, Dorchester County, Maryland *(A)* 2002, *(B)* 2100 assuming a 3-millimeter-per-year rise in sea level, and *(C)* 2100 assuming a 6.2-millimeter-per-year rise in sea level (modified from Larsen and others, 2004). Sea-level rise during the coming century will impact tidal wetlands throughout the estuary.

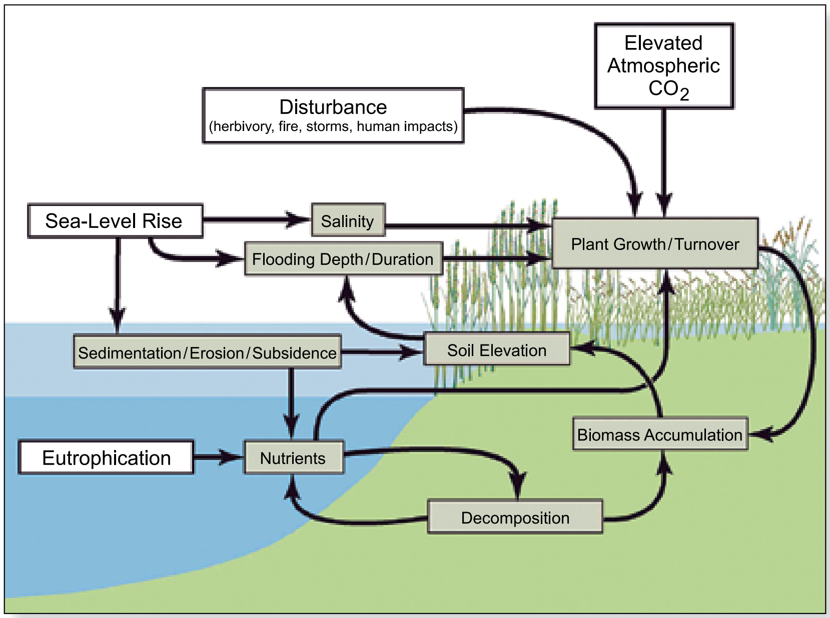


Figure 12.2. Conceptual diagram of processes affecting wetland loss. Multiple factors influence marsh loss, including grazing of vegetation by muskrat and nutria, altered flooding and salinity patterns, annual prescribed burning of vegetation, and the rate of sea-level rise. Managers need to identify which factors are occurring, including continued sea-level rise, at a site to plan for successful wetland restoration.

of the important processes controlling and limiting habitat quality in these reconstructed wetlands. At Kingman and Kenilworth marshes, studies showed there is a large, functionally diverse seed bank of wetland species in the Anacostia River available to colonize dredged sediment deposits (Neff and Baldwin, 2005). The combination of natural colonization and vegetative planting efforts facilitated rapid development of vegetated marsh habitats wherever restored soil elevations were suitable (Hammerschlag and others, 2006). However, marsh establishment at several sites was affected by grazing from an overabundance of resident Canada geese. USGS scientists also found geese herbivory to be an important factor in the decline of wild rice along the tidal Patuxent River (Haramis and Kearns, 2007). Removal of geese by hunting, and efforts to protect and re-establish rice by fencing and planting, led to successful restoration of this marsh type. The results imply that tidal wetland creation from dredged sediments is an effective method for restoring wetland habitats when the proper intertidal soil elevations are established and maintained and herbivory is managed. The results also imply the presence of an existing seedbank may enhance the success of wetland restoration.

USGS studied the correlation between wetland restoration and changes in bird populations at Poplar Island, which eroded to less than 5 acres in 1996, and is undergoing wetland restoration that will include 550 or more acres of constructed tidal wetlands, creeks, ponds, and mudflats. USGS found that the restored habitat is attracting desired common terns, least terns, snowy egrets, cattle egrets, American black ducks, and osprey (Erwin and others, 2003). This site is the only nesting area for common terns in the Maryland part of the Bay and thus, is critical to species survival in Maryland. However, constructed upland habitats also attract undesirable bird species such as gulls and great horned owls and mammal predators (red foxes) that harass or prey upon the desired bird species.

USGS studies showed the diversity of coastal and nontidal wetlands are affected by multiple factors. Grazing by exotic species such as resident Canada geese at Anacostia River marshes (see above) can prohibit plant development and change vegetation composition. Exotic colonizers, such as Phragmites, can out-compete native vegetation and cause a loss in diversity and in habitat value and function. USGS studies of native and invasive varieties of Phragmites reveal that the invasive variety can grow in saltwater concentrations at which the native varieties cannot survive. They also produce more shoots per gram of rhizome tissue and have a higher relative growth rate than the native varieties (Vasquez and others, 2005). These findings imply that the diversity of a tidal wetland will depend on controlling competition and predation from non-desired species, which also attempt to colonize restored and native wetlands.

In forested wetlands, patterns of plant zonation and diversity are strongly influenced by physical conditions, such as flooding patterns related to variations in river flows and local geomorphology (such as hydrogeomorphology). Nontidal riparian and flood-plain wetland communities are typically highly diverse areas in the landscape, but the reasons for this are poorly understood. Although plant diversity and composition can be attributed in part to hydrologic conditions (such as seasonal flooding patterns), recent USGS investigations reveal that hydrologic conditions alone do not describe forested wetland plant patterns (Alexander-Augustine and Hupp, 2002). Plant diversity is strongly impacted by hydroperiod (the period during which wetlands are flooded), micro-scale changes in relief, and upstream-downstream position within the stream corridor. More importantly, however, the influence of hydrogeomorphology on species richness varies with spatial scale. Species richness was described by hydrogeomorphic variables (downstream position, river discharge, stream power, and topographic relief) at the plot scale (400 square miles). Tree diversity was best explained at the site scale (1 hectare), and hydrogeomorphic variables were best explained at the watershed scale (Alexander-Augustine and Hupp, 2002). Thus, a combination of spatial, hydrologic, and geomorphic conditions explains plant diversity patterns in forested wetlands. These findings imply that the diversity of a tidal and forested wetland will depend on controlling competition and predation from non-desired species, which also attempt to colonize a restored wetland. Resource managers need to understand these conditions when developing management plans for riverine wetlands.

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Chapter 13: Factors Affecting Fish Health

By Vicki S. Blazer, Christopher A. Ottinger, and Christine L. Densmore

The CBP has a restoration goal in the Chesapeake 2000 agreement to "restore, enhance, and protect finfish, shellfish, and other resources, their habitats and ecological relationships to sustain all fisheries and provide for a balanced ecosystem." To address this restoration goal, the USGS had a science goal to "address the factors affecting the health of fish, wildlife, and their habitats." This chapter summarizes USGS findings about fish health in the Bay and its watershed; the following chapter presents findings on waterbird populations. The USGS addressed four primary topics related to fish health including (1) menhaden and ulcerative lesions, (2) striped bass and mycobacteria, (3) tributary health assessments, and (4) intersex conditions in the Potomac. Multi-species management plans are being prepared by the National Oceanic and Atmospheric Administration (NOAA) and state partners for menhaden and striped bass as part of the CBP restoration goal for fisheries.

In 1997, USGS scientists were asked to assist in research directed toward understanding the causes of the high incidence of skin lesions and kills of Atlantic menhaden in a number of Chesapeake Bay tributaries. Menhaden are both ecologically critical and commercially valuable species. The lesions and fish kills were thought to be associated with the presence of *Pfiesteria*, which is believed to produce a toxin that affects fish as well as humans. However, the chronic nature of the lesions (fig. 13.1*A*) and the consistent presence of an invasive fungal pathogen (fig. 13.1*B*) raised many questions as to the actual cause of these lesions and the associated environmental stressors (Blazer and others, 1999).

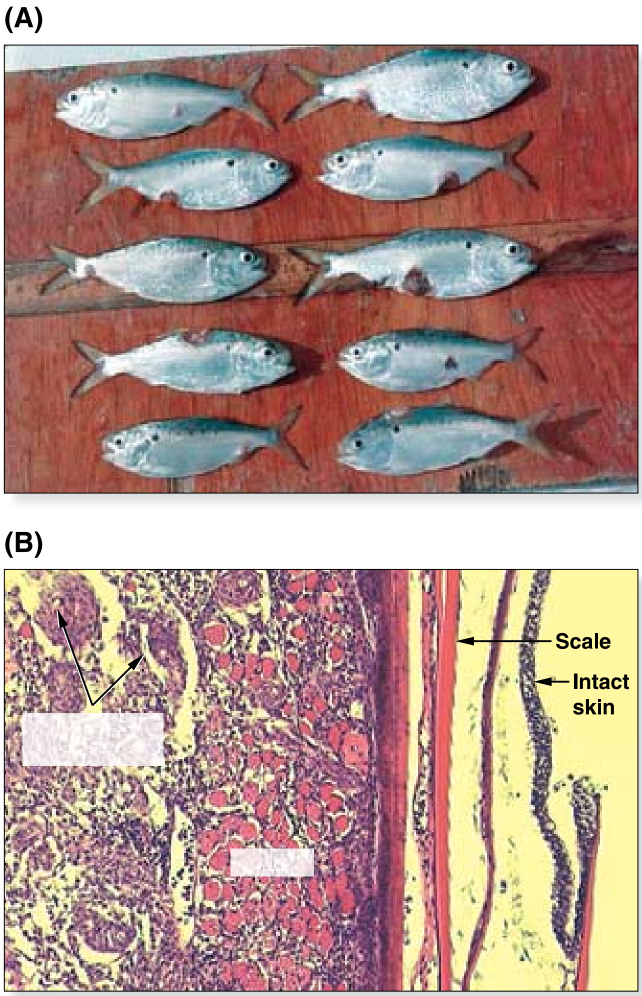

Figure 13.1. Photographs of *(A)* ulcerative mycosis of menhaden, and *(B)* microscopic appearance of ulcers illustrating the invasive fungal hyphae and chronic inflammatory response within muscle tissue, underlying skin. The USGS and collaborators determined lesions on menhaden were caused by a fungal pathogen *Aphanomyces invadans*. It is now recognized that *A. invadans* is a serious pathogen of both estuarine and freshwater fishes worldwide.

Figure 13.2. Photograph of mycobacteriosis lesions in striped bass (courtesy of Maryland Department of Natural Resources). The USGS and collaborators identified the cause of skin lesions in striped bass to be mycobacteriosis, which are species of bacteria that can impact both marine and freshwater fish. Improving environmental conditions in the Bay could improve the ability of striped bass to resist the impact of mycobacteriosis.

Research conducted by USGS scientists and collaborators resulted in the isolation and identification of the fungal pathogen *Aphanomyces invadans*, based on morphology, temperature and salinity growth characteristics, infectivity, and DNA sequence. Using the polymerase chain reaction (PCR) method, the same organism was found in menhaden with lesions from Delaware to South Carolina, and in similar lesions in selected freshwater fish species in Georgia and Louisiana (Blazer and others, 2002). Once isolated, the infectivity and relation of *A. invadans* to the skin ulcers of menhaden were investigated. Using injection of the infective zoospores, a dose-response in ulcer development and mortality was shown, with only about 10 spores needed to cause death in 50 percent of exposed menhaden (LD_{50}). Injection of as few as one zoospore was sufficient to induce lesions in 31 percent of the fish (Kiryu and others, 2003). Experiments using bath exposure to the infective zoospores indicated that a low percentage of unstressed menhaden developed ulcers; however, stressed (net-handled) and traumatized menhaden had significantly higher mortality and incidence of ulcerative lesions (Kiryu and others, 2002, 2003). These findings suggest that a high incidence of menhaden with lesions in the wild may be a result of environmental factors that favor the proliferation of the pathogen, as well as damage the skin and/or cause immunosuppression.

Many factors, including water-quality parameters (temperature, dissolved oxygen, salinity, and nutrients), contaminants, toxins including algal toxins such as *Pfiesteria*, and other infectious agents may play a role in predisposing menhaden to *A. invadans* infections (Blazer and others, 1999; Reimschuessel and others, 2003). It is now recognized that *A. invadans* is serious pathogen of both estuarine and freshwater fishes worldwide. USGS scientists have worked with international colleagues to reexamine causal factors, describe a case definition, and attempt to standardize nomenclature for a number of syndromes associated with this pathogen (Baldock and others, 2005), as well as review existing knowledge (Blazer and others, 2005). The USGS findings imply that understanding the multiple factors that contribute to the occurrence of pathogens affecting fish will allow for more comprehensive multi-species ecosystem management plans to be developed to protect and restore fisheries in the Bay. The USGS findings also suggest that improving environmental conditions for menhaden, such as improved dissolved oxygen and lower contaminant concentrations, will make them less susceptible to *A. invadans* infections and other toxic algae.

Striped bass are a highly prized sport and commercial fish in the Chesapeake Bay and along the eastern coast of the United States. They are also one of the five targeted species for which the CBP partners are developing Ecosystem-Based Fisheries Management Plans. The striped bass population has increased in the Bay after a moratorium helped provide relief from overfishing. In the late 1990s, however, fishermen and field biologists began to report a high incidence of emaciated striped bass, many with skin lesions (fig. 13.2). The USGS and collaborators identified the cause of the skin lesions to be mycobacteriosis, which are species of bacteria that can

USGS investigator processing fish for health evaluations. Fish are bled, organs cultured for bacteria and viruses, and pieces of tissue removed and fixed for microscopic evaluation. (Photograph by U.S. Geological Survey.)

impact both marine and freshwater fish. A variety of previously described species of mycobacteria have been isolated from diseased Chesapeake Bay striped bass (Rhodes and others, 2004, 2005); some of these are potential human pathogens (Ottinger and others, 2005). The bacteria affects relatively high numbers of striped bass caught in the Chesapeake Bay with external lesions observed in up to 28 percent of bass caught and internal lesions in more than 62 percent (Ottinger and others, 2005). The multiple factors that promote the presence of mycobacteria and lower the resistance of striped bass to the bacteria are still not well understood. In 2006, the USGS co-hosted a workshop with NOAA to summarize the state of the knowledge and prioritize next steps to address the issue (Ottinger and Jacobs, 2006). The USGS and NOAA findings imply that the resistance of striped bass populations to disease appears to have been lowered due to multiple environmental conditions including low dissolved oxygen, contaminant concentrations, and improper diet. Improving these environmental conditions in the Bay could improve the ability of striped bass to resist the impact of mycobacteria.

Given the problems with lesions in key fish species of the Chesapeake Bay, the USGS conducted tributary health assessments from 1998 to 2003 to better understand fish health in the Bay and its tributaries. The assessments included developing new methods to document fish health and to use the information to compare the "health" of various tributaries. White perch were selected as a sentinel species because they are less migratory than menhaden or striped bass. Several methods to assess fish health were enhanced (Blazer, 2000; Smith and others, 2002), while new methods were developed (including cellular and subcellular assays) to better identify immunosuppression (Gauthier and others, 2003; Harms and others 2000; Iwanowicz and others, 2004). Findings from the assessments showed that the suppression of the white perch's immune system occurred in several tributaries and increased from the spring to the summer. The immunosuppression that occurred in the summer coincided with the finding of lesioned menhaden in the same tributaries (Harms, Ottinger, and Kennedy-Stoskopf, 2000). The new techniques that USGS developed for fish-health assessments could be adopted by resource management agencies to provide a more thorough understanding of the health of fisheries in the Bay. The National Ocean Service (NOS) of NOAA is implementing these methods in a program to monitor fish health in Chesapeake Bay tributaries.

Since 2002, USGS has been involved with numerous cooperators in examining potential causes for skin lesions and kills of various fish species in the watershed, particularly smallmouth bass and redbreast sunfish. The presence of various pathogens, including multiple bacteria, fungi, and parasites, indicated these fishes suffer from immunosuppression. During more comprehensive fish-health assessments, the presence of testicular oocytes, a form of intersex, was noted in the male bass. As previously stated, the CBP has a restoration goal "to achieve and maintain the water quality necessary to support the aquatic living resources of the Bay and its tributaries and to protect human health." The toxic reduction strategy requires information on (1) the sources and occurrences of contaminants, and (2) the potential for contaminants to adversely impact aquatic-dependent wildlife. Reproductive abnormalities in fishes have been strongly linked with a variety of contaminants that have endocrine-modulating activity. Intersex, specifically testicular oocytes, has been linked to exposure to estrogenic compounds, which also have immunomodulatory activity. A preliminary assessment of the occurrence of testicular oocytes in smallmouth bass indicates that (1) it is widespread within the Potomac drainage, and (2) the prevalence and severity may increase as human population and agricultural intensity increase. Further research is underway to assess causes of intersex and fish kills in the watershed, document the spatial distribution, and compare species and life stages to determine the population effects.

Fish kill in Choptank River, suspected to be from toxic algal bloom entrapped in floating seagrass mat. Photograph by Adrian Jones, IAN Image Library (www.ian.umces.edu/imagelibrary/).

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Chapter 14: Changes in Food and Habitats of Waterbirds

By Matthew C. Perry

The Chesapeake Bay is an important area for waterbirds because it is located in the Atlantic Flyway. The Bay winters over one million ducks, geese, and swans annually, provides stopover habitat to thousands of migrating marsh, shore, and wading birds, and maintains substantial breeding populations of colonial waterbird species. While migratory bird protection is not one of the goals in Chesapeake 2000, the DOI has the responsibility to restore populations under the North American Waterfowl Management Plan. The USGS supported the DOI management need through studies addressing the factors affecting waterbird populations and their habitats. The synthesis of USGS findings is focused on loss of food sources and alteration of habitat for waterbird populations.

During 2001–06, USGS focused on the factors affecting the declines in sea duck populations, which are a group of ducks not frequently seen by the public due to the fact that they feed in deep water in the Bay. USGS findings indicate that these declines could be from changes in diversity and abundance of shellfish and other benthic foods (Kidwell and Perry, 2005; Perry and others, 2005; Niven and others, 2005). The declines of food sources, such as mussels and other invertebrates, and changes in foodweb and habitat relations (fig. 14.1) have possibly contributed to the declines in sea ducks. The findings imply that the collapse of the once vast native oyster population has possibly had a major impact on sea ducks by removing mussels and other invertebrates associated with the oyster bars. Decline in these communities represents a major loss in foods and foraging habitat available to a variety of waterbirds. The findings imply that if oyster populations and other invertebrates are restored in the Bay, populations of waterbirds that depend on them as a food source could also increase.

Food sources and habitats of waterbirds also are affected by exotic and invasive species. The exotic mute swan has increased its population size in Chesapeake Bay (Maryland and Virginia) to approximately 4,500 since 1962, when five swans were released in the Bay (Perry, 2004). The Bay population of mute swans now represents 30 percent of the total Atlantic Flyway population (12,600), and had a phenomenal increase of 1,200 percent from 1986 to 1999. Unlike the tundra swans that migrate to the Bay for the winter, the mute swan is a year-round resident. There are concerns about their impact on nesting native waterbirds and the consumption of SAV. Although data on the consumption of SAV by nesting mute swans and their offspring during the spring and summer are limited, USGS studies of their food habits show that mute swans rely heavily on SAV during these months (Perry and others, 2004). It has been reported that a mute swan can consume about 8 pounds of SAV per day, raising concerns among resource managers (Perry and others, 2004).

While concern grows over the increasing number of exotic mute swans on the Chesapeake Bay, less attention seems to be given to the highly familiar and native Canada goose, which has developed unprecedented non-migratory, or resident, populations over time. Although nuisance flocks of Canada geese have been well developed at city parks, athletic fields, and golf courses over the past three decades, recent expansion of populations to an estimated one million birds in the Atlantic Flyway, and to over 500,000 in Maryland, carries a threat of broader ecological consequences. USGS findings revealed that herbivory by invasive resident Canada geese has led to a major decline of wild rice in tidal marshes of the Patuxent River and probably in other areas (Haramis and Kearns, 2004). Wild rice is a critical fall resource to a variety of migrating wetland birds, especially sora rails, and rails have declined in abundance with loss of these habitats. Chesapeake Bay historically provided valuable habitat for wintering rails and several species have supported hunting seasons. These findings imply that better understanding of factors affecting food sources and habitat of waterbirds will give managers more reliable information to manage and regulate waterbird populations. Monitoring the effectiveness of management plans of bird populations that are considered invasive or problematic (such as mute swans and resident geese) will be needed to determine if strategies need to be revised.

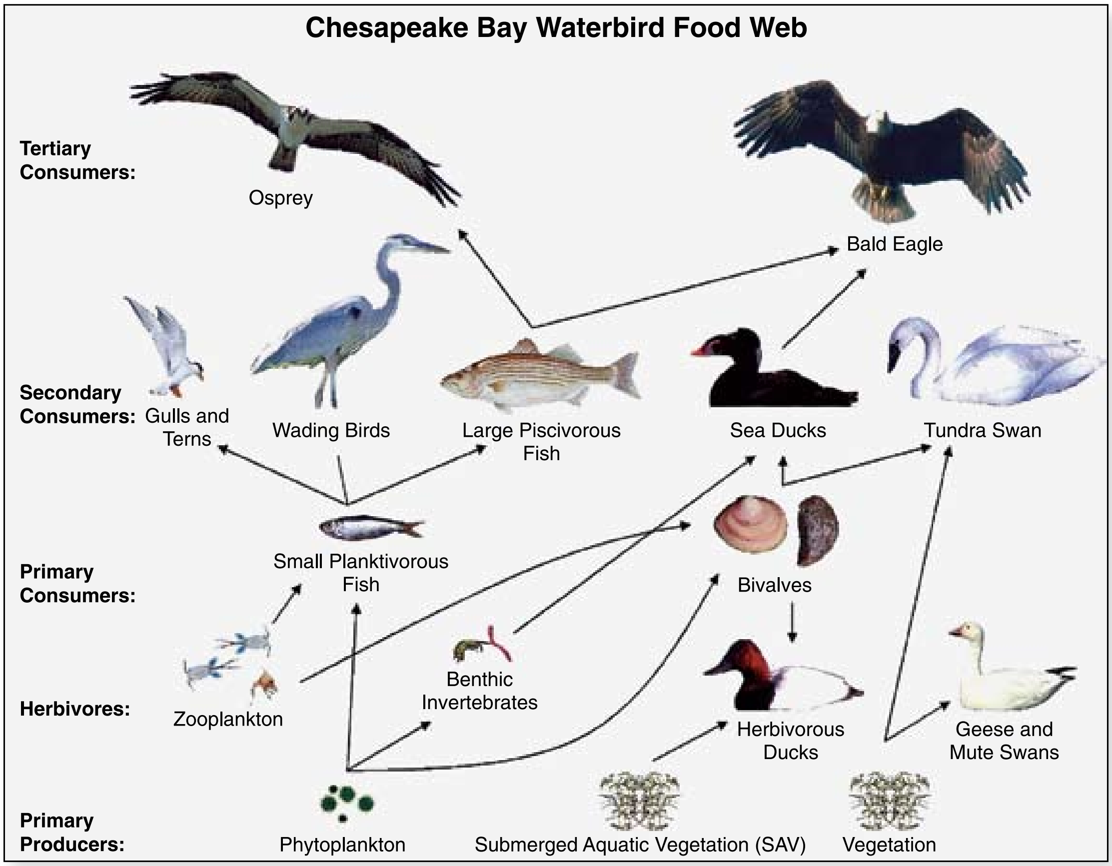

Figure 14.1. Generalized food web for some of the major waterbirds that frequent the Chesapeake Bay (modified from Perry and others, 2005). Food sources and habitats of waterbirds are affected by multiple factors, including exotic and invasive species. A better understanding of these factors will provide managers with stronger information to manage and regulate populations.

Collection of benthic samples which are used to help determine food sources for sea ducks in Chesapeake Bay. (Photograph courtesy of Matthew Perry, U.S. Geological Survey.)

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Birds on the water at Blackwater National Wildlife Refuge. Photograph by Heather Lane, IAN Image Library (www.ian.umces.edu/imagelibrary/).

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